DNR

WATER RESOURCE AVAILABILITY IN THE KANKAKEE RIVER BASIN, INDIANA

STATE OF INDIANA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATER

1990

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MAJOR ACRONYMS AND ABBREVIATIONS

DOW	Division of Water
IDEM	Indiana Department of Environmental Management
IDNR	Indiana Department of Natural Resources
IGS	Indiana Geological Survey
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
cfs	cubic feet per second
°F	degrees Fahrenheit
I.C.	Indiana Code
m.s.l.	mean sea level
gpd	gallons per day
gpm	gallons per minute
MCL	maximum contaminant level
mg	million gallons
mgd	million gallons per day
mg/l	milligrams per liter
ml	milliliter
SMCL	secondary maximum contaminant level
sq. mi.	square miles

SELECTED CONVERSION FACTORS

Multiply	By	To obtain
	AREA	
Acres	43,560	Square feet
	0.001562	Square miles
	VOLUME	
Acre-feet	0.3259	Million gallons
	43,560	Cubic feet
	FLOW	
Cubic feet per second	0.646317	Million gallons per day
Gallons per minute	0.002228	Cubic feet per second
Gallons per minute	0.0014	Million gallons per day

WATER RESOURCE AVAILABILITY IN THE KANKAKEE RIVER BASIN, INDIANA

INTRODUCTION

Water is a vital resource which greatly influences Indiana's socioeconomic development. Ground-water and surface-water supplies serve a diversity of human needs, ranging from non-withdrawal uses such as instream recreation to large water withdrawals for public supply, industry, power generation and agriculture.

Demands on the water resource are expected to increase as Indiana's economy and population continue to grow. Effective management of the water resource is possible only through a continuing assessment of the interactions between water availability and use.

BACKGROUND AND APPROACH

Issues concerning water supply and use in Indiana historically have been addressed on a case-by-case basis. The need for a comprehensive approach to conservation and management of Indiana's water resource led to the 1983 enactment of the Water Resource Management Act (I.C. 13-2-6.1).

Under this legislative mandate, the Natural Resources Commission must 1) conduct a continuing assessment of water resource availability, 2) conduct and maintain an inventory of significant withdrawals of surface water and ground water, and 3) plan for the development and conservation of the water resource for beneficial uses.

The legislation further mandates the continuing investigation of 1) low stream-flow characteristics, 2) water use projections, 3) the capabilities of streams and aquifers to support various uses, and 4) the potential for alternative water supply development.

The Indiana Department of Natural Resources, Division of Water, serving as the commission's technical staff, is achieving these legislative directives through ongoing investigations of water resource availability, water use, and conflicts involving limited water supply or competing uses.

Although conflicts between supply and demand typically are of a local nature, ongoing assessments of water availability and use are being conducted on a regional scale using the 12 water management basins designated by the Natural Resources Commission (figure 1).

A *drainage basin*, or *watershed*, is defined by the land surface divide that separates surface-water runoff between two adjoining regions (figure 2). A basin encompasses all of the land that eventually drains to a common river.

One disadvantage of using a drainage divide as the boundary of a water management unit is the potential oversight of factors that influence water resource issues but are located geographically outside of the basin. On the other hand, the basin approach allows local conditions or problems to be evaluated as parts of a unified hydrologic system. This integrated approach to a basin's water resource stems primarily from a recognition of the interrelated elements of the hydrologic cycle (figure 2), a continual exchange of water between the atmosphere and earth.

A comprehensive assessment of a basin's water resource requires an understanding of the socioeconomic setting, physical environment and hydrologic regime (figure 3). The complex interactions among these natural and manmade factors define the availability of a suitable water supply, which subsequently influences urban expansion, economic and agricultural development, and population growth. The

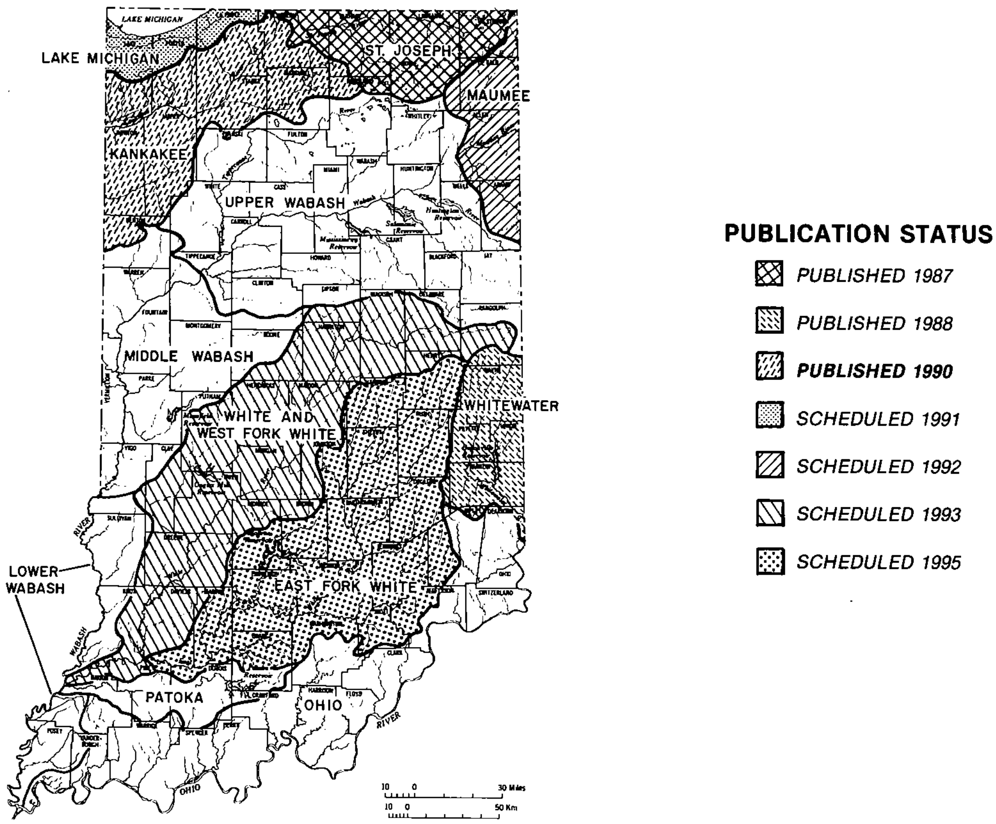


Figure 1. Location of Indiana water management basins and status of water availability reports

water availability reports prepared by the Division of Water address these interactions in an attempt to comprehensively assess the water resource and its potential for further development.

PURPOSE AND SCOPE

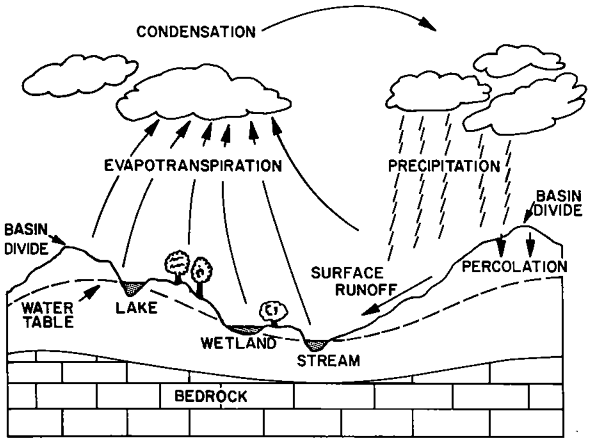
This report describes the availability, distribution, quality and use of surface water and ground water in the Kankakee River Basin, Indiana (figure 4). The third in a series of 12 regional investigations (figure 1), the report is intended to provide background hydrologic information for persons interested in managing or developing the basin's water resource.

The Kankakee River Basin in Indiana is predominantly rural and is one of the state's most productive agricultural areas. The basin's flat to gently rolling landscape is characterized by the broad corridor of the Kankakee River valley, networks of man-made drainage ditches, and small areas of natural lakes and wetlands. About 8 percent of Indiana's land area lies within the Kankakee River watershed.

Thirteen Indiana counties lie wholly or partly within the Kankakee River Basin (table 1). The largest city within the basin is LaPorte. South Bend, except for its far southwestern portions, is located just outside the basin's northeastern boundary (figure 4). Crown Point and Valparaiso, except for their outermost suburbs, are located just outside the basin's northern boundary.

The northern boundary of the Kankakee River Basin lies about 10 to 20 miles south of the Indiana shoreline of Lake Michigan (figure 4). Most areas of the basin are located less than 100 miles from downtown Chicago, Illinois.

The Kankakee River watershed, which lies within the Illinois River Basin of the Upper Mississippi River drainage system, drains a total of 2989 sq. mi. (square



Water that falls to the earth as precipitation follows many paths on its way back to the atmosphere. Precipitated water may be intercepted and taken up by plants; it may infiltrate the soil; it may be stored in small depressions, wetlands and lakes; or it may flow over the land surface to a nearby stream channel.

Some of the water used by plants returns to the atmosphere through the process of transpiration. Some of the water in streams, lakes and soils returns to the atmosphere through the process of evaporation.

Precipitated water that is not taken up by plants, evaporated, or stored in upper portions of the ground surface can *percolate* through open spaces in soil and rock formations to become ground water. A portion of the slowly moving ground water eventually returns to the surface as seepage to springs, lakes, wetlands and rivers. Some of the discharged water is evaporated from the surface to re-enter the atmosphere, and the hydrologic cycle continues.

Figure 2. Major components of hydrologic cycle

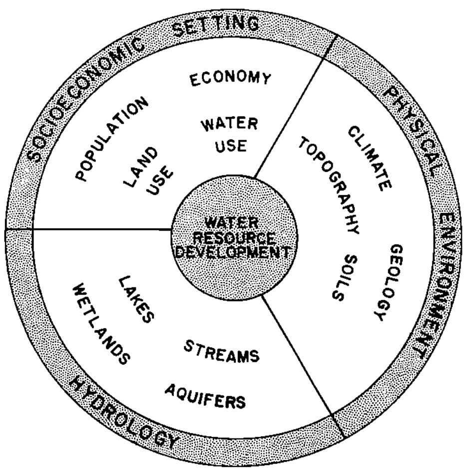


Figure 3. Factors influencing water availability

miles) in northwest Indiana, 2169 sq. mi. in northeast Illinois, and about 7 sq. mi. in southwest Lower Michigan (figure 4). For this report, the portion of the Little Calumet River Basin in Indiana and Illinois that drains artificially to the Illinois River is not considered as part of the Kankakee River Basin study area.

The Kankakee River originates near South Bend, Indiana (as Dixon West Place Ditch), then flows westward for about 104 miles to near Kankakee, Illinois. After being joined by the Iroquois River, the Kankakee River flows northwestward for about 36 miles. The Kankakee River then joins with the Des Plaines River to form the Illinois River (figure 4).

Although the Kankakee River Basin covers parts of three states, this report examines only the Indiana portion unless otherwise indicated. In general, discussions apply to in-basin portions of the nine counties constituting most of the basin's land area in Indiana: namely, Benton, Jasper, Lake, LaPorte, Marshall, Newton, Porter, St. Joseph and Starke Counties (figure 4, table 1).

In studies of the entire Kankakee River drainage system, the term "upper basin" typically refers to areas in Indiana, whereas the "lower basin" encompasses areas in Illinois. This report, however, redefines these terms to include only areas in Indiana. For mapping purposes, the upper basin in Indiana extends from the Indiana-Michigan state line to the LaPorte-Porter and Pulaski-Jasper county lines. The lower basin extends from this line westward to the Indiana-Illinois state line (figure 4).

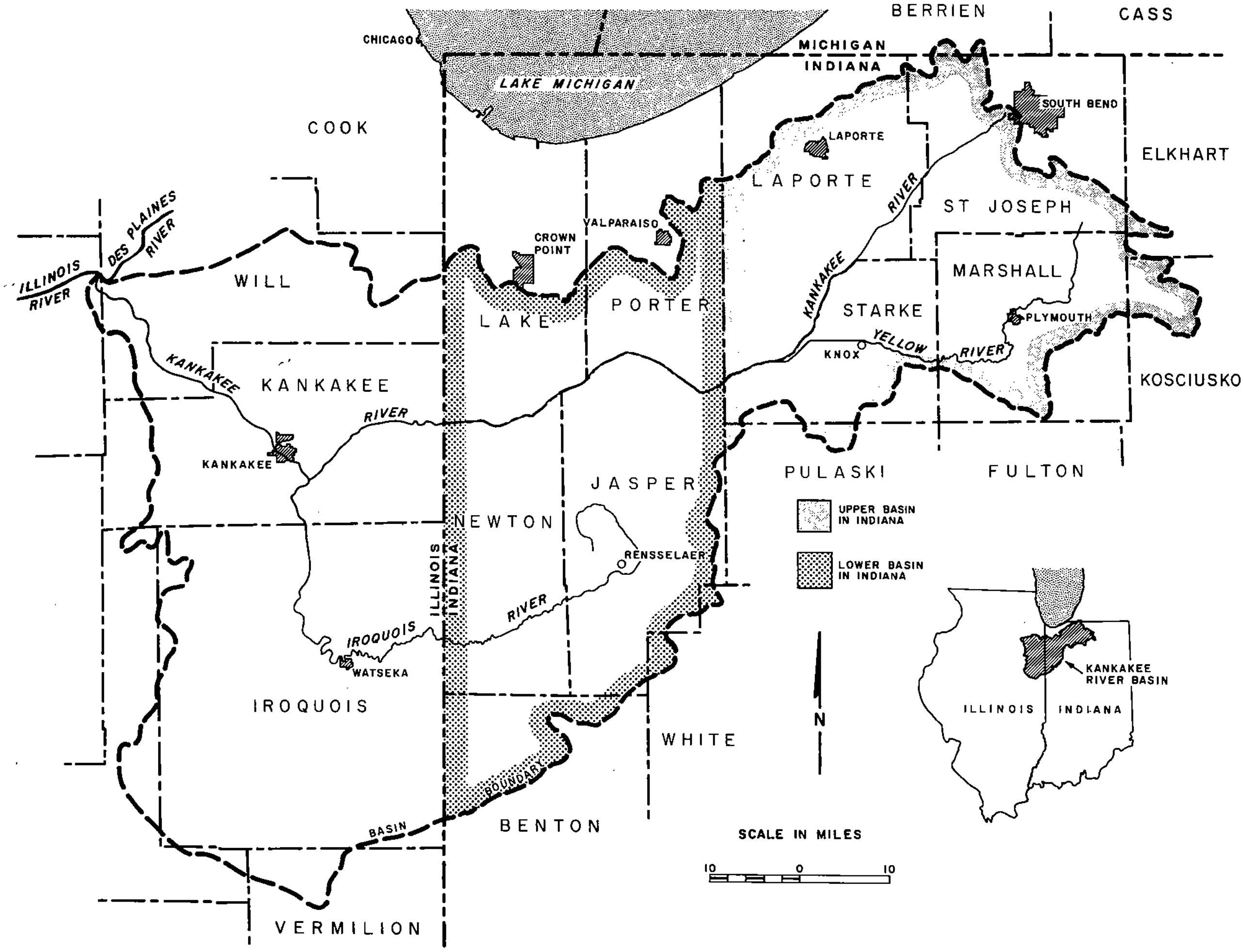


Figure 4. Location of Kankakee River Basin

The information presented in this report should be suitable as a comprehensive reference source for governmental, agricultural, commercial, industrial, recreational and other public and private interests. However, the report is not intended for evaluating site-specific water resource development projects. Persons involved in such projects should contact the Division of Water for further information.

The contents of the report follow the generalized scheme shown in figure 3. An overview of the population, economy, land use, and categories of water use is followed by a discussion of climate, geology and soils. The report then describes the basin's surface-water and ground-water hydrology, including water quality. The final section of the report summarizes current and potential water use, and examines areas of past or potential conflicts between water demand and available water supply.

Unless otherwise noted, data in this report are compiled only for areas lying within the basin boundary. However, some economic, land use and agricultural information are for entire counties.

Because the report is written for a wide spectrum of readers, key technical words within the text are italicized the first time they appear, and where appropriate thereafter. Brief definitions are given in the glossary. An appendix includes data tabulations and illustrations which supplement the information found within the body of the report.

Table 1. Area of Indiana counties within the Kankakee River Basin

County	Total area (sq mi)	In-basin area (sq mi)	Percent of total basin area
Benton	407	165	5.5
Elkhart	466	12	0.4
Jasper	561	536	17.9
Kosciusko	540	51	1.7
Lake	501	237	7.9
LaPorte	600	466	15.6
Marshall	444	324	10.8
Newton	402	402	13.5
Porter	419	222	7.4
Pulaski	435	20	0.7
St. Joseph	459	274	9.2
Starke	309	260	8.7
White	506	20	0.7
Total	6049	2989	100

Water-use information presented in this report was derived from data compiled by the Division of Water on a continuing basis. Water-well records and other data on file at the division were used to define the hydrogeologic conditions of the basin.

Field investigations conducted by the Division of Water and the Indiana Geological Survey between 1986 and 1988 provided additional data on the geology and ground-water quality of the basin. A series of gamma-ray logs and test borings in areas of sparse geologic data were conducted in order to better define the basin's geology and the hydraulic characteristics of surficial materials. The collection and analysis of 200 water-well samples yielded detailed information on natural ground-water quality throughout the basin.

The remainder of the information in this report was derived, summarized or interpreted from data, maps and technical reports by various state and federal agencies. Specific sources of data are referenced within the report. A list of selected references is included at the end of the report.

PREVIOUS INVESTIGATIONS

Because published and unpublished documents relating to the Kankakee River Basin in Indiana and Illinois are so numerous, only the primary sources used to prepare this report are discussed below. These primary documents and other major references are cited at the end of the report. Additional sources of information are listed within these cited references.

Reports by Campbell (1882), Doggett (1933), Meyer (1936), and U.S. Army Corps of Engineers (1944) are the primary sources of historical information for this report. Other significant historical accounts include Ball (1900), U.S. Department of Agriculture (1909), Andrews and Andrews [1915], U.S. House of Representatives (1916, 1931), U.S. Army Corps of Engineers (1941), State of Illinois (1954), Conway (1964), and Houde and Klasey (1968). Reports by Bhowmik and others (1980) and Machan (1986) also contain historical summaries.

A cooperative federal-state report (U.S. Department of Agriculture, 1976) and its accompanying technical supplement (Chenoweth, 1977) describe the availability, use and development of water and related land resources of the Kankakee River Basin in Indiana. A report by the Governor's Water Resources Study Commission (1980) assesses various aspects of water availability and use for 18 planning and development regions. The Kankakee River Basin lies primarily in three of these regions. Topics addressed in both reports include flood hazard mitigation, land use, soil erosion, sedimentation, water supply, water quality, drainage, irrigation, fish and wildlife habitat, and outdoor recreation.

A report by the Kankakee River Basin Task Force in Illinois (State of Illinois, 1978) contains 11 working papers summarizing the status of technical knowledge concerning the river system. The task force report presents a series of management recommendations for protecting the river and its environment. This report updated an earlier study (Barker and others, 1967) which reviewed water supply, recreation, water quality, flood control, and agricultural drainage for the Kankakee River Basin in Illinois.

Mitsch and others (1979) describe the economic value of wetlands bordering the Kankakee River near Momence, Illinois. Bhowmik and others (1980), Brigham and others (1981), and Gross and Berg (1981) present the results of three investigations dealing with the hydraulics of flow, sediment transport, biology and geology of the Kankakee River system in Illinois and portions of Indiana. Ivens and others (1981) summarize the results of these three investigations. DeMissie and others (1983) supplement the existing data with additional hydrologic, hydraulic, and sediment transport data.

The geology and ground-water resources of several Indiana counties lying wholly or partly within the basin are addressed in a series of reports by the Indiana Department of Natural Resources and the U.S. Geological Survey (Rosenshein, 1961; Rosenshein and Hunn, 1962a, 1962b, 1964a, 1964b, 1964c, 1964d, 1968a, 1968b; Hunn and Rosenshein, 1969). Maps and reports by the Indiana Geological Survey include descriptions of the surficial and bedrock geology of northwestern Indiana (Wayne, 1956, 1958, 1963; Pinsak and Shaver, 1964; Wayne and others, 1966; Lineback, 1970; Schneider and Keller, 1970; Becker, 1974; Doheny and others, 1975; Hartke and others, 1975; Hill and others, 1979; Gray, 1982, 1983, 1989; Droste and Shaver, 1982, 1983; Hartke, 1984; Shaver and others, 1986; Gray and others, 1987).

The response of the ground-water system to irrigation pumpage in Jasper and Newton Counties is described by Bergeron (1981), Indiana Department of Natural Resources (1982d), Camp Dresser and McKee, Inc. (1983), GeoTrans, Inc. (1983), Basch and Funkhouser (1985), and Cushman and Leap (1986). Irrigation impacts on the ground-water resources of northwestern Indiana and portions of east-central Illinois are discussed by Arihood and Basch (in preparation). The regional ground-water availability and irrigation potential in Kankakee and Iroquois Counties, Illinois are described by Cravens and others (1990).

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The following divisions of the Indiana Department of Natural Resources (IDNR) provided valuable data and assistance during the preparation of this report: Engineering, Fish and Wildlife, Forestry, Geological Survey, Nature Preserves, Soil Conservation, State Parks, and Outdoor Recreation. The following organizations also made significant contributions: Indiana Department of Environmental Management; Indiana State Board of Health; Indiana Department of Highways; Indiana State Library (Indiana Division, Reference and Loan Division, Indiana State Data Center); Purdue University (Department of Agronomy); Indiana University (School of Public and Enviromental Affairs, Indiana Business Research Center); Illinois Department of Energy and Natural Resources (Water Survey, Geological Survey); National Oceanic and Atmospheric Administration (National Climatic Data Center, National Weather Service); U.S. Department of Interior (Fish and Wildlife Service, Geological Survey); U.S. Environmental Protection Agency (Region 5); and U.S. Department of Agriculture (Soil Conservation Service, Agricultural Stabilization and Conservation Service).

The authors of this report thank residents of the Kankakee River Basin for their cooperation during the ground-water sampling project. In addition, well-drilling contractors contributed water-well records and cooperated with the gamma-ray logging project.

The authors extend their appreciation to technical and support staff of the IDNR, Division of Water, who contributed greatly to the report writing and review. The authors extend special thanks to chief draftsman Burton C. Daniels, who provided technical guidance during the preparation of illustrations and throughout the final production and printing. Information specialist Eddie Reynolds prepared the camera copy. Margaret Petrey of the IDNR Division of Public Information typeset the report.

SOCIOECONOMIC SETTING

The demand for water in the Kankakee River Basin is directly linked to the area's population, economy and land use. Agricultural irrigation creates the greatest total demand for water in the basin, particularly during the crop-growing season. Water demand also is high in and near highly populated urban centers, where large quantities of water are needed for public supply and industrial purposes. In rural areas, water is needed primarily for domestic and agricultural uses. Moreover, large amounts of surface water are withdrawn from the Kankakee River for cooling purposes at a power generating station in northern Jasper County.

POPULATION

In 1980, the estimated population of the Kankakee River Basin (223,186) constituted about 4 percent of Indiana's total population (5,490,224). More than three-fourths of the basin population in 1980 resided in LaPorte, Lake, Marshall, Jasper, St. Joseph and Porter Counties, which are located primarily along the northern and eastern basin boundary (figure 4). Each of these six counties had at least 20,000 in-basin residents in 1980.

About 22 percent of the basin's total population in 1980 lived in urban areas of at least 2,500 persons. LaPorte, the basin's largest city, had a 1980 population of 21,796. Valparaiso, most of which is located just north of the basin boundary, had a 1980 population of 22,247 (table 2). Crown Point, which also lies near the northern basin boundary but is not considered further in this report, had a 1980 population of 16,455.

Cedar Lake, Plymouth and Lowell had between 5,000 and 10,000 residents in 1980. Rensselaer, St. John, Knox, Bremen, Westville and Hebron had populations of 2,500 to 5,000 (table 2). The remainder of the basin's residents in 1980 lived in rural areas, which are defined by the U.S. Bureau of the Census as non-urban farm and non-farm areas of less than 2,500 persons.

Historic and projected population

Historic and *projected* population totals for in-basin portions of the 13 counties comprising the Kankakee River Basin are presented in appendix 1. The appendix also includes population values for entire counties, from which the in-basin values were derived. Figure 5 illustrates the historic and projected population

Table 2. Recent and projected population of selected cities and towns

{Tabulation includes only cities and towns having at least 2,500 residents in 1980. Population values for 1960-80 are from U.S. Bureau of the Census (1982). Values for 1990 and 2000 are Division of Water projections.}

City or town	County	1960	1970	1980	1990	2000
Bremen	Marshall	3062	3487	3565	4070	4250
Cedar Lake	Lake	5766	7589	8754	9190	9780
Hebron	Porter	1401	1624	2696	2880	3010
Knox	Starke	3458	3519	3674	3320	3290
LaPorte	LaPorte	21157	22146	21796	21700	21020
Lowell	Lake	2270	3839	5827	6290	6690
Plymouth	Marshall	7558	7661	7693	8260	8620
Rensselaer	Jasper	4740	4688	4944	4660	4750
St. John[1]	Lake	1128	1757	3974	4560	4850
Valparaiso[1]	Porter	15227	20020	22247	25570	28090
Westville	LaPorte	789	2614	2887	2670	2580

[1]Corporate limit lies partially (St. John) or primarily (Valparaiso) outside of the basin boundary.

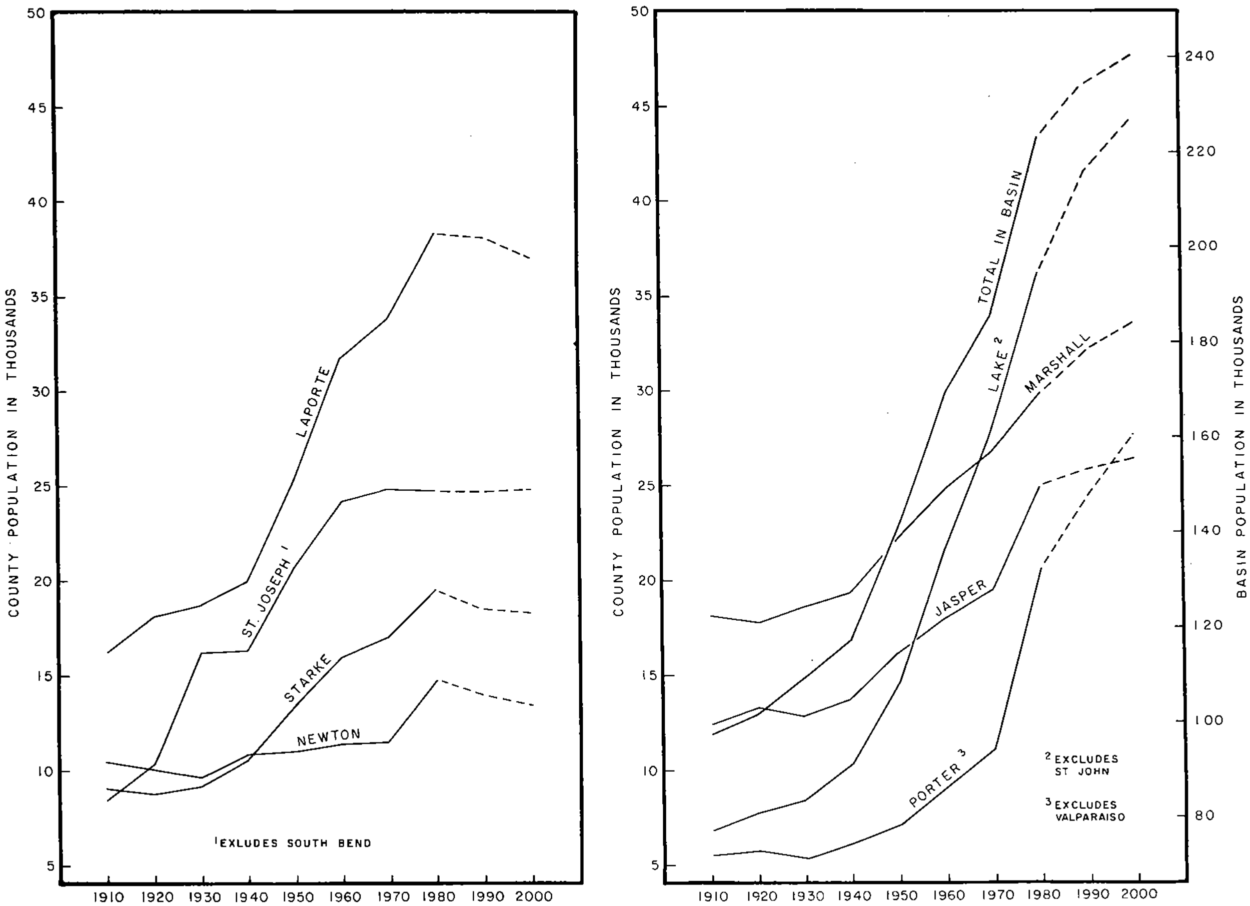


Figure 5. Historic and projected population for in-basin portions of the eight most populous counties

changes for the entire basin and for the in-basin portions of the eight most populous counties.

As figure 5 and appendix 1 show, the total population of the Kankakee River Basin has more than doubled between 1910 and 1980. The most rapid population growth occurred during the 1940s, 1950s and 1970s. According to projections by the Division of Water, a moderate increase in the basin population is expected in the 1990s.

The basin's eight most populous counties have experienced varying degrees of historic population growth (figure 5). The in-basin portion of Porter County is expected to experience the largest percent increase in population during the 1990s (appendix 1).

According to Division of Water projections, a population increase is expected in the basin portion of Lake County, even though the county's total population is expected to continue its decline (appendix 1). The contrasting projections for Lake County primarily reflect the southward shift in population from highly urbanized areas lying north of the Kankakee River Basin to urban and suburban areas lying within the basin.

The growth rates of cities and towns in the basin have varied widely in recent decades. Between 1960 and 1980, the population of Lowell doubled and the population of Westville tripled. The population of other cities and towns increased less dramatically (table 2).

Division of Water projections show an increasing trend in the population of most cities and towns during the 1990s. Slight decreases are anticipated in LaPorte, Knox and Westville (table 2).

Table 3. Per capita income

{Values, for entire counties, are for 1985.}

County	Per capita income		Estimated population
	Dollars	Percent of state average	
Benton	8,885	89	9,800
Jasper	8,939	90	26,300
Lake	9,737	98	491,700
LaPorte	9,634	97	106,100
Marshall	9,235	93	41,300
Newton	8,682	87	13,900
Porter	10,778	108	123,100
St. Joseph	10,517	105	241,400
Starke	7,375	74	21,400

Table 4. Average annual unemployment rate

{Values, for entire counties, are for 1979-88.}

County	Average	Range
Benton	7.9	5.1-10.1
Jasper	9.2	6.8-12.6
Lake	11.8	7.0-16.2
LaPorte	9.5	6.4-14.4
Marshall	7.8	5.2-11.0
Newton	8.1	5.5-10.6
Porter	9.4	4.9-14.0
St. Joseph	7.5	5.5- 9.9
Starke	11.4	6.8-14.9

ECONOMY

Economic activity within the Kankakee River Basin is an important factor determining water use because different types of industry have different water resource requirements. In turn, the availability of water resources partially determines which industries can be located in an area. A region's economic dependence on an industry can be measured by the number of residents employed and the proportion of county earnings produced by that industry.

Economic data for the major counties of the basin were obtained from a computerized database (STATIS) maintained by the Indiana Business Research Center. It should be noted that the following discussion refers to entire counties, and thus includes areas lying outside the basin boundary.

In the nine major counties of the basin, estimated *per capita income* in 1985 averaged $9,309 (see table 3), or about 93 percent of the statewide average of $9,978. Unemployment rates ranged from 4.9 percent to 16.2 percent of the labor force during the 10-year period 1979-88 (table 4).

Manufacturing, services, and wholesale and retail trade constitute the four largest employment classes in eight of the basin's nine major counties (table 5). Manufacturing accounts for the largest percentage of total earnings in seven of the nine major counties. Most manufacturing in the basin region occurs in urban areas, particularly in the cities of LaPorte, Plymouth, Cedar Lake, Lowell and Rensselaer. Services, wholesale and retail trade, and government activities also are concentrated in urban areas.

Transportation and public utilities generally constitute less than 8 percent of county employment and earnings. In Jasper County, however, this category is among the leading sources of employment and provides the greatest percentage of total earnings (table 5). Most earnings in this category are derived from the R.M. Schahfer generating station, operated by the Northern Indiana Public Service Company.

Although agriculture is the major land-use category in the Kankakee River Basin, it is the leading source of employment and earnings only in Benton County (table 5). Farming is one of the major employment categories in Jasper, Newton and Starke Counties; however, farm earnings are less than earnings from other *industries*.

Agricultural data from the U.S. Bureau of the Census (1984a, 1989) show a net increase in average farm size for the nine major basin counties during the 10-year period 1978-87, but a net decrease in the number of farms and land in farms in eight of the nine counties. The overall trend of increasing farm size and decreasing number of farms parallels trends which have been evident on a statewide basis since at least the 1950s.

Small farms are common in the rolling morainal areas of the eastern Kankakee River Basin. In 1987, Marshall, LaPorte and St. Joseph Counties had the largest number of farms (between 900 and 1100). St. Joseph and Marshall Counties had farms of the smallest average size (about 200 acres).

The southwestern part of the basin is characterized by fewer numbers of relatively large farms, many of which are corporately owned. The average size of farms in Benton, Newton and Jasper Counties in 1987 ranged from about 390 to 470 acres, which was more than twice the average farm size in eastern parts of the basin.

Corn and soybean production in the nine-county basin region is among the highest of any region in Indiana. Benton and Jasper Counties led the state in soybean production in 1987, and Jasper, LaPorte and Benton Counties ranked in the top six Indiana counties for corn production (U.S. Department of Agriculture, 1987b).

Winter wheat, hay and oats are significant crops in portions of northern Indiana. Among the nine major counties of the Kankakee River Basin, winter wheat production during 1987 was highest in LaPorte County; hay production was highest in Marshall and LaPorte Counties; and oat production was highest in Marshall, Porter and Lake Counties (U.S. Department of Agriculture, 1987b).

Apples, peaches, berries, vegetables and other crops constitute only a minor percentage of the basin's total crop income. However, the production of mint for oil is significant on a state and national level. Berries and orchard crops are important to both local and regional farm economies.

Spearmint and peppermint are grown on the muck and peat soils of the Kankakee River valley. In 1987, Starke County led Indiana counties in the number of farms growing mint. Moreover, a significant part of the total mint production in the United States is derived from counties in the Kankakee River Basin.

Blueberries also are a common specialty crop in the low-lying Kankakee River valley, particularly in portions of Jasper, Marshall, LaPorte and St. Joseph Counties. North of the main valley on the Valparaiso Moraine, frost-sensitive orchard crops are fairly com-

Table 5. Employment and earnings by industry as a percent of total

{Values, for entire counties, are for 1986.}

Column headings are abbreviated as follows: Agri Serv, agricultural services, forestry, fisheries and others; Trade, wholesale and retail trade; Fin, financial, insurance and real estate; Serv, services; Const, construction; Manuf, manufacturing (durable and non-durable); Trans, Util, transportation and public utilities; Govern, federal civilian, federal military, state and local government.

County totals may not equal 100 percent because of differences in rounding and/or because data were not available, NA.

County	Farm	Agri Serv	Trade	Fin	Serv	Mining	Const	Manuf	Trans, Util	Govern
Employment										
Benton	23.6	1.0	NA	7.6	NA	NA	5.8	6.9	4.2	16.9
Jasper	12.8	0.7	20.1	5.5	18.8	0.3	6.1	11.3	11.8	13.0
Lake	0.5	0.4	22.8	5.4	24.7	0.0	5.6	21.3	6.1	13.1
LaPorte	3.3	0.9	20.4	4.8	22.0	0.1	4.2	25.7	4.2	14.0
Marshall	8.1	0.6	17.3	5.4	17.5	0.1	3.8	33.4	4.9	9.0
Newton	14.8	NA	17.4	5.0	19.0	NA	4.7	20.0	2.8	14.6
Porter	1.9	0.5	21.0	5.7	23.7	0.1	4.6	22.9	5.2	14.4
St. Joseph	1.2	0.5	24.2	6.6	29.6	0.0	4.7	18.9	4.2	10.0
Starke	12.3	0.7	21.4	4.9	18.6	NA	3.6	15.0	4.6	18.7
Earnings										
Benton	28.0	0.7	NA	4.9	NA	0.3	6.4	8.1	5.0	17.0
Jasper	9.4	0.4	16.1	2.9	12.7	0.3	9.3	14.1	22.7	12.1
Lake	0.5	0.2	13.2	3.1	19.7	0.2	7.4	37.0	8.5	10.3
LaPorte	1.8	0.5	13.3	2.9	18.3	0.3	5.5	36.0	7.7	13.7
Marshall	4.1	0.3	12.5	3.6	12.9	0.2	5.8	44.0	7.7	9.0
Newton	6.3	NA	15.9	3.8	14.9	NA	8.1	28.0	4.4	16.7
Porter	0.8	0.3	12.0	2.6	16.1	0.3	5.8	43.9	6.5	11.7
St. Joseph	0.4	0.3	17.5	5.4	25.6	0.2	6.2	28.9	6.1	9.4
Starke	8.9	0.3	18.5	2.9	16.3	NA	6.4	20.2	6.4	20.0

mon, partly because of the milder climate induced by Lake Michigan. In 1987, LaPorte County had the largest acreage of land in orchards of any Indiana county.

Hogs and beef cattle are the leading source of livestock income in the nine-county basin region. The number of hogs and pigs in Jasper County was the eighth highest in Indiana during 1987 (U.S. Department of Agriculture, 1987b).

Poultry, poultry products, and milk production constitute a moderate portion of livestock income in the basin. Income from sheep production is fairly small relative to other livestock income.

Regional assessment

A report by the Indiana Department of Commerce (1988) identifies the economic strengths, weaknesses and growth potential of 14 regions in Indiana. Although the findings of the study are regional, they provide an overview of the economic status of the basin and surrounding areas.

The study concluded that Region 1 (Lake, Porter, LaPorte, Newton, Jasper, Starke and Pulaski Counties) has numerous economic factors below the state average. The percentage of the population with college degrees is below the state average. Although the region has an overall low student dropout rate and high per pupil expenditure, it also has the highest percentage of students failing to meet minimum scores on the state Basic Competency Skills Test.

Air pollution may limit growth in Region 1, mainly along the urban corridor of the Lake Michigan shore. Water quality is a concern because the capacity of some wastewater-treatment facilities may be exceeded.

Transportation access in Region 1 is good, except for the lack of air transportation service and the presence of many obsolete bridges. The proposed construction of a third Chicago-area airport in or near this region would significantly increase commuter and air carrier service.

Most factors of capital availability are at or slightly below state averages, except for bank deposits per capita, which are much below average. The region has a high level of per capita government indebtedness, much of which is being used to fund infrastructure in densely populated urban areas.

Region 2 (St. Joseph, Elkhart, Marshall and Kosciusko Counties) has a mix of positive and negative development factors. Although the educational level of the work force exceeds the state average, the student dropout rate also is high, and per pupil expenditures are below the state average.

Air pollution may limit industrial growth in St. Joseph and Elkhart Counties. Some wastewater-treatment facilities may be approaching their capacity.

Region 2 is the only region with two airports providing commercial air carrier service. Access to divided highways is limited, and the percentage of obsolete bridges is above the state average.

The economic strength of Region 2 is its fiscal stability. Measures of capital availability are high, and levels of government indebtedness are low.

LAND USE

The landscape of the Kankakee River Basin today bears little resemblance to the natural landscape of presettlement times. Until the early 1800s, the basin was characterized by forests, wetlands, and both dry and wet prairies. Hardwood forests were common throughout the basin, particularly on the morainal uplands and sand ridges. Many areas, particularly south of the Kankakee River and in the Iroquois River Basin, were dominated by prairie grasses and oak *savannas*. Most of the Kankakee River valley was covered by a vast *marsh* and wooded *swamp*.

The current landscape of the Kankakee River Basin is dominated by agricultural crops and artificial drainage networks. Remnants of the natural prairie, savanna and wetland landscapes remain only in isolated parcels.

The U.S. Geological Survey has produced a series of land-use and land-cover maps by using aerial photographs and other remotely sensed data (see Anderson and others, 1976). Land use refers to man's activities which are directly related to the land. Land cover describes the vegetation, water, natural surface and artificial constructions at the land surface (U.S. Geological Survey, 1982).

Land uses in Indiana are grouped into six general categories, which are further subdivided into more specific categories. These categories are identified in the land-use and land-cover map for the Kankakee River Basin (figure 6).

It should be noted that only urban areas, bodies of water, gravel pits and certain agricultural areas of at least 10 acres are mapped in figure 6. For other land

Table 6. Selected land use data for farmland

{Values are for entire counties.}

Total area: Acreages are from county land areas listed in Marcus (1985).

Land in farms, total cropland, total woodland, other land: Upper numbers are for 1987 (U.S. Bureau of the Census, 1989); lower numbers are for 1978 (U.S. Bureau of the Census, 1984a).

County	Total area (acres)	Land in farms		Total cropland		Total woodland		Other land	
		Acres	Percent of total area	Acres	Percent of farmland	Acres	Percent of farmland	Acres	Percent of farmland
Benton	260,480	—	98	259,283	94[1]	3,920	1[1]	8,313	1[1]
		256,225		252,253		5,105		11,738	
Jasper	359,040	306,098	85	276,307	90	13,955	5	15,836	5
		300,638		263,005		16,043		21,590	
Lake	320,640	145,566	45	133,998	92	4,826	3	6,742	5
		146,177		130,919		4,561		10,697	
LaPorte	384,000	258,506	67	230,944	89	13,011	5	14,551	6
		276,416		239,903		16,375		20,138	
Marshall	284,160	222,394	78	194,272	87	15,542	7	12,580	6
		237,038		200,551		20,180		16,307	
Newton	257,280	227,126	88	209,701	92	6,626	3	10,799	5
		239,550		209,909		13,098		16,543	
Porter	268,160	162,544	61	147,170	90	6,233	4	9,141	6
		170,470		150,786		9,031		10,653	
St. Joseph	293,760	174,226	59	156,357	90	8,773	5	9,096	5
		180,941		157,615		11,789		11,537	
Starke	197,760	140,869	71	119,726	85	14,092	10	7,051	5
		149,094		121,086		15,674		12,334	

[1]Based on 1982 data.

use categories, the minimum mapping unit is 40 acres (U.S. Geological Survey, 1982).

Because the land use map in figure 6 does not include numerical data, county and regional data obtained from state and federal agencies were used to derive acreage estimates for each of the six major land use categories defined by the U.S. Geological Survey. According to these estimates, agricultural land constitutes more than three-fourths of the land area within the basin boundary. Forest land accounts for about 9 percent of the basin's land area; urban or built-up land for about 8 percent; and water, wetlands and barren land for the remaining 8 percent.

Agricultural land

The U.S. Bureau of the Census compiles and publishes land use data for agricultural land, which is designated as "land in farms." A farm is defined by the bureau as any place from which the sale of agricultural products normally amounts to at least $1,000 during the census year.

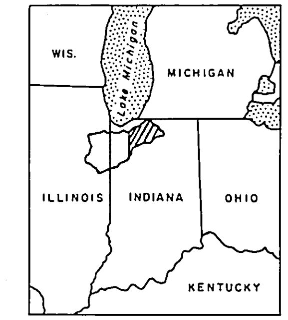
Of the five agricultural land use categories defined by the bureau, the following four are mutually exclusive: cropland, woodland, other land, and land set aside in federal farm programs. The fifth category, total pastureland, is the sum of cropland, woodland, and other land used for pasture or grazing.

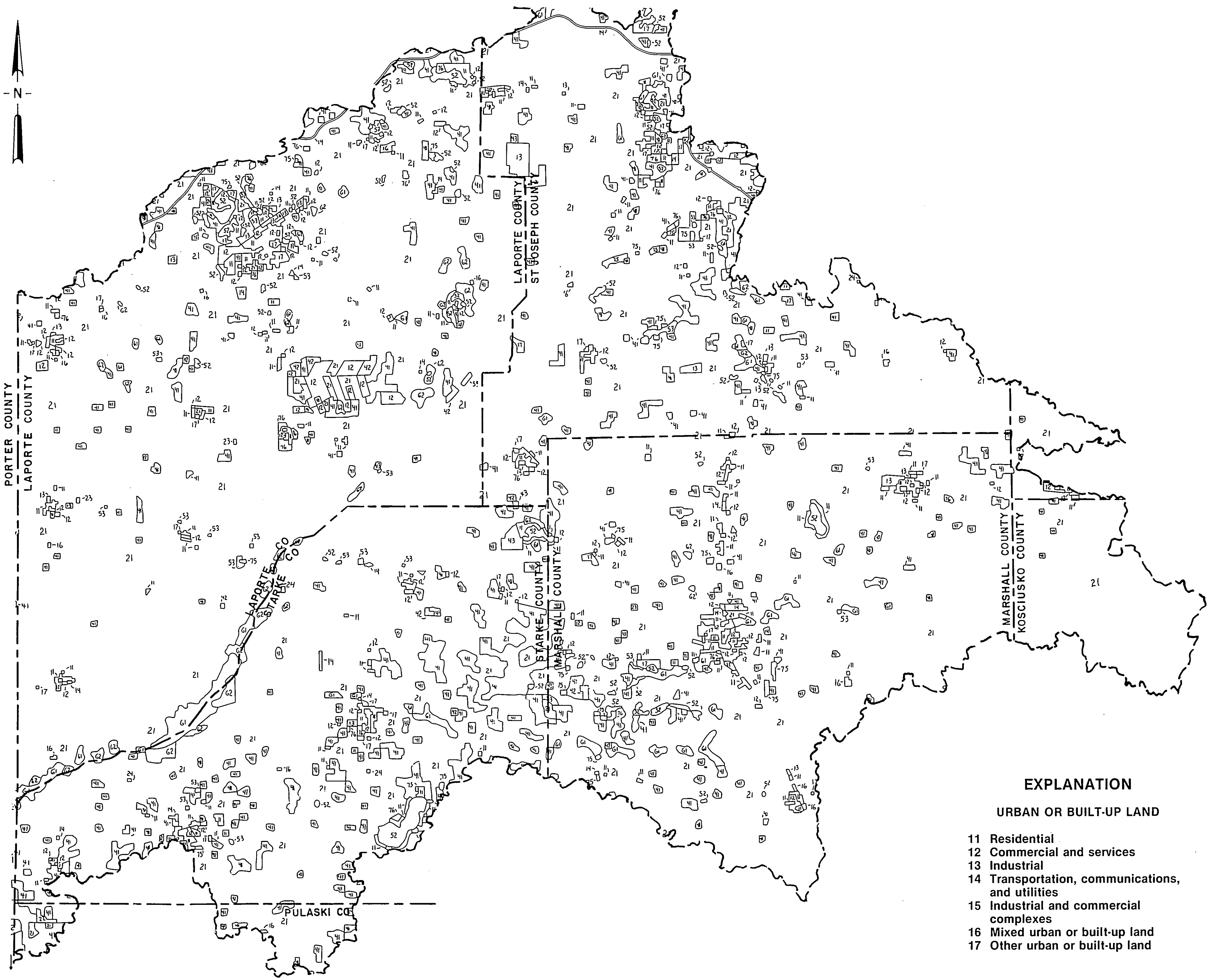
Agricultural statistics published by the U.S. Bureau of the Census are available on a county basis, and thus include areas lying outside the Kankakee River Basin boundary. However, the data available for the nine major counties lying wholly or partially within the Kankakee River Basin nonetheless provide a general overview of agricultural land use.

Table 6 presents county data for the three major land uses on farmland. Cropland accounts for an average of about 90 percent of total farmland in the nine-county basin region. Most of the cropland in the basin region

STATE OF INDIANA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATER

UPPER KANKAKEE RIVER BASIN





EXPLANATION

URBAN OR BUILT-UP LAND

11 Residential
12 Commercial and services
13 Industrial
14 Transportation, communications, and utilities
15 Industrial and commercial complexes
16 Mixed urban or built-up land
17 Other urban or built-up land

AGRICULTURAL LAND

21 Cropland and pasture
22 Orchards, groves, vineyards, nurseries, and ornamental horticultural areas
23 Confined feeding operations
24 Other agricultural land

FOREST LAND

41 Deciduous forest land
42 Evergreen forest land
43 Mixed forest land

WATER

51 Streams and canals
52 Lakes
53 Reservoirs

WETLAND

61 Forested wetland
62 Nonforested wetland

BARREN LAND

75 Strip mines, quarries, and gravel pits
76 Transitional areas

Figure 6a. Land use and land cover
(Adapted from U.S. Geological Survey, 1979, 1982)

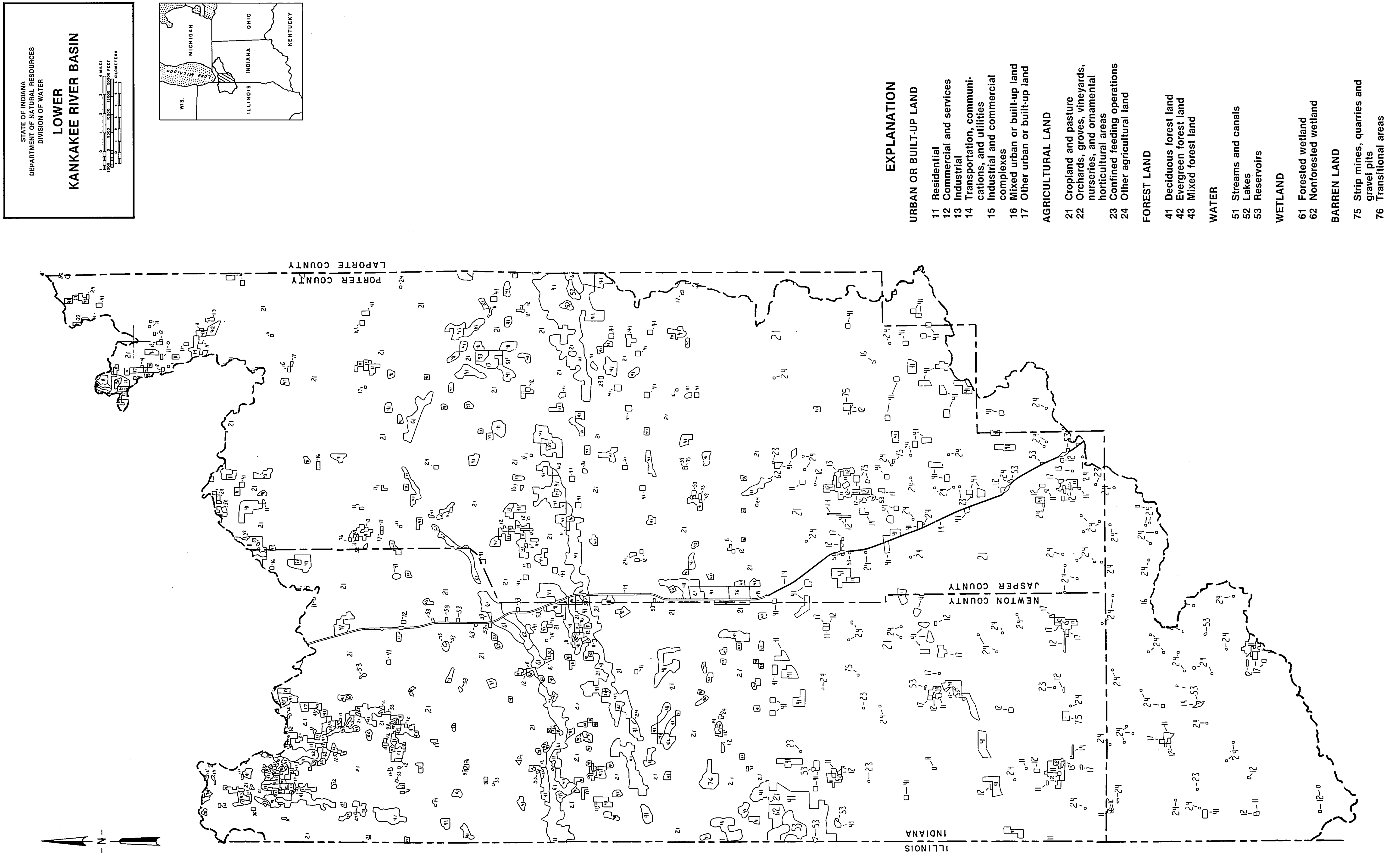


Figure 6b. Land use and land cover
(Adapted from U.S. Geological Survey, 1979, 1982)

is classified as harvested cropland, which includes not only land for field crops but also for orchards, vineyards, nurseries and greenhouses. Some small tracts of cropland are used for pasture, grazing, cultivated summer fallow, idle cropland or soil improvement crops. During the 10-year period 1978-87, cropland acreage showed a net increase in Benton, Jasper and Lake Counties, but a net decrease in other counties.

Woodland accounts for an average of about 5 percent of all land in farms in the nine-county region (table 6). Most woodland is used for woodlots, timber production and Christmas tree production. On average, about one-fourth of the woodland acreage is used for pasture or grazing. Woodland acreage in all basin counties except Lake County decreased during the 10-year period 1978-87 (table 6).

Farmland designated as "other land" (table 6) constitutes about 5 percent of all farmland, and includes primarily land in house and barn lots, ponds, roads and wasteland. Only small tracts are used solely for pasture or are considered as barren land. It should be noted that some of the barren land and land in lots or roads which the U.S. Bureau of the Census considers as agricultural land may be classified and mapped as barren, non-agricultural land by the U.S. Geological Survey.

Land used solely for pasture decreased in most basin counties during the period 1978-87. Land set aside in federal farm programs probably has increased since the establishment of the Conservation Reserve Program, which was created following enactment of the 1985 Food Security Act.

Table 7. Area of timberland

{Values, for entire counties, are from a 1986 inventory report by Smith and Golitz, 1988.}

County	Acres	Percent of county area
Benton	1,500	1
Jasper	27,000	8
Lake	17,800	6
LaPorte	41,400	11
Marshall	31,000	11
Newton	17,900	7
Porter	30,600	11
St. Joseph	22,500	8
Starke	26,900	14

Prime farmland is defined by the U.S. Department of Agriculture as land best suited for producing food, feed, forage, fiber, and oil-seed crops. This land has the soil quality, length of crop-growing season, and available moisture supply needed to sustain high yields of crops economically when the land is properly managed according to modern farming methods. Prime farmland may be in cropland, pasture, range, forest, or other uses (excluding waterbodies and urban areas) which make it available for agricultural conversion.

According to a generalized map (U.S. Department of Agriculture, 1977), the largest areas encompassing at least 75 percent prime farmland are located in the flat or nearly flat areas of the Kankakee, Iroquois and lower Yellow River watersheds. Smaller areas of prime farmland occur on nearly flat upland tills of southern St. Joseph County and extreme northern Marshall County.

Other land

Forest land, which constitutes about 9 percent of the basin's land area, generally occurs as small parcels scattered among cropland (figure 6). The predominant forest types in the basin are oak-hickory, elm-ash-soft maple, maple-beech, and cherry-ash-yellow poplar (Smith and Golitz, 1988).

The largest tracts of forested land are located along and south of the Kankakee River, particularly within the five state-owned fish and wildlife areas. (Many of the wooded areas on these properties and throughout the river valley also may be classified as forested wetlands by the U.S. Fish and Wildlife Service.) Upland forest south of the main Kankakee River Valley is found primarily on low sand ridges, particularly in Jasper and Newton Counties.

Data on timberland are available on a county basis from the U.S. Forest Service (Smith and Golitz, 1988). Timberland is defined as commercial forest land producing or capable of producing crops of industrial wood and not withdrawn from timber utilization.

Table 7 presents timberland data for the nine major counties of the Kankakee River Basin. Because the tabulated values include not only forest land held for non-agricultural uses but also woodland on farms, there is some overlap between timberland values in table 7 and total woodland values in table 6.

The area of timberland reported in the U.S. Forest Service's 1986 inventory is greater than the area reported in a 1967 inventory (Smith and Golitz, 1988). One factor in timberland increases may be procedural changes between the two surveys, including the reclassification as forest land of some areas previously classified as range, pasture and other land (see U.S. Department of Agriculture, 1989).

In Marshall County, much of the increase may be the result of pastureland reverting to timberland. The large increases in LaPorte, and to a lesser extent, in Lake and Porter Counties, may reflect both changes in agricultural land use within the Kankakee River Basin and increases in timberland near the Lake Michigan shoreline.

About 8 percent of the land area within the Kankakee River Basin is in **urban or built-up land**. As figure 6 shows, urban or built-up land is situated primarily in northern and eastern areas of the basin region. LaPorte is the major urban center lying totally within the basin. Large tracts of built-up land also are found in and near smaller towns and around a few of the large lakes such as Bass Lake, Cedar Lake, Lake of the Woods, and Koontz Lake.

Wetlands account for at least 5 percent of the basin's land area. Figure 6 gives a general indication of the abundance and distribution of some large wetlands. Hundreds of other wetlands are not shown on the map. Moreover, the figure is not appropriate for all purposes because various agencies may use significantly different classification schemes for wetlands.

Some areas mapped as cropland in figure 6 may be classified by the U.S. Fish and Wildlife Service as wetlands. Other areas mapped as forested wetlands may be classified by the U.S. Forest Service as riparian forest, or by the U.S. Bureau of the Census as wooded farmland. A discussion of wetlands and wetland classification used by the U.S. Fish and Wildlife Service is found in the ***Surface-Water Hydrology*** chapter of this report under the subheading ***Wetlands***.

Minor land uses in the Kankakee River Basin are categorized by the U.S. Geological Survey as **water**, including lakes, reservoirs and rivers, and **barren land**, including sand and gravel operations and transitional areas. Figure 6 shows several of the largest natural and manmade lakes. These lakes and other large lakes not shown on the map account for about 1 percent of the basin's total land area. A discussion of major lakes is found in the ***Surface-Water Hydrology*** chapter of this report under the subheading ***Lakes***.

WATER-USE OVERVIEW

The demand for water in the Kankakee River Basin is influenced by a variety of factors, including socioeconomic characteristics, the physical environment, and hydrologic systems. A brief overview of current water use in the basin is provided below as a prelude to discussions of climate, geology, soils and hydrology. Details of current and projected water use are presented in the final chapter of this report.

Withdrawal uses

Withdrawals involve the physical removal of water from its surface-water or ground-water source, and conveyance to its place of use. The water withdrawn can be used in either a consumptive or nonconsumptive manner.

Water applied for irrigation, incorporated into a manufactured product, lost to *evapotranspiration*, or otherwise removed from the immediate water supply is considered to be consumed if it is unavailable for reuse in a short period of time. Other applications, such as public water supply, energy production and many industrial uses, typically return most of the withdrawn water to surface-water or ground-water systems.

Water-use data for Indiana historically has been obtained by combining limited data for public water supplies with various estimation techniques and voluntary responses to mailed questionnaires. Recent water-use summaries include those by the Indiana Department of Natural Resources (1982a, 1982b) and Solley and others (1983, 1988).

Since 1985, annual water-use data for large withdrawal facilities in Indiana have been compiled as mandated in the 1983 Water Resource Management Act (I.C. 13-2-6.1). This legislation requires owners of significant water withdrawal facilities to register these facilities and report annual water use to the Natural Resources Commission through the Indiana Department of Natural Resources, Division of Water. Significant facilities are defined as facilities capable of withdrawing at least 100,000 gallons per day of surface water, ground water, or surface water and ground water combined.

Reported water use for registered facilities typically is determined by metering devices, the multiplication of pump capacity and total time of pumpage, or by other methods approved by the Division of Water.

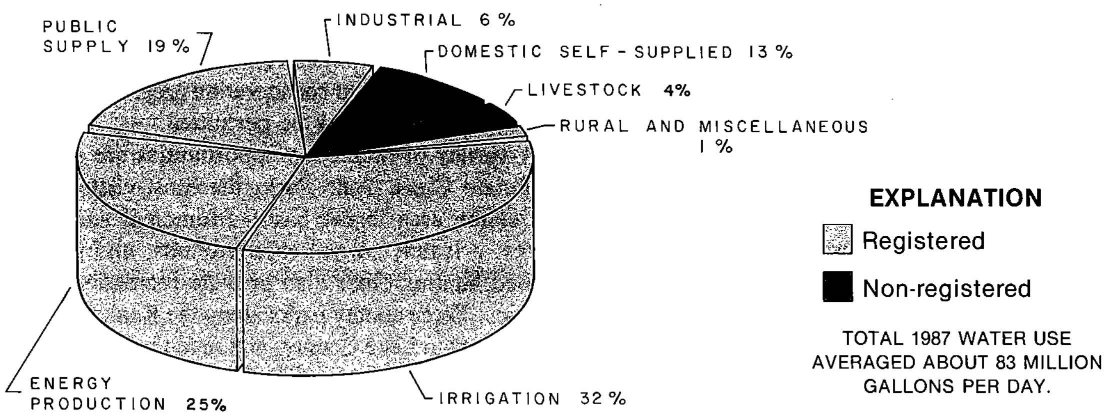


Figure 7. Percentage of water withdrawn by registered and non-registered facilities

Total non-registered water withdrawals generally are estimated using approximated values for population and per capita water use.

Although water withdrawals from a single well or surface-water intake may serve several purposes, each registered water withdrawal facility is grouped by the Division of Water into one of the following six categories: irrigation, energy production, public supply, industrial, rural and miscellaneous. These categories differ slightly from those used in the 1980 report by the Governor's Water Resources Study Commission.

Facilities capable of withdrawing less than 100,000 gallons of water per day are not required to register with the Division of Water or to monitor their annual water use. However, some types of facilities can create a large aggregate demand for water. Non-registered withdrawals for domestic self-supply and livestock watering purposes are included in water-use calculations to present a clearer picture of total water use in the basin.

Figure 7 shows the percentage of reported withdrawals by registered facilities and estimated withdrawals by non-registered facilities in 1987. As the figure shows, total registered and non-registered withdrawals averaged about 83 mgd (million gallons per day).

Irrigation is the major withdrawal use in the Kankakee River Basin, constituting about one-third (26 mgd) of all water withdrawals. The 446 registered irrigation facilities account for about 84 percent of all registered facilities. It should be noted, however, that only about 6 percent of all farms in the nine-county basin region have irrigation equipment, and less than 5 percent of the basin's cropland acreage is irrigated.

Energy production is the second highest water use in the basin, accounting for about one-fourth (21 mgd) of total withdrawals (figure 7). Most of the water withdrawn for energy production is used at the R.M. Schahfer generating station in northern Jasper County, primarily for cooling purposes. Unlike withdrawals at the Schahfer plant, withdrawals by the other five registered facilities are relatively small and are not used directly for power generation.

Public supply, the third major water use in the Kankakee River Basin, constitues about 19 percent (16 mgd) of total basin withdrawals. In general, withdrawals for this purpose are greatest in counties having large cities or towns.

About 63 percent of the basin residents obtain their water from non-registered, privately owned domestic wells rather than from public supply systems. Non-registered, **domestic self-supplied** withdrawals account for about 13 percent (11 mgd) of all water withdrawals (figure 7).

Industrial self-supplied water uses in the basin, which occur in both urban and rural areas, account for about 6 percent (5 mgd) of total water withdrawals (figure 7). Most of the water is withdrawn from stone quarries and gravel pits.

About 1 percent (1 mgd) of all water withdrawals in the basin are used for purposes such as recreation, flooding and drainage control, and fish rearing. These withdrawals are registered with the Division of Water under the **rural** and **miscellaneous** categories (figure 7).

Some withdrawals for **livestock** watering are included in either the irrigation or rural categories of registered significant water withdrawal facilities. For example, a large poultry operation based in White County is registered as a rural use.

In most cases, however, withdrawals for livestock watering are not included in water-use summaries by registered facilities. Estimated withdrawals from non-registered facilities constitute about 4 percent (3 mgd) of the basin's water use (figure 7). About three-fourths of the water for livestock is utilized by hogs and beef cattle.

Instream uses

Instream uses are defined as non-withdrawal uses taking place within a stream, lake or reservoir. Instream uses in the Kankakee River Basin primarily include recreation activities, fish and wildlife habitat, and waste assimilation.

The generation of **hydroelectric power** is a common instream use in some areas of Indiana where stream flows are sufficient and the hydraulic head (difference in water surface elevation) above and below the turbines is adequate. Because of the nearly flat stream gradient and low average velocity, no sites on the Kankakee River in Indiana are suitable for the economic production of hydroelectric power. However, a hydropower plant once operated on the Kankakee River in Illinois near the city of Kankakee (figure 2).

Water-based **recreation** activities such as fishing, swimming, boating (including motorboating, canoeing and sailing), water skiing, and ice skating are available throughout the Kankakee River Basin. Hunting, camping, nature study, birdwatching, walking, jogging, running, and bicycling are among the activities that are strongly associated with or enhanced by the presence of water. These water-oriented activities account for at least half of all recreation occasions in the basin.

Fishing and boating occur mainly on the major lakes and on the Kankakee, Yellow and Iroquois Rivers. Swimming opportunities are available primarily on large lakes, such as Worster Lake (Potato Creek Reservoir), Bass Lake and Cedar Lake.

Hunting and fishing are major activities at the five state-owned fish and wildlife areas, three of which are located along the mainstem Kankakee River. Other outdoor recreation activities compatible with fish and wildlife management are permitted and encouraged. Hiking, boating and nature study are popular at the basin's three wetland conservation areas, where additional public uses may be permitted.

A variety of recreation opportunities are available at Potato Creek State Park, the most-visited public recreation area in the basin. Municipal and county parks, privately owned campgrounds, and privately owned hunting clubs also provide recreation opportunities. Three county parks along the Kankakee River are located in Lake County, and seven municipal parks along the Yellow River are located in Marshall and Starke Counties.

Most lakes and streams in the Kankakee River Basin are surrounded by land in private ownership, and public access to recreational waters is limited. However, the IDNR Division of Fish and Wildlife has developed public access sites on the Kankakee, Yellow and Iroquois Rivers. Access sites managed by the IDNR also have been developed on more than a dozen lakes. Rivers and lakes also may be accessible in public or private recreation areas, parks, or from highway bridges.

Water-dependent **wildlife habitat** in the Kankakee River Basin primarily is composed of the wetlands associated with natural lakes and streams. Open waters and the adjoining wetlands are excellent habitat for shorebirds, waterfowl, beaver, muskrat, raccoon and a variety of upland game. Although most wetland habitats have been drained or filled as a consequence of development, some high-quality wetlands still remain as remnants of former wetland complexes. The conservation of these areas is discussed in the ***Surface-Water Hydrology*** chapter of this report under the subheading ***Wetlands***.

Warmwater **fisheries** are predominant in the basin's streams, although a few streams and one lake are stocked with trout, a coldwater species. Because the type of fish population found in streams and lakes largely depends on ambient water quality, fisheries are summarized in the ***Surface-Water Hydrology*** chapter of this report in the section entitled ***Surface-Water Quality***.

The effluents of **wastewater treatment** plants normally are discharged into streams having a sufficient ability to assimilate the wastes. Wastewater discharges are discussed in the ***Surface-Water Quality*** section of this report.

PHYSICAL ENVIRONMENT

Climate, geology and soils affect the availability of surface-water and ground-water resources. Climatic factors largely determine the amount of available precipitation in the basin. Geologic and soil factors determine the proportion of precipitation which runs off the land to become surface water, as opposed to that which infiltrates the soil and *percolates* through underlying materials to become ground water. Geology and soils also determine surface drainage characteristics, the vulnerability of *aquifers* to contamination, and the limits of ground-water development.

CLIMATE

Water availability and use in the Kankakee River Basin is directly linked to the regional climate, which is the long-term composite of daily weather events. The climate of the basin is broadly classified as temperate continental, which describes areas located within the interior of a large continent and characterized by warm summers, cool winters, and the absence of a pronounced dry season.

Precipitation and temperature throughout the basin vary considerably on a daily, seasonal and yearly basis. This variability is primarily the result of interactions between tropical and polar *air masses*, the passage of low-pressure systems, and the shifting location of the jet stream, a powerful air current about 6 miles above the land surface.

Water, topographic and land-use features in northwest Indiana produce unique climatic variations in parts of the Kankakee River Basin. As discussed later in this section under the subheading ***Lake Effect***, the most widespread and well-documented modifications of the basin's climate stem from its position relative to Lake Michigan.

Areas in the main Kankakee River valley south of the Valparaiso Moraine experience greater-than-normal temperature fluctuations and a shorter frost-free crop-growing season because of the low-lying terrain and the poor heat retention of sand, muck and peat soils. This land-based feature is described later in this section under the subheading ***Growing Season***.

An unusual precipitation record at LaPorte may be linked to urban-induced weather modifications originating from the Chicago-Gary metropolis, but the validity of the anomaly remains debatable (see box on next page).

Sources of climatic data

Most climatic data for Indiana are collected and analyzed by the National Weather Service (NWS) of the National Oceanic and Atmospheric Administration (NOAA). The agency gathers data from more than 100 Indiana stations belonging to one or more of three networks (climatic, hydrologic or agricultural).

Temperature and precipitation data from the **climatic** network are primarily intended to represent long-term conditions over large areas of uniform terrain and climate. Rainfall-intensity data collected from the **hydrologic** network of recording precipitation gages are used for river forecasting, flood forecasting and related planning purposes. (About two-thirds of these recording gages are co-located with non-recording gages belonging to the climatic network.) Data on precipitation, air and soil temperature, relative humidity and other parameters are collected at **agricultural** stations. All but two of these agricultural stations also belong to the climatic or hydrologic networks, or both.

At most NWS stations, precipitation and/or temperature data are collected once daily by observers who typically are employed by water utilities, wastewater facilities, industries, municipalities or agribusiness. More detailed meteorological data are collected at the 24-hour NWS offices at Indianapolis, South Bend, Ft. Wayne and Evansville. The NWS Midwest Agricultural Weather Service Center at Purdue University also collects and maintains detailed meteorological records, including hourly updates of weather and soil conditions at automated agricultural stations throughout the state.

Figure 8 shows the locations of official NWS stations in or adjacent to the Kankakee River Basin in Indiana. Table 8 presents selected information for these stations and additional stations located within 8 miles of the basin boundary. The 8-mile limit was selected primarily for convenience rather than meteorological considerations.

Climatic stations in and near the Illinois portion of the Kankakee River Basin are not listed in table 8 or

LaPorte anomaly

Although the greater-than-normal snowfall amounts at LaPorte and other areas in the Lake Michigan snowbelt can be attributed directly to lake-effect processes, the causes of LaPorte's so-called rainfall anomaly have not been conclusively determined. Since the publication of papers by Stout (1962) and Changnon (1968a), the climatological record at LaPorte has been cited widely as evidence of urban-related increases in convective precipitation and storm events. The validity of the alleged anomaly, however, has been questioned by those who attribute the unusual precipitation record to poor gage exposure or observer error.

Changnon (1968a) showed that from about 1925 to the mid-1960s, LaPorte experienced 1) increases in annual and monthly precipitation totals during the warm season of April through October, and 2) increases in the frequency of moderate to heavy rain days, thunderstorms and hailstorms. He presented evidence that the large metropolis and industrial activities in the Gary-South Chicago area, particularly the smoke and haze emanating from the area, may be responsible for increased summer precipitation downwind in LaPorte.

The LaPorte findings focused scientific interest on the controversial subject of inadvertent weather modification, which generally refers to artificially induced changes in weather occurring over fairly small geographic areas and under certain atmospheric conditions. The cumulative effect of these modifications over many years can potentially result in local or regional climate changes.

Throughout the 1970s, the Illinois State Water Survey and many other investigators conducted detailed studies of urban-related weather impacts in Chicago, St. Louis, Detroit, Cleveland, Houston, New Orleans, Washington, D.C. and other large cities. A brief summary of research projects and an extensive list of references are presented by Changnon and Semonin (1979). Additional results of studies conducted in the Chicago area have been published since that time (Changnon and others, 1979; Changnon, 1980a, 1980b).

Although the degree to which atmospheric processes originating over Chicago may influence LaPorte's rainfall remains debatable, the existence of urban-induced weather modification is well documented and is largely accepted by the scientific community. In general, large cities experience more clouds or haze than rural areas, more summer convective storms (including hailstorms and thunderstorms), and higher average temperatures. These differences result primarily from (1) the addition to the atmosphere of microscopic particles that serve as nuclei for the formation of tiny water droplets or ice crystals, and (2) the addition of heat from streets, buildings and other surfaces.

The existence of a precipitation anomaly at LaPorte during the 1930s to 1960s is supported by not only meteorological but also geophysical, economic and crop-yield data (Changnon and others, 1979). Moreover, Hidore (1971) established a correlation between rainfall data recorded at LaPorte and stream-flow data recorded on the Kankakee River at Davis.

Despite the documented evidence for urban-induced rain changes at LaPorte, the true existence of the anomaly was questioned throughout the 1970s (Holzman and Thom, 1970; Holzman, 1971a, 1971b; Maxwell, 1975; Machta and others, 1977). Critics typically discredited the precipitation record at LaPorte because of suspected observer bias, improper observational techniques, change in station location, or change in precipitation reporting procedures.

It is interesting to note that more than 10 years before discussions of the local precipitation anomaly appeared in the scientific literature, published weather records contained comments regarding the possibility of a non-representative gage location at LaPorte. The average annual precipitation of 50 inches for the 18-year period between 1931 and 1948, for example, exceeded averages of other basin stations by 12 to 15 inches (National Oceanic and Atmospheric Administration, [1958]).

Later data summaries for LaPorte did not contain any qualifying statements, but 30-year averages continued to be significantly higher than averages at nearby locations. The most recent 30-year average of 41.6 inches is at least 4 inches more than averages at other stations in and near the Kankakee River Basin (table 9).

This unusually high average of 41.6 inches can be partially attributed to the extremely high precipitation totals recorded in 1954 (71 inches) and 1959 (66 inches). Moreover, annual amounts of at least 45 inches were recorded in 1951, 1955, 1957, 1958, 1961 and 1968. However, the accuracy of these annual totals remains questionable.

The debate over the existence of the LaPorte anomaly was further complicated when the rain gage was relocated in 1967 and the station was moved in 1970. Changnon and Huff (1977) postulated that the LaPorte anomaly was fallaciously ended when the gage was moved to a poor exposure, which subsequently yielded erroneously low rainfall readings. The 30-year average for the period 1951-80 shown in table 9 thus encompasses two periods, one of questionably high values and one of questionably low values.

In any case, the LaPorte anomaly has not been detectable since the 1960s. Causes for its disappearance or lack of detection do not appear to be related to alterations in urban influences. Instead, climatological evidence indicates that meteorological conditions resulting from changes in general circulation patterns could have produced a temporal and/or spatial shift in the anomaly to an ungaged area over Lake Michigan (Changnon, 1980c).

shown in figure 8. However, precipitation and temperature data are available for the following locations in Illinois: Crete and Peotone in Will County; Kankakee in Kankakee County; Watseka in Iroquois County; and Hoopeston in Vermilion County. Data from any of these five stations in northeastern Illinois can supplement data collected in northwestern Indiana. The general locations of these stations are apparent in figure 4.

Climatic data collected at NWS stations are published in a variety of formats by NOAA's National Climatic Data Center (NCDC) in Asheville, North Carolina (see Hatch, 1983). Most of the data presented in the following pages were obtained from tabular summaries for

Indiana stations (National Oceanic and Atmospheric Administration, 1976, 1982a, 1982b, 1983a, 1984, 1985). The data in four of these source documents encompass the most recent climatic base period, 1951-80. A 30-year period ending on the decade is used by NOAA to evaluate climatic conditions and to calculate climatic *normals* (National Oceanic and Atmospheric Adminstration, 1983b).

Data are available from the NCDC on a monthly and annual basis in several serial publications, including three entitled ***Climatological Data***, ***Hourly Precipitation Data***, and ***Local Climatological Data***. Additional data are available in other serial and periodic publications.

A vast array of climatic data and climate-related products also are available at the Midwestern Climate Center, a federally funded regional center located at the Illinois State Water Survey in Champaign, Illinois. The center collects, analyzes and disseminates climatic data for nine midwestern states, including Indiana. Some databases and special data products are oriented toward agriculture and water resources, and could therefore be of benefit to water management applications in the Kankakee River Basin.

Unpublished daily and monthly precipitation data are collected at official NWS stations recently established at North Liberty, Knox, Fair Oaks, and Morocco. In addition, unpublished daily and monthly precipitation data are available from the NWS forecast office in Indianapolis for several unofficial stations in and near the Kankakee River Basin. Data from unofficial stations are collected by amateur radio operators as part of a statewide volunteer network used to enhance the NWS river and flood forecasting program. Data from this network would be of limited use for most water management applications because the network is modified often and the data are filed only on a temporary basis.

The Indiana Department of Natural Resources, Division of Water operates a network of precipitation stations in Indiana, including five stations in the Kankakee River Basin (figure 8). Data from these stations are used for hydrologic and hydraulic studies. Precipitation records are filed for an indefinite period at the division.

Climatic features

Although the climate of the Kankakee River Basin encompasses variations in wind, clouds, humidity, solar radiation and other elements, the following sections focus on variations in precipitation, temperature, and *evapotranspiration*. Precipitation is the source of fresh water occurring on or below the land surface. Temperature defines the frost-free growing season for most crops, and largely controls the process of evapotranspiration, which consumes about 70 percent of the average annual precipitation in northern Indiana.

The discussion of climatic features is intended to present an overview of the basin's climate rather than to provide detailed data for site-specific planning or design work. Moreover, the discussion does not address long-term climatic changes or future trends. Additional data for specialized applications can be found in references cited in the text.

In some regional summaries of climate, data are grouped and analyzed on the basis of geographic areas having homogeneous climate. The U.S. Department of Agriculture has divided Indiana into nine crop-reporting districts, which are synonymous with the nine climatic divisions defined by NOAA.

In the following sections of this report, however, summaries of precipitation and temperature for the Kankakee River Basin are derived from analyses of station data for Kentland, LaPorte, Plymouth and Wheatfield. These stations are located within the basin boundary and have at least 30 years of data record. Data for Rensselaer are not included in the discussion because published climatic summaries are not available (table 8, column 6).

Because the historical precipitation record at LaPorte has been of questionable accuracy (see box on previous page), precipitation amounts at Valparaiso and South Bend are included in some analyses. Both cities are located within 2 miles of the basin boundary and data from these stations are considered to be representative of climatic conditions in the northern basin. Moreover, South Bend, like LaPorte, lies within the major snow belt associated with Lake Michigan.

Lake effect

The presence of Lake Michigan produces unique climatic conditions in northwestern Indiana, including modifications of temperature, humidity, cloudiness,

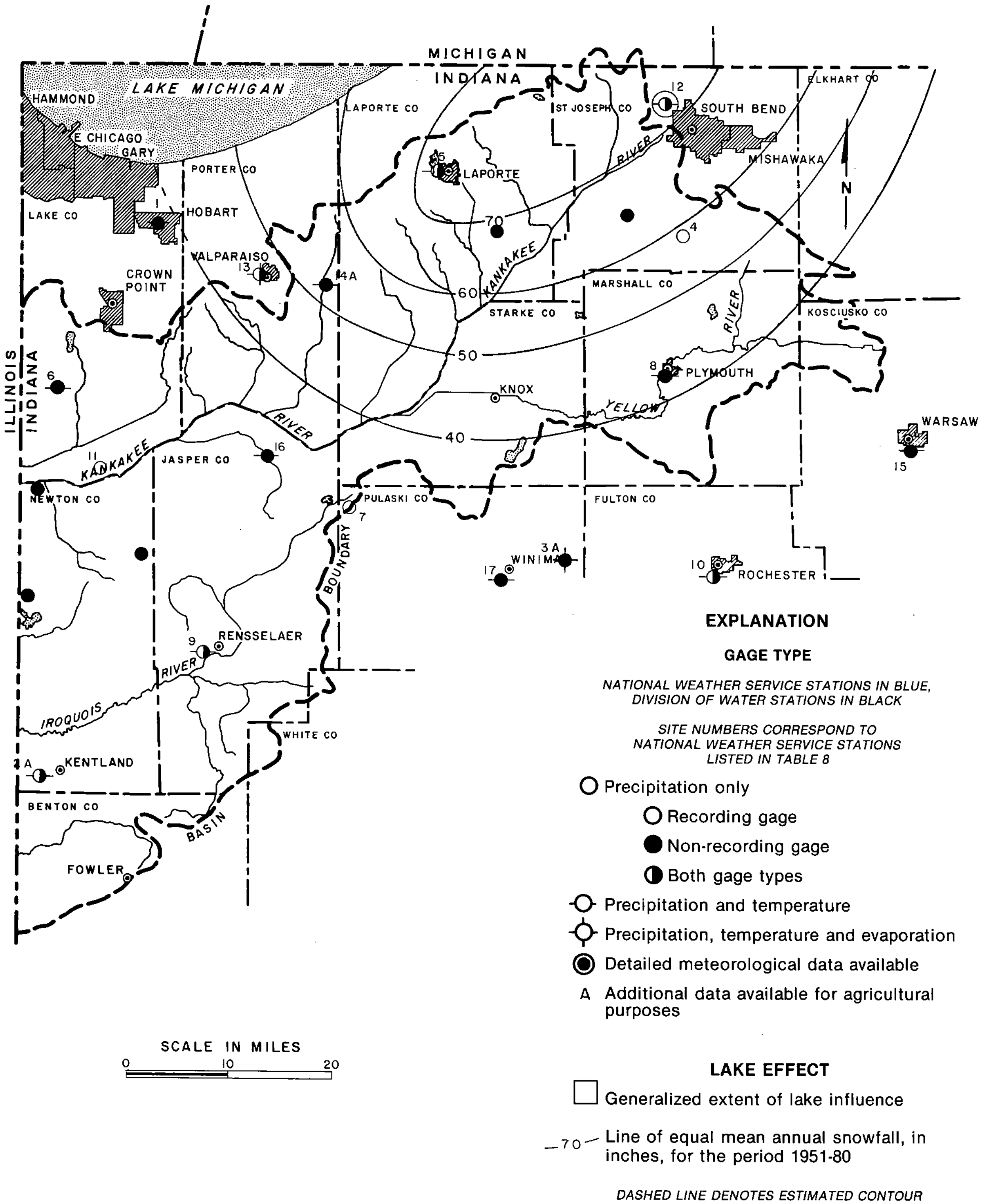


Figure 8. Location of climate stations, extent of lake effect, and mean annual snowfall in and near the Kankakee River Basin

Table 8. National Weather Service stations in and near the Kankakee River Basin

Map number: Station locations are shown in figure 8.

Station: Only active stations are tabulated. Historical data for discontinued stations in Indiana are available for Culver, Fowler, Michigan City, University of Notre Dame, and Winona Lake, all of which were located either in the basin (Fowler) or within 8 miles of the basin boundary.

Data network: A, climatological network and/or B, hydrologic network (National Weather Service); AG, agricultural network (Purdue University).

Data type: P, precipitation; T, temperature; E, evaporation and wind; S, soil temperature; D, detailed data on a variety of parameters. Additional agricultural-related data are collected at Kentland, Kewanna, and Wanatah, but are not published by the National Oceanic and Atmospheric Administration.

Publication, ongoing: Precipitation and/or temperature data are published monthly and annually by the National Oceanic and Atmospheric Administration in the following reports — CD, *Climatological Data* (precipitation amounts are from non-recording gages); HP, *Hourly Precipitation Data* (precipitation amounts are from recording gages); LCD, *Local Climatological Data* (detailed data published).

Publication, periodic: Climatological summaries are published every 10 years, generally at the end of a 30-year period. Numbers refer to footnotes.

Period of record: Approximate total length of precipitation record, through 1980 inclusive. Years of record are taken from 1980 annual summaries of *Climatological Data* and *Hourly Precipitation Data*. Hourly precipitation data may not be available for all years of record at hydrologic (B) network stations.

Map no.	Station name	Data network	Data type	Publication		Period of record	
				Ongoing	Periodic	Years	Dates
1	Hobart[1]	A	P,T	CD	2,3,4	61	1920-
2	Kentland	A,B,AG	P,T	CD,HP	3,4	41	1940-
3	Kewanna[1]	A,AG	P,T,E,S	CD	——	4	1977-
4	Lakeville	B	P	HP	——	39	1942-
5	LaPorte	A,B	P,T	CD,HP	2,3,4	86	1895-
6	Lowell	A	P,T	CD	——	18	1963-
7	Medaryville St. Nursery[1]	B	P	HP	——	39	1942-
8	Plymouth Power Substation	A	P,T	CD	2,3,4	76	1905-
9	Rensselaer[5]	A,B	P,T	CD,HP	——	84	1897-
10	Rochester[1]	A,B	P,T	CD,HP	2,3,4	67	1914-
11	Shelby	B	P	HP	——	40	1941-
12	South Bend NWSO[1,6]	A,B,AG	P,T,D	CD,HP,LCD	3,7	93	1888-
13	Valparaiso Waterworks[1]	A,B	P,T,E	CD,HP	3,4	81	1900-
14	Wanatah	A,AG	P,T,S	CD	——	20	1961-
15	Warsaw[1]	A	P,T	CD	——	72	1909-
16	Wheatfield	A	P,T	CD	3	63	1918-
17	Winamac[1]	A	P,T	CD	3,4	74	1907-

[1]Within 8 miles of basin boundary in Indiana.
[2]National Oceanic and Atmospheric Administration, 1976.
[3]_______1982a, 1983a.
[4]_______1985.
[5]Located at Collegeville until July 1970.
[6]NWSO, National Weather Service Office.
[7]National Oceanic and Atmospheric Administration, 1982b.

wind and precipitation. The effects of Lake Michigan on local and regional climate are discussed in detail by Changnon (1968b), Changnon and Jones (1972), and Eichenlaub (1979).

Although modifications of climate by Lake Michigan are most pronounced within a mile or two of the shore, several lake-effect features extend about 25 miles inland. As figure 8 shows, this lake-effect area encompasses the northern part of the Kankakee River Basin, particularly the morainal areas lying north of the main river valley.

In general, northern parts of the Kankakee River Basin can experience warmer falls, cooler springs, higher humidity, increased winter cloudiness, and greater amounts of snow than other areas of comparable latitude. The most critical factor producing these and other climatic modifications is the lag in the warming and cooling rate of the lake's water surface relative to temperature changes of the adjacent land surface (Changnon and Jones, 1972).

The slower change in water temperature tends to moderate extremes in air temperature, a feature which typically is ascribed to a semi-marine climate rather than a continental climate. Although local lake breezes during summer reach only a mile or two inland, lake-induced changes in air-mass temperature can extend far enough south to help reduce the number of extremely hot or bitterly cold days in northern portions of the Kankakee River Basin.

Seasonal temperatures in northern parts of the basin also may reflect lake influences. Because the lake retains some of its summer warmth through midwinter, minimum temperatures during the fall and early winter are higher than in areas farther south. Conversely, the water retains its winter chill long after the land has thawed; hence, areas near the lake tend to experience maximum spring temperatures that are cooler than those in areas of comparable latitude.

Lake-effect clouds in the Kankakee River Basin most commonly occur in Lake, Porter, LaPorte and northwestern St. Joseph Counties, especially during the fall when the lake is warm relative to land. Depending on wind speed, wind direction and other weather conditions, large areas of the basin also may experience occasional periods of lake-induced cloudiness during the fall and winter.

Winter-season clouds and snow can develop near Lake Michigan when polar air gains warmth and moisture as it passes over the relatively warm water. As the warmed, moisture-laden air rises, it cools *adiabatically*. If the air is cooled to its condensation point, clouds, rain or snow may form.

Under certain weather conditions, an additional impetus for winter-season cloud formation and snowfall may be provided by frictional effects as the air passes over land, which can produce further lifting of the moist air. Another impetus for cloud formation and snowfall may be provided by *orographic lifting* as the air ascends the elevated Valparaiso Moraine (see figure 14), whose crest is as much as 300 feet above the lake surface.

Lake-effect snows of the Great Lakes region are unique because only a few areas of the world experience this mesoscale feature on a significant scale (Eichenlaub, 1979). In Indiana, lake-effect snows are most common in Lake, Porter, LaPorte and St. Joseph Counties, an area which includes the northern Kankakee River Basin (figure 8). Depending on weather conditions, lake-effect snows sometimes can occur farther inland, affecting other portions of northern and even central Indiana.

Fetch, the length of wind travel over the open water surface, is a major factor in determining where the heaviest lake-effect snow will occur. North or northwest winds sweeping over Lake Michigan have a very large fetch and can aquire large amounts of warmth and moisture before crossing the downwind shoreline.

The major snow belt in Indiana associated with these northwest lake winds encompasses the northernmost part of the Kankakee River Basin in LaPorte and St. Joseph Counties (figure 8). Annual snowfall in the northern basin averages about 70 inches, which is twice the annual amount normally received in southern and western areas of the basin.

In unusually snowy years, annual snowfall amounts often exceed 100 inches in the snow-belt area of the northern Kankakee River Basin. Although storm systems deriving their moisture from the Gulf of Mexico can produce heavy snows, the higher average snowfall amounts in the northern basin are largely attributable to the high frequency of moderate to heavy lake-effect snows deriving their moisture from Lake Michigan. Changnon and Jones (1972) estimated that lake-effect snows account for 30 to 50 percent of the annual average snowfall in the snow belt.

Figure 9 illustrates the difference in average monthly snowfall amounts at cities located within and outside of the snow belt. Monthly amounts are considerably higher at LaPorte and South Bend, where lake-effect snows are common, than at other basin

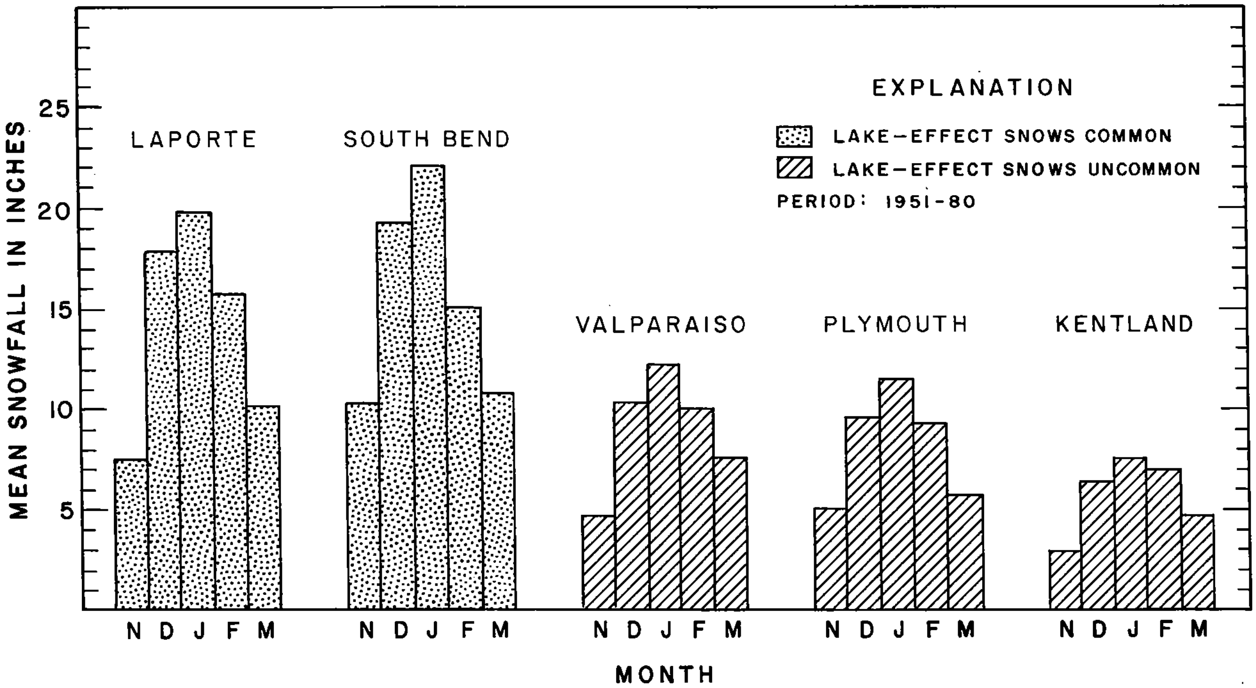


Figure 9. Comparison of mean November-March snowfall in and near the Lake Michigan snowbelt
(Data from National Oceanic and Atmospheric Administration, 1984, 1985)

cities, where lake-effect snows are relatively uncommon. Moreover, snowfall at LaPorte and South Bend constitutes about half of the average precipitation occurring from November through March. Elsewhere in the basin, less than one-third of the precipitation during this 5-month period is snow.

Figure 10 illustrates the variability in mean snowfall for November through March at selected cities. Snowfall amounts are plotted as 5-year *moving averages* to help detect possible trends in snowfall and to facilitate comparisons among different stations.

As figure 10 shows, seasonal snowfall amounts at the snow-belt city of South Bend are consistently higher than amounts at Valparaiso and Plymouth, which are located outside of the major snow belt. The values for South Bend also reflect several unusually snowy years. In the three snowfall seasons between 1976 and 1979, the city received a total of 400 inches of snow, or roughly twice the total amount which normally would have been expected. In the heavy snow season of 1981-82, South Bend received 135 inches of snow, which is second only to the 172 inches received in the 1977-78 season.

The steep and steady decline in 5-year mean snowfall at LaPorte appears to be anomalous, but no studies addressing the snowfall record were found during the preparation of this report. However, an analysis by Changnon (1979) revealed an anomalous trend toward decreasing winter precipitation at LaPorte and an increasing trend at South Bend.

The abrupt increases in 5-year values at Plymouth and Valparaiso during the late 1970s primarily reflect the heavy snowfall seasons of 1976-77 and 1977-78. The heaviest snows during these two seasons derived their moisture from the Gulf of Mexico, rather than from Lake Michigan.

Precipitation

Variations in **daily** precipitation are produced by daytime convection and the periodic passage of frontal systems. Precipitation events typically are interspersed among several dry days. The greatest 24-hour precipitation amount in the basin (6.4 inches) was recorded at Kentland on July 22, 1963.

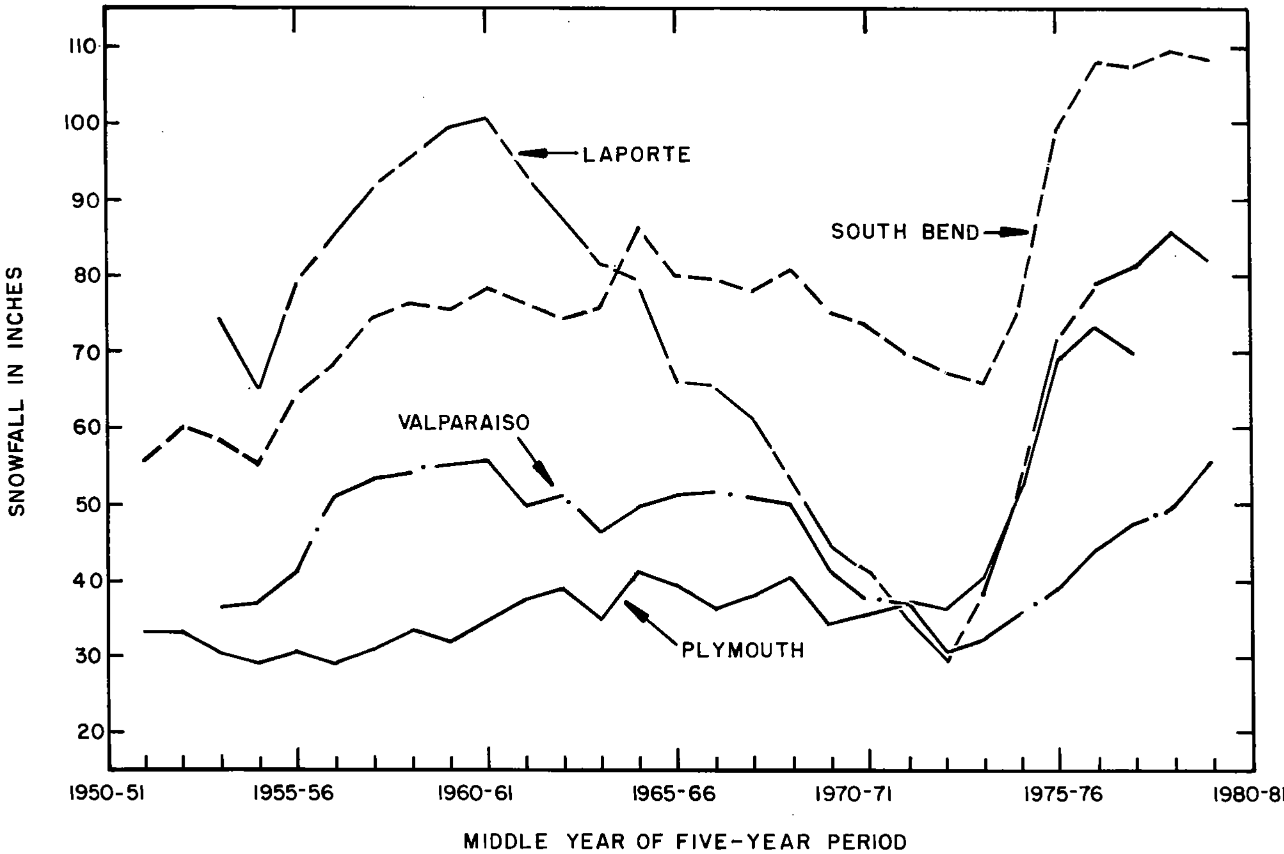


Figure 10. Five-year moving averages of total November-March snowfall

The National Oceanic and Atmospheric Administration has computed normal daily precipitation for South Bend by using a statistical function to *interpolate* from the less variable monthly normals. These daily values range from 0.07 inch in February, the driest month, to 0.14 inch in June, the wettest month. Although daily normal values do not exhibit the typical daily random patterns, they can be used to compute normal precipitation over selected time intervals (National Oceanic and Atmospheric Administration, 1982b).

Normal **monthly** precipitation at Kentland, Plymouth, Wheatfield, Valparaiso and South Bend ranges from 1.5 inches in February to 4.8 inches in June (table 9). Normal **seasonal** precipitation averages 6.2 inches in winter (December-February), 10.5 inches in spring (March-May), 12.1 inches in summer (June-August), and 8.9 inches in fall (September-November).

Precipitation during spring and autumn, which typically is associated with the passage of frontal systems, often occurs in the form of slow, steady rains over large areas. Most of the rainfall in late spring and throughout the summer is produced during localized thundershowers generated by the passage of cold fronts or by daytime convection. Local thunderstorms occasionally can become severe, and may be accompanied by strong winds, large hail, frequent lightning, funnel clouds or tornadoes.

In most areas of the Kankakee River Basin, about two-thirds of the winter-season precipitation falls as rain, and the remainder falls primarily as snow. The majority of snowfall occurs between the months of November and March, although light snows have been recorded as early as September and as late as May near the basin's northern boundary. (As defined by the National Weather Service, the annual snowfall season ex-

Table 9. Normal monthly, seasonal and annual precipitation for the period 1951-80

{All values in inches; monthly data from National Oceanic and Atmospheric Administration, 1982a.}

Month	Kentland	Plymouth	Wheatfield	LaPorte[1]	Valparaiso	South Bend
SPRING						
March	2.9	2.8	2.9	3.2	2.9	3.1
April	4.1	4.1	4.1	4.3	4.3	4.1
May	3.7	3.5	3.4	3.2	3.6	2.8
Seasonal	*10.7*	*10.4*	*10.4*	*10.7*	*10.8*	*10.0*
SUMMER						
June	4.8	4.4	4.4	4.2	4.1	3.9
July	4.5	4.0	4.1	4.5	4.0	3.7
August	3.5	3.4	3.6	4.1	4.0	3.9
Seasonal	*12.8*	*11.8*	*12.1*	*12.8*	*12.1*	*11.5*
AUTUMN						
September	3.1	3.2	3.3	3.8	3.7	3.2
October	2.6	3.1	2.7	3.8	3.4	3.2
November	2.5	2.6	2.4	2.8	2.6	2.8
Seasonal	*8.2*	*8.9*	*8.4*	*10.4*	*9.7*	*9.2*
WINTER						
December	2.3	2.5	2.4	3.1	2.6	3.0
January	1.7	1.9	1.7	2.4	2.0	2.5
February	1.6	1.8	1.5	2.2	1.6	2.0
Seasonal	*5.6*	*6.2*	*5.6*	*7.7*	*6.2*	*7.5*
ANNUAL	37.3	37.3	36.5	41.6	38.8	38.2

[1]Base data may be anomalous.

tends from July of a given year to June of the following year.)

As mentioned previously in this section under the subheading ***Lake Effect***, annual snowfall in the basin ranges from about 70 inches in northern areas lying within the Lake Michigan snow belt to 30 inches in southern and western portions. In northern areas which frequently experience lake-effect snows, about 20 percent of the total annual precipitation falls as snow. In areas not significantly influenced by the lake, about 9 percent of the annual precipitation is snow.

Monthly and seasonal precipitation at any given location varies widely from year to year. Monthly precipitation during the frost-free season commonly ranges from about 2 to 6 inches (see National Oceanic and Atmospheric Administration, 1985), but monthly extremes may range from trace amounts to more than 14 inches. In general, total monthly rainfall amounts are more variable during the warm season than during the cool season.

The maximum monthly precipitation amounts in the basin for the period 1951-80 were recorded in October 1954, when a massive storm system passed through northwest Indiana. Plymouth received 14.5 inches of rain from the storm, and Valparaiso, located just outside the basin boundary, received 11.6 inches. LaPorte may have received as much as 18.3 inches, but this amount may be erroneously high.

Normal **annual** precipitation at Kentland, Plymouth, Wheatfield, Valparaiso and South Bend averages 37.6 inches for the period 1951-80 (see table 9). Normal precipitation appears to be highest along the basin's northern edge, as based on the historically higher annual averages at Valparaiso and LaPorte.

Total annual precipitation in the Kankakee River Basin ranges from about 25 inches, recorded at Wheat-

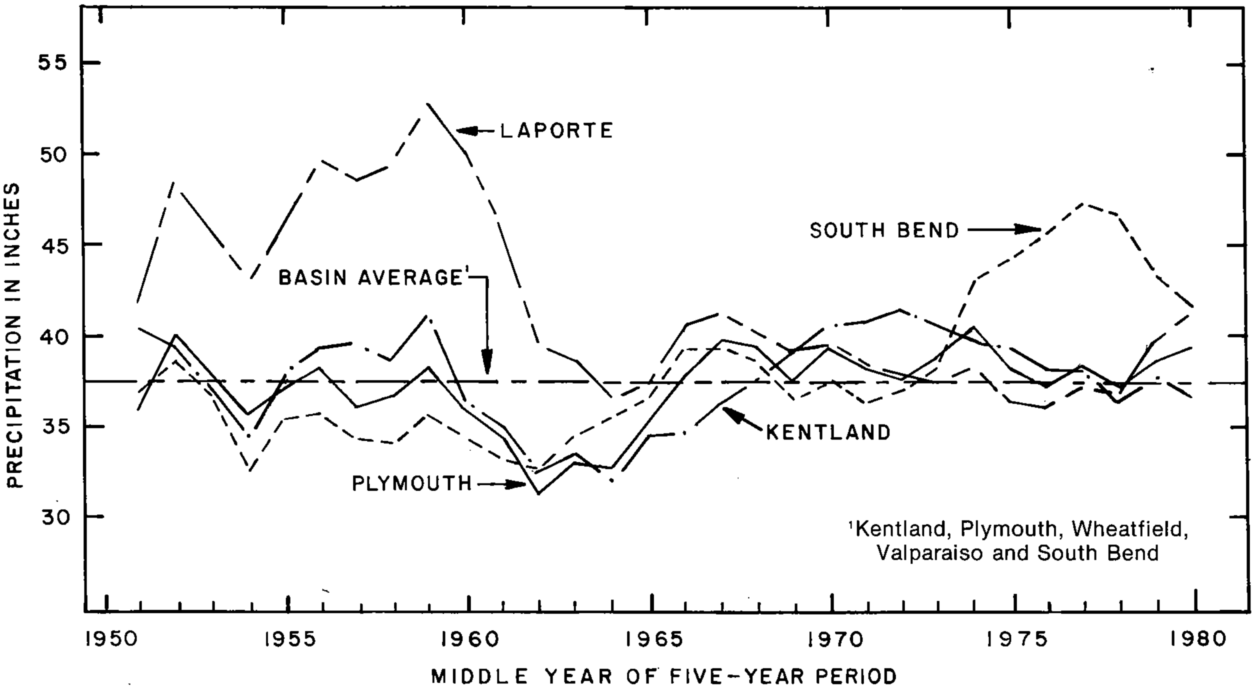


Figure 11. Five-year moving averages of total annual precipitation

field in 1956, to nearly 55 inches, recorded at Plymouth in 1954. An annual total of nearly 71 inches was reported at the LaPorte station in 1954, but the accuracy of the data is questionable.

Figure 11 illustrates the temporal and spatial fluctuations in annual precipitation at four stations in and near the basin. Values for Valparaiso and Wheatfield were not plotted because nearly all the points lie within the range defined by the curves for Kentland, Plymouth and South Bend.

The figure illustrates the fairly dry period of the 1950s to early 1960s, and the wet period of the 1970s. Also evident is the unusually wet period experienced at South Bend during the 1970s. It is likely that LaPorte experienced a very wet period from the 1930s (see box on previous page) through the mid-1960s (figure 11), but the degree of departure from normal is debatable.

Annual probability data (National Oceanic and Atmospheric Administration, 1983a) show that there is a 9-in-10 chance that the annual precipitation over a long period of time will average 30 inches or greater. Conversely, there is only a 1-in-10 chance that the annual precipitation will average 45 inches or greater. The data also reveal that annual amounts at Valparaiso are slightly more variable than amounts at other stations, perhaps owing to the presence of lake and topographic influences.

Temperature

The normal annual temperature at Kentland, LaPorte, Plymouth, and Wheatfield averages 50° F (degrees Fahrenheit). Normal seasonal temperature averages 49° F in spring, 72° F in summer, 53° F in autumn, and 26° F in winter.

Spring and autumn months generally are characterized by moderate temperatures, although brief periods of unusually cool or warm temperatures may occasionally occur. Summer months bring warm, humid conditions and occasional periods of oppressive heat. Winter months are characterized by short periods of extreme cold alternating with several days of milder temperatures.

January, the coldest month, has an average normal monthly temperature of 23° F and an average normal daily minimum of 14° F. On the average, about 5 days in January have minimum daily temperatures less than 0° F.

July, the warmest month, has an average normal monthly temperature of 74° F and an average normal daily maximum of 86° F. In most of the basin, an average of about 8 days in July have maximum daily temperatures of at least 90° F. In the basin's northern area between Valparaiso and South Bend, maximum temperatures of at least 90° F typically occur on only about 5 days, primarily because of the tempering effect of the cool lake on air mass temperature.

The range in daily temperature is generally least in winter, and greatest in summer. The average difference between normal daily maximum and minimum temperatures in the Kankakee River Basin is 17° F in winter, 22° F in spring and fall, and 24° in summer.

Near the basin's northern boundary, daily average temperature variations are about 2 to 3 degrees less than in southern portions because of the moderating effect of Lake Michigan on air-mass temperature. The lake's influence is especially apparent during autumn when the water's relative warmth causes average daily minimum temperatures to be higher in northwest Indiana than in areas farther south.

Extreme temperatures recorded at Kentland, LaPorte, Plymouth and Wheatfield for the period 1951-80 range from -24° F to 104° F. The highest temperature ever recorded in Indiana, 116° F, occurred at the Collegeville station on July 14, 1936 (Schaal, 1959). Also in 1936, the Wheatfield station reported a temperature of 112° F on July 10, 12 and 14.

Growing season

Along the northern edge of the Kankakee River Basin, the warming effect of Lake Michigan reduces the risk of early fall frosts. Conversely, spring cooling prevents the premature budding of sensitive fruit trees and other early crops, thus reducing the chances of crop loss due to late spring frosts. As a result of the fall warming and spring cooling, the length of the frost-free growing season for most crops is generally 2 or 3 weeks longer than in areas farther south. The average length of the growing season near the basin's northern boundary is about 170 days. The season typically extends from late April through the middle of October.

The longer growing season in the northern Kankakee River Basin, in combination with the moderate temperatures, higher humidity and hilly terrain, produces an environment suitable for the growing of frost-sensitive fruit crops such as apples, pears, peaches, grapes and berries. Orchards are especially commmon in northern LaPorte County along and just north of the Kankakee River Basin boundary.

In the southern part of the Kankakee River Basin, the length of the growing season is about 160 days. The season generally extends from early May through early October. The date of the last freezing temperature in spring and the first killing frost in fall varies greatly from year to year. For example, frost has been reported as late as June and as early as September.

In the main valley of the Kankakee River, the length of the average frost-free growing season is only about 150 days. The season, which typically extends from the middle of May through early October, is the shortest average season in Indiana. The unusually short season is mainly the result of the low-lying terrain and the predominance of sandy soils covered in places by mucks or peats. Because the soils gain and lose heat quite rapidly, they are highly susceptible to frost and freezing temperatures (Schaal and Newman, 1981).

Evapotranspiration

Precipitated water is continually being returned to the atmosphere as vapor through the processes of evaporation and plant *transpiration*. The combined processes of evaporation from water, soil, snow, ice, vegetation and other surfaces commonly are referred to as evapotranspiration.

In general, the rate of evapotranspiration ultimately is limited by the availability of water. The rate is affected by 1) meterological variables, including solar radiation, air temperature, vapor pressure gradients, and wind, 2) soil moisture, and 3) vegetative features such as plant type, plant growth characteristics, and the surrounding plant density.

Measurements of evaporation from the water surface in a shallow, circular pan can be used to estimate the maximum water loss possible from shallow lakes or saturated soils. The standard Class A evaporation pan used by the National Weather Service is an unpainted, galvanized metal tank about 4 feet in diameter and 10 inches deep. The pan typically is mounted on a wood frame a few inches above the ground. Proper

Table 10. Estimated mean monthly pan evaporation at South Bend

{Monthly values, from Farnsworth and Thompson (1982b), are averages of estimated pan evaporation derived from hydrometeorological measurements using a form of the Penman equation.}

Month and season	Estimated evaporation, in inches (1956-70)
WARM SEASON	
May	5.63
June	6.73
July	6.64
August	5.93
September	4.26
October	3.17
Season total	32.36
COOL SEASON	
November	1.61
December	0.88
January	0.83
February	1.00
March	2.08
April	3.80
Season total	10.20
Annual total	42.56

observation techniques are described in a National Weather Service handbook (National Oceanic and Atmospheric Administration, 1972).

Pan evaporation stations typically are operated between May and October, the frost-free growing season for most crops. In general, evaporation pans are not operated between November and April because frequent ice cover would produce erroneous measurements. Estimated monthly means of pan evaporation at South Bend (Farnsworth and Thompson, 1982b) show that nearly 25 percent of the annual total pan evaporation occurs during the 6-month winter period (table 10).

Although no pan evaporation stations are located within the Kankakee River Basin, stations within 8 miles of the basin boundary are located at Valparaiso and Kewanna (figure 8, table 8). Another Class A pan station in northwestern Indiana is operated south of the Kankakee River Basin at West Lafayette in Tippecanoe County. From 1961-74, pan measurements also were recorded at Culver, which is just south of the basin boundary in Marshall County.

Table 11 presents period-of-record averages of monthly and seasonal pan evaporation at the four stations. Differences in station exposure, observational techniques, and years of data record may largely account for the considerable variations among the average values.

As table 11 shows, mean monthly pan evaporation during the growing season ranges from an average of

Table 11. Warm-season mean monthly pan evaporation in northwest Indiana

{Monthly values, in inches, are from evaporation summaries in unpublished files of the Indiana Department of Natural Resources, Division of Water, August 1988.}

Station	May	June	July	Aug.	Sept.	Oct.	Total
Valparaiso 1947-87	5.27	5.90	5.89	5.06	3.43	2.22	27.77
Kewanna 1977-87	6.28	7.03	6.96	5.42	4.16	2.60	32.45
West Lafayette 1957-87	6.36	7.35	7.39	6.13	4.81	3.38	35.42
Culver 1961-74	6.64	7.69	7.38	6.25	4.77	3.20	35.93

about 7 inches in June and July to less than 3 inches in October. Although not shown in the table, monthly extremes range from a summer maximum of more than 9 inches (measured at West Lafayette) to an October minimum of about 1 inch (measured at Valparaiso).

It is generally accepted that multiplying total annual pan evaporation by a factor of 0.70 to 0.75 yields a reasonable estimate of annual evaporation from lakes or reservoirs. In turn, annual lake evaporation can be considered as approximately equivalent to free-water evaporation, which is defined as the evaporation from a thin film of water having no appreciable heat storage (Farnsworth and Thompson, 1982a). This interchanging of terms is probably valid for general usage because the net change in heat storage in a lake is negligible over a 12-month period, particularly if the lake is shallow.

Estimates of lake or free-water evaporation are important in reservoir design, rainfall-runoff modeling, and various water-supply studies. In most applications, the free-water value represents potential evaporation, which is the maximum water loss expected to occur from a shallow water body, saturated soil, or an adequately watered vegetative surface with an unlimited supply of water. As a good index to the maximum consumptive use of water by evaporation and transpiration, estimates of potential evaporation (or potential evapotranspiration) also can be helpful in determining soil moisture deficits for irrigation.

If average seasonal pan evaporation for the Kankakee River Basin is assumed to be 33 inches (see table 11), average annual pan evaporation is about 43 inches, according to the seasonal-to-annual ratio for South Bend (see table 10). Average annual lake (potential) evaporation, therefore, is 70 percent of this value, or about 30 inches. Visual extrapolation from maps of eastern Illinois (Jones, 1966) also yields a basin estimate of 30 inches.

This evaporation value of 30 inches is a generalized indicator of the maximum water loss that could be expected in a year of normal precipitation. Because the average annual precipitation in the Kankakee River Basin is nearly 38 inches, it can be concluded that there is, on the average, a potential water surplus in years of normal precipitation.

In dry years, the amount of moisture available from precipitation may be less than the potential maximum moisture needs for evapotranspiration. The moisture deficit in a dry year can be considered a conservative index of the amount of water that must be applied through irrigation to supplement precipitation. However, the actual amount of water needed would depend on many variables, including local rainfall, soil type and soil moisture conditions.

In theory, it can be assumed that when soil moisture is not limiting to crop growth, the potential evapotranspiration is the same as the actual evapotranspiration. Because the availability of moisture for evapotranspiration varies continually in time and space, however, actual evapotranspiration often occurs at less than the potential rate.

Studies in central Illinois revealed that average annual evapotranspiration is roughly 84 percent of the average annual potential evapotranspiration during years of normal or above-normal precipitation (Schicht and Walton, 1961). If annual potential evapotranspiration in the Kankakee River Basin is assumed to be 30 inches, then the actual evapotranspiration is about 25 inches during years of normal precipitation.

Estimated values of 25 to 26 inches also have been obtained by Jones (1966), who used a water-budget approach for the Illinois part of the basin, and by Newman (1981), who used the Thornwaite method as described by Palmer and Havens (1958) for the crop-reporting districts of Indiana. The agreement among values derived from different methods is notable, considering the large basin size, the spatial-temporal variability of rainfall and runoff, and the theoretical and empirical weaknesses inherent in estimating techniques.

The loss of 25 inches (nearly 70 percent) of the average annual precipitation to evaporative processes represents the single largest consumptive use of water in the Kankakee River Basin. Although the remaining 12 to 13 inches of water is considered adequate with respect to the basin's overall water budget, the spatial and temporal variability of rainfall from year to year and its uneven distribution during any given year can occasionally limit crops and water supplies.

Climatic extremes

Extreme climatic events such as droughts and flood-producing storms are infrequent but can have far-reaching economic impacts. In the Kankakee River Basin, economic losses caused by floods and drought are most widespread in agriculture areas, although some urban and residential areas also can sustain major damage.

Heavy rainstorms can be described statistically using rainfall frequency analysis. Rainfall frequency data are used primarily in developing design criteria for drainage, flood-control and water-supply projects. These water-control projects generally are designed for flood events of selected magnitude and frequency in order to achieve an economic balance between the average cost of damages from occasional floods, and the cost of protecting facilities against larger, less frequent floods.

Three reports published by NOAA summarize rainfall frequency data for selected durations from 5 minutes to 10 days and return periods from 1 to 100 years (Hershfield, 1961; U.S. Weather Bureau, 1957, 1964; National Oceanic and Atmospheric Administration, 1977). Other reports provide data on *probable maximum precipitation* (Schreiner and Riedel, 1978; Ho and Riedel, 1980) and rainfall intensity-duration-frequency (U.S. Weather Bureau, 1955). A report by the Indiana Department of Natural Resources (1982e) summarizes the NOAA data for Indiana and provides interpolated estimates of rainfall values.

The Midwestern Climate Center in Illinois is updating heavy-rainfall frequency values for midwestern states. The analyses, which utilize data from NWS stations, will provide values on a more detailed scale than values published by NOAA. A preliminary report was in preparation in early 1990 (J. Angel, Illinois State Water Survey, personal communication, 1990).

The term **drought** is generally associated with a sustained period of abnormally low water or moisture supply. Drought, unlike a flood, is not a distinct event because its onset and termination are difficult to recognize. Moreover, the variation in duration, severity and spatial extent leads to a wide variation in environmental and socioeconomic impacts.

Although the most well-known droughts encompass large areas, the variability of rainfall in combination with other factors can produce localized drought conditions in areas having an overall water surplus. In the Kankakee River Basin, for example, rainfall deficits in localized areas may lead to crop stress during critical periods of the crop-growing season, even though precipitation in the basin as a whole may be at normal levels.

