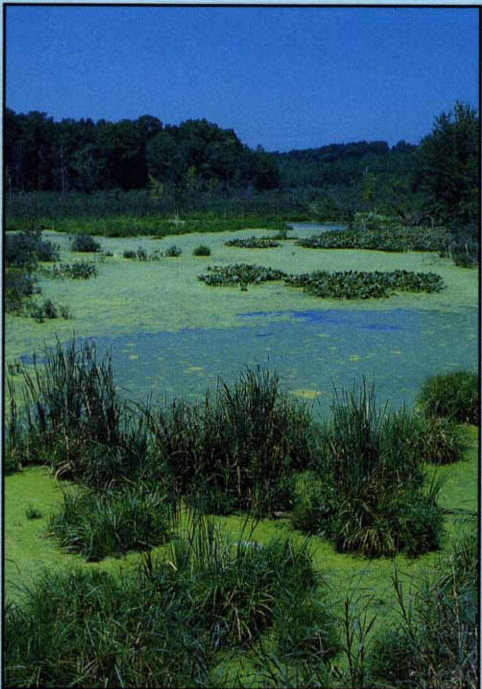
WATER RESOURCE AVAILABILITY IN THE ST. JOSEPH RIVER BASIN, INDIANA



STATE OF INDIANA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATER

1987

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Water Resource Assessment 87-1

Printed By Authority of the State of Indiana
Indianapolis, Indiana: 1987

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SELECTED LIST OF ACRONYMNS AND ABBREVIATIONS

FDA	Food and Drug Administration
GWRSC	Governor's Water Resource Study Commission
IAC	Indiana Administrative Code
IC	Indiana Code
IDNR	Indiana Department of Natural Resources
IDEM	Indiana Department of Environmental Management
MACOG	Michiana Area Council of Governments
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
SCS	U.S. Soil Conservation Service
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
°F	degrees Fahrenheit
ft^3/s	cubic feet per second
mi^2	square miles
m.s.l.	mean sea level
mg/l	milligrams per liter
app.	appendix
fig.	figure
pl.	plate

WATER RESOURCE AVAILABILITY IN THE ST. JOSEPH RIVER BASIN, INDIANA

BY THE DIVISION OF WATER

INTRODUCTION

BACKGROUND

The Water Resource Management Act (I.C. 13-2-6.1) was signed into law on April 7, 1983 by Governor Robert D. Orr. Under Section 3 of the act, the Natural Resources Commission must (1) conduct a continuing assessment of water resource availability, (2) conduct and maintain an inventory of significant withdrawals of ground and surface water, and (3) plan for the development, conservation and utilization of the water resource for beneficial uses.

Section 5 further mandates the statewide 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. These and other directives reflect a comprehensive approach to water resource management and establish a legislative foundation upon which management programs can be further developed.

To help meet mandated responsibilities, the Commission has divided Indiana into 12 water management basins (fig. 1). Through a series of basinwide investigations, the Indiana Department of Natural Resources (IDNR), Division of Water (the Commission's technical staff) will characterize water on and below the earth's surface. Together with atmospheric water, these hydrologic elements constitute the state's total water resource, a singular entity which will be treated as such in ongoing assessment projects.

PURPOSE AND SCOPE

The St. Joseph River basin drains 1699 mi^2 (square miles) in northern Indiana and 2586 mi^2 in southern Lower Michigan (fig. 2). The Indiana part of the basin contains a unique combination of natural lakes, wetlands, streams with well-sustained flows, and extensive sand and gravel aquifer systems. The relative abundance of surface- and ground-water supplies serves a diversity of human needs, ranging from in-stream recreational uses to large water withdrawals for industrial manufacturing and irrigation. Demands on the water resource are expected to increase as both the economy and population continue to grow.

This report describes the availability, distribution, quality and use of ground and surface waters in the St. Joseph River basin, Indiana. The first in a series of 12 regional investigations (fig. 1), it is intended to provide background hydrologic information for water resources decisionmaking. Industrial, agricultural, commercial, recreational, governmental and other public interests can utilize the summarized data in developing and managing the basin's water resource.

APPROACH

Much of the data in this report has been summarized from maps and data files of federal and state agencies, from various technical reports, and from departmental communication. Some new water quality data were collected during the investigation, and other data have been compiled, analyzed and interpreted.

Because the main body of the report is written for a wide spectrum of readers, detailed data are segregated into technical appendices. However, this report does not provide adequate information for evaluating site-specific water resource development projects. Persons involved in such projects should contact the Division of Water for further information.

Although the St. Joseph River basin includes parts of two states (fig. 2), "the basin" refers only to the Indiana portion unless otherwise indicated. County data are generally presented only for the portions lying within the basin boundary. (The economic summary utilizes data for the whole county, however.) Table 1 lists the in-basin areas and percentages used in this report. A glossary is included at the end of the text.

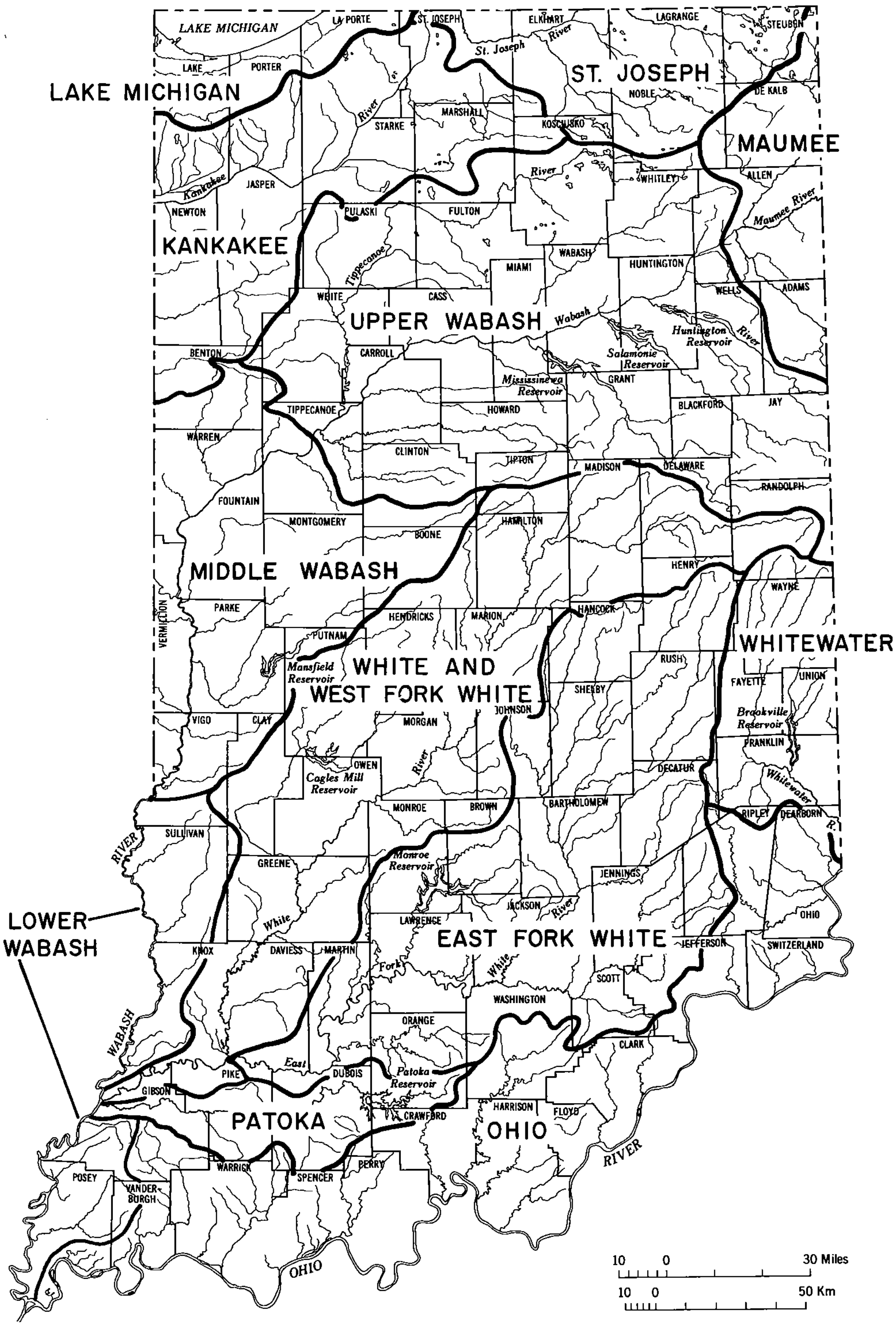

Figure 1. Water Management Basins

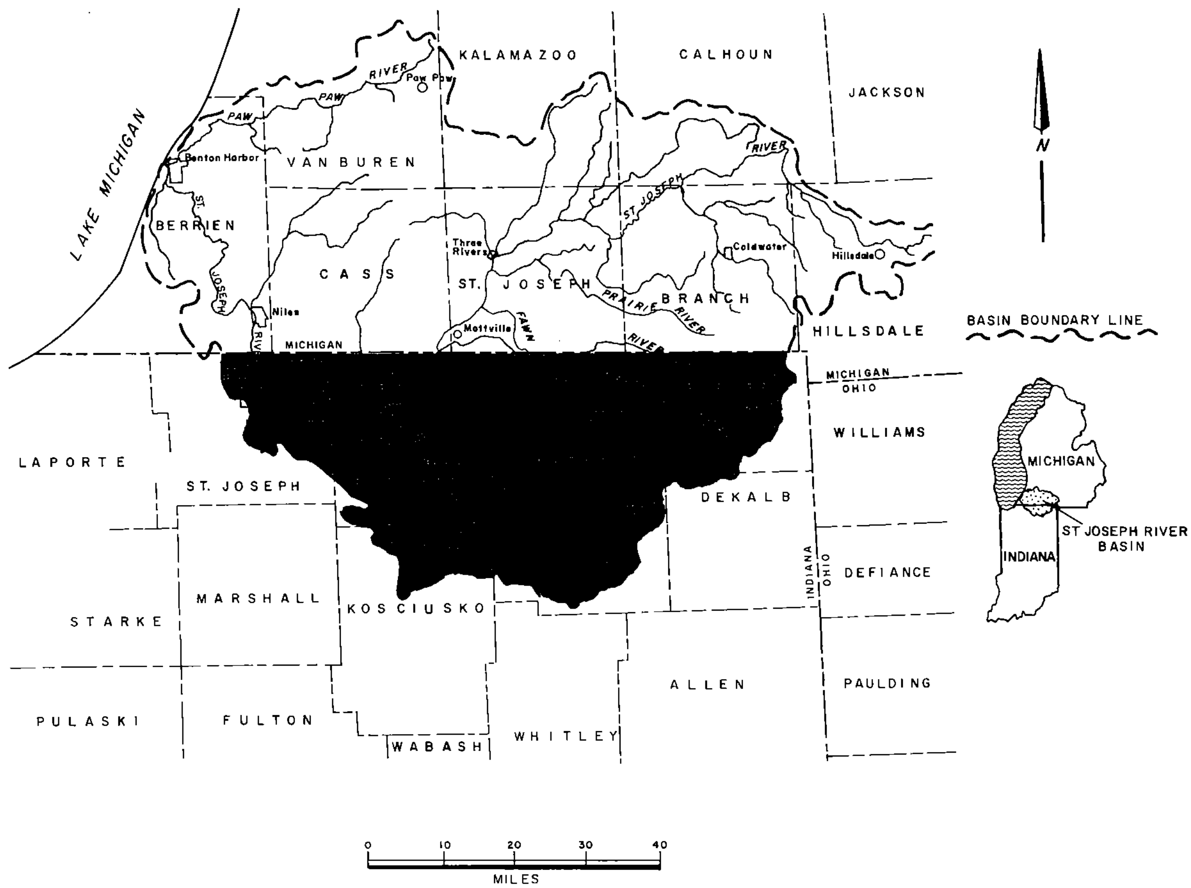

Figure 2. St. Joseph River Basin

TABLE 1. St. Joseph River Basin Area

County	Total Area (mi^2)	In-basin Area (mi^2)	Percent
Dekalb	364	9.2	2.5
Elkhart	466	438.9	94.2
Kosciusko	540	110.8	20.5
LaGrange	379	379.0	100.0
Noble	413	300.6	72.8
St. Joseph	459	226.7	49.4
Steuben	308	233.8	75.9
Total	2930	1699	

PREVIOUS INVESTIGATIONS

Klaer and Stallman (1948) and Marie (1975) present a quantitative evaluation of the ground-water resources of the South Bend area, while Stallman and Klaer (1950), Rosenshein and Hunn (1962), Pettijohn (1968), Hunn and Rosenshein (1969), and Imbrigiotta and Martin (1981) discuss the ground-water resources within larger areas of the basin.

An evaluation by Crompton and others (1986) assesses the adequacy of basinwide hydrologic data collection for management purposes. Bailey and others (1985) and Lindgren and others (1985) evaluate the local effects of simulated pumpage on ground and surface water systems. Three plates by Reussow and Rohne (1975) summarize the water resources of the basin: ground water, surface water, and precipitation.

A cooperative federal-state report (State of Indiana, 1976) details both the land and water resources of the Elkhart River basin (a subbasin of the St. Joseph study area). A report by the Governor's Water Resource Study Commission (1980) assesses various aspects of water availability and use for 18 planning and development regions in Indiana. The St. Joseph basin lies primarily in two of these regions.

ACKNOWLEDGEMENTS

The following agencies provided valuable information and assistance during the preparation of this report: Indiana Geological Survey; Indiana State Board of Health; Indiana Department of Environmental Management; Indiana Business Research Center; Indiana State Data Center; Indiana Department of Commerce; Division of Fish and Wildlife (IDNR); Purdue University; Indiana University; Michiana Area Council of Governments; Michigan Department of Agriculture (Climatology Division); U.S. Geological Survey (Water Resources Division); U.S. Department of Agriculture (Soil Conservation Service); and the National Oceanic and Atmospheric Administration (National Weather Service).

The authors also thank the City of Elkhart, Curtis Creek Fish Hatchery (IDNR), and residents of the St. Joseph River basin for their cooperation during the 1985 ground-water sampling project. In addition, well-drilling contractors and county courthouses contributed water-well and property records during the study.

The authors also extend their thanks to Amy S. James and Cynthia J. Harrington, who prepared drafts of the manuscript, and Margaret L. Petrey, who typeset the final text.

POPULATION AND ECONOMIC FRAMEWORK

POPULATION[1]

In 1980, the estimated population of the St. Joseph River basin (432,565) comprised 7.9 percent of Indiana's total population (5,490,224). Nearly half of the in-basin residents lived within the corporate boundaries of South Bend[2], Mishawaka, Elkhart, and Goshen, while an estimated 75,000 persons resided in urbanized areas adjacent to these four major cities. An estimated 28 percent of the basin population lived in rural areas (non-urban farm and non-farm areas of less than 2500 residents). Twenty-eight percent of the total in-basin Noble County population lived in Kendallville (7299), while 29 percent of the in-basin Steuben County population lived in Angola (5486).

Total basin population increased from 146,931 in 1900 to 432,565 in 1980 (app. 1). Fig. 3 shows population changes of four major cities, as well as 1980 census totals of cities with at least 2500 residents. Population trends for the in-basin portions of six counties are shown in fig. 4. (Although not shown in the figure, estimated population within the northwest tip of Dekalb County ranged from 626 in 1940 to 850 in 1980.)

In-basin population is expected to total 450,351 by 1990 and 467,148 by the year 2000. As figs. 3 and 4 show, the recent decline in the population of St. Joseph County closely reflects the sharp drop in South Bend's population. According to data of Marcus

1 Population data are taken or derived from Marcus (1985) and from the U.S. Census Bureau. Numbers are estimates of in-basin population unless otherwise indicated.

2 South Bend's entire population is included, because water supplied from in-basin eastern portions is distributed to western areas lying outside of the basin boundary.

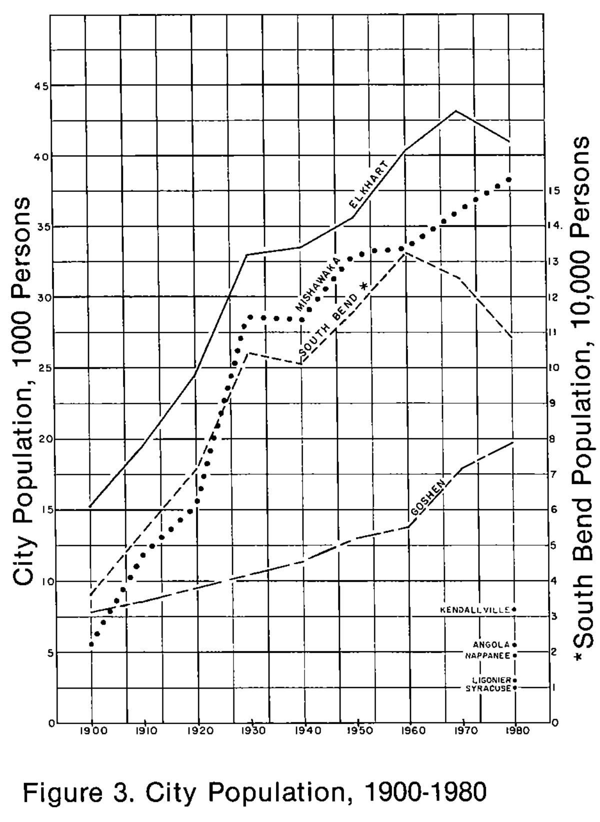

Figure 3. City Population, 1900-1980

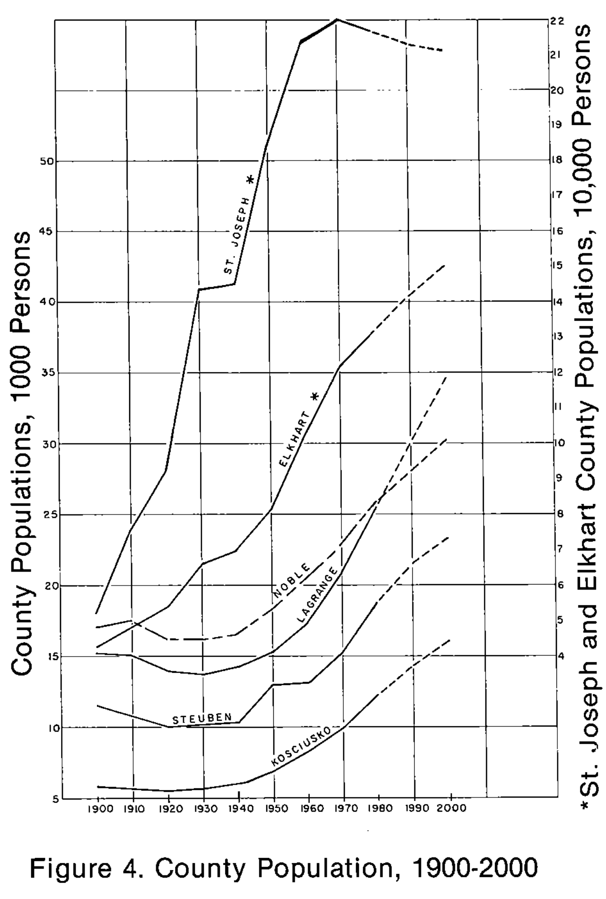

Figure 4. County Population, 1900-2000

(1985), the decline in St. Joseph County's population is expected to continue through the 1990s. Other county populations are expected to increase, although at varying rates.

App. 1 lists in-basin county population estimates and whole-county census totals (used to derive the in-basin estimates). From 1940 to 1960, whole-county population in St. Joseph and Elkhart Counties increased an average of 47 percent, but from 1960 to 1980 increased only 1 and 29 percent, respectively. Despite these decreased growth rates, St. Joseph County constituted the fourth most populous Indiana county in 1980, and Elkhart County was the seventh most populous.

Whole-county population in Kosciusko, LaGrange and Steuben Counties increased an average 46 percent from 1960 to 1980. The increase in LaGrange County's population from 1980 to 1983 (3.7 percent) was the fourth highest county percentage increase in Indiana for this period. The projected 35 percent increase in LaGrange County's population between the years 1980 and 2000 surpasses the whole-county percentage increase of other basin counties.

ECONOMY

Manufacturing, services and retail trade constitute the three largest employment classes in the basin's economic area[3]. In 1982, manufacturing comprised 37 percent of the basin area's non-farm labor force, while services and retail trade employed 20 and 16 percent, respectively. Most of the basin's manufacturing, retail trade and service industries were found in St. Joseph and Elkhart Counties.

Manufacturing within the basin accounted for an average of 50 percent of 1983 earnings by industry. In 1982, major manufacturing included machinery, rubber-plastics, lumber-wood, fabricated metal, and printing-publishing. Elkhart County led Indiana in the number of industries which manufacture transportation equipment (137), and was second only to Marion County in the number of fabricated metal plants (116).

Between 1972 and 1982, manufacturing decreased in all counties except Steuben and Kosciusko. However, at least 50 percent increases in non-farm wage and salary employment by industry between 1972 and 1982 have been observed within the following categories: (1) wholesale trade (LaGrange, Noble, Steuben and Kosciusko Counties); (2) finance, insurance, and real estate (Steuben); (3) transportation, communication, and public utilities (Steuben—a 156 percent increase); and (4) agricultural services, fisheries, and forestry (LaGrange).

Estimated per capita income in 1981 was greatest for St. Joseph County ($8620) and Elkhart County ($8374), and least for LaGrange County ($6671). For the six-county basin area, per capita income averaged 94 percent of the statewide average. Per capita money income in Elkhart and St. Joseph Counties equalled or slightly exceeded the state average in 1981, while per capita personal income in 1983 averaged 9 percent higher than the state average.

Corn, soybeans and winter wheat are the three major crops grown within the basin. In 1983, the average production of corn for grain exceeded average soybean production 5 to 1 and winter wheat production 7 to 1.

Although agriculture comprised less than 3 percent of the basin's employed labor force in 1982, it played a major role in Indiana's overall farm economy. In 1982, Elkhart County (with 1055 farms) was second only to Allen County in the total number of farms[4]. However, Elkhart County had the state's greatest number (209) of small farms (50 acres or less) in Indiana, while LaGrange County had the state's greatest number (594) of 50- to 179-acre farms. (Both counties also led the state in the number of farm operators having full ownership.) Indiana's dairy product sales and hay production also were highest in these two counties, while LaGrange County had the state's second highest oats production. Sales of Indiana poultry and poultry products were greatest in Kosciusko and LaGrange Counties.

Members of the Old Order Amish and Mennonite communities play a major role in the farm economy of Elkhart and LaGrange Counties. An estimated 80 percent (28,000) of the basin's total Amish-Mennonite population reside in these two counties. Approximately three-fourths of LaGrange County's farm population is comprised of Old Order Amish (S.L. Yoder, Goshen College, personal communication, 1986).

LAND USE

The St. Joseph River basin constitutes 4.7 percent of Indiana's total land area. Lakes, wetlands and small

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3 "Basin" in this section refers to entire county areas, because economic data (taken from Marcus, 1985) are available only on a county-wide basis. Furthermore, DeKalb County is excluded from the discussion, because only 2.5 percent of its land area lies within the topographic basin. Economic data are based on 1982 County Business Patterns unless otherwise indicated.

4 "Farms" refers to those with sales of at least $10,000. All farm data are for 1982.

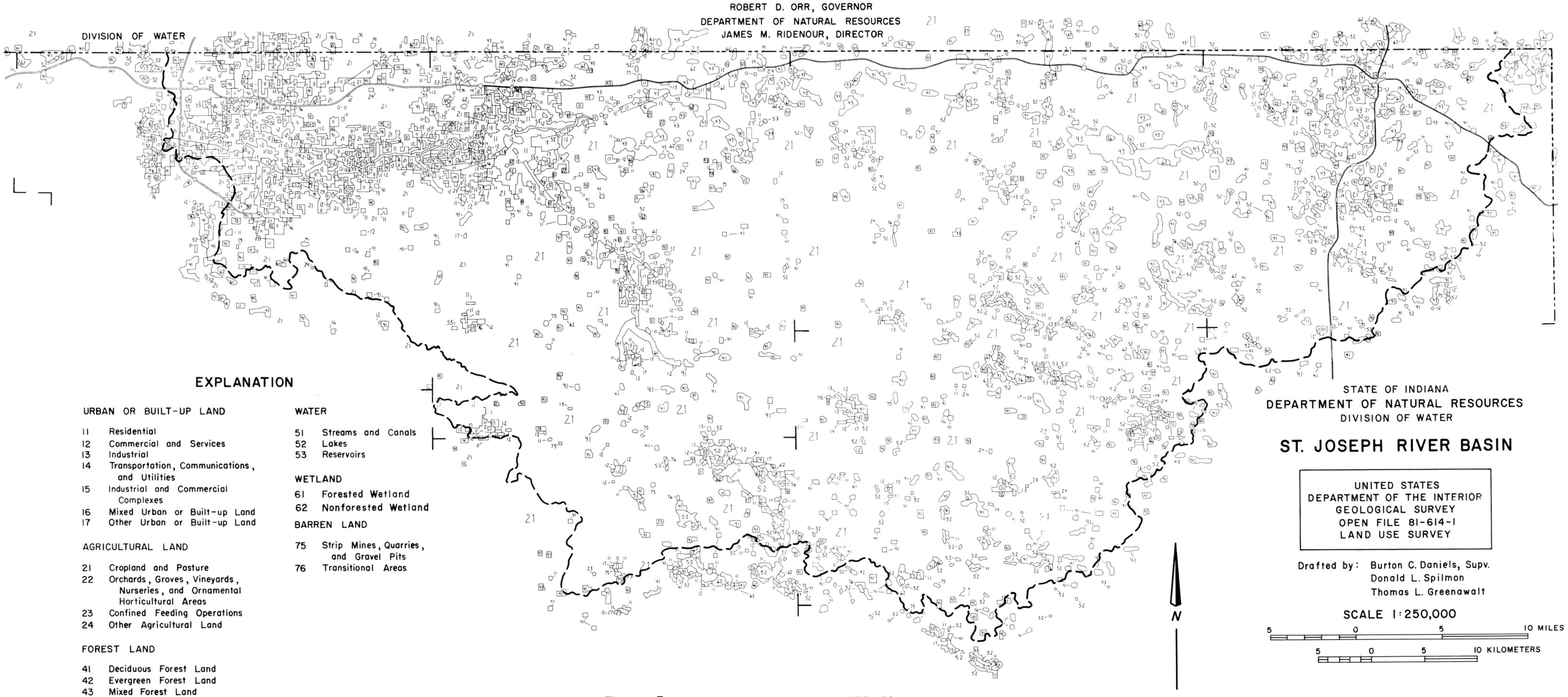

Figure 5. Land Use and Land Cover 1975-81

parcels of forested land are scattered throughout the basin, as fig. 5 shows. Several forested areas are also classified as wetlands and are found along the flood-plains of major streams such as the Pigeon, Fawn and Elkhart Rivers, the north and south branches of the Elkhart River, and lower reaches of Turkey Creek.

Agriculture is the primary land use in the basin. (App. 2 contains county profiles of agricultural land use.) Industrial and residential development is most extensive in and near the cities of South Bend and Elkhart. Heavy residential development also exists around many of the basin's lakes, and to a lesser extent along the larger streams such as the St. Joseph and Elkhart Rivers.

GEOLOGIC FRAMEWORK

Topography, geology and soils affect the availability of surface- and ground-water resources. These factors largely determine the proportion of precipitation which runs off the land to become surface water, as opposed to that which infiltrates into the soil and percolates through underlying materials to become ground water.

The geologic timescale (fig. 6) illustrates the sequence of geologic events for Indiana and the rock types associated with each geologic period. During the Pleistocene Epoch (Ice Age), glacial lobes repeatedly entered Indiana. The glacial lobes entered the state from at least two directions: from the northeast out of the Lake Erie and Saginaw Bay basins, and from the northwest out of the Lake Michigan basin (fig. 7). Advancing glaciers scoured the land surface while retreating glaciers left behind large deposits of scoured materials. Erosion has subsequently modified the glacial deposits to produce currently existing landforms.

This glacial and post-glacial activity has been the predominant influence upon the present topography and surficial geology of the St. Joseph River basin. Glacial deposits, some as thick as 450 feet (fig. 8), cover the basin bedrock as a legacy of the most recent period of glaciation. Land surface elevation ranges from 665 feet m.s.l. (mean sea level) near South Bend to 1205 feet m.s.l. north of Angola. Local topographic relief in areas containing kame deposits may exceed 200 feet.

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 0-500 ft.
	TERTIARY	60 MILLION	*Cherty gravels* *Sand and clay* *Scattered deposits*
MESOZOIC	CRETACEOUS JURASSIC TRIASSIC	70 MILLION 35 MILLION 30 MILLION	No deposits in Indiana
PALEOZOIC	PERMIAN	25 MILLION	
	PENNSYLVANIAN	20 MILLION	*Shale (including carbonaceous shale), mudstone, sandstone, coal, clay limestone, and conglomerate* 1,500 ft.
	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.
	DEVONIAN	60 MILLION	Upper Part: *carbonaceous shale* 100 ft. Lower Part: *limestone, dolomite: a few sandstone beds* 40-80 ft.
	SILURIAN	40 MILLION	*Dolomite, limestone, chert, siltstone, and shale* 100-300 ft.
	ORDOVICIAN	70 MILLION	*Shale, limestone and dolomite* 700 ft. *Limestone, dolomite, and sandstone* (Not exposed at the surface in Indiana)
	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 6. Geologic Timescale for Indiana

TOPOGRAPHY

The St. Joseph River basin is characterized by complex topographic features that include moraines having rugged topography and relatively level till plains interspersed among braided meltwater (outwash) channels and hummocky ridges. This terrain includes small enclosed basins occupied by lakes or marshes, as well as broad pitted outwash fans. Simpler topographic features include the broad, level till plain of the Wakaruska-Wyatt-Nappanee area and the wide coalesced outwash surfaces of the St. Joseph River valley itself. The basin's topographic complexity suggests the complexity of distribution of Quaternary sediment types, which in turn relates to the complex glacial history.

The basin can be subdivided into six regions on the basis of topography and distribution of surface sediments. The southern margin of the basin is defined by the combined Mississinewa and Packerton Moraines (fig. 9, region 1). The southwestern part of the moraines is characterized by sag and swell topography having as much of 40 feet of relief. There are many lakes in the northwestern part of the morainal area, many of which are more than 50 feet deep. Sediments within these moraines consist of a heterogeneous assemblage of both clayey basal melt-out and flow tills of the Lagro Formation, sand and gravel outwash, and lake muds juxtaposed both vertically and laterally.

The northwestern flank of the morainal area is cut by open channel heads and probable collapsed ice trough cut into till (fig. 9, region 2, white pattern). The channels trend at right angles away from the morainal area and coalesce into an apron. Some channels remain active, especially those that are part of the channel system of the main tributaries within the St. Joseph River basin. The channels are filled with outwash sand and gravel that is overlain in places by organic muds and peat. The presence of closed basins within the St. Joseph basin suggests that the original longitudinal profiles of the channels have been disturbed by events subsequent to channel formation.

Northwest of the previously mentioned apron, the outwash channels coalesce to form broad outwash plains that are laterally extensive along the moraine front (fig. 9, region 3). The outwash deposits are interrupted locally by hummocky ridges of morainal material and ice-contact deposits. These outwash materials are inset within remnants of the loamy till that underlie the more clayey tills in the moraines of the Erie Lobe.

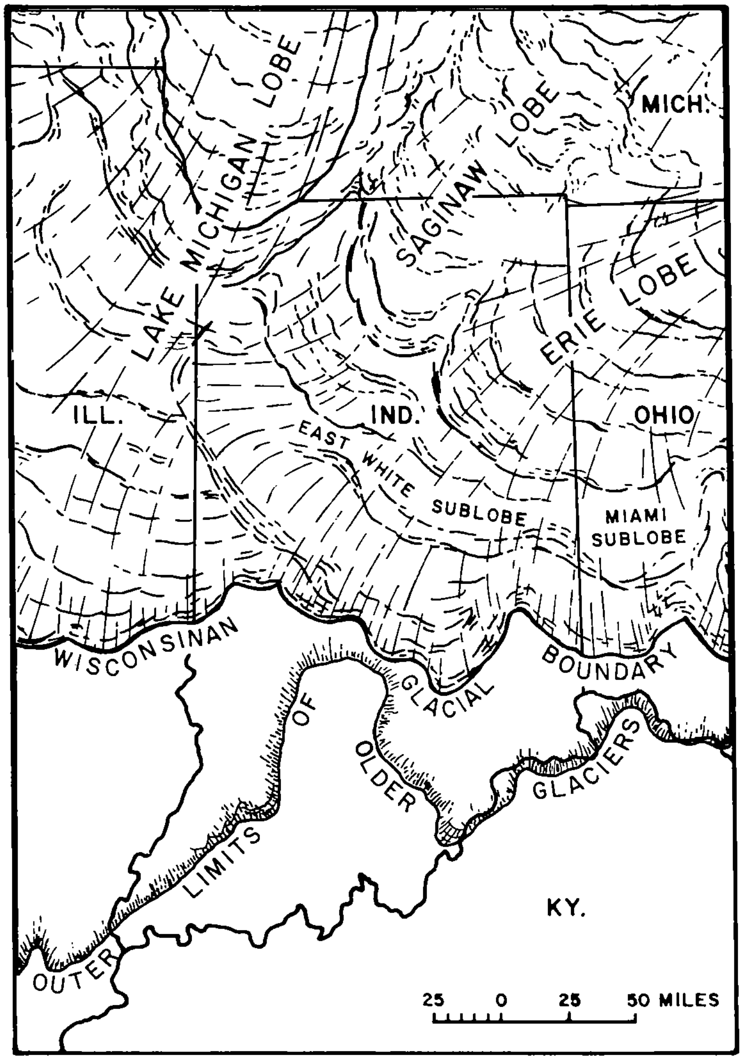

Figure 7. Major Ice Lobes during Wisconsinan Age

Outwash deposits extend northwestward and northward into a broad lowland that can be subdivided into two parts. The northeastern part (fig. 9, region 4a) has a complex array of gravel-filled outwash channels, ground moraine composed of loamy till, and hummocky ridges that may represent minor moraines and/or ice-contact deposits of the Saginaw Lobe. The southwestern part (fig. 9, region 4b) is characterized by larger outwash channels that are now valleys of major tributaries of the St. Joseph River, including the Elkhart, Little Elkhart and Pigeon Rivers.

The lowland to the southwest, however, is occupied by a more extensive plain that is cut by few channels (fig. 9, region 5). Only the northern part of this till plain lies within the St. Joseph River basin. The plain is bounded on the west by the Maxinkuckee Moraine, which has been considered to be the terminal moraine of the Saginaw Lobe and which possesses rugged topography with numerous closed basins.

The Kankakee Lowland (fig. 9, region 6), is a broad, flat region that extends from Illinois, across northwestern Indiana, and into southwestern Michigan. That part of the lowland extending southwestward from South Bend is now the floodplain of the Kankakee River. That part extending east of South Bend is now occupied by the St. Joseph River. The lowland forms an exceptionally level plain covered by fine-grained Holocene alluvium that is underlain by thick outwash sand and gravel which in turn overlie lake muds.

Soils in the St. Joseph basin generally fall within one of three classes: 1) sandy or loamy soils developed on outwash and allumium; 2) silty or clayey soils developed on till; and 3) muck soils developed in depressional wetland areas. Descriptions of soil associations are given in app. 3.

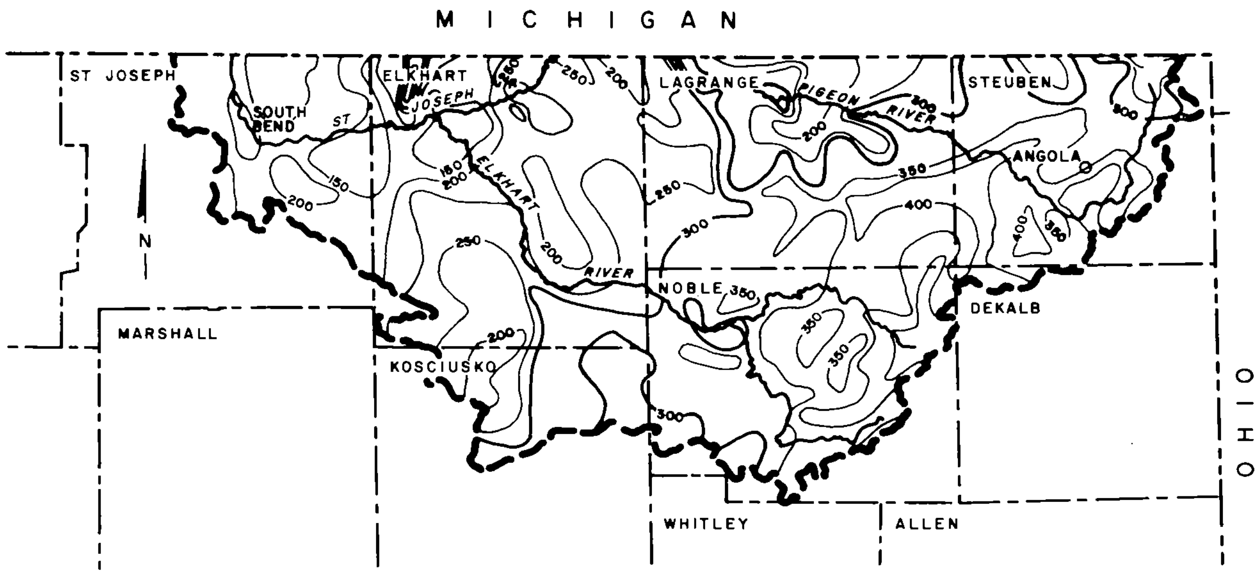

Figure 8. Thickness of Unconsolidated Materials

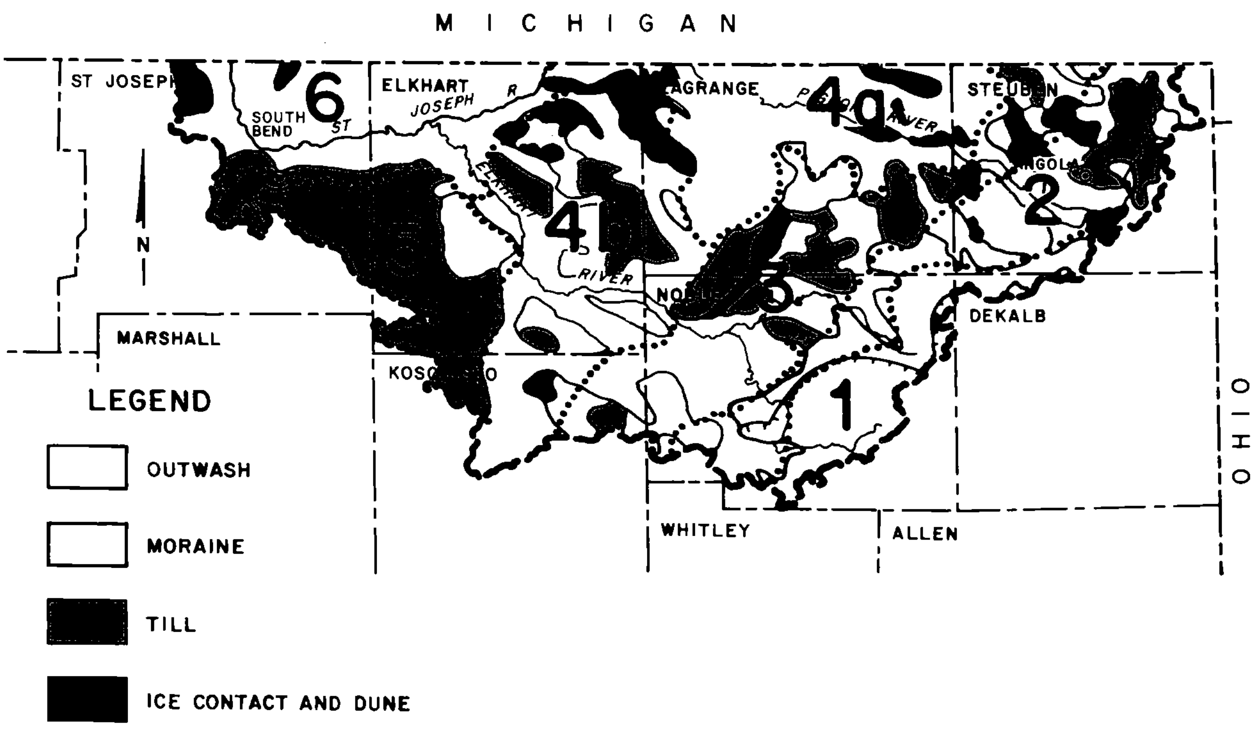

Figure 9. Geomorphic Regions

GLACIAL GEOLOGY

The surficial geology of the St. Joseph River basin reflects a very complex glacial history. Interpretations of geomorphology and soils have resulted in revised mapping of surficial materials (Gray, in preparation). Insights from this mapping, combined with knowledge from existing geologic and topographic maps, have yielded a hypothesized sequence of glacial events in the St. Joseph basin.

This hypothesis, which includes a concept presented as early as 1883 that northeastern Indiana is an area of interlobate relationships, assumes that the present topography is entirely of Wisconsinan age materials. (Little is known of relationships of earlier glacial material due to a lack of subsurface stratigraphic data.)An outline of the hypothesized events is presented in table 2 and related to the map in fig. 10.

TABLE 2.
Relationships of Quaternary Stratigraphic Units and Hypothesized Glacial and Drainage Events

AGE	FORMATION MEMBER	GLACIAL LOBE: LAKE MICHIGAN	GLACIAL LOBE: EASTERN UNDIFF.	GLACIAL LOBE: ERIE	GLACIAL LOBE: SAGINAW	DRAINAGE ROUTE
	Largo Fm.		Clayey till southern Noble Co. (event 6)			Northeast to the St. Joseph and Kankakee rivers through pre-existing troughs
	Wedron Fm.	Ice-contact proximal fans, tectonic struc-tures(?), southern St. Joseph valley margin (event 5)				Southward, down pre-existing troughs to the Tippecanoe and Wabash rivers
	Trafalgar Fm., upper tongue			Loamy tills and ice-contact deposits; exemplified by the Ligonier-Topeka-LaGrange line of ice contact deposits (event 4)		Northeast to the St. Joseph and Kankakee rivers through pre-existing troughs; exempli-fied by the massive fan at Topeka
	unassigned				Sandy and clayey tills of uplands, Elkhart, LaGrange counties (event 3)	Westward as ice-prominal fans on uplands; ice-frontal lateral drainage in troughs between ice (on northeast) and ice-contact slopes (on southwest), northwestward to St. Joseph and Kankakee rivers
	unassigned		Sandy tills of Nappanee area westward (event 2)			(ice covered)
	Wedron Fm., Snider Till Mb.	Clayey till, subsurface of Wyatt area (event 1)				Eastward, up St. Joseph River, thence south (routes unknown) to Wabash River

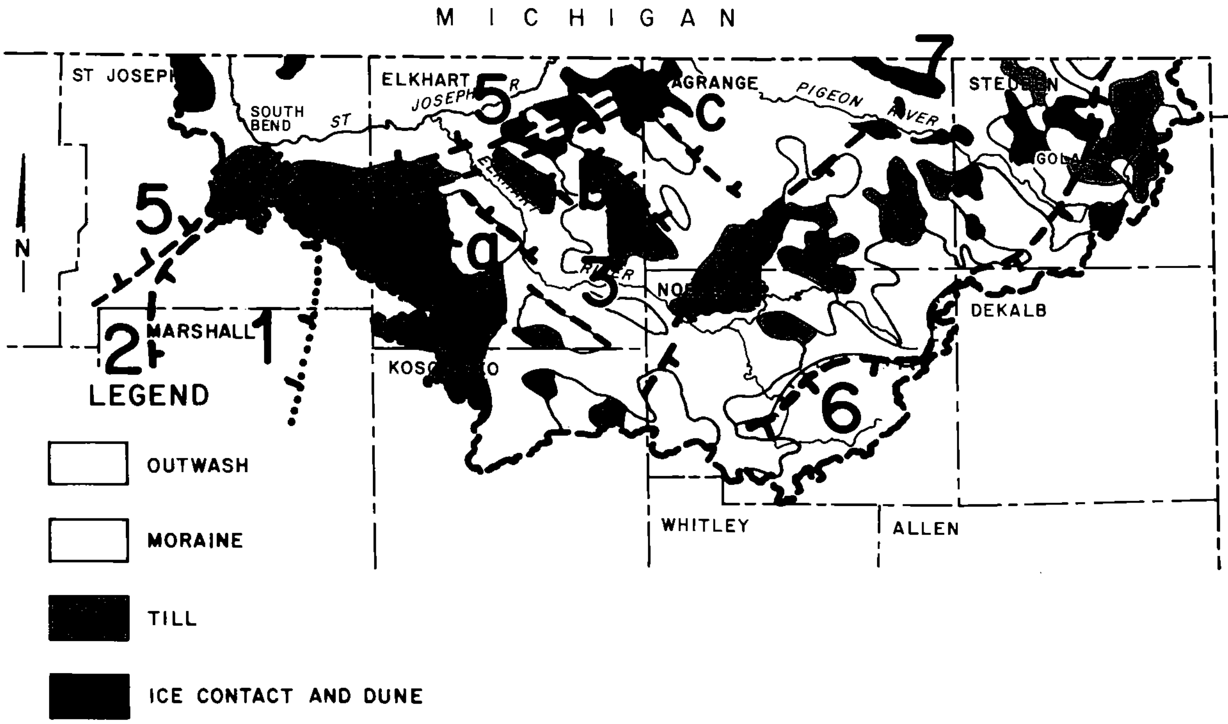

Figure 10. Sequence of Wisconsinan Glacial Events

BEDROCK GEOLOGY

The bedrock underlying the St. Joseph River basin in Indiana consists mainly of layered Paleozoic limestone, dolomite, sandstone, siltstone and shale, which represent deposits of ancient inland seas. Beneath these rocks are Precambrian igneous basement rocks composed mainly of granite, basalt and arkose. All of these rocks are deformed regionally to form the Kankakee and Cincinnati Arches (fig. 11), which together are a bedrock structural high that extends from northwestern through southeastern Indiana. Along the northern side of this high, including the St. Joseph basin, the sedimentary formations dip about 30 feet per mile to the northeast into the major structural feature called the Michigan Basin. The rocks at the bedrock surface become progressively younger toward the northeast.

Bedrock is covered by a thick mantle of glacial drift and does not appear at the modern land surface anywhere in the drainage basin. Therefore, knowledge of bedrock is based on logs of exploratory drilling, mostly for oil and gas.