Because of its complex nature, drought can be defined in several ways. Terms referring primarily to the physical conditions of moisture deficiency include **meteorologic drought**, which focuses on deficiencies of precipitation, and **hydrologic drought**, which explains drought in terms of reduced stream flow, ground-water levels, or reservoir storage.

Terms referring to impacts of below-normal precipitation on sectors of society include **agricultural drought** and **urban** or **water-supply drought**. Agricultural drought is defined as a continued period of moisture deficiency so serious that crops, trees and other vegetation fail to develop and mature properly. In a water-supply drought, water shortages lead to adjustments in water-supply management, such as the implementation of conservation measures or the use of alternate water supplies.

One well-known measure of the severity and extent of meteorologic drought is the Palmer Drought Severity Index, one of three Palmer indices (see Palmer, 1965; also see Alley, 1984, 1985). Values of the Palmer Index for climatic divisions of each state are reported monthly, and sometimes weekly, in documents published jointly by the U.S. Departments of Commerce and Agriculture. Other drought indices are based on cumulative precipitation deficits, reservoir storage, stream flows, ground-water levels, or other hydrologic factors relevant to water supply and agricultural activities.

Because drought severity indices commonly are used to initiate drought response activities such as water conservation measures and financial assistance, it is crucial that the selected indices provide a representative assessment of drought conditions. Researchers at Purdue University are working cooperatively with the Indiana Department of Natural Resources, Division of Water to develop regional drought indicators for Indiana (Delleur and others, 1990).

Although the drought of 1988 brought the driest April-June period on record and the hottest June-August period on record to northwest Indiana, a discussion of its characteristics and impacts is beyond the scope of this report. A report by Fowler (in preparation) describes the drought's effects in Indiana.

Several publications describe various aspects of drought preparedness. Reports by the former Indiana Drought Disaster Preparedness Committee (1977), the former Indiana Drought Advisory Committee (1988), and the Great Lakes Commission (1989) discuss drought preparedness and planning for Indiana. Articles by Changnon (1987), Easterling and Changnon (1987), and Changnon and Easterling (1989) are three among many publications by staff of the Illinois State Water Survey which address drought climatology, impacts and preparedness in Illinois.

GEOLOGY

Geology of the Kankakee River Basin affects water resource availability by influencing the distribution of precipitation between surface-water and ground-water regimes. Geology also helps control the storage of water in the basin because it largely determines the *topography*, soils and *aquifers*.

The surface deposits in the basin are of glacial origin. A complex series of sediments deposited during repeated advances of *glacial lobes* (figure 12) form the major unconsolidated aquifers of the Kankakee River Basin.

Sources of geologic data

Ground-water and aquifer information for the Kankakee River Basin comes from many sources including water-well records, the observation-well network, *lithologic* descriptions from oil- and gas- well records, engineering borings, *seismic* information, and local project results, which include *pumping tests* and other analytical and mathematical models.

Since 1959, water-well drilling contractors have been required to submit to the Indiana Department of Natural Resources (IDNR) a complete record of every water well that is drilled in the state. More than 15,000 water-well records on file at the IDNR, Division of Water were analyzed for the ground-water assessment portion of this study. Most of the records are for shallow domestic wells less than 150 feet deep.

In 1987-88, the Division of Water and Indiana Geological Survey (IGS) drilled 54 test holes to supplement the water-well records and provide information on deep unconsolidated formations (appendix 2). Geologists from both offices made on-site geologic descriptions and collected samples for laboratory analysis by the IGS. This information was important in determining aquifer characteristics and the geologic history of the basin. Much of the interpretation of the glacial geology in this report comes from an unpublished report by Bleuer and Fraser (1989).

Physiography

Indiana can be divided into three broad *physiographic regions* according to the effect of glaciers on the landscape: 1) the area south of the

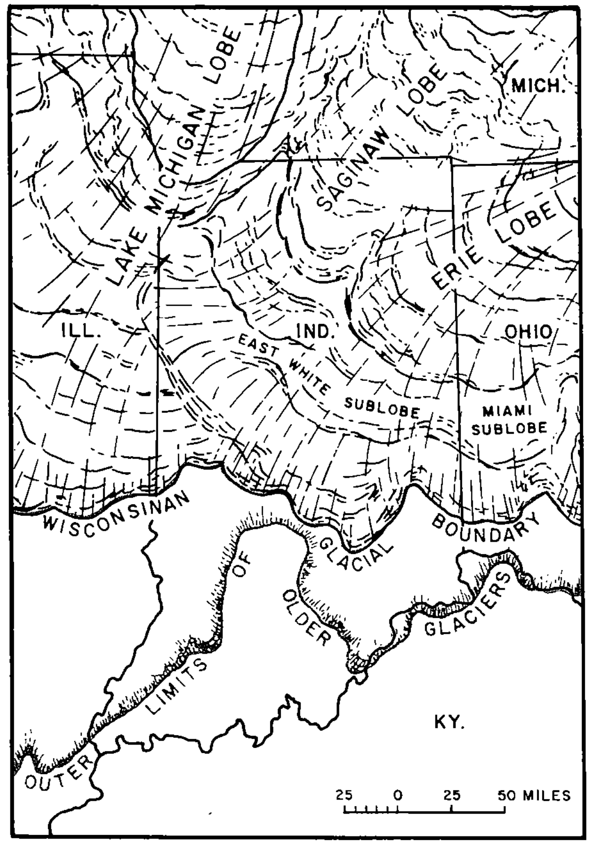


Figure 12. Extent of major ice lobes in Indiana during the Wisconsinan glaciation
(Adapted from Wayne, 1965)

Wisconsinan glacial boundary where bedrock controls the physiography; 2) a central area with a gently undulating *till-plain* surface; and 3) a northern region of glacial deposits characterized by fairly rugged relief.

Guided by the topography of these regions, Malott (1922) divided the state into nine physiographic regions (figure 13). Except for a small part of the basin in Benton County which is part of the Tipton Till Plain, the Kankakee River Basin lies in the Northern Lake and *Moraine* Region. Within this region, the Kankakee River Basin includes part of the Valparaiso Morainal Area, Kankakee Outwash and Lacustrine Plain, and Steuben Morainal Lake Area (figure 13).

Most of the landscape of the Kankakee River Basin is a product of latest Wisconsinan glacial events of the Lake Michigan Lobe (figure 12). The landscape of the

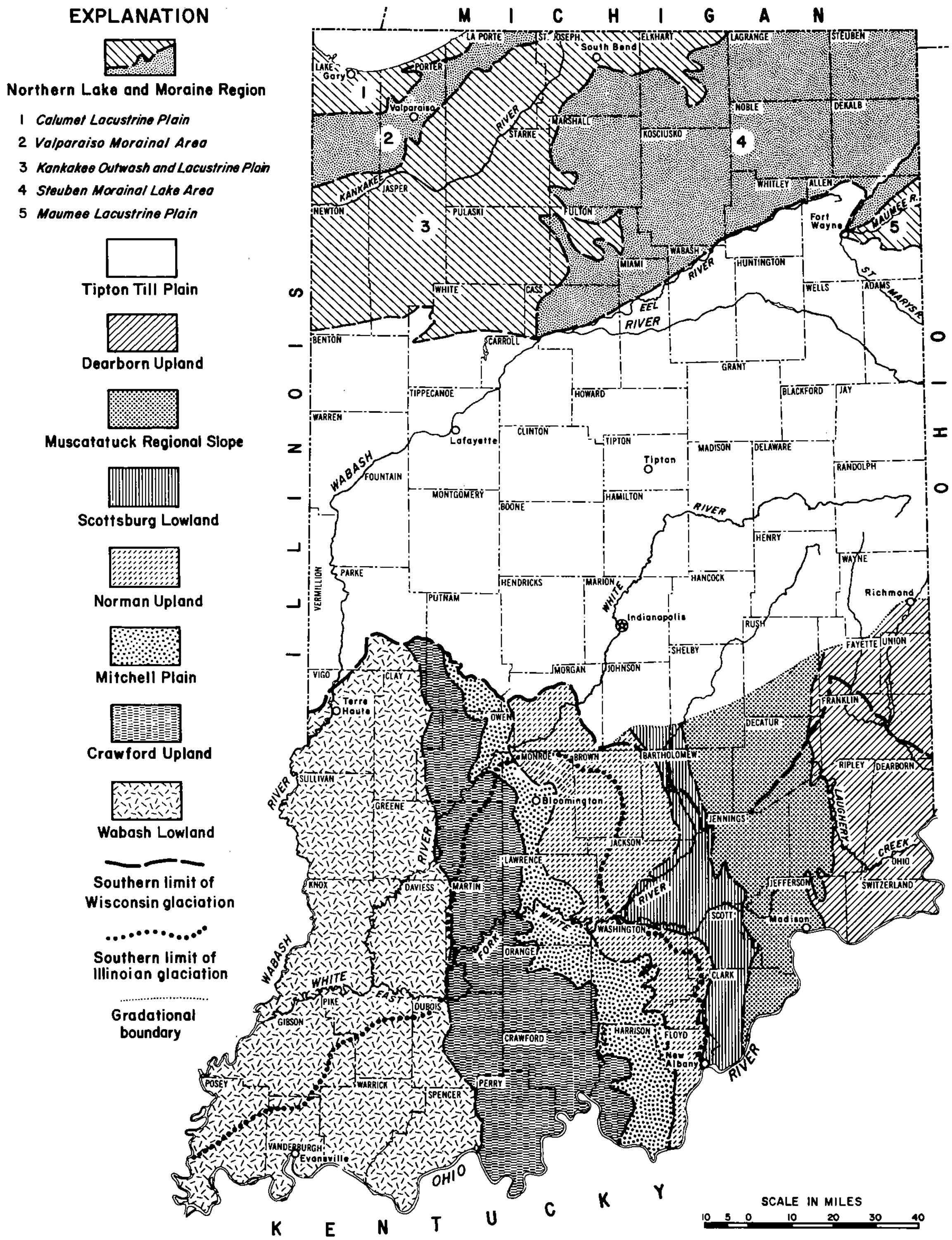


Figure 13. Physiographic regions of Indiana
(After Malott, 1922; modified by Wayne, 1956)

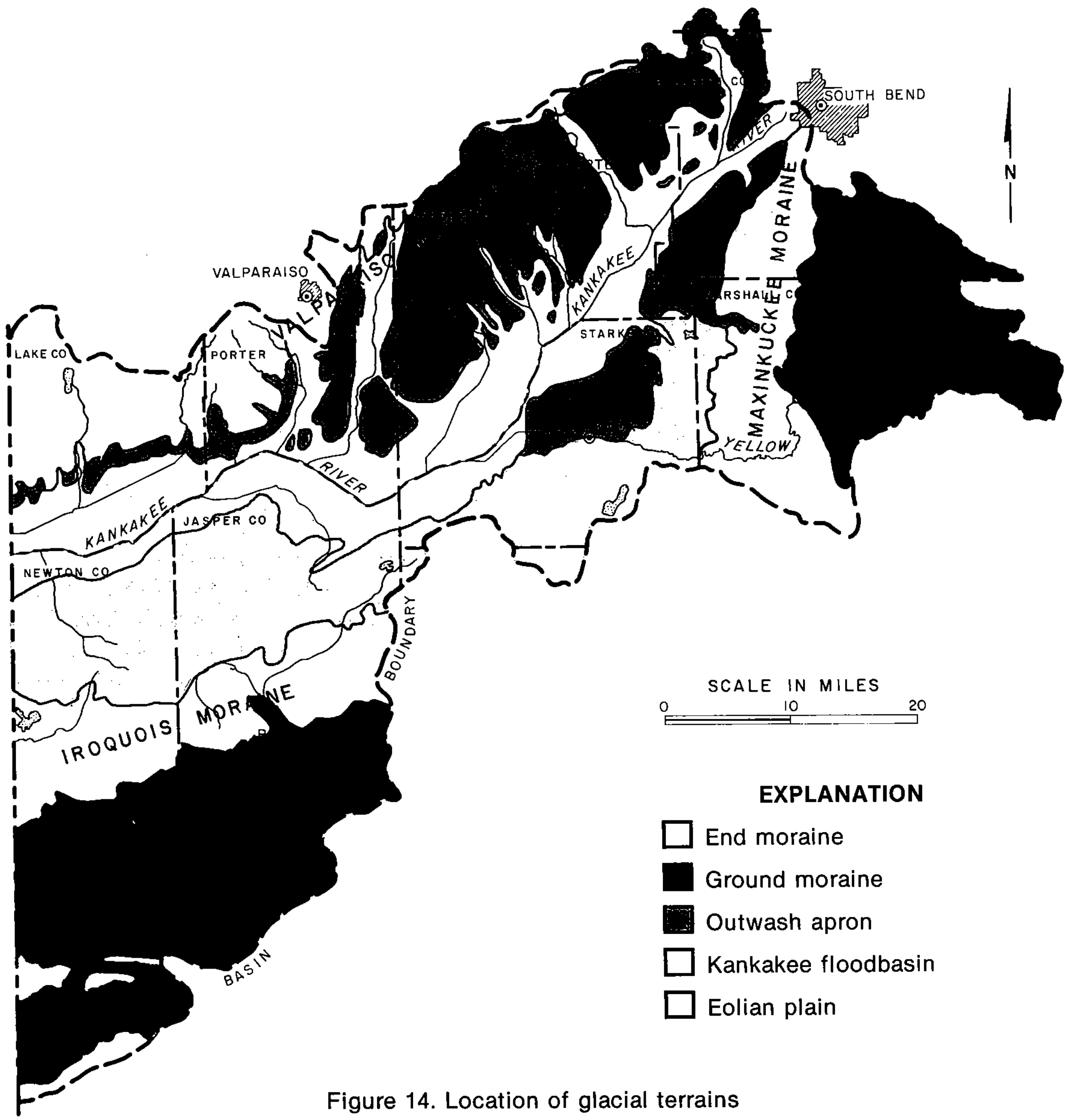


Figure 14. Location of glacial terrains
(Adapted from Wayne and others, 1966 and Schneider and Keller, 1970)

easternmost part of the basin, however, is a product of the Lake Michigan Lobe and eastern lobes, and in places overlies subdued or scoured topography on older *drifts*.

Various landscape elements in the basin have been identified on the basis of topographic form and internal composition. These elements, mapped as glacial terrains in figure 14, are characterized as *end moraine*, *ground moraine*, *outwash apron*, *floodbasin*, and *eolian plain*.

End moraines are the elements of greatest internal relief and highest regional elevation. End moraines are traditionally thought to be representative of ice-marginal or near-ice-marginal deposition.

The end moraines recognized in the Kankakee River Basin are of three general types: 1) classic till-rich, 2) dominantly *outwash*, and 3) tectonic. The portion of the Valparaiso Moraine west of the city of Valparaiso, which most closely resembles the classic concept of a till-rich moraine, is composed of thick, stacked tills of the Lake Michigan Lobe, overlying *outwash-fan* sediments. The Maxinkuckee Moraine and the portion of the Valparaiso Moraine east of the city of Valparaiso are composed of predominantly outwash materials which represent *subaqueous* and *subaerial* fans. Both outwash moraines have inner zones of complex ice-contact terrain; however, the inner zones are dissimilar in architecture as a result of different mechanisms of deposition. The Iroquois Moraine, a tectonic moraine and a form of push-moraine, is cored by up-thrust *lacustrine* sediments and till of the Lake Michigan Lobe, and is capped by till of the Huron-Erie Lobe.

The Valparaiso Moraine (figure 14) is an *arcuate* ridge that can be traced around the south end of Lake Michigan from southern Wisconsin through northeastern Illinois and northwestern Indiana to west-central Michigan. In Indiana, the moraine forms the northern boundary of the Kankakee River Basin.

The surface of the moraine in Indiana is asymmetric, being steeper on the north slope than on the south slope. Moreover, the moraine's thickness and surface elevation increases to the east.

West of Valparaiso, the moraine's crest elevation ranges from 700 to 800 feet m.s.l. (mean sea level). East of Valparaiso, the crest elevation is more than 800 feet m.s.l. and in some areas exceeds 950 feet m.s.l. Local relief east of Valparaiso exceeds 100 feet in many places along the crest and northern flank of the moraine.

The Maxinkuckee Moraine, which trends north-south through Marshall County and part of St. Joseph County (figure 14), is not as topographically distinct as the Valparaiso Moraine. The moraine has crest elevations as much as 900 feet m.s.l and average local relief of 75 feet.

The Iroquois Moraine, which trends northeast-southwest through Newton and Jasper Counties (figure 14), is an even more subtle topographic feature than the Valparaiso and Maxinkuckee Moraines. The moraine, characterized by *hummocky* local topography, stands as much as 80 feet above the till plain to the south. The elevation of its crest is about 740 feet m.s.l., and average local relief is 60 feet or less.

Across much of its northern boundary in Newton and Jasper Counties, the Iroquois Moraine is well defined, but becomes less defined to the northeast in Pulaski and Starke Counties. In this northeastern area it drops in elevation and grades into the till underlying the intermoraine lowland, which is identified as part of the Eolian Plain on figure 14.

Ground moraine, best illustrated by the relatively flat landscape south of the Iroquois Moraine, represents deposition of sediment by bottom meltout from ice disintegrated (downmelted) in place. The composition of the ground-moraine till is similar to that found in end moraines, but the topography of ground moraines is less pronounced.

Ground moraine underlies the Iroquois River Basin and the area east of the Maxinkuckee Moraine (figure 14). These areas have gently rolling topography and average local relief less than 40 feet. The Iroquois River Basin is surrounded by uplands, and the basin-floor elevation ranges from 630 to 700 feet m.s.l. The ground moraine east of the Maxinkuckee Moraine is a relatively high area and has elevations ranging from 800 to 850 feet m.s.l.

The **outwash apron** of the Valparaiso Moraine (figure 14) is a large wedge of sandy sediment that forms the southern slope of the moraine. The slope descends about 5 to 10 feet per mile from the crest of the moraine to the *scarp* of the *incised* valley of the Kankakee River.

The Kankakee **floodbasin** (figure 14) is a broad, nearly level, featureless plain that was once occupied by a glacial lake and is now surrounded by the uplands of moraines. The elevation of the floodbasin is about 700 feet m.s.l. in upstream reaches near South Bend, and descends to about 630 feet m.s.l. at the Indiana-Illinois state line. The floodbasin is about 2 miles wide near South Bend and widens to about 8 miles at the Indiana-Illinois state line. Part of the floodbasin is occupied by the modern floodplain of the Kankakee River.

An **eolian plain** (figure 14) has formed on the nearly level surface of the southern margin of the central lowland of the Kankakee River Basin. Dunes derived from fine-grained outwash sediment formed on the southern margin of the floodplain and migrated into the intermoraine lowland in Starke County. The dunes are oriented with their long axis north-south, indicating dominantly westward winds. The dunes stand 15 to 50 feet above the surrounding floodplain, which has an average elevation of about 650 feet m.s.l.

The topography of the eolian sand sheet is somewhat complex in Pulaski County where two different dune types occur. Areas covered with large coalesced dunes form ridges generally oriented north-south. Interdune areas are relatively level and merge gradually into the

Kankakee River floodplain. Isolated smaller dunes are scattered on the interdune surfaces.

Glacial geology

The landscape elements in the Kankakee River Basin are primarily the product of glacial processes (see box on next page). The occurrence of ground water within glacial deposits depends on the detailed *stratigraphy* of the deposits. Grain size, sorting, thickness, and the arrangement of deposits are important factors of an aquifer's hydraulic characteristics, and the occurrence of these hydrogeologic elements can be understood from the glacial context.

Meltwater streams flowing from a glacier carry and sort glacial debris. The finest material is carried farthest from the glacial front, whereas coarser material is deposited near the glacial front. The deposits of meltwater streams, or outwash, may form aquifers.

Till is a sediment that has been transported and deposited by or from glacier ice, with little or no sorting by water. The matrix material of till is generally fine-grained and can restrict rapid ground-water flow. An intratill aquifer is formed where outwash is surrounded by till in a complex glacial deposit.

Lakes occurring in glacial environments often form as meltwater is trapped by ice or glacial debris. In calm lake water, fine sediment deposits on the lake bed. Fine-grained lacustrine deposits can restrict rapid ground-water flow.

The previous discussion on physiography focused primarily on topographic forms in the Kankakee River Basin. The following discussion emphasizes internal composition of the landscape elements to provide a context for assessing ground-water availability.

Unconsolidated deposits

The **Valparaiso Moraine** west of the Valparaiso topographic sag generally is characterized by a broad till-capped area of subdued topography which is flanked to the south by a narrow apron of *outwash-fan* deposits. Thick surficial tills were deposited directly from glacial ice as it advanced over the fan deposits.

The moraine east of Valparaiso is characterized by a till cap of pronounced topography which covers the moraine's north flank and a narrow area on its crest. Glacial ice apparently did not advance far over the wide fan surface draping the moraine's southern slope. In some places in LaPorte County, no tills are present, and sand and gravel occur at the top of the sequence.

Medium-grained sands occur beneath the tills in the area west of Valparaiso and are the predominant *facies* of the outwash fan to the east. These sands extend from the morainal complex into the Kankakee River floodplain. The sands may occur as stacked channel fills with erosional *basal contacts*.

Lacustrine muds, underlying the Valparaiso moraine in most places, consist of interbedded laminated silt, silty *loam*, and silty clay loam containing small localized amounts of fine sand in thin layers. In some cases, the muds form a distinct coarsening-upward deposit that culminates in *deltaic* sands. In most places, however, the sands overlie muds with a sharp contact, which suggests an intervening period of erosion or nondeposition. The muds are thickest in the lower basin beneath the Valparaiso Moraine.

Thinner, less extensive deposits of lacustrine muds occur in the elevated part of the moraine. In this area the muds probably originated in depressions on the moraine surface that formed closed basins. The lacustrine muds are commonly interbedded with *debris-flow* tills or sands in deltaic sequences.

Despite variation in the occurrence of the morainal deposits, the vertical sequences of the Valparaiso Moraine usually indicate that deposition occurred with increasing proximity to the ice through time, which in turn suggests that much of the complex was deposited during a time of ice advance. The thinning and fining-upward sequences in channel deposits indicate the occurrence of channel abandonment, and coarsening and thickening-upward sequences indicate *progradation* of depositional lobes away from the ice front.

The typical sequence of deposits is related to the distance between the deposits and the ice front. In the most common sequence, lacustrine muds deposited far from the ice margin in a large glacial lake are overlain by sands deposited on the outer and middle parts of an outwash fan. The outwash sands are interbedded with black shale gravels deposited in mid-fan debris flows.

Black shale gravels occur throughout the Valparaiso Moraine and its outwash apron. Shale *clasts* can be as large as cobbles. In the lower basin the gravels fill channels which were cut in till, probably by debris flows. In the outwash fan east of Valparaiso, gravels

Glacial History of the Wisconsinan Stage

During the Pleistocene Epoch, glaciers advanced into Indiana several times, from several directions (figure 12). Most of the surficial deposits of the Kankakee River basin are the result of the latest events of the Wisconsinan Stage of glaciation, which lasted from 24,000 to 10,000 years ago.

Earliest Wisconsinan ice entered the basin area from the northwest and the east. Ice covered the entire basin, but representative deposits are found only in upland areas north and east of Plymouth in the subsurface of the Maxinkuckee Moraine and landscape to the east. In general, deposits derived from the earliest Wisconsinan advances are mutually exclusive in their distribution within this eastern area.

The two sequences of deposits appear to be plastered onto the edges and atop a pre-existing drift upland. Gray *loam* till of the Huron-Erie Lobe, derived from the southeast, occurs beneath surficial moraine/fan deposits in the Kosciusko County part of the basin. A pinkish loam till of the Lake Michigan Lobe, derived from the northwest, was deposited at about the same time and is present beneath surficial moraine/fan deposits in the Plymouth area.

Latest Wisconsinan ice entered the Kankakee River Basin area from the northwest, northeast and east. The deposits of these advances include a shaley, greenish-gray till of the Lake Michigan Lobe; a pinkish clayey till of the Saginaw Lobe; and a loamy till of the Huron-Erie Lobe (figure 12). The advance of the Lake Michigan and Saginaw Lobes appear to be roughly contemporaneous, followed by the advance of the Huron-Erie Lobe.

The shaley, greenish-gray till of the Lake Michigan Lobe in Indiana, is considered to be the equivalent of the Snider till in Illinois. This Snider-equivalent till, along with its thin cap of Trafalger till, constitutes most of the surficial materials in and south of the Iroquois Moraine. The Snider-equivalent till is associated with the stratified sediments of the Maxinkuckee Moraine to the east, and is present discontinuously beneath the Kankakee plain, where it is associated with lacustrine clays.

The Iroquois and the Maxinkuckee are topographically distinguishable moraines associated with the Snider till. The Iroquois Moraine is cored by Snider till and lacustrine clays, the clays apparently having been placed by ice thrust. The Maxinkuckee Moraine is predominantly a complex of outwash fans that drained eastward and southeastward.

The pinkish, clayey till deposited by the latest Wisconsinan advance of the Saginaw Lobe was deposited at about the same time as the shaley, greenish-gray till of the Lake Michigan Lobe. Associated, collapsed *supraglacial* outwash, expressed as *kames* near Nappanee, discharged westward from the Saginaw Lobe. *Proglacial* outwash fans from the Saginaw ice converged with distal aspects of the Maxinkuckee fan(s) in the lowland south of Bremen. A series of northwest-southeast trending ridges between Bremen and Nappanee may represent minor ridged moraine forms associated with this advance.

The later advance from the Huron-Erie Lobe, derived from the east, covered the southern part of the Kankakee River Basin along and south of the Iroquois Moraine. This ice left a thin cap of loamy till of the Trafalgar Formation. The Trafalgar till in the basin is associated with low-relief *disintegration* landforms, and is not associated with major topographic forms. The overall ground-moraine and moraine landscape reflects relief on the surface of the underlying till.

During the late stages of Wisconsinan glaciation of the Kankakee River Basin, the central part of the basin was covered by a large lake fed by *meltwater* streams. The lake formed as meltwater from the Lake Michigan Lobe was trapped by moraines to the east and south, ice to the north, and a bedrock high to the west near Momence, Illinois. This lake may have been part of a larger system of lakes whose deposits are found scattered throughout northeastern Illinois. The fine-grained sediment carried by meltwater streams was deposited on the lakebed, thus forming a distinctive clay layer.

The Lake Michigan Lobe formed the Valparaiso Moraine during the last major advance of the general recession of the Late Wisconsinan ice. The *prograding* deposits of the glacial streams formed an apron of sediment in front of the glacier. The south edge of the moraine is generally considered to mark a terminal position of the Lake Michigan lobe during the latest Wisconsinan.

When the ice moved southward following a brief northward retreat, meltwater streams deposited outwash sand and gravel over the glacial lakebed in most of Lake, Porter and LaPorte Counties, and parts of Jasper, Newton, and Starke Counties. In places, the glacial ice advanced over its outwash apron. When the glacial ice finally retreated from the basin, the wasting glacier deposited till over its outwash apron, forming the crest of the Valparaiso Moraine.

Since the retreat of the glaciers from the Kankakee River Basin 11,000 years ago, the existing surface drainage system of the basin has developed. The Grand Marsh formed where the Kankakee River flowed through the low-lying lake basin. Tributaries of the Kankakee River have incised their channels into the moraines and fan surfaces, reversed flow direction, or made other adjustments following the retreat of the glaciers and the discontinuation of the meltwater discharge.

LAKE MICHIGAN LOBE	***SAGINAW LOBE***	***ERIE LOBE***
Retreat		
Advance out of basin, building of Valparaiso Moraine **(event 4)**		
		Advance of sublobe of Huron-Erie Lobe from east, deposition of basal Trafalger till; general disintegration deposits across terrain south of valley **(event 3)**
Collapse into lake basin, basal and glaciolacustrine mudflow deposition in Kankakee lowland *(present basal deposits)*	General retreat or zonal stagnation	?
Advance out of basin over lake sediments, general recession, building of Iroquois Moraine — fan(s), western fan-delta additions to Bremen lowland *(shaley, greenish-gray till; Snider equivalent)* **(event 2)**	Advance onto existing eastern uplands, deposition of proglacial fan sequences, culminating in contributions to fill of Bremen lowland *(pinkish-clay till)*	?
Recession into lake basin	?	?
East edge of lobe advances to west edge of existing upland deposits near Plymouth. *(pink loam till; found only in subsurface beneath moraine/fan in Plymouth area)* **(event 1)**		West edge of lobe advances to south rim of existing upland deposits *(gray till, associated with kame topography of collapsed fan southeast of Plymouth; found only in subsurface beneath moraine/fan in Koscuisko County)*

fill buried channels and make up a significant portion of the fan deposit.

The upper portion of the Yellow River Basin occurs in the **Maxinkuckee Moraine** (figure 14) and ground moraine east of the moraine. The moraine consists of coalesced deposits of several glacial advances and is the most complicated terrain in the Kankakee River Basin. The deposits are uncommonly heterogeneous and are predominantly derived from a complex of outwash fans that drained eastward and southeastward. The moraine surface shows evidence of glacial stagnation that produced a mixture of deposits formed in outwash plains, collapsed drainage channels and lakes, till plains, and eolian plains.

The **Iroquois Moraine** is capped by thin *ablation* tills composed of moderately variable sandy or silty loams. Two major till sequences, thick lacustrine materials, and sand deposits lie beneath the ablation till. The upper till sequence is comprised of vertically uniform, silty loams having low areal variability. The lower till sequence is comprised of silty clay loams having low to moderate areal variability and no consistent vertical variability. Thick underlying lacustrine deposits are highly variable and have no consistent vertical variability. Sand deposits within the moraine are generally thin and are highly variable in occurrence.

The southern slope of the Iroquois Moraine is dominated by linear ridges, probably resulting from the Erie Lobe ice shearing up against the moraine which was formed earlier by the Michigan Lobe. The ridges are commonly sand-dominated and comprise some of the principle sand deposits of the moraine.

The **Iroquois Lowland**, consisting primarily of ground moraine, encompasses the floodplain of the Iroquois River and a major tributary, Sugar Creek. The lowland was formed during stagnation of the Erie Lobe. The Iroquois River Basin is coincident with the area where the Erie Lobe ice extended into the basin.

Low relief and subdued ice-disintegration features characterize the western part of the Iroquois Lowland. Features include broadly undulating topography, basins of internal drainage, and scattered linear sand ridges. The topography to the east is somewhat more rugged, and ice-disintegration features, especially ridge and trough systems, are better developed. The surficial cover in this eastern area is sand-dominated. Southeast of Rennselaer the sand has been remobilized into dunes.

A typical vertical sequence of deposits in the Iroquois Lowland consists of a thin upper unit of various ice-disintegration deposits overlying even thinner basal-ice deposits of silty loam till. These normally overlie a considerably thicker, older silty clay loam till which in turn rests either on lacustrine mud or bedrock.

Where deep bedrock valleys cross the area, the deposits in the valleys probably are tills and associated sand deposits. Some of the thicker sand accumulations may be alluvial channel fills.

There is relatively little sand throughout much of the volume of unconsolidated sediments in the Iroquois Lowland, and the sand that is present occurs at the surface or in deep bedrock valleys.

East of the Maxinkuckee Moraine the topography is dominated by features that are characteristic of ground-moraine deposits. The surface deposits are part of the **Nappanee Till Plain**. Numerous closed depressions form lakes or marshes covered by peat. The ground moraine of the Nappanee Till Plain is characterized by thick sequences of till which contain sand and gravel lenses of variable thickness and distribution.

A very broad apron of permeable sand and localized gravels characterizes the **Valparaiso Outwash Fan** east of the city of Valparaiso. A veneer of till caps the outwash on the moraine crest. The surface of the outwash fan is generally smooth, especially in the southern fan area. However, in the upper fan and locally in the mid-fan area, the topography is more irregular and is characterized by numerous muck and peat-filled basins of internal drainage.

West of Valparaiso, a narrow fringe of outwash drapes the southern margin of the moraine. Drilling information suggests that this sand deposit extends under the moraine and that it is continuous with sand deposits of the Kankakee River floodplain to the south. At the surface, however, the outwash sands are distinguished from those of the floodplain by a prominant erosional scarp as much as 50 feet high.

During the late Pleistocene Epoch the **Kankakee Floodbasin** was occupied by a broad low-gradient meltwater stream, which deposited a widespread sand sheet over lacustrine muds. During the subsequent Holocene Epoch the channel sands were mantled by fine-grained overbank *alluvium* and organic-rich muds deposited as the low-gradient, highly sinuous post-glacial Kankakee River migrated across the floodplain.

In the upper Kankakee River Basin in St. Joseph County, outwash deposits of the floodbasin are more complex than they are farther west. In upper reaches, outwash deposits are thicker, include many gravel

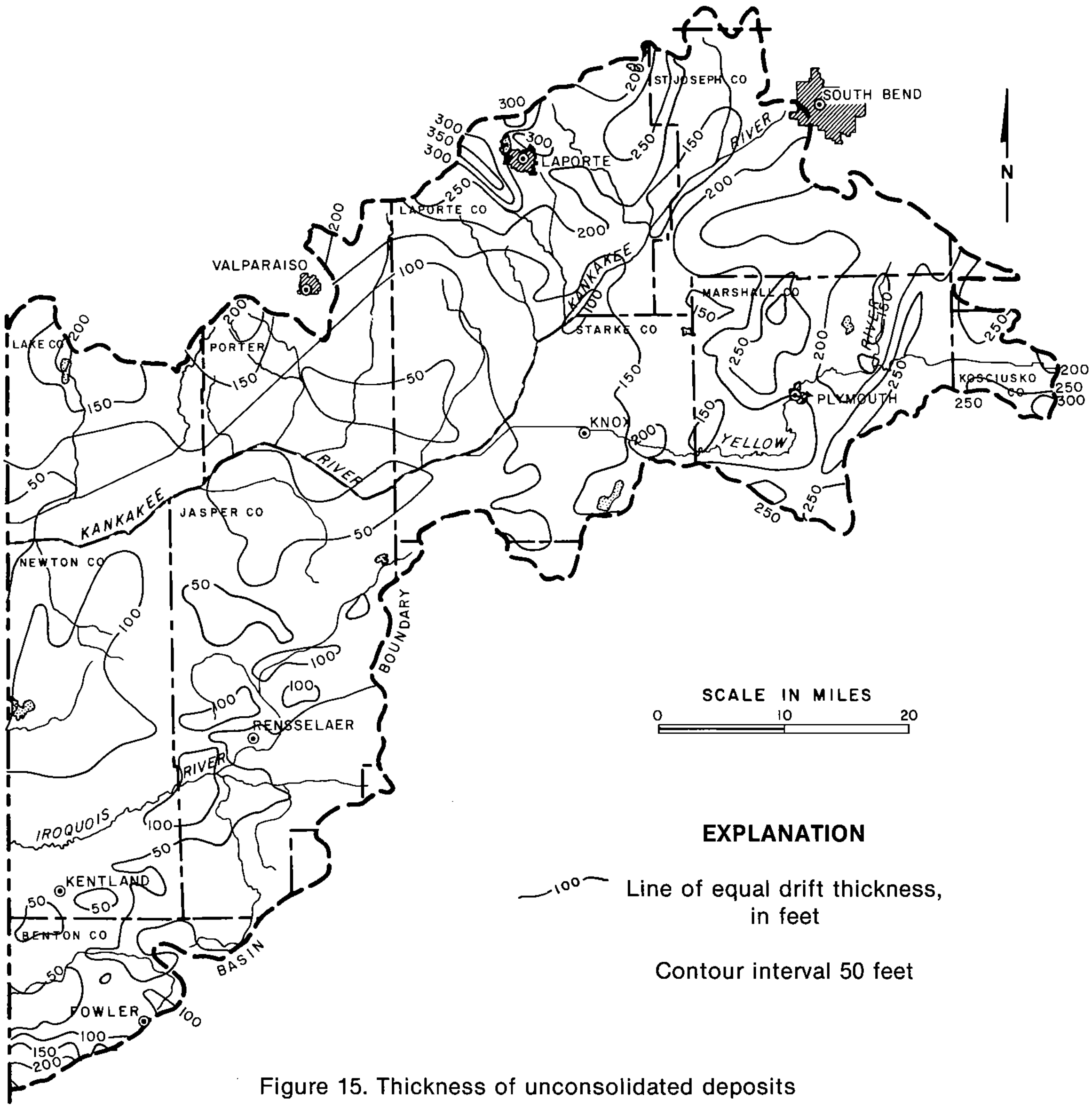


Figure 15. Thickness of unconsolidated deposits
(Adapted from Gray, 1983)

lenses, and appear to represent multiple stages of formation. The sediments in this area were deposited through interaction of processes that formed the Maxinkuckee and Valparaiso Moraines and the *fluvial* deposits in the St. Joseph River Basin.

The north margin of the floodbasin west of Kouts is characterized by a pronounced scarp which marks where the meltwater stream eroded the toe of the Valparaiso outwash apron and incised the modern floodplain.

Eolian sands (figure 14) occur primarily along the southern margin of the floodbasin where they form a broad plain. The sands are fine grained and well sorted and overlie heterogeneous material deposited in earlier glacial stages. In the Kankakee Floodbasin, dunes and sheets of eolian sand overlie fluvial sands or organic muds, whereas on the northern flank of the Iroquois Moraine, they overlie a mix of ice-contact gravels, organic mud and peat, and till. In the intermoraine lowland, the sand sheet and dunes overlie till.

Unconsolidated thickness

The thickness of unconsolidated deposits in the Kankakee River Basin is related to the topography of the underlying bedrock and the types of glacial deposits. In general, unconsolidated deposits are thickest where moraines form topographic highs over bedrock valleys, and thinnest where a modern river valley overlies a bedrock high.

Unconsolidated deposits typically are thinner in the lower Kankakee River Basin than in the upper basin (figure 15). Unconsolidated thickness generally ranges from 50 to 100 feet in the lower basin, and from 100 to 250 feet in the upper basin. Unconsolidated thickness exceeds 350 feet west of LaPorte where the Valparaiso Moraine forms a topographic high over a bedrock valley.

In the eastern part of the upper basin, the unconsolidated thickness is generally more than 150 feet in the Nappanee Till Plain. Beneath the Maxinkuckee Moraine, the thickness exceeds 300 feet in places.

Bedrock geology

Bedrock of the Kankakee River Basin is Paleozoic sedimentary rock except for the very deep Precambrian *igneous* basement rocks. More than 4,000 feet of gently dipping sedimentary rocks were deposited in shoreline and near-shore environments as the level of ancient seas alternately rose and fell relative to the land surface. The box on the following page summarizes the major depositional environments found in the Kankakee River Basin during the Paleozoic Era.

The Kankakee River Basin lies across the crest of the Kankakee Arch, which is a broad upward bow of the bedrock surface (figure 16). A low area in the arch called the Jasper Sag occurs in Newton, Jasper and Starke Counties (Pinsak and Shaver, 1964). The Kankakee Arch extends into southeast Indiana, where it is known as the Cincinnati Arch.

The Kankakee Arch separates two large structural basins, the Michigan Basin to the northeast and the Illinois Basin to the southwest (figure 16). Formations dip from the crest of the arch toward the basins at about 35 feet per mile. The crest of the arch has been planed off by erosion, and as a result, the oldest rocks at the bedrock surface occur along the crest of the arch and younger rocks slope away from the arch into neighboring basins.

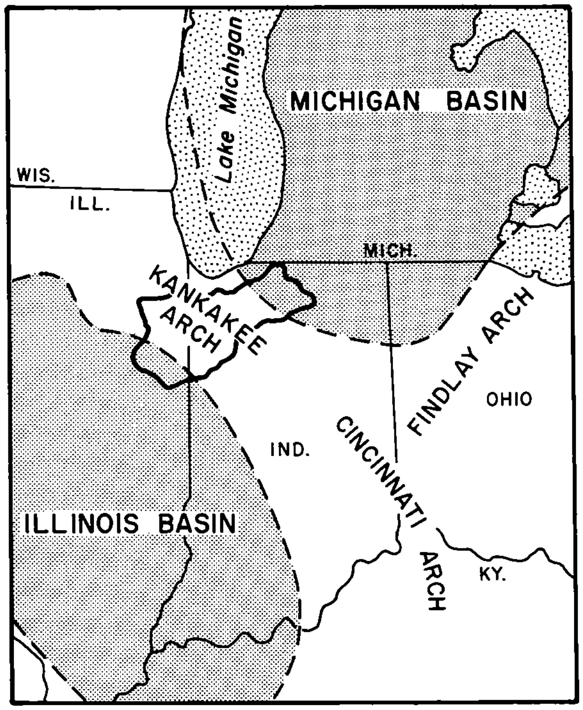


Figure 16. Regional bedrock structure

A major structural disturbance known as the Kentand Dome occurs near Kentland in south-central Newton County. The complexly folded, faulted, and truncated dome covers about 5 square miles, and is located on the extreme northeastern margin of the Illinois Basin. Within the anomalous structure, steeply dipping Ordovician and Silurian rocks have been uplifted more than 2,000 feet vertically from their normal stratigraphic position. Nearly horizontal Mississippian and Pennsylvanian rocks lie adjacent to the area (Gutschick, 1983).

Topographic differences in the bedrock surface in the Kankakee River Basin (figure 17) result from a combination of bedrock structure, differential erosion by streams and glaciers, and orientation and direction of glacial advances.

Bedrock surface elevations do not appear to be lithologically controlled. Bedrock highs are formed by different types of bedrock having differing ranges of resistance to erosion. The Borden Group siltstones, found in northern Benton County (figures 17, 18), form the highest bedrock elevations in the basin. The New Albany Shale forms an adjacent bedrock high in

History of bedrock deposition

Deposition of the preserved sedimentary rocks began in the Late Cambrian Period as the sea invaded the area which is now the Kankakee River Basin. Beach sands derived by erosion from the igneous basement rocks were deposited to form the Mount Simon Sandstone. As sea level continued to rise through the Early Ordovician Period, the depositional environment shifted to one progressively favoring shale and limestone. Toward the end of the Lower Ordovician Period, the shallow sea began to retreat from the area and erosion removed the upper portion of the Knox Formation (Gutstadt, 1958).

Sea level again rose and reached its maximum known *transgression* upon the North American continent. The basal St. Peter Sandstone was deposited, followed by extensive and fairly uniform limestones. An abrupt change at the end of Trenton Limestone deposition marked the end of widespread carbonate deposition. Physical and biological environments changed rapidly as the shallow water in which the Maquoketa Group was deposited alternated between clear and muddy (Gutstadt, 1958).

A period of non-deposition and erosion occurred through the Late Ordovician and Early Silurian Periods. Land-locked reef-fringed basins developed in the region now occupied by the Great Lakes. As inland seas withdrew at the end of Early Paleozoic time, precipitation of evaporites such as salt and gypsum occurred within the basins (Levin, 1989). Traces of the evaporities extend into LaPorte County.

Deposition of Silurian and Devonian sediments was largely influenced by local conditions. The subsidence of the Michigan Basin and the expansion of reefs determined the local conditions under which the limestones and shales of the Silurian and Devonian Age were deposited (Pinsak and Shaver, 1964).

Predominant carbonate sedimentation gave way to shales in Middle and Late Devonian in the region east of the Mississipi Valley. The change to *clastic* deposition was a consequence of mountain-building in the Appalachians. Highlands formed during this time were rapidly eroded and *clastics* were transported westward to form an extensive apron of sediments (Levin, 1989).

Sediment that ultimately became black shale was deposited in a transgressing *epicontinental* sea that covered much of Indiana. Deoxygenated conditions caused by lack of water circulation between the epicontincental waters and the open ocean resulted in an accumulation of organic matter as an important part of the sediment.

A densely intertwined mat of floating algae is postulated as the source of much of the organic matter in the New Albany black shale. Such a mat may have aided in establishing *reducing* conditions by restricting wind-induced water circulation. Extensive disruption and/or destruction of the floating mat by storms or other cause resulted in deposition of extensive greenish-gray shale beds having little or no organic matter. Correlative rocks in the Michigan Basin sequence were continuous with the New Albany Shale before erosion removed upper Devonian rocks from the crest of the Kankakee Arch (Lineback, 1970).

The sea again invaded the land, shifting the depositional environment to one favoring carbonates. Carbonate deposition of the Mississippian sea was extensive and was the last of great Paleozoic flooding of the North American *craton*.

At the end of Mississippian time, seas finally left the craton and the exposed terrain was subjected to erosion that resulted in one of the most widespread regional unconformities in the world. Erosion not only was areally extensive, but also beveled entire systems of older rocks on arches and domes. Subsequent burial of the erosion surface by sedimentation during Pennsylvanian time created the regional Mississippian-Pennsylvanian unconformity.

This period of erosion removed progressively older Mississippian formations at increasing distances north of the Ohio River. In northern Indiana, the Mississippian-Pennsylvanian unconformity may represent as much as 8 million years of erosion. In southern Indiana that same unconformity may represent less than 3 million years of erosion. In the Kankakee River Basin, Pennsylvanian strata lie on rocks as old as Late Devonian. Rocks above the erosional hiatus differ markedly from those below (Droste and Keller, 1989).

It was not until near the beginning of Middle Pennsylvanian time that the seas were able to encroach onto the long exposed surface of the craton. The initial Pennsylvanian deposits, largely shales, were deposited over a *karst* topography developed on Mississipian limestone. One of the most notable aspects of Pennsylvanian sedimentation in the middle and eastern states is the repetitive alternation of marine and non-marine strata caused by minor oscillations in sea level. In Indiana, the deposits are approximately half marine and half non-marine. Vegetation accumulated in this coastal swamp condition producing coal deposits as a predominate feature of Pennsylvanian deposition. The bedrock was subsequently exposed to erosion for many years, thus allowing the existing bedrock surface topography to develop.

ERAS	PERIODS	APPROXIMATE LENGTH IN YEARS	ROCK TYPES IN INDIANA
CENOZOIC	QUATERNARY (PLEISTOCENE EPOCH) 	1 MILLION	Glacial drift: *till, gravel, sand, silt (including loess), clay, marl, and peat* *(Till and gravel contain boulders of many kinds of sedimentary, igneous, and metamorphic rocks)* Thickness O-500 ft.
CENOZOIC	TERTIARY	60 MILLION	*Cherty gravels* *Sand and clay* — *Scattered deposits*
MESOZOIC	CRETACEOUS	70 MILLION	No deposits in Indiana 
MESOZOIC	JURASSIC	35 MILLION	No deposits in Indiana
MESOZOIC	TRIASSIC	30 MILLION	No deposits in Indiana
PALEOZOIC	PERMIAN	25 MILLION	No deposits in Indiana
PALEOZOIC	PENNSYLVANIAN 	20 MILLION	*Shale (including carbonaceous shale), mudstone, sandstone, coal, clay limestone, and conglomerate* 1,500 ft.
PALEOZOIC	MISSISSIPPIAN 	20 MILLION	Upper Part: *alternating beds of shale, sandstone, and limestone* 500 ft.
			Middle Part: *limestone, dolomite; beds of chart and gypsum* 300 ft.
			Lower Part: *shale, mudstone, sandstone; and some limestone* 600 ft.
PALEOZOIC	DEVONIAN 	60 MILLION	Upper Part: *carbonaceous shale* 100 ft.
			Lower Part: *limestone, dolomite; a few sandstone beds* 40-80 ft.
PALEOZOIC	SILURIAN 	40 MILLION	*Dolomite, limestone, chert, siltstone, and shale* 100-300 ft.
PALEOZOIC	ORDOVICIAN  	70 MILLION	*Shale, limestone and dolomite* 700 ft.
			Limestone, dolomite, and sandstone — Not exposed at the surface in Indiana
PALEOZOIC	CAMBRIAN	80 MILLION	*Sandstone and dolomite* — Not exposed at the surface in Indiana
	PRECAMBRIAN ERAS	3 BILLION	*Granite, marble, gneiss, and other igneous and metamorphic rock types* — Not exposed at the surface in Indiana

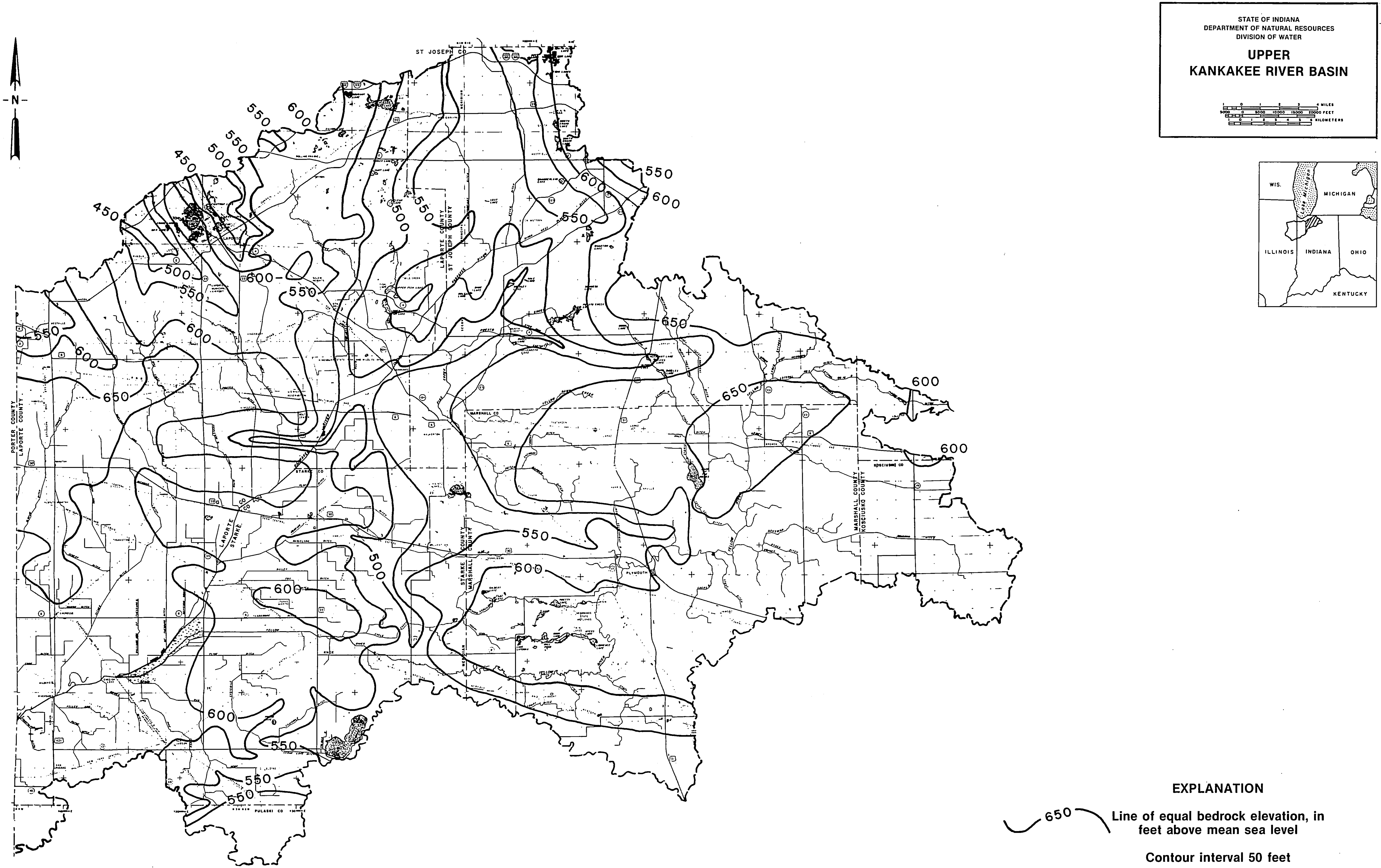


Figure 17a. Bedrock topography

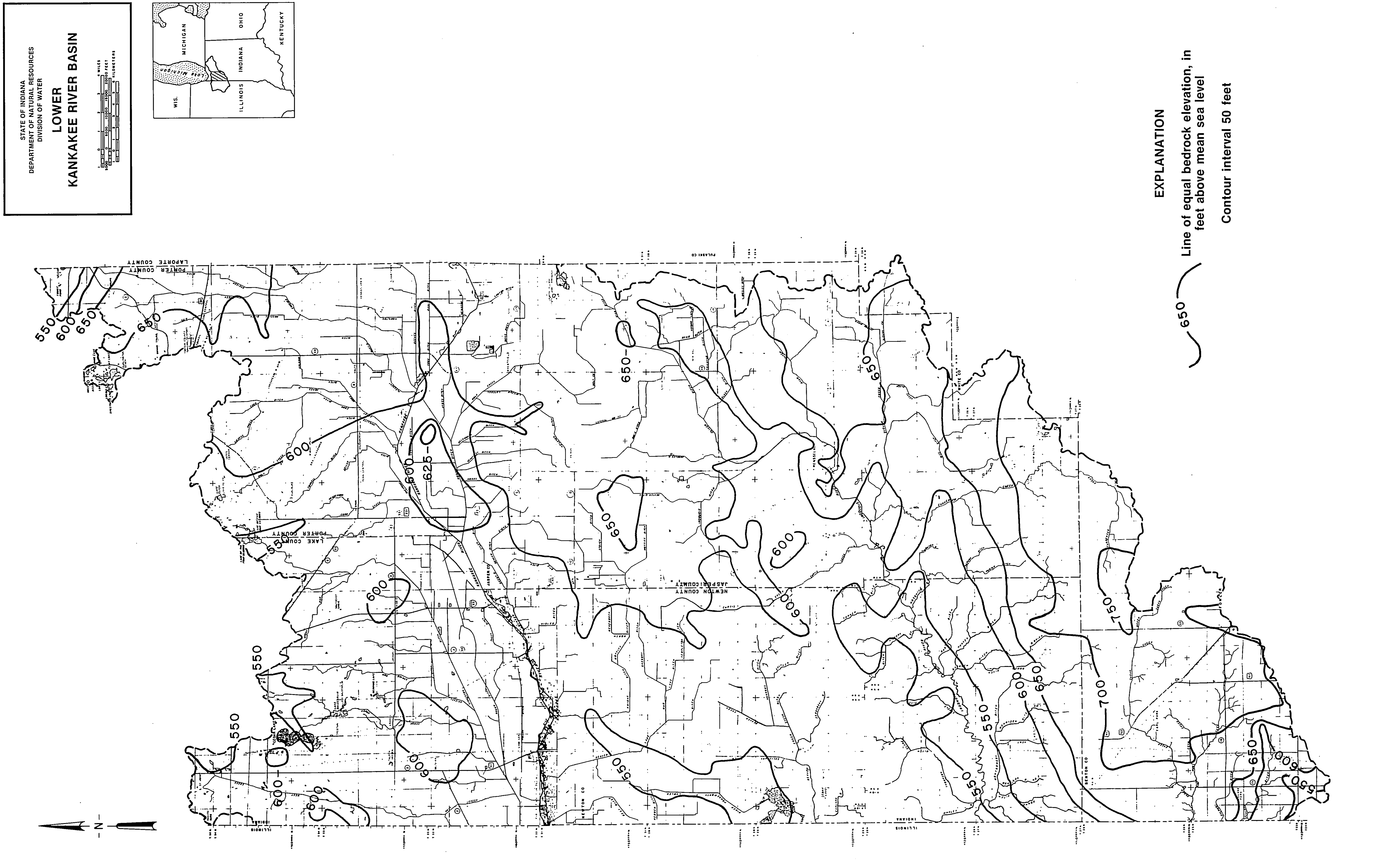


Figure 17b. Bedrock topography

southern Jasper County. Ellsworth Shale forms bedrock highs in northeastern Marshall County, southeastern St. Joseph County, and in an area southeast of Valparaiso in Porter and LaPorte Counties. Silurian and Devonian limestone and dolomite form bedrock highs on the crest of the Kankakee Arch.

Bedrock valleys radiate away from the crest of the Kankakee Arch following the regional dip of the bedrock. The valleys were incised into the bedrock during the long period of erosion following the Pennsylvanian Period.

The most well developed bedrock valley system trends north-south through eastern LaPorte and Starke Counties (figure 18). The elevation of the main valley is 500 feet m.s.l. Tributary valleys branch east and west from the main valley.

Equally deep but less developed valleys radiate from the basin of Lake Michigan southward to the Valparaiso Moraine. These valleys may have been enlarged or deepened by the Lake Michigan Lobe when it advanced southward.

Another large bedrock valley lies beneath the Iroquois River and extends from the town of Mt. Ayr into eastern Illinois. This valley has a moderately well-developed drainage network.

Rocks in the Kankakee River Basin which occur at the bedrock surface represent a veneer of the 4,000 feet of sedimentary rock covering the granitic basement (figure 19). Most of the sedimentary rock is Cambrian and Ordovician in age. Rocks at the bedrock surface range from Silurian to Pennsylvanian in age. Details of stratigraphy, structure, and sedimentology of the basin may be obtained from Becker (1974), Doheny and others (1975), Droste and Shaver (1982), and other references cited in the text.

Silurian-Age rocks are the oldest rocks at the bedrock surface in the Kankakee River Basin. Gray and others (1987) identify these rocks as members of the Wabash Formation, which consists of dolomite, dolomitic limestone, and limestone. Shaver and others (1986) describe four principal lithologies that intergrade and replace one another spatially within the Wabash Formation.

Rocks of **Devonian** Age are found at the bedrock surface in much of the basin (figure 18). The oldest of the Devonian rocks in the basin belong to the Muscatatuck Group. The Muscatatuck Group consists of limestone, dolomite, and perhaps evaporite deposits in its lower part. Common lithologies are described by Shaver and others (1986).

The upper Devonian Antrim Shale lies above the Muscatatuck Group on the northern slope of the Kankakee Arch. The Antrim Shale consists mainly of brown to black non-calcareous shale. However, calcareous shale, limestone and sandstone are reported in the lower parts of the unit in some areas in LaPorte County (Shaver and others, 1986).

In the Illinois Basin, the **Upper Devonian** to **Lower Mississippian** New Albany Shale overlies the Muscatatuck Group. The New Albany Shale consists of brown to black carbonaceous shale, green to gray shale, and minor amounts of dolomite and sandstone. The New Albany Shale is largely correlative with the Antrim Shale of the Michigan Basin (Shaver and others, 1986).

The **Devonian** and **Mississippian**-Age Ellsworth Shale occupies a large area of the bedrock surface in the northern part of the Kankakee River Basin (figure 18). The Ellsworth Shale is characterized by gray-green shale having limestone or dolomite lenses in the upper part and alternating beds of gray-green shale and brown-black shale in the lower part. The boundary between the Antrim Shale and the Ellsworth Shale is *conformable* and marked by the lowest green-gray shale bed.

The **Mississippian** Rockford Limestone conformably overlies the New Albany Shale in the Illinois Basin. Limestone is the predominant lithology, but shale, siltstone, and dolomite also occur. The limestone is usually gray, fine grained, *ferruginous*, and slightly *fossiliferous*. It may be dolomitic and *argillaceous*, having thin gray-green shale zones interbedded in the limestone.

The Mississippian Borden Group makes up the bedrock surface in the southwest part of the basin (figure 18). The Borden Group mainly consists of gray argillaceous siltstone and shale interbedded with limestone lenses.

Small *outliers* of **Pennsylvanian** Age rocks occur in southwest parts of the basin (figure 18), including the area known as the Kentland Dome. These rocks are of the lower Pennsylvanian Raccoon Creek Group, which consists of sandstone, shale, and minor amounts of limestone and coal.

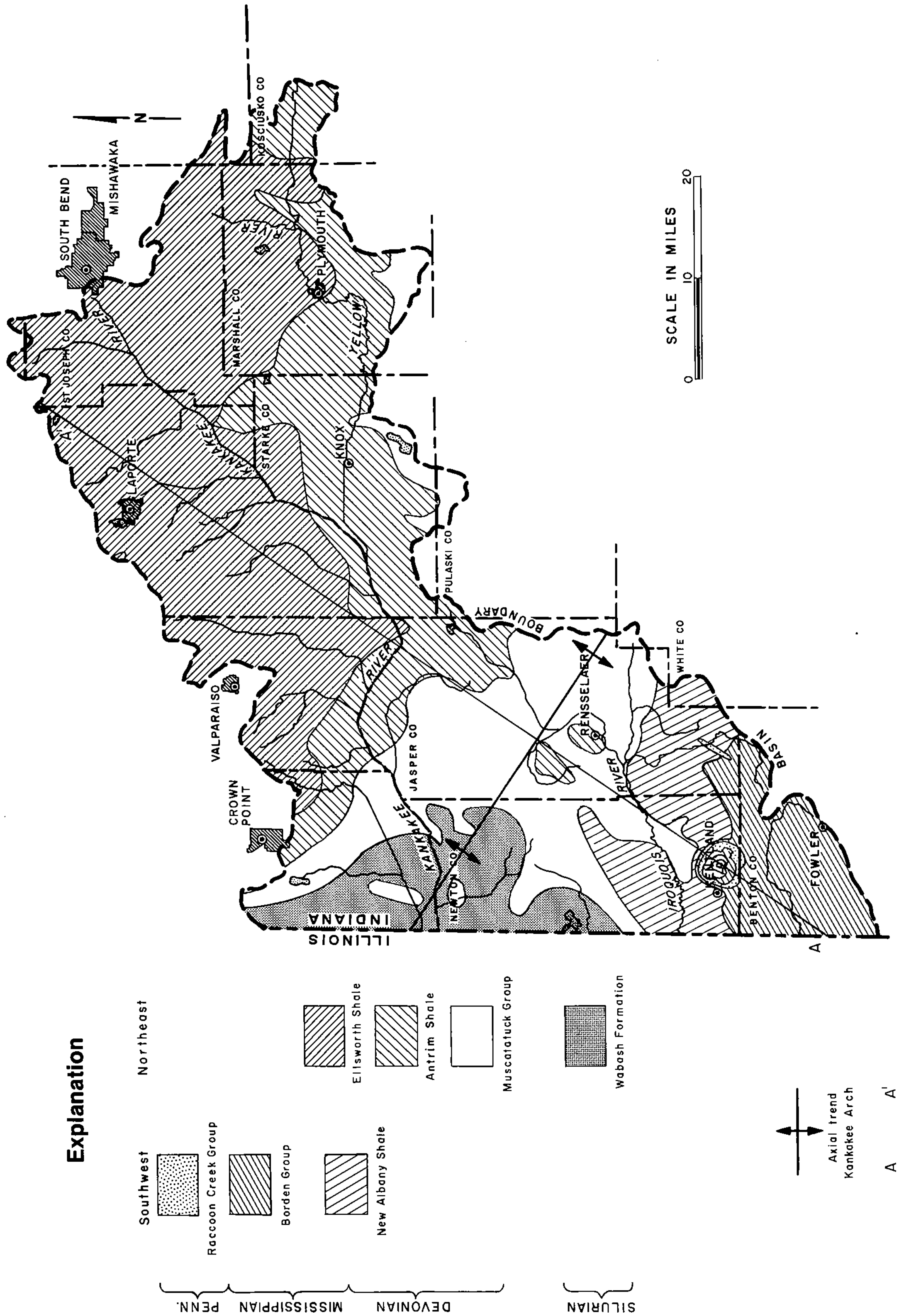


Figure 18. Bedrock Geology
(Adapted from Gray and others, 1987)

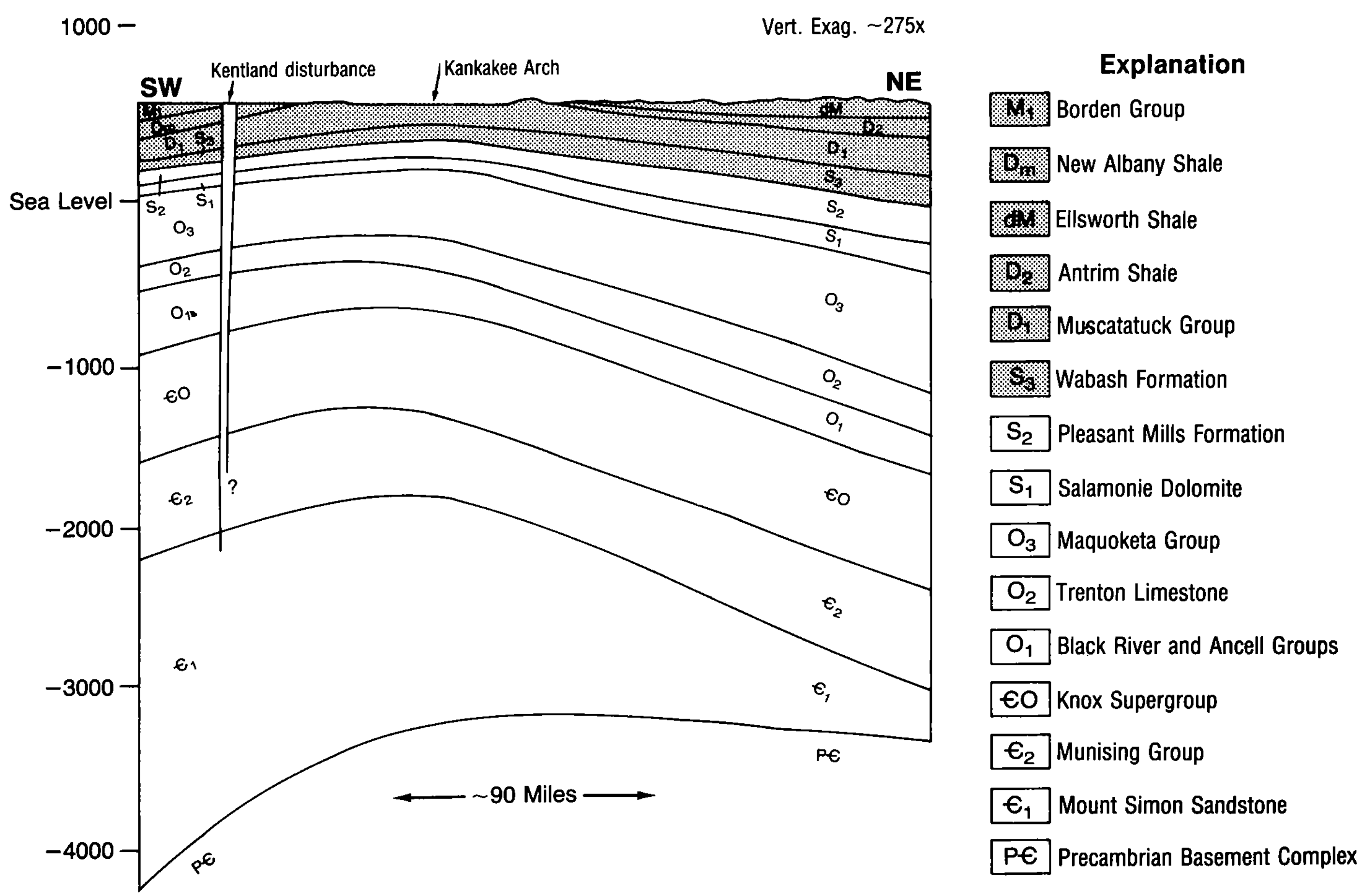


Figure 19. Generalized cross section of bedrock structure

SOILS

Soil is the end-product of various agents acting on glacial and bedrock deposits. The properties of different soils are determined by chemical, physical and biological processes acting on soil *parent materials* over long periods of time (see box below).

Soil properties influence the generation of surface-water runoff and help determine the suitability of an area for crops, pasture, woodland, wildlife habitat, recreational facilities, buildings, highways and other uses. The type of land use can directly or indirectly modify hydrology, which in turn can further influence land and water development.

Soil data and basic information on the economy, land use and water resources of major basin counties and two adjoining Illinois counties are presented in soil survey reports (Persinger, 1972; Benton, 1977; Paschke, 1979; Smallwood, 1980; Furr, 1981, 1982; Barnes, 1982, 1989, [in press]; Kiefer, 1982; and Smallwood and Osterholz, 1990). Soil maps and related data found in these reports can be used for general planning purposes. The following discussions are based on generalized maps which provide an even broader overview of basin soils.

Soil associations and hydrologic soil groups

Soils can be classified according to similarities of parent materials, texture, *horizon* characteristics, topography, natural drainage, and special features. A soil series, the most common category used in county soil surveys, allows detailed evaluations of specific tracts of land. For generalized applications, however,

Factors affecting soil formation

Soil is produced by chemical, physical and biological processes acting on glacial or bedrock deposits. The characteristics of soil at any given location are determined by 1) the physical and mineralogical composition of the parent material, 2) the past and present climate, 3) the plant and animal life on and in the soil, 4) the relief, or topography, and 5) the length of time the forces of soil formation have acted on the soil material.

The properties of soils in the Kankakee River Basin vary greatly, sometimes within small areas, depending on how the **parent materials** were deposited. The main parent materials in the basin were deposited as glacial outwash, lacustrine material, organic material, alluvium, and glacial till.

Outwash was deposited by water flowing from melting glaciers. Outwash deposits generally consist of layers of coarse particles, such as sand and gravel. Tracy soils are an example of soils that formed in outwash deposits.

Lacustrine material settled out of still or ponded glacial meltwater. Because the coarser fragments drop out of moving water to form outwash, only the finer particles, such as very fine sand, silt, and clay remain to settle out in ponded water as lacustrine deposits. Rensselaer soils are an example of soils that formed in lacustrine material.

Organic deposits consist of partially decomposed plant materials. The remains of grasses, sedges, and water-tolerant trees accumulated in wet depressional areas of outwash, lake, and till plains. In some areas, the plant residues subsequently decomposed; in other areas, the material has changed little since deposition. Houghton soils are an example of soils that formed in organic material.

Alluvium was deposited by streams in geologically recent time. The texture of the alluvium depends on the flow rate of the water from which it was deposited. The alluvium deposited along the relatively swift Yellow River is coarser-textured than that deposited along the slower moving Kankakee River. Genessee soils are an example of soils that formed in alluvial deposits.

Glacial *till* was laid down directly by glaciers with a minimum of water action. Till consists of particles of different sizes mixed together. Soils in the basin that have developed on till typically have a well-developed structure. Riddles and Morley soils are examples of soils that formed in glacial till.

Climate determines the kinds of plants and animals on and in the soil. Climate also determines the amount of water available for weathering minerals and transporting soil material. Through its influence on soil temperature, climate also determines the rate of physical and chemical reactions in the soil.

The chief contribution of **plants and animals** to soil formation is the addition of organic matter and nitrogen. The kind of organic material in the soil depends mainly on the kinds of plants that grow on the soil. Soils that developed under dominantly forest vegetation generally have less total accumulated organic matter than soils in the basin that developed under predominantly grassy vegetation. Many soils in the Iroquois River Basin and developed under prairie grasses.

Relief, or topography, has a marked influence on soils through its influence on erosion, plant cover, soil temperature, soil moisture and natural drainage. For example, slight topographic differences produce soil-moisture differences, and thereby influence soil development.

Runoff of water is greatest on steep slopes, in contrast to runoff in low areas, where water often is temporarily ponded. Water and air move freely through soils that are well drained, but slowly through soils that are very poorly drained. Oshtemo soils are an example of well-drained, well-aerated soils, whereas Brookston soils are very poorly drained and poorly aerated.

Long periods of **time** usually are required for distinct soil horizons (layers) to form in parent material. The differences in length of time that parent materials have been in place commonly are reflected in the degree of development of the soil profile. Moreover, some soils develop rapidly and others develop slowly because of differences in positions on the landscape.

a soil association is a commonly used category.

A soil association is a landscape having a distinctive pattern of soil series in relation to similar parent materials, landforms and slopes. Within a given soil association, each soil series occupies a characteristic position on one of three major landform types; namely, 1) hillslopes, *swells*, or depressions within broad uplands, 2) terraces, outwash plains, or lacustrine plains, and 3) floodplains or bottomlands (Galloway and Steinhardt, 1984).

A soil association is composed primarily of two to four major soils and a few minor soils, and is named for the major soils. The soils in one association may occur in another, but in a different pattern.

A total of 108 soil associations were identified in a series of generalized county soil maps developed in 1970 by the U.S. Department of Agriculture's Soil Conservation Service and Purdue University's Agricultural Experiment Station. A few of the general soil maps were revised slightly when they were later printed with supplementary data tables and a user's guide in 1975 (U.S. Department of Agriculture, 1971; Galloway and others, [1975]).

Appendix 3 presents the general soil maps for nine major counties of the Kankakee River Basin, as compiled from the 1971/1975 series. The map units outlined in black show broad areas that have a distinctive pattern of soils, relief, drainage, and parent materials. The colors represent the potential response of soils to irrigation, which will be discussed in the final chapter of this report in the section entitled ***Water Use and Projections***.

It should be emphasized that the maps in appendix 3, compiled from the comprehensive 1971/1975 county map series, differ from general soil maps included in detailed county soil survey reports referenced on the previous page. Moreover, general soil maps in survey reports, unlike those in the 1971/1975 series, may not always join with maps for adjacent counties. The differences in mapping are the result of several factors, including changes in concepts of soil series and differences in grouping detailed soil map units into general areas.

In 1977, the Soil Conservation Service and Purdue University combined the 1971/1975 series of general soil maps to produce a 1:500,000-scale map of Indiana showing major soil associations on a broad basis. Figure 20, adapted from a 1982 revision of the state map (U.S. Department of Agriculture, 1982), shows the location of major soil associations in the Kankakee River Basin. The table accompanying figure 20 lists, for the basin region only, the relation between numbered soil associations of the 1971/1975 generalized county maps and alphanumeric groupings of the 1982 state map.

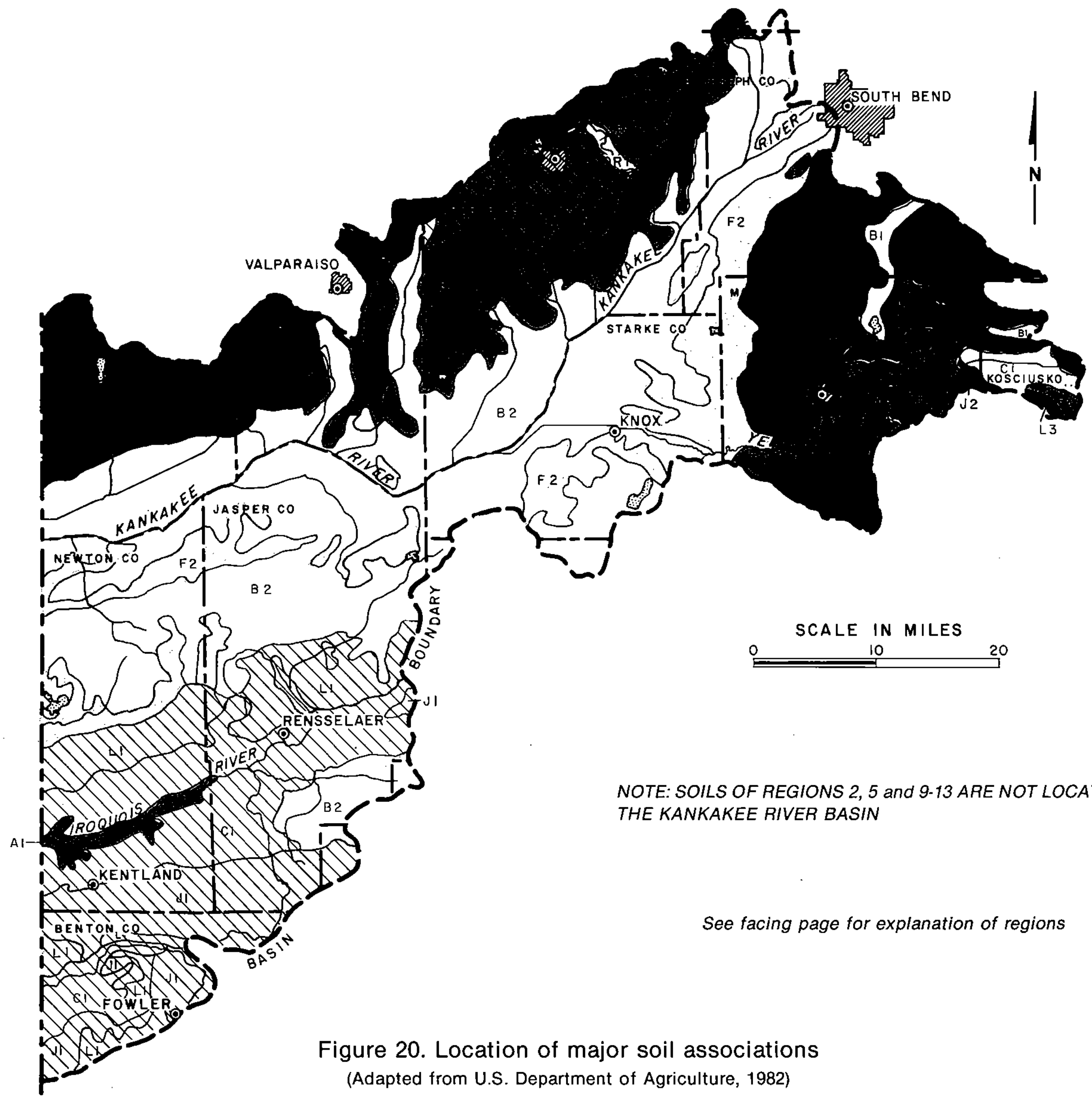
Figure 20 also shows the regions of similar parent materials into which the major associations are grouped. It should be noted that Region 3 along rivers is characterized by both glacial outwash and recent alluvial parent materials.

The maps in figure 20 and appendix 3 can be useful in relating basin soils to surficial geology, topography and vegetation types (see explanatory text accompanying figure 20). A report by Galloway and Steinhart (1984) discusses the influences of geology, physiography and climate on the formation of soil associations, and summarizes the relations among associations occupying specific landscape positions.

Soil survey reports (referenced on the previous page) contain detailed descriptions of soil properties that affect land use, and include tables which outline the potentials and limitations of individual soils for cultivated crops, woodland, urban and recreation uses. Although the maps in figure 20 and appendix 3 are too generalized for such detailed land-use planning, they can be used to compare the suitability of large areas for general land uses. A few examples are given in the box on page 56.

In addition to their utility in assessing general land uses, the maps in figure 20 and appendix 3 also can be helpful in examining, on a broad basis, the role of soils in the generation of surface-water runoff. The Soil Conservation Service has classified soils into four hydrologic groups (A, B, C, D) according to the soil's ability to absorb rainfall and thereby reduce runoff. Classifying bare soils on the basis of their minimum *infiltration rate* after an extended period of wetting reflects the properties of both the surface and underlying soil horizons.

Soils in hydrologic group A have high infiltration rates even when thoroughly wetted, and consist chiefly of deep, well to excessively drained sands and gravels. These soils also have high *transmission rates*. Plainfield soils, which are found on sand ridges and *knolls* (association F2 in figure 21), are the only major soils in the Kankakee River Basin that naturally fall into hydrologic soil group A. Maumee, Houghton and Adrian soils, found primarily in the Kankakee River valley (associations B1 and B2), may be classified into



NOTE: SOILS OF REGIONS 2, 5 and 9-13 ARE NOT LOCATED IN THE KANKAKEE RIVER BASIN

See facing page for explanation of regions

Figure 20. Location of major soil associations
(Adapted from U.S. Department of Agriculture, 1982)

hydrologic soil group A after artificial drainage measures have improved their ability to absorb rainfall and reduce runoff.

Soils in hydrologic group B have moderate infiltration and transmission rates. Well-drained soils that typify this soil group include those that have formed on outwash-plain deposits, such as soils of the Tracy-Door-Lydick association (E1). Other soils classified into hydrologic soil group B include those that have formed on outwash deposits in Marshall County (associations E3 and E4), on alluvial deposits of the lower Iroquois River valley (association A1), and on loess-covered, loamy glacial till deposits of the Iroquois River Basin (associations J1 and L1).

Soils in hydrologic group C have slow infiltration and transmission rates. These soils consist chiefly of soils with a layer that impedes downward movement of water, or soils having a moderately fine to fine texture. In the Kankakee River Basin, these soils are found primarily on the Valparaiso Moraine (associations M1 and M2), where the soils have formed on clayey glacial till deposits. Other areas of C-group soils are found

Explanation To Figure 20

REGION 1 — SOILS FORMED IN SANDY AND LOAMY LACUSTRINE AND OUTWASH DEPOSITS AND EOLIAN SAND DEPOSITS

The nearly level, very poorly drained soils of the **Maumee-Gilford-Sebewa** association (B2) developed on the broad lacustrine and outwash plains found primarily in the main valleys of the Kankakee River and its major tributaries. Parent materials range from sand to loam in texture. Native vegetation was grasses and water-tolerant mixed hardwoods.

The nearly level, very poorly drained soils of the **Houghton-Adrian** association (B1) formed in organic materials deposited in ancient lakes, and developed under a cover of trees, shrubs and sedges. Because these soils occur as relatively small muck pockets scattered throughout the main Kankakee River Valley, they are not mapped.

Loamy soils in the **Rensselaer-Darroch-Whitaker** association (C1) predominate on the nearly level lacustrine plains of the Iroquois River Basin. The very poorly drained Rensselaer soils occur in swales and broad, flat areas. Somewhat poorly drained Whitaker and Darroch soils are found on convex swells in the lake plain. Whitaker and Rensselaer soils formed under a cover of mixed hardwoods, whereas Darroch soils developed under prairie grasses.

REGION 3 — SOILS FORMED IN ALLUVIAL AND OUTWASH DEPOSITS

Soils of the **Genesee-Eel-Shoals** association (A1) developed on *calcareous* loamy alluvium found along the nearly level floodplain of the lower Iroquois River. Native vegetation included a large variety of hardwood species such as beech, maple, oak, elm, sycamore and buckeye. Genesee is well drained; Eel is moderately well drained; and Shoals is somewhat poorly drained.

Well-drained soils of the **Tracy-Door-Lydick** association (E1) occupy the pitted *outwash fan* which extends from eastern Porter County to northwest St. Joseph County. The parent materials are loamy and sandy outwash deposits that were high in sulfur-containing shale particles and which weathered to form acid soils. The native vegetation on Tracy soils was mainly oak; on Door it was prairie grasses; and on Lydick, it was a mixture of the two vegetation types. Tracy soils are found on 0 to 12 percent slopes. Lydick and Door soils are mainly on 0 to 2 percent slopes.

Soils of the **Oshtemo-Fox** (E3) and **Fox-Ockley-Westland** (E4) associations are found on undulating *outwash plains* and *moraines* in Marshall County. Parent materials are loamy, sandy and gravelly drift. Native vegetation was mixed hardwoods, especially beech, maple, white oak and hickory. Except for the very poorly drained Westland soils found in nearly level drainageways and swales, these soils are well drained and are located mainly on 0 to 6 percent slopes.

REGION 4 — SOILS FORMED IN EOLIAN SAND DEPOSITS

Soils of the **Plainfield-Maumee-Oshtemo** association (F2) developed in the *eolian* sands and sandy outwash deposits located primarily south and east of the Kankakee River. Well-drained Plainfield soils have a fine sand texture throughout and typically are found on 2 to 12 percent slopes on sand dunes, where the native vegetation was mainly white and black oak. Very poorly drained Maumee soils, which are fine sand or loamy fine sand throughout, occupy the level, low-lying areas around the dunes. Oshtemo soils, located on outwash plains, are well drained and are comprised of loamy sands or sandy loams.

REGIONS 6-7 — SOILS FORMED IN LOAMY OR CLAYEY GLACIAL TILL

Soils of the **Crosier-Brookston** (J2) association and **Miami-Crosier-Brookston-Riddles** (L3) association are found in St. Joseph and Marshall Counties on *till plains* with swell-and-swale topography, on rolling areas near streams *dissecting* the till plain, and on end moraines. The parent material is calcareous loam till, covered on the till plain by up to 20 inches of loess. Native vegetation was mainly oak, beech and maple forests.

Well-drained Miami and Riddles soils are located on 2 to 12 percent slopes. Somewhat poorly drained Crosier soils are found on toe slopes and on nearly flat areas of swells. The very poorly drained Brookston soils are located in drainageways and swales.

Soils of the **Markham-Elliott-Pewamo** (M1) and **Morley-Blount-Pewamo** (M2) associations are found on the Valparaiso Moraine in Lake, Porter and western LaPorte Counties. The parent material is calcareous silty clay loam or clay loam till. Soils of the Markham-Elliott-Pewamo association developed under prairie grasses, whereas soils of the Morley-Blount-Pewamo association formed under beech, oak and maple forests.

Well-drained Markham and Morely soils are found on 2 to 12 percent slopes. The somewhat poorly drained Elliott and Blount soils occupy nearly level areas. Very poorly drained Pewamo soils are found in drainageways and swales.

REGION 8 — SOILS FORMED IN THIN LOESS OVER LOAMY GLACIAL TILL

Soils of the **Brookston-Odell-Corwin** association (J1) are located in the Iroquois River Basin on the nearly level till plains having swell-and-swale topography. Soils of the **Parr-Brookston** association (L1) are found on end moraines and on rolling areas near streams that dissect the till plain. Most soils in these associations formed in loess. Soils of both associations formed under native prairie grasses.

The somewhat poorly drained Odell soils are found on swells, moderately well-drained Corwin soils are found on 2 to 6 percent slopes, and well-drained Parr soils are found on 2 to 12 percent slopes. The very poorly drained Brookston soils are located in swales.

Predominantly prairie soils

RELATION BETWEEN SOIL MAP UNITS

{Major soil associations on the state map (U.S. Department of Agriculture, 1982; see facing page) represent clusters of soil associations on county general soil maps (U.S. Department of Agriculture, 1971; see appendix 3).}

State	County	State	County
B1	*108*		
B2	*13, 23, 24*	L3	*63, 78, 79*
C1	*10, 37, 47, 48, 49*	J2	*58*
A1	*4*	M1	*65*
E1	*14, 15, 51*	M2	*61*
E3	*35*	J1	*59, 88*
E4	*27*	L1	*69, 70, 89*
F2	*39, 40, 41, 42*	L2	*12*

General land-use considerations for major soil associations

In outwash areas of the upper Kankakee River Basin, nearly level to gently sloping soils of the **Tracy-Door-Lydick** association (E1 in figure 21) are fairly well suited for cultivated crops, pasture, woodland, recreation areas and urban development. A few soils located on steep slopes, however, are better suited for woodland uses because they tend to be droughty and are subject to wind erosion if not protected by plant cover.

Considerable residential and urban development occurs on swells of the **Markham-Elliott-Pewamo** (M1) and **Morley-Blount-Pewamo** (M2) associations on the Valparaiso Moraine. Nearly level soils are poorly suited for sanitary facilities and building-site development, however, because of slow to moderately slow *permeability*. Some flat areas are well suited for cultivated crops, particularly if depressional areas are drained. Erosion, sedimentation, and drainage are major farm management concerns.

Soils of the **Maumee-Gilford-Sebewa** association (B2), found primarily in the Kankakee River valley, are well suited for cultivated crops if adequately drained by artificial means such as deep ditching, supplementary tiling, and *water-table control structures*. Subsurface and sprinkler irrigation are used during the summer to increase crop yields. In contrast to their high agricultural value, these intensively cropped soils generally are unsuitable for building-site development and sanitary facilities because of wetness, ponding, poor filtering qualities and frost action. Wind-erosion control is a major farming concern.

Depressional areas of the Kankakee River valley containing mucks and peats of the **Houghton-Adrian** association (not mapped in figure 20) are subject to ponding, wetness, flooding, and instability of organic matter. In their natural state, these soils are poorly suited for building-site development, sanitary facilities, recreation areas and cultivated crops, and are better suited for wetland plants or fish and wildlife habitat. Much of the acreage that has been artificially drained can be cultivated, and the larger muck areas with intensive water-management systems produce valuable vegetable and mint crops.

The irregular topography and large number of soils within the **Parr-Brookston** association (L1) make this only a moderately productive area for crop production (Galloway and Steinhardt, 1984). In the nearly flat lacustrine plain to the south, however, soils of the **Rensselaer-Darroch-Whitaker** association (C1) are well suited for crop production, although improved drainage is needed on most farms to increase crop yields. Alluvial bottomland soils of the **Genesee-Shoals-Eel** association (A1), found along the lower Iroquois River floodplain, are subject to overflow during floods, and excess water often limits crop production. Most bottomland soils are well suited for woodland and wildlife uses.

on lacustrine deposits of the Iroquois River Basin (association C1).

Soils in hydrologic group D have very slow rates of infiltration and transmission. In the Kankakee River Basin, this soil group consist chiefly of soils having a permanent high water table and clay soils having a high swelling potential, or soils having a clay layer at or near the surface. Undrained tracts dominated by Maumee, Houghton or Adrian soils (associations B1 and B2) are included in this hydrologic soil group. Undrained depressional areas dominated by Pewamo or Brookston soils also are classified in soil group D. Undrained Pewamo and Brookston soils commonly are found in *swales* and drainageways on the Valparaiso Moraine (assocations M1 and M2) and on the rolling morainal areas of St. Joseph and Marshall Counties (associations L3 and J2).

Drainage and erosion

Soil drainage is a major problem in much of the Kankakee River Basin. Reports by the U.S. Department of Agriculture (1958, 1962, 1963) are among a large number of publications by various agencies which address drainage problems in the basin.

Most soils in the basin that have poor natural drainage are drained artificially to allow or enhance agricultural cultivation. In many drained areas, however, wetness, ponding and flooding can continue to pose moderate to severe limitations.

Some soils cannot be adequately or economically drained because of the difficulty in obtaining a sufficient drainage outlet. Undrained tracts primarily are located in depressional areas having Houghton, Adrian, Gilford and Edwards soils. In these low-lying areas, wetland or fish and wildlife uses may be more appropriate than attempted cultivation.

Some sandy soils having a high water table do not have adequate drainage outlets. Open ditches constructed in these sandy soils often are not stable and tend to become filled with sand within a few years. When these ditches are filled, the capacity of the open ditch and the drains discharging water into them is severely restricted.

Some organic soils have special drainage problems. When the pore spaces of organic soils are filled with air, the soils oxidize and compact, causing surface subsidence. Special drainage systems therefore are needed to control the depth and period of draining. Maintaining the water table below the ground surface during the crop-growing season and raising the water table to at or near the surface during the rest of the year minimizes the oxidation and subsidence of these organic soils.

Subsurface drainage is usually not considered feasible in soils that are muck over marl, such as Edwards and Martisco soils. In contrast, overdrainage is a possibility in soils that are muck over sand, such as Houghton and Adrian mucks. Overdrainage can lead to rapid oxidation and surface subsidence of the organic material. *Water-table control structures* are commonly used to maintain a high water table during the fall and winter to help limit oxidation and subsidence.

The design of both surface and subsurface drainage systems varies with the kind of soil. In general, drains need to be more closely spaced in slowly permeable soils than in rapidly permeable soils. A combination of surface and subsurface drains and pumping systems is needed in most areas of very poorly drained soils that are used for intensive row cropping. Information on drainage designs for specific soils is available from the Purdue University Cooperative Extension Service, the IDNR Division of Soil Conservation, and local offices of the USDA Soil Conservation Service.

Soil erosion is the detachment and movement of soil particles by natural forces, primarily water and wind. In general, there is a potential for water erosion where the land slope is at least 2 percent. Sandy or organic soils can be susceptible to wind erosion during certain times of the year, particularly when the soil surface is dry and when vegetative or surface cover is minimal.

Excessive erosion can reduce the soil's inherent productivity, whereas the associated sedimentation can damage young plants and fill drainage ditches, lakes and streams. These erosive processes can reduce farm income by decreasing crop yields and increasing maintenance costs for drainage systems. Additional erosion damages in both rural and urban areas include reduced property values, deteriorated water quality, and increased costs of removing sediment from roadways, roadside ditches, and surface-water supplies.

Compared to other *major land resource areas* of Indiana, the two areas encompassing the Kankakee River Basin have a low overall erosion rate, primarily because of their low relief, permeable soils and low runoff rates. Within the two designated areas, estimated soil losses on cropland by *sheet* and *rill* erosion in 1982 averaged 2.8 to 3.3 tons per acre, which was considerably less than than the state average of 6.1 tons per acre (U.S. Department of Agriculture, 1987a).

Soil losses by wind erosion, however, are higher in northwestern Indiana, including the Kankakee River Basin, than in other regions. Average wind erosion on cropland in 1982 was estimated to be 3.0 tons per acre in large parts of the basin, and 1.9 tons per acre or less in remaining portions (U.S. Department of Agriculture, 1987a).

A special study of soil erosion and land-treatment needs in the Kankakee River Basin in Indiana and Illinois was conducted in the early 1980s by the U.S. Department of Agriculture in cooperation with the State of Indiana, State of Illinois, and Soil and Water Conservation Districts (U.S. Department of Agriculture, 1986). The purpose of the study was to provide alternatives for the land-treatment element of a previous Kankakee River Basin study (U.S. Department of Agriculture, 1976).

The 1986 study identified major erosion problems on more than 1.4 million acres of cropland in eight Indiana counties and three Illinois counties. These areas are characterized by a predominance of land that is eroding substantially in excess of rates at which long-term crop productivity can be maintained.

Major erosion areas in the Indiana part of the study region where water erosion was identified as the dominant form of soil loss include parts of Marshall and St. Joseph Counties and the end moraines in central Lake, Porter, LaPorte, Newton and Jasper Counties. Wind erosion was identified as the dominant form of erosion in much of the main Kankakee and lower Yellow River valleys, particularly in Starke County, southwest LaPorte, and northern Newton and Jasper Counties. Erosion in Benton County was not examined in the study.

In major erosion areas of the Kankakee River Basin study region in Indiana where sheet and rill erosion by water was identified as the dominant problem, soil loss from all sources was estimated to be about 3 million tons per year, or roughly 5.9 tons per acre per year. In areas where sheet erosion by wind is the dominant problem, total sheet erosion by wind was estimated to be about 3.6 million tons per year, or 7.1 tons per acre per year.

As part of the Kankakee River Basin soil erosion study, three alternative management plans were developed for each county (U.S. Department of Agriculture, 1986). Each alternative would reduce soil loss from sheet and rill erosion by both water and wind action to three different levels. Alternative 2, the most cost-effective alternative, would reduce soil loss to the tolerable limit (T), or the maximum annual rate of soil erosion at which a high level of crop productivity can be sustained economically and indefinitely. Alternative 1 would reduce soil loss to 2T, and Alternative 3 would reduce soil loss to 1/2T. In each alternative, *gully* erosion and *ephemeral gully* erosion would be controlled to aid in localized erosion reduction.

Major management practices that can be used to reduce wind and water erosion include conservation tillage, contour farming, diversion terracing, grassed waterways, grade stabilization structures, and water- and sediment-control basins. Additional soil conservation measures include the use of crop residues, green-manure crops, and winter cover crops.

Since the completion of the basin erosion study (U.S. Department of Agriculture, 1986), additional studies have been completed in adjoining areas of northern and central Indiana (U.S. Department of Agriculture, 1988a, 1990). These reports present data and management alternatives similar to those described in the 1986 Kankakee River Basin report.

In 1987, the Division of Soil Conservation was established within the Department of Natural Resources. This division is responsible for administering the state's accelerated soil erosion/sedimentation reduction program. The goals of the program include 1) reducing erosion on all land to at least the tolerable limit, and 2) applying the best practical technology to control off-site sedimentation by the year 2000 (Governor's Soil Resources Study Commission, 1985).

Major projects implemented jointly by the division, county Soil and Water Conservation Districts, and the U.S. Department of Agriculture's Soil Conservation Service in the Kankakee River Basin have included erosion-control projects at Koontz Lake and Lake of the Woods, and the installation of erosion-control structures on seriously eroding cropland.

A variety of programs administered by public and private agencies encompass research projects, education programs, technical assistance, and cost-share financial assistance for erosion control. Other major agricultural programs intended to reduce soil erosion include the 1985 Food Security Act, commonly known as the Farm Bill. The act sets forth mandatory conservation plans by the year 1990 on lands classified as *highly erodible*.

Under the act's conservation reserve program, financial incentives are provided to farmers who remove highly erodible land from production for a minimum of 10 years. In 1987, an average of 0.4 percent of farmland in the Kankakee River Basin was placed in the program (see U.S. Bureau of the Census, 1989). In Starke County, where wind erosion is the dominant form of soil loss, conservation reserve lands totaled about 2 percent of all farmland.

Stream sedimentation

Sediment is inorganic and organic material that is transported by, suspended in, or deposited by streams. Sediment load, which is the quantity of sediment transported by a stream, is a function of stream discharge, soil and land-cover features, meteorological conditions, land-use activities, and many other factors.

Sediment load can be divided into two components on the basis of the mode of sediment transport. **Suspended sediment** consists of silt- and clay-size particles held in suspension by turbulence in flowing water. **Bedload sediment** consists of larger particles which slide, roll or bounce along the streambed by the force of moving water.

Much of the sediment load carried by the Kankakee River appears to be moving as suspended load. Moreover, most of the suspended load is transported during flood events, although the largest suspended sediment discharges are not necessarily associated with the largest water discharges.

Reports by Bhowmik and others (1980) and DeMissie and others (1983) concluded that the watershed of the Iroquois River in Indiana and Illinois contributes more suspended load per square mile of drainage area than the watershed of the mainstem Kankakee River. In addition, the suspended load carried by the Iroquois River is composed primarily of fine materials, mostly silts and clays, whereas the Kankakee River carries substantial amounts of sand, particularly during high stream discharges. These particle-size differences can be attributed largely to the predominance of silty, clayey soils in the Iroquois River watershed, in contrast to the predominance of sandy streambed materials and basin soils in the Kankakee River watershed (Gross and Berg, 1981).

Sediment yield is the total quantity of sediment transported from a drainage basin at a given location in a given period of time. A study by Crawford and Mansue (1988) concluded that suspended sediment yields and concentrations for streams in the Northern Lake and Moraine Region, which encompasses the Kankakee River Basin (figure 13), are notably less than values for streams in other parts of Indiana. The median suspended-sediment yield computed for the northern region was 68 tons per square mile per year, in contrast to 195 tons per square mile per year for the rest of Indiana.

The low suspended sediment yields in northern Indiana, including the Kankakee River Basin, can be largely attributed to the region's low erosion rate. In most areas, the low relief and permeable soils help limit the availability of eroded material from within watersheds. Moreover, fairly low stream velocities help limit the sediment-transport capacities of streams, and significant amounts of *base flow* are available for dilution of suspended sediment concentrations.

Although sediment yields in the Kankakee River Basin are fairly low, changes in land use, stream-flow characteristics and drainage patterns can alter the natural sedimentation rate. For example, the conversion of wetlands or woodlands to cropland can increase soil erosion and the associated sedimentation in streams. Activities that increase stream slope and velocity can increase the stream's erosive capacity and sediment-transport capability. Construction projects within or adjacent to streams, particularly activities that disturb the streambed and streambanks, can contribute to sedimentation problems, primarily by dislodging or exposing soils and sediments.

Sedimentation problems along streams of the Kankakee River Basin often are caused by the erosion of unstable agricultural ditch banks and adjacent cropland. Windblown soil particles also contribute to sedimentation problems and associated water-quality problems through the deposition of sediment-borne pollutants into ditches, streams and rivers. Unstable spoil banks along newly excavated ditches and unvegetated portions of existing spoil banks can be a source of excessive streambank erosion and its associated sedimentation.

Excessive amounts of sediment resulting from natural or man-made causes can result in the destruction of aquatic habitat and a reduction in the diversity and abundance of aquatic life. A study in Illinois (Brigham and others, 1981) concluded that if the amount of sand and silt moving downstream in the Kankakee River in Illinois were to increase and subsequently cover cobble, gravel and rock substrates with substrates chiefly composed of sand, the diversity and population size of fish species, mussels and benthic macroinvertebrates associated with the coarse substrates would be greatly reduced. Where sand substrates have historically predominated, however, increased sand deposition may have little detrimental impact on sand-associated aquatic life.

Excessive amounts of suspended sediment cause the water to be cloudy (turbid). Increased turbidity affects the growth of algae and aquatic plants, which adversely affects the entire aquatic *ecosystem*. Moreover, increased turbidity decreases the water's aesthetic appeal and the enjoyment of recreational activities. In addition, some metal ions, pesticides, and nutrients may adhere to sediment particles and be transported downstream (Crawford and Mansue, 1988).

A report by Bhowmik and others (1980) suggested preventive measures for reducing excessive sediment load in a river. The measures included 1) the proper repair and maintenance of drainage ditches and levees, 2) minimal disturbance of the riverbanks, 3) avoidance of structural disturbance of the river, 4) reduction of sediment excesses arising from construction activities, 5) application of artificial and natural means for preventing erosion, and 6) the use of proper land and water management practices on the watershed. These preventive measures were preferred over remedial measures, which included 1) construction of detention reservoirs, sedimentation ponds, or settling basins, 2) development of side-channel flood-retention basins, and 3) removal of deposited sediment by dredging.

A draft report by the Indiana Nonpoint Source Task Force (1989) outlines recommendations for protecting water quality through erosion control. Several recommendations involve regulatory measures associated with current Indiana and federal statutes administered by the state Departments of Natural Resources, Environmental Management, and Highways, and the U.S. Army Corps of Engineers. These laws provide some consideration of erosion and sedimentation control along streams and lakes during flood-control, drainage, highway, bridge, and other stream-related construction projects.

SURFACE-WATER HYDROLOGY

The surface-water resources of the Kankakee River Basin include the mainstem Kankakee River; its principal tributaries, the Yellow and Iroquois Rivers; an extensive network of smaller tributary streams and ditches; several large natural and man-made lakes; scores of smaller lakes and perhaps hundreds of ponds and man-made excavations; and scattered remnants of *marshes, swamps* and other wetlands.

These surface-water features constitute a significant part of the hydrologic cycle (figure 2), a continual movement of water between the atmosphere and earth. The hydrology of streams, lakes and wetlands is closely related not only to precipitation, but also to topographic, *geomorphic* and hydrogeologic conditions.

HISTORICAL PERSPECTIVE

The hydrology of the Kankakee River Basin has undergone significant changes since the region was first settled in the early 1800s. Drainage of the Grand Kankakee Marsh and *channelization* of the Kankakee River dramatically altered the hydrology of the main river valley. Moreover, the combined impacts of tiling, ditching and related drainage activities further modified local and regional hydrology in areas adjoining the main valley and in many areas of the Yellow and Iroquois River subbasins.

A historical overview of major drainage and flood protection projects provides a broad perspective for assessing potential constraints and impacts of future water and land development. Although many books and reports have been published concerning the history, navigability and channelization of the Kankakee River, only a few major references are cited in this discussion.

The following summary of early history was derived primarily from reports by Campbell (1882), Doggett (1933), Meyer (1936), and U.S. Army Corps of Engineers (1944). Other significant historical accounts are provided by Ball (1900), U.S. Department of Agriculture (1909), Andrews and Andrews [1915], U.S. House of Representatives (1916, 1931), U.S. Army Corps of Engineers (1941), State of Illinois (1954), Conway (1964), and Houde and Klasey (1968). Reports by Bhowmik and others (1980) and Machan (1986) also contain historical summaries.

Early and recent history

The Kankakee River of today bears little resemblance to the naturally meandering river which once traversed the marshy valley lowlands. In its natural state, the Kankakee River upstream of Momence, Illinois followed a sinuous 250-mile course through the wide, 90-mile-long river valley. The natural Kankakee River upstream of Momence had about 2000 bends (Kankakee Valley Draining Company, 1871b) and an average channel slope of about 4 or 5 inches per mile.

The meandering nature of the Kankakee River was produced by many basin characteristics, including: 1) the nearly flat gradient of the geomorphically oversized river valley; 2) the loose, sandy sediments of the valley floor; 3) the presence of wetland vegetation; and 4) the frequent occurrence of floods. These and other factors, such as the high *water table*, also combined to produce a maze of *sloughs* and *oxbows* along the river corridor (Meyer, 1936).

A vast marsh and wooded swamp occupied most of the Kankakee River valley and adjoining lowlands. The area often termed the Grand Kankakee Marsh referred to the marsh-swamp-dune complex which extended from the river's headwaters near South Bend, Indiana to the outcropping limestone ledge in the riverbed near Momence, Illinois, located about 7 miles west of the state line. Figure 21 shows the approximate extent of the marsh in Indiana prior to the massive drainage and channelization projects of the late 1800s and early 1900s.

According to many historic acounts, the Grand Marsh covered more than 400,000 acres, or 625 square miles. The main body of the Grand Marsh was from 3 to 10 miles wide, and smaller arms extended 5 to 10 miles farther out into many tributary valleys and low-lying areas of the floodplain. Isolated dunes and sand ridges, some up to 30 feet high, dotted the interior of the vast marsh, appearing as wooded islands in a sea of aquatic sedges and grasses, marsh hay, wild rice, cattails, and other wetland plants.

A strip of swamp timber bordered the river downstream of the former English Lake (figure 21). Dominant tree species included silver maple, black ash, white ash, and elm. The swampy river corridor averaged about one-half to one mile in width, and reached its maximum width of nearly 3 miles in northern Jasper

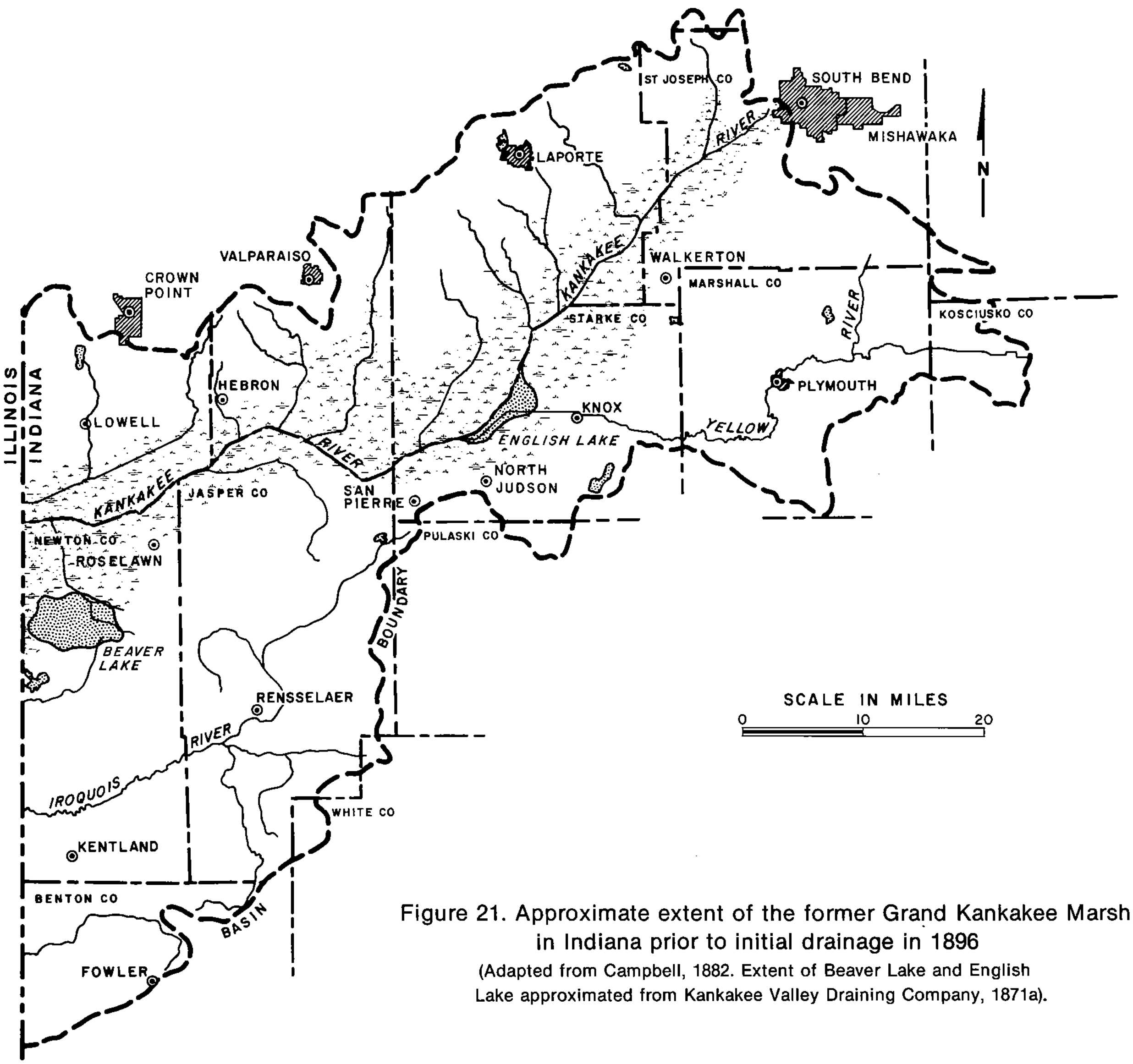


Figure 21. Approximate extent of the former Grand Kankakee Marsh in Indiana prior to initial drainage in 1896
(Adapted from Campbell, 1882. Extent of Beaver Lake and English Lake approximated from Kankakee Valley Draining Company, 1871a).

County, southwest Porter County and southeast Lake County.

For 8 to 9 months of the year, about 1 to 4 feet of water covered a 3- to 5-mile-wide area on either side of the river. The sluggish river and its adjoining marshes thus assumed many characteristics of a wide, shallow lake.

The Grand Kankakee Marsh teemed with wildlife. The Kankakee River and its adjoining open-water areas supported a large number of game fish, including largemouth and smallmouth bass, northern and walleye pike, pickerel and catfish. Millions of waterfowl used portions of the marsh for resting, feeding and nesting. The diversified habitat of the marsh attracted fur-bearing animals such as muskrat, mink, beaver, fox, weasel and raccoon. Squirrel, rabbit, quail, prairie chicken, woodcock, white-tailed deer and other game animals inhabitated the dunes, sand ridges and other uplands. Woodland and wetland habitats also supported a variety of non-game mammals, birds and other animals.

The natural abundance of the marsh's flora and fauna provided a haven for the Pottawatomi and other native Indian tribes. French explorers, voyageurs and missionaries traveled on the Kankakee River as early as the 1670s (Baker, 1929). During the 17th and 18th centuries, hunters and trappers established temporary settlements along the river.

Treaties in 1832 and 1836 ended the Pottawatomi's occupancy of the Kankakee River valley and transferred the tribe to a reservation in Kansas. The first white frontiersmen subsequently entered the valley, seasonally or temporarily occupying uplands bordering the river's marshes and the low dunes and sand ridges within the marsh. By the 1850s and 1860s, farmers, loggers, cattle stockmen and other settlers had replaced the migratory hunters and trappers, and had established permanent settlements throughout the valley.

The Kankakee River was commonly used for transportation, particularly in its lower reaches, and the clear river water provided a valuable source for ice harvesting. At Momence and several other locations in Illinois, the river was used to power grist mills and saw mills. The river also provided many recreational opportunities, including fishing, swimming, boating and ice skating.

By the middle 1800s, the Grand Kankakee Marsh had become widely known as a "sportsman's paradise." Hunting lodges were built along the river corridor by sportsmen's clubs based in the Great Lakes region and the East Coast. The river and its associated marshes attracted U.S. presidents and even European nobility who sought hunting and fishing opportunities.

Although sportsmen, naturalists and other outdoorsmen valued the Kankakee River's vast marshlands, many landowners needed well-drained land for agricultural production and other development. As the population increased in the valley, marshlands began to be converted into tracts of drained farmland.

Early attempts to drain portions of the Grand Kankakee Marsh for agricultural development took many forms and met with varying degrees of success. Pioneer farmers in the early to middle 1800s drained small tracts of land by digging ditches, first by hand and later with the help of oxen and horses.

In 1852, the Governor of Indiana proposed draining the Kankakee's marshes to create new agricultural lands. Early attempts to drain an elevated portion of the Grand Marsh known as the Beaver Lake District met with limited success, however, and early agricultural efforts in the area failed. In later decades, however, the large, shallow lake (figure 21) and most of the surrounding marshes were totally drained.

The expansion of state drainage statutes in 1869 and 1871 and the invention of the steam dredge paved the way for large-scale drainage projects in the Kankakee River Basin. Construction of Singleton Ditch in the 1880s was the first of many large ditching and dredging projects completed under Indiana drainage statutes.

In 1889 and 1891, the Indiana legislature appropriated funds to lower the limestone ledge that outcrops in a 2-mile reach of the Kankakee River bed near Momence, Illinois. In 1893, the ledge was partially excavated, and the channel was widened and deepened in an effort to facilitate drainage upstream in Indiana.

Channelization of the mainstem Kankakee River began in 1896, nearly 30 years after it had been first proposed by a private draining company (Kankakee Valley Draining Company, 1869). Although construction of a 7-mile ditch near South Bend was conducted by private interests, the remaining channelization work was completed under state drainage statutes.

By 1917, the entire length of the Kankakee River in Indiana had been channelized. The sinuous, 250-mile-long river had been converted to a series of seven relatively straight dredged ditches extending about 82 miles from near South Bend downstream to the Indiana-Illinois state line. The river's flow was now confined to a well-defined channel bordered in many places by high spoil banks which topped the natural streambanks.

Moreover, the Kankakee River channelization projects and the subsequent construction of lateral and subsidiary ditches throughout the river valley had converted most of the 625-square-mile Grand Kankakee Marsh to agricultural development, and had increased drainage on more than 900 square miles of marginal land bordering the marsh. By the early 1900s, only about 39 square miles (6 percent) of the original marsh remained in Indiana.

The hydrologic effects of the channelization and drainage projects have long been a topic of debate among engineers, hydrologists, sportsmen, conservationists, farmers, government officials, and others interested in the basin's water resources. Although a lack of historical data prevents a quantitative analysis of stream-flow modifications incident to the drainage projects, interpretations can be made on the basis of hydrologic principles and a recognition of watershed features (see box on next page).

Hydrologic effects of drainage projects

Prior to the channelization, dredging and ditching projects of the late 1800s and early 1900s, soils in the Kankakee River valley were seasonally saturated as a result of the region's high water table. Water often was ponded in surface depressions by runoff and ground-water seepage from tributary basins.

During storm events, the water depth on the valley floor and its bordering marshlands would have increased as the water table rose and tributary runoff was stored in the low-lying areas of the Kankakee River corridor. *Overland flow* would have been obstructed on the floodplain and its bordering marshes by slight topographic rises and dense vegetation, helping to reduce floodwater velocities and attenuate flood peaks.

Following the extensive ditching and dredging projects, the water table was lowered in the Kankakee River valley, and the once-saturated soils were drained. Under certain hydrologic conditions, the unsaturated soils and drained surface depressions could provide temporary storage of precipitation during storm events and perhaps during the early stages of floods. This available storage could therefore contribute in some cases to the further attenuation of flood flows along the Kankakee River.

Once the drained soils become saturated, however, ditches and tile systems transport excess water to drainage outlets, and ultimately to the mainstem Kankakee River. The improved runoff efficiency and the confinement of floodwaters between spoil banks along the straightened Kankakee River can serve to increase flood stages, floodwater velocities and peak flows.

Because stream gages near Shelby, Indiana and Momence, Illinois were not installed until the massive drainage and channelization work was nearly complete, no studies can be conducted to determine actual differences in flood-flow characteristics under pre- and post-channelization conditions. Moreover, any speculations regarding flow modifications are complicated by the unique combination of topographic, geomorphic and hydrologic features of the Kankakee River valley.

As discussed in a later subsection of this chapter entitled ***Flood Flows***, the valley's nearly flat gradient and the availability of an unusually large amount of overbank storage are among the factors which help attenuate flood peaks on the mainstem Kankakee River. According to an investigation by Dodson, Kinney and Lindblom (1968), the frequency and duration of overbank flooding probably did not change significantly following the channelization and ditching projects. However, their report did not describe potential changes in either flood stage or discharge.

A report by the Kankakee River Basin Commission (1989) noted a long-term historical increase in **annual peak flows** at the Davis and Shelby gages during the post-channelization period 1926-86. A report by the Illinois Water Survey (Bhowmik and others, 1980) similarly concluded that 3-year *moving averages* of annual peak flows at the Shelby gage in Indiana and the Momence gage in Illinois showed an increasing trend during the post- channelization period 1931-79. Moving averages of **annual average flows** at the Momence and Wilmington gages in Illinois also showed an increasing trend. No discernible trends could be identified for other gaging stations on the Kankakee and Iroquois Rivers.

It must be emphasized that these analyses did not include the 10 years immediately following completion of the channelization and drainage projects. Because alterations in stream-flow characteristics would be expected to stabilize shortly after the projects had been completed, the observed trends in peak and annual average flows may be the result of continuing natural and man-made changes in the basin.

Changes in precipitation patterns are among the natural factors that may increase peak flows in a given drainage basin. The investigation by Bhowmik and others did not detect any trends in annual precipitation within the Kankakee River Basin as a whole during the period 1931-79. However, because the interactions between precipitation and stream flow are so complex, Bhowmik's analysis of annual precipitation seems inadequate without a further investigation of local and regional storm patterns. A more thorough precipitation analysis might have revealed changes or peculiarities in the frequency, intensity or spatial distribution of flood-producing storm events.

Man-made factors that may be responsible for the increasing trend in peak and average flows along some reaches of the Kankakee River include the ongoing drainage and pumping projects in tributary watersheds and in the main valley. Another potential factor is the construction, enlargement, and improvement of private levees and dikes. Increased pumping and the

In the decades following the Kankakee River channelization and other major ditching projects, drainage work continued on a smaller scale to further enhance agricultural production and help reduce flooding. Many projects in tributary basins were conducted through local drainage boards.

The density of drainage ditches has been partially determined by topography, soils, and the value of farmland. In some parts of the main valley, dredge ditches have been constructed on each section line. Some areas of prime farmland have even denser drainage networks. Pumping stations often are used to facilitate agricultural drainage.

In general, the construction of drainage networks has allowed the successful cultivation of many crops, and the Kankakee River Basin continues to be one of the most agriculturally productive areas of Indiana. However, some small, mucky depressions and low-lying areas along a few streams still remain inadequately drained for profitable agriculture. These poorly drained tracts may be better suited to alternative uses such as wildlife habitat.

Levees and flood control

Flood protection along the Kankakee River historically has been provided to some extent by banks of dredge spoil from early channelization and ditching projects. Additional flood protection has been provided by the Williams and Brown Levees in southern Lake County, and by smaller levees along residential and resort communities located along lower reaches of the river.

Large areas of farmland in tributary basins are partially protected against flooding by agricultural dikes addition of levees can increase the volume of surface runoff while decreasing the amount of available storage. It is also possible that peak and average flows are merely approaching their maximum levels in a periodic cycle, and may exhibit a decreasing trend in coming decades.

An analysis of potential changes in **low-flow characteristics** in the Kankakee River Basin was conducted by Bhowmik and others (1980). Contrary to some expectations, no discernible trend was detected.

In general, draining the soil profile and removing expanses of wetland storage along a river such as the Kankakee would have been expected to reduce low flows. Increasing the efficiency of surface drainage also would have been expected to reduce low flows by reducing the amount of water available to stream systems on a short-term basis as *bank storage*. Moreover, lowering of the local water table in a basin by ditching, tiling and dredging would have been expected to reduce the amount of ground water available for sustained seepage to streams during prolonged dry spells.

The absence of any noticeable changes in low flows in the Kankakee River Basin may be the result of the high degree of ground-water discharge to the river and some of its major tributaries. Other factors might include the hydrologic properties of soils and underlying geologic materials, or changes in flow characteristics of the river itself.

Because drainage modifications within the Kankakee River's tributary watersheds can be complex, and because discharge data typically are unavailable, no conclusions can be drawn concerning flow trends on tributary streams and ditches. Localized flow changes along these watercourses will largely depend on geomorphic factors and on manmade activities such as surface-water and ground-water pumpage, the operation of *water-table control structures*, diversions, and discharge of wastewater effluent.

Changes in **sediment-transport** characteristics downstream of the channelized reaches have been difficult to quantify (see Gross and Berg, 1981). Documented statements typically have been of a qualitative or subjective nature.

A study by the U.S. Army Corps of Engineers (U.S. House of Representatives, 1931) noted that channelization of the Kankakee River in Indiana increased the flow so that, at least initially, more sand and silt were being carried downstream into Illinois upstream of Momence, depositing among trees and creating sand bars in the riverbed. Although not mentioned in the 1931 report, the river's increased sediment load following channelization also could be attributed to 1) the loose, sandy nature of the soils, 2) caving of unstable sandy streambanks, 3) sloughing of spoil banks, 4) streambed scour, and 5) sedimentation from eroding cropland.

Sedimentation in the mainstem and tributary ditches created an ongoing need for ditch reconstructions and channel-cleaning activities in the decades following the major ditching and dredging projects. Between 1906 and 1915, for example, many shoals had formed in the first five segments of the straightened Kankakee River, thereby reducing the river's depth in places (U.S. House of Representatives, 1916).

In 1925, about 23 miles of the Kankakee River upstream of Dunns Bridge were redredged, but there continued to be evidence of considerable sedimentation (Frazier and Sapirie, 1934). More than 3 feet of sediment was reported to have accumulated above the original bottom grade of the channelized Kankakee River at some points in its middle to lower reaches (Doggett, 1933). Doggett's report also noted that some tributary drainage ditches had shoaled to half their original depth, and in some places were overgrown with weeds and other aquatic plants.

A report by the U.S. Army Corps of Engineers (1941) noted that large quantities of sand had been deposited between the state line and Momence, Illinois, thus reducing low-flow depths to less than 1 foot. However, the rate of siltation between the state line and Momence was reported to have decreased, perhaps indicating that the straightened channel in Indiana was stabilizing.

A report by the Illinois State Water Survey (Gross and Berg, 1981) concluded that sedimentation resulting in sand bars, *spit* extensions, and island growth had attained some stability by the early 1950s. Increasing stabilization of *accretionary* sand deposits during the period 1954-73 attested to the stabilizing condition of the Kankakee River. Moreover, the geometric form of the channelized Kankakee River appeared to be nearly stable, based upon the virtual absence of post-channelization river meandering.

and spoil-bank levees formed by dredge material (spoil) from ditching and channel maintenance projects. Ditch-and-levee systems often are supplemented by pumping stations intended to deliver excess water to major drainageways.

Although continuous ridges of spoil banks can act as levees, the degree of flood protection can be quite variable, particularly in areas bordered by agricultural dikes. Spoil-bank dikes and levees vary greatly in height and cross section because of the haphazard placement of dredge material and because the levees usually have been constructed without coordination among local groups.

In many places, spoil-bank levees are interrupted by drainage ditches and abandoned stream channels. Moreover, the sandy, debris-laden dredge spoil is highly susceptible to seepage and erosion. These factors, combined with limited local maintenance and clogged drainage ditches, can result in the failure of spoil-bank levees during floods.

The repair of levees and spoil banks has been one method for reducing flood damage along the Kankakee River. During the 1950s and 1960s, for example, the U.S. Army Corps of Engineers financed or supervised a number of levee inspection and repair projects in Lake and Newton Counties. However, subsequent reports (U.S. Army Corps of Engineers, 1979, 1984) noted that a general lack of maintenance continues to reduce the effectiveness of levees and spoil banks for flood protection.

Developments since 1970

Because of recurring flood problems in the Kankakee River Basin and local concern over water- and land-related resources, a joint federal-state study of the region was conducted in the early 1970s. The study was led by the U.S. Department of Agriculture's Soil Conservation Service, but involved six other agencies, including the Indiana Department of Natural Resources and the U.S. Geological Survey.

The investigation addressed resource-related problems whose solutions would require a cooperative effort among government agencies and basin residents. The final report of the investigation (U.S. Department of Agriculture, 1976) contained five planning alternatives for land and water development. A combination of plan elements was formulated as a 13-point suggested plan.

Major features of the plan included the following: 1) proposed channel work for flood control and drainage on 26 miles of the upper Kankakee River mainstem and more than 240 miles of 13 tributaries, with levees (and no channel work) along 49 miles of the Kankakee River from U.S. Highway 30 in LaPorte and Starke Counties downstream to U.S. Highway 41 in Lake and Newton Counties; 2) amendments or adoption of floodplain zoning ordinances and building codes to allow eligibility for flood insurance; 3) an accelerated land-treatment program to help facilitate on-farm drainage, reduce soil erosion, and increase agricultural production efficiency; 4) implementation of land-use changes to help ensure sustained agricultural capabilities; 5) proper management and conservation of fish, wildlife, woodland and wetland habitat; and 6) development of recreational areas, trails and water-access sites.

Although not directly implemented, the suggested plan elements were used as a guide by the Kankakee River Basin Commission, which was formed in 1977 by the Indiana General Assembly. The main purpose of the 24-member commission is to address water-resource development issues, including flood-control and drainage problems, in an eight-county area along the Kankakee River and its major tributary in Indiana, the Yellow River.

The Kankakee River Basin Commission received an appropriation in 1979 from the Indiana General Assembly to clear and snag debris from the Kankakee and Yellow Rivers, and to improve damaged or inadequate dikes and levees. Spoil-bank levees near Shelby were repaired, and some minor clearing and snagging was completed on a short stretch of the Yellow River. However, the U.S. Army Corps of Engineers denied the commission a permit to clear and snag the mainstem Kankakee River on the grounds that increased floodwater velocities, increased sediment loads, and environmental damage downstream of the project would outweigh flood protection benefits in the project area. Reports by the U.S. Army Corps of Engineers (1982a, b) contain environmental assessments of the proposed project.

Following such attempts to conduct channel maintenance, the commission adopted a new set of guidelines (Kankakee River Basin Commission, 1983). The guideline resolution incorporated comments from representatives of the agricultural community, environmental organizations and state government.

Since 1983, the commission has cooperated with various organizations in developing a master plan which proposes four basic elements for implementation in the coming decades, namely: 1) flood control and protection along the Kankakee River through the development of a widely spaced levee system; 2) improvement of agricultural drainage in 39 tributary basins; 3) improved land-treatment practices and suggested land-use alternatives for some agricultural lands; and 4) enhancement of natural areas, wildlife habitats and recreation facilities (Kankakee River Basin Commission, 1989).

The proposed levees described in the master plan would be located on both sides of the Kankakee River. The levee system would extend for a length of about 60 miles, from U.S. Highway 30 in LaPorte and Starke Counties downstream to the Indiana-Illinois state line.

Unlike conventional levees, which are constructed on or near the riverbank, the proposed levees would be set back from the river at varying distances to allow *overbank* storage of floodwater in low-lying lands between the levees. The proposed levee system would provide flood protection for nearly 110 square miles (70,000 acres) of floodprone land while containing waters from a *100-year flood* event on approximately 48 square miles (30,714 acres) of land between the levees.

A computer model developed by the Soil Conservation Service and the IDNR Division of Water has been used to establish the approximate location and height of the proposed setback levees. The levees would be located as close to the river as 150 feet and as far back as 2 miles, depending on local topography, land-use practices, and the hydrologic requirements for storing floodwaters.

Proposed levee heights would vary from 2 to 11 feet depending on local grade elevations and the proposed floodwater-storage requirements. Levees are not being planned in areas where sufficiently high ground is located at or near the proposed levee alignment.

Reconstruction of Williams Levee, which is considered as the first phase of the wide levee plan, was completed in Lake County in 1988. A tributary pumping project, known as the Bailey-Cox-Newtson Watershed Project, was completed in Starke County in 1984, and will be incorporated into the wide-levee plan if it is implemented.

If constructed, the proposed levee system should improve agricultural drainage on nearly 700 square miles (447,805 acres) throughout 39 tributary drainage basins. The drainage would be accomplished through the use of tributary control gates, pumping stations, and levees along the tributaries back to high ground.

The proposed project also would provide opportunities for additional recreational development and the potential enhancement of fish, wildlife, woodland and wetland habitats along some segments of the river corridor. These goals would be accomplished primarily through management practices, acquisition, and land-use changes on selected lands lying between the proposed levees (Kankakee River Basin Commission, 1989).

As of July 1990, elements of the Kankakee River master plan are under review by the Kankakee River Basin Commission and the Indiana Department of Natural Resources. Individual projects compatible with the setback-levee concept are possible, but the future of the proposed levee system remains uncertain.

SURFACE-WATER RESOURCES

Streams of the Kankakee River Basin not only supply large quantities of water for withdrawal uses such as irrigation and public supply, but also provide water for non-withdrawal uses such as instream recreation. Wetlands and lakes typically are not considered as potential water-supply sources, but their occurrence and regulation directly affect land use and its associated water resources development.

Wetlands

Wetlands are a major hydrologic feature of the Kankakee River Basin. In general terms, wetlands occur where the ground-water table is usually at or near the ground surface, or where the land is at least periodically covered by shallow water. Because the water's presence creates a unique environment, wetlands support plants and animals specifically adapted for life in water or saturated soil.

Wetland types in Indiana can be grouped according to the classification scheme used by the U.S. Fish and Wildlife Service (Cowardin and others, 1979; Cowardin, 1982; U.S Fish and Wildlife Service, 1986). The structure of this classification is hierarchical, progressing from the most general levels of systems and subsystems to the more specific levels of classes and subclasses. The latter two levels in the hierarchy can be further subdivided according to water regime (duration and frequency of flooding), water chemistry, soil type, and dominant plants or animals.

Wetlands in Indiana belong to three of the five major wetland systems identified by Cowardin and others (1979). **Lacustrine** wetlands include permanently flooded lakes or reservoirs of at least 20 acres, and smaller impoundments whose maximum depths exceed 6.6 feet at low water. **Riverine** wetlands are contained within a natural or artificial channel that at least periodically carries flowing water. **Palustrine** wetlands are associated with areas and/or shallow bodies of water which usually are dominated by wetland plants. Palustrine wetlands include not only vegetated wetlands commonly called *marshes, swamps, bogs, sloughs,* or *fens,* but also isolated catchments, small ponds, islands in lakes or rivers, and parts of river floodplains. Palustrine wetlands also may include farmland that would support *hydrophytes* if the land were not tilled, planted to crops, or partially drained.

A comprehensive inventory of Indiana's wetlands was initiated in 1981 by the U.S. Fish and Wildlife Service as part of its National Wetlands Inventory. The inventory process involves identifying and classifying wetlands from high-altitude aerial photographs, then transforming the photographs into detailed maps (1:24,000 scale). The location and classification of each wetland then is digitized and stored in a computer. The computerized data will be accessible for analysis through the use of a geographic information system.

The Indiana Department of Natural Resources, Division of Fish and Wildlife entered a cost-share agreement with the U.S. Fish and Wildlife Service in 1985 for mapping and digitizing Indiana's wetlands. The statewide aerial photography was completed in 1988, and the mapping and digitizing was completed in 1990.

Because preliminary data on Indiana's wetlands were needed during the inventory's early stages for ongoing wetland conservation efforts, the Division of Fish and Wildlife initiated two studies between 1984 and 1986 to determine the abundance of wetlands in northern Indiana (Rolley and New, 1987) and east-central Indiana (figure 22). Wetland acreages were estimated using draft wetland maps and enlargements of interpreted aerial photographs from the U.S. Fish and Wildlife Service's National Wetlands Inventory. The estimates were extrapolated from a random sample of about 3 percent of the 1-square-mile sections occuring within the study regions.

In another investigation conducted by the Indiana Department of Natural Resources (1988c), the degree of wetland loss by natural processes and human activities over the past 200 years was determined by comparing estimates of current wetland acreage with estimates of original wetland acreage. The original extent of wetlands was estimated using *hydric soils* data supplied by the U.S. Soil Conservation Service.

The IDNR report concluded that nearly 2200 square miles of wetlands have been eliminated in the Kankakee and Wabash River Drainage Area, one of the four regions studied (figure 22). This value represents an 88 percent loss of the original wetland acreage within the study region, which encompasses much of the Kankakee River Basin (figure 22).

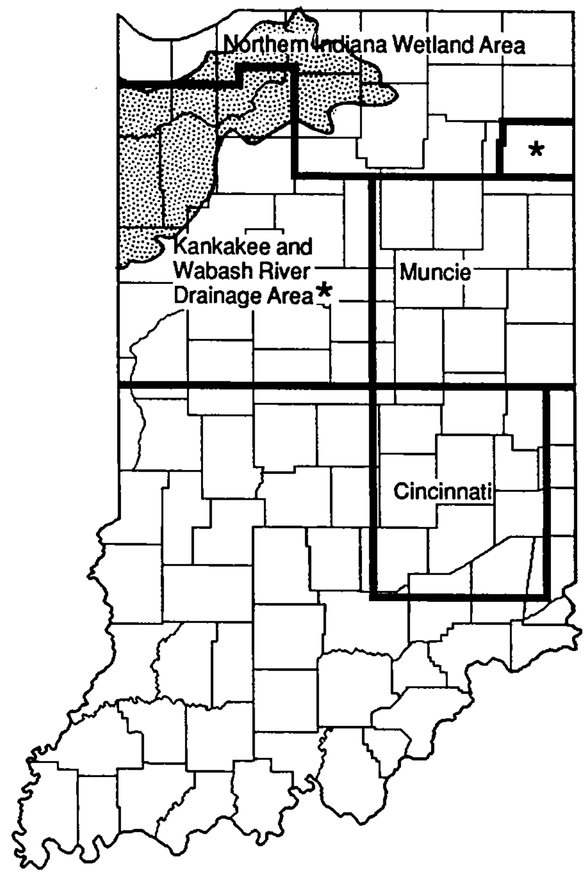


Figure 22. Location of wetland study regions

Inventory of basin wetlands

The number and acreage of wetland types remaining today in the Kankakee River Basin were estimated using the preliminary database developed by Rolley and New (1987) for the Kankakee and Wabash River Drainage Area and the Northern Indiana Wetland Area (figure 22). Estimates of in-basin wetlands were extrapolated from a 3-percent random sample of 76 1-square-mile sections in the 83 legal townships that approximately encompass the basin.

Although this sampling scheme yields reasonable estimates of the total number and acreage of the basin's wetlands, some values for specific wetland categories should be interpreted with caution. These preliminary results will be updated when a statewide geographic information system with a digital wetlands inventory becomes operational.

According to the preliminary estimates, the Kankakee River Basin contains about 17,000 to 27,000 wetlands covering a total of approximately 100 to 200 square miles (table 12), or roughly 5 percent of the basin's total land area. Palustrine wetlands constitute more than 96 percent of the basin's wetlands, and about 95 percent of the total wetland area. Riverine and lacustrine wetlands account for about 2 and 3 percent of the basin's total wetland area, respectively.

Palustrine forested and palustrine emergent wetlands together constitute nearly 75 percent of the basin's wetlands and about 81 percent of the wetland area (table 12). Staff of the IDNR have preliminarily identified these wetland classes as state priority wetland types (Indiana Department of Natural Resources, 1988c).

Palustrine forested wetlands are characterized by large, woody vegetation that is at least 20 feet tall. Palustrine emergent wetlands, commonly called marshes, meadows, fens or sloughs, are characterized by erect, rooted, *herbaceous* hydrophytes, excluding

Table 12. Estimated number and area of basin wetlands

{Values are preliminary estimates of the Indiana Department of Natural Resources, Division of Fish and Wildlife, as based upon maps and aerial photographs obtained from the U.S. Fish and Wildlife Service's National Wetlands Inventory.}

Wetland classification: Classification follows the system described by Cowardin and others (1979).

Estimated number, estimated area: Lower numbers, in italics, represent the 95 percent confidence interval.

Wetland classification	Estimated number	Percent of total	Estimated area (sq. mi.)	Percent of total
Palustrine, aquatic bed	275 *213*	1	1.4 *0.7*	1
Palustrine, emergent	9,950 *2,590*	46	52.8 *16.8*	35
Palustrine, forested	6,017 *1,677*	28	69.6 *22.0*	46
Palustrine, open water	3,382 *1,055*	16	7.1 *2.6*	5
Palustrine, scrub shrub	1,298 *533*	6	11.5 *3.9*	8
Riverine, lower perennial, open water	747 *377*	3	3.4 *1.4*	2
Lacustrine, limnetic, open water	118 *136*	1	4.6 *1.8*	3
Total	21,788 *5,314*	100	150.5 *47.2*	100

mosses and lichens. In emergent wetlands, hydrophytic vegetation is present for most of the growing season in most years.

The greatest number of palustrine forested and emergent wetlands in the Kankakee River Basin occur in the morainal and outwash areas of St. Joseph, Marshall, and northeastern LaPorte Counties. The largest tracts of contiguous palustrine wetlands are located along the middle and lower Kankakee River corridor. The five state-owned fish and wildlife areas located along or near the river contain broad zones of forested and emergent palustrine wetlands.

Open-water palustrine wetlands account for about 16 percent of the basin's wetlands, but account for only about 5 percent of the total wetland area (table 12). These wetlands typically include shallow lakes and excavated ponds, but also may include sloughs and *oxbow lakes* of the lower Kankakee River valley.

Wetlands in the Kankakee River Basin can be further characterized by the duration and timing of surface inundation, using the classification scheme described by Cowardin and others (1979). According to preliminary estimates based on this classification, about three-fourths of the basin's wetlands are either seasonally flooded (47 percent) or temporarily flooded (28 percent). About 12 percent of the basin's wetlands are semi-permanently flooded, and about 10 percent are either saturated or permanently flooded. The box on the next page describes these five wetland categories.

> ***Water regime of wetlands in the Kankakee River Basin***
>
> **Seasonally flooded** wetlands contain surface water for extended periods, especially early in the frost-free crop growing season, but usually become dry by season's end. When surface water is absent, the ground-water table often is near the land surface.
>
> In **temporarily flooded** wetlands, surface water is present for brief periods during the growing season, but the ground-water table usually lies well below the land surface for most of the season. Plants that grow both in uplands and wetlands are characteristic of the temporarily flooded regime.
>
> **Semi-permanently flooded** wetlands contain surface water throughout the growing season in most years. When surface water is absent, the ground- water table is usually at or near the land surface. The basin's semi-permanently flooded wetlands typically are found along river corridors or adjacent to the larger lakes.
>
> In **saturated** wetlands, such as fens, ground water is at the land surface for extended periods during the growing season, but surface water is seldom present.
>
> In **permanently flooded** wetlands, water covers the land surface throughout the year in all years. Riverine and lacustrine systems constitute the majority of permanently flooded wetlands.

Wetlands in the Kankakee River Basin also can be described by size category. According to preliminary estimates, about 4 percent of the basin's individual wetlands are one acre or smaller; 42 percent are between one acre and 10 acres; 42 percent are between 10 and 40 acres; and 12 percent are greater than 40 acres. Lacustrine wetlands probably constitute most of the larger wetlands, although some palustrine wetlands along the Kankakee River corridor and a few remnant natural areas containing wetland complexes are fairly extensive.

Wetland protection programs

Once perceived as "wastelands," Indiana's wetlands historically have been ditched, dredged, tiled or filled to allow for agricultural production and other economic development. Although the perception of wetlands as barren or useless land still persists, there is a growing awareness of the valuable functions of wetlands.

Wetlands not only play a role in the hydrologic cycle (figure 2), but also provide a wide range of benefits, including floodwater retention, water-quality protection, erosion control, fish and wildlife habitat, and recreational and aesthetic opportunities (see box on next page). Although no studies have been conducted on the economic value of wetlands in the Kankakee River Basin, Indiana, an economic assessment was published for the Momence Wetlands, a 6-mile, 1900-acre swamp-marsh-upland complex located along the Kankakee River just west of the Indiana-Illinois state line (Mitsch, Hutchison and Paulson, 1979).

In general, wetland values have largely been overlooked until recent years, when state and federal agencies developed or expanded programs that at least indirectly afford some protection for wetlands. These state and federal programs generally are designed to balance the need for wetland protection with developmental and drainage needs. Appendix 4 summarizes selected programs having a good potential for protecting the wetlands of northern Indiana, including the Kankakee River Basin.

The Indiana Flood Control and Lake Preservation Acts and the federal 404/401 permit process afford some protection to wetlands that meet specific criteria. Because the number and extent of wetlands protected through these regulatory programs are limited, however, non-regulatory programs involving land acquisition and voluntary measures often are the major factors in wetland protection.

Changes in land use are limited on lands acquired for specific purposes, such as parks or nature preserves. Moreover, many financial incentive programs and public-private partnership programs discourage certain developments or land-use changes that would harm wetland habitats.

In the Kankakee River Basin, significant wetland tracts totaling about 3 square miles are being protected on the following state-owned properties: 1) Menominee, Round Lake and Koontz Lake wetland conservation areas in Starke and Marshall Counties; 2) Kankakee Fen (St. Joseph County), Fish Creek Fen (LaPorte County), and Beaver Lake (Newton County) Nature Preserves; and 3) Potato Creek State Park (St. Joseph County).

More than 14 natural areas containing small but significant wetland tracts are being protected voluntarily through the Indiana Natural Areas registry as of early 1990. Some partially protected wetlands also are located in Lake County's 1.5-square-mile Grand Kankakee Marsh County Park and in other county and municipal parks along the Kankakee and Yellow Rivers.

Several contiguous tracts of floodplain forest and/or artificially manipulated wetlands are found in LaSalle, Willow Slough, Kankakee, Jasper-Pulaski and Kingsbury State Fish and Wildlife Areas. A total of about 10 square miles of marshes and open-water areas have been constructed or restored on these properties. In addition, a total of about 10 square miles are composed of floodplain forests and seasonally flooded lands, including cropland.

In general, water levels in the artificial wetlands and

Wetland values and benefits[1]

Wetlands as a landform provide a unique **water storage** function in river basins by temporarily retaining water in upstream reaches and slowing its release to downstream reaches. During flood periods, the storage capacity of the low-lying areas characteristic of wetlands can help to decrease floodwater velocity and increase the duration of flow, consequently reducing flood peaks. During dry periods, some of the stored water may discharge into the main river channel, thereby helping to maintain stream flow.

The beneficial water storage provided by the former Grand Kankakee Marsh was recognized in a report by the U.S. Army Corps of Engineers (U.S. House of Representatives, 1916). The report noted that the marsh and the permeable soils acted as a shallow reservoir, impounding waters from the watershed upstream of Momence, Illinois during highwater periods, then slowly releasing the waters to downstream reaches.

In the present-day Kankakee River valley, the floodwater storage provided by wetlands and other depressional areas helps reduce the velocity of overland runoff and attenuate flood peaks. Because some depressional areas have no defined drainage outlet, they do not contribute directly to surface runoff during flood events. Many of these noncontributing areas may contain lakes, ponds or other wetlands.

Under certain conditions, water from wetlands situated within a regional topographic high may supplement **ground-water recharge** at certain times of the year. Local ground-water recharge may occur in the vicinities of Pine Lake and adjacent lakes in the city of LaPorte, and Bass Lake in Starke County.

In most of the Kankakee River Basin, however, lakes and other wetlands primarily act as areas of **ground-water discharge**. These wetlands typically have formed where the ground surface intersects the *water table*. Wetlands are most likely to serve as ground-water discharge points at depressional lakes and along major river systems where regional ground-water flow patterns are toward the main channels. Ground-water dicharge into floodplain wetlands is especially significant during dry periods because the ground-water seepage helps to maintain stream flow. Similarly, ground-water discharge into lacustrine and palustrine wetlands can help maintain water levels in these systems.

Wetlands can play an important role in **water-quality maintenance** and improvement by functioning as natural filters to trap sediment, recycle nutrients, and remove or immobilize pollutants, including toxic substances, that would otherwise enter adjoining lakes and streams. Although natural wetlands in Indiana cannot be used for wastewater treatment, a few artificial wetlands have been created to filter wastewater effluent. For example, just south of the Kankakee River Basin boundary at Lake Maxinkuckee, sediment traps are being built and wetlands are being restored to filter pollutants before they reach the lake. At Marsh Lake in extreme northeastern Indiana, artificial wetlands have been created to act as a natural wastewater treatment system. In the Kankakee River Basin, a project is underway at Koontz Lake that involves artificial wetland construction.

Wetlands play a role in **erosion control** along lakeshores and streambanks by stabilizing substrates, dissipating wave and current energy, and trapping sediments. Lakeshores frequently subjected to wave action generated by heavy boat traffic can especially benefit from the stabilizing effect of adjoining wetlands. Along the Kankakee River and its tributaries, riparian vegetation helps decrease scour of the sandy streambanks and spoil banks.

The value of wetlands as **fish and wildlife habitat** has long been recognized. Most freshwater fish species can be considered wetland-dependent because 1) almost all important game fish spawn in the aquatic portions of wetlands, 2) many fish use wetlands as nursery grounds, and 3) many species feed in wetlands or upon wetland-based food. A variety of game fish in the Kankakee River use the oxbows and sloughs for cover (Robertson and Ledet, 1981).

Hundreds of species of vertebrate animals found in Indiana require wetlands at some time in their lives. Muskrats and beavers are examples of common Indiana furbearers that are totally dependent on wetland environments.

The popularity of waterfowl hunting relates directly to the importance of wetlands as feeding, nesting, resting, and wintering grounds for waterfowl. Waterfowl habitat management is a primary purpose of the five state-owned fish and wildlife areas located within the Kankakee River Basin. The presence of wetland habitats within these and other areas has played a major role in the re-establishment and enhancement of nesting populations of giant Canada geese.

Wetlands in the Kankakee River Basin also provide habitat for many bird species. Migratory wetland-dependent species designated by the U.S. Fish and Wildlife Service as regional species of special interest include the wood duck, mallard, black duck, redhead, canvasback, several species of geese and swans, osprey, sandhill crane, woodcock, least tern, common tern, great blue heron, and bald eagle.

Heron rookeries are located in forested floodplain wetlands of the Kankakee River. In 1987, the Division of Nature Preserves identified a total of 261 nests at five rookeries along middle and lower reaches of the river corridor. Three of the rookeries were located on state-owned fish and wildlife properties.

In the southeast part of the Kankakee River Basin, wetlands and food plots at the Jasper- Pulaski Fish and Wildlife Area serve as major resting and feeding sites during the spring and fall migrations of the eastern population of sandhill cranes. It is estimated that about 90 percent of the sandhill crane population east of the Mississippi River uses the area as a semiannual stopover point.

Wetlands provide the natural habitat necessary for the survival of some endangered species. In Indiana, more than 120 plant species and 60 animal species that depend on wetlands at some time in their lives are considered as either endangered, threatened, rare or of special concern. In the Kankakee River Basin, a number of these state-listed plant and animal species depend entirely on wetlands for their continued existence.

Although the greater prairie chicken is now extirpated in Indiana, populations once thrived in an elevated area of the former Grand Kankakee Marsh known as the Beaver Lake District. This unique area and other regions south of the Kankakee River once contained a mixture of wet prairies, forested sandhills, and other prairie and savanna features. Today, only remnants of the prairie-grass communities remain along some railroad rights-of-way and highway corridors. Oak-savanna remnants occur only in isolated parcels.

Many **recreational activities** take place in and around wetlands, including hunting, fishing, nature study and birdwatching. Because of the aesthetic quality of wetlands, these lands often are key features of public parks and outdoor recreation areas. In the Kankakee River Basin, wetlands are an important visitor attraction at most state-owned properties and at many public and private parks, recreation areas, and natural areas.

[1]Portions of this discussion were adapted from a report by the Division of Outdoor Recreation (Indiana Department of Natural Resources, 1988c).

open-water areas on these properties are regulated by extensive systems of dikes, levees and water control structures. In late spring, certain tracts are drained to allow plantings of corn, buckwheat or millet as food for migratory waterfowl and other wildlife. Some of these food plots and other marshy or forested areas are later flooded to attract waterfowl during the fall migration and consequently to improve hunting.

A project involving the creation of artificial wetlands is being conducted at Koontz Lake in Starke County as part of the state lake-enhancement program. This program, administered by the IDNR's Division of Soil Conservation, provides financial assistance on a cost-sharing basis for projects that will improve water quality in public freshwater lakes by controlling sedimentation in the lake and its tributaries.

The IDNR's various wildlife habitat programs (appendix 4) are helping to protect, enhance or restore a small portion of Indiana's remaining wetlands. In addition, the 1990 state legislature appropriated $1 million to the IDNR for the purchase or restoration of Indiana wetlands. These programs, however, currently do not include any wetlands within the Kankakee River Basin.

Other state programs which may indirectly contribute to wetland protection but do not currently encompass basin wetlands include the Indiana waters program; the clean lakes program; and the natural, scenic and recreational rivers program. Non-regulatory federal programs which provide the potential for wetlands protection include the wetlands restoration program; the land and water conservation fund; the wildlife refuge system; the natural landmarks program; and various fish and wildlife programs, including the North American waterfowl management plan.

Lakes

Freshwater lakes are a distinctive feature of the Kankakee River Basin. Most of the basin's natural lakes probably were formed in depressions left by the irregular deposition of glacial drift. Other lakes, known as kettle-hole lakes, probably were formed by the melting of isolated masses of buried glacial ice. A few lakes which occur as part of a narrow lake chain may have been formed by the erosion and subsequent damming of glacial meltwater streams.

An unknown number of lakes in the Kankakee River Basin have been totally destroyed or greatly diminished in size by artificial drainage. Other lakes have been filled in gradually by natural or man-induced sedimentation and *eutrophication*.

Two of the largest natural lakes in Indiana once were located in the Kankakee River valley, but both lakes were destroyed by drainage activities. English Lake was a 12-mile long lake which was a wide, permanent spread of the Kankakee River in western Starke County (figure 21). It was the largest lake shown on early state maps, but was totally drained after the Kankakee River dredging project was inaugurated in the late 1800s.

Beaver Lake in northern Newton County once occupied the interior of a nearly flat, slightly elevated 50-square-mile basin surrounded by sand ridges and other high ground. By 1917, the large, shallow lake had been diminished to 16 square miles (Lindsey, 1966), and has since disappeared entirely as a result of successive drainage projects. Figure 21 shows the approximate location of the former lake.

Upland lakes similarly have been affected by human activities. In the early 1800s, for example, Lower, Clear, Lily, and Stone Lakes in the present-day City of LaPorte formed a single 1.3-square-mile lake. Pine and North Pine Lakes formed a slightly larger lake of 1.4 square miles (Tucker, 1922a). Activities related to agricultural drainage and urban development later diminished the total lake area and eventually resulted in the current cluster of smaller lakes, which today represents approximately half of the total area of the original lakes.

Other upland lakes have been either greatly diminished in size or totally drained by ditching, dredging and tiling activities. The water level of Cedar Lake in Lake County, for example, was lowered 8 to 12 feet, and the normal shoreline receded 50 to 90 feet from its former margins as a result of ditching (Blatchley and Ashley, 1901). The water level of Flint Lake in Porter County was lowered by channelization of the stream draining it (Doggett, 1933).

The majority of naturally formed lakes remaining today in the Kankakee River Basin are located in morainal and outwash regions of St. Joseph, LaPorte, Starke and Marshall Counties. At least 30 of the more than 60 named lakes shown on recent topographic maps occur in clusters or chains located west and southwest of South Bend in St. Joseph County; west and southwest of New Carlisle and along the northern edge of LaPorte in LaPorte County; west and southwest of Plymouth in Marshall County; and just north of Valparaiso in Porter County.

Some small, shallow lakes remain scattered along middle and lower reaches of the mainstem Kankakee River corridor. These lakes, most of which are remnant oxbows of the old river channel, typically are classified by the U.S. Fish and Wildlife Service and the IDNR Division of Fish and Wildlife as palustrine wetlands because of their shallow depth and because they are not considered as part of the main channel. Most oxbow lakes are only temporarily or seasonally flooded, but some may be semi-permanently flooded.

In one sense, the remnant lakes (wetlands) of the Kankakee River corridor are man-made because they were formed when the river was dredged and straightened. In another sense, they are considered as natural lakes because oxbow lakes commonly are formed along meandering rivers. Regardless of type, shallow remnant oxbows probably account for the majority of small lakes in the lower Kankakee River valley.

Appendix 5 presents information on 37 natural and seven manmade lakes throughout the Kankakee River Basin having a surface area of at least 25 acres. The table also includes two smaller lakes which have historical and current gage records. The locations of most lakes in the basin are apparent from fold-out maps or plates presented elsewhere in this report.

According to Hoggatt (1975), the drainage basins of most natural lakes in the upper Kankakee River Basin contain depressional areas which do not contribute directly to surface runoff (appendix 5, column 2). Many of these lake systems once occupied closed basins having no defined inlet or outlet. Lake levels in some closed systems would have been maintained primarily by ground-water seepage through either the lakebed or side slopes and by direct rainfall onto the lake surface. Water loss would have occurred by evaporation and *percolation*.

Bass Lake in Starke County, for example, formed a closed drainage system before drainage ditches and an artificial outlet were constructed in the early 1900s. Because the lake occupies a shallow basin on a regionally elevated ridge, natural surface drainage primarily slopes away from the lake.

Springs in the lakebed and the waters of nearby flowing wells once were thought to be the major source of lake water (Blatchley and Ashley, 1901). However, later investigators pointed out that the lake may receive ground water from more than one water-bearing zone, including an unconfined surficial aquifer. Ground-water conditions around Bass Lake are briefly discussed in the ***Ground-Water Hydrology*** section of this report under the subheading entitled ***Ground-Water Levels***.

The drainage systems of the lakes in the city of LaPorte have involved only subsurface routes since the middle or late 1800s, when a surface outlet to Clear Lake ceased flowing (Tucker, 1922a). Despite extensive development during the late 1800s and early 1900s that drastically changed the drainage system, no surface outlet to these lakes has ever been constructed.

The 37 natural lakes tabulated in appendix 5 occupy a total of about 6500 acres, or 10 square miles. Six lakes having surface areas of at least 250 acres account for about 60 percent of the total acreage of all natural lakes. These six lakes, in order of decreasing size, are as follows: Bass Lake, Cedar Lake, Pine Lake, Hudson Lake, Lake of the Woods and Koontz Lake (appendix 5, column 4).

At their maximum pool level, six large man-made lakes constitute a total of about 2500 acres, or approximately 4 square miles. Worster Lake (Potato Creek Reservoir) and Lake of the Four Seasons were constructed primarily for recreational purposes such as fishing, swimming, and boating. J.C. Murphey Lake in Willow Slough State Fish and Wildlife Area and Ringneck Lake in Jasper-Pulaski Fish and Wildlife Area are shallow impoundments which are managed primarily for fishing activities and waterfowl habitat management. Lake Dalecarlia in Lake County and Lake Latonka in Marshall County are two slightly smaller lakes used primarily for recreation.

Skitz Lake in Starke County was a shallow, 1400-acre impoundment which once occupied the northeastern portion of the Kankakee Fish and Wildlife Area (formerly the Kankakee Game Preserve). The impoundment, which was located between the Kankakee and Yellow Rivers near Highway 8, was used primarily to attract migratory waterfowl and improve hunting opportunities. From 1949-53, records of daily lake-level fluctuations were maintained by the Division of Water in cooperation with the U.S. Geological Survey.

Skitz Lake probably was destroyed in the 1950s when severe floods caused extensive damage to levees throughout the area. Although no identifiable lake currently exists on the fish and wildlife property, a system of levees and water control structures allows certain areas between the rivers to be temporarily flooded for waterfowl habitat management.

Lake of the Woods, Cedar Lake, Hudson Lake and Koontz Lake have the largest storage capacities of the natural lakes for which capacity data are available (appendix 5, columns 4 and 5). Each of these lakes, in addition to the man-made Worster Lake, holds at least 1 billion gallons at either the average or established level. Although the storage capacity of Bass Lake has not been accurately determined, it has been estimated to be 1.5 billion gallons (McCormack, 1947). These six natural and man-made lakes account for about half of the known total capacity of 16 billion gallons for all basin lakes.

The mean depths of basin lakes are quite variable. South Clear and Mud Lakes in St. Joseph County have mean depths of only 2 feet, whereas Saugany Lake in LaPorte County has a mean depth of 30 feet (Indiana Department of Environmental Management, 1986). Maximum depths of basin lakes range from less than 4 feet at Ringneck Lake to about 70 feet at Pine Lake (appendix 5, column 6).

Since 1942, records of the water-surface elevations of many Indiana lakes have been collected by the U.S. Geological Survey through a cooperative agreement with the Indiana Department of Natural Resources (formerly the Indiana Department of Conservation). Before 1976, lake stations generally were equipped with a staff gage which was read once daily by a local observer. Automatic digital water-stage recorders have since been installed at many lake stations, including 12 of the 13 stations currently gaged in the Kankakee River Basin (appendix 5, column 8).

Lake-level data today are used primarily to monitor maximum and minimum levels, determine the location of shoreline contours for lakeshore construction projects, and investigate water quality and flooding problems. Gage records also are used in the occasional establishment of normal water-surface elevations, as described in Indiana law (I.C. 13-2-13). As of January 1990, levels have been established at about half of the major lakes in the basin (appendix 5, column 7).

Between 1954 and 1968, the U.S. Geological Survey in cooperation with the Indiana Department of Natural Resources mapped more than 200 natural and man-made lakes in Indiana, including more than 20 lakes in the Kankakee River Basin. Although originally intended for use in the establishment of normal water-surface elevations, these depth contour maps have since been used for many purposes, including fisheries studies and recreation. A map of Bass Lake completed in 1988 is available from the Division of Water.

Lake-level fluctuations

The historic drainage projects conducted throughout the Kankakee River Basin since the 1800s have greatly affected the basin's natural lakes. In general, ditching near a lake can intercept or divert surface drainage which normally would have entered the lake basin, thus reducing the drainage area contributing to the lake. If the ditch is constructed downgradient of a lake, ground-water leakage may be induced from the lake to the ditch. Moreover, lowering the local water table by surface or subsurface drainage or ground-water pumpage can reduce the amount of ground-water inflow to lakes.

State laws enacted since the 1940s have helped protect public freshwater lakes of natural origin from detrimental development and excessive water-level fluctuations (see box below). Although many lake-level problems have been eased by provisions found in these

Lake regulations

Because water-level fluctuations in lakes can restrict their usefulness for recreation, residential development, flood control and water supply purposes, state and local organizations have attempted to maintain average water levels on many lakes. In accordance with a 1947 state law (I.C. 13-2-13), the Indiana Department of Natural Resources (formerly the Indiana Department of Conservation) is authorized to have normal lake levels established by appropriate legal action. The Department also has the authority to initiate and supervise the installation of dams, spillways, or other control structures needed to maintain the established levels.

Established lake levels typically represent the average water-surface elevation that has prevailed for several years. Once an average normal water level is established by a local circuit court, the average lake level is to be maintained at that elevation. Temporary lowering of a lake level below its designated level requires prior approval from the local court and from the Natural Resources Commission, the administrator of the lake-level law. Such approval typically is granted only for shoreline improvements or lake restoration procedures.

A related lake law (I.C. 13-2-11.1) enacted in 1947 and amended in 1982 requires prior approval from the Natural Resources Commission for any alteration of the bed or shoreline of a public freshwater lake of natural origin. Permits are required not only for minor projects such as the construction of seawalls or sand beaches, but also for larger projects such as channel or lakebed dredging, boat-ramp construction and boat-well construction. In addition, a permit is required to pump water from a public freshwater lake.

Under a law passed in 1947 and amended in 1987 (I.C. 13-2-15), a permit is required for the construction, reconstruction, repair or recleaning of a ditch or drain that has a bottom elevation lower than the normal average water level of a public freshwater lake of 10 acres or more, and that is located within one-half mile of the lake.

statutes, undesirable fluctuations continue to occur on some lakes, including Bass and Pine Lakes in the Kankakee River Basin.

Problems with low lake levels have been documented at Bass Lake since the 1920s. As mentioned in the previous section, Bass Lake is located on a topographic high, and once formed a closed basin with no natural inlet or defined outlet (Blatchley and Ashley, 1901).

Various investigations beginning in the 1920s typically ascribed the major causes of undesirable water-level declines at Bass Lake to 1) evaporation from the large lake surface; 2) lack of surface inflow from the small drainage area; 3) leakage from the old dam; and 4) diversions or lowered ground-water levels from ditching, dredging and drainage activities near the lake (Doggett, 1924, 1941, 1947). Moreover, because the lakeshore slope is unusually flat, slight reductions in water-surface elevation can cause the water's edge to recede hundreds of feet, exposing vast expanses of the lakebed.

Proposed solutions to the low water levels at Bass Lake have included diverting the flow from streams or ditches into the lake, and controlling or impounding water in these watercourses to help reduce ground-water leakage away from the lake (Doggett, 1941). Although these suggested solutions were never implemented due to their impracticality and cost constraints, further investigations led to a petition by property owners to maintain the lake level by ground-water pumpage from a deep well (Doggett, 1947; McCormack, 1947; Indiana Department of Conservation, 1956).

In 1964, a 110-foot well rated at 1-3 mgd was installed on the east shore of the north lobe. Although pumping has occurred periodically since that time, the success of the well in alleviating low water levels is not clearly defined in lake-level records.

Early studies (Doggett, 1947; Indiana Department of Conservation, 1956) had postulated but had not conclusively demonstrated a hydrologic connection between the surficial sand aquifer intersecting the lakebed and the deeper confined aquifer which would later be utilized by the high-capacity well. However, if a connection were to exist in the vicinity of the lake, pumpage from the confined aquifer would to some extent merely recirculate the lake water (Indiana Department of Conservation, 1956).

In the late 1980s, the Division of Water investigated reports of residential well problems near Bass Lake. Investigators found that pumpage from the high-capacity well on the shoreline was lowering ground-water levels near the lake and adversely impacting some domestic wells. Two years later, the division noted that potential ground-water level declines induced by high-capacity pumpage from a proposed second well could further impact some nearby domestic wells, especially those equipped with shallow-well jet pumps (Division of Water, written communication, 1989).

The group of lakes in the city of LaPorte near the Kankakee River Basin's northern boundary have experienced problems with both above- and below-normal water-level fluctuations. Unacceptably low levels documented since the 1920s resulted in several investigations, proposed solutions, and the eventual diversion of some surface runoff into the lake through a constructed drain (Tucker, 1922a; Indiana Department of Conservation, 1963; Link, 1963; Indiana Department of Natural Resources, 1982c).

In the 1960s, a property owners association financed the installation of a ground-water well on the south shore of Pine Lake to augment lake levels. The well probably was used, but no data are available to determine what effects the pumping had on lake levels (Indiana Department of Natural Resources, 1982c).

A period of high lake stages caused severe flooding around the lakes in the 1950s. A deep well was drilled to allow disposal of excess water into a porous formation, but the well was not used (Indiana Department of Natural Resources, 1982c).

After the lakes rose to unusually high levels in 1982, investigations (Indiana Department of Natural Resources, 1982c; Baxmeyer, 1982) led to the establishment of procedures by which excess lake water could be released through a water pipeline for eventual discharge into the Kankakee River via the Little Kankakee River.

Between about 1983 and 1986, water was pumped from Lily Lake for brief periods following severe rainstorms to help alleviate flooding on Pine and Stone Lakes. The capability still exists for using the diversion during extreme flood events; however, the pipeline currently is being used for water-supply purposes rather than flood control (T. Taylor, Water Superintendent, City of LaPorte, personal communication, 1989).

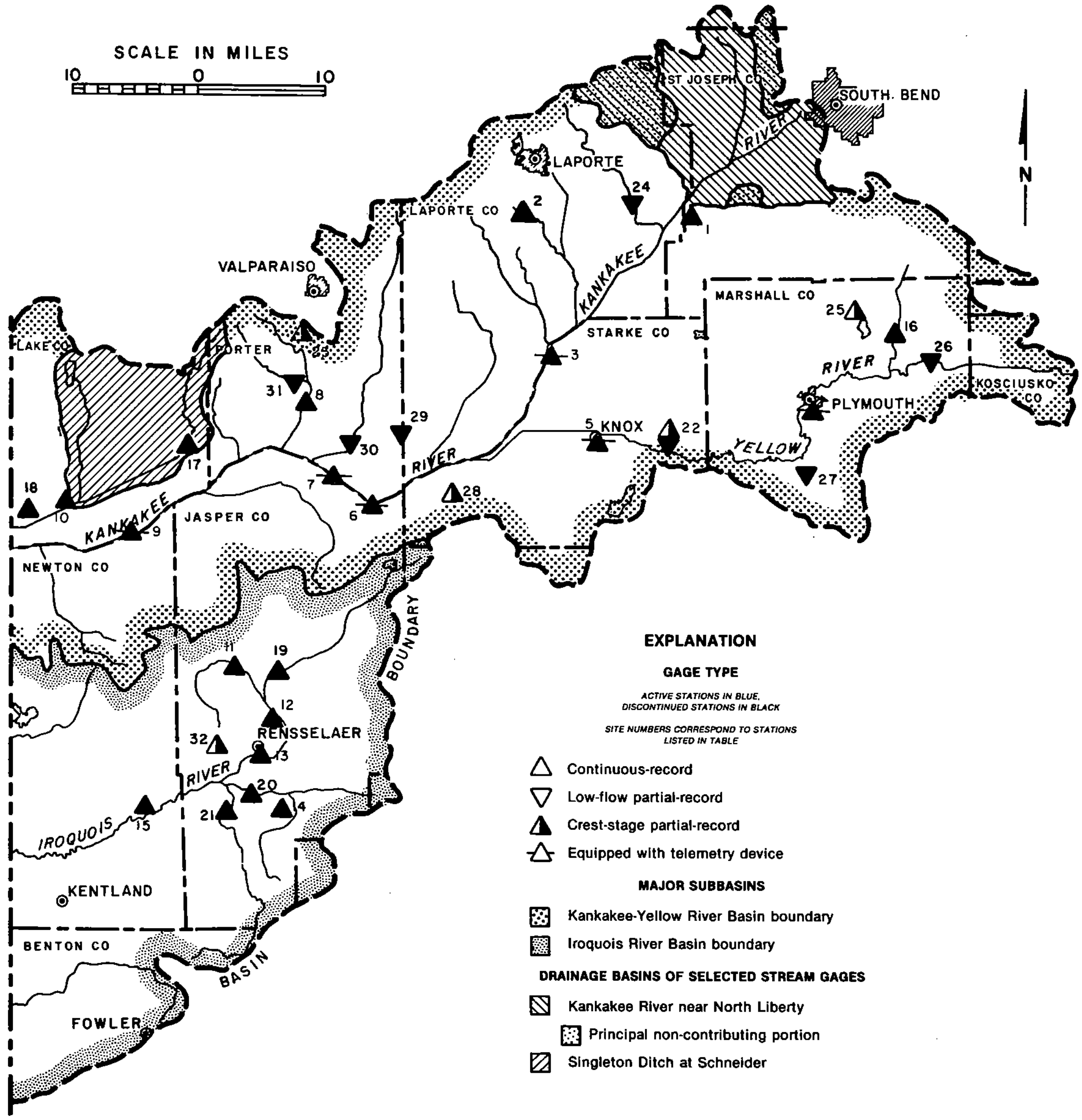


Figure 23. Location of stream gaging stations and selected subbasins

Streams

The Kankakee River Basin in Indiana consists of the drainage basins of the Kankakee River and its principal tributaries, the Yellow and Iroquois Rivers. About 64 percent of the Kankakee River Basin in Indiana lies within the Kankakee-Yellow River Basin, and the remaining 36 percent lies within the Iroquois River Basin (figure 23).

A high degree of channelization exists on rivers and streams of the Kankakee River Basin. The entire length of the Kankakee River in Indiana is characterized by straight channels produced from ditching, dredging and channelization associated with agricultural development in the late 1800s and early 1900s. All tributaries to the Kankakee River have been either partially or wholly reconstructed. The IDNR Division of Fish and Wildlife has estimated that of the 1200 miles of streams

Table 13. Stream gaging stations

Map number: Station locations are shown in figure 23.

Station number: Numbers are U.S. Geological Survey downstream-order identification numbers. Lettered abbreviations are as follows: T, telemetered station; S, satellite station; L, low-flow partial-record station, frequency data published in Stewart (1983); C, crest-stage partial-record station, frequency data published in Glatfelter (1984).

Contributing drainage area: Portion of watershed that contributes directly to surface runoff. Total drainage area is shown in parentheses for watersheds with non-contributing portions. Area data are taken or derived from Glatfelter and others (1986), Glatfelter (1984), Stewart (1983) or Hoggatt (1975), depending on station type.

Period of record: Refers to calendar year, whether or not data encompasses entire year. Years of record are tabulated through 1985 inclusive for active stations.

		Map no.	Station no.	Station name	Contributing drainage area (sq mi)	Period of record	
						Years	Dates
Continuous-record	Active	1	05515000	Kankakee River near North Liberty	116 (174)	35	1951-
Continuous-record	Active	2	05515400	Kingsbury Creek near LaPorte	3.0 (7.1)	16	1970-[1]
Continuous-record	Active	3	05515500 T	Kankakee River at Davis	400 (537)	62	1905-[2]
Continuous-record	Active	4	05516500 T	Yellow River at Plymouth	272 (294)	38	1948-
Continuous-record	Active	5	05517000 T	Yellow River at Knox	384 (435)	43	1905-[2]
Continuous-record	Active	6	05517500 T	Kankakee River at Dunns Bridge	1160 (1352)	38	1948-
Continuous-record	Active	7	05517530 T	Kankakee River near Kouts	1182 (1376)	12	1974-
Continuous-record	Active	8	05517890	Cobb Ditch near Kouts	30.3	18	1968-
Continuous-record	Active	9	05518000 S	Kankakee River at Shelby	1578 (1779)	64	1922-
Continuous-record	Active	10	05519000	Singleton Ditch at Schneider	123	38	1948-
Continuous-record	Active	11	05521000	Iroquois River at Rosebud	35.6	38	1948-
Continuous-record	Active	12	05522000	Iroquois River near North Marion	144	38	1948-
Continuous-record	Active	13	05522500	Iroquois River at Rensselaer	203	38	1948-
Continuous-record	Active	14	05523000	Bice Ditch near South Marion	21.8	38	1948-
Continuous-record	Active	15	05524500	Iroquois River near Foresman	449	38	1948-
Continuous-record	Discontinued	16	*05516000*	*Yellow River near Bremen*	*135*	*19*	*1955-73[3]*
Continuous-record	Discontinued	17	*05518500*	*Singleton Ditch near Hebron*	*34.2*	*3*	*1949-51*
Continuous-record	Discontinued	18	*05519500*	*West Creek near Schneider*	*54.7*	*24*	*1948-72[2]*
Continuous-record	Discontinued	19	*05521500*	*Oliver Ditch near Aix*	*79.6*	*4*	*1948-51*
Continuous-record	Discontinued	20	*05523500*	*Slough Creek near Collegeville*	*83.7*	*35*	*1948-82[2]*
Continuous-record	Discontinued	21	*05524000*	*Carpenter Creek at Egypt*	*44.8*	*35*	*1948-82[2]*
Partial-record	Active	22	05516950 LC	Eagle Creek near Grovertown	29.9(31.9)		1973-
Partial-record	Active	23	05517780 C	Cobb Ditch near Valparaiso	0.4		1973-
Partial-record	Discontinued	24	*05515100 L*	*Little Kankakee River near Mill Ck.*	*22.3(33.8)*		*1960-69*
Partial-record	Discontinued	25	*05516150 C*	*Walt Kimble Ditch near Lapaz*	*1.5*		*1973-82*
Partial-record	Discontinued	26	*05516300 L*	*Dausman Ditch near Bremen*	*47.8(53.4)*		*1956-69*
Partial-record	Discontinued	27	*05516650 L*	*Wolf Creek near Argos*	*21.4(31.1)*		*1970-78*
Partial-record	Discontinued	28	*05517400 C*	*Payne Ditch trib. near North Judson*	*2.6*		*1973-82*
Partial-record	Discontinued	29	*05517550 L*	*Reeves Ditch near Lacrosse*	*44.1*		*1960-69*
Partial-record	Discontinued	30	*05517750 L*	*Crooked Creek near Kouts*	*64.6(69.9)*		*1975-78*
Partial-record	Discontinued	31	*05517880 L*	*Wolf Creek near Kouts*	*13.8*		*1975-78*
Partial-record	Discontinued	32	*05524300 C*	*Yeoman Ditch trib. near Rensselaer*	*0.6*		*1972-81*

[1]Discontinued in 1986.
[2]Gaps occur in years of record.
[3]Continued as a partial-record station through 1984.

constituted by the Kankakee River and its minor tributaries, only 16 miles remain in a natural state (Robertson, 1971).

Sources of stream-flow data

Stream gages in the Kankakee River Basin monitor flow variations among different streams and throughout the lengths of the basin's three major watercourses. Hydrologic parameters derived from stream-flow records can be used to evaluate the potential of streams for water-supply development.

The U.S. Geological Survey, in cooperation with other government agencies and private industry, has maintained records of daily stream flow in the Kankakee-Yellow River Basin since 1905. Currently, records of daily *mean* discharge are collected at five *continuous-record stations* on the mainstem Kankakee River, at two stations on its tributaries, and at two stations on the Yellow River (table 13, figure 23).

Seven active stations in the Kankakee-Yellow River Basin are part of a cooperative program between the U.S. Geological Survey (USGS) and the State of Indiana. The Kankakee River station at Shelby is operated by the USGS in cooperation with the U.S. Army Corps of Engineers. The Kankakee River station near Kouts is operated in cooperation with the Northern Indiana Public Service Company.

Data from most stations in the Kankakee-Yellow River Basin are used primarily for flood hydrology and river forecasting. More than half of the stations are equipped with telemetering instruments for audible reporting of real-time water-level data. The station at Shelby is equipped with a special device for transmitting encoded data via an earth-orbiting satellite.

A continuous-record network was established in the Iroquois River Basin in 1948 through a cooperative agreement between the USGS and the State of Indiana. Records of daily discharge currently are collected at four stations on the mainstem Iroquois River (table 13, figure 23). Discharge data also are collected for Bice Ditch.

Two stations, both located in the Kankakee-Yellow River Basin, currently operate as *partial-record* stations (table 13). At the low-flow partial-record site on Eagle Creek in Starke County, flow measurements are made during dry periods when stream flow is primarily composed of ground-water discharge.

A series of low-flow discharge measurements collected at a partial-record site can later be correlated with simultaneous daily mean discharges at a nearby continuous-record gage on a stream draining a hydrologically similar basin. From this discharge relation, low-flow frequency characteristics of the partial-record site can then be estimated using frequency characteristics for the continuous-record gage. Table 13 lists active and discontinued partial-record stations for which low-flow frequency data have been reported by Stewart (1983).

The partial-record site on Eagle Creek also serves as a *crest-stage* station, as does Cobb Ditch near Valparaiso (table 13). A crest-stage gage is a device which registers the peak stream stage occurring between inspections of the gage. Stage readings can later be converted to discharge values, and flood frequency characteristics can be determined. Table 13 lists active and discontinued partial-record stations for which flood frequency data have been reported by Glatfelter (1984).

The U.S. Geological Survey, in cooperation with the Indiana Department of Natural Resources, has collected sediment data at gaging stations on the Kankakee River at Shelby and the Iroquois River at Foresman since the 1960s. The frequency of data collection has averaged about once a month. These data are published annually in water-resource data reports by the U.S. Geological Survey, and are incorporated in a summary report by Crawford and Mansue (1986).

Stream gaging networks in the Kankakee-Yellow River Basin and Iroquois River Basin were evaluated by Neyer (1985) as part of a Division of Water review of Indiana's hydrologic data collection networks. As Neyer observed, the Kankakee-Yellow River Basin is heavily gaged on the larger watercourses but sparsely gaged on tributaries draining areas less than 100 sq. mi. As table 13 shows, only one gage in the Kankakee-Yellow River Basin (Cobb Ditch near Kouts) currently monitors tributary flows in a small watershed.

Neyer suggested the establishment of new stations on Wolf Creek in Jasper County, and/or Cook Ditch (Porter County), Geyer Ditch (St. Joseph County), or Robbins Ditch (Starke County) to help offset the lack of data on tributary flows. Neyer also suggested that gaging stations in the Iroquois River Basin should be added in irrigated and non-irrigated areas of Newton and Jasper Counties to more adequately assess potential irrigation impacts. Partial-record stations which operated only during selected periods would probably be sufficient for this purpose.

Neyer also pointed out that interpreting discharge data from the North Marion gage on the Iroquois River is complicated by the potential diversion of flow via Ryan Ditch. A supplemental station on Ryan Ditch could be established to monitor the diverted flow; otherwise, funding for the North Marion gage could better be applied to the installation of a new gage site.

Factors affecting stream flow

Stream flow varies in response to available precipitation, topographic features, soil conditions, land cover, hydrogeologic characteristics, and channel geometry. Changes in land use, drainage patterns, stream geometry, and ground-water levels also produce variations in stream flow.

The time variation in stream flow and its relation to temperature and precipitation can be illustrated by a graph of mean monthly values (figure 24). It might be expected that stream flow would directly parallel total precipitation, which is the source of all available water. However, as figure 24 shows, mean monthly precipitations is least in February, whereas mean monthly *runoff* is least in September. Conversely, precipitation is greatest in June whereas runoff is greatest in March and April.

These differences in precipitation and runoff can be attributed primarily to differences in evapotranspiration rates, although soil and ground-water conditions also can play an important role. In late summer and early fall, temperatures are warm and evapotranspiration losses are high; hence, much of the precipitation that would otherwise be available to streams is lost to the atmosphere. Moreover, ground-water levels are at or near their seasonal low, and *base flow* may be limited.

In late winter and early spring, temperatures are mild, plants are dormant or very young, and evapotranspiration rates are low. The ground often is either frozen or saturated, and may be covered by melting snow. As a result of these factors, more of the total precipitation is available to streams in the form of *overland flow* and base flow.

The geographic variation in stream flow can be illustrated by comparing runoff characteristics along the same stream and among different streams. Although many stream-flow parameters can be used to compare runoff characteristics, flow-duration analysis is used in this illustration because it does not depend on the chronological sequence of daily flows.

The annual flow-duration curve of daily mean discharges is a cumulative frequency curve that shows the percent of time that specified daily discharges are equaled or exceeded during a given period of record. For example, daily mean flows of the Kankakee River near North Liberty were at least 52 cfs (cubic feet per second) on 99.9 percent of the days during the period 1952-85 (figure 25, in red). Daily flows for this period exceeded 750 cfs only 0.1 percent of the time.

The shape of the duration curve is related to the storage characteristics of the drainage basin, which in turn are related to topographic and hydrogeologic features. A steeply sloping duration curve indicates a stream draining a basin with little surface or subsurface storage. Flood peaks on this type of stream are high and rapid because most excess precipitation runs off the land surface and enters the stream. During dry periods when overland flow has ceased, this type of stream may cease flowing because the amount of base flow is negligible.

A duration curve that is gently sloping indicates a stream draining an area with substantial basin storage. Flood peaks on this type of stream are attenuated because much of the excess precipitation is stored in surface depressions, permeable soils, or surficial geologic deposits. During dry periods, stream flow is sustained by the slow, steady release of water from these surface and/or underground sources.

Duration curves for the Kankakee River and Singleton Ditch, one of its major tributaries, illustrate the effect of topography and geology on stream-flow characteristics. A common period of record was used for the duration analysis to minimize flow differences which may be attributed to differences in local precipitation from short-term events. Discharge was calculated on a per-square-mile (*unit*) basis to minimize the effect of unequal basin sizes on stream-flow characteristics.

As figure 25 shows, the duration curve for Singleton Ditch is fairly steep in relation to the Kankakee River curve. The higher unit discharges on Singleton Ditch at durations less than 15 percent indicate a higher runoff rate per square mile of drainage basin during periods of heavy rainfall.

The higher unit flows on Singleton Ditch primarily reflect the limited amount of floodplain storage and the channel's relatively steep slope. The high levee along

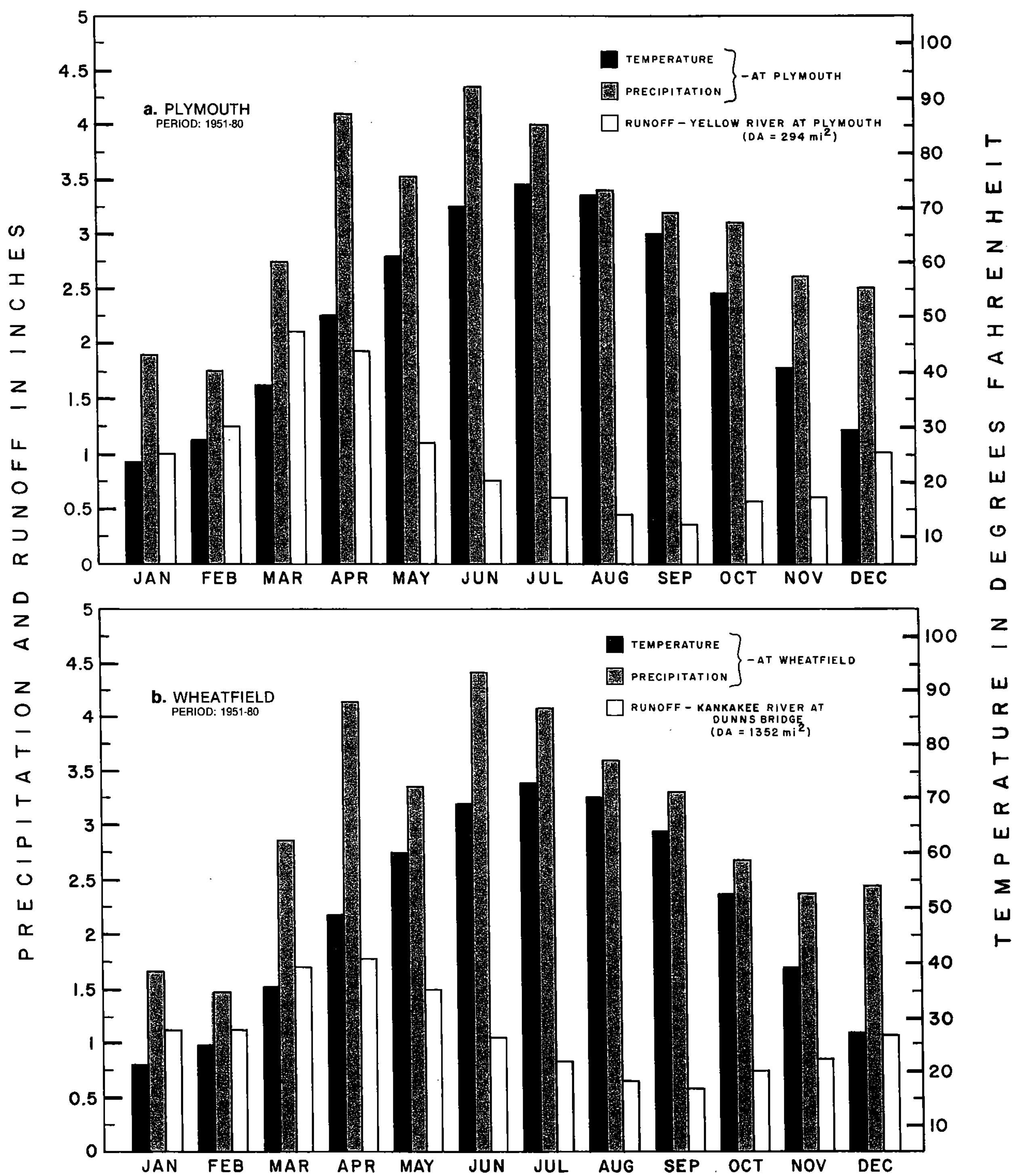


Figure 24. Variation of mean monthly temperature, precipitation and runoff
(Data from National Oceanic and Atmospheric Administration, 1985 and U.S. Geological Survey, unpublished data)

Singleton Ditch and the nearly straight flow path confine flood runoff to a narrow, deeply dredged channel; hence, flood peaks are reached quickly with little attenuation.

Differences in *channel slope* also help create differences in stream-flow characteristics. The channel gradient of 3.2 feet per mile upstream of the Schneider gage is nearly three times that of the Kankakee River gradient upstream of the gage at North Liberty (see Glatfelter, 1984). The length of each stream is nearly equal (about 23 miles).

Moreover, northern tributaries of Singleton Ditch descend from the elevated Valparaiso Moraine (figure 14); consequently, tributary gradients can be quite steep. The rapid runoff from these clayey till uplands is subsequently reflected in high flows along Singleton Ditch.

Unlike the duration curve for Singleton Ditch, the relatively flat upper end of the Kankakee River curve (figure 25) indicates the presence of flow-attenuating factors. The large amount of *overbank* storage available

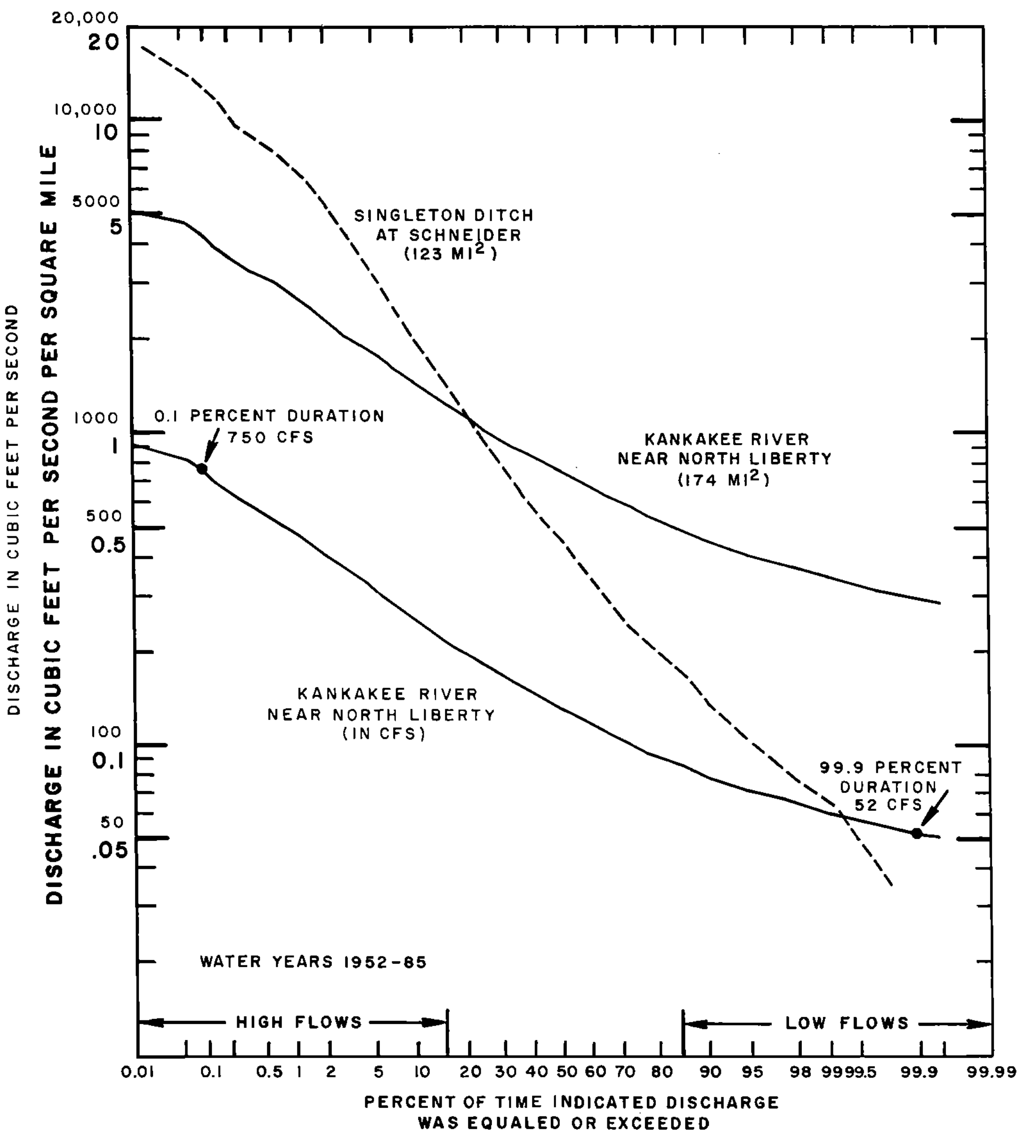


Figure 25. Duration curves of daily mean stream flow for Singleton Ditch at Schneider and Kankakee River near North Liberty

in the Kankakee River valley is primarily responsible for the reduced peak flows.

Closed depressional areas, most of which are located in the tributary basins of County Line and Geyer Ditches (figure 23) provide additional surface storage in the Kankakee River Basin upstream of North Liberty. These depressional areas, which include some small lakes or wetland remnants, do not contribute directly to surface runoff because of their lack of a defined drainage outlet. The large amount of ground-water storage afforded by the valley deposits of permeable sands and gravels also helps reduce flood peaks along the Kankakee River.

The large storage capacity of outwash deposits in the Kankakee River valley helps attenuate flood peaks during storm events, and also helps sustain low stream flows during periods of little or no rainfall. Ground water stored during recharge events is available for later discharge to streams, lakes and wells. The high base flow at the Kankakee River above North Liberty is evident in figure 25 by the sustained unit low flows at durations greater than 85 percent.

The steep lower end of the duration curve for Singleton Ditch indicates a limited amount of base flow. The main channel of Singleton Ditch lies within the Kankakee River valley, but about three-fourths of its drainage area is developed on clayey tills; hence, ground-water contribution from its upper reaches is minimal. In addition, Brown Ditch may intercept some of the ground-water flow which may have discharged into Singleton Ditch upstream of the Schneider gage.

SURFACE-WATER DEVELOPMENT POTENTIAL

The potential of surface-water systems for water-supply development can have a great impact on agricultural development and other economic activities. Rivers, streams and ditches are expected to remain the major source for surface-water development in the Kankakee River Basin. Although withdrawals occur on ponds, gravel pits, lakes, and within wetlands, these systems are not considered as significant water supply sources because of their limited storage capacity, water-quality considerations, economic constraints, and in some cases, regulatory and environmental constraints.

Wetlands and lakes

As described previously in the ***Surface-Water Resources*** section of this chapter, there are two types of non-riverine wetlands in the Kankakee River Basin. Palustrine wetlands include marshes, swamps, bogs, and other areas covered at least periodically by shallow water. Lacustrine wetlands include the deep portions of lakes, gravel pits, and large ponds.

Although some palustrine wetlands in the Kankakee River Basin may store considerable amounts of water at certain times, the shallow water depths and the temporary nature of ponding does not make these wetlands suitable as water-supply sources. Moreover, regulatory and non-regulatory programs administered by state and federal agencies (appendix 4) discourage the detrimental exploitation of wetlands, including certain land uses which would adversely affect nearby wetlands. The values of wetlands and the need for their conservation was discussed earlier in this chapter.

Surface-water withdrawals in the Kankakee River Basin occur on many privately owned ponds and small lakes, primarily for irrigation purposes. Other withdrawals occur on ponds at sand and gravel production facilities.

Public freshwater lakes in the basin generally are not used for water supply. An exception is Flint Lake in Porter County, which is used as a supplementary water-supply source by the Valparaiso Waterworks. In Lake County, an inlet ditch to Cedar Lake is used to supply water for golf-course irrigation.

As discussed previously in this chapter, existing state laws discourage both direct and indirect pumpage from natural lakes. Most notably, IC 13-2-13 requires that lakes having a legally established average normal water level are to be maintained at that level. Temporary lowering of the lake level below its designated elevation requires prior approval from a local circuit court and the Natural Resources Commission.

Even if state laws were amended to allow lowering of lakes levels for water-supply purposes, treatment and distribution costs probably would limit uses to irrigation, livestock watering, or fire protection. Pumpage-induced lowering of water levels could detrimentally affect existing water quality, fisheries habitat, and adjacent wetlands. Moreover, even a minor lowering of lake levels would be objectionable to most lakeside property owners.

Adding lake storage for supply purposes also has considerable drawbacks. Amendments to current lake laws or approval for temporary lake-level increases would be required. Moreover, existing control structures at potential supply sites would have to be modified, because few lake-level control structures are designed to store water at elevations above the legal level. Furthermore, the inundation of lakefront property would be objectionable to lakeside property owners.

Streams

The water-supply potential of streams can be evaluated on the basis of selected stream-flow characteristics, which are defined as statistical or mathematical parameters derived from records of stream discharge. In this report, average and low stream-flow characteristics were defined at gaged sites using flow-duration curves, frequency analysis, and hydrograph separation techniques. The characteristics and techniques described below also can be used in other applications, including the design and operation of water-supply facilities, waste-treatment plants, reservoirs, and hydroelectric power plants; water-quality studies; waste-discharge regulation; and management of fish and wildlife habitat.

Methods of analysis

Average flow

Average flow is the arithmetic mean of individual daily mean discharges during a selected time period, such as a week, month, season, year, or period of several years. The long-term mean annual discharge, commonly known as the average flow, is the arithmetic mean of the annual mean discharges for the period of data record.

Because the statistical distribution of stream flows is *skewed*, average discharge usually is greater than the median discharge, which is the flow equaled or exceeded 50 percent of the time. On the Yellow and Iroquois Rivers, average discharge is equaled or exceeded 25 to 30 percent of the time. On the mainstem Kankakee River, average flow is equaled or exceeded 35 to 40 percent of the time. Average flow on the Kankakee River more closely approximates median flow because discharge values are more normally distributed.

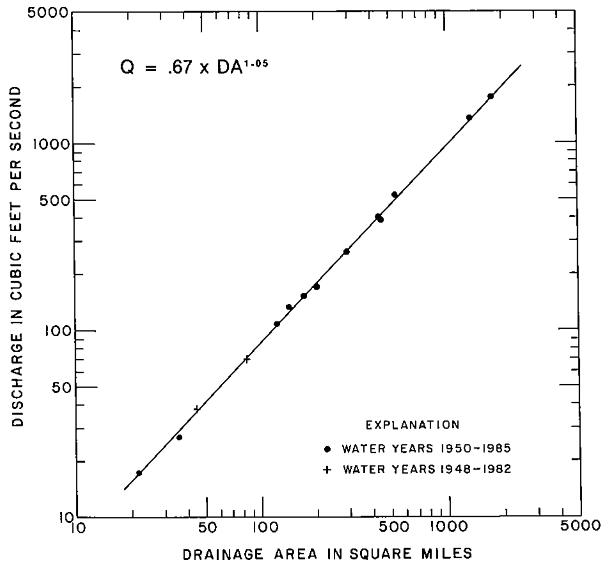


Figure 26. Relation of average annual discharge at continuous-record gaging stations to total drainage area

The relation between average flow and drainage area is commonly used in hydrologic applications. Figure 26 illustrates a relation derived from concurrent long-term flows for selected continuous-record gages in the Kankakee River Basin. The equation shown can be used to estimate average flows at ungaged sites on streams in the Indiana part of the basin that drain areas of at least 20 square miles.

Because average flow encompasses the amount of water leaving a basin as both surface-water runoff and ground-water discharge to streams, this flow can be considered as the theoretical upper limit of the long-term yield that can be developed from a stream. If it were possible to store, in a single hypothetical reservoir, all the water that flows from a watershed during a specified period and then release the water at a uniform rate over the same period, that rate would be the average flow. **Average runoff** is defined as the depth to which a drainage basin would be covered by water if the average discharge for a given time period were uniformly distributed upon the land surface of that basin.

Flow duration

Flow-duration curves, as described in a previous section, show the percent of time that specified daily discharges are equaled or exceeded during a given period of record. Because duration curves provide information on a stream's entire range of flows, these curves are useful in characterizing overall flow characteristics and in identifying differences in stream-flow variability. Duration curves also can be used to estimate the percent of time that a given demand for stream flow can be met, on average, over a long period of time. However, curves cannot be used to determine the sequence, statistical frequency, or duration of either adequate or deficient flows.

For example, if a daily flow of 100 cubic feet per second were needed on the Kankakee River near North Liberty to support a designated withdrawal, the flow would be sufficient about 70 percent of the time (figure 25), or an average of 235 days per year over a period of many years. In any one year, however, all 235 days of sufficient flow would not occur consecutively. Moreover, the total number of days having sufficient flow would vary widely from year to year.

Flow ratio is a general term that can apply to many stream-flow parameters. In this report, the maximum-to-minimum ratio of annual mean flows and the ratio of 20-percent-duration to 90-percent-duration flows are used to indicate the variability of stream flow.

The 20-to-90-percent **flow-duration ratio** is a numerical index that represents the slope of the middle portion of the flow-duration curve (figure 25). As described previously, the flow-duration ratio (slope) reflects not only the presence in a watershed of flood-attenuating factors, but also the degree of base flow.

The Kankakee River near North Liberty, for example, has a flow-duration ratio of approximately 2, whereas Singleton Ditch at Schneider has a ratio of nearly 9 (figure 25). The lower ratio of the Kankakee River relative to Singleton Ditch indicates a higher amount of base flow and the existence of more sustained stream flows during dry weather.

Low flows

Low-flow frequency data can be used to estimate how often, on the average, minimum mean flows are expected to be less than selected values. Low-flow characteristics commonly are described by points on low-flow frequency curves prepared from daily discharge records collected at continuous-record gaging stations. Correlation techniques can be used to estimate curves, or selected points on curves, for sta-

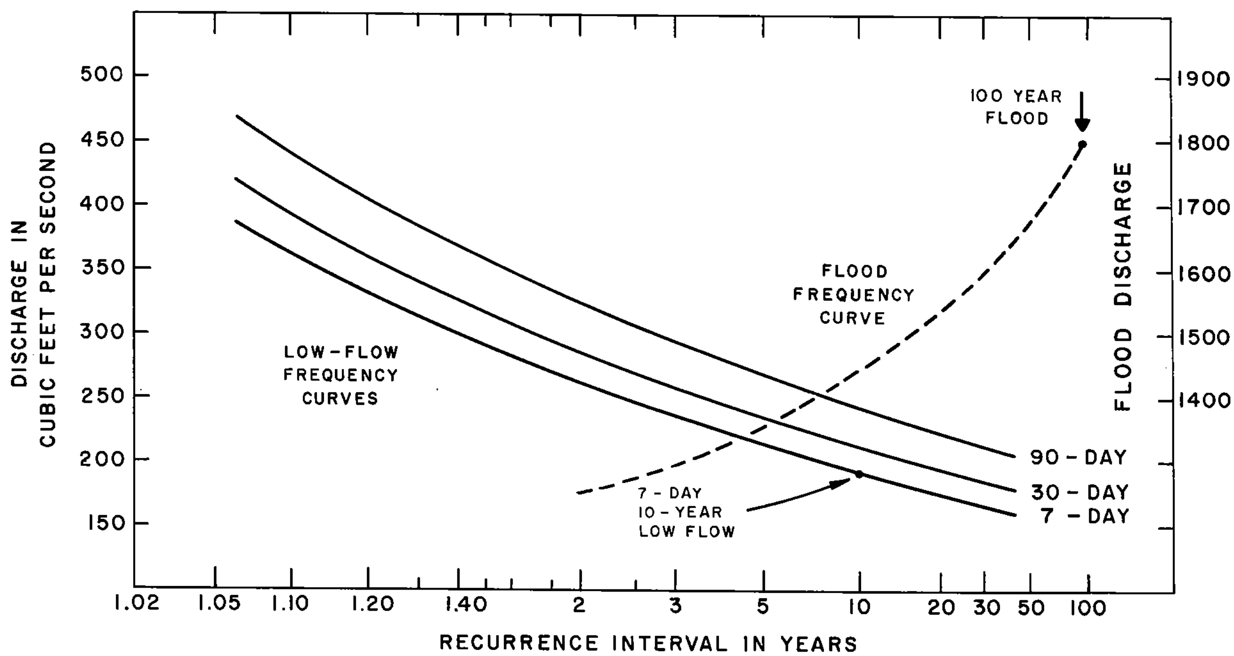


Figure 27. Frequency curves of annual peak discharge and annual lowest mean discharge for indicated number of consecutive days for the Kankakee River at Davis

tions where short-term records and/or base-flow measurements are available.

Low-flow frequency curves show the probability of minimum mean flows being equal or less than given values for a specified number of consecutive days. Figure 27 shows the relation of annual minimum mean discharges for 7-day, 30-day, and 90-day periods for the Kankakee River at Davis. The 1-day curve is not shown because it nearly coincides with the 7-day curve.

In this report, the following points on the 1-day and 7-day curves have been selected as indices of low flow: the minimum daily (1-day mean) flow having a 30-year *recurrence interval,* and the annual minimum 7-day mean flow having a 10-year recurrence interval (figure 27).

The 1-day, 30-year low flow is the annual lowest 1-day mean flow that can be expected to occur once every 30 years, on the average. In other words, it is the annual lowest daily mean flow having a 1-in-30 chance of occurrence in any given year. In this report, the 1-day, 30-year low flow indicates the dependable supply of water without artificial storage in reservoirs or other impoundments. In many cases, the 1-day, 30-year low flow equals or closely approximates the minimum daily discharge of record for streams in the Kankakee River Basin.

The 7-day, 10-year low flow is the annual lowest mean flow for 7 consecutive days that can be expected to occur, through a long period, on the average of once every 10 years. There is a 1-in-10 chance that the annual minimum 7-day mean flow in any given year will be less than this value.

In Indiana, the 7-day, 10-year low flow (7Q10) is the index for water-quality standards. The flow is used for siting, design, and operation of wastewater-treatment plants; for evaluating wastewater discharge applications and assigning wasteload limits to industrial and municipal dischargers; and as an aid in setting minimum water-release requirements below impoundments. In the future, the 7Q10 or other low-flow parameters may be used by the Indiana Department of Natural Resources to establish minimum flows of selected streams.

The U.S. Geological Survey has developed a method for estimating the 7Q10 on ungaged streams in Indiana (Arihood and Glatfelter, 1986). Regression analysis was used to derive an equation which is most accurately applied to unregulated streams in northern and central Indiana which drain areas between 10 and 1000 square miles, and have 7Q10s greater than zero. The equation determined by Arihood and Glatfelter (1986) is as follows:

$$7Q10 = 1.66 \times DA^{1.03} \times RATIO^{-1.51}$$

where

DA = the contributing drainage area, in square miles;

and

RATIO = the 20-to-90 percent flow duration ratio.

In the Kankakee River Basin, regionalized flow-duration ratios mapped by Arihood and Glatfelter (1986) are summarized as follows:

* Mainstem Kankakee River Basin — 3
* Kankakee River tributaries in Lake, Newton and Jasper Counties — 5-10
* Upper Yellow River Basin — 10
* Lower Yellow River Basin — 3-5
* Iroquois River Basin — 20-25
* Bice Ditch, selected tribs. to Iroquois River — 25
* Carpenter Creek Basin — flow-duration ratio is undefined (7Q10 = 0).

Although 7Q10s estimated from the equation and flow-duration ratios shown above may differ from values based on other regionalization techniques or partial-record data, the estimates are suitable for broad planning purposes. Site-specific design flows should be determined according to local watershed conditions and more detailed analyses.

Hydrograph separation

Hydrograph separation is a technique used to divide stream flow (*total runoff*) into its component parts of surface runoff, interflow and base flow. *Surface runoff* is the combination of precipitation falling directly upon the stream and water flowing over the land surface toward the stream (*overland flow*). *Interflow* occurs when precipitation that has infiltrated the soil moves laterally through the soil toward the stream. For convenience, interflow and surface runoff can be combined into one category called *direct runoff.* Base flow is the portion of stream flow that is derived largely or entirely from ground-water discharge.

A graphical technique can be used to separate the base-flow hydrograph from a stream-flow hydrograph

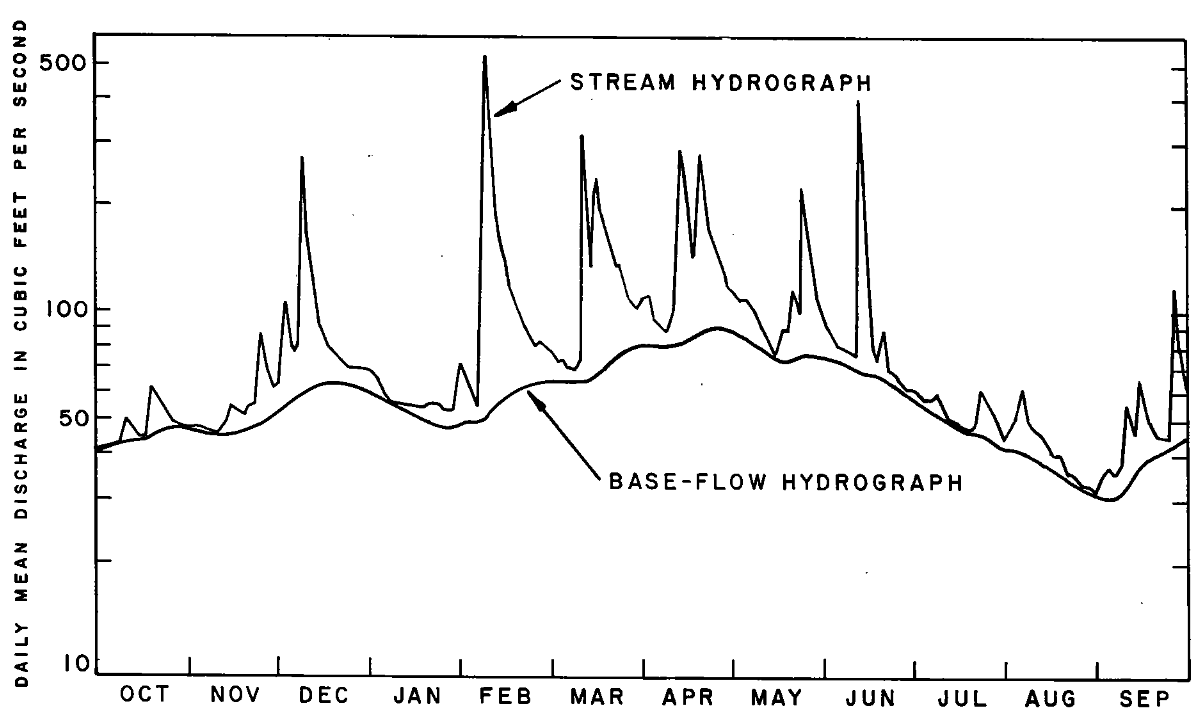


Figure 28. Example of stream-flow and base-flow hydrographs

of daily discharges. As figure 28 shows, the hydrograph of daily stream flows is composed of peaks and valleys which often are quite sharp. The peaks represent the quick response of stream flow to storm runoff received as overland flow and interflow, and occasionally as ground-water flow from hillslopes adjacent to the stream. The base level to which the peaks return represents the base flow which continues to occur after overland flow has ceased. The base-flow hydrograph therefore can be approximated by eliminating the sharp hydrograph peaks and drawing a smooth curve (figure 28).

The volume of total runoff for a given water year is computed by converting each daily discharge to a daily volume, then summing these values over the year in question. The total runoff volume can then be converted to inches by dividing it by drainage area. A similar technique can be used to compute the total annual base-flow volume.

The ratio of base flow to total runoff is one measure of the degree to which stream flow is sustained by ground-water discharge. This ratio therefore is an indicator of the dependability of a stream for water supply.

Average runoff of Kankakee River Basin

The total water-supply potential of a basin is the average precipitation that falls on the land surface and is not lost to evapotranspiration or used consumptively, such as being incorporated into a manufactured product. The theoretical maximum supply potential of the Kankakee River Basin as a whole can be defined as the long-term average runoff, which includes both surface runoff and ground-water discharge to streams.

Table 14 shows the mean monthly stream flow leaving the Indiana portion of the Kankakee River Basin. These values represent all the water leaving the basin as stream flow, including flows in upper reaches of minor tributaries which drain to streams in Illinois.

Average discharges for gages on the Kankakee River at Shelby, Singleton Ditch at Schneider, and the Iroquois River at Iroquois, Illinois were used to approximate the total volume of water leaving the Indiana portion of the Kankakee River Basin. Discharges were modified to represent flows at the Indiana-Illinois state line by using drainage-area adjustments. Discharges also were adjusted to a long-term base period 1922-85.

Table 14. Average monthly runoff of the Kankakee River Basin

{Values were approximated for a total drainage area of 2,989 sq. mi.}

Month	Vol. (bg)	Discharge (cfs)	Runoff (in)
April	91.3	387.7	1.75
May	74.9	318.1	1.44
June	53.9	228.9	1.03
July	36.4	154.6	0.70
August	23.9	101.5	0.46
September	21.6	91.7	0.41
October	27.6	117.2	0.53
November	33.5	142.3	0.64
December	48.3	205.1	0.93
January	55.6	236.1	1.07
February	60.1	255.2	1.16
March	87.2	370.3	1.68
Total	614.3	2608.7	11.81

Table 14, like the graphs in figure 24, show that water availability in the form of stream flow generally is greatest in spring and least in late summer and early fall. In any given year, however, water availability may vary greatly from the tabulated values. Moreover, future developments which cause increased consumptive use could potentially reduce the amount and temporal distribution of available water.

Supply potential of streams

The potential of individual streams in the basin for water-supply development is discussed in the following pages. It should be emphasized that stream flows are assessed without regard to the potential construction of impounding reservoirs (either in-channel or off-channel) that could greatly improve the water-supply potential of some streams. Moreover, the LaPorte precipitation anomaly is not considered because the existence of a true climatic anomaly remains questionable. Variations in stream-flow characteristics are interpreted primarily on the basis of geologic, soil and topographic differences among and within drainage basins.

Table 15 lists selected stream-flow characteristics for active and inactive continuous-record gaging stations having at least 15 years of data record as of water year 1985. Average and low-flow values for these stations and low-flow values for partial-record stations are plotted in figure 29 to facilitate an assessment of the geographic variation in flows.

Mainstem Kankakee River Basin

The stream-flow values in table 15 indicate that the Kankakee River has by far the greatest potential for water-supply development of any basin stream. As described later in this report, the Kankakee River currently supports the largest number of high-capacity withdrawals, mainly for irrigation purposes.

The abundant supply of water in the Kankakee River is attributable to the large drainage area and the geomorphic and hydrogeologic features of the river valley. As discussed earlier in the ***Physical Environment*** chapter of this report, the Kankakee River valley is characterized by permeable loamy and sandy soils overlying medium- to coarse-grained outwash deposits, predominantly sands.

The large amount of ground water stored in the Kankakee River valley and discharged to surface-water systems produces well-sustained stream flows throughout the year that can support a variety of withdrawal and instream uses. The river's value as a potential water-supply source is further increased by the fairly small variability of flows.

The small range in flows on the Kankakee River is evident in several stream-flow parameters, including flow ratios. Maximum annual mean flows calculated for four gaging stations average three times the minimums (table 15). In contrast, maximum annual means on the Yellow River are nearly four times the minimums, and maximums on the Iroquois River are eight to ten times the minimums. Maximum-to-minimum ratios for other major rivers in northern and central Indiana range from 4 to 8 (see Arvin, 1989).

The nearly horizontal slopes of flow-duration curves for the mainstem Kankakee River (figure 30) also reflect the small range in stream flows. The slope of the middle portion of the duration curve, which can be defined as the ratio of the 20-percent duration flow to the 90-percent duration flow (Arihood and Glatfelter, 1986), ranges from about 2 at the North Liberty gage to 4 at the Dunns Bridge gage. In contrast, flow-duration ratios for gages on the Yellow and Iroquois Rivers range from 5 to 13.

Table 15. Stream-flow characteristics at selected continuous-record gaging stations

{Stations selected had at least 15 years of data record through water year 1985.}

Total drainage area, average discharge, annual runoff, extremes: From Arvin (1986) except as noted. Contributing drainage area is shown in parentheses for watersheds with non-contributing portions.

Extremes: Daily maximum represents maximum instantaneous peak discharge; daily minimum represents minimum daily mean discharge.

Low flows: Estimated by Division of Water using regression analysis.

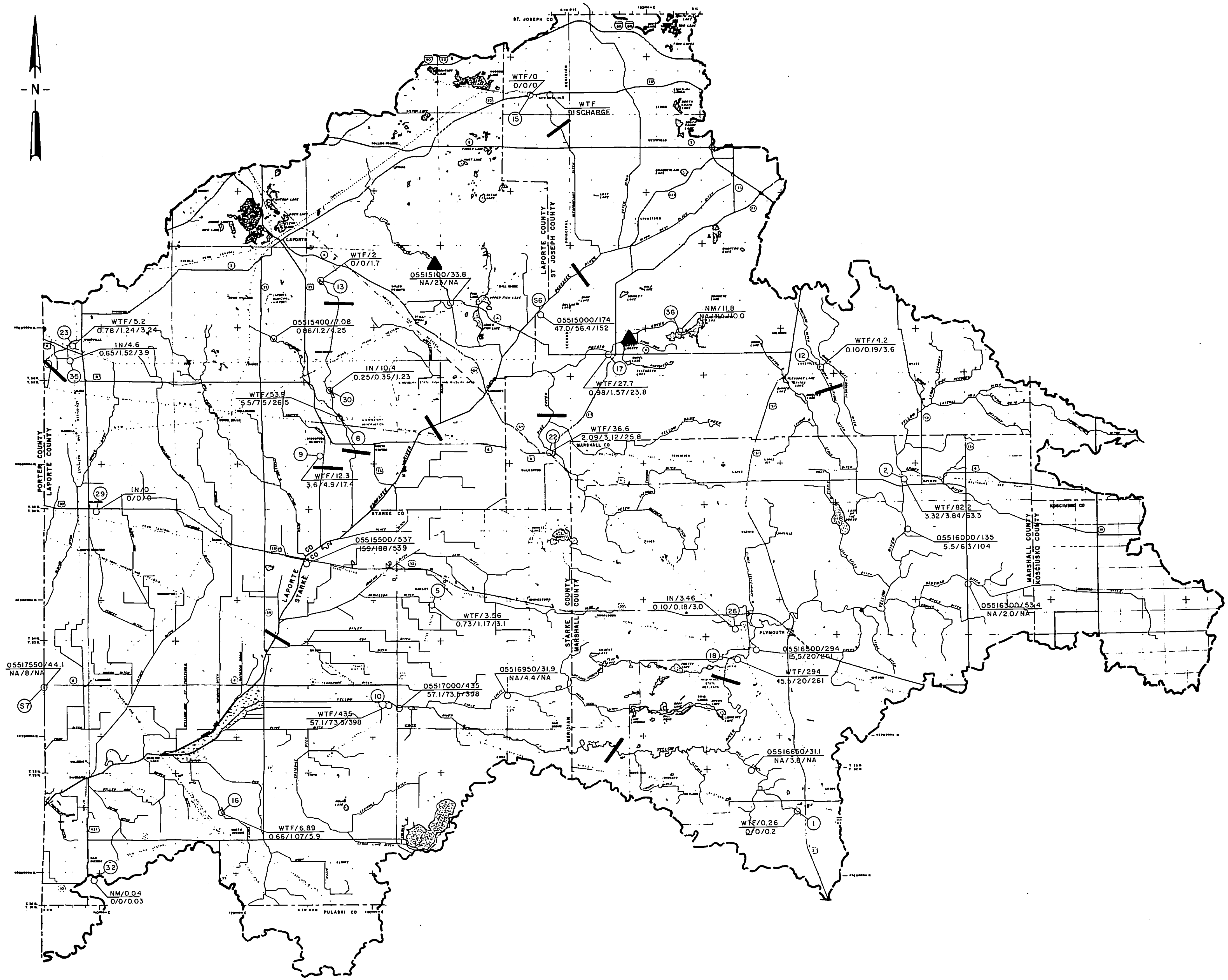
Ground-water contribution: Estimated by Division of Water using graphical method of hydrograph separation. Values are for water year 1970 except as noted.

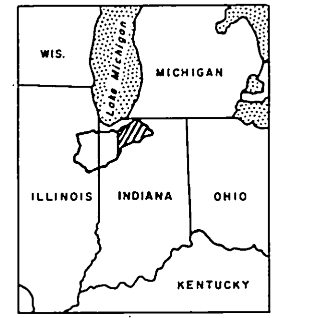
Station name	Total drainage area (sq mi)		Average discharge (cfs)	Annual runoff (in)	Extremes (cfs)				Low flows			Baseflow (percent of total runoff)
					Annual mean		Daily		1-day, 30-year	7-day, 10-year		
					max	min	max	min	cfs	cfs	cfsm	
KANKAKEE RIVER												
near North Liberty	174	(116)	152	11.9	206	95	908	46	47	56.4	0.32	83
at Davis	537	(400)	539[1]	13.6[1]	755	293	1920	154	159	188	0.35	86
at Dunns Bridge	1352	(1160)	1336	13.4	1980	618	5870	280	300	345	0.26	80
at Shelby	1779	(1578)	1751[1]	13.4[1]	2720	775	7650	260	347	423	0.24	85
YELLOW RIVER												
near Bremen[2]	135		104	10.5	171	46	1650	6.2	5.5	6.3	0.05	—
at Plymouth	294	(272)	261	12.0	434	119	5390	13	15.5	20	0.07	43
at Knox	435	(384)	398	12.4	661	180	5660	50	57.1	73.5	0.17	65
IROQUOIS RIVER												
at Rosebud	35.6		27.1	10.3	48	6	475	0.5	1.05	2.0	0.06	56
near North Marion	144		133	12.5	245	24	2040	1.6	2.29	4.19	0.03	47
at Rensselaer	203		169	11.3	303	30	2550	2.2	3.34	5.74	0.03	45
near Foresman	449		384	11.6	683	78	5930	6.3	6.94	11	0.02	40
TRIBUTARIES												
Kingsbury Creek near Laporte	7.08	(3.0)	4.3	8.2	7.4	2.9	306	0.8	0.86	1.2	0.17	87
Cobb Ditch near Kouts	30.3		33.7	15.1	48	19	795	8.9	9.12	10.9	0.36	60
Singleton Ditch at Schneider	123		109	12.0	211	24	3550	3.6	4.84	7.4	0.06	46
West Creek near Schneider[2]	54.7		41.4	10.3	70	11	1840	2.6	2.83	4.6	0.08	—
Bice Ditch near South Marion	21.8		17.5	10.9	36	3.5	1080	0	0	0.08	0.01	24
Slough Creek near Collegeville[2]	83.7		70.1	11.4	135	16	2390	0.7	0.83	1.43	0.01	—
Carpenter Creek at Egypt[2]	44.8		38.3	11.6	75	9	3720	0	0	0	0	—

[1]Calculated for water years 1950-85 to allow comparison with values for North Liberty and Dunns Bridge gages.
[2]Gage discontinued.

STATE OF INDIANA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATER

UPPER KANKAKEE RIVER BASIN





EXPLANATION

7- Map number

A- Stream gaging station or wastewater discharge point

05517530 U.S. Geological Survey stream gaging station number
WTF Municipal wastewater treatment facility
NM Non-municipal wastewater discharge
IN Industrial wastewater discharge

NOTE: ONLY WASTEWATER DISCHARGES REGULATED UNDER THE NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM PERMIT PROGRAM ARE MAPPED

B- Drainage are in square miles

C- 1-day, 30-year low flow in cubic feet per second

D- 7-day, 10-year low flow in cubic feet per second

E- Average flow in cubic feet per second

NA- Data not available

/ Water quality problems documented in some reaches since 1982

▲ Put-and-take trout stream

Figure 29a. Selected stream-flow characteristics

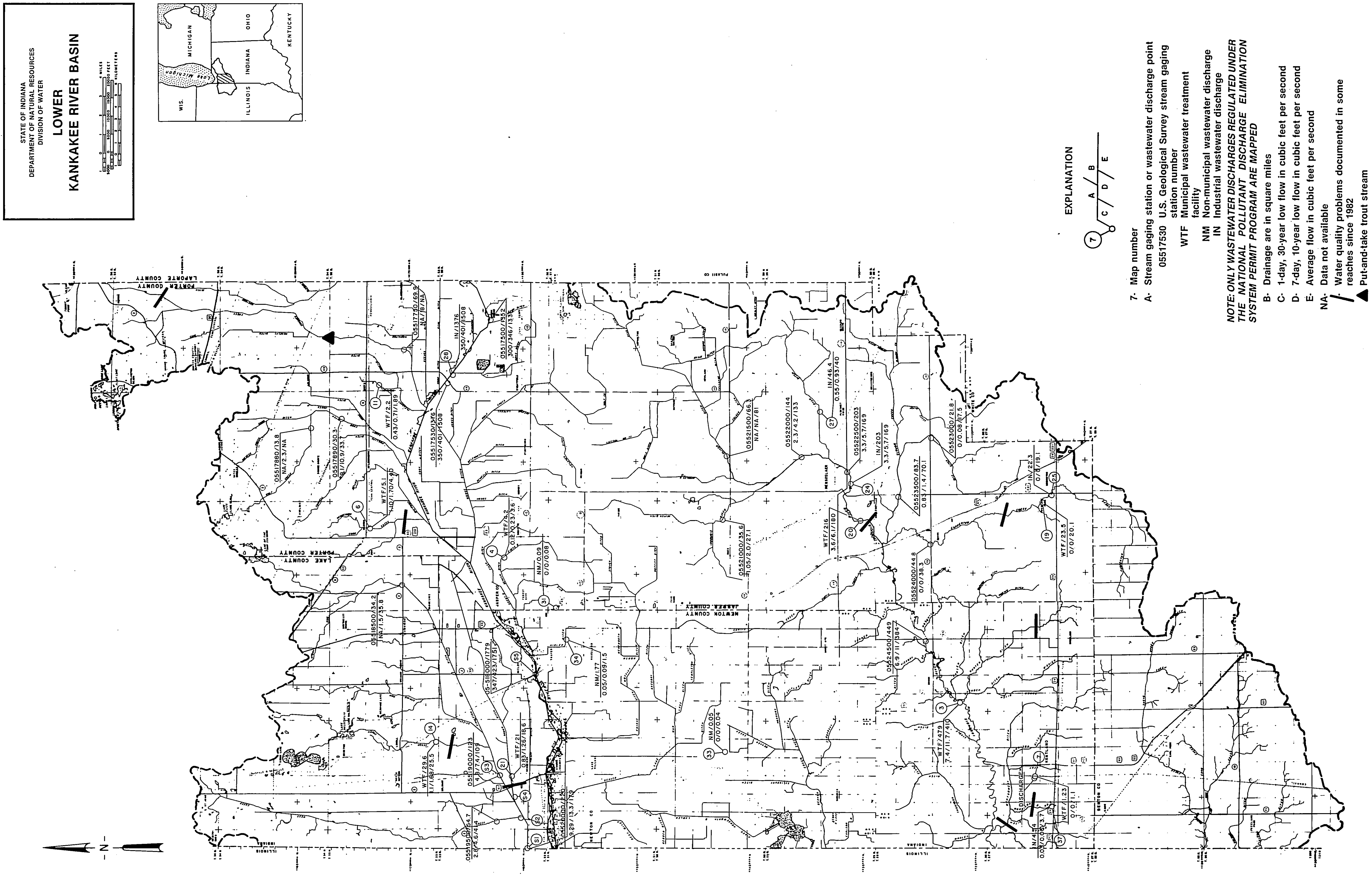


Figure 29b. Selected stream-flow characteristics

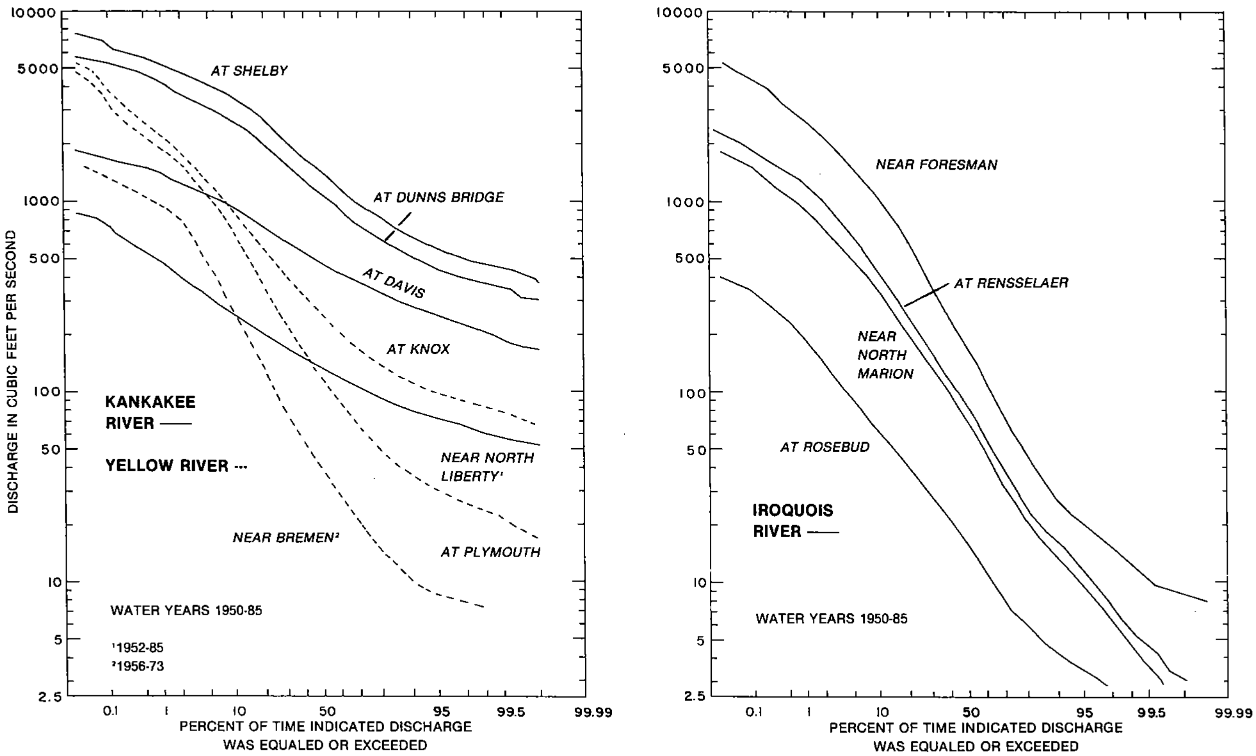


Figure 30. Duration curves of daily mean stream flow for gaging stations on the Kankakee, Yellow and Iroquois Rivers

The large amount of ground-water contribution to the Kankakee River is apparent from hydrograph analysis. As table 15 shows, base flow constitutes at least 80 percent of the flow on the Kankakee River during years of normal runoff.

The large amount of ground-water contribution to the Kankakee River also is reflected in low-flow parameters, including the lowest daily flows of record (table 15). These values are considerably higher than values for sites on the Yellow and Iroquois Rivers having comparable drainage areas.

As table 15 shows, low flows on the Kankakee River increase as drainage area increases. However, on a per-square-mile basis, low flows are slightly greater in upper reaches of the Kankakee River, as represented by the North Liberty and Davis gages, than in lower reaches, as represented by the Dunns Bridge and Shelby gages.

The amount of ground-water contribution may be greater in upper reaches of the Kankakee River than in lower reaches because of the presence of thick, coarse-grained, and laterally extensive outwash deposits. These productive deposits are found in the main valley but are most extensive north of the river in LaPorte, eastern Porter and northwestern St. Joseph Counties.

In the river's lower reaches, outwash deposits are thinner and finer grained than in upper reaches. The deposits are largely confined to the main river valley, and are flanked by clay- or silt-dominated morainal systems.

The lower unit flows in downstream reaches of the Kankakee River also could be reflecting the influence of the moderately to poorly sustained unit flows of the Yellow River, whose watershed is encompassed by the drainage basin of the lower Kankakee River. Unit values at and downstream of Dunns Bridge can be interpreted as composites of the less sustained flows of the Yellow River and the more sustained flows of the upper Kankakee River.

A third explanation for the lower unit flows of the lower Kankakee River may be related to the large number of stream withdrawals in southern Lake County and southwestern Porter County. However, a comparison of 7-day, 10-year low flows for the periods ending in 1958 (Rohne, 1962), 1978 (Stewart, 1983), and 1985 (Arvin, 1989) reveal the same trend of lower unit flows downstream of Dunns Bridge, even though the number of stream withdrawals increased during these three decades. Although a detailed analysis may have revealed temporal trends in stream flow, it appears that geomorphic and hydrogeologic features are the major factors determining low stream-flow characteristics.

Selected tributaries

Kingsbury Creek, Cobb Ditch, Singleton Ditch and West Creek are four northern tributaries of the Kankakee River which have at least 15 years of data record through 1985 (see table 13). Of these tributaries, Cobb Ditch exhibits the most sustained low flows, probably because the Cobb Ditch watershed is underlain by outwash sand and gravel deposits very similar in nature to deposits underlying the mainstem Kankakee River valley. The sustained nature of flows on Cobb Ditch is illustrated by the relatively flat slope of its flow duration curve (figure 31).

Several northern tributary watersheds of at least 30 sq. mi. which similarly encompass major extensions of the Kankakee River valley outwash system include the following: Sandy Hook Ditch, Crooked Creek, and Greiger Ditch watersheds in Porter County; the Little Kankakee River and Mill Creek watersheds in LaPorte County; and the Geyer Ditch watershed in St. Joseph County. These and other major tributaries in the main valley of the Kankakee River are expected to yield dependable quantities of water during much of the year because of their high base flows.

The drainage basin of Kingsbury Creek in LaPorte County has developed on productive outwash deposits; however, the creek's small drainage area limits the amount of ground-water storage available for discharge to the stream system. Based on its small drainage area and low unit flows (table 15), Kingsbury Creek is not expected to yield significant quantities of water on a dependable basis. Similar limitations are expected on other tributaries having small drainage areas.

Singleton Ditch supports the largest number of high-capacity withdrawals of any tributary in the Kankakee River valley. As described in a previous section entitled ***Factors Affecting Stream Flow***, Singleton Ditch traverses clayey morainal till in its upper reaches and productive outwash sands in its lower reaches. Most withdrawals occur in the outwash portion of the Singleton Ditch watershed, which is located primarily south of State Road 2 in Lake County (see figure 29).

Because the number and density of irrigation withdrawals from Singleton Ditch is large, the potential exists for water-supply conflicts, particularly during dry years. Other main-valley tributary ditches that support several registered withdrawals include Brown Ditch and Griesel Ditch in Lake County; Greiger Ditch in Porter County; and Pitner Ditch and Hanna Arm of Tuesberg Ditch in LaPorte County. A discussion of potential conflicts on selected tributaries is included in the final chapter of this report under the subheading ***Impacts of Stream Withdrawals***.

Southern tributaries of the mainstem Kankakee River are not used extensively for water withdrawals. Robbins Ditch in Starke County, Beaver Lake and Curtis Ditches in Newton County, and Dehaan and Barnard Ditches in Jasper County are examples of a few major ditches used as sources of irrigation water. Unit low flows on these and other ditches in the main valley are expected to approximate those of the mainstem Kankakee River, but small drainage areas may limit the quantity of available water.

Yellow River Basin

Although not as significant as the Kankakee River, the Yellow River is a major source of surface-water supply, particularly in its middle to lower reaches. Several registered water withdrawal facilities currently are located downstream of Plymouth, near the Marshall-Starke county line, and near Knox.

Flows on the Yellow River, like those on the Kankakee River, increase as drainage area increases (table 15). Unlike unit flows on the Kankakee River, however, unit flows along the Yellow River increase downstream.

The difference between unit flows on the upper and lower Yellow River is primarily the result of geologic differences between upper and lower portions of the Yellow River Basin. The Yellow River upstream of Plymouth drains a geologically complex area dominated by clayey tills; hence, only a moderate to limited amount of ground water is available for storage and discharge to streams. As the river approaches the main Kankakee River valley, it traverses productive outwash deposits, where more ground water is available.

The higher degree of ground-water seepage from the sands and gravels of the lower Yellow River valley is illustrated by the flatter duration-curve slope (figure 30) and the greater unit flows for the Yellow River at Knox relative to flows at Plymouth (table 15). Hydrograph analysis shows that ground water constitutes about 65 percent of the stream flow at Knox, in contrast to about 43 percent at Plymouth.

Because of the predominance of clayey or silty tills in the middle to upper Yellow River Basin, tributaries of the Yellow River have little potential for development. Unit low flows for Dausman Ditch and Wolf Creek (see figure 29) indicate a limited degree of ground-water contribution.

Iroquois River Basin

Of the Kankakee River Basin's three major rivers, the Iroquois River has the most limited potential for water-supply development. Very few withdrawals occur on the river, even in its lower reaches.

As table 15 shows, low flows on the Iroquois River increase as drainage area increases. Unit flows, however, decrease between the upper reaches, as represented by the Rosebud gage, and middle to lower reaches, as represented by the North Marion, Rensselaer, and Foresman gages.

About 60 percent of the drainage basin upstream of Rosebud is developed on windblown sand deposits; hence, ground-water contribution from tributary ditches probably helps to sustain flow in the mainstem Iroquois River. Farther downstream, the drainage basin of the Iroquois River is dominated by clayey and silty tills with a limited ability to transmit water; consequently, unit flows are smaller than those at Rosebud (table 15).

The three continuously gaged tributaries of the Iroquois River are not expected to yield significant quantities of water on a dependable basis. Flows on Slough Creek, Bice Ditch and Carpenter Creek approach zero during dry periods because of the limited degree of ground-water contribution from underlying till and lacustrine deposits.

As table 15 shows, Bice Ditch and Carpenter Creek have ceased flowing during extremely dry years because of the lack of ground-water discharge. Ground water constitutes only about 24 percent of the stream flow at the Bice Ditch gage. The steep duration-curve slopes for all three tributaries (figure 31) further illustrate the poorly sustained nature of low flows.

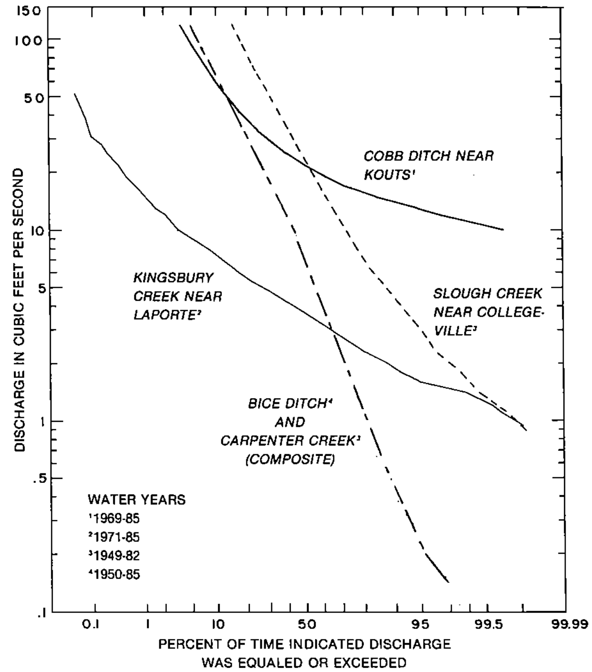


Figure 31. Duration curves of daily mean stream flow on selected tributaries

Although streams in the Iroquois River Basin are not expected to be a major source of future water-supply development, upland reservoirs could provide additional water supply where the soils and topography are suitable for reservoir construction. Water stored in these upland (side-channel) reservoirs during periods of high stream flows can later be made available for various uses.

Unlike in-channel reservoirs, upland reservoirs do not require a spillway and sedimentation is much less of a problem. Moreover, the storage capacity of upland reservoirs can be increased by excavating and contructing additional storage units or cells.

FLOODING

River flooding occurs when the transport capacity of a river is exceeded and its banks are overflowed. The Kankakee River overflows its banks, on average, about three times per year, causing minor to moderate damage. The average duration of flooding is about 3 to 7 days, but flood conditions may occur for several weeks to several months. Severe floods occur infrequently but cause extensive damage to agricultural, residential and urban areas.

About 135 square miles along the Kankakee River and 150 square miles in its tributary basins in Indiana are prone to flooding. Floods primarily inundate roads and farmland, although the cities of Plymouth and Knox along the Yellow River and some residential and resort communities flanking lower reaches of the Kankakee River can incur considerable damage during major floods.