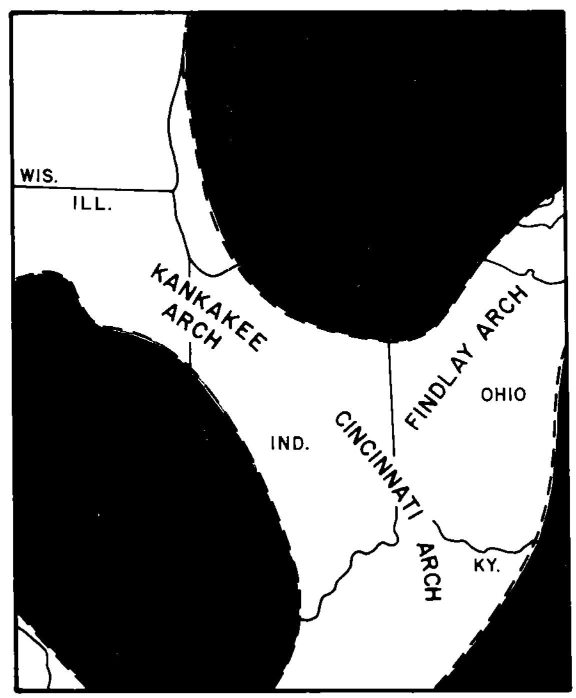

Figure 11. Regional Geologic Structure

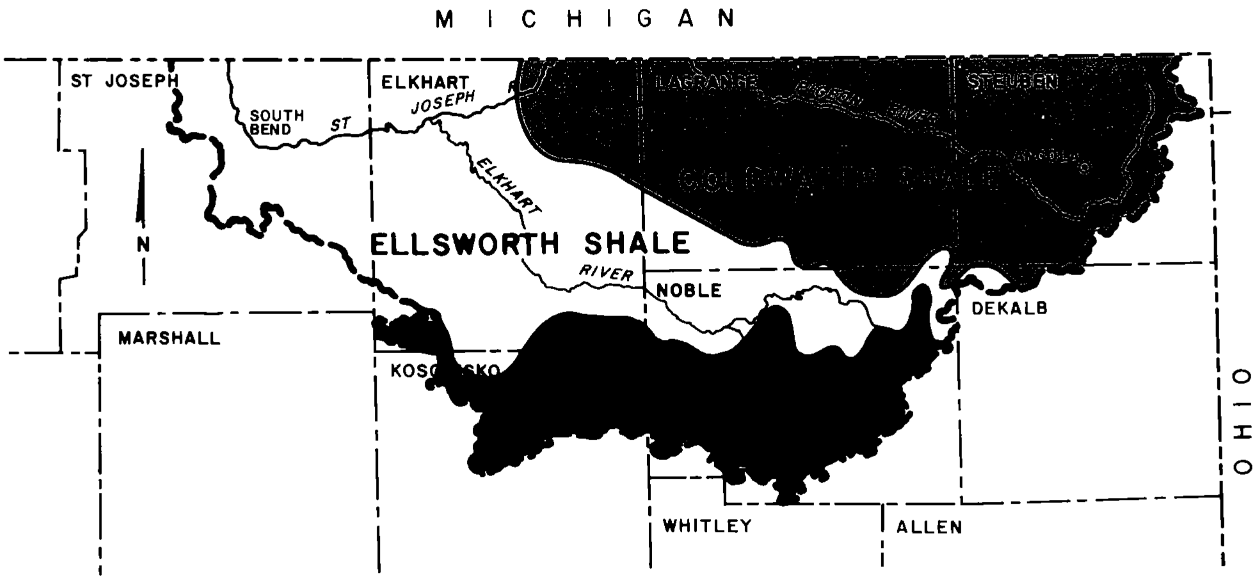

Figure 12. Areal Distribution of Bedrock Units

An exploratory well in Steuben County provides an exemplary section of bedrock formations in that part of the basin where the sedimentary bedrock section is thickest. Here, 450 feet of glacial material overlies about 4450 feet of sedimentary rock sequence (app. 4) that in turn overlies granitic basement rocks. The sedimentary rock sequence ranging between the uppermost and lowermost units, the Coldwater Shale and the Mt. Simon Sandstone, respectively, spans Mississippian through Cambrian time, from about 360 million to more than 600 million years ago.

Three major shale units generally constitute the bedrock surface within the St. Joseph River basin (fig. 12). The slightly silty, gray to greenish-gray Coldwater Shale lies in the northeast. In much of the western and south-central parts of the basin, alternating beds of black and gray-green Ellsworth Shale form the bedrock surface. The brownish-black, noncalcareous Antrim Shale lies to the south. Detailed descriptions of these and other St. Joseph basin bedrock units are given in app. 4.

BEDROCK TOPOGRAPHY

Depth to bedrock is highly variable within the St. Joseph River basin, ranging from less than 30 feet in the Mishawaka area to nearly 500 feet in the eastern part of the basin. This variability is due to an eroded, irregular shale bedrock surface and a complex series of glacial deposits.

Bedrock elevations range from over 900 feet m.s.l. (mean sea level) in Steuben County to less than 350 feet m.s.l. near Elkhart where a deep narrow valley is present (fig. 13). Deeply incised valleys similar to the one near Elkhart are expected for other portions of the basin.

Because most water wells and test wells are completed in glacial materials, depth-to-bedrock data are lacking. Fig. 13 is therefore a generalized depiction of a diverse bedrock surface having rugged hills and V-shaped valleys.

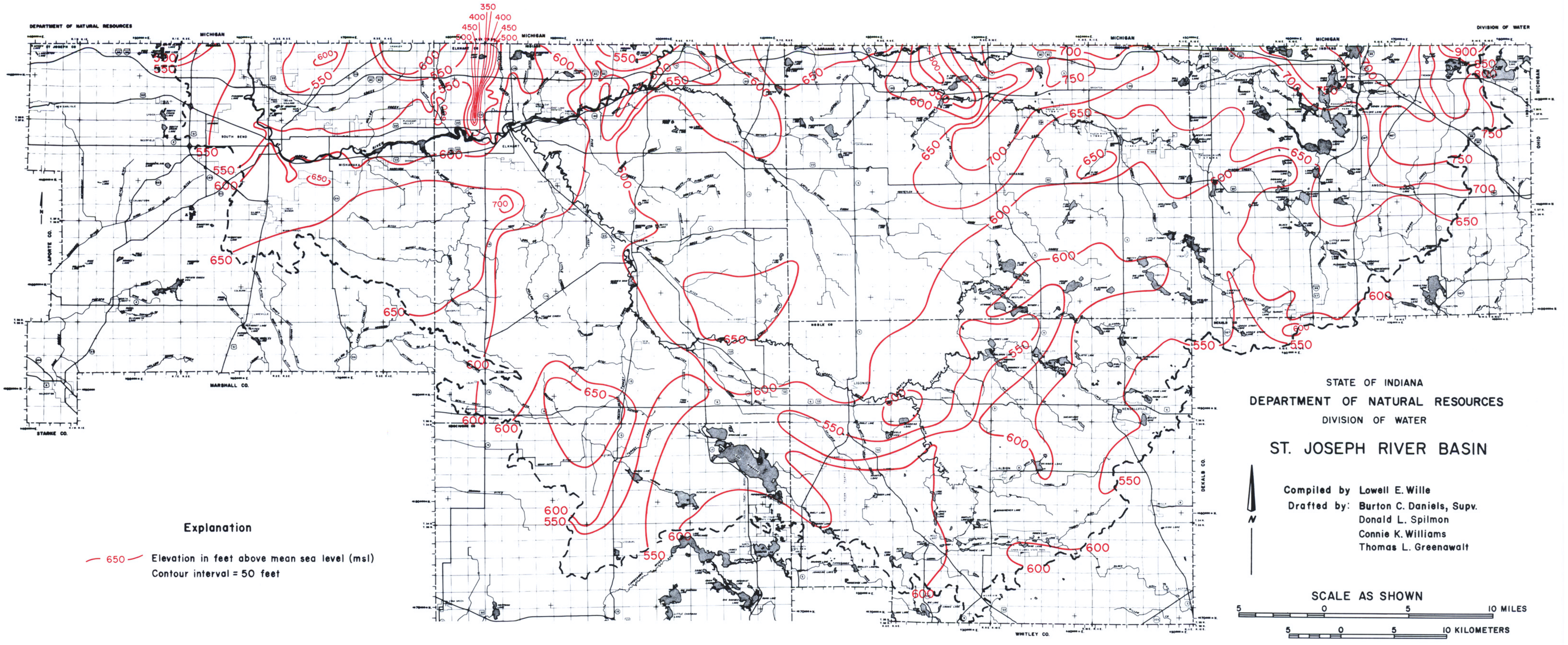

Figure 13. Bedrock Topography

BASIN HYDROLOGY AND AVAILABLE WATER SUPPLY

CLIMATE

The climate of the St. Joseph River basin, classified as temperate continental, is characterized by warm, occasionally hot summers, cold winters, and considerable daily variations in temperatures.

Northern Indiana frequently encounters cyclonic disturbances generated by the interactions of northeast-moving tropical and south-moving arctic air masses. Locally heavy amounts of rain or snow associated with the eastward passage of low pressure centers are often recorded, although basinwide, precipitation is fairly evenly distributed throughout the year.

Other climatic characteristics of the basin include moderate to high humidities, light to moderate winds (typically from the southwest), and a large proportion of partly cloudy to cloudy days interspersed with clear days. Severe local storms generated by daytime convection or by the passage of cold fronts are most common in spring and early summer. These storms may produce frequent lightning, strong winds, or large hail, as well as sporadic funnel clouds and tornadoes.

The climate of the western part of the basin in both states is influenced by Lake Michigan, particularly from the vicinity of South Bend, Indiana northward to near Hartford and Paw Paw, Michigan (see app. 5).

Although meteorological parameters such as wind, solar radiation, relative humidity and soil temperature also constitute an area's climate, only air temperature and precipitation will be summarized here. Temperature regime defines growing season (the number of days between the last spring and first autumn temperature of 32° F) and largely controls the process of evapotranspiration, which consumes more than 70 percent of the average annual precipitation. Precipitation is the source of all fresh water either on the surface or in the subsurface of the earth. The amount, distribution and mode of occurrence of precipitation will largely define a region's water supply and help determine its hydrologic regime.

Temperature[5]

Annual temperatures within the St. Joseph basin average 49° F (degrees Fahrenheit). Seasonal temperatures average 48° F in spring (March-May), 70° F in summer (June-August), 52° F in autumn (September-November), and 26° F in winter (December-February). January, the coldest month, has a mean monthly temperature of 23° F and a mean daily minimum of 15° F. July is the warmest, and has an average temperature of 72° F and a mean daily maximum of 83° F. Diurnal temperature variations (the difference between normal daily maximums and minimums) typically range from about 15° F in winter to 23° F in summer, although diurnal ranges in South Bend average 1° F to 3° F less. Extreme temperature readings in the basin have ranged from 101° F (Three Rivers, 1971) to -20° F (Goshen and Coldwater, 1963).

Mean growing season ranges from less than 150 days in the more elevated eastern parts of the basin to about 170 days just inland of Lake Michigan. Vegetative cover, soils, impervious surfaces and obstructions to wind are factors which can influence climatic features, particularly growing season. However, these factors typically affect climate only over small areas.

Precipitation

Annual precipitation in the basin averages 35 inches. During extremely dry and wet years, annual totals have ranged from 21 inches to 54 inches. There is a 90 percent probability, however, that annual precipitation will be about 29 inches in the South Bend area, and 27 inches in the rest of the basin.

Monthly precipitation totals have varied from zero to nearly 12 inches, but monthly averages are fairly uniform, as table 3 shows. An average of nearly 20 inches, or 57 percent of the mean annual precipitation, falls from May through October (the crop season). During this time, monthly amounts average 3.3 inches.

Daily precipitation is quite variable due to the

5 Temperature and precipitation data are taken or derived from data published in several NOAA reports (see references) and unpublished data obtained from the Michigan Department of Agriculture, Climatology Division. Data from South Bend, Goshen, Three Rivers (Michigan) and Coldwater (Michigan) for the period 1951-80 were used to obtain in-basin averages and extremes. The Michigan stations were included due to the lack of published 30-year summaries for Indiana in central and eastern parts of the basin. All other information refers to Indiana unless otherwise indicated.

TABLE 3. Normal Monthly and Annual Precipitation in Inches, 1951-80

Month	South Bend Indiana	Goshen College Indiana	Coldwater Michigan	Three Rivers Michigan
January	2.48	1.78	1.72	1.84
February	1.99	1.58	1.56	1.49
March	3.05	2.60	2.36	2.44
April	4.06	3.59	3.48	3.35
May	2.81	2.97	3.03	3.12
June	3.94	3.61	3.73	3.95
July	3.67	3.61	4.01	3.79
August	3.94	3.66	3.40	3.16
September	3.22	3.03	3.03	3.01
October	3.22	2.73	2.60	2.71
November	2.83	2.32	2.38	2.37
December	2.95	2.23	2.19	2.32
Annual	38.16	33.71	33.49	33.57

periodic passage of frontal systems, and 24-hour amounts have ranged from zero to more than 5 inches. Although precipitation events are generally interspersed among several dry days, daily normals fall between 0.07 inch in February to 0.14 inch in April and June, as interpolated from monthly normals by the use of a statistical function.

Annual snowfall for Angola (1951-72) and Goshen (1951-80) averages roughly 35 inches, while snowfall at South Bend averages 72 inches (1951-80). Snowfall accounts for nearly 20 percent of the average annual precipitation in the South Bend vicinity, where lake-effect snows are common. Elsewhere in the basin,snowfall accounts for less than 10 percent.

Climatic Data

Climatic data for the St. Joseph River basin are gathered as part of several statewide networks operated by federal and state agencies. The most extensive networks are operated and maintained by the National Weather Service (NWS) of the National Oceanic and Atmospheric Administration (NOAA). Official climatic data in the basin are collected at a 24-hour NWS office (South Bend) and at NWS cooperative observer stations operated by water and wastewater utilities, municipalities, universities or private citizens (table 4). Additional precipitation data are gathered by about 10 amateur radio operators as part of a statewide volunteer network (WETNET) which aids the NWS river and flood forecasting program.

The majority of data from NWS stations are published by NOAA in monthly and annual climatic summaries, although WETNET data remain unpublished. Data from selected NWS stations are periodically published in specialized climatic reports.

Other precipitation data are collected at three sites by the Division of Water for hydrologic and hydraulic studies. Data from these stations are unpublished by NOAA, but monthly records remain filed at the division.

Fig. 14 shows the location of active NWS and Division of Water stations. (Amateur radio stations are not included, because the statewide network changes frequently.) Crompton and others (1986) list nine discontinued NWS stations not shown in fig. 14 or in table 4: Albion, Elkhart, Goshen Airport, Howe Military Academy, Kendallville, LaGrange, Notre Dame, Syracuse, and Topeka.

SURFACE-WATER HYDROLOGY

Drainage Characteristics

The surface-water system of the St. Joseph River basin is characterized by more than 200 natural lakes, approximately 27,000 wetlands, and low-gradient streams developed on outwash and till deposits. Part of the St. Lawrence drainage system, the St. Joseph basin drains 1699 mi^2 (square miles) in Indiana and 2586 mi^2 in Lower Michigan (fig. 2).

The St. Joseph River heads near Hillsdale, Michigan and flows generally to the southwest. In South Bend, Indiana, the river turns abruptly northward, then flows toward the northwest until it empties into Lake Michigan near Benton Harbor, Michigan.

Approximately 41 miles (about 19 percent) of the St. Joseph River mainstem lie in Indiana. The river enters Indiana in northern Elkhart County and exits in northern St. Joseph County. Average channel slope of this reach is 2.5 feet per mile, which is typical of most major Indiana rivers.

The chief tributary of the St. Joseph River in Indiana is the Elkhart River, which drains 699 mi^2, mainly in Noble and Elkhart Counties. Pigeon River (basin area: 374 mi^2) and Fawn River (basin area: 130 mi^2) drain parts of LaGrange and Steuben Counties before entering the St. Joseph River in Michigan. Other streams draining more than 100 mi^2 include North Branch Elkhart River (277), Turkey Creek (183), Little Elkhart River (129), Christiana Creek (128), and South Branch Elkhart River (114)[6].

Although drainage is not well developed due to the geologically recent deposition of glacial drift, a Horton-Strahler analysis of the basin (based on an examination of stream lengths and orders as described by Horton, 1945 and modified by Strahler, 1957) indicated a ''normal'' drainage system having a dendritic stream pattern. Drainage in the Indiana part of the basin is generally toward the northwest.

TABLE 4.
Official National Weather Service Stations

Station	Observation[1,2]	Gage[2,3]
Angola	P,T	R,NR
Goshen College	P,T	R,NR
LaGrange Sewage Plant	P,T	R,NR
Ligonier	(P)	(NR)
Kendallville	P	R,(NR)
Prairie Heights	P,T,A	NR
South Bend WSO	P,T,A	NR
Waterford Mills	(P,T,A)	(NR)

[1]Precipitation (P), Temperature (T), Additional parameters (A).

[2]Data not published by NOAA (( )).

[3]Recording precipitation gage (R) -- data automatically recorded at selected intervals; Non-recording precipitation gage (NR) -- data collected manually once daily.

Stream-flow Data

The U.S. Geological Survey (USGS), in cooperation with the State of Indiana, has collected daily stream-flow data since 1931 at a total of 16 gaging stations within the St. Joseph River basin. As of late 1986, 11 continuous-record stream gaging stations remained active (table 5). Stream-flow data are published in reports prepared annually by the USGS.

Records of stream discharge during periods of low flow and high flow have been collected at partial-record sites where daily discharge data were not available. Additional measurements of discharge have been obtained at miscellaneous sites. Data from partial-record and miscellaneous sites are primarily used in regional hydrology studies to estimate flow characteristics at both gaged and ungaged locations.

Table 5 lists Indiana's continuous-record gaging stations (both active and discontinued), as well as partial-record stations for which discharge-frequency data have been published (Stewart, 1983 and Glatfelter, 1984). Gaging locations are shown in fig. 14.

6 Drainage areas from Hoggatt (1975); may include drainage in Michigan.

TABLE 5. Stream-Flow Gaging Stations

Station Number[1,2]		Station Name	County	Total Drainage Area (mi²)	Period of Record[3]	Remarks[4]
04-097970		Lime Lake Outlet at Panama	Steuben	17.5	1969-	NC,OR
04-098000	D	Fawn River at Orland	Steuben	86.4	1943-47	Staff
04-09902050	L	Ewing Ditch near Angola	Steuben	4.0	1973-74	
04-09904050	L	Berlien Ditch near Angola	Steuben	3.2	1973	
04-099060	C	Pigeon Creek Trib. near Ellis	Steuben	1.22	1972-82	
04-099500	D	Pigeon Creek & Hogback L. near Angola	Steuben	103.	1945-74	NC; moved to 04-099510
04-099510		Pigeon Creek near Angola	Steuben	106.	1945-	NC
04-099610	D	Pretty Lake Inlet near Stroh	LaGrange	1.96	1963-80	NC
04-099750		Pigeon River near Scott	LaGrange	361.	1968-	NC
04-099805	L	Little Elkhart River near Middlebury	Elkhart	60.6	1971-79	
04-099808		Little Elkhart River at Middlebury	Elkhart	97.6	1979-	NC
04-099850		Pine Creek near Elkhart	Elkhart	31.0	1979-	NC
04-100000	D	Christiana Creek at Elkhart	Elkhart	127.	1947-52	Staff gage
04-10009550	L	Dove Creek near Valentine	LaGrange	2.20	1973-74	
04-100165	C	Wible Lake Inlet near Kendallville	Noble	2.47	1973-82	
04-100220	D	N. Br. Elkhart River near Cosperville	Noble	134.	1950-71	OR; wire-weight
04-100222		N. Br. Elkhart River at Cosperville	Noble	142.	1971-	OR
04-100252		Forker Creek near Burr Oak	Noble	19.2	1969-	OR
04-100295		Rimmell Branch near Albion	Noble	10.7	1979-	
04-100375	L	Solomon Creek near Syracuse	Elkhart	33.9	1973-79	
04-100465		Turkey Creek at Syracuse	Kosciusko	43.8	1969-	OR
04-100490	L	Turkey Creek near New Paris	Elkhart	169.	1960-69	
04-100500		Elkhart River at Goshen	Elkhart	594.	1931-	OR
04-100800	L,C	Yellow Creek at Dunlap	Elkhart	32.4	1971-	
04-101000		St. Joseph River at Elkhart	Elkhart	3370.	1947-	R
04-101300	L	Judy Creek at Roseland	St. Joseph	37.3	1973-79	

[1]Numbers are U.S. Geological Survey downstream order identification numbers.
[2]D = discontinued gaging station; L = lowflow partial-record station; C = crest-stage partial-record station.
[3]Refers to calendar year or portion thereof.
[4]NC = non-contributing: portion of drainage basin does not contribute directly to surface runoff; OR = occasional regulation of flow by lake control structure; R = flow regulated by power plant(s) above station.

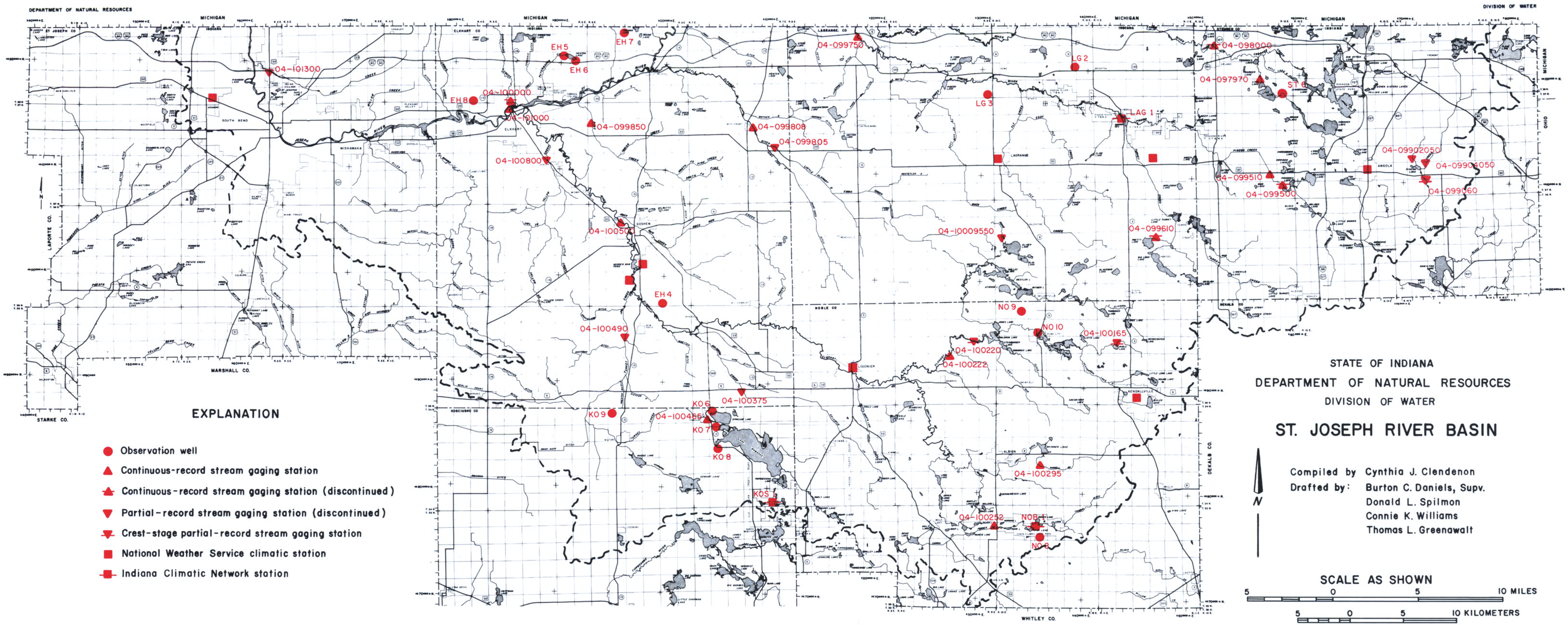

Figure 14. Hydrologic data collection stations

(Miscellaneous station listings and locations are not included. Five low-flow partial-record stations not tabulated or mapped are listed in Crompton and others, 1986.)

Although additions to the basin's stream gaging network currently are not feasible due to funding constraints, future network revisions may be necessary to meet expanding water management needs. In the past, the division primarily used discharge data for flood frequency determinations, hydraulic design studies, clearing and snagging studies, and monitoring of lake outflows. As water management programs develop further, data will also be needed for monitoring potential withdrawal impacts, determining low-flow characteristics, and relating stream-flow characteristics to local and regional hydrogeology. The addition of gages which can provide data useful for several purposes is the most desirable.

For example, a gage installed near the mouth of Christiana Creek could provide data useful in flood-flow calculations. The gage could also have benefits with respect to ground-water and surface-water quality issues, particularly if routine sampling were established. A gage on Solomon Creek, perhaps near the former low-flow partial-record site, could monitor flows in an extensively ditched agricultural area characterized by relatively flat topography and by the presence of both outwash and till deposits.

Partial-record sites may be sufficient for some specific uses. The effects of major ground-water and/or surface-water irrigation withdrawals on stream flow, particularly on smaller streams, could be monitored by two gages operated during the growing season—one upstream of the withdrawal site and one downstream. The interactions of ground water and surface water in undeveloped (and/or protected) wetland areas could best be determined by the installation of a stream gage and a series of observation wells.

Although such additions are not currently scheduled, the discontinuation of three stream gages is recommended: (1) Lime Lake Outlet at Panama; (2) Forker Creek near Burr Oak; and (3) Turkey Creek at Syracuse. Data from these gages, which are located immediately downstream of lake-level control structures, have little value for regional hydrology purposes. Monitoring lake outflows appears to be the major justification for maintaining these gages.

Lakes

Most of Indiana's natural freshwater lakes are found within an area that was covered by the joint terminal moraines of the Michigan, Erie and Saginaw lobes of the Wisconsinan glaciation (fig. 7). Sedimentation, natural erosion associated with drainage basin development, and artificial drainage have destroyed an unknown number of glacial lakes. However, more than 500 lakes formed by the irregular deposition of glacial drift, by the melting of buried isolated blocks of ice, or by erosion and subsequent damming of meltwater stream channels still remain in the interlobate moraines.

The densest zone of glacial lakes extends from eastern Fulton County to Steuben County and thus includes the southeastern half of the St. Joseph basin[7]. About 200 natural lakes of widely varying surface acreages and storage capacities are located within the basin, primarily within LaGrange, Steuben and Noble counties.

App. 6 lists 107 natural and manmade lakes having a surface area of at least 50 acres and/or a storage volume of at least 500 acre-feet (163 million gallons). Depth contour maps are available for most of these lakes, as well as 26 smaller lakes. (At least 65 in-basin lakes listed in IDNR files are neither tabulated in app. 6 nor mapped.)

The values most frequently ascribed to in-basin lakes include recreational use, residential development, and fish and wildlife habitat. Lakes also act as areas of ground-water recharge and discharge.

Estimated rates of leakage from and ground-water seepage into basin lakes are not available. However, the similarity of lake and observation well hydrographs for Heaton Lake (in northwest Elkhart County) indicate a hydraulic connection between the lake and surrounding sand and gravel outwash deposits. From an examination of hydrographs (fig. 15), static water levels in the two wells, and a generalized piezometric surface map (Plate 2), it appears that water levels of Heaton Lake reflect regional ground-water flow. The lake probably gains ground water along its northern shore, then loses water on its southern shore as the ground water continues to move downgradient. Ground water similarly seems to flow through Cedar Lake (in northeast LaGrange County). Here, water probably seeps from the lake into the ground-water system along the northwest (outlet) side, where ground-water levels are lower than lake levels (Bailey and others, 1985).

7 The second belt of glacial lakes, lying primarily within the Kankakee River basin, extends from northwest Fulton County to LaPorte County. The rest of Indiana's 1820 lakes, ponds and reservoirs are nearly all manmade and are scattered across the entire state.

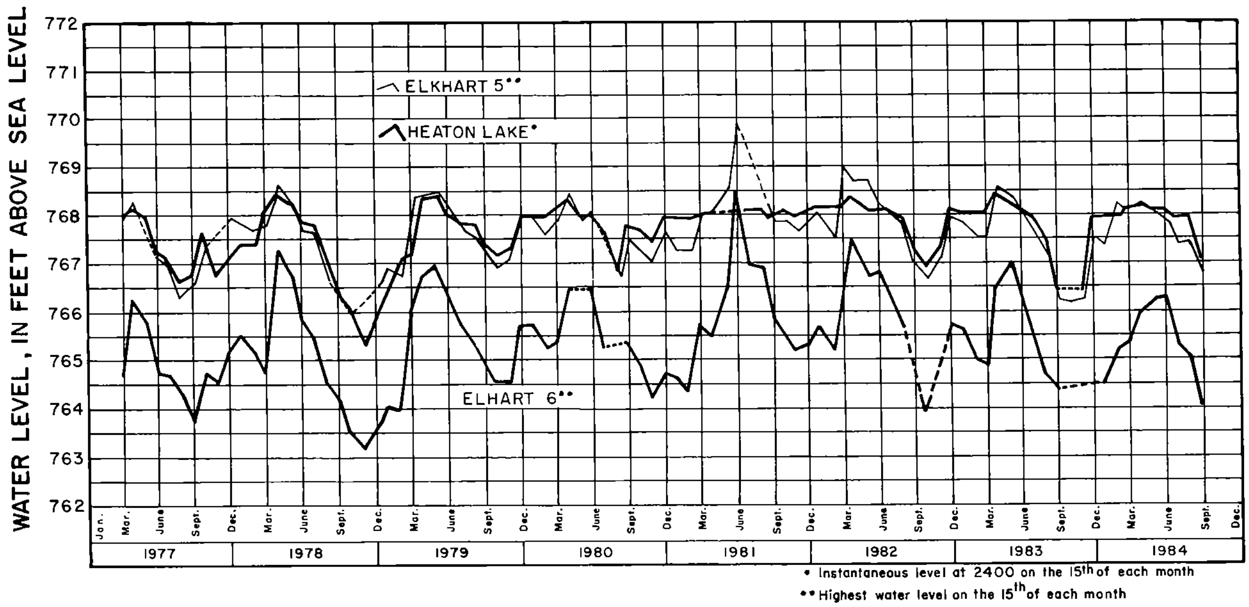

Figure 15. Correlation between Lake Levels and Ground-water Levels at Heaton Lake

Supply Potential of Lakes

Despite the tremendous storage capacities of lakes such as Wawasee and James, Indiana statutes effectively preclude the use of most public freshwater lakes as water supply sources.[8] In accordance with IC 13-2-11.1 and IC 13-2-13, lakes with a legally established average water level are to be maintained at that level. Temporary lowering of the established level requires approval by a local court and the Natural Resources Commission. Such approval is typically granted only for shoreline improvements or lake restoration procedures.

Even if state laws were amended to allow lowering of lake levels for supply purposes, treatment costs would limit non-drought uses to irrigation or livestock watering. In addition, pumpage-induced lowering of lake levels, even during non-drought periods, could not only affect water quality, fisheries habitat, and surrounding wetlands, but would be opposed by lakeside property owners.

The addition of lake storage (again assuming amendments to current lake laws) could similarly affect water quality and fish and wildlife habitat. Moreover, not only would the proximity of most homes to the lakeshore limit the amount of additional storage, but few lake-level control structures are designed to store water at elevations above the legal level. Increasing storage would therefore require the modification of existing structures.

Hence, given the current statutory and economic constraints and the abundance of ground-water and riverine supplies, the use of lakes as a water supply source in the St. Joseph basin is not a viable or a necessary alternative.

Lake Data

Historical records regarding lakes and drainage in Indiana date back to the early 1800s, but systematic records of lake levels have only been maintained for the past few decades. In 1943, the IDNR (formerly the Indiana Department of Conservation) entered into a cooperative agreement with the U.S. Geological Survey for the collection of water-surface elevations of selected Indiana lakes.

Lake data were primarily intended for use in the establishment of normal lake levels as defined by Indiana law (IC 13-2-13). Although legal levels are still occasionally established, stage data are presently

8 According to IDNR data files, significant water withdrawals only occur on three in-basin lakes: Wawasee, Syracuse, and Sylvan. These withdrawals (for golf course irrigation) have no observable effect on water-level hydrographs.

utilized for other regulatory and management purposes, such as monitoring maximum and minimum levels, determining the location of shoreline for lakeshore construction and engineering projects, defining a lake's recreation potential, or investigating water quality problems.

The U.S. Geological Survey currently monitors daily water levels of about 50 lakes in the St. Joseph basin. Historical water-level data are available for about 40 additional lakes. Nearly 80 lakes in the basin have legal levels (app. 6).

Wetlands

In general terms, inland wetlands occur where the water table is usually at or near ground surface. Because wetland soils are periodically or permanently covered by water, these areas support plants and animals specifically adapted for life in the water or in saturated soil.

Wetlands can be classified by dominant plants, soils, and frequency of flooding. The U.S. Fish and Wildlife Service (USFWS) utilizes a hierarchical classification that progresses from systems and subsystems to classes, subclasses, and dominance types (characteristic plants and animals)[9]. To more fully describe wetlands, users of the system can apply modifying terms to classes and subclasses (for water regime, water chemistry and soil type, for example).

Based on the USFWS classification scheme, wetland systems in the St. Joseph River basin are defined as lacustrine, riverine and palustrine. In general, the wetlands and deep-water habitats classified as lacustrine and riverine consist of lakes and reservoirs (within the normal pool contour), and stream channels (ranging from intermittent tributaries to major rivers). Palustrine areas include not only vegetated wetlands traditionally termed marshes, swamps, bogs, sloughs and prairies, but also isolated catchments, small ponds, islands in lakes or rivers, and parts of river floodplains. Palustrine wetlands may also include farmland, because land so designated would support hydrophytes (wetland plants) if it were not tilled, planted to crops, or partially drained.

Lacustrine and riverine systems often share common boundaries, and are generally bounded by palustrine systems on either side. However, some wetlands may occur as isolated systems, bounded on all sides by non-wetland areas.

Despite the historical draining, clearing and filling of wetlands to facilitate agricultural or other development, the St. Joseph basin contains an estimated 27,000 wetlands that cover approximately 200 mi^2 (table 6). As the table shows, palustrine wetlands constitute 98 percent of in-basin wetlands and 75 percent of total wetland acreage. The densest zone of lakes and wetlands occurs in the morainal areas of Steuben, Noble, and LaGrange counties.

Major functions of wetlands include fish and wildlife habitat, water quality improvement, flood-water storage, aquatic food chain support, sediment entrapment, shoreline stabilization, recreation, and ground-water recharge and discharge.

Although direct data are not available, riverine wetlands, and to a lesser extent, lacustrine and palustrine wetlands in the St. Joseph basin are expected to be areas of ground-water discharge, particularly along major river systems where ground-water flow patterns have been well established. Locally, water may seep from wetlands to ground-water, either as a general rule (refer to discussion in the "Lakes" section) or at certain times of the year. However, regional ground-water levels within the basin are probably maintained by rainfall-derived recharge.

Wetland Conservation

Six areas representing palustrine, lacustrine and/or riverine wetland systems are at least partially protected from harmful development under IDNR's wetland conservation program: Eagle Lake and Mallard Roost (Noble County); Jimmerson Lake, Marsh Lake, and Ropchan (Steuben County); and Lake Wawasee (Kosciusko County).

Other protected wetlands, some of which are dedicated nature preserves, occur in or near the Pigeon River State Fish and Wildlife Area and Pokagon State Park. Four additional nature preserves containing wetlands are located near Olin, High and Little Whitford lakes and along the South Branch Elkhart River. In Steuben County, two other preserves are located northeast of Orland and northeast of Angola.

Some wetlands associated with rivers and public freshwater lakes are protected under various state and federal laws dealing with dredging, filling, alterations

9 Cowardin and others (1979) present details of the classification system, which for most purposes replaces the wetland classification described in Shaw and Fredine (1956).

TABLE 6. Estimated Number and Acreage of Wetlands[1]

Wetland classification	Frequency in sample	Estimated frequency	% of total	Acreage in sample	Estimated acreage	% of total acreage
Lacustrine, limnetic, open water	11	396	1.44	868.30	31,258.80	24.66
Lacustrine, littoral, open water	1	36	0.13	2.10	75.60	0.06
Palustrine, aquatic bed	2	72	0.26	2.00	72.00	0.06
Palustrine, emergent	408	14,688	53.47	885.75	31,887.11	25.15
Palustrine, forested	181	6,516	23.72	1,103.66	39,731.76	31.34
Palustrine, open water	88	3,168	11.53	123.20	4,435.27	3.50
Palustrine, scrub shrub	61	2,196	7.99	518.36	18,660.92	14.72
Palustrine, unconsolid. bottom	2	72	0.26	0.30	10.80	0.01
Palustrine, unconsolid. shore	2	72	0.26	1.10	39.60	0.03
Palustrine, lower perennial, open water	7	252	0.92	16.50	593.85	0.47
Total	763	27,468	100.00	3,521.27	126,765.71	100.00

[1]Division of Fish and Wildlife estimates, based on maps and aerial photographs obtained from U.S. Fish and Wildlife Service, National Wetlands Inventory. Estimates were derived from a 3% random sample of each of 49 legal townships encompassing the St. Joseph basin.

of water level, changes to shoreline or lake-bed, and other modifications that are detrimental to fish, wildlife and botanical resources.

Most wetlands in the basin, however, are not protected under state or federal laws. For example, less than 3 percent of total wetland acreage is protected under IDNR's wetland conservation and nature preserve programs. In non-protected areas, wetland acreage continues to be drained or filled each year, primarily for agricultural development (J.F. New, IDNR Division of Fish and Wildlife, personal communication, 1986). In addition, ponds dug in wetland areas (as mapped on USGS 7.5-minute topographic quadrangles) are used as sources of irrigation water, particularly in northern LaGrange and northern Steuben Counties. High-capacity wells (mainly for irrigation, rural, or public supply uses) are also located in wetland areas as based upon IDNR water use information and USGS topographic maps.

Stream-flow Characteristics

Net precipitation is the limiting factor of stream flow. However, factors that affect the spatial and temporal distribution of flow (and hence largely determine the water supply potential of given stream reaches) include the following: climate (evapotranspiration, storm events); soils and land cover (vegetation, lakes and wetlands, impervious surfaces); topography and physiography (including drainage area, drainage density, channel morphometry); geology (surficial and bedrock); ground-water movement; and manmade modifications to surface- and ground-water systems (stream channelization, instream dams, diversions, and pumpage).

Geographic variations of these factors account for the diversity of stream-flow characteristics within and among basins. Quantitative interpretations of flow regimes require intensive studies of sites on both gaged and ungaged streams. Although some site-specific data have been collected in parts of the St. Joseph River basin, the complex combination of factors controlling stream discharge precludes regionalized extrapolations from such data. However, selected hydrologic parameters derived from discharge records provide a framework for characterizing the basin's surface-water system.

Average Flows

Of all hydrologic parameters, average (mean) discharge is the most easily recognized and one of the most widely used. The combined effects of the factors listed above are reflected in this parameter, which can be defined as follows: 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 it at a uniform rate over the same period, that rate would be the average flow. This flow represents the theoretical upper limit of the long-term yield which can be developed from a stream, even with regulation.

Long-term (period of record) average daily discharge is given in table 7 for continuous-record gaging stations. Average discharge, the arithmetic mean of all daily flows, is greater than the median flow (the discharge equalled or exceeded 50 percent of the time). Based on data from Stewart (1983), average discharges at continuous-record stations in the St. Joseph basin are equalled or exceeded 30 to 40 percent of the time.

Low Flows

Low-flow discharge information is essential to the planning, management and regulation of activities associated with surface-water resources. Low-flow data are used in the design and operation of wastewater treatment facilities, power plants, engineering works (such as dams, reservoirs and navigation structures), and water supply facilities. Low-flow information is also used to evaluate water quality and its suitability for various uses. Some low-flow parameters may also be used in the development of regional draft-storage relations, in the forecasting of seasonal low flows, as indicators of the amount of ground-water influx to streams, or as the basis for environmental decisions regarding wetland preservation.

Low-flow characteristics are commonly described by points on low-flow frequency curves prepared from daily discharge records at continuous-record gaging stations. Correlation techniques can be used to estimate curves, or selected points on curves, for stations where short-term records and/or base-flow measurements are available.

Frequency curves are developed from annual minimum flows for selected numbers of consecutive days. 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 average) flow having a 30-year recurrence interval, and the annual minimum 7-day average flow having a 10-year recurrence interval.

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 (that is, the annual lowest mean daily flow having a 1-in-30 chance of occurrence in any given year). In this report, the 1-day, 30-year flow indicates the dependable supply of water without storage, and is discussed further in the "Future Water Resource Development" section.

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

In Indiana, the 7-day, 10-year low flow is the legal index for water quality standards. This 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. As the need for integrated water resource management increases, the 7-day, 10-year low flow or other low-flow parameters may be utilized by the IDNR to establish minimum flows of selected streams.

Table 7 presents annual 7-day, 10-year low flows as reported in Stewart (1983). Stream flows at continuous-record stations are greater than these values an average of 98.6 percent of the time. Estimates of 1-day, 30-year low flows (the lower of the two flows) are given in table 31 later in this report.

Extreme Flows

Table 7 includes extremes for the periods of record at continuous-record gaging stations. Maximum discharge is the instantaneous maximum corresponding to the crest stage obtained by use of a water-stage recorder (Glatfelter and others, 1985). Minimum discharge may either be an instantaneous minimum or a minimum daily mean.

The discharges listed in table 7 may not be representative of extremes under current conditions. For example, the minimum for Elkhart River at Goshen was recorded in 1964 during regulation by three upstream power plants which today are no longer in operation. Extremes for other gages may similarly reflect man-made regulation more closely than natural conditions.

Surface- and Ground-Water Interactions

Hydraulic interactions between surface- and ground-water systems account for much of the diversity of stream-flow characteristics, particularly low flows, within the St. Joseph basin. Hydrograph separation techniques and comparisons of flow duration curves have allowed inferences regarding system interactions at selected continuous-record gaging stations. Recent estimates of ground-water gains or losses to reaches of Pigeon River, Fawn River, Turkey Creek, and their tributaries have provided additional data for areas in LaGrange, Elkhart and Kosciusko Counties where surface- and ground-water pumpage is extensive (Bailey and others, 1985; Lindgren and others, 1985).

Hydrograph Separation

A stream-flow hydrograph is a graphical plot of stream discharge versus time. An example is shown in app. 7 for the Little Elkhart River at Middlebury and a brief explanation of hydrograph components is in app. 8. Through the process of hydrograph separation, an analysis has been made of the stream-flow characteristics at continuous-record gaging stations in the St. Joseph basin. These analyses result in dividing stream discharge into its component parts: surface runoff, interflow, and ground-water flow (base flow). The path, or combination of paths, that water follows during a precipitation event is dependent upon a number of variables, including the intensity of precipitation, soil moisture conditions, soil infiltration capacity, underlying geology, and areal basin characteristics.

Overland flow is the water that flows over the land surface to small channels that eventually reach the main stream channel. The combination of overland flow and precipitation that falls directly upon the stream is defined as surface runoff.

Interflow occurs when rainfall that has infiltrated into the soil moves laterally through the soil to the stream. For convenience, interflow and surface runoff are sometimes combined into one category, direct runoff.

Base flow represents the portion of stream discharge which is contributed from the ground-water system.

TABLE 7. Selected Stream-Flow Characteristics[1]

Station Number[2]		Station Name	Maximum Observed Discharge[3]	Minimum Daily Discharge[3]	Average Discharge[3]	7-Day, 10-Year Low Flow[4]
04-097970	OR	Lime Lake Outlet at Panama	46	0	7.7	0
04-098000	D	Fawn River at Orland	205	2.5	-	-
04-099500	D	Pigeon Creek & Hogback Lake nr. Angola	744	3.4	73.	6.0
04-099510		Pigeon Creek near Angola	795	3.4	78.9	5.8
04-099610	D	Pretty Lake Inlet near Stroh	33	0	0.48	0
04-099750		Pigeon River near Scott	2,370	42	361	86.
04-099808		Little Elkhart River at Middlebury	1,690	32	100.4	-
04-099850		Pine Creek near Elkhart	509	3.8	19.9	-
04-100000	D	Christiana Creek at Elkhart	452	40	-	-
04-100220	OR,D	N. Br. Elkhart R. near Cosperville	717	2.2	106	4.5
04-100222	OR	N. Br. Elkhart R. at Cosperville	919	2.4	137	4.0
04-100252	OR	Forker Creek near Burr Oak	338	0.13	17.8	0.2
04-100295		Rimmell Branch near Albion	397	0.14	-	-
04-100465	OR	Turkey Creek at Syracuse	170	0.82	36.8	1.3
04-100500	OR	Elkhart River at Goshen	6,180	7.0	514	81.
04-101000	R	St. Joseph River at Elkhart	18,600	336	3176	818.
Partial-Record Stations						
04-09902050		Ewing Ditch near Angola	-	-	-	0
04-09904050		Berlien Ditch near Angola	-	-	-	0
04-099805		Little Elkhart River near Middlebury	-	-	-	8.0
04-10009550		Dove Creek near Valentine	-	-	-	0
04-100375		Solomon Creek near Syracuse	-	-	-	4.9
04-100490		Turkey Creek near new Paris	-	-	-	14.0
04-100800		Yellow Creek at Dunlap	-	-	-	1.4
04-101300		Judy Creek at Roseland	-	-	-	2.4

[1]All values in cubic feet per second; multiply by 0.646317 to obtain million gallons per day.

[2]D = Discontinued gaging station; OR = occasional regulation; R = regulation.

[3]Active station data from Glatfelter and others (1985) and through water year 1984; discontinued station data given per period of record.

[4]All values from Stewart (1983) and through climatic year 1978, except stations 04-099500 D and 04-100220 D, which are from Rohne (1972) and through climatic year 1967.

The amount of base flow relative to direct runoff is a measure of the degree to which stream flow is sustained by ground-water contribution. Graphical techniques exist to separate base-flow from the stream-flow hydrograph. App. 7 illustrates a hydrograph separation for a one-year period (1984) at the Middlebury gage.

This graphical technique was used to separate annual hydrographs for six gages located on streams having little to no artificial regulation. Separations were made for a normal year (1984) and a wet year (1982) to determine if any significant difference existed in the percent of ground-water contribution. The results are shown in table 8.

Examination of the values of ground-water contribution shows that these six streams can be divided into two distinct groups. Rimmell Branch and Forker Creek have values of ground-water contribution roughly equal to 30 percent. In contrast, Pine Creek and the Pigeon, Little Elkhart, and North Branch Elkhart Rivers have ground-water components of approximately 70 percent (table 8).

In table 9 under the heading of major surficial materials, the six streams are again divided into the same two groups. As the table shows, Rimmell Branch and Forker Creek represent basins which are dominated by till, whereas the other four streams drain areas mainly composed of outwash.

With regard to the six gaged streams presented here, differences in geologic materials appear to be the most significant control of ground-water contribution to stream discharge. The two basins which are dominated by till have low infiltration capacity; therefore, most precipitation is routed to the surface drainage network and subsequently leaves the basin as surface runoff. On the other hand, the four basins dominated by outwash have relatively high infiltration capacities. In these basins, precipitation is readily accepted into the well-drained soils. With downward percolation, the water becomes part of the ground-water system and is ultimately delivered to the local streams as ground-water discharge.

Additional hydrograph separations were completed for four gages located on streams whose low flows may be affected by upstream hydroelectric plants or lake regulation (app. 8). The ground-water component of these streams, whose basins are dominated by outwash, average 70 percent. This percentage equals the average value derived for non-regulated or partially regulated streams draining other outwash-dominated areas (table 8).

Flow Duration

The flow duration curve is a cumulative frequency curve that shows the percent of time that specified discharges are equalled or exceeded during a given

TABLE 8. Hydrograph Separation for Unregulated to Partially Regulated Streams

			1982[a] (Wet)					1984[a] (Normal)				
Station Number	Station Name	Drainage Area (Mi²)	RO[b] (in)	DR[c] (in)	GW[d] (in)	DR %	GW %	RO[b] (in)	DR[c] (in)	GW[d] (in)	DR %	GW %
04099750	Pigeon R. near Scott	361	19.9	5.20	14.70	26.1	73.9	13.31	3.80	9.51	28.5	71.5
04099808	Little Elkhart R. at Middlebury	97.6	16.75	4.05	12.70	24.2	75.8	11.85	2.74	9.11	23.1	76.9
04099850	Pine Ck. near Elkhart	31.0	11.92	3.68	8.24	30.9	69.1	7.25	1.89	5.26	26.1	73.9
04100222	North Branch Elkhart R. at Cosperville (partially)	142	17.82	6.57	11.25	36.9	63.1	12.73	4.85	7.88	38.1	61.9
04100252	Forker Ck. near Burr Oak (partially)	19.2	20.49	15.00	5.49	73.2	26.8	12.73	9.61	3.12	75.5	24.5
04100295	Rimmell Branch near Albion	10.7	17.57	11.99	5.58	68.2	31.8	12.50	8.78	3.72	70.2	29.8

[a]Water Years.
[b]RO = Total runoff.
[c]DR = Direct runoff.
[d]GW = Ground water or base flow.

period of record. For example, daily mean flows of Pigeon River near Scott were at least 97 ft^3/s during 99 percent of the time for water years 1972-84 (as derived from fig. 16). Daily flows for this period exceeded 1400 ft^3/s only 1 percent of the time.

Duration data are used in connection with water supply and hydroelectric power studies, industrial and waste treatment plant siting, reservoir design and pollution control. Because a duration curve is derived from all selected discharges for the period of record, the time sequence of flow occurrence is obscured. Hence, a duration curve should only be taken as a probability curve that the flow distribution over several years will be approximately that of prior years, and not as a curve for one or a few years (Rohne, 1972).

The shape of the duration curve is an index of the natural surface-water and ground-water storage within a basin. The more horizontal the curve, the greater is the storage effect, and the greater the potential for high sustained yield from both surface and ground water. By plotting duration curves on a per-square-mile (unit) basis, comparisons can be made among streams having different drainage areas. The unit curves in fig. 16 exemplify three typical flow patterns found throughout the St. Joseph basin.

The flattened duration-curve slope for Pigeon River indicates the moderating effects of natural storage. The presence of a broad floodplain (often bordered by wetlands) and the occurrence of well-drained, loamy soils on permeable valley-train deposits provide large amounts of flood-water storage. These same factors, particularly the presence of transmissive outwash sands and gravels, also facilitate ground-water seepage into the river.[10] The curve for Pigeon River near Scott reflects both the attenuated peak flows (by its relatively flat upper end) and sustained low flows (by its flat lower end). Curves for other rivers developed on outwash deposits would probably exhibit similar overall slopes.