The largest and most damaging floods of record typically occur during early spring when saturated or frozen soils, prolonged or widespread rainfall, and snowmelt can combine to produce maximum runoff over large areas. Major floods also can occur in summer, fall and winter under certain combinations of precipitation events and hydrologic conditions.

Flooding along the Kankakee River and its major tributaries often becomes most severe after breaches develop in dikes and levees (U.S. Army Corps of Engineers, 1979). Flooding can be aggravated when accumulated debris and sediment obstructs outlets of drainage ditches, or when extremely high river stages cause backwater in drainage tiles, thus flooding fields that are not otherwise flooded by direct bank overflow.

The highest floods of record on the mainstem Kankakee River were established during the March 1982 flood when melting of a dense snowpack in combination with saturated or frozen soil and moderate rains resulted in record-breaking runoff (see Glatfelter and others, 1984; Glatfelter and Chin, 1988).

Severe floods on the Kankakee River also have occurred in December 1927, April 1950, July 1953, October 1953, October 1954, June 1958, February 1959, February 1968, January 1973, March 1976, April 1978, March 1979, and March 1985. Major floods also have occurred prior to and during the channelization projects of 1893-1917, including a series of severe floods in the 1850s.

The highest recorded floods on middle to lower reaches of the Yellow and Iroquois Rivers occurred in October 1954 and June 1958, respectively, following widespread rains and heavy thunderstorms. Hale (1954), Huff and others (1955), and Daniels and Hale (1955) provide detailed discussions of the 1954 flood.

Flood-flow characteristics of the Kankakee River

Although historic channelization projects, levee construction and associated drainage projects probably have altered the hydrology of the Kankakee River Basin, the flood-flow characteristics of the mainstem Kankakee River remain unique among Indiana rivers. Flood volumes on the mainstem Kankakee River are quite large, but floods have unusually low peaks and unusually long durations. These and other factors combine to produce a flood hydrograph that is nearly flat relative to flood hydrographs of other major rivers in Indiana.

The availability of a large amount of *overbank* storage in most of the Kankakee River valley is the principal cause of reduced peak runoff and sustained flood duration. In upper reaches, however, depression storage on pitted outwash and morainal surfaces is a major attenuating factor. Because many depressional areas near the LaPorte-St. Joseph County line have no defined drainage outlet, they do not significantly contribute to surface runoff during flood events. These non-contributing drainage areas may cover up to several square miles and may contain lakes, ponds, or other isolated wetlands.

The low topographic relief, flat stream gradient, sandy soils with a low soil runoff coefficient, and permeable surficial deposits of the Kankakee River valley are among the other factors contributing to the relatively low rate of runoff along the mainstem. The low drainage density and elongated basin shape may also help reduce flood peaks along the mainstem, although these and other geomorphic factors have more pronounced influences on flood-flow characteristics of smaller basins.

The Kankakee River flows through a wide, flat floodplain surrounded by an upland plateau of nearly uniform width. The 100-year floodplain varies in width from about 2500 feet near the Jasper-Starke County line to nearly 5 miles at the town of English Lake.

The *channel slope* of the mainstem Kankakee River is the least of any major Indiana river (see Glatfelter, 1984). Although slightly steeper in upper and extreme lower reaches, most of the mainstem Kankakee River in Indiana has a downstream gradient of about one foot per mile.

The Kankakee River and its principal tributaries within the main valley are quite shallow. Maximum water depth on the floodplain is about 5 feet for an extreme flood event. However, most of the floodplain experiences flooding of a much shallower nature (Chenoweth, 1977).

The floodplain of the mainstem Kankakee River does not convey substantial amounts of water during flood periods, primarily because water depths on the floodplain are very shallow and the downstream gradient is nearly flat (Chenoweth, 1977). However, great expanses of the river floodplain periodically are inundated as floodwaters overtop the riverbanks.

Overbank flooding is so prevalent along the mainstem Kankakee River that flood runoff appears to reflect characteristics typical of a shallow reservoir (Dodson, Kinney and Lindblom, 1968). Small increases in river stage and rate of flow produce significant increases in overbank flooding.

Flood frequency

Although the initial indicator of a flood is the river's water stage, the determination of a flood's relative size is related to the peak discharge, because ice, debris or vegetation can cause higher water stages than would otherwise occur for a given flow. Peak-discharge data in the Kankakee River Basin are collected from a network of continuous-record and crest-stage partial-record stream gaging stations operated jointly by the U.S. Geological Survey and IDNR Division of Water (see figure 23, table 13).

Deriving peak-flow characteristics from stream gage records is one step in helping mitigate flood damages and in planning for future floods. Discharge-frequency characteristics can be used for 1) the design and construction of roads, bridges, dams, levees and spillways; 2) the regulation of floodplains; 3) the management of water-control works such as dams and spillways; 4) the mapping of flood-prone lands; and 5) flood forecasting.

Table 15 presents maximum peak flows recorded at continuous-record gaging stations in the Kankakee, Yellow, and Iroquois Basins having at least 30 years of data for the period of record ending in 1985. The relatively low peak flows on the mainstem Kankakee River are apparent. The drainage basins of Singleton Ditch at Schneider, Iroquois River at North Marion, and the Kankakee River at North Liberty are of comparable size, for example, but maximum peak flows at the Singleton Ditch and Iroquois River gages are two to four times greater than maximum peaks on the Kankakee River.

The unusually low peak runoff rates per square mile on the mainstem Kankakee River also are apparent from table 15. Except for a slightly higher rate per square mile at the North Liberty gage, unit discharges for maximum flood peaks on the mainstem Kankakee River average 5 cubic feet per second per square mile (cfsm) of contributing drainage area, as derived from columns 2 and 7 of table 15.

The variability of flood or peak flows, like the variability of low flows, can be statistically described by frequency curves. Flood frequency is generally expressed as the probability, in percent, that a flood of a given magnitude (discharge) will be equaled or exceeded in any one year. The recurrence interval, the reciprocal of the exceedance probability multiplied by 100, is the average number of years between exceedances of a given flood magnitude.

The *100-year flood*, for example, is the peak discharge that is expected to be equaled or exceeded on the average of once in a 100-year period (see example in figure 27). In other words, there is a 1 percent chance that a peak discharge of at least this magnitude will occur in any given year. Similarly, the 50-year flood has a 2 percent chance of occurring in any given year, the 25-year flood has a 4 percent chance, and the 10-year flood has a 10 percent chance.

It should be noted that recurrence interval, or frequency, represents the long-term average time period during which a flood exceeding a certain magnitude is expected to occur once. It does not imply a regular periodicity between floods. A peak discharge having a 100-year recurrence interval, for example, could possibly occur in two consecutive years, or even in two consecutive weeks. On the other hand, the 100-year flood may not occur for several hundred years.

Moreover, the discharge-frequency values only are accurate to the extent that the available discharges used in the statistical analysis are representative of the long-term discharge record. In general, a minimum of 30 years of data record is required to yield reliable flood frequency values for large floods.

Since 1976, the Division of Water has coordinated with the U.S. Geological Survey, U.S. Soil Conservation Service and U.S. Army Corps of Engineers to determine peak discharge-frequency values for Indiana streams (Indiana Department of Natural Resources, 1988). A comparison of computed flood frequency values with maximum recorded discharges on the Kankakee, Yellow and Iroquois Rivers reveal that, with the exception of the Iroquois River at Foresman, peak discharges recorded at stream gages (table 15) have recurrence intervals greater than 100 years.

For a given flood frequency, a relation between peak discharge and drainage area can be developed to allow the estimation of discharges at ungaged sites within a watershed, or within other watersheds having similar basin characteristics. Figure 32 illustrates the relationship between peak discharge and drainage area for the Kankakee, Yellow and Iroquois Rivers.

The unusually low flood flows on the Kankakee River are evident in figure 32. For example, a site on the Kankakee River with a contributing drainage area of 150 square miles has an estimated 100-year flood discharge of approximately 950 cubic feet per second. At a comparable site on the Yellow River, the 100-year flood is about 2750 cfs. On the Iroquois River, the 100-year flood for this drainage area is about 2075 cfs.

The curves in figure 32 also show that although peak flows on the Yellow River typically exceed those on the Iroquois River for comparable drainage areas, flood discharges increase more rapidly downstream on the Iroquois River. The greater variability of flood peaks on the Iroquois River probably is the result of the more rapid overland runoff from clayey or silty soils, and the limited amount of overbank storage in the Iroquois River valley.

Floodplain management

Since the Kankakee River Basin was first settled in the 1800s, public and private agencies have expended billions of dollars to improve drainage and control flooding. Although most methods of floodplain management historically have involved channelization, ditching, dredging, levee construction, and land-treatment measures, increasing emphasis is being placed on floodplain regulation and non-structural alternatives, such as land-use regulations, flood insurance, floodproofing, flood warning, and flood damage relief.

A report by Grady and Rutledge (1982) describes floodplain management measures and various aspects of land-use planning for Indiana communities. Detailed floodplain management reports and flood insurance studies are available for most counties of the Kankakee River Basin. Most of these reports have been prepared by cooperative efforts of the U.S. Department of Agriculture (Soil Conservation Service), the Federal Emergency Management Agency, the State of Indiana (Department of Natural Resources), soil and water conservation districts, planning commissions, and other local agencies.

Existing floodplain management regulations in Indiana are governed by a combination of statutory laws at both the state and federal levels. In brief, the state establishes minimum standards governing the delineation and regulation of flood hazard areas. Moreover, the 1945 Indiana Flood Control Act (I.C. 13-2-22) prohibits construction, excavation, or the placement of fill in a floodway without prior approval from the Natural Resources Commission.

The Indiana Department of Natural Resources, Division of Water administers the flood control law and also acts as the state coordinator of the National Flood Insurance Program, which further helps to regulate the development of flood-prone lands. According to requirements of the program, new construction in a flood hazard area must be located and built in such a way that the potential for damages and loss of life is minimized.

Under this program, which is administered by the Federal Insurance Administration of the Federal Emergency Management Agency, property owners are eligible to purchase federal flood insurance if their flood-prone community adopts and enforces adequate floodplain management regulations. For properties located in the 100-year floodplain, flood insurance is a mandatory requirement for mortgage loans which are in any way federally connected.

A community can initially enter the **emergency phase** of the flood insurance program by adopting preliminary floodplain management regulations to guide new construction in flood-prone areas, which are approximately delineated on a flood hazard boundary map based on a generalized study. During the initial emergency phase, limited amounts of flood insurance become available to local property owners.

The community can then enter the **regular phase** of the program after a detailed flood insurance rate map is issued following a flood insurance study, and after local officials enact comprehensive regulations that require all new or substantially improved structures to be built in accordance with federal floodplain management criteria. Under the regular program, the full limits of flood insurance coverage become available.

Table 16 shows participation in the National Flood Insurance Program by communities within the Kankakee River Basin as of January 1990. The term "community" refers to both unincorporated and incorporated areas which have a government authority

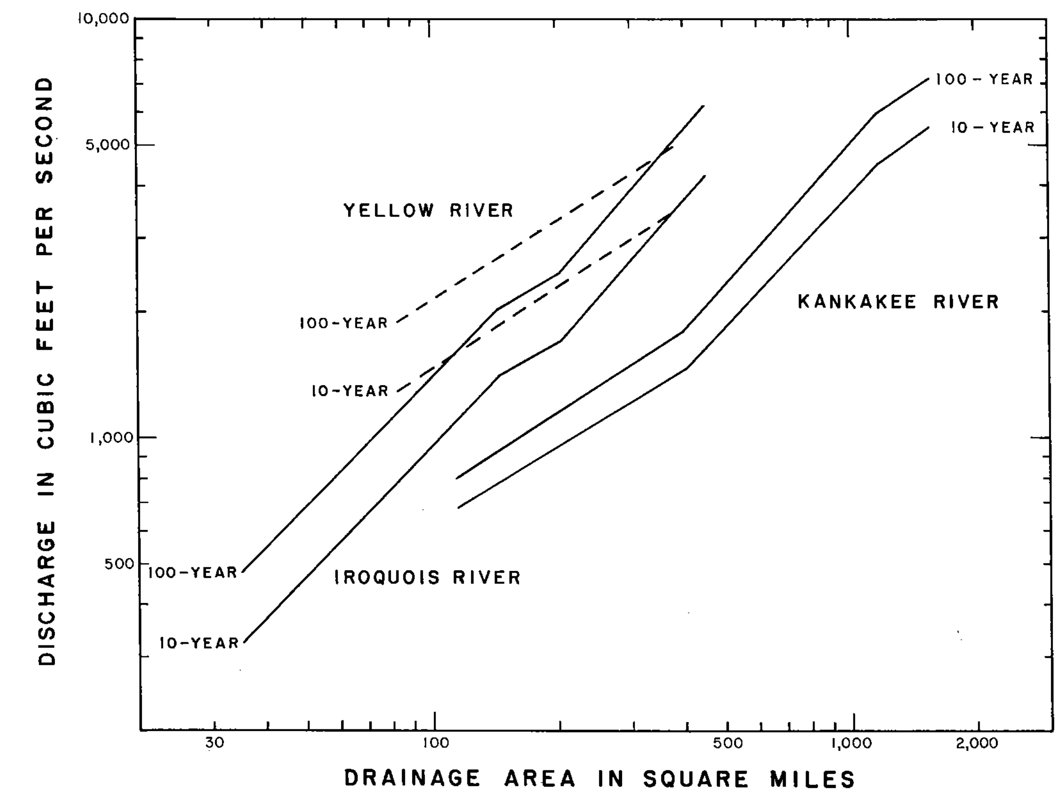


Figure 32. Relation between drainage area and flood discharge for the Kankakee, Yellow and Iroquois Rivers
(Data from Division of Water, 1988e)

Table 16. Community participation in the National Flood Insurance Program for major basin counties

{All communities in regular phase unless indicated as follows: NP, not participating; E, emergency}

County	Community
Benton (NP)	Fowler
Jasper (E)	Remington (E), Rensselaer (E), Demotte
Lake	Lowell, St. John, Schneider, Shelby[1]
LaPorte	LaCrosse, LaPorte (E)
Marshall	Argos, Bremen, Plymouth
Newton	Brook, Goodland, Kentland
Porter	Hebron, Valparaiso
St. Joseph	Lakeville, North Liberty, Walkerton
Starke (NP)	Knox (E), North Judson[2]

[1]Under county
[2]Not applicable

capable of adopting and enforcing floodplain management regulations. By virtue of this definition, an incorporated town is considered independent of unincorporated areas, which are collectively defined as a separate community.

SURFACE-WATER QUALITY

The water quality of rivers, streams and lakes can be an important factor in planning water and land development. The presence of high-quality watercourses can facilitate or enhance development by providing a surface-water source suitable for public water supply, industrial cooling, irrigation, livestock watering, recreation, or aquatic life. In contrast, watercourses containing certain toxic substances can pose a health threat to humans who consume tainted fish taken from the contaminated waters. Moreover, the value of a surface-water source for designated uses can be diminished by bacterial pollution, high levels of nutrients, or unacceptable concentrations of inorganic and organic chemicals.

Streams

Rivers, streams and ditches in the Kankakee River Basin are used to assimilate wastewater discharged primarily from public supply and industrial facilities. A facility must treat its effluent to maintain the water quality standards established for the receiving watercourse.

The concentrations of polluting materials in these point-source effluents are regulated by the National Pollutant Discharge Elimination System (NPDES) permit program, administered in Indiana by the Department of Environmental Management. The discharge limits set in the permit are designed to protect all designated uses of the receiving watercourse.

Treated effluents discharged into streams normally require dilution to maintain water-quality requirements. Because the volume of water in streams is at a minimum during dry weather, low-flow periods are used as the basis of design for wastewater-treatment facilities.

Table 17 lists most NPDES-permitted municipal, non-municipal, and industrial wastewater-treatment facilities in the Kankakee River Basin. (Some facilities, including motels, mobile home parks, and private businesses, are not listed because of insufficient data.) Figure 29 shows the locations of the tabulated facilities and selected stream-flow characteristics of the receiving streams. The 7-day, 10-year low flow is shown because it determines the level of wastewater treatment needed to meet water-quality standards. The 1-day, 30-year low flow is an indicator of stream-flow dependability, and the average flow is a general measure of water volume in a stream.

Table 17 also shows 1) the reported water use for facilities registered with the IDNR, and 2) the estimated wastewater discharge of facilities having sufficient data. Although wastewater discharges generally approximate total water withdrawals for any given facility, discharges at some municipal facilities exceed withdrawals. In most cases, these facilities receive and treat not only their own wastewater but also wastewater from nearby communities or industries. Stormwater runoff and ground-water infiltration also are probable causes for increased wastewater discharges.

Sources of stream-quality data

The water quality of rivers and streams in Indiana is monitored by several state and federal agencies. Table 18 summarizes the types of data and years of data record for stream- quality stations in the Kankakee River Basin. The location of active and discontinued stream-quality monitoring stations can be determined from figure 29 because stream-quality sites generally are co-located with U.S. Geological Survey stream-flow gaging stations.

The Indiana Department of Environmental Management (IDEM) currently collects monthly, near-surface *grab samples* at two stream-quality monitoring stations on the Kankakee River near Kingsbury and Shelby (see figure 29). Samples are analyzed for physical parameters, chemical constitutents, and the abundance of *fecal coliform*. The IDEM also collects samples of fish tissue and streambed sediment at the two Kankakee River stations for the detection of potential contamination by metals, *polychlorinated biphenyls* (PCBs), and pesticides. In summer 1990, the IDEM conducted chemical and biological surveys of selected streams throughout the Kankakee River Basin.

Data from the IDEM studies generally are summarized in annual and biennial water-quality reports. The data are used primarily to determine water-quality trends, support pollution-abatement activities and enforcement actions, locate potential pollution sources, determine the background levels of chemical constituents, and help document Indiana's progress toward meeting goals of the federal Clean Water Act.

The Illinois Environmental Protection Agency, in cooperation with the U.S. Geological Survey, monitors stream quality at four stations in the Illinois portion of the Kankakee River Basin (table 18). Depth-integrated composite samples are collected at these stations every six weeks, on average. Results of physical, chemical and bacteriological analyses are published annually in U.S. Geological Survey water-resources data reports for Illinois. Data from these stations can be used to supplement the sparse data for the Indiana portion of the basin because most of the drainage area influencing downstream water quality lies in Indiana.

The U.S. Geological Survey is conducting a comprehensive assessment of the surface-water quality of the Upper Illinois River Basin in Illinois, Indiana and Wisconsin as part of a pilot project in the National Water-Quality Assessment Program (Mades, 1987). Some water-quality samples are being collected on the

Table 17. Wastewater discharges and water withdrawals for selected facilities permitted under the National Pollutant Discharge Elimination System

{Data compiled from unpublished files of the IDNR Division of Water and the Indiana Department of Environmental Management.}

Map number: Site locations are shown in figure 29.
Facility type and name: Facilities are municipalities except where indicated as IN, industrial and NM, non-municipal.
Total drainage area: Contributing drainage area is shown in parentheses for watersheds with non-contributing portions.
Wastewater discharge: For 1987 calendar year. Monthly data is incomplete for some facilities.
Water withdrawal: For 1987 calendar year. N/A, data not available (facility is not registered with the IDNR Division of Water).

Map no.	Facility type and site name	Receiving stream	Total drainage area	Wastewater discharge (mgd)	Water withdrawal (mgd)
UPPER KANKAKEE RIVER BASIN					
15	New Carlisle	Niespodziany Ditch	0.0	N/A	0.14
13	LaPorte	Travis Ditch	2.0	3.71	3.40
30	IN Roll Coater	Travis Ditch	10.4	0.08	N/A
8	Kingsbury Utilities[1]	Travis Ditch	53.9 (18.8)	0.29	0.60
9	Kingsford Heights	Porter Ditch	12.3	0.12	0.14
29	IN Packaging Corp of America	Echert Ditch	0	0.01	0.01
23	Westville	Crumpacker Arm	3.55 (2.19)	0.11	0.09
		Forbes Ditch	5.15 (3.77)		
35	IN Westville Correction Center	Crumpacker Arm	4.6	0.37	0.60
36	NM Potato Creek SRA	Potato Creek	11.8[7]	0.01	0.01
17	North Liberty	Potato Creek	27.7	0.18	0.24
22	Walkerton	Pine Creek	36.6 (30.0)	0.21	0.25
5	Hamlet	Donaldson Ditch	3.56	0.09	0.08
16	North Judson	Pine Creek	6.89	0.26	0.17
28	IN Northern Indiana Public Service Company	Kankakee River	1376	3.57	15.58
LOWER KANKAKEE RIVER BASIN					
4	Demotte	Evers Ditch	4.22	0.18	0
31	NM Kankakee Rest Area	UNT DeFries Ditch	0.9	0.01	N/A
34	NM Lincoln Elem. School	Hibler Ditch	1.77	—[2]	N/A
11	Kouts	Plant Township Ditch	2.20	0.18	0.17
6	Hebron	Cobbs Creek	5.12	0.24	0.32
14	Lowell	Cedar Creek	29.6	2.34	0.65
21	Schneider	Brown Ditch	21.0	0.03	0.05
YELLOW RIVER BASIN					
12	Lakeville	Shidler-Hoffman Ditch	4.20	0.09	0.08
2	Bremen	Yellow River	82.2	0.87	0.71
26	IN Del Monte Corporation	Schuh Ditch	3.46	0.07	0.18
18	Plymouth	Yellow River	294	1.37	1.57
1	Argos	UNT Meyers Ditch	0.26	0.12	0.13
		Meyers Ditch	3.6	—	—
10	Knox	Yellow River	435 (384)	0.44	0.43
IROQUOIS RIVER BASIN					
32	NM Little Co/Mary Health Fac.	UNT W. Arm Scholts Ditch	0.04	0.02[3]	N/A
27	IN Rensselaer Stone Co.	Ryan Ditch	46.4	0.81	N/A
24	IN W.C. Babcock Const. Inc.	Iroquois River	203	0.81	1.34
20	Rensselaer	Iroquois River	216	0.86	0.74
25	IN Central Soya	Carpenter Creek	22.3	0.05	N/A
19	Remington	Carpenter Creek	23.5	0.21	0.27
3	Brook	Iroquois River	479	0.07	0.07
7	Kentland	Ditch to Montgomery Ditch	1.23	0.35	0.31
		Montgomery Ditch	35.6	—	—
37	IN Capital Products Corp.	Morrison Ditch #2	4.34	0.07	N/A
33	NM North Newton Jr. & Sr. High School	UNT Beaver Creek	0.05	0.01[4]	0.01

[1]Industrial park; does not serve town of Kingsbury, which has septic system.
[2]Included in discharge of Site 33.
[3]Discharges into Upper Wabash River Basin.
[4]Includes discharge from Site 34.

Table 18. Stream-quality monitoring stations

{Additional water-quality data were collected in St. Joseph, LaPorte and Marshall Counties by Michiana Area Council of Governments (1978), and in Porter County by the U.S. Geological Survey (Bobo and Renn, 1980).}

Station name: Except for the Kingsbury station, all stations are co-located with U.S. Geological Survey stream-gaging sites shown in figure 30.

Agency: USGS, U.S. Geological Survey; IDEM, Indiana Department of Environmental Management; IEPA, Illinois Environmental Protection Agency; NAWQA, National Water-Quality Assessment Program of U.S. Geological Survey

Data type: S, suspended sediment; s, chemical analysis of sediment; P, physical; C, chemical; B, bacteriological; b, biological; f, fish tissue; R, radiological. Parameters analyzed may vary from year to year.

Station name	Agency	Data type	Period of record
Kankakee River			
near North Liberty[1]	USGS	S	1978-81
Kingsbury area[2]	IDEM	P,C,B,f,b,s	1978-
at Shelby[3]	IDEM	P,C,B,f,b,s,R	1957-
at Shelby[1]	USGS	S	1964-79
at Momence, Ill.	IEPA, NAWQA	P,C,B,b,s,S	1959-
Yellow River			
at Plymouth	IDEM	P,C,B	1971-72
at Plymouth[4]	USGS	S	1979-82
at Knox	IDEM	P,C,B,b,s	1957-70
Iroquois River			
at Rosebud[1]	USGS	S	1978-80
near Foresman	IDEM	P,C,B	1957-70
near Foresman	USGS	S	1968-80
at Iroquois, Ill.	IEPA	P,C,B	1972-
near Chebanse, Ill.	IEPA, NAWQA	P,C,B,b,s,S	1959-
Tributaries			
Cobb Ditch near Kouts[1]	USGS	S	1979-80
Singleton Ditch at Schneider[1]	USGS	S	1979-82
Sugar Creek at Milford, Ill.	IEPA	P,C,B	1978-

[1]Partial-record sediment station
[2]In Kingsbury State Fish and Wildlife Area
[3]Gaps occur in years of record
[4]Daily-record sediment station

Kankakee and Iroquois Rivers and Sugar Creek in Indiana, but most sampling sites are located in Illinois.

As part of the initial phase of the Upper Illinois River Basin study, sources of existing water-quality data were compiled and evaluated (Steffeck and Striegl, 1989; Blanchard, 1989). A low-flow synoptic survey of nutrients and dissolved oxygen was performed during drought conditions in the summer of 1988 (Terrio, 1989). The results of additional water-quality sampling projects and special studies are scheduled for publication in the early 1990s.

When complete, the Upper Illinois River Basin study will provide detailed assessments of water quality, including the description of potential water-quality trends and the investigation of relationships among selected water-quality constituents, hydrologic characteristics, and land use. Data collected from the Kankakee River at Momence and the Iroquois River near Chebanse will be compared to determine the effects of geology on the water quality of streams draining similar watersheds (Mades, 1987). This type of data for east-central Illinois should be useful in characterizing and interpreting water-quality data for Indiana streams in the Kankakee River Basin.

The U.S. Geological Survey, in cooperation with the U.S. Department of Agriculture's Soil Conservation Service, collected water-quality data for the Porter County portion of the lower Kankakee River watershed in 1978 (Bobo and Renn, 1980). The data were used to determine baseline water quality and evaluate environmental needs for the local watershed.

In 1977, the Michiana Area Council of Governments collected water samples from the Kankakee River and its major tributaries in Laporte and St. Joseph Counties, and from the Yellow River and its major tributaries in Marshall County. The samples were analyzed for physical and chemical parameters, and the results were used in the development of a waste-treatment management plan (Michiana Area Council of Governments, 1978).

From 1964 to 1982, the U.S. Geological Survey, in cooperation with the Indiana Department of Natural Resources, collected suspended sediment data on a periodic basis from the Kankakee and Iroquois Rivers, Cobb Ditch, and Singleton Ditch (table 18, figure 29). Daily records of sediment data were collected on the Yellow River at Plymouth for water years 1979-81. Summaries of the data are included in a report by Crawford and Mansue (1988). Erosion and associated stream sedimentation were discussed previously in the ***Physical Environment*** chapter of this report in the section entitled ***Soils***.

Assessment of stream quality

Stream quality can be evaluated by the degree of compliance with enforceable standards or recommended criteria established by state and federal agencies. Water-quality regulations for Indiana's streams and lakes are developed and administered primarily by the Indiana Department of Environmental Management. Appendix 6 lists either enforceable standards or recommended criteria for public water supply, aquatic life, livestock watering, and irrigation.

Standards for recreation are intended to protect the public from possible health risks from waterborne diseases and to maintain the aesthetic quality of a body of water. Counts of fecal coliform are used to monitor the suitability of surface waters for body-contact recreation such as swimming and wading.

As of early 1990, all streams and lakes in Indiana must meet water-quality standards for whole-body contact recreation. In previous years, most streams in Indiana, including all streams in the Kankakee River Basin, had to meet water-quality standards for partial-body contact recreation. Lakes had to meet more stringent bacterial limits for whole-body contact recreation.

Most streams and lakes in the Kankakee River Basin are designated for support of warmwater fisheries (see box on next page). Worster Lake, Potato Creek, Little Kankakee River, and Crooked Creek are put-and-take trout fisheries and are designated for support of coldwater species. Water-quality requirements to protect fish communities include criteria for pH, temperature, and concentrations of dissolved oxygen, ammonia, and *toxic* substances.

The IDEM periodically assesses potentially fishable and swimmable streams in the Kankakee River Basin to determine their degree of support of designated recreation and aquatic life uses. Assessments are based either on the evaluation of monitored biological or chemical parameters or on the assessment of land use, location of nonpoint-source pollution, and citizen complaints.

Studies by the IDEM in 1986-87 and 1988-89 revealed that roughly 80 percent of the 464 stream miles assessed in the Kankakee River Basin fully supported aquatic-life uses. About 20 percent of the stream miles, including reaches of the mainstem Kankakee River, Travis Ditch, and lower Yellow River, partially supported aquatic-life uses. These impairments were due primarily to low dissolved oxygen and high ammonia concentrations associated with inadequately treated sewage (Indiana Department of Environmental Management, [1988], [1990]). The mainstem Kankakee River did not support whole-body contact recreation uses because of fecal coliform violations (Indiana Department of Environmental Management, [1990]).

The number and frequency of aquatic-life and recreation-use impairments in streams receiving wastewater discharges are expected to decrease in the 1990s as municipalities and industries continue to upgrade existing wastewater-treatment facilities, build new facilities, and improve their treatment operations. However, water-quality problems may continue to occur in some local watersheds, particularly where facilities still do not meet their NPDES discharge limits. Construction projects, maintenance dredging,

Fisheries of the Kankakee River Basin

At least 77 species of fish are believed to exist in lakes and streams of the Kankakee River Basin, according to results of a 1986 sampling project involving 89 stations (Seegert, 1987). Forty-eight species of fish were identified in a 1981 survey of the mainstem Kankakee River (Robertson and Ledet, 1981). Fewer species were identified in a 1989 survey of the Yellow and Iroquois Rivers (Robertson, 1989a, 1989b).

Game fish constitute about 10 percent of the basin's total fish population (Robertson, 1971). Northern pike, walleye, smallmouth bass, rock bass, largemouth bass, channel catfish, bluegill, crappie, yellow perch and other game fish are caught in the basin's streams. The current state-record walleye was caught in the Kankakee River, and the state-record northern pike was taken from the Yellow River in 1983. Large numbers of suckers and redhorse are harvested from some of the basin's streams during spring spawning runs.

The Division of Fish and Wildlife stocks both warmwater and coldwater fish in selected watercourses in the Kankakee River Basin when fish population data indicate that stocked fish have a good chance of improving fishing quality. The division has stocked smallmouth bass, largemouth bass, rock bass, walleye, bluegill, redear sunfish, channel catfish, tiger muskellunge, hybrid striped bass, northern pike and crappie at various locations in the basin. Catchable-size trout are stocked annually in Crooked Creek in Porter County; in the Little Kankakee River in LaPorte County; and in Potato Creek and Worster Lake in St. Joseph County.

J.C. Murphey, Worster, Cedar, Bass, Pine, Stone and Koontz Lakes are among the larger lakes known for their warmwater fisheries. Largemouth bass, bluegill, channel catfish, crappie, redear, walleye and northern pike are popular game fish caught in these and other lakes in the basin. A fish renovation project completed in 1989 at J.C. Murphey Lake should greatly improve the fishery at this large, shallow lake located in Willow Slough Fish and Wildlife Area.

Indiana's only two coldwater fish hatcheries are located in and near the Kankakee River Basin. More than 1 million rainbow trout, mostly migratory steelhead, and coho and chinook salmon are reared annually at Mixsawbah State Fish Hatchery in LaPorte County and at Twin Branch State Fish Hatchery located just east of the basin boundary in St. Joseph County. In addition to raising trout and salmon for a Lake Michigan fishery, these two coldwater hatcheries provide trout for stocking in inland lakes and streams having aquatic habitat and water quality that is adequate to support a put-and-take trout fishery.

A warmwater fish hatchery was operated at Bass Lake in Marshall County from the 1930s to 1988. The facility raised smallmouth bass, channel catfish and other fish for stocking in selected streams and lakes throughout Indiana. Although the Bass Lake facility no longer is used for daily hatchery production, it may be used as a back-up or emergency facility.

bank clearing, and poor agricultural practices are among the activities that may cause localized, short-term sedimentation problems on some streams and ditches.

Mainstem Kankakee River Basin

Water in the mainstem Kankakee River is predominantly of the calcium-bicarbonate type and is characterized by high hardness, high alkalinity, and high concentrations of iron and manganese (figure 33). The river's water quality, as reflected by data from the Kingsbury, Shelby and Momence gages, is similar to the quality of ground water in the hydrologically connected outwash sands and gravels underlying the main valley. A detailed discussion of ground-water quality is presented in the ***Ground-Water Hydrology*** chapter of this report.

Although the Kankakee River is not a source for public water supply, the river's water quality may be compared with drinking-water standards (appendix 6) for descriptive purposes. Data from a selected 10-year period 1978-87 show that iron and manganese concentrations, which are naturally high in ground water, commonly exceeded the secondary *maximum contaminant* levels (figure 33). Concentrations of other constituents such as sulfate, chloride, barium, and trace metals generally were well below the secondary and primary (maximum) contaminant levels (appendices 6, 7).

The water quality of the mainstem Kankakee River usually is suitable for aquatic life, but occasionally high fecal coliform counts at the Kingsbury and Shelby stations impair both partial-body and whole-body contact recreation uses. Because the amount of data is limited, it cannot be determined whether the violations were caused by point sources, *combined sewer overflows*, or runoff associated with agricultural activities (Indiana Department of Environmental Management, [1988]).

The *biochemical oxygen demand* in the Kankakee River is low, indicating a limited presence of oxygen-consuming wastes in the water. Concentrations of dissolved oxygen typically are high enough to support a diverse aquatic biota, including many species of game fish (see box above). The *median* dissolved oxygen concentration of about 8.8 mg/L (milligrams per liter) is well above the 5.0 mg/L critical limit recommended for most fish life.

Fairly well-balanced *benthic* invertebrate communities were found in the mainstem Kankakee River near Hebron during a study of southern Porter County

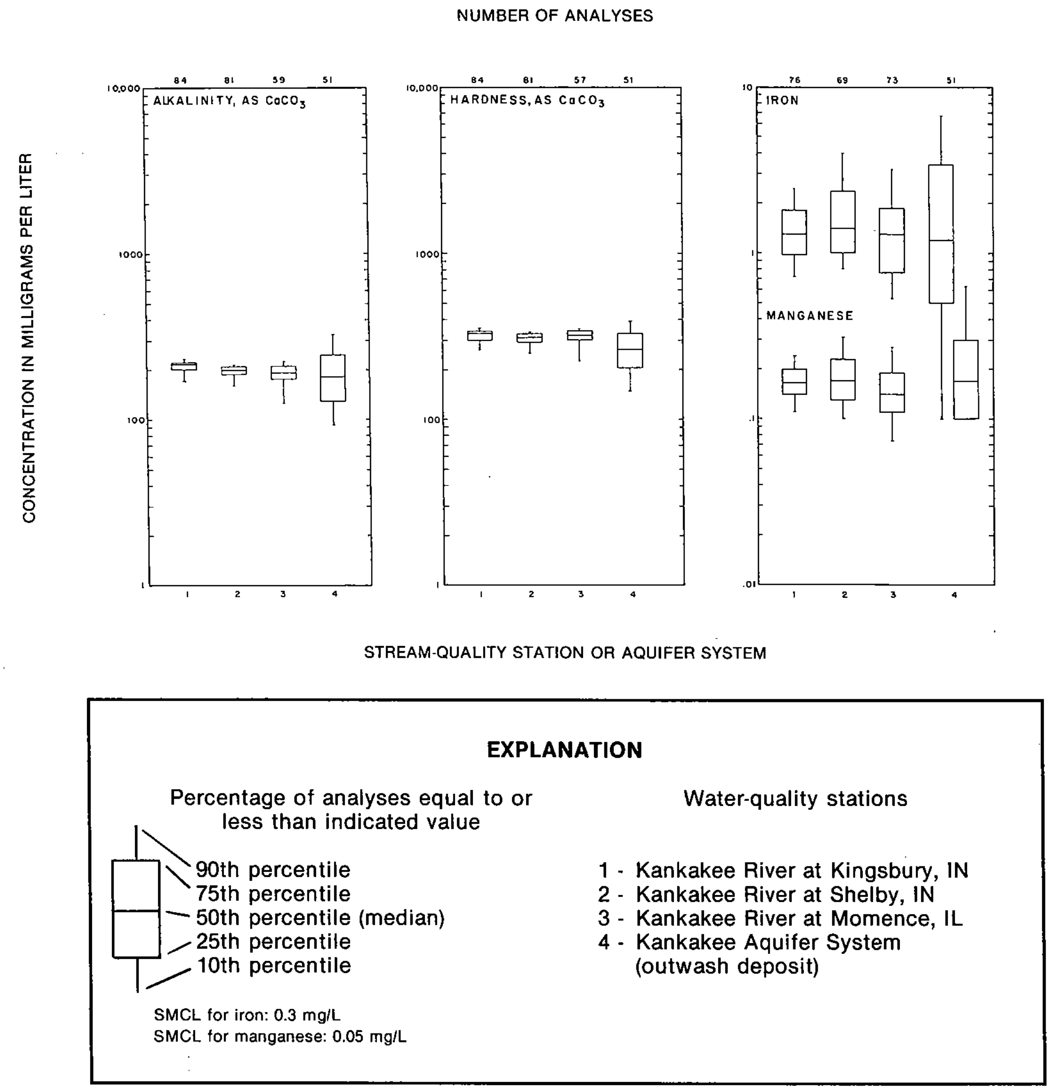


Figure 33. Statistical summary of selected water-quality constituents for stream monitoring stations on the Kankakee River and for the hydrologically connected outwash system

(Bobo and Renn, 1980). The river also supports a unique and diverse population of caddisflies, whose larval stage is completely aquatic and is an important source of fish food.

Concentrations of ammonia and several trace metals in the Kankakee River have rarely exceeded criteria for aquatic life during the period 1978-87 (appendices 6,7). However, lead concentrations in the lower Kankakee River occasionally exceeded the chronic aquatic-life criterion (Indiana Department of Environmental Management, [1990]).

Iron concentrations in the Kankakee River commonly exceeded the aquatic-life criterion during the period 1978-87. Phosphorus concentrations sometimes exceeded the limit (0.1 mg/L) recommended for prevention of nuisance algal growth in flowing water, but excessive algal populations were not reported.

Fish-tissue analyses conducted since 1979 have revealed that metals, PCBs, and pesticide levels in fish from the Kankakee River remain among the lowest in Indiana, and are well below levels that may affect human health (Indiana Stream Pollution Control Board, 1984; Indiana Department of Environmental Management, [1986], [1988], [1990]). Since the monitoring of toxics in fish tissue began in 1979, no samples collected at the Kankakee River station have exceeded *action levels* established by the federal Food and Drug Administration (FDA) for PCBs, chlordane and dieldrin in the edible portions of fish.

As discussed previously in the ***Physical Environment*** chapter of this report in the section entitled ***Soils***, sedimentation and turbidity resulting from soil erosion can adversely affect water quality. Although the Kankakee River frequently is turbid, no reports of water-quality degradation from excessive sedimentation have been documented.

Selected tributaries

Some tributaries of the mainstem Kankakee River frequently do not support aquatic-life uses, primarily as a result of discharges of inadequately treated sewage from municipal and industrial wastewater-treatment facilities. Most stream segments having aquatic-life impairment generally are less than 5 miles in length. Figure 29 shows the general locations of stream reaches where water quality problems have been documented in the last 10 years (Michiana Area Council of Governments, 1978; Indiana Stream Pollution Control Board, 1984; Indiana Department of Environmental Management, [1986], [1988], [1990]).

Perhaps the most serious water-quality problems documented in the upper Kankakee River Basin have occurred in the Travis Ditch watershed in LaPorte County. Travis Ditch receives the effluent of the LaPorte wastewater-treatment facility, the largest point-source discharge of municipal wastewater in the Kankakee River Basin (see table 17). LaPorte's effluent has had demonstrated toxicity problems, possibly due to metals, surfactants, and dissolved solids (Indiana Department of Environmental Management, [1988]). Moreover, equipment failures at the facility recently have resulted in ammonia and copper violations (Indiana Department of Environmental Management, [1990]).

Travis Ditch also receives waste discharges from several industries in the Kingsbury area, one of which has frequently violated its NPDES discharge limits and has produced an effluent with demonstrated toxicity (Indiana Department of Environmental Management, [1986], [1988], [1990]). During the IDEM's 1988-89 survey period, sediments in Travis Ditch were found to contain metal concentrations considerably above background levels (Indiana Department of Environmental Management, [1990]). The recent expansion of the LaPorte municipal sewage-treatment plant and the implementation of enforcement proceedings against the industry are expected to improve local water quality in Travis Ditch.

Another industry located in the Kingsbury area was identified as a potential source of dioxin contamination related to herbicide production. However, extensive soil sampling by the U.S. Environmental Protection Agency in 1984 revealed no traces of dioxin on the property; hence, the risk of dioxin contamination in the Kankakee River from this source is extremely low (Indiana Department of Environmental Management, [1986]).

In the lower Kankakee River Basin, chronic water-quality problems have been documented in the Crooked Creek watershed in Porter and western LaPorte Counties (figure 29). In past years, discharges of inadequately treated sewage were the probable cause of aquatic-life impairments in segments of Crooked Creek and two tributaries, Crumpacker Arm and Forbes Ditch (Indiana Department of Environmental Management, [1988]). Oil spills and inadequate wastewater treatment at a formerly operating oil company created additional water-quality violations in Crumpacker Arm during the 1980s. Moreover, streambed sediments in several parts of the Crooked Creek watershed were found to be contaminated with PCBs and pesticides such as DDT, dieldrin and chlordane (Bobo and Renn, 1980; Indiana Department of Environmental Management, [1986]).

An expanded treatment system at the former oil company, the remedial dredging of contaminated streambed sediments in Crumpacker Arm, and operational changes at the Westville sewage-treatment plant have helped to improve some aspects of the water quality in this local watershed (Indiana Department of Environmental Management, [1986], [1988]). During the IDEM's 1988-89 survey period, Crumpacker Arm, Forbes Ditch and Crooked Creek fully supported aquatic-life uses (Indiana Department of Environmental Management, [1990]).

Low dissolved oxygen and high ammonia concentrations sometimes impaired aquatic-life uses in Cedar Creek downstream of Lowell and Lake Dalecarlia in Lake County during the mid-1980s (Indiana Department of Environmental Management, [1988]).

Undesirably low dissolved oxygen concentrations in Cedar Creek also were documented during an IDNR fisheries survey (Robertson, 1971).

The town of Lowell, which treats its own wastewater in addition to wastewater from the town of Cedar Lake, recently has eliminated raw sewage bypasses into Cedar Creek and has constructed ammonia-removal facilities (Indiana Department of Environmental Management, [1990]). These improvements, plus the recent construction of a new wastewater-treatment facility at Lake Dalecarlia, should help alleviate water-quality problems in the Cedar Creek watershed. In the 1988-89 survey period, Cedar Creek fully supported aquatic-life uses (Indiana Department of Environmental Management, [1990]), indicating an improvement in local water quality since previous surveys.

Yellow River Basin

Although few water-quality problems have been documented on the upper Yellow River in the past 10 years (1978-87), frequent fish kills and other violations of aquatic-life criteria (appendices 6, 7) have occurred on the lower 25 miles of the river. Many water-quality problems on the Yellow River downstream of Plymouth have been attributed to sewage bypasses, combined sewer overflows, and inadequately treated effluents from the municipal wastewater-treatment facility and several major industries that discharge their wastes into the municipal sewer system.

High fecal coliform counts, high concentrations of ammonia and metals, and low concentrations of dissolved oxygen are among the water-quality problems that have been documented downstream of Plymouth (Michiana Area Council of Governments, 1978; Indiana Department of Environmental Management, [1988]). Effluents from several industries and the Plymouth wastewater-treatment plant have contained high oil and grease concentrations, high biochemical oxygen demand, low dissolved oxygen concentrations, occasionally high temperatures, and wide and rapid fluctuations in pH (Indiana Stream Pollution Control Board, 1984).

Although legal actions were taken against Plymouth and the industries during the 1980s for water-quality violations, the recent expansion of the Plymouth sewage-treatment plant, the elimination of eight bypass points, and the continued use of an industrial pretreatment program have alleviated some of the water-quality problems in the lower Yellow River (Indiana Department of Environmental Management, [1988], [1990]).

Eagle Creek, Craigmile Ditch, Wolf Creek, and other tributaries in the Yellow River Basin fully supported designated uses in a 1986-87 study (Indiana Department of Environmental Management, [1988]). In contrast, a portion of Hoffman Ditch, which receives discharge from the Lakeville wastewater-treatment plant in St. Joseph County, is designated as a limited-use stream because instream habitat, physical conditions, and stream flow are insufficient to support well-balanced aquatic communities.

Iroquois River Basin

Because no stream-quality stations currently are operating in the Iroquois River Basin, Indiana, inferences were made from data collected by the Illinois Environmental Protection Agency at two sites in eastern Iroquois County. The general location of these sites is apparent from figure 4.

The two monitoring sites in Illinois are located at the U.S. Geological Survey gaging stations on the Iroquois River at Iroquois, and on Sugar Creek at Milford. Appendix 7 summarizes selected physical and chemical parameters for these stations for the period 1978-87.

The Iroquois River, like the Kankakee and Yellow Rivers, is characterized by high iron and manganese concentrations which frequently exceed secondary maximum contaminant levels for public drinking-water supplies. (Water from the Iroquois River is not used for public supply.) Trace metals generally did not exceed secondary levels or primary standards during the period 1978-87, but occasionally high concentrations of lead have been reported at Iroquois, Illinois.

The Iroquois River, like the Kankakee and Yellow Rivers, frequently is turbid, but no reports of water-quality degradation from excessive sedimentation have been documented. Phosphorus concentrations occasionally exceed recommended limits for flowing waters, but nuisance algal growths have not been reported.

Although NPDES discharge permits occasionally have been violated at Rennsselaer and Foresman, the lower Iroquois River in Indiana fully supported aquatic-life uses in the late 1980s (Indiana Department of Environmental Management, [1988], [1990]). At Iroquois, Illinois, concentrations of ammonia and trace metals generally were below limits recommended for aquatic life, but iron concentrations commonly exceeded its criterion.

A water sample taken from the Iroquois River near Foresman, Indiana in early 1989 contained concentrations of two pesticides in excess of acceptable limits. In contrast, levels of two herbicides were below health advisory levels (U.S. Geological Survey, 1989).

A study in Illinois (Mitsch and others, 1979) showed that water quality was not as good in the Iroquois River near Chebanse as in the Kankakee River at Momence. Although the drainage areas above the two stations are similar in size, water-quality data for 1975-76 from the Iroquois River showed higher concentrations of total phosphorus, nitrates, and ammonia. Moreover, fecal coliform counts and total dissolved solids concentrations had higher maxima in the Iroquois River than in the Kankakee River. The finer-grained soils, lesser amounts of riparian vegetation, and limited water-storage capability in the Iroquois River watershed may account for some of these water-quality differences (Mitsch and others, 1979).

Sugar Creek, a major tributary of the Iroquois River, fully supported aquatic-life uses in Indiana during 1986-87 (Indiana Department of Environmental Management, [1988]). Data from the Milford, Illinois station, however, show that concentrations of iron and some metals occasionally exceed recommended criteria for aquatic life.

A few tributaries of the Iroquois River in Indiana have segments that in past years only partially supported aquatic-life uses. Low dissolved-oxygen and high ammonia concentrations were the most common problems in these tributary reaches, which are located downstream of municipal and industrial discharge points (see figure 29). Improved NPDES compliance at Morocco and the recent expansion of the treatment facility at Remington have helped reduce water-quality impairments for aquatic life in Beaver Creek and Carpenter Creek (Indiana Department of Environmental Management, [1988], [1990]). The proposed construction of a municipal sewage-treatment plant at Goodland should improve water quality in Hunter Ditch.

A portion of the ditch downstream from the Kentland sewage-treatment plant is designated as a limited-use stream because instream habitat, physical conditions, and stream flow are insufficient to support well-balanced aquatic communities. In nearby Morrison Ditch, aquatic-life uses have been impaired due to high ammonia concentrations in an industrial effluent (Indiana Department of Environmental Management, [1988], [1990]).

Recent improvements in the industry's treatment process have reduced ammonia concentrations in its effluent and are expected to alleviate aquatic-life impairments in the ditch. New sewers and a new treatment plant in Kentland are scheduled for completion in 1990 (Indiana Department of Environmental Management, [1990]).

Lakes

The Kankakee River Basin contains more than 9000 acres (14 square miles) of open water in natural lakes and reservoirs. Because of moderate to high productivity resulting from nutrient inputs from surrounding land uses, many lakes in the basin are vulnerable to accelerated *eutrophication*. Monitoring and management programs have been aimed largely at determining the extent of eutrophy and prescribing measures to control nutrient inputs from point and nonpoint sources. The major programs are identified below.

Sources of lake-quality data

In 1970 the Indiana State Board of Health began sampling public freshwater lakes and reservoirs for physical, chemical and biological data. The goal of the sampling, now coordinated by the IDEM, was to generate a database from which a classification system could be developed for comparing lake quality and establishing a priority system for lake management and restoration. The IDEM uses 10 trophic parameters to derive a composite numerical index scaled from 0 (least eutrophic) to 75 (most eutrophic), which in turn defines a generic four-tiered classification of lakes. The lakes are further grouped by morphometric and trophic similarity into seven major lake management categories. Appendix 5 lists 46 lakes and reservoirs in the Kankakee River Basin, 40 of which have been placed in the IDEM's Indiana Lake Classification System and Management Plan.

In the mid-1980s the IDEM resurveyed a subset of lakes in the Indiana Lake Classification System, including Cedar Lake and Lake of the Woods in the Kankakee River Basin. The primary purpose of this resurvey was to detect apparent lake-quality trends by comparing trophic index numbers determined first in the mid-1970s then later in the mid-1980s (Indiana Department of Environmental Management, [1988]).

The IDEM also samples fish tissue and sediments to assess the extent of contamination by toxic and bioconcentrating substances in lakes and reservoirs having high recreational use or a potential for contamination (Indiana Department of Environmental Management, [1988]). In the Kankakee River Basin, Cedar Lake and Lake of the Woods are part of this monitoring program.

Lake-quality management programs include the lake-enhancement program, administered by the IDNR Division of Soil Conservation, and the Indiana Clean Lakes Program, administered jointly by the IDEM and the Environmental Systems Application Center at Indiana University. The lake-enhancement program provides technical and financial help to control sediment input and associated nutrient problems in public access lakes, including Koontz Lake in the Kankakee River Basin. The Indiana Clean Lakes Program encourages participation at the local level to refine and implement plans outlined in the IDEM's Indiana Lake Classification System and Management Plan. In the Kankakee River Basin, 14 lakes were monitored in 1989 for nutrient and dissolved oxygen levels, pH, and clarity as part of the Indiana Clean Lakes Program.

Other state programs monitor lake quality for public health, recreational, or fisheries management purposes. The IDNR Division of Engineering samples water from lakes and reservoirs having state-operated public beaches, including Bass Lake, to determine violations of fecal coliform standards for swimming and wading. The IDNR Division of Fish and Wildlife conducts lake surveys in which physical, chemical and fish community data form the basis for fisheries management recommendations. The Division of Fish and Wildlife also conducts aquatic weed control and fish restoration projects to improve game fishing and enhance the recreational value of selected lakes. In the Kankakee River Basin, lake surveys or other fisheries projects have been conducted on J.C. Murphey Lake, Koontz Lake, Lake of the Woods, Riddles Lake, and Bass Lake.

On the federal level, the U.S. Environmental Protection Agency (USEPA) conducted a National Eutrophication Survey in 1973 and 1974 in which 27 Indiana lakes and reservoirs were seasonally sampled. In 1977 Purdue University resurveyed 15 of these lakes to determine changes in trophic condition. In the Kankakee River Basin, only Bass Lake was surveyed (U.S. Environmental Protection Agency, 1976a; Spacie and Bell, 1980).

The USEPA and the State of Indiana (IDNR) cooperatively administer the federal Clean Lakes Program, which provides funds for studies and management activities on publicly-owned freshwater lakes. In 1979 the Environmental Systems Application Center at Indiana University initiated a restoration feasibility study on Cedar Lake which has since come under the federal Clean Lakes Program (Echelberger and Jones, 1979, 1984).

Assessment of lake quality

The 40 major lakes and reservoirs of the Kankakee River Basin which are included in the Indiana Lake Classification System range widely in water-quality characteristics, lake *morphometry*, and management needs. Two-thirds of the lakes and reservoirs that are assigned a trophic class are of either low (Class I) or moderate (Class II) eutrophy and rarely have water quality problems that impair attainable lake uses. About 20 percent of lakes in the basin are highly productive (Class III). These lakes usually support periodic algal blooms and growth of aquatic weeds which impair one or more lake uses.

Four of the lakes in the basin are assigned a Class IV status in the IDEM's Lake Classification System. Class IV lakes have low nutrient profiles, but morphometric characteristics, advanced stages of *senescence* or dense growths of *macrophytes* contribute to an intermediate trophic index. The water quality is generally good and is characterized by high visual clarity, dissolved oxygen to the lake bottom, low *plankton* counts, and rapid nutrient uptake by macrophytes. Attainable uses of Class IV lakes include hunting, fishing, trapping, and wildlife habitat.

Although appendix 5 lists only four Class IV lakes, smaller potential Class IV lakes may exist in the basin. Remnant and oxbow lakes are scattered along the middle and lower reaches of the mainstem Kankakee River and constitute a distinctive feature of the basin. Many of the oxbows, however, are only temporarily or seasonally flooded, and therefore may not be mapped as lakes.

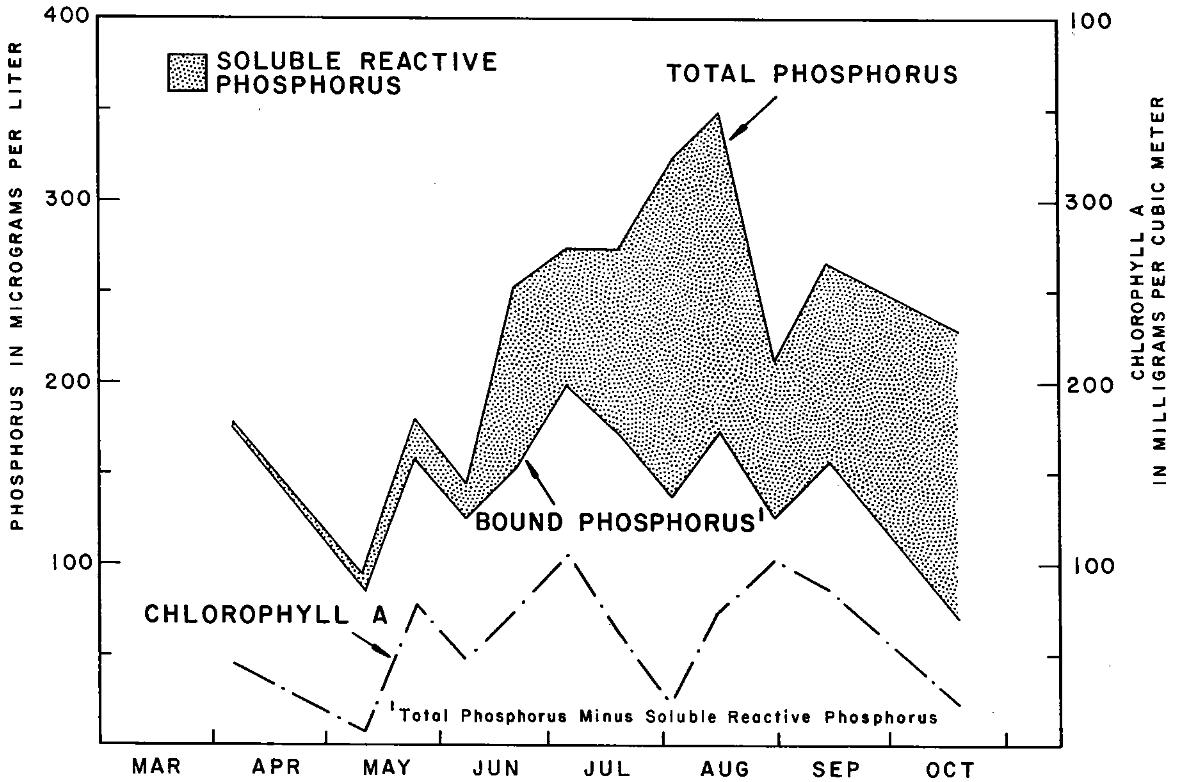


Figure 34. Phosphorus components in averaged samples for Cedar Lake, and the relationship of averaged chlorophyll *a* and bound phosphorus
(Adapted from Echelberger and Jones, 1984)

Mainstem Kankakee River Basin

The mainstem Kankakee River Basin features several lakes of high water quality. Saugany Lake in LaPorte County has unusually high visual clarity (secchi disc depth of nearly 32 feet) and the lowest trophic index (1) of any lake in the Indiana lake classification system. Other high-quality Class I lakes in the basin include Fishtrap, Lower Fish, Pine, and Stone Lakes.

Koontz Lake in Starke County is an intermediate-quality lake characterized by a small surface area and shallow mean depth. In recent years the lake has exhibited symptoms of accelerated eutrophication such as 1) large sediment inputs, especially during peak run off; 2) consequential shoaling in the lake, especially near the inlet of the principal tributary; 3) resuspension of sediments and associated nutrients from boating activity; 4) major expansion of weed beds impairing navigation; and 5) decline in the quality of sport fishing (Earth Plan Consultants, 1987).

In the fall of 1987 the General Assembly appropriated funds for a project on Lawrence Pontius Ditch, a tributary of Koontz Lake, to reduce sediment and nutrient input. The project, which is being coordinated by the IDNR, Division of Soil Conservation includes grade stabilization structures, bank stabilization, a sediment trap, and construction of an artificial wetland to filter nutrients. As of early 1990, the project was partially complete. A lake-enhancement project also is underway at Lake of the Woods in Marshall County.

Cedar Lake in Lake County, one of the most productive natural lakes in the Kankakee River Basin, has experienced deteriorating water quality since the 1940s. Shoreline development and associated wastewater discharges have contributed to large nutrient loadings in the lake.

In 1979 a study was initiated in response to requests by local citizens concerned about Cedar Lake's deteriorating quality (Echelberger and Jones, 1979).

During this restoration feasibility study, it was found that the lake was nitrogen-limited and that high phosphorus concentrations in the water were being maintained by release from sediments. Total phosphorus concentrations were as high as 350 ug/L (micrograms per liter) during late summer (figure 34) compared to 10-50 ug/L for unpolluted lakes. The relationship between *phytoplankton* abundance and levels of non-soluble phosphorus also is apparent in figure 34. The consequences of nutrient enrichment were nuisance algal blooms dominated by blue-green species and a fish community dominated by carp and other bottom feeders. In addition, sediment sampling in 1987 by the IDEM revealed that heptachlor concentrations were well above background levels (Indiana Department of Environmental Management, [1988]), but as yet there is no documentation of water-use impairment from any priority pollutants.

The 1979 study, now administered under the federal Clean Lakes Program, recommended a restoration program that includes a complete fisheries renovation, modification of the lake's outlet structure to prevent rough fish from re-entering, a one-time alum treatment to inactivate nutrients, and a ban on live-bait fishing (Echelberger and Jones, 1984). As of 1990, additional water-quality data is being collected through a state-funded effort.

Yellow River Basin

Myers Lake in Marshall County is a small but moderately deep natural lake. Its high water quality is attributable to high visual clarity, relatively low phosphorus, and lake morphometry. Myers Lake has also been noted for thermally stable vertical zones and for highly oxygenated conditions in intermediate depths (Eberly, 1959).

Bass Lake in Starke County has the largest surface area (1400 acres) of any natural lake in the Kankakee River Basin. Because Bass Lake is quite shallow, it lacks a *thermocline* and is naturally aerated throughout the water column. A state-managed beach provides recreational opportunities such as swimming and wading. Analysis of water samples collected by the IDNR Division of Engineering revealed that there were no fecal coliform violations for whole-body contact recreation within the last three years (1987-1989).

In a 1973-1974 survey by the U.S. Environmental Protection Agency (1976a), Bass Lake was determined to be eutrophic and phosphorus-limited. A Purdue University survey in 1977 (Spacie and Bell, 1980) revealed that Bass Lake remained trophically stable, and that its phosphorus loading was the lowest of 15 Indiana lakes examined. The phosphate ban instituted in 1972 may have helped reduce phosphate loading below levels thought to cause eutrophy.

Lake of the Woods in Marshall County is a moderately productive but trophically stable lake (Indiana Department of Environmental Management, [1988]). Although sediment samples collected by the IDEM contained nearly three times the phosphorus concentration considered acceptable for the prevention of nuisance algal blooms, the actual effects on Lake of the Woods have not yet been determined.

Gilbert Lake in Marshall County is a small, very productive lake which has been assigned the highest trophic index possible (75). The high index is due largely to the water's very low clarity (secchi disc depth of 1 foot) and a phosphorus concentration which is more than eight times the recommended limit for nonflowing water. Fish kills and impairment of most uses were documented in the mid-1980s and were attributed to heavy weed and algal growth. Gilbert Lake has no tributary streams and receives runoff only from the surrounding terrain and effluent from one small wastewater-treatment plant (Indiana Department of Environmental Management, [1988]).

Iroquois River Basin

J.C. Murphey Lake in Newton County is a moderately productive impoundment in the Willow Slough State Fish and Wildlife Area. Several fish eradication and selective restocking projects have been conducted at this lake since the 1960s to improve game fishing. The most recent restoration project, completed in 1989, is expected to produce an excellent fishery by the early 1990s.

Ringneck Lake in the Jasper-Pulaski State Fish and Wildlife Area is the only other major impoundment in the Iroquois River Basin. The shallow lake has a small drainage area of less than 2 square miles and has not been placed in the IDEM's Indiana Lake Classification System.

GROUND-WATER HYDROLOGY

Ground-water supplies are obtained from *aquifers*, or subsurface formations of rock saturated with water. The hydrologic characteristics of aquifers and natural chemistry of ground water determine the availability and suitability of regional ground-water resources for specific uses.

GROUND-WATER RESOURCES

Ground water is the part of precipitation which enters the ground and continues to move downward through openings in soil and bedrock until it reaches the *water table* (figure 35). The water table is the elevation below which all openings in the rock or soil are filled with water. Water entering the saturated zone is called *recharge*.

In a general way, the configuration of the water table approximates the overlying topography (figure 35). At a depression where the land surface intersects the water table, water is discharged from the ground-water system to become part of the surface-water system.

The interaction between ground water and surface water can moderate seasonal water-level fluctuations in both of these systems. During dry periods, ground-water discharge can help maintain water levels in streams. Conversely, surface water can recharge ground water through soils saturated by flooding or through streambeds during periods when the water table falls below the elevation of the water surface in a stream.

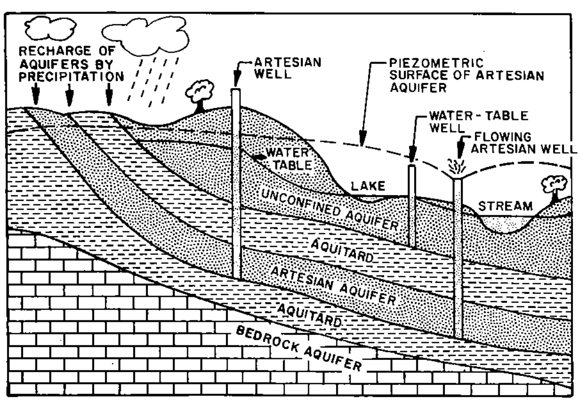


Figure 35. Aquifer types and ground-water movement

Porosity and *permeability* are the most important hydraulic properties affecting ground-water availability. Porosity is the amount of open space in rock and soil. Permeability is the degree to which pores are connected and determines how quickly water moves through the material.

In bedrock, pores occur as fractures, solution openings, and openings between grains composing the rock. In unconsolidated deposits, all of the pores are intergranular, but fine-grained deposits such as clays or silts may have secondary porosity in the form of fractures.

The size and sorting of material determines the amount and interconnection of intergranular pores. Sand and gravel deposits have a high proportion of pore space and high permeability, whereas fine-grained or clay-rich deposits have a greater proportion of pores, but a lower degree of permeability.

Aquifers have high porosity and permeability so that they may absorb, store and transmit water in usable quantities. Materials with low permeability, called *aquitards*, restrict ground-water movement. An aquitard overlying an aquifer may limit the recharge to the aquifer but may also protect an aquifer from surface contamination.

Where an aquitard overlies an aquifer, the water in the aquifer may be under hydrostatic pressure. The aquifer is said to be confined or *artesian* because the aquitard prevents or restricts upward movement of water from the aquifer. In an artesian well, the water level will rise to an elevation higher than the elevation of the top of the aquifer (figure 35). In a flowing artesian well, the water level in the well rises above the land surface. The level of water in wells in a confined aquifer is known as the potentiometric or *piezometric surface* (figure 35).

As a well discharges water from an aquifer, the water level is lowered around the well. This depression in the water level, called drawdown, causes ground water around the well to flow toward the well to compensate for water pumped from the aquifer. A greater pumping rate causes a greater depression in the water level and induces recharge to the aquifer; however, the recharge rate may be limited by the permeability of the aquifer and surrounding formations.

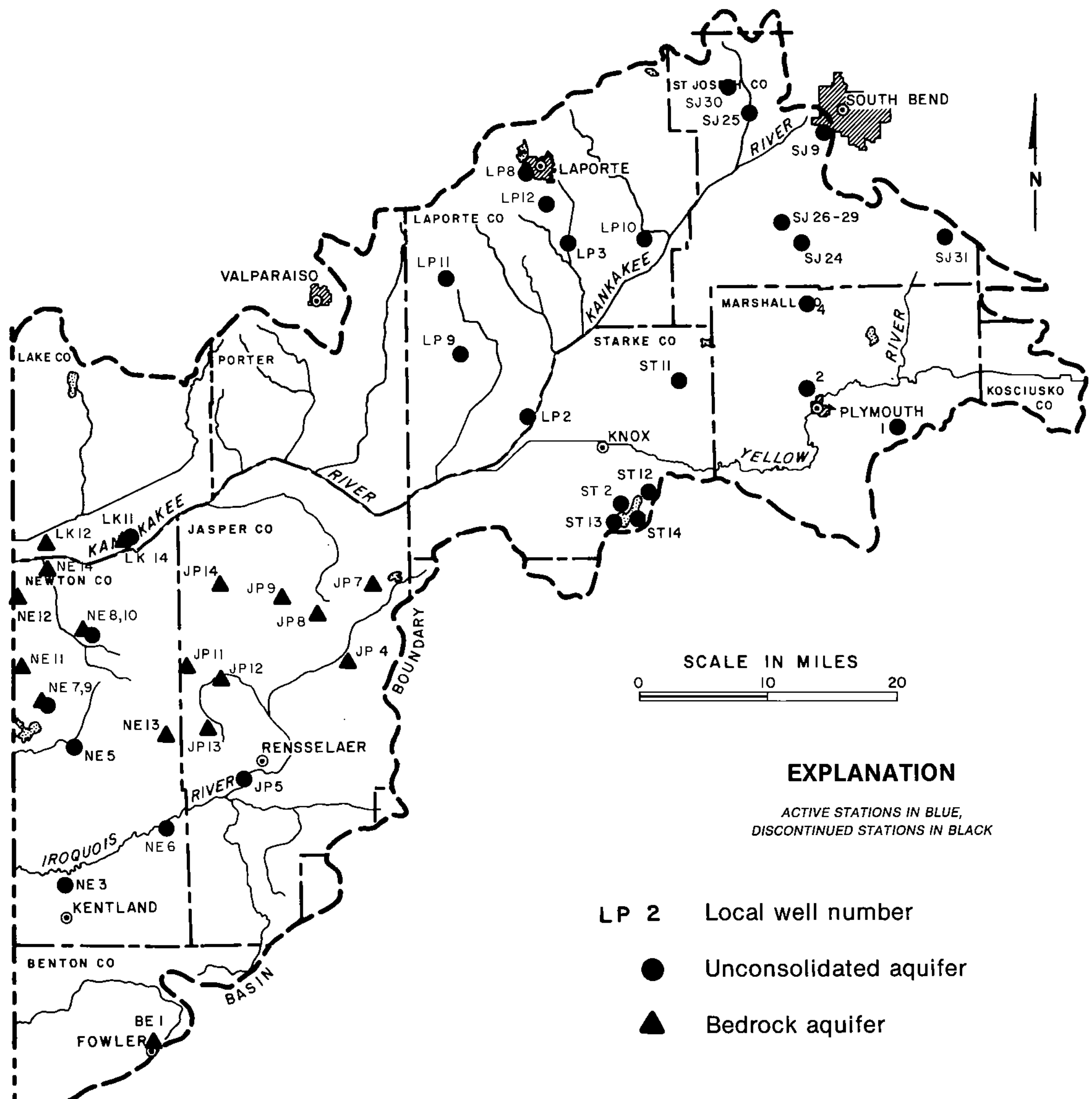


Figure 36. Location of observation wells

Ground-water levels

The ground-water level within an aquifer constantly fluctuates in response to rainfall, evapotranspiration, ground-water movement (including recharge and discharge), and ground-water pumpage. The U.S. Geological Survey, in cooperation with the Indiana Department of Natural Resources, has maintained records of ground-water levels in the Kankakee River Basin since 1935. By 1950 the observation well network within the basin included 5 wells. By late 1989 there were 25 active observation wells and 23 wells which had been discontinued from service (table 19, figure 36).

Water level is recorded automatically in each of the active observation wells. Daily records of ground-water levels are collected periodically by the U.S. Geological Survey and published annually in water-resource data reports.

Two wells in the Kankakee River Basin are equipped with special devices for transmitting encoded data via an earth-orbiting satellite. Water-level data from these wells can be obtained immediately to allow monitoring of pumpage-induced drawdown.

Table 19. Observation wells

Well number: U.S. Geological Survey county code and well number. Well locations are shown in figure 36.
Period of record: Refers to calendar year, whether or not data encompasses entire year.
Aquifer system: VM, Valparaiso Moraine; VOA, Valparaiso Outwash Apron; ES, Eolian Sands; MM, Maxinkuckee; KK, Kankakee; IQB, Iroquois Basin; NAP, Nappanee; SD, Silurian/Devonian carbonates; +SD, Silurian/Devonian carbonates overlain by Devonian shale; M1, Mississippian Borden Group.
Aquifer type: LS, limestone; DOL, dolomite; SG, sand and gravel; S, sand; G, gravel; Drift, undifferentiated glacial deposit.
Aquifer classification: A, affected by pumpage; UA, unaffected; SP, special purpose.

Status	County	Well no.	Period of record	Aquifer system	Aquifer type	Well diameter (in.)	Well depth (ft.)	Aquifer class
Active	Jasper	JP4	1956-	SD	LS	16	300	A
		7	1967-	+SD	LS	6	130	A
		8	1978-	SD	LS	12	310	A
		9	1978-	SD	LS	18	260	A
		11	1981-	+SD	LS	16	630	A
		12	1982-	+SD	LS	5	150	A
		13	1982-	+SD	DOL	5	150	A
		14	1989-	SD	LS	6	97	A
	Lake	LK12	1967-	SD	DOL	6	82	A
		14	1989-	SD	LS	6	107	A
	LaPorte	LP8	1976-	VM	SG	3	22	SP
		9	1976-	KK	S	6	32	A
		10	1980-	VOA	SG	6	104	A
		11	1981-	VOA	SG	6	100	A
		12	1981-	VM	SG	6	77	A
	Newton	NE6	1967-	IQB	SG	6	80	A
		7	1976-	SD	LS	6	150	A
		8	1976-	SD	LS	6	150	A
		9	1978-	KK	S	2	45	UA
		10	1978-	KK	S	2	45	UA
		11	1981-	SD	LS	5	150	A
		14	1985-	SD	DOL	6	150	A
	St. Joseph	SJ30	1980-	KK	S	5	87	A
		31	1986-	NAP	SG	6	109	UA
	Starke	ST2	1935-	ES	G	6	85	SP
Discontinued	*Benton*	*BE1*	*1944-58*	*M1*	*LS*	*10*	*114*	*A*
	Jasper	*JP5*	*1955-56*	*IQB*	*SG*	*16*	*47*	*A*
	Lake	*LK11*	*1956-81*	*KK*	*SG*	*4*	*18*	*UA*
	LaPorte	*LP2*	*1942-66*	*VOA*	*SG*	*6*	*116*	*SP*
		3	*1955-69*	*VOA*	*SG*	*7.5*	*89*	*A*
	Marshall	*1*	*1948-66*	*NAP*	*Drift*	*12*	*18*	*UA*
		2	*1956-71*	*MM*	*SG*	*16*	*127*	*A*
		4	*1957-71*	*MM*	*SG*	*6*	*141*	*A*
	Newton	*NE3*	*1954-71*	*IQB*	*SG*	*10*	*103*	*A*
		5	*1956-74*	*KK*	*SG*	*16*	*49*	*A*
		12	*1981-85*	*SD*	*LS*	*5*	*150*	*A*
		13	*1982-85*	*SD*	*DOL*	*5*	*130*	*A*
	St. Joseph	*SJ9*	*1945-71*	*KK*	*SG*	*8*	*82*	*UA*
		24	*1957-70*	*MM*	*SG*	*12*	*92*	*UA*
		25	*1959-80*	*KK*	*SG*	*6*	*41*	*UA*
		26	*1975-82*	*MM*	*SG*	*1.5*	*25*	*SP*
		27	*1975-82*	*MM*	*SG*	*1.5*	*16*	*SP*
		28	*1975-82*	*MM*	*SG*	*1.5*	*25*	*SP*
		29	*1975-82*	*MM*	*SG*	*1.5*	*14*	*SP*
	Starke	*ST11*	*1948-70*	*ES*	*G*	*1*	*67*	*UA*
		12	*1976-86*	*ES*	*S*	*2*	*17*	*SP*
		13	*1976-86*	*ES*	*S*	*3*	*13*	*SP*
		14	*1976-86*	*ES*	*S*	*2*	*24*	*SP*

Three active observation wells in the basin record natural water-level fluctuations in unconsolidated deposits. Twenty wells record ground-water levels in areas affected by high-capacity pumpage, mostly for irrigation. There are no unaffected observation wells completed in bedrock in the Kankakee River Basin.

Figure 37a shows the hydrograph of observation well Newton 9, which is completed in a shallow *unconfined* aquifer. Although there is extensive irrigation in the area, the water level in Newton 9 is classified by the Division of Water as unaffected by nearby pumpage. The annual fluctuation shown in figure 37a ranges from 2 to 6 feet. The difference between the maximum high and low for the period 1978-1988 is 14.2 feet.

Figure 37b shows the hydrograph of Cass 3. This observation well is located outside of the Kankakee River Basin, but is completed in the same Silurian and Devonian dolomitic limestone that is used extensively for irrigation in Jasper and Newton Counties. The water level in Cass 3 is unaffected by high-capacity withdrawal. The range of the seasonal fluctuation shown in the hydrograph of Cass 3 is 1 to 3 feet, and the maximum fluctuation over the period 1967-1988 is 5.1 feet.

Figure 37c shows the hydrograph for Jasper 13, which records the piezometric water-level change in a bedrock aquifer affected by nearby pumpage. The Jasper 13 hydrograph shows that irrigation pumpage induces a decline of 15 to 25 feet in the piezometric level during the irrigation season, May through September. The difference between the minimum and maximum water levels in Jasper 13 is 39.3 feet for the period 1982-1988.

When irrigation ceases, typically in September, the ground-water level in Jasper 13 begins to rise as recharge replaces water removed from the aquifer. Water levels reach their seasonal peaks during March through May of the following year.

In general, the effect of irrigation on unconfined aquifers is not as great as the effect on the Silurian and Devonian carbonate aquifer. Observation wells LaPorte 9 and St. Joseph 30 monitor the water table level near irrigation wells. These wells have recorded an annual water-table fluctuation of 2 to 7 feet during the period 1983-87 (appendix 8). The difference between the recorded maximum and minimum water-table levels in both wells is approximately 7 feet.

The remaining observation wells in the Kankakee River Basin have a special-purpose classification. The active and discontinued special-purpose observation

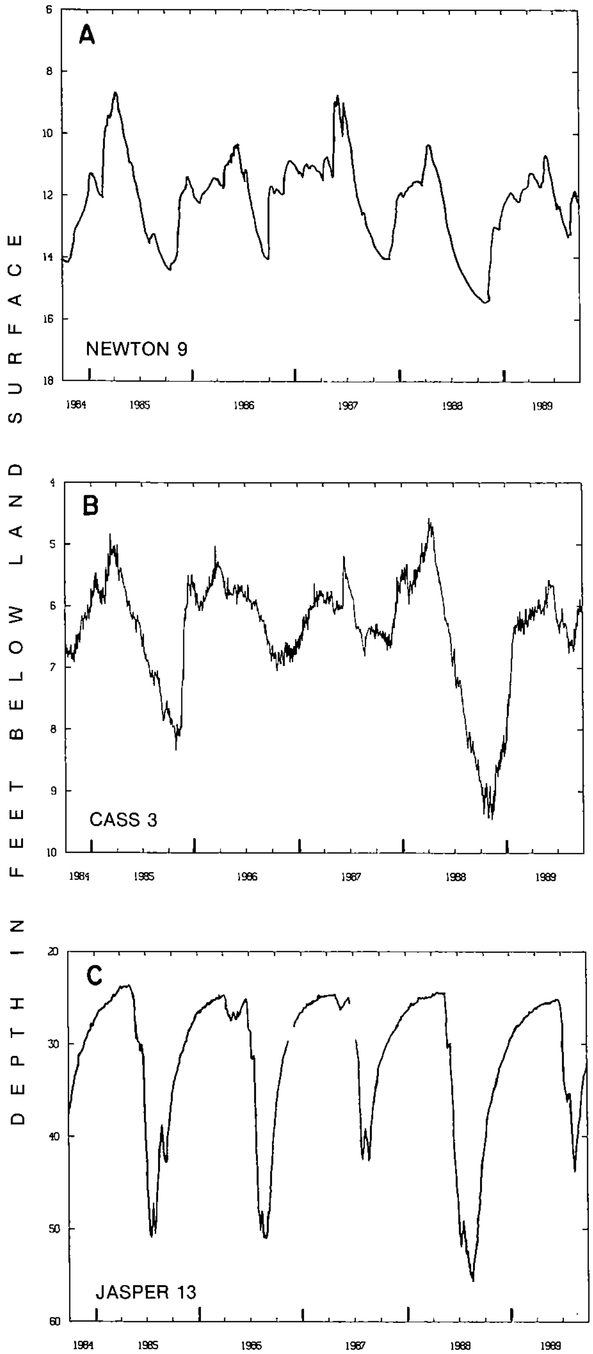


Figure 37. Water-level fluctuations in observation wells affected or unaffected by nearby pumpage

wells in the Kankakee River floodplain and near Pine and Bass Lakes were intended to monitor hydrologic interactions between surface-water and ground-water systems. Discontinued special-purpose observation wells in St. Joseph County were intended to monitor the effect of Worster Lake (Potato Creek Reservoir) on the surrounding water table.

Detailed analysis of the data from special-purpose wells is not available and was not attempted for this study. However, hydrographs for observation wells near Bass Lake were plotted in figure 38 to provide general information on local ground-water conditions.

Although the discontinuity of interbedded sand and clay deposits underlying Bass Lake make it difficult to determine the nature of the lake and ground-water interaction, ground-water levels near the lake indicate that the water table slopes to the northwest. As figure 38 shows, water-table levels in observation wells Starke 12 and 14 located east of the lake are consistently higher than lake level, whereas water levels west of the lake in Starke 13 are consistently lower than lake level. Because water flows from higher to lower elevations, the water levels in shallow observation wells near Bass Lake show a potential movement of water following the regional trend from the basin divide northwestward toward the Yellow River.

Piezometric surface

The piezometric surface map for the Kankakee River Basin (plate 1) depicts the elevation to which water levels will rise in wells. The map is created by plotting elevations of the *static water level* and contouring lines of equal elevation. Static water levels used to develop the piezometric surface map are from wells completed at various depths and under confined and unconfined conditions.

The piezometric level is a measure of the pressure of water in an aquifer. Water in a water-table aquifer is at atmospheric pressure, whereas water in a confined aquifer is under hydrostatic pressure and will rise in a well above the top of the water-bearing formation.

The piezometric map may be used to calculate expected depths to water in a well completed in a specific aquifer, but cannot be used to determine recommended depths of wells. The appropriate well depth is determined by the local geologic conditions.

The piezometric surface map also may be used to define the probable regional flow path of contaminants or to identify areas of ground-water recharge and discharge. In general, the composite piezometric surface follows overlying land-surface topography and intersects the land surface at major streams. The expected

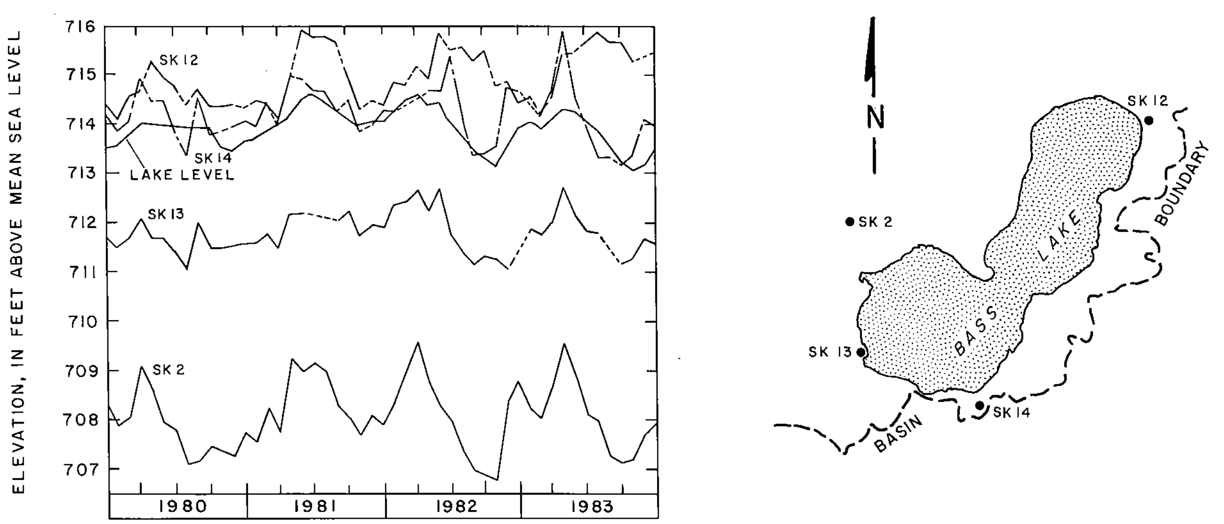


Figure 38. Water-level fluctuations in observation wells near Bass Lake

flow path is downslope or perpendicular to lines of equal elevation of the piezometric surface. In general, ground water flows from areas of recharge toward areas of discharge.

In the Kankakee River Basin, ground-water levels range from an elevation of 825 feet m.s.l. at the basin divide in St. Joseph County to a low of about 625 feet m.s.l. where the Kankakee River enters Illinois. This range is a function of the basin topography and the ground-water flow from areas of recharge to areas of ground-water discharge. Regional ground-water flow is toward the Kankakee River and its major tributaries.

The surficial aquifers in the low-lying center of the basin have a very high water table. The ground-water level in the Kankakee floodplain is often less than 10 feet below land surface.

Until the late 1800s, the Kankakee River floodplain was a large marsh with water above the ground surface most of the year. Extensive ditching of the floodplain provided an outlet for water in the marsh and resulted in some dewatering of the surficial sand deposits and more rapid runoff (Rosenshein and Hunn, 1968a).

AQUIFER SYSTEMS

The ground-water resources of the Kankakee River Basin are mapped and described as regional aquifer systems (plate 2). Lack of data and complexity of the glacial geology preclude detailed aquifer mapping.

Ground-water supplies in the Kankakee River Basin are obtained from unconsolidated and bedrock aquifer systems. Ten unconsolidated aquifer systems and one subsystem are defined according to hydrologic characteristics of the deposits and their environments of deposition. Seven bedrock aquifer systems are defined on the basis of hydrologic and lithologic characteristics; however, not all of the bedrock formations are productive aquifers.

Unconsolidated aquifer systems

Unconsolidated aquifer systems in the Kankakee River Basin are glacial and eolian deposits formed in various environments and at different times. Unconsolidated aquifer systems have gradational boundaries and individual aquifers may extend across the boundaries of aquifer systems.

The most productive unconsolidated formations are outwash deposits of the Kankakee, St. Joseph and Tributary Valley, and Valparaiso Outwash Apron Aquifer Systems. As figure 39 shows, thick sands and gravels predominate in these systems.

The least productive unconsolidated systems are the clayey tills of the Iroquois Moraine Aquifer System. Water-bearing sand and gravel deposits in this system generally are thin and discontinuous.

The following discussion of unconsolidated aquifer systems begins in the northeast portion of the Kankakee River Basin and progresses westward and southward to the Iroquois River Basin. The locations of aquifer systems are shown in plate 2.

Nappanee Aquifer System

Wisconsinan glacial lobes deposited materials that form an elevated till plain in the eastern part of the Kankakee River Basin. This till plain with its *intratill* sand and gravel aquifers forms the Nappanee Aquifer System.

This aquifer system covers much of Marshall County (plate 2) and extends into the St. Joseph River Basin. The aquifer system grades into deposits of the Maxinkuckee Moraine Aquifer System to the west.

The Nappanee Aquifer System is characterized by surficial till, in places as much as 90 feet thick, which overlies variably thin, coarse sand and fine gravel lenses interbedded with thin layers of clay. Individual aquifers, which typically range from 3 to 10 feet thick, seldom cover more than 1 or 2 square miles. Locally, sand and gravel units may thicken to 30 feet, and in general are thickest to the west where they grade into deposits of the Maxinkuckee Moraine.

Aquifers in the Kankakee River Basin portion of the Nappanee Aquifer System commonly occur at an elevation of 720 to 740 feet m.s.l.

The Nappanee Aquifer System yields from 5 to 50 gpm to domestic wells, and may yield 50 to 600 gpm to properly constructed, large-diameter wells (table 20).

Maxinkuckee Moraine Aquifer System

The Maxinkuckee Moraine was deposited at the eastward terminus of the Lake Michigan Lobe and the western edge of Saginaw Lobe (see figure 12). The

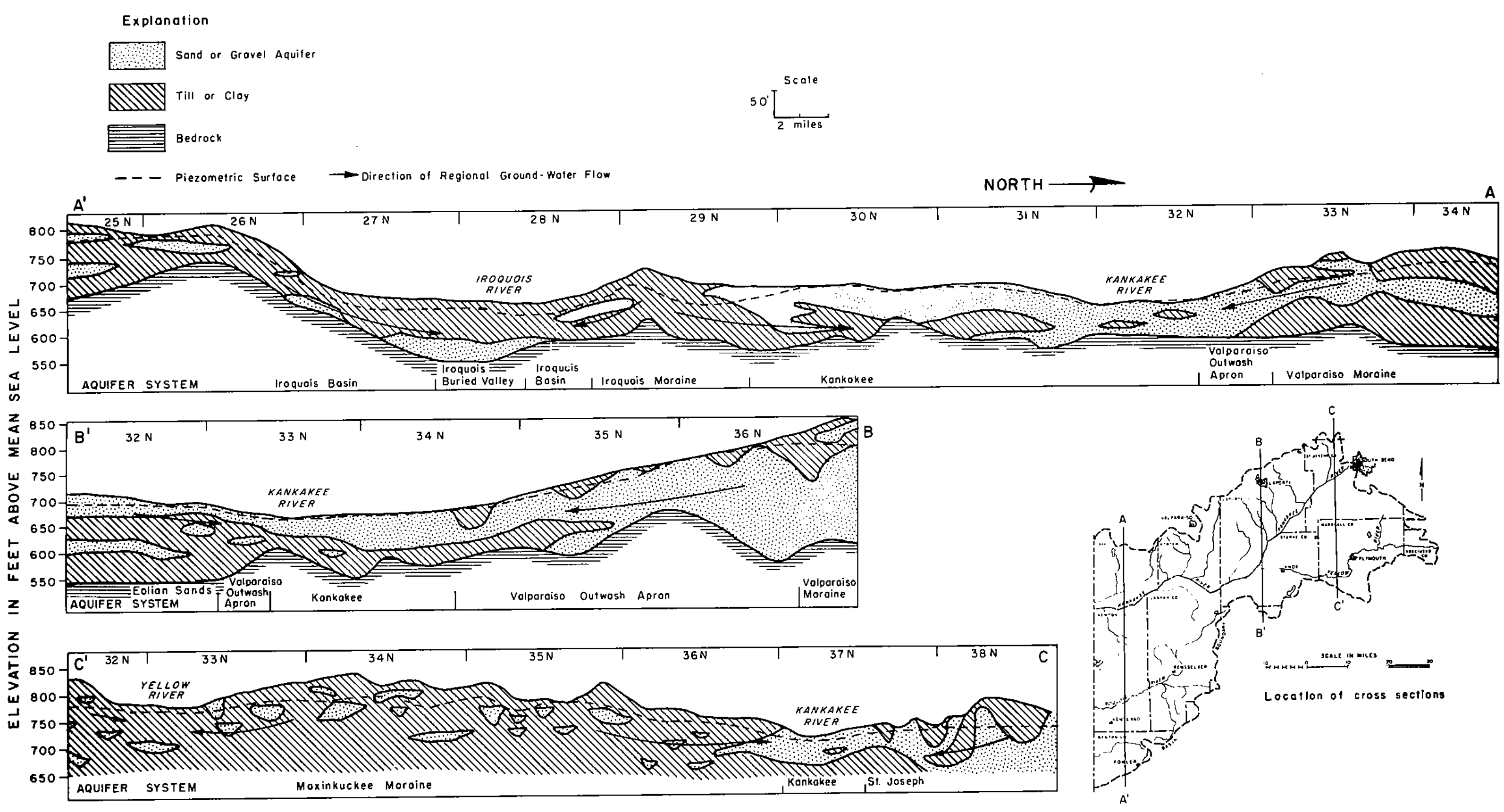


Figure 39. Generalized cross section of unconsolidated aquifer systems

Table 20. Hydrologic characteristics of unconsolidated aquifer systems

Aquifer system	Range of aquifer thickness (ft)	Common aquifer thickness (ft)	Range of pumping rates (gpm)		Expected high-capacity yield (gpm)	Hydrologic condition
			Domestic	High-capacity		
Nappanee	3 - 30	3 - 10	5 - 50	50 - 1000	50 - 600	Confined
Maxinkuckee Moraine	3 - 35	5 - 20	4 - 80	100 - 1400	100 - 600	Confined, Unconfined
Hilltop	10 - 100+	60	10 - 15	25 - 250	25 - 150	Confined, Unconfined
St. Joseph and Tributary Valleys	10 - 100+	10 - 60	8 - 60	500 - 1500	500 - 1000	Unconfined, Confined
Valparaiso Moraine	18 - 100+	40	10 - 60	100 - 800	100 - 600	Confined, Unconfined
Valparaiso Outwash Apron	10 - 100+	50	15 - 60	100 - 1100	150 - 600	Unconfined
Kankakee	20 - 150	30	15 - 50	100 - 1500	100 - 1200	Unconfined
Eolian Sands	4 - 72	10 - 30	10 - 50	100 - 1200	100 - 600	Confined, Unconfined
Iroquois Moraine	3 - 25	3	4 - 10	NA	0 - 50	Confined
Iroquois Basin	2 - 3	3	4 - 25	10 - 400	10 - 100	Confined, Unconfined
Iroquois Buried Valley Subsystem	3 - 40	5 - 20	10 - 40	50 - 500	100 - 400	Confined

combined influence of these glaciers left a complex interbedded deposit of till and outwash.

The extent of the Maxinkuckee Moraine Aquifer System follows the trend of the Maxinkuckee Moraine from southwest of South Bend to Lake Maxinkuckee and into the Tippecanoe River Basin. The eastern border of the moraine grades into the Nappanee Aquifer System. To the west, the deposits grade into the Kankakee Aquifer System and the Eolian Sands Aquifer System (plate 2).

The Maxinkuckee Moraine Aquifer System, the most complicated aquifer system in the Kankakee River Basin, consists of a complex mixture of outwash sand and gravel, eolian sand, and till. Permeable materials consist of locally thick, coarse-grained, surficial sand and gravel deposits and intratill lenses of sand or sandy gravel.

The coarse-grained deposits are commonly outwash which occur as *alluvial fans* on the surface and buried intratill aquifers within the moraine. The surficial aquifers were probably deposited in an ice-contact or ice-marginal environment where coarse sediments accumulated in *kames* and alluvial fans. Where they occur at relatively low elevations, the surficial aquifers may be saturated and produce significant volumes of water.

Although relatively thick surficial deposits of sand and gravel may be productive aquifers, most wells in the Maxinkuckee Moraine Aquifer System are completed in thin intratill sand and gravel lenses. Intratill aquifer thickness ranges from 3 to 35 feet, and deep wells may penetrate several intratill lenses.

Well depths in the Maxinkuckee Moraine Aquifer System range from 26 to 273 feet; however, most wells are 50 to 150 feet deep. Wells less than 40 feet deep typically are completed in surficial sand and gravel deposits.

Aquifer elevations generally range from 660 to 790 feet m.s.l. Static water levels range from 0 to 90 feet deep, but in most areas are 10 to 50 feet deep.

Domestic wells may produce 4 to 80 gpm, although yields of 10 to 25 gpm are most common. High-capacity wells may produce up to 1400 gpm, but maximum expected yields are 100 to 600 gpm (table 20).

Hilltop Aquifer System

The Hilltop Aquifer System is located in a small area of St. Joseph County southeast of South Bend (plate 2). The system is a thick outwash fan of sand and gravel containing a few interbedded clay lenses and locally thin to moderately thick surficial till deposits. Surficial sand and gravel deposits in excess of 100 feet thick are commonly encountered. In contrast to the adjoining till-dominated Nappanee Aquifer System, the Hilltop Aquifer is comprised primarily of sand and gravel.

Static water levels are relatively deep in the Hilltop Aquifer System, and range from 40 to 60 feet below ground surface.

Domestic wells usually yield 10 to 15 gpm. In most areas of the Hilltop system, large-diameter wells can yield 25 to 150 gpm (table 20).

St. Joseph and Tributary Valley Aquifer System

The St. Joseph Tributary Valley Aquifer System consists of thick deposits of outwash sand and gravel in the major tributary valleys of the St. Joseph River. Large meltwater rivers sorted and deposited thick beds of coarse-grained sand and gravel.

In the Kankakee River Basin, the aquifer system is located in St Joseph and Kosciusko Counties (plate 2). In St. Joseph County, the aquifer system is interbedded with the outwash deposits of the Kankakee Aquifer System. In Kosciusko County, it is bordered by the Nappanee Aquifer System, which is primarily an intratill system.

Sand and gravel thickness of the St. Joseph Tributary Valley Aquifer System increases toward the southeast. Sand and gravel deposits in this system are as much as 129 feet thick, but are commonly from 10 to 60 feet thick. The aquifer texture ranges from very fine-grained or muddy sand to gravel.

Clay layers within the outwash are thin or absent in St. Joseph County, but are as much as 50 feet thick in Kosciusko County. Most wells in Kosciusko County pass through two sand and gravel deposits which are separated by thick clays.

Shallow well depths of 40 to 90 feet are common in this system due to the presence of thick, near-surface sands and gravels. Well depths range from 30 to 145 feet.

Shallow aquifers range in elevation from 775 to 855 feet m.s.l. Static water levels range from 4 to 70 feet deep, but primarily are between 10 and 30 feet deep.

Although large-diameter well yields as high as 1500 gpm have been reported, yields of 500 to 1000 gpm are expected in the Kankakee River Basin portion of this system. Domestic wells produce from 8 to 60 gpm (table 20).

Valparaiso Moraine Aquifer System

The Valparaiso Moraine Aquifer System lies beneath the crest of the moraine and extends from the Illinois state line to Hudson Lake (plate 2). Although the glacial environment was similar, there are differences in the glacial deposits which comprise the Valparaiso Moraine east and west of Valparaiso.

East of Valparaiso the moraine is composed of a thick outwash apron formed by coalesced stream deposits capped by till. The thick outwash core of the moraine forms a continuous aquifer.

West of Valparaiso, the meltwater stream deposits within the moraine are discrete and separated by till. The intratill channel-shaped sands form many discrete aquifers.

Although isolated sand lenses occur at various elevations within the moraine east of Valparaiso, the primary aquifer consists of widespread fine- to medium-grained sand and fine-grained gravel deposited in an outwash fan. Within the Valparaiso Moraine Aquifer System, the outwash is buried beneath the till cap and grades into the unconfined Valparaiso Outwash Apron Aquifer System to the south (figure 39). In portions of Lake and Porter Counties, outwash channels filled with sand and gravel occur at elevations between 670 and 775 feet m.s.l.

The outwash thickness ranges from 18 feet in the outwash apron near Lomax to as much as 136 feet within the moraine near LaPorte. Average thickness of the aquifer is 40 feet.

In general, deep static water levels of 25 to 80 feet are expected in this system. Because of the deep static water levels, the saturated thickness ranges from 20 to 60 feet. Thickness of the till cap ranges from 15 to as much as 72 feet.

Production from domestic wells typically is between 10 to 20 gpm, although yields up to 60 gpm have been reported. High-capacity wells yield 100 gpm to more than 600 gpm (table 20).

Valparaiso Outwash Apron Aquifer System

This aquifer system is the wedge of outwash sediments forming the southern slope of the Valparaiso Moraine. The deposits are continuous with the outwash within the Valparaiso Moraine and overlap the till in the Eolian Sands Aquifer System. The outwash apron consists of interbedded sand and fine-grained gravel, and has clay lenses and zones of shale-rich gravel.

The Valparaiso Outwash Apron Aquifer System is distinguished from other aquifer systems by its position as the southern slope of the Valparaiso Moraine. The apron is dissected in part by the Kankakee Aquifer System which underlies the floodplain of the Kankakee River and some of its major tributaries. A distinct *scarp* separates the Kankakee Aquifer System from the outwash apron in Lake and Porter Counties.

The outwash apron was deposited over lacustrine clays and channel sands. The clays are of unknown lateral extent and vary in thickness up to 20 feet. Although in places the clay separates the outwash apron deposits and the deeper channel sands, the two permeable units are considered to be one aquifer system.

South of the Kankakee River in Starke County, the Valparaiso Outwash Apron Aquifer System consists of sand and gravel overlying either the bedrock surface or a thick till. Some intratill sand and gravel lenses are present, but the overlying outwash apron is the dominant aquifer.

The thickness of the outwash apron ranges from 10 feet near the Kankakee River to 50 feet on the river terraces in southern LaPorte County, and can exceed 100 feet near the crest of the moraine.

The thickness of the lower aquifer unit is primarily determined by bedrock topography. The thickness ranges from zero at bedrock ridges where clay rests on bedrock to more than 100 feet in deep bedrock valleys.

Most wells are completed in the upper aquifer unit and have depths ranging from 30 feet to more than 100 feet. The wells completed in the lower aquifer unit typically exceed 50 feet deep and may be more than 150 feet deep.

The depth to the static water level typically is less than 20 feet deep, but at higher surface elevations, depths may exceed 40 feet.

Yields in the upper and lower aquifer units are similar, ranging from 15 to 60 gpm for domestic wells and 100 to 600 gpm for large-diameter wells. Yields up to 1100 gpm are reported for some areas. Special well-construction techniques may be necessary because of the dominance of fine-grained sand.

Kankakee Aquifer System

The Kankakee Aquifer System is an unconfined deposit of sand in the floodplain of the Kankakee River and some of its tributaries. Meltwater streams sorted and deposited glacial sediments into this slightly entrenched valley that dissects the Valparaiso outwash apron.

Most of the sediments of the Kankakee Aquifer System are well-sorted, fine- to medium-grained sand, which is interbedded with gravel in the tributary valleys. Some of the sand, particularly south of the river, has been reworked by wind into dunes. In the valley of the Little Kankakee River in LaPorte County and in St. Joseph County where the Kankakee Aquifer System grades into the St. Joseph Aquifer System, the glacial deposits generally are coarser grained than in the main river valley.

The thickness of the aquifer ranges from 20 feet or less in the lower basin to as much as 150 feet in the Little Kankakee River valley. The aquifer is about 30 feet thick in most areas, and overlies bedrock or clay. The clay is as much as 145 feet thick in the lower basin.

The Kankakee Aquifer System has a gradational boundary with the Valparaiso Outwash Apron Aquifer System to the north (figure 39, plate 2). The deposits of these systems are interbedded and hydrologically connected. The distinction between these two aquifer systems is mostly topographic, but clay lenses are more common in the outwash apron system. Recharge to the Kankakee Aquifer System comes in part from the Valparaiso Outwash Apron Aquifer System.

In the lower basin, the Kankakee Aquifer System deposits lap onto the Iroquois Moraine Aquifer System to the south. The distinction between these systems is based on topography and the absence of interbedded clays in the Kankakee Aquifer System.

Static water levels are shallow in the Kankakee River floodplain, and are usually less than 20 feet deep. Wells typically are shallow, and few exceed depths of 50 feet. In the tributary valleys, however, the depth to the water table may exceed 50 feet and well depths may exceed 150 feet.

Domestic wells usually produce from 15 to 50 gpm, and high-capacity wells may produce 100 to 1200 gpm depending on the saturated thickness and coarseness of aquifer material. Yields up to 1500 gpm for high-capacity wells may be possible in some locations in the upper basin, whereas high-capacity wells in the lower basin may yield 100 to 500 gpm. Areas which have thick coarse-grained deposits have high potential yield. High-yield areas include the Little Kankakee River Valley in LaPorte County and the Kankakee River Valley in St. Joseph County.

Eolian Sands Aquifer System

Sand dunes are the most visible geologic feature in the intermoraine lowlands of Starke County. The dunes were formed from the blanket of sand that overlies till in this relatively flat area of the basin.

The Eolian Sands Aquifer System is characterized by a thick blanket of windblown sand overlying a variable but generally thick till deposit. Additional sand and gravel zones usually are found beneath the till. Some of these deeper aquifers are thick and have multiple sand and gravel lenses separated by till. The proportion of gravel in a sand deposit may increase with depth. In a few locations, surficial sand is absent and till is present at the surface. The thickness of the till ranges from less than 5 feet to as much as 100 feet.

Aquifer materials range from fine-grained sand to gravel. The thickness of the aquifers ranges from 4 to 72 feet. Most wells produce from aquifers 10 to 30 feet thick.

The Eolian Sands Aquifer System borders the Valparaiso Outwash Apron Aquifer System to the west (plate 2). The outwash apron system contains very little till compared to the eolian sand. Furthermore, the Eolian Sands Aquifer System occupies higher ground than the outwash apron.

The Eolian Sands Aquifer System is bounded to the east by the Maxinkuckee Moraine Aquifer System. The boundary between these aquifer systems is marked by the eastward thinning of the eolian sand deposit as the distance from the source of the sand increases.

Although some shallow wells are completed in surficial sand less than 40 feet deep, most wells pass through till to produce from deep sand and gravel beds. Well depths in this system range from 24 to 211 feet, but most wells are between 50 and 120 feet deep.

Static water levels throughout the Eolian Sands Aquifer System range from land surface to 48 feet deep. Most static water levels are between 5 and 20 feet deep.

Most large-diameter wells produce at least 150 to 200 gpm and some large-diameter wells reportedly produce up to 1200 gpm (table 20). Domestic-well yields range from 10 to 50 gpm. Despite the erratic distribution of sand lenses, only one dry hole has been reported in the aquifer system.

Iroquois Moraine Aquifer System

The Iroquois Moraine Aquifer System consists of isolated sand and gravel deposits encompassed within thick sections of clay (figure 39). Dunes overlie portions of the moraine in western Newton and Jasper Counties, but these sand deposits contain very little water.

There are severe limitations to water resources in this aquifer system. Thickness of the discontinuous aquifers range from 3 to about 37 feet, but most aquifers are less than 10 feet thick. Fine-grained sand deposits which occur near the land surface have limited saturated thickness and therefore have a limited potential for water-supply development. Deeper and generally thicker sand and gravel lenses may yield higher quantities of water.

The Iroquois Moraine Aquifer System is distinguished from the Kankakee Aquifer System to the north by the increase in elevation at the moraine's northern slope and the lack of till in the Kankakee Aquifer System. The Iroquois Basin Aquifer System, which forms the southern border of Iroquois Moraine Aquifer System (plate 2), has a lower surface elevation and thinner unconsolidated deposits with more variation in aquifer elevations.

Two potential zones for water production exist within the Iroquois Moraine. The first zone is a deposit of fine- to medium-grained sand at elevations between 640 and 685 feet m.s.l. Thickness of these discontinuous sand deposits ranges from 3 to 25 feet, and averages about 9 feet. Although some shallow domestic wells produce from the upper sands, the deposits commonly are not saturated and thus have limited potential as aquifers.

A second aquifer zone may occur at elevations between 545 and 590 feet m.s.l. These sand and gravel deposits range from 5 to 37 feet thick, and have an average of 13 feet. Where present, the deposits occur at depths between 60 and 125 feet. Static water levels are most often between 15 and 30 feet, although reported values range from 5 to 80 feet. Well depths for the Iroquois Moraine Aquifer System range from less than 50 to more than 170 feet.

Domestic wells completed in deeper aquifers yield from 4 to 10 gpm (table 20). However, because these aquifers are present only in small areas of the moraine, many wells pass through the unconsolidated deposits to obtain water from the underlying bedrock.

Iroquois Basin Aquifer System

The Iroquois Basin Aquifer System consists predominantly of glacial till having thin intratill aquifers and some deeply buried aquifers in bedrock valleys. Two- to three-foot-thick lenses of intratill sand and gravel are present in a wide range of elevations, but most occur between 630 to 650 feet m.s.l. These deposits consist of fine- to medium-grained sand with local gravel deposits.

This system adjoins the Iroquois Moraine Aquifer System to the north (plate 2). Several of the sand and gravel units in this system occur at elevations similar to those in the Iroquois Moraine Aquifer System, and the two aquifer systems may be hydrologically connected in places.

Static water levels in this aquifer system generally range from 7 to 20 feet deep, but records include flowing wells and static water levels as much as 75 feet deep.

The elevation of the bedrock surface increases toward the southern boundary of the Iroquois Basin (figure 39), and in this area many of the wells are drilled through the unconsolidated deposits of the Iroquois Basin Aquifer System to obtain water from the underlying bedrock. The northern part of the aquifer system overlies the New Albany Shale, Antrim Shale and Silurian and Devonian carbonates. The Borden Group forms the bedrock high to the south.

Well yields generally are adequate for domestic use (4-25 gpm), but dry holes can occur because of the erratic distribution of the intratill aquifers. Large-diameter wells completed in locally thick, deeper sand and gravel deposits may be capable of producing from 100 to 400 gpm (table 20), but lower yields commonly are expected.

Iroquois Buried Valley Subsystem

This subsystem of the Iroquois Basin Aquifer System parallels the Iroquois River from southwest of Rensselaer into Illinois (plate 2). The deposit is composed of sand and gravel in a buried bedrock valley beneath tills of the Iroquois Basin Aquifer System. The thickness of the sand and gravel deposits ranges from about 3 to 40 feet and the aquifers occur at elevations between 540 and 590 feet m.s.l. Well depths to these aquifers range from about 60 to 125 feet, with an average of about 80 feet.

In contrast to the overlying deposits, sand and gravel zones in the Iroquois Buried Valley subsystem are more consistent, and wells may encounter more lenses of water-bearing sand and gravel. Domestic wells produce from 10 to 40 gpm, and high-capacity wells yielding up to 400 gpm can be expected (table 20).

Bedrock aquifer systems

The occurrence of bedrock aquifers depends on the original composition of the rocks and subsequent changes which influenced the hydraulic properties. Erosion has removed layers of bedrock from the crest of the Kankakee Arch and has increased permeability in the exposed bedrock by weathering and solution activity.

Because permeability is greatest near the bedrock surface, the upper bedrock units are in many cases the most productive aquifers. Rock types exposed at the bedrock surface range from unproductive shales to highly productive limestones and dolomites.

The yield of bedrock aquifers depends on hydraulic characteristics and the nature of the overlying deposits. In part, the overlying glacial deposits determine the recharge rate to the bedrock aquifers. In many locations, the bedrock aquifer has a high potential yield, but has little use because the overlying strata have good hydraulic characteristics.

In general, bedrock aquifers are not used in the upper Kankakee River Basin because of the predominance of unproductive shales and the availability of water from the unconsolidated materials overlying bedrock. In the lower basin, a thin mantle of unconsolidated materials and the presence of thick, highly productive carbonate aquifers favor the development of bedrock aquifers.

In the southwest part of the lower basin in and near Benton County, shale, sandstone, siltstone, and thin limestone are covered by a variable but often thin covering of unproductive drift. There are a large number of bedrock wells in this shale-dominated area but they generally yield water in amounts sufficient only for domestic use.

Silurian and Devonian Carbonate

In the Kankakee River Basin, the Silurian and Devonian carbonate rocks are the most productive bedrock aquifers. Because individual units of the Silurian and Devonian Systems are composed of similar carbonate rock types and cannot be distinguished on the basis of water-well records, they are considered as a single water-bearing system. The small areas of Silurian and Devonian carbonate occurring in the upper basin are not used because adequate water supplies generally can be obtained from the overlying unconsolidated materials (Plate 2).

In carbonate aquifers water is stored and transmitted in joints, fractures, bedding planes and solution openings within the rock. The reef facies of the Silurian carbonates have high porosities (from 5 to 25 percent) and high permeabilities. The bank and inter-reef facies contain significantly lower porosities and permeabilities. Devonian carbonates have porosity values which are highly variable and range from 0 to 14 percent (Rupp, Indiana Geological Survey, written communication, 1988).

The carbonate bedrock strata in and near the Kankakee River Basin may be extremely thick. Deep, high-capacity wells commonly penetrate 200 to 450 feet of carbonate rock, and some wells have been reported to penetrate up to 550 feet of uninterrupted rock. Domestic wells commonly only penetrate the upper 15 to 100 feet of the carbonate bedrock.

In some areas near the contact between the Antrim Shale and the Devonian carbonates, wells are drilled through the shale and into the more productive underlying carbonate rocks. Because the overlying shale inhibits recharge and fracturing may not be well developed in the carbonates, these wells are less productive than wells completed in carbonates not overlain by shale. In many places, limestones and dolomites are interbedded with shale units of variable thickness.

Static water levels are quite variable in the wells completed in the carbonate aquifer. Water levels ranging from 1 foot to 117 feet have been reported; however, levels usually are between 10 and 40 feet. Flowing wells in this bedrock unit are rare. Only three flowing wells have been reported at scattered locations in the basin.

Well yields depend on the diameter of the well and aquifer characteristics. Most of the wells in this bedrock system are 4- to 6-inch-diameter domestic wells. Most domestic wells can be expected to produce between 10 and 30 gpm, but well yields range from 8 to 200 gpm.

The Silurian and Devonian carbonate system is the only bedrock system in the Kankakee River Basin capable of sustaining high-capacity well yields. Most deep, large-diameter wells produce 300 to 1000 gpm, but some wells yield up to 1850 gpm. Large wells, having 8- to 16-inch diameters, are usually industrial, municipal, or irrigation supply wells. Only a few dry holes have been reported in this aquifer system.

Devonian Antrim Shale

The Devonian Antrim Shale forms the bedrock surface in a broad east-to-west band across the basin and in a few scattered areas in Jasper County (plate 2). Although the Antrim Shale is not considered to be a significant aquifer, it may yield sufficient quantities of water for domestic uses.

In areas where the Antrim Shale is at the bedrock surface, wells are usually attempted in the unconsolidated glacial material overlying bedrock.

Less than two dozen wells producing from the Antrim Shale have been reported, and most are located in the lower basin. The wells are from 66 to 140 feet deep and penetrate as much as 62 feet into the shale.

Static water levels in the wells range from 10 to 50 feet deep. Wells in the Antrim Shale have varying yields, but most produce 15 gpm or less. No high-capacity wells have been reported. No dry holes have been reported, but it is likely that many dry holes exist.

Devonian and Mississippian New Albany Shale

The Devonian and Mississippian New Albany Shale forms the bedrock surface in southern Newton and Jasper Counties. Like the Antrim Shale, the New Albany is a black shale, often mistakenly reported as slate, and overlies the Devonian carbonate bedrock. Although several dozen wells are reported producing water from the New Albany Shale, the formation is not considered as a significant aquifer. Wells often are drilled through the New Albany Shale into the underlying carbonates in an attempt to get higher well yields.

Most wells developed in the New Albany Shale penetrate at least 30 feet of shale, but wells are reported to penetrate from 11 to 102 feet. Well depths range from 45 to 120 feet and static water levels are usually between 4 and 15 feet.

Most wells in the Devonian and Mississippian New Albany Shale yield 5 gpm or less, but some yields of up to 20 gpm have been repoted. A number of dry holes have been reported in the New Albany Shale.

Devonian and Mississippian Ellsworth Shale

The Devonian and Mississipian Ellsworth Shale is at the bedrock surface over a large area in the northern portion of the basin (plate 2). Because thick glacial deposits overlying the shale usually provide adequate water supplies, the Ellsworth Shale is an unlikely supply source. There are no known wells in the Kankakee River Basin that produce from the Ellsworth Shale.

Mississippian Borden Group

Mississippian Borden Group rocks are at the bedrock surface in the southwestern portion of the Kankakee River Basin in Benton County. Most of the productive wells in this area have penetrated limestone, although some wells produce from shale or sandstone units.

Although most bedrock wells in this area produce sufficient quantities of water for domestic purposes, there is little chance for development of high-capacity wells. A number of dry holes have been reported.

Many deep wells are completed in this aquifer system. Deep wells may pass through the shales to reach more productive limestones or to increase the storage capacity of a well completed in a low-yield aquifer.

Most wells penetrate less than 70 feet of bedrock, but wells penetrate from 8 to 270 feet. Bedrock well depths range from 40 to 325 feet. Most wells are more than 100 feet deep.

Static water levels range from 3 to 150 feet but are usually between 20 and 50 feet.

Generally, domestic wells completed in the Borden Group yield from 5 to 15 gpm, although reported yields range from 4 to 55 gpm. One high-capacity well reportedly produces 80 gpm.

Pennsylvanian Raccoon Creek Group

Several small areas of Pennsylvanian-age rock occur in the lower basin. Wells drilled in these areas reportedly encounter sandstone, but these areas are too small to be well defined on the basis of water-well data. The water-bearing capabilities of this aquifer system should be similar to the adjacent bedrock aquifers.

Kentland Anomaly

Beneath a small area in Newton County, the bedrock has been faulted and folded by undetermined forces that brought deeply buried Ordovician rocks to the bedrock surface where they contact Pennsylvanian formations. The faulting has probably increased the permeability of the dolomite and limestone in this feature, but the aquifer characteristics are unknown.

GROUND-WATER DEVELOPMENT POTENTIAL

The development or potential yield of an aquifer depends on aquifer characteristics (*transmissivity*, *hydraulic conductivity*, and storage), aquifer thickness, areal extent, ground-water levels and recharge. The outwash aquifers cover a large part of the basin and are very thick in places. In particular, the tributaries and northeastern areas of the Kankakee Aquifer System have exceptional ground-water development potential. Of the basin's bedrock aquifers, the Silurian and Devonian Carbonate has the greatest potential for ground-water development, but in places *recharge* to it is limited by overlying till or shale.

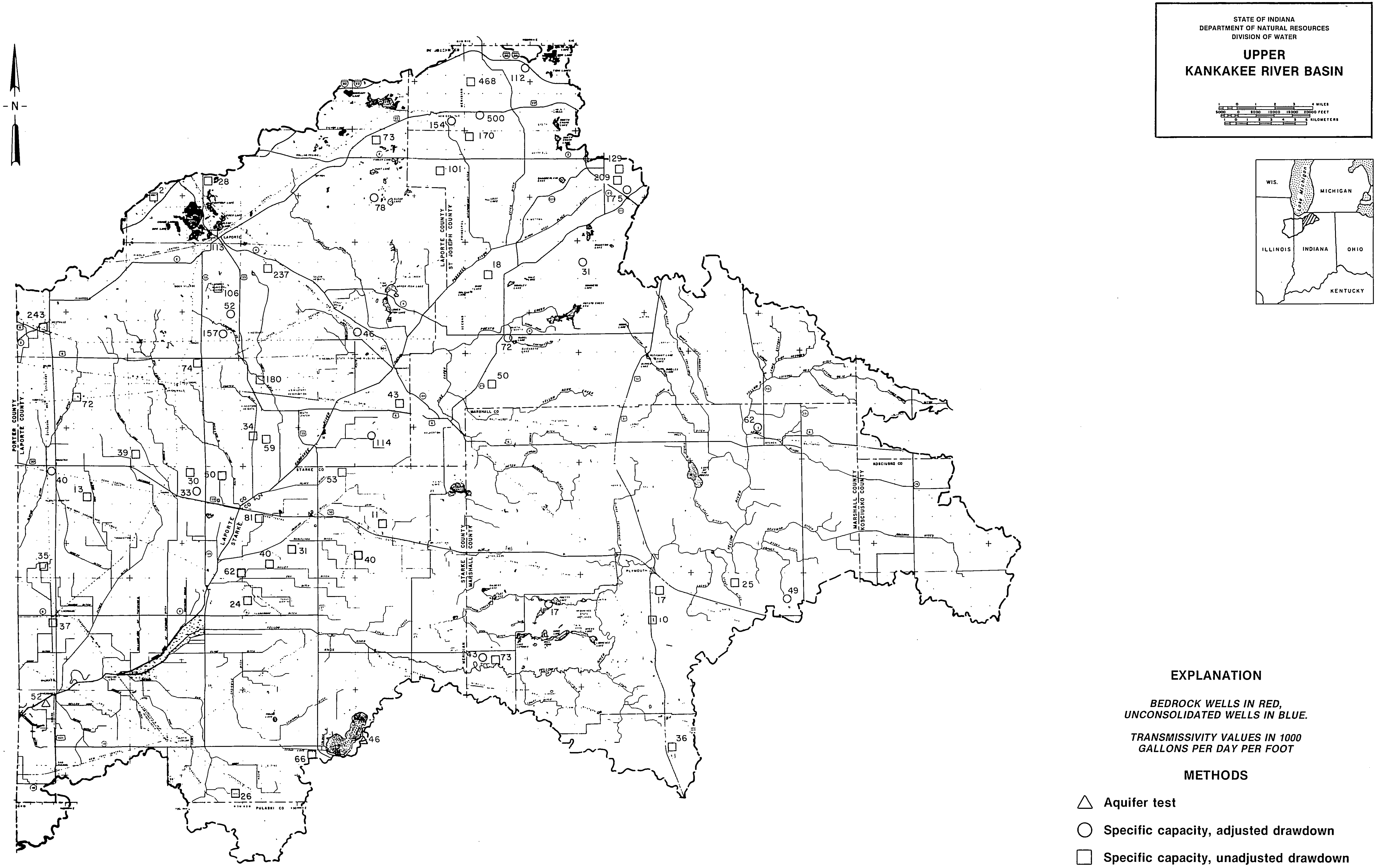


Figure 40a. Transmissivity values

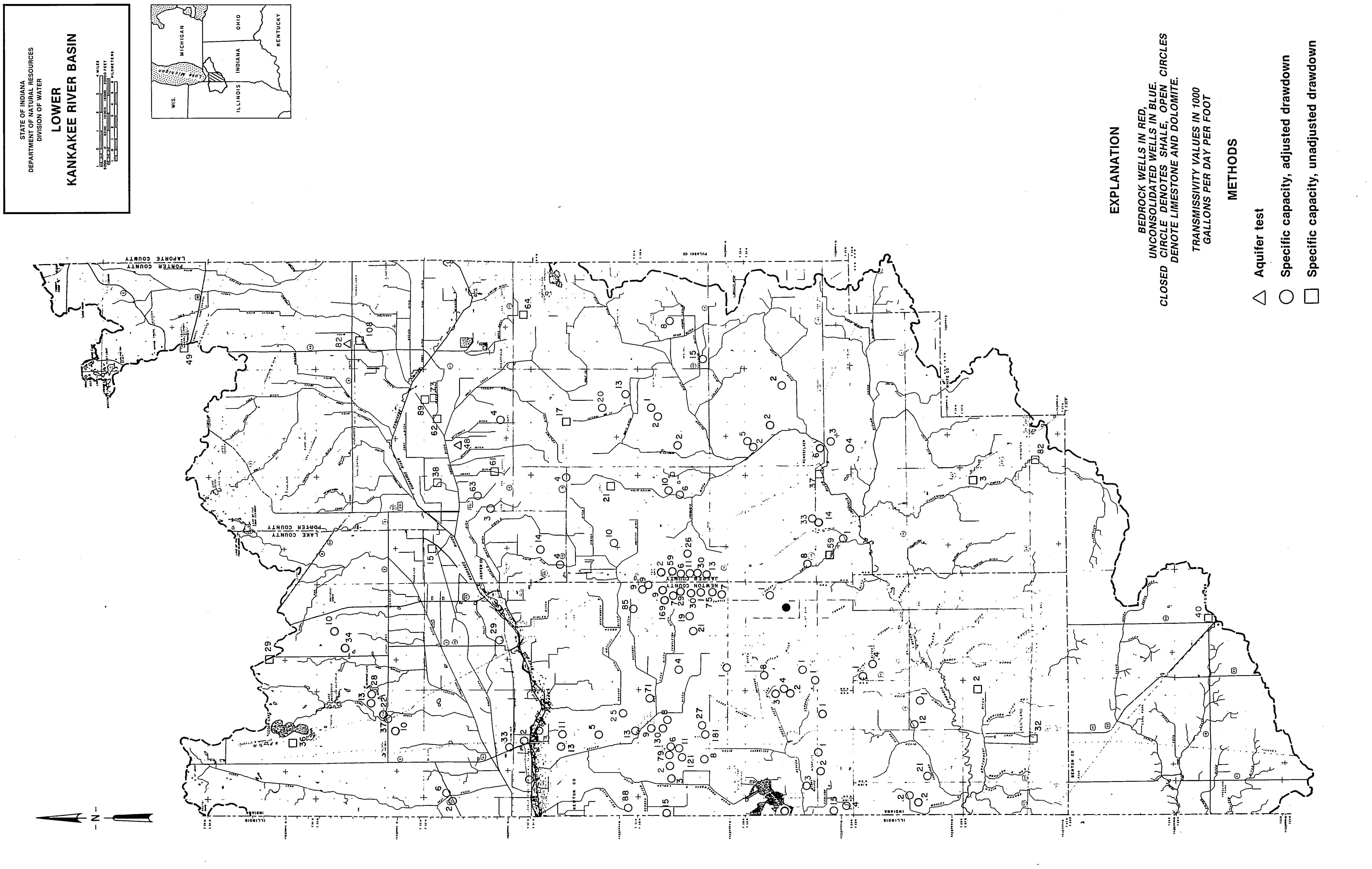


Figure 40b. Transmissivity values

Transmissivity

Transmissivity, a measure of the water-transmitting capability of an aquifer, is defined as the product of the hydraulic conductivity and the saturated thickness of an aquifer. Methods used to compute transmissivity establish a mathematical relationship between the pumping rate and the resultant drawdown in the aquifer for a given set of well and aquifer conditions. The three methods used to estimate the transmissivities of aquifers within the Kankakee River Basin include the use of 1) graphical plots based on aquifer-test data, 2) specific capacity data based on adjusted drawdown, and 3) specific capacity data based on unadjusted drawdown (figure 40).

The graphical approach can be used only when extensive data have been collected from aquifer tests. In most aquifer tests, water levels are recorded simultaneously at observation wells while the test well is being pumped. The response of the aquifer is monitored over an areal extent that is determined by the spatial distribution of the observation wells. Graphical plots of time versus drawdown and distance versus drawdown can yield reliable estimates of the hydraulic parameters of the aquifer. However, unless an extensive well field is being developed, an aquifer test is not warranted because the cost of installing observation wells is too high.

Piezometer tests are much less expensive than aquifer tests because drawdown is measured only at the test well while it is being pumped. After the completion of a water well, the driller conducts a piezometer test to determine the specific capacity of the aquifer. Specific capacity, defined as the rate at which water can be pumped from a well under unit decline in head, can be used to estimate hydraulic properties of aquifers if other information is not available (Peters, 1987). Specific capacity data can be easily attained by inspection of the driller's log. Prior to estimation of aquifer tranmissivity, drawdown must be adjusted for the effects of well loss, partial penetration, and dewatering of the aquifer unless it is confined. In most cases, these factors tend to cause lower estimates of specific capacity (Walton, 1970).

Transmissivity estimates based on specific capacity data may not be very accurate in cases where an aquifer of unknown thickness is partially penetrated by a test well. These values represent minimum estimates of transmissivities and are described as aquifer transmissivity based on unadjusted drawdown. As a result, these values are the least reliable estimates of aquifer transmissivity.

For this report, estimates of aquifer transmissivity from specific capacity data were generated using a computer program called 'Tguess' (Bradbury and Rothschild, 1985). The computer program adjusts specific capacity data for well loss, partial penetration and dewatering of the aquifer if appropriate, and generates estimates of transmissivity by using an iterative technique.

The transmissivities of the aquifers within the Kankakee River Basin are highly variable (figure 40). The wide range in values is probably the result of the heterogeneity of the geologic formations and the use of different methods in estimating aquifer transmissivity.

For comparative purposes, it may be best to examine transmissivity values that were computed by the same method. The differences from such comparison may reflect local variations in the geologic conditions, especially aquifer thickness and permeability. However, interpretation of a given transmissivity is complex because it is a product of hydraulic conductivity and saturated thickness. A thick, moderately permeable aquifer can have a similar transmissivity as a thin, highly permeable aquifer.

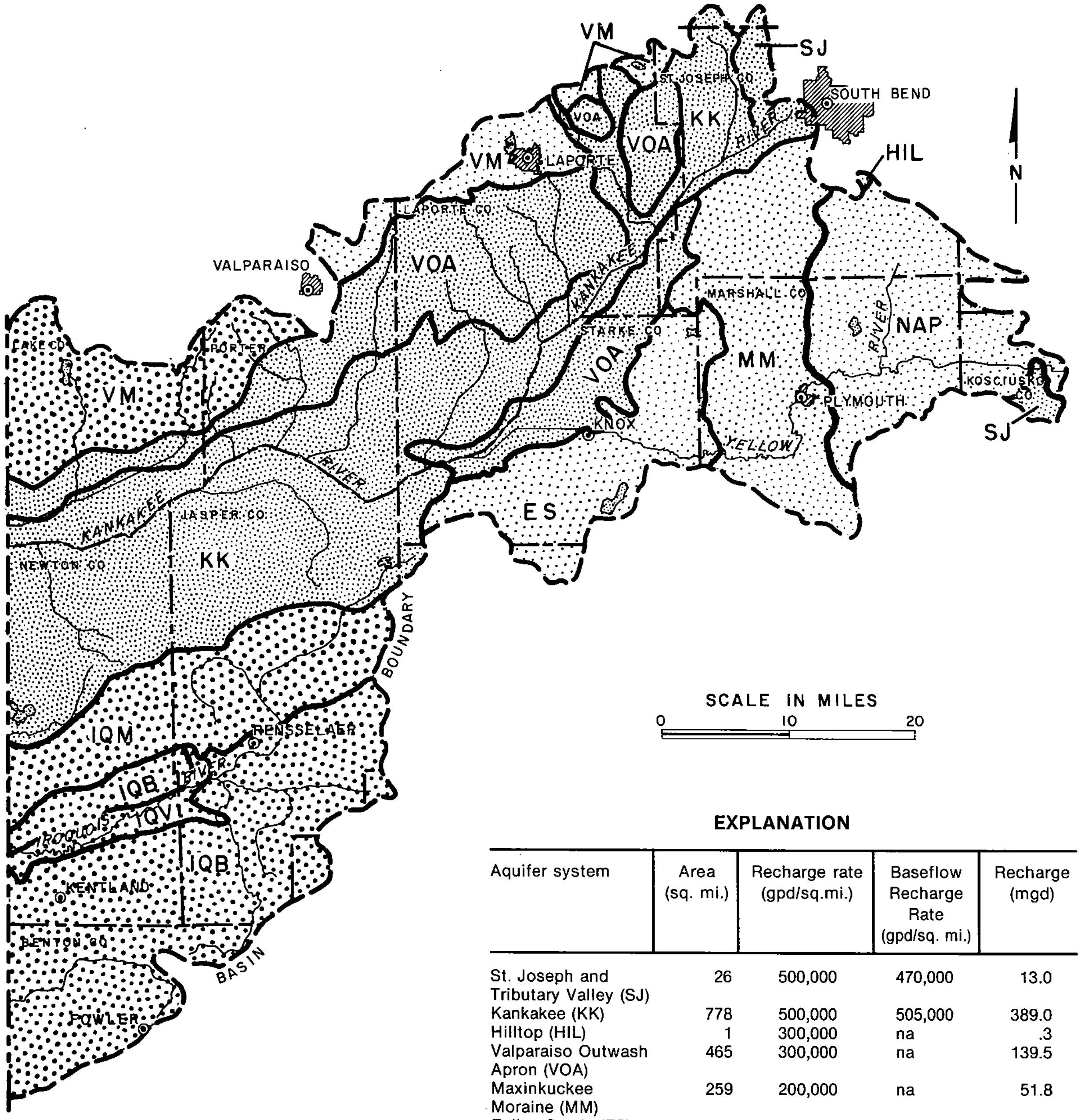
Recharge

The yield of an aquifer depends primarily on its porosity, permeability and saturated thickness. These factors determine the amount of water available for use and the rate at which it can be removed. However, the long-term productivity of an aquifer depends on recharge, which determines how quickly ground water is replenished.

The potential amount of ground water available for development in the Kankakee River Basin is a combination of natural recharge (derived chiefly from precipitation), recharge which can be induced to infiltrate from existing streams, and water in storage.

Natural recharge rates for aquifer systems in the Kankakee Basin have been estimated on the basis of aquifer geometry and hydrogeologic conditions. The sum of the recharge to the aquifer systems (806 mgd) is an estimate of the recharge to the entire basin.

Recharge rates are highest in the unconfined outwash aquifer systems, including the St. Joseph and Tributary Valley, Kankakee, Hilltop, and Valparaiso Outwash



EXPLANATION

Aquifer system	Area (sq. mi.)	Recharge rate (gpd/sq.mi.)	Baseflow Recharge Rate (gpd/sq. mi.)	Recharge (mgd)
St. Joseph and Tributary Valley (SJ)	26	500,000	470,000	13.0
Kankakee (KK)	778	500,000	505,000	389.0
Hilltop (HIL)	1	300,000	na	.3
Valparaiso Outwash Apron (VOA)	465	300,000	na	139.5
Maxinkuckee Moraine (MM)	259	200,000	na	51.8
Eolian Sands (ES)	188	175,000	na	32.9
Nappanee (NAP)	249	175,000	240,000	43.6
Valparaiso Moraine (VM)	286	125,000-200,000	343,000	46.5
Iroquois Basin (IQB)	487	150,000	210,000	73.1
Iroquois Buried Valley (IQB)	38	150,000	na	5.7
Iroquois Moraine (IQM)	215	50,000	250,000	10.8

Figure 41. Estimated recharge rates of unconsolidated aquifer systems

Apron Aquifer Systems (figure 41). Two of these aquifer systems, the Kankakee and Valparaiso Outwash Apron, account for approximately 70 percent of the total recharge to the basin even though they only occupy about 50 percent of the basin area.

The aquifer systems underlying the Iroquois Moraine and the western portion of the Valparaiso Moraine have fairly low recharge rates of 50,000 gpd/sq mi (gallons per day per square mile) and 125,000 gpd/sq mi, respectively. The thick tills in the moraines and the sloping land surface limit the infiltration and percolation of precipitation. Because the overlying till cover in the eastern portion of the Valparaiso Moraine Aquifer System is thinner than in the western portion, the eastern portion has a somewhat higher recharge rate of 200,000 gpd/sq mi.

The aquifer systems with lowest recharge rates occur in the Iroquois River Basin. The recharge to intratill aquifers in this area is limited by the surrounding material of low permeability.

Recharge rates to the bedrock aquifers are largely influenced by the overlying strata. Where shale or till overlies a bedrock aquifer, recharge to the underlying aquifer is generally limited by the overlying material of low permeability.

Rosenshein (1963) estimated an average recharge rate of 20,000 gpd/sq mi for the till-covered Silurian carbonate in Lake County. Areas of Silurian and Devonian carbonate which are overlain by outwash sand and gravel are expected to have higher recharge rates than the till-covered bedrock.

GROUND-WATER QUALITY

Water quality is an important factor in determining the utility of a ground-water source. Naturally-occurring concentrations of various constituents define ground-water quality and determine whether the resource is potable or otherwise suitable for municipal and domestic supplies, industrial processing, irrigation, or livestock watering. Human-induced levels of naturally-occurring or man-made chemicals may diminish the use of the resource or render it unacceptable as a water supply.

Sources of ground-water quality data

Inorganic chemical analyses of water samples from 374 wells were used to characterize the ground-water quality of the unconsolidated and bedrock aquifer systems defined in the Kankakee River Basin (appendices 9, 10, 11; plate 2). Major data sources include the following: 1) 200 domestic, livestock, industrial, public-supply, irrigation, and observation wells sampled during the summer and fall of 1986 in a cooperative effort between the Division of Water and the Indiana Geological Survey (DOW-IGS); 2) municipal and other public-supply wells sampled periodically by the Indiana State Board of Health (ISBH); 3) domestic, commercial, and public-supply wells sampled by the ISBH in 1981 for a ground-water strategy study in Lake and Porter Counties; 4) wells in northern Jasper and Newton Counties sampled by a private consulting firm during the summer of 1985; and 5) public supply, irrigation, industrial, commercial, and domestic wells sampled by the U.S. Geological Survey (USGS). Appendices 12 and 13 list data for individual wells.

A subset of the 200 wells included in the DOW-IGS sampling program were selected for organic chemical analyses (appendices 9, 10, 11). Samples from 23 of these wells were analyzed for 10 pesticides and 24 organic chemicals in a cooperative effort with the Indiana Department of Environmental Management (IDEM). In addition, during 1987 and 1988 Purdue University studied agricultural impacts on ground-water quality in Newton and Jasper Counties from point and nonpoint sources of nitrate-nitrogen and pesticides (Turco and Konopka, 1988).

Additional inorganic chemistry data provided information on the water quality of aquifer systems but were not used in the statistical analyses (Rosenshein, 1961, 1962; Rosenshein and Hunn, 1962a, 1962b, 1964a, 1964b, 1964c, 1964d). The reports were used for summarizing occurrence of hydrogen sulfide and interpreting generalized concentration maps for sulfate, hardness, iron, and alkalinity. A ground-water quality study conducted by Indiana University (1985) and funded by the U.S. Environmental Protection Agency (USEPA) provided 367 nitrate-nitrogen analyses.

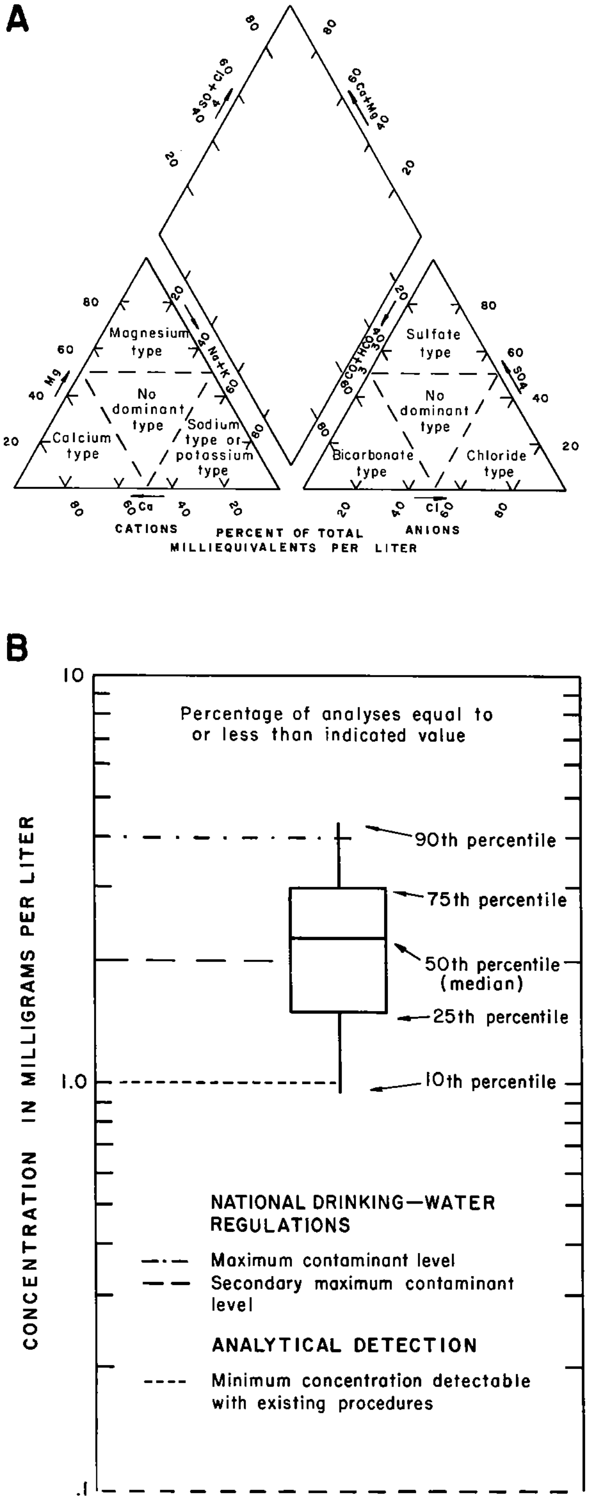


Figure 42. Explanation of piper trilinear diagrams and box-and-whisker plots

Analysis of data

Percentages of the major *cations* and *anions* in ground water were plotted on Piper trilinear diagrams for major unconsolidated and bedrock aquifer systems in the Kankakee River Basin (appendix 14). These diagrams are useful for showing differences in major-ion chemistry. Ground-water types are designated by specifically defined domains on the Piper trilinear diagram segments (figure 42a, appendix 14). Cation ground-water types include sodium and potassium, calcium, magnesium, and no dominant cation. Anion ground-water types include bicarbonate, sulfate, chloride, and no dominant anion. Cation and anion water types combined define the major-ion character of the ground water.

Box plots (figure 42b) were prepared for selected ground-water constituents. Box plots are useful for depicting descriptive statistics, showing the overall variability in constituent levels occurring in an aquifer system, and making general comparisons among aquifer systems.

The areal distributions of some major constituents were mapped according to aquifer system. The maps presented throughout the following discussion show only estimated contour lines because data are widely distributed and because the chemical composition of ground water depends on many complex factors that can change with depth and over short distances. The box on the next page discusses natural factors which affect ground-water quality.

Although the data from well-water samples in the Kankakee River Basin are treated as point values, they represent the average concentration of an unknown water volume in the aquifer. The extent of aquifer representation depends mostly on the depth of the well, hydraulic conductivity of the aquifer, and rate of pumping. For example, the chemistry of water sampled from high-capacity wells may represent average ground-water quality for a large cone of influence (Sasman and others, 1981). Water collected from deep bedrock wells can be a mixture of water from different production zones.

The chemistry of original aquifer water may be altered by contact with plumbing, residence time in a pressure tank, method of sampling, and time elapsed between sampling and laboratory analysis. Because the degree to which these factors affect original aquifer water is unknown, ground-water analyses generally typify the quality of water at the tap rather than the

Factors affecting ground-water chemistry

The chemical composition of ground water varies because of many complex factors that change with aquifer depth and over geographic distances. Ground-water quality can be affected by the composition and solubility of rock materials in the soil or aquifer, water temperature, partial pressure of carbon dioxide, acid-base reactions, oxidation-reduction reactions, loss or gain of constituents as water percolates through clay layers, and mixing of ground water from adjacent strata. The extent of the effect will be determined in part by the residence time of the water within the different environments.

Rain and snow are the major sources of recharge to ground water. As precipitation infiltrates the soil, biologically-derived carbon dioxide reacts with the water to form a weak solution of carbonic acid. The reaction of oxygen with reduced iron minerals such as pyrite is an additional source of acidity in ground water. The slightly acidic water dissolved soluble rock material, thereby increasing the concentrations of chemical constituents such as calcium, magnesium, chloride, iron, and manganese. As ground water moves slowly through an aquifer, the composition of water continues to change, usually by the addition of dissolved constituents (Freeze and Cherry, 1979). Ground water in recharge areas typically has a short residence time and therefore contains lower concentrations of **dissolved solids** than water occurring deeper in the same aquifer or in shallow discharge areas.

Dissolved carbon dioxide, bicarbonate, and carbonate are the principal sources of **alkalinity**, or the capacity of solutes in water to neutralize acid. Carbonate contributors to alkalinity include atmospheric and biologically-produced carbon dioxide, carbonate minerals, and biologically-mediated sulfate reduction. Noncarbonate contributors to alkalinity include hydroxide, silicate, borate, and organic compounds. Alkalinity helps to buffer natural water so that the **pH** is not greatly altered by addition of acid. The pH of most natural ground waters in Indiana is neutral to slightly alkaline.

Calcium and **magnesium** are the major constituents responsible for **hardness** in water. Their presence is the result of dissolution of carbonate minerals such as calcite and dolomite.

The weathering of feldspar and clay is a source of **sodium** and **potassium** in ground water. Sodium and **chloride** are produced by the solution of halite (sodium chloride) which can occur as grains disseminated in unconsolidated and bedrock deposits.

Cation exchange is often a modifying influence of ground-water chemistry. The most important cation exchange processes are those involving sodium-calcium, sodium-magnesium, potassium-calcium, and potassium-magnesium. Cation exchanges occurring in clay-rich semi-confining layers can cause magnesium and calcium reductions which result in natural softening.

Concentrations of **sulfate, sulfide, iron,** and **manganese** depend on the geology and hydrology of the aquifer system, the amount of dissolved oxygen, pH, minerals available for solution, the amount of organic matter, and microbial activity. In particular, the chemical behavior of sulfate and sulfide is strongly related to oxidation-reduction reactions.

Sulfate generally occurs under oxidizing conditions and can be abundant where sulfur-containing minerals are found. Mineral sources of sulfate can include pyrite, gypsum, barite, and celestite.

Sulfide is derived from reduction of sulfate when dissolved oxygen concentrations are low and *anaerobic* bacteria are present. Sulfate-reducing bacteria derive energy from oxidation of organic compounds and obtain oxygen from sulfate ions (Lehr and others, 1980). Hydrogen sulfide gas, a common reduced form of sulfide, has a distinctive rotten egg odor which can be detected in water containing only a few tenths of a milligram per liter of sulfide (Hem, 1985).

Reducing conditions which produce hydrogen sulfide typically occur in deep wells completed in carbonate and shale bedrock. Oxygen-deficient conditions are more likely to occur in deep wells than in shallow wells in Indiana because permeability of the carbonate bedrock decreases with depth, and solution features and joints become smaller and less abundant (Rosenshein and Hunn, 1968a; Bergeron, 1981; Basch and Funkhouser, 1985). Consequently, deeper portions of the bedrock are not readily flushed by ground water with high dissolved oxygen.

Oxidation-reduction reactions also constitute an important influence on concentrations of both iron and manganese. High dissolved iron concentrations can occur in ground water when pyrite is exposed to oxygenated water or when ferric oxide or hydroxide minerals are in contact with reducing substances (Hem 1985). Sources of manganese include manganese carbonate, dolomite, limestone, and weathering crusts of manganese oxide.

Sources of **fluoride** in bedrock aquifer systems include fluorite, which may be associated with Devonian limestone, and fluoroapatite, which can occur in New Albany Shale. Both rock types are found in the Kankakee River Basin. Fluorite and fluoroapatite may also be found in unconsolidated deposits as disseminated grains.

Natural concentrations of **nitrate-nitrogen** in ground water originate from the atmosphere and from living and decaying organisms. High nitrate levels can result from leachates of industrial and agricultural chemicals or decaying organic matter such as animal waste or sewage.

The chemistry of **strontium** is similar to that of calcium, but strontium is present in ground water in much lower concentrations. Natural sources of strontium in ground water include strontianite (strontium carbonate) and celestite (strontium sulfate). Naturally-occurring **barium** sources include barite (barium sulfate) and witherite (barium carbonate). Areas associated with deposits of coal, petroleum, natural gas, oil shale, black shale, and peat may also contain high levels of barium.

composition of in-situ aquifer water. Despite these limitations, results of sample analyses can provide basic information on ground-water quality characteristics of aquifer systems.

Assessment of ground-water quality

Major chemical constituents of ground water in the Kankakee River Basin include calcium, magnesium,

National drinking-water standards

National Interim Primary Drinking Water Regulations (U.S. Environmental Protection Agency, 1986a, 1986c) and National Secondary Drinking Water Regulations (U.S. Environmental Protection Agency, 1979) list concentration limits of specified inorganic and organic chemicals for the purpose of controlling amounts of contaminants in drinking water. Primary regulations list maximum contaminant levels (MCLs) for inorganic constituents considered toxic to humans if present above certain concentrations. These standards are health-related and are legally enforceable. Secondary maximum contaminant levels (SMCLs) are recommended concentration limits for constituents that may adversely affect the aesthetic quality of drinking water. The SMCLs are intended to be guidelines rather than enforceable standards. Although these regulations apply only to drinking water at the tap for public-supply systems, they may be used to assess water quality for privately-owned wells. The table below lists selected inorganic constituents of drinking water covered by the regulations, the significance of each constituent, and the respective MCL or SMCL. Fluoride and nitrate are the only constituents listed which are covered by the primary regulations.

Constituent	Remarks
Sulfate	Concentrations greater than 250 mg/l, the secondary maximum contaminant level, in combination with ions (especially sodium and magnesium) can impart odors and a medicinal or bitter taste to water. Amounts above 600 mg/l may have a laxative effect for people unaccustomed to sulfate-rich water.
Chloride	Concentrations in excess of 250 mg/l, the secondary contaminant level, in combination with high sodium may impart a salty taste. Amounts above 1000 mg/l may be physiologically unsafe. Large amounts may accelerate corrosion.
Fluoride	Fluoride concentrations ranging from 0.7 to 1.4 mg/l help prevent tooth decay. Amounts above 2.0 mg/l, the secondary maximum contaminant level, may cause mottled teeth. Crippling skeletal defects may occur with concentrations above 4.0 mg/l, the maximum contaminant level.
Nitrate as nitrogen	Concentrations above 20 mg/l impart a bitter taste to drinking water. Concentrations greater than 10 mg/l, the maximum contaminant level, may cause infant methemoglobinemia, a disease characterized by cyanosis or a bluish coloration of the skin.
Iron	Concentrations exceeding 0.3 mg/l, the secondary maximum contaminant level, cause staining of laundry, utensils and fixtures and may impart a metallic taste to water. Concentrations above 0.5 mg/l may cause well screens to become encrusted. Large quantities stimulate the growth of iron bacteria.
Manganese	Concentrations above 0.2 mg/l discolors food during cooking and stains laundry utensils and fixtures black. Food and water may have metallic taste at amounts above 0.5 mg/l. Amounts as low as 0.1 mg/l stimulate growth of certain bacteria. Manganese tends to precipitate at concentrations above 0.05 mg/l, the secondary maximum contaminant level, and may form a filter clogging sludge or slime.
Total Dissolved Solids	Water with concentrations greater than 500 mg/l, the secondary maximum contaminant level, may have a disagreeable taste. Amounts greater than 1000 mg/l may accelerate corrosion of well screens, pumps and casings and cause foaming and scaling in boilers.

References: Hunn and Rosenshein, 1969; Governor's Water Resource Study Commission, 1980; Lehr and others, 1980; Todd, 1980; and U.S. Environmental Protection Agency, 1986a.

sodium, potassium, bicarbonate, chloride, and sulfate (appendix 14). Less abundant components include iron, manganese, fluoride, nitrate, strontium, and barium. Additional information is on file at the Division of Water for bromide, zinc, phosphate, and silica.

About 85 percent of the analyses in the unconsolidated aquifer systems of the Kankakee River Basin can be classified as the calcium-bicarbonate ground-water type (appendix 14), which is characterized by high alkalinity, high hardness, and generally basic pH. The three most common ground-water types among the remaining 15 percent are bicarbonate, calcium, and sodium-potassium bicarbonate.

In bedrock aquifer systems, nearly all of the samples contain bicarbonate as the dominant anion (appendix 14). Nearly half of the samples have no dominant cation and most other samples are classified as either calcium bicarbonate or sodium-potassium bicarbonate ground-water types.

Where applicable, ground-water quality is assessed in the context of national primary and secondary drinking-water standards (see box on this page). General water-quality criteria for irrigation and livestock and standards for public supply are given in appendix 6.

Alkalinity and pH

Alkalinity, or the capacity of water to neutralize acid, is determined from levels of bicarbonate, carbonate, hydroxide, borates, and certain organic compounds in the water. In the Kankakee River Basin, alkalinity is due mostly to the presence of bicarbonate, which is the dominant anion in nearly all water samples from wells completed in both unconsolidated deposits and bedrock. The bicarbonate is derived primarily from the atmosphere, carbon dioxide produced in the soil zone, and the solution of carbonate minerals such as calcite and dolomite (Hem, 1985).

Alkalinity as $CaCO_3$ generally is high in the unconsolidated aquifer systems of the Kankakee River Basin (figure 43) and typically increases with well depth. Very high alkalinity (greater than 400 mg/L) occurs only in the Valparaiso Moraine Aquifer System whereas low alkalinity (less than 200 mg/L) occurs mostly in the Eolian Sands, Kankakee, and Valparaiso Outwash Apron Aquifer Systems. The four intratill systems (Maxinkuckee Moraine, Nappanee, Iroquois Moraine, and Iroquois Basin) are similar to each other in terms of degree of alkalinity.

The high alkalinity in the morainal and intratill aquifer systems may be caused by long residence time of ground water in low-permeability till and the increased solution of carbonate minerals. Abundance of carbonate materials in the till cap may be contributing to the notably high alkalinities in the Valparaiso Moraine Aquifer System.

Low alkalinity in the Eolian Sands Aquifer System and the outwash deposits may be the result of the ground water's short residence time in the permeable sands and gravels. Low alkalinities, particulary in the Eolian Sands system, also may be explained by 1) reduced amounts of carbonate minerals in the surficial sand, 2) release of carbon dioxide from porous sands to the atmosphere, and 3) low carbon dioxide production which is due to reduced amounts of organic material.

Alkalinity is high in all bedrock systems of the basin (figure 43), and is highest in the shale-capped Silurian and Devonian carbonates. Alkalinity is lowest in the Devonian and Mississippian shales.

Alkalinity of less than 200 mg/L or greater than 400 mg/L occurs only in scattered areas in the basin. Because unconsolidated deposits often supply recharge to underlying Silurian and Devonian carbonates, alkalinity tends to be similar in the two types of systems (Rosenshein and Hunn, 1968a). In some areas underlying the Kankakee Aquifer System, however, alkalinity is higher in bedrock units than in overlying deposits and may be caused by bicarbonate production from biochemical sulfate reduction (Freeze and Cherry, 1979) or longer residence time in the bedrock units.

The pH of water, or hydrogen ion activity, is expressed on a logarithmic scale (0-14) which represents the negative base-10 log of the hydrogen ion concentration. Water is acidic when the pH is less than 7 and basic when the pH is greater than 7. Ground water in the basin is predominantly basic, but median pH values in the unconsolidated aquifer systems range from 6.9 to 7.7. Median values in bedrock aquifer systems range from 7.1 to 7.6.

Hardness, calcium and magnesium

Hard water and soft water are relative terms because water considered hard in one region might be considered soft in another region. For discussion purposes the following classification is commonly used: soft water, 0-60 mg/L (as $CaCO_3$); moderately hard water, 61-120 mg/L; hard water, 121-180 mg/L; and very hard water, more than 180 mg/L (Durfor and Becker, 1964). Hardness is a water-quality concern because hard water consumes excessive amounts of soap and detergents, forms an insoluble scum, and causes scale to encrust water heaters, boilers, and pipes, thus decreasing their capacity and heat-transfer properties.

Unconsolidated deposits in the Kankakee River Basin generally contain hard to very hard water. Very hard water is especially common in the Valparaiso Moraine Aquifer System, which has a median hardness of 406 mg/L (figure 44). Ground water having less than 180 mg/L of hardness occurs mainly in the Eolian Sands Aquifer System, but also can be found in the Kankakee, Iroquois Moraine, Valparaiso Outwash Apron, Iroquois Basin, and Iroquois Valley Aquifer Systems.

Water from bedrock units is more variable in its hardness than water from unconsolidated deposits, and more samples may be classified as soft or only moderately hard. The softest water occurs in parts of Newton County. In general, water is moderately hard in the shale-capped Silurian and Devonian carbonates and the Devonian and Mississippian shales, but very hard in the Silurian and Devonian Aquifer System and the Mississippian Aquifer System (figure 44). The hardest water occurs in southeastern Jasper County and Lake County in the Silurian and Devonian system.

Because calcium and magnesium are the major constituents responsible for hardness in water, their medians and ranges of concentrations correspond closely to degree of hardness for most aquifer systems (figures

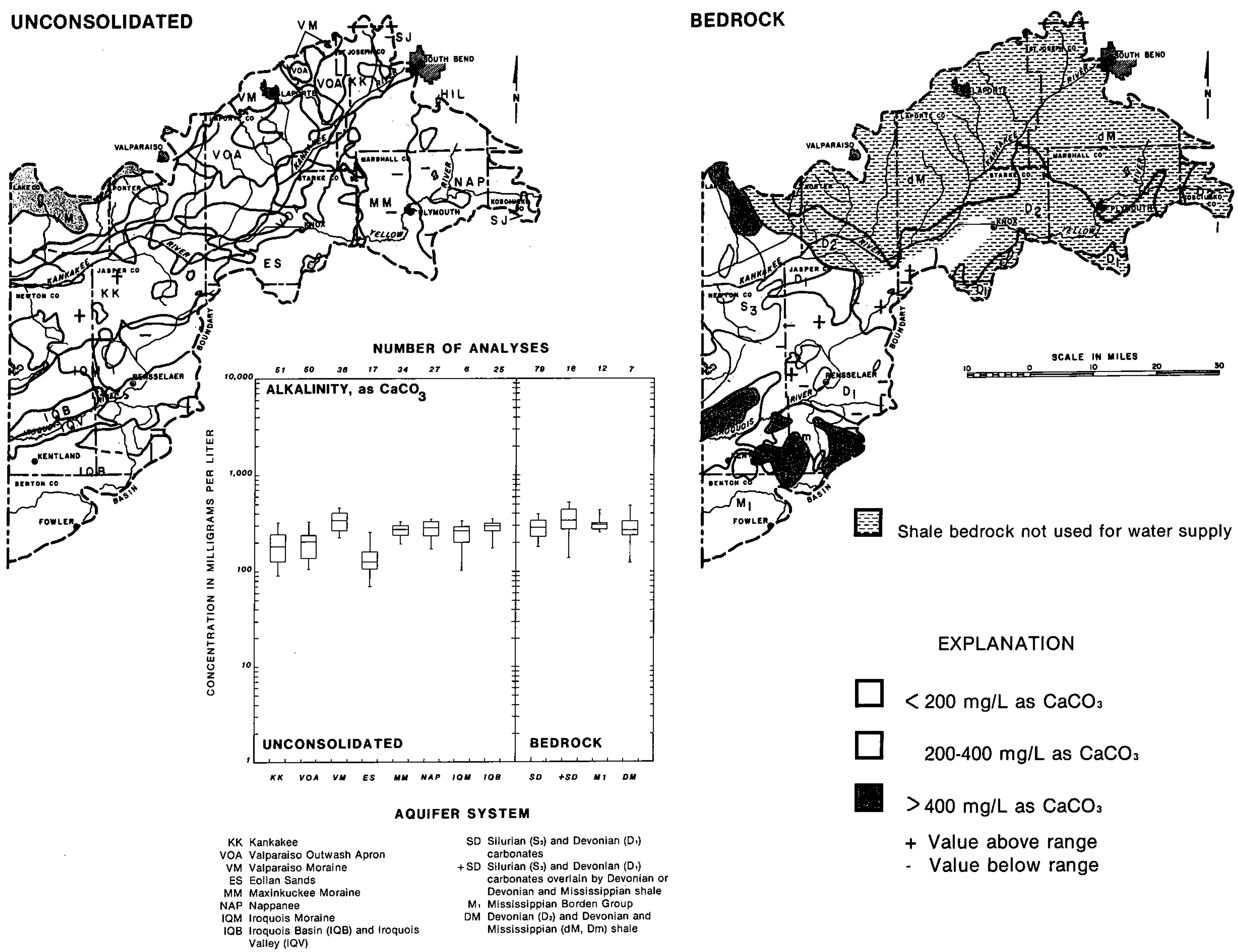


Figure 43. Generalized areal distribution and statistical summary for alkalinity

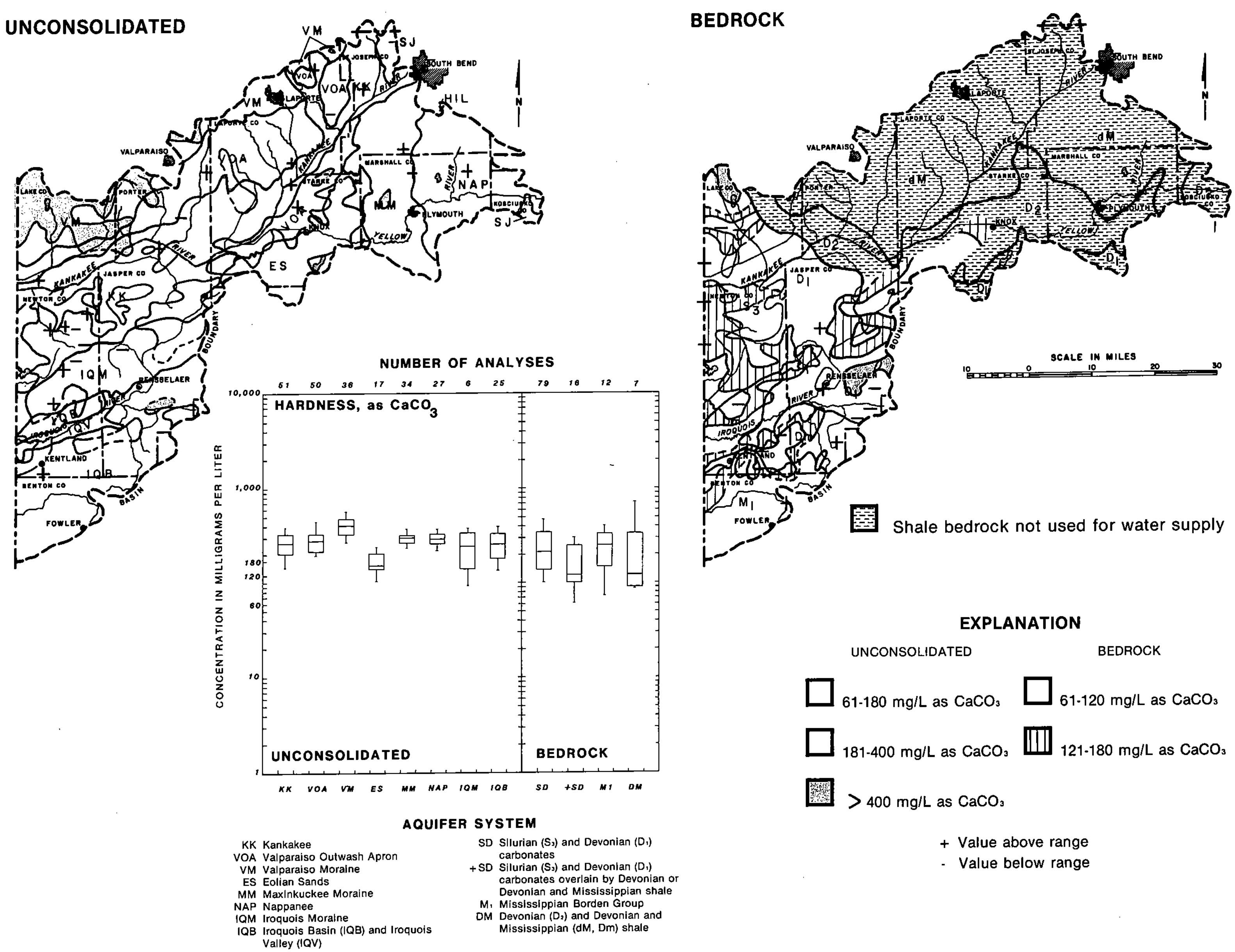


Figure 44. Generalized areal distribution and statistical summary for hardness

44, 45). In unconsolidated deposits, median calcium and magnesium concentrations are highest in the Valparaiso Moraine Aquifer System and lowest in the Eolian Sands Aquifer System. In bedrock, the highest concentrations are in the Mississippian Aquifer System and lowest in the shale-capped Silurian and Devonian carbonates and in the Devonian and Mississippian shales.

Low median hardness, calcium, and magnesium levels in the Eolian Sands Aquifer System may be attributed to the same factors which cause low alkalinity. Factors such as short residence time, low carbon-dioxide production, and scarcity of carbonate materials can limit solution of carbonate materials. The very hard water and high calcium and magnesium concentrations in the Valparaiso Moraine Aquifer System may be explained by abundant carbonate minerals in the till cap.

The low hardness, calcium, and magnesium levels in bedrock aquifers is probably caused by cation-exchange processes occurring in the semi-confining clay, till, and shale beds overlying the carbonate rocks. Because recharge water from the glacial material is saturated with calcium and magnesium, little dissolution of carbonate materials occurs in the bedrock (Rosenshein and Hunn, 1968a).

Chloride, sodium and potassium

Chloride concentrations vary widely in the unconsolidated deposits, as shown by the large percentile ranges in figure 45. The lowest chloride concentrations (generally less than 10 mg/L) are found mainly in the Nappanee, Maxinkuckee Moraine, Eolian Sands, Iroquois Moraine, and Iroquois Basin Aquifer Systems. High chloride levels (between 100 and 250 mg/L) occur locally, but concentrations are less than the secondary maximum contaminant level (SMCL) of 250 mg/L in all water samples from unconsolidated deposits.

In general, chloride concentrations decrease with depth in each unconsolidated aquifer system. Median chloride concentrations are greater in water from wells less than 50 feet deep than in water from wells greater than 100 feet deep. Two wells having high chloride concentrations also contain elevated sodium concentrations. Because both wells are shallow, the high sodium and chloride concentrations may be due to surface contamination.

Bedrock systems also have wide variability in chloride levels, but all median concentrations are less than 20 mg/L (figure 45). Locally high chloride levels (ranging from 88 to 240 mg/L) can be found in three of the bedrock systems. Chloride concentrations in two wells, one each in the Silurian and Devonian System and the shale-capped Silurian and Devonian carbonates, exceed the SMCL of 250 mg/L.

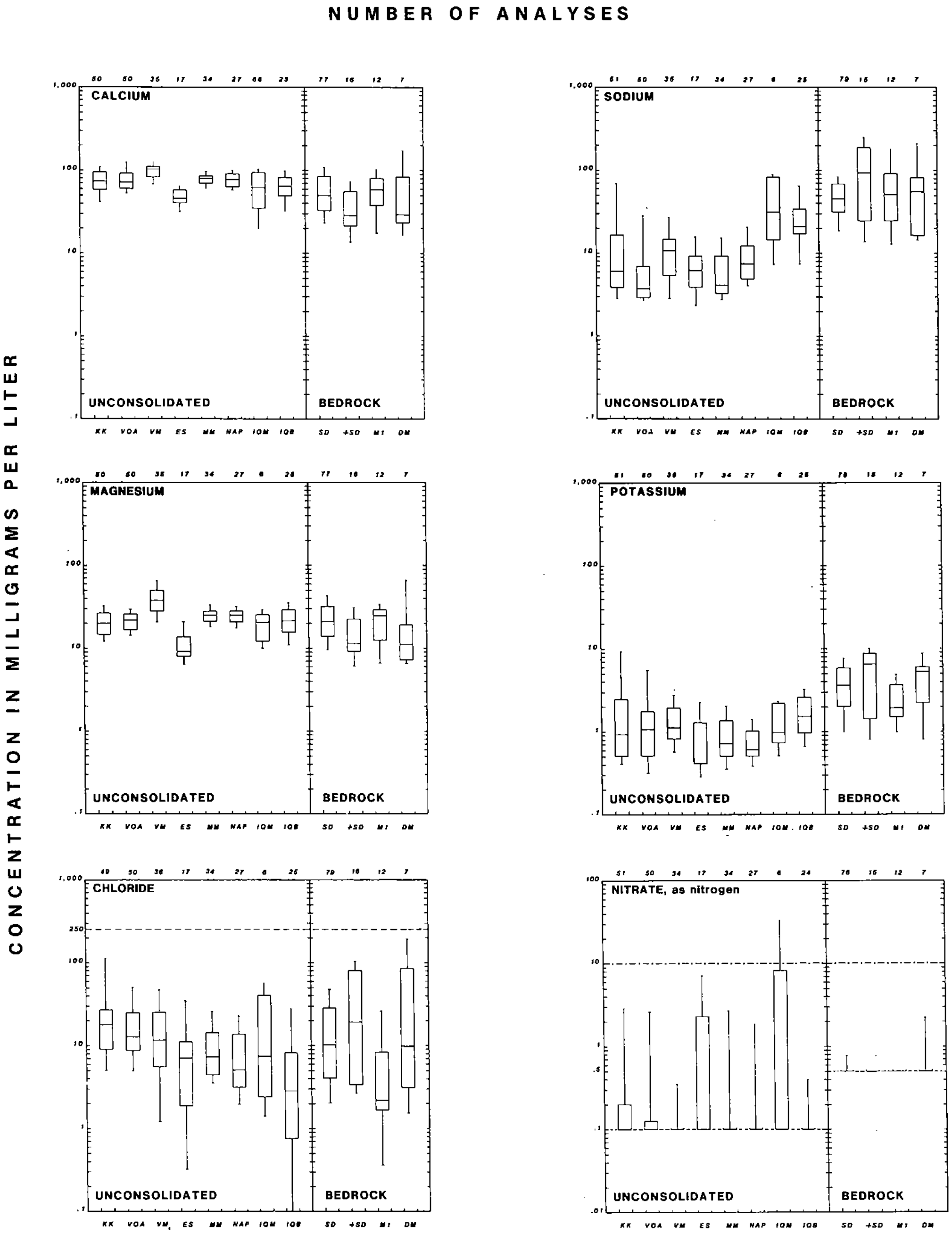
Sodium levels are moderately variable in unconsolidated aquifer systems. Concentrations are highest in the Iroquois Moraine and Iroquois Basin Aquifer Systems, where at least half of the samples in each system have sodium levels exceeding 20 mg/L. Sodium levels in most samples from the other unconsolidated systems are less than 20 mg/L.

Median sodium levels in bedrock systems generally are several times higher than median levels in overlying unconsolidated systems, and range from nearly 50 mg/L to nearly 100 mg/L (figure 45). Seven bedrock wells containing high sodium concentrations (ranging from 90 mg/L to 695 mg/L) also have elevated chloride levels.

Median potassium levels in all unconsolidated systems are less than 2 mg/L (figure 45). The Eolian Sands Aquifer System has the lowest median potassium concentration (0.4 mg/L), but potassium concentrations also are low in other parts of the upper basin, including the Maxinkuckee Moraine and Nappanee Aquifer Systems. In the Iroquois Basin and Iroquois Moraine Aquifer Systems, the moderately high sodium and potassium levels may reflect natural softening.

Like sodium, median potassium levels are noticeably higher in bedrock systems than in unconsolidated deposits (figure 45). Conversely, calcium and magnesium are generally higher in the unconsolidated deposits than in bedrock units, except in the Mississippian Borden Group. These patterns probably are the result of natural softening caused by cation exchange of sodium-calcium, sodium-magnesium, potassium-calcium, and potassium-magnesium in shale, clay, and till overlying the bedrock.

An example of natural softening occurs in the Silurian and Devonian Aquifer System in Lake County near Lowell. In this area water is softer, calcium and magnesium concentrations are much lower, and sodium and potassium concentrations are much higher in the bedrock units than in water from the overlying unconsolidated aquifer systems. High-capacity pumping may be increasing the recharge of naturally softened water from overlying clays. Sources of chloride, sodium, and



AQUIFER SYSTEMS

KK	Kankakee	SD	Silurian (S_3) and Devonian (D_1) carbonates
VOA	Valparaiso Outwash Apron	+SD	Silurian (S_3) and Devonian (D_1) carbonates overlain by Devonian or Devonian and Mississippian shale
VM	Valparaiso Moraine	M_1	Mississippian Borden Group
ES	Eolian Sands	DM	Devonian (D_2) and Devonian and Mississippian (dM, Dm) shale
MM	Maxinkuckee Moraine		
NAP	Nappanee		
IQM	Iroquois Moraine		
IQB	Iroquois Basin (IQB) and Iroquois Valley (IQV)		

Figure 45. Statistical summaries for selected ground-water quality constituents

potassium and the modifying influence of cation exchange were discussed in the previous section.

Sulfate and sulfide

Ground water in the Kankakee River Basin contains sulfur in the oxidized form of sulfate and the reduced form of sulfide. Sulfate concentrations are typically highest in unconsolidated systems and upper portions of the Silurian and Devonian carbonates where oxidizing conditions result from active flushing of ground water. Sulfide is found more commonly in deeper bedrock wells where reducing conditions are most likely to occur.

DOW-IGS sampling in 1986 included field testing for sulfide occurrence in the Kankakee River Basin. During subsequent data analysis, however, it was discovered that a procedural error made during field measurements had invalidated the results. Analyses for the determination of sulfate concentrations were not affected by the erroneous field measurements.

Sulfate concentrations are moderately to highly variable in four of the unconsolidated systems in the Kankakee River Basin, as seen by the large percentile ranges in figure 46. In the Kankakee, Valparaiso Moraine, and Valparaiso Outwash Apron Aquifer Systems, sulfate concentrations are less variable and generally higher than in the other unconsolidated deposits, but very few samples contain elevated sulfate levels (more than 100 mg/L). The SMCL of 250 mg/L is exceeded in water from only one well. Possible sources of sulfate in these systems include organic decay in poorly-drained soils (Rosenshein and Hunn, 1968a, 1968b) and broken crystals of pyrite and shale fragments, especially in the Valparaiso Moraine. High sulfate in the Valparaiso Moraine also may be due to slow percolation of the ground water and increased contact with the till (Hartke and others, 1975). *Gypsiferous* material has been known to originate from Devonian bedrock and may influence sulfate chemistry locally.

In unconsolidated systems sulfate concentrations generally decrease with depth. Water from wells less than 50 feet deep typically has higher sulfate concentrations than water from wells greater than 100 feet deep (appendix 12). The higher sulfate concentrations in shallow wells may be due to greater prevalence of oxidizing conditions.

Sulfate occurrence is highly variable in bedrock systems, especially in the shale-capped Silurian and Devonian carbonates and Devonian and Mississippian shales. These two systems generally contain the lowest sulfate levels, as shown by the low median values in figure 46. Although a few samples contain more than 100 mg/L sulfate, mainly in the Silurian and Devonian system, the SMCL is exceeded in only two samples. Sources of sulfate in Devonian carbonates (figure 46) may include trace pyrite and shale beds, which have been found in a quarry near Rensselaer (GeoTrans, Inc., 1983). Reduction of sulfate to sulfide may be the reason for low sulfate levels in some areas of the bedrock.

Hydrogen sulfide gas is known to occur in detectable levels in portions of the basin, especially in wells completed in Silurian and Devonian carbonates. Drillers often note on water-well records the occurrence of "sulfur water". This observation usually indicates the presence of hydrogen sulfide gas in the well water.

Well-record data in Jasper, Newton, and Lake Counties indicate occurrence of hydrogen sulfide odor in about 25 percent of bedrock wells (Rosenshein, 1961; Rosenshein and Hunn, 1964c, 1964d). Hydrogen sulfide occurrence was geographically widespread, but more common in wells deeper than 75 feet. Hydrogen sulfide was rarely reported for wells completed in unconsolidated deposits.

Occurrence of hydrogen sulfide gas may be underreported because this type of information is reported only on a voluntary basis on water-well records. The gas, or conditions favorable for gas production, can still be present even when the odor is not detected. Moreover, hydrogen sulfide may occur more frequently in unconsolidated deposits than is reported. For example, a 100-foot test well recently drilled near Kingsbury in the Valparaiso Outwash Apron Aquifer System contained water with a detectable sulfide odor.

The vertical distribution of hydrogen sulfide gas in aquifer systems in the Kankakee River Basin has not yet been completely documented, although IDNR investigators have noticed a general trend of increasing hydrogen sulfide with well depth in the Silurian and Devonian carbonates in Jasper and Newton Counties (Basch and Funkhouser, 1985). Determining the lateral and vertical movement of hydrogen sulfide in response to changing aquifer conditions requires further research. The response of hydrogen sulfide to changing chemical conditions, such as the length of time it

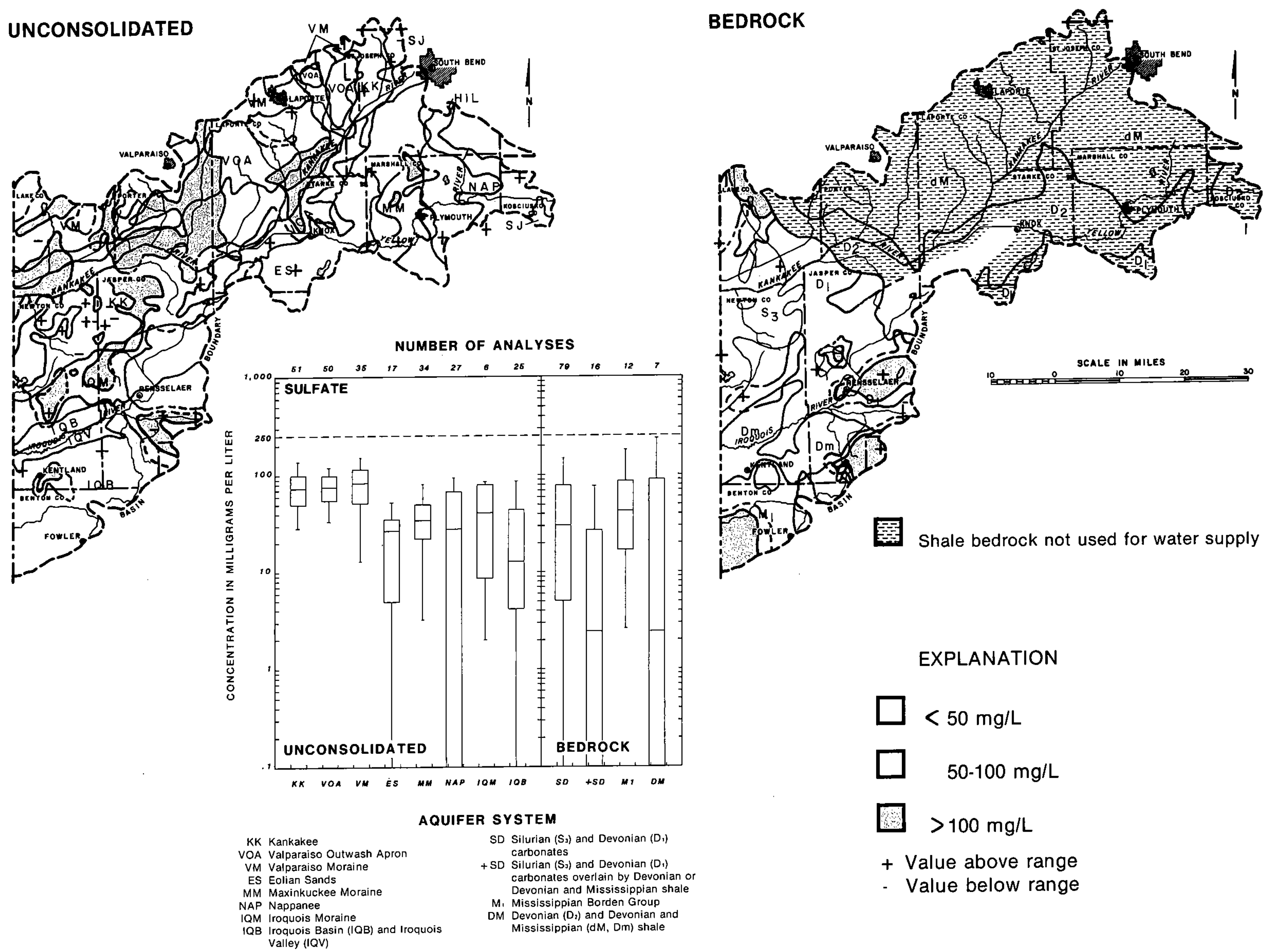


Figure 46. Generalized areal distribution and statistical summary for sulfate

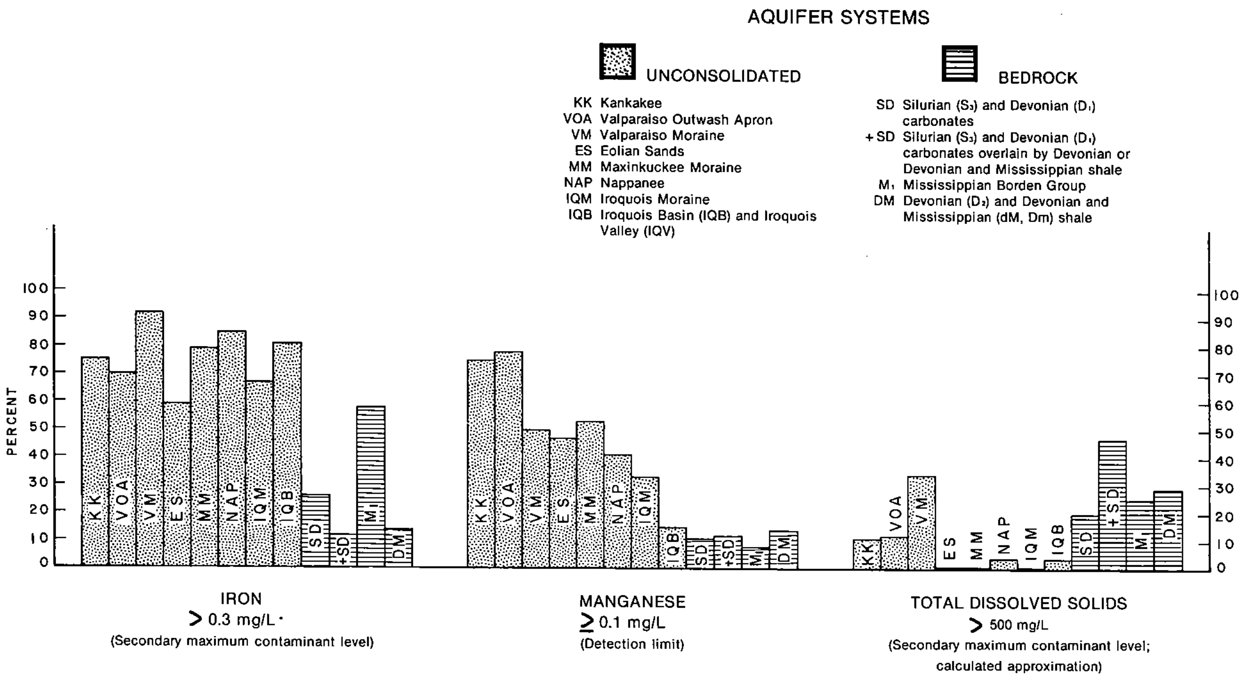


Figure 47. Percent of ground-water samples exceeding selected concentration limits

takes hydrogen sulfide to alter to sulfate when brought into an oxidizing aquifer, has yet to be fully quantified.

Iron and manganese

Iron concentrations commonly exceed the SMCL of 0.3 mg/L in unconsolidated aquifer systems (figures 47 and 48). Median concentrations range from 0.4 mg/L in the Eolian Sands Aquifer System to 2.2 mg/L in the Valparaiso Moraine Aquifer System.

Oxidation of pyrite may produce high iron concentrations in the Kankakee, Valparaiso Moraine, and Valparaiso Outwash Apron Aquifer Systems. The occurrence of high sulfate concentrations in many samples containing high iron concentrations is one indication that pyrite may be a source of dissolved iron.

In the Valparaiso Moraine, Eolian Sands, Nappanee, and Maxinkuckee Moraine Aquifer Systems, iron concentrations often are higher in deep wells than in shallow wells. Reducing conditions in deep, confined aquifers may have increased the solubility of ferric hydroxide minerals, thus producing dissolved iron (Hem, 1985). Several other sources of iron, however, may be present in a single aquifer system.

The SMCL for iron is less commonly exceeded in bedrock systems than in unconsolidated deposits (figures 47 and 48). Although more than half of all samples in the Mississippian Borden Group have iron concentrations exceeding the SMCL, median iron concentrations in the other three bedrock systems are less than the detection limit of 0.1 mg/L. Iron concentrations, however, can be locally high, as indicated by the 90th percentiles in figure 48. High iron concentrations are known to occur locally in the Silurian and Devonian carbonates in southern Lake County (Hartke and others, 1975).

Low iron concentrations in the bedrock systems may be explained by precipitation of iron minerals from activity of reducing bacteria (Hem, 1985) or by the loss of iron from cation-exchange processes occurring in the semiconfining clay, till or shale which overlies bedrock (Rosenshein and Hunn, 1968a).

Manganese typically is less abundant than iron in natural waters (Hem, 1985) and rarely exceeds 1.0 mg/L in the Kankakee River Basin. Manganese has a low SMCL (0.05 mg/L) because even in small quantities this constituent can cause objectionable taste and deposition of black oxides. Because the analytical detection limit of 0.1 mg/L is twice the SMCL, the

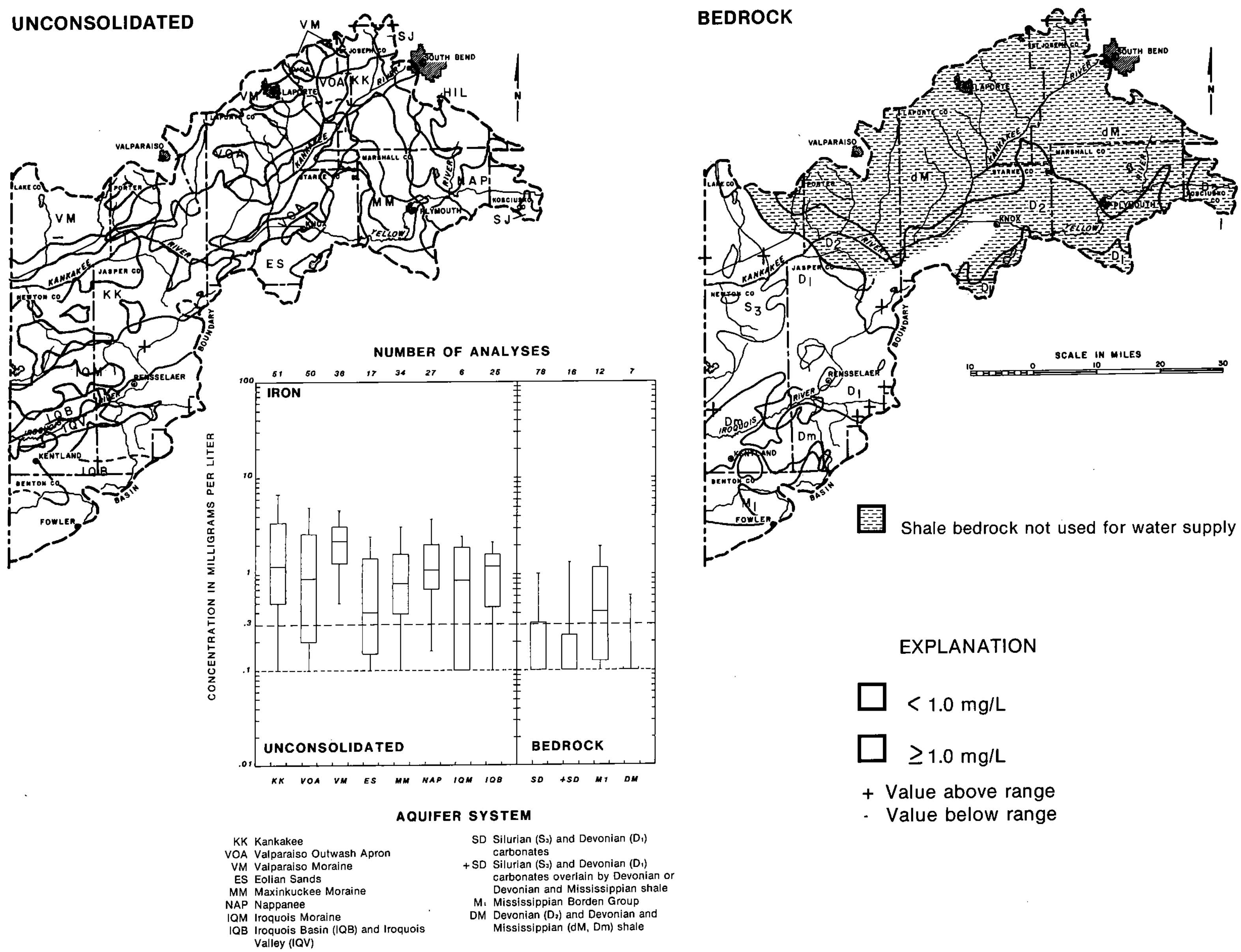


Figure 48. Generalized areal distribution and statistical summary for iron

percentage of samples exceeding the standard cannot be quantified for DOW-IGS samples. In some unconsolidated systems, exceedance of the detection limit and therefore the SMCL is common, especially in the Kankakee and Valparaiso Outwash Apron Aquifer Systems (figure 47). Manganese concentrations greater than 0.1 mg/L are less common in the Iroquois Basin, Iroquois Moraine, and Nappanee Aquifer Systems.

Manganese concentrations are generally lower in bedrock systems than in unconsolidated systems. Less than 15 percent of samples in any bedrock system contain manganese levels greater than 0.1 mg/L and all median values are below the detection limit.

Fluoride

Fluoride levels in unconsolidated systems of the Kankakee River Basin are generally less than 1.0 mg/L, and in DOW-IGS samples of 1986 there are no exceedances of either the SMCL (2.0 mg/L) or the MCL (4.0 mg/L). The highest fluoride levels (generally between 0.5 mg/L and 1.0 mg/L) occur in the Iroquois Basin, Iroquois Moraine, and the Nappanee Aquifer Systems.

The bedrock systems generally have higher fluoride concentrations than do most of the unconsolidated systems, and portions of all bedrock units contain fluoride levels greater than 0.5 mg/L. Samples from six bedrock wells (four in the Silurian and Devonian System and two in the shale-capped Silurian and Devonian carbonates) contain fluoride concentrations above the SMCL. Groundwater from two of the four Silurian and Devonian wells also exceed the MCL.

Areas of high fluoride concentrations in the bedrock tend to coincide with areas of low hardness and calcium (figures 45 and 49). This relationship of fluoride, calcium, and hardness may be due to processes affecting the solubility of fluorite and other sources of calcium (Hem, 1985).

High flouride levels and reduced water hardness occur along the Indiana-Illinois state line in Newton County. In Lake County, fluoride concentrations increase and calcium levels and hardness decrease toward the pumping center for Lowell's municipal water supply. To achieve the MCL for fluoride in drinking water, the municipality of Lowell mixes ground water from several sources (A. Viere, Indiana Department of Environmental Management, personal communication, 1989).

Nitrate-nitrogen

Nitrate-nitrogen data from a study by Indiana University (1985) and the joint DOW-IGS basin assessment are evaluated in the context of concentration ranges as defined by Madison and Brunett (1984). These ranges reflect background levels and varying degrees of human influence. The concentration categories include 1) less than 0.20 mg/L, which represents natural, or background levels; 2) 0.21 to 3.0 mg/L, which represents concentrations considered to be transitional between natural levels and those due to human influence; 3) 3.1 mg/L to 10.0 mg/L, which indicates human activity such as the presence of leachates of industrial and agricultural chemicals or decaying organic matter such as animal waste or sewage; and 4) concentrations exceeding the MCL of 10 mg/L, the level associated with *methemoglobinemia* in infants.

Because analytical detection limits vary among laboratories it was difficult to evaluate the occurrence of background concentrations using data from several agencies. For this report, the detection limit of 0.30 mg/L was selected to represent near-background levels.

In most areas of the basin, nitrate concentrations are at or below the near-background level of 0.30 mg/L in both unconsolidated and bedrock systems. Of all 733 samples in the DOW-IGS and Indiana University data sets combined, more than three-fourths of the samples contain nitrate levels less than 0.30 mg/L. Median nitrate concentrations in DOW-IGS samples from unconsolidated systems are less than 0.02 mg/L, (figure 50) and median concentrations from bedrock aquifers are less than 0.5 mg/L.

Nearly 20 percent (140 wells) of all DOW-IGS and Indiana University samples show elevated nitrate levels, but most of these analyses (98 wells) are in the range considered as transitional between near-background levels and human influence (0.31 mg/L to 3.0 mg/L). DOW-IGS data reveal that transitional nitrate levels in bedrock units are found mostly in the Silurian and Devonian Aquifer System but can occur in almost all unconsolidated deposits.

About 3 percent (24 wells) of the analyses show nitrate levels between 3.0 mg/L and 10.0 mg/L. According to DOW-IGS data, five of 10 unconsolidated wells are located in the Kankakee Aquifer System, which has been designated as susceptible to contamination (Indiana Department of Environmental Management, [1988]).

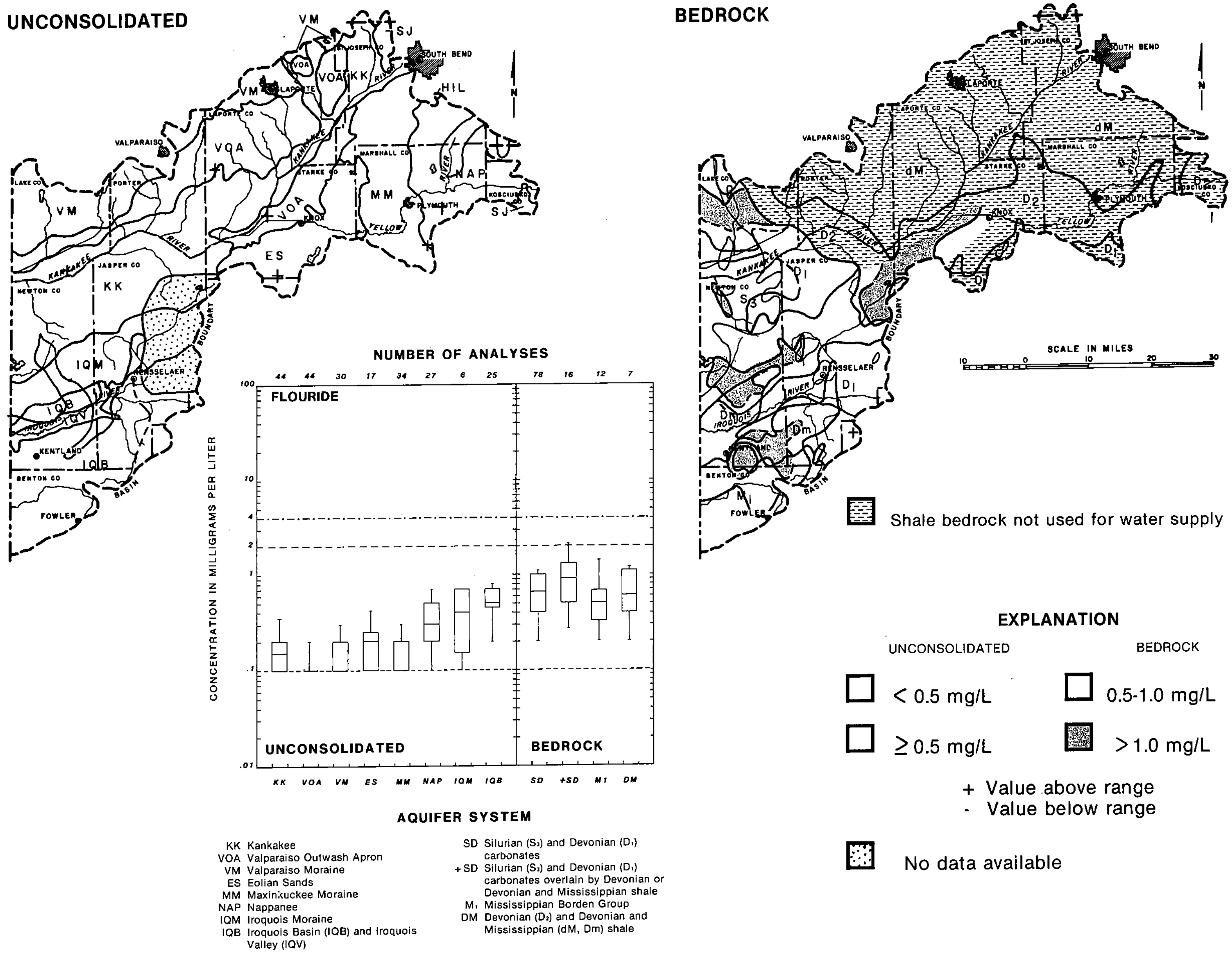


Figure 49. Generalized areal distribution and statistical summary for fluoride

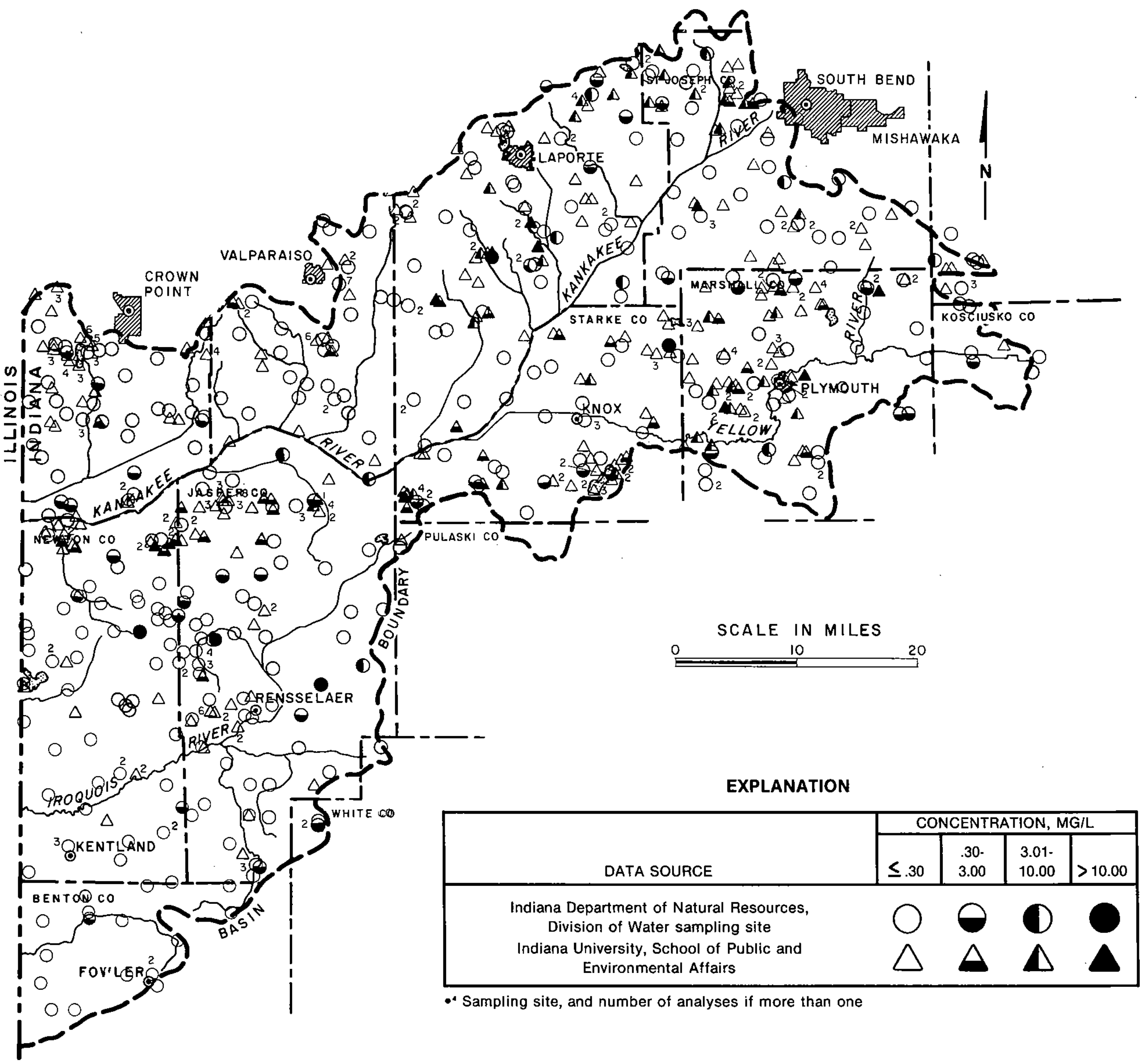


Figure 50. Distribution of nitrate-nitrogen concentrations for wells sampled in bedrock and unconsolidated deposits

About 2 percent (18 wells) of all DOW-IGS and Indiana University analyses show nitrate levels above the MCL of 10 mg/L. According to DOW-IGS data, MCL exceedances occurred in water from five wells, one each in the Kankakee, Valparaiso Outwash Apron, Eolian Sands, and Iroquois Moraine Aquifer Systems and the Silurian and Devonian System (figure 50).

Strontium and barium

Strontium, one of the less common alkaline-earth metals, rarely exceeds 1.0 mg/L in ground water of the Kankakee River Basin. In unconsolidated deposits, median strontium concentrations are at or near the detection limit of 0.1 mg/L except for the Iroquois

Moraine and Iroquois Basin Aquifer Systems, where the median concentration is 0.7 mg/L. In bedrock units, strontium is generally slightly higher than in unconsolidated systems. All median levels are above the detection limit, and range from 0.4 mg/L to 0.7 mg/L.

Barium is a minor ground-water constituent in the Kankakee River Basin and generally is present in much lower concentrations than strontium. For both unconsolidated and bedrock systems, median levels are at or below the detection limit of 0.1 mg/L. In bedrock systems, barium levels can be locally high, but exceed the MCL of 1.0 mg/L in only two samples.

Total dissolved solids

Total dissolved solids (TDS), a measure of the concentration of dissolved mineral constituents in water, typically are present in unconsolidated systems in concentrations less than 700 mg/L. The lowest TDS concentrations are found primarily in the Eolian Sands Aquifer System (figure 51), but low TDS levels also occur locally in other unconsolidated systems. There are no exceedances of the 500 mg/L SMCL standard in the Eolian Sands, Maxinkuckee Moraine, and Iroquois Moraine Aquifer Systems; however, concentrations exceeding 500 mg/L can be found occasionally in other unconsolidated deposits (figure 47). In the Valparaiso Moraine Aquifer System, the most highly mineralized of all the unconsolidated deposits, about one-third of the samples have TDS concentrations exceeding the SMCL.

The Valparaiso Moraine has the highest median TDS concentration (449 mg/L) and the highest median hardness, alkalinity, calcium, magnesium, potassium, iron, and sulfate concentrations. In contrast, median levels for these constituents (except sulfate) are lowest in the Eolian Sands. The differing concentrations indicate that the amount of carbonate materials and ground-water residence time exert substantial control over the levels of chemical constituents in ground water.

TDS levels generally are higher in the bedrock systems than in the unconsolidated deposits but are still mostly less than 700 mg/L. SMCL exceedances occur in localized areas of all bedrock aquifer systems (figure 51). In the shale-capped Silurian and Devonian carbonate system, nearly half of the samples contain TDS concentrations exceeding the SMCL (figure 47). Water from one livestock well contains more than 2000 mg/L TDS.

Of the bedrock systems, the shale-capped Silurian and Devonian carbonate system contains the highest median TDS levels and also the highest median alkalinity, chloride, potassium, sodium, and fluoride concentrations. The high TDS levels are probably due to cation-exchange processes in the shale cap or overlying glacial deposits. The exchange of calcium for sodium results in high sodium levels, and total dissolved solids increase in ground water when calcium ions are exchanged for sodium ions (Freeze and Cherry, 1979).

Wells completed in bedrock aquifers and used for drinking water in the Kankakee River Basin are rarely deeper than 400 feet and generally contain TDS concentrations less than 1000 mg/L. Water in much deeper bedrock aquifers, however, is saline, containing TDS levels greater than 10,000 mg/L (J. Rupp, Indiana Geological Survey, personal communication, 1989). In the Kankakee River Basin, saline water is encountered in Cambrian and Ordovician rock units. Brines, or water having chloride concentrations greater than 100,000 mg/L, occur in the basal sandstone unit of the Cambrian system (Hartke and others, 1975). Ground water in these deep systems is highly mineralized from temperature, pressure, age, and natural filtering mechanisms (Freeze and Cherry, 1979). Because concentrations of chloride and total dissolved solids can exceed U.S. EPA standards substantially, use of water from these formations for public supply is restricted.

Ground-water contamination

A ground-water supply that under natural conditions would be acceptable for a variety of uses can be affected by contamination from human activities. Contamination, as defined by the Indiana Department of Environmental Management ([1988]), occurs when levels of contaminants are in excess of public drinking-water standards, proposed standards, or health-protection guidance levels promulgated by the USEPA.

Inorganic and organic substances contaminating ground water in Indiana can include petroleum and petroleum products; metals; chlorides and salts; nitrates; pesticides; and chlorinated, non-halogenated, and aromatic *volatile organic compounds* (VOCs). About two dozen cases of ground-water contamination within the Kankakee River Basin have been documented by the IDEM in the mid-1980s. A registry

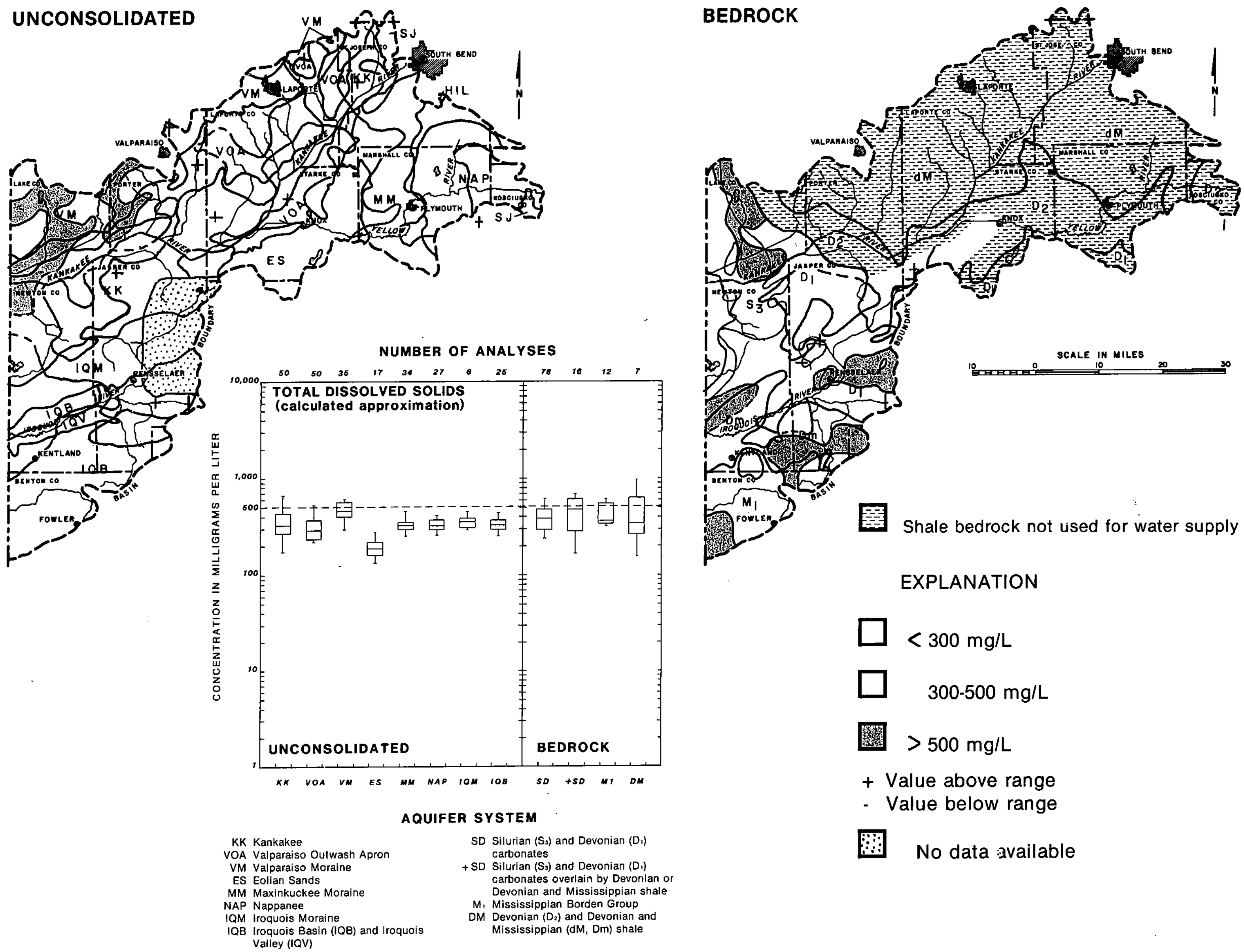


Figure 51. Generalized areal distribution and statistical summary for total dissolved solids

of these case histories is maintained by the IDEM and provides additional details on chemical contamination.

Recent studies

VOCs have been the focus of numerous monitoring activities. VOC occurrences in ground water in the Kankakee River Basin have been detected through monitoring efforts and studies conducted by the USEPA, the IDEM, and Indiana University.

Since 1981, the USEPA has been conducting a survey in Indiana on the occurrence of 26 volatile organic compounds (VOCs) in the ground-water supplies of more than 400 community water systems each serving more than 25 persons year-round. In the Kankakee River Basin, detectable levels of at least one VOC were found in the raw water of public supplies for Newton, Jasper, and in-basin portions of Porter and Marshall Counties (Indiana Department of Environmental Management, [1988]). If VOC levels were above USEPA standards in both raw and finished water, corrective action was taken such as well abandonment, mixing of water supplies, or use of treatment systems. For other water supplies, the water utilities were advised to continue monitoring if there were detectable levels of VOCs.

Beginning in 1989, the USEPA has required communities serving more than 3300 residents to monitor their finished water supplies for 59 VOCs and other organics. In the future, results from this monitoring could provide information on the occurrence of VOCs in some ground-water supplies.

From a subset of the wells selected for DOW-IGS sampling in 1986, the IDEM analyzed 23 well-water samples for 18 halogenated, two non-halogenated, and four aromatic VOCs. None of the wells sampled contained concentrations of these VOCs above the detection limit.

Other well-water samples were collected in the summer of 1988 for VOC analysis during the second phase of an USEPA-funded study on non-community water systems conducted by Indiana University. Data will be available for approximately 47 sampling sites in the in-basin portions of Marshall, St. Joseph, LaPorte, Starke, Jasper, Newton, Lake, Porter, and Elkhart Counties.

While VOCs often are associated with point-source pollution, pesticides are more typically involved in nonpoint-source impacts on ground water. In Indiana, however, there is generally less information on pesticide contamination than for other substances in ground water. The IDEM analyses of samples from 23 wells selected for DOW-IGS basin assessment and a study by Purdue University (Turco and Konopka, 1988) provide some information on pesticide occurrence in the Kankakee River Basin.

The IDEM analyzed water samples for 10 pesticides from the subset of 23 wells which were tested for VOCs. One well contained Lasso (Alachlor) levels close to the USEPA health advisory of 1.5 mg/L (U.S. Environmental Protection Agency, 1985a). Ground-water conditions may vary over time at this site, as indicated by the fluctuation of alachlor concentrations in duplicate samples taken at different times. The presence of Alachlor may be due to improper well construction or a Lasso application washed into the well by rain, but there was insufficient information to determine the exact cause of contamination. No pesticides were detected in any of the other sampled wells.

In 1987-1988 Purdue University studied the effects of agricultural activities such as pesticide applications and confined feedlots on ground-water quality (Turco and Konopka, 1988). A total of 19 farm wells in Newton and Jasper Counties were monitored for various chemicals including five pesticides and nitrate-nitrogen. Well placement, well depth, soil types, and results of seasonal sampling were evaluated in an attempt to determine patterns of agricultural contamination.

Pesticide contamination of wells was not extensive in the Purdue study area. Of the 153 samples collected in Newton and Jasper Counties over a one-year period, only one well exhibited contamination by the pesticides Atrazine, Alachlor, and Metolachlor. Pesticide occurrence was considered transient and localized because 1) most concentrations were detected briefly in August, and 2) a nearby deeper well did not contain detectable levels of any of the three pesticides (Turco and Konopka, 1988). Because Metolachlor is considered nonleachable, its occurrence may reflect activity at the well head.

Analyses of samples collected as part of the Purdue study showed some occurrence of elevated nitrate levels in the Kankakee River Basin. One well each in Newton and Jasper Counties contained average nitrate-nitrogen concentrations above the MCL of 10 mg/L. In addition, three wells (two in Newton County and one in Jasper County) contained average nitrate-nitrogen concentrations greater than 1 mg/L, a level that is indicative of the potential for the development of human and animal health problems (Turco and Konopka, 1988; also see Madison and Brunett, 1984).

The Purdue study did not directly trace elevated nitrate-nitrogen levels to either feedlot waste or fertilizer application as the major contributing factor in their study area. However, the study suggested that factors contributing to variability in nitrate concentrations include drainage characteristics of soil and horizontal and vertical separation distances from potential nitrate sources.

A 1989 pesticide survey conducted by the IDEM revealed detectable levels of nitrate occurring at least once in each of 25 wells completed in or passing through the Kankakee Aquifer System in Newton County (Indiana Department of Environmental Management, [1990]). The MCL for nitrate was exceeded in four of these wells. In addition, eight pesticides were detected in three wells.

In a 1977 ground-water survey conducted by the Michiana Area Council of Governments, it was found that 72 out of 1055 water-well samples contained nitrate-nitrogen concentrations in excess of 10 mg/L. In the area encompassed by the survey, including Elkhart, LaPorte, Marshall, and St. Joseph Counties, many of these exceedances were clustered in localized areas (Michiana Area Council of Governments, 1978).

Information pertaining to potential agricultural impacts on ground-water was obtained during a 1981 ground-water strategy study in Lake and Porter Counties (Indiana State Board of Health, 1982). The purpose of the study was to evaluate the circumstances surrounding ground-water contamination in urban and rural settings so that the adequacy of Indiana's laws, regulations and policies for ground-water protection could be ascertained. Two agricultural areas in this study that are located in the Kankakee River Basin include the Schneider-Shelby area in Lake County and the Kouts area in Porter County. Both areas have similar land-use patterns such as confined feeding and irrigation.

Samples were tested for total organic carbon (TOC), chemical oxygen demand (COD), and common inorganic constituents and physical parameters. Six out of 30 wells sampled in the Shelby-Schneider area contained more than 5 mg/L TOC. Four out of these six wells also contained elevated COD (ranging from 17 to 25 mg/L). The study recommended additional testing in the two wells containing the highest TOC levels to identify specific organic substances and to determine the cause for contamination. In the Kouts area, one out of 13 wells sampled contained high COD and TOC, but no cause for the elevated levels was obvious.

Susceptibility of aquifers to surface contamination

The susceptibility of an aquifer system to contamination from surface sources depends in part on the type of material that forms the unsaturated layer above the water table. Contaminants can be transmitted from the surface through the unsaturated zone by percolating water. A sand-rich surficial layer can easily transmit water from the surface. A clay-rich surface deposit can limit the movement of water and contaminants carried by the water. Plate 2 briefly summarizes the susceptibility to contamination of eight unconsolidated aquifer systems in the Kankakee River Basin. The degree of protection of bedrock aquifers from contamination depends on the thickness of overlying till or clay.

The unconfined outwash aquifers of the Valparaiso Outwash Apron, Kankakee, St. Joseph, Maxinkuckee, and Hilltop Aquifer Systems and the surficial sands of the Eolian Sands Aquifer System are highly susceptible to surface contamination. These aquifer systems are particularly vulnerable where the water table is near the surface, as it is in most of the Kankakee Aquifer System.

Aquifer systems with variably thick surficial clay deposits are susceptible to surface contamination where the clay layer is absent or discontinuous. For example, the Valparaiso Moraine Aquifer System is susceptible to surficial contamination near the upper reaches of the Little Kankakee Valley where the surficial clay layer is thin or absent. West of Valparaiso, however, the intratill aquifers may be only slightly susceptible because they are overlain by consistently thick surficial clay deposits.

In some areas along the extent of the Eolian Sands Aquifer System, deep sand and gravel lenses are overlain by a thick till. This low-permeable layer restricts migration of contamination from surficial deposits. Thick clay deposits also protect the intratill aquifers of the Nappanee, Iroquois Moraine, and Iroquois Basin Aquifer Systems and the Iroquois Buried Valley Subsystem.

WATER RESOURCE DEVELOPMENT

The potential for agricultural and economic development partially depends on the availability of adequate supplies of surface water and ground water. Surface-water withdrawals are expected to remain high in areas along the lower Kankakee River and its major tributary ditches, where stream flow provides an adequate and dependable supply. Ground-water withdrawals are expected to remain high in the main Kankakee River valley where outwash deposits and carbonate systems can sustain high-capacity pumpage.

As water demands in the basin continue to grow, it will be necessary to develop additional surface-water and ground-water supplies, protect the quantity and quality of existing supplies, and increase the efficiency of water use. Although pumpage-induced drawdown of ground-water levels and heavy withdrawals from tributary ditches may cause recurrences of localized or short-term conflicts among water users, surface-water and ground-water supplies in most of the basin should be adequate to satisfy a variety of water demands in the coming decades.

WATER USE AND PROJECTIONS

The total demand for water in the Kankakee River Basin is expected to increase in future decades as the population and economy continue to grow. Annual water withdrawals for the major water-use categories were *projected* through the 1990s to help identify areas of potential conflict between supply and demand. Projections beyond the year 2000 were not included because of data limitations and the variability of socioeconomic factors.

Withdrawal uses

Withdrawal uses involve the physical removal of water from its surface-water or ground-water source. As discussed in the ***Socioeconomic Setting*** chapter of this report in the section entitled ***Water-Use Overview***, the Division of Water maintains a registry of facilities capable of withdrawing at least 100,000 gallons per day of surface water, ground water, or surface water and ground water combined. The division also maintains reports of annual water use for registered facilities. Reported water use is determined by metering devices, the multiplication of pump capacity and total time of pumpage, or other methods approved by the Division of Water.

It should be emphasized that the term ''water use'' in this report refers both to the total amount of water withdrawn from available sources and to the intended purpose of the withdrawal. The term ''use'' does not refer to the amount of water which is consumed, or made unavailable for reuse within a fairly short period of time.

The portion of withdrawn water that is consumed varies with the intended purpose of the withdrawal. Livestock watering and irrigation are estimated to consume from 80 to 100 percent of the withdrawn water. Energy production, public supply and industrial uses generally consume between 3 and 25 percent. Because most of the water withdrawn for these latter three purposes is returned to surface-water or ground-water systems within a short time period, less potential exists for significant impacts on water availability.

It also should be noted that the term ''withdrawal capability'' represents the amount of water which theoretically could be withdrawn by registered facilities if all pumps were operating at their rated capability 24 hours a day. However, because few facilities in the basin operate in this manner, reported use constitutes only a small percentage of the total withdrawal capability. During 1987, owners of registered facilities in the Kankakee River Basin reported withdrawals totaling only about 5 percent of the total withdrawal capability.

Basin overview

A total of 533 significant water withdrawal facilities representing about 570 wells and 230 surface-water intakes were registered in the Kankakee River Basin in 1987, the base year for this report. These facilities had a combined withdrawal capability of 1366 million gallons a day (mgd), and reported withdrawals of 25.2 billion gallons, or 69 mgd. As figure 52 shows, most of the registered facilities are located in the main valley of the Kankakee River.

During the drought conditions of 1988, 18 new facilities were registered, adding 175 mgd of withdrawal capability and 41 mgd of reported use. Sixteen of the new facilities were registered in the irrigation category.

Non-registered uses in the Kankakee River Basin include domestic wells, livestock operations, and other facilities capable of withdrawing less than 100,000 gallons of water per day. The total water use for any non-registered facility is fairly small, but the aggregate demand for domestic self-supply and livestock watering purposes is notable.

Nearly equal amounts of water are withdrawn from surface-water and ground-water sources throughout the entire Kankakee River Basin; however, the major water source differs among individual categories. Water withdrawn for energy production primarily is from surface water, whereas most of the water for public and domestic supply is from wells. Water for irrigation is obtained both from surface-water and ground-water sources (figure 53).

About one-third of all water withdrawals in the Kankakee River Basin were for irrigation purposes, and another third were for public and domestic water supply. About one-fourth of the total water withdrawals were related to energy production.

Registered facilities

The reported water use by category and county in 1987 and 1988 is summarized in table 21. As the table shows, total reported water withdrawals are highest in Jasper, St. Joseph and LaPorte Counties.

Appendix 15 summarizes, by county and by water source, the withdrawal capability and reported use by registered facilities in calendar years 1986-88 for all water-use categories combined. Appendices 16-19 present similar information for each water-use category.

Irrigation

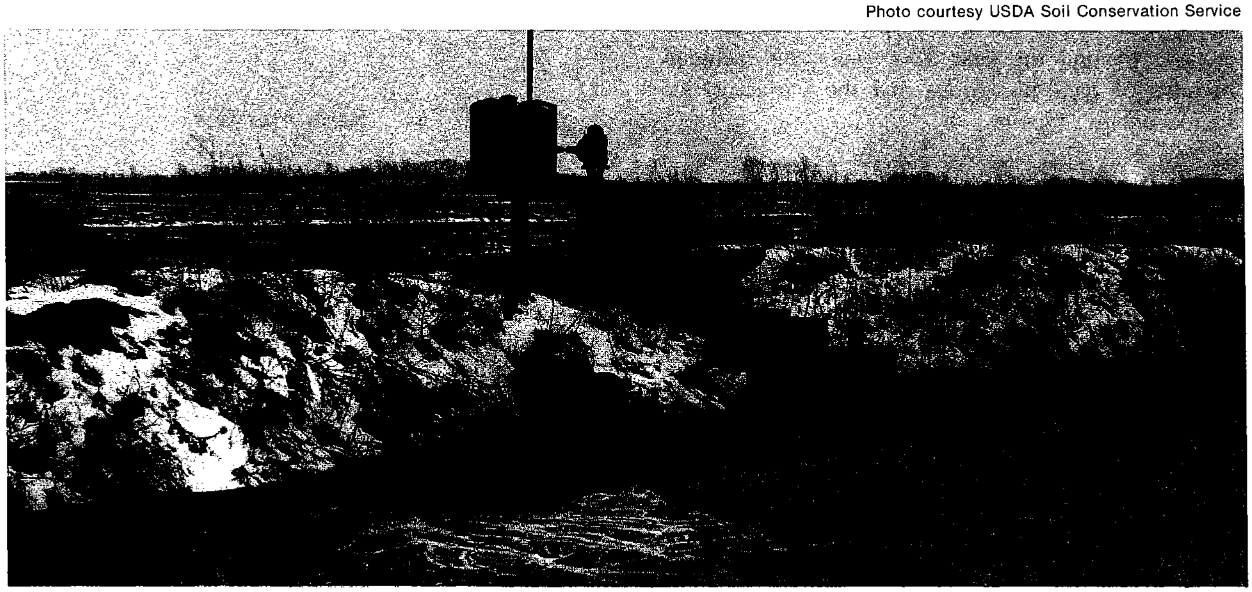
Irrigation water use refers to withdrawals for both agricultural and non-agricultural purposes, such as golf-course irrigation. In the Kankakee River Basin, most irrigation withdrawals are for agricultural purposes.

It should be emphasized that some water-withdrawal facilities categorized by the IDNR Division of Water as agricultural irrigation facilities do not apply water to crops. Instead, excess water is pumped from agricultural land to improve field drainage. The amount of water withdrawn in the Kankakee River Basin for drainage purposes in 1987 constituted about 2 percent of the water withdrawn in the irrigation category.

Irrigation is a seasonal water use that artificially replaces water in the root zone of droughty soils. Because irrigation water primarily is intended to replace water transpired by the irrigated crop, irrigation withdrawals are treated as a totally consumptive use.

Agricultural irrigation in Indiana is most intensive in northwest and north-central regions, including the Kankakee River Basin. The large amount of irrigation

Photo courtesy USDA Soil Conservation Service



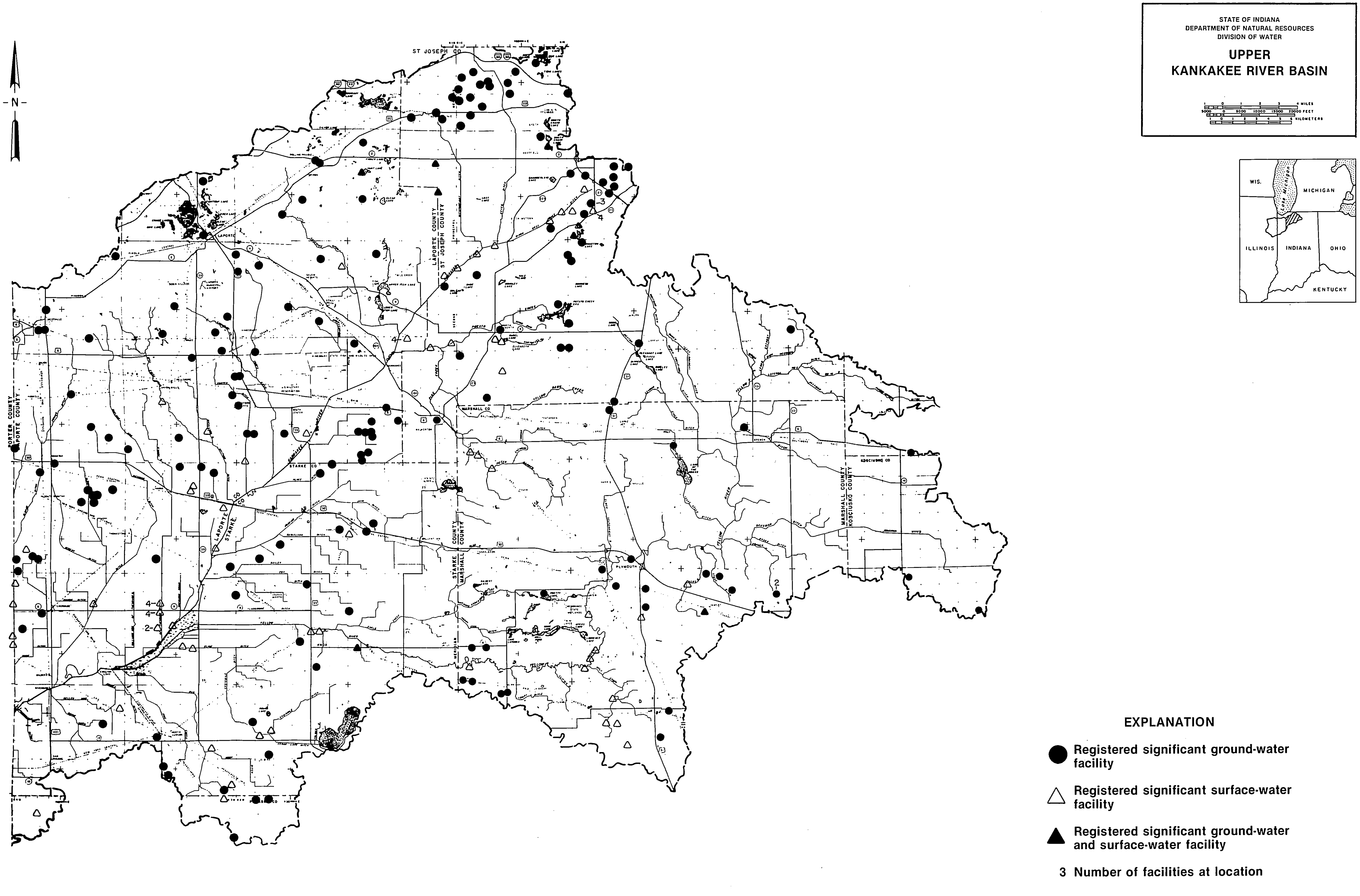


Figure 52a. Location of registered water withdrawal facilities

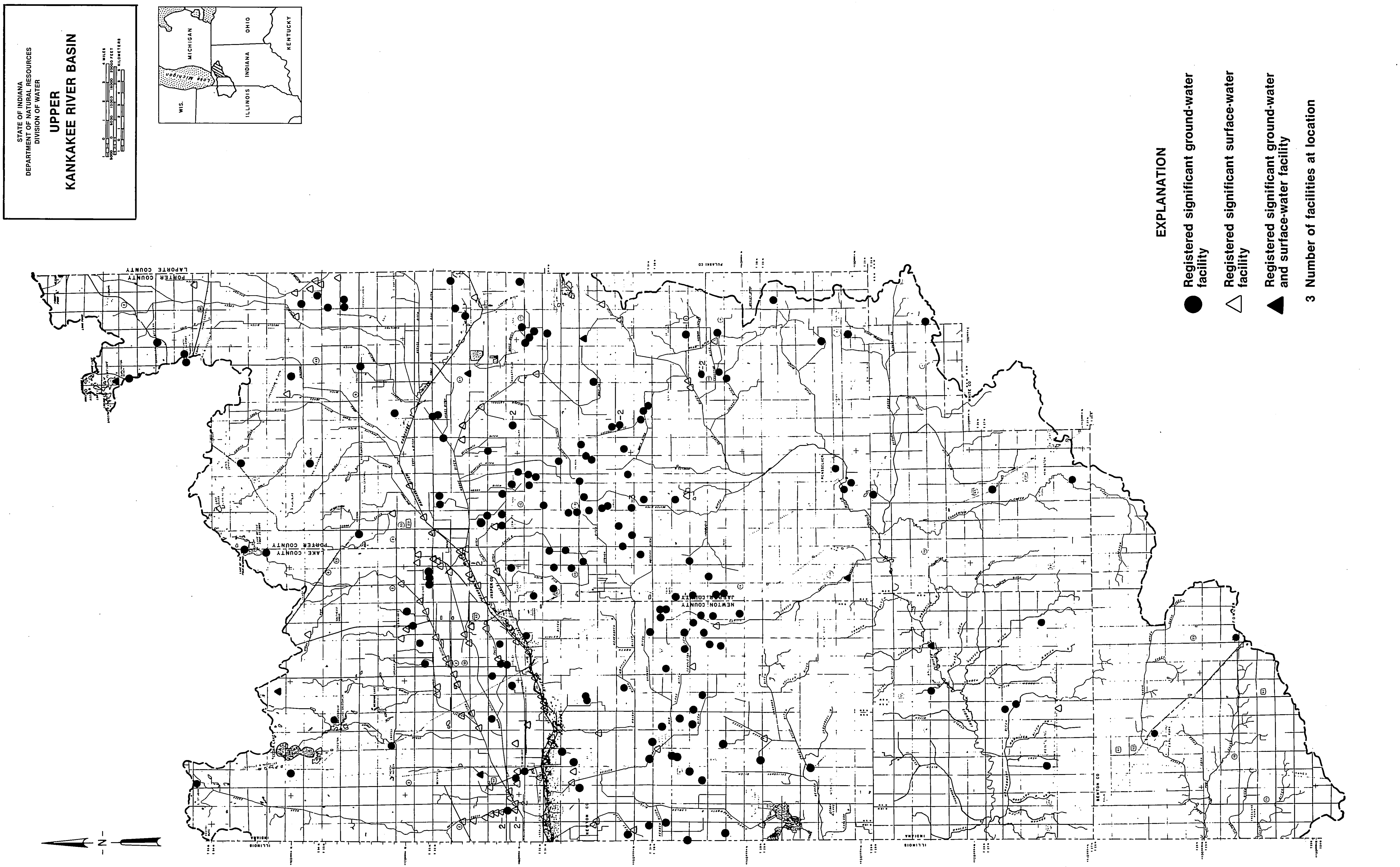


Figure 52b. Location of registered water withdrawal facilities

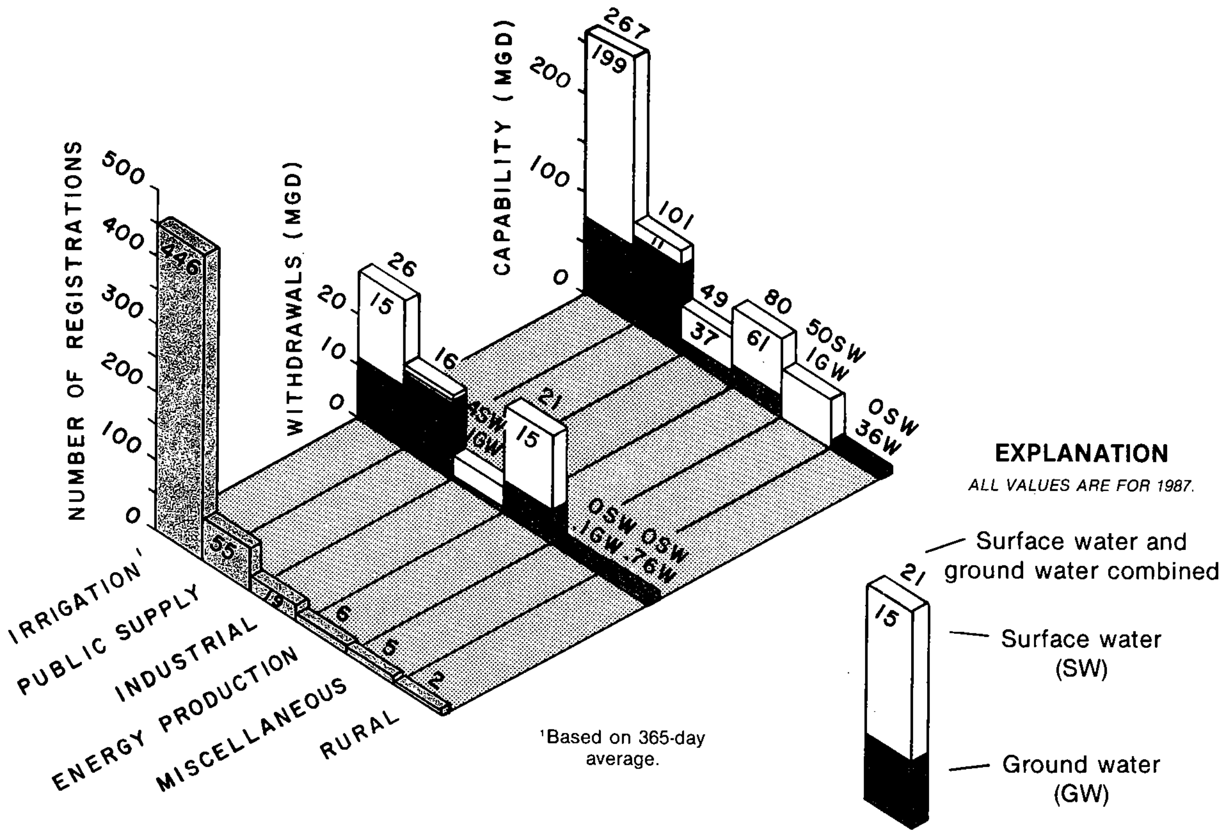


Figure 53. Number of registered water-withdrawal facilities, withdrawal capability, and reported water use

in northern Indiana reflects not only the availability of adequate surface-water and ground-water supplies, but also the suitability of soils, the presence of adequate drainage (either natural or artificial), the large areas having low relief, and the predominance of crops which respond favorably to irrigation.

In 1987, the Kankakee River Basin accounted for about one-third of the total number of Indiana's registered irrigation facilities, about one-third of the state's irrigated land, and 43 percent of the state's reported withdrawals in the irrigation category. In 1988, a drought year, the Kankakee River Basin constituted 47 percent of Indiana's reported irrigation water use.

The large amount of water withdrawn for irrigation in the Kankakee River Basin is used on a relatively small number of farms. In the basin's eight major counties where irrigation is extensive, an average of 7 percent of the 5400 farms utilize irrigation. Moreover, irrigated land in the eight counties represents less than 5 percent of the total cropland area of 1.5 million acres (U.S. Bureau of the Census, 1989).

Even though the number of farms using irrigation and the acreage of irrigated land are small, water withdrawals in the irrigation category during 1987 constituted about one-third of all water withdrawals in the Kankakee River Basin. Moreover, average irrigation withdrawals during the 90-day period of June, July and August exceeded withdrawals for public supply, energy production and industrial uses (figure 54). The 90-day average daily withdrawal for irrigation purposes was 106 mgd, which is approximately four times greater than the 365-day average of 26 mgd.

Appendix 16 summarizes, by water source, the withdrawal capability and reported use by registered irrigation facilities in each county of the Kankakee River Basin in calendar years 1986-88. (Values are presented as 90-day averages.) Table 22 summarizes irrigation data for 1987, but presents data for entire counties rather than in-basin areas.

Table 21. Annual reported water use for registered facilities

{Upper numbers denote average water use in million gallons per day; lower numbers denote number of registered facilities. Rural and miscellaneous water use did not differ significantly from 1987 to 1988.}

County	Irrigation		Energy production		Public supply		Industrial		Rural and miscellaneous	Total[2]	
	1987	1988	1987	1988	1987	1988	1987	1988	1987	1987	1988
Benton	0	0	0	0	0.23	0.26	0	0	0	0.23	0.26
	0	0	0	0	2	2	0	0	0	2	2
Elkhart	0	0	0	0	0	0	0.04	0.04	0	0.04	0.04
	0	0	0	0	0	0	1	1	0	1	1
Jasper	6.83	17.12	15.43	17.93	1.10	1.15	1.35	1.48	0	24.71	37.63
	104	111	1	1	4	4	2	2	1	112	119
Kosciusko	0.06	0.11	0	0	0	0	0	0	0	0.06	0.11
	2	2	0	0	0	0	0	0	0	2	2
Lake	4.38	10.93	0	0	1.75	1.97	0	0	0	6.14	13.62
	75	76	0	0	6	6	0	0	0	81	83
LaPorte	5.29	10.91	0.60	0.56	4.43	4.48	0.15	0.18	0.66	11.13	16.75
	84	87	2	2	10	10	4	4	2	102	105
Marshall	0.59	1.25	0	0	2.42	2.61	0.27	0.24	0	3.28	4.10
	27	28	0	0	5	5	4	4	0	36	37
Newton	3.00	6.65	0	0	0.62	0.74	0.17	0.31	0	3.79	7.68
	49	48	0	0	6	6	1	1	1	57	56
Porter	1.34	3.04	0	0	3.78[1]	4.16[1]	0.01	0.01	0.06	5.19	7.27
	23	26	0	0	5	5	1	1	1	30	33
Pulaski	0.05	0.30	0	0	0	0	0	0	0	0.05	0.30
	4	5	0	0	0	0	0	0	0	4	5
St. Joseph	3.73	8.58	5.13	4.03	0.83	3.19	2.94	3.08	0	12.63	18.86
	52	51	3	3	13	13	4	5	1	73	73
Starke	0.87	2.50	0	0	0.69	0.81	0.01	0.01	0	1.57	3.32
	26	28	0	0	4	4	2	2	0	32	34
White	0	0	0	0	0	0	0	0	0.08	0.08	0.08
	0	0	0	0	0	0	0	0	1	1	1
Total[2]	26.14	61.40	21.15	22.52	15.85	19.37	4.94	5.35	0.81	68.90	110.02
	446	462	6	6	55	55	19	20	7	533	551

[1]Includes withdrawals by the city of Valparaiso, which lies primarily outside of the basin.
[2]Totals may not equal sum of county values because of differences in rounding.