The duration curve for North Branch Elkhart River at Cosperville illustrates the combined effects of natural drainage characteristics and artificial regulation. The high-flow end of the Cosperville curve closely resembles that of the Scott curve, probably due to the similar occurrence of upstream wetlands, vegetation, and large amounts of channel and floodplain storage. Although the presence of loam, silt and muck soils on clayey tills in some parts of the drainage basin may partially account for lower low flows, operation of the Waldron Lake control structure less than 3 miles upstream probably explains the sharp drop in unit flows with exceedence percentages greater than 98 (and particularly greater than 99.5).

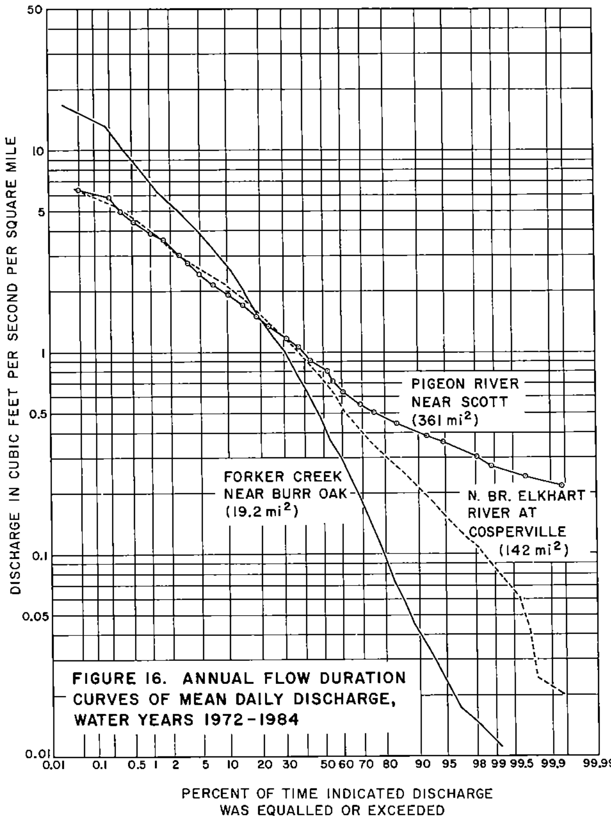

Figure 16. Annual Flow Duration Curves

The wide range of discharges along Forker Creek, as depicted by the steep duration-curve slope, can be attributed primarily to natural factors. The small drainage basin, narrow channel, and clayey soils on glacial till are largely responsible for the poorly sustained stream discharges. However, operation of the Miller Lake control structure about 400 feet upstream of the gage can further reduce stream flows, particularly when the control elevation is increased to maintain upstream lake levels for recreational purposes.

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10 Although direct determinations were not made at the Scott gage, discharge measurements along upstream reaches indicated a uniform rate of ground-water seepage from Mongo to Howe (Bailey and others, 1985). Similar rates are expected further downstream.

Data Selection

Unit flow duration curves (fig. 16), selected streamflow characteristics (table 7), percentage estimates of ground-water contribution to stream flow (table 8), drainage basin characteristics (table 9), underlying aquifer systems and additional data were used to examine the integrated effects of geology, physiography, topography, soils, vegetative cover, land use and artificial modifications on stream-flow characteristics in the St. Joseph basin. Available data for six continuous-record gages were utilized.

Gaging records for Pigeon River near Scott were considered the most reliable and indicative of natural flow patterns. (The presence of three dams between Mongo and Howe, and surface- and ground-water pumpage from Mongo downstream to the Michigan-Indiana state line should be considered during site-specific analysis, however.)

Flow characteristics of the St. Joseph River at Elkhart and Elkhart River at Goshen were not considered for this discussion because of the presence of upstream hydroelectric power plants on the St. Joseph River, low-head dams from previously operated hydropower facilities on the Elkhart River, and urbanization at both sites. However, because the effect of upstream facilities on duration characteristics has not been quantitatively determined, and because the water supply of these rivers is quite large, unit flow duration curves for a selected base period (1972-84) were included in app. 9.

Two gages (North Branch Elkhart River at Cosperville and Forker Creek near Burr Oak) are located downstream of two lake chains with artificially controlled water levels. Data from these gages were primarily summarized to illustrate the effects of man-made regulation. Gaging records for Lime Lake Outlet at Panama, Pigeon Creek near Angola, and Turkey Creek at Syracuse were not considered because of lake regulation and the data's lack of utility in defining regional hydrology.

Stream flows at three gages (Little Elkhart River at Middlebury, Pine Creek near Elkhart, Rimmell Branch near Albion) are unaffected by man-made regulation. However, available data are of limited use because of the short periods of published discharge record (water years 1979-84). Although records are not concurrent, data from partial-record stations on Little Elkhart River, Turkey Creek, and Solomon Creek were used to supplement low-flow information and to represent unregulated flow conditions.

Supply Potential of Streams

Based on available hydrologic, geologic, and geomorphic data, it is evident that base flows on non-regulated streams are well sustained in the following river valleys: Fawn and Pigeon Rivers in LaGrange County; Little Elkhart River in LaGrange and Elkhart Counties; and Solomon and Turkey Creeks, primarily in Elkhart County. Geologic and topographic factors largely account for the sustained flows.

In general, these drainage basins have developed on outwash deposits (primarily valley trains) which roughly coincide in areal extent with the Howe Aquifer System and tributary valley portions of the St. Joseph Aquifer System (Plate 1). The drainage basins are characterized by relatively low topographic relief and medium- to coarse-grained, loamy soils. Major soils, generally of the Oshtemo-Fox association (well drained) and Sebewa-Gilford-Homer association (poorly drained) are classified by the Soil Conservation Service as Group B soils having above-average infiltration. Agriculture constitutes the major land use in these major river basins, but forested areas and wetlands occur along some reaches of the Pigeon, Fawn and Little Elkhart Rivers and Turkey Creek.

On a unit basis, published 7-day, 10-year low flows for unregulated, gaged sites are highest for Pigeon River near Scott, Solomon Creek near Syracuse, Little Elkhart River near Middlebury, and Turkey Creek near New Paris. Hydrograph separation for the Pigeon and Little Elkhart rivers shows a 75-percent ground-water contribution to stream flow. Unit flow duration curves for the two gages closely correspond (except for high flows on Little Elkhart having exceedence percentages less than one, which more closely resemble those of the Forker Creek curve).

Although no attempt was made to estimate natural flow characteristics for the St. Joseph and Elkhart Rivers, sustained base flows are expected because of the presence of transmissive valley-train and outwash-plain deposits and sandy (St. Joseph) or loamy (Elkhart) soils in downstream portions of these two large basins (which correspond to the main St. Joseph Aquifer System). Unit flow duration curves for the regulated St. Joseph and Elkhart Rivers (app. 9) resemble the Pigeon Creek curve (fig. 16), and average ground-water contribution to stream flow (70 percent) is only slightly less than average estimates for the Pigeon River and Little Elkhart River gages.

Although data is sparse, base flows of selected tributaries of the St. Joseph River in northwest Elkhart County appear to be moderately to well sustained by

TABLE 9. Selected Basin Characteristics

Gage & County	Drainage Area[1] (mi²)	Drainage (Density)	Max. Basin Relief[2] (ft)	Relief Ratio[2]	Ruggedness Number	Basin Shape[2]	Major Surficial Materials[3]	Major Soil Associations[4]
Rimmell Branch near Albion (Noble)	10.7	2.16	60	10.0	130	.30	Till (some outwash, muck near gage)	Morley-Blount-Pewamo
Forker Creek near Burr Oak (Noble)	19.2	5.0*	100	10.4	500	.20	Till (some outwash)	Morley-Blount-Pewamo
Pine Creek near Elkhart (Elkhart)	31.0	5.7	170	15.7	969	.27	Outwash Ice-contact(kame) Till	Oshtemo-Fox, Miami-Crosier Brookston-Riddles
Little Elkhart R. at Middlebury (Elkhart)	97.6	3.0	125	8.9	375	.60	Outwash (valley train)	Oshtemo-Fox (Elk.), Sebewa-Gilford-Homer (Lag.)
North Branch Elkhart River at at Cosperville (Noble)	142	3.5*	150	4.2	525	.68	Outwash Till (some ice-contact)	Oshtemo-Fox, Miami-Crosier-Brookston-Riddles
Pigeon River at Scott (LaGrande)	361	1.6	295	8.4	472	.29	Outwash (valley train)	Oshtemo-Fox, (3 other associations)

*Values estimated from limited data set

[1]Glatfelter and others (1985).
[2]Maximum basin relief - the difference of the elevations of the highest and lowerst points in the basin; relief ratio - maximum basin relief divided by basin length; ruggedness number - maximum basin relief times drainage density; basin shape - basin area divided by basin length squared; basin length - the straight line distance, measured parallel to the channel, between the basin mouth and the drainage divide.
[3]Johnson & Keller (1972).
[4]Soil Conservation Service (1982).
[5]Max. basin relief - the difference, in feet, of all elevations of the highest and lowest points in the basin; basin length (L) - the straight line distance, measured parallel to the channel, between the basin mouth and the drainage divide.

ground-water contribution. Discharge measurements along lower reaches of the Elkhart River and Christiana, Baugo and Pine Creeks showed that stream segments not affected by heavy ground-water pumpage were gaining segments (Imbrigiotta and Martin, 1981). Hydrograph separation for Pine Creek near Elkhart (table 8) showed about a 71-percent ground-water contribution to stream flow, approximately equal to average percentages obtained for the Elkhart River at Goshen and the St. Joseph River at Elkhart, Indiana and Niles, Michigan (app. 8).

Drainage basins from Steuben County southwestward to the southern St. Joseph basin boundary in Noble County generally are characterized by variable relief and clayey soils on till deposits which roughly coincide in areal extent with the Kendallville Aquifer System (Plate 1). Although natural flow data are lacking, base flows appear to be moderately to poorly sustained, depending on local geologic, geomorphic and manmade conditions. The relatively small ground-water component of stream flow (30 percent) and the presence of Group C soils (below-average infiltration) on till are reflected in the steep duration-curve slopes for Forker Creek (fig. 16) and Rimmell Branch (not shown, but very similar). Stream-flow characteristics for the North Branch Elkhart River and Pigeon Creek near Angola include a moderate amount of ground-water contribution (62 to 68 percent), but moderately to poorly sustained unit low flows, possibly due to upstream lake effects.

Surface-Water Quality[11]

The water quality of rivers, lakes and streams in the St. Joseph River basin is protected under Indiana Water Pollution Control Board Regulations 330 IAC 1-1 and 330 IAC 2-4. These state regulations designate surface-water use for aquatic life, public supply, industry, agriculture, recreation, limited use and exceptional use. App. 10 summarizes recommended water quality standards from the U.S. Environmental Protection Agency (USEPA), Indiana Environmental Management Board, and the Indiana Water Pollution Control Board for aquatic life, public supply, irrigation and stock.[12] (Standards for industries are not listed, because the water quality required varies widely depending on the manufacturing process and because industrial standards generally are less stringent than for other uses.)

Standards for recreation include regulations that maintain the aesthetics of a body of water and that protect the public from possible health risks. Concentrations of fecal coliform bacteria are used to monitor the suitability of surface water for body-contact recreation. More stringent limits for fecal coliform have been established for whole-body contact recreation (swimming) than for partial-body contact (wading). All lakes and reservoirs and a few streams in Indiana (including the St. Joseph River) are designated for whole-body contact recreation from April through October, and for partial-body contact recreation during the cool season. The remainder of the streams in Indiana are designated for partial-body contact recreation year-round.

Regulations to protect warm- and cold-water fish communities include limits on pH, temperature, and concentration of dissolved oxygen and toxic substances. More stringent regulations (330 IAC 2-4) apply to natural spawning, rearing and imprinting areas and migration routes for salmonid fishes (app. 11). Portions of the St. Joseph River, as well as other stream reaches in extreme northwest Indiana must meet these higher standards.

Waters designated as "limited use" have naturally poor chemical quality, naturally poor physical conditions (including lack of sufficient flow), irreversible man-induced conditions, or any combination of these factors. Such streams are incapable of supporting diverse communities of fish and other aquatic life for much of the year. Two waterways in the St. Joseph basin, both in southwestern Elkhart County, have been designated for limited use: (1) Berlin Court Ditch from the Nappanee sewage treatment plant to two miles downstream and (2) an unnamed tributary and Werntz Ditch from the Wakarusa sewage plant to the confluence of Werntz Ditch and Baugo Creek.

Exceptional-use streams are high-quality waters which provide exceptional aquatic habitat, support unique assemblages of aquatic organisms, or are integral features of protected or particularly scenic areas. However, no exceptional-use streams have been designated in the basin.

11 Data in this section were taken primarily from publications of the Indiana Department of Environmental Management, Indiana Stream Pollution Control Board, Indiana State Board of Health, Michiana Area Council of Governments, U.S. Environmental Protection Agency (see references), and personal communication with Steve Boswell and Dennis Clark, IDEM.

12 State water quality rules are presently being recodified by the Indiana Department of Environmental Management.

River Quality Data

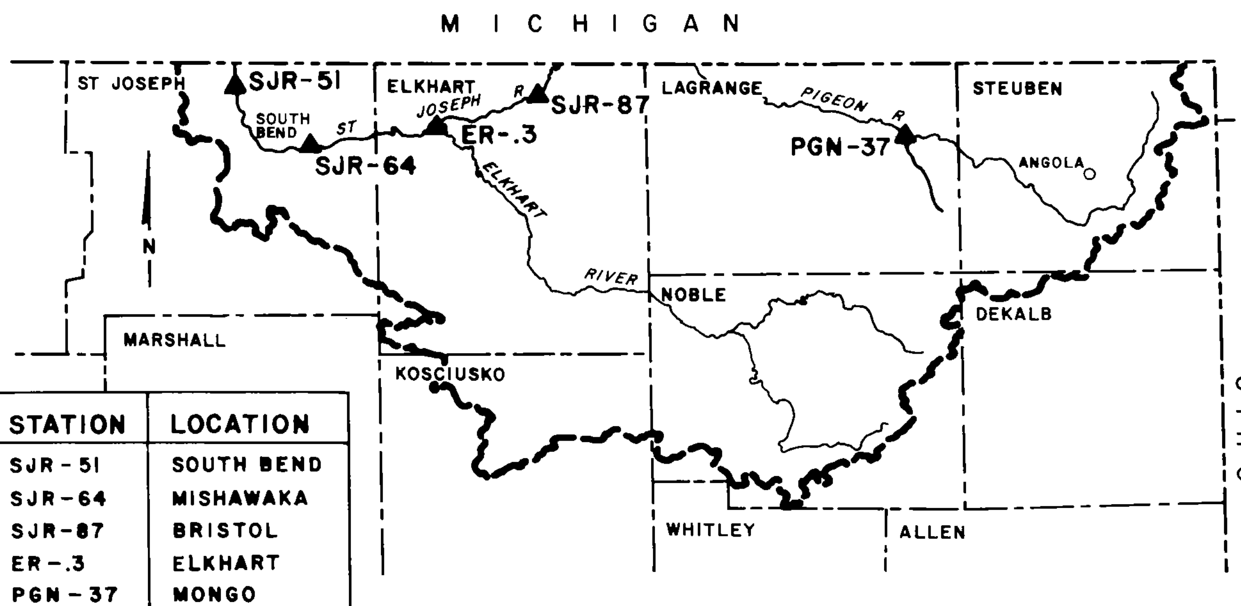
The Indiana Department of Environmental Management (IDEM) routinely monitors water quality at four stations in the St. Joseph River basin: St. Joseph River at Bristol, Mishawaka, and South Bend; and Elkhart River at Elkhart (fig. 17). A temporary station is located on Pigeon River at Mongo for IDNR fisheries purposes. These stations are part of a statewide surface-water quality monitoring network established in 1957 by the Indiana State Board of Health (now operated and maintained by IDEM). Physical, chemical and bacteriological data are used to detect water quality trends, support pollution abatement activities and enforcement actions, locate potential pollution sources, and obtain background data for surface-water users.

Since 1979, periodic sampling has been conducted at selected stations throughout Indiana (including Bristol and South Bend) to monitor the composition of fish and aquatic invertebrate communities and to detect toxic materials in fish flesh. Additional stream monitoring activities in the basin (and statewide) have included primary productivity studies, sediment sampling, and habitat evaluations, as well as bioassays of wastewater effluents.

Comprehensive water quality data are available from two IDEM surveys (1985-86) of at least 40 sites along the St. Joseph River. Data from these surveys are needed primarily for water quality modeling and wasteload allocations as they relate to the 1985 salmonid designation. In 1977, the Michiana Area Council of Governments collected data on the St. Joseph and Elkhart rivers and their major tributaries to provide background information used in developing a waste-treatment management plan (MACOG, 1978).

Rivers and Streams

All available data indicate that water quality in the St. Joseph and Elkhart rivers is generally good. For the most part, standards for public drinking water and aquatic life have not been exceeded at the South Bend and Bristol monitoring stations during the period 1975-84. For the same period, ammonia and BOD (biochemical oxygen demand) data from the South Bend and Bristol stations were studied by the IDEM in an effort to statistically describe water quality trends. Results show that ammonia concentrations remained well below the recommended criteria and BOD levels decreased. In general, low BOD levels indicate a low amount of oxygen-consuming wastes in a river, which allows for greater availability of oxygen for aquatic life.



STATION	LOCATION
SJR - 51	SOUTH BEND
SJR - 64	MISHAWAKA
SJR - 87	BRISTOL
ER - .3	ELKHART
PGN - 37	MONGO

Figure 17. Location Map of IDEM Surface — Water Quality Monitoring Stations

Since monthly sampling of dissolved oxygen by IDEM comprises a single measurement, diurnal variations are not detected. However, seasonal variations, due primarily to the inverse relation between oxygen concentrations and water temperature, can be generalized. As fig. 18 shows, monthly dissolved oxygen concentrations averaged over the period 1975-84 for monitoring stations on the St. Joseph and Elkhart Rivers have remained above the 5.0 milligrams per liter limit, a critical amount for most fish life, and 6.0 milligrams per liter for salmonid fish (see app. 11). The summer 1985 IDEM survey of the St. Joseph River revealed dissolved oxygen concentrations well above recommended limits at all sites sampled during 24-hour periods.

Biological studies by the IDEM have indicated diverse benthic invertebrate and fish communities at the Bristol and South Bend stations. IDNR surveys show that quality fisheries for many of Indiana's sport fish (bass, muskie, pike, and walleye, for example) are found throughout the basin. Put-and-take trout fisheries are maintained by the IDNR in numerous lakes and streams. According to reports of local fishermen, small isolated populations of trout are reproducing naturally in some tributaries of the St. Joseph and Elkhart Rivers (Thomas Lauer, IDNR Division of Fish and Wildlife, personal communication, 1986).

Michigan and Indiana are cooperatively working to establish and maintain a salmonid fishery in the St. Joseph River. A cold-water hatchery (Twin Branch) has been constructed near Mishawaka, and fish ladders are being built over hydroelectric dams at Mishawaka and South Bend, as well as in Michigan. In 1985, the St. Joseph River below the Twin Branch dam and downstream to the state line was upgraded to a migration route for salmonid fish (app. 11). Consequently, a more stringent water quality regulation (330 IAC 2-4) now applies to this reach.

Regulations for whole-body contact recreation have been met at the Bristol station in the St. Joseph River since at least 1975. However, fecal coliform concentrations in the river show a marked increase in water samples analyzed from Elkhart downstream to the Indiana-Michigan state line. Despite significant improvement in fecal coliform counts at the South Bend station, violations for whole-body contact continue to occur. Violations for partial-body contact recreation on the Elkhart River have occurred less frequently since 1982. Continued improvements are anticipated along both rivers as combined sewer overflows are controlled and sewage treatment facilities are upgraded.

For the most part, concentrations of metals such as cadmium, lead and mercury have been below established limits at the Bristol and South Bend stations for the past 10 years, as well as during the 1985 survey. Concentrations of metals, pesticides and polychlorinated biphenyls (PCBs) were below detection limits during the 1985 survey in sediment of the mainstem St. Joseph River near Elkhart, Mishawaka and South Bend; however, low levels of PCBs were detected in sediment samples near the mouths of five major tributaries.

No detectable levels of dioxin (TCDD) were found in fish from the St. Joseph River during a 1982 IDEM-USEPA study. However, analyses of fish for toxic substances have shown violations of Food and Drug Administration action levels for PCBs (1983-85) and the pesticide chlordane (1979-84) downstream of South Bend. A fish consumption advisory was issued in 1985 for carp, smallmouth bass and redhorse suckers taken

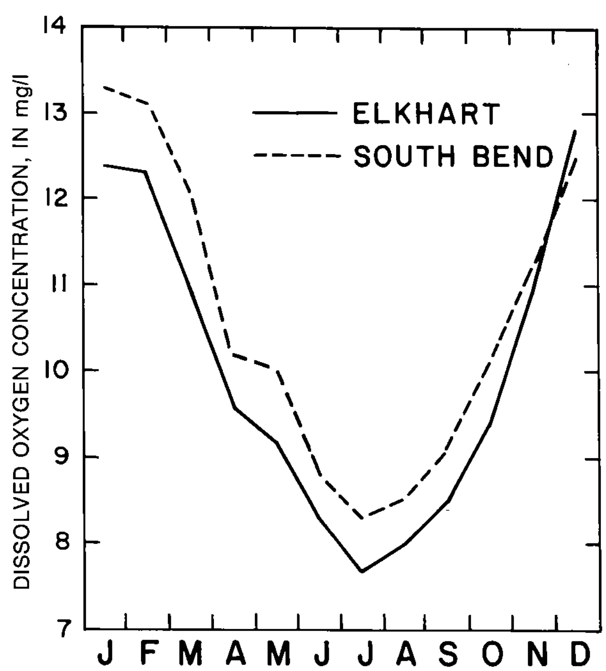


Figure 18. Average Monthly Concentrations of Dissolved Oxygen for St. Joseph and Elkhart River Water Quality Monitoring Stations Based on IDEM Monthly Sampling 1975-1984

from the St. Joseph River downstream of South Bend. Further research is being conducted to trace the sources of PCBs so that corrective action can be taken.

Lakes

Since 1970, most public freshwater lakes in Indiana have been sampled periodically by the Indiana State Board of Health (now by IDEM) for physical, chemical and biological parameters. Data obtained were used to develop a trophic classification system[13], as mandated by Section 314(a) of the 1977 amendment to the Federal Clean Water Act (PL 92-500). The IDEM further identified seven lake management groups based on a lake's trophic state, acreage and mean depth. Intensive surveys by the IDEM and U.S. Environmental Protection Agency (USEPA) further characterized the trophic state of selected lakes, particularly those exhibiting advanced eutrophy, and outlined restoration measures for problem lakes.

Lakes in the St. Joseph River basin have been classified into all trophic classes and assigned to all management groups (app. 6), thus indicating a wide range of trophic characteristics and lake morphometry. Seventy-nine percent of the in-basin lakes of at least 50 acres or 500 acre-feet have been designated as Class I or Class II (app. 12). These lakes rarely have water quality problems or impairment of designated uses. About 17 percent of in-basin lakes may support periodic algal blooms or excessive weed growths, but seldom have impairment of designated uses (Class III). Four lakes considered as Class IV only partially support designated uses due to excessive weed or algal growth.

Curbing nutrient input is the most common IDEM recommendation for long-term lake management (app. 12). Successful nutrient control schemes (primarily directed at nitrogen and phosphorus) can often be accomplished by improving wastewater treatment and land-use practices. In some cases, however, in-lake restoration measures may be required to limit the availability of nutrients already present in the lake.

Special limnological investigations of 14 lakes in the St. Joseph River basin have been conducted either by the IDEM (as part of the Indiana Lakes Program), the USEPA (as part of the National Eutrophication Survey), or both agencies (see "Selected References"). These lakes, primarily found in Steuben and LaGrange counties, include the following: Crooked, Dallas, James, Long, Marsh, Martin, Olin, Oliver, Pigeon, Sylvan, Wabee, Wawasee, Westler and Witmer. Additional studies have been conducted on these and other basin lakes, generally in association with universities.

Sylvan Lake in Noble County is the most widely studied lake in the St. Joseph basin. Unnatural acceleration of nutrient loading led to algal blooms and dense growths of aquatic weeds in the early 1900s. Decades later, this shallow, manmade lake was described as "one of the most productive lakes in the temperate regions of the world" (Wetzel, 1966). The historical degradation of water quality was accompanied by an explosion of carp and sucker populations and a decline in game fish, particularly during the 1960s and 1970s.

Temporary water quality improvements were made following the upgrading of Kendallville's sewage treatment facility, the construction of Rome City's sewer system, and periodic algacide treatments and lake-level drawdowns. However, both water quality and game fishing have improved dramatically following an IDNR fish eradication and selective restocking project in 1984. Continued control of nutrient inputs and carp populations should maintain the lake in its present condition.

Since sparse information is available on toxic substances in Indiana lakes, recent studies by IDEM included sampling of sediment and fish tissue for toxic substances in addition to collection of limnological data. Twenty-eight lakes and reservoirs in Indiana with a potential for contamination and/or high recreational use were selected as 1985-86 monitoring stations. Crooked Lake in Steuben County, the only in-basin lake selected, was sampled during summer 1986. Although data are not yet available, sediment and fish samples will be analyzed for metals, PCBs and pesticides.

GROUND-WATER HYDROLOGY

Ground-water resources in the St. Joseph River basin are probably the most abundant in Indiana. Wells yielding 200 to 500 gpm (gallons per minute) are common throughout the basin. Yields of 500 to 1500 gpm are common in areas where sand and gravel deposits are thick. In contrast, the presence of thick localized clay deposits can make a sufficient domestic supply (10 gpm) difficult to obtain.

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13 Indiana Lake Classification System and Management Plan (1980; currently under revision).

Significant ground-water supplies are confined to unconsolidated glacial sand and gravel deposits. Underlying bedrock, which consists primarily of shale (and a small area of limestone in Kosciusko County), is not considered an important ground-water source.

Ground-Water Data

Ground-water data for the St. Joseph River basin come from several sources: water-well records, the observation well network, lithologic logs, seismic information and localized project data (for example, pump tests and other analytical and mathematical models).

Since 1959, water-well drilling contractors have been required to submit to the state (IDNR) a complete record of every water well that is drilled (IC 25-39-1). More than 18,000 water-well records are maintained in the IDNR, Division of Water files for the St. Joseph River basin and were reviewed and screened for the ground-water resource assessment of this study. Most of the records are for relatively shallow wells (less than 150 feet).

Water-level data in the St. Joseph River basin have been collected from observation wells by the U.S. Geological Survey in cooperation with the IDNR (formerly the Department of Conservation) since 1935. Seven wells monitored water levels from that time until the period 1944-47, when 21 wells were added to the basin network. Seventeen of the 21 wells were added in St. Joseph County and were used to monitor changes in water levels near South Bend. By the mid-1950s, many of the wells were discontinued because of the close similarity of water-level patterns (Crompton and others, 1986).

Currently, water-level data are collected from 13 observation wells in Elkhart, Kosciusko, LaGrange, Noble and Steuben Counties (table 10). Four of these wells monitor water-level fluctuations in aquifers near natural lakes and six monitor water levels in areas of extensive high-capacity ground-water pumpage. The other three wells, two in Noble County and one in Steuben County, monitor long-term changes in water levels in areas not affected by extensive pumpage.

Water-level data from six observation wells and the three adjacent lakes were collected for approximately 10 years to establish general relationships between ground water and selected natural lakes within the St. Joseph River basin. (Two of these wells were discontinued in 1986.) Water-level correlation between Heaton Lake and the surrounding outwash aquifer was previously discussed in the first "Lakes" section. Ground-water and lake levels for the other two lakes either show graphical correlations (Sylvan Lake) or are inconclusive (Syracuse Lake).

Six observation wells are located in areas of extensive ground-water pumpage. Five of the six are located in areas of agricultural irrigation (Elkhart 4 and 7, LaGrange 2 and 3, Kosciusko 9) and one is located in an urban area near industrial and public supply wells (Elkhart 8). No apparent impact on water levels has yet been observed in these wells. The hydrograph for Elkhart 4 (fig. 19) typifies water-level fluctuations in observation wells located in areas of intensive irriga-

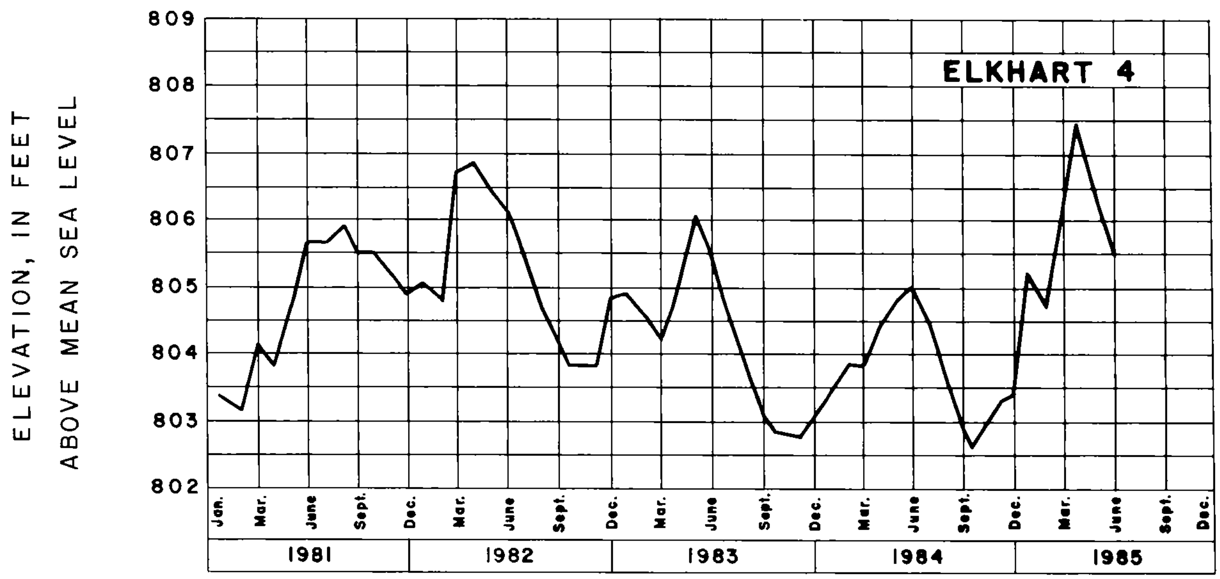

Figure 19. Water-level Fluctuations in Observation Well Near Irrigation Pumpage

TABLE 10. Observation Wells[1]

County Code[2]	County and Well Number[2]		Period of Record[3]	Aquifer System[4]	Aquifer Type[5,6]	Well Dia. (in.)[6]	Screened Depth (feet)[6]	Aquifer Class[7]	Remarks
EH	Elkhart	4	1966-	Elkhart Trib.	S & G	6	60	A	
		5	1976-	St. Joseph	S & G	1.5	13	SP	Lake-Ground Water Connection
		6	1976-	St. Joseph	S & G	1.5	22	SP	Lake-Ground Water Connection
		7	1981-	St. Joseph	Sand	6	61	A	
		8	1983-	St. Joseph	S & G	5	80	A-SP	
KO	Kosciusko	6	1978-	Turkey C. Trib.	Sand	2	23	SP	Lake-Ground Water Connection
		7	1978-	Lakes & Moraines	Sand	2	24	SP	Lake-Ground Water Connection
		9	1982-	Turkey C. Trib.	S & G	4	102	A	
LG	LaGrange	2	1980-	Howe	S & G	5	86	A	
		3	1981-	Howe	S & G	6	40	A	
NO	Noble	8	1966-	Kendallville	S & G	6	148	UA	No record 1971-74
		9	1976-	Lakes & Moraines	Sand	6	42	UA	
	Steuben	6	1986-	Lakes & Moraines	S & G	6	76	UA	
Discontinued Wells[8]									
Elkhart		3	1950-71		S & G	-	-	A	
Kosciusko		2	1937-67		S & G	-	-	SP	Flowing Well
		5	1976-82		Sand	1.5	13	UA	
		8	1978-86		Sand	2	27	SP	Lake-Ground Water Connection
Noble		6	1946-66		S & G	-	-	A	
		10	1978-86		S & G	2	24	SP	Lake-Ground Water Connection
Steuben		3	1955-71		S & G	-	-	UA	
		5	1979-82		S & G	5	103	UA	Destroyed

[1]Locations shown in fig. 14.
[2]U.S. Geological Survey county code and local well number.
[3]Calendar year or portion thereof.
[4]Division of Water designation; Tributary Valley (Trib.); discussed in text.
[5]Sand and Gravel (S & G).
[6]From Glatfelter, Stewart, and Nell (1985).
[7]Division of Water classification: affected by ground-water pumpage (A), unaffected (UA), special purpose (SP).
[8]Wells included in Division of Water data files; additional wells are listed in Crompton and others (1986).

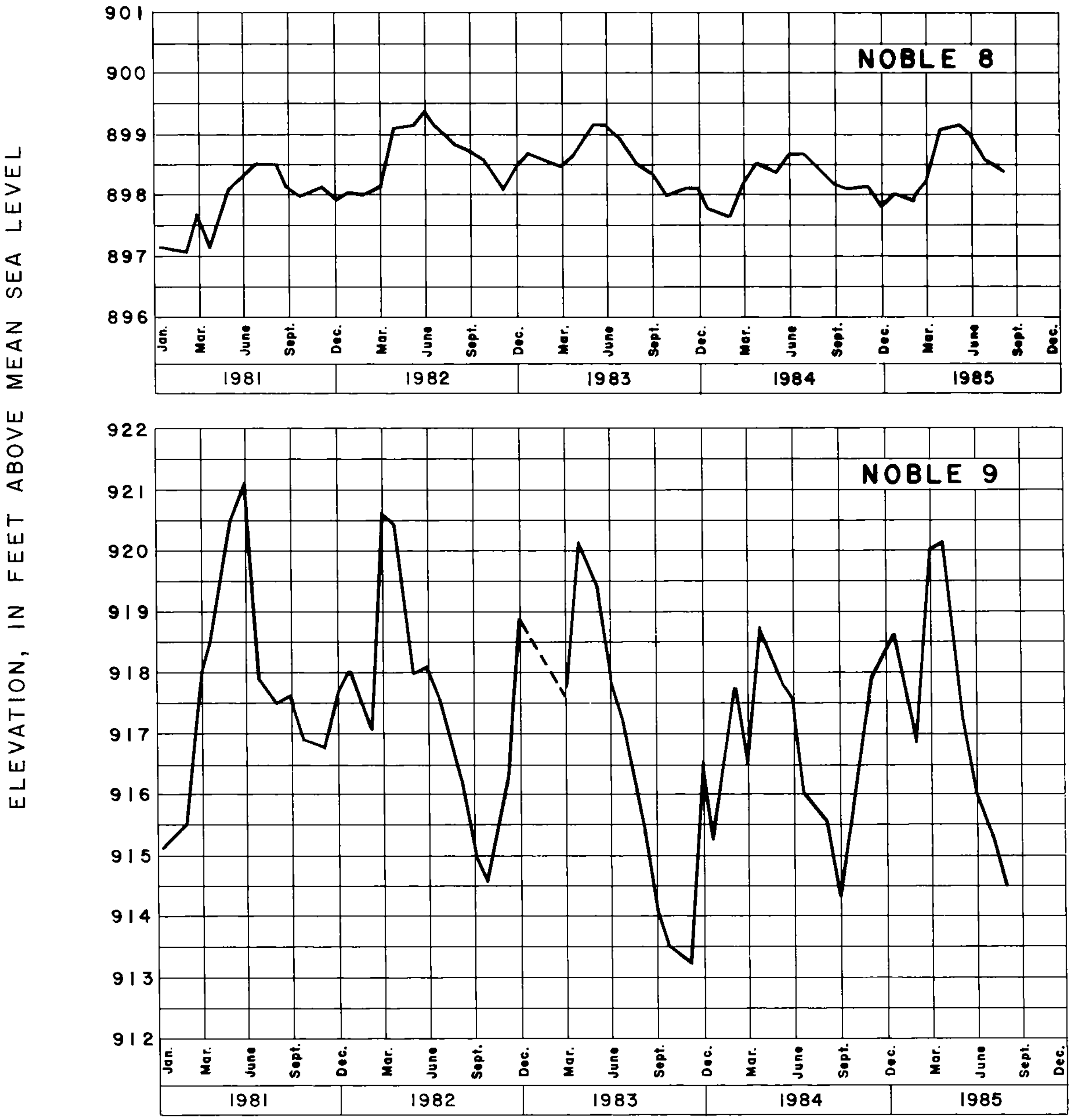

Figure 20. Water-level Fluctuations in Selected Observation Wells

tion. Hydrographs for the other five wells are shown in app. 13.

Noble 8 and 9 and Steuben 6 (recently drilled) were installed to monitor natural water-level fluctuations. Although neither Noble 8 nor 9 is affected by nearby pumpage, the fluctuations in Noble 8 are considerably less than those in Noble 9 (fig. 20). Crompton and others (1986) suggest that the larger water-level fluctuations in Noble 9 could be a result of the well's position on a ground-water divide (although a distinct divide is not apparent from IDNR data). The smaller water-level fluctuations in Noble 8 probably reflect changes in a deep regional flow system with lesser variability in recharge and discharge.

Modifications to the St. Joseph River basin observation well network are scheduled as a result of an IDNR evaluation of Indiana's hydrologic data collection programs. Steuben 6 has recently been added to detect long-term water-level trends. Because most of the ground-water/lake wells have either served their intended purpose or have provided inconclusive data, two (Noble 10 and Kosciusko 8) were removed from the network in late 1986. The continuous recorder will be removed from Elkhart 6 and manual measurements will be made periodically. Funding for two of the remaining ground-water/lake wells (Kosciusko 6 and 7) has been assumed through 1987 by the City of Syracuse, after which the wells may also be discontinued. Elkhart 5 will remain in the network to monitor anticipated increases in high-capacity pumpage. Three nested wells are planned for construction near Kendallville in 1987. These wells will provide information about recharge to the deeper confined aquifer in the Kendallville area.

Piezometric Surface (Water Table)

The ground-water level within an aquifer constantly fluctuates in response to rainfall events, evapotranspiration, ground-water movement, and ground-water pumpage. Maximum fluctuations recorded at 14 in-basin observation wells average 5 feet. Because the natural fluctuations are small, static water levels can be used to approximate regional ground-water flow direction.

Static water levels used to develop the piezometric surface map for the St. Joseph River basin (Plate 2) include data for aquifers at various depths. The map represents a composite of water levels of the major aquifer systems, and it may or may not be a true representation of water levels in very shallow or very deep aquifers.

The piezometric surface map can be used to define the probable flow path of contaminants and to identify significant areas of ground-water recharge and discharge. The map can also be used to calculate expected depths to water in a well, but not to determine recommended depths of wells.

In a general way, ground-water flow approximates overlying topography and intersects the land surface at major streams. However, where thick deposits of sand and gravel occupy high topographic positions, as near Bristol (Plate 2), regional flow may not be controlled by topography.

In the St. Joseph River basin, ground-water levels range from an elevation of 1030 m.s.l. (mean sea level) in Steuben County to a low of about 670 m.s.l. along the St. Joseph River north of South Bend (Plate 2). Regional ground-water flow, which generally reflects regional topographic drainage, is toward the St. Joseph River. Ground water in southwest Steuben County, however, tends to flow out of the St. Joseph basin and into adjoining watersheds.

St. Joseph River Basin Aquifer Systems

The St. Joseph River basin presents one of the most complex geologic settings in Indiana for defining groundwater resources. The complexity is due to the impact of three major ice lobes, a thick mass of glacial drift and an irregular bedrock surface. Because of the complex glacial deposition, it is not possible in most cases to delineate discrete aquifers for any distance. Hence, seven regional aquifer systems were identified within the St. Joseph River basin (Plate 1) based on the similarities of geologic environments. These systems consist of aquifer complexes within outwash-plain, valley-train, till-plain, and intertill morainal glacial deposits. Table 11 summarizes selected hydrologic characteristics of the seven aquifer systems.

St. Joseph Aquifer System

The St. Joseph Aquifer System, an outwash plain extending from eastern Elkhart County to the basin divide in western St. Joseph County, is one of Indiana's major aquifer systems. It is composed primarily of fine to medium sand with local layers of coarse sand and gravel.

Although hundreds of well records are available to define aquifer conditions to a depth of 100 feet, little information describing greater depths is available. The St. Joseph Aquifer System is highly variable in thickness, ranging from less than 20 feet near its southern boundary to its greatest known thickness of approximately 400 feet over the buried bedrock valley at the west edge of Elkhart. Sand and gravel thicknesses of 40 to 120 feet are typical.

The main body of the outwash contains numerous interspersed thin (3 to 5 feet) layers of clay. Locally, clay deposits may extend to considerable depths, as in much of the area south of the St. Joseph River between Elkhart and South Bend. Clay deposits in an area southeast of Elkhart (Plate 1) essentially preclude significant occurrences of ground water and can make even domestic supplies difficult to obtain.

TABLE 11. Hydrologic Characteristics of Major Aquifer Systems

Aquifer System	Areal Extent (mi^2)	Range of Aquifer Thickness (ft)	Common Aquifer Thickness (ft)	Range of Pumping Rates (GPM)	Common Depth to Aquifer (ft)	Hydrostatic Condition
St. Joseph	381	20 - 400	40 - 120	100 - 1500	20 - 120	confined & unconfined
Hilltop	35	10 - 100	10 - 30	25 - 150	5 - 50	confined & unconfined
Nappanee	241	3 - 30	3 - 20	50 - 600	80-90	confined
Kendallville	327	3 - 20	3 - 5	25 - 600	15 - 100	confined
Howe Outwash	243	5 - 145	15 - 50	100 - 1000	25 - 180	confined
Natural Lakes and Moraines	450	4 - 35	5 - 20	25 - 80	20 - 100	confined
Topeka	23	5 - 126	30 - 50	100 - 600	25 - 50	confined & unconfined

In the South Bend-Mishawaka area, moderately thick deposits of clay/till separate an upper deposit of sand and gravel from a deeper productive sand and gravel aquifer. The clay unit separating the upper and lower sand and gravel has an irregularly sloping surface that trends generally to the northwest. The bottom elevation of this layer ranges from about 600 feet m.s.l. near the Michigan state line to 635 feet m.s.l. in the South Bend area. Similar conditions are present east and north of Mishawaka (Plate 1), where elevations of the bottom of the clay layer are about 630 to 675 feet m.s.l. Locally, irregular clay conditions are also present in some areas north of the St. Joseph River near Bristol.

St. Joseph Tributary Valley Aquifer System

The Tributary Valley portion of the St. Joseph System encompasses valleys of the Elkhart and Little Elkhart rivers and Turkey, Solomon and Pine Creeks. These valley-train outwash systems are similar to the principal St. Joseph Aquifer System except that they often contain coarser grained deposits.

In the Goshen area and in the Elkhart River valley northwestward toward Elkhart, a well-defined sequence of surficial sand and gravel overlies a clay/till unit, which in turn overlies a confined sand and gravel aquifer. The surficial sand and gravel ranges up to 60 feet in thickness. The lower confined aquifer of this sequence ranges up to 50 feet in thickness.

South of Goshen, outwash materials of the Elkhart River and Turkey Creek-Rock Run valleys coalesce. Here the clay/till confining bed is generally absent, and thicknesses of sand and gravel exceeding 150 feet may be found.

(Turkey Creek)

The reappearance of an intermediate confining clay is noted along the Turkey Creek valley south of New Paris. The Turkey Creek Aquifer System is typified by the hydrogeology of the Milford area, where characteristic surficial sand and gravel overlie localized clay/till lenses and a lower confined sand and gravel aquifer.

Thicknesses of surficial sand and gravel units commonly average 40 feet, but may range from 10 to 100 feet. Outwash sands and gravels are thicker in the Turkey Creek System than in areas to the north, and in broader portions of the valley commonly range from 50 to 100 feet in thickness. A subsurface clay/till zone is frequently encountered at an elevation ranging from 750 to 820 feet m.s.l. While the approximate thickness of the clay/till zone is variable, it apparently thickens toward the edges of the Turkey Creek System. Although localized clay/till lenses contained within the outwash are normally thin, thicknesses of 25 to 50 feet have been reported.

A deeper 5- to 75- foot thick sand and gravel aquifer complex is frequently encountered at an elevation of 740 to 770 feet m.s.l. This aquifer complex is locally confined beneath the clay/till zone, and is probably interconnected with thick sequences of surficial sand and gravel. The deeper sand and gravel unit extends laterally to the west into the Nappannee Aquifer System and to the east into the transitional portion of the Natural Lakes and Moraines Aquifer System.

A few water wells have penetrated a third deep sand and gravel zone at elevations between 690 to 720 feet m.s.l. This zone is confined by a lenticular clay/till layer. Only the thickest sequences of surficial sand and gravel may intersect this deeper aquifer locally. The lateral extent of the deepest aquifer complex is not known; however, a few wells in the transitional and main parts of the Lake and Moraine System encounter aquifer material at the same elevation range as the deepest Turkey Creek aquifer complex.

Ground-water levels in the surficial outwash sand and gravel deposits are normally shallow, and static water levels are less than 10 feet below ground surface. Near the boundaries of the aquifer system, static water levels deepen to nearly 40 feet.

Thicker deposits of this aquifer system can be expected to yield 500 to 1000 gpm per well. A few scattered high-capacity wells south of Milford along Coppes Ditch have reportedly produced 750 to 1350 gpm during brief pumping tests.

(Solomon Creek)

The Solomon Creek Tributary Valley Aquifer System is composed of thick layers of outwash sand and gravel with interbedded clay layers. Data for this system are sparse, but the aquifer appears to be less complex than the Turkey Creek System. From its junction with the Elkhart River, the Solomon Creek System trends in a southeasterly direction. Thicknesses of sand and gravel units average 60 to 70 feet but vary from 20 to 160 feet. Greatest thicknesses occur southeastward of the Elkhart-Kosciusko County line where up to 104 feet of saturated sand and gravel deposits have been found. Sand and gravel thins in the southeastern portion of the system.

In the area of Wolf Lake, clay layers become more common in the system and increase in thickness. Whereas the sand and gravel occurs as one thick unit to the northwest, in the Wolf Lake area several sand and gravel layers generally are separated by clay zones of variable thickness.

Generally the Solomon Creek Aquifer System is capable of yielding 300 to 1000 gpm from individual wells; however, some wells near the Noble-Elkhart County line have yields of over 1200 gpm. High-capacity yields may not be possible in areas within the aquifer where localized thick clay deposits are present, such as in some areas between Benton and the Elkhart-Kosciusko county line. Well depths generally average 50 feet, but may range up to 250 feet.

(Pine Creek)

Although little is known about the Pine Creek-Rock Run Aquifer System, this tributary valley outwash system is potentially the most complex. Morainal deposits have blocked the lower reaches of this valley where it merges with the St. Joseph Aquifer System, and have substantially modified the surface appearance of the Pine Creek valley. Where data are available, sand and gravel is a major component of the materials contained within the valley. Deeper sand and gravel is expected to underlie a clay layer which in turn underlies the surficial sand and gravel. The outwash contained within the Pine Creek valley may be related to the materials deposited in the Turkey Creek valley. It is expected that moderately high producing (300 to 600 gpm) wells could be developed in the Pine Creek Aquifer System.

(Little Elkhart River)

The Little Elkhart Aquifer System originates northwest of Topeka in LaGrange County, where outwash deposits of surficial sand and gravel are found in the valleys of Little Elkhart River and Rowe-Eden Ditch. The sand and gravel deposits, which range up to 50 feet in thickness, overlie a thick clay sequence which may, in turn, overlie a deeper sand and gravel aquifer sequence. Data in the southeastern part of the valley system are quite limited.

Southeast of Middlebury, the valley system becomes more defined and outwash sand and gravel deposits up to 60 feet in thickness can be found. At Middlebury the surficial sand and gravel is underlain by a 50- to 60- foot clay/till layer that separates the upper aquifer from a deeper sand and gravel deposit that locally exceeds 60 feet in thickness. The elevation at the bottom of the confining clay unit is about 730 to 740 feet m.s.l. at Middlebury, and probably declines to the northwest.

Wells completed in the Little Elkhart System typically can be expected to yield 500 to 1000 gpm to properly constructed, large-diameter wells.

Topeka Aquifer System

The Topeka Aquifer System, characterized by thick surficial deposits of outwash sands and gravels, is bounded on all sides by the Natural Lakes and Moraines Aquifer System. Along the gradational system boundaries, surficial sands and gravels thin and interfinger with clays of the Natural Lakes and Moraines System.

The Topeka Aquifer System consists of two separate areas that are geologically similar. The main (western) portion, located near the town of Topeka, is composed of surficial sand and gravel deposits up to 126 feet in thickness, but having common thicknesses of 30 to 50 feet. Interbedded clay layers up to 10 feet in thickness, occasionally found in the main system, become thicker and more common near the aquifer system boundaries. Static water levels in the unconfined surficial sand and gravel deposits are generally 25 to 50 feet. Yields from shallow unconfined wells are unknown due to limited data.

A deeper confined aquifer underlies the main Topeka system, commonly at an elevation of about 850 feet m.s.l. This deeper system may be related to the Natural Lakes and Moraines Aquifer System. A primary sand and gravel deposit comprising the deeper Topeka aquifer is up to 20 feet in thickness and seems to be continuous throughout the Topeka system. Other minor sand and gravel layers are locally present in clays underlying the surficial outwash deposits, but do not appear to be laterally extensive or continuous.

The main Topeka Aquifer System is used by several high-capacity irrigation wells. These wells are usually from 120 to 160 feet deep and produce water from confined or semi-confined sand and gravel aquifers beneath clay layers. Reported well yields range from 1000 to 2000 gpm. Although these yields are greater than can normally be expected, properly constructed, large diameter wells can produce yields in the range of 300 to 1000 gpm.

The eastern portion of the Topeka Aquifer System is a surficial outwash deposit that averages 40 feet in thickness, but may be as much as 80 feet. Static water levels in the unconfined outwash are about 30 feet. Deeper confined aquifers underlie the outwash at elevations of about 725 to 850 m.s.l. and are 5 to 20 feet thick. As with the main Topeka system, the deeper aquifers are probably related to the adjacent Natural Lakes and Moraines Aquifer System.

The eastern section of the Topeka Aquifer System is similar to the main system but exhibits more discontinuous outwash deposits and is not as productive. Shallow wells (40 to 60 feet) reportedly produce 10 to 45 gpm. Some deeper wells in the eastern system can produce from 90 to 205 gpm and create only slight (about 10 feet) drawdown. Although few high-capacity wells are present to test the aquifer's adequacy, yields from 150 to 500 gpm are anticipated from properly constructed, largediameter wells.

Natural Lakes and Moraines Aquifer System

The Natural Lakes and Moraines Aquifer System, one of the largest in the St. Joseph basin, is a complex intertill aquifer system covering large areas in Noble, LaGrange, Elkhart and Kosciusko Counties. At ground surface, this system is essentially a till plain. Most aquifer materials occur below the surficial till. Although the topographic drainage divide of the St. Joseph River basin defines the southern boundary of the aquifer system, it is presumed that the aquifer system continues further south.

The Natural Lakes and Moraines Aquifer System can be subdivided into two parts on the basis of surficial deposits. Most of the system is characterized by surficial clays of varying thickness having only scattered, localized areas of surficial sand and gravel. Surficial clay thickness is generally from 20 to 100 feet. The surficial clays are underlain by multiple intertill sand and gravel lenses. As many as five distinct layers of sand and gravel may be present in any area, although two or three are more common. Typically the upper sand and gravel layers, if present, are non-productive. Thickness of these upper layers ranges from 4 to 35 feet and averages 10 to 20 feet. The deepest layers are generally thinner (5 to 10 feet) than the upper units, but are productive.

Significant areas of surficial sand and gravel zones are present within the Lakes and Moraines Aquifer System, but layers are generally thin (less than 20 feet) and lack continuity. Three localized areas northeast of Topeka, east of Emma, and at LaGrange, however, appear to have continuity of surficial sand and gravel deposits.

Most of the Lakes and Moraines Aquifer System (except where it borders the Kendallville) has water-bearing sand and gravel zones which occur at fairly consistent elevations. There appears to be good elevation correlation of these water-bearing zones with the deeper confined aquifers of the Topeka Aquifer System and even with aquifers on either side of the Solomon Creek Aquifer System. Elevations of the Lakes and Moraines water-bearing sands and gravels decrease to the west and northwest (from 840 to 880 feet m.s.l. in southwest and central to 800 to 850 feet m.s.l. in northwest, north, and west). Domestic well yields for the west, southwest, north and central areas of the system range from 15 to 30 gpm. One highcapacity well in the southwest has a reported yield of 800 gpm and one in the central region a reported yield of 1200 gpm.

To the east and northeast, aquifers of the Lakes and Moraines System appear to lose continuity and to become more scattered and variable. Well yields generally decrease for these two regions (6 to 20 gpm) as opposed to the remainder of the aquifer system. Aquifer elevations in the east and northeast are closely related to elevations of aquifers in the bordering Kendallville and Howe Aquifer Systems.

Near Dallas Lake, Oliver Lake and Atwood Lake, very thick clay sequences are uninterrupted by sand and gravel lenses. Clay layers near these lakes reach up to 200 feet in thickness. The sands and gravels when encountered at depth may be exceptionally thick. Locally, there are saturated thicknesses of granular deposits up to 160 feet near this group of lakes.

In the extreme southern portion of the Lakes and Moraines System, aquifer conditions change abruptly. Wells in this area are often very deep (200 to 360 feet), but produce adequate water for domestic purposes. Yields of 10 to 20 gpm are reported for most wells. Aquifer elevations become highly variable (600 to 850 feet m.s.l.) and exhibit little correlation. Sand and gravel layers may be quite thick (up to 55 feet), but are usually fairly thin (5 to 10 feet), especially in deeper zones. Surficial clays over 100 feet thick are common.

The northwestern portion of the Lakes and Moraines Aquifer System has diverse and irregular terrain due to glacial processes associated with the Saginaw Lobe (fig. 10 and table 2) and to subsequent dissection by major drainage systems. Aquifers of some apparent continuity are present at elevations of 710 to 760 feet m.s.l. Shallower sand and gravel units are present locally at an elevation of about 800 to 825 feet m.s.l. Water levels are quite deep in some areas and depths to water greater than 100 feet have been reported. Surficial sands and gravels are sometimes present, but typically do not contain water because of deep static water levels. Locally, where the deeper sand and gravel aquifer (710 to 750 feet m.s.l.) is from 20 to 40 feet thick, high yields of water can be expected from large-diameter, properly constructed wells.

The Natural Lakes and Moraines Subsystem occurs adjacent to the Solomon Creek and Turkey Creek Aquifer Systems (see cross-hatched area, Plate 1). The subsystem is characterized by a somewhat continuous surficial deposit of sand and gravel. Thicknesses range from 8 to 90 feet but 20 to 30 feet are common. The sand and gravel units thin to the east and northeast towards the main part of the Natural Lakes and Moraines System. Few if any wells are developed in this surficial layer. Deeper sand and gravel layers present within the clays under the surficial deposit are tapped for water supplies. Two aquifers are commonly found at elevations of about 770 and 870 feet and are approximately 4 and 25 feet thick, respectively. Other aquifer layers are sporadically encountered from 730 to 900 feet m.s.l. These layers vary from 8 to 33 feet thick but do not seem to be continuous, nor is their occurrence predictable.

Wells in the Natural Lakes and Moraine Subsystem are typically 80 to 120 feet deep. Average well depths and primary aquifer elevations correlate with the adjacent part of the Natural Lakes and Moraines System to the north and east. Wells in the subsystem have reported yields from 30 to 375 gpm. The more productive wells tend to be in areas closer to the Solomon Creek outwash.

Kendallville Aquifer System

The Kendallville Aquifer System is a highly variable intertill complex. It is characterized by a lack of surficial sand and gravel and the presence of variable, but often thick clays and clay-rich zones that have multiple discontinuous sand and gravel lenses at varying depths.

The Kendallville System as mapped is bounded on the west by indistinct, gradational boundaries with the Natural Lakes and Moraines and the Howe Aquifer systems, and on the south and east by the topographic drainage divide of the St. Joseph River basin. The aquifer system is expected to extend eastward beyond the topographic divide.

Surficial sand and gravel deposits, when present, are merely a thin veneer which overlie the clay/till sequence. Exceptions are present as narrow, thick outwash bands trending northwestward along valleys of present drainageways.

The surficial clay/till layer varies from 5 feet in thickness to more than 100 feet, generally thickening to the south and east.

The Kendallville System and the Natural Lakes and Moraines System to the west are similar except for the ratio of clay to sand and gravel. The Kendallville System is more clay-rich and has less surficial sand and gravel. In addition, sand and gravel zones within the Kendallville are generally thinner and less continuous than those of the Lakes and Moraines System.

Intertill sands and gravels occur within zones in the Kendallville system, but rarely occur at consistent elevations. In the northwestern portion, however, aquifer materials consistently occur from 800 to 850 feet m.s.l. The aquifer materials in this range closely correspond to similar materials in the Lakes and wells. An area of exceptionally low capability exists in southwest Steuben County where one dry hole has been reported. Even here, dry holes are uncommon, however, and domestic yields of 8 to 15 gpm are more typical. Larger diameter wells in southwest Steuben occasionally yield 50 to 70 gpm, and 150 gpm capacities have been reported.

Well yields of at least 10 gpm for domestic supplies are expected for most regions within the Kendallville System, and yields of 15 to 30 gpm are typical. The most productive regions within the Kendallville System are in the northeast and west where respective yields of 1000 gpm and 1400 gpm are reported for larger diameter wells. An area of exceptionally low capability exists in southwest Steuben County where one dry hole has been reported. Even here, dry holes are uncommon, however, and domestic yields of 8 to 15 gpm are more typical. Larger diameter wells in southwest Steuben occasionally yield 50 to 70 gpm, and 150 gpm capacities have been reported.

The northernmost intertill aquifers seem to be hydrologically connected, as reflected in the interrelationship of water levels (Plate 2). Static water levels in the Kendallville System are usually shallow (40 feet or less), but have occurrences from above the surface (flowing wells) to more than 100 feet below.

Howe Aquifer System

The Howe Aquifer System occurs primarily in LaGrange County, but extends eastward into Steuben County. A narrow "leg" of outwash included as part of the Howe system trends northwest-southeast, cutting the adjacent Kendallville Aquifer System in Steuben County into two parts.

The Howe Aquifer System may be described as variable glacial deposits in a predominently clay-rich environment. It is characterized by surficial outwash sand and gravel deposits of variable thickness overlying an altered till plain which includes thinner zones of sand and gravel in a clay-rich intertill deposit. The surficial sand and gravel deposits have been identified by Johnson and Keller (1972) as outwash deposits to the west and ice-contact kame and kame moraine deposits to the system's eastern edge. The outwash sand and gravel is continuous except for minor "windows" where the system is till capped.

Thicknesses of the Howe surficial sand and gravel may reach 145 feet, but thicknesses of 15 to 50 feet are much more common. Although these unconfined deposits have abundant granular material, they are only rarely utilized for water supplies. Most wells are completed in deeper confined sand and gravel layers that alternate with clays in an underlying till sequence.

The intertill system consists of moderately thick clay and clay-rich sequences alternating with lenses of sand, gravel, or a combination of sand and gravel. These lenses, locally continuous at best, average 5 to 25 feet thick, but may reach 100 feet. The tops of sand and gravel lenses characteristically occur between 780 to 805 feet m.s.l. in western portions of the Howe system, and from 800 to 850 feet m.s.l. further east. At least one confined, unconsolidated aquifer is present at depth throughout the Howe system. In some areas, as many as four confined sand and gravel lenses occur above bedrock.

An unexpectedly large clay constituent occurs around Pigeon, North and South Twin and Still lakes. Clay sequences ranging from 25 to 180 feet in thickness (considerably thicker than the clays in the remainder of the Howe Aquifer System) underlie up to 30 feet of surficial sand and gravel. Sand and gravel lenses underlying this clay, however, closely resemble the intertill sequences found throughout the Howe System.

Ground-water availability within the Howe system is excellent. Most domestic wells produce at least 10 to 20 gpm, though rates up to 60 gpm are common. High-capacity wells within the system can produce as much as 2600 gpm.

Well depths vary from 30 to as much as 200 feet, but are generally from 50 to 150 feet. Most wells penetrate lower confined intertill aquifers.

Static water levels throughout the Howe system are at fairly shallow depths, but have occurrences from above the surface (flowing wells) to more than 50 feet below.

Nappanee Aquifer System

This glacial till plain aquifer system consists of a series of zones of interbedded medium to coarse sand and fine gravel separated by thin clay layers within a thick till sequence. The Nappanee Aquifer System is almost uniformly characterized by surficial clay/till, often 80 to 90 feet in thickness, overlying a persistent 3- to 20- foot thick sand and gravel aquifer complex. Typically, the individual aquifers are clustered in a 25- to 30-foot vertical section within the till sequence. This clustering of aquifers is common to this aquifer system which underlies extensive areas in western Elkhart and eastern St. Joseph counties.

Individual aquifers, which locally thicken to 30 feet or more, seldom are found under more than 1 to 2 square miles in a given area. Near Nappanee System boundary edges, the aquifers commonly thicken, and an abrupt change in both the surface topography and aquifer character becomes apparent. In areas adjacent to major streams and river valleys, it is possible that the Nappanee System blends into the outwash deposits contained in the Tributary Valley and St. Joseph Aquifer System.

It is common to have two or more sand and gravel aquifers within a given elevational range (zone), such as near Nappanee, where several discontinuous aquifers are found from about 750 to 800 feet m.s.l. This zone of aquifers does not always appear to be thick enough to be used for well supplies.

At Nappanee, city wells ranging from 150 to 164 feet in depth receive water from the aquifer occurring at elevation 750 feet m.s.l. These wells produce about 1000 gpm each and are completed in about 35 to 40 feet of sand and gravel. A thick sand and gravel aquifer loosely associated with the Nappanee Aquifer System appears to be present in some areas below a depth of 150 to 175 feet.

South of Nappanee in Kosciusko County, a persistent 5- to 20- foot thick sand and gravel complex is frequently encountered below the glacial clay/till at an elevation of about 740 to 770 feet m.s.l. Some wells are completed at a shallower depth. Wells are occasionally completed below the 740- to 770- foot clustering of individual aquifers.

Near Foraker and Wakarusa, the aquifer cluster is found at about 770 to 780 feet m.s.l. Further north toward Dunlap, aquifers within the Nappanee system occur at a lower elevation, typically from about 735 to 770 feet m.s.l.

In the Millersburg area of eastern Elkhart County the cluster of individual aquifers comprising the Nappanee System is at a generally higher elevation (800 to 850 feet m.s.l.) than to the west. Individual water-bearing sand and gravel units are more erratic than those to the west, and well depths and aquifer elevations are more variable. Locally, zones of sand and gravel exceeding 30 feet in thickness can occur, although most units range from 3 to 10 feet. The production potential for high-capacity wells is expected to be less near Millersburg than in other areas of the aquifer system.

Hilltop Aquifer System

The Hilltop Aquifer System is located at the south edge of South Bend. The north boundary of the Hilltop System abuts the St. Joseph Aquifer System while all other boundaries merge into the Nappanee Aquifer System. The St. Joseph—Hilltop contact is marked by a sharp topographic rise from the low, flat St. Joseph outwash valley to the higher and more rugged topography where the Hilltop System is present. There is no noticeable topographic contrast along the gradational Hilltop System Nappanee System contact.

Records for water wells completed in the Hilltop system normally indicate significant thicknesses of sand and fine gravel and few interbedded clay/till lenses. The Hilltop Aquifer System differs from the St. Joseph Aquifer System by virtue of its higher elevation. In contrast to the clay/till dominated Nappanee Aquifer System, the Hilltop Aquifer is typically comprised of 60 to 100 percent sand and gravel.

A variable, but mostly thin, 5- to 50- foot thick clay/till unit is found at the surface throughout much of the Hilltop System. A 4- to 5- mile wide section of thick surficial or nearsurface sand and gravel, locally approaching 100 feet in thickness, extends north-south throughout the central portion of the system. Below, a lenticular 5-to 20- foot thick, clay/till unit overlies a partially confined sand and gravel aquifer unit having a top elevation ranging from 740 to 760 feet m.s.l. Where the lenticular clay/till unit is absent, upper and lower sand and gravel units coalesce. Static water levels for most wells range from approximately 100 feet near the northern edge of the system, to 40 to 60 feet southward.

Continuity of the sand and gravel aquifer units decreases from north to south. Near the contact with the St. Joseph Aquifer System, a persistent 10- to 30-foot thick confined sand and gravel unit is frequently encountered at an elevation of 720 to 690 feet m.s.l. This elevation range nearly matches that of the surficial sand and gravel unit found in the nearby St. Joseph outwash valley, thus suggesting some degree of depositional interconnection between the two systems.

Various aquifers are tapped in the southern portion of the system where a number of wells are finished in the thick sand and gravel sequences. Nearby wells are completed in confined or partially confined aquifer units at elevations of approximately 740 to 780 feet m.s.l. A few wells in the south half of the system have total depth elevations either slightly greater or less than 700 feet m.s.l.

Major residential development overlies much of the west and north portions of the Hilltop Aquifer System, where domestic wells commonly yield 10 to 60 gpm. The City of South Bend Rum Village well No. 2, located at the extreme northwest edge of the Hilltop Aquifer System, pumped 1450 gpm with 31 feet of drawdown during an 8-hour test. In much of the area underlain by the Hilltop Aquifer System, high-capacity wells can be expected to yield from 50 to 250 gpm.

Ground-Water Development Potential

Transmissivity Values

Transmissivity is a measure of the water-transmitting capability of an aquifer. Expressed as the rate at which water flows through a unit width of an aquifer, transmissivity is obtained by multiplying the aquifer's hydraulic conductivity by its saturated thickness.

Fig. 21 shows transmissivity values at various locations throughout the St. Joseph River basin. The wide range of values is due partly to variations in geologic materials and partly to the method used to estimate transmissivity.

The most accurate method of estimating transmissivity utilizes aquifer test data. The next most accurate method utilizes specific capacity data (pumping rate divided by drawdown) which has been adjusted for the effects of dewatering and/or partial penetration of the aquifer. The least accurate method utilizes specific capacity data with unadjusted drawdowns. If the total thickness of the aquifer utilized was unknown, drawdowns could not be adjusted for the effects of dewatering and partial penetration. Fig. 21 is color-coded to show which method was used to estimate each transmissivity value.

For comparative purposes, it is best to examine transmissivity values of the same color, thus eliminating one of the sources of variation. The resulting comparison is based solely on differences in the thickness and permeability of the water-bearing formation.

Interpretation of a given transmissivity value is complicated by the fact that transmissivity is the product of hydraulic conductivity and saturated thickness. Therefore, a given transmissivity value could result from a thick sequence of relatively lowpermeability materials or from a thin sequence of relatively high-permeability materials.

Despite the limitations, fig. 21 is useful in making generalizations on a regional scale. Transmissivities are higher in areas having thick sequences of high-permeability materials (such as in the South Bend area), and lower in areas having thinner sequences of low-permeability materials (such as in northeastern Steuben County).

Recharge

The potential amount of ground water available for development in the St. Joseph 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 have been estimated based on the prevailing geologic and hydrologic conditions (tables 12 and 13). Applying these rates across an aquifer system yields total system recharge. Summing the totals for each system gives an estimate of the recharge rate to the entire basin. Using this method, the St. Joseph River basin total recharge is estimated to be in excess of 500,000,000 gallons per day.

''Safe yield'' is a term frequently used to describe the amount of ground water which can be withdrawn without exceeding a given criteria. For example, safe yield is often defined as an amount not exceeding average annual natural recharge. However, safe yield estimates based solely on natural recharge are conservative because they ignore the effects that ground-water development may have on the recharge capability of an aquifer. For example, pumping ground water from an aquifer which is hydraulically connected to a river may induce recharge to the aquifer through the streambed. If the hydraulic connection is good, the pumped water will eventually be derived from stream flow reduction, in which case safe yield is limited by an allowable reduction in stream flow.

Safe yield is also defined in terms of the maximum pumpage which will avoid lowering water levels below some predetermined level. For example, it may be decided that for an unconfined aquifer, the maximum allowable reduction in saturated thickness is 50 percent. Analytical and numerical models can then be used to estimate the amounts of water which can be pumped at given locations without exceeding the 50 percent reduction criterion.

Minimum ground-water levels may be legally established by the Natural Resources Commission (IC 13-2-6.1). If established, the minimum level criteria may govern the safe yield of a given ground-water withdrawal facility.

Ground-Water Quality

Rain and snow, the major sources of recharge to ground water, contain small amounts of dissolved substances. However, the natural chemistry of ground water depends primarily on the composition and solubility of rock materials, as well as on the water's temperature and residence time in the materials. As rain infiltrates through the soil, biologically-derived carbon dioxide reacts with the water, forming a weak solution of carbonic acid. Concentrations of chemical constituents such as bicarbonate, sodium, calcium, magnesium, chloride, iron and manganese are increased or added as the slightly acidic water dissolves rock material. These dissolved constituents are increased further as the ground water slowly moves along a flow path to deeper parts of the zone of saturation (aquifer). The chemical composition of ground water may also change by loss or gain of some constituents as the water percolates through layers or materials of varying composition (such as interbedded sand or clay).

With longer residence time, concentrations of dissolved solids in ground water usually increase. Ground water in recharge areas commonly contains lower concentrations of dissolved constituents than water occurring deeper in the same aquifer. Because recharge to intertill aquifers must travel through low permeability till, these aquifers generally contain water which has greater concentrations of dissolved solids

TABLE 12. Aquifer System Recharge

Aquifer System	System Rate	St. Joseph	Elkhart	Kosciusko	LaGrange	Noble	Steuben	Dekalb	System Total
	GPD/Mi.²	MGD	MGD	MGD	MGD	MGD	MGD	MGD	MGD
St. Joseph	500,000	70.9	54.8	-	4.5	-	-	-	130.2
Tributaries	500,000	-	34.3	17.3	-	8.8	-	-	60.4
(Sub-Total)		(70.9)	(89.1)	(17.3)	(4.5)	(8.8)	-	-	(190.6)
Nat. Lakes & Mor.	250,000	-	24.1	11.0	31.9	36.8	-	-	103.8
Transition	300,000	-	-	5.1	-	5.1	-	-	10.2
(Sub-Total)		-	(24.1)	(16.1)	(31.9)	(41.9)	-	-	(114.0)
Nappanee	175,000	8.8	28.3	2.8	2.2	-	-	-	42.1
Howe	500,000	-	1.1	-	76.2	-	44.5	-	121.8
Kendallville	200,000	-	-	-	14.7	19.8	29.1	1.8	65.4
Topeka	300,000	-	-	-	1.2	5.7	-	-	6.9
Hilltop	300,000	10.4	-	-	-	-	-	-	10.4
County Total (MGD)		90.1	142.6	36.2	130.7	76.2	73.6	1.8	551.2

GPD = Gallons per day System Recharge Rate (per square mile); GPD/Mi² x 0.0575 x 10^{-6} = inches/day.
MGD = Millions of Gallons per day Recharge (for total area).

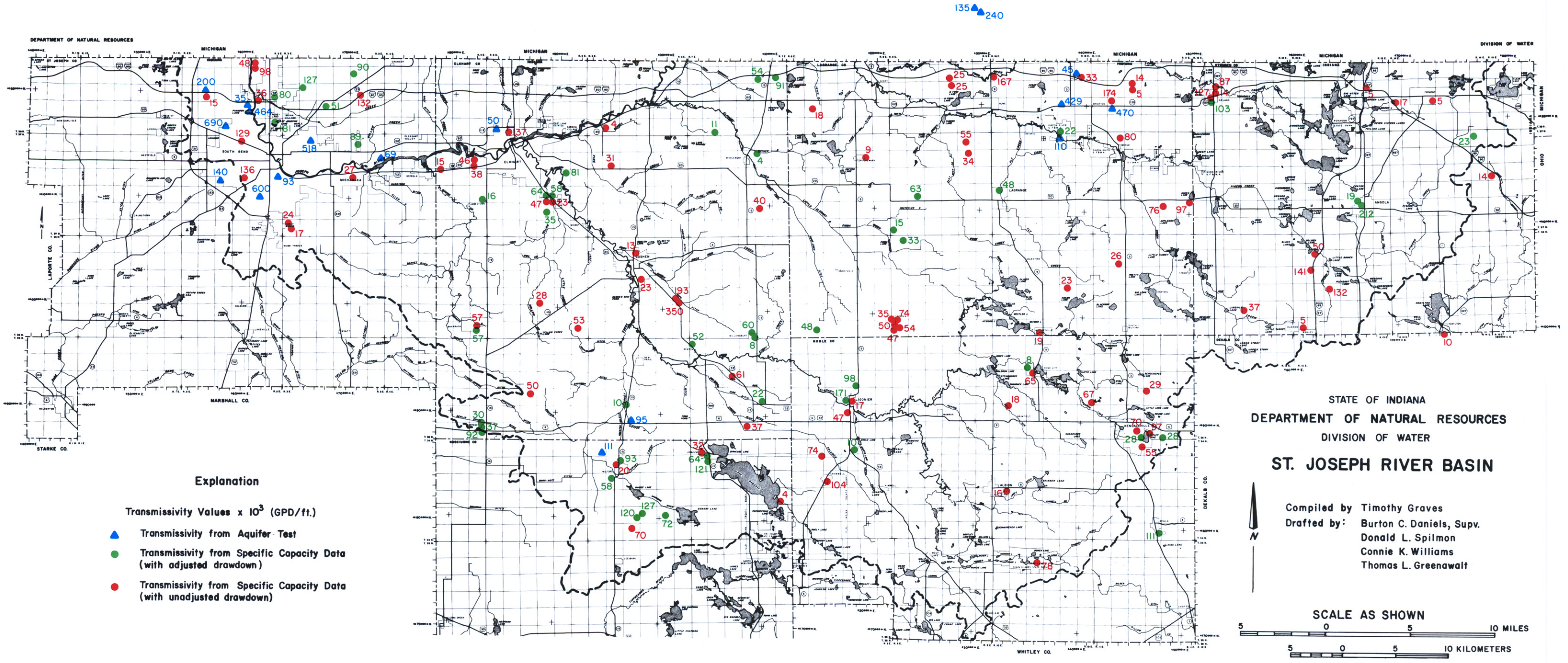

Figure 21. Transmissivity Values

TABLE 13. Aquifer System Area

Aquifer System	COUNTY							Total System	
	St. Joseph	Elkhart	Koscuisko	LaGrange	Noble	Steuben	Dekalb	Acres	Sq. Miles
St. Joseph	90,759	70,105	-	5,761	-	-	-	166,625	260
Outwash Tributaries	-	43,902	22,087	-	11,319	-	-	773,308	121
(Sub-Total)	(90,759)	(114,007)	(22,087)	(5,761)	(11,319)	-	-	(243,933)	(381)
Nat. Lakes & Moraines	-	61,727	28,174	81,725	94,322	-	-	265,948	416
Nat. Lakes & Mor. -transition-	-	-	10,796	-	10,961	-	-	21,757	34
(Sub-Total)	-	(61,727)	(38,970)	(81,725)	(105,283)	-	-	(287,705)	(450)
Nappanee	32,288	103,598	10,220	7,949	-	-	-	154,055	241
Howe	-	1,363	-	97,511	-	56,897	-	155,771	243
Kendallville	-	-	-	46,938	63,377	93,008	5,888	209,211	327
Topeka	-	-	-	2,509	12,129	-	-	14,638	23
Hilltop	22,275	-	-	-	-	-	-	22,275	35
Total County Acres (in basin)	145,322	280,695	71,277	242,393	192,108	149,905	5,888	1,087,588	-
Sq. Mi. (in basin)	226.7	438.9	110.8	379	300.6	233.8	9.2		1,699

Miscellaneous-
- •Clay Layer 10,112 (St. Joseph Aquifer System)
- •Thick Clay 1,490 (St. Joseph Aquifer System)
- •Lake Area 883 (Howe Aquifer System)

than outwash aquifers.

Elevated concentrations of natural inorganic components (such as nitrate, chloride and sodium) and of organic components may be induced by man. The susceptibility of an aquifer system to contamination depends on the geologic setting. Contamination is less likely to occur in intertill aquifers because they are protected by layers of semipermeable clay which retard the vertical and horizontal migration of potential pollutants. Outwash and valley-train aquifers, however, are highly susceptible to contamination because protecting clay layers are either discontinuous or absent. Plate 1 briefly summarizes the susceptibility to contamination of seven aquifer systems identified within the St. Joseph basin.

Basin Assessment

Chemical data on samples from a total of 410 water and test wells were used to characterize the ground-water quality in the St. Joseph River basin. Major sources of information included: (1) analyses of 200 water samples collected in a cooperative effort between the Division of Water and the Indiana Geological Survey (summer 1985); (2) Indiana State Board of Health analyses of municipal, public supply, fish hatchery, and test wells; and (3) U.S. Geological Survey data from studies of St. Joseph County (Rosenshein and Hunn, 1962) and northwest Elkhart County (Imbrigiotta and Martin, 1981). Additional data on nitrate contamination were provided by the Indiana Department of Environmental Management (IDEM). Most data summarized in this report were collected between 1975 and 1985; however, older data were occasionally utilized. The water quality analyses used in this study generally typify the composition of water consumed by users rather than the composition of in-situ aquifer water. A number of factors may cause alteration of original aquifer water (for example, contact with plumbing, residence time in a pressure tank, and time elapsed between sampling and lab analysis).

Ground water in the St. Joseph River basin, primarily of the calcium bicarbonate type, is characterized by high alkalinities, high hardness, and mostly basic pH. Major chemical constituents include calcium, magnesium, sodium, bicarbonate, sulfate, and chloride. Less abundant components include potassium, iron, manganese, fluoride, and nitrate. Ranges of selected physical and chemical parameters are summarized in table 14 for the seven aquifer systems within the St. Joseph basin. (See Plate 1 for locations and descriptions of these systems.) Individual data for each of the 410 selected wells are presented in app. 14. Well locations are shown in Plate 3.

Alkalinity, the capacity of water to neutralize acid, is produced by bicarbonate, carbonate, and hydroxide. In the St. Joseph River basin, alkalinity is mainly produced by bicarbonate and ranges from 37 to 456 mg/l (milligrams per liter) as calcium carbonate ($CaCO_3$). Higher concentrations of alkalinity (greater) than 300 mg/l as $CaCO_3$) are found primarily in areas of Nappanee, Natural Lakes and Moraines, and Kendallville Aquifer Systems (Plate 1).

Hardness is principally caused by calcium and magnesium, and is commonly associated with water's effect on soap. Ground water in the basin contains large amounts of calcium and magnesium, and is considered hard to very hard. Hardness ranges from 73 to 580 mg/l as $CaCO_3$ (table 14). Of all wells sampled, 97 percent contain very hard water (hardness greater than 180 mg/l as $CaCO_3$). Although not included in this report, mapped trends of hardness distribution show that ground water in at least half of the basin (mostly within the intertill Nappanee, Kendallville, and Natural Lakes and Moraines Aquifer Systems) has a hardness of greater than 300 mg/l.

The hydrogen ion activity in water (pH) is expressed on a scale of zero to 14. Water with a pH of less than 7 is acidic, greater than 7 is basic, and equal to 7 is neutral. The pH of ground water in the St. Joseph River basin is predominantly basic, but ranges from 6.0 (slightly acidic) to 8.9 (basic), as table 14 shows.

National Interim Primary Drinking Water Regulations (USEPA, 1979a) and National Secondary Drinking Water Regulations (USEPA, 1979b) were examined to determine the suitability of ground water in the St. Joseph River basin for public supply (app. 15; also see app. 10 and table 14). The primary regulations list maximum concentration limits for inorganic constituents considered toxic or harmful to human health. These concentration limits are not to be exceeded in public water supplies. The secondary regulations list recommended concentration limits for inorganic constituents that are not known to be harmful to health but have undesirable aesthetic effects (taste and odor). Secondary drinking water standards are not mandatory and are commonly exceeded in ground-water supplies.

In general, the natural ground-water quality in the basin is within regulation for public supply. However, recommended (secondary) concentration limits for iron and manganese are commonly exceeded in wells throughout the basin. Although iron and manganese are not known to be harmful to human health, they

TABLE 14. Ranges of Chemical Constituents [a]

Constituent	U.S. EPA Drinking Water Standard	St. Joseph River Basin Aquifer System[b]					
		St. Joseph and Tributary Valley	Howe	Hilltop	Nappanee	Natural Lakes and Moraines	Kendallville
Alkalinity (as $CaCO_3$)	-	37.0-376.0	160.0-333.3	187.0-456.0	221.8-402.5	209.3-374.3	262.8-398.3
Hardness (as $CaCO_3$)	-	118-580	174-463	216-364	73-393	217-513	180-576
pH	5.0-9.0[c]	6.0-8.8	6.1-7.9	7.2-7.9	6.9-8.6	6.1-8.0	6.8-8.9
Calcium (Ca)	-	35.0-164.0	67.1-133.0	57.0-94.0	17.0-98.8	59.0-141.7	42.9-158.0
Magnesium (Mg)	-	10.0-41.0	1.0-30.5	19.0-30.0	7.4-36.4	15.0-36.6	17.0-42.4
Sodium (Na)	-	1.5-170.0	1.7-19.4	1.6-21.0	3.4-91.1	2.0-18.0	1.4-88.0
Sulfate (SO_4)	250[c]	1.0-250.0	1.2-144.0	14.0-50.0	0-116.0	0-148.0	<.1-134.0
Chloride (Cl)	250[c]	0-180.0	1.6-35.2	1.8-61.0	1.1-106.0	<.1-43.5	0.7-194.0
Potassium (K)	-	0.4-6.8	0.4-2.2	0.5-2.0	0.5-1.6	0.4-3.0	0.5-6.0
Iron (Fe)	0.3[c]	0-8.9	<.1-3.2	0.01-0.5	<.1-6.4	0-8.8	0.07-8.5
Manganese (Mn)	0.05[c]	0-1.3	0.02-0.4	0-0.2	0.02-0.5	0-0.5	0-0.5
Fluoride (F)	2.4[d]	0-2.7	<.1-1.2	0-0.2	0.2-1.4	0-1.1	0-1.7
Nitrate (NO_3 as N)	10[d]	0-16.0	<.02-15.1	<.02-5.2	<.02-13.6	<.02-20.3	0-7.2
Total Dissolved Solid (TDS)	500[c]	88-773	190-755	245-585	246-655	274-784	331-899
Number of selected wells		167	39	10	43	83	66

[a]Except for pH, all values are in milligrams per liter.
[b]The Topeka Aquifer System was not included because data on only two wells was available.
[c]U.S. EPA National Secondary Drinking Water Regulations.
[d]U.S. EPA National Interim Primary Drinking Water Regulations.

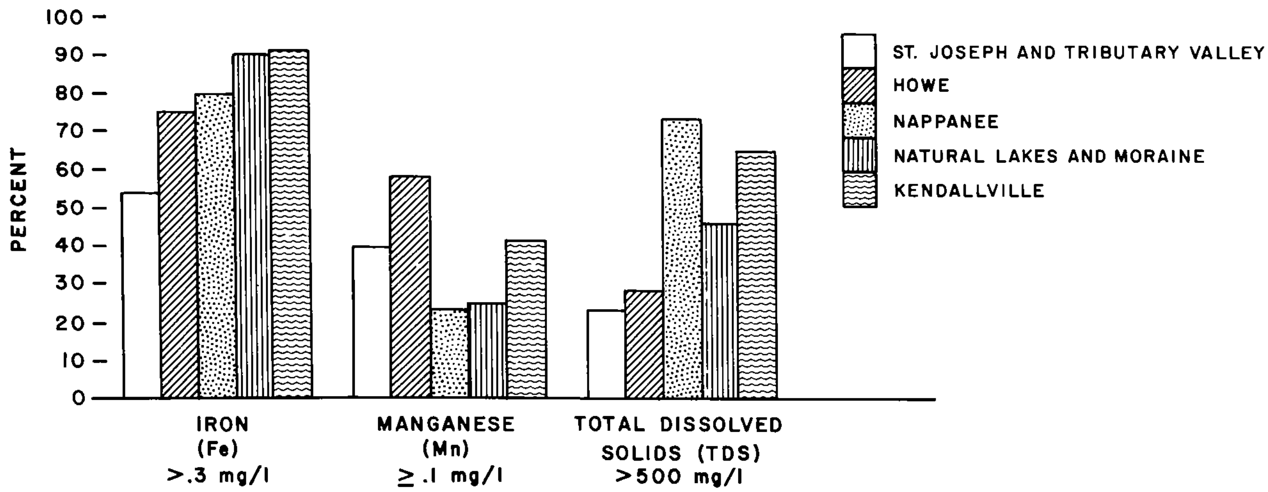

Figure 22. Percentage of Water Samples from Major Aquifer Systems Exceeding Recommended Limits for Iron and Total Dissolved Solids and a Selected Concentration of Manganese

cause taste problems, staining of utensils and laundry, and may clog well screens (app. 15). Concentrations of iron exceeding recommended limits are found in all aquifer systems, as are concentrations of manganese equal to or exceeding .1 mg/l, a selected concentration (fig. 22). Iron concentrations are generally higher (greater than 1 mg/l) in the eastern half of the basin, primarily within the Natural Lakes and Moraines, Kendalville, and (eastern) Howe Aquifer Systems. Lower concentrations (less than 1 mg/l) are commonly found in the St. Joseph, (western) Howe, and Nappanee Aquifer Systems, although some localized areas have values greater than 1 mg/l.

Total dissolved solids (TDS) is a measure of the concentration of mineral constituents dissolved in water. TDS values in the basin (the calculated sum of major constituents expected in an anhydrous residue of a ground-water sample) range from 88 mg/l to 899 mg/1 (table 14). The recommended concentration limit for TDS (500 mg/1) is not exceeded for most wells in the main St. Joseph Aquifer System and Howe System (fig. 22). However, the limit is exceeded in areas of the Natural Lakes and Moraines, Nappanee, and Kendallville Aquifer Systems, as well as the tributary valley portion of the St. Joseph Aquifer System. Sulfate, chloride, and sodium concentrates also do not exceed USEPA's recommended concentration limit; however, values can be locally high (100-250 mg/l).

Fluoride concentrations are less than the maximum (primary) concentration limit of 2.4 mg/l throughout the basin. However, concentrations greater than or equal to 1 mg/l are found in several localized areas, as well as in 15 wells which trend northeast-southwest on the eastern basin edge (fig. 23). The wells in this trend are completed in sediments of the Mississinewa Moraine (deposited by the Erie Lobe) where ground water is known for having elevated concentrations of fluoride (W.J. Steen, IDNR Division of Water, personal communication, 1986).

Natural concentrations of nitrate in ground water originate from the atmosphere in addition to living and decaying organisms. High levels of nitrates can result from leachates of industrial and agricultural chemicals or decaying organic matter such as animal waste or sewage. In the St. Joseph basin, nitrate concentrations greater than the maximum (primary) concentrations limit of 10 mg/l have been found in 13 of the 410 selected wells (nine sampled in summer 1985). These 13 wells (nine of which are less than 60 feet deep) are located mainly in the St. Joseph, Tributary Valley, and Howe Aquifer Systems and sandier areas of the Natural Lakes and Moraines Aquifer System (fig. 23). Forty-six sites (58 wells, primarily shallow), contain lesser concentrations of nitrate between 1 mg/l and 10 mg/l. Twenty-nine of these 46 sites are located in the St. Joseph and Tributary Valley Aquifer System (fig. 23). In general, wells with concentrations of nitrates above 1 mg/l are associated with shallow and/or deep outwash sand and gravel aquifers designated by IDEM as easily susceptible to contamination.

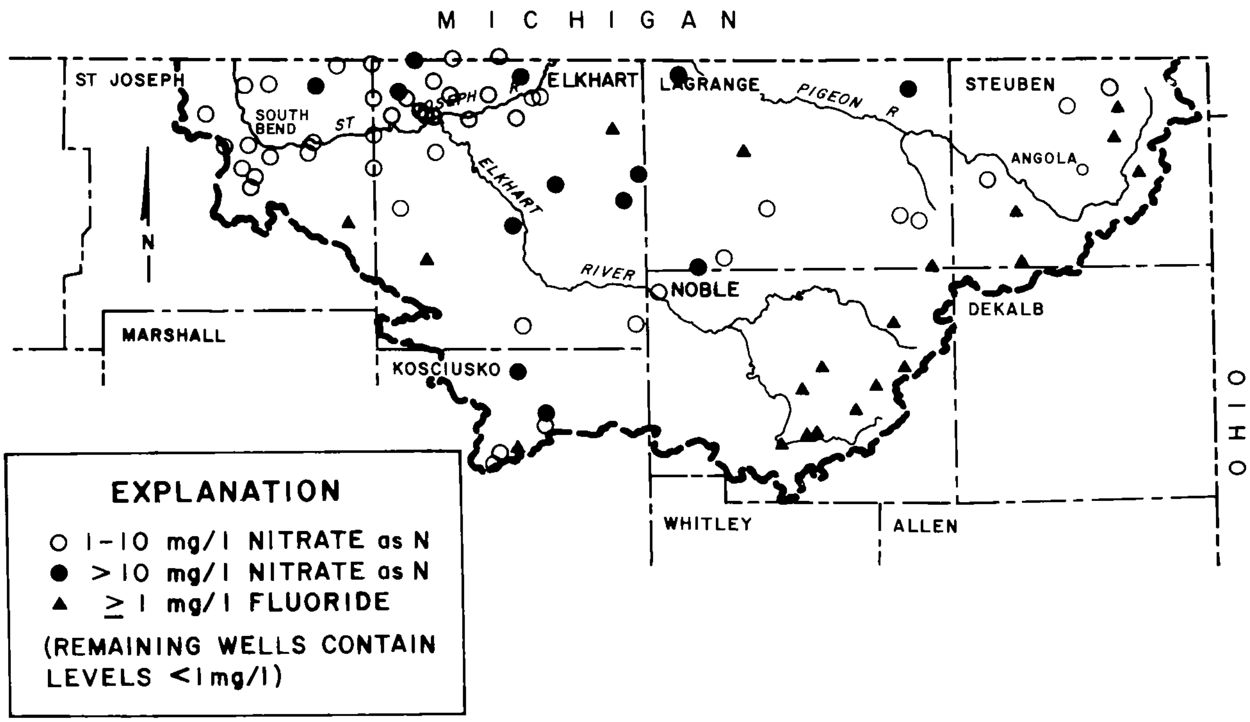

Figure 23. Concentration Ranges of Nitrate and Fluoride

Ground-Water Contamination[14]

A ground-water supply that otherwise would be plentiful can be diminished by contamination from man's activities. Contamination, as defined by IDEM [1986], occurs when concentrations of chemicals are in excess of public drinking water standards, proposed standards, or health protection guidance levels from the U.S. Environmental Protection Agency. To protect Indiana's ground-water resource, officials on state (IDEM and ISBH) and federal (USEPA) levels are working in a cooperative effort for prevention, detection and correction of ground-water problems in Indiana.

One important step in developing a ground-water management and protection program is identifying geographic areas more susceptible to ground-water contamination than others. The IDEM has designated 11 counties in Indiana— three in the St. Joseph River Basin (St. Joseph, Elkhart and Kosciusko)— as geographic areas where ground-water protection may be most needed. Screening criteria used to identify these areas include: (1) the susceptibility of an area to contamination; (2) the magnitude of current and potential water use; (3) the location of known sites of contamination; and (4) the presence of potential sources of contamination. In general, geographic areas of concern are located near major rivers and highly productive ground-water resources where there is an association among the prevalence of industry, spills, and ground-water or water-well contamination.

In 1986, the Indiana Department of Environmental Management summarized organic and inorganic contamination sites documented in Indiana. In general, substances contaminating ground water in Indiana include volatile organic chemicals, petroleum and petroleum products, metals and heavy metals, chlorides and salts, and nitrates.

Within the St. Joseph River basin, 33 sites of ground-water contamination have been documented by the IDEM. Three sites of contamination have been identified in Steuben County: two in the Howe Aquifer System and one in the Kendallville Aquifer System.

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14 Information in the following paragraphs was summarized from IDEM [1986].

Two sites have been documented in Kosciusko County; five in St. Joseph County; and 23 in Elkhart County. These 30 sites, which occur in counties of major concern, are primarily within the St. Joseph and Tributary Valley Aquifer Systems. In St. Joseph and Elkhart Counties, sites occur predominately in the industrial areas of South Bend and Elkhart. The need for ground-water protection in Elkhart County is being addressed by the Elkhart County Health Department which is implementing an aggressive ground-water protection program.

Nitrates were the contaminating substance at four of the documented contamination sites, according to County Health Department data supplied by the IDEM. Nitrates above recommended limits were found in 23 wells at the following sites: Orland (11) in Steuben County; Leesburg (2) and Milford (2) in Kosciusko County; and south of Middlebury (8) in Elkhart County.

Since 1981, the USEPA has been conducting a survey of 26 volatile organic chemicals (VOCs) in Indiana's public ground-water supplies serving more than 25 customers. These chemicals include both chlorinated VOCs which are associated with hazardous waste disposal and hazardous material spills and aromatic VOCs which are associated with fuel and solvent spills and leaking underground storage tanks. Detectable levels of at least one VOC were found in seven public water supplies in in-basin portions of St. Joseph, Elkhart, LaGrange, Steuben and Dekalb counties. If levels were a risk to public health, corrective action was taken; otherwise, levels are continuing to be monitored. (Contamination of Elkhart's Main Street well field is discussed later in this report.)

WATER USE

EXISTING WATER UTILIZATION

Indiana's Water Resource Management Act (IC 13-2-6.1, Section 3) calls for an ongoing inventory of large-scale withdrawals of surface and ground water. Section 7 requires owners of "significant water withdrawal facilities" to register these facilities with the Natural Resources Commission (through the Division of Water) and to report annual water usage. "Significant" facilities are those capable of withdrawing 100,000 gallons per day of surface water, ground water, or surface and ground water combined.

Fig. 24 shows the locations of registered facilities in the St. Joseph basin as of October 1986. Table 15 lists, by county, the number of facilities and summarizes both the withdrawal capability and 1985 usage of all registered facilities. Approximately 14 percent of the facilities had not yet reported their 1985 usage at the date of this compilation (October 1986).

Withdrawal capability represents the amount which could theoretically be withdrawn if all pumps were operating at their rated capabilities 24 hours a day. Few facilities operate in this manner, however, and reported uses generally comprise only a small percentage of total withdrawal capabilities (fig. 25). Estimates of total usage may be based on metering devices, the multiplication of pump capacity and total time of pumpage, or by other methods approved by the Division of Water.

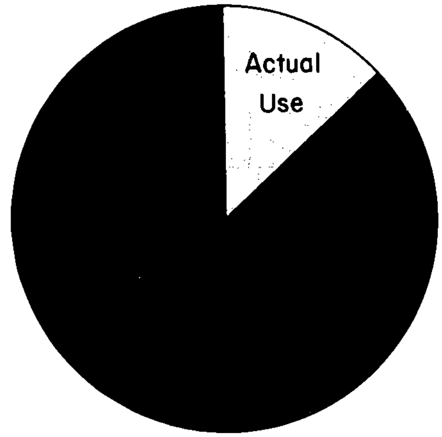


Figure 25. Water Use 1985 vs. Registered Capability

TABLE 15. Withdrawal Capability and Use by Registered Significant Water Withdrawal Facilities: All Uses Combined (1985)

		Withdrawal Capability (MGD)			Reported Use (MGD)[1]		
County	Number of Facilities	Ground Water	Surface Water	Combined	Ground Water	Surface Water	Combined
Dekalb	1	0.36	0.00	0.36	0.01	0.00	0.01
Elkhart	215	203.86	73.16	277.02	27.41	6.25	33.66
Kosciusko	38	34.92	27.06	61.98	2.57	0.64	3.21
LaGrange	152	99.94	70.17	170.11	4.87	4.44	9.31
Noble	45	35.10	4.03	39.13	3.43	0.05	3.48
St. Joseph	53	122.31	13.81	136.12	34.67	4.05	38.72
Steuben	25	15.26	12.86	28.12	1.79	0.36	2.15
Total	529	511.75	201.09	712.84	74.75	15.79	90.54

[1]As of October 1986. Reports for approximately 14 percent of registered facilities had not yet been received at the date of this compilation.