As table 22 shows, Jasper County had the highest number of irrigation facilities and the highest reported irrigation water use in 1987. Reported irrigation withdrawals also were high in LaPorte, Lake, St. Joseph and Newton Counties.

It is interesting to note that Jasper County had the highest irrigation water use in Indiana during 1987. Elkhart County had the second highest irrigation water use, but no irrigation withdrawals occurred in the small portion of the county located within the Kankakee River Basin boundary.

Based on 1987 water-use data from the Division of Water and land-use data from the U.S. Bureau of the Census (1989), Lake and Jasper Counties had the highest per-acre water use in the irrigation category (more than 10 inches). LaPorte and St. Joseph Counties had the greatest number of irrigated acres, and a per-acre water use of 5 inches. Possible causes for the

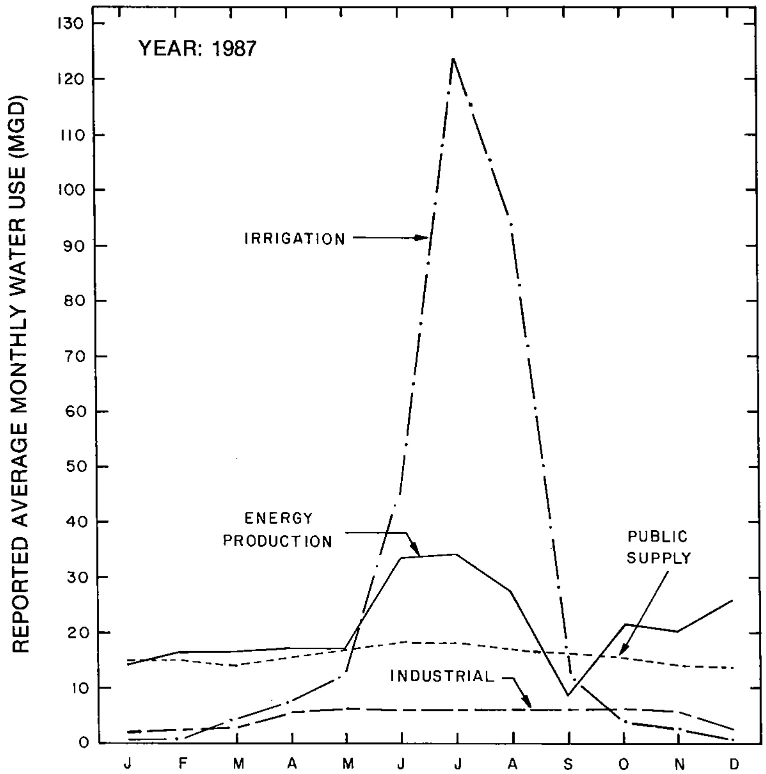


Figure 54. Variation of monthly water use

significant difference in per-acre water use among these counties include not only differences in irrigation practices, but also differences in compliance for water-use reporting and methods for estimating water use. It is also possible that some reported withdrawals were for agricultural drainage purposes rather than for irrigation.

In some counties, a relatively small number of registered irrigation facilities accounts for the majority of irrigation water withdrawals. For example, 12 registered facilities in Lake County that withdraw water from either Singleton Ditch or the Kankakee River accounted for nearly two-thirds of the county's reported irrigation withdrawals in 1987. In Jasper County, 24 facilities (registered by 10 owners) accounted for nearly three-fourths of the county's irrigation withdrawals.

As figure 53 illustrates, about 15 mgd (56 percent) of water withdrawn in 1987 for irrigation within the Kankakee River Basin was derived from surface-water sources, and about 11 mgd (44 percent) was from ground-water sources. The largest number of surface-water withdrawals occur along the Kankakee River, especially in its lower reaches, and along Singleton Ditch and other tributary ditches in Lake County (figure 52). Ground-water withdrawals occur throughout the river valley, but are slightly more common in the extreme upper and lower portions.

Although registered withdrawal capability in Jasper and LaPorte Counties are considerably greater for surface-water sources than for ground-water sources, the reported use in 1987 was fairly evenly distributed between surface water and ground water. In Lake and Porter Counties, both the capability and use predominantly were from surface-water sources. In Newton County, ground water provided more than three-fourths of the irrigation water.

The most common methods for large-scale agricultural irrigation in the Kankakee River are center-pivot sprinkler irrigation and subsurface irrigation. In a center-pivot system, water is applied to crops from sprinkler or spray heads on a pipeline supported on mobile towers. The pipeline is fixed at one end (the pivot), where it is connected to the water supply. Automated controls on the towers regulate their mo-

Table 22. Irrigated land and irrigation water use

{Values are for 1987 and are for entire counties to allow comparisons of data from different agencies.}

Irrigated farms, irrigated land: Data are from U.S. Bureau of the Census (1989).

Registered irrigation facilities, number of registered withdrawal points, irrigation water use: Data are from unpublished files of the IDNR, Division of Water. County values may differ from in-basin values shown in table 21 and appendix 16. One irrigated farm may comprise several registered facilities; one facility may encompass several withdrawal points.

Irrigation water use: Values are expressed in million gallons (mg), 90-day average in million gallons per day (mgd), inches per acre of irrigated cropland, and percent withdrawn from ground water.

County	Irrigated farms		Irrigated land		Registered irrigation facilities	Number of registered withdrawal points		Irrigation water use		
	Number	% of total farms	Acres	% of total cropland		Ground water	Surface water	mg (mgd)	inches	% GW
Jasper	49	6	9,138	3	106	132	31	2516 28.0	10	50
Lake	34	6	5,524	4	83	34	77	1766 19.6	12	13
LaPorte	78	9	15,607	7	84	72	31	1932 21.5	5	48
Marshall	44	4	4,086	2	34	25	19	316 3.5	3	74
Newton	16	3	9,874	5	49	44	13	1094 12.2	4	73
Porter	33	6	3,618	3	28	26	15	553 6.1	6	21
St. Joseph	71	8	10,632	7	70	63	28	1560 17.3	5	50
Starke	44	10	8,650	7	42	40	17	416 4.6	2	65

tion to move the pipeline slowly in an arc about the pivot.

Center-pivot towers typically are from 1000 to 2500 feet long and irrigate 1/4- to 1-square-mile plots. Large end-guns often are used to partially irrigate each corner of the field.

Subsurface irrigation continues to be a major irrigation method in Jasper, Newton and southern Lake Counties. In most cases, water-control structures in drainage ditches are closed off to retain water and consequently raise the water level. The water subsequently travels through tile lines and/or seeps through the soil layers to supply water to the root zone of crops. In some instances, ground water from wells or surface water from nearby streams or ditches is used to supplement the water supply in the ditch.

It should be noted that subsurface irrigators who do not withdraw water via pumps or intakes are not required to register with the Division of Water; hence, reported water withdrawals by registered irrigation facilities may not include all the water applied to crops for irrigation purposes.

Crops commonly irrigated by sprinkler and subsurface methods include corn, soybeans, hay and forage crops, potatoes, and mint.

Irrigation projections

In the past three decades, Indiana farmers have shown increasing interest in the irrigation of field crops. Between 1967 and 1977, the number of irrigated acres in Indiana more than doubled, from about 30,000 acres to nearly 65,000 acres (see Indiana Department of Natural Resources, 1969; Governor's Water Resources Study Commission, 1980). Between 1978 and 1987, irrigated acreage again doubled, from about 75,000 to nearly 170,000 acres (U.S. Bureau of the Census, 1984a, 1989).

Irrigation increases in major counties of the Kankakee River Basin are shown in figure 55. Average annual increases in irrigated land between 1967 and 1987 have been greatest in LaPorte County, St. Joseph County, Starke County, Newton County, and Jasper County.

Improving crop yields and protecting against crop failure during drought periods are the major incentives for utilizing large-scale irrigation systems. Other factors also have fostered interest in irrigation, including: 1) improvements in irrigation equipment; 2) rising land values; and 3) escalating costs of fertilizer, herbicides, machinery, and other crop inputs which will lose efficiency if crop yields are poor.

The demand for irrigation water, the desirability of irrigating, and the choice of an appropriate irrigation system are related to a variety of physical, economic and legal factors, including: 1) the nature of local soils and topography; 2) the specific moisture requirements of the crop under cultivation; 3) the economic costs of system operation and production; 4) the nature of the agricultural management strategy; and 5) the existence of jurisdictional or legal limitations on water use (Bedell and Van Til, 1979).

The irrigation potential of a soil, or its adaptability to irrigation, is determined by many soil properties, particularly soil texture, structure, and depth. These properties determine a soil's water-holding capacity, water intake (*infiltration*), and internal drainage (*permeability*).

In general, irrigation potential is highest on shallow, droughty, coarse-textured soils having high intake rates and good drainage. However, on soils which hold more than 4 inches of water in the root zone, the gains in crop production may not be favorable enough to economically justify irrigation (Robbins and others, 1977). Moreover, if the land is not naturally well drained, artificial drainage must be established before or at the same time the irrigation system is installed.

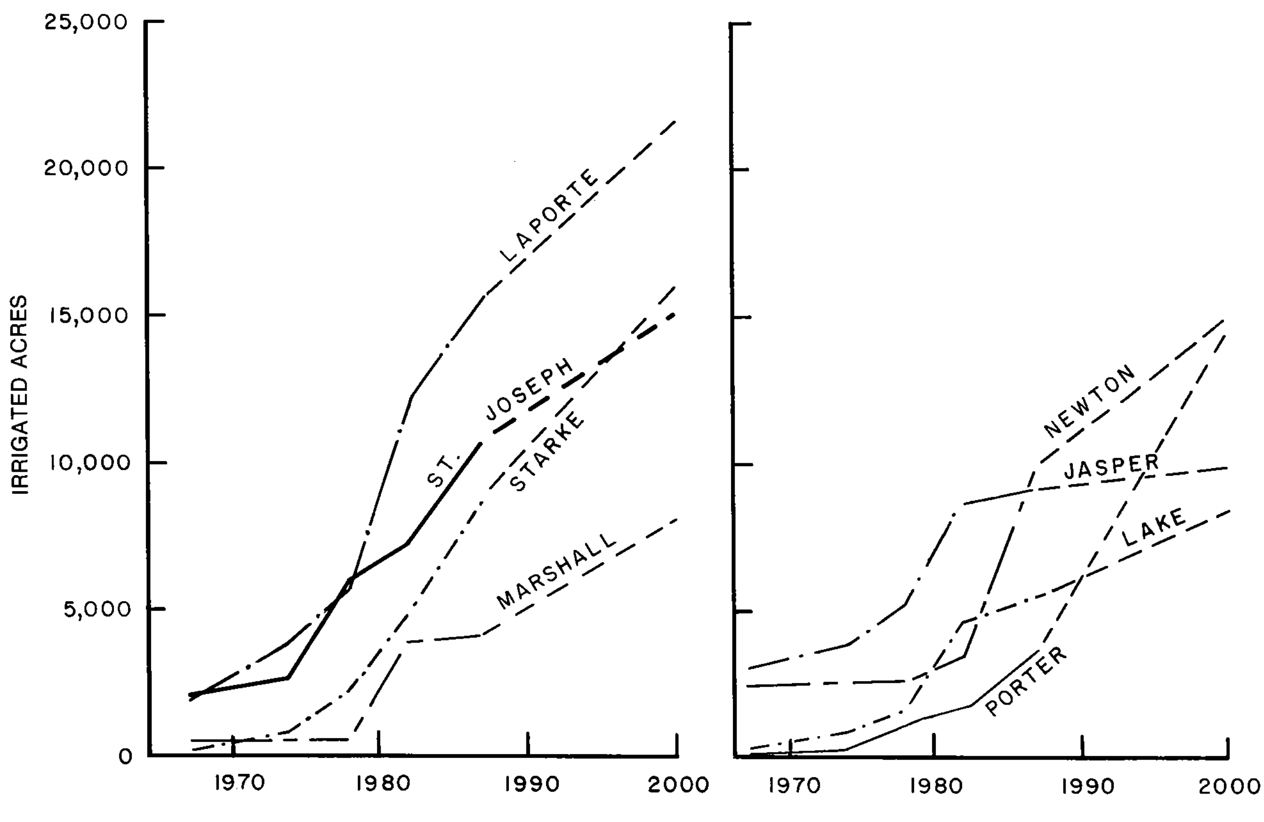


Figure 55. Historic and projected acreage of irrigated land for major basin counties

Soils in the Kankakee River Basin were evaluated for irrigation potential on the basis of major soil associations, which were described in the ***Physical Environment*** chapter of this report in the section entitled ***Soils***. Descriptions of general soil associations in the basin are found in appendix 3.

Each soil association can be assigned to one of four categories that describe the soil's response to irrigation. These categories were developed on the assumption that crop yields in sandier soils would significantly increase with irrigation, whereas yields in deep loam, silt loam, and fine-textured soils would not increase sufficiently to make irrigation profitable for grain crops at historic average corn price-to-cost ratios.

Soil associations in Group 1 and Group 2 are poorly adapated to irrigation, whereas soils in Group 3 and Group 4 are moderately to well adapted to irrigation. In this analysis, soil associations categorized into Group 1 and Group 2 are not considered further because it is assumed that a profitable response to irrigation in less than 2 years out of 5 is economically undesirable.

About 60 percent (987,000 acres) of the land area in the Kankakee River Basin falls into Groups 3 and 4 (table 23). As appendix 3 shows, these soils lie primarily in the main Kankakee River valley and in the lower Yellow River Basin.

It is estimated that at least one-fourth of the soils in Groups 3 and 4 within the Kankakee River Basin are not irrigable because of unsuitable physical characteristics, including topography. For example, irrigation is not recommended on lands having slopes greater than 6 percent.

Lands covered by lakes, rivers, and urban or built-up areas are considered as unavailable for agriculture, and consequently unavailable for irrigation. Other lands that are considered unavailable for agriculture and irrigation include public properties such as parks, wildlife refuges and nature preserves.

The percent of irrigable land actually utilized for irrigation depends on economic, farm management, and climatic factors. For example, an increase in energy prices, a decrease in corn prices, or a period of unusually wet years would probably cause a decrease in irrigation. Conversely, water use in a dry year is expected to exceed water use in a wet or average year. From 1987 (a year of average to above-average precipitation) to the drought year of 1988, irrigation water use doubled in the eight-county basin region (table 21).

Because the interactions of these and other variables cannot be predicted, recent trends in irrigation were considered too volatile to use as a basis for projecting irrigated acreage and irrigation water use. Increases in irrigated acreage provided by local county extension agents are considered to be more realistic than projections derived either from a detailed analysis of the soil maps in appendix 3 or from statistical methods.

Projections of irrigated land in the year 2000 are shown in table 24 and illustrated in figure 55 for major basin counties. Projections of irrigation water use also are given in the table. Values were computed for years of average and below-average precipitation to approximate a range in potential withdrawals. In this application, the term "dry year" does not refer to an extreme drought but to a year in which there is a sizeable deficiency in rainfall.

Table 24 also shows water-use projections derived from a ratio of irrigated cropland to reported water use for 1987. A comparison of these values with values for an average and dry year shows considerable variation among counties.

As table 24 shows, irrigation water use in the Kankakee River Basin is expected to remain high in Jasper County, even though increases in irrigated land are expected to be minor relative to other county increases. Irrigation water use also is expected to remain high in LaPorte County, which has the largest acreage of potentially irrigable soils but a high degree of urbanization and government-owned lands. The projected increase in water use for Porter County may be conservatively high, but the potential for significant irriga-

Table 23. Irrigation potential by soil associations

Category	Area
1- Little or no profitable response (none)	729,990 acres
2- Response 1-2 years in 5 years (slight)	24,800 acres
3- Response 3-4 years in 5 years (moderate)	776,100 acres
4- Response expected yearly (high)	210,600 acres

tion expansion in southern Porter County must be considered. Irrigation water use in other basin counties also is expected to increase, but the degree of increase is difficult to determine.

Energy production

Energy production, the second highest water use in the Kankakee River Basin, includes any self-supplied water withdrawal related to the energy production process,such as coal preparation, oil recovery, cooling water, mineral extraction, and power generation. Of the six facilities in the Kankakee River Basin registered under the Division of Water's energy production category (appendix 17), only one uses water directly for power generation.

The R.M. Schahfer electric generating station, owned by the Northern Indiana Public Service Company, uses a closed-cycle cooling system for its coal-fired steam turbines. The plant withdraws water from the Kankakee River for recycling between the cooling towers and the power station. Additional water withdrawn from ground-water sources is primarily used for drinking water and sanitary purposes.

The other five registered energy production facilities in the Kankakee River Basin use ground water primarily for drinking water, sanitary purposes, fire protection, process water, and cooling water. These facilities include a liquified natural gas storage facility near New Carlisle, a correctional center near Westville, an ethanol plant in South Bend, and electric-service substations in southwestern St. Joseph County.

In 1987, about 21 mgd of water was withdrawn by these six registered energy production facilities. As figure 53 illustrates, about 15 mgd (71 percent) of the water withdrawn was derived from surface water (the Kankakee River). The remainder was from ground water.

As figure 54 shows, the peak water use by energy production facilities occurs in June and July, when energy needs are high for air conditioning and other purposes. A secondary peak occurs in December when heating demands are high.

Water withdrawals for energy production are expected to increase slightly during the 1990s as the population within the basin continues to grow. Demands for energy also are expected to increase during a drought, such as the one experienced in 1988, when withdrawals in the energy production category showed a 6 percent increase over 1987 values.

Table 24. Water use projections for irrigation category

{Values, for the year 2000, are for entire counties, including non-basin areas.}

Irrigated cropland: Projections are from county extension agents.

Irrigation water use: Values for average year are based on application rate of 9 inches; values for dry year are based on application rate of 10 inches.

County	Irrigated cropland (acres)	Projected irrigation water use			
		At 1987 rate		Avg. year (mgd)	Dry year (mgd)
		mg	mgd		
Jasper	10,000	2753	30.6	27.0	30.2
Lake	8,500	2717	30.2	23.0	25.6
LaPorte	21,600	2673	29.8	58.7	65.2
Marshall	8,000	618	6.9	21.7	24.1
Newton	15,000	1662	18.5	40.7	45.3
Porter	14,500	2214	24.5	39.4	43.7
St. Joseph	15,000	2200	24.4	40.7	45.3
Starke	16,000	769	8.5	43.4	48.3

Public supply

The public supply category includes the water that is withdrawn by public and private water suppliers and delivered to users who do not provide their own water. Water suppliers provide water for a variety of uses such as residential, commercial, and industrial use. As presently defined by the Division of Water, public supply also refers to subdivisions, mobile home parks, schools, healthcare facilities, hotels and motels, conservancy districts, and other facilities that have their own water supplies (usually wells) and that use water primarily for drinking water, washing, cooking and sanitary purposes. This categorization system differs from systems used by some states and organizations, in which most of the latter water-use types generally are considered as either domestic self-supplied or commercial uses.

Of the 55 registered water withdrawal facilities classified under the Division of Water's public supply category (table 25), 32 are municipal utilities, 13 are schools, three are subdivisions, and three are parks. The remaining four include a motel, a mobile home park, an industrial park, and a nursing home.

In 1987, these public supply facilities withdrew a total of nearly 16 mgd (table 21), or about 19 percent of the total water use in the basin. Appendix 18 summarizes, by water source, the withdrawal capability and reported use by registered public supply facilities during 1986-88 for each county within the basin.

It is important to note that the public supply water-use values in table 21 and appendix 18 include withdrawals by three municipalities whose corporate limits are located partly or entirely outside of the Kankakee River Basin but whose well fields are located inside the basin boundary. Valparaiso in Porter County, St. John in Lake County, and Fowler in Benton County all withdraw water from inside the Kankakee River Basin but supply some or all of the water to residents in adjoining river basins.

Most of the water withdrawn in the Kankakee River Basin in 1987 for public supply purposes was derived from ground-water sources. The only surface-water withdrawals occurred on Flint Lake near Valparaiso and on a small pond in a St. Joseph County park near New Carlisle.

As figure 54 shows, withdrawals for public supply remain fairly constant throughout a year of normal precipitation. In the drought year of 1988, however, public-supply use was unusually high in the summer months, probably as a result of increases in lawn and garden watering.

According to a Division of Water analysis, total and per capita water use increases with increasing municipal population. Per capita use may be higher for municipalities with many industries than for municipalities of comparable size with a small industrial base.

One method of estimating mean water use for a given population is by using the following equation, which was developed using data for the years 1960, 1970, 1980, and 1986-87:

$$\text{mgd} = 3.735 \times 10^{-5} \times p^{1.125}$$

where mgd is water use in million gallons per day, and p is population served. Mean water use also can be estimated by multiplying the median water-use value by a correction factor of 1.06. The relationship between median water use and population is illustrated in graphical form in figure 56.

During the 1990s, water withdrawals by public supply facilities are expected to increase slightly in most basin counties, roughly paralleling the anticipated increases in population (figure 5, appendix 1). The only exception is LaPorte County, whose population and public-supply water use are expected to decline slightly during the 1990s. Water-use projections for public supply are shown in table 26.

Industrial self-supplied

Industrial self-supplied water use refers to process water, waste assimilation, dewatering, sand and gravel operations, and some cooling and mineral extraction uses. Under the Division of Water's categorization system, industrial water use includes only the withdrawals that a company develops for itself. If an industry also purchases water from a public-supply utility, the amount of water purchased is included in the public supply category.

In 1987, industrial self-supplied water withdrawals totaled about 5 mgd (table 21), or 6 percent of total registered and non-registered withdrawals. Of the total amount of water withdrawn, 76 percent was derived from surface water and 24 percent from ground water.

About 86 percent of industrial water withdrawals in 1987 occurred in Jasper and St. Joseph Counties (ap-

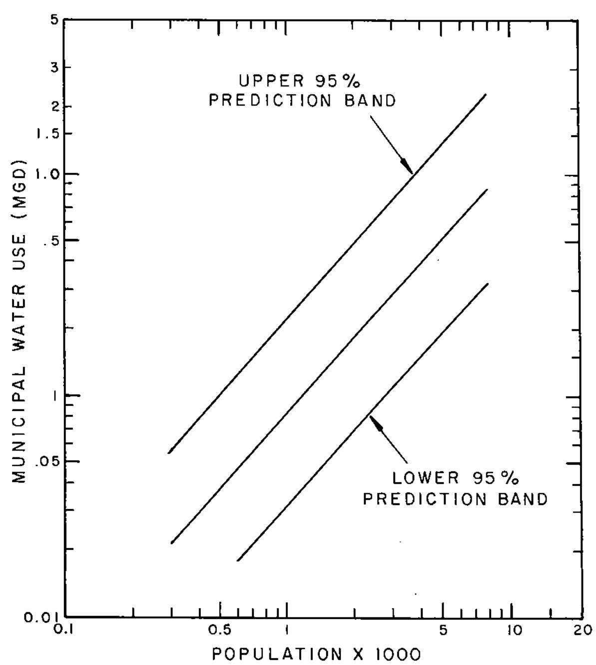


Figure 56. Relation of median water use to municipal population

Table 25. Public water supply facilities and type of water use

Facility name	Type	Facility name	Type
BENTON COUNTY		NEWTON COUNTY	
Earl Park	Municipality	Brook	Municipality
Fowler	Municipality	Goodland	Municipality
		Kentland	Municipality
JASPER COUNTY		Morocco	Municipality
		North Newton School	School
Best Western-Remington	Motel	South Newton School	School
Remington	Municipality		
Rensselaer	Municipality	PORTER COUNTY	
St. Joseph College	School		
		Hebron	Municipality
LAKE COUNTY		Kouts	Municipality
		Porter Twp. School	School
Dalecarlia Utilities	Subdivision	Valparaiso[1,2]	Municipality
Lowell	Municipality		
St. John[1]	Municipality	ST. JOSEPH COUNTY	
Schneider	Municipality		
Utilities Inc. — Utopia	Subdivision	Lakeville	Municipality
Utilities Inc. — Lake of the Four Seasons	Subdivision	New Carlisle	Municipality
		North Liberty	Municipality
		Penn-Harris-Madison School	School
LAPORTE COUNTY		Potato Creek State Park[2]	Park
		St. Joseph Co. Parks	Park
Kingsbury Utilities	Industrial park	South Bend Comm. School[2]	School
Kingsford Heights	Municipality	South Bend	Municipality
LaCrosse	Municipality	Union North United School	School
LaPorte[2]	Municipality	Walkerton	Municipality
New Durham Estates	Mobile home		
New Prairie School Corp.[3]	School	STARKE COUNTY	
Wanatah	Municipality		
Westville	Municipality	Hamlet	Municipality
		Knox	Municipality
MARSHALL COUNTY		North Judson	Municipality
		Oregon Davis Jr.-Sr. High School	School
Argos	Municipality		
Bremen	Municipality		
Marshall Co. Comm.	Nursing Home		
Plymouth	Municipality		
Union United School Corp.	School		

[1]Corporate limit lies partly outside of the basin boundary
[2]Two facilities
[3]Three facilities

pendix 17). Most of the water was withdrawn from stone quarries and gravel pits for sand and gravel production.

Withdrawals for industrial purposes remain fairly constant throughout the year (figure 54).

The methodology used to make industrial water-use projections is explained in a report by the Governor's Water Resource Study Commission (1980). As the projections show (table 26), only slight increases in industrial water use are anticipated during the 1990s.

Rural and miscellaneous

Water withdrawals by rural and miscellaneous facilities in the Kankakee River Basin constitute only about 1 percent of water use in the basin. Of the total 0.8 mgd withdrawn under these two categories in 1987, 0.7 mgd was for rural uses, including the Mixsawbah State Fish Hatchery in LaPorte County and a large poultry operation in White County (appendix 19). Nonregistered, self-supplied domestic withdrawals are not categorized as rural uses, unlike an earlier classifica-

Table 26. Water use projections for public supply and industry categories for the year 2000

{Values are in million gallons per day.}

	Public supply	Industry
Benton	0.20	—
Elkhart	—	0.05
Jasper	1.15	1.84
Lake	1.97	—
LaPorte	4.30	0.17
Marshall	2.66	0.34
Newton	0.62	0.15
Porter	0.70	0.01
Valparaiso	3.99	—
St. Joseph	1.02	3.33
Starke	0.74	0.01
Total	17.35	5.90

tion used by the Governor's Water Resources Study Commission (1980).

The remaining 0.1 mgd withdrawn in 1987 was used for miscellaneous purposes, which may include activities such as fire protection, flood control, drainage control, water slides, snow-making and lake-level maintenance. Of these potential uses, however, the only reported withdrawal in 1987 was for maintaining the water level of a shallow lake for recreational purposes.

Because water withdrawals for rural and miscellaneous uses constitute only about one percent of all withdrawals, projections were not calculated for this report.

Non-registered use categories

Domestic self-supplied

Domestic self-supplied water use refers to residential water users who obtain water from private water wells rather than from public supply systems. It is estimated that about 146,000 basin residents, or 63 percent of the basin population, have domestic wells. As mentioned previously, the Division of Water categorizes withdrawals by commercial or institutional organizations as public supply uses rather than as domestic self-supplied or commercial uses.

Estimated withdrawals by domestic self-supplied facilities in 1987 (11 mgd) constituted approximately 13 percent of the total water use in the basin. Table 27 lists the estimated withdrawals by county. The estimated values were obtained by multiplying the approximated self-supplied population within the basin portion of each county by an estimated per capita usage of 76.46 gallons per day (Indiana Department of Natural Resources, 1982a).

Projected domestic self-supplied water uses for the year 2000 are shown in table 27. Withdrawals are expected to increase slightly or remain fairly stable in most basin counties over the next 10 years. Decreases are anticipated only in LaPorte, Newton and Starke Counties, primarily because of projected decreases in population.

Livestock

Livestock water use (table 28) was determined by multiplying the estimated population of a particular livestock category by an estimate of the amount of water consumed daily per animal (Indiana Department of Natural Resources, 1982a). According to these calculations, withdrawals for livestock watering purposes totaled 3.2 mgd in 1987. About 75 percent of the water withdrawn was used for beef cattle and hogs. In a few cases, water withdrawals tabulated as livestock

Table 27. Estimated and projected annual water use for domestic self-supplied category

County	Self-supplied population	Water use (mgd)	
		1987	2000
Benton	2,486	0.19	0.19
Elkhart	5,361	0.41	0.44
Jasper	19,191	1.47	1.51
Kosciusko	3,649	0.28	0.30
Lake	24,022	1.84	2.03
LaPorte	10,568	0.81	0.78
Marshall	17,897	1.37	1.46
Newton	9,162	0.70	0.67
Porter	18,506	1.41	1.67
Pulaski	635	0.05	0.05
St. Joseph	20,444	1.56	1.57
Starke	13,046	1.00	0.97
White	914	0.07	0.07
Total	145,881	11.15	11.71

Table 28. Estimated annual water use for livestock category

{Data derived or adapted from Indiana Department of Natural Resources, 1982a; U.S. Department of Agriculture, 1987b, 1988c; U.S. Bureau of Census, 1989.}

Livestock class	Estimated number (1,000 head)	Average daily water use (gal/hd/day)	Average annual water use (mgd)
Beef cattle	101.0	11.5	1.16
Dairy cattle	22.1	22.5	0.50
Hogs	313.8	4	1.26
Sheep	6.9	1.5	0.01
Chickens	2,382.0	0.1	0.24
Turkeys	150.0	0.2	0.03
		Total	3.20

Table 29. Estimated recreation participation and occasions for the basin region

{Data from Indiana Department of Natural Resources, 1988d.}

Activity	Number of participants	Number of occasions
Fishing	500,427	12,655,804
Swimming	538,338	12,182,597
Motorboating	288,125	3,555,459
Sailing	98,569	2,062,063
Waterskiing	144,062	1,979,417
Canoeing	128,898	1,205,196
Ice skating	83,405	1,046,727
Other activities	11,092,804	322,745,975
Total		357,433,238

water use also may have been included either in the irrigation or rural categories of registered significant water withdrawal facilities.

Livestock water use is expected to increase only slightly during the 1990s. Increases will depend largely on the farm economy and climatic factors.

Instream uses

Instream uses are defined as non-withdrawal uses taking place within a stream, lake or reservoir. Instream uses in the Kankakee River Basin primarily include recreation activities, fish and wildlife habitat, and waste assimilation. The generation of hydroelectric power is a common instream use in some areas of Indiana; however, no sites are suitable in the Kankakee River Basin for the development of a hydropower facility.

Water-related recreation needs in the 1990s will depend on user demand, the availability of facilities, and a variety of demographic and socioeconomic factors. Estimates of potential recreational use were calculated for a 14-county service area that includes the 13 counties of the Kankakee River Basin and also Fulton County (Indiana Department of Natural Resources, 1989). It was assumed that residents of the 14-county area would participate in water-based or water-enhanced recreation activities at the same rate as all persons living in the northern planning region, for which information was obtained in an outdoor recreation issues study (Indiana University, 1987).

The values shown in table 29 represent the number of recreationists and amount of participation for the 14-county service area. It does not imply that all participants use waters of the Kankakee River Basin exclusively as the location of their activity. Moreover, the values do not account for the number of visits from non-service area residents, nor the number of times persons from within the service area go outside the area for recreation.

It should be recognized that future recreation needs may differ from present needs. The change in the age distribution of the basin's population will significantly affect the demand for recreation opportunities. Other concerns include: 1) the need for more water-based recreation facilities; 2) increasing need for access to the state's waters; 3) particularly high demand for greenways; and 4) a significant need for more public land. These factors are discussed in more detail in a 5-year recreation plan (Indiana Department of Natural Resources, 1988a).

Summaries of basin fisheries and wastewater treatment were provided in the ***Surface-Water Hydrology*** chapter of this report under the subheading ***Surface-Water Quality***. The future quality of basin fisheries will depend largely on the water quality and presence of suitable habitat, the availability of sufficient stream flow, stocking activities by the IDNR, and fishing pressure. Factors that will help maintain or improve surface-water quality in future years include control of nonpoint-source pollution, upgrading of wastewater-treatment facilities, improved treatment-plant operations, and improved compliance with discharge limits. Detailed information on wastewater-management plans is available from the Indiana Department of Environmental Management.

The conservation of wetland wildlife habitat was discussed in the ***Surface-Water Hydrology*** chapter of this report under the subheading ***Wetland Protection Programs***. Compliance with existing regulations, implementation of existing programs, and establishment of additional programs will help ensure the future conservation of wetland and riparian habitats.

SURFACE-WATER DEVELOPMENT

Most surface-water withdrawals in the Kankakee River Basin occur along the Kankakee River and its major tributary ditches, particularly in Lake, Porter, Jasper and Newton Counties. As future demands increase on streams and ditches, additional steps may be needed toward the establishment of protected minimum flows.

Some withdrawals occur along lakes and wetlands, but these systems are not considered as probable water supply sources because of their limited storage capacity, water quality considerations, and regulatory, economic and environmental constraints.

Wetlands and lakes

Although some palustrine wetlands in the Kankakee River Basin may store considerable amounts of water at certain times, their shallow depths and the temporary nature of ponding does not make these wetlands suitable as water supply sources. Moreover, regulatory and non-regulatory programs administered by state and federal agencies (appendix 4) discourage the detrimental exploitation of wetlands, including certain land uses which would adversely impact nearby wetlands. The values of wetlands and the need for continued conservation of these areas was discussed earlier in this report.

Despite the large storage capacity of some public freshwater lakes in the Kankakee River Basin, few lakes are used as water supply sources. Some water is withdrawn from Flint Lake by the Valparaiso Waterworks; however, water from the lake is primarily intended to supplement the municipal supply derived primarily from ground water.

Existing state laws effectively preclude significant pumpage from natural lakes. In accordance with Indiana law, lakes with a legally established average level are to be maintained at that level. Temporary lowering of the lake requires approval by a local court and the Natural Resources Commission. Approval typically is granted only for shoreline improvements or lake restoration.

Even if state laws were amended to allow lowering of lake levels for supply purposes, treatment costs would probably limit uses to irrigation, livestock watering, or fire protection. Pumpage-induced lowering of water levels could detrimentally affect existing water quality, fisheries habitat, and adjacent wetlands. Moreover, significant lowering of lake levels would be objectionable to most lakeside property owners.

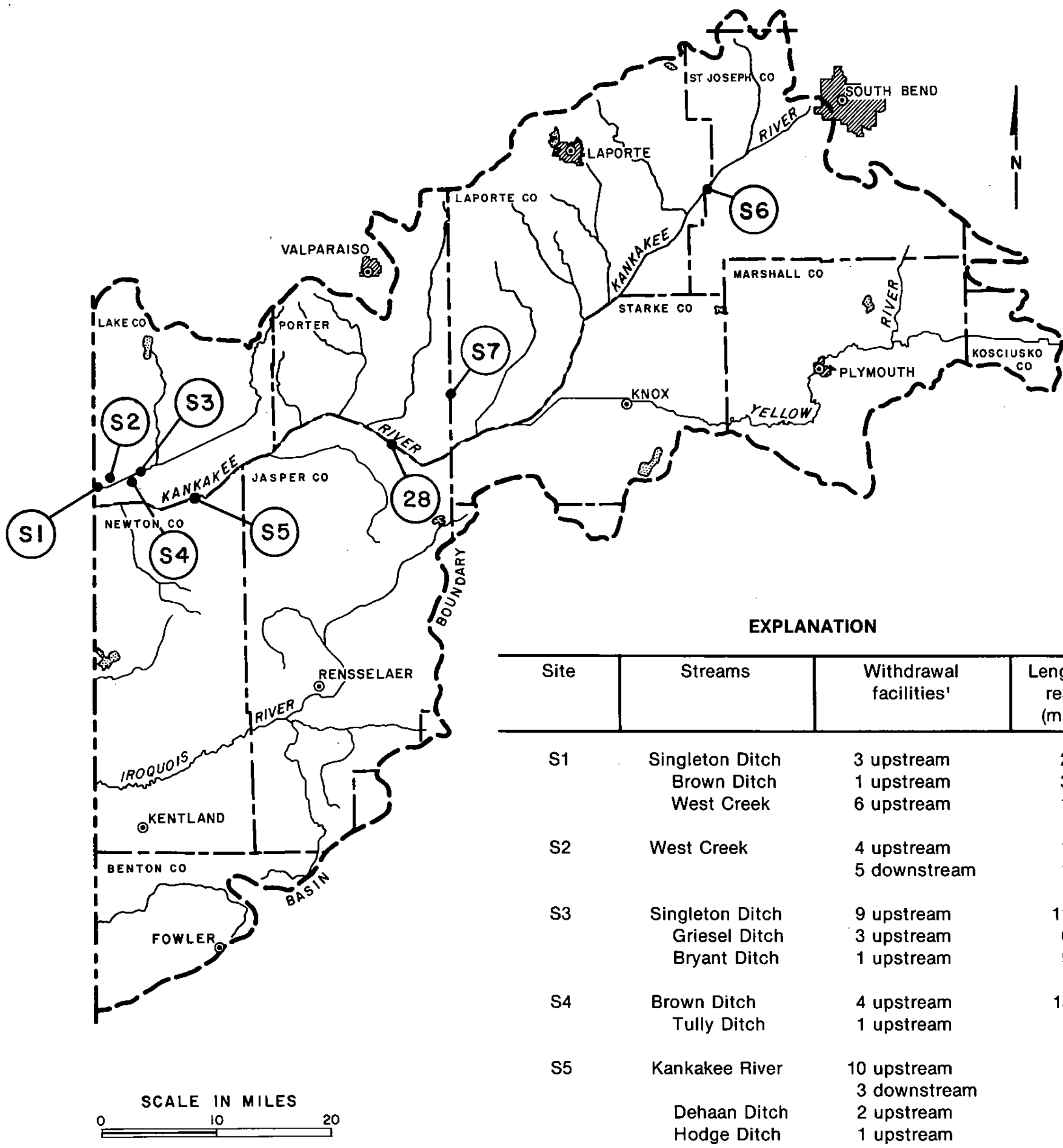
Adding lake storage for supply purposes also has considerable drawbacks. Amendments to current lake laws or approval for temporary lake-level increases would be required. Moreover, existing control structures at potential supply sites would have to be modified, because few lake-level control structures are designed to store water at elevations above the legal level. Furthermore, the inundation of lakefront property would be objectionable to lakeside property owners.

Because of these and other limitations, lakes are not considered as potential water supply sources in the Kankakee River Basin. Instead, the primary source of surface water in the basin should continue to be streams and ditches.

Streams

Streams are a major surface-water resource in the Kankakee River Basin and support a variety of withdrawal and non-withdrawal (instream) uses. As demand for water continues to increase, there will be a greater need to protect the quantity and quality of water in streams.

Although many streams in the Kankakee River Basin exhibit well-sustained flows as a result of the high degree of interconnection between surface-water and ground-water systems, the seasonal, monthly, and daily variability of stream flows coupled with increasing withdrawal uses are expected to produce localized or short-term conflicts between water supply and demand.



EXPLANATION

Site	Streams	Withdrawal facilities[1]	Length of reach (miles)
S1	Singleton Ditch	3 upstream	2.7
	Brown Ditch	1 upstream	3.1
	West Creek	6 upstream	1.9
S2	West Creek	4 upstream	1.9
		5 downstream	1.1
S3	Singleton Ditch	9 upstream	11.4
	Griesel Ditch	3 upstream	6.1
	Bryant Ditch	1 upstream	9.7
S4	Brown Ditch	4 upstream	13.6
	Tully Ditch	1 upstream	8.2
S5	Kankakee River	10 upstream	7.6
		3 downstream	1.8
	Dehaan Ditch	2 upstream	4.3
	Hodge Ditch	1 upstream	7.6
S6	Kankakee River	14 upstream	10.1
S7	Reeves Ditch	2 downstream	1.9
	Grieger Ditch	7 upstream	3.9
28	Kankakee River	NIPSCO	—

[1]Some withdrawal facilities are common to sites S1, S2 and S3 because of the proximity of withdrawal facilities

Figure 57. Location of significant stream sites

Table 30. Monthly stream-flow characteristics and water withdrawals at significant stream sites

{Values are in million gallons per day.}

Site number: Significant site locations are shown in figures 57 and 29.

7Q10: The annual lowest mean flow for seven consecutive days that can be expected to occur on the average of once every 10 years.

Lowest stream flow: Lowest daily flow that occurred during specified month and year.

Average withdrawal: Withdrawal averaged over the number of days of operation.

Site no.	7Q10	Year	JULY		AUGUST	
			Lowest streamflow	Average withdrawal	Lowest streamflow	Average withdrawal
S1[1]	8.6	1988	8.6	11.0	9.2	9.7
		1987	38.0	6.1	28.1	3.6
		1986	18.4	14.4	11.1	6.2
S2[2]	3.0	1988	2.1	7.4	2.6	6.1
		1987	9.2	3.7	8.0	0.7
		1986	4.5	9.5	3.1	3.95
S3	4.8	1988	4.5	20.7	4.7	20.7
		1987	20.0	11.7	14.2	7.3
		1986	9.7	11.2	5.6	11.2
S4[3]	0.8	1988	0.8	3.0	0.8	3.0
		1987	3.5	4.7	2.5	2.2
		1986	1.7	3.5	1.0	0.8
S5	273	1988	229	42.6	183	42.6
		1987	418	27.8	419	27.2
		1986	756	38.9	453	31.7
S6	36.4	1988	35.6	38.2	28.4	38.2
		1987	53.0	25.4	44.6	25.6
		1986	70.4	29.3	47.8	28.9
S7[3]	10.2	1988	9.4	8.6	8.7	8.6
		1987	13.2	4.9	11.3	5.1
		1986	16.9	4.6	13.2	4.6

[1]Parameters were calculated or estimated from gages on Singleton Ditch (05520000 Illini, Illinois, 1945-1977 and 05519000 Schneider, Indiana, 1948-present).
[2]Parameters were calculated or estimated from a gage on West Creek (05519500 Schneider, Indiana, 1948-1952 and 1954-1972) and a gage (05519000) on Singleton Ditch.
[3]Flows were estimated (no gage at this site).

Impacts of stream withdrawals

Impacts of stream withdrawals are not confined to the point of withdrawal, but can result in reduced stream-flow availability in downstream segments. A number of withdrawal uses reach their peaks during the seasonal periods of low stream flow. The demands placed upon low flows by withdrawal and instream uses are greatly exacerbated during droughts.

The relationship between withdrawal uses and available water supply in streams was examined at eight sites within the Kankakee River Basin (figure 57). The significant sites were selected in areas where total or cumulative water withdrawals near the site are large relative to low stream flows (figures 29, 52). The largest number of significant sites are in the lower Kankakee River Basin, where large amounts of water are withdrawn from the mainstem Kankakee River and from several tributary ditches.

Agricultural irrigation is the primary water use for seven of the eight significant stream sites (figure 57, sites S1-S7). Irrigation, which is considered to be a totally consumptive use, occurs during periods when stream flows are in seasonal decline. Moreover, irriga-

Table 31. Stream flow and withdrawals at NIPSCO's Schahfer plant

{Values are in million gallons per day. Site locations are shown in figures 57 and 29.}

Year	Historical minimum flow, Dunns Bridge[1]	Historical minimum flow, Kouts[2]	Monthly mean flow, Dunns Bridge	Monthly mean flow, Kouts	Net mean withdrawal
		JULY			
1988	271	266	271	226	20.7
1987	—	—	474	472	14.4
1986	—	—	876	939	15.7
		AUGUST			
1988	240	257	260	257	13.5
1987	—	—	435	412	18.2
1986	—	—	522	505	8.1

[1]The 7Q10 flow is 224 mgd.
[2]The 7Q10 flow is 259 mgd.

tion withdrawals place a relatively high demand on the water resource per unit area within the region of irrigation.

July and August were selected for analysis of potential conflict between water supply and demand because these two months typically are characterized by maximum irrigation withdrawals and low stream flows. Average water withdrawals at facilities along a stream reach upstream of a significant site or along a series of reaches associated with a site were totaled and compared to the following stream-flow parameters: 1) the annual 7-day, 10-year low flow (7Q10); and 2) the lowest daily mean flow of July and August for the years 1986-88. It is interesting to note that during the drought year of 1988, stream flow reached record lows in July and August at many of the sites.

Monthly withdrawals at significant sites S1, S2, S3 and S4 were large in comparison to gaged and estimated stream flows for the three years analyzed (table 30). Site 3 on Singleton Ditch is especially noteworthy because cumulative withdrawals are four to five times greater than the low stream flows, and because base flows are only moderately sustained by ground-water contribution.

The analysis provides a reasonable assessment of potential conflict between water supply and demand, but it may not represent a worst-case condition because water use was averaged over the total number of operating days; hence, higher withdrawals may have occurred for any given day. Moreover, the exact relationship between stream withdrawals and stream flow is not clearly understood, due in part to ground water contribution to stream flow.

Despite these limitations, it is apparent that there is a high potential for water-use conflicts on Singleton Ditch and several of its tributaries in southwestern Lake County during periods of drought. The IDNR Division of Water has no record of existing conflicts on these ditches; however, a county extension agent and several farmers reported that water shortages and water-use conflicts occurred at several locations on Singleton Ditch during the summer of 1988. It is assumed that water-supply problems also occurred on smaller ditches with limited storage capacities and/or minimal ground-water contribution.

Lower reaches of the Kankakee River support a large number of high-capacity withdrawals (figure 52), primarily for irrigation. Although cumulative withdrawals in some reaches are quite high, the river's flow appears to be adequate for large seasonal withdrawals.

At one site on the Kankakee River (figure 57, site 28), water is used by the R.M. Schahfer electric generating station operated by the Northern Indiana Public Service Company. Energy production at this site requires a high degree water-supply dependability, even under adverse conditions.

The power station, which is permitted under Indiana's navigable river statute (I.C. 13-2-4-9), withdraws water from the Kankakee River, uses it primarily for cooling and air-pollution control, and discharges a portion of the withdrawn water to an onsite settling pond. Under the terms of the permit, the plant can withdraw up to 106 cfs (68.5 mgd) from the river, and must return enough water to the river so that the consumptive use, measured as the net reduction in stream flow (the difference in flow between the plant's intake and discharge points) does not exceed 41 cfs (26.5 mgd). The return flow from the settling pond to the river can be as high as 65 cfs (42 mgd), or can be reduced to as low as 0 cfs, provided that stream flow as measured at the Dunns Bridge station on the Kankakee River is greater than 289 cfs. Special conditions for withdrawals and return flows are applied when stream flows are at or below 289 cfs.

The station's water intake on the Kankakee River is about 0.7 miles upstream of a stream gage near Kouts. Stream flows at this gage were compared to stream flows at the Dunns Bridge gage which is located upstream of the intake and about 4.2 miles upstream of the Kouts gage (see figure 29). Reported net withdrawal at the power plant was analyzed for July and August of 1986-88 (table 31) and compared to mean monthly stream flow at the two stream gages.

Table 31 shows that mean monthly flows were less at the downstream gage than at the upstream gage for August for all three years analyzed and for July in 1987 and 1988. However, it should be emphasized that the differences in mean monthly flows are within the 10-percent margin of error commonly associated with reliable stream-flow measurements. During extreme low flows, the margin of error may be even higher.

A graphical plot of daily stream flows at the two stations against daily net withdrawals for 1985 and 1988 revealed that during periods of low stream flow, sharp increases in net water withdrawals at the plant appeared to produce distinct decreases in stream flow at the Kouts gage relative to the more constant flows at the Dunns Bridge gage. Conversely, abrupt decreases in net withdrawals at the plant appeared to produce distinct increases in flow at the Kouts gage. The degree to which stream flows are modified at the Kouts gage cannot be quantified, however, because of data limitations and because of the complex interactions of surface-water and ground-water systems.

Stream rights

The impacts of withdrawal uses on stream flows must be considered to determine how the potential for water-use conflicts can be minimized, particularly during a drought. Historically, water users have developed the most readily available source of supply without consideration of the effects of such development on other uses, particularly instream uses. Constraints on water use in a particular location may result from its competing value for various instream and withdrawal uses.

Indiana has long recognized the "riparian rights doctrine". Riparian rights are based on ownership of land abutting a watercourse. Indiana has adopted a modified reasonable-use policy in which each riparian landowner's right to use water from the watercourse is limited to uses that are reasonable under the circumstances. The person who asserts the unreasonableness of the use has the burden of proof.

Withdrawal rights are considered as private rights arising out of land ownership. Instream-use rights, unlike withdrawal rights, may exist both for private individuals and public entities; however, public rights are not held to be paramount to every conflicting private riparian right or public activity. Resolution of conflicting interests as well as statutory expansion of public rights, are influenced by the state's economic interests.

Under Indiana law (I.C. 13-2-4-9), a permit is required for any facility planning to withdraw water from a navigable waterway. (In the Kankakee River Basin, the Kankakee and Yellow Rivers have been designated as navigable.) The navigable river program is administered by the IDNR Division of Water.

Under the navigable rivers law, permit applications are evaluated for their impacts on navigability, the environment, and safety of life and property at the withdrawal site. Although the permitting program is directly relevant to water-resource management, it has a number of shortcomings. First, the program is limited in scope because it applies only to navigable rivers and excludes public water-supply utilities. Second, the law is difficult to enforce because no administrative rules have been promulgated. Finally, the program's effectiveness is limited because no defined criteria exist for evaluating the effects of proposed withdrawals.

The existing stream program does not adequately provide certainty of rights to use, mitigation or resolution of conflicts over withdrawal and conveyence of water from its source, impacts of such withdrawals on other uses and interests, or over competing or conflicting uses. At present, there is no procedure, other than through the courts, by which questions of use may be resolved on a timely basis.

Because of such limitations in existing programs, additional steps may be needed to help protect streams in localized areas. The Natural Resources Commission may establish criteria for determination of minimum streamflow (I.C. 13-2-6.1). If established, the minimum stream-flow criteria may govern the amount of water withdrawn from streams in some areas.

In an ongoing effort to establish a sound framework for administrative and statutory decisions, the Division of Water has contracted researchers to examine technical issues related to surface-water withdrawals. In one study (Delleur and others, 1988), investigators examined the ability of a variety of statistical models to reliably and accurately forecast low flows and assess the severity of a given low flow. The study further explored design flows for waste assimilation.

Another study (Delleur and others, 1990) expanded on the first study by evaluating how much stream flow should be protected from withdrawal in order to provide for instream needs such as fish habitat, waste assimilation, and recreation. This study examined 25 stream gage sites in Indiana, including two sites in the Kankakee River Basin: namely, Cobb Ditch near Kouts and the Kankakee River at Dunns Bridge. The study also suggested a general minimum flow criteria to be applied at a site when a detailed study is not warranted.

A pilot study also is being planned with the Illinois State Water Survey in which an Illinois model for estimating low-flow parameters at ungaged locations would be applied to the Kankakee River Basin in Indiana. Through this effort, division staff would gain the expertise needed to apply the model to streams throughout Indiana.

The Illinois model begins with flow records at gaged locations, then develops regression equations from which low-flow parameters can be estimated for ungaged locations. The model allows these parameters to be estimated for three conditions: namely, flows that would occur if the stream were unaffected by human activities; flows that presently occur; and flows that would occur if the present condition were modified by further withdrawals or discharges.

In other attempts to resolve legal and technical problems associated with stream withdrawals, Division of Water staff are developing administrative rules for the existing navigable rivers permitting program. Staff also are providing technical advice to the Water Resources Study Committee, which has been meeting periodically since 1989 to develop recommendations for the legislature regarding surface and ground water resources in Indiana.

GROUND-WATER DEVELOPMENT

Ground-water resources of the Kankakee River Basin are among the most abundant in Indiana. Because ground-water availability in much of the basin is considered moderate to excellent, a significant potential exists for further ground-water development.

However, localized or short-term conflicts among ground-water users are expected to recur as ground-water demands continue to increase. Provisions found in Indiana laws, particularly I.C. 13-2-2.5, will remain a key factor in developing and protecting ground-water resources in the Kankakee River Basin. Additional regulations, water conservation practices, and improved management may be needed to protect ground water in localized areas.

Impacts of ground-water withdrawals

Ground-water withdrawals for irrigation purposes are responsible for most of the water-supply conflicts

Table 32. Ground-water withdrawals for irrigation in Jasper and Newton Counties

County	Number of registered wells	Registered ground-water withdrawal capability (mgd)[1]	Reported ground-water withdrawals	
			mgd[1]	mg
1985				
Jasper	130	73.06	18.06	1625.4
Newton	44	46.89	13.25	1192.5
Total	174	119.95	31.31	2817.9
1986				
Jasper	130	73.06	14.91	1341.9
Newton	44	46.89	11.89	1070.1
Total	174	119.95	26.80	2412.0
1987				
Jasper	130	73.49	13.81	1242.9
Newton	44	46.89	8.86	797.4
Total	174	120.38	22.67	2040.3
1988				
Jasper	135	77.67	25.59	2303.1
Newton	43	48.35	21.83	1964.7
Total	178	126.02	47.42	4267.8

[1]90-day average

in the Kankakee River Basin. Irrigation has been practiced since the 1950s, but the number of acres irrigated and the amount of water used have increased dramatically since the 1970s, particularly in LaPorte, Jasper, Lake, St. Joseph, and Newton Counties (see figure 55). As discussed in a previous section entitled ***Water Use and Projections***, irrigation is used primarily to improve crop yields on drought-prone sandy soils.

Water withdrawn for irrigation in LaPorte and St. Joseph Counties is pumped from streams, ditches, and outwash deposits, whereas irrigation water in Lake County is supplied largely by streams and ditches. Most irrigation water in Newton County is pumped from a carbonate bedrock aquifer. Ground water from the carbonate aquifer and surface water from streams and ditches provide most of the irrigation water for Jasper County.

Ground-water conflicts caused by irrigation pumpage in the Kankakee River Basin have occurred primarily in Jasper and Newton Counties. Ground-water withdrawals for irrigation in these two counties increased from about 1 billion gallons in 1977 to about 2 billion gallons in 1987, and exceeded 4 billion gallons in the drought year of 1988. As table 32 shows, reported water withdrawals in the irrigation category varied widely from 1985 to 1988, even though the number of registered irrigation wells did not increase

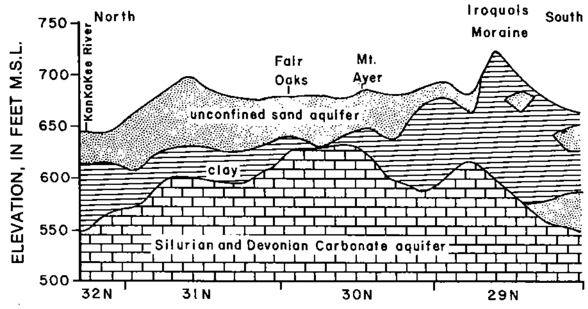


Figure 58. Generalized geologic cross section in irrigation areas near the Jasper-Newton County line

significantly. The greatest increase in irrigation withdrawals occurred between 1987 and the drought year of 1988, when reported withdrawals more than doubled.

The major irrigation area in Jasper and Newton Counties is located south of the Kankakee River and north of the Iroquois Moraine (see figures 14, 52). Although some domestic, livestock, and irrigation wells in this area are completed in an unconfined sand aquifer known as the Kankakee Aquifer System (plate 2), most wells pump from the underlying carbonate rocks of Silurian and Devonian age (figure 58). A relatively impermeable clay deposit separates the two

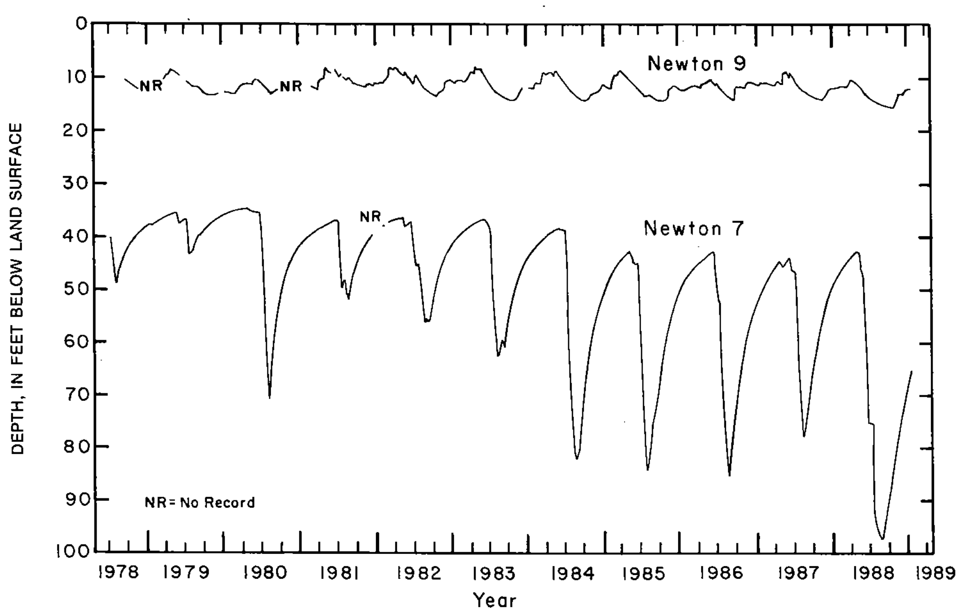


Figure 59. Water-level fluctuations in observation wells completed in the unconfined sand aquifer and Silurian and Devonian carbonate aquifer in west-central Newton County

aquifers in most of the two-county area. Thickness of the clay unit typically is from 20 to 80 feet, but ranges from 0 to 140 feet (Basch and Funkhouser, 1985; Arihood and Basch, in preparation).

In areas where the clay unit is present, water levels in the surficial sand aquifer and the deeper bedrock aquifer appear to fluctuate independently. As the hydrograph for observation well Newton 9 shows (figure 59), water levels in the sand aquifer follow the typical seasonal pattern of springtime highs and autumn lows. In contrast, the hydrograph for Newton 7, a bedrock well, shows a pumpage-induced decline in water level during the summer irrigation season, followed by a winter and spring recovery.

Although the Indiana Department of Natural Resources (formerly the Department of Conservation) first investigated the impacts of irrigation pumpage on water levels in 1954 (Uhl and Kingsbury, 1957), IDNR staff intensified their efforts in 1981, when irrigation pumpage from the carbonate aquifer increased sharply in Jasper and Newton Counties (see Bruns, 1981; Indiana Department of Natural Resources, 1982). In an attempt to better understand the effects of pumping on ground-water levels, the IDNR Division of Water, in cooperation with the U.S. Geological Survey, has conducted ground-water modeling studies (see box on this page).

Historically, under Indiana's "common law" approach to water-rights issues, a ground-water user was not held liable for damages to surrounding landowners if his use of ground water was reasonable and beneficial, and was not done maliciously or gratuitously. Conflicts involving ground-water supply and demand were handled on a case-by-case basis, and often were resolved by court decisions.

In 1982, a new law (I.C. 13-2-2.5) was enacted to provide protection for individuals in Jasper and Newton Counties whose domestic or livestock wells were being adversely affected by declines in ground-water levels caused by nearby high-capacity withdrawals. Under the provisions of this law, the owner of a high-capacity ground-water withdrawal facility (capable of pumping at least 100,000 gallons per day) can be liable for impacts on adjacent domestic wells if high-capacity pumpage has substantially lowered ground-water levels in the area, subsequently causing the domestic wells to fail. In order to have protection under the statute, affected domestic or livestock wells had to meet minimum well-construction standards established by the IDNR. Because ground-water availability conflicts were occurring elsewhere in Indiana, the law was amended on September 1, 1985 to provide protection for small-capacity well owners throughout the state.

Between 1981 and 1989, IDNR staff investigated about 25 complaints of water-supply problems in wells completed in the surficial sand aquifer in northern Jasper and Newton Counties. Investigators determined that losses of water supply in most of these wells were primarily the result of seasonal water-level fluctuations, and not a result of nearby irrigation pumpage from either the surficial sand or the underlying carbonate aquifer. In general, shallow wells that experienced ground-water supply problems either were equipped with inadequate pumps, or were not drilled deep enough to function properly during seasonal water-level declines, particularly during the drought conditions of 1988. Water-supply problems in most of these shallow wells were corrected by deepening the wells or replacing them with more efficient, larger-diameter wells equipped with pumps capable of lifting water from greater depths.

The losses of water supply in wells completed in the carbonate bedrock aquifer frequently resulted from water-level declines induced by high-capacity irriga-

Ground-water modeling

Since 1981, the U.S. Geological Survey in cooperation with the IDNR Division of Water has conducted two studies to assess the effects of irrigation pumpage on the ground-water levels and stream flow in Jasper and Newton Counties. In the first study (Bergeron, 1981), a quasi-three dimensional, two-layered digital model was developed to simulate steady-state flow conditions in the carbonate and unconfined sand aquifers. The model was calibrated to actual water levels and stream discharges measured in June 1978. Once calibrated, the model was used to simulate the effect of withdrawals on ground-water levels in the bedrock and unconfined sand aquifers.

Because of limited data, the model did not accurately simulate pumping impacts on the carbonate aquifer. However, the model did show that two of the most important factors controlling the drawdown or water-level decline in the bedrock are the variation in the thickness and vertical hydraulic conductivity of the semi-confining clay layer overlying bedrock.

In a more recent three-dimensional digital model constructed by the USGS (Arihood and Basch, in preparation), the area of consideration was extended to the Iroquois and Valparaiso Moraines. The new model incorporates nine layers and provides greater variability in the characteristics of the aquifers and confining clay layer. The model was calibrated to 1986 hydrologic data and validated using data from the drought year of 1988. The emphasis of this model is to predict the effect of pumpage from high-capacity irrigation wells and the potential effect of new irrigation wells. The results of this study should be available in 1991.

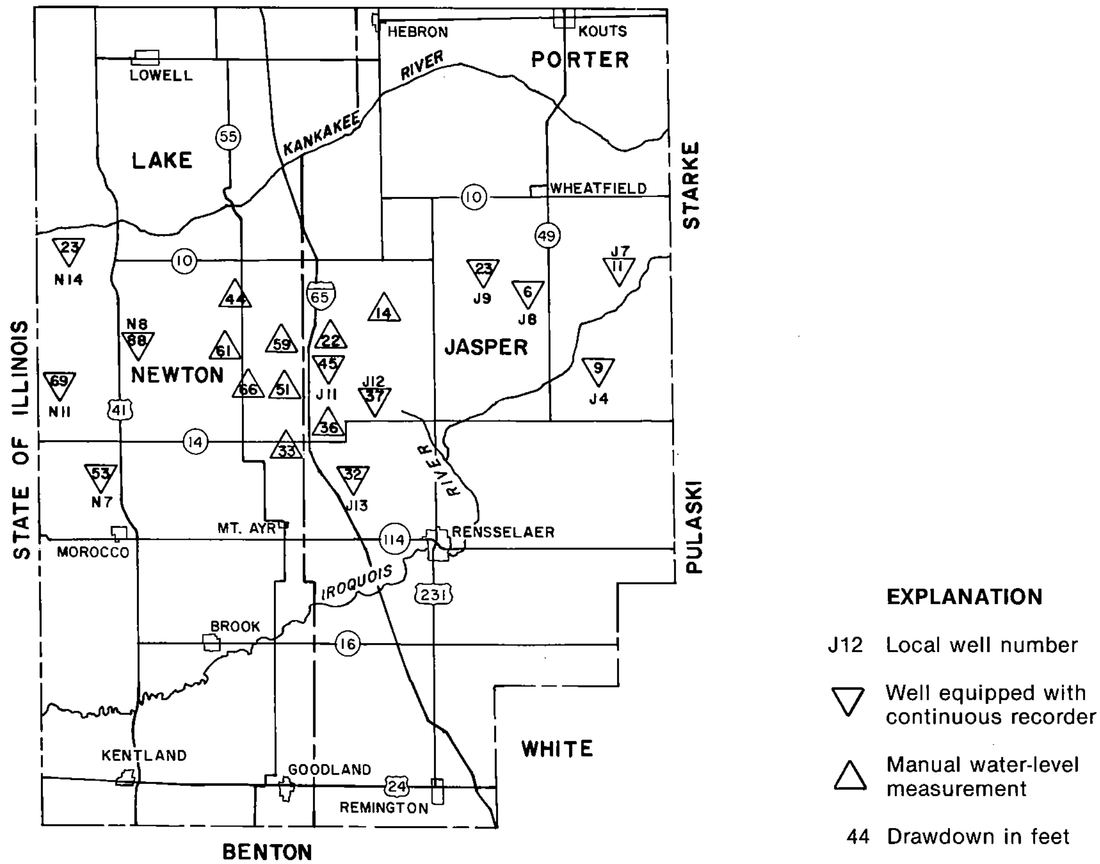


Figure 60. Water-level declines in selected bedrock wells in Jasper and Newton Counties during August 17-19, 1988

tion pumpage. Between 1981 and 1989, more than 200 domestic and livestock wells completed in the bedrock aquifer were reported to be adversely impacted by the reduction in ground-water levels caused by irrigation pumpage.

Many of the domestic and livestock wells in Jasper and Newton Counties that were shown to be affected by high-capacity irrigation pumpage were voluntarily upgraded by area irrigators, and the provisions of I.C. 13-2-2.5 were not invoked. However, about 10 temporary ground-water emergency orders were declared in the two-county area between 1982 and 1989. The primary purpose of the temporary orders was to provide the affected domestic well owner with an immediate temporary supply of potable water. Each matter was subsequently brought before the Natural Resources Commission to determine timely and reasonable compensation as specified in I.C. 13-2-2.5.

A few of the groundwater problems resulted in litigation.

It should be emphasized that present irrigation water use in years with normal or near-normal precipitation appears to have minimal effects on the ground-water resource in Jasper County and portions of Newton County. In these areas, ground-water supply problems experienced in past years have been limited to the summer crop-growing season. Aquifer recharge and recovery in fall and winter typically compensates for summer irrigation withdrawals so that on an annual basis, the carbonate aquifer appears to be able to support high-capacity irrigation pumpage without significant long-term depletion. An exception may occur during extended drought when the potential rate of pumpage may exceed the rate of ground-water recharge.

In northwest and west-central Newton County, ground-water levels in the bedrock aquifer are more strongly impacted by ground-water pumpage than levels in eastern Newton County, primarily because of hydrogeologic differences and the proximity of major pumping centers in both Indiana and Illinois. In western Newton County, ground-water levels in the bedrock recover slowly from seasonal irrigation withdrawals, and in some years may not fully recover before pumping resumes the following season.

During the drought conditions in the summer of 1988, record low ground-water levels were recorded in dozens of observation wells in Indiana, including 19 of the 23 bedrock and unconsolidated observation wells in the Kankakee River Basin. Record low levels resulted from a combination of the following factors: 1) below-normal precipitation in 1987, which produced lower-than-normal water levels in the spring of 1988; 2) hot, dry conditions during the summer of 1988; and 3) increased irrigation pumpage from surface-water and ground-water sources.

To monitor the effects of drought and irrigation pumpage on ground-water levels in Jasper and Newton Counties, IDNR staff frequently measured water levels in selected bedrock and unconsolidated wells. Figure 60 shows the difference in water levels between the springtime highs and the reduced summertime levels measured in bedrock wells during August 17-19, 1988 in Jasper and Newton Counties. The drawdowns measured in most bedrock wells on these dates either equaled or were within 3 feet of the maximum drawdown recorded for the entire year of 1988.

As figure 60 shows, water-level declines in four Jasper County wells exceeded 30 feet, and drawdowns in seven Newton County wells exceeded 50 feet. The greatest water-level declines in Newton County during the summer of 1988 were recorded in observation wells Newton 8 and Newton 11, where maximum drawdowns were 88 and 71 feet, respectively (see Glatfelter and others, 1989). In observation well Newton 8, the minimum water levels during much of July and August were near the top of the carbonate bedrock aquifer. In Newton 11, minimum levels during the two-month period often were approximately 10 feet below the top of the bedrock aquifer. Although dewatering of the carbonate aquifer probably did not occur over a large area, localized dewatering occurred near points of substantial ground-water withdrawals.

The large drawdowns measured in Newton County probably were related not only to the prolonged drought conditions, but also to hydrologeologic conditions and extensive irrigation. Substantial drawdowns near the Indiana-Illinois state line also were influenced by extensive irrigation pumpage from the carbonate aquifer in Kankakee and Iroquois Counties, Illinois (see figure 4). Studies by the Illinois State Water Survey have investigated the impacts of irrigation and drought on the ground-water resources of Illinois, particularly in eastern Kankakee and northern Illinois Counties (Changnon and others, 1982; Bowman and Collins, 1987; Cravens and others, 1989, 1990).

Because the reductions in water level during the summer of 1988 affected several small-capacity wells in Jasper and Newton Counties, and because it was believed that continued irrigation pumpage would exceed the recharge capability of the ground-water resource, provisions of I.C. 13-2-2.5 were invoked to restrict high-capacity pumpage in certain areas of the two counties. The pumpage restrictions were imposed to reduce the rate of water-level decline in the bedrock aquifer and to allow ground-water levels to recover.

Also during the summer of 1988, IDNR staff investigated numerous complaints of water-supply problems in and near the town of Shelby along the lower Kankakee River. The majority of the well failures occurred in shallow wells completed in the surficial sand aquifer. These wells were believed to have failed as the result of ground-water level declines caused by the hot, dry conditions. An emergency supply of potable water was provided to Shelby residents by the Indiana National Guard until seasonal recovery of water levels occurred in the area, allowing the shallow wells to once again function properly.

The town of Lowell in Lake County has experienced high fluoride levels in the public water supply, as discussed in the ***Ground-Water Hydrology*** chapter of this report in the section entitled ***Ground-Water Quality***. In an attempt to meet requirements by the U.S. Environmental Protection Agency (USEPA), the town has examined the possibility of drilling shallow wells in an unconsolidated aquifer, then blending water from the shallow wells with water from four existing bedrock wells in order to achieve compliance with the water-quality standard for fluoride.

However, if the USEPA lowers the standard for fluoride, mixing water from bedrock and unconsolidated wells may be a short-term solution to the water-quality problem. Lowell therefore is attempting to establish an interconnecting supply line, approximately 15 miles long, with the Gary-Hobart Water Corportion. Because the interconnection would require the transfer of about 1 million gallons per day of water from the Lake Michigan Basin to the Kankakee River Basin, approval must be obtained from the governors of the eight states which border the Great Lakes. The Great Lakes Charter (Section 1109 of Public Law 99-662) requires that a prior notice and consultation process be initiated for interbasin diversions from the Great Lakes. The Governor of Indiana recently has initiated the process on behalf of the town of Lowell.

Suggested approaches to future ground-water development

As demands on ground water increase, the role of the IDNR Division of Water in protecting and managing the ground-water resource will continue to increase. One ground-water management goal in the Kankakee River Basin, and particularly in Jasper and Newton Counties, is to prevent long-term depletion of the ground-water resource while allowing continued ground-water development for both high-capacity and small-capacity uses. Another goal is to balance the need for ground-water development with the right of homeowners to an adequate supply of water.

With these goals in mind, the Division of Water has developed the following water-management alternatives in an attempt to reduce the potential for future conflicts between ground-water supply and ground-water use in these two counties:

1. Additional irrigation wells could be developed in the surficial sand aquifer (Kankakee Aquifer System) to be used as an alternative to, or in conjunction with, wells completed in the carbonate aquifer. Where sufficiently thick, the surficial sand aquifer can produce adequate quantities of water for various uses, including irrigation. However, manifold systems or multiple wells may be required to support high-capacity pumpage for irrigation.

2. Restrictions on drilling new high-capacity bedrock wells may be needed in areas where the greatest seasonal declines in water level are observed. Proposed well sites should be evaluated with regard to not only individual needs but also proper well spacing that would help prevent or minimize interference with nearby wells and reduce impacts to the source aquifer.

3. Irrigators should closely evaluate the benefits of irrigating crops grown on soils that have developed on dune deposits. Moreover, water conservation practices should be implemented on soils composed primarily of sand.

4. Domestic and livestock wells should be installed in a manner that will allow the wells to continue producing an adequate water supply during seasonal water-level declines and during periods of irrigation-induced drawdowns.

5. Continued coordination with the State of Illinois is needed to best manage irrigation development in the bi-state area where the carbonate aquifer is the major source of ground water. A resolution adopted in 1990 by the Indiana General Assembly encouraged the State of Illinois to cooperate with the State of Indiana in developing and conserving shared water resources.

In the coming years, the IDNR Division of Water will continue to closely monitor the ground-water conditions in Jasper and Newton Counties and in other areas of the basin where ground-water conflicts are occurring or are likely to occur. Improved management may be needed in areas where the ground-water resource is being extensively developed.

Minimum ground-water levels may be established by the Natural Resources Commission (I.C. 13-2-6.1). If established, the minimum level criteria may govern the amount of ground water withdrawn in some areas.

The amended water-rights law (I.C. 13-2-2.5) and its associated well-construction requirements will continue to be a key factor in developing and protecting ground water. Additional regulations that also will help ensure the protection of available ground-water supplies include: 1) a 1990 law (I.C. 13-2-2.6) protecting natural freshwater lakes from water-level declines due to nearby ground-water pumpage; 2) amendments to regulations concerning water-well drilling (I.C. 25-39-1.5); and 3) proposed revisions to statewide well-construction guidelines that were first developed in 1985 under the provisions of I.C. 13-2-2.5 (Indiana Department of Natural Resources, 1985).

SUMMARY

In response to legislative directives contained in the 1983 Water Resource Management Act, the Indiana Department of Natural Resources, Division of Water published a report describing the availability, distribution, quality and use of surface water and ground water in the Kankakee River Basin, Indiana. The third in a series of 12 regional watershed assessments, this report provides hydrologic data and related information for persons interested in the basin's water resource.

The Kankakee River Basin drains 2989 sq. mi. (square miles) in northwest Indiana, 2169 sq. mi. in northeast Illinois, and about 7 sq. mi. in southwest Lower Michigan. The Kankakee River heads near South Bend, Indiana, then flows westward into Illinois, where it joins with the Des Plaines River to form the Illinois River. The area of Lake County which originally drained to Lake Michigan but now drains by means of artificial diversion to the Illinois River is not considered to be part of the Kankakee River Basin study region.

SOCIOECONOMIC SETTING

Thirteen Indiana counties lie wholly or partially within the Kankakee River Basin, but nine counties constitute more than 90 percent of the basin's land area in Indiana. For mapping and discussion purposes, the basin in Indiana is divided into an upper region (St. Joseph, LaPorte, Marshall and Starke Counties) and a lower region (Porter, Lake, Jasper, Newton and Benton Counties).

In 1980, more than three-fourths of the basin's total population of 223,000 resided in rural areas. About one-fourth of the residents lived in urban areas, including the cities of LaPorte, Cedar Lake, Plymouth and Lowell.

Significant increases in population are expected in the basin portions of Lake and Porter Counties during the 1990s. Increasing trends in population are projected for most cities and towns in the basin, although decreases are anticipated in LaPorte, Knox and Westville.

Manufacturing, services, and wholesale and retail trade constitute the largest employment classes and account for the largest percentage of total earnings in most basin counties. In Benton County, however, agriculture is the leading source of county employment and earnings. In Jasper County, an electrical generating station provides the highest percentage of county earnings.

Cropland accounts for more than three-fourths of the basin's total land area. Corn and soybean production in the Kankakee River Basin is among the highest of any region in Indiana. Although sales of spearmint, peppermint, blueberries and orchard crops constitute only a small percentage of the basin's crop income, these crops are important to the local and regional farm economy. The production of mint for oil is significant on both a state and national level.

Forest land occurs primarily as small parcels scattered among cropland; however, some large tracts are found on the lower Kankakee River floodplain and on dunes and low sand ridges south of the river. Lakes and wetlands are most common in the morainal and outwash areas of the upper Kankakee and Yellow River watersheds. Urban or built-up land is concentrated in the basin's cities and towns and around some large lakes.

PHYSICAL ENVIRONMENT

The climate of the Kankakee River Basin is classified as temperate continental, which describes areas with warm summers, cool winters, and the absence of a pronounced dry season. The variability of climate in the basin is partially attributable to the proximity of Lake Michigan. Lake-effect processes in northern areas of the basin help to moderate extremes in temperature, thereby extending the length of the frost-free season by 2 to 3 weeks. The lake effect also causes more cloudiness, on average, and can produce frequent snows. In snow-belt areas of LaPorte and St. Joseph County, annual snowfall averages 70 inches, or about twice the normal amount received elsewhere in the basin.

Annual evapotranspiration in the Kankakee River Basin consumes at least 25 inches (70 percent) of the 38 inches of normal annual precipitation. The theoretical average annual water surplus of 12 to 13 inches is considered adequate for the basin as a whole; however, the variability of rainfall and its uneven geographic distribution can occasionally limit crops and water supplies.

The landscape of the Kankakee River Basin is primarily a product of latest Wisconsinan glacial events of the Lake Michigan lobe. Major landscape elements include 1) the nearly level to gently rolling surfaces of ground moraine, eolian plains, outwash-apron deposits, and the Kankakee River floodbasin; and 2) the more pronounced topography of end moraines. Local relief ranges from about 60 feet on the Iroquois Moraine to more than 100 feet along the crest and northern flank of the Valparaiso Moraine.

Outwash deposits occur in a broad northeast-to-southwest trending band through the basin's interior. Along and south of the Kankakee River floodplain, fine-grained outwash sediments have been sorted by wind to form a broad eolian-sand sheet with scattered dunes and dune ridges. Lacustrine silts and clays underlie and are interbedded with outwash deposits in many parts of the basin.

Fine-grained tills predominate in the basin's southwest portion and the elevated morainal areas in the east and northwest. Tills and stratified drift of chaotic form predominate in the Maxinkuckee Moraine.

The thickness of unconsolidated deposits generally ranges from 50 to 100 feet in the lower Kankakee River Basin, and from 100 to 250 feet in the upper basin. West of LaPorte where the Valparaiso Moraine forms a topographic high over a bedrock valley, unconsolidated thickness exceeds 350 feet.

The Kankakee River Basin lies across the crest of the Kankakee Arch, a major structural feature which separates the Michigan and Illinois Basins. The bedrock surface in the upper Kankakee River Basin is composed primarily of Ellsworth and Antrim Shales of Devonian and Mississippian age. Silurian and Devonian limestones, dolomites and dolomitic limestones predominate in the lower basin.

Soils in and near the Kankakee River valley formed primarily in sandy and loamy lacustrine, outwash and eolian deposits. Soils that formed in loamy and clayey glacial till predominate in eastern and southwestern areas of the basin.

Soil losses by wind erosion are high where sandy and silty soils are dominant. The basin's overall erosion rate is low, however, because of the region's low relief, permeable soils and low runoff rates. Suspended-sediment yields in most basin streams also are low, although unstable ditch banks, poor agricultural practices and stream-related construction projects can lead to local sedimentation problems. Artificial drainage systems have been extensively employed in areas having a high water table and/or soils with inadequate natural drainage outlets.

SURFACE-WATER HYDROLOGY

The surface-water resources of the Kankakee River Basin include the mainstem Kankakee River; its principal tributaries, the Yellow and Iroquois Rivers; extensive networks of drainage ditches; and scattered zones of natural lakes and wetlands. Some small wetlands in the mainstem Kankakee River valley represent remnants of the former Grand Kankakee Marsh, a 625-square-mile marsh-swamp-dune complex which once occupied much of the valley.

Of the basin's streams, the Kankakee River supports the largest number of high-capacity withdrawals, primarily for irrigation purposes. The river's value as a water-supply source stems from its large drainage area and the presence of extensive outwash deposits which provide a high degree of base flow (more than 80 percent of total runoff) and consequently produce well-sustained stream flow.

The lower Yellow River has a moderate potential for water-supply development, and currently supports a few high-capacity withdrawals. Base flow constitutes about 65 percent of total runoff in the river's lower reaches, which traverse productive outwash deposits.

Major tributaries in outwash-dominated areas of the Kankakee and lower Yellow River Basins can yield significant quantities of water during much of the year. Many tributary ditches in the Kankakee-Yellow River system support high-capacity withdrawals, primarily for irrigation.

The Iroquois River and upper Yellow River have a limited potential for water-supply development, primarily because of limited base flow from tills. Except for a few major ditches in sand-dominated upper reaches of the Iroquois River Basin, tributaries in these watersheds cannot support large withdrawal uses on a dependable basis because of poorly sustained flows. Upland (side-channel) reservoirs could provide additional water supply in the Iroquois River Basin where soils and topography are suitable for reservoir construction.

Flood protection along the Kankakee River has been provided to some extent by spoil banks, levees and agricultural dikes; however, floods continue to plague low-lying lands along the river and some of its major tributaries. A comprehensive plan recently developed by the Kankakee River Basin Commission contains a proposal for the development of a levee system along 60 miles of the Kankakee River. Unlike spoil banks and conventional levees, the proposed levees would be set back at varying distances from the river to allow storage of overbank floodwaters between the levees while providing flood protection and improved drainage on adjacent lands. As of late 1990, the future of the proposed levee system remains uncertain.

SURFACE-WATER QUALITY

Water quality generally is good in the Kankakee, Yellow and Iroquois Rivers, although iron and manganese concentrations commonly are high and the rivers frequently are turbid. Available data for the Kankakee River show that concentrations of toxic substances in streambed sediment and fish tissue are negligible.

Violations of the bacterial standard for recreational uses sometimes occur on the Kankakee River and lower Yellow River. During the 1980s, frequent fish kills attributable to sewage-related pollution were reported on the lower Yellow River. Stream reaches in the Travis Ditch, Crooked Creek, Cedar Creek and Montgomery Ditch watersheds also have experienced chronic water-quality problems from inadequately treated sewage. The number and frequency of water-quality impairments in these and other streams receiving wastewater discharges are expected to decrease in the 1990s as municipalities and industries continue to upgrade treatment facilities and improve operations.

Recent lake surveys have revealed few water-quality problems. Of the basin's large natural lakes, only Cedar Lake and Koontz Lake have experienced documented problems attributable to accelerated eutrophication. J.C. Murphey Lake, an artificial impoundment, has undergone several fish eradication and selective restocking projects.

GROUND-WATER HYDROLOGY

Ground-water availability in much of the Kankakee River Basin is considered moderate to excellent. Ten unconsolidated aquifer systems and one subsystem are defined according to hydrologic characteristics of the deposits and their environments of deposition. Seven bedrock aquifer systems are defined on the basis of hydrologic and lithologic characteristics.

Extensive deposits of outwash sand and gravel characterize the Valparaiso Outwash Apron, St. Joseph and Tributary Valley, Kankakee, and eastern Valparaiso Moraine Aquifer Systems. Common thicknesses of these highly productive aquifer systems generally range from about 30 to 50 feet, but in some locations thicknesses exceed 100 feet. Domestic wells produce from less than 10 gpm to more than 50 gpm. Yields of up to 600 gpm generally can be expected from high-capacity wells. Wells completed in the upper Kankakee Aquifer System and the St. Joseph and Tributary Valley Aquifer System may produce 1000 gpm or more.

The Maxinkuckee Moraine and the Eolian Sands Aquifer Systems are moderately productive unconsolidated aquifer systems. Although the systems are overlain by generally thick, permeable materials, ground-water production primarily is from deep wells completed in intratill sand and gravel lenses. Well yields for domestic supplies are more variable in the Maxinkuckee Moraine Aquifer System (4-80 gpm) than in the Eolian Sands Aquifer System (10-50 gpm). High-capacity wells in these systems can produce 100 to 600 gpm.

Intratill sand and gravel lenses characterize the till-dominated Nappanee and Iroquois Basin Aquifer Systems. The Nappanee Aquifer System typically yields 5 to 50 gpm to domestic wells, and may yield 50 to 600 gpm to high-capacity wells. Domestic well yields in the Iroquois Basin Aquifer System seldom exceed 10 to 25 gpm, and maximum production from high-capacity facilities is expected to be 50 to 100 gpm.

The Iroquois Buried Valley Aquifer Subsystem, part of the Iroquois Basin Aquifer System, consists of sand and gravel deposits in a buried valley overlain by till. Coarse-grained zones are more predominant in the buried valley than in overlying deposits. Yields of 10 to 40 gpm are common from domestic wells and production from high-capacity wells is expected to range from 100 to 400 gpm.

There are severe limitations to water resources in the Iroquois Moraine Aquifer System, which consists of isolated sand and gravel deposits encompassed within thick clays. Domestic wells may yield from 4 to 10 gpm. However, because the aquifers in this system are present only in small areas of the moraine, many wells pass through the unconsolidated deposits to obtain water from underlying bedrock.

Carbonate rocks of Silurian and Devonian age form the most productive bedrock aquifer system in the Kankakee River Basin. Development of joints, fractures and solution cavities have considerably enhanced the secondary permeability of the upper part of these rocks, especially at the bedrock surface. Domestic wells commonly penetrate the upper 15 to 100 feet of bedrock and produce about 8 to 200 gpm. High-capacity wells typically penetrate 200 to 450 feet of rock and generally produce 300 to 1000 gpm.

Carbonate rocks of the Mississippian Borden Group are utilized as aquifers in northern Benton County. Wells generally penetrate less than 70 feet of bedrock to produce from limestone units. Wells also penetrate less productive shale and sandstone units, and some dry holes have been reported. Domestic wells yield about 5 to 15 gpm, and one high-capacity well reportedly produces 80 gpm; however, the development potential for high-capacity wells in this system is poor.

Shales of considerable areal extent are utilized as minor aquifers, primarily in the lower Kankakee River Basin. Wells are completed in the Antrim and New Albany Shale in areas where unconsolidated aquifers are rare or absent and where more productive carbonate aquifers are far beneath the bedrock surface. Wells are drilled as much as 62 feet into the Antrim Shale and as much as 102 feet into the New Albany Shale. Well yields can range up to 15 or 20 gpm. However, the occurrence of dry holes is likely in the Antrim Shale.

Devonian and Mississippian-age Ellsworth Shale forms a large area of the bedrock surface in the northern part of the basin. However, no wells are known to produce water from the bedrock because of the availability of ground water in unconsolidated deposits.

Sandstone units of the Pennsylvanian Raccoon Creek Group may be utilized as aquifers in small areas of the lower basin. Water-yielding capabilities of the sandstone units are not known, but may be similar to those of adjacent bedrock aquifers.

GROUND-WATER QUALITY

Ground water in the Kankakee River Basin is hard, neutral to slightly alkaline, and dominated by calcium and bicarbonate. Ground water generally meets drinking-water standards, although iron commonly exceeds the Secondary Maximum Contaminant Level (SMCL). Other constituents that commonly exceed SMCLs include manganese and total dissolved solids. Chloride and sulfate concentrations can be variable and are sometimes high, but rarely exceed the SMCLs. Nitrate concentrations generally are at or near background levels, but water in a few wells scattered throughout the basin contains nitrate levels exceeding the 10 mg/L Maximum Contaminant Level.

The Valparaiso Moraine Aquifer System, the most highly mineralized of the basin's unconsolidated systems, has ground water containing the highest median alkalinity and hardness, and the highest median concentrations of calcium, magnesium, iron and sulfate. In contrast, ground water of the Eolian Sands Aquifer System contains the lowest median concentrations of these constituents except for sulfate.

Bedrock aquifer water is similar in alkalinity to overlying recharge water, but commonly is softer and contains higher concentrations of sodium and potassium because of cation exchange occurring in overlying clays, tills or shales. Fluoride concentrations can be higher in ground water of the Silurian and Devonian carbonates than in other bedrock systems. Hydrogen sulfide gas most commonly has been detected in deep wells completed in Silurian and Devonian carbonates, where reducing conditions are most likely to occur.

Detectable levels of pesticides have been found in isolated cases in both unconsolidated and bedrock wells. Volatile organic compounds were not detected in private wells sampled in 1986 but have been present in the raw water of some public supplies in Newton, Jasper, Porter and Marshall Counties.

Unconsolidated aquifer systems that are highly susceptible to contamination from surface sources include the Kankakee, Valparaiso Outwash Apron, St. Joseph, Hilltop, and Maxinkuckee Moraine Aquifer Systems, and surficial deposits of the Eolian Sands Aquifer System. The Valparaiso Moraine Aquifer System can be susceptible where surficial clay layers are absent or discontinuous. The thick clay deposits overlying the intratill aquifers in the Eolian Sands, Nappanee, Iroquois Moraine and Iroquois Basin Aquifer Systems, and the Iroquois Buried Valley Subsystem afford some protection from surface contamination.

WATER USE AND PROJECTIONS

Registered and non-registered water withdrawals in the Kankakee River Basin averaged 83 million gallons per day in 1987. About one-third of the withdrawals were for irrigation purposes, and another third were for public and domestic water supply. About one-fourth of the total withdrawals were related to energy production. The remaining withdrawals were by industries (primarily stone quarries and sand and gravel pits), a fish hatchery, livestock operations, and miscellaneous facilities.

Nearly equal amounts of water are withdrawn from surface-water and ground-water sources throughout the basin as a whole; however, the major water source differs among counties and water-use categories. For example, most registered withdrawals in Jasper and Lake Counties are from streams and ditches, whereas withdrawals in LaPorte and Newton Counties are primarily from ground water. The Kankakee River is the major water source for withdrawals in the energy production category, whereas ground water is the major source for public and domestic supplies.

Irrigation in the Kankakee River Basin constituted more than 40 percent of Indiana's reported irrigation water withdrawals in 1987, and about one-third of the state's irrigated land. Although only 7 percent of the basin's farms and less than 5 percent of the total cropland are irrigated, seasonal withdrawals for irrigation far exceed other types of withdrawals. Irrigation facilities in the basin accounted for 84 percent of the 533 water-withdrawal facilities registered with the IDNR Division of Water in 1987.

The total number of irrigated acres in the eight-county basin region is projected to increase from 67,000 acres in 1987 to nearly 109,000 acres by the year 2000. Variable increases in irrigation water withdrawals are expected. Water withdrawals for energy production, public supply, industrial, domestic self-supplied, and livestock watering purposes are expected to increase slightly as the basin's population continues to grow.

WATER RESOURCE DEVELOPMENT

Stream withdrawals are expected to remain high in areas along the lower Kankakee River and its major tributary ditches, where stream flow provides an adequate and dependable supply. Although water supplies in these areas should be sufficient for a variety of withdrawal and instream uses, the cumulative effects of irrigation withdrawals and seasonal declines in stream-flow availability may cause significant stream-flow reductions in dry years, particularly in watercourses with a limited storage capacity and large clusters of withdrawals. In Lake County, there is a high potential for water-use conflicts on Singleton Ditch and several of its tributaries, primarily because of the large number of seasonal withdrawals for irrigation.

During periods of low stream flow, withdrawals from the Kankakee River for use at an electrical generating station may produce minor impacts on stream flow immediately downstream of the intake point. However, the degree of impact cannot be quantified because of data limitations.

Lakes and wetlands will continue to provide a wide range of recreational opportunities, fish and wildlife habitat, various hydrologic benefits, and, in a few cases, minor water supply sources. However, these systems are not considered as significant sources of supply because of their limited storage capacity, water-quality considerations, and regulatory, economic and environmental constraints.

Although ground-water supplies are abundant in much of the Kankakee River Basin, increasing demands may continue to create localized or short-term conflicts among ground-water users. In past years, water-use conflicts in the basin have occurred primarily in Jasper and Newton Counties as a result of seasonal ground-water pumpage for irrigation purposes. Most irrigation wells pump from carbonate rocks of Silurian and Devonian age, but some wells utilize the surficial sand aquifer designated as the Kankakee Aquifer System.

Between 1981 and 1989, IDNR staff investigated more than 225 complaints of water-supply problems in northern Jasper and Newton Counties. Most problems reported for shallow wells were the result of seasonal water-table fluctuations in the sand aquifer, and generally were corrected by upgrading the wells. Losses of water supply in wells completed in the carbonate aquifer, however, frequently resulted from water-level declines induced by high-capacity irrigation pumpage from the bedrock.

Many of the domestic and livestock wells in Jasper and Newton Counties that were shown to be adversely affected by irrigation pumpage were voluntarily upgraded by area irrigators. In some cases, however, provisions of I.C. 13-2-2.5 were invoked to provide an immediate temporary supply of potable water to owners of affected small-capacity wells. Each matter was subsequently brought before the Natural Resources Commission to determine timely and reasonable compensation as specified in I.C. 13-2-2.5.

During the drought conditions of 1988, record low ground-water levels were recorded in 19 of the 23 bedrock and unconsolidated observation wells in the Kankakee River Basin. The greatest water-level declines were recorded in two bedrock wells in western Newton County, where maximum drawdowns were 88 and 71 feet. In the area monitored by these two wells, localized dewatering of the bedrock aquifer occurred during much of July and August, primarily as a result of hydrogeologic conditions, the prolonged drought conditions, and heavy irrigation pumpage on either side of the Indiana-Illinois state line.

In response to recurring ground-water conflicts in Jasper and Newton Counties, the IDNR Division of Water has suggested several water-management alternatives in an attempt to alleviate the potential for future conflicts, particularly during the irrigation season and during periods of drought. The suggested alternatives call for 1) the additional development of the surficial sand aquifer as an alternative or complementary ground-water source for irrigation; 2) an examination of the need for localized restrictions on the drilling of new high-capacity bedrock wells; 3) the implementation of water-conservation practices in some irrigation areas; 4) the proper installation of small-capacity wells; and 5) continued coordination with the State of Illinois to manage irrigation development in the bistate area where the carbonate aquifer is heavily pumped.

Existing provisions in Indiana law will continue to be a key factor in both developing and protecting the surface-water and ground-water resources of the Kankakee River Basin. As demands for water increase, additional steps may be needed to protect the resource.

GLOSSARY

ablation—describes processes that remove snow or ice from a glacier, including melting, evaporation, wind erosion, and sublimation

accretionary—in this usage, describes the gradual addition of new land to old by the deposition of sediment carried by stream flow

action level—the Food and Drug Administration's recommended limit for a toxic substance in the edible portion of a fish, above which fish are not safe to consume and interstate sales are not allowed

adiabatically—occurring without loss or gain of heat

air mass—a large portion of the atmosphere that is fairly uniform in temperature and humidity

alluvial fan—a cone-shaped, poorly sorted deposit of sand, gravel, and fine material formed by a stream where its gradient lessens abruptly

alluvium—a general term describing deposits of clay, silt, sand, gravel, or other particulate rock material in a streambed, on a floodplain, or on a delta

anaerobic—occurring in the absence of free oxygen

anion—a negatively charged ion

aquifer—a saturated geologic unit that can transmit significant quantities of water under ordinary hydraulic gradients

aquitard—a confining layer that retards but does not prevent the flow of water to or from an adjacent aquifer

arcuate—curved or bowed

argillaceous—pertaining to, largely composed of, or containing clay-sized particles or clay minerals

artesian—*see* confined

bank storage—the water absorbed into the banks of a stream channel when the stage rises above the water table, then returns to the channel as effluent seepage when the stage falls below the water table

basal contact—the bottom interface of a rock unit

base flow—the portion of stream flow derived largely or entirely from ground-water discharge

benthic—describes organisms, sediment, and other material at the bottom of an aquatic system

biochemical oxygen demand (BOD)—the amount of dissolved oxygen needed for the decomposition of organic matter in water

bog—a poorly drained wetland, usually found in a glacial depression, which is characterized by the presence of saturated organic soil (peat) and acidic ground water; plant decomposition is very slow in this environment

calcareous—describes a rock or sediment that contains calcium carbonate

cation—a positively charged ion

channel slope—the difference in elevation between points 10 percent and 85 percent of the distance along the channel from a gaging station (or discharge point) upstream to the watershed boundary, divided by the distance between the two points; expressed in feet per mile

channelization—in this usage, any excavation and construction activities intended to widen, deepen, straighten or relocate a natural river channel; the term does not include maintenance activities on existing channels, such as the clearing of debris or dredging of accumulated sediments

clast (geology)—a fragment of rock produced by erosion or weathering

clastic—pertaining to a rock or sediment composed principally of broken fragments that are derived from pre-existing rocks or minerals and that have been transported some distance from their places of origin

combined sewer overflow—a discharge composed of untreated or partially treated sewage mixed with stormwater

confined—describes an aquifer which lies between impermeable formations; confined ground-water is generally under pressure greater than atmospheric; also referred to as artesian

conformable—describes strata or groups of strata lying one above another in parallel order as a result of successive depositions uninterrupted by crustal movement

contaminant (drinking water)—as defined by the U.S. Environmental Protection Agency, any physical, chemical, biological, or radiological substance in water, including constituents which may not be harmful

continuous-record station—a site on a stream or lake where continuous, systematic observations of stage and/or discharge are obtained by recording or nonrecording instruments and periodic measurements of flow

craton—a part of the Earth's crust that has attained stability and has been little deformed for a long period of time

crest-stage station—a site on a stream or lake where peak stage and/or discharge data are collected systematically over a period of years

debris flow—a high-velocity flow of water-laden sediment

deltaic—associated with an alluvial deposit at the mouth of a river

direct runoff—*see* runoff, direct

disintegration—applied to the natural mechanical breaking down of a rock due to weathering

dissecting—the process of being cut by erosion into hills and valleys or into flat upland areas separated by valleys

drainage basin—the land area drained by a river and its tributaries; also called watershed or drainage area

drawdown (ground water)—the difference between the water level in a well before and during pumping

drift—a general term to describe unconsolidated sediment and rock debris transported and deposited by glaciers or glacial streams

ecosystem (aquatic)—the community of plants and animals interacting together and with their physical and chemical environment

end moraine—*see* moraine, end

eolian—describes sediments deposited after transport by wind

eolian plain—a region of low relief consisting primarily of wind-blown deposits

ephemeral gully erosion—*see* erosion, ephemeral gully

epicontinental—situated upon a continental plateau or platform

erosion, ephemeral gully—uneven removal of soil on tilled land caused by runoff waters converging and flowing along a concentrated flow path, causing scouring of land; a short-term feature, obscured by tillage, which normally occurs more than once per year

erosion, gully—uneven removal of soil by running water that forms distinct, narrow channels that are larger and deeper than rills and that cannot be obscured by normal tillage operations

erosion, rill—uneven removal of soil by running water that forms many small, closely-spaced channels, typically a few inches deep, that can be obscured by normal tillage operations

erosion, sheet—removal of a thin, fairly uniform layer of soil from an extensive area of gently sloping land by broad, continuous sheets of running water or by wind

eutrophication—in this usage, a general term describing the process by which lakes and streams become enriched by high concentrations of nutrients such as nitrogen and phosphorus

evapotranspiration—a collective term that includes water discharged to the atmosphere as a result of evaporation from the soil and surface-water bodies and by plant transpiration

facies—features, such as bedding characteristics or fossil content, which characterize a sediment as having been deposited in a unique environment

fecal coliform—bacteria that occur naturally in the intestines of humans and animals; bacterial counts in waterways are used as indicators of pollution from human and animal waste

fen—a saturated wetland characterized by the presence of basic or calcareous ground water (as contrasted to a bog); often found as seepage areas on gentle slopes comprised of glacial deposits

ferruginous—iron-bearing; also describes rocks of red color

flood, 100-year—a statistically-derived flood discharge having an average frequency of occurrence of once in 100 years, or a one percent chance of being equaled or exceeded in any given year

floodbasin—in this usage, a physiographic lowland once occupied by a glacial lake and which now includes the geologically recent floodplain and adjacent depositional features

flowing well—a well completed in a confined aquifer in which the hydrostatic pressure is greater than atmospheric pressure, and the water rises naturally to an elevation above land surface

fluvial—of or pertaining to rivers

fossiliferous—containing fossils, which are preserved plant or animal imprints or remains

geomorphic—describes physical characteristics of the land surface that are the result of geologic processes

glacial lobe—one of the lobate protrusions of the margin of a slowly moving ice mass (glacier) originating from the compaction of snow

grab sample—water collected at a single location and at a single time as opposed to a sample composited over space or time

ground-water discharge—in this usage, the part of total runoff which has passed into the ground and has subsequently been discharged into a stream channel

gully erosion—*see* erosion, gully

gypsiferous—containing gypsum, a mineral consisting of hydrous calcium sulfate

herbaceous—with the characteristics of a herb; a plant with no persistent woody stem above ground

highly erodible (cropland)—as defined by the U.S. Department of Agriculture, Soil Conservation Service, land on which the potential erosion is at least eight times the rate at which the soil can maintain continued productivity

horizon (soils)—a layer of soil, approximately parallel to the land surface, having distinct characteristics produced by soil-forming processes

hummocky—describes glacial deposits arranged in mounds with intervening depressions

hydraulic conductivity—a parameter that describes the conductive properties of a porous medium; often expressed in gallons per day per square foot

hydric soil—soil that in its undrained condition is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions that favor the growth and regeneration of hydrophytic vegetation

hydrophyte—plants typically found in wet habitats; any plant growing in water or on a substrate that is at least periodically deficient in oxygen as a result of excessive water content

igneous—describes rocks that solidified from molten or partly molten material

incised—describes the result of the process whereby a downward-eroding stream deepens its channel or produces a narrow, steep-walled valley

industry—in this usage, a general term encompassing all major employment categories

infiltration—the process (rate) by which water enters the soil surface and which is controlled by surface conditions

interflow—the part of precipitation which infiltrates the surface soil, and moves laterally toward streams as perched ground water

interpolate—to estimate intermediate values of a function between two known points

intratill—describes geologic materials contained within a single till unit or between two till units

kame—a conical hill or short irregular ridge of gravel or sand deposited in contact with glacial ice

karst—topography characterized by closed depressions or sinkholes, caves, and underground drainage formed by dissolution of limestone, dolomite or gypsum

knoll—a small, low, rounded hill

lacustrine—pertaining to, produced by, or formed in a lake or lakes

lithologic—describes the physical character of a rock; includes features such as composition, grain size, color and type of bedding

loam—describes a soil composed of a mixture of clay, silt, sand, and organic matter

macrophyte—a plant large enough either as an individual or in communities to be readily visible without the aid of optical magnification

major land resource area—as defined by the U.S. Department of Agriculture, Soil Conservation Service, a geographic area characterized by a particular pattern of soils, climate, water resources, and land uses

marsh—a wet, level, treeless area covered mostly with grasses, sedges or cattails and usually underlain by a mucky or mineral soil; sometimes referred to as a wet meadow

maximum contaminant level—the maximum permissible level of a contaminant in water which is delivered to the free-flowing outlet of the user of a public water system

mean—arithmetic average of a set of observations

median—middle value of a set of observations arranged in order of magnitude

meltwater—water resulting from the melting of snow or glacial ice

methemoglobinemia—a disease, primarily in infants, caused by the conversion of nitrates to nitrites in the intestines, and which limits the body's ability to receive oxygen

moraine—glacial drift deposited chiefly by the direct action of glacial ice

moraine, end—a ridgelike accumulation of glacial drift built along any part of the outer margin of an active glacier

moraine, ground—glacial drift deposited on the ground surface over which the glacier moved, and generally forming a region of low relief

morphometry—in this usage, the structure and form of a lake

moving average—a consecutive chronological sequence of arithmetic averages

normal (climate)—the average (mean) value for a particular parameter over a designated period, usually the most recent 30-year period ending on the decade

organic (soils)—containing partially decomposed plant remains; formal designation depends on relative percentage of organic material and clay

orographic lifting—the rising and adiabatic cooling of air as it passes upward over mountains or rough terrain

outlier (geology)—an area or group of rocks surrounded by dissimilar rocks

outwash—sand and gravel deposited by meltwater streams in front or beyond the margin of active glacial ice

outwash apron—a broad slope formed by coalescing outwash fans deposited by meltwater streams

outwash fan—a fan-shaped accumulation of primarily sand and gravel deposited by meltwater streams flowing in front of or beyond a glacier

outwash plain—a broad, flat or gently sloping sheet of outwash deposited by glacial meltwater streams

overbank—describes water or sediment carried out of a stream channel onto the surrounding land surface during a flood

overland flow—the part of runoff which passes over the land surface to the nearest stream channel

oxbow—a sharp bend in a river forming a distinct crescent or U-shape

oxbow lake—the crescent-shaped body of shallow, standing water formed by a cut-off river meander

parent material (soils)—the horizon of weathered rock or partly weathered soil material from which soil is formed

partial-record station—a site where limited stream-flow and/or water quality data are collected systematically over a period of years

per capita income—the total money income of the residents of a given area divided by the resident population of that area; as defined by the U.S. Bureau of the Census, total money income is the sum of all sources of cash income, excluding transfer payments, the imputed value of non-monetary income, and other income included under the Bureau of Economic Analysis' definition of personal income

percolate (geology)—to seep downward from an unsaturated zone to a saturated zone

permeability—the capacity of a porous medium to transmit a fluid; highly dependent upon the size and shape of the pores and their interconnections

plankton—an assemblage of suspended or floating microscopic plants and animals that drift passively with water currents

physiographic region—an area of characteristic soils, landforms and drainage that have been developed on geologically similar materials

phytoplankton—an assemblage of suspended or floating microscopic plants and animals that drift passively with water currents

piezometric surface—an imaginary surface representing the level to which water from a given aquifer will rise under the hydrostatic pressure of the aquifer

polychlorinated biphenyls (PCBs)—a family of chlorinated hydrocarbons potentially toxic to animals and humans and that persists in the environment for as long as 30 years

porosity—the amount of pore space; specifically, the ratio of the total volume of voids to the total volume of a porous medium

probable maximum precipitation—the theoretically greatest depth of precipitation for a given duration that is physically possible over a particular drainage basin at a certain time of year

proglacial—describes deposits formed just beyond the outer limits of a glacier

progradation—a seaward advance of the shoreline resulting from the nearshore deposition of sediments brought to the sea by rivers

projected—describes a number based on trends and patterns of the past

pumping test—a test conducted by pumping a well at a constant rate for period of time, and monitoring the change in hydraulic head in the aquifer

recharge (ground water)—the process by which water is absorbed and added to the zone of saturation

recurrence interval—the average number of years within which a stream-flow event is expected to occur once

reducing—describes the process of removing oxygen from a compound

rill erosion—*see* erosion, rill

runoff, direct—water entering a stream channel promptly after a precipitation event; it is presumed to consist of surface runoff and a substantial portion of the interflow

runoff, surface—water which passes over the land surface to the nearest stream channel (overland flow) plus precipitation falling directly onto the stream

runoff, (total)—the part of precipitation that appears in surface-water bodies; it is the same as stream flow unaffected by artificial manipulation

savanna—tract of land having wet soil except during periods of dry weather, and supporting grass and other low vegetation; sometimes applied to open prairie land

scarp—a steep slope along the margin of an elevated surface

seismic—pertaining to an earthquake or earth vibration, including those that are artificially induced

senescence (lakes)—approaching the end stages of eutrophication when the lake is being filled in by organic sediments and aquatic weeds

sheet erosion—*see* erosion, sheet

skewed—describes the state of asymmetry of a statistical frequency distribution, which results from a lack of coincidence of the mode, median, and arithmetic mean of the distribution

slough—a backwater area or remnant of a former river channel which contains standing water and serves as the main river channel only during high water

spit—a small point of land or narrow shoal projecting into a body of water from the shore

standard industrial classification code—a four-digit code established by the Office of Management and Budget, and used in the classification of establishments by type of activity

static water level—the level of water in a well that is not being affected by withdrawal of ground water

stratigraphy—the geologic study of the formation, composition, sequence and correlation of unconsolidated or rock layers

subaerial—formed, existing, or taking place on or near a sediment surface significantly above sea level

subaqueous—formed, existing, or taking place under water

supraglacial—describes sediment or processes occurring on the surface of a glacier

surface runoff—*see* runoff, surface

swale—a slight depression, sometimes marshy, in the midst of generally level land

swamp—a forested wetland that usually is seasonally flooded and that is dominated by either trees or shrubs; the interior of swamps may contain open-water areas such as ponds

swell—a well-rounded hill with a gentle slope in the midst of elevated and generally level land

thermocline—the horizontal plane in a thermally stratified lake located at the depth where temperature decreases most rapidly with depth

till—sediment transported by and deposited directly from glacier ice with little or no sorting by water, and consisting of a heterogeneous mixture of clay, sand, and gravel

till plain—an extensive area with a flat to undulating surface, underlain by till and commonly covered by ground moraines and subordinate end moraines

topography—the relief and contour of a surface, especially land surface

toxic—describes materials which are or may become harmful to plants or animals when present in sufficient concentrations

transgression—the gradual expansion of a shallow sea resulting in the progressive submergence of land, as when sea level rises or land subsides

transmission (soils)—process by which water moves through the soil and which is controlled by the soil horizons

transmissivity—the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient

transpiration—process by which water is evaporated from plants, primarily through microscopic air spaces in their leaves

unconfined—describes an aquifer whose upper surface is the water table which is free to fluctuate under atmospheric pressure

unit (discharge)—a general term describing a stream-flow parameter calculated on a unit-area basis, usually per square mile, during a specified period of time

water table—the upper surface of the zone of saturation below which all voids in rock and soil are saturated with water

water-table control structure—a structure placed in a ditch or tile line to alter the water-table elevation for subsurface irrigation and/or drainage purposes

watershed—*see* drainage basin

SELECTED REFERENCES

Alley, W.M., 1984, The Palmer drought severity index—limitations and assumptions: *J. Climate Appl. Meteor.* ***23*** (7), 1100-1109

____1985, The Palmer drought severity index as a measure of hydrologic drought: *Water Resources Bulletin* ***21*** (1), 105-113

Anderson, J.R., Hardy, E.E., Roach, J.T., and Witmer, R.E., 1976, A land use and land cover classification system for use with remote sensor data: U.S. Geological Survey, Professional Paper 964

Andrews, R.C., and Andrews, E., [1915], Report on proposed Kankakee River improvement (photocopy of typescript): report to the Kankakee River Improvement Association of Indiana and Illinois, made from examination of county and state records

Arihood, L.D., and Basch, M.E., [in preparation], Effect of irrigation pumpage on the ground-water system in the Kankakee River Valley, northwestern Indiana: U.S. Geological Survey, Water-Resources Investigations report

Arihood, L.D., and Glatfelter, D.R., 1986, Method for estimating low-flow characteristics of ungaged streams in Indiana: U.S. Geological Survey, Open-File Report 86-323

Arvin, D.V., 1989, Statistical summary of streamflow data for Indiana: U.S. Geological Survey, Open-File Report 89-62

Baker, G.A., 1929, The St. Joseph-Kankakee portage (2d ed.): South Bend, Northern Indiana Historical Society, Publication No. 1

Ball, T.H., 1900, Northwestern Indiana from 1800 to 1900: Chicago, Donohue and Henneberry

Barker, B., Carlisle, J.B., and Nyberg, R., 1967, Kankakee River Basin study—a comprehensive plan for water resource development: State of Illinois, Department of Public Works and Buildings, Bureau of Water Resources

Barnes, J.R., 1982, Soil survey of Starke County, Indiana: U.S. Department of Agriculture, Soil Conservation Service

____1989, Soil survey of Benton County, Indiana: U.S. Department of Agriculture, Soil Conservation Service

____[in press], Soil survey of Newton County, Indiana: U.S. Department of Agriculture, Soil Conservation Service

Bartlett, C.H., 1904, Tales of Kankakee land: New York, Charles Scribner and Sons

Basch, M.E., and Funkhouser, R.V., 1985, Irrigation impacts on ground-water levels in Jasper and Newton Counties, Indiana, 1981-84: Indiana Department of Natural Resources, Division of Water, Water Resource Assessment 85-1

Baxmeyer, C.H., 1982, Pine, Stone and Lily Lake flooding—alternative solutions, analysis of costs: Office of LaPorte County Planner

Becker, L.E., 1974, Silurian and Devonian rocks in Indiana southwest of the Cincinnati Arch: Indiana Department of Natural Resources, Geological Survey, Bulletin 50

Bedell, D.J., and Van Til, R.L., 1979, Irrigation in Michigan, 1977: Michigan Department of Natural Resources, Water Management Division

Bellrose, F.C., 1976, Ducks, geese and swans of North America—a completely new and expanded version of the classic work by F.H. Kortright (2d ed.): Harrisburg, Pennsylvania, Stackpole Books

Benton, H., Jr., 1977, Soil survey of St. Joseph County, Indiana: U.S. Department of Agriculture, Soil Conservation Service

Bergeron, M.P., 1981, Effect of irrigation pumping on the ground-water system in Newton and Jasper Counties, Indiana: U.S. Geological Survey, Water-Resources Investigations 81-38

Bhowmik, N.G., Bonini, A.P., Bogner, W.C., and Byrne, R.P., 1980, Hydraulics of flow and sediment transport in the Kankakee River in Illinois: Illinois State Water Survey, Report of Investigation 98

Blanchard, S.F., 1989, Surface-water quality of the Upper Illinois River Basin in Illinois, Indiana and Wisconsin—analysis of existing information [abs.], in Pederson, G.L, and Smith, M.M. (compilers), U.S. Geological Survey second national symposium on water quality—abstracts of technical sessions, Orlando, Florida, November 12-17, 1989: U.S. Geological Survey, Open-File Report 89-409

Blatchley, W.S., and Ashley, G.H., 1901, The lakes of northern Indiana and their associated marl deposits, *in* Indiana Department of Geology and Natural Resources, 25th annual report (1900): Indianapolis, Wm. B. Burford

Bleuer, N.K., and Fraser, G.S., 1989, Kankakee basin study reports: unpublished report prepared for Indiana Department of Natural Resources, Division of Water

Bobo, L.L., and Renn, D.E., 1980, Water-quality assessment ot the Porter County watershed, Kankakee River Basin, Porter County, Indiana: U.S. Geological Survey, Open-File Report 80-331

Bowman, J.A., and Collins, M.A., 1987, Impacts of irrigation and drought on Illinois ground-water resources: Illinois State Water Survey, Report of Investigation 109

Bradbury, K.R., and Rothschild, E.R., 1985, A computerized technique for estimating the hydraulic conductivity of aquifers from specific capacity data: *Ground Water* ***23***, 240-246

Brentlinger, J.L., Hays, J.B., Lauster, R.L., and Pierce, C.S., 1979, Agricultural erosion assessment for the non-designated and designated 208 planning areas of Indiana: Indiana Department of Natural Resources, State Soil and Water Conservation Committee

Brigham, A.R., Suloway, L.B., and Page, L.M., 1981, The effects of sedimentation on aquatic life of the Kankakee River—phase II, quantitative studies and threatened, endangered and rare species: Illinois Natural History Survey, Document No. 81/37

Bruns, T.M., 1981, General summation of geologic and hydrologic condition near Parr, Indiana: Indiana Department of Natural Resources, Division of Water

Bruns, T.M., Hebenstreit, J.J., Basch, M.E., and Funkhouser, R.V., 1984, Investigation of soil depressions on the LaCosse property in northern Newton County: Indiana Department of Natural Resources, Division of Water

Bushnell, T.M., 1928, Physiography of the Kankakee Region: *Proc. Ind. Acad. Sci.* ***37***, 141-142

Camp Dresser and McKee, Inc., 1983, Fair Oaks Farms—effects of irrigation pumpage, Newton and Jasper Counties, Indiana: Austin, Texas, report to Bose, McKinney and Evans

Campbell, J.L., 1882, Report upon the improvement of the Kankakee River and the drainage of marshlands in Indiana: Indianapolis, Wm. B. Burford

Changnon, S.A., Jr., 1968a, The LaPorte weather anomaly—fact or fiction: *Bull. Amer. Meteor. Soc.* ***49*** (1), 4-11

____1968b, Precipitation climatology of Lake Michigan basin: Illinois State Water Survey, Bulletin 52

____1979, Temporal trends in precipitation in the Chicago region, *in* Changnon, S.A., Jr., Gatz, D.F., Jameson, A.R., Dzurisin, G.L., Scott, R.W., and Grosh, R.C., Studies of urban and lake influences on precipitation in the Chicago area (v. 2): Illinois State Water Survey, Final Report, NSF Grant ENV77-15375

____1980a, Summer flooding at Chicago and possible relationships to urban-increased heavy rainfall: *Water Resources Bulletin* ***16*** (2), 323-325

____1980b, More on the LaPorte anomaly—a review: *Bull. Amer. Meteor. Soc.,* ***61*** (7), 702-711

____1980c, Evidence of urban and lake influences on precipitation in the Chicago area: *J. Appl. Meteor.* ***19*** (10), 1137-1159

____1984, Climate fluctuations in Illinois, 1901-1980: Illinois State Water Survey, Bulletin 68

____1987, Detecting drought conditions in Illinois: Illinois State Water Survey, Circular 169

Changnon, S.A., Jr., Achtemeier, G.L., Hilberg, S.D., Knapp, H.V., Olson, R.D., Roberts, W.J., and Vinzani, P.G., 1982, The 1980-81 drought in Illinois—causes, dimensions, and impacts: Illinois State Water Survey, Report of Investigation 102

Changnon, S.A., Jr., and Easterling, W.E., 1989, Measuring drought impacts—the Illinois case: *Water Resources Bulletin* ***25*** (1), 27-41

Changnon, S.A., Jr., and Huff, F.A., 1977, LaPorte again—a new anomaly: *Bull. Amer. Meteor. Soc.* ***58*** (10), 1069-1072

Changnon, S.A., Jr., and Jones, D.M.A., 1972, Review of the influences of the Great Lakes on weather: *Water Resources Research* ***8*** (2), 360-371

Changnon, S.A., Jr. and Semonin, R.G., 1979, Impact of man upon local and regional weather: *Reviews of Geophysics and Space Physics* ***17*** (7), 1891-1900

Chenoweth, J.W., 1977, Guide for interpretation of hydrology data—Kankakee River Basin study, Indiana-Illinois: U.S. Department of Agriculture, Soil Conservation Service, draft report

Conway, T.G., 1964, The settlement of the Kankakee Valley, 1830-1855: Southern Illinois University, Department of History, unpublished thesis

Cowardin, L.M., 1982, Some conceptual and semantic problems in wetland classification and inventory: *Wild. Soc. Bull.* ***10***, 57-60

Cowardin, L.M., Carter, V., Golet, F.C., and LaRoe, E.T., 1979, Classification of wetlands and deep-water habitats of the United States: U.S. Department of Interior, Fish and Wildlife Service, Report FWS/OBS-79/31

Cravens, S.J., Wilson, S.D., and Barry, R.C., 1989, Regional assessment of the ground-water resources in eastern Kankakee and northern Iroquois Counties— summary report: Illinois State Water Survey, SWS Contract Report 456

____1990, Regional assessment of the ground-water resources in eastern Kankakee and northern Iroquois Counties: Illinois State Water Survey, Report of Investigation 111

Crawford, C. G., and Mansue, L.J., 1988, Suspended-sediment characteristics of Indiana streams, 1952-84: U.S. Geological Survey, Open-File Report 87-527

Cushman, J.H., and Leap, D., 1986, Monitoring report of Newton and Jasper Counties, Indiana: report prepared for Hydroscience Associates, Inc.