TABLE 16. Water Use by Category 1985[a]

County	Registered Water Withdrawal Facilities						Non-Registered
	Public Supply	Irrigation[b]	Industry	Energy Production	Rural	Misc.	Domestic Self-Supplied
Dekalb	-----[c]	0	.01	0	0	0	0.03
Elkhart	15.33	9.78	8.55	0	0	0	5.08
Kosciusko	.49	2.00	.71	0	0	0	0.71
LaGrange	.59	7.07	.02	0	1.52	.11	1.81
Noble	2.42	.41	.65	0	0	0	0.88
St. Joseph	32.19	.43	5.03	0	1.08	0	3.69
Steuben	1.33	.52	.13	0	0.17	0	0.94
TOTAL	52.35	20.21	15.10	0	2.77	.11	13.14

[a]All values in million gallons per day.
[b]Estimated water use for non-registered livestock operations is 5.55 MGD. Less than 5 percent of this total is already accounted for in the "Irrigation" category. A minimal percentage is accounted for in the "Rural" category (one facility) and "Industrial" category (one facility).
[c]Data not available during report preparation.

The division recognizes six water use categories for registered facilities: public supply, irrigation, industrial, rural, energy production, and miscellaneous. Non-registered withdrawals (discussed in a later section) primarily include domestic self-supplied uses and large livestock operations. Total reported and estimated withdrawals for 1985 for registered and non-registered facilities are as follows:

Registered water use	90.54 MGD
Non-registered water use	18.69 MGD
Total	109.23 MGD

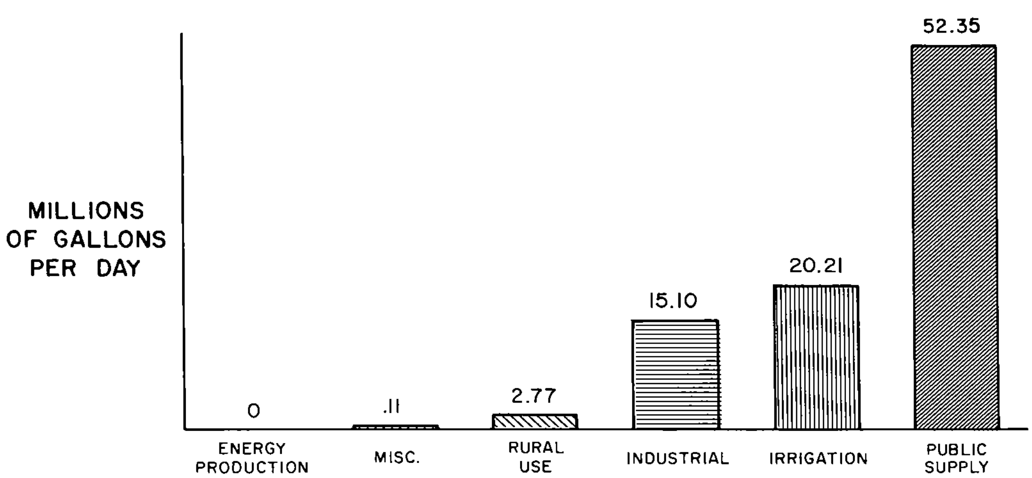


Figure 26. Water Use

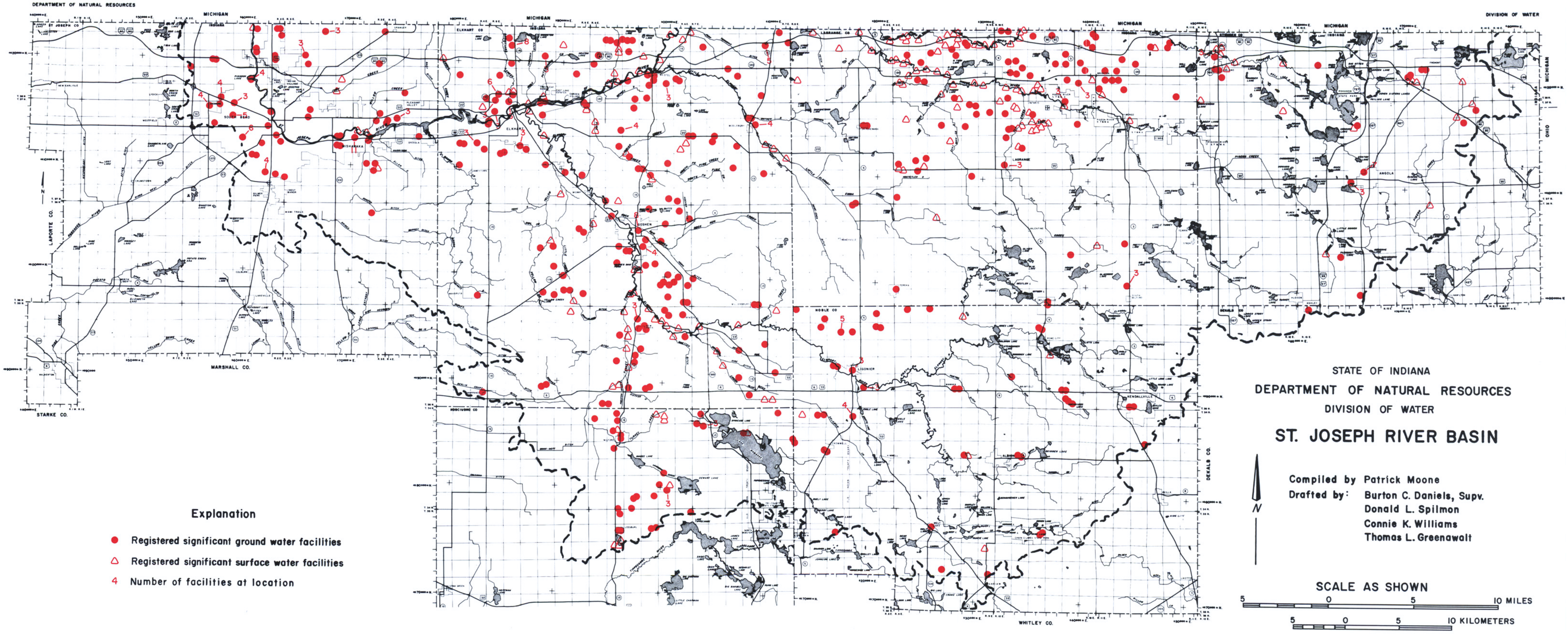


Figure 24. Registered significant withdrawal facilities

TABLE 17. Withdrawal Capability and Use: Public Supply

	Withdrawal Capability (MGD)			Reported 1985 Use (MGD)		
County	Ground Water	Surface Water	Combined	Ground Water	Surface Water	Combined
Dekalb	-----[a]	0.00	-----[a]	-----[a]	0.00	----- [a]
Elkhart	63.60	0.00	63.60	15.33	0.00	15.33
Kosciusko	5.01	0.00	5.01	0.49	0.00	0.49
LaGrange	8.15	0.72	8.87	0.59	0.00	0.59
Noble	14.44	0.00	14.44	2.42	0.00	2.42
St. Joseph	94.35	0.29	94.64	32.18	0.01	32.19
Steuben	4.80	0.00	4.80	1.33	0.00	1.33
Total	190.35	1.01	191.36	52.34	0.01	52.35

[a]Data not available during report preparation.

Table 16 categorizes by county the reported 1985 water use (reported as of October 1986) for registered facilities. Fig. 26 summarizes total in-basin water use by registration category. As the exhibits show, withdrawals for public supply, which constitute the largest daily average use in the basin (approximately 52 MGD), occur primarily in St. Joseph and Elkhart counties. During the summer crop season, however, daily public supply withdrawals (as averaged over one year) may be exceeded by irrigation withdrawals (which average 82 MGD for a 90-day period or 130 MGD for a 60-day period).

Ground water is the source of 83 percent of all water withdrawn by registered facilities, or nearly five times the amount of surface water (fig. 27). Eighty-five percent (85%) of ground-water withdrawals occur within St. Joseph and Elkhart counties, primarily for public supply uses. Ninety-seven percent (97%) of all surface-water withdrawals occurred within St. Joseph, Elkhart, and LaGrange counties, primarily for agricultural irrigation.

Registered Use Categories

Public supply (table 17) refers to water withdrawn by public and private water utilities and delivered for domestic (household), municipal, industrial, and commercial uses. In 1985, public supply uses in the St. Joseph basin totalled approximately 52 MGD (27 percent of the total withdrawal capability). Over 99 percent of the water withdrawn was derived from ground-water sources. The small amount of surface water withdrawn under the "Public Supply" category in St. Joseph County was used for non-drinking purposes.

The two most populous counties, St. Joseph and Elkhart, accounted for 91 percent of total withdrawals, as well as 91 percent of ground-water withdrawals. Public supply constituted the largest water use for Noble and Steuben, as well as Elkhart and St. Joseph counties. This usage is a reflection of the population (fig. 3) for cities within these four counties.

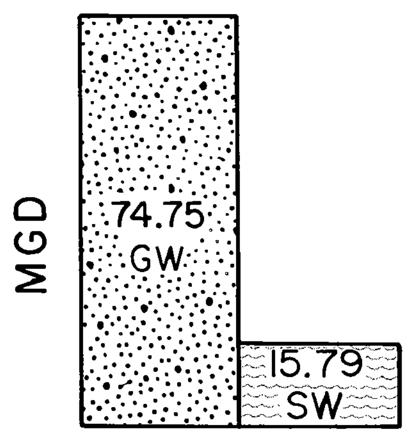


Figure 27. Total Use By Source

TABLE 18. Withdrawal Capability and Use: Irrigation

County	Withdrawal Capability (MGD)			Reported 1985 Use (MGD)		
	Ground Water	Surface Water	Combined	Ground Water	Surface Water	Combined
Dekalb	0.00	0.00	0.00	0.00	0.00	0.00
Elkhart	97.29	58.04	155.33	5.06	4.72	9.78
Kosciusko	24.56	9.22	33.78	1.55	0.45	2.00
LaGrange	81.52	67.22	148.74	4.26	2.81	7.07
Noble	16.11	2.59	18.70	0.36	0.05	0.41
St. Joseph	13.62	5.33	18.95	0.31	0.12	0.43
Steuben	6.39	12.10	18.49	0.31	0.21	0.52
Basin Total	239.49	154.50	393.99	11.85	8.36	20.21

Irrigation (table 18) refers to both agricultural and non-agricultural uses (such as for golf courses). Irrigation uses in the St. Joseph basin totalled 20 MGD, only 5 percent of total capability. Sixty percent (60%) of irrigation water was derived from ground-water sources. Surface-water withdrawals occurred primarily along Pigeon and Fawn Rivers (LaGrange County), the Elkhart and St. Joseph Rivers (Elkhart County), and portions of Turkey Creek (Kosciusko and Elkhart Counties).

Ninety-four percent (94%) of all irrigation uses occurred in Elkhart (49%), LaGrange (35%), and Kosciusko (10%) Counties. These three counties also accounted for similar percentages of ground-water withdrawals for irrigation (42%, 36% and 13%, respectively). Irrigation usage is generally confined to outwash areas.

Industrial self-supplied (table 19) refers to process water, waste assimilation, dewatering, and some cooling and mineral extraction uses. In 1985, self-supplied industrial water use totalled 15 MGD (approximately 14 percent of the total withdrawal capability). Nearly 63 percent of industrial water was derived from ground-water sources. Approximately 90 percent of all industrial uses occurred in Elkhart and St. Joseph counties. This usage reflects the economic activities of the two counties. As discussed earlier in the "Economy" section of this report, major types of manufacturing in these two counties include machinery, fabricated metals, and transportation equipment.

TABLE 19. Withdrawal Capability and Use: Industrial

County	Withdrawal Capability (MGD)			Reported 1985 Use (MGD)		
	Ground Water	Surface Water	Combined	Ground Water	Surface Water	Combined
Dekalb	0.36	0.00	0.36	0.01	0.00	0.01
Elkhart	41.10	15.12	56.22	7.02	1.53	8.55
Kosciusko	5.35	17.84	23.19	0.53	0.18	0.71
LaGrange	0.82	0.00	0.82	0.02	0.00	0.02
Noble	4.55	1.44	5.99	0.65	0.00	0.65
St. Joseph	12.18	8.19	20.37	1.10	3.93	5.03
Steuben	2.84	0.00	2.84	0.13	0.00	0.13
Basin Total	67.20	42.59	109.79	9.46	5.64	15.10

TABLE 20. Withdrawal Capability and Use: Rural

County	Withdrawal Capability (MGD)			Reported 1985 Use (MGD)		
	Ground Water	Surface Water	Combined	Ground Water	Surface Water	Combined
Dekalb	0.00	0.00	0.00	0.00	0.00	0.00
Elkhart	0.32	0.00	0.32	0.00	0.00	0.00
Kosciusko	0.00	0.00	0.00	0.00	0.00	0.00
LaGrange	5.13	1.73	6.86	0.00	1.52	1.52
Noble	0.00	0.00	0.00	0.00	0.00	0.00
St. Joseph	2.16	0.00	2.16	1.08	0.00	1.08
Steuben	1.23	0.76	1.99	0.02	0.15	0.17
Basin Total	8.84	2.49	11.33	1.10	1.67	2.77

Rural uses (table 20) in the St. Joseph Basin only include fish hatcheries, although large-scale livestock operations also constitute a rural use. Non-registered, self-supplied domestic withdrawals are not categorized as rural uses, unlike an earlier classification utilized by the Governor's Water Resource Study Commission (1980).

Rural water use totalled nearly 3 MGD for 1985. In contrast to public supply, irrigation, and industrial uses, rural water use was primarily derived from surface-water sources.

Energy Production includes any self-supplied, water withdrawal use involved in the energy production process including: coal preparation, oil recovery, cooling water, mineral extraction, power generation, heating/air conditioning, and dewatering.

The St. Joseph River basin, as defined in this study, has no registered withdrawal facilities for energy production within its boundaries. However, a South Bend ethanol plant lies approximately one-half mile outside the western topographic boundary. The plant uses ground water from the St. Joseph Aquifer System and discharges most of its water to the St. Joseph River, and must therefore be considered when examining water use within the basin. The ethanol facility has a registered capability of 12.4 MGD and a reported usage of approximately 3 MGD for 1985. Existing hydropower plants are discussed as instream uses.

Miscellaneous (table 21) includes water withdrawn for recreational purposes (for example, water slides and snow-making) and fire protection. Only three facilities in the basin are classified as miscellaneous. In 1985, miscellaneous uses totalled 0.11 MGD (approximately 2 percent of the registered capability). Less than 40 percent of the water withdrawn was derived from ground-water sources.

TABLE 21. Withdrawal Capability and Use: Miscellaneous

County	Withdrawal Capabilty (MGD)			Reported 1985 Use (MGD)		
	Ground Water	Surface Water	Combined	Ground Water	Surface Water	Combined
Dekalb	0.00	0.00	0.00	0.00	0.00	0.00
Elkhart	1.55	0.00	1.55	0.00	0.00	0.00
Koscuisko	0.00	0.00	0.00	0.00	0.00	0.00
LaGrange	4.32	0.50	4.82	0.00	0.11	0.11
Noble	0.00	0.00	0.00	0.00	0.00	0.00
St. Joseph	0.00	0.00	0.00	0.00	0.00	0.00
Steuben	0.00	0.00	0.00	0.00	0.00	0.00
Basin Total	5.87	0.50	6.37	0.00	0.11	0.11

Non-Registered Uses

Domestic self-supply refers to water users who obtain water from individual water wells rather than municipal (public supply) systems. Table 22 lists the estimated amount of domestic self-supplied water use for 1985. The values were obtained by multiplying estimated self-supplied population by a calculated average usage of 76 gallons per day per person (IDNR, 1982a).

Livestock water use (table 23) has been estimated by multiplying the estimated population of a particular livestock category by an estimate of the amount of water consumed daily per animal (IDNR, 1982a). In a few cases, water used for livestock purposes by large farm operations may have also been included in the "Irrigation" category of registered significant water withdrawal facilities.

Consumptive use refers to the amount of withdrawn water which is evaporated, transpired by plants, incorporated into a product, or otherwise made unavailable for re-use within a short time period. The percentage of withdrawn water that is consumed depends on the type of water use.

Irrigation and rural uses consume most of the utilized water (90 to 100 percent). Industrial and public supply consume relatively little water (5 to 25 percent). Once-through cooling for energy production generally consumes a minimal amount (1 to 2 percent).

Instream (non-withdrawal) uses primarily include recreation and fish and wildlife habitat. In addition, two hydroelectric power plants within the basin are also categorized as instream uses because no diversion channels are involved. The two hydropower plants, Twin Branch at Mishawaka and Elkhart Dam at Elkhart, are both owned and operated by the Indiana and Michigan Electric Company. The Twin Branch facility has six units with a total rated capacity of 7260 kilowatts. Elkhart Dam's three units have a total rated capacity of 3440 kilowatts.

Water-based recreational activities are available throughout the basin, and many additional activities such as picnicking, camping, and hiking are generally enhanced by the presence of water. Most in-basin lakes are surrounded by land in private ownership and therefore are not legally accessible by the public. However, public lake access is available within state properties such as parks and nature preserves, as well as on dozens of other lakes, particularly in the basin's "lake zone" extending from northwest Steuben to northeast Kosciusko county. River access sites administered by the IDNR are located on the St. Joseph, Elkhart, North Branch Elkhart, South Branch Elkhart, and Pigeon Rivers. Public fishing areas are located on Lake Wawasee (no boat ramp available) and on Pigeon River's Scott Mill Pond.

Boating, fishing, canoeing, swimming, ice skating, and water skiing are six major water-related activities in the St. Joseph basin. Table 24 shows estimates of instream uses and needs for these activities for 1985, 1990, and 1995. As the table shows, there are projected shortages in boating, fishing and ice skating needs, and

TABLE 22. Estimated Domestic Self-Supplied Water Use, 1985

County	Use (MGD)
Dekalb	0.03
Elkhart	5.08
Kosciusko	0.71
LaGrange	1.81
Noble	0.88
St. Joseph	3.69
Steuben	0.94
Basin Total	13.14 MGD

TABLE 23. Estimated Livestock Water Use, 1985

Livestock Category	Estimated Population Within Basin	Total Water Use (MGD)
Beef Cattle	148,600	1.71
Dairy Cattle	40,100	0.90
Hogs	239,300	0.96
Chickens	1,962,400	1.96
Sheep	9,800	0.01
Turkeys	39,800	0.01
Basin Total		5.55 MGD

TABLE 24. Recreational Instream Uses and Needs

Activity	Activity Occasions	Density Guidelines	Demand	Supply	Needs
Boating					
1985	1765055	58.8 Boaters/AC/YR	30018 Acres	16990 Acres	-13028 Acres
1990	1781928	58.8 Boaters/AC/YR	30305 Acres	16990 Acres	-13315 Acres
1995	1854430	58.8 Boaters/AC/YR	31538 Acres	16990 Acres	-14548 Acres
Canoeing					
1985	68037	1170 Canoeists/Mi/YR	58 Miles	89 Miles	+31 miles
1990	67265	1170 Canoeists/Mi/YR	57 Miles	89 Miles	+32 Miles
1995	69005	1170 Canoeists/Mi/YR	59 Miles	89 Miles	+30 Miles
Water Skiing					
1985	156835	34.4 Skiers/AC/YR	4559 Acres	7017 Acres	+2458 Acres
1990	155057	34.4 Skiers/AC/YR	4507 Acres	7017 Acres	+2510 Acres
1995	156537	34.4 Skiers/AC/YR	4550 Acres	7017 Acres	+2467 Acres
Swimming					
1985	3241891	76608 Swimmers/AC/YR	42 Acres	59 Acres	+17 Acres
1990	3331748	76608 Swimmers/AC/YR	43 Acres	59 Acres	+16 Acres
1995	3463450	76608 Swimmers/AC/YR	45 Acres	59 Acres	+14 Acres
Fishing					
1985	3647863	66 Fishermen/AC/YR	55271 Acres	20319 Acres	-34952 Acres
1990	3629646	66 Fishermen/AC/YR	54995 Acres	20319 Acres	-34676 Acres
1995	3693144	66 Fishermen/AC/YR	55957 Acres	20319 Acres	-35638 Acres
Ice Skating					
1985	81419	4200 Skaters/AC/YR	19 Acres	6 Acres	-13 Acres
1990	81301	4200 Skaters/AC/YR	19 Acres	6 Acres	-13 Acres
1995	83857	4200 Skaters/AC/YR	20 Acres	6 Acres	-14 Acres

projected surpluses in canoeing, water skiing, and swimming needs. (It should be emphasized, however, that the data from which table 24 is derived were obtained from surveys taken in 1976 (IDNR, 1979). It is likely that new trends in recreational instream uses are being seen.)

As discussed in the ''Rivers and Streams'' section earlier in this report, fish habitat in the St. Joseph River basin is generally quite good, and quality sport fisheries are found throughout the basin. During a 1979 fisheries survey of Indiana's portion of the St. Joseph River, 46 fish species were collected. The St. Joseph River, as well as the Elkhart River, is particularly known for its smallmouth bass fishing. In addition, trout and salmon migrate annually up the St. Joseph River from Lake Michigan. When two planned fish ladders are completed, trout and salmon fishing will be brought to the river as far upstream as Mishawaka.

Put-and-take trout fisheries are maintained by IDNR on portions of the following streams: Fawn, Pigeon, Little Elkhart, and North Branch Elkhart Rivers; Solomon, Turkey, Cobus, Curtis, Clock, and Bloody Run Creeks; and Rowe-Eden Ditch. The following lakes are also stocked with trout: Clear, Gage, Lake-of-the-Woods, Martin, McClish, Olin, Oliver, Pretty, Rainbow Pit, Sand, South Twin, and Wyland.

High-quality riparian habitat is mainly comprised of the wetlands associated with natural lakes and streams. Currently existing marshes and wooded swamps are excellent habitat for waterfowl (such as mallards, blue-wing teal, and woodduck), various shorebirds, beaver, muskrat, raccoon, and upland game. Because urban development (particularly along portions of the Elkhart and St. Joseph rivers), residential development on the larger lakes, and agricultural development throughout the basin have significantly reduced suitable habitat for many desirable fish and wildlife species, the protection and conservation of wetland areas has been an ongoing concern of IDNR.

Areas protected under IDNR's Wetland Conservation Program and in association with state and federal laws were mentioned earlier in this report. Wetlands associated with stream segments that are included in IDNR's Natural and Scenic Rivers Program are also protected from detrimental development. Nearly 14 miles of the South Branch Elkhart River have been proposed for inclusion in the IDNR river system, but local opposition has prevented any further action. The proposed segment flows through Bender Woods Nature Preserve and the largest, contiguous wetland area remaining in the state, including Mallard Roost Wetlands Conservation Area. (No other streams in the basin have been proposed for inclusion in this system: Indiana Natural and Scenic Rivers Report, Division of Outdoor Recreation, 1986.)

WATER USE PROJECTIONS

Public Supply

Table 25 shows the projected public water supply withdrawals for 1990 and 2000 in the St. Joseph basin. (App. 16 describes the methodology used.)The projected withdrawals were developed from both 1980 and 1985 data. Where the projections differ, both projections are shown.

The large difference between the two projections for Elkhart is due in part to two interceptor wells used by the City of Elkhart to reduce the amount of polluted ground water reaching water supply wells. The two wells accounted for 2.11 MGD in 1985. The City of Elkhart also had a very large increase in water use from 1980 to 1985, even after water withdrawn from the interceptor wells was neglected.

Irrigation

Soil associations with moderate to high irrigation potential are located primarily within outwash areas of the St. Joseph basin (fig. 28). A soil association has characteristic topography and repeating patterns of soils wherever it occurs. It normally consists of one or more major soils and at least one minor soil, and is named for the major soils. The soils in one association may occur in another, but in a different pattern.[15] Descriptions of in-basin soil associations may be found in app. 3.

Each soil association can be assigned to an irrigation potential category. These categories are based on the assumption that crop yields in sandier soils would significantly increase, whereas yields in deep loam, silt loam and finer textured soils would not increase suffi-

15 Soil associations on the general soil map in one soil survey may not fully agree with those on the general soil maps of adjacent counties. Differences are the result of improvements in the classification of soils, particularly the modification or refinement in soil series concepts. Another difference is caused by the range in slope that is permitted within associations in different surveys.

TABLE 25. Public Water Supply Projections[a]

County	Estimated Use, 1980[b]	Reported Use, 1985	Projected Withdrawals 1990	2000
Dekalb[c]	——	——	——	——
Elkhart	10.11	15.33	15.98[d]	17.27[d]
			11.60	12.89
Kosciusko	0.48	0.49	0.54	0.58
LaGrange	0.46	0.59	0.63	0.83
Noble	2.01	2.42	2.62[d]	3.00[d]
			2.42	2.79
St. Joseph	30.53	32.19	33.44	36.41
Steuben	1.03	1.33	1.46[d]	1.66[d]
			1.30	1.50
Total	44.62	52.35	54.67[d]	56.75[d]
			49.93	55.00

[a]All values in million gallons per day.
[b]From Indiana Department of Natural Resources, 1982b.
[c]Data not available during report preparation.
[d]Projections based upon reported 1985 use.

ciently to make irrigation profitable for grain crops at historic average corn price/cost ratios.

Soils in the St. Joseph River basin were grouped into four categories according to the favorability of crop response to irrigation. (Soil associations from Soil Conservation Service generalized county soil maps were used for the classification, as shown in fig. 28.)The results are shown in table 26.

Groups 1 and 2 are not considered further, because it is assumed that a profitable response less than half the time is economically unacceptable. Of the soils in Groups 3 and 4, only 86.5 percent (317,713 acres) are considered irrigable, since not all soils within a given association are irrigable. The percent of irrigable land (Groups 3 and 4) actually utilized will depend on the interaction of three major factors:

1) *Corn prices*. Corn is the major crop of the St. Joseph River Basin. If corn prices were to increase significantly due to an action such as increased exports, farmers may find it more economically feasible to install irrigation equipment. On the other hand, if corn prices were to fall dramatically, a shift in cropping patterns could occur. Depending on the water demands of the crops which replace corn, irrigation could increase or decrease.

TABLE 26. Irrigation Potential by Soil Associations

	Category	Area
1 -	Little or no profitable response (none)	874.29 mi² 559,546 acres
2 -	Response 1-2 years in 5 years (slight)	251.10 mi² 160,704 acres
3 -	Response 3-4 years in 5 years (moderate)	384.66 mi² 246,182 acres
4 -	Response expected yearly (high)	188.96 mi² 120,928 acres
	Total	1699. mi² 1,087,360 acres

TABLE 27. Irrigated Land by County (Acres)

Source		St. Joseph[1]	Elkhart	Kosciusko[1]	LaGrange	Noble[1]	Steuben
GWRS Survey	1977	3,000	9,000	2,800	11,500	2,000	1,000
Census of Agriculture	1978	5,853	11,313	2,640	12,581	1,895	1,739
Census of Agriculture	1982	7,128	15,875	7,150	17,898	2,265	1,760
Local Estimates	1986	little change within basin	20,000	10,000	20,000	little change	little change within basin
(County Extension Agents)	Near Future		continued growth but slower rate	15,000	continued growth but slower rate		

[1]Figures shown are for the entire county. In-basin acreage is estimated from reported water use: St. Joseph - 1000 acres; Kosciusko - 6400 acres; and Noble - 2100 acres.

2) *Cost of energy*. If electricity prices fall, pumping costs to individuals would decrease, making irrigation a more viable option for farmers. Of course, increased energy costs would likely cause a decrease in the amount of irrigated land.

3) *Climatic anomalies*. Adequate moisture at the appropriate time during the growing season is essential to maximize crop production. An increasing incidence of drought in various parts of the state (as occurred in 1966, 1967, 1974, 1976, and 1983) can influence irrigation decisions. In the long term, development of a dry climate may cause increased irrigation if cropping patterns do not change. The amount of irrigated land may remain stable or decrease if corn were replaced by crops tolerant of dry conditions (for example some wheat varieties). A longer growing season could increase irrigation if farmers were able to raise two crops in one season. Naturally, a shift to a wetter climate would decrease irrigation.

Land use also plays an important role in irrigation expansion. How land is used affects water requirements, and water availability in turn affects how land is used. Although there is little quantitative data on St. Joseph River basin land use, the land use map (fig. 5), combined with information from topographic, soils, and water use maps can be helpful in detecting general patterns or trends. These maps are not suited for site specific planning, but are adequate for determining the interaction of some basin characteristics.

For example, the northwestern portion of the basin contains a large area of soils highly responsive to irrigation. A significant portion of this area, however, exists as urban land. So, it is a safe assumption that such land will not become irrigated agricultural land. Increased water demands here would come from residential and/or industrial expansion, not from irrigation. Agricultural lands adjacent to the urban areas are expected to experience development pressure and may convert to higher economic uses.

Other high irrigation response areas exist as forested land, which would be more likely to come into irrigated agricultural production than urban land. Increased irrigation demands would be most likely on moderate to high response soils already used for agriculture.

Recent trends may also give an indication of future irrigation growth. As table 27 shows, Elkhart and LaGrange Counties remain the largest irrigators within the basin in terms of acres irrigated. At the time of the last Census of Agriculture (1982), acreage of land irrigated in these two counties totalled 33,773 acres. Local estimates for 1986 totalled 40,000 irrigated acres for Elkhart and LaGrange Counties.

These two counties also have the highest potential for future irrigation in terms of favorable soil associations (fig. 28). Elkhart County has approximately 97,000 acres which are in groups 3 or 4, while LaGrange has approximately 88,800 acres. However, Elkhart is more highly urbanized along the outwash corridors than LaGrange, which may reduce the potential for continued irrigation expansion, as compared to LaGrange.

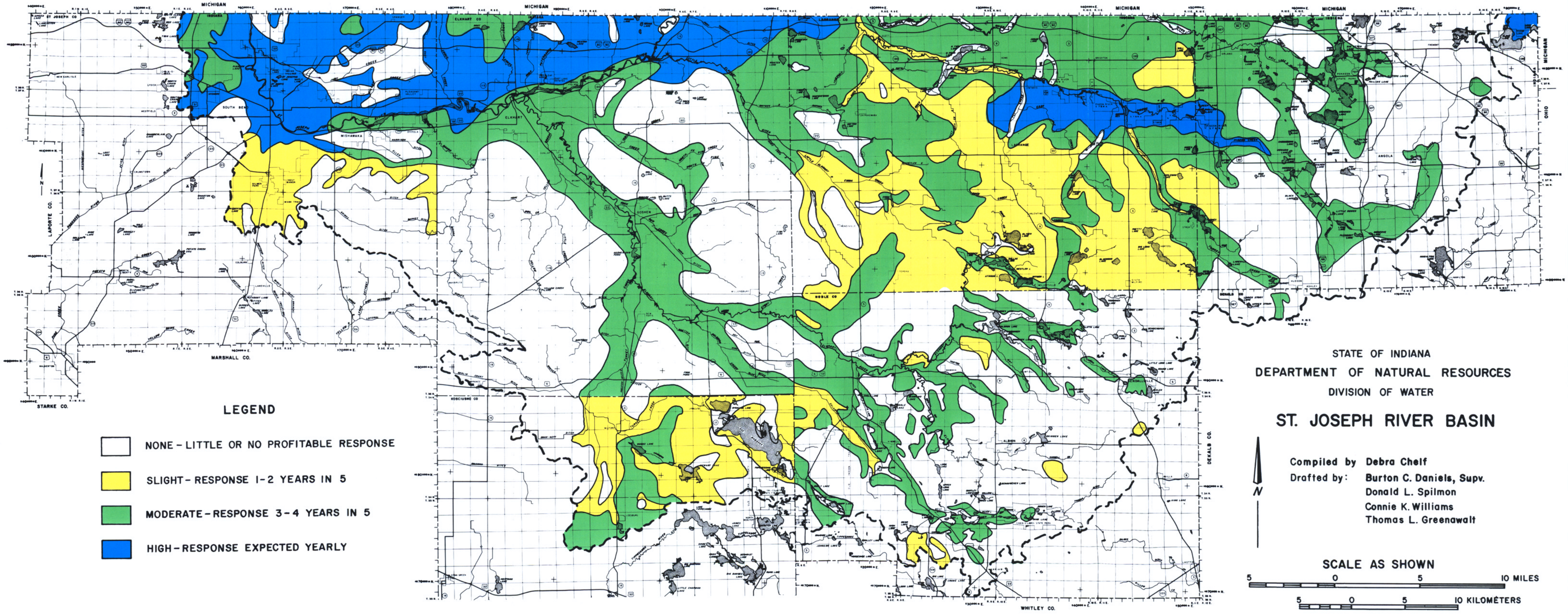


Figure 28. Irrigation potential

Two sets of water use projections were made for these counties based on the following two assumptions: (1) that the current rate of irrigation growth remains constant through the year 2000 (fig. 29) and (2) that the irrigated acreage doubles by the year 2000. Projections were also made for Kosciusko County because of the recent irrrigation expansion. Both sets of projections are considered to be conservative. County extension agents anticipate lower rates of growth.

Irrigation expansion in the St. Joseph River basin within the foreseeable future (to year 2000) is primarily limited to Elkhart, LaGrange and Kosciusko Counties (table 28). If current growth rates were maintained, an increase in water use for irrigation of approximately 33 percent is projected for the basin.

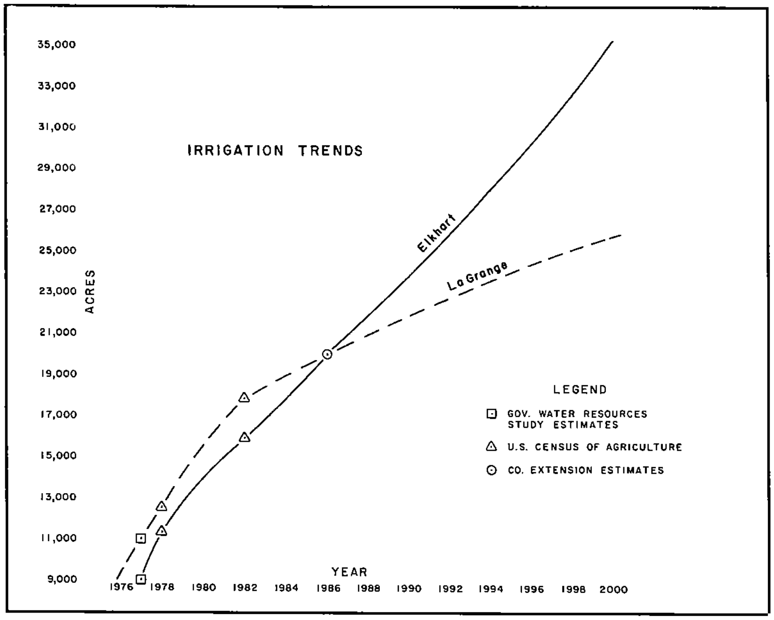


Figure 29.

TABLE 28. Irrigation Water Use Projections

	Elkhart	LaGrange	Kosciusko
Reported Water Use 1985*			
365 - day average MGD	9.78	7.07	2.00
90 - day average MGD	39.7	28.7	8.1
acres irrigated (approximate)	20,000	20,000	6,400
Predicted Water Use 1986**			
365 - day average MGD	13.4	13.4	4.3
90 - day average MGD	54.3	54.3	17.4
Projected Water Use 2000 (present growth trend)			
365 - day average MGD	23.4	17.4	6.4
90 - day average MGD	95.0	70.6	26.1
acres irrigated (approximate)	35,000	26,000	9,600
Projected Water Use 2000 (double present acreage)			
365 - day average MGD	26.8	26.8	8.7
90 - day average MGD	108.6	108.6	35.3
acres irrigated (approximate)	40,000	40,000	13,000

* The reported water use for 1985 includes only the registered significant withdrawal facilities which had reported by October 1986.

** Calculations are based on a requirement of 9 inches of irrigation water for an average precipitation year, per acre-inch.

TABLE 29. Industrial Self-Supplied Water Use Projections[a]

County	1985[b]	1990	2000
Dekalb	0.01	0.01	0.01
Elkhart	10.01	11.77	13.41
Kosciusko	0.73	0.75	0.73
LaGrange	0.04	0.04	0.03
Noble	0.68	0.70	0.73
St. Joseph	5.18	5.38	5.74
Steuben	0.24	0.29	0.32
Total	16.89	18.94	20.97

[a]All values in million gallons per day.
[b]Includes reported uses by registered facilities and estimated uses by non-registered facilities (obtained from a 1985 Division of Water questionnaire).

Industrial Self-Supplied

Most industries in the St. Joseph basin purchase water from utilities, but many, in addition to purchasing water, also supply their own. Most of the self-supplied water is ground water, but there are significant surface water withdrawals in St. Joseph and Elkhart, and Kosciusko Counties.

The largest water-using industries in the St. Joseph basin are: rubber and plastic; stone, clay and glass; chemicals and allied products; fabricated metals; and food and kindred products. (Included in the category "stone, clay and glass" was quarrying, which technically is mining and not manufacturing. Quarrying was included because there were significant water withdrawals from quarries in the St. Joseph basin.)

Industrial water withdrawal projections were developed using the methodology in the report by the Governor's Water Resource Study Commission (1980). Table 29 presents projected industrial self-supplied withdrawals for registered and nonregistered facilities. There is a projected increase of 12 percent in average daily use from 1985 to the year 1990 and a projected increase of 24 percent from 1985 to the year 2000.

TABLE 30. Proposed Hydropower Sites

Site Name	County	Stream	as listed-on Permit
Bainter Town	Elkhart	Elkhart River	200 KW
Benton	Elkhart	Elkhart River	300 KW
Elkhart	Elkhart	Elkhart River	500 KW
Goshen	Elkhart	Elkhart River	450 KW
Mishawaka	St. Joseph	St. Joseph River	1,900 KW
Mongo	LaGrange	Pigeon River	125 KW
Nevada Mills	Steuben	Crooked Creek	100 KW
Ontario #1	LaGrange	Pigeon River	100 KW
Ontario #2	LaGrange	Pigeon River	100 KW
St. Joseph	St. Joseph	St. Joseph River	2,720 KW

Energy Production

Favorable changes in federal and state policies concerning hydropower and recent cost increases for electric power generation may influence future energy production in the St. Joseph River basin. The State of Indiana has identified 20 sites which have the potential for either redevelopment of former hydropower plants or installation of hydropower generating equipment at low-head dams. Only 10 of the 20 sites, however, have been considered under the Federal Energy Regulatory Commission permit system (table 30). The 10 plants have a total capacity of 6495 kilowatts. It is difficult to predict, at this time, if and when any of the plants will become a reality or if any will be categorized as a withdrawal facility.

Expansion of the gasahol plant just outside the basin boundary will largely be determined by alternative energy prices.

FUTURE WATER RESOURCE DEVELOPMENT

As the population and economy of the St. Joseph River basin continue to grow, it will be necessary to develop additional ground-water and surface-water supplies, protect the quantity and quality of existing supplies, and increase water use efficiency. Although ground water will increase in overall importance as a source of supply, surface water is expected to remain a major supply source for industrial uses, agricultural irrigation, and waste assimilation.

SELECTION OF SIGNIFICANT SURFACE WATER SITES

One objective of this study is the identification of sites where there will be growth in demand for surface water or where surface water supply may be developed. Also important is the identification of sites where potential withdrawals may exceed statistical low flows. This basin report is not able to evaluate all locations throughout the St. Joseph River basin; therefore, only significant sites have been considered.

In general, a ''significant'' surface water site may be any one of the following types of locations:

1. A site where there is a large supply of water with little or no present demand.

2. A site where there is a large supply of water which meets a present substantial demand and where demand may increase.

3. A site where cumulative upstream withdrawal capability may exceed statistically-derived low flows.

4. A wastewater treatment facility where upstream withdrawals could adversely affect water quality downstream of the facility.

The above definition of significant sites includes sites where a reservoir could be constructed for supply. However, there are few locations in the St. Joseph River basin where a reservoir could be constructed due to topography and geology. Also, the construction of a reservoir is more costly than developing ground water in the St. Joseph basin. Therefore, significant sites will be limited, for the most part, to streams or rivers.

The significant sites that have been selected are listed in tables 31 and 32 and are shown in fig. 30. The types of significant sites shown in the tables correspond to the four location types discussed above. Also shown in fig. 30 are the stream gages that were not designated as significant but were included for information.

The major urban areas were selected as significant sites because both supply and demand are large and there is the likelihood of population or industrial growth. Sites were selected in the rural areas where increases in irrigation are anticipated.

Tables 31 and 32 list cumulative surface water withdrawal capabilities upstream of each site. These withdrawals are not actual usages but rather registered maximum capacities which are measures of demand. These withdrawal capabilities for the urban areas listed include not only demand from that particular urban area but also demand from upstream usage.

The significant sites in rural areas are points on streams or rivers where it is desired to compare supply and demand to determine if stream flow and potential withdrawals could be in conflict. A significant site, therefore, is not necessarily a point on a stream where water is needed but where the cumulative upstream withdrawal capability is large.

To characterize surface water supply in the St. Joseph basin, three types of flow have been selected. The 1-day, 30-year low flow (Q1-30), an indicator of dependable flow, is the annual lowest 1-day flow that can be expected to occur on the average of once every 30 years. The 7-day, 10-year low flow (Q7-10), used in the design of wastewater treatment facilities, is the annual lowest mean flow for seven days that can be expected to occur on the average of once every 10 years. The average flow for the period of record (Qave) represents the theoretical upper limit of supply. As tables 31 and 32 show, low flows far exceed cumulative upstream withdrawal capacities at most sites.

Except for Goshen, Indiana (table 31, site 37), all urban areas have been classified as type 2. There is little surface water withdrawal at Goshen, yet the cumulative upstream withdrawal capability is larger than the Q1-30. Therefore, Goshen has been classified as both types 1 and 3.

Where the withdrawal capability upstream of a site in table 31 is large relative to Q1-30, the site was classified as type 3. In most cases, the upstream withdrawals are for irrigation.

TABLE 31. Significant Sites

Stream	Site No.	Gage	Contributing Drainage Area Mi^2	1-Day, 30-Year Low Flow (ft^3/s)[g]	7-Day, 10-Year Low Flow (ft^3/s)[g]	Average Discharge (ft^2/s)[g]	Registered Capacity Upstream (ft^3/s)[g]	Type	Remarks
Christiana Ck.	18	No	128	18.2[a]	21.6[c]	125[a]	1.94[f]	2	Urban Area
Elkhart R.	29	No	309	16.7[a]	22.1[c]	301[a]	3.12	1	Potential Irrigation
Elkhart R.	37	Yes	594	11.5[b]	81[b]	514[d]	29.0	1,3	Irrigation Upstream
Fawn R.	3	No	157	22.7[c]	26.7[c]	153[a]	44.4[f]	3	Irrigation Upstream
Fly Ck.	9	No	41.7	5.35[a]	6.81[c]	40.7[a]	13.7	3	Irrigation Upsteam
Little Elkhart R.	13	Yes	91.7	9.2[a]	12[c]	100.4[d]	7.35	3	Irrigation Upstream
Pigeon Ck.	6	Yes	83.5	3.8[b]	5.8[b]	78.9[d]	7.13	3	Irrigation Upstream
Pigeon R.	11	Yes	307	24[b]	86[b]	361[d]	43.9	3	Irrigation Upstream
St. Joseph R.	15	Yes	1866	65[e]	366[e]	1580[e]	NA[f]	--	In Michigan
St. Joseph R.	39	Yes	3370	440[b]	818[b]	3176[d]	73.5[f]	2	Urban Area
St. Joseph R.	42	No	3506	442[a]	879[a]	3197[a]	76.1[f]	2	Urban Area
St. Joseph R.	45	No	3662	468[a]	945[a]	3348[a]	94.3[f]	2	Urban Area
Solomon Creek	32	No	42.3	5.44[a]	6.91[c]	41.2[a]	13.4	3	Irrigation Upstream
S. Br. Elkhart R.	27	No	114	5.62[a]	7.9[c]	111[a]	1.78	3	Potential Irrigation
Turkey Ck.	7	No	62.8	4.6[a]	6.3[c]	61.2[a]	0	1	Potential Irrigation
Turkey Ck.	36	No	183	14.7[a]	18.8[c]	178[a]	25.4	3	Irrigation Upstream
Turkey Ck.	33	Yes	43.8	0.3[b]	1.3[b]	36.8[d]	1.89	3	Upstream Lakes

NA Not Available

a. Division of Water, Indiana Department of Natural Resources.
b. Stewart, 1983.
c. Arihood, 1986.
d. Glatfelter, 1984.
e. U.S. Geological Survey, Lansing, Michigan.
f. Upstream withdrawal in Michigan unknown.
g. Multiply by 0.646317 to obtain million gallons per day.

TABLE 32. Wastewater Treatment Facilities

City	Site No.	Stream	Contributing Drainage Area Mi^2	1-Day 30-Year Low Flow (ft^3/s)[g]	7-Day 10-Year Low Flow (ft^3/s)[g]	Average Discharge (ft^3/s)[g]	Registered Capacity Upstream (ft^3/s)[g]	Type	Remarks
Albion	25	Croft D	24.7	0.88[a]	1.40[c]	24.1[a]	0	--	
Angola	4	Mudd Ck.	2.39	0	0	NA	0	--	Effluent may be a problem
Ashley	5	Johnson D.	0.72	0	0	NA	0	--	Effulent may be a problem
Bristol	16	St. Joseph R.	2445	243[a]	544[a]	2172[a]	12.9[f]	4	Irrigation
Cromwell	31	Solomon Ck.	12.0	1.38[a]	1.9[c]	11.7[c]	0	--	
Elkhart	40	St. Joseph R.	3375[e]	440[b]	818[b]	3176[d]	73.5[f]	4	Irrigation
Fremont	1	--	0.16	0	0	NA	0	--	Effluent may be a problem
Goshen	38	Elkhart R.	594[e]	11.5[b]	81[b]	514[d]	29.0	2,4	Goshen Pond Upstream
Kendallville	20	Henderson Lk. D.	7.49	0.24[a]	0.41[c]	7.3[a]	0	--	
LaGrange	8	Fly Ck.	13.8	1.6[a]	2.18[c]	13.3[a]	1.34	4	Irrigation
Ligonier	28	Elkhart R.	289	12.9[a]	17.6[c]	282[a]	3.12	4	Irrigation
Middlebury	14	Little Elkhart R.	91.7[e]	9.2[a]	12.0[c]	100.4[d]	7.35	4	Irrigation
Milford	34	Turkey Ck.	72.7	NA	2.0[g]	70.8[a]	9.36	4	Upstream Lakes
Millersburg	30	Stoney Ck.	15.9	0.54[a]	0.89[c]	15.5[a]	2.45	4	Irrigation
Mishawaka	43	St. Joseph R.	3547	449[a]	891[a]	3237[a]	91.2[f]	4	Irrigation
Nappanee	35	Berlin Court D.	5.73	0.18[a]	0.31[c]	5.6[a]	0	--	
Rome City	21	N. Br. Elkhart R.	35.8	1.32[a]	2.04[c]	34.9[a]	0.22	4	Upstream Lakes
Shipshewana	10	Page D.	1.21	0	0	NA	0	--	Effluent may be a problem
South Bend	44	St. Joseph R.	3610	461[a]	911[a]	3298[a]	91.2[f]	4	Irrigation
Syracuse	33	Turkey Ck.	43.8[e]	0.3[b]	1.3[b]	36.8[d]	1.89	4	Upstream Lakes
Topeka	19	Shrock D.	0.37	0	0	NA	0	--	Effluent may be a problem
Wakarusa	41	Werntz D.	0.61	0	0	NA	0	--	Effluent may be a problem
Wolcottville	22	Little Elkhart Ck.	31.6	1.2[a]	1.8[c]	30.8[a]	0	4	Upstream Lakes

NA: Not Available

a. Division of Water, Indiana Department of Natural Resources
b. Stewart, 1983.
c. Arihood, 1986.
d. Glatfelter, 1984.
e. Stream Gage.
f. Upstream withdrawal in Michigan unknown.
g. Indiana State Board of Health.
h. Multiply by 0.646317 to obtain million gallons per day.

It should be noted that at site 33 (Syracuse) there are two lakes immediately upstream. There is a control structure on Syracuse Lake which can be used to restrict releases downstream in order to maintain the lake level during low inflow to Lake Wawasee.

Wastewater treatment facilities where there were no registered upstream withdrawals were not classified as significant sites. It should also be noted that there are some sites where the Q7-10 low flow is zero, indicating there are times when the only flow in the stream at the site is the effluent from the facility.

Regression equations, which were developed from stream gage data on unregulated streams, were used to estimate the Q1-30, Q7-10, and Qave for drainage basins less than 1200 mi^2. However, many of the sites in Tables 31 and 32 are on regulated streams and there may therefore be discrepancies between estimated and actual values of discharges.

Also, these regression equations were developed from raw stream gaging data which do not necessarily represent natural conditions, but may include industrial, wastewater, or other discharges.

Considering the above comments, caution should be used when interpreting values of Q1-30 and Q7-10 in tables 31 and 32.

POTENTIAL IMPACTS OF GROUND-WATER DEVELOPMENT

Although ground-water supplies in the St. Joseph River basin should be adequate to satisfy most needs in the coming decades, local overdraft and contamination problems are expected to arise. The 1985 enactment of IC 13-2-2.5 (Water Rights: Emergency Regulation) has been a major step toward proper management of Indiana's ground-water resource, and the law will no doubt be a key factor both in developing and protecting ground water in the St. Joseph basin.

This law attempts to strike a balance between the interests of both small-capacity well owners and high-capacity users who plan to develop the ground-water resource. If small-capacity well failures (with respect to quantity or quality) are due to significant water-level drawdowns caused by high-capacity pumpage, and if certain statutory conditions are met, high-capacity well owners may be required to provide a replacement water supply for owners of impacted wells. Ground-water pumpage restrictions may also result if ground-water withdrawals exceed the aquifer's recharge capability or if the large-scale user refuses to provide an alternate supply[16]. The law does not apply to high-capacity users whose wells are impacted by other high-capacity withdrawals.

Although many types of high-capacity ground-water withdrawals can potentially create excessive water-level declines, irrigation, public supply, and industrial withdrawals have been identified as the most significant uses in the St. Joseph basin.

Ground-water Modeling

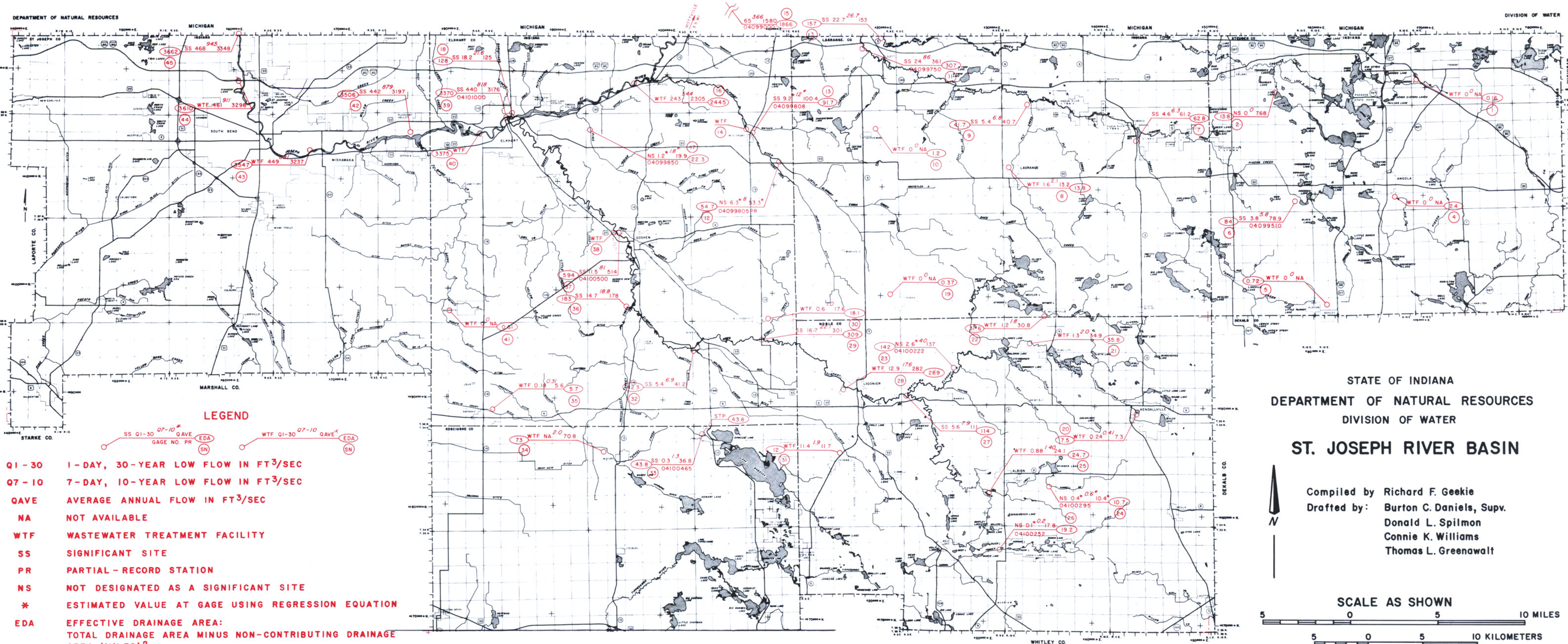
Agricultural irrigation is extensive in the St. Joseph River basin and is expected to increase in future decades. In an effort to study the potential effects of increased irrigation water usage, the Indiana Department of Natural Resources, Division of Water engaged in a cooperative study with the United States Geological Survey.

Two areas (near the towns of Milford and Howe, fig. 31) were chosen for intensive study. The Milford area is a 16.5-mi^2 area in northern Kosciusko and southern Elkhart Counties. The Howe area ia a 46.5-mi^2 area primarily in northern LaGrange County, with a small portion of the area extending into southern Michigan. In both investigations, the U.S. Geological Survey applied a three-dimensional digital ground-water flow model in order to predict the effects of hypothetical pumping plans (Lindgren and others, 1985; Bailey and others, 1985).

These two areas were chosen because they are representative of outwash areas where irrigation is extensive. The goal of both studies was to evaluate the effects of intensive pumping of surface and ground water on streams, wetlands, lakes, and aquifers.

In the Milford study, four pumping plans representing differences in the amount of land irrigated and in rainfall conditions were simulated. A fifth pumping plan simulated maximum year round water use. The Milford simulation representing the maximum amount of irrigated acreage and below normal precipitation computed a thirteen-fold increase in the volume of water pumped from wells and surface water intakes over the amount actually used in the study area during base year 1982. With this pumping scheme, the model predicts a water level decline of as much as 20.7 feet

16 Copies of IC 13-2-2.5 and other water-related laws referenced in this report can be obtained from the Division of Water.



LEGEND

SS Q1-30 Q7-10* QAVE EDA
GAGE NO. PR SN

WTF Q1-30 Q7-10 QAVE EDA
SN

Q1-30	1-DAY, 30-YEAR LOW FLOW IN FT^3/SEC
Q7-10	7-DAY, 10-YEAR LOW FLOW IN FT^3/SEC
QAVE	AVERAGE ANNUAL FLOW IN FT^3/SEC
NA	NOT AVAILABLE
WTF	WASTEWATER TREATMENT FACILITY
SS	SIGNIFICANT SITE
PR	PARTIAL-RECORD STATION
NS	NOT DESIGNATED AS A SIGNIFICANT SITE
*	ESTIMATED VALUE AT GAGE USING REGRESSION EQUATION
EDA	EFFECTIVE DRAINAGE AREA: TOTAL DRAINAGE AREA MINUS NON-CONTRIBUTING DRAINAGE AREA $(MILES)^2$
SN	SITE NUMBER

STATE OF INDIANA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATER

ST. JOSEPH RIVER BASIN

Compiled by Richard F. Geekie
Drafted by: Burton C. Daniels, Supv.
Donald L. Spilmon
Connie K. Williams
Thomas L. Greenawalt

SCALE AS SHOWN

5 0 5 10 MILES

5 0 5 10 KILOMETERS

DRAFTED 1986

Figure 30. Significant Sites

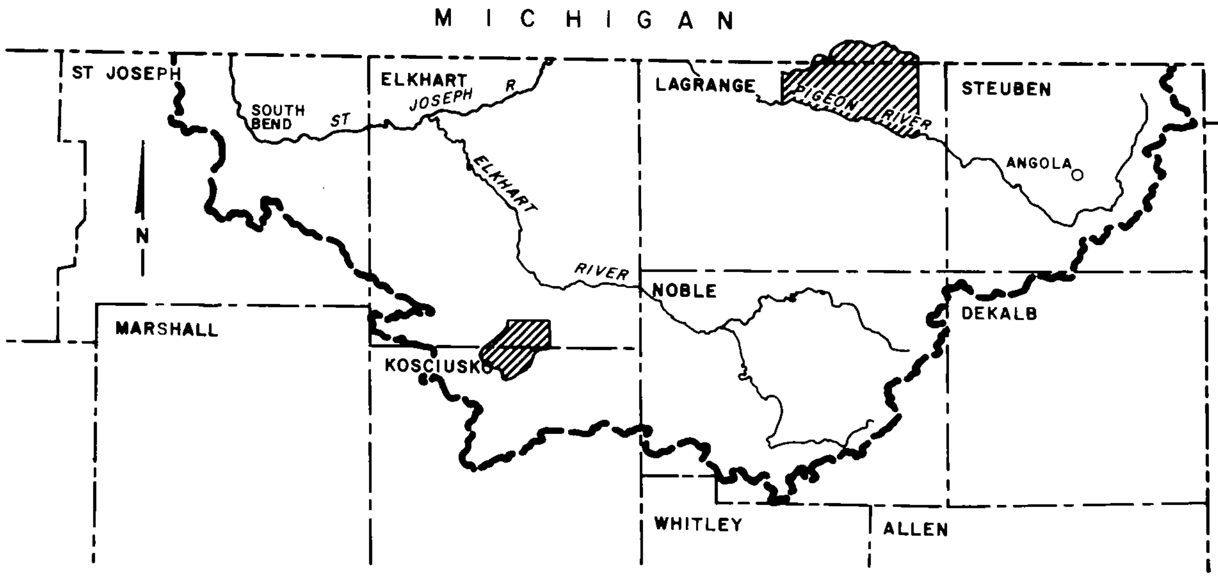


Figure 31. Howe and Milford Study Areas

over an 8-acre area of the aquifer. However, that much of a decline would only be about one-fourth of the available drawdown, so the source aquifer would not be dewatered.

Also, this pumping scheme predicts that stream flow in Turkey Creek would be reduced by 39 percent, but the remaining flow would still be equal to twice the 7-day, 10-year low flow. Flow in some smaller streams would cease.

The results of the Milford area study generally indicated that the outwash system can support substantial growth in irrigation. However, maximum irrigation development may cause temporary, local competition for water in some parts of the area (Lindgren and others, 1985).

The Howe modeling study simulated five pumping plans with varying amounts of irrigated acreage and precipitation. A sixth pumping plan simulated year-round pumping. The simulation representing maximum potential irrigation development and below normal rainfall calculated the greatest drawdowns.

Drawdowns over 30 feet were simulated with this pumping scheme. Stream flow under this pumping plan would be reduced to approximately 90 percent flow duration.

The Howe results indicate that pumping large amounts of water over short time periods (such as an irrigation season) generally will have a small effect on aquifer water levels, stream flow, lakes, and wetlands in the study area. The hydrologic system would probably recover to normal between irrigation seasons (Bailey and others, 1985).

Observation Well Hydrographs

Hydrographs which record fluctuations of water levels in observation wells within the basin can be used to monitor pumpage impacts. Five observation wells (Elkhart 4 and 7, Kosciusko 9, and LaGrange 2 and 3) are located in four areas of intensive irrigation. From three to eight registered high-capacity irrigation wells are within a 1-mile radius of each of the wells. Hydrographs of the five wells, examined by Crompton and others (1986), show no apparent impacts due to pumpage.

The hydrographs of the five observation wells with nearby irrigation pumpage closely resembled those of observation wells in similar outwash aquifers which have no irrigation pumpage. A comparison of hydrographs recorded during the 1983 growing season

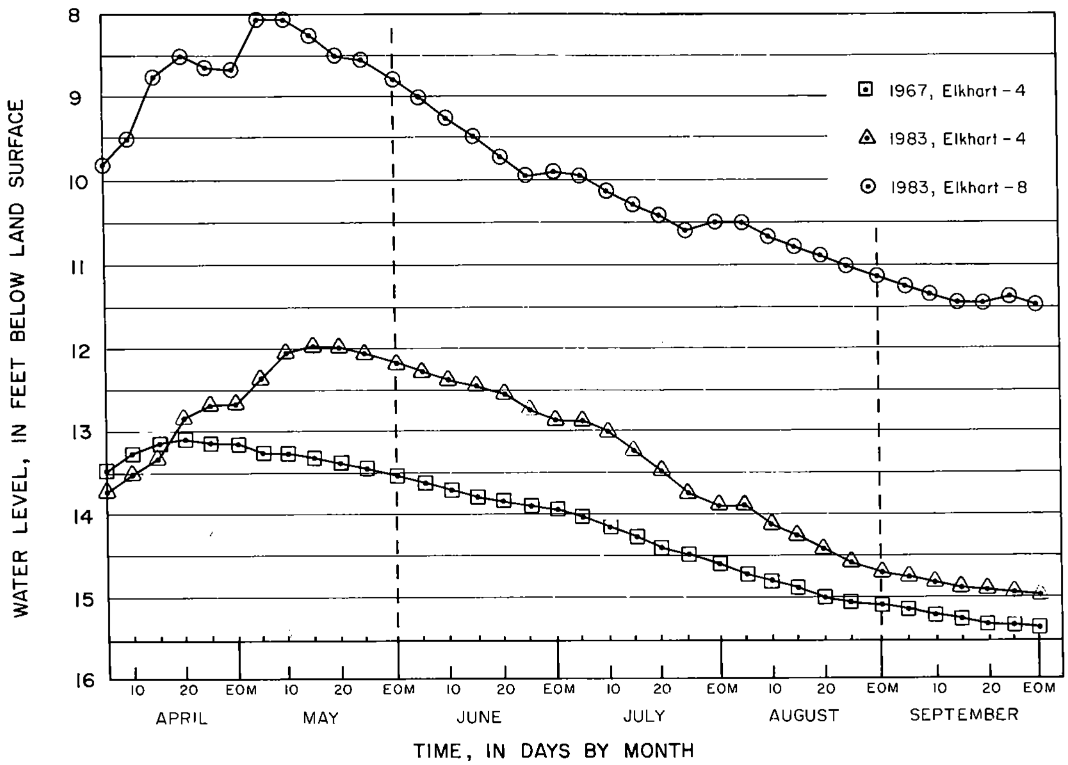


Figure 32. Maximum Daily Water Levels in Observation Wells Elkhart-4 (1967-1983) and Elkhart-8 (1983). From Crompton and others (1986).

for Elkhart 4 and Elkhart 8 (located away from irrigation pumpage) provide an example (fig. 32). The figure also shows the 1967 seasonal hydrograph for Elkhart 4, recorded before extensive irrigation commenced in the area. Based on the similarity of these and other hydrographs, Crompton and others (1986) concluded that any effects of irrigation pumping (June through August) on the water levels in observation wells Elkhart 4 and 7, Kosciusko 9, and LaGrange 2 and 3 are not apparent from water-level records collected to date.

They cite relatively high aquifer transmissivity, relatively high rates of recharge, and relatively small demand as reasons for the apparent lack of effect of irrigation on ground-water levels.

Water Quality Constraints[17]

As discussed in the ''Ground-Water Contamination'' section of this report, an abundant ground-water supply can be diminished by pollution due to man's activities. In the St. Joseph River basin, future constraints on ground-water development will probably result from the pollution of existing or potential supplies rather than shortages of available water. This is illustrated in Elkhart County where the activities of man have threatened the potability of a major portion of the ground-water supply for the city of Elkhart.

About 70 percent of the drinking water for the residents of Elkhart is provided at the North Main Street well field. In April 1981, 94 parts per billion of trichloroethylene (TCE) and other volatile organic chemicals (VOCs) were detected in this well field during a routine U.S. Environmental Protection Agency (USEPA) survey of VOCs in public water supplies. Because this level exceeded the one-in-one-million cancer risk concentration set by the USEPA, immediate action was taken by state, county and city officials to determine the extent of the VOC contamination.

17 Information in this section was summarized from USEPA Fact Sheets and Layne-Western phase reports (see references).

A study of the area was completed in March 1982 which revealed the extent of the contamination on the east side of the well field. As a short-term remedial action, the city of Elkhart placed two interceptor wells on the east side of the well field to reduce the levels of contamination reaching the existing production wells. Between one and four million gallons of TCE-contaminated ground water is pumped daily into Christiana Creek to divert the contamination from the well field.

In December 1982, the USEPA added the Main Street well field to the National Priorities List, a roster of the most serious hazardous waste sites in the country, making it eligible for federal funds (Superfund) for investigation and possible cleanup. Continued monitoring of the contamination has been and will be an ongoing activity at the site.

In March 1985, the USEPA authorized planning for a short-term action to provide a safe and sufficient drinking water supply for the residents of Elkhart while the USEPA conducts its long-term remedial investigation. After several alternatives were studied, treatment of water from production and/or interceptor wells by air stripping (a process which separates the contaminants from the water and turns them into gases) was recommended and selected as the short-term action. After several delays in funding, design of the air stripper was completed and construction of the $2.7 million facility began in summer 1986. The State of Indiana is contributing 10 percent of the initial cost of $2.7 million for construction. The State will also contribute 10 percent of the first year's Operation and Maintenance (O & M) costs, which were estimated to be $166,000, and 100 percent of O & M costs after the first year of operation.

In addition to the short-term action, the USEPA began field activities associated with the remedial investigation (RI) of the site in late 1986. The RI will be completed in two phases. Phase I is designed to collect and analyze data in order to closely define the nature and extent of contamination. Phase II will evaluate Phase I data and all existing studies in order to develop a work plan for the Feasibility Study. This study will address and screen technologies until a recommended long-term alternative is identified. The short-term action is compatible with long-term action alternatives and may continue as part of the long-term plan. However, until the RI is complete, the final action can only be speculated.

One possible long-term action is development of an additional or replacement well field. In 1983, the City of Elkhart hired the Layne-Western Company to identify and evaluate a new uncontaminated well field with sufficient capacity to meet existing and future supply demands. Layne conducted a four-phase study which included reviewing available reports, test drilling, aquifer testing, and numerical modeling. Following test drilling, a proposed well field site was selected. In 1986, preliminary testing and modeling was completed on the proposed site.

The detection of VOCs in the St. Joseph Aquifer system in the Elkhart vicinity (at the North Main Street Well Field, in private residential wells on the east and south sides of the city, and on the west side north of US 33 near CR 1) has identified the need to carefully evaluate the potential for contamination of future well fields. To accomplish this, the city of Elkhart is currently scheduling further hydrologic and chemical testing to assess the potential for ground-water contamination with respect to projected withdrawal rates for the proposed new well field.

In addition to possible water quality problems, supply problems could develop if the proposed well field's production were to substantially lower ground-water levels and consequently affect water supplies for nearby residential housing. In their modeling study, Layne-Western considered what well field design alternatives could be used to limit the effect of the pumpage on nearby ground-water users. If substantial lowering of ground water were to occur, the city could be required to provide reasonable compensation as specified in IC 13-2-2.5 (discussed earlier in this section). Coordination between local and state government throughout planning stages may help to minimize the potential for such future conflicts.

DEVELOPMENT POTENTIAL

Extensive and productive aquifer systems in the St. Joseph River basin tend to facilitate a high degree of water usage by increasing both the area over which the water resource is distributed and the length of its residence time within the basin. Also, many streams exhibit well-sustained flows as a result of the high degree of interconnection between the aquifer and stream systems. Future water use choices must, therefore, be made in the context of a theoretical maximum supply of the total water resource.

A theoretical maximum water supply may be estimated using monthly discharges to derive average long-term (1924-85) total runoff. These figures give a general idea of the amount of precipitation which falls

TABLE 33. Mean Monthly Discharge (million gallons/month)

Month	Indiana portion of St. Joseph basin (1699 mi²)	Michigan portion of St. Joseph basin which drains into Indiana (1963 mi²)	Total at the state line (3662 mi²)
April	49925	54151	104076
May	40009	45360	85367
June	28365	33483	61848
July	23100	24482	47582
August	19914	19814	39728
September	17643	19039	36663
October	21156	21397	42553
November	22064	25069	47133
December	27567	30853	58420
January	28349	36583	64932
February	33922	34250	68172
March	49966	52470	102436

on the basin and is not used consumptively on a long-term basis. The discharges in table 33 were generated for the Indiana portion of the basin and the Michigan portion which contributes to Indiana.

Water in the basin is often used and reused many times before it is lost to evaporation or as outflow from the state. As long as the water is not used consumptively and the quality of the resource is not altered to the point that it becomes unsuitable for some purposes, there are very few limitations on total water use. However, constraints on water use in a particular location may result from its competing value for the maintenance of lake levels, for recreation, for support of aquatic life, for the availability of supply for downstream domestic and industrial water users, and for the provision of assimilative capacity for thermal loadings and wastewater treatment plant effluents. It is important to keep in mind that the listed potential monthly supplies represent long-term average values. During dry years when consumptive demands such as irrigation are at high levels, the available water supplies can be significantly less than average.

SUMMARY: DATA RECOMMENDATIONS

Because hydrologic data forms a framework upon which management decisions are based, the adequacy of data networks for ongoing water management purposes was assessed. Unless otherwise indicated, the following discussion summarizes hydrologic monitoring needs as identified by the Division of Water.

Climate

The distribution of official National Weather Service stations is adequate; however, the availability of published climatic summaries is insufficient for characterizing climate (particularly precipitation) on a county scale. Although recently published 30-year summaries (NOAA, 1985) for South Bend and Goshen College provide sufficient precipitation and temperature data for St. Joseph and Elkhart counties, such summaries are lacking elsewhere in the basin. Because both South Bend and Goshen are located in areas affected by Lake Michigan, the development of precipitation summaries for the period 1951-80 should be considered for LaGrange, Angola and Kendallville. Period-of-record precipitation summaries for Elkhart, Ligonier, Waterford Mills, and Prairie Heights would also be beneficial. Such summaries could best be prepared (or obtained) in cooperation with Purdue University's agricultural meteorology office, where both historical and recent climatic data files are maintained.

Lakes

In general, the network of lake level monitoring stations is adequate for IDNR's ongoing management purposes. The Division of Water will continue to evaluate the magnitude and frequency of flooding around lakes as well as the effectiveness of control structures in maintaining legal levels. Crompton and others (1986) also point out that legal levels could probably be established for additional lakes with adequate data.

Rivers and Streams

As discussed earlier in this report, two stream sites could be investigated for potential installation of continuous-record gages. A gage near the mouth of Christiana Creek could provide data pertinent to both quantity and quality issues; and a gage on Solomon Creek could monitor flow in a ditched agricultural area characterized by relatively flat topography.

Because of sufficient record and the limited utility of data currently collected, three stream gages are recommended for discontinuation: (1) Lime Lake Outlet at Panama; (2) Forker Creek near Burr Oak; and (3) Turkey Creek at Syracuse.

Ground Water

Plans for improving the observation well network, as discussed in an earlier section, include the following: 1) addition of Steuben 6 (already completed) to monitor long-term water-level changes in an area not affected by large-scale pumpage; 2) installation of three nested wells near Kendallville to provide data for a deep confined aquifer; 3) removal of the continuous water-level recorder from Elkhart 6; and 4) discontinuation of IDNR funding for two ground-water/lake wells (Kosciusko 6 and 7).

SUMMARY: WATER RESOURCE AVAILABILITY

In response to a 1983 legislative mandate, the Indiana Department of Natural Resources, Division of Water published a report describing the availability, distribution, quality, and use of ground and surface waters of the St. Joseph River basin, Indiana. This report, one element of the division's statewide water management program, is intended to provide information to managers, planners, government officials, and others involved with water resources decision-making.

The St. Joseph River basin drains 2586 mi^2 in Lower Michigan and 1699 mi^2 in Indiana before emptying into Lake Michigan near Benton Harbor, Michigan. Two-thirds of Indiana's 1980 basin population (432,600) resided in the cities of South Bend, Mishawaka, Elkhart, and Goshen and their adjacent urbanized areas. The population decline of St. Joseph County is expected to continue during the next two decades, primarily as a result of the sharp drop in South Bend's population since the 1960s. Other county populations are expected to increase, particularly in LaGrange County.

Manufacturing, services and retail trade, primarily concentrated in St. Joseph and Elkhart Counties, are the largest employment classes within the basin. Agriculture is the primary land use, yet it comprised less than three percent of the basin's employed labor force in 1982. In Elkhart, LaGrange, and Kosciusko Counties, the total number of farms, sales of dairy and poultry products, and hay and oats production were among the highest in Indiana.

In general, soils of the St. Joseph basin fall within one of three categories: 1) sandy or loamy soils developed on outwash and alluvium; 2) silty or clayey soils developed on till; and 3) muck soils developed in depressional wetland areas.

Basin topography has been most significantly influenced by deposition during Wisconsinan glaciation and subsequent erosional modifications. The highly variable topography is composed of lowlands containing significant volumes of outwash sand and gravel, and uplands dominated by morainal till. Local relief may exceed 200 feet in some areas containing kame deposits. The massive Packerton and Mississenewa moraines, predominant along the basin's southern boundary, are characterized by complex sag and swell topography and by a zone of glacially formed lakes. The intermorainal lowlands are for the most part underlain by glacial till and small areas of lacustrine deposits.

Thickness of glacial deposits range from about 30 feet near Mishawaka to nearly 500 feet in the eastern part of the basin. However, most of the basin is covered with deposits ranging from 200 to 350 feet in thickness.

Three shale units primarily constitute the basin's bedrock surface: the Coldwater Shale in the northeast, the Ellsworth Shale in the west, and the Antrim Shale in the south. Bedrock elevations range from about 350 feet m.s.l. near Elkhart, where a deep narrow valley is present, to more than 900 feet m.s.l. in northeastern Steuben County.

Annual temperatures average 49° F and annual precipitation averages 35 inches. Annual snowfall averages about 35 inches, but increases to more than 70 inches at South Bend, where the climate is considerably influenced by Lake Michigan. Snowfall at South Bend accounts for nearly 20 percent of the average annual precipitation; elsewhere in the basin, snowfall accounts for less than 10 percent.

More than 200 natural lakes and an estimated 27,000 wetlands (including partially drained farmland) remain within the St. Joseph basin, despite past and present drainage modifications. The densest zone of wetlands (including lakes) occurs in LaGrange, Steuben, and Noble Counties.

Lakes, rivers and wetlands are expected to be primarily areas of ground-water discharge. Hydrographs derived from observation wells and lake gages revealed good hydraulic connections between selected lakes and the surrounding outwash aquifers. Lakes investigated for this report appear to reflect regional ground-water flow, but surface- and ground-water interactions are expected to be locally complex. Legal and environmental constraints either preclude or discourage the use of lakes and wetlands as major sources of water supply, although significant surface-water withdrawals occur on three in-basin lakes and an unknown number of wetlands.

Rivers most commonly utilized for water supply generally have developed on permeable outwash deposits. Stream flows of these rivers (including the St. Joseph, Pigeon, Fawn, and Little Elkhart Rivers, as well as Turkey and Solomon Creeks) are moderately to well sustained by ground-water contribution. Based on hydrograph separation techniques, ground water comprises about 70 percent of the stream discharge measured at eight gaging stations. In contrast, stream flows are moderately to poorly sustained in eastern and southeastern areas of the basin (primarily in parts of Steuben and Noble Counties), where present drainage systems have developed on till.

Available data indicates that the general water quality in the St. Joseph and Elkhart Rivers is good; however, bacterial standards for whole-body and partial-body contact recreation are exceeded downstream of urban areas. Conditions necessary for well-balanced fish and benthic invertebrate communities are maintained in both rivers. Data collected on the St. Joseph River in summer 1985 revealed that for the most part, salmonid fisheries could be supported downstream of Mishawaka.

Downstream of South Bend, concentrations of PCBs and chlordane in fish flesh exceeding FDA action levels have been reported since 1979. The source of low-level PCB contamination in sediment samples collected near the mouths of five major St. Joseph River tributaries is currently under investigation.

Recent lake surveys have revealed few eutrophication problems. A 1984 fish eradication and selective restocking project at Sylvan Lake was primarily responsible for major water quality improvements at this historically eutrophic to hypereutrophic lake. Put-and-take trout fisheries are maintained in about 12 basin lakes (and on about 12 rivers and streams).

Unconsolidated deposits of glacial sands and gravels are the principal source of ground water. Yields of 200 to 500 gpm are common throughout the basin, and can increase to 1500 gpm where sand and gravel deposits are thick. Underlying bedrock is not used as a supply source. Seven major unconsolidated aquifer systems have been recognized and defined on the basis of geologic environments and aquifer characteristics.

The St. Joseph and Tributary Valley Aquifer System occurs in the western portion of the basin. It is characterized by outwash and valley train deposits of sand and gravel with local clay layers. Aquifer thicknesses of 40 feet or more are typical. Ground water availability in this system is good to excellent. High capacity wells in most of the St. Joseph and Tributary Valley Aquifer System may be expected to yield 500 to 1,000 gpm.

The Topeka Aquifer System occurs in two areas in the central portion of the basin. In this system, unconfined outwash sands and gravels overlie thick clay units containing confined intertill sand and gravel layers. Thickness of the surficial outwash is usually 30 to 50 feet while the deeper intertill aquifers are usually less than 20 feet thick. Ground water conditions here are generally good. High capacity wells may be expected to yield 150 to 500 gpm from the deeper aquifers of this system.

The Natural Lakes and Moraines Aquifer System covers a large area in the central portion of the basin. This is an intertill system with sand and gravel aquifer occurring sporadically within thick clay till sequences. Productive aquifer zones are commonly only 5 to 10 feet thick. Ground-water availability is variable, but generally good. Domestic wells throughout this system may produce 25 gpm and in local areas high capacity wells may produce up to 800 gpm.

The Kendallville Aquifer System is found in the eastern part of the St. Joseph River basin. Like the adjacent Natural Lakes and Moraines Aquifer System, the Kendallville is an intertill aquifer system. Producing aquifers occur as confined sand and gravel layers within thick clay tills. Aquifers are usually 10 feet or less in thickness. Limited to good ground water conditions exist here. High capacity wells in some areas may produce up to 1000 gpm. Domestic wells generally yield 15 to 30 gpm throughout the system.

The Howe Aquifer System covers much of the northeast area of the basin. The system is characterized by surficial outwash sands and gravels overlying tills containing sand and gravel aquifer zones. The upper outwash sand and gravel aquifers are commonly 15 to 50 feet thick. The intertill sand and gravel aquifers average 5 to 25 feet in thickness. The deeper intertill aquifers are more frequently utilized. Ground-water availability in this system is good to excellent. Domestic wells commonly produce up to 60 gpm and high capacity wells may be expected to yield up to 1000 gpm.

The Nappanee Aquifer System is an intertill system in the western areas of the basin. Zones of sand and gravel separated by thin clay layers occur within a thick till sequence. Individual sand and gravel aquifers are usually less than 30 feet in thickness. This is an area of moderate to good ground water availability. Well yields of 50 to 600 gpm may be expected from this system.

The Hilltop Aquifer System is a small outwash sand and gravel system near the western edge of the St. Joseph River basin. A few clay till lenses are present above and within the outwash. Sand and gravel thickness may approach 120 feet in this system. Ground-water availability is moderate. Domestic wells often produce 10 to 60 gpm. High capacity wells may be expected to yield 50 to 250 gpm.

Ground water in the basin is of the calcium bicarbonate type, and is characterized by high alkalinities, high hardness, and mostly basic pH. Overall, natural ground-water quality is good; however, iron, manganese and total dissolved solids commonly exceed U.S. Environmental Protection Agency recommended limits. Nitrate concentrations exceeded recommended limits in nine wells sampled in summer 1985, and in four other wells sampled during previous studies. The Indiana Department of Environmental Management had documented 33 sites contaminated by various chemicals as of early 1986. Also, at least one volatile organic chemical has been detected by the USEPA in seven public water supply wells.

The detection of trichloroethylene and other volatile organic chemicals in Elkhart's North Main Street well field has prompted investigative and protective action by local, state and federal agencies. Two interceptor wells installed in 1982 will remain operational for an indefinite period. In addition, an air stripper is currently under construction to treat contaminated water from production and/or interceptor wells. The City of Elkhart is also evaluating a proposed new well field about one mile northwest of the Elkhart Municipal Airport.

Ground water is the source of three-fourths of all water withdrawn in the basin. In 1985, 85 percent of registered ground-water withdrawals occurred in St. Joseph and Elkhart Counties, primarily for public supply uses. About 97 percent of all surface-water withdrawals occurred within St. Joseph, Elkhart, and LaGrange Counties, mainly for public supply and agricultural irrigation.

The major water use categories in the basin are public supply (54 MGD in 1985), irrigation (20 MGD), and industry (15 MGD). Ground water was the source of all public drinking water withdrawals, 63 percent of industrial withdrawals, and 60 percent of irrigation withdrawals. About 90 percent of both industrial and public supply uses occurred in Elkhart and St. Joseph counties, whereas 94 percent of all irrigation uses occurred in Elkhart, LaGrange, and Kosciusko counties.

Rural uses, which include large-scale livestock operations and fish hatcheries but not self-supplied rural domestic uses, totaled 3 MGD in 1985. Rural water withdrawals primarily utilized surface-water sources.

Even though the St. Joseph basin has no registered water withdrawals for energy production within its topographic boundaries, a South Bend ethanol plant near the western basin divide withdrew 3 MGD from the St. Joseph Aquifer System in 1985. Only three facilities in the basin are classified as miscellaneous. These reported uses totalled 0.11 MGD. Estimates for non-registered, domestic self-supply uses in 1985 totalled 13 MGD, while non-registered livestock uses totalled about 5.5 MGD.

Percentage increases in public water supply withdrawals are expected to be the highest in LaGrange, Noble and Steuben Counties. Significant irrigation expansion is expected to occur in Elkhart, LaGrange, and Kosciusko counties. Percentage increases in industrial withdrawals are expected to be the greatest in Steuben and Elkhart Counties. Future redevelopment of former hydropower plants or the installation of hydropower generating equipment at low-head dams is possible, but final actions can only be speculated.

Stream sites have been identified where water supplies may be developed, where demands may increase, and/or where withdrawal capacities may exceed statistical low flows. (Wastewater treatment facilities downstream of registered surface-water withdrawals were also included.) Potential development sites in urban areas have primarily been identified along the St. Joseph River. Most sites where cumulative upstream withdrawal capabilities exceed estimated low flows occur in irrigation areas.

Ground-water modeling studies and observation well hydrographs indicate that ground-water levels in outwash aquifers are not affected by current irrigation pumpage. These and other studies show that such aquifers can support considerable ground-water development. However, substantial increases in localized pumpage could create large drawdowns, decreased ground-water seepage to streams, and decreased water levels in nearby streams, lakes and wetlands. In addition, maximum irrigation development could cause temporary, local competition for both ground and surface water.

In general, however, ground-water resources of the St. Joseph River Basin are the most abundant in Indiana. Because ground-water availability in most of the basin is considered good to excellent, a significant potential exists for further water supply development. In coming decades, ground water will undoubtedly increase in overall importance as a source of supply for irrigation, municipal, industrial, and other purposes. However, streams with moderately to well sustained flows are expected to remain a major supply source for both withdrawal and instream uses. The numerous lakes and wetlands will not only continue to offer a wide range of recreational opportunities, but will also provide fish and wildlife habitat and various hydrologic benefits.

A theoretical maximum water supply for the St. Joseph basin, estimated on a monthly basis, ranges from 36,660 million gallons in September to 104,080 million gallons in April. These values represent the amount of precipitation which is not evaporated or used consumptively on a long-term basis. As additional hydrogeologic data becomes available and the interactions between ground-water and surface-water systems are better understood, better estimates can be derived for potential water supply. Moreover, an integrated water management program can be further developed to help ensure an adequate, balanced water supply for meeting future demands.

GLOSSARY

Acre-foot—volume of water required to cover 1 acre of land to a depth of 1 foot; equivalent to 325,851 gallons

Acre-inch—volume of water required to cover 1 acre of land to a depth of 1 inch; equivalent to 27,154 gallons

Action level—Food and Drug Administration's recommended limit for a toxic substance in the edible portion of a fish; if an action level is exceeded, fish are not safe to consume and interstate sales are not allowed

Alluvium—general term for deposits of clay, silt, sand, gravel, or other particulate rock material in a streambed, on a flood plain, or on a delta

Apron—coalesced series of outwash fans

Aquifer—a geologic formation, part of a formation, or a group of formations that contain sufficient saturated permeable material to yield significant quantities of water to wells and springs

Average discharge—the arithmetic average of all complete water years of record, whether consecutive or not

Benthic—sediment and other material at the bottom of an aquatic system

Biochemical oxygen demand (BOD)—amount of dissolved oxygen needed for the decomposition of organic matter in water; if the amount of oxygen is high and the organic material is low, the BOD is low, and vice versa

Channel head—uppermost reach of a channel

Climatic normal—average (or mean) conditions over a designated period, usually the most recent 30-year period ending every decade (1941-70, 1951-80, for example)

Climatic year—the 12-month period, April 1 to March 31, designated by the calendar year in which it begins; for example, climatic year 1984 is from April 1, 1984 to March 31, 1985

Confined (aquifer)—an aquifer in which ground water is confined under pressure that is significantly greater than atmospheric pressure

Contributing drainage area—total drainage area minus the area which does not contribute directly to surface runoff as defined by the U.S. Geological Survey annual water data reports

Cubic foot per second—unit of measurement for water discharge representing a volume of 1 cubic foot passing a given point in 1 second; equivalent to 448.8 gallons per minute

Dendritic—a drainage pattern characterized by irregular branching in all directions with the tributaries joining the main stream at all angles

Drawdown—difference between the water level in a well before and during pumping

Drift—rock debris deposited by glaciers or glacial streams

Eutrophication—process by which water becomes enriched with plant nutrients, most commonly phosphorus and nitrogen; generally refers to conditions in lakes or reservoirs

Evapotranspiration—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

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 wastes

Flow till—debris accumulated downslope of a retreating glacier due to the movement of semi-plastic or near-fluid materials

Hummocky—describes an area of rounded, irregular topography

Hydraulic conductivity—a constant describing the rate at which water moves through a permeable medium

Hydrograph—graph showing stage, flow, velocity, or other properties of water with respect to time

Ice contact—materials in direct contact with glacier ice at the time of deposition

Ice trough—channel cut into glacial ice

Igneous—rocks that solidified from molten or partly molten material

Interlobate—lying between adjacent glacial lobes

Interpolate—to estimate intermediate values of a function between two known points

Kame—a conical hill or short irregular ridge of gravel or sand deposited in contact with glacier ice

Lacustrine—includes areas of wetlands and deepwater habitats greater than 20 acres situated in a topographic depression or dammed river channel, and lacking significant vegetation; also includes smaller areas with a water depth exceeding 6.6 feet at low water

Limnology—refers to characteristics of fresh waters, including biological properties as well as chemical and physical properties

Lithology—rock features such as composition, grain size, color, and kind of bedding

Loam—soil composed of a mixture of clay, silt, sand, and organic matter

Mean—the arithmetic mean (average) of a set of observations

Melt-out till—unsorted debris which has been deposited directly by glacier ice

Moraine—an accumulation of drift deposited by the direct action of glacier ice

Morphometry—in this usage, refers to the structure and form of a lake (for example, surface area, volume, depth)

Nested—wells at the same approximate location which are open to the aquifer at different depths in order to detect the vertical component of flow

Outwash—drift deposited by meltwater streams beyond active glacier ice

Palustrine—includes wetlands dominated by vegetation such as trees, shrubs and persistent emergents; or an area less than 20 acres lacking such vegetation and having a water depth less than 6.6 feet at low water

Per capita money income—total money income of the residents of a given area divided by the resident population of that area; represents the amount of income received before deductions for personal income taxes, Social Security, bond purchases, union dues, etc.; receipts not counted include "lump sum" payments such as capital gains or inheritances

Per capita personal income—total personal income of the residents of a given area divided by the resident population of that area; measured after deduction of personal contributions to old age and survivors insurance, government retirement, and other social insurance programs, but before deduction of income and other personal taxes

Permeability—the capacity of a rock for transmitting a fluid; a measure of the relative ease of fluid flow in a porous medium

Physiography—the origin and evolution of landforms

Piezometric surface—an imaginary surface representing the static head of ground water in tightly cased wells that tap a water-bearing rock unit; in the case of unconfined aquifers, often called the water table

Polychlorinated biphenyls (PCBs)—a family of chlorinated hydrocarbons toxic to animals and humans

Reach—a specified length of a river or stream channel

Recharge (ground water)—process of entry of water into the zone of saturation

Recurrence interval—the average time interval within which the magnitude of a given event, such as a flood or storm, will be equalled or exceeded

Runoff—the part of precipitation that appears in surface-water bodies; it is the same as stream flow unaffected by artificial manipulations

Sag and swell—a landscape of regularly alternating topographic highs and lows

Salmonid—a family of elongate soft-finned fishes, including salmon and trout

Stratigraphy—the formation, composition, sequence, and correlation of rock strata

Stream regulation—artificial manipulation of the flow of a stream

TCDD—the toxic chemical 2,3,7,8-tetrachlorodibenzo-p-dioxin, shown to cause cancer in animals and skin disease in humans

Till—non-sorted, non-stratified sediment carried or deposited by a glacier

Transmissivity—rate at which water is transmitted through a unit width of an aquifer under a unit of hydraulic gradient

Transpiration—process by which water passes through living plants and into the atmosphere

Trophic—in this usage, refers to amount of nutrients in a lake (for example, eutrophic, oligotrophic)

Unconfined (aquifer)—an aquifer whose upper surface is a water table free to fluctuate under atmospheric pressure

Valley train—a long, narrow body of outwash confined within a valley

Volatile organic chemical—a chemical compound composed mostly of carbon and hydrogen, that easily evaporates (for example, trichloroethylene, or TCE)

Water year—the 12-month period, October 1 to September 30, designated by the calendar year in which it ends; for example, water year 1984 is from October 1, 1983 to September 30, 1984

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Appendix 1. Historic and Projected County Population[a]

County	1900	1910	1920	1930	1940	1950	1960	1970	1980	1985	1990	1995	2000
Dekalb	650	634	648	630	626	658	715	780	850	873	895	918	938
	25711	25054	25600	24911	24756	26023	28271	30837	33606	34500	35400	36300	37100
Elkhart	43399	47209	54315	66347	69968	81410	102870	121885	132290	137078	141894	146325	150371
	45052	49008	56384	68875	72634	84512	106790	126529	137330	142300	147300	151900	156100
Kosciusko	5995	5755	5587	5663	6090	6798	8317	9914	12268	13369	14440	15388	16171
	29109	27936	27120	27488	29561	33002	40373	48127	59555	64900	70100	74700	78500
LaGrange	15284	15148	14009	13780	14352	15347	17380	20890	25556	27700	30000	32300	34600
	15284	15148	14009	13780	14352	15347	17380	20890	25556	27700	30000	32300	34600
Noble	17156	17503	16381	16333	16604	18280	20530	22877	25838	27046	28212	29305	30399
	23533	24009	22470	22404	22776	25075	28162	31382	35443	37100	38700	40200	41700
St. Joseph	52881	75721	92777	143726	145333	184163	214299	220075	216996	214376	213478	212490	211413
	58881	84312	103304	160033	161823	205058	238614	245045	241617	238700	237700	236600	235400
Steuben	11566	10848	10154	10173	10442	12986	13060	15321	18767	20140	21432	22420	23256
	15219	14274	13360	13386	13740	17087	17184	20159	24694	26500	28200	29500	30600
TOTAL	146931	172818	193871	256652	263415	319642	377171	411742	432565	440582	450351	459146	467148
	212789	239741	262247	330877	339642	406104	476774	522969	557801	571700	587400	601500	614000

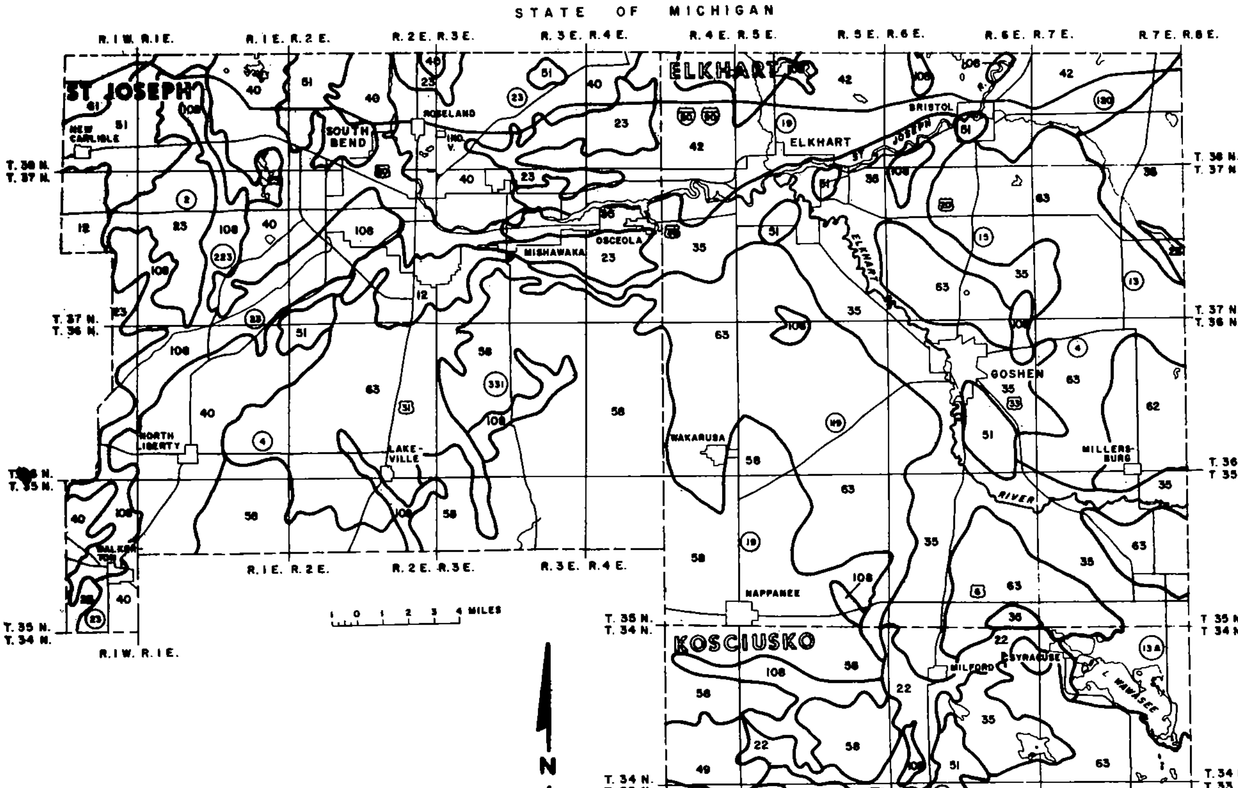
[a]Upper Figures: Division of Water estimates, in-basin portion only.

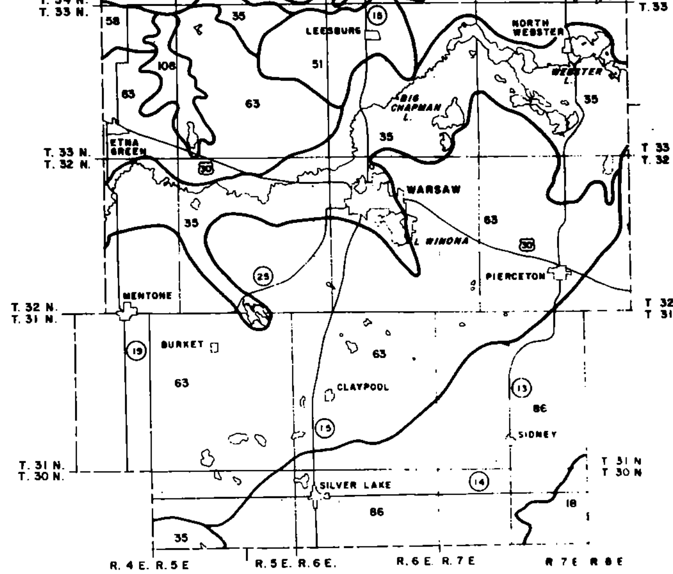
Lower Figures: U.S. Census Bureau, total county (1900-1980); Indiana State Board of Health, 1983, total county (1985-2000).

Appendix 2. Agricultural Land Use[a]

Counties	St. Joseph	Elkhart	LaGrange	Kosciusko	Noble	Steuben
Approximate Land Area (Acres)	293,817	298,291	243,161	345,382	264,057	197,094
Land in Farms	173,814	213,225	194,035	274,364	201,388	142,580
Percent in Farms	59.2	71.5	79.8	79.4	76.3	72.3
Increase/Decrease (Acreage) 1982 from 1978	Decrease	Increase	Decrease	Decrease	Decrease	Decrease
Increase/Decrease (Acreage) 1982 from 1978 (Ave. Farm Size)	Increase	Decrease	Decrease	Increase	Increase	Increase
Cropland (Acres)	149,693	182,178	152,043	226,490	164,553	113,610
Woodland (Acres)	11,904	14,587	17,954	24,921	18,590	13,546

[a]All values from U.S. Census Bureau, 1982 Census of Agriculture (county data).