Daniels, W.S., and Hale, M.D., 1955, Floods of October 1954 in the Chicago area, Illinois and Indiana: U.S. Geological Survey, Open-File Report

DeMissie, M., Bhowmik, N.G., and Adams, J.R., 1983, Hydrology, hydraulics, and sediment transport—Kankakee and Iroquois Rivers: Illinois State Water Survey, Report of Investigation 103

Delleur, J.W., Rao, A.R., and Bell, J.M., 1988, Criteria for the determination of minimum stream flows—executive summary: Purdue University, Report CE-HSE-88-6

Delleur, J.W., Rao, A.R., Bell, J.M., Voeller, T., Chairat, S., and Stevens, S., 1990, Instream flow requirements and regional drought indicators for Indiana—executive summary: Purdue University, Report CE-HSE-90-5

Dodson, Kinney and Lindblom, 1968, Hydrologic and frequency study—Kankakee River Basin, Indiana: report prepared for Indiana Department of Natural Resources, Division of Water

Doggett, D., 1924, Water level of Bass Lake: memorandum to Richard Lieber, Director, Indiana Department of Conservation

____1933, Report on the investigation of drainage conditions of the Kankakee River Basin: Indiana Department of Conservation, Division of Engineering

____1941, Preliminary investigation of the water level at Bass Lake: memorandum to Hugh Barnhart, Director, Indiana Department of Conservation

____1947, Preliminary report on some methods for maintaining the level of Bass Lake: Indiana Department of Conservation, Division of Water Resources

Doheny, E.J., Droste, J.B., and Shaver, R.H., 1975, Stratigraphy of the Detroit River Formation (Middle Devonian) of northern Indiana: Indiana Department of Natural Resources, Geological Survey, Bulletin 53

Droste, J.B., and Keller, S.J., 1989, Development of the Mississippian-Pennsylvanian unconformity in Indiana: Indiana Department of Natural Resources, Geological Survey, Occasional Paper 55

Droste, J.B., and Shaver, R.H., 1982, The Salina Group (Middle and Upper Silurian) of Indiana: Indiana Department of Natural Resources, Geological Survey, Special Report 24

____1983, Atlas of Early and Middle Paleozoic Paleogeography of the southern Great Lakes area: Indiana Department of Natural Resources, Geological Survey, Special Report 32

Durfor, C.N., and Becker, E., 1964, Public water supplies of the 100 largest cities in the United States, 1962: U.S. Geological Survey, Water-Supply Paper 1812

Earth Plan Consultants, 1987, An application for assistance from the Indiana Lake Enhancement Program—Koontz Lake, Indiana: prepared for Koontz Lake Environmental Enhancement Committee

Earth Source, Inc., 1988, The cultural eutrophication of Koontz Lake, Indiana— causes, consequences, correction: prepared for Koontz Lake Environmental Enhancement Committee

Easterling, W.E., and Changnon, S.A., Jr., 1987, Climatology of precipitation droughts in Illinois based on water supply problems: *Physical Geography* ***8*** (4), 362-377

Eberly, W.R., 1959, The metalimnetic oxygen maximum in Meyers Lake [abs.]: *Invest. Indiana Lakes and Streams* ***5*** (1), 1

Echelberger, W.F., and Jones, W.W., 1979, Cedar Lake restoration feasibility study: Indiana University, Environmental Systems Application Center, School of Public and Environmental Affairs

____1984, Cedar Lake restoration feasibility study—final report: Indiana University, Environmental Systems Application Center, School of Public and Environmental Affairs

Edwards, W.R., 1978, Wildlife survey of bottomland forest habitats along the Kankakee River in Illinois east of Momence: Illinois Natural History Survey, unpublished report

Eichenlaub, V.L., 1979, Weather and climate of the Great Lakes Region: Notre Dame, University of Notre Dame Press

Eschman, D.F., 1985, Summary of the Quaternary history of Michigan, Ohio and Indiana: *Journal of Geological Education* ***33***, 161-167

Farnsworth, R.K., and Thompson, E.S., 1982a, Evaporation atlas for the contiguous 48 United States: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, NOAA Technical Report NWS 33

____1982b, Mean monthly, seasonal and annual pan evaporation for the United States: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, NOAA Technical Report NWS 34

Fowler, K.K., 1988, Annual maximum and minimum lake levels for Indiana, water years 1942-85: U.S. Geological Survey, Open-File Report 88-331

____[in preparation], Effects of the drought of 1988 in Indiana on ground-water levels, streamflow, and reservoir levels: U.S. Geological Survey, Water-Resources Investigations report

Frazier, W.H., and Sapirie, S.R., 1934, Report on Kankakee River survey to determine areas for restoration: Indiana Department of Conservation

Frederick, R.P., Meyers, V.A., and Auciello, E.P., 1977, Five- to 60-minute precipitation frequency for the eastern and central United States: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, NOAA Technical Memorandum NWS HYDRO-35

Freeze, R.A., and Cherry, J.A., 1979, Groundwater: New Jersey, Prentice-Hall

Furr, G.F., Jr., 1981, Soil survey of Porter County, Indiana: U.S. Department of Agriculture, Soil Conservation Service

____1982, Soil survey of LaPorte County, Indiana: U.S. Department of Agriculture, Soil Conservation Service

Galloway, H.M., Yahner, J.E., Srinivasan, G., and Franzmeier, D.P., [1975], User's guide to the general soil maps and interpretive data for counties of Indiana: Purdue University Cooperative Extention Service/Agricultural Experiment Station and U.S. Department of Agriculture, Soil Conservation Service, Supplement to AY-50 series

Galloway, H.M., and Steinhardt, G.C., 1984, Indiana soils and landscapes—their origin and patterns of occurrence, with maps of soil resource areas: Purdue University Cooperative Extension Service, Extension Publication AY-250

GeoTrans, Inc. 1983, Assessment of Prudential pumping on the ground-water system of Jasper and Newton Counties, Indiana: Reston, Virginia, report to J.R. Nesbitt

Gibb, J.P., and O'Hearn, M., 1980, Illinois ground-water quality data summary: Illinois State Water Survey, Contract Report No. 230

Gibb, J.P., Schuller, R.M., and Griffin, R.A., 1981, Procedures for the collection of representative water quality data for monitoring wells: Illinois State Water Survey and Illinois State Geological Survey, Cooperative Ground-Water Report 7

Gillespie, G.L., 1876, Report on preliminary examination of Kankakee River: Annual report of Chief of Engineers

Glatfelter, D.R., 1984, Techniques for estimating magnitude and frequency of floods on streams in Indiana: U.S. Geological Survey, Water-Resources Investigations Report 84-4134

Glatfelter, D.R., Butch, G.K., and Stewart, J.A., 1984, Floods of March, 1982, Indiana, Michigan, and Ohio: U.S. Geological Survey, Water-Resources Investigations Report 83-4201

Glatfelter, D.R., and Chin, E.H., 1988, Floods of March 1982 in Indiana, Ohio, Michigan and Illinois: U.S. Geological Survey, Professional Paper 1467

Glatfelter, D.R., Thompson, R.E., Jr., and Nell, G.E., 1986, Water-resources data, Indiana, water year 1985: U.S. Geological Survey, Water-Data Report IN-85-1

____1989, Water-resources data, Indiana, water year 1988: U.S. Geological Survey, Water-Data Report IN-88-1

Governor's Soil Resources Study Commission, 1984, Indiana's erosion and sedimentation situation: interim report

____1985, T by 2000, an accelerated program to reduce soil erosion and sedimentation in Indiana: final report

Governor's Water Resources Study Commission (Clark, G.D., ed.), 1980, The Indiana water resource—availability, uses and needs: Indiana Department of Natural Resources

Grady, D.M., and Rutledge, R.M., 1982, A floodplain management handbook for local planners: Indiana Department of Natural Resources, Division of Water

Gray, H.H., 1982, Map of Indiana showing topography of the bedrock surface: Indiana Department of Natural Resources, Geological Survey, Miscellaneous Map 36, scale 1:500,000

____1983, Map of Indiana showing thickness of unconsolidated deposits: Indiana Department of Natural Resources, Geological Survey, Miscellaneous Map 38, scale 1:500,000

____1989, Quaternary geologic map of Indiana: Indiana Department of Natural Resources, Geological Survey, Miscellaneous Map 49, scale 1:500,000

Gray, H.H., Ault, C.H., and Keller, S.J., 1987, Bedrock geologic map of Indiana: Indiana Department of Natural Resources, Geological Survey, Miscellaneous Map 48, scale 1:500,000

Great Lakes Commission, 1989, Guide to drought planning, management and water level changes in the Great Lakes: Task Force on drought management and Great Lakes water levels, draft report

____1990, A guidebook to drought planning, management and water level changes in The Great Lakes: final report

Green, A.R., and Hoggatt, R.E., 1960, Floods in Indiana—magnitude and frequency: U.S. Geological Survey, Open-File Report

Gross, D.L., and Berg, R.C., 1981, Geology of the Kankakee River system in Kankakee County, Illinois: Illinois State Geological Survey Division, Environmental Geology Notes 92

Gutschick, R.G., 1983, Geology of the Kentland Dome structurally complex anomaly, northwestern Indiana (field trip 5), *in* Shaver, R.H., and Sunderman, J.A., Field trips in midwestern geology (v. 1): Geological Society of America, Indiana Geological Survey, and Indiana University Department of Geology

Gutstadt, A.M., 1958, Cambrian and Ordovician stratigraphy and oil and gas possibilities in Indiana: Indiana Department of Conservation, Geological Survey, Bulletin 14

Hale, M.D., 1954, Flood flow in Kankakee River Basin, October-November 1954, a preliminary report: U.S. Geological Survey, provisional draft

Hartke, E.J., 1984, Geology for Environmental Planning in Starke County, Indiana: Indiana Department of Natural Resources, Geological Survey, Occasional Paper 42

____1986, Environmental geologic considerations in Koontz Lake, Starke County, Indiana, and its 6-mile fringe: Indiana Department of Natural Resources, Geological Survey, Occasional Paper 51 (Environmental Study 20)

Hartke, E.J., Hill, J.R., and Reshkin, M., 1975, Environmental geology of Lake and Porter Counties, Indiana—an aid to planning: Indiana Department of Natural Resources, Geological Survey, Special Report 11 (Environmental Study 8)

Hatch, W.L., 1983, Selective guide to climatic data sources: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Climatic Data Center, Key to Meteorological Records Documentation No. 4.11

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water (3d ed.): U.S. Geological Survey, Water-Supply Paper 2254

Hershfield, D.M., 1961, Rainfall frequency atlas of the United States for durations from 30 minutes to 24 hours and return periods from 1 to 100 years: U.S. Department of Commerce, Weather Bureau, Technical Paper No. 40

Hidore, J.J., 1971, The effects of accidental weather modification in the flow of the Kankakee River: *Bull. Amer. Meteor. Soc.* ***52***, 99-103

Hill, J.R., Carr, D.D., Hartke, E.J., and Rexroad, C.B., 1979, Geology as a contribution to land use planning in LaPorte County, Indiana: Indiana Department of Natural Resources, Geological Survey, Special Report 14

Ho, F.P., and Riedel, J.T., 1980, Seasonal variation of 10-square-mile probable maximum precipitation estimates—United States east of the 105th meridian: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Hydrometeorological Report No. 53

Hoggatt, R.E., 1975, Drainage areas of Indiana streams: U.S. Geological Survey, unnumbered report

Holzman, B.G., 1971a, More on the LaPorte fallacy: *Bull. Amer. Meteor. Soc.* ***52***, 572-573

____1971b, The LaPorte precipitation fallacy: Science, 172, 847

Holzman, B.G., and Thom, H.C.S., 1970, The LaPorte precipitation anomaly: *Bull. Amer. Meteor. Soc.* ***51***, 335-337

Houde, M.J., and Klasey, J., 1968, Of the people—a popular history of Kankakee County: Chicago, The General Printing Company

Huff, F.A., Hiser, H.W., and Stout, G.E., 1955, The October 1954 storm in northern Illinois: State of Illinois, Water Survey Division, Report of Investigation 27

Hunn, J.D., and Rosenshein, J.S., 1969, Geohydrology and ground-water potential of St. Joseph County, Indiana: Indiana Department of Natural Resources, Division of Water, Bulletin 33

Hutchison, M.D., 1978, The natural character of the Momence Wetlands, Kankakee County, Illinois: Rockford Illinois, Natural Land Institute

Indiana Department of Commerce, 1988, Capacity of multi-county regions in Indiana to support economic growth: Division of Economic Analysis, prepared for the Indiana Economic Development Council, Inc.

Indiana Department of Conservation, 1956, Report on the feasibility of maintaining a higher water level in Bass Lake by pumping water from a well or wells: Division of Water Resources

____1963, Investigation of receding water levels of Pine and Stone Lakes, LaPorte County, Indiana: Division of Water Resources

Indiana Department of Environmental Management, 1986, Indiana lake classification system and management plan

____[1986], 305(b) Report, 1984-85

____[1988], 305(b) Report, 1986-87

____[1990], 305(b) Report, 1988-89 [in preparation]

Indiana Department of Natural Resources, 1969, Indiana agricultural irrigation in 1967: State Water Plan Section

____1971, Agricultural irrigation in the Kankakee and Elkhart River Basins of Indiana for 1967: State Water Plan Section

____1973, Investigation of flooding along the Kankakee River from the Indiana-Illinois state line to the Jasper-Newton county line: Division of Water, unpublished report

____[1976], Lakes inventory: Division of Water, unpublished data

____1977, Potential erosion map: Soil and Water Conservation Committee, scale 1:500,000

____1982a, The 1980 survey of domestic self-supplied and livestock water uses in Indiana: Division of Water

____1982b, The 1980 survey of public water supply utilities in Indiana: Division of Water

____1982c, Report of preliminary examination of flooding problems at natural freshwater lakes in and adjacent to LaPorte, Indiana: Division of Water, Report No. P.E. 14

____1982d, Preliminary report on ground-water levels in Jasper and Newton Counties, 1982: Division of Water, Report of Investigation No. 18

____1982e, Rainfall frequency for Indiana: Division of Water

____1985, Recommended guidelines for the construction of wells and the type and setting of pumps in the state of Indiana: Division of Water, Bulletin WM-1

____1986, Indiana natural and scenic rivers report: Division of Outdoor Recreation

____(Clendenon, C.J., and Beaty, J.E., eds.),1987, Water resource availability in the St. Joseph River Basin, Indiana: Division of Water, Water Resource Assessment 87-1

____1988a, Directory of Indiana's dedicated Nature Preserves: Division of Nature Preserves

____1988b, Indiana Outdoor Recreation, 1989—an assessment and policy plan: Division of Outdoor Recreation

____1988c, Wetlands, Indiana's endangered resource, an appendix to Indiana outdoor recreation 1989—an assessment and policy plan: Division of Outdoor Recreation

____1988d, Recreation use analysis of the Kankakee River Basin: Division of Outdoor Recreation, draft report prepared for Division of Water

____1988e, Coordinated discharges of selected streams in Indiana: Division of Water

____[1989], Indiana wetland conservation areas: Division of Fish and Wildlife, revised report

____[1990], Guide to Indiana lakes: Division of Water, revised report, [in press]

Indiana Drought Advisory Committee, 1988, Report: summary compiled September, 1988

Indiana Drought Disaster Preparedness Committee, 1977, Report to Governor Otis R. Bowen: report compiled June, 1977

Indiana Environmental Management Board, 1979, Drinking water standards: Regulation EMB-4 (320 IAC 3-3.1)

Indiana Nonpoint Source Task Force, 1989, Indiana nonpoint source water pollution management program: draft report

Indiana State Board of Health, 1983, Indiana county population projections, 1985-2020 (2d ed.): prepared by Division of Research, Indiana University School of Business

——1984, Data on Indiana public water supplies: Division of Public Water Supply, Bulletin PWS-3

——1986, Indiana township population projections, 1985-2020: prepared by Indiana Business Research Center, Indiana University School of Business

——1988, Indiana county population projections, 1985-2020: prepared by Indiana Business Research Center, Indiana University School of Business

Indiana Stream Pollution Control Board, 1984, 305(b) report, 1982-83

——1985, Water quality standards applicable to all state waters: Regulation 330 IAC 1-1

Indiana University, 1985, Nitrate-nitrogen levels in non-community water supply sites: School of Public and Environmental Affairs, unpublished data

——1987, Study of Hoosier leisure activities: Center for Survey Research, report prepared for Indiana Department of Natural Resources, Division of Outdoor Recreation

Indiana Water Pollution Control Board, 1987, Proposed revisions to 327 IAC 2-1, The water quality standards

Ivens, J.L., Bhowmik, N.G., Brigham, A.R., and Gross, D.L., 1981, The Kankakee River yesterday and today: Illinois State Water Survey, Miscellaneous Publication 60

Jones, D.M.A., 1966, Variability of evapotranspiration in Illinois: Illinois State Water Survey, Circular 89

Kankakee River Basin Commission, 1983, The Kankakee River in Indiana, a program for the future: unnumbered report

——1989, Kankakee River master plan, a guide for flood control and land use alternatives in Indiana: Indianapolis, SEG Engineers and Consultants, Inc.

Kankakee Valley Draining Company, 1869, Prospectus and articles of association of the Kankakee Valley Draining Company of Indiana: New York, Baker and Godwin

——1871a, Map of the Kankakee Valley, Indiana: Indianapolis, Braden and Burford

——1871b, Prospectus of the Kankakee Valley Draining Company of Indiana, $2,000,000 first mortgage, sinking fund, 20-year gold bonds: LaPorte, Stoll and Wadsworth

Kemp, K., 1970, Predictions of agricultural irrigation for Indiana and irrigation potential of selected Indiana soil series: Indiana Department of Natural Resources, Division of Water

Kiefer, L.M., 1982, Soil survey of Iroquois County, Illinois: U.S. Department of Agriculture, Soil Conservation Service

Kingsbury, T.M., 1947, Ground-water conditions near Bass Lake: memorandum, Indiana Department of Conservation, Division of Water Resources

Klaer, F.H., Jr., and Stallman, R.W., 1948, Ground-water resources of St. Joseph County, Indiana—pt. 1, South Bend area: Indiana Department of Conservation, Division of Water Resources, Bulletin 3

Kurz, D., 1978, Vegetation of the Momence Wetlands: Rockford, Illinois, Natural Land Institute, unpublished report

Lehr, J.H., Gass. T.E., Pettyjohn, W.A., and DeMarre, J., 1980, Domestic water treatment: New York, McGraw-Hill

Levin, H.L., 1988, The earth through time (3d ed.): Philadelphia, Saunders College Publishing

Lindsey, A.A. (ed.), 1966, Natural features of Indiana: Indiana Academy of Science and Indiana State Library

Lineback, J.A., 1970, Stratigraphy of the New Albany Shale in Indiana: Indiana Department of Natural Resources, Geological Survey, Bulletin 44

Lineback, J.A., Bleuer, N.K., Mickelson, D.M., Farrand, W.R., and Goldthwait, R.P., (Richmond, G.M., and Fullerton, D.S., eds.), 1983, Quaternary geologic map of the Chicago 4° x 6° Quadrangle, United States: U.S.Geological Survey, Miscellaneous Investigations Series, Map I-1420 (NK-16), scale 1:1,000,000

Link, W.K., 1963, Those vanishing lakes (photocopies): LaPorte, Indiana, The Herald-Argus, September-October issues, dates unknown

Linsley, R.K., Jr., Kohler, M.A., and Paulhus, J.L.H., 1982, Hydrology for engineers (3d ed.): New York, McGraw-Hill

Machan, W., 1986, Fish and wildlife restoration in Indiana—a history of federal aid programs, 1939-1986: Indiana Department of Natural Resources, Division of Fish and Wildlife, Pittman-Robertson Bulletin No. 17

Machta, L., Angell, J.K., Korshover, J., and Mitchell, J.M., Jr., 1977, Demise of the LaPorte precipitation anomaly: *Bull. Amer. Meteor. Soc.* ***58*** (10), 1067-1069

Mades, D.M., 1987, Surface-water quality assessment of the Upper Illinois River Basin in Illinois, Indiana and Wisconsin—project description: U.S. Geological Survey, Open-File Report 87-473

Madison, R.J. and Brunett, J.O., 1984, Overview of the occurrence of nitrate in ground water of the United States, *in* National Water Summary 1984: U.S. Geological Survey, Water-Supply Paper 2275

Malott, C.A., 1922, The physiography of Indiana, in Indiana Department of Conservation, Handbook of Indiana Geology: Division of Geology

Marcus, M. (ed.), 1985, Indiana factbook 1985: Indiana Business Research Center, Indiana University School of Business

Marie, J.R., 1975, Hydraulic characteristics and water supply potential of the aquifers in the vicinity of the wastewater treatment plant, South Bend, Indiana: U.S. Geological Survey, Water-Resources Investigations Report 49-74

Maxwell, D., 1975, The validity of the LaPorte anomaly—a critical review: Paper presented at the 14th Annual Air Quality Conference, Purdue University

McCormack, J.T., 1947, Report on a proposed method of maintaining the level of Bass Lake, Starke County, Indiana: (publishing agency unknown)

McFadden, S.S., Morse, W.J., Orozco, P.J., Smith, E.E., and Wegscheid, C.D., 1988, Geophysical study of shallow groundwater geology in Kankakee and northern Iroquois Counties, Illinois: Illinois State Geological Survey

Meyer, A.H., 1936, The Kankakee Marsh of northern Indiana and Illinois: University of Michigan, thesis (1934); reprinted from *Papers of the Michigan Academy of Sciences, Arts and Letters* ***21*** (1935), 359-396

Michiana Area Council of Governments, 1978, Section 208 water quality management plan: Phase IV, review and adoption, final plan

Miller, D.M., 1984, Reducing transformation bias in curve fitting: *The American Statistician* ***38*** (2), 124-126

Mitsch, W.J., Hutchison, M.D., and Paulson, G.A., 1979, The Momence Wetlands of the Kankakee River in Illinois—an assessment of their value: Illinois Institute of Natural Resources, Doc. No. 79/17

National Academy of Sciences and the National Academy of Engineering, 1974, Water quality criteria 1972: U.S. Government Printing Office

National Oceanic and Atmospheric Administration [n.d.], Climatological summaries, [1934-63, selected periods]: U.S. Department of Commerce, Weather Bureau, Climatography of the United States No. 20-12

____[1958], Climatic summary of the United States, supplement for 1931 through 1952: U.S. Department of Commerce, Weather Bureau, Climatography of the United States No. 11-10

____1972, National Weather Service observing handbook no. 2, substation observations (revised): Washington, D.C.

____1976, Climate of (city), Indiana, Climatography of the United States No. 20, 1951-74: U.S. Department of Commerce, Environmental Data Service, National Climatic Center

____1977, Five to 60 minute precipitation frequency for the eastern and central United States: NOAA Technical Memorandum NWS HYDRO-35

____1982a, Monthly normals of temperature, heating and cooling degree days, and precipitation, 1951-80: Climatography of the United States No. 81 (Indiana), U.S. Department of Commerce, National Environmental Satellite, Data and Information Service, National Climatic Data Center

____1982b, Daily normals of temperature, heating and cooling degree days, and precipitation, 1951-80: Climatography of the United States No. 84, U.S. Department of Commerce, National Environmental Satellite, Data and Information Service, National Climatic Data Center

____1983a, Monthly precipitation probabilities, selected probability levels derived from the 1951-80 normals: Supplement to Climatography of the United States No. 81, Department of Commerce, National Environmental Satellite, Data and Information Service, National Climatic Data Center

____1983b, Climatic normals: U.S. Department of Commerce, National Environmental Satellite, Data and Information Service, National Climatic Data Center, Environmental Information Summaries C-23

____1984, Local climatological data—1983 annual summary with comparative data (South Bend, Chicago): U.S. Department of Commerce, National Environmental Satellite, Data and Information Service, National Climatic Data Center

____1985, Climatography of the United States No. 20 (Indiana), Climatic summaries for selected sites, 1951-80: U.S. Department of Commerce, National Environmental Satellite, Data and Information Service, National Climatic Data Center

Newman, J.E., 1981, Weekly water-use estimates by crops and natural vegetation in Indiana: Purdue University, Agricultural Experiment Station, Bulletin No. 344

Neyer, M.W., 1985, An evaluation of the cooperative surface-water gaging program in Indiana: Indiana Department of Natural Resources, Division of Water

O'Hearn, M., and Gibb, J.P., 1980, Groundwater discharge to Illinois streams: Illinois State Water Survey, Contract Report 246

Office of Management and Budget, [1987], Standard industrial classification manual: Washington, D.C.

Palmer, W., 1965, Meteorological drought: U.S. Weather Bureau, Research Paper 45

Palmer, C.W., and Havens, A.V., 1958, A graphic technique for determining evapotranspiration by the Thornwaite method: *Monthly Weather Review* ***82***, 123-128

Paschke, J.E., 1979, Soil survey of Kankakee County, Illinois: U.S. Department of Agriculture, Soil Conservation Service

Perrey, J.I. and Corbett, D.M., 1956, Hydrology of Indiana lakes: U.S. Geological Survey, Water-Supply Paper 1363

Persinger, I.D., 1972, Soil survey of Lake County, Indiana: U.S. Department of Agriculture, Soil Conservation Service

Peters, J.G., 1987, Description and comparison of selected models for hydrologic analysis of ground-water flow, St. Joseph River Basin: U.S. Geological Survey, Water-Resources Investigations Report 86-4199

Pinsak, A.P., and Shaver, R.H., 1964, The Silurian formations of northern Indiana: Indiana Department of Conservation, Geological Survey, Bulletin 32

Rexroad, C.B., and Droste, J.B., 1982, Stratigraphy and conodont paleontology of the Sexton Creek Limestone and the Salamonie Dolomite (Silurian) in northwestern Indiana: Indiana Department of Natural Resources, Geological Survey, Special Report 25

Robbins, P.R., Carson, E.E., Wheaton, R.Z., and Mannering, J.V., 1977, Irrigation of field crops in Indiana: Purdue University, Cooperative Extension Service, Report ID-119

Robertson, B., 1971, Kankakee River Basin stream survey report: Indiana Department of Natural Resources, Division of Fish and Wildlife

____1989a, Iroquois River fish population survey: Indiana Department of Natural Resources, Division of Fish and Wildlife

____1989b, Yellow River fish population survey: Indiana Department of Natural Resources, Division of Fish and Wildlife

Robertson, B. and Ledet, N., 1981, A fisheries survey of the Kankakee River in Indiana, part one: Indiana Department of Natural Resources, Division of Fish and Wildlife

Rohne, P.B., Jr., 1972, Low-flow characteristics of Indiana streams: U.S. Geological Survey, Open-File Report

Rolley, R.E. and New, J.F., 1987, Abundance and characteristics of northern Indiana wetlands: *Proc. Ind. Acad. Sci.* ***96***, 249-256

Rosenshein, J.S., 1961, Ground-water resources of northwestern Indiana—preliminary report, Lake County: Indiana Department of Conservation, Division of Water Resources, Bulletin 10

____1962, Ground-water resources of northwestern Indiana—preliminary report, Porter County: Indiana Department of Conservation, Division of Water Resources, Bulletin 12

____1963, Recharge rates of principal aquifers in Lake County, Indiana: Ground Water 1 (4), 13-20

Rosenshein, J.S., and Hunn, J.D., 1962a, Ground-water resources of northwestern Indiana—preliminary report, LaPorte County: Indiana Department of Conservation, Division of Water Resources, Bulletin 13

____1962b, Ground-water resources of northwestern Indiana, preliminary report, St. Joseph County: Indiana Department of Conservation, Division of Water Resources, Bulletin 15

____1964a, Ground-water resources of northwestern Indiana, preliminary report, Marshall County: Indiana Department of Conservation, Division of Water Resources, Bulletin 19

____1964b, Ground-water resources of northwestern Indiana, preliminary report, Starke County: Indiana Department of Conservation, Division of Water Resources, Bulletin 22

____1964c, Ground-water resources of northwestern Indiana, preliminary report, Jasper County: Indiana Department of Conservation, Division of Water Resources, Bulletin 25

——1964d, Ground-water resources of northwestern Indiana, preliminary report, Newton County: Indiana Department of Conservation, Division of Water Resources, Bulletin 26

——1968a, Geohydrology and ground-water potential of Lake County, Indiana: Indiana Department of Natural Resources, Division of Water, Bulletin 31

——1968b, Geohydrology and ground-water potential of Porter and LaPorte Counties, Indiana: Indiana Department of Natural Resources, Division of Water, Bulletin 32

Sasman, R.T., Schicht, R.J., Gibb, J.P., O'Hearn, M., Benson, C.R., and Ludwigs, R.S., 1981, Verification of the potential yield and chemical quality of the shallow dolomite aquifer in DuPage County, Illinois: Illinois State Water Survey, Circular 149

Schaal, L.A., 1959, The climate of Indiana *in* National Oceanic and Atmospheric Administration, Climates of the States, v. 1 (1974): New York, Water Information Center, Inc.

Schaal, L.A., and Newman, J.E., 1981, Determining spring and fall frost-freeze risks in Indiana: Purdue University, Cooperative Extension Service, Agronomy Guide (Weather) AY-231

Schicht, R.J., Adams, J.R., and Stall, J.B., 1976, Water resources availability, quality, and cost in northeastern Illinois: Illinois State Water Survey, Report of Investigation 83

Schicht, R.J., and Walton, W.C., 1961, Hydrologic budgets for three small watersheds in Illinois: Illinois State Water Survey, Report of Investigation 40

Schneider, A.F., 1966, Physiography, *in* Lindsey, A.A. (ed.), Natural features of Indiana: Indiana Academy of Science and Indiana State Library

Schneider, A.F., and Keller, S.J., 1970, Geologic map of the 1° x 2° Chicago Quadrangle, Indiana, Illinois and Michigan, showing bedrock and unconsolidated deposits: Indiana Department of Natural Resources, Indiana Geological Survey, Regional Geologic Map 4, Chicago sheet, scale 1:250,000

Schreiner, L.C., and Riedel, J.T., 1978, Probable maximum precipitation estimates, United States east of the 105th meridian: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Hydrometeorological Report No. 51

Scott, S.L., 1928, Has dredging the Kankakee basin "overdrained" the principal soil types: Purdue University, unpublished thesis

Searcy, J.K., 1959, Flow duration curves; Manual of Hydrology, Part 2, Low-flow techniques: U.S. Geological Survey, Water-Supply Paper 1542-A

Seegert, G., 1987, Distribution of fishes in the Kankakee River Basin of Indiana: grant report prepared for Indiana Department of Natural Resources, Division of Fish and Wildlife, Nongame and Endangered Wildlife Program

Shaver, R.H., 1974, The Muscatatuck Group (New Middle Devonian Name) in Indiana: Indiana Department of Natural Resources, Geological Survey, Occasional Paper 3

Shaver, R.H., Ault, C.H., Burger, A.M., Carr, D.D., Droste, J.B., Eggert, D.L., Gray, H.H., Harper, D., Hasenmueller, N.R., Hasenmueller, W.A., Horowitz, A.S., Hutchison, H.C., Keith, B.D., Keller, S.J., Patton, J.B., Rexroad, C.B., and Wier, C.E., 1986, Compendium of Paleozoic rock-unit stratigraphy in Indiana, a revision: Indiana Department of Natural Resources, Geological Survey, Bulletin 59

Smallwood, B.F., 1980, Soil survey of Marshall County, Indiana: U.S. Department of Agriculture, Soil Conservation Service

Smallwood, B.F., and Osterholz, L.C., 1990, Soil survey of Jasper County, Indiana: U.S. Department of Agriculture, Soil Conservation Service

Smith, C.A., [1981], An evaluation of the fishery in the Kankakee River in Indiana: U.S. Army Corps of Engineers, Chicago District

Smith, J.A., 1879, Report on improvement of Kankakee River: Annual report of Chief of Engineers

Smith, W.B., and Golitz, M.F., 1988, Indiana forest statistics, 1986: U.S. Department of Agriculture, North Central Forest Experiment Station, Resource Bulletin NC-108

Solley, W.B., Chase, E.B., and Mann, W.B., 1983, Estimated use of water in the United States in 1980: U.S. Geological Survey, Circular 1001

Solley, W.B., Merk, C.F., and Pierce, R.F., 1988, Estimated use of water in the United States in 1985: U.S. Geological Survey, Circular 1004

Spacie, A., and Bell, J.M., 1980, Trophic status of fifteen Indiana lakes in 1977: Purdue University, Department of Forestry and Natural Resources, Publication RB 966

State of Illinois, 1954, Report on Illinois-Indiana interstate drainage, Yellowhead-Singleton Ditch system, June 1, 1954: Division of Waterways, Department of Public Works and Buildings

——1976, Water quality management, basin plan, phase I, Kankakee River Basin: Illinois Environmental Protection Agency

——1978, Final report to the governor: Kankakee River Basin task force

Steffeck, D.W., and Striegl, R.G., 1989, An inventory and evaluation of biological investigations that relate to stream-water quality in the Upper Illinois River Basin of Illinois, Indiana and Wisconsin: U.S. Geological Survey, Water-Resources Investigations Report 89-4041

Stewart, J.A., 1983, Low-flow characteristics of Indiana streams: U.S. Geological Survey, Open-File Report 82-1007

Stout, G.E., 1962, Some observations of cloud initiation in industrial areas—air over cities: Cincinnati, SEC Technical Report A62-65, p. 147-153

Terrio, P.J., 1989, Occurrence and distribution of nutrients and dissolved oxygen in the Upper Illinois River Basin in Illinois, Indiana and Wisconsin—results of a 1988 low-flow synoptic survey [abs.], *in* Pederson, G.L., and Smith, M.M. (compilers), U.S. Geological Survey second national symposium on water quality, abstracts of technical sessions, Orlando, Florida, November 12-17, 1989: U.S. Geological Survey, Open-File Report 89-409

Todd, D.K., 1980, Ground-water hydrology (2d ed.): New York, John Wiley

Tucker, W.M., 1922a, History of the lakes near LaPorte, Indiana: *Proc. Ind. Acad. Sci.* ***12***, 83-94

——1922b, Hydrology of Indiana, *in* Indiana Department of Conservation, Handbook of Indiana geology: Division of Geology

Turco, R.F., and Konopka, A.E., 1988, Agricultural impact on groundwater quality: Purdue University, Water Resources Research Center, Technical Report 185

Uhl, J., and Kingsbury, T., 1957, Irrigation in Indiana using groundwater sources: Indiana Department of Conservation, Division of Water Resources

U.S. Army Corps of Engineers, 1941, Review report of the Kankakee River, Illinois and Indiana, for flood control: Chicago District

____1944, Survey report for flood control, Illinois River, Illinois and tributaries—appendix B, Kankakee River, Illinois and Indiana: Chicago District, report resubmitted 1945
____1979, Kankakee River, Indiana levee study, Williams Levee: Chicago District
____1982a, Hydrologic and sedimentation impacts of proposed clearing and snagging activities, Kankakee River, Indiana: Chicago District, Floodplain Management Services Section
____1982b, Final environmental assessment of the snagging and clearing of the Kankakee River in Indiana by the Kankakee River Basin Commission: Chicago District
____1984, Levee condition survey, Kankakee and Yellow Rivers, Indiana: Detroit District
U.S. Bureau of the Census, 1963, Census of Manufactures: Summary and subject statistics, v. 1, ch. 10, Water use in manufacturing
____1971, Census of Manufactures, 1967: Summary and subject statistics, v. 1, ch. 7, Water use in manufacturing
____1975, Census of Manufactures, 1972: Special report series, Water use in manufacturing, MC72(SR)-4
____1981, Census of Manufactures, 1977: Subject series, Water use in manufacturing, MC77-SR-8
____1982, Census of population, 1980: Population of places, Number of inhabitants, Indiana
____1984a, Census of Agriculture 1982: Geographic Area Series, v. 1, pt. 14, Indiana (county data)
____1986, Census of Manufactures, 1982: Subject series, Water use in manufacturing, MC82-S-6
____1989, Census of Agriculture, 1987: Geographic Area Series, v. 1, pt. 14, Indiana (county data)
U.S. Bureau of Economic Analysis, 1985a, OBERS BEA regional projections: Metropolitan statistical area projections to 2035, v. 2
____1985b, OBERS BEA regional projections: State projections to 2035, v. 1
____1987, County-level projections of economic activity and population, Indiana, 1990-2035: Regional Economic Analysis Division
U.S. Department of Agriculture, 1909, A report upon the drainage of agricultural lands in the Kankakee Valley, Indiana: Office of Experiment Stations, Circular 80
____1958, Survey report for major and local drainage for Yellow River, Indiana: Soil Conservation Service
____1962, Survey report on major and local drainage for Iroquois River, Indiana: Soil Conservation Service
____1963, Survey report on major and local drainage for Kankakee River, Indiana-Illinois: Soil Conservation Service
____1971, General soils maps and interpretation tables for the counties of Indiana: Soil Conservation Service and Purdue University Cooperative Extension Service/Agricultural Experiment Station, Extension Publication AY-50, scale 1:190,000, 92 sheets
____1976, Report on the water and related resources, Kankakee River Basin, Indiana: report prepared in cooperation with State of Indiana and U.S. Department of Interior
____1977a, Prime farmland of Indiana: Soil Conservation Service and Purdue University Agricultural Experiment Station, Map SCS 5, R-36, 228, scale 1:500,000
____1977b, Irrigation Guide for Indiana: Soil Conservation Service
____1977c, Soil regions of Indiana: Soil Conservation Service and Purdue University Agricultural Experiment Station, Map SCS 5, N-36, 199, revised 4/86, scale 1:2,000,000
____1982, Map of the soil associations of Indiana: Soil Conservation Service and Purdue University Cooperative Extension Service/Agricultural Experiment Station, Extension Publication AY-209, scale 1:500,000
____1986, Kankakee River Basin special study for land treatment, Illinois and Indiana: Soil Conservation Service, in cooperation with State of Indiana, State of Illinois, and Soil and Water Conservation Districts
____1987a, Indiana's soil and water: Soil Conservation Service, [1982] Natural Resources Inventory
____1987b, Indiana agricultural statistics 1987: report compiled by Indiana Agricultural Statistics Service, Purdue University
____1988a, East-central Indiana erosion study: Soil Conservation Service, in cooperation with State of Indiana
____1988b, Northeast Indiana erosion study: Soil Conservation Service, in cooperation with State of Indiana
____1988c, Indiana agricultural statistics 1988: report compiled by Indiana Agricultural Statistics Service, Purdue University
____1989, Summary report, 1987 Natural Resources Inventory: Soil Conservation Service, in cooperation with Iowa State University Statistical Laboratory, Statistical Bulletin 790
____1990, West-central Indiana erosion study: Soil Conservation Service, in cooperation with State of Indiana [in preparation]
U.S. Department of Interior, 1932, A report on suitability for migratory bird refuge purposes of the Kankakee River bottoms, Indiana: Bureau of Biological Survey
____1950, A preliminary report on fish and wildlife resources in relation to the flood control plan for the Kankakee River Basin in Illinois and Indiana—Illinois River Subbasin, Upper Mississippi Basin: Fish and Wildlife Service, unpublished open-file report
U.S. Environmental Protection Agency, 1976a, National Eutrophication Survey, Report on Bass Lake, Starke County, Indiana: USEPA Region 5, Working Paper 323
____1976b, Quality criteria for water: U.S. Government Printing Office
____1979, National secondary drinking water regulations: *Federal Register 44* (140), 42195-42202
____1980, Water quality criteria documents, availability, appendix A, summary of water quality criteria: Federal Register 45 (231), 79318-79379
____1985a, Water quality criteria, availability of documents, app. A—summary of water quality criteria: *Federal Register 50* (145), 30784-30796
____1985b, National primary drinking water regulations—volatile synthetic organic chemicals, proposed rule: *Federal Register 50* (219), 46902-46933
____1985c, National primary drinking water regulations—synthetic organic chemicals, inorganic chemicals, and microorganisms, proposed rule: *Federal Register 50* (219), 46936-47022
____1986a, National primary and secondary drinking water regulations—fluoride, final rule: *Federal Register 51* (63), 11396-11412
____1986b, Water quality criteria, availability of documents, app. A—summary of water quality criteria: *Federal Register 51* (232), 43665-43667
____1986c, National primary drinking water regulations: Water Programs (as amended through July 1, 1986): *Federal Register*, volume and page unknown
____1986d, Quality criteria for water 1986: Office of Water Regulations and Standards, EPA 440/5-86-001

____1987a, Water quality criteria, availability of document, app. A—summary of water quality criteria for zinc: *Federal Register* *52* (40), 43665-43667

____1987b, Update #2 to Quality criteria for water 1986: Office of Water Regulations and Standards, Criteria and Standards Division

____1988a, Ambient water quality criteria for chloride—1988: Office of Water Regulations and Standards, EPA 440/5-88-001

____1988b, Drinking water regulations, maximum contaminant level goals and national primary drinking water regulations for lead and copper, proposed rule: *Federal Register 53* (160), 31516-31578

U.S. Fish and Wildlife Service, 1986, Photointerpretation conventions for the National Wetlands Inventory: (publication number unknown)

U.S. Geological Survey, 1979, Land use and land cover: Land Use Series, Open-File 79-1053-1, Chicago sheet, scale 1:250,000

____1982, Land use and land cover and associated maps: brochure

____1983, Land use and land cover: Land Use Series, Open-File 82-008-1, Danville sheet, scale 1:250,000

____1989, Herbicide levels in water samples from midwestern stream sites: unpublished data on file at Division of Water Resources, Indianapolis

U.S. House of Representatives, 1879, Report upon survey of Kankakee River: Letter from the Secretary of War, 45th Congress, 3rd session, Executive Document 73

____1916, Report on preliminary examination of Kankakee River, Illinois and Indiana: Letter from the Secretary of War, 64th Congress, 1st session, House Document 931

____1931, Report on Kankakee River, Illinois and Indiana: letter from the Secretary of War, 71st Congress, 3rd session, Document 784

U.S. Water Resources Council, 1981, Guidelines for determining flood flow frequency: Hydrology Committee, Bulletin 17B

U.S. Weather Bureau, 1955, Rainfall intensity-duration-frequency curves for selected stations in the United States, Alaska, Hawaiian Islands, and Puerto Rico: U.S. Department of Commerce, Technical Paper 25

____1957, Rainfall intensity-frequency regime—pt. 5, Great Lakes Region: U.S. Department of Commerce, Technical Paper 29

____1964, Two- to ten-day precipitation for return periods of 2 to 100 years in the contiguous United States: U.S. Department of Commerce, Technical Paper 49

Walton, W.C., 1962, Selected analytical methods for well and aquifer evaluation: Illinois State Water Survey, Bulletin 49

____1970, Groundwater resource evaluation: New York, McGraw-Hill

Wayne, W.J., 1956, Thickness of drift and bedrock physiography of Indiana north of the Wisconsin glacial boundary: Indiana Department of Conservation, Geological Survey, Report of Progress 7

____1958, Glacial geology of Indiana: Indiana Department of Conservation, Geological Survey, Atlas of mineral resources of Indiana, Map 10

____1963, Pleistocene formations in Indiana: Indiana Department of Conservation, Geological Survey, Bulletin 25

____1965, The Crawfordsville and Knightstown Moraines in Indiana: Indiana Department of Conservation, Geological Survey, Report of Progress 28

Wayne, W.J., Johnson, G.H., and Keller, S.J., 1966, Geologic map of the 1° x 2° Danville Quadrangle, Indiana and Illinois, showing bedrock and unconsolidated deposits: Indiana Department of Natural Resources, Geological Survey, Regional Geologic Map 2, Danville sheet, scale 1:250,000

Wilhite, D.A., 1989, Planning for drought, a process for state government: University of Nebraska, Project Completion Report to National Science Foundation

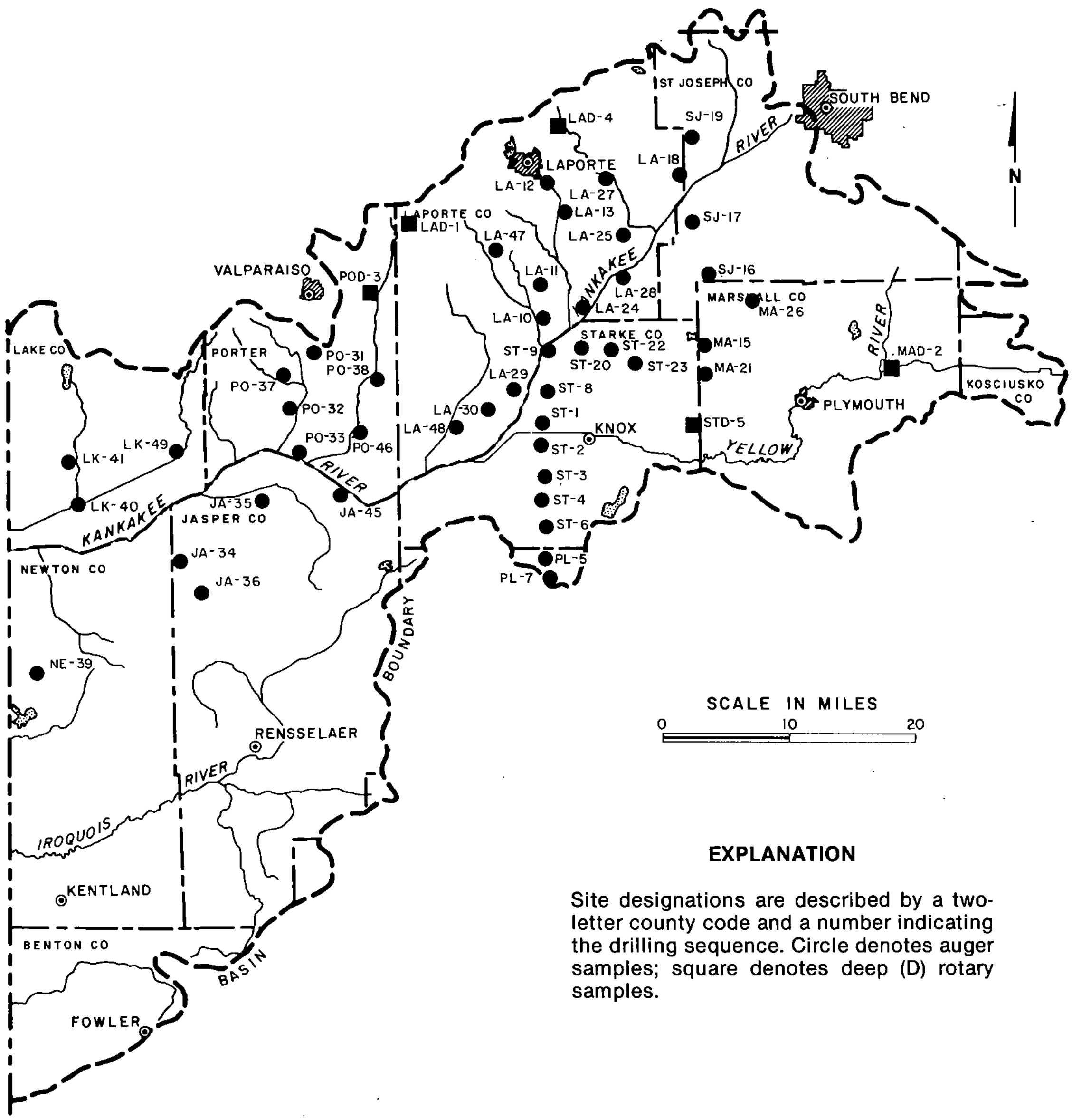
Yahner, J.E., 1978, Irrigable soils: Purdue University, Water Resources Research Center, report to Governor's Water Resource Study Commission

APPENDICES

Appendix 1. Historic and projected county population

Upper figures: Division of Water estimates, in-basin portion only.
Lower figures: U.S. Census Bureau, total county (1910-1980); Indiana State Board of Health (1988), total county (1990-2000).

County	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000
Benton	5139	4943	4814	5402	4642	4824	4561	4138	4086	4050
	12688	12206	11886	11117	11462	11912	11262	10218	10090	10000
Elkhart	1799	2069	2528	2666	3102	3920	4644	5040	5499	5799
	49008	56384	68875	72634	84512	106790	126529	137330	149840	158020
Jasper	12457	13333	12786	13749	16265	17994	19510	24962	25861	26415
	13044	13961	13388	14397	17031	18842	20429	26138	27080	27660
Kosciusko	1703	1502	1502	1521	1718	2230	2830	3488	3739	3879
	27936	27120	27488	29561	33002	40373	48127	59555	64130	66800
Lake	6991	7715	8488	10433	14643	21930	27742	36270	41560	44202
	82864	159957	261310	293195	368152	513269	546253	522965	490330	473860
LaPorte	16349	18194	18759	20032	25468	31752	33979	38375	38229	37008
	45797	50443	60490	63660	76808	95111	105342	108632	104400	99390
Marshall	18151	17734	18764	19493	22360	24807	26610	29930	32115	33556
	24175	23744	25077	25935	29468	32443	34986	39155	42060	43880
Newton	10504	10144	9841	10775	11006	11502	11606	14844	14150	13650
	10504	10144	9841	10775	11006	11502	11606	14844	14150	13650
Porter	5667	5815	5489	6291	7091	9006	11235	20549	24576	27597
	20540	20256	22821	27836	40076	60279	87114	119816	127850	133710
Pulaski	612	570	515	555	575	590	577	610	646	677
	13312	12385	11195	12056	12493	12837	12534	13258	14040	14720
St. Joseph	8513	10450	16216	16383	20774	24185	24845	24488	24443	24590
	84312	103304	160033	161823	205058	238614	244827	241617	241140	242530
Starke	9031	8820	9251	10606	13489	15945	17032	19561	18585	18360
	10567	10278	10620	12258	15282	17911	19280	21997	21480	21240
White	686	677	617	664	704	769	819	931	906	882
	17602	17351	15831	17037	18042	19709	20995	23867	23220	22620
Total	97602	101966	109570	117670	141837	169454	185990	223186	234395	240665
	412349	517533	698855	752284	922392	1179592	1289284	1339392	1329810	1328080



EXPLANATION

Site designations are described by a two-letter county code and a number indicating the drilling sequence. Circle denotes auger samples; square denotes deep (D) rotary samples.

Appendix 2. Location of test drilling sites

Appendix 3. Location of general soil associations and generalized irrigation potential

{General soil maps are adapted from U.S. Department of Agriculture (1971), and are intended only for general planning. For operational planning, use detailed maps that may be available in published or unpublished form at the local Soil and Water Conservation District Office. Irrigation maps are derived from methods described by Yahner (1978).}

DESCRIPTION OF SOIL ASSOCIATIONS

4. *Genesee-Shoals-Eel:* Nearly level, well drained, loamy Genesee, moderately well drained, loamy Eel, and somewhat poorly drained, loamy Shoals in alluvial deposits.

10. *Alida-Del Rey-Whitaker:* Nearly level, somewhat poorly drained, loamy Alida on shaley outwash sand and gravel, clayey Del Rey in lake deposits, and loamy Whitaker in outwash or lacustrine sand and silt.

11. *Bono-Maumee-Warners:* Nearly level, very poorly drained, clayey Bono, sandy Maumee, and mineral over organic Warners in lake deposits.

12. *Chelsea-Hillsdale-Oshtemo:* Sloping, excessively drained, sandy Chelsea in wind-blown sands, well drained, loamy Hillsdale in glacial till, and well drained, loamy Oshtemo on outwash sand and gravel.

13. *Conrad-Wooten-Weiss:* Nearly level, somewhat poorly drained, sandy Weiss and Wooten and poorly drained, sandy Conrad in mixed sandy and organic strata in lake beds.

14. *Door-Tracy-Quinn:* Nearly level, well drained, loamy Door and Tracy, and poorly drained, loamy Quinn on shaley outwash sand and gravel.

15. *Door-Lydick:* Nearly level, well drained, loamy soils on shaley outwash sand and gravel.

23. *Maumee-Gilford-Rensselaer:* Nearly level, very poorly drained, sandy Maumee and loamy Gilford and Rensselaer in outwash or lake-deposited sand and silt.

24. *Maumee-Newton:* Nearly level, very poorly drained, sandy soils in outwash or lake-deposited sands.

27. *Martinsville-Whitaker:* Nearly level and sloping, well drained, loamy Martinsville and nearly level, somewhat poorly drained, loamy Whitaker in outwash or lake-deposited sand and silt.

34. *Oakville-Plainfield-Adrian:* Sloping, excessively drained, sandy Oakville and Plainfield in wind-blown sands, and very poorly drained organic Adrian in the depressions.

35. *Oshtemp-Fox:* Nearly level and sloping, well drained, loamy soils on outwash sand and gravel.

37. *Ockley-Wea:* Nearly level, well drained, loamy soils on outwash sand and gravel.

39. *Plainfield-Brems-Morocco:* Sloping, excessively drained, sandy Plainfield, nearly level, moderately well drained, sandy Brems, and nearly level, somewhat poorly drained, sandy Morocco in wind-blown or outwash sands.

40 *Plainfield-Tyner-Oshtemo:* Sloping, excessively drained, sandy Plainfield in wind-blown sands and sloping and nearly level, excessively drained, sandy Tyner and well drained, loamy Oshtemo on outwash sand and gravel.

41. *Plainfield-Watseka:* Sloping, excessively drained, sandy Plainfield and nearly level, somewhat poorly drained, sandy Watseka soils in wind-blown or outwash sand.

42. *Plainfield-Chelsea:* Sloping, excessively drained, sandy soils in wind-blown sands.

47. *Rensselaer-Montgomery:* Nearly level, very poorly drained, loamy Rensselaer and clayey Montgomery in lake deposits.

48. *Rensselaer-Darroch:* Nearly level, very poorly drained, loamy Rensselaer and somewhat poorly drained, loamy Darroch on outwash or lake-deposited sand and silt.

49. *Rensselaer-Whitaker:* Nearly level, very poorly drained, loamy Rensselaer and somewhat poorly drained, loamy Whitaker on outwash or lake-deposited sand and silt.

51. *Volinia:* Nearly level, well drained, loamy soils on outwash sand and gravel.

58. *Crosier-Brookston:* Nearly level, somewhat poorly drained, loamy Crosier and very poorly drained, loamy Brookston in glacial till.

59. *Brookston-Odell-Corwin:* Nearly level, very poorly drained, loamy Brookston, Somewhat poorly drained, loamy Odell, and moderately well drained, loamy Corwin in glacial till.

61. *Blount-Morely-Pewamo:* Nearly level, somewhat poorly drained, clayey Blount and very poorly drained, clayey Pewamo and sloping, well drained, clayey Morley in glacial till.

63. *Miami-Riddles-Crosier:* Sloping, well drained, loamy Miami and Riddles and nearly level, somewhat poorly drained, loamy Crosier in glacial till.

65. *Elliott-Markham-Pewamo:* Nearly level, somewhat poorly drained, clayey Elliott and very poorly drained, clayey Pewamo and sloping, well drained, clayey Markham in glacial till.

69. *Parr-Miami:* Sloping, well drained, loamy soils in glacial till.

70. *Parr-Corwin:* Sloping, well drained, loamy Parr and moderately well drained, loamy Corwin in glacial till.

78. *Miami-Metea-Celina:* Sloping, well drained, loamy Miami and moderately well drained, loamy Celina soils in glacial till, and well drained, loamy Metea in sandy deposits and till.

79. *Miami-Owosso-Riddles:* Sloping, well drained, loamy soils in glacial till.

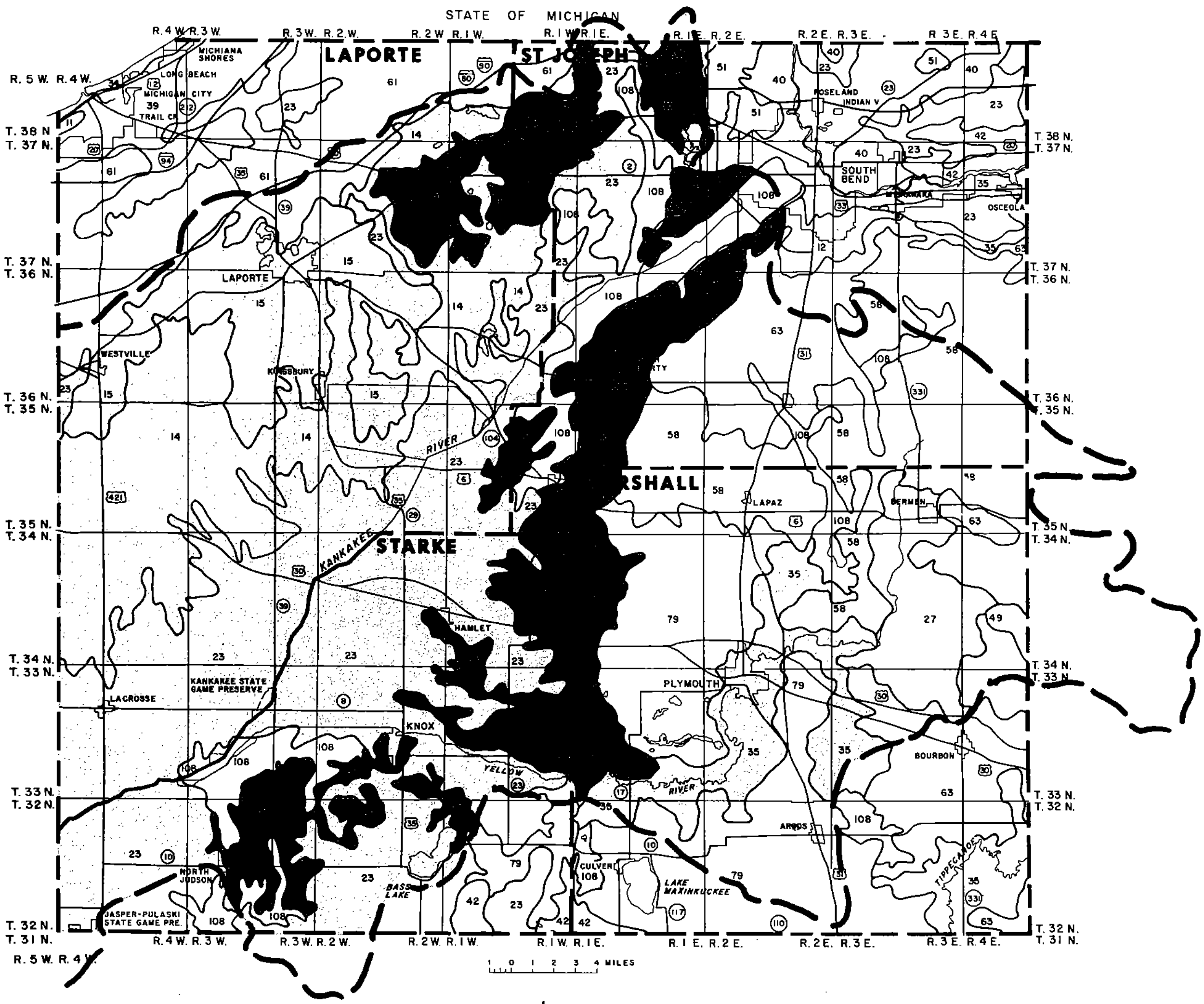
81. *Miami-Russell-Fincastle:* Sloping, well drained, loamy Miami in glacial till and silty Russell in wind-blown silts and glacial till and nearly level somewhat poorly drained, silty Fincastle in wind-blown silts and glacial till.

88. *Odell-Chalmers:* Nearly level, somewhat poorly darined, loamy Odell and very poorly drained, loamy Chalmers in glacial till.

89. *Sidell-Parr:* Sloping, well drained, silty Sidell in wind-blown silts and glacial till and loamy Parr in glacial till.

108. *Mucks and peats:* Nearly level, very poorly drained soils developed in organic materials.

Appendix 3. Location of general soil associations and generalized irrigation potential — Continued



EXPLANATION

IRRIGATION POTENTIAL OF SOIL ASSOCIATIONS

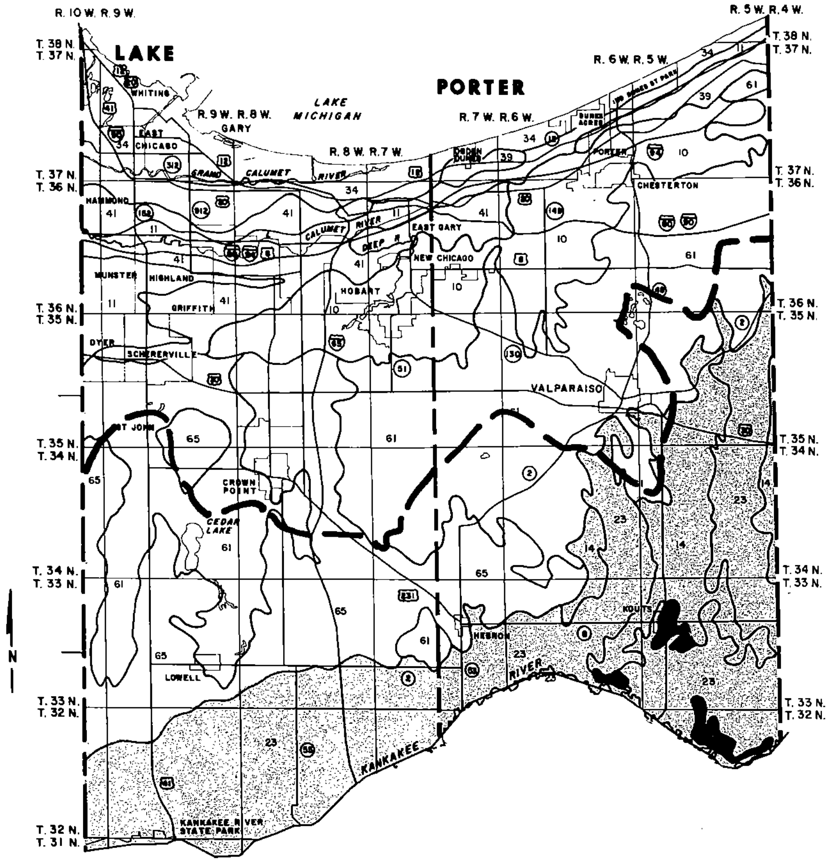
None — little or no profitable response

Slight — response 1-2 years in 5 years

Moderate — response 3-4 years in 5 years

High — response expected yearly

NOTE: MAP UNITS FOR IRRIGATION RESPONSE ARE DEFINED ON THE BASIS OF SOIL PROPERTIES, WITHOUT REGARD TO TOPOGRAPHY AND LAND USE; CONSEQUENTLY, MAP UNITS CONTAIN AREAS WHERE IRRIGATION IS IMPRACTICAL, SUCH AS SLOPING OR POORLY DRAINED CROPLAND, URBAN OR BUILT-UP LAND, AND MAJOR WATERBODIES.



0 1 2 3 4 MILES

EXPLANATION

IRRIGATION POTENTIAL OF SOIL ASSOCIATIONS

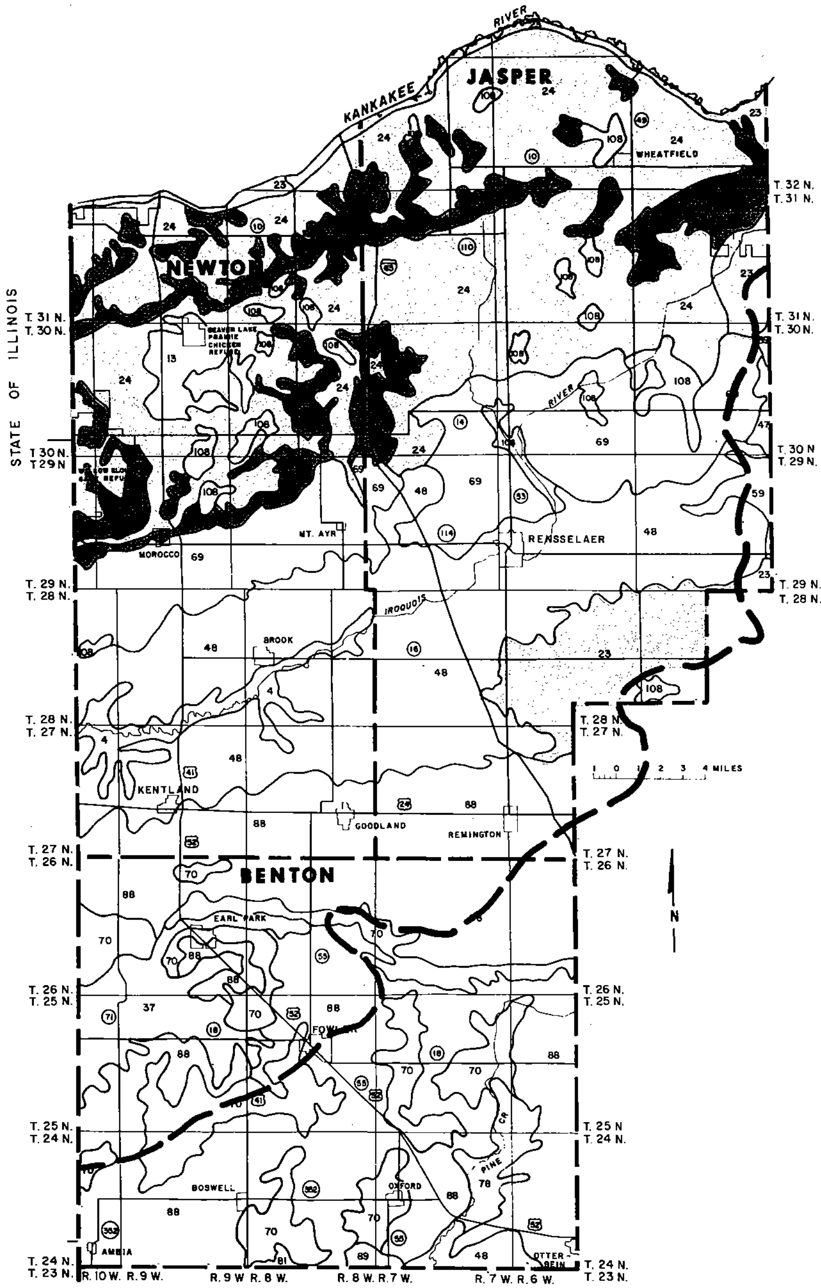
None — little or no profitable response

Slight — response 1-2 years in 5 years

Moderate — response 3-4 years in 5 years

High — response expected yearly

NOTE: MAP UNITS FOR IRRIGATION RESPONSE ARE DEFINED ON THE BASIS OF SOIL PROPERTIES, WITHOUT REGARD TO TOPOGRAPHY AND LAND USE; CONSEQUENTLY, MAP UNITS CONTAIN AREAS WHERE IRRIGATION IS IMPRACTICAL, SUCH AS SLOPING OR POORLY DRAINED CROPLAND, URBAN OR BUILT-UP LAND, AND MAJOR WATERBODIES.



EXPLANATION

IRRIGATION POTENTIAL OF SOIL ASSOCIATIONS

- None — little or no profitable response
- Slight — response 1-2 years in 5 years
- Moderate — response 3-4 years in 5 years
- High — response expected yearly

NOTE: MAP UNITS FOR IRRIGATION RESPONSE ARE DEFINED ON THE BASIS OF SOIL PROPERTIES, WITHOUT REGARD TO TOPOGRAPHY AND LAND USE; CONSEQUENTLY, MAP UNITS CONTAIN AREAS WHERE IRRIGATION IS IMPRACTICAL, SUCH AS SLOPING OR POORLY DRAINED CROPLAND, URBAN OR BUILT-UP LAND, AND MAJOR WATERBODIES.

Appendix 4. Description of wetland protection programs

Administrative agency: IDNR, Indiana Department of Natural Resources — Divisions of Water (DOW), Nature Preserves (DNP), Fish and Wildlife (DFW), and Soil Conservation (DSC); IDEM, Indiana Department of Environmental Management; USACE, U.S. Army Corps of Engineers; USEPA, U.S. Environmental Protection Agency; USDA, U.S. Department of Agriculture; TNC, The Nature Conservancy. Slash denotes cooperative program.

		Program	Administrative agency	Relevance or benefit to wetlands
REGULATORY	STATE	Flood Control Act (IC 13-2-22)	IDNR-DOW	Requires permit from Natural Resources Commision for construction, excavation or filling within a stream's floodway and its encompassed wetlands
REGULATORY	STATE	Lake Preservation Act (IC 13-2-11.1)	IDNR-DOW	Requires permit from Natural Resources Commission to alter the bed or shoreline of a public freshwater lake of natural origin
REGULATORY	STATE	Nature Preserves Act (IC 14-4-5)	IDNR-DNP	Protects wetlands contained within a dedicated Nature Preserve[2]
REGULATORY	STATE	Water quality regulations	IDEM	Authority to protect most wetland types is inherent in the Indiana Stream Pollution Control Law (IC 1971, 13-1-13) and portions of 330 IAC 1-1, which establishes water quality standards for designated water use categories. Antidegradation provisions typically are applied to wetlands
REGULATORY	FEDERAL	Section 404/401 permit program	USACE/IDEM/USEPA	Regulates discharge of dredge or fill into wetlands and waterways; Section 401 of Federal Clean Water Act requires a water quality certification or waiver by IDEM prior to issuance of a Section 404 dredge-and-fill permit from USACE; USEPA may evaluate suitability of sites for fill placement
REGULATORY	FEDERAL	1986 Emergency Wetlands Resources Act		Requires that statewide outdoor recreation plans include wetland priority conservation plan

Appendix 4. Description of wetland protection programs — Continued

		Program	Administrative agency	Relevance or benefit to wetlands
NON-REGULATORY	STATE	Wetland conservation program	IDNR-DFW	Funds land acquisition for wetland protection and waterfowl management
		Natural areas registry	IDNR-DNP/TNC	Encourages voluntary conservation efforts on private land containing significant natural communities or rare plant or animal species
		Natural heritage protection campaign (IC 14-4-5.1)	IDNR-DNP/TNC	Identifies and ranks significant natural areas according to the need for protection; funds acquisition and protection of these areas
		Non-game and endangered wildlife program	IDNR-DFW	Protects wetland habitat if it supports endangered, threatened or special concern wildlife species; program includes monitoring surveys of wetland wildlife
		Wildlife habitat cost-share project	IDNR-DFW	Reimburses landowners for developing or improving wildlife habitat, including wetlands
		Classified wildlife habitat and riparian lands program	IDNR-DFW	Provides technical assistance and reduced property tax assessment for land and wetlands placed in the program
	FEDERAL	Food Security Act (1985 Farm Bill)	USDA	"Swampbuster" provision revokes certain federal farm program benefits if wetlands are converted into farmland Conservation Reserve Program promotes financial incentives for removing wetlands from production for at least 10 years Conservation Easements Program grants easements on wetlands to aid in farm debt reduction

[1]Portions of this table were summarized from the appendix to "Indiana Outdoor Recreation 1989: An Assessment and Policy Plan" (Indiana Department of Natural Resources, 1988).
[2]Nature Preserves, which may be publicly or privately owned, possess significant natural communities, geologic features, or rare plant and animal species.

Appendix 5. Selected data for major lakes

{Data compiled from Glatfelter and others, 1986; Hoggatt, 1975; Indiana Department of Environmental Management, 1986; and Indiana Department of Natural Resources, Division of Water, revised *Guide to Indiana Lakes* and miscellaneous unpublished files.}

Surface area: Acreage at established level; only lakes having a surface area of at least 25 acres and/or U.S. Geological Survey gage records are tabulated. Twin Lakes (St. Joseph County), Redwing Lake (Lake County), and Round Lake (Starke County) are excluded because of limited morphometric data.

Capacity: At average or established level; expressed in acre-feet (af) and million gallons (mg).

Established level: Average normal water level, as determined by local courts; expressed in feet above mean sea level (fmsl).

Period of record: Refers to lake-level data collected by the U.S. Geological Survey under cooperative agreement with the Indiana Department of Natural Resources, Division of Water.

Trophic class and lake management group: Data from Indiana Department of Environmental Management, 1986.

Lake	Drainage Area (mi^2)	Surface area (acres)	Capacity		Maximum depth (ft)	Established level (fmsl)	Period of record	Trophic class[1]	Lake management group[2]
			af	mg					
JASPER COUNTY									
Ringneck[3]	1.94	300	—	—	<4	—	1949-55	—	—
LAKE COUNTY									
Cedar	8.14	781	6750	2200	16	—	1943-	3	IVC
Dalecarlia[3]	20.10	193	—	—	8	—	1947-52	3	IVA
Lake of the 4 Seasons[3]	—	309	2105	686	34	—	—	—	
LAPORTE COUNTY									
Clear	.65[5]	106	760	248	12	798.20	1942-[4]	2	VIIA
Crane[3]	—	58	—	—	12	—	—	3	VIIC
Fishtrap[3]	—	102	—	—	37	—	—	1	V
Hudson	7.92[5]	432	5060	1649	42	763.09	1946-	2	VIIA
Lower Fish	10.4[5]	134	870	284	16	688.22	1946-53	1	V
Pine	10.7[5]	564	—	—	71	796.20	1946-[4]	1	VIIA
Saugany	2.34[5]	74	2190	714	66	781.21	1946-50	1	IIA
Silver[3]	1.72[5]	54	—	—	12	795.20	1946-66	—	—
Stone	10.7[5]	140	—	—	36	796.20	1946-[4]	1	V
Upper Fish	9.65[5]	139	1040	339	24	688.22	1946-53	2	VIIA

See footnotes at end of table

Appendix 5. Selected data for major lakes — Continued

Lake	Drainage Area (mi²)	Surface area (acres)	Capacity af	Capacity mg	Maximum depth (ft)	Established level (fmsl)	Period of record	Trophic class[1]	Lake management group[2]
MARSHALL COUNTY									
Cook	—	93	1651	538	64	—	—	2	VIIB
Dixon	6.67[5]	33	479	156	48	—	—	2	VIIB
Flat	—	26	209	68	24	—	—	2	VIIA
Gilbert	—	37	491	160	41	—	—	3	IVB
Holem	—	40	390	127	74	—	—	1	VIIA
Lake of the Woods	9.45[5]	416	6810	2219	48	803.85	1945-	2	VIIB
Latonka[3]	5.77[5]	100	488	159	—	—	—	—	—
Lawrence	—	69	1580	515	63	—	—	1	IIA
Mill Pond-(Kreighbaum)	5.34[5]	168	1020	332	36	767.75	1945-53	4 (2)	IVA (VIIA)
Myers	1.41	96	2000	652	59	768.69	1945-53	1	VIA
Pretty	.85	97	2140	697	40	787.36	1954-66	1	IVA
NEWTON COUNTY									
J.C. Murphey	13.0	1400	—	—	8	—	1952-61	2	III
PORTER COUNTY									
Eliza[3]	1.70	45	—	—	35	738.70	1954-[4]	3	VIIB
Flint[3]	2.62	86	—	—	67	797.66	1946-	1	VIA
Long	1.31	65	520	169	27	797.66	1947-52	2	VIIA
Loomis-(Spectacle)	.53	62	540	176	30	812.82	1946-53	3 (2)	IVB (VIIC)
Mink[3]	—	35	—	—	24	—	—	3	VIIC
Wauhob	.40	21	—	—	48	—	1946-	2	IIC
ST. JOSEPH COUNTY									
Chamberlain[3]	—	51	—	—	27	—	—	4	IVA
Mud[3]	—	197	—	—	8	—	—	4	IVA
North Chain (Bass)	3.89[5]	88	1400	456	37	721.17	1946-53	1	V
Pleasant[3]	—	29	—	—	39	—	—	2	VIIB
Worster Lake (Potato Creek Reservoir)	—	327	3270	1066	25	—	—	2	VIIA
Riddles	11.7[5]	77	640	209	20	817.50	1946-[4]	2	VIIA
Sously[3]	—	40	—	—	19	—	—	2	IVA
South Chain (Szmanda)	6.32[5]	90	270	88	9	717.04	1946-53	4	IVA
South Clear[3]	—	51	—	—	15	—	—	3	IVA
Wharton (Goodman)	1.85[5]	18	—	—	25	—	1960-[4]	—	—

See footnotes at end of table

Appendix 5. Selected data for major lakes — Continued

Lake	Drainage Area (mi^2)	Surface area (acres)	Capacity		Maximum depth (ft)	Established level (fmsl)	Period of record	Trophic class[1]	Lake management group[2]
			af	mg					
STARKE COUNTY									
Bass	5.18	1405	—	—	30	713.65	1943-	2	III
Eagle	25.5[5]	24	160	52	21	713.25	1946-53	2	VIIC
Koontz	6.25[5]	346	3170	1033	31	714.56	1943-	—	—
Skitz[3],[6]	—	1400	—	—	6	—	1949-53	—	—

[1]Class 1 — high-quality lakes assigned a total of 0-25 eutrophy points; class 2 — intermediate-quality lakes assigned a total of 26-50 eutrophy points; class 3 — poor-quality lakes assigned a total of 51-75 eutrophy points; class 4 — remnant natural lakes and oxbow lakes.

[2]Groups of similar lake types were derived from cluster analysis based on lake morphometry and trophic state. Groups applicable to in-basin lakes are summarized as follows:

Group	*Surface area (acres)*	*Mean depth (feet)*	*Eutrophy points*
I	3060-3180	17.5-22.0	16-20
IIA	50-488	17.5-31.0	1-16
IIC	37-388	32.7-40.5	18-41
III	1291-1864	5.0-24.5	23-48
IVA	26-385	2.0-7.3	50-65
B	25-326	7.9-20.0	50-75
C	150-575	5.0-14.0	62-75
V	30-414	5.5-15.7	2-18
VIA	25-421	15.0-27.0	13-39
VIIA	25-828	5.0-13.2	18-37
B	28-551	12.2-19.6	27-54
C	25-424	5.5-14.4	33-46

[3]No depth contour map available for sale by the Indiana Department of Natural Resources, Division of Water.

[4]Gaps occur in years of record.

[5]Contains drainage area (5 percent or greater) that does not contribute directly to surface-water runoff.

[6]Artificial impoundment is no longer maintained; area is now a seasonally flooded marsh.

Appendix 6. Maximum contaminant levels for selected inorganic constituents

{All values except pH and mercury are in milligrams per liter. If multiple uses have been designated, the most protective standard applies. Dash indicates no available criterion. References to standards are current as of late 1988.}

Aquatic life: Values for all constituents except iron, pH, selenium, and silver are 4-day average concentrations; selenium value is the 24-hour average; silver criterion is not to be exceeded at any time. All values are chronic aquatic criteria which apply outside the mixing zone, except for silver which is the acute aquatic criterion. Where applicable, trace metal standards were calculated using a hardness value of 325 milligrams per liter.

Public supply: Maximum permissable level of contaminant in water at the tap. National secondary regulations (reference e) are not enforceable; both national primary regulations and state regulations are enforceable (references b, c and f); lead and copper have new proposed national primary regulations (reference l) which are not enforceable until promulgated.

Irrigation and livestock: All values from the National Academy of Sciences, 1974.

Constituent	Aquatic life		Public supply		Irrigation	Livestock
	Value	Reference	Value	Reference		
Arsenic (trivalent)	0.190	a	0.05	b,c	0.10	0.2
Barium	—	—	1.0	b,c	—	—
Cadmium	0.003	a	0.01	b,c	0.01	0.05
Chloride	230	i	250	d,e	—	—
Chlorine	0.011	a	—	—	—	—
Chromium (hexavalent)	0.011	a	0.05	b,c	0.1	1.0
Copper	0.032	a	1.0 1.3	e l	0.20	0.5
Cyanide	0.005	a	—	—	—	—
Flouride	—	—	4.0 prim 2.0 sec	f f	1.0	2.0
Iron	1.00	j	0.3	e	5.0	—
Lead	0.014	a	0.05	b,c	5.0	0.1
Manganese	—	—	0.05	e	0.20	—
Mercury (ug/1)	0.012	a	2.0	b,c	—	0.01
Nickel	0.427	k	—	—	0.20	—
Nitrate (as nitrogen)	—	—	10.0	b,c	—	—
pH (standard unit)	6.0-9.0	d	6.5-8.5	e	4.5-9.0	—
Selenium	0.035	g	0.01	b,c	0.02	0.05
Silver	0.015	g	0.05	b,c	—	—
Sulfate	—	—	250	d,e	—	—
Total dissolved solids	—	—	500	e	500-1000	3000
Zinc	0.288	h	5.0	e	2.0	25.0

[a]U.S. Environmental Protection Agency, 1985a.
[b]Indiana Environmental Management Board, 1979.
[c]U.S. Environmental Protection Agency, 1986c.
[d]Indiana Stream Pollution Control Board, 1985.
[e]U.S. Environmental Protection Agency, 1979.
[f]_______1986a.
[g]_______1980.
[h]_______1987a.
[i]_______1988a.
[j]_______1976b.
[k]_______1986b.
[l]_______1988b.

Appendix 7. Summary of selected stream quality constituents

{Values are for 1978-87. Constituents are reported as total recoverable, and in milligarms per liter, except as indicated. Dash indicates limited or unavailable data.}

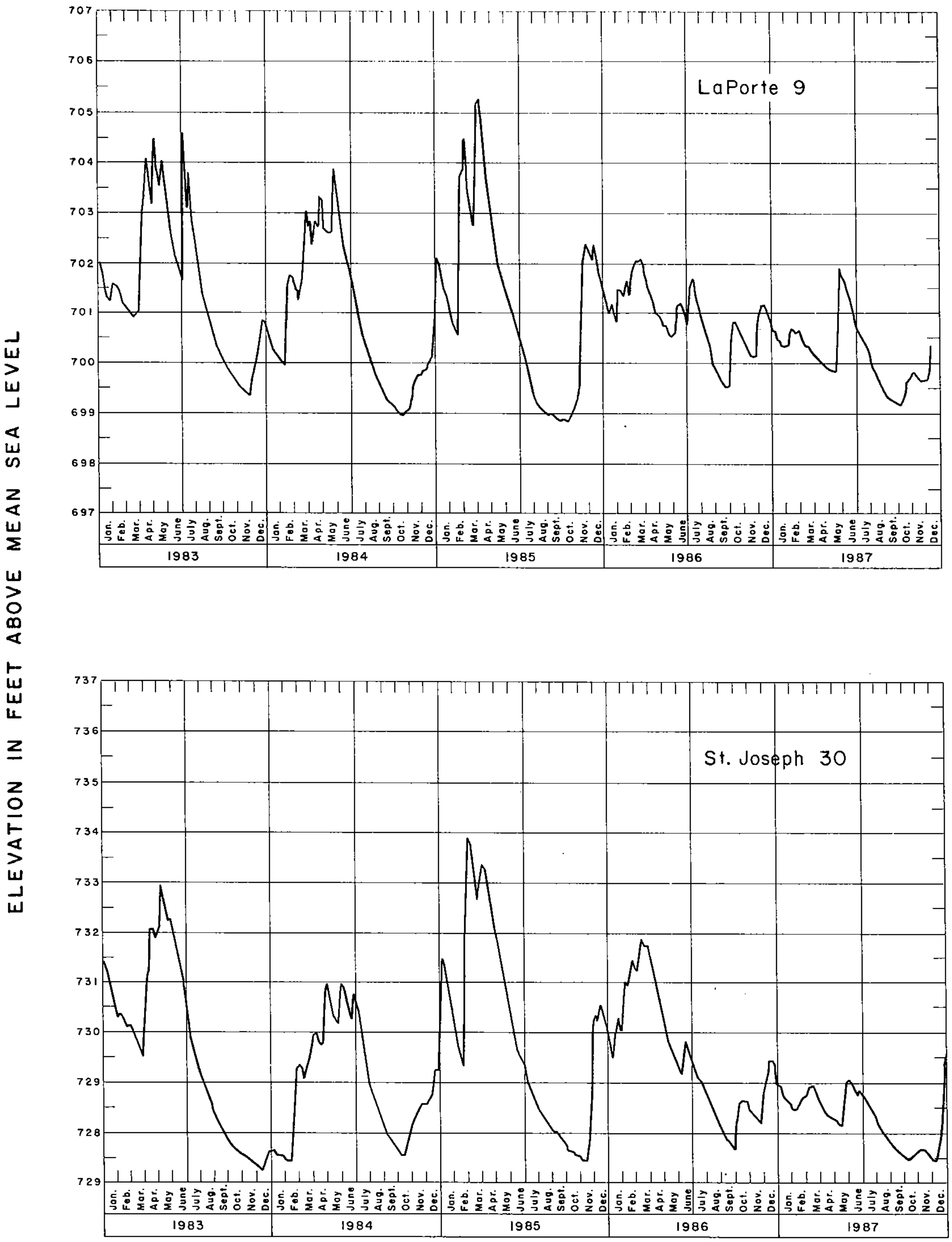
Station 1: Indiana Department of Environmental Management, KR118 (KR125), Kankakee River near Kingsbury, Indiana
Station 2: Indiana Department of Environmental Management, KR68 (KR65), Kankakee River at Shelby, Indiana
Station 3: Illinois Environmental Protection Agency, 05520500, Kankakee River at Momence, Illinois
Station 4: Illinois Environmental Protection Agency, 05525000, Iroquois River at Iroquois, Illinois
Station 5: Illinois Environmental Protection Agency, 05525500, Sugar Creek at Milford, Illinois

Constituent	Station	No. of samples	Percentiles 10th	Percentiles 50th	Percentiles 90th	Mean	Range of values
Specific conductance (micro-mhos)	1	106	407	580	680	569	150-900
	2	101	436	590	679	570	322-780
	3	106	506	633	733	624	291-900
	4	94	479	683	763	651	221-840
	5	99	400	670	760	637	80-980
Dissolved oxygen	1	107	6.7	8.7	11.6	8.9	5.9-13.7
	2	99	6.7	8.8	11.6	9.0	6.0-14.7
	3	90	6.8	9.8	12.7	9.9	5.8-13.9
	4	71	5.2	8.3	12.4	8.5	4.1-13.4
	5	72	5.9	8.8	13.5	9.3	4.7-19.8
Chemical oxygen demand (low level)	1	106	11	17	28	19	5-65
	2	100	13	21	34	3	10-83
	3	100	12	18	29	19.4	0-60
	4	93	12	19	31	21	1-44
	5	97	6	13	40	20	<1-130
Fecal coliform (cols./ 100ml)	1	106	50	495	3050	1972	<10-56000
	2	97	20	140	976	955	<10-35000
	3	63	25	190	1340	1342	10-39000
	4	52	110	345	3600	1037	10-8000
	5	54	205	2850	7950	5018	71-84000
Suspended solids, residue at 105 °C	1	104	7	18	38	21	4-104
	2	101	6	23	57	31	2-206
	3	90	3	20	72	33	1-370
	4	93	6	49	128	61	1-242
	5	98	5	37	180	216	0-1930
Nitrate-nitrite, total as N	1	106	0.8	1.2	3.1	1.5	0.5-5.6
	2	100	0.7	1.2	2.9	1.6	0.1-5.3
	3	102	0.60	1.4	3.9	1.9	0.12-6.5
	4	94	0.4	5.4	9.7	5.1	0-14
	5	99	0.4	6.4	11.0	6.1	0-19
Ammonia, total at N	1	106	≤0.1	≤0.1	0.3	0.16	<0.1-1.4
	2	100	≤0.1	≤0.1	0.2	—	0-0.4
	3	102	≤0.1	≤0.1	0.27	0.12	0-.79
	4	94	≤0.1	≤0.1	0.29	—	<.1-1.2
	5	99	≤0.1	≤0.1	0.3	0.13	<.1-.96
TKN-ammonia and organic nitrogen, total as N	1	86	0.4	0.7	1.1	0.8	0.2-2.4
	2	80	0.4	0.7	1.2	0.8	.1-2.6
	3	79	0.5	0.8	1.9	1.1	.2-11
	4	6	—	1.4	—	1.35	.8-1.8
Sulfate, dissolved	1	82	74	90	110	90	33-150
	2	79	77	92	110	94	40-180
	3	104	72	100	125	100	19-140

Appendix 7. Continued

Constituent	Station	No. of samples	Percentiles			Mean	Range of values
			10th	50th	90th		
Phosphorus	1	106	< 0.03	0.06	0.15	0.07	< .03-.33
	2	100	0.05	0.09	0.14	1.10	< .03-.42
	3	92	0.03	0.08	0.22	0.11	0-.64
	4	36	0.05	0.15	0.24	0.15	.03-.26
	5	36	0.04	0.1	0.33	0.15	.03-.97
Chloride, dissolved	1	83	13	16	27	18	9-42
	2	79	17	20	23	20	14-38
	3	103	18	22	27	26	9-400
	4	7	—	32	—	30	7-40
Potassium	3	62	1.9	2.3	3.2	2.4	1.4-4.1
	4	57	1.8	2.4	3.2	2.5	1.3-4.8
	5	61	1.1	1.8	3.2	2.0	1.1-6.6
Sodium	3	65	6.1	10	15	10.2	4.1-21
	4	58	5.9	11	22	12.4	4.7-26
	5	62	4.0	9.8	18.4	10.4	1.9-27
Arsenic[1]	1	105	1	2	3	2.2	1-8
	2	98	1	2.0	4	2.4	1-6
	3	96	0	2	4	1.8	0-9
Barium[1]	3	65	40	52	72	62	0-500
	4	64	45	70	90	67	0-100
	5	63	32	50	85	54	0-200
Zinc[1]	1	76	10	10	20	15	< 10-90
	2	69	10	20	40	20	< 10-70
	3	72	< 50	—	—	—	—
	4	64	< 50	< 50	—	—	< 50-250
	5	67	—	< 50	—	—	< 50-300

[1]Micrograms per liter.

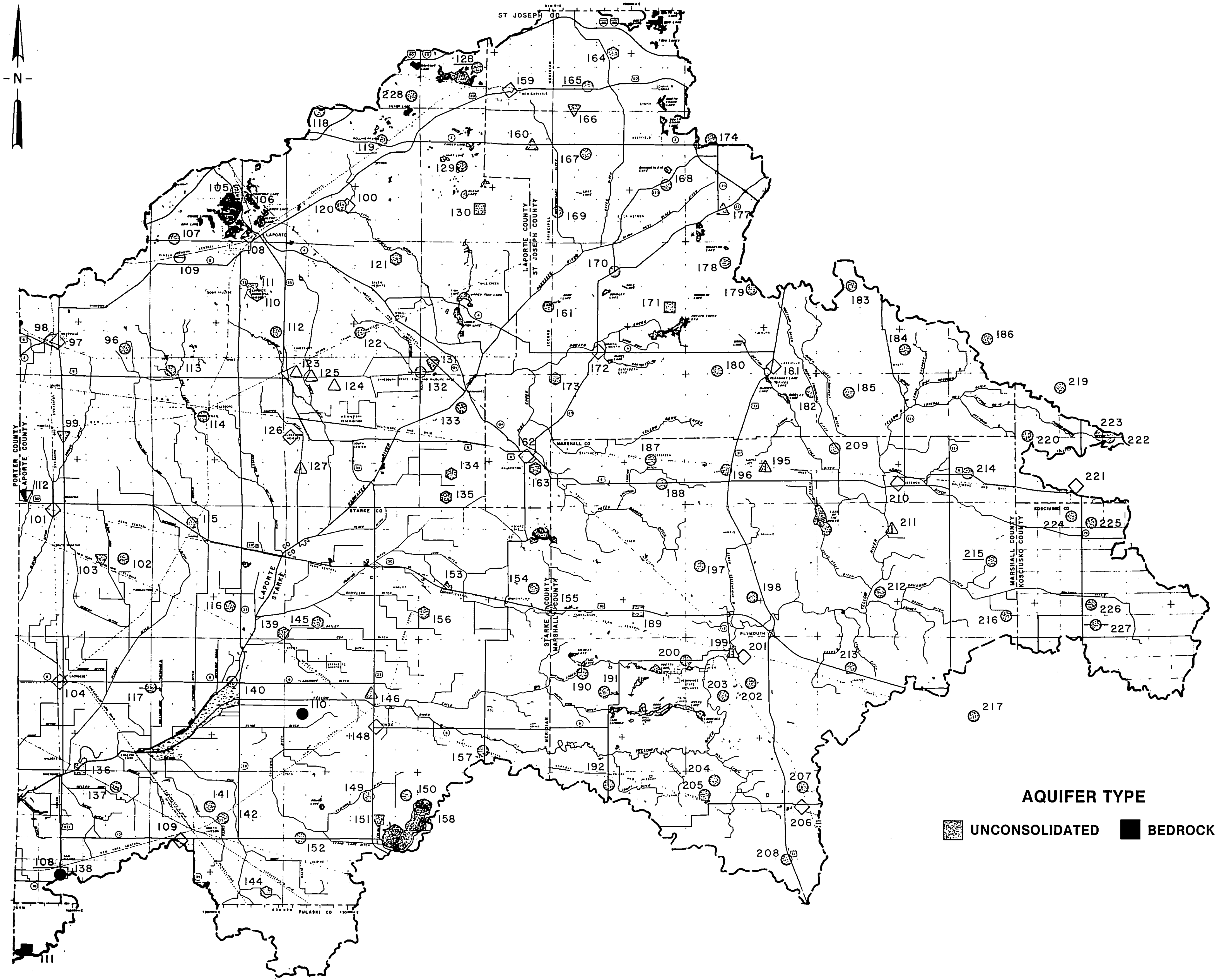


Appendix 8. Water-level fluctuations in unconfined aquifers in irrigation areas

{Values are the average of maximum daily water levels every fifth day.}

STATE OF INDIANA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATER

UPPER KANKAKEE RIVER BASIN



AQUIFER TYPE

UNCONSOLIDATED — BEDROCK

EXPLANATION

WELL TYPE	MAJOR DATA SOURCE[2] IGS	ISBH	USGS	PRIVATE LAB
Municipal[1]	◆	◇	◆ (half)	◆ (half)
Public supply[1]	■	□	■ (half)	■ (half)
Industrial or commercial	▲	△	▲ (half)	▲ (half)
Irrigation	⬢	⬡	⬢ (half)	⬢ (half)
Domestic	●	○	◐	◓
Observation and test	▼	▽	▼ (half)	▼ (half)
Rural (livestock, fish)	-●-	-○-	-◐-	-◓-

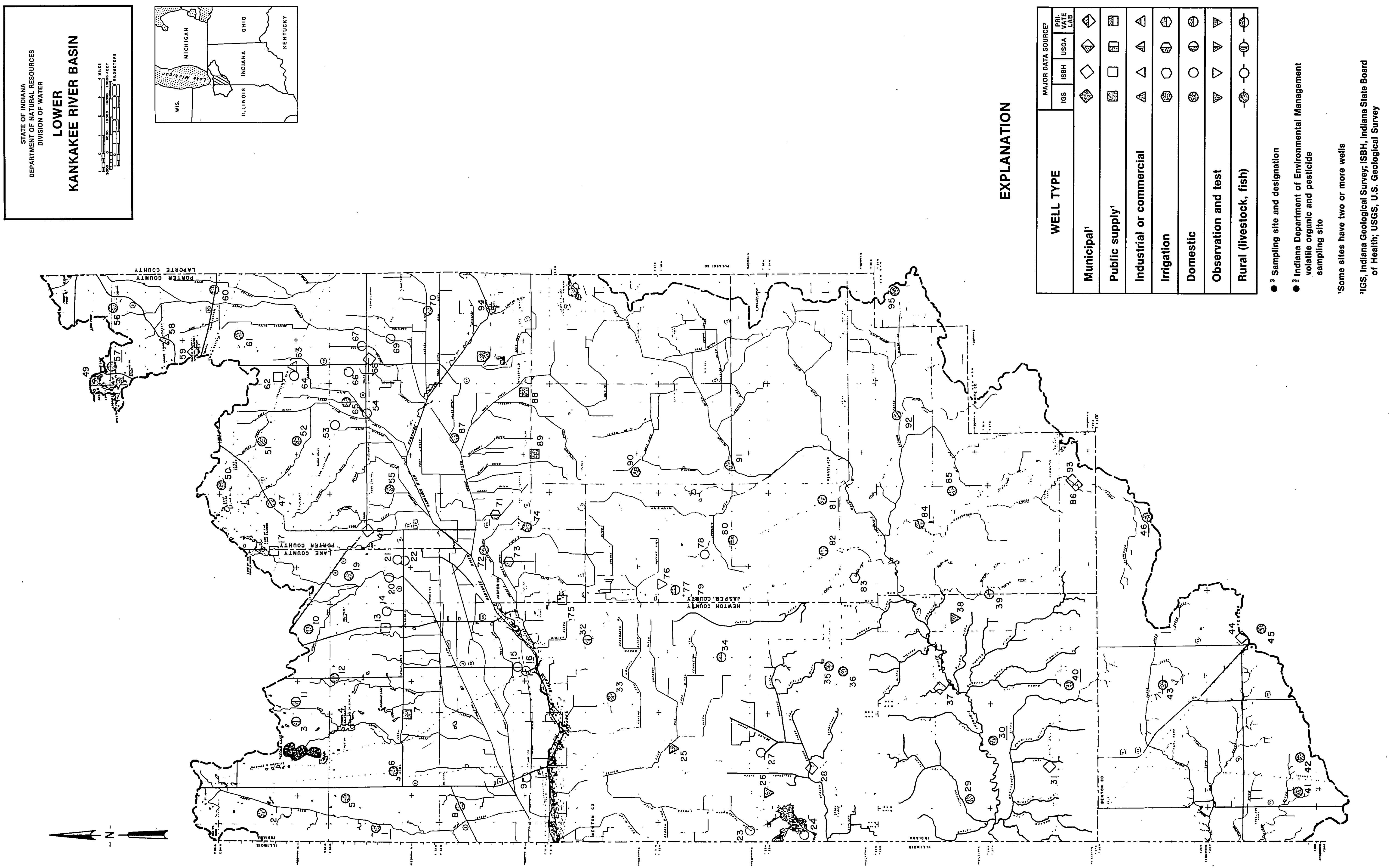
● [3] Sampling site and designation

● [3] Indiana Department of Environmental Management volatile organic and pesticide sampling site

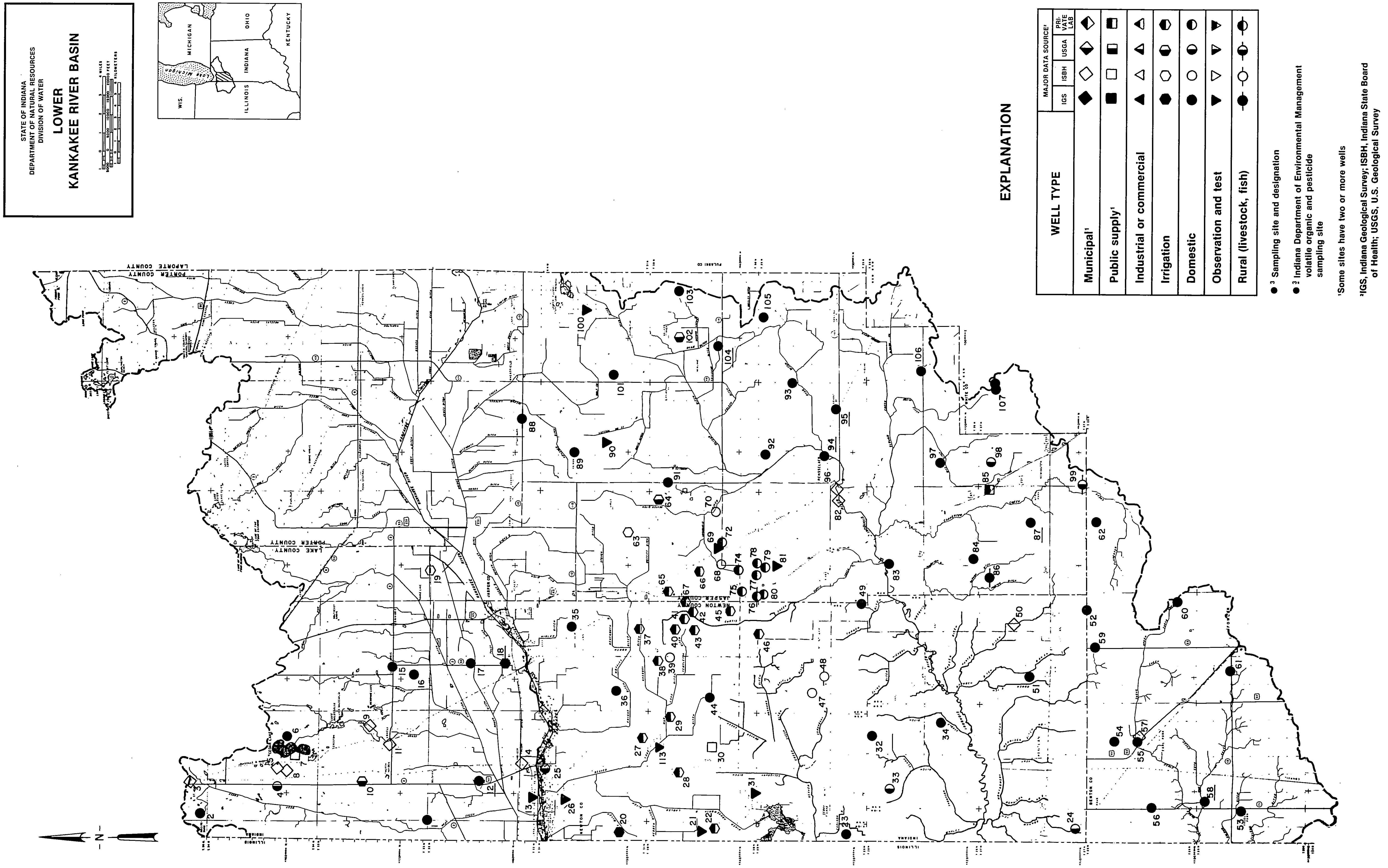
[1]Some sites have two or more wells

[2]IGS, Indiana Geological Survey; ISBH, Indiana State Board of Health; USGS, U.S. Geological Survey

Appendix 9. Location of ground-water chemistry sites for bedrock and unconsolidated deposits of the upper Kankakee River Basin



Appendix 10. **Location of ground-water chemistry sites for unconsolidated deposits of the lower Kankakee River Basin**



Appendix 11. Location of ground-water chemistry sites of bedrock wells sampled in the lower Kankakee River Basin

Appendix 12. Results of chemical analysis from selected water wells completed in unconsolidated deposits

{All values in milligrams per liter except as indicated.}

Location Number: *, analysis of softened water; -, anomalous analysis (epm balance error >5%); X, Indiana Department of Environmental Management volatile organic and pesticide sampling site; #, incomplete analysis.

Well owner: CC, Country Club; CH, Church; F&W, Fish and Wildlife; IDNR, Indiana Department of Natural Resources; Lapt, LaPorte County; New, Newton County; Obs, Observation; S, Shallow; Stark, Starke County; USGS, United States Geological Survey; (133), sample number for data collected in joint Division of Water and Indiana Geological Survey Study. Data collected summer and fall, 1986, except where prefixed with SJ (St. Joseph River Basin) and LM (Lake Michigan Basin).

Township: N, North.

Range: E, East; W, West.

Section: M, MRL (Michigan Road Land).

Aquifer system: ES, Eolian Sands; IQB, Iroquois Basin; IQM, Iroquois Moraine; IQV, Iroquois Buried Valley; KK, Kankakee; MM, Maxinkuckee Moraine; NAP, Nappanee; SJ, St. Joseph; VM, Valparaiso Moraine; VOA, Valparaiso Outwash Apron.