SOIL ASSOCIATIONS

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.

18. *Fox-Martinsville-Alluvial soils:* Sloping and nearly level, well drained, loamy Fox on outwash sand and gravel, and loamy Martinsville on outwash sand and silt and associated soils in alluvial deposits.

21. *Fulton-Rimer-Milford-Rensselaer:* Nearly level, somewhat poorly drained, clayey, Fulton and sand over clayey Rimer, and very poorly drained, clayey Milford and loamy Rensselaer, all in lake deposits.

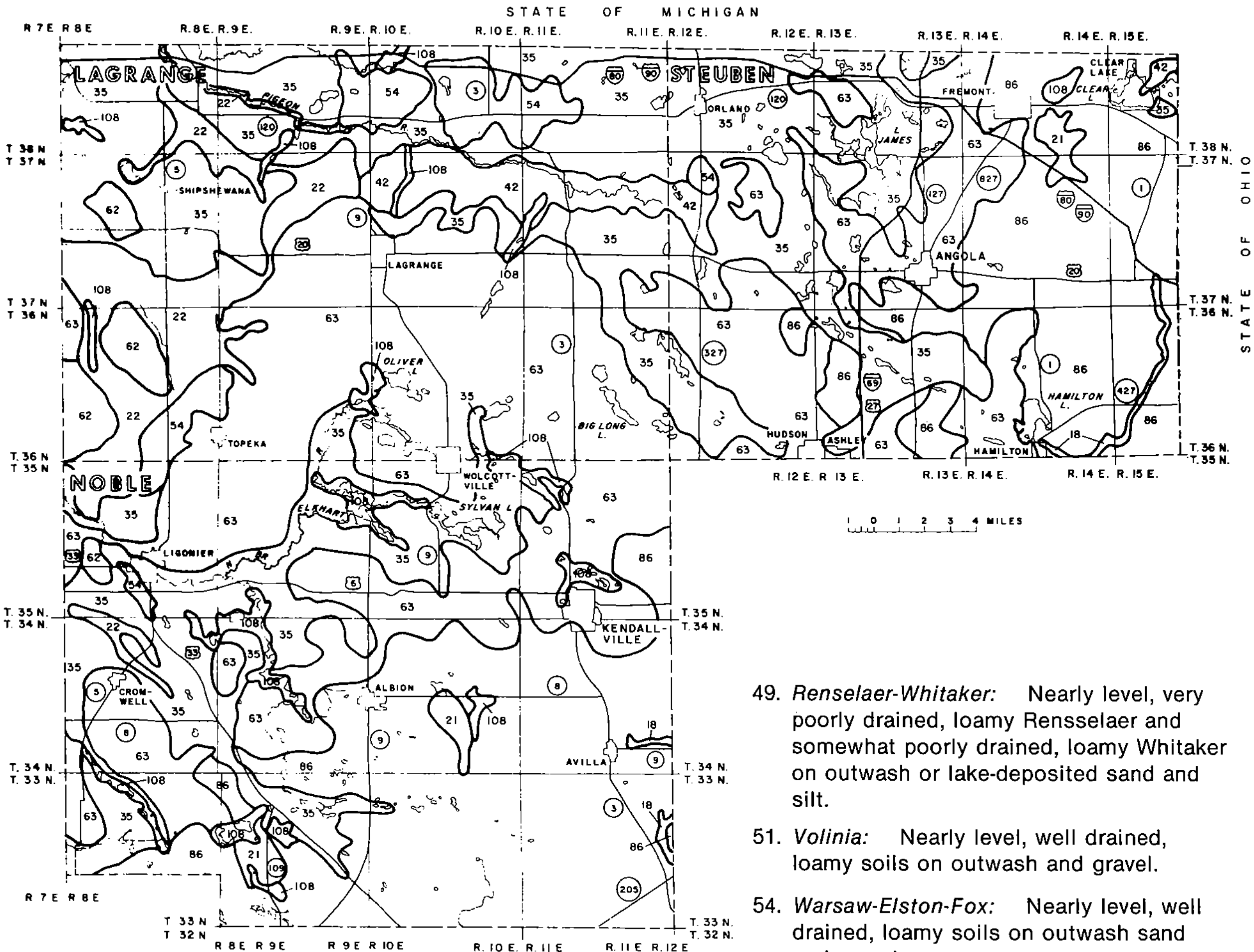
22. *Sebewa-Homer-Gilford:* Nearly level, very poorly drained, loamy Sebewa, somewhat poorly drained, loamy Homer, and very poorly drained, loamy Gilford on outwash sand and gravel.

23. *Maumee-Gilford-Renssalaer:* Nearly level, very poorly drained, sand, Maumee and loamy Gilford and Rensselaer in outwash or lake deposited sand and silt.

35. *Oshtemo-Fox:* Nearly level and sloping, well drained, loamy soils on outwash sand and gravel.

40. *Plainfield-Tyner-Oshtemo:* Sloping, excessively drained, sandy Plainfield in wind-blown sands and sloping and nearly level, excessively drained, sand Tyner and well drained, loamy Oshtemo on outwash sand and gravel.

42. *Plainfield-Chelsea:* Sloping, excessively drained, sandy soils in wind-blown sands.



General Soil Map

AGRICULTURAL EXPERIMENT STATION AND COOPERATIVE EXTENSION SERVICE, PURDUE UNIVERSITY; AND THE SOIL CONSERVATION SERVICE, U.S. DEPARTMENT OF AGRICULTURE

Note: This map is intended for general planning. Each delineation contains soils different from those shown in the legend. For operational planning, use detailed soil maps that may be available in published or unpublished form at the local Soil and Water Conservation District Office.

Appendix 3. Soil Associations

49. *Renselaer-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 and gravel.

54. *Warsaw-Elston-Fox:* 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.

61. *Blount-Morley-Pewamo:* Nearly level, somewhat poorly drained, clayey Blount and very poorly drained, clayey Pewamo and sloping, well drained, clayey Morley in glacial till.

62. *Blount-Pewamo:* Nearly level, somewhat poorly drained, clayey Blount and very poorly drained, clayey Pewamo 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.

86. *Morley-Blount:* Sloping, well drained, clayey Morley and nearly level, somewhat poorly drained, Blount in glacial till.

108. *Mucks and peats:* Nearly level, very poorly drained soils developed in organic materials.

Appendix 4. Bedrock sequence* underlying the St. Joseph River basin

System/Series	Rock Unit	Thickness in meters (feet)	Description
Quaternary: Holocene, Pleistocene		15-150 (49-490)	Unconsolidated material
Mississippian	Coldwater Sh.	50 (165)	Shale: gray to greenish-gray, slightly silty
	Sunbury Sh.	3 (10)	Shale: black
Devonian	Ellsworth Sh.	12-60 (39-196)	Shale: alternating gray-green and black in bottom part; grayish-green and containing some limestone dolomite lenses in top part
	Antrim Sh.	18-66 (59-216)	Shale: black, fissile; greenish-gray shale in places in lower third; pyrite common in bottom part
	Traverse Fm.	6-37 (20-121)	Limestone and dolomitic limestone: brown, tan and gray, very fine grained to coarse grained, biofragmental; light-colored to tan fine-grained oolitic dolomitic limestone common in top part
	Detroit River Fm.	5-50 (16-164)	Limestone and dolomite: mostly tan to gray, variably fine grained, argillaceous, bioclastic, sublithographic, and, in places, brecciated and mottled; contains a gray to tan fine-grained argillaceous dolomite in lower part and a tan lithographic limestone near the top
Silurian	Wabash Fm.	30-61 (98-200)	In upper part, limestone and dolomotic limestone: light-colored, granular, fossil-fragmental, cherty, slabby bedded. In lower part, dolomotic siltstone and silty dolomite: gray, dense to fine-grained, argillaceous, thick-bedded to massive. Carbonate bank, reef, and reef-detrital facies throughout, mostly dolomite: light-colored, granular, vuggy, notably fossiliferous
	Pleasant Mills Fm.	37-91 (121-298)	Dolomite and dolomitic limestone: light-, medium-, and dark-brown, dense to medium-grained; finely vuggy in part, algal laminated in part
	Salamonie Dol.	45-80 (148-262)	In upper part, mostly fairly pure dolomite: light-colored, granular, vuggy, very porous, partly reefy. In lower part, mostly dolomite: gray and tan, dense to fine-grained, argillaceous, partly cherty

Continued

Appendix 4. Continued

System/Series	Rock Unit		Thickness in meters (feet)	Description
Silurian	Cataract Fm.		6-25 (20-82)	Dolomite or limestone: light- to medium-brown, fine- to medium-grained, impure, cherty, and shaly in parts
Ordovician	Maquoketa Grp.		75-250 (246-820)	In upper and lower parts, shale: in middle part, gray dolomite and calcareous shale
	Trenton Ls.		50-70 (164-230)	Dolomitic limestone and dolomite: tan, fossilferous
	Black River Grp.		30-75 (98-246)	Limestone: tan, very finely crystalline to lithographic, argillaceous and dolomitic
	St. Peter Ss.		0-18 (59)	Sand and friable sandstone: fine to medium, in well-sorted, rounded, and frosted quartz grains
	Joachim Dol.		0-30 (98)	In upper part, dolomite: light- to dark-colored, very fine to fine-grained, silty to very argillaceous; interbedded with greenish to black shales. In middle part, dolomite and limestone: very fine to fine-grained; interbedded with greenish argillaceous dolomite
	Knox Dol.		50-105 (164-344)	Dolomite: gray to tan, fine crystalline; very cherty in the upper part
Cambrian	Franconia Fm.	Davis Fm.	45 (148)	Franconia--sandstone: light-gray, fine-grained, friable; some glauconitic and gray compact dolomite
	Ironton Ss.			Ironton--sandstone: white to medium-gray; some dolomitic sandstone and dolomite
	Galesville Ss.			Galesville--sandstone: fine- to coarse-grained, clean Davis (replaces other formations in eastern part of area)--dolomite: brownish-gray, fine- to medium-grained; dolomitic siltstone: yellowish-gray; shale: dark-gray, brittle; and limestone: brownish-gray, shaly
	Eau Claire Fm.		120-185 (394-607)	Dolomitic sandstone: pink; shale: green, maroon, and black; and silty dolomite: tan
	Mt. Simon Ss.		90-530 (295-1738)	Sandstone: pink to white, fine- to very coarse grained, in angular to subrounded quartz grains, mostly poorly cemented but well-indurated in some places
PreCambrian				Granite, basalt, and arkose

*Compiled from Becker and Hreha (1978), Gray and others (in preparation), Doheny and others, (1975), Droste and others (1982), Rexroad and Droste (1982), Keller and Burger (1970), and Shaver and others (in press). Thicknesses are not scaled into vertical height of table.

Appendix 5. Effects of Lake Michigan on the Climate of the St. Joseph Basin

Lake Michigan has a considerable effect on the temperature and precipitation regimes of the western St. Joseph Basin. Nearest the lake (from shore to approximately 15 miles inland), there is a one- to two-week lag in springtime warming, because water heats more slowly than land. Average spring and summer temperatures remain slightly lower just inland of the lake, while fall and winter temperatures are slightly warmer. In autumn, the first killing frosts arrive one to two weeks later due to the water's warmth relative to the quicker cooling of the land.

Warm, moisture-laden air from the lake is also largely responsible for increased cloudiness (particularly during winter) and greater snowfall amounts in western areas of the basin. "Lake-effect snows" most commonly extend 35 miles inland of Lake Michigan, and thus primarily affect that part of the St. Joseph River basin bounded on the east by a line extending from Kalamazoo, Michigan to near Elkhart, Indiana. However, strong westerly and northwesterly winds can occasionally cause these snowfalls over most parts of the basin.

In Indiana, the heaviest snows occur in the South Bend-Elkhart area. Since 1966, the South Bend weather station has recorded five seasons having more than 100 inches of total snowfall, including the record 172 inches during the winter of 1977-78. During the unusually snowy seasons between 1976-77 and 1981-82, snowfall averaged nearly 115 inches per year (roughly equivalent to 11.5 inches of rain) and accounted for about 27 percent of the average annual precipitation for that period. Similar heavy snows have been reported in the Michigan portion of the basin. For example, record amounts were reported during the 1976-77 season, when 155.5 inches accumulated at Paw Paw. (Normal seasonal snowfall in Michigan ranges from 45 inches in some inland areas to more than 60 inches in western counties and from 70 to 80 inches in far northwestern areas of the basin.)

Despite the heavy snowfall amounts in western areas, the total influence of lake-effect snows upon annual precipitation is not well defined. For example, normal annual precipitaion totals within the basin are greatest at Niles, Michigan (39.2 inches) and South Bend, Indiana (38.2 inches), although Hillsdale, Michigan--more than 100 miles east of the lake--averages 37.8 inches. Amounts in other parts of the basin vary from about 34 to 36 inches but in no descernible pattern with respect to the lake effect. Nearest the lakeshore, greater precipitation totals during winter can be offset by lesser amounts during summer, since summertime convection is often reduced near the lake due to the stabilizing influence of the colder water surface. Further away, however, other factors influence the precipitation regime. A combination of lake-effect snows and apparent urban-related increases in summer rainfall (Huff and Changnon, 1971), for example, may explain the higher precipitation amounts near South Bend.

Appendix 6. Major Lakes[a]

Lake	Drainage Area (mi^2)	Surface Area[b] (acres)	Capacity[b] (MG)	Established Level	Records Available	Trophic Class[d]	Lake Management Group[d]
STEUBEN							
Barton	-	94	436	-	-	II	VII B
Bass	0.39	61	146	979.68	1954-66	II	VII A
Bell	-	38	166	-	-	II	VII A
Big Otter	21.30	69	580	965.18	1946-53	II	IV D
Big Turkey	35.8	450	2378	926.61	1945-66	II	VII B
Crooked	10.40	828	3440	988.17	1946-	I	VII A
Fish	-	59	244	-	-	III	IV B
Fox	1.25	142	1026	1018.83	1946-53	II	IV A
Hog	-	48	185	-	-	-	-
Hogback	103.00	146	472	948.50	1946-	III	IV B
Gage	17.30	332	3304	954.25	1946-	I	II B
George	14.70	488	-	985.28	1946-	I	II B
Golden	88.80	119	589	948.50	1946-71, 76-	III	IV B
James	47.80	1034	10943	964.96	1943-49	I	II B
Jimmerson	51.60	434	1431	964.66	1946-	I	II B
Lime	17.50	57	139	954.25	1946-	IV	V
Little Turkey	-	58	254	-	-	-	-
Little Otter	15.70	34	241	965.18	1946-53	III	IV D
Long	67.90	92	501	-	1946-	III	IV B
Loon	2.13	138	205	1011.98	1954-66	IV	V
Marsh[c]	14.90	56	-	-	1967-69	III	IV B
McClish	1.28	35	394	951.09	1951-74, 76-	I	II C
Otter	6.91	118	638	934.15	1954-66	II	VII B
Pigeon	35.20	61	303	988.24	1954-63	III	IV B
Pleasant	1.12	53	387	960.95	1946-66	I	II A
Pleasant	3.18	424	1137	961.50	1954-69, 71-	II	II C
Shallow[c]	-	65	-	-	-	IV	V
Silver	3.79	238	827	959.40	1945-53	II	VII A
Snow	40.20	310	2606	964.96	1943-49	I	II B
Walters	-	53	179	-	-	IV	V

Appendix 6. Continued

Lake	Drainage Area (mi^2)	Surface Area[b] (acres)	Capacity[b] (MG)	Established Level	Records Available	Trophic Class[d]	Lake Management Group[d]
LAGRANGE							
Adams	5.62	308	2505	953.59	1946-	I	VI A
Appleman	-	52	192	-	-	II	VII A
Atwood	1.23	170	508	899.99	1948-53	-	-
Big Long	4.77	388	-	956.21	1954-	II	II C
Blackman	0.98	67	394	974.20	1953-59	II	VI A
Cass	0.68	89	284	873	1970-	-	-
Cedar	1.60	120	332	871.90	1948-51	I	V
Dallas	39.80	283	3248	897.36	1945-	II	II C
Emma	13.60	42	228	880.87	1954-66	II	VII A
Eve	-	31	218	-	-	II	VI A
Fish	10.60	100	1319	936.50	1945-	II	II C
Fish	6.21	139	834	814.42	1954-73, 76-	-	-
Hackenburg	55.40	42	166	897.36	1945-	II	VII A
Lake of the Woods	5.25	136	1782	951.09	1951-74, 76	I	II A
Little Turkey	56.50	135	505	925.72	1945-66	II	VII A
Martin	4.93	26	290	899.45	1945-	U	II C
Messick	56.40	68	472	897.36	1945-	II	VI A
Mongo Reservoir[c]	213.00	76	237	-		III	V
North Twin	1.54	135	690	843.56	1953-	I	V
Olin	5.81	103	2991	899.45	1945-	I	II B
Oliver	11.10	362	5005	899.45	1945-	I	II B
Ontario Millpond[c]	-	31	175	-		-	-
Pigeon	-	61	377	-		II	VII B
Pretty	2.89	184	1538	965.50	1949-53 63-65	I	VI A
Royer	4.69	69	531	936.50	1952-	II	VI A
Shipshewana	6.74	202	439	852.04	1951-	III	IV A
South Twin	2.22	116	1173	843.56	1953-70	I	II A
Still	-	30	202	-		I	VI A
Stone	1.51	152	671	818.76	1954-73, 76-	I	V
Wall	1.61	141	534	942.25	1953-54	I	V
Westler	37.80	88	576	897.36	1945-	II	VI A
Witmer	36.10	204	2293	897.36	1945-	II	II C

Appendix 6. Continued

Lake	Drainage Area (mi²)	Surface Area[b] (acres)	Capacity[b] (MG)	Established Level	Records Available	Trophic Class[d]	Lake Management Group[d]
NOBLE							
Bear	6.98	136	987	894.60	1943-	II	VI B
Bixler	5.28	120	681	963.65	1945-	II	VII B
Bowen	-	30	351	-	-	II	VII B
Bristol	-	27	241	-	-	-	-
Cree	4.85	58	296	945.23	1949-66	II	VII B
Diamond	4.80	105	840	-	1946-	II	VII A
Eagle	3.22	81	342	-	1946-48	-	-
Engle	4.19	48	218	878.90	1956-71, 77-	II	VII A
Gordy	9.40	31	221	876.68	1953-66	II	VII B
High	4.43	123	404	896.35	1961-	II	VII B
Jones	70.30	114	312	885.55	1948-	-	-
Knapp	6.02	88	990	878.25	1946-	II	VII A
Latta	2.52	42	293	918.71	1954-66	II	VI A
Little Long	4.55	71	570	954.50	1954-	II	VI A
Long	12.00	40	205	895.82	1954-71	II	VII B
Lower Long	4.35	66	508	889.81	1946-52	-	-
Marl	-	30	166	-	-	-	-
Muncie	42.80	47	188	-	1954-	II	VII C
Pleasant	0.29	20	175	-	1952-53	II	VI A
Round	3.47	99	697	954.50	1954-	II	VI A
Sacarider	1.43	33	241	-	1954-63	II	VI A
Sand	14.90	47	413	893.56	1946-51	II	VI A
Skinner	14.00	125	570	927.74	1945-72, 77-	III	VII C
Steinberger	24.30	73	518	885.55	1948-	II	VI A
Sylvan	33.80	669	1951	916.20	1943-	III	IV C
Tamarack	15.90	50	286	885.55	1948-	II	VII A
Tamarack	19.40	84	436	-	-	-	-
Upper Long	2.08	86	619	891.19	1956-	II	VI A
Waldron	134.00	216	1016	885.55	1948-	II	VII C
Wible	-	49	211	-	-	III	IV B
Williams	-	46	348	-	-	-	-

Appendix 6. Continued

Lake	Drainage Area (mi²)	Surface Area[b] (acres)	Capacity[b] (MG)	Established Level	Records Available	Trophic Class[d]	Lake Management Group[d]
DEKALB							
Upper Story	3.16	77	332	942.20	1946, 54-66	III	IV B
ELKHART							
Goshen Pond[c]	-	164	358	-	-	-	-
Heaton	9.33	87	208	767.30	1946-53 69-74, 76-	I	V
Hunter	0.51	99	364	856.90	1946-53	I	VII A
Indiana	0.62	122	1107	759.73	1946-53	I	II A
Simonton	7.44	282	508	772.19	1946-	I	II A
Wolf[c]	1.29	100	-	813.00	1947-57	-	-
KOSCIUSKO							
Dewart	8.05	551	2932	867.70	1945-	II	VII B
Flatbelly[c]	4.66	326	-	-	1964-69	III	IV B
Papakeechie[c]	5.52	300	488	-	1964-69	-	-
Shock	-	37	394	-	-	II	II C
Syracuse	38.20	414	1746	858.87	1943-	I	V
Wabee	14.60	187	1547	829.79	1946-53	III	IV D
Wawasee	36.90	3410	21900	858.89	1943-66	I	I

[a]having a surface area of at least 50 acres and/or capacity of at least 500 acre-feet

[b]at established level

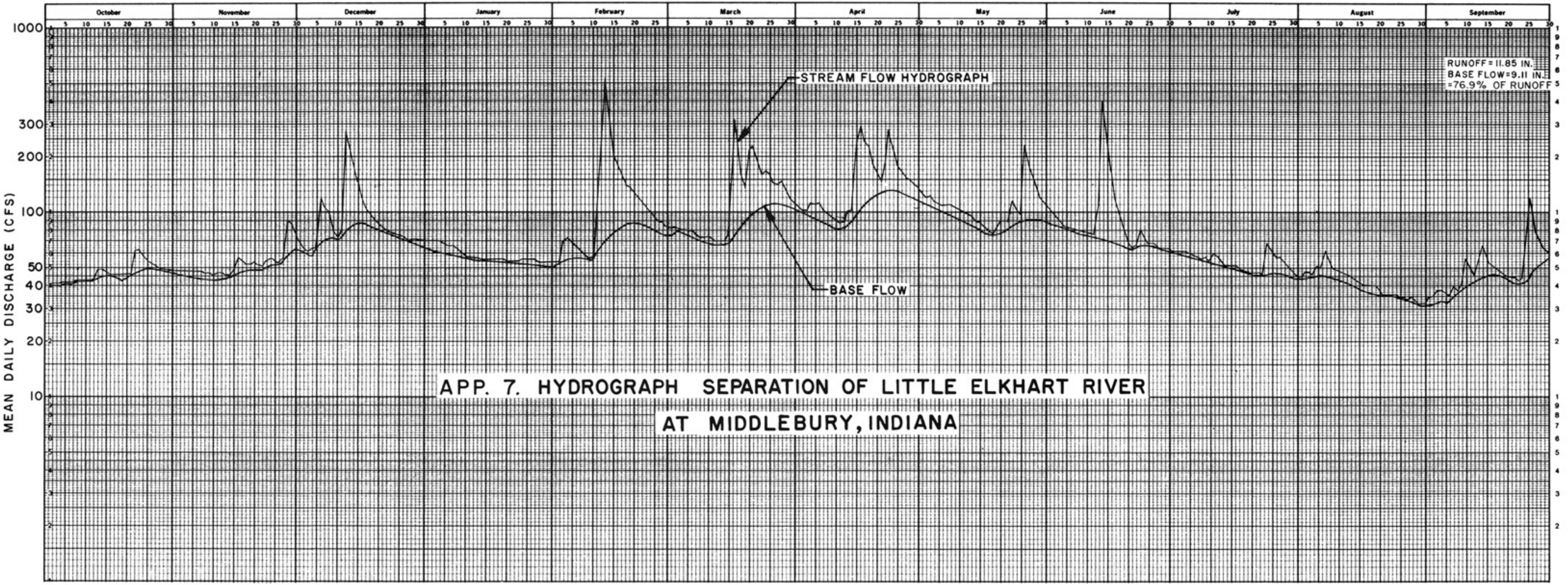
[c]no lake map available

[d]data from revised Indiana Lake Classification System and Management Plan (1986), Indiana Department of Environmental Management

Form 9-285 (9-77)

UNITED STATES DEPARTMENT OF THE INTERIOR GEOLOGICAL SURVEY (WATER RESOURCES DIVISION)
SEMI-LOG PLOT OF DAILY VALUES

Station Name LITTLE ELKHART RIVER AT MIDDLEBURY, IN. DRAINAGE AREA = 97.6 SQ. MI. Station Number 04099808 Year 1984



APP. 7. HYDROGRAPH SEPARATION OF LITTLE ELKHART RIVER AT MIDDLEBURY, INDIANA

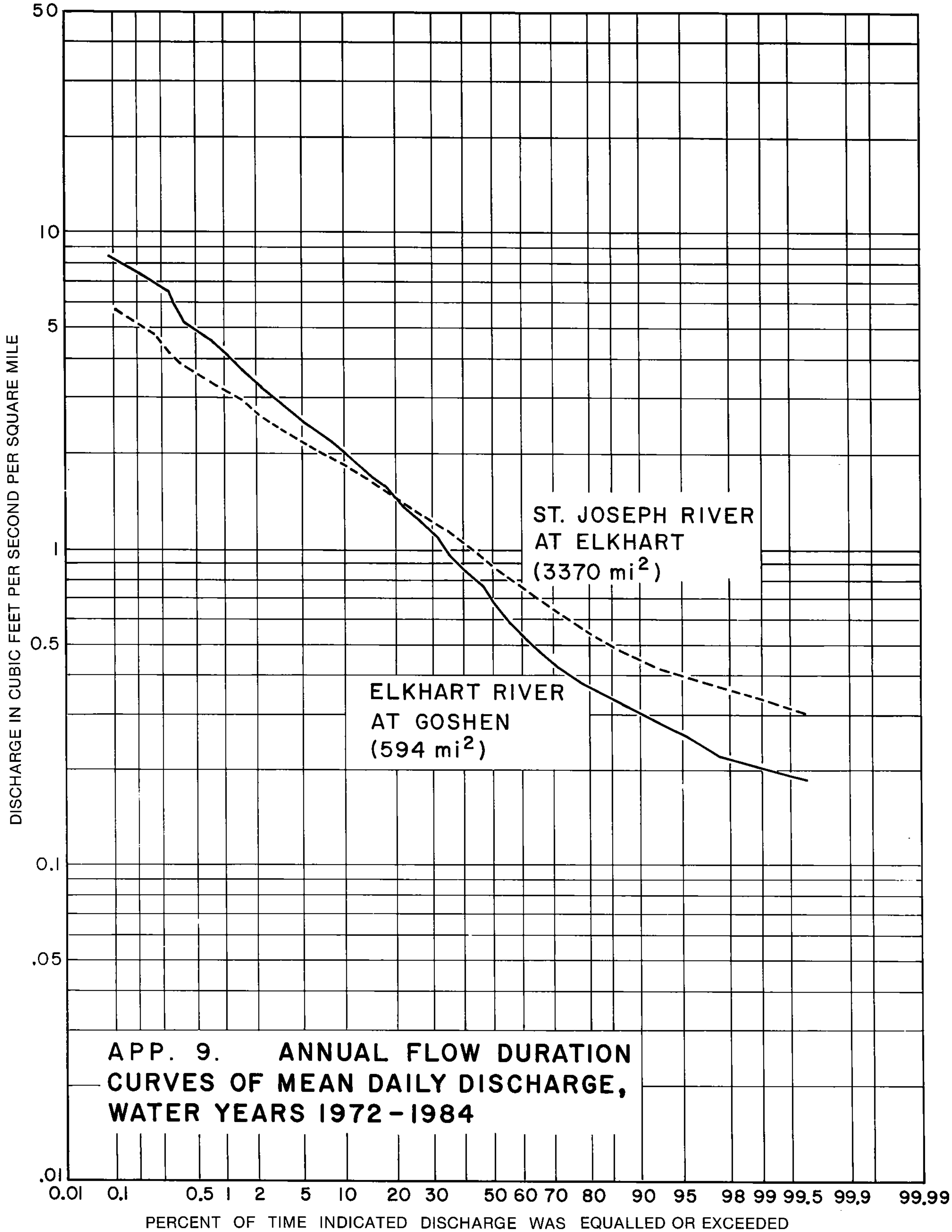
PLOTTED BY– R. GEEKIE DATE 9/86

Appendix 8. Hydrograph for Regulated Streams

Station Number		Drainage Area[a] (Mi^2)	Dry Year[b]					Normal Year[c]				
			RO[d] (in)	DR[e] (in)	GW[f] (in)	DR %	GW %	RO[d] (in)	DR[e] (in)	GW[f] (in)	DR %	GW %
04099510	Pigeon Ck. near Angola IN.	102[b]/106[c]	2.59	0.97	1.62	37	63	12.69	4.02	8.67	32	68
04100500	Elkhart R. at Goshen IN.	580[b]/594[c]	4.62	1.02	3.53	24	76	11.38	3.49	7.89	31	69
04101000	St. Joseph R. at Elkhart IN.	3339[b]/3370[c]	5.23	1.76	3.47	34	66	13.05	4.38	8.67	34	66
04101500	St. Joseph R. at Niles MI.	3666	5.43	1.59	3.84	29	71	12.57	3.37	9.20	27	73

a. Some drainage areas have changed as a result of re-measurement or gage re-siting.
b. Water year 1964.
c. Water year 1975.
d. RO = Runoff.
e. DR = Direct runoff.
f. GW = Ground water or base flow.

The peaks of the hydrograph in Appendix 7 represent the response of stream flow to precipitation events. These peaks generally are composed of overland flow and interflow, and sometimes include ground-water flow. An increase in ground-water discharge during a peak is probably due to local ground-water flow as opposed to regional ground-water flow. The gradual seasonal variation of the hydrograph (base flow) represents a slow response of regional ground-water flow to precipitation events (Freeze and Cherry, 1979). The graph of base flow (as shown) was used to compute the total annual volume of base flow in inches.



APP. 9. ANNUAL FLOW DURATION CURVES OF MEAN DAILY DISCHARGE, WATER YEARS 1972-1984

Appendix 10. Selected Recommended Water Quality Standards[1]

	Aquatic Life	Public Supply	Irrigation	Stock
Arsenic (As)	.44[8]	.05[2,4]	0.1[6,7]	0.2[6]
Barium (Ba)	---	1.0[2,4]	---	---
Boron (B)	---	---	.75[6,7]	5.0[6]
Cadmium (Cd)*	.0063[8]	.01[2,4]	.01[6]	.05[6]
Chloride (Cl)	---	250[3,5]	---	---
Chromium (Cr)*	(Hex).021[8]	(Hex).05[2,4]	.1[6]	1.0[6]
Copper (Cu)*	.043[8]	1.0[5]	---	---
Cyanide (CN) (free)	.052[8]	---	---	---
Dissolved Solids (TDS)	---	500[5]	500-1000[7]	5,000[7]
Fluoride (F)	---	2.4[2,4]	1.0[6]	2.0[6]
Iron (Fe)	1.00[7]	.3[5]	---	---
Lead (Pb)*	.400[8]	.05[2,4]	5.0[6]	.1[6]
Manganese (Mn)	---	.05[5]	---	---
Mercury (Hg)*	.0041[8]	.002[2,4]	---	.001[7]
Nickel (Ni)*	3.1[8]	---	.1[7]	---
Nitrate (NO_3 as N)	---	10.0[2,4]	---	10.0[6]
pH	6.0-9.0[3]	5.0-9.0[5]	4.5-9.0[7]	---
Sulfate (SO_4)	---	250[3,5]	---	---
Zinc (Zn)*	.570[8]	5.0[5]	---	---

[1]Values represent maximum values. All values except pH are in mg/l; in the case of multiple uses the most protective standard applies. Refer to 330 IAC 2-4 for water quality regulations on natural salmonid areas.
[2]Indiana Environmental Management Board, Regulation EMB-4 (320 IAC 3-3.1), Drinking Water Standards, 1979.
[3]Indiana Stream Pollution Control Board, Regulation 330 IAC 1-1, 1985.
[4]U.S. EPA National Interim Primary Drinking Water Regulations, 1979a.
[5]U.S. EPA National Secondary Drinking Water Regulations, 1979b.
[6]U.S. Environmental Protection Agency, 1973.
[7]U.S. Environmental Protection Agency, 1976.
[8]U.S. Environmental Protection Agency, 1980.

*Values are maximum allowable at anytime at 200 mg/l hardness (as provided by IDEM). Values vary with hardness.

Appendix 11. Selected Aquatic Life Standards

Fish Community		Minimum Concentration of Dissolved Oxygen	Temperature
[1]Warm Water Fish		4.0 mg/l (5.0* mg/l)	Streams +5°F (2.8°C)** Lakes +3°F (1.7°C)**
Cold Water Fish	[1]Areas designated for for Put-and-take trout	6.0 mg/l	Streams<65°5F (18.3°C) or +5° F (2.8°C)** Lakes no heat added
	[2]Areas designated for Salmonid Fish		
	Spawning or rearing or imprinting	6.0 mg/l (7.0 mg/l-spawning season)	No heat added
	Migration route	5.0 mg/l 6.0 mg/l* (also limit during migration)	85°F (29.4°C) or +2°F (1.1°C)** 70°F (21.1°C) during migration

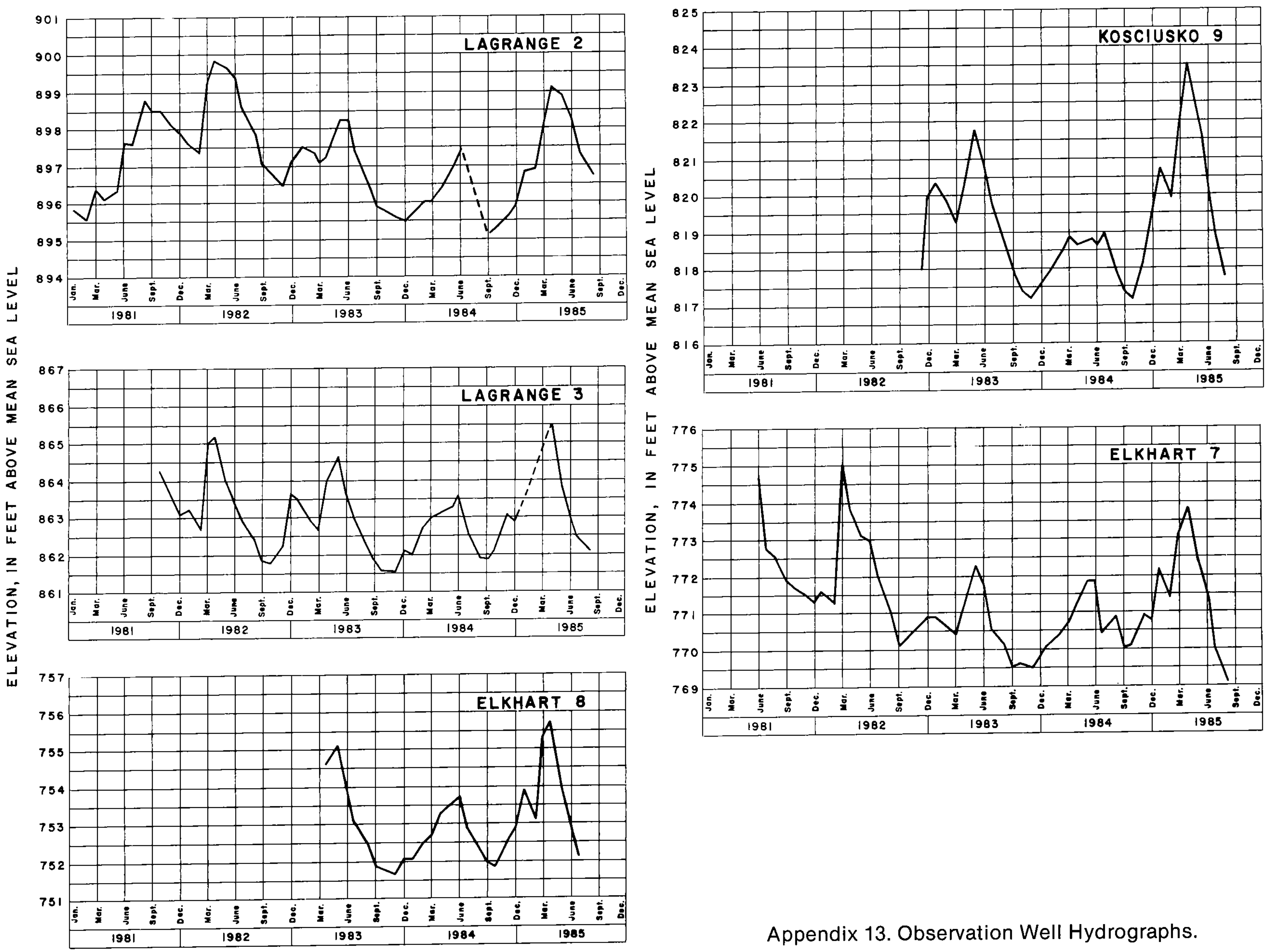
*Average per day.
**Maximum rise above natural temperature.

[1]Indiana Stream Pollution Control Board Reglation 330 IAC 1-1, 1984.
[2]Indiana Stream Pollution Control Board Regulation 330 IAC 2-4, 1985.

Appendix 12. Trophic Classes and Lake Management Groups

Trophic Class: Bonhomme Trophic Index	Trophic Class: Characteristics	Lake Management Groups: Group	Lake Management Groups: Characteristics	General Management Approach
I (1-25 points)	Least eutrophic, best water quality, few aquatic plants and algae, low nutrient levels.	I	large size (>3,000), good water quality (16-20 points).	Maintain good conditions, protect by curbing nutrients.
II (26-50 points)	Mesotrophic, medium water quality, diverse communities of plants and algae, stable ecosystem	IIa	best water quality (1-16 points), intermediate mean depths of 17.6-31 ft.	Protect and maintain present water quality and natural features.
		IIb	best water quality (3-25 points) large mean depths of 31.2-45 ft.	
		IIc	medium water quality (18-41 points), large mean depths of 32.7-40.5 ft.	For group IIc, improve water quality by curbing nutrients. Other techniques depend on lake.
III (51-75 points)	Eutrophic, large supply of nutrients, shallow, always support extensive communities of plants and algae, organic rich bottom sediment, can have low D.O. level caused by decomposition of organics.	III	large bodies of water (1,291-1,864 acres), medium water quality (23-48 points), mean depths of 5-24.5 ft.	Prevent further degradation by curbing nutrients; for problem lakes, use macrophyte harvesting, sediment consolidation.
			Lakes with poorest water quality (50-75 points)	Problem lakes, improve water quality as quickly as possible through restorative measures and nutrient abatement program. Specific restoration techniques depend on individual lakes.
		IVa	very shallow from 2-7.3 ft.	
		IVb	mean depths of 7.9-20 ft.	
		IVc	no distinction from other subgroups	
		IVd	mean depth 21-31.1 ft.	
IV (75 points)	Remnant lakes, very shallow, extensive plant and algae communities.	V	good water quality (2-18 points), shallow mean depths of 5-16 ft.	Maintain present good condition.
		VI	good-med. water quality (13-39 points) mean depth of 15-27 ft.	Main priority-limitation of nutrient inputs-depends on lake condition.
		VII	trophic state 18-54 points mean depth of 5-19.6 ft.	Limit nutrient inputs. Other techniques depend on lake.

Source of data: Indiana Lake Classification System and Management Plan (1980); Indiana Department of Environmental Management



Appendix 13. Observation Well Hydrographs.

Appendix 14. Results of Chemical Analysis from Selected Water Wells (in mg/l except as indicated)

Location number: *, anomalous analysis (EPM balance error >5%); +, analysis of softened water; -, composite sample from two wells in same aquifer; #, incomplete analysis.

Well Owner: d, deep; Elk, Elkhart; N, north; obs, observation well; s, shallow; S., south; S.B., South Bend; t, test; (122), sample number for well sampled in joint IDNR and IGS study, summer 1985.

Well depth: n.a., not available.

Date sampled: month and year.

Aquifer System: STJ, St. Joseph and Tributary Valley; HOW, Howe; HIL, Hilltop; TOP, Topeka; NAT, Natural Lakes and Moraines; KEN, Kendallville; NAP, Nappanee.

Remarks: For location and information on well type and major source of data, see location map.

[1]Field measurement; results in pH units; [2]TDS values are the calculated sum of major constituents expected in an anhydrous residue of a ground-water sample.

Location Number	Well Owner	Township (N)	Range (E)	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCO_3$	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Iron (Fe)	Manganese (Mn)	Alkalinity as $CaCO_3$	Chloride (Cl)	Sulfate (SO_4)	Fluoride (F)	Nitrate (NO_3 as N)	Total Dissolved[2] Solids (TDS)
	ST. JOSEPH COUNTY																				
1	Wedgewood Park	38	2	12	77	STJ	01/66	6.8	228	55.0	22.0	3.0	1.0	0.40	.1	166.0	3.0	56.0	0.1	0	241
2	River Commons	38	2	14	151	STJ	11/73	7.7	250	64.0	22.0	4.0	.9	1.20	.07	198.0	12.0	48.0	0.1	<.1	271
3	R. Bartsch (22)	38	2	16	202	STJ	06/85	8.3	307	78.2	27.1	4.3	0.7	<.10	<0.1	249.7	9.8	69.4	0.2	<0.2	499
4#	German Twp.	38	2	19	160	STJ	11/60	.	292	.	.	.		0.30		289.0	4.0	70.0	.		345
5	Christ King Ch. (21)	38	2	24	71	STJ	06/85	8.4	360	99.8	26.9	38.8	2.1	<0.10	<0.1	312.7	61.8	47.0	0.2	3.1	677
6	S. Bend Pinhook 1	38	2	26	131	STJ	09/76	7.4	328	78.0	32.0	12.0	2.0	0.90	.13	250.0	30.0	55.0	0.2	<.1	360
	S. Bend Pinhook 3	38	2	26	131	STJ	09/76	7.8	320	76.0	32.0	15.0	2.0	1.00	.11	260.0	23.0	54.0	0.1	<.1	359
7#	C. Wiggins	38	2	29	100	STJ	01/60	.	360	.	.	.		.50		326.0	8.0	90.0	.	.	415
8	S. Bend Arpt 1	38	2	33	103	STJ	09/77	7.8	368	88.0	36.0	18.0	3.0	<0.10	<.02	288.0	35.0	58.0	0.2	1.6	592
	S. Bend Arpt 2	38	2	33	96	STJ	09/77	8.0	339	80.0	34.0	9.0	3.0	<0.10	<.02	280.0	16.0	49.0	0.1	1.1	360
	★ S. Bend Arpt 3 (74)	38	2	33	108	STJ	06/85	7.1	310	80.5	26.6	4.5	0.9	<0.10	0.1	270.2	23.5	57.0	0.1	0.3	529
9	Drewrys Ltd	38	2	34	157	STJ	07/54	7.9	310	74.0	30.0	3.6	.7	1.80	.13	257.0	3.8	46.0	0.0	.4	328
10	S. Bend N. 5	37	2	1	105	STJ	12/61	7.9	305	78.0	27.0	5.0	1.0	0.00	.1	224.0	8.0	85.0	0.1	.1	478
	S. Bend N. 6	37	2	1	106	STJ	12/61	7.9	343	88.0	30.0	10.0	2.0	0.60	.1	251.0	13.0	101.0	0.1	0	551
	S. Bend N. 7	37	2	1	112	STJ	12/61	7.9	336	86.0	29.0	6.0	2.0	0.10	.05	247.0	13.0	78.0	0.1	.2	516
11	S. B. Bait Co.	37	2	13	78	STJ	08/54	7.7	303	76.0	27.0	3.9	1.0	0.28	0	242.0	6.3	41.0	0.1	4.3	334
12#	Walker Fld t-81A	37	2	14	120	HIL	06/81	7.8	364	.	.	.		0.20	0.1	285.0	61.0	32.0	.		.