Date sampled: month and year

Location Number	Well Owner	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCo_3$	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCo_3$[2]	Chloride	Sulfate	Fluoride	Nitrate as Nitrogen	Total Dissolved Solids[3]
										LAKE COUNTY											
1X	D. Doodeman (111)	33N	10W	13	53	VM	8/86	7.2	444	108.2	42.4	10.8	0.9	2.70	< 0.10	393.9	14.3	92.9	0.3	< 0.02	509
2	L. Sylvester (89)	34N	9W	18	76	VM	7/86	7.4	403	98.0	38.6	10.3	0.9	2.30	< 0.10	420.0	6.9	11.1	0.2	< 0.02	420
3	M. Strake	34N	9W	25	62	VM	5/62	7.0	573	114.0	70.0	12.0	2.5	3.50	0.05	471.0	1.0	120.0	0.1	0.18	606
4	Dalecarlia 1	33N	9W	1	86	VM	7/74	7.4	468	106.0	49.0	18.0	3.0	2.50	0.05	418.0	3.0	80.0	0.3	0.40	513
5	C. Williams (90)	33N	9W	5	56	VM	7/86	7.1	408	101.6	37.6	40.7	0.9	2.30	0.10	271.6	112.0	120.0	0.2	< 0.02	578
6	G. Fox (91)	33N	9W	21	72	VM	7/86	6.2	351	80.8	36.2	15.0	1.1	1.80	< 0.10	375.2	13.9	22.0	0.3	< 0.02	396
7	First Church of the Nazarene (96)	33N	9W	25	46	VM	7/86	6.4	515	131.0	45.8	13.5	0.9	2.20	0.20	330.4	48.0	150.0	0.2	< 0.02	590
8	C. Bailey (106)	32N	9W	6	74	VM	10/87	7.6	358	96.7	28.3	6.5	0.5	1.30	0.10	246.3	12.9	98.1	0.1	< 0.02	400
9	Huber Sod Farm	32N	9W	28	32	KK	8/81	6.8	466	124.0	38.0	30.0	42.0	5.50	1.00	344.0	59.0	150.0		0.90	657
10	A. Moos (117)	34N	8W	26	86	VM	8/86	7.6	283	61.3	31.6	50.9	1.6	1.70	< 0.10	400.2	9.8	< 0.1	0.3	< 0.02	397

Appendix 12. Results of chemical analysis from selected water wells completed in unconsolidated deposits — Continued

Location Number	Well Owner	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCo_3$	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCo_3$[2]	Chloride	Sulfate	Fluoride	Nitrate as Nitrogen	Total Dissolved Solids[3]
LAKE COUNTY - Continued																					
11	W. Heath	34N	8W	30	67	VM	5/62	6.8	618	132.0	70.0	14.0	2.0	9.30	0.11	451.0	1.5	178.0	0.1	0.11	678
12	D. Randall (94)	33N	8W	4	108	VM	7/86	6.7	424	104.6	39.6	12.2	1.0	3.20	< 0.10	403.8	1.3	43.2	0.3	< 0.02	448
13	IN I-65	33N	8W	14	63	VM	8/86	7.7	480	99.0	56.0	9.4	1.5	2.50	0.05	452.0	< 5.0	59.0	0.2	0.10	499
14	J. Hayden	33N	8W	24	56	VM	8/81	7.1	516	121.0	52.0	8.0	1.6	2.40	0.05	376.0	9.0	140.0		< 0.10	560
15	R. Mathis Farm	32N	8W	28	27	KK	8/81	7.3	229	64.0	17.0	10.0	0.8	1.80	0.22	123.0	15.0	93.0		0.20	276
16	E. Fraikin	32N	8W	28	34	KK	7/81	8.1	290	64.0	32.0	100.0	5.2	1.20	0.02	330.0		74.0	0.5	< 0.10	475
17	Twin Lakes 2	34N	7W	16	118	VM	4/78	7.5	590	118.0	71.0	20.0	4.0	2.80	0.02	472.0	3.0	150.0	0.3	0.30	653
19	D. Osburn (83)	33N	7W	5	47	VM	7/86	7.9	398	97.5	37.7	6.8	0.7	3.20	0.10	297.9	5.1	114.0	0.2	< 0.02	444
20	R. Creekmur	33N	7W	20	48	VM	8/81	7.2	412	83.0	50.0	14.0	1.7	3.80	0.04	352.0	7.0	86.0		< 0.10	457
21	H. Henson	33N	7W	21	63	VM	8/81	7.1	516	106.0	61.0	12.0	1.9	5.40	0.06	378.0	< 5.0	150.0		< 0.10	563
22	R. Sherman	33N	7W	28	40	VOA	8/81	7.1	586	128.0	65.0	26.0	2.1	0.31	0.18	386.0	44.0	200.0		0.50	698
NEWTON COUNTY																					
23	Willow Slough	30N	10W	25	36	KK	10/79	8.2	150	41.0	12.0	2.0	1.0	0.60	0.10	102.0	5.0	44.0	0.1	< 0.10	167
24	IDNR	29N	10W	12	27	KK	4/78	7.4	156	40.0	14.0	9.0	2.0	0.50	0.18	114.0	11.0	39.0	0.1	< 0.10	184
25	USGS New10 (185)	30N	9W	2	45	KK	10/86	7.2	411	120.9	26.5	15.7	0.8	7.00	0.10	397.0	17.3	56.1	0.3	< 0.02	483
26-	USGS New9 (183)	30N	9W	32	45	KK	10/86	8.4	55	15.4	3.9	3.4	0.3	< 0.10	0.10	49.3	2.7	27.1	< 0.1	< 0.02	83
27	R. Gumz	30N	9W	34	153	KK	9/84	8.1	168	45.0	14.0	73.0	4.0	1.10	0.02	282.0	26.0	< 5.0	0.8	< 0.10	333
28	Morocco	29N	9W	15	51	KK	4/86	6.7	216	62.0	15.0	19.0	1.9	1.20	0.16	168.0	35.0	50.0	0.1	< 0.10	285
29	V. Buswell (171)	28N	9W	30	85	IQB	8/86	8.0	123	33.1	9.9	55.1	1.1	0.50	< 0.10	241.7	7.6	< 0.1	0.6	< 0.02	253
30X	S. Olszyk (148)	27N	9W	2	107	IQV	8/86	7.0	184	48.5	15.4	32.9	0.9	0.60	< 0.10	258.3	2.6	3.3	0.6	< 0.02	260
31	Kentland 3	27N	9W	21	105	IQB	11/82	7.7	143	33.0	15.0	70.0	2.4	0.15	< 0.02	281.0	< 5.0	5.0	0.7	< 0.10	295
31	Kentland 2	27N	9W	21	115	IQB	11/82	7.6	149	33.0	16.0	68.0	2.5	0.14	< 0.02	284.0	< 5.0	5.0	0.6	< 0.10	296
31	Kentland 1	27N	9W	21	121	IQB	11/82	7.8	144	33.0	15.0	65.0	2.6	0.12	< 0.02	274.0	< 5.0	5.0	0.7	< 0.10	286
32	A. Villanova	31N	8W	14	20	KK	5/62	7.3	258	77.0	16.0	63.0	28.0	0.04	1.40	182.0	112.0	59.0	0.2	4.42	470
33	Dugan (174)	31N	8W	19	34	KK	8/86	8.5	93	27.5	5.9	5.1	0.4	< 0.10	< 0.10	54.1	8.0	23.1	0.1	2.34	105
34-	L. Prohosky	30N	8W	22	30	KK	7/85	7.4	187	47.0	17.0	8.5	2.7	< 0.10	0.07	98.0	25.0	56.0	< 0.5	23.00	238
35	D. Weston (115)	29N	8W	21	36	IQM	8/86	7.4	325	91.1	23.8	7.5	0.5	1.70	0.10	234.4	8.5	73.7	0.2	< 0.02	348

Appendix 12. Results of chemical analysis from selected water wells completed in unconsolidated deposits — Continued

Location Number	Well Owner	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCo_3$	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCo_3$[2]	Chloride	Sulfate	Fluoride	Nitrate as Nitrogen	Total Dissolved Solids[3]
NEWTON COUNTY — Continued																					
36	J. Talley (114)	29N	8W	28	167	IQM	8/86	7.9	93	20.6	10.1	89.6	2.5	< 0.10	< 0.10	267.6	6.1	2.0	0.7	< 0.02	292
37	Brook 2	28N	8W	19	127	IQV	5/83	7.2	266	67.0	24.0	21.0	1.2	1.20	0.05	306.0	< 5.0	6.0	0.5	< 0.10	313
37	Brook 1	28N	8W	19	119	IQV	5/83	7.2	240	62.0	20.0	28.0	1.8	0.92	0.03	292.0	< 5.0	< 5.0	< 0.1		288
38	USGS New6 (188)	28N	8W	23	80	IQV	10/86	7.6	265	62.2	26.7	31.8	1.4	0.90	< 0.10	356.1	2.8	1.6	0.8	< 0.02	342
39	L. Putt (123)	28N	8W	36	33	IQB	8/86	7.1	174	50.6	11.6	18.6	0.5	< 0.10	0.10	106.2	27.8	64.1	0.2	0.59	238
40X	L. Garring (150)	27N	8W	30	30	IQB	8/86	7.3	330	83.6	29.6	29.5	1.2	1.70	< 0.10	308.8	5.7	83.9	0.5	< 0.02	421
BENTON COUNTY																					
41	D. Scherer (120)	25N	9W	30	84	IQB	8/86	6.8	264	70.8	21.2	19.8	1.3	1.50	< 0.10	304.9	1.7	15.3	0.6	< 0.02	315
42	D. Klenme (118)	25N	9W	33	198	IQB	8/86	7.7	221	61.3	16.6	49.1	2.0	1.10	< 0.10	294.4	2.2	39.1	0.9	< 0.02	349
43	J. Budreau (170)	26N	8W	19	174	IQB	8/86	8.1	254	66.9	21.3	33.4	1.5	0.90	< 0.10	296.8	8.5	34.6	0.8	< 0.02	346
44	Fowler 10	25N	8W	10	119	IQB	4/79	7.5	276	70.0	25.0	19.0	3.0	1.60	0.02	304.0	4.0	18.0	0.5	< 0.10	323
44	Fowler 9	25N	8W	10	122	IQB	4/79	7.4	310	77.0	28.0	16.0	2.0	1.60	0.02	308.0	4.0	33.0	0.4	< 0.10	347
45	R. Nesbitt (137)	25N	8W	15	40	IQB	8/86	6.2	375	99.0	31.1	8.5	0.6	2.20	0.10	279.5	10.9	89.2	0.2	< 0.02	410
46X	P. Clark (144)	26N	7W	14	75	IQB	8/86	6.6	229	62.9	17.5	35.3	1.5	1.20	< 0.10	309.4	1.7	12.8	0.7	0.00	319
PORTER COUNTY																					
47	G. Hammond (82)	34N	7W	13	120	VM	7/86	7.8	255	65.7	22.1	9.9	0.8	0.60	0.10	262.1	7.2	14.3	0.2	< 0.02	278
48	Hebron 3	33N	7W	11	85	VM	2/82	7.5	452	105.0	46.0	11.0	1.6	1.50	0.05	365.0	23.0	83.0	0.2	0.10	491
49	Hebron 1	33N	7W	14	87	VM	2/82	7.4	470	108.0	49.0	19.0	1.9	1.80	0.06	396.0	24.0	83.0	0.2	0.10	525
50	Kielpikowski (88)	35N	6W	31	105	VM	7/86	7.2	507	112.7	55.0	14.5	1.1	2.80	< 0.10	476.0	1.5	83.9	0.2	< 0.02	560
51	C. Graeber (87)	34N	6W	16	51	VM	7/86	6.8	396	101.7	34.6	3.1	0.6	1.70	0.10	270.5	7.3	113.0	0.2	< 0.02	425
52	W. Herlitz (85)	34N	6W	28	75	VOA	7/86	7.2	457	115.1	41.4	3.9	0.6	2.50	0.10	325.9	5.4	152.0	0.2	< 0.02	517
53	M. Jinks	33N	6W	3	35	VOA	10/81	7.2	296	74.0	27.0	2.1	3.1	3.70	0.26	224.0	11.0	73.0		< 0.10	329
54-	H. Rumpke	33N	6W	14	27	KK	10/81	7.6	303	74.0	28.0	16.0	3.1	0.90	0.02	183.0	20.0	170.0		0.30	422
55	Hansel (84)	33N	6W	19	45	KK	7/86	7.0	374	94.7	33.6	24.3	1.0	0.90	0.10	129.4	157.0	119.0	0.1	< 0.02	508
49	K. Berkober	36N	5W	31	146	VM	10/81	7.2	572	136.0	56.0	5.0	2.3	6.00	0.16	416.0	32.0	120.0			607
56	K. Kuehn (81)	35N	5W	2	76	VM	7/86	7.1	420	109.9	35.4	2.3	0.8	1.30	0.10	287.8	20.8	106.0	0.1	< 0.02	449
57X	J. Frencl (167)	35N	5W	5	150	VM	8/86	7.1	385	104.2	30.3	4.2	0.7	2.20	0.10	343.1	10.5	64.4	< 0.1	< 0.02	422
58	M. Samuelson (166)	35N	5W	21	51	VM	8/86	7.5	320	88.5	24.0	5.0	1.1	1.10	0.10	235.9	34.4	68.2	< 0.1	< 0.02	364

Appendix 12. Results of chemical analysis from selected water wells completed in unconsolidated deposits — Continued

Location Number	Well Owner	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCo_3$	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCo_3$[2]	Chloride	Sulfate	Fluoride	Nitrate as Nitrogen	Total Dissolved Solids[3]
PORTER COUNTY — Continued																					
59	Valparaiso 1	35N	5W	29	138	VOA	9/87	7.4	332	90.0	26.0	3.4	1.7	1.70	0.14	246.0	5.0	79.0	< 0.1	< 0.10	222
59	Valparaiso 2	35N	5W	29	125	VOA	9/87	7.3	386	109.0	28.0	3.1	1.6	2.00	0.16	236.0	5.0	120.0	< 0.1	< 0.10	283
59	Valparaiso 3	35N	5W	29	126	VOA	9/87	7.4	314	90.0	22.0	2.8	1.6	3.60	0.22	200.0	< 5.0	100.0	< 0.1	< 0.10	232
59	Valparaiso 4	35N	5W	29	124	VOA	9/87	7.4	319	85.0	26.0	3.0	1.5	1.40	0.14	224.0	6.0	82.0	0.1	< 0.10	219
59	Valparaiso 5	35N	5W	28	122	VOA	9/87	7.3	310	85.0	24.0	3.7	1.4	6.70	0.20	214.0	6.0	85.0	< 0.1	< 0.10	225
59	Valparaiso 6	35N	5W	28	139	VOA	9/87	7.4	296	82.0	22.0	6.1	1.3	2.20	0.13	200.0	15.0	82.0	< 0.1	< 0.10	200
59	Valparaiso 7	35N	5W	28	142	VOA	9/87	7.4	270	71.0	22.0	3.5	1.2	1.20	0.11	174.0	7.0	88.0	< 0.1	< 0.10	204
60	R. Grass (165)	35N	5W	36	40	VOA	8/86	7.5	500	134.7	39.9	3.0	0.3	9.80	0.80	245.6	26.8	249.7	< 0.1	< 0.02	612
61	M. Nova (169)	34N	5W	9	46	VOA	8/86	7.7	234	64.1	18.0	3.4	0.4	0.20	0.10	87.9	26.8	115.8	< 0.1	< 0.02	282
62	Shults & Lewis	34N	5W	19	62	VOA	10/81	7.8	237	53.0	26.0	2.9	11.0	0.17	0.17	140.0	16.0	100.0		< 0.10	293
63	Porter Co. Co-op	34N	5W	19	59	VOA	10/81	7.3	276	66.0	27.0	3.1	1.7	0.33	0.06	164.0	13.0	110.0		0.20	320
64	C. Birkey	34N	5W	30	26	VOA	10/81	7.4	288	69.0	28.0	3.0	1.3	0.17	0.11	190.0	11.0	100.0		< 0.10	327
65	W. Geese (86)	33N	6W	1	29	VOA	7/86	7.8	238	64.1	18.8	5.0	0.5	0.20	0.10	138.9	13.4	83.3	< 0.1	< 0.02	269
66	D. Briars	33N	5W	6	26	VOA	10/81	7.5	165	40.0	16.0	12.0	2.9	0.30	0.05	107.0	16.0	71.0		0.20	222
67	Birkey	33N	5W	9	25	KK	10/81	7.2	332	80.0	32.0	6.2	1.4	3.50	0.26	216.0	20.0	110.0		< 0.10	383
68	Kouts 1	33N	5W	17	43	KK	5/77	7.5	218	59.0	17.0	17.0	3.0	0.60	0.19	136.0	25.0	73.0	0.2	< 0.10	277
68	Kouts 3	33N	5W	17	44	KK	5/87		235	61.0	20.0	13.0	2.2	0.51	0.16	129.0	28.0	85.0		< 0.10	291
69	G. Haman	33N	5W	21	56	KK	10/81	7.4	262	69.0	22.0	6.2	0.9	4.80	0.29	164.0	9.0	110.0		< 0.10	321
70	C. Goodwin (59)	33N	5W	34	30	KK	7/86	6.3	345	96.6	25.1	10.6	13.4	7.50	0.30	296.8	28.9	100.0	0.2	< 0.02	461
JASPER COUNTY																					
71	F. Modlenaar	32N	7W	14	40	KK	5/60	7.2	204	55.0	16.0	4.8	0.4	1.50	0.04	123.0	7.6	72.0	0.2	0.09	231
72X	M. Moolenaar (103)	32N	7W	16	25	KK	7/86	7.6	173	52.5	10.2	3.2	0.6	3.50	0.30	96.3	17.7	56.7	0.1	< 0.02	203
73	P. Dittner	32N	7W	21	25	KK	5/62	7.2	233	62.0	19.0	5.7	0.5	2.20	0.21	117.0	16.0	103.0	0.1	0.14	279
74	G. Glessner (102)	32N	7W	26	30	KK	7/86	5.8	382	104.4	29.6	78.1	0.9	9.10	0.90	212.8	117.0	204.0	0.3	< 0.02	672

Appendix 12. Results of chemical analysis from selected water wells completed in unconsolidated deposits — Continued

Location Number	Well Owner	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCo_3$	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCo_3$[2]	Chloride	Sulfate	Fluoride	Nitrate as Nitrogen	Total Dissolved Solids[3]
JASPER COUNTY — Continued																					
75	I-65 South	31N	7W	6	54	KK	10/84	7.9	132	38.0	9.0	2.3	0.5	0.54	0.08	74.0	8.0	49.0	0.1	< 0.10	200
75#	I-65 North	31N	7W	6	57	KK	12/76	8.1	136			5.0	< 1.0	0.40	0.06	92.0	15.0	38.0		< 0.10	152
76	Prudential 49	30N	7W	6	48	KK	5/84	7.6	148	43.0	10.0	3.0	0.8	0.99	0.12	128.0	< 5.0	35.0	< 0.1	< 0.10	170
77	J. McKinney	30N	7W	6	36	KK	7/85	7.2	81	23.0	5.7	3.1	2.4	< 0.10	< 0.05	54.0	5.0	27.0	< 0.5	3.00	102
78	H & H Feedlot	30N	7W	16	54	KK	8/82	7.1	372	116.0	20.0	10.0	13.0	2.60	0.36	248.0	15.0	140.0	0.2	0.20	466
79	Prud. Jasp11S Obs	30N	7W	18	34	KK	5/83	7.3	324	97.0	20.0	23.0	1.3	1.90	0.15	184.0	85.0	71.0	0.1	< 0.10	410
80	R. Hammond	30N	7W	22	20	IQM	7/85	6.6	153	40.0	13.0	82.0	2.1	< 0.10	< 0.05	105.0	55.0	63.0	< 0.5	33.00	351
81X	J. Gawthrop (152)	29N	7W	13	172	IQM	8/86	7.0	255	62.1	24.3	37.2	1.0	0.50	< 0.10	334.1	1.4	10.8	0.5	< 0.02	338
82	E. Prohosky (128)	29N	7W	21	49	IQM	8/86	6.4	379	103.2	29.4	17.2	0.8	2.40	0.10	263.4	34.5	95.6	0.3	< 0.02	441
83	Curtis Creek CC	29N	7W	29	91	IQV	11/83	7.7	232	65.0	17.0	6.0	0.9	0.41	0.06	186.0	6.0	49.0	0.2	< 0.10	258
84X	Maienbrook (151)	28N	7W	15	50	IQB	8/86	7.0	249	63.5	22.0	26.0	0.9	2.40	< 0.10	314.6	2.0	< 0.1	0.7	< 0.02	306
85	G. Sutton (126)	28N	7W	24	45	IQB	8/86	6.9	109	28.0	9.4	21.2	1.0	0.10	< 0.10	156.1	1.5	< 0.1	0.8	< 0.02	156
86	Remington 3	27N	7W	25	55	IQB	7/83	7.2	330	84.0	29.0	17.0	3.1	1.40	0.02	342.0	< 5.0	10.0	0.5	0.30	351
87	W. Misch (175)	32N	6W	3	20	KK	10/87	7.3	234	60.7	20.1	2.9	2.1	0.10	0.40	160.9	22.2	53.0	0.2	4.20	281
88	Wheatfield Fire Department (95)	32N	6W	25	31	KK	7/86	7.1	263	78.4	16.2	24.6	2.5	0.10	0.50	180.3	39.4	71.1	0.1	1.45	342
89	Kankakee Valley High School (97)	32N	6W	33	35	KK	7/86	7.3	251	73.8	16.3	7.3	1.0	< 0.10	0.20	128.8	7.9	131.1	< 0.1	< 0.02	315
90	G. Fritts 2 (101)	31N	6W	29	42	KK	8/86	7.2	298	87.2	19.5	4.4	0.5	1.70	0.30	141.7	17.3	110.0	0.2	1.39	327
91	R. Bozell (99)	30N	6W	20	108	IQM	8/86	6.7	226	61.9	17.3	26.7	0.9	1.20	< 0.10	280.0	2.7	18.5	0.7	< 0.02	298
92X	R. Walter (129)	28N	6W	2	35	IQB	8/86	6.7	458	123.0	36.7	4.6	0.7	1.40	0.50	229.6	27.3	235.0	0.2	< 0.02	567
93	Remington 4	27N	6W	30	54	IQB	7/83	7.2	388	98.0	35.0	17.0	3.3	1.60	0.03	352.0	11.0	52.0	0.5	0.10	430
93	Remington 1	27N	6W	30	43	IQB	7/83	7.3	340	82.0	33.0	18.0	2.8	1.30	0.03	346.0	5.0	9.0	0.5	0.30	360
93	Remington 2	27N	6W	30	48	IQB	7/83	7.2	388	95.0	36.0	18.0	3.2	2.10	0.03	354.0	30.0	29.0	0.5	0.50	427
94	D. Hargis (61)	32N	5W	14	18	KK	7/86	6.8	231	72.6	12.2	3.1	0.6	< 0.10	0.10	111.9	22.0	53.0	0.2	5.36	236

Appendix 12. Results of chemical analysis from selected water wells completed in unconsolidated deposits — Continued

Location Number	Well Owner	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCo_3$	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCo_3$[2]	Chloride	Sulfate	Fluoride	Nitrate as Nitrogen	Total Dissolved Solids[3]
									WHITE COUNTY												
95-	P. Tiede (179)	28N	5W	2	27	IQB	8/86	8.3	205	62.2	11.9	2.7	0.6	0.60	0.30	172.4	6.2	70.5	0.1	< 0.02	259
									LAPORTE COUNTY												
96	A. Rutz (66)	36N	4W	26	27	VOA	8/86	7.9	278	77.5	20.5	11.6	0.6	2.90	0.20	180.2	16.8	98.2	< 0.1	< 0.02	336
97	Westville 1	36N	4W	29	125	VM	1/86	7.5	250	69.0	19.0	5.5	2.7	1.10	0.08	180.0	25.0	70.0		< 0.10	300
98	Westville 2	36N	4W	29	150	VM	1/86	7.6	303	81.0	25.0	13.0	2.7	1.70	0.09	231.0	28.0	75.0		< 0.10	365
99-	USGS Lapt11 (197)	35N	4W	16	100	VOA	10/86	7.9	139	39.7	9.7	2.5	0.2	0.10	0.10	78.0	3.2	75.0	< 0.1	< 0.02	177
101	Wanatah 1	34N	4W	5	72	VOA	1/84	8.2	326	94.0	22.0	62.0	5.5	2.90	0.18	228.0	93.0	79.0	0.6	< 0.10	496
101	Wanatah 2	34N	4W	5	68	VOA	1/84	8.1	340	100.0	22.0	55.0	6.4	4.00	0.24	250.0	87.0	76.0	0.2	0.20	501
102	W. Stull (64)	34N	4W	14	60	KK	7/86	6.9	162	47.1	10.7	2.8	0.4	0.10	0.10	68.5	8.9	77.8	< 0.1	< 0.02	189
103	USGS Lapt9 (196)	34N	4W	15	32	VOA	10/86	7.8	144	41.7	9.8	2.6	0.3	0.20	0.10	57.6	12.2	83.7	< 0.1	< 0.02	185
104	Lacrosse 1	33N	4W	17	29	KK	4/86	6.9	408	109.0	33.0	140.0	6.5	4.20	0.62	360.0	210.0	79.0	0.2	< 0.10	708
104	Lacrosse 2	33N	4W	17	30	KK	4/86	6.8	390	99.0	35.0	89.0	9.3	4.30	0.64	320.0	130.0	93.0	0.2	< 0.10	656
105	Pine Lake Cem. (71)	37N	3W	22	163	VM	7/86	7.7	227	66.4	15.0	2.6	0.4	0.80	0.10	202.0	11.0	8.6	< 0.1	< 0.02	226
106	J. Magnuson (70)	37N	3W	26	42	VM	7/86	7.1	410	110.8	32.5	16.4	1.0	0.30	0.10	321.2	46.0	54.4	< 0.1	0.30	455
107	L. Olson (69)	37N	3W	32	69	VM	7/86	7.4	380	103.6	29.6	15.0	0.7	0.20	0.20	252.9	23.2	109.0	< 0.1	< 0.02	433
108	Lapt Hawthorne	37N	3W	35	139	VM	11/73	7.8	342	93.0	27.0	10.0	2.0	3.80	0.15	296.0	22.0	42.0	0.1	0.60	378
109#	Scott-Forseman Co.	36N	3W	5	237	VM	4/86	7.0	288					1.00	0.15	272.0	26.0		0.2		
110	J. Ridgeway (168)	36N	3W	14	150	VOA	8/86	7.2	302	79.7	25.1	3.0	0.4	1.10	0.10	226.7	18.2	66.7	< 0.1	< 0.02	330
111-	USGS Lapt12 (198)	36N	3W	14	77	VOA	10/86	7.8	302	79.2	25.3	3.0	0.5	0.80	0.10	228.8	24.6	78.1	0.1	< 0.02	349
112	J. Fishbaher (65)	36N	3W	24	41	VOA	7/86	7.8	211	56.7	17.0	5.0	0.6	0.50	0.10	106.3	12.2	93.0	0.1	< 0.02	249
113	W. Lange (67)	36N	3W	31	69	VOA	7/86	6.7	340	98.1	23.0	4.5	0.6	5.00	0.30	285.3	6.1	49.3	0.1	< 0.02	358
114	W. Lindburg (68)	35N	3W	16	34	VOA	7/86	7.3	349	101.0	23.6	13.4	16.1	< 0.10	0.10	199.7	40.3	70.0	< 0.1	18.23	403
115	Stephenson (164)	34N	3W	5	40	VOA	8/86	7.9	202	55.7	15.2	3.5	0.4	0.20	0.10	91.6	22.0	88.4	< 0.1	< 0.02	240
116	Kankakee F&W (36)	34N	3W	27	53	KK	7/86	7.8	185	55.4	11.4	2.4	3.6	0.50	0.30	134.1	10.1	54.9	0.2	< 0.02	219
117	F. Swanson (37)	33N	3W	18	26	KK	7/86	7.2	362	109.0	21.8	6.8	0.6	3.20	0.30	286.5	27.5	72.1	0.3	< 0.02	414
228-	G. Bladecki (LM7)	38N	2W	36	116	KK	9/87	7.5	390	108.0	29.6	3.4	0.6	0.10	0.30	376.6	22.1	41.3	0.1	1.20	441

Appendix 12. Results of chemical analysis from selected water wells completed in unconsolidated deposits — Continued

Location Number	Well Owner	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCo_3$	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCo_3$[2]	Chloride	Sulfate	Fluoride	Nitrate as Nitrogen	Total Dissolved Solids[3]
LAPORTE COUNTY — Continued																					
118	L. Sims (72)	37N	2W	5	190	VM	7/86	7.2	299	79.6	24.4	2.0	0.6	< 0.10	< 0.10	250.4	6.7	34.0	< 0.1	2.00	299
119X	J. Harris (57)	37N	2W	11	50	VOA	10/87	7.2	454	132.5	30.0	39.4	2.5	< 0.10	< 0.10	341.9	76.2	61.5	< 0.1	8.96	595
120	G. Anderson (73)	37N	2W	28	36	VM	7/86	7.8	282	79.6	20.2	3.1	0.5	1.70	0.10	190.2	12.0	66.5	< 0.1	< 0.02	298
100	Lapt Kankakee	37N	2W	28	125	KK	5/69	8.0	316	89.0	23.0	6.0	2.0	3.00	0.17	222.0	9.0	100.0	0.1	0.20	365
121-	D. Tuholski (78)	36N	2W	2	105	KK	7/86	7.4	291	81.9	20.9	4.3	1.5	1.20	0.10	143.4	13.0	77.1	< 0.1	0.32	286
122	R. Tarnow (74)	36N	2W	27	41	VOA	7/86	7.4	216	60.7	15.7	3.4	0.5	0.10	0.20	118.1	13.6	72.7	< 0.1	< 0.02	238
123	Kingsbury E	36N	2W	31	80	VOA	8/83	7.6	228	62.0	18.0	14.0	1.1	4.30	0.45	200.0	11.0	30.0	0.2	< 0.10	271
124	Kingsbury B	35N	2W	4	76	VOA	4/78	7.6	252	65.0	22.0	3.0	1.0	0.10	0.06	160.0	12.0	54.0	0.1	9.60	263
125	Kingsbury A	35N	2W	5	74	VOA	8/84	8.1	240	64.0	19.0	10.0	1.8	0.66	0.11	172.0	17.0	55.0	0.1	0.10	271
126	Kingsford Heights 5	35N	2W	18	60	VOA	3/82	7.7	192	53.0	15.0	5.8	1.0	0.54	0.12	133.0	10.0	57.0	0.1	0.20	223
126	Kingsford Heights 4	35N	2W	18	68	VOA	3/82	7.8	197	54.0	15.0	5.3	1.1	0.33	0.09	133.0	12.0	55.0	0.1	1.10	224
126	Kingsford Heights 3	35N	2W	18	74	VOA	3/82	6.7	194	53.0	15.0	5.3	1.6	0.26	0.08	122.0	12.0	60.0	0.1	2.00	223
127	R. Gumz	35N	2W	30	24	VOA	6/56	7.0	414	115.0	31.0	3.9	5.8	3.10	0.69	246.0	18.0	160.0	0.1	0.02	485
128X	W. Wolfe (54)	38N	1W	28	42	VM	7/86	7.2	359	97.2	28.3	38.5	1.5	4.20	0.40	308.8	77.7	51.9	< 0.1	< 0.02	485
129	A. Pekofske (55)	37N	1W	17	104	VOA	7/86	8.0	243	65.9	19.2	3.2	0.4	< 0.10	< 0.10	213.2	9.0	22.6	0.1	2.68	251
130	Sauktown CH (56)	37N	1W	28	22	VOA	7/86	7.7	226	66.6	14.4	2.7	1.2	1.60	0.10	212.0	5.0	31.2	0.1	< 0.02	250
131	Mixsawbah Hatchery	36N	1W	31	41	KK	11/79	7.9	268	74.0	20.0	4.0	0.4	6.90	0.26	214.0	5.0	55.0	0.2	< 0.10	295
131-	USGS Lapt10 (199)	36N	1W	31	104	KK	11/86	7.9	67	10.6	9.9	11.0	0.7	< 0.10	< 0.10	93.0	7.0	< 0.1	0.3	< 0.02	95
132	Kingsbury F & W (79)	36N	1W	31	175	VOA	7/86	7.0	286	75.2	23.8	19.5	1.0	0.50	0.10	226.2	7.4	112.0	0.3	< 0.02	375
133	C. Daube (75)	35N	1W	8	26	KK	7/86	7.4	329	84.0	29.1	5.8	1.0	2.20	0.60	217.6	12.1	100.0	0.3	< 0.02	366
134	H. Cole (160)	35N	1W	29	43	VOA	8/86	7.2	207	59.1	14.6	4.1	0.5	< 0.10	0.10	128.0	18.2	37.3	< 0.1	7.64	218
135	L. Johnson (159)	35N	1W	32	105	VOA	8/86	7.4	423	126.6	25.9	3.7	0.3	12.60	0.70	366.6	33.1	53.1	< 0.1	< 0.02	476
STARKE COUNTY																					
136	Nazarene Church	33N	4W	33	30	KK	5/62	6.9	302	82.0	28.0	16.0	0.5	6.00	0.31	243.0	12.0	81.0	0.4	0.09	372
137	J. Adams (5)	32N	4W	2	61	KK	7/86	8.1	221	62.0	16.1	20.9	0.8	1.80	0.10	214.9	23.3	23.4	0.4	< 0.02	278
138	Co. Mary Hosp. 2	32N	4W	28	40	ES	12/75	8.2	156	46.0	10.0	11.0	2.0	0.60	0.10	102.0	25.0	36.0	0.1	2.20	194
138	Co. Mary Hosp. 1	32N	4W	28	40	ES	12/75	8.1	236	70.0	15.0	16.0	3.0	0.80	0.10	120.0	71.0	49.0	0.1	2.60	300
139-	B. Lawrence (76)	34N	3W	36	90	KK	7/86	7.7	313	94.1	19.0	4.6	0.3	9.20	0.80	165.9	21.2	112.0	0.2	< 0.02	361
140	KK Game Preserve	33N	3W	10	107	VOA	3/80	8.0	212	45.0	24.0	95.0	4.4	1.00	0.02	332.0	58.0	7.0	0.8	< 0.10	435

Appendix 12. Results of chemical analysis from selected water wells completed in unconsolidated deposits — Continued

Location Number	Well Owner	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCo_3$	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCo_3$[2]	Chloride	Sulfate	Fluoride	Nitrate as Nitrogen	Total Dissolved Solids[3]
STARKE COUNTY — Continued																					
141	B. Manns (4)	32N	3W	9	94	ES	7/86	7.2	89	27.4	5.0	6.7	0.3	0.20	< 0.10	100.5	0.4	2.9	0.2	< 0.02	103
142	M. Vermilyer (3)	32N	3W	15	25	ES	7/86	7.4	169	51.0	10.1	6.9	1.0	< 0.10	< 0.10	117.9	11.9	26.1	< 0.1	5.05	183
144	H. Lippelt (153)	32N	3W	36	126	ES	8/86	7.3	136	39.6	9.1	8.6	0.4	0.20	0.10	153.0	< 0.1	3.6	0.5	< 0.02	154
145X	M. Riley (77)	34N	2W	32	33	VOA	7/86	7.1	461	142.0	25.9	4.6	0.5	8.20	0.80	319.4	25.4	106.0	0.1	< 0.02	505
146	J. Shilling (8)	33N	2W	15	26	VOA	7/86	7.6	212	59.7	15.3	29.4	1.1	2.10	0.50	179.7	51.3	32.7	0.2	< 0.03	300
148	Knox 3	33N	2W	23	124	ES	9/80	7.7	146	44.0	9.0	4.0	0.4	1.50	0.09	112.0	9.0	29.0	0.2	< 0.10	165
148	Knox 2	33N	2W	23	128	ES	9/80	7.4	174	54.0	9.0	4.0	0.4	3.00	0.11	168.0	6.0	9.0	0.2	< 0.10	187
148	Knox 1	33N	2W	23	124	ES	9/80	7.4	146	43.0	9.0	4.0	0.4	1.40	0.06	116.0	10.0	23.0	0.2	< 0.10	161
149	Rev. Hurlbut (7)	32N	2W	10	30	ES	7/86	8.4	109	32.4	6.8	8.0	0.4	0.10	< 0.10	74.5	7.0	37.9	< 0.1	< 0.02	137
150	M. Milo (1)	32N	2W	12	81	ES	7/86	7.2	144	45.1	7.6	2.3	0.2	0.40	0.10	125.4	1.0	18.7	0.3	< 0.02	151
151	USGS Strk2 (195)	32N	2W	14	85	ES	10/86	8.0	191	55.4	12.8	6.2	0.4	2.30	0.10	209.5	8.9	< 0.1	0.4	0.27	213
152	B. Sakaguchi (2)	32N	2W	18	125	ES	7/86	6.2	112	32.8	7.4	17.7	1.5	< 0.10	0.10	57.2	15.2	66.2	< 0.1	2.36	178
153	Hensler Nursery(158)	34N	1W	20	21	ES	8/86	7.5	152	44.7	9.7	2.4	1.7	1.30	0.20	127.8	2.0	33.4	< 0.1	< 0.02	172
154	J. Garcia (35)	34N	1W	24	40	ES	7/86	7.6	219	63.3	14.8	5.2	0.5	< 0.10	< 0.10	126.1	7.0	34.0	< 0.1	15.68	216
155	S. Clark (34)	34N	1W	25	153	ES	7/86	7.6	236	60.3	20.8	6.3	0.6	0.40	< 0.10	264.7	1.7	< 0.1	0.1	< 0.02	249
156	H. Sinn (157)	34N	1W	30	92	VOA	8/86	7.9	201	62.5	11.0	3.1	0.3	1.20	0.10	108.8	27.2	65.6	< 0.1	< 0.02	236
157	R. Dickson (156)	33N	1W	27	75	ES	8/86	7.7	148	45.5	8.5	10.1	0.3	0.30	< 0.10	131.6	8.8	30.2	0.3	< 0.02	183
158	Bass Lake State Beach	32N	1W	18	136	ES	5/60	7.3	248	63.0	22.0	5.8	0.7	1.50	0.02	253.0	2.4	6.2	0.2	0.50	254
ST. JOSEPH COUNTY																					
159	New Carlisle 3	38N	1W	34	192	VOA	3/83	7.6	302	80.0	25.0	5.0	1.0	1.10	0.04	242.0	12.0	48.0	0.2	< 0.10	318
159	New Carlisle 2	38N	1W	35	132	VOA	4/60	7.8	241	54.0	26.0	4.0	1.0	1.00	0.05	202.0	4.0	35.0	0.0	0.10	246
159	New Carlisle 1	38N	1W	35	116	VOA	5/78	7.6	280	72.0	24.0	3.0	1.0	0.60	0.03	224.0	11.0	52.0	0.2	< 0.10	298
160	Bendix Auto (53)	37N	1W	12	106	KK	7/86	7.5	281	71.8	24.6	10.4	0.6	< 0.10	< 0.10	233.8	21.3	48.0	0.1	1.75	319
161	P. Ives (46)	36N	1W	13	44	VOA	7/86	7.5	278	76.1	21.4	3.1	0.6	0.50	0.10	221.2	9.1	68.2	0.1	< 0.02	312
162	Walkerton 2	35N	1W	23	95	MM	9/78	7.6	270	73.0	21.0	13.0	2.0	0.20	0.19	220.0	22.0	48.0	0.1	0.10	312
163	R. Pugsley (80)	35N	1W	25	48	MM	7/86	7.4	238	70.5	15.2	14.9	0.8	< 0.10	< 0.10	185.9	21.4	23.0	0.1	2.93	260
164	D. Millar (163)	38N	1E	21	88	KK	8/86	7.0	310	80.5	26.5	3.8	0.5	< 0.10	< 0.10	259.8	6.6	52.3	< 0.1	3.07	329
165X	J. Wilson (162)	38N	1E	29	27	KK	8/86	7.9	274	72.7	22.5	4.5	0.4	0.70	< 0.10	214.9	17.8	61.4	< 0.1	< 0.02	309

Appendix 12. Results of chemical analysis from selected water wells completed in unconsolidated deposits — Continued

Location Number	Well Owner	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCo_3$	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCo_3$[2]	Chloride	Sulfate	Fluoride	Nitrate as Nitrogen	Total Dissolved Solids[3]
166	USGS SJ30 (200)	38N	1E	32	88	KK	11/86	7.7	271	71.8	22.4	5.5	0.4	0.50	< 0.10	218.5	17.6	68.9	0.2	< 0.02	318
167	Dobrzykowski (51)	37N	1E	17	45	KK	7/86	7.2	236	65.8	17.3	9.1	0.7	1.00	0.10	180.5	22.2	51.6	0.1	< 0.02	277
168	R. Hay (50)	37N	1E	24	73	KK	7/86	7.6	151	43.1	10.5	5.8	0.3	1.40	0.10	159.9	2.8	13.4	0.1	< 0.02	174
169	H. Wordinger (52)	37N	1E	30	80	KK	10/87	7.9	527	146.5	39.2	3.7	0.4	5.70	0.10	252.3	3.6	297.0	< 0.1	< 0.02	656
170	N. Kenkle (47)	36N	1E	9	105	MM	7/86	7.9	250	67.3	20.0	4.4	0.4	0.70	< 0.10	240.7	4.0	32.9	0.1	< 0.02	274
171	Potato Creek 3 (45)	36N	1E	24	109	MM	7/86	7.7	318	82.9	27.0	3.8	0.6	0.80	0.20	321.5	4.5	24.7	0.1	< 0.02	337
172	N. Liberty 1	36N	1E	28	67	MM	7/66	7.2	320	74.0	33.0	9.0	2.0	0.40	0.30	296.0	6.0	36.0	0.1	0.08	338
172	N. Liberty 2	36N	1E	28	100	MM	6/72	7.6	290	70.0	28.0	8.0	2.0	0.50	0.22	268.0	4.0	23.0	0.2	0.20	297
172	N. Lberty 3	36N	1E	33	69	MM	1/69	7.7	332	86.0	28.0	6.0	1.0	0.60	0.31	288.0	5.0	47.0	0.2	< 0.10	347
173	Clingenpeel (161)	35N	1E	6	116	MM	8/86	7.7	225	63.2	16.4	3.4	0.3	0.60	0.10	174.1	9.5	57.4	< 0.1	< 0.02	255
174	D. Lee (48)	37N	2E	8	40	SJ	7/86	7.8	256	70.3	19.5	13.8	1.0	1.00	0.20	221.2	25.3	52.2	0.0	0.00	316
177	H & R Product (49)	37N	2E	29	44	MM	7/86	7.0	297	75.7	26.3	3.3	0.5	0.40	0.20	276.8	6.8	41.6	0.1	< 0.02	321
178	J. Fenters (44)	36N	2E	5	161	MM	7/86	6.6	299	75.3	27.1	4.4	0.5	2.10	< 0.10	323.7	3.2	10.1	0.1	< 0.02	317
179	R. Rogers (43)	36N	2E	16	85	MM	7/86	6.9	398	103.1	34.2	8.1	1.4	< 0.10	< 0.10	343.8	16.8	51.0	0.1	5.77	427
180	R. Vater (27)	36N	2E	32	190	MM	7/86	7.3	304	80.6	24.9	4.3	0.6	3.40	< 0.10	297.8	5.1	12.9	0.1	< 0.02	311
181	Lakeville 1	36N	2E	34	84	MM	6/83	7.4	346	96.0	26.0	10.0	1.3	0.36	0.09	264.0	29.0	74.0	0.2	0.10	395
181	Lakeville 2	36N	2E	35	85	MM	6/77	7.5	294	72.0	28.0	4.0	0.8	0.89	0.08	232.0	6.0	50.0	0.2	< 0.10	295
182	D. Drake (41)	35N	2E	1	44	NAP	7/86	7.2	220	56.5	19.3	3.3	0.3	0.20	0.10	133.5	13.5	85.5	0.1	< 0.02	259
183	H. Dunning (42)	36N	3E	17	97	NAP	7/86	7.1	327	85.3	27.7	4.6	0.5	2.00	0.30	309.4	5.8	50.1	0.2	< 0.02	362
184*	M. Fox (39)	36N	3E	26	145	NAP	7/86	7.5	68	18.0	5.6	74.2	0.9	0.30	< 0.10	234.4	2.0	< 0.1	1.2	< 0.02	243
185	D. Carbiener (40)	35N	3E	5	130	NAP	7/86	7.7	271	79.0	17.8	7.5	0.5	6.00	0.10	283.6	6.3	< 0.1	0.2	< 0.02	287
186	R. Eberhart (SJ7)	36N	4E	29	153	NAP	6/85	8.6	259	59.6	25.8	21.5	0.9	2.10	< 0.10	326.3	5.0	< 0.1	0.5	< 0.02	312
	MARSHALL COUNTY																				
187	M. Shaw (29)	35N	1E	23	114	MM	7/86	6.4	241	59.6	22.4	9.2	0.6	0.10	0.20	239.6	4.7	< 0.1	0.2	< 0.02	241
188	E. Hostetler (28)	35N	1E	35	30	MM	7/86	6.7	315	84.5	25.2	52.7	2.4	< 0.10	< 0.10	243.0	120.0	27.5	0.3	2.50	461
189	Jellystone Park - Resort (33)	34N	1E	27	98	MM	7/86	7.5	452	98.6	50.0	4.2	0.8	1.60	0.10	376.5	6.4	103.0	0.1	< 0.02	491
190	B. Ballinger (9)	33N	1E	8	99	MM	7/86	7.7	236	64.2	18.4	3.1	0.4	0.80	< 0.10	204.5	7.5	20.0	0.1	< 0.02	237
191	R. Suseland (155)	33N	1E	16	123	MM	8/86	7.2	228	57.1	20.8	7.7	0.5	0.50	< 0.10	245.0	7.4	3.7	0.1	< 0.02	245

Appendix 12. Results of chemical analysis from selected water wells completed in unconsolidated deposits — Continued

Location Number	Well Owner	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCo_3$	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCo_3$[2]	Chloride	Sulfate	Fluoride	Nitrate as Nitrogen	Total Dissolved Solids[3]
192X	S. Ulery (154)	32N	1E	4	81	MM	8/86	7.4	390	108.4	29.0	23.3	1.7	0.30	0.20	302.5	51.7	86.6	0.1	1.59	484
195	B & O RR	35N	2E	27	156	NAP	5/56	7.8	275	69.0	25.0	5.9	0.7	4.50	0.04	271.0	2.0	8.8	0.1	0.54	279
196*	R. Kaser (26)	35N	2E	M5	40	MM	7/86	7.5	2	0.6	0.2	203.1	0.6	< 0.10	< 0.10	321.2	23.4	102.0	< 0.1	< 0.02	523
197	J. Batcho (32)	34N	2E	18	42	MM	7/86	7.8	290	78.0	23.2	3.0	0.5	0.60	0.10	245.9	8.5	46.3	< 0.1	< 0.02	308
198	D. Koontz (16)	34N	2E	27	134	MM	7/86	6.8	233	56.4	22.5	16.4	0.8	0.90	< 0.10	273.8	3.2	< 0.1	0.3	< 0.02	265
199	Schlosser Dairy	33N	2E	4	54	MM	8/54	7.9	350	84.0	34.0	12.0	1.4	2.10	0.03	257.0	17.0	93.0	0.0	0.11	398
200	R. Peterson (31)	33N	2E	6	NA	MM	10/87	7.3	250	69.8	18.4	2.2	0.3	2.80	0.20	163.4	17.9	75.5	0.1	< 0.02	291
201	Plymouth 2B	33N	2E	M13	187	MM	5/77	7.6	319	82.0	28.0	4.0	1.0	1.60	0.34	284.0	4.0	34.0	0.2	0.10	326
201	Plymouth 1	33N	2E	M13	192	MM	5/77	7.4	319	82.0	28.0	4.0	1.0	1.50	0.33	281.0	4.0	34.0	0.2	< 0.10	324
202	L. Klingerman (30)	33N	2E	M14	135	MM	7/86	7.9	312	84.8	24.3	2.9	0.5	1.10	0.20	269.3	7.6	48.9	0.1	< 0.02	332
203	W. Ralston (13)	33N	2E	17	78	MM	7/86	7.7	279	76.4	21.3	2.7	0.6	3.50	0.20	219.5	7.5	58.1	0.1	< 0.02	302
204	H. Berger (12)	32N	2E	5	26	MM	7/86	7.8	273	79.2	18.4	2.2	8.7	< 0.10	< 0.10	235.7	13.2	18.3	0.2	9.82	291
205	M. Corey (11)	32N	2E	7	117	MM	7/86	8.4	301	82.8	22.9	3.9	0.4	4.80	0.10	280.2	7.5	22.9	0.2	< 0.02	314
206	Argos 2	32N	2E	12	143	MM	9/80	7.5	312	82.0	26.0	7.0	1.0	1.80	0.03	298.0	7.0	25.0	0.4	< 0.10	329
206	Argos 1	32N	2E	12	148	MM	9/80	7.3	368	95.0	32.0	11.0	0.9	1.70	0.04	330.0	13.0	44.0	0.9	< 0.10	396
207	P. Nifong (14)	32N	2E	19	148	MM	7/86	7.5	315	88.2	22.9	2.9	0.5	1.10	0.10	275.0	4.0	33.0	0.2	< 0.02	318
208	E. Hughes (10)	32N	2E	23	176	MM	7/86	6.8	305	82.1	24.3	9.3	0.6	1.10	< 0.10	324.1	2.7	2.7	0.3	< 0.02	318
209	J. Rader (25)	35N	3E	19	72	NAP	7/86	7.6	247	63.0	21.9	8.5	0.6	0.90	< 0.10	222.5	4.2	39.0	0.3	< 0.02	272
210	Bremen 5	35N	3E	34	126	NAP	3/82	7.4	260	61.0	26.0	21.0	1.4	1.10	< 0.02	300.0	5.0	< 5.0	0.7	< 0.10	296
210	Bremen 3	35N	3E	27	157	NAP	3/82	7.4	262	64.0	25.0	20.0	1.3	1.00	< 0.02	278.0	16.0	7.0	0.6	0.80	303
210	Bremen 4	35N	3E	34	153	NAP	3/82	7.8	260	62.0	25.0	24.0	1.4	1.10	0.02	300.0	9.0	< 5.0	0.7	0.70	304
211	Clay Products	34N	3E	10	75	NAP	6/55	7.7	286	68.0	28.0	12.0	0.5	3.50	0.00	300.0	2.5	0.7	0.6	0.05	296
212	J. Taylor (19)	34N	3E	28	26	NAP	7/86	7.7	209	58.0	15.7	6.9	5.5	0.70	0.40	149.5	6.1	67.4	0.2	< 0.02	251
213	R. Filson (15)	33N	3E	8	116	NAP	7/86	7.6	215	58.5	16.8	8.9	0.4	2.00	0.20	232.8	2.4	< 0.1	0.5	< 0.02	230
214	Pla Mor Campground (24)	35N	4E	30	71	Nap	7/86	7.6	372	99.5	30.0	14.1	0.5	2.20	0.10	292.1	32.7	62.3	0.2	< 0.02	417
215X	J. Rowe (20)	34N	4E	17	74	NAP	7/86	7.8	290	76.9	23.8	7.1	0.5	0.80	0.40	267.0	4.7	31.5	0.3	< 0.02	306
216	J. Lemler (18)	34N	4E	28	56	NAP	10/86	7.4	309	89.1	21.1	6.9	0.3	0.80	< 0.10	260.7	5.1	80.1	0.2	< 0.02	368
217	E. Gochenour (17)	33N	4E	19	48	NAP	7/86	7.5	455	127.5	33.1	5.0	0.9	0.40	0.30	281.3	24.3	140.0	0.1	2.07	502

Appendix 12. Results of chemical analysis from selected water wells completed in unconsolidated deposits — Continued

Location Number	Well Owner	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCo_3$	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCo_3$[2]	Chloride	Sulfate	Fluoride	Nitrate as Nitrogen	Total Dissolved Solids[3]
									ELKHART COUNTY												
219	W. Harter (SJ5)	35N	4E	1	125	NAP	6/85	8.2	295	74.7	25.6	12.7	0.8	1.90	<0.10	340.4	3.1	<0.1	0.5	<0.02	324
220	E. Bolt (38)	35N	4E	15	27	NAP	7/86	7.7	254	67.9	20.6	4.4	0.4	<0.10	<0.10	177.6	12.9	40.4	0.2	7.09	260
221	Nappanee 2A	35N	4E	36	164	NAP	6/82	7.7	330	87.0	27.0	11.0	1.0	1.50	0.03	338.0	5.0	5.0	0.5	0.10	341
221	Napannee 1	35N	4E	36	154	NAP	6/82	7.8	318	88.0	24.0	11.0	1.1	1.60	0.02	336.0	5.0	5.0	0.5	0.10	338
221	Nappanee 2	35N	4E	36	150	NAP	1/75	7.7	320	81.0	28.0	10.0	1.0	2.20	0.04	334.0	2.0	1.0	0.5	0.10	326
222	R. Hahn (SJ16)	35N	5E	17	185	NAP	6/85	7.9	363	91.7	32.2	7.6	0.6	0.80	<0.10	379.7	1.7	27.6	0.4	<0.02	390
223	R. Hahn (SJ15)	35N	5E	18	140	NAP	6/85	7.9	307	74.5	28.8	12.5	0.7	1.20	<0.10	363.5	1.3	<0.1	0.7	<0.02	338
									KOSCIUSKO COUNTY												
224	G. Flowers (21)	34N	4E	1	51	NAP	7/86	7.3	377	99.3	31.5	5.5	0.5	0.40	0.10	269.3	13.5	90.1	0.2	<0.02	403
225	R. Hoffer (SJ36)	34N	5E	6	65	NAP	6/85	7.3	356	91.0	31.2	4.3	0.5	0.30	0.20	243.9	17.9	111.0	0.3	<0.02	403
226	D. Hartzell (22)	34N	5E	30	140	NAP	7/86	7.7	284	84.4	17.8	3.8	0.4	0.90	<0.10	227.1	4.5	52.3	0.2	<0.02	300
227	E. Kuhns (23)	34N	5E	31	44	NAP	7/86	7.9	304	90.3	19.0	4.3	0.7	<0.10	0.20	180.8	21.7	85.8	<0.1	1.75	332

[1]Results in standard pH units.
[2]Laboratory analysis
[3]TDS values are the sum of major constituents expected in an anhydrous residue of a ground-water sample with bicarbonate converted to carbonate in the solid phase.

Appendix 13. Results of chemical analysis from selected bedrock water wells

{All values in milligrams per liter except as indicated.}

Location Number: *, analysis of softened water; -, anomalous analysis (epm balance error > 5%); X, Indiana Department of Environmental Management volatile organic and pesticide sampling site; #, incomplete analysis.

Well owner: F&W, Fish and Wildlife; Jasp, Jasper County; Lk, Lake County; New, Newton County; Obs, Observation; Prud, Prudential; Pul, Pulaski County; Subd, Subdivision; USGS, United States Geological Survey; (133), sample number for data collected in joint Division of Water and Indiana Geological Survey Study. Data collected summer and fall, 1986, except where prefixed by SJ (St. Joseph River Basin) and LM (Lake Michigan Basin).

Township: N, North.

Range: E, East; W, West.

Aquifer system: D2, Devonian Antrim shale; Dm, Devonian/Mississippian New Albany shale; dM, Devonian/Mississippian Ellsworth shale; M1, Mississippian Borden group; SD, Silurian (S3)/Devonian (D1) carbonates; +SD, Silurian (S3)/Devonian (D1) carbonates overlain by Devonian/Mississippian shale; und., undetermined.

Date sampled: month and year

Location Number	Well Owner	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as CaCo3	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as CaCo3[2]	Chloride	Sulfate	Fluoride	Nitrate as Nitrogen	Total Dissolved Solids[3]
										LAKE COUNTY											
1	J. Henning (112)	32N	10W	1	132	SD	8/86	7.2	316	80.6	27.9	20.3	0.8	0.10	<0.10	336.2	2.1	24.6	0.3	<0.02	359
2	Buchmeier (110)	35N	9W	31	202	SD	8/86	7.4	303	66.5	33.2	34.4	2.1	0.10	<0.10	383.6	12.0	16.4	0.5	<0.02	396
3	St. John 2	35N	9W	33	280	SD	11/78	7.2	602	112.0	78.0	51.0	5.0	1.90	0.02	464.0	4.0	220.0	0.5	<0.10	751
3	St. John 1	35N	9W	33	277	SD	11/78	7.2	610	114.0	79.0	48.0	5.0	1.90	0.02	460.0	6.0	230.0	0.4	<0.10	760
3	St. John 3	34N	9W	5	150	SD	11/82	7.6	431	86.0	52.0	75.0	7.5	1.10	<0.02	415.0	<5.0	190.0	0.6	<0.10	661
4	J. Stanko	34N	9W	20	243	SD	5/62	7.0	385	80.0	45.0	35.0	8.6	0.36	0.06	380.0	3.5	69.0	0.6	2.40	473
5	Utilities, Inc. 4	34N	9W	21	302	SD	5/76	7.5	464	104.0	50.0	20.0	5.0	1.70	<0.02	396.0	2.0	100.0	0.4	<0.10	521
6	H. Mackey (104)	34N	9W	26	199	SD	8/86	7.4	484	109.6	51.2	71.6	4.2	0.30	<0.10	426.5	13.6	224.0	0.4	<0.02	731
7	Lake Shore Subd1	34N	9W	27	273	SD	8/61	7.6	353	78.0	39.0	36.0	6.0	0.80		394.0	2.0	30.0	0.1	0.00	428
8	Utilities, Inc. 2	34N	9W	28	216	SD	7/61	7.7	382	84.0	42.0	28.0	5.0	1.10	0.00	388.0	3.0	63.0	0.3	0.90	460
9	Lowell 4	33N	9W	13	397	SD	5/82	8.3	37	12.0	2.0	420.0	8.8	0.16	0.02	524.0	240.0	78.0	8.0	<0.10	1086
10	N. Cumming	33N	9W	16	703	SD	5/55	7.8	48	11.0	4.9	111.0	5.3	0.19	0.00	246.0	7.0	39.0	1.6	0.02	328

Appendix 13. Results of chemical analysis from selected bedrock water wells — Continued

Location Number	Well Owner	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCo_3$	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCo_3$[2]	Chloride	Sulfate	Fluoride	Nitrate as Nitrogen	Total Dissolved Solids[3]
LAKE COUNTY — Continued																					
11	Lowell 3	33N	9W	23	280	SD	6/87	7.9	119	27.0	12.0	140.0	5.7	0.07	<0.02	332.0	41.0	62.0	2.9		490
11	Lowell 2	33N	9W	23	300	SD	5/82	7.7	67	18.0	6.0	180.0	5.4	0.58	0.02	336.0	47.0	44.0	5.7	0.10	509
11	Lowell 1	33N	9W	23	285	SD	12/75	8.2	96	21.0	11.0	170.0	8.0	0.10	0.02	348.0	57.0	52.0	3.5	0.10	532
12X	J. Bruce (107)	32N	9W	16	57	SD	8/86	7.3	339	87.6	29.3	26.6	1.3	<0.10	<0.10	308.2	28.2	<0.1	0.1	<0.02	424
13-	USGS LK12 (189)	32N	9W	32	82	SD	10/86	8.0	157	39.9	14.1	65.7	1.6	0.90	<0.10	265.0	1.6	<0.1	0.8	<0.02	284
14	Schneider 2	32N	9W	34	200	SD	10/73	7.5	248	56.0	26.0	62.0	6.0	0.20	<0.02	296.0	38.0	46.0	0.7	1.40	414
15	C. Ebert (93)	33N	8W	21	169	SD	7/86	6.7	234	58.0	21.6	107.3	3.5	<0.10	<0.10	375.2	35.4	5.9	1.1	<0.02	458
16	Van Deursen (105)	33N	8W	32	76	SD	8/86	7.3	300	68.9	31.1	23.7	1.2	0.30	<0.10	356.8	9.9	<0.1	0.2	<0.02	355
17	E. Fraikin (108)	32N	8W	16	90	SD	8/86		334	106.9	16.3	69.8	3.5	3.90	0.40	274.4	66.6	161.0	0.3	0.59	594
18-	R. Mathis (109)	32N	8W	28	406	SD	8/86	7.5	280	70.3	25.3	108.4	4.3	<0.10	<0.10	256.4	278.0	45.7	0.6	<0.02	686
19	J. Little 2	32N	7W	5	291	SD	3/81	7.6	352	90.0	31.0	60.0	6.0	0.60	0.03	316.0	110.0	6.0	0.2	<0.10	493
NEWTON COUNTY																					
20	T. Schuster (133)	31N	10W	25	427	SD	8/86	7.4	167	43.6	14.2	31.2	1.2	0.10	<0.10	207.2	7.9	9.3	0.7	<0.02	232
21	USGS New11 (190)	30N	10W	13	150	SD	10/86	7.6	58	14.5	5.2	59.8	0.9	0.10	<0.10	178.6	2.4	<0.1	0.8	<0.02	191
22	Prudential 40	30N	10W	24	360	SD	7/85	7.1	147	34.0	15.0	53.0	1.2	0.13	<0.05	160.0	30.0	58.0	<0.5	<0.50	287
23	N. Johnson (141)	29N	10W	25	170	SD	8/86	7.5	103	26.7	8.9	71.7	1.2	0.20	<0.10	223.9	21.6	<0.1	0.8	<0.02	266
24	A.Saxton	27N	10W	35	100	M1	5/62	7.5	90	20.0	9.9	100.0	3.8	0.41	0.07	264.0	2.0	40.0	0.6	0.09	335
25	Kankakee St. Park	31N	9W	4	128	SD	8/56	7.5	191	47.0	18.0	80.0	3.4	0.36	0.00	279.0	65.0	2.0	0.6	0.02	384
26	USGS New14 (187)	31N	9W	8	153	SD	10/86	7.6	123	32.2	10.3	58.1	2.0	0.10	<0.10	240.1	7.1	<0.1	1.0	<0.02	255
27	Prudential 30	31N	9W	35	600	SD	7/85	7.5	194	43.0	21.0	71.0	5.5	<0.10	<0.05	283.0	27.0	3.0	0.9	<0.50	341
113-	USGS News (186)	30N	9W	2	150	SD	10/86	7.7	167	45.8	12.8	79.8	1.6	0.80	<0.05	219.9	29.3	1.6	1.0	0.61	305
28	Prudential 37	30N	9W	9	505	SD	7/85	7.3	183	42.0	19.0	56.0	4.6	<0.10	<0.05	266.0	32.0	2.0	0.8	<0.50	316
29	Prudential 46	30N	9W	12	550	SD	7/85	7.5	191	42.0	21.0	78.0	4.6	<0.10	<0.05	294.0	28.0	11.0	0.8	<0.50	362
30#	North Vernon HS	30N	9W	23	260	SD	8/65	7.6	166			90.0		0.08		317.0	33.0	20.0			389
31	USGS New7 (184)	30N	9W	32	150	SD	10/86	7.8	99	25.4	8.6	69.2	1.2	0.50	<0.10	223.2	15.9	<0.1	0.8	<0.02	256
32	V. Elijah (113)	28N	9W	2	294	+SD	8/86	7.7	54	12.4	5.7	262.2	8.6	<0.10	<0.10	513.4	120.0	1.3	2.3	<0.02	720
33	G. Best	28N	9W	8	196	+SD	5/60	7.6	82	15.0	11.0	197.0	8.6	0.24	0.05	448.0	38.0	9.0	0.5	0.00	548
34-	Standish 2(149)	28N	9W	23	140	+SD	10/87	7.8	200	50.7	18.0	40.0	1.4	<0.10	<0.10	304.8	10.0	<0.1	0.5	<0.02	311
35	J. Pierson (121)	31N	8W	11	112	SD	8/86	6.4	122	32.6	9.9	29.1	0.8	<0.10	<0.10	178.8	4.4	<0.1	0.8	<0.02	185

Appendix 13. Results of chemical analysis from selected bedrock water wells — Continued

Location Number	Well Owner	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCo_3$	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCo_3$[2]	Chloride	Sulfate	Fluoride	Nitrate as Nitrogen	Total Dissolved Solids
NEWTON COUNTY — Continued																					
36	W. Eck (173)	31N	8W	29	130	SD	8/86	7.8	201	50.3	18.4	61.7	1.9	0.60	<0.10	327.4	18.2	<0.1	0.5	<0.02	348
37-	Prudential 8	31N	8W	35	639	SD	7/85	7.0	385	95.0	36.0	19.0	4.5	0.15	<0.05	371.0	9.0	6.0	<0.5		392
38	Prudential 28	30N	8W	4	400	SD	7/85	7.2	305	68.0	33.0	36.0	3.6	0.22	<0.05	334.0	11.0	2.0	0.5	<0.50	355
39#	Prohosky	30N	8W	9	95	SD	8/84	7.8	260			41.0	2.9			320.0	12.0	14.0	0.6	<0.10	
40	Prudential 10	30N	8W	11	349	SD	7/85	7.1	305	76.0	28.0	21.0	2.5	0.13	0.05	288.0	14.0	54.0	<0.5	<0.50	368
41-	Prudential 26	30N	8W	12	528	SD	7/85	7.4	271	59.0	30.0	28.0	5.4	0.11	<0.05	276.0	2.6	92.0	0.8	<0.50	383
42	Prudential 15	30N	8W	13	455	SD	7/85	7.2	297	68.0	31.0	35.0	5.1	0.11	<0.05	286.0	26.0	55.0	0.9	<0.50	393
43-	Prudential 11	30N	8W	14	372	SD	7/85	7.0	243	53.0	27.0	33.0	3.9	<0.10	<0.05	267.0	18.0	59.0	0.7	<0.50	355
44	G. Schultz (116)	30N	8W	19	108	SD	8/86	7.4	199	50.2	17.8	81.8	2.1	0.20	<0.10	321.9	33.9	<0.1	0.5	<0.02	380
45	Prudential 17	30N	8W	25	585	SD	7/85	7.4	125	27.0	14.0	45.0	4.7	0.21	<0.05	194.0	4.0	30.0	1.0	<0.50	242
46	B. Summers	29N	8W	2	100	SD	7/85	7.5	184	36.0	23.0	81.0	6.6	<0.10	<0.05	284.0	14.0	63.0	0.9	<0.50	395
47	M. Miller	29N	8W	20	160	SD	9/84	8.3	174	39.0	18.0	64.0	9.4	0.08	0.03	246.0	9.0	54.0	1.0	<0.10	342
48	T. Garrison	29N	8W	20	227	+SD	8/84	7.5	220	48.0	24.0	58.0	12.0	0.14	<0.02	300.0	11.0	63.0	1.0	<0.10	397
49	R. Zak (172)	29N	8W	36	138	SD	8/86	8.1	209	54.5	17.8	38.7	1.0	1.00	<0.10	255.0	10.4	41.9	0.4	<0.02	319
50	Goodland 2	27N	8W	14	160	+SD	6/82	7.6	104	25.0	10.0	190.0	8.7	0.11	0.02	400.0	95.0	28.0	1.3	0.10	598
50	Goodland 1	27N	8W	14	185	+SD	6/82	6.8	100	22.0	11.0	190.0	8.7	0.28	0.02	396.0	95.0	29.0	1.3	0.10	595
51	Larsen (147)	27N	8W	17	230	und.	8/86	7.6	28	6.0	3.2	203.8	3.4	<0.10	<0.10	439.1	4.0	2.1	1.5	<0.02	487
52	R. Bower (145)	27N	8W	36	200	M1	8/86	7.0	64	17.2	5.2	209.3	5.3	<0.10	<0.10	470.7	14.5	66.9	1.6	<0.02	602
BENTON COUNTY																					
53	G. Hamilton (136)	25N	10W	13	95	M1	8/86	7.0	364	93.8	31.5	56.0	1.7	1.20	<0.10	288.7	1.6	181.7	0.4	<0.02	541
54	A Wetli (140)	26N	9W	10	120	M1	8/86	6.7	242	56.2	24.6	42.5	2.1	0.20	<0.10	318.0	2.3	20.9	1.0	<0.02	341
55	M. Bennett (139)	26N	9W	14	300	M1	8/86	7.3	284	71.9	25.4	20.5	1.4	<0.10	<0.10	272.1	4.7	48.4	0.2	<0.02	336
56	L. Lanie (134)	26N	9W	19	140	M1	8/86	7.1	141	37.4	11.5	69.3	1.7	0.40	<0.10	257.2	1.8	36.8	0.7	<0.02	314
57	Earl Park	26N	9W	23	185	M1	3/82	7.5	242	58.0	24.0	48.0	3.6	1.00	0.04	291.0	<5.0	49.0	0.5	0.40	359
58X	J. Hawkins(135)	25N	9W	6	320	M1	8/86	6.6	250	60.1	24.4	107.0	3.6	0.10	<0.10	311.1	2.5	166.8	0.3	<0.02	551
59	Schlutnhofr (146)	26N	8W	3	50	M1	8/86	7.2	166	41.2	15.4	60.7	3.5	0.20	<0.10	314.0	1.2	<0.1	0.6	<0.02	311
60	M. Moore (138)	26N	8W	36	178	M1	8/86	6.6	416	108.5	35.4	14.6	1.2	1.50	0.10	315.7	30.7	91.0	0.2	<0.02	473
61	B. Gick (119)	25N	8W	8	100	M1	8/86	7.2	260	60.6	26.4	37.3	1.7	1.00	<0.10	308.1	1.8	15.4	0.5	<0.02	330
62	G. Martin (143)	26N	7W	3	60	M1	8/86	6.6	337	84.8	30.4	12.8	0.9	2.10	<0.10	355.9	9.4	8.7	0.4	<0.02	363

Appendix 13. Results of chemical analysis from selected bedrock water wells — Continued

Location Number	Well Owner	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCo_3$	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCo_3$[2]	Chloride	Sulfate	Fluoride	Nitrate as Nitrogen	Total Dissolved Solids[3]
JASPER COUNTY																					
63	Dekoch Farm	31N	7W	27	315	SD	9/71	7.3	316	89.0	23.0	8.0	1.0	0.10	0.05	318.0	2.0	5.0	0.4	0.90	320
64	R. Kolhagen 1	30N	7W	1	598	SD	8/56	7.3	425	121.0	30.0	11.0	3.0	0.71	0.00	443.0	2.3	2.3	0.3	0.30	437
65	Prudential 7	30N	7W	7	475	SD	7/85	7.4	167	44.0	14.0	18.0	1.6	<0.10	<0.05	173.0	8.0	27.0	0.6	<0.50	217
66	Prudential 1	30N	7W	17	350	SD	7/85	7.4	208	44.0	24.0	46.0	6.0	0.15	<0.05	277.0	9.0	20.0	0.9	<0.50	316
67	Prud Jasp11 OBS	30N	7W	18	630	SD	6/81	7.5	180	41.0	18.0	30.0	3.6	0.05	0.01	210.0	8.4	17.0	0.6	0.72	245
68	Randolph Estate	30N	7W	21	91	SD	8/82	6.8	314	80.0	28.0	32.0	6.5	0.06	<0.02	338.0	10.0	45.0	0.6	<0.10	405
69	USGS Jasp12 (192)	30N	7W	22	150	SD	10/86	7.5	201	47.1	20.4	61.9	4.7	<0.10	<0.10	258.1	5.3	91.3	1.1	<0.02	387
70	B.Webb	30N	7W	23	169	SD	8/82	7.1	366	91.0	34.0	41.0	6.2	0.06	<0.02	286.0	17.0	170.0	0.6	<0.10	531
72	B. Stephenson 2	30N	7W	27	120	SD	7/85	7.2	112	25.0	12.0	39.0	2.1	0.34	<0.05	183.0	1.0	4.0	1.0	<0.50	194
72	B. Stephenson	30N	7W	27	116	SD	7/85	7.5	135	31.0	14.0	42.0	3.6	<0.10	<0.05	199.0	3.0	20.0	1.0	<0.50	234
74	E. Kosta	30N	7W	29	105	SD	7/85	7.4	262	59.0	28.0	42.0	9.7	<0.10	<0.05	303.0	10.0	43.0	0.8	<0.50	374
75	A. Brinkman	30N	7W	31	95	SD	8/85	7.6	162	37.0	17.0	50.0	4.5	<0.10	<0.05	232.0	4.0	40.0	1.0	<0.50	293
76	B. Callahan	30N	7W	31	125	SD	8/85	7.5	170	37.0	19.0	52.0	5.9	<0.10	<0.05	258.0	6.0	40.0	1.0	<0.50	316
77	R. Prohosky	30N	7W	32	96	SD	7/85	7.8	100	22.0	11.0	63.0	5.0	<0.10	<0.05	198.0	2.0	25.0	1.0	<0.50	248
78	W. Conley	30N	7W	33	100	SD	7/85	7.4	105	24.0	11.0	60.0	5.9	<0.10	<0.05	210.0	4.0	5.0	1.0	<0.50	237
79	E. Prohosky	29N	7W	5	125	SD	7/85	7.6	126	24.0	16.0	76.0	6.5	<0.10	<0.05	186.0	4.0	110.0	1.0	<0.50	349
80	J. Lane 1	29N	7W	6	85	SD	8/85	7.5	99	23.0	10.0	52.0	2.6	0.16	<0.05	188.0	1.0	11.0	1.0	<0.50	214
81	USGS Jasp13 (191)	29N	7W	9	150	SD	10/86	6.6	102	24.7	9.9	72.8	3.1	<0.10	<0.10	236.1	1.7	11.9	1.2	<0.02	267
82	Rensselaer 3	29N	7W	25	355	SD	4/84	7.4	492	126.0	43.0	44.0	3.2	0.38	0.11	352.0	52.0	147.0	0.4	0.30	628
83	H. Putnam (127)	28N	7W	8	102	+SD	8/86	7.4	252	70.5	18.5	7.2	0.5	1.30	<0.10	265.5	2.9	2.2	0.3	<0.02	263
84	F. Steinkamp (142)	28N	7W	33	110	DM	8/86	7.2	119	29.4	11.1	55.8	3.2	<0.10	<0.10	240.5	9.6	<0.1	1.2	<0.02	255
85#	Carson Inn 1	27N	7W	1	250	+SD	4/71	7.5	294	77.0	25.0			0.01	0.00	330.0	51.0	0.0	0.5		440
86	G. Pettet (122)	27N	7W	5	205	+SD	8/86	6.8	98	21.8	10.5	243.7	6.7	<0.10	<0.10	483.7	87.8	<0.1	1.1	<0.02	662
87X	D. Bledsoe (124)	27N	7W	15	219	+SD	8/86	7.5	310	72.4	31.4	72.3	3.9	1.40	<0.10	347.0	23.8	107.0	0.2	<0.02	521
88	Hamstra Bldr (96)	32N	6W	26	75	SD	8/86	7.9	313	90.2	21.3	31.9	0.6	2.10	0.20	157.6	110.0	77.8	<0.1	<0.02	429
89	Pfledderer (98)	31N	6W	9	42	SD	8/86	7.5	241	67.9	17.4	7.1	0.6	0.10	0.20	133.3	11.1	98.6	<0.1	<0.02	283
90	USGS Jasp9 (194)	31N	6W	21	260	SD	10/86	7.5	104	30.4	6.8	14.7	0.4	0.20	<0.10	137.5	0.5	<0.1	0.8	<0.02	136
91-	M. Risner (100)	30N	6W	6	90	SD	8/86	7.1	175	51.5	11.3	49.7	1.0	0.70	<0.10	225.7	3.7	10.9	0.8	<0.02	265
92-	R. Bozell (176)	29N	6W	4	200	SD	10/87	7.5	240	57.6	23.5	39.8	3.1	<0.10	<0.10	337.6	3.7	29.5	0.4	<0.02	367

Appendix 13. Results of chemical analysis from selected bedrock water wells — Continued

Location Number	Well Owner	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCO_3$	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCO_3$[2]	Chloride	Sulfate	Fluoride	Nitrate as Nitrogen	Total Dissolved Solids[3]
JASPER COUNTY — Continued																					
93	D. Parkinson (131)	29N	6W	12	42	SD	8/86	6.6	583	161.1	43.8	46.7	13.4	< 0.10	0.30	252.6	42.5	258.6	< 0.1	27.77	746
94X	R. Sayler (132)	29N	6W	20	90	SD	8/86	6.6	356	85.2	34.9	41.3	3.2	< 0.10	< 0.10	310.0	39.6	112.0	0.6	< 0.02	503
95X	F. Taylor (130)	29N	6W	26	130	SD	8/86	6.6	472	117.8	43.2	7.5	2.8	0.10	0.10	310.0	17.6	140.1	0.2	2.32	518
96	Rensselaer 1	29N	6W	30	550	SD	11/82	7.4	406	98.0	39.0	32.0	2.7	0.09	0.04	336.0	33.0	85.0	0.3	0.30	492
96	Rensselaer 2	29N	6W	30	553	SD	4/84	7.4	376	89.0	37.0	29.0	2.5	0.51	< 0.02	336.0	16.0	78.0	0.4	0.30	454
97	K. Howard (125)	28N	6W	20	45	DM	8/86	7.1	291	68.6	29.2	14.6	5.8	< 0.10	< 0.10	343.3	3.1	< 0.1	0.6	< 0.02	328
98	M. Carlisle	27N	6W	5	94	DM	5/60	7.3	708	173.0	67.0	70.0	5.9	0.61	0.02	490.0	84.0	232.0	0.2	0.05	927
99	Fairview Htchry	27N	6W	31	192	+SD	5/55	7.4	270	58.0	31.0	94.0	7.2	0.08	0.00	431.0	14.0	23.0	0.4	0.05	486
100	USGS Jasp7 (193)	31N	5W	15	130	+SD	10/86	7.6	62	14.4	6.4	114.6	5.8	< 0.10	< 0.10	302.1	4.4	< 0.1	1.4	< 0.02	328
101	J. Klein (177)	31N	5W	30	83	D2	10/87	7.6	89	23.8	7.2	81.9	2.2	< 0.10	< 0.10	267.6	1.5	< 0.1	1.0	< 0.02	284
102	W. Gerhing	30N	5W	9	260	SD	6/56	7.0	200	47.0	20.0	85.0	6.9	0.10	0.00	263.0	39.0	77.0	1.2	0.00	434
103	J. Stevens (178)	30N	5W	11	205	SD	10/87	7.9	136	33.9	12.6	37.7	0.9	< 0.10	0.10	222.6	0.5	< 0.1	1.0	< 0.02	229
104X	E. Corbin (62)	30N	5W	20	95	SD	7/86	7.9	167	41.1	15.7	47.0	1.9	< 0.10	< 0.10	242.3	8.3	29.0	0.7	< 0.02	289
105	D. Tillett (60)	29N	5W	3	82	SD	7/86	6.5	513	141.3	39.0	14.8	10.0	< 0.10	0.30	372.6	20.1	145.0	0.3	4.11	598
106-	C. Schleman (180)	28N	5W	18	27	SD	8/86	7.9	332	86.5	28.3	8.1	0.4	< 0.10	0.10	290.7	23.7	92.2	0.1	< 0.02	414
WHITE COUNTY																					
107-	Hasslebring (101)	27N	6W	1	80	DM	10/87	7.8	328	85.0	28.2	30.7	5.2	< 0.10	0.10	316.3	23.2	88.6	0.4	2.26	468
107-	Hasslebring (182)	27N	6W	1	228	+SD	10/86	7.8	280	61.5	30.9	675.0	20.0	0.10	0.10	469.2	695.0	622.0	3.1	< 0.02	2429
STARKE COUNTY																					
108X	D. Germann (63).	32N	4W	29	172	+SD	7/86	7.3	115	25.9	12.1	184.7	6.4	< 0.10	< 0.10	511.4	38.2	2.6	2.0	< 0.02	579
109	N. Judson 3	32N	3W	17	198	+SD	6/75	8.5	120	34.0	9.0	23.0	3.0	0.20	< 0.02	152.0	3.0	3.0	0.8	< 0.10	177
109	N. Judson 2	32N	3W	17	197	+SD	10/77	7.7	101	28.0	8.0	17.0	1.0	0.10	< 0.02	127.0	3.0	2.0	0.8	0.50	138
110	M. Koenig (6)	33N	2W	19	126	+SD	7/86	9.1	126	30.0	12.5	24.9	1.2	< 0.10	< 0.10	180.3	2.0	< 0.1	1.0	< 0.02	180

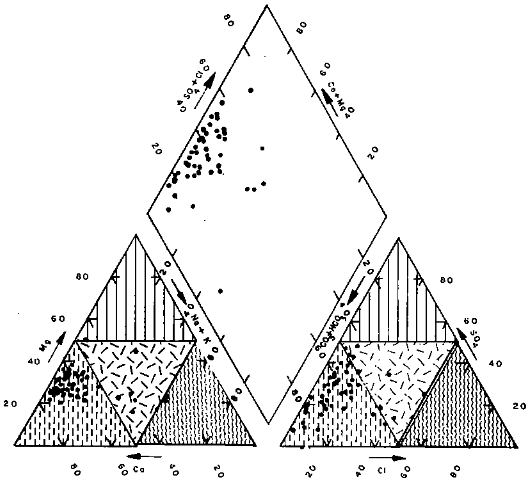
Appendix 13. Results of chemical analysis from selected bedrock water wells — Continued

Location Number	Well Owner	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCo_3$	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCo_3$[2]	Chloride	Sulfate	Fluoride	Nitrate as Nitrogen	Total Dissolved Solids[3]
PULASKI COUNTY																					
111	Jasp Pul F&W (58)	31N	4W	18	70	D2	7/86	7.7	102	29.8	6.7	16.6	0.8	< 0.10	< 0.10	126.1	5.2	15.7	0.6	< 0.02	151
LAPORTE COUNTY																					
112	In Hwy. Dept.	35N	4W	31	184	DM	3/57	7.7	87	17.0	10.0	211.0	8.7	0.07	0.03	266.0	193.0	2.4	1.1	0.20	603

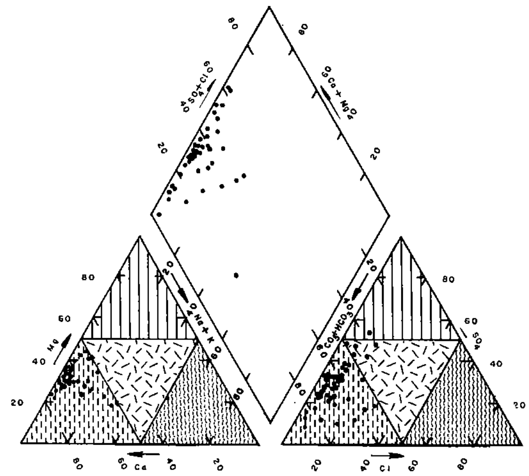
[1]Results in standard pH units.
[2]Laboratory analysis.
[3]TDS values are the sum of major constituents expected in an anhydrous residue of a ground water sample with bicarbonate converted to carbonate in the solid phase.

Appendix 14. Piper trilinear diagrams of ground-water quality data for major aquifer systems

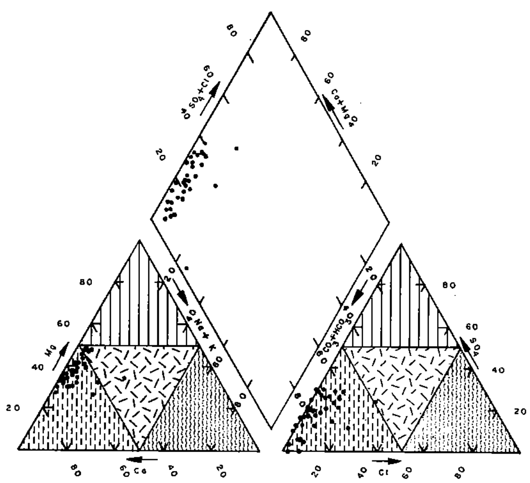
KANKAKEE (KK)



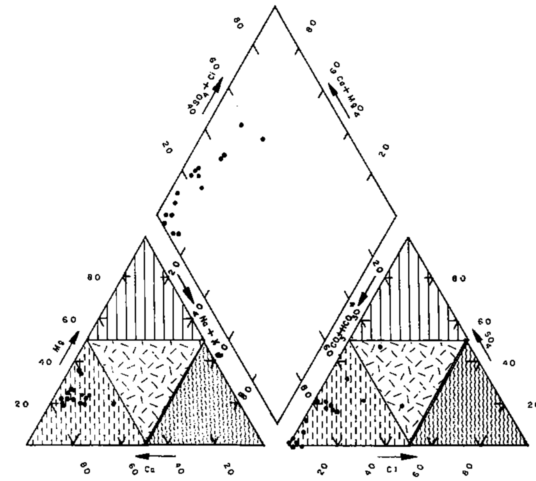
VALPARAISO OUTWASH APRON (VOA)



VALPARAISO MORAINE (VM)



EOLIAN SANDS (ES)



EXPLANATION

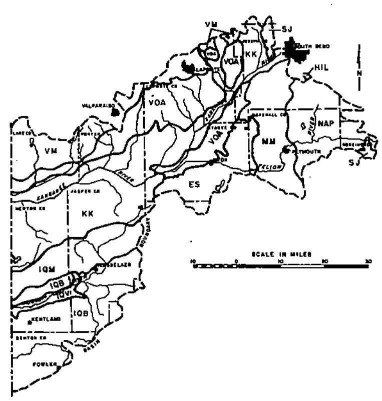
UNCONSOLIDATED AQUIFER SYSTEMS

Cation ground-water types

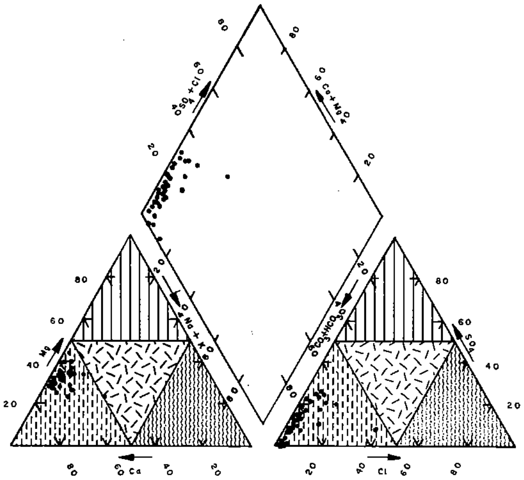
- Magnesium
- Calcium
- Sodium or potassium
- No dominant cation

Anion ground-water types

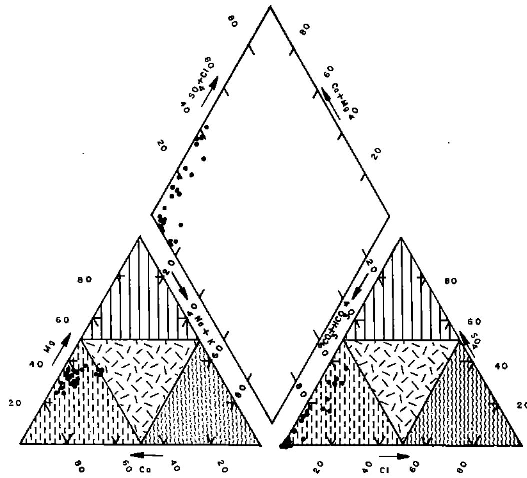
- Sulfate
- Bicarbonate
- Chloride
- No dominant anion



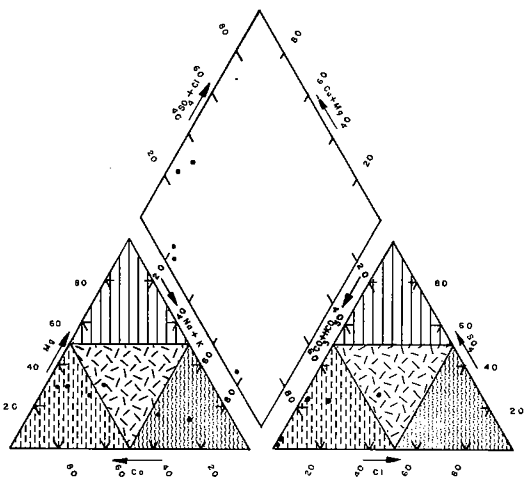
MAXINKUCKEE MORAINE (MM)



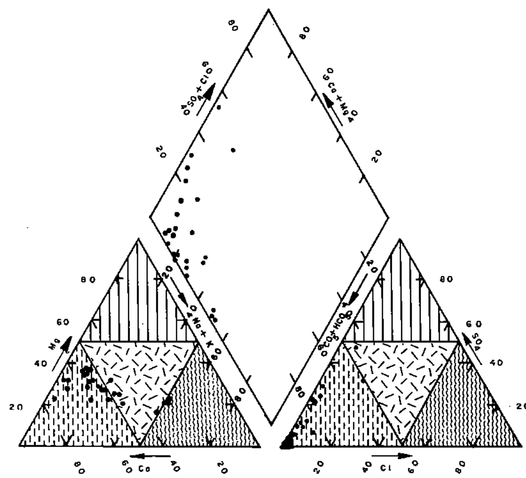
NAPPANEE (NAP)



IROQUOIS MORAINE (IQM)



IROQUOIS BASIN (IQB) AND
IROQUOIS VALLEY (IQV)



EXPLANATION

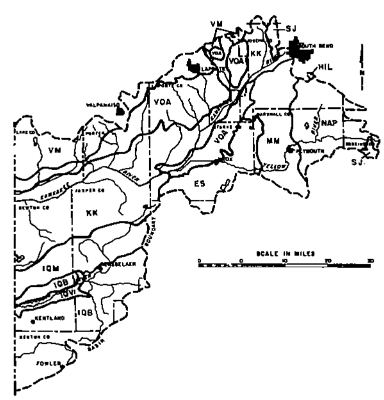
UNCONSOLIDATED AQUIFER SYSTEMS

Cation ground-water types

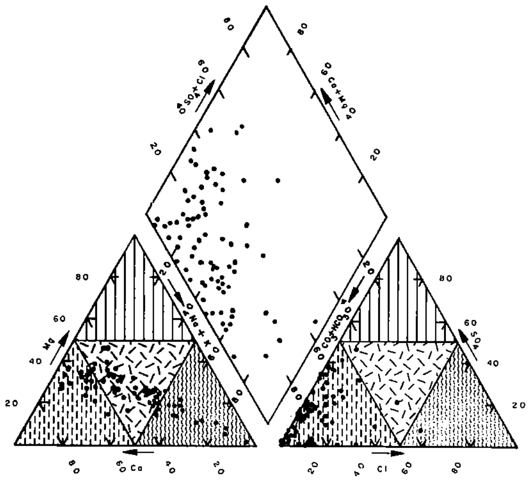
- Magnesium
- Calcium
- Sodium or potassium
- No dominant cation

Anion ground-water types

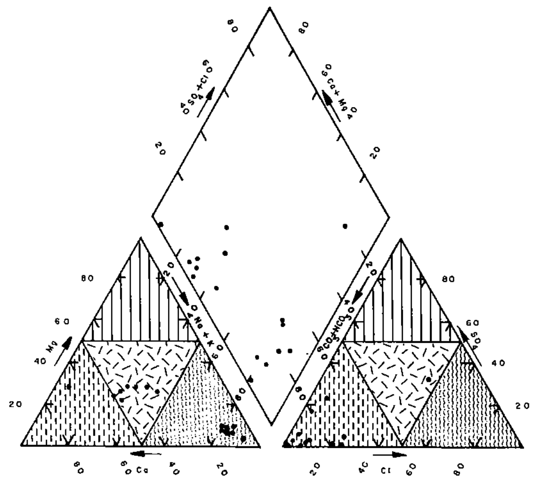
- Sulfate
- Bicarbonate
- Chloride
- No dominant anion



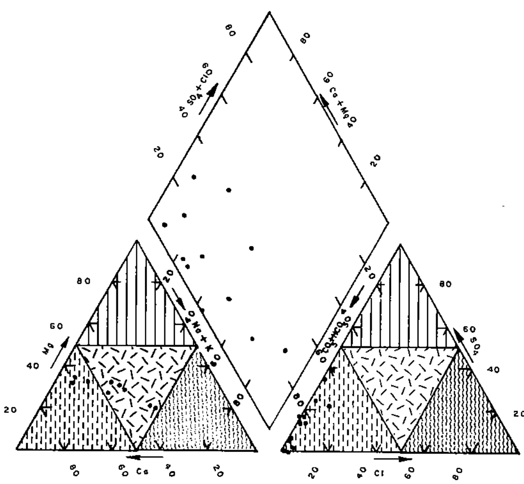
SILURIAN (S_3) AND
DEVONIAN (D_1) CARBONATES



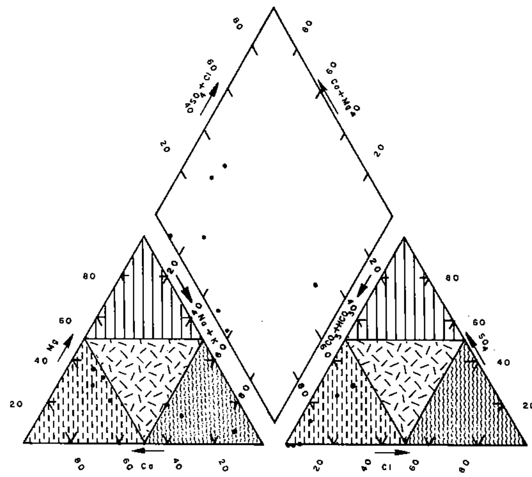
SILURIAN (S_3) AND DEVONIAN (D_1)
CARBONATES OVERLAIN BY DEVONIAN OR
DEVONIAN AND MISSISSIPPIAN SHALE



MISSISSIPPIAN BORDEN GROUP (M_1)



DEVONIAN (D_2) AND DEVONIAN AND
MISSISSIPPIAN (dM, Dm) SHALE



EXPLANATION

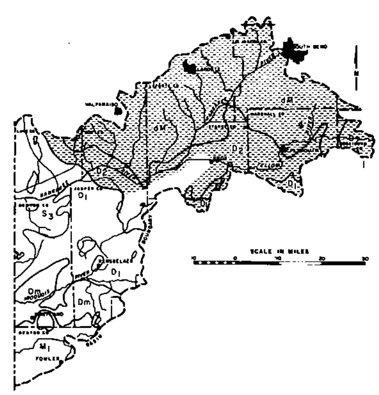
BEDROCK AQUIFER SYSTEMS

Cation ground-water types

- Magnesium
- Calcium
- Sodium or potassium
- No dominant cation

Anion ground-water types

- Sulfate
- Bicarbonate
- Chloride
- No dominant anion



Appendix 15. Annual water withdrawal capability and use for all categories combined

{All values in million gallons per day. Totals may not equal sum of county totals because of differences in rounding.}

County	Year	No. of facilities	Withdrawal capability			Reported use		
			Ground water	Surface water	Combined	Ground water	Surface water	Combined
Benton	1986	2	1.66	0.00	1.66	0.60	0.00	0.60
	1987	2	1.66	0.00	1.66	0.23	0.00	0.23
	1988	2	1.66	0.00	1.66	0.26	0.00	0.26
Elkhart	1986	1	0.43	0.00	0.43	0.04	0.00	0.04
	1987	1	0.43	0.00	0.43	0.04	0.00	0.04
	1988	1	0.43	0.00	0.43	0.04	0.00	0.04
Jasper	1986	110	82.74	164.09	246.82	5.04	15.37	20.41
	1987	112	83.17	173.88	257.04	4.85	19.86	24.71
	1988	119	87.35	285.06	372.41	7.94	29.70	37.63
Kosciusko	1986	2	1.66	0.00	1.66	0.04	0.00	0.04
	1987	2	1.66	0.00	1.66	0.06	0.00	0.06
	1988	2	1.66	0.00	1.66	0.11	0.00	0.11
Lake	1986	79	23.89	390.74	414.63	2.14	6.68	8.83
	1987	81	26.41	392.18	418.59	2.24	3.89	6.14
	1988	83	27.25	406.58	433.84	3.83	9.79	13.62
LaPorte	1986	101	82.29	186.62	268.91	9.06	6.05	15.10
	1987	102	82.20	189.50	271.70	8.27	2.86	11.13
	1988	105	82.95	206.21	289.16	10.78	5.97	16.75
Marshall	1986	36	26.78	20.12	46.90	2.82	0.22	3.04
	1987	36	27.21	20.12	47.33	3.10	0.19	3.28
	1988	37	27.93	19.54	47.48	3.55	0.55	4.10
Newton	1986	58	51.71	71.86	123.56	3.59	1.15	4.74
	1987	57	51.81	70.42	122.22	2.81	0.98	3.79
	1988	56	53.27	79.06	132.32	6.11	1.58	7.68
Porter	1986	30	19.45	31.20	50.66	3.73	1.91	5.64
	1987	30	19.45	31.20	50.66	3.67	1.52	5.19
	1988	33	20.89	34.44	55.34	3.83	3.44	7.27
Pulaski	1986	6	1.51	7.42	8.93	0.01	0.08	0.10
	1987	4	1.51	2.52	4.03	0.02	0.04	0.05
	1988	5	2.66	2.52	5.18	0.18	0.12	0.30
St. Joseph	1986	73	81.56	54.65	136.21	8.08	3.84	11.92
	1987	73	81.56	54.65	136.21	8.54	4.09	12.63
	1988	73	82.39	54.36	136.75	11.15	7.70	18.86
Starke	1986	34	24.81	32.14	56.94	1.06	0.69	1.75
	1987	32	24.20	29.74	53.94	1.17	0.39	1.57
	1988	34	24.13	39.82	63.95	2.03	1.29	3.32
White	1986	1	1.20	0.00	1.20	0.00	0.00	0.00
	1987	1	1.20	0.00	1.20	0.08	0.00	0.08
	1988	1	1.20	0.00	1.20	0.08	0.00	0.08
Total	1986	533	399.68	958.83	1358.50	36.20	36.00	72.20
	1987	533	402.47	964.21	1366.21	35.08	33.82	68.90
	1988	551	413.77	1127.59	1541.38	49.87	60.14	110.00

Appendix 16. Annual water withdrawal capability and seasonal use for irrigation category

{All values in million gallons per day. Totals may not equal sum of county totals because of differences in rounding. Reported use is averaged for 90-day irrigation season.}

County	Year	No. of facilities	Withdrawal capability			Reported use		
			Ground water	Surface water	Combined	Ground water	Surface water	Combined
Jasper	1986	102	73.06	101.45	174.51	14.91	3.11	18.02
	1987	104	73.49	111.24	184.73	13.81	13.90	27.71
	1988	111	77.67	135.07	212.74	25.59	43.83	69.42
Kosciusko	1986	2	1.66	0.00	1.66	0.16	0.00	0.16
	1987	2	1.66	0.00	1.66	0.23	0.00	0.23
	1988	2	1.66	0.00	1.66	0.43	0.00	0.43
Lake	1986	74	18.59	390.74	409.34	3.06	27.11	30.17
	1987	75	18.59	392.18	410.78	1.99	15.79	17.78
	1988	76	19.11	403.27	422.39	7.55	36.76	44.31
LaPorte	1986	82	54.13	162.00	216.13	11.88	15.51	27.39
	1987	84	54.13	164.88	219.01	10.25	11.21	21.46
	1988	87	54.89	181.58	236.47	20.59	23.66	44.25
Marshall	1986	27	14.09	19.40	33.49	1.11	0.34	1.45
	1987	27	14.52	19.40	33.92	1.65	0.75	2.40
	1988	28	14.52	19.54	34.06	2.22	2.85	5.08
Newton	1986	50	46.89	20.45	67.34	11.89	4.68	16.57
	1987	49	46.89	19.01	65.90	8.86	3.30	12.16
	1988	48	48.35	27.65	76.00	21.83	5.15	26.98
Porter	1986	23	9.83	20.66	30.50	0.88	5.94	6.82
	1987	23	9.83	20.66	30.50	0.92	4.53	5.45
	1988	26	11.27	23.90	35.18	1.89	10.44	12.34
Pulaski	1986	6	1.51	7.42	8.93	0.05	0.34	0.39
	1987	4	1.51	2.52	4.03	0.07	0.15	0.22
	1988	5	2.66	2.52	5.18	0.73	0.51	1.23
St. Joseph	1986	52	37.97	46.73	84.69	7.39	7.81	15.20
	1987	52	37.97	46.73	84.69	6.95	8.19	15.14
	1988	51	37.32	46.44	83.76	12.41	22.39	34.80
Starke	1986	28	18.92	32.14	51.06	1.61	2.79	4.40
	1987	26	18.32	29.74	48.05	1.95	1.60	3.55
	1988	28	18.24	39.82	58.06	4.93	5.23	10.16
Total	1986	446	276.65	801.00	1076.65	52.95	67.62	120.57
	1987	446	276.91	806.36	1083.27	46.68	59.41	106.09
	1988	462	285.69	879.79	1165.50	98.17	150.82	249.00

Appendix 17. Annual water withdrawal capability and use for energy production and industrial categories

{All values in million gallons per day. Values are for industrial use unless denoted as energy production (EP). Totals may not equal sum of county totals because of differences in rounding.}

County	Year	No. of facilities	Withdrawal capability			Reported use		
			Ground water	Surface water	Combined	Ground water	Surface water	Combined
Elkhart	1986	1	0.43	0.00	0.43	0.04	0.00	0.04
	1987	1	0.43	0.00	0.43	0.04	0.00	0.04
	1988	1	0.43	0.00	0.43	0.04	0.00	0.04
Jasper	1986	3	0.32	2.16	2.48	0.00	1.34	1.34
	1987	2	0.14	2.16	2.30	0.01	1.34	1.35
	1988	2	0.14	2.16	2.30	0.14	1.34	1.48
Jasper (EP)	1986	1	3.35	60.48	63.82	0.30	13.26	13.56
	1987	1	3.35	60.48	63.82	0.34	15.08	15.43
	1988	1	3.35	60.48	63.83	0.35	17.58	17.93
LaPorte	1986	4	2.40	21.02	23.42	0.03	1.57	1.60
	1987	4	2.42	21.02	23.45	0.05	0.10	0.15
	1988	4	2.42	21.02	23.45	0.03	0.15	0.18
LaPorte (EP)	1986	2	3.18	0.00	3.18	0.53	0.00	0.53
	1987	2	3.18	0.00	3.18	0.60	0.00	0.60
	1988	2	3.18	0.00	3.18	0.56	0.00	0.56
Marshall	1986	4	2.79	0.72	3.51	0.20	0.14	0.34
	1987	4	2.79	0.72	3.51	0.27	0.00	0.27
	1988	4	3.51	0.00	3.51	0.24	0.00	0.24
Newton	1986	1	0.00	5.33	5.33	0.00	0.00	0.00
	1987	1	0.00	5.33	5.33	0.00	0.17	0.17
	1988	1	0.00	5.33	5.33	0.00	0.31	0.31
Porter	1986	1	0.72	0.00	0.72	0.01	0.00	0.01
	1987	1	0.72	0.00	0.72	0.01	0.00	0.01
	1988	1	0.72	0.00	0.72	0.01	0.00	0.01
St. Joseph	1986	4	5.04	7.63	12.67	0.62	1.92	2.54
	1987	4	5.04	7.63	12.67	0.87	2.07	2.94
	1988	5	6.52	7.63	14.16	0.88	2.19	3.08
St. Joseph(EP)	1986	3	12.86	0.00	12.86	4.94	0.00	4.94
	1987	3	12.86	0.00	12.86	5.13	0.00	5.13
	1988	3	12.86	0.00	12.86	4.03	0.00	4.03
Starke	1986	2	0.59	0.00	0.59	0.01	0.00	0.01
	1987	2	0.59	0.00	0.59	0.01	0.00	0.01
	1988	2	0.59	0.00	0.59	0.01	0.00	0.01
Total	1986	20	12.29	36.86	49.15	0.91	4.97	5.88
	1987	19	12.13	36.86	49.00	1.25	3.69	4.94
	1988	20	14.33	36.14	50.49	1.35	3.99	5.35
Total (EP)	1986	6	19.39	60.48	79.86	5.77	13.26	19.03
	1987	6	19.39	60.48	79.86	6.06	15.08	21.15
	1988	6	19.39	60.48	79.87	4.94	17.58	22.52

Appendix 18. Annual water withdrawal capability and use for public supply category

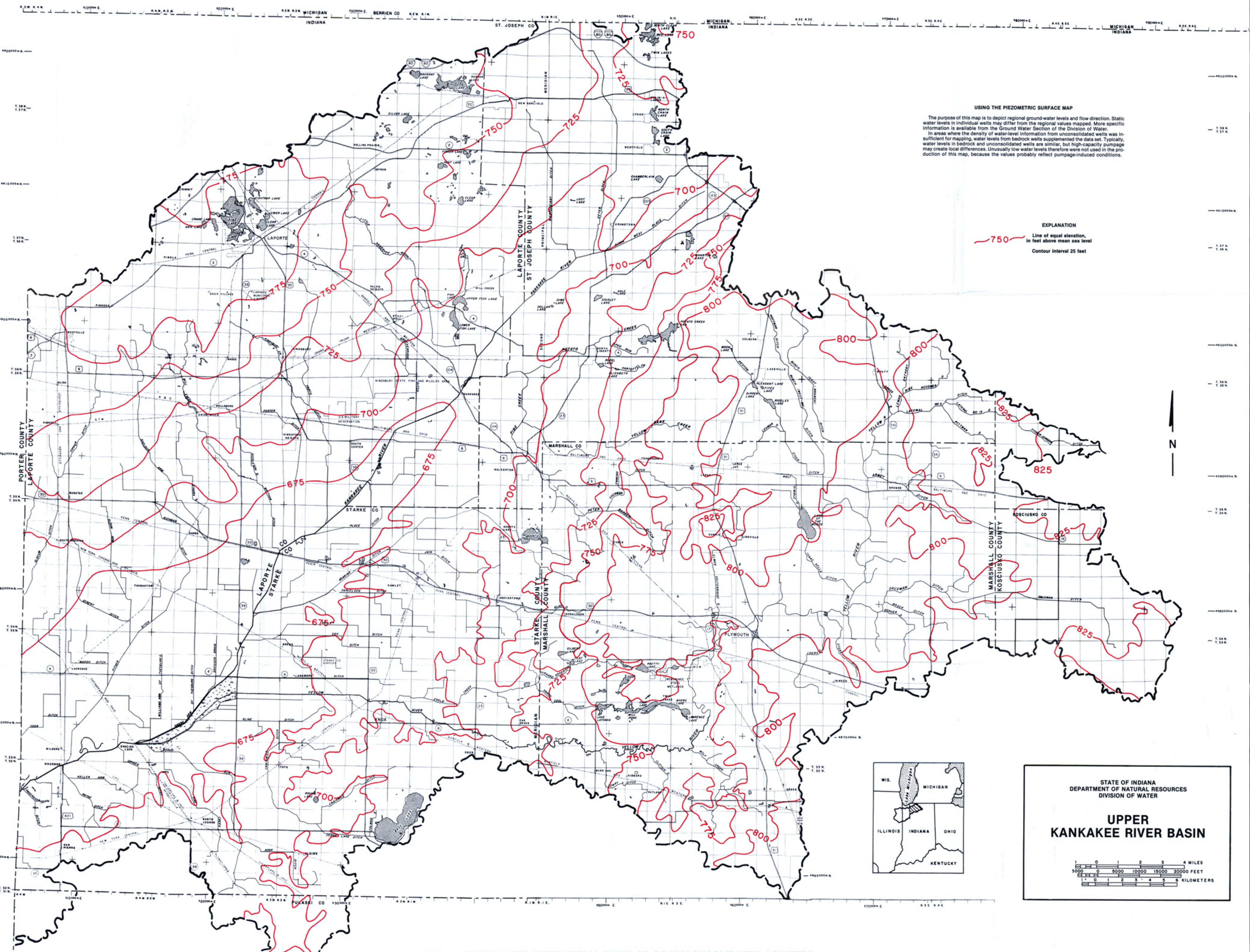
{All values in million gallons per day. Totals may not equal sum of county totals because of differences in rounding.}

County	Year	No. of facilities	Withdrawal capability			Reported use		
			Ground water	Surface water	Combined	Ground water	Surface water	Combined
Benton	1986	2	1.66	0.00	1.66	0.60	0.00	0.60
	1987	2	1.66	0.00	1.66	0.23	0.00	0.23
	1988	2	1.66	0.00	1.66	0.26	0.00	0.26
Jasper	1986	4	6.01	0.00	6.01	1.06	0.00	1.06
	1987	4	6.01	0.00	6.01	1.10	0.00	1.10
	1988	4	6.01	0.00	6.01	1.15	0.00	1.15
Lake	1986	5	5.30	0.00	5.30	1.39	0.00	1.39
	1987	6	7.82	0.00	7.82	1.75	0.00	1.75
	1988	6	8.14	0.00	8.14	1.97	0.00	1.97
LaPorte	1986	11	20.79	0.00	20.79	4.87	0.00	4.87
	1987	10	20.68	0.00	20.68	4.43	0.00	4.43
	1988	10	20.68	0.00	20.68	4.48	0.00	4.48
Marshall	1986	5	9.90	0.00	9.90	2.34	0.00	2.34
	1987	5	9.90	0.00	9.90	2.42	0.00	2.42
	1988	5	9.90	0.00	9.90	2.61	0.00	2.61
Newton	1986	6	4.82	0.00	4.82	0.66	0.00	0.66
	1987	6	4.82	0.00	4.82	0.62	0.00	0.62
	1988	6	4.82	0.00	4.82	0.74	0.00	0.74
Porter	1986	5	8.61	10.54	19.15	3.44	0.45	3.89
	1987	5	8.61	10.54	19.15	3.38	0.40	3.78
	1988	5	8.61	10.54	19.15	3.30	0.87	4.16
St. Joseph	1986	13	25.37	0.29	25.66	0.70	0.00	0.70
	1987	13	25.37	0.29	25.66	0.83	0.00	0.83
	1988	13	25.37	0.29	25.66	3.19	0.00	3.19
Starke	1986	4	5.29	0.00	5.29	0.66	0.00	0.66
	1987	4	5.29	0.00	5.29	0.69	0.00	0.69
	1988	4	5.29	0.00	5.29	0.81	0.00	0.81
Total	1986	55	87.75	10.83	98.58	15.73	0.45	16.18
	1987	55	90.07	10.83	101.00	15.45	0.40	15.85
	1988	55	90.48	10.83	101.31	18.51	0.87	19.37

Appendix 19. Annual water withdrawal capability and use for rural and miscellaneous categories combined

{All values in million gallons per day. Totals may not equal sum of county totals because of differences in rounding.}

County	Year	No. of facilities	Withdrawal capability			Reported use		
			Ground water	Surface water	Combined	Ground water	Surface water	Combined
Jasper	1986	0	0.00	0.00	0.00	0.00	0.00	0.00
	1987	1	0.18	0.00	0.18	0.00	0.00	0.00
	1988	1	0.18	0.00	0.18	0.00	0.00	0.00
Lake	1986	0	0.00	0.00	0.00	0.00	0.00	0.00
	1987	0	0.00	0.00	0.00	0.00	0.00	0.00
	1988	1	0.00	3.31	3.31	0.00	0.76	0.76
LaPorte	1986	2	1.79	3.60	5.39	0.69	0.65	1.34
	1987	2	1.79	3.60	5.39	0.66	0.00	0.66
	1988	2	1.79	3.60	5.39	0.66	0.00	0.66
Newton	1986	1	0.00	46.08	46.08	0.00	0.00	0.00
	1987	1	0.10	46.08	46.18	0.00	0.00	0.00
	1988	1	0.10	46.08	46.18	0.00	0.00	0.00
Porter	1986	1	0.29	0.00	0.29	0.06	0.00	0.06
	1987	1	0.29	0.00	0.29	0.06	0.00	0.06
	1988	1	0.29	0.00	0.29	0.07	0.00	0.07
St. Joseph	1986	1	0.32	0.00	0.32	0.00	0.00	0.00
	1987	1	0.32	0.00	0.32	0.00	0.00	0.00
	1988	1	0.32	0.00	0.32	0.00	0.00	0.00
White	1986	1	1.20	0.00	1.20	0.00	0.00	0.00
	1987	1	1.20	0.00	1.20	0.08	0.00	0.08
	1988	1	1.20	0.00	1.20	0.08	0.00	0.08
Total	1986	6	3.60	49.68	53.28	0.76	0.65	1.41
	1987	7	3.88	49.68	53.56	0.81	0.00	0.81
	1988	8	3.88	52.99	56.87	0.81	0.76	1.57



USING THE PIEZOMETRIC SURFACE MAP

The purpose of this map is to depict regional ground-water levels and flow direction. Static water levels in individual wells may differ from the regional values mapped. More specific information is available from the Ground Water Section of the Division of Water.

In areas where the density of water-level information from unconsolidated wells was insufficient for mapping, water levels from bedrock wells supplemented the data set. Typically, water levels in bedrock and unconsolidated wells are similar, but high-capacity pumpage may create local differences. Unusually low water levels therefore were not used in the production of this map, because the values probably reflect pumpage-induced conditions.

EXPLANATION

—750— Line of equal elevation, in feet above mean sea level

Contour interval 25 feet

STATE OF INDIANA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATER

UPPER KANKAKEE RIVER BASIN

PLATE 1A. GENERALIZED PIEZOMETRIC SURFACE OF UNCONSOLIDATED AQUIFERS

USING THE PIEZOMETRIC SURFACE MAP

The purpose of this map is to depict regional ground-water levels and flow direction. Static water levels in individual wells may differ from the regional values mapped. More specific information is available from the Ground Water Section of the Division of Water.

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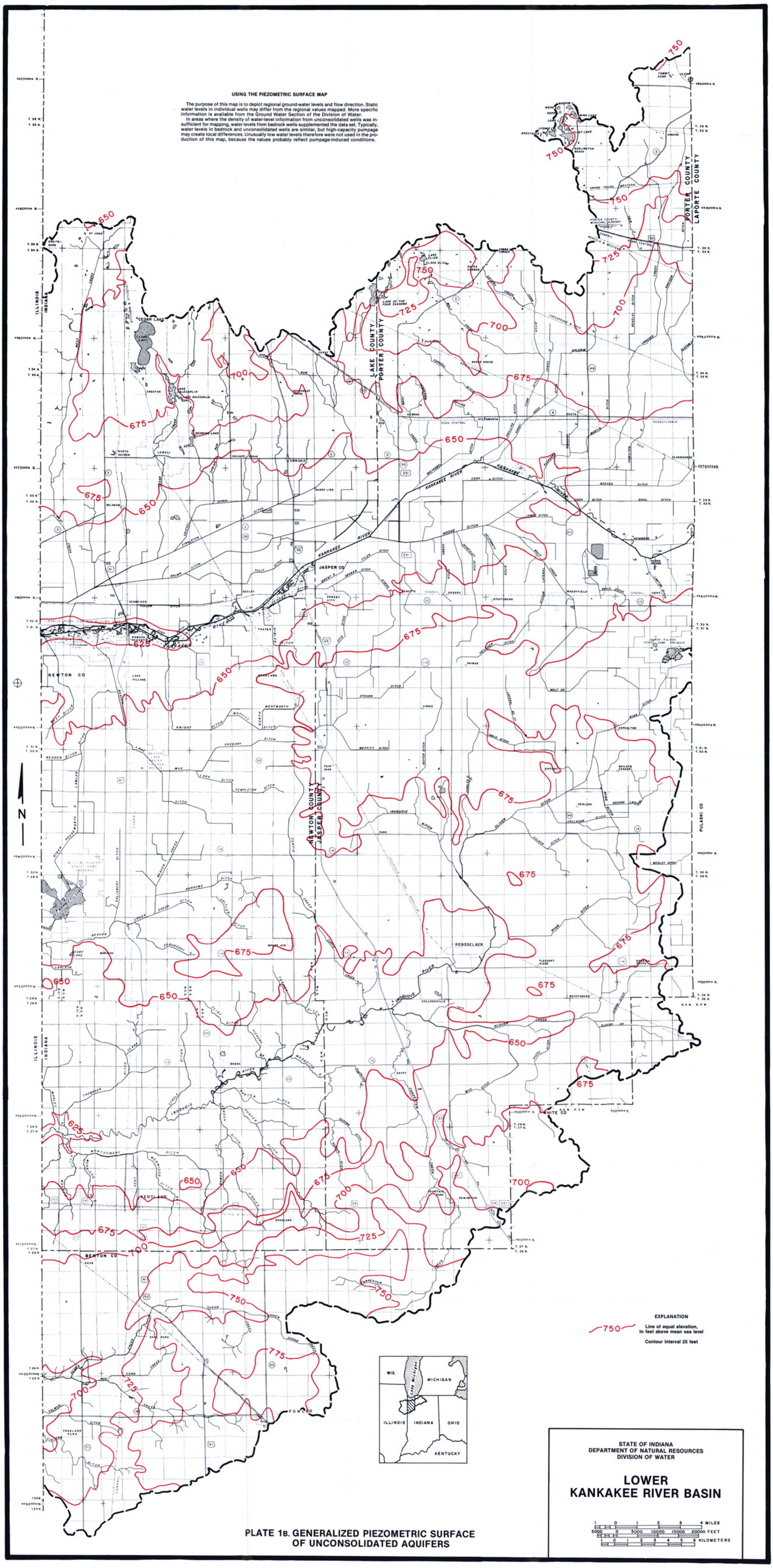


EXPLANATION

750 Line of equal elevation, in feet above mean sea level

Contour interval 25 feet

STATE OF INDIANA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATER

LOWER KANKAKEE RIVER BASIN

1 0 1 2 3 4 MILES
5000 0 5000 10000 15000 20000 FEET
1 0 1 2 3 4 5 6 KILOMETERS

PLATE 1B. GENERALIZED PIEZOMETRIC SURFACE OF UNCONSOLIDATED AQUIFERS

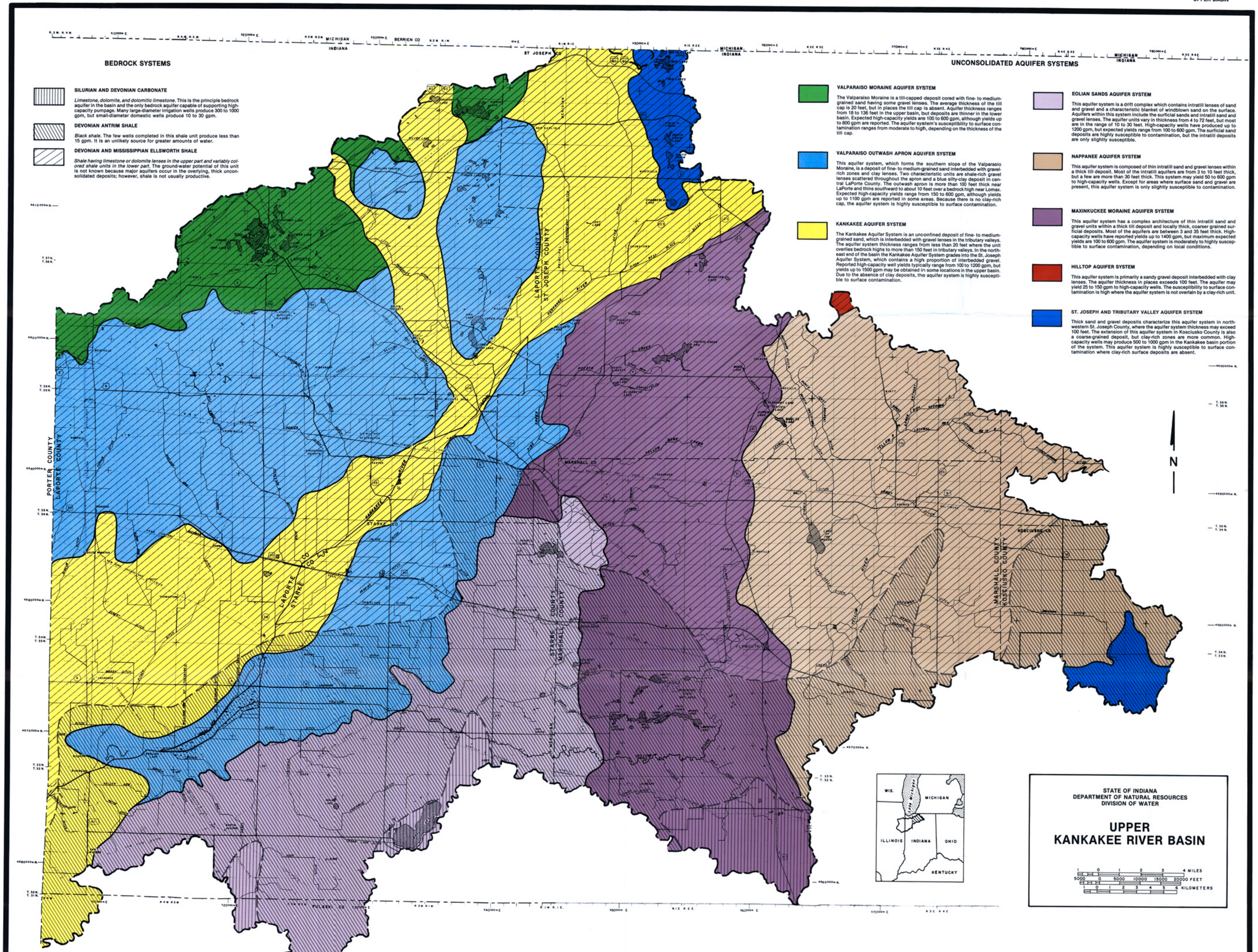


PLATE 2A. UNCONSOLIDATED AND BEDROCK AQUIFER SYSTEMS

UNCONSOLIDATED AQUIFER SYSTEMS

VALPARAISO MORAINE AQUIFER SYSTEM

The Valparaiso Moraine is a till-capped deposit cored with fine- to medium-grained sand having some gravel lenses. The thickness of the morainal deposits decreases westward in the lower basin, and the moraine stratigraphy is most complex in Lake County. Aquifer thickness ranges from 18 to 100 feet in the lower basin, but is greater in the upper basin. Expected high-capacity yields are 100 to 600 gpm, although yields up to 800 gpm are reported. Where overlain by thick till, this aquifer system is only slightly susceptible to surface contamination.

VALPARAISO OUTWASH APRON AQUIFER SYSTEM

This aquifer system, which forms the southern slope of the Valparaiso Moraine, is a deposit of fine- to medium-grained sand having some gravel-rich zones and clay lenses. The gravel commonly is shale-rich. The outwash apron thins southward from the crest of the moraine toward the Kankakee River and the proportion of clay-rich zones increases westward. Expected high-capacity yields range from 150 to 600 gpm, although yields up to 1100 gpm are reported in some areas. The absence of a clay-rich surface deposit makes this aquifer system highly susceptible to surface contamination.

KANKAKEE AQUIFER SYSTEM

The Kankakee Aquifer System is an unconfined deposit composed of fine- to medium-grained sand, which is interbedded with gravel lenses in the tributary valleys. The aquifer system thickness ranges from less than 20 feet where the unit overlies bedrock highs to as much as 65 feet in tributary valleys. The average thickness is about 30 feet. The aquifer system in the lower basin may yield 100 to 500 gpm to high-capacity wells, but yields are higher in the upper basin. This aquifer system is highly susceptible to surface contamination because of the absence of clay-rich deposits.

IROQUOIS MORAINE AQUIFER SYSTEM

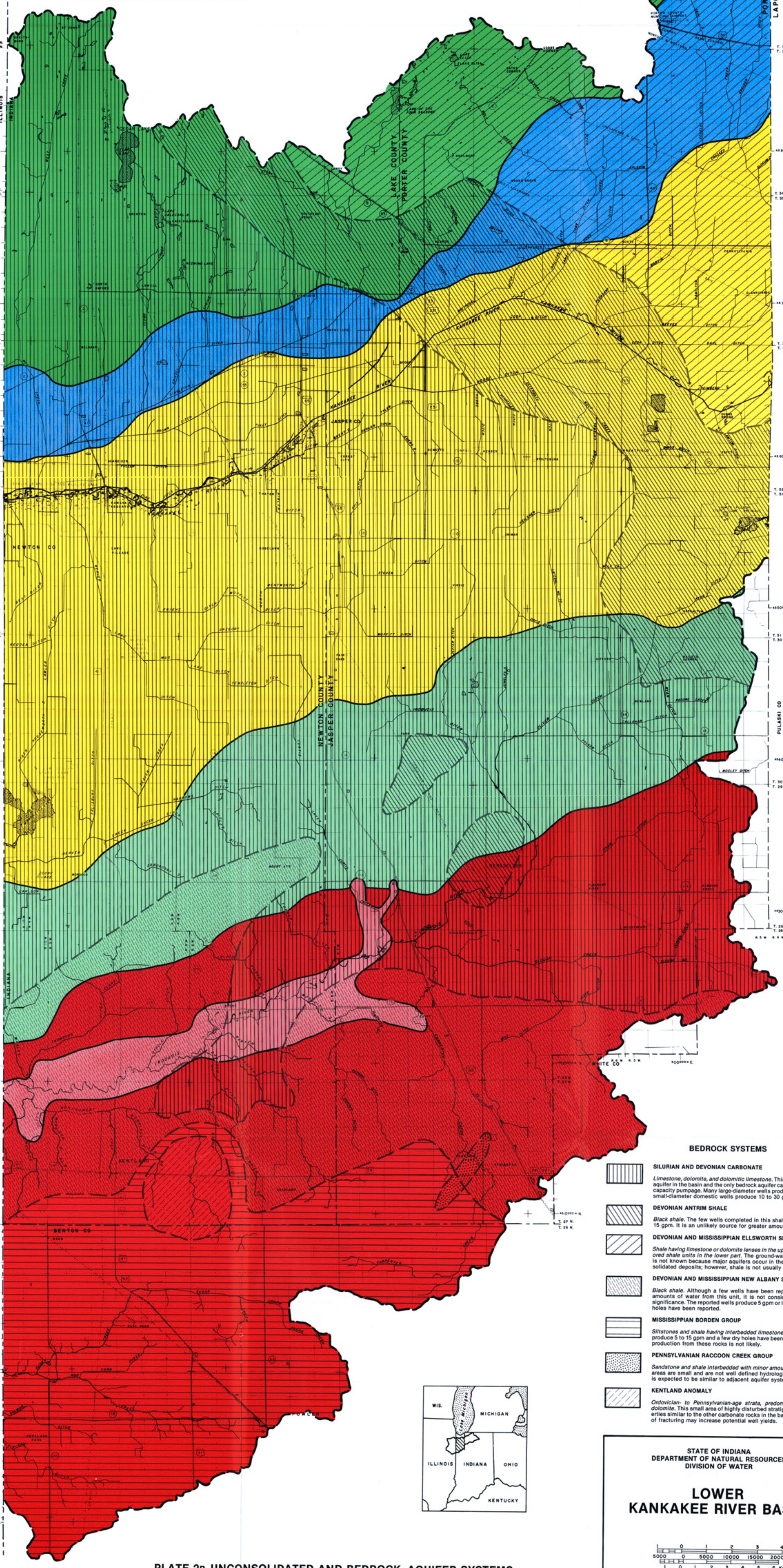
The Iroquois Moraine contains a few thin intratill sand and gravel lenses as aquifer units. The intratill aquifers are usually less than 10 feet thick and yield only quantities of water sufficient for domestic use. Intratill aquifers are only slightly susceptible to surface contamination because of the surrounding till deposits.

IROQUOIS BASIN AQUIFER SYSTEM

This aquifer system is a mostly clay-rich deposit having scattered intratill sand or gravel lenses and isolated surface sands. The thickness of the system, which is largely controlled by the underlying bedrock topography, ranges from 12 to 120 feet. A few flowing wells have been reported in stream valleys. Well yields are adequate for domestic use, and the few thick intratill deposits may yield up to 400 gpm. The surficial sand deposits are highly susceptible to contamination, but the intratill aquifers are moderately susceptible.

IROQUOIS BURIED VALLEY AQUIFER SUBSYSTEM

The subsystem of the Iroquois Basin Aquifer System is a deposit of interbedded till and sand and gravel lenses which occupies a buried valley beneath the main till body. The deposits are found at an elevation between 540 and 590 feet msl, and aquifer thickness ranges from 3 to 40 feet. The aquifer system is only slightly susceptible to surface contamination.



BEDROCK SYSTEMS

SILURIAN AND DEVONIAN CARBONATE

Limestone, dolomite, and dolomitic limestone. This is the principle bedrock aquifer in the basin and the only bedrock aquifer capable of supporting high-capacity pumpage. Many large-diameter wells produce 300 to 1000 gpm, but small-diameter domestic wells produce 10 to 30 gpm.

DEVONIAN ANTRIM SHALE

Black shale. The few wells completed in this shale unit produce less than 15 gpm. It is an unlikely source for greater amounts of water.

DEVONIAN AND MISSISSIPPIAN ELLSWORTH SHALE

Shale having limestone or dolomite lenses in the upper part and variably colored shale units in the lower part. The ground-water potential of this unit is not known because major aquifers occur in the overlying, thick unconsolidated deposits; however, shale is not usually productive.

DEVONIAN AND MISSISSIPPIAN NEW ALBANY SHALE

Black shale. Although a few wells have been reported to produce small amounts of water from this unit, it is not considered an aquifer of any significance. The reported wells produce 5 gpm or less, and a number of dry holes have been reported.

MISSISSIPPIAN BORDEN GROUP

Siltstones and shale having interbedded limestone lenses. Wells generally produce 5 to 15 gpm and a few dry holes have been reported. High-capacity production from these rocks is not likely.

PENNSYLVANIAN RACCOON CREEK GROUP

Sandstone and shale interbedded with minor amounts of limestone. These areas are small and are not well defined hydrologically. Water availability is expected to be similar to adjacent aquifer systems.

KENTLAND ANOMALY

Ordovician- to Pennsylvanian-age strata, predominantly limestone and dolomite. This small area of highly disturbed stratigraphy has aquifer properties similar to the other carbonate rocks in the basin, yet the high degree of fracturing may increase potential well yields.

STATE OF INDIANA
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DIVISION OF WATER

LOWER KANKAKEE RIVER BASIN

1 0 1 2 3 4 MILES
5000 0 5000 10000 15000 20000 FEET
1 0 1 2 3 4 5 6 KILOMETERS

PLATE 2B. UNCONSOLIDATED AND BEDROCK AQUIFER SYSTEMS