Location Number	Well Owner	Township (N)	Range (E)	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCO_3$	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Iron (Fe)	Manganese (Mn)	Alkalinity as $CaCO_3$	Chloride (Cl)	Sulfate (SO_4)	Fluoride (F)	Nitrate (NO_3 as N)	Total Dissolved[2] Solids (TDS)
13	S. Bend Oliver 1	37	2	15	169	STJ	01/74	7.2	348	90.0	30.0	7.0		<0.10	0.2	276.0	16.0	46.0	.	2.6	528
	S. Bend Oliver 2	37	2	15	165	STJ	01/74	7.1	432	114.0	36.0	31.0		1.80	.05	304.0	68.0	82.0	.	3.3	707
	S. Bend Oliver 3	37	2	15	155	STJ	09/77	7.3	580	164.0	41.0	79.0	3.0	< 0.10	.44	302.0	100.0	250.0	0.1	7.1	.
	S. Bend Oliver 4	37	2	15	192	STJ	09/77	7.8	448	136.0	26.0	20.0	2.0	< 0.10	<.02	318.0	44.0	95.0	0.1	1.6	713
14	S. Bend S. 1	37	2	23	93	HIL	09/77	7.9	310	78.0	28.0	19.0	2.0	<0.10	<.02	260.0	37.0	27.0	0.1	2.6	511
	S. Bend S. 2	37	2	23	92	HIL	05/66	7.2	300	75.0	27.0	9.0	1.0	<0.05	.03	250.0	10.0	33.0	0.0	3.5	464
	S. Bend S. 3	37	2	23	100	HIL	05/76	7.4	354	94.0	28.0	21.0	2.0	<0.10	<.02	272.0	50.0	37.0	0.1	4.1	568
15	S. B. Erskine	37	2	25	175	HIL	05/76	7.6	316	85.0	25.0	7.0	2.0	<0.10	<.02	248.0	25.0	30.0	0.1	3.9	481
16	Forest Hay Sch.	37	2	36	124	HIL	08/56	7.7	220	57.0	19.0	1.6	1.2	0.01	.0	187.0	1.8	23.0	0.1	4.1	245
17#	F. D. Wilson	36	2	3	177	HIL	11/58		216					.10	.	456.0	12.0				359
18	Knollwood C.C. (23)	38	3	9	156	STJ	06/85	8.0	254	64.8	22.4	2.9	0.5	<0.10	<0.1	240.0	3.8	32.2	0.2	<.02	425
19#	P. Van Es	38	3	17	92	STJ	07/58	.	232	.	.	.		<0.10		244.0	16.0	.	.		240
20	S.B. Car. Hills 2	38	3	20	117	STJ	08/82	7.5	316	78.0	29.0	13.0	1.1	0.08	.06	245.0	29.0	43.0	0.2	2.7	495
21	IN Dept. Hwy (29)	38	3	23	70	STJ	06/85	7.4	311	80.9	26.5	25.0	1.0	<0.10	<0.1	253.1	37.1	36.5	0.3	10.6	568
22#	Clay Twp.	38	3	30	163	STJ	01/60	.	360	.	.	.		< .1		282.0	16.0	115.0	.	.	421
23	S.B. Edison 2 (20)	37	3	5	200	STJ	06/85	8.2	307	78.6	26.5	14.8	0.7	0.70	0.1	260.2	33.1	47.3	0.2	<.02	526
	S.B. Edison 3	37	3	5	204	STJ	09/77	7.7	302	77.0	27.0	10.0	1.0	1.20	.10	220.0	26.0	57.0	0.2	< .1	468
24	Mishawaka 2	37	3	11	97	STJ	07/83	7.0	306	83.0	24.0	14.0	2.0	0.34	.13	242.0	25.0	65.0	0.1	.5	509
	Mishawaka 3	37	3	11	89	STJ	06/83	7.1	294	86.0	19.0	18.0	2.2	0.10	.04	236.0	32.0	57.0	0.1	1.2	504
	Mishawaka 4	37	3	11	84	STJ	06/83	7.4	280	78.0	21.0	11.0	1.9	0.21	.05	222.0	20.0	42.0	0.1	1.3	409
	Mishawaka 5	37	3	11	329	STJ	06/83	7.4	336	79.0	34.0	13.0	1.5	0.65	.02	254.0	15.0	74.0	0.2	< .1	539
	Mishawaka 6	37	3	14	100	STJ	06/83	7.2	420	122.0	28.0	31.0	3.0	<.05	.06	294.0	54.0	87.0	0.1	1.8	686
	Mishawaka 7	37	3	14	91	STJ	06/83	7.4	280	77.0	21.0	13.0	1.8	0.17	.06	208.0	24.0	52.0	0.1	.9	444
	Mishawaka 8	37	3	11	89	STJ	06/83	7.4	282	79.0	20.0	12.0	2.0	0.11	.04	218.0	23.0	49.0	0.1	.6	452
	Mishawaka 9	37	3	11	85	STJ	06/83	7.5	260	74.0	18.0	9.0	1.9	0.12	.04	204.0	17.0	39.0	0.2	.9	409
	Mishawaka 10	37	3	14	107	STJ	06/83	7.3	316	90.0	22.0	20.0	1.9	1.00	.26	242.0	31.0	63.0	0.2	.3	525
25	Twin Branch 1 (17)	37	3	12	133	STJ	06/85	8.3	262	66.8	22.8	13.8	0.7	<0.10	0.4	229.6	15.8	54.6	0.3	<.02	463
	Twin Branch 2	37	3	12	144	STJ	06/80	7.7	196	48.0	18.0	10.0	1.0	0.05	.22	188.0	5.0	16.0	0.2	.1	329
26#	NIPSCO	37	3	12	111	STJ	10/79	7.3	.	.	.	.	.	0.10	.24	218.0	.	48.0	0.2	.2	.
27#	Bendix Aviation	37	3	14	125	STJ		.	453	.	.	.	.	2.00		348.0	.	.	.	.	362
28	Byrkit 6	37	3	15	70	STJ	06/83	7.4	328	101.0	18.0	10.0	1.8	<.05	<.02	238.0	20.0	63.0	0.2	3.9	508

Location Number	Well Owner	Township (N)	Range (E)	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCO_3$	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Iron (Fe)	Manganese (Mn)	Alkalinity as $CaCO_3$	Chloride (Cl)	Sulfate (SO_4)	Fluoride (F)	Nitrate (NO_3 as N)	Total Dissolved[2] Solids (TDS)
29	Concrete Products	37	3	20	129	HIL	06/54	7.8	313	76.0	30.0	3.2	.8	0.06	.1	265.0	3.7	23.0	0.0	5.2	334
30#	J. Kurth	37	3	21	176	HIL	12/58	.	232	.	.	.	.	0.50		327.0	6.0	.	.	.	280
31	John Ringle (65)	37	3	23	38	STJ	11/86	7.7	302	85.1	21.9	15.7	1.2	<0.1	<0.1	242.3	39.9	37.9	0.2	4.5	524
32	D. Murphy (18)	37	3	28	203	HIL	06/85	7.8	338	90.9	26.9	5.4	0.5	0.20	0.2	357.2	2.9	14.0	0.2	<.02	585
33#	R. Parcell	36	3	2	131	NAP	12/58		240	.	.	.	.	1.20		292.0	10.0	.	.	.	266
34	C. Contat (19)	36	3	3	100	NAP	06/85	8.0	353	90.2	28.3	4.9	0.5	6.40	0.1	365.8	3.0	16.5	0.3	<.02	605
35#	C. Shafer	36	3	7	210	NAP	11/58		204					0.80		283.0	106.0	.	.	.	345
36	Standard Oil Co.	38	4	18	80	STJ	05/60	7.5	228	55.0	22.0	2.6	1.3	0.05	.01	169.0	8.6	48.0	0.2	3.0	263
37#	Indiana Toll Road	38	4	21	73	STJ	04/55	.	118	.	.	.		0.70		54.0	14.0	2.0	.		.
38	John Rake (24)	38	4	29	50	STJ	06/85	7.5	260	68.3	21.1	3.6	0.5	1.30	0.1	199.4	19.4	50.6	0.2	<.02	413
39#	Moran School	37	4	17	114	STJ	01/60	.	264	.	.	.	.	1.00		273.0	8.0	125.0	.		386
40	F. Besinger (9)	36	4	5	125	NAP	06/85	8.6	213	46.8	22.5	39.3	1.5	1.70	<0.1	307.5	15.4	<0.1	0.9	<.02	510
41+	W. Copp (8)	36	4	18	128	NAP	06/85	8.8	73	17.0	7.4	91.1	1.6	0.10	<0.1	269.6	13.8	1.5	1.2	<.02	468
42	R. Eberhart (7)	36	4	29	153	NAP	06/85	8.6	259	59.6	25.8	21.5	0.9	2.10	<0.1	326.3	5.0	<0.1	0.5	<.02	522
	ELKHART COUNTY																				
43	USGS Elk 47	38	4	15	24	STJ	06/78	7.9	220	65.0	14.0	95.0	4.7	0.00	.01	143.0	190.0	16.0	.01	3.1	578
44	USGS Elk 34 s	38	4	23	24	STJ	06/78	7.3	190	46.0	19.0	4.0	.5	2.00	.08	138.0	7.0	44.0	.0	0.1	293
	USGS Elk 34 d	38	4	23	240	STJ	06/78	7.8	230	56.0	21.0	38.0	1.7	0.91	.09	237.0	45.0	2.0	.0	.01	465
45	IN Toll Rd. Ser. 5	38	4	24	60	STJ	11/73	7.8	216	58.0	17.0	2.0	.8	1.00	.06	180.0	2.0	36.0	<.1	.1	33.7
46	USGS Elk A-1	38	4	25	135	STJ	04/79	8.0	230	56.0	21.0	14.0	6.8	0.42	.13	220.0	11.0	11.0	.	.00	401
	USGS Elk A-2	38	4	25	17	STJ	04/79	8.7	160	46.0	12.0	13.0	1.2	0.00	.002	37.0	55.0	23.0	.	16.00	215
47	USGS Elk 49 s	38	4	25	27	STJ	06/78	7.6	370	100.0	30.0	3.0	1.0	0.00	.0	75.0	12.0	250.0	0.0	7.3	496
48	USGS Elk 32 s	38	4	27	24	STJ	06/78	8.2	160	43.0	13.0	4.0	1.1	0.04	.07	74.0	16.0	35.0	0.0	7.8	208
49	USGS Elk I-1	38	4	36	172	STJ	04/79	7.7	190	46.0	19.0	11.0	1.1	0.79	.03	215.0	5.0	2.0	.06	.0	341
50	USGS Elk L-2	38	4	36	183	STJ	04/78	7.6	230	61.0	19.0	4.0	0.9	0.78	.17	157.0	8.0	63.0	0.1	.05	349
51	USGS Elk B-1	38	4	36	475	STJ	04/79	8.3	210	49.0	21.0	57.0	2.1	0.32	.05	250.0	62.0	1.0	.03	.07	510
	USGS Elk B-3	38	4	36	135	STJ	04/79	8.5	230	61.0	20.0	3.0	0.6	0.24	.23	129.0	23.0	71.0	.	.00	362
	USGS Elk B-4	38	4	36	173	STJ	04/79	8.4	200	52.0	18.0	3.0	0.6	0.32	.16	172.0	3.0	30.0	.	.00	328

Location Number	Well Owner	Township (N)	Range (E)	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCO_3$	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Iron (Fe)	Manganese (Mn)	Alkalinity as $CaCO_3$	Chloride (Cl)	Sulfate (SO_4)	Fluoride (F)	Nitrate (NO_3 as N)	Total Dissolved[2] Solids (TDS)
52	USGS Elk C-1	38	4	36	340	STJ	04/79	7.1	240	59.0	22.0	11.0	1.1	0.38	.88	230.0	8.7	1.5	0.1	.00	406
	USGS Elk C-3	38	4	36	195	STJ	04/79	7.7	220	56.0	20.0	5.0	0.6	0.17	.15	212.0	4.0	21.0	.	.00	339
	USGS Elk C-4	38	4	36	128	STJ	04/79	8.0	220	56.0	20.0	5.0	0.7	0.51	.08	239.0	2.0	5.0	.03	.00	382
53	USGS Elk D-2	38	4	36	174	STJ	04/79	8.4	200	51.0	18.0	5.0	0.8	0.65	.16	193.0	4.0	14.0	.	.03	338
54	USGS Elk E-1	38	4	36	80	STJ	04/79	7.9	300	92.0	26.0	88.0	3.1	1.20	.06	376.0	36.0	96.0	.	.0	660
	USGS Elk E-3	38	4	36	174	STJ	04/79	8.1	240	58.0	22.0	10.0	0.9	0.50	.03	245.0	7.0	10.0	.	.05	426
55	USGS Elk 20 s	37	4	2	27	STJ	06/78	7.8	200	58.0	14.0	22.0	1.5	0.00	0	134.0	44.0	35.0	.0	3.9	338
56	USGS Elk 18 s	37	4	10	27	STJ	04/79	7.7	250	72.0	18.0	25.0	.9	0.01	.001	198.0	60.0	35.0	.	4.2	435
	USGS Elk 18 d	37	4	10	126	STJ	04/79	7.9	180	52.0	12.0	70.0	.7	0.23	.04	248.0	51.0	40.0	.	2.0	509
57	USGS Elk 17 s	37	4	12	25	STJ	04'79	7 7	250	69.0	19.0	8.0	.8	0.64	.16	220.0	14.0	40.0	.	.3	408
	USGS Elk 17 d	37	4	12	190	STJ	04/79	7.4	250	66.0	20.0	8.0	1.0	0.84	.12	261.0	9.0	10.0	.	0	408
58	El Paco Manor	37	4	12	99	STJ	05/66	7.5	235	65.0	18.0	28.0	2.0	0.10	.2	187.0	34.0	52.0	.	.1	427
59	USGS Elk 4 s	37	4	27	32	STJ	06/78	7.2	210	55.0	18.0	3.0	1.3	0.01	.01	142.0	10.0	33.0	.01	6.1	307
60	J. Luse (2)	37	4	27	86	NAP	06/85	7.5	293	74.2	25.9	13.8	0.8	0.30	0.2	298.9	6.4	38.4	<0.1	<.02	532
61	E. Squibb (3)	37	4	36	49	NAP	06/85	7.8	315	76.9	28.1	11.2	0.8	4.10	0.1	312.1	13.2	31.3	.3	<.02	553
62	E. Eby (4)	36	4	12	90	NAP	06/85	8.1	304	70.7	30.7	15.1	1.1	<0.10	0.5	325.0	4.9	26.4	0.5	1.2	559
63	E. Davidhizar (6)	36	4	27	47	NAP	06/85	8.6	291	68.1	28.5	16.3	1.0	2.00	<0.1	347.9	4.0	<0.1	0.7	<0.02	554
64	Wakarusa 1	36	4	36	155	NAP	01/75	7.9	278	78.0	20.0	10.0	1.0	3.10	.04	284.0	3.0	4.0	0.6	.1	466
	Wakarusa 2	36	4	36	131	NAP	05/77	7.5	292	77.0	24.0	10.0	1.0	3.20	.02	282.0	6.0	19.0	0.5	0.9	485
65	W. Harter (5)	35	4	1	125	NAP	06/85	8.2	295	74.7	25.6	12.7	0.8	1.90	<0.1	340.4	3.1	<0.1	0.5	<.02	544
66	Nappanee 1	35	4	36	154	NAP	06/82	7.8	318	88.0	24.0	11.0	1.1	1.60	.02	336.0	5.0	5.0	0.5	0.1	546
	Nappanee 2	35	4	36	150	NAP	01/75	7.7	320	81.0	28.0	10.0	1	2.20	.04	334.0	2.0	1.0	0.5	.1	246
	Nappanee 2a	35	4	36	164	NAP	06/82	7.7	330	87.0	27.0	11.0	1.0	1.50	.03	338.0	5.0	5.0	.5	.1	551
67	USGS Elk 46 s	38	5	7	45	STJ	06/78	7.9	260	63.0	24.0	3.0	.7	0.08	.02	181.0	5.0	21.0	0.1	11.0	458
68	USGS Elk 43 s	38	5	10	27	STJ	03/79	8.1	140	35.0	12.0	4.0	.6	0.00	.01	88.0	8.0	22.0	.	6.20	190
	USGS Elk 43 d	38	5	10	172	STJ	03/79	7.5	260	63.0	26.0	28.0	1.0	1.10	.1	266.0	36.0	6.0	.	.04	490
69	USGS Elk 35 s	38	5	20	25	STJ	06/78	7.9	170	50.0	11.0	170.0	1.7	0.80	0	198.0	210.0	25.0	0.1	4.20	723
	USGS Elk 35 d	38	5	20	131	STJ	06/78	7.7	260	63.0	26.0	12.0	1.7	0.51	.16	261.0	7.0	4.0	0.2	.02	445
70	USGS Elk 30 s	38	5	27	24	STJ	03/79	8.5	160	43.0	12.0	13.0	1.8	0.00	0.0	105.0	23.0	29.0	.	4.2	260
	USGS Elk 30 d	38	5	27	172	STJ	03/79	7.8	230	56.0	22.0	31.0	2.1	0.00	.18	248.0	26.0	9.0	.	.0	451
71	Miles Lab	38	5	31	42	STJ	06/54	8.0	166	43.0	13.0	4.0	.8	.14	.04	131.0	3.1	29.0	0.1	1.7	183

Location Number	Well Owner	Township (N)	Range (E)	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCO_3$	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Iron (Fe)	Manganese (Mn)	Alkalinity as $CaCO_3$	Chloride (Cl)	Sulfate (SO_4)	Fluoride (F)	Nitrate (NO_3 as N)	Total Dissolved[2] Solids (TDS)
72★	USGS Elk 21 s	38	5	32	24	STJ	06/78	7.3	290	75.0	26.0	19.0	2.2	0.36	.17	243.0	30.0	18.0	0.1	0.28	481
73	Elkhart 1 North	38	5	32	44	STJ	11/58	7.8	205	49.0	20.0	4.0	1.0	0.30	.2	188.0	4.0	19.0	0.1		327
	Elkhart 1a North	38	5	32	58	STJ	05/77	7.5	254	62.0	24.0	7.0	1.0	0.10	.06	216.0	16.0	28.0	0.2	.4	269
	Elkhart 2a North	38	5	32	50	STJ	04/75	8.0	246	63.0	21.0	6.0	1	0.30	.09	208.0	10.0	27.0	0.1	.3	383
	Elkhart 2b North	38	5	32	50	STJ	04/83	7.4	240	59.0	22.0	6.0	0.9	0.20	0.08	208.0	12.0	28.0	0.1	0.6	383
	Elkhart 3 North	37	5	5	44	STJ	05/77	7.5	238	59.0	22.0	5.0	2.0	<.10	.02	204.0	14.0	28.0	0.2	< 0.1	379
	Elkhart 4 North	38	5	32	46	STJ	05/77	7.5	240	62.0	21.0	7.0	2.0	<.10	.03	204.0	17.0	27.0	0.2	0.1	385
	Elkhart 5 North	38	5	32	61	STJ	04/83	7.4	240	63.0	20.0	6.0	1.2	<.05	.02	196.0	11.0	28.0	0.1	1.2	327
	Elkhart 6 North	38	5	32	60	STJ	04/83	7.4	232	60.0	20.0	6.0	1.3	<.05	<.02	196.0	11.0	25.0	1.0	1.0	364
	Elkhart 7 North	38	5	32	58	STJ	04/83	7.3	248	62.0	23.0	6.0	1.1	<.05	.03	206.0	12.0	25.0	0.1	0.8	381
	Elkhart 8 North	38	5	32	54	STJ	04/83	7.3	240	65.0	19.0	6.0	1.1	<.05	.02	208.0	12.0	24.0	0.1	0.9	383
	Elkhart 9 North	37	5	5	62	STJ	04/83	7.4	264	74.0	19.0	11.0	1.6	<.05	.03	216.0	22.0	39.0	0.1	0.8	431
	Elkhart 10 North	38	5	32	62	STJ	04/83	7.2	282	78.0	21.0	16.0	1.9	0.11	.07	226.0	30.0	42.0	0.1	0.6	466
	Elkhart A North	38	5	32	44	STJ	04/83	7.4	220	59.0	17.0	5.0	1.3	<.05	<.02	188.0	10.0	24.0	0.2	1.1	347
	Elkhart B North	38	5	32	41	STJ	04/75	7.9	224	51.5	21.0	5.0	2.0	<.1	<0.2	188.0	8.0	26.0	0.2		347
	Elkhart C North	38	5	32	46	STJ	04/83	7.4	234	59.0	21.0	6.0	1.2	<.05	.05	194.0	11.0	27.0	0.1	0.9	363
	Elkhart D North	38	5	32	45	STJ	04/83	7.4	238	65.0	18.0	6.0	1.4	0.63	.13	204.0	12.0	25.0	0.1	0.4	378
	Elkhart E North	38	5	32	44	STJ	05/77	7.5	254	66.0	22.0	10.0	2.0	0.20	.06	206.0	20.0	30.0	0.2	0.3	402
74	USGS Elk 23 s	37	5	2	24	STJ	04/79	7.6	280	78.0	21.0	43.0	1.6	0.04	.04	203.0	93.0	30.0	.	1.6	534
	USGS Elk 23 d	37	5	2	140	STJ	04/79	7.9	230	60.0	20.0	15.0	1.4	2.10	.1	245.0	13.0	1.0	.	.0	406
75	Elkhart Bower 1	37	5	6	67	STJ	04/75	7.8	180	48.0	15.0	13.0	3.0	2.50	.1	158.0	21.0	26.0	0.2	.1	322
	Elkhart Bower 2	37	5	6	68	STJ	04/75	7.8	196	56.0	14.0	10.0	3.0	1.20	.3	164.0	15.0	41.0	0.2	.5	341
	Elkhart Bower 3 (92)	37	5	6	143	STJ	07/85	7.7	220	61.0	16.3	11.0	0.9	0.20	0.3	184.8	38.3	29.2	0.3	<.02	389
76	Elkhart South 1	37	5	17	104	STJ	04/83	7.3	338	98.0	22.0	11.0	2.0	0.96	.19	246.0	27.0	77.0	0.2	0.4	539
	Elkhart South 2	37	5	17	100	STJ	04/83	7.2	402	124.0	22.0	28.0	3.8	1.40	.50	316.0	40.0	100.0	0.1	0.2	706
	Elkhart South 3	37	5	17	102	STJ	04/83	7.3	326	97.0	20.0	16.0	2.2	0.64	.14	256.0	28.0	78.0	0.1	1.7	556
77★	USGS Elk 15 s	35	5	17	24	STJ	06/78	7.5	320	95.0	21.0	27.0	2.2	0.00	0.0	209.0	36.0	40.0	0.0	.17	501
78	USGS Elk 7 s	37	5	19	34	STJ	06/78	7.8	170	48.0	13.0	20.0	1.0	0.09	.01	154.0	30.0	15.0	0.1	.49	318
79	Dunlap School	37	5	26	138	STJ	09/72	7.7	306	80.0	26.0	.		0.56	0.0	231.0	0.0	48.0	0.3		370
80	Earthmovers Inc. (10)	37	5	32	105	NAP	06/85	7.2	393	96.2	36.4	7.9	0.8	1.90	< 0.1	300.9	21.6	116.0	0.3	<.02	655
81	D. Imhoff (11)	36	5	9	71	NAP	06/85	8.4	316	78.2	28.3	8.6	0.7	2.10	0.1	337.1	3.2	11.6	0.5	<.02	553
82	W. Jessup (13)	36	5	11	82	NAP	06/85	8.1	313	85.5	23.9	3.4	0.5	0.80	<0.1	312.7	2.2	28.0	0.4	<.02	533

Location Number	Well Owner	Township (N)	Range (E)	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCO_3$	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Iron (Fe)	Manganese (Mn)	Alkalinity as $CaCO_3$	Chloride (Cl)	Sulfate (SO_4)	Fluoride (F)	Nitrate (NO_3 as N)	Total Dissolved[2] Solids (TDS)
83	M. Loucks (66)	36	5	18	76	NAP	11/86	7.4	323	85.8	26.5	8.5	.5	2.50	0.1	347.1	16.0	< 0.1	0.4	<.02	575
84★	J. Martin (12)	36	5	29	104	NAP	06/85	8.3	214	56.0	17.9	13.9	0.9	0.30	<0.1	270.0	1.1	< 0.1	1.4	<.02	430
85	J. Ramer (68)	35	5	2	58	NAP	06/85	7.3	306	75.7	28.1	9.7	0.8	0.80	<0.1	289.0	11.3	50.4	0.3	<.02	536
86	L. Martin (67)	35	5	8	113	NAP	06/85	6.9	315	72.4	32.2	17.7	1.1	1.20	<0.1	389.0	1.1	<0.1	0.8	.02	611
87	E. Kulp (38)	35	5	13	92	NAP	06/85	7.2	280	68.6	26.0	9.3	0.7	0.80	<0.1	292.0	18.4	0.3	0.6	<.02	489
88	A. Martin (14)	35	5	16	155	NAP	06/85	8.1	310	78.5	27.1	10.4	0.7	1.30	<0.1	354.9	1.6	< 0.1	0.5	<.02	563
89	R. Hahn (16)	35	5	17	185	NAP	06/85	7.9	363	91.7	32.2	7.6	0.6	0.80	<0.1	379.7	1.7	27.6	0.4	<.02	634
90	R. Hahn (15)	35	5	18	140	NAP	06/85	7.9	307	74.5	28.8	12.5	0.7	1.20	<0.1	363.5	1.3	< 0.1	0.7	<.02	572
91★	J. Weaver (85)	35	5	22	52	NAP	06/85	7.3	379	95.6	33.8	7.9	0.8	0.90	<0.1	221.8	19.6	102.0	0.4	<.02	537
92	USGS Elk 41 s	38	6	8	24	STJ	04/79	8.3	140	40.0	10.0	4.0	1.1	0.00	.0	78.0	14.0	27.0	.	8.1	193
	USGS Elk 41 d	38	6	8	214	STJ	04/79	7.6	280	66.0	28.0	6.0	1.1	1.00	1.3	270.0	4.0	13.0	.	.01	448
93	Elk 7 obs	38	6	9	60	STJ	06/81	6.8	290	79.0	22.0	4.0		0.64	.16	180.0	16.0	76.0	0.0	.66	418
94	USGS Elk 38 s	38	6	21	24	STJ	06/78	7.8	300	82.0	24.0	3.0	0.9	0.00	.01	178.0	18.0	32.0	0.0	15.0	405
95	Bristol 1	38	6	27	51	STJ	04/83	7.4	252	71.0	18.0	4.0	0.9	<.05	.02	212.0	7.0	27.0	0.1	1.3	388
	Bristol 2	38	6	27	52	STJ	04/83	7.4	252	68.0	20.0	4.0	0.8	<.05	<.02	212.0	7.0	26.0	0.1	2.1	387
96	USGS Elk 28 s	38	6	27	26	STJ	06/78	7.4	360	100.0	27.0	10.0	1.2	0.05	.01	316.0	13.0	19.0	0.1	5.7	587
97	USGS Elk 29 s	38	6	30	24	STJ	04/79	7.7	190	54.0	14.0	13.0	1.3	0.01	0.0	120.0	37.0	30.0	0.0	4.4	300
98	USGS Elk 26 s	37	6	4	24	STJ	04/79	7.6	210	58.0	15.0	3.0	0.6	0.00		158.0	8.0	23.0	.	5.2	308
	USGS Elk 26 d	37	6	4	256	STJ	04/79	7.5	240	59.0	23.0	33.0	3.3	0.81	.28	276.0	22.0	4.0	.	0.0	474
99★	USGS Elk 14 s	37	6	7	24	STJ	06/78	7.8	180	50.0	13.0	2.0	0.8	0.00	0.0	111.0	14.0	16.0	0.0	0.0	236
100★	USGS Elk 13 s	37	6	15	39	NAT	12/77	6.1	270	72.0	22.0	17.0	1.3	1.10	.09	230.0	7.0	13.0	0.1		414
101	USGS Elk 10 s	37	6	17	44	STJ	04/79	7.9	210	56.0	17.0	3.0	0.8	0.28	.14	171.0	4.0	43.0	.	.01	331
	USGS Elk 10 d	37	6	17	193	STJ	04/79	8.2	250	65.0	21.0	7.0	1.0	1.10	.17	259.0	2.0	2.0	.	.01	416
102	USGS Elk 12 s	37	6	22	55	STJ	12/77	7.0	280	78.0	20.0	15.0	2.3	0.14	.01	250.0	17.0	25.0	0.1		463
103	USGS Elk 11 s	37	6	28	37	STJ	12/77	7.1	350	99.0	24.0	4.0	2.6	3.80	.16	311.0	14.0	11.0	0.1	.01	538
104	G. Wood (70)	37	6	35	58	NAT	06/85	7.2	301	79.6	24.9	4.2	0.5	<.10	<0.1	216.4	36.4	26.7	0.2	11.7	494
105	P. Yoder (69)	36	5	1	27	STJ	06/85	6.0	249	68.1	18.7	5.0	0.6	1.10	<0.1	236.6	1.5	31.2	0.3	<.02	422
106	Goshen 1	36	6	9	165	STJ	01/61	7.7	238	63.0	20.0	6.0	2.0	1.90	.05	246.0	3.0	11.0	0.0	.09	407
	Goshen 1 A	36	6	9	170	STJ	04/83	7.3	332	98.0	21.0	17.0	1.5	1.40	.12	244.0	45.0	67.0	0.1	0.1	549
	Goshen 2	36	6	9	145	STJ	04/83	7.5	234	70.0	15.0	7.0	1.0	2.20	.06	238.0	6.0	<5.0	0.2	0.3	392
	Goshen 3	36	6	9	159	STJ	04/83	7.4	272	74.0	21.0	6.0	1.0	2.30	.06	246.0	13.0	17.0	0.2	0.3	435

Location Number	Well Owner	Township (N)	Range (E)	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCO_3$	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Iron (Fe)	Manganese (Mn)	Alkalinity as $CaCO_3$	Chloride (Cl)	Sulfate (SO_4)	Fluoride (F)	Nitrate (NO_3 as N)	Total Dissolved[2] Solids (TDS)
	Goshen 4	36	6	9	171	STJ	04/83	7.3	288	80.0	21.0	9.0	1.2	1.20	.09	248.0	20.0	29.0	0.7	<.1	465
	Goshen 5	36	6	9	166	STJ	04/83	7.3	294	82.0	22.0	10.0	1.2	1.10	.10	248.0	22.0	34.0	0.1	<.1	475
	Goshen 6	36	6	9	154	STJ	04/83	7.3	298	83.0	22.0	10.0	1.2	1.10	0.1	252.0	24.0	34.0	0.1	<.1	483
	Goshen 7	36	6	9	170	STJ	04/83	7.3	312	92.0	20.0	18.0	1.6	1.60	0.11	252.0	34.0	52.0	0.1	0.3	527
107	Goshen 10 (81)	36	6	15	183	STJ	04/85	7.3	293	85.1	19.2	6.4	0.7	0.60	<0.1	233.9	23.1	51.2	0.3	<.02	478
	Goshen 11	36	6	15	177	STJ	08/63	7.8	282	78.0	21.0	4.0	1.0	1.60	.05	226.0	5.0	54.0	0.1	.1	301
108	R. Hay (82)	36	6	17	62	STJ	06/85	7.4	262	78.3	16.1	4.1	0.8	<0.1	<0.1	197.6	15.6	24.8	0.8	12.1	440
109	Goshen Milk	36	6	15	80	STJ	06/54	7.7	292	83.0	21.0	112.0	1.2	1.30	0.0	223.0	180.0	45.0	0.0	.5	596
110	C. Garber (83)	36	6	22	46	STJ	06/85	7.0	309	91.1	19.1	3.4	6.0	1.20	0.6	236.6	16.7	74.7	0.9	<.02	506
111★	D. Harper (46)	36	6	26	72	STJ	06/85	7.4	316	87.4	23.4	5.5	0.7	0.70	<0.1	282.8	16.2	56.8	0.2	<.02	541
112	Elkhart 4	36	6	35	62	STJ	06/67	7.7	292	79.0	23.0	3.0	2.0	0.78	.05	239.0	4.5	45.0	0.1	.2	315
113	L. Jones (47)	35	6	1	78	STJ	06/85	7.5	289	79.8	21.5	3.2	0.7	0.90	<0.1	279.4	3.5	41.1	0.2	<.02	498
114	Brookview Farms (84)	35	6	5	88	NAP	11/86	7.9	279	71.5	24.5	9.5	0.5	3.00	0.1	303.7	5.3	15.2	0.4	<.02	509
115	N. Maurer (43)	35	6	13	180	NAT	06/85	7.1	270	76.7	18.6	3.9	0.9	0.90	<.1	276.3	4.3	13.8	0.3	<.02	463
116	Hoskins (25)	35	6	21	80	STJ	06/85	8.0	303	84.6	22.2	3.4	0.7	<.1	<0.1	244.0	9.7	45.7	0.2	4.0	486
	Hoskins (26)	35	6	21	234	STJ	06/85	8.8	240	54.8	25.0	116.0	2.4	<.1	<0.1	309.4	11.2	177.0	0.4	<.02	773
117	M. Myers (39)	35	6	32	43	STJ	06/85	7.4	304	84.6	22.0	5.2	0.6	1.00	<0.1	269.8	7.5	45.8	0.3	<.02	503
118	R. Eisenhour (42)	35	6	35	184	NAT	06/85	7.1	266	65.2	25.0	14.9	0.9	0.20	<0.1	308.8	2.7	4.9	0.4	<.02	501
119	D. Murphy (75)	38	7	15	30	STJ	06/85	7.6	195	57.1	12.6	69.7	1.6	0.20	0.1	141.1	135.0	42.2	0.9	<.02	496
120	K. Shaw (93)	38	7	19	52	STJ	07/85	7.7	183	56.5	10.1	30.3	1.3	<0.1	<0.1	148.0	53.8	24.7	0.2	.9	366
121	R. Mauk (73)	38	7	23	44	HOW	06/85	7.6	239	74.1	13.1	5.8	0.5	<0.1	<0.1	200.3	26.4	20.7	0.1	<.02	389
122★	R. Zickafoose (72)	38	7	23	80	NAT	06/85	7.0	274	78.2	19.1	4.2	0.6	0.20	<0.1	274.2	13.8	22.7	0.2	<.02	480
123	Middlebury 3	37	7	10	159	STJ	04/83	7.3	266	67.0	24.0	12.0	1.1	1.30	.08	256.0	8.0	7.0	1.3	<.10	434
	Middlebury 4	37	7	3	158	STJ	03/82	7.6	244	66.0	19.0	13.0	1.1	1.10	.10	254.0	7.0	5.0	1.9	.2	424
124	State Line S&G (71)	37	7	8	215	NAT	06/85	7.1	250	66.6	20.0	6.5	0.7	0.40	0.1	256.8	9.6	12.9	0.3	<.02	438
125	A. Yoder (1)	37	7	21	230	NAT	06/85	7.8	249	65.8	20.4	5.3	0.6	0.40	0.1	289.7	3.2	2.5	0.3	<.02	428
126	A. Miller (175)	37	7	25	50	STJ	07/85	7.4	414	116.1	30.0	9.3	1.5	0.50	<0.1	287.1	25.3	28.3	<.1	13.3	628
127	E. Chupp (52)	36	7	1	130	NAP	06/85	7.1	349	81.2	34.6	9.3	0.7	1.90	<0.1	402.5	2.7	2.4	0.5	<.02	634
128	E. Miller (51)	36	7	2	44	NAP	06/85	7.0	370	98.8	30.0	4.0	0.7	<.10	<0.1	285.8	20.2	50.4	0.5	13.6	619
129	A. Yoder (48)	36	7	16	188	NAP	06/85	7.3	213	55.0	18.2	6.3	0.8	0.20	0.1	249.1	1.6	<0.1	0.3	<.02	394
130	Clinton Frame Mennonite Church (44)	36	7	16	224	NAP	11/86	7.4	216	59.1	16.6	10.3	0.4	<0.10	0.1	240.8	3.2	<0.1	0.3	<.02	393

Location Number	Well Owner	Township (N)	Range (E)	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCO_3$	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Iron (Fe)	Manganese (Mn)	Alkalinity as $CaCO_3$	Chloride (Cl)	Sulfate (SO_4)	Fluoride (F)	Nitrate (NO_3 as N)	Total Dissolved[2] Solids (TDS)
131★	L. Schrock (50)	36	7	22	119	NAP	06/85	7.7	254	64.0	22.2	4.5	0.5	1.50	<0.1	292.1	2.0	1.7	0.2	<.02	462
132	E. Mast (45)	36	7	19	56	NAP	06/85	7.6	274	69.2	24.0	10.1	0.7	1.20	<0.1	323.9	1.4	<0.1	0.4	<.02	510
133	Millersburg 2	36	7	34	153	NAP	09/80	7.4	312	78.0	28.0	6.0	1.0	1.40	.05	300.0	<5.0	15.0	0.3	<0.1	501
	Millersburg 3	36	7	34	142	NAP	09/80	7.5	304	75.0	28.0	6.0	0.9	1.95	0.05	296.0	<5.0	17.0	0.3	<0.1	496
134	W. Whirledge (49)	36	7	35	213	NAP	06/85	7.7	302	76.7	25.6	7.4	0.7	2.90	0.1	328.3	3.1	9.6	0.3	<.02	534
135	G. Showalter (64)	35	7	16	112	NAT	06/85	7.4	299	81.4	22.7	8.5	0.7	1.20	<0.1	263.3	43.5	23.8	0.3	<.02	512
136	T. Hire (113)	35	7	26	24	NAT	07/85	7.3	266	79.3	16.6	6.8	0.6	<.10	<0.1	230.0	10.7	20.2	0.2	7.3	451
	KOSCIUSKO COUNTY																				
137	R. Hoffer (36)	34	5	6	65	NAP	06/85	7.3	356	91.0	31.2	4.3	0.5	0.30	0.2	243.9	17.9	111.0	0.3	<.02	561
138	D. Mikel (35)	34	5	10	102	NAP	06/85	7.0	285	71.6	25.4	11.9	0.9	0.80	<0.1	317.4	2.6	<0.1	0.5	<.02	511
139	J. Gingerick (37)	34	5	11	155	NAP	06/85	7.3	262	65.3	23.5	30.4	1.6	1.40	<0.1	325.0	5.1	13.2	0.4	<.02	547
140	D. McIntire (34)	33	5	1	80	STJ	06/85	6.9	401	117.2	25.9	9.8	0.9	1.00	<0.1	279.0	46.4	97.5	0.5	<.02	644
141	USGS B-116-ID	34	4	4	130	NAT	12/81	7.5	332	82.0	31.0	7.7	1.0	1.20	.06	324.0	5.0	21.0	0.4	.1	280
142	USGS Kos. 9	34	6	5	102	STJ	12/81	7.5	302	82.0	24.0	5.2	1.0	1.10	.08	248.0	11.0	53.0	0.2	.1	340
143	USGS R-101-2	34	6	6	76	STJ	06/81	7.3	200	60.0	12.0	3.0	0.7	0.65	.05	181.0	5.0	25.0	0.2	.1	328
144	Milford 1	34	6	8	52	STJ	07/82	7.5	396	119.0	24.0	8.0	5.8	0.08	.21	300.0	27.0	62.0	0.1	10.7	623
	Milford 2	34	6	8	48	STJ	07/83	7.8	322	106.0	14.0	6.0	1.4	1.30	.10	213.0	20.0	80.0	0.1	.4	489
145	H. Beer (40)	34	6	18	30	STJ	06/85	7.1	302	86.6	20.4	2.7	0.4	1.10	<0.1	235.8	7.8	76.2	0.2	<.02	488
146	H. Miller (41)	34	6	19	147	STJ	06/85	7.6	278	78.8	19.7	3.4	0.6	0.30	<0.1	266.0	2.2	25.1	0.2	<.02	462
147	Maple Leaf Farm (30)	34	6	26	92	NAT	06/85	7.1	417	120.0	28.6	5.0	1.0	<.1	<.1	298.0	18.6	49.4	0.2	20.3	681
	Maple Leaf Farm (31)	34	6	26	210	NAT	06/85	7.3	314	88.0	22.4	2.8	0.6	0.90	<0.1	283.4	4.8	45.8	0.2	<.02	518
148	D. Morgan (33)	34	6	31	36	STJ	06/85	7.3	217	61.0	15.2	7.7	0.6	1.00	<0.1	237.4	1.8	5.7	0.4	<.02	391
149	K. Miller (32)	34	6	34	104	NAT	06/85	7.1	279	75.1	21.9	8.9	0.7	0.70	<0.1	300.1	2.9	11.8	0.4	1.4	503
150	Leesburg Sch. (27)	33	6	8	140	STJ	06/85	7.2	385	110.0	26.4	22.7	1.4	0.50	0.2	285.4	58.2	90.1	2.7	<.02	665
151	C. Zimmerman (28)	33	6	18	130	STJ	06/85	7.5	305	89.0	20.2	6.1	0.5	<0.1	<0.1	265.3	7.9	31.1	0.4	3.0	496
152	D. Longenecker (192)	33	5	13	65	STJ	08/85	7.3	339	94.7	25.0	1.5	0.4	<0.1	<0.1	270.9	3.7	47.3	0.1	1.1	513
153	M. Crow (59)	34	7	4	68	NAT	06/85	7.5	344	90.9	28.2	3.3	0.5	0.70	<0.1	282.8	13.2	78.3	0.7	<.02	567
154	Syracuse 1	34	7	6	112	NAT	10/73	7.7	350	92.0	29.0	9.0	1.0	1.50	.02	316.0	11.0	28.0	0.3	<.1	562

Location Number	Well Owner	Township (N)	Range (E)	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCO_3$	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Iron (Fe)	Manganese (Mn)	Alkalinity as $CaCO_3$	Chloride (Cl)	Sulfate (SO_4)	Fluoride (F)	Nitrate (NO_3 as N)	Total Dissolved[2] Solids (TDS)
154a	Syracuse 2	34	7	6	172	NAT	10/73	8.0	246	59.0	24.0	11.0	2.0	2.30	.02	256.0	4.0	1.0	0.5	0.4	417
154b	Syracuse 3	34	7	6	111	NAT	10/73	7.8	332	89.0	27.0	6.0	1.0	2.20	.04	294.0	7.0	35.0	0.3	<0.1	343
155	M. Yoder (148)	34	7	11	160	NAT	07/85	7.1	284	76.3	22.0	16.5	0.7	1.40	<0.1	296.2	3.0	17.2	0.7	<.02	510
156	H. Gants (87)	34	7	35	85	NAT	06/85	6.6	355	92.3	30.0	8.3	1.0	0.90	<0.1	334.7	2.0	22.9	0.8	<.02	574
313	A. Peterson (86)	34	6	11	100	NAT	06/85	6.5	292	77.9	23.3	5.6	0.7	0.70	<0.1	305.1	3.4	16.8	0.2	<.02	509

LA GRANGE COUNTY

Location Number	Well Owner	Township (N)	Range (E)	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCO_3$	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Iron (Fe)	Manganese (Mn)	Alkalinity as $CaCO_3$	Chloride (Cl)	Sulfate (SO_4)	Fluoride (F)	Nitrate (NO_3 as N)	Total Dissolved[2] Solids (TDS)
157	E. Miller (80)	38	8	21	46	HOW	06/85	7.4	220	59.8	17.1	4.6	0.4	<.10	<0.1	160.0	3.6	28.3	0.3	15.1	382
158	S. Chupp (79)	38	8	25	53	HOW	06/85	7.6	257	73.2	17.7	10.4	0.7	0.30	0.3	285.0	15.1	1.2	0.5	<.02	475
159	Shipshewanna Church of Nazarene	37	8	10	43	HOW	11/86	6.4	329	95.5	22.0	6.5	0.7	<.10	0.1	213.6	31.5	91.6	0.8	<0.02	513
160	Shipshewanna 1	37	8	11	210	HOW	06/79	7.9	250	69.0	19.0	11.0	1.0	3.00	0.15	272.0	<5.0	<5.0	0.4	0.4	444
	Shipshewanna 2	37	8	11	220	HOW	06/79	7.9	242	67.0	18.0	11.0	1.0	1.00	0.17	260.0	<5.0	8.0	0.4	0.3	428
161★	O. Yoder (173)	37	8	15	134	NAT	07/85	7.7	248	72.1	15.5	5.5	0.5	2.10	0.1	228.5	2.5	<.1	0.5	<.02	386
162	S. Weaver (147)	37	8	25	45	NAT	07/85	7.2	289	87.4	16.5	4.0	0.5	1.60	0.1	219.0	7.9	73.3	0.6	<.02	464
312	M. Yoder (174)	37	8	31	92	NAP	07/85	7.5	324	79.7	28.4	6.3	0.6	4.60	0.1	311.8	2.9	<.1	0.5	<.02	513
163	E. Lehman (58)	36	8	7	26	STJ	06/85	7.3	271	74.3	20.4	4.7	0.4	0.50	0.3	257.9	5.4	29.1	0.3	<.02	456
164	A. Beachy (53)	36	8	17	43	STJ	06/85	7.0	321	92.4	18.0	2.8	0.5	8.90	0.3	297.0	3.9	38.6	0.2	<.02	532
165	M. Miller (54)	36	8	14	44	NAT	06/85	7.2	334	90.5	25.7	15.0	0.8	1.30	<0.1	394.7	3.2	3.0	0.7	<.02	633
166	S. Kauffman (55)	36	8	14	102	NAP	06/85	7.7	326	90.4	21.7	3.4	0.7	6.00	<0.1	312.2	14.0	36.8	0.3	<.02	561
167	F. Miller (57)	36	8	28	98	NAT	06/85	7.6	302	89.0	18.8	2.5	0.5	1.60	<0.1	243.8	5.1	66.6	0.2	<.02	487
168	L. Eash (56)	36	8	33	91	NAT	06/85	7.4	317	97.3	15.0	4.8	0.5	6.60	0.1	312.2	2.9	36.6	0.2	<.02	554
169★	D. Phillips (101)	38	9	25	62	HOW	07/85	7.3	248	73.5	15.5	2.3	0.6	0.30	<0.1	210.3	20.3	41.1	0.3	<.02	414
170★	C. Troyer (94)	38	9	34	177	HOW	07/85	7.9	174	67.0	1.0	9.2	0.8	2.00	.02	264.0	7.0	5.0	0.2	.2	414
171★	C. Troyer (100)	38	9	34	255	HOW	07/85	7.2	250	70.6	17.0	10.1	0.7	2.00	<0.1	278.5	23.6	3.2	0.4	<.02	474
314	LaGrange obs. 3	38	9	36	40	HOW	06/81	7.2	300	89.0	20.0	4.7	1.3	0.89	.12	200.0	12.0	82.0	0.1	.49	455

Location Number	Well Owner	Township (N)	Range (E)	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCO_3$	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Iron (Fe)	Manganese (Mn)	Alkalinity as $CaCO_3$	Chloride (Cl)	Sulfate (SO_4)	Fluoride (F)	Nitrate (NO_3 as N)	Total Dissolved[2] Solids (TDS)
172	M. Burgi (102)	37	9	2	39	HOW	07/85	7.6	308	91.7	17.7	7.2	0.6	3.20	0.1	271.6	10.3	34.5	0.3	<.02	503
173	Sandy Lane Farm (78)	37	9	7	50	HOW	06/85	7.5	317	93.2	20.3	3.0	0.6	0.60	<0.1	247.3	15.0	77.2	0.5	<.02	517
174	M. Atwater (77)	37	9	17	81	HOW	06/85	7.5	332	96.2	21.8	3.6	0.6	1.00	0.4	276.9	9.2	64.9	1.2	<.02	544
175	Lambrights's Inc. (95)	37	9	27	59	NAT	07/85	7.5	370	103.0	27.4	5.5	0.6	0.30	<0.1	209.3	22.0	148.0	0.2	<.02	568
176	P. Yoder (99)	36	9	6	104	NAT	07/85	7.2	284	82.3	18.5	4.8	0.5	1.40	<0.1	292.9	12.7	9.1	0.4	<.02	496
177	Y. Lehman (91)	36	9	7	57	NAT	06/85	7.4	266	76.3	18.0	5.9	0.5	0.90	<0.1	276.9	1.8	2.3	0.6	<.02	453
178	M. Hershberger (97)	36	9	10	31	NAT	07/85	7.1	362	104.0	24.8	2.9	0.6	<.10	<0.1	243.9	26.8	52.1	0.3	8.2	550
179★	L. Byler (96)	36	9	12	75	NAT	07/85	7.5	278	70.9	23.9	14.6	0.7	1.30	0.1	329.6	12.6	<0.1	0.8	<.02	538
180	G. Beachy (98)	36	9	16	93	NAT	07/85	7.3	284	78.1	20.7	8.0	0.6	2.10	<0.1	317.9	1.5	1.5	0.6	<.02	513
181	G. Yoder (176)	36	9	18	61	NAT	07/85	7.5	274	70.5	23.1	9.9	0.50	1.60	<0.1	271.4	11.5	31.4	0.6	<.02	488
182	Topeka 1	36	9	31	29	NAT	01/85	7.5	280	78.0	21.0	4.0	3.0	0.00	0.0	242.0	5.0	19.0	0.0	3.3	278
	Topeka 3	36	9	31	105	NAT	06/79	7.5	400	110.0	30.0	3.0	1.1	1.50	.04	328.0	7.0	78.0	0.2	<.1	428
	Topeka 4	36	9	31	107	NAT	06/79	7.6	381	106.0	28.0	2.0	1.0	1.10	.04	322.0	<5.0	62.0	0.2	<.1	394
183	Toll Rd. 5A S.A. 7	38	10	13	108	HOW	11/73	7.8	270	78.0	18.0	5.0	0.8	1.40	.08	250.0	4.0	21.0	0.2	.3	279
184	USGS Howe B-45-1	38	10	19	128	HOW	12/81	7.5	292	85.0	19.0	3.4	0.8	0.23	.23	224.0	7.0	69.0	0.1	.1	310
185	USGS Howe B-45-4	38	10	21	148	HOW	12/81	7.5	280	80.0	19.0	7.2	1.3	0.88	.16	232.0	8.0	45.0	0.2	.1	300
186	USGS Howe B-5-10	38	10	22	152	HOW	12/81	7.4	312	86.0	23.0	3.4	1.0	0.83	.10	240.0	11.0	59.0	0.2	.1	250
187	FBI Farms (201)	38	10	23	65	HOW	08/85	7.4	330	94.4	22.8	1.7	0.6	0.30	0.1	234.6	10.4	67.5	<0.1	<.02	489
188	USGS Howe B-49-1	38	10	36	83	HOW	12/81	7.4	276	77.0	20.0	11.0	1.0	0.18	.15	268.0	5.0	32.0	0.1	.1	330
189	Curtis Creek (202)	37	10	2	n.a.	HOW	08/85	7.3	320	89.6	23.2	4.5	0.6	0.10	0.1	292.0	5.4	24.2	<0.10	<.02	511
	Curtis Creek 1	37	10	2	77	HOW	05/76	7.4	303	82.0	24.0	8.0	1.0	1.80	.07	279.0	5.0	24.0	0.3	<.1	313
	Curtis Creek 3	37	10	2	66	HOW	04/80	7.4	294	81.0	22.0	8.0	1.0	1.90	.06	288.0	8.0	22.0	0.3	<.1	250
	Curtis Creek old well	37	10	2	73	HOW	05/76	8.0	308	86.0	22.0	11.0	<1.0	1.80	.09	282.0	14.0	22.0		<.1	370
190★	A. Hochstetler (120)	37	10	10	93	NAT	07/85	7.4	268	75.2	19.5	4.4	0.6	0.20	<0.1	246.0	11.7	45.3	0.8	<.02	465
191	LaGrange 2	37	10	19	120	NAT	10/76	7.4	272	75.0	20.0	9.0	1.0	3.10	.06	274.0	9.0	5.0	0.3	<.1	287
192	LaGrange 3	37	10	19	110	NAT	10/76	7.6	264	74.0	19.0	7.0	1.0	1.40	.19	270.0	6.0	2.0	0.3	<.1	274
193	Earnest Miller (181)	37	10	28	81	NAT	07/85	7.2	392	111.6	26.9	11.8	0.9	1.30	0.2	373.3	38.2	22.5	<.1	<.02	676
194	R. Ackerman (111)	36	10	2	148	KEN	07/85	7.0	262	74.1	17.4	8.3	0.6	2.90	0.1	300.3	1.2	<0.1	0.5	<.02	480
195	E. Bontrager (150)	36	10	5	252	NAT	07/85	7.1	266	72.0	20.0	13.8	0.8	2.30	<0.1	295.2	1.4	<0.1	0.7	<.02	482
196	LaGrange Animal Shelter (149)	36	10	7	54	NAT	07/85	7.0	356	99.3	24.9	7.1	0.5	2.90	0.1	286.2	6.3	87.0	0.4	<.02	586

Location Number	Well Owner	Township (N)	Range (E)	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCO_3$	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Iron (Fe)	Manganese (Mn)	Alkalinity as $CaCO_3$	Chloride (Cl)	Sulfate (SO_4)	Fluoride (F)	Nitrate (NO_3 as N)	Total Dissolved[2] Solids (TDS)
197	J. Gaff (119)	36	10	23	183	KEN	07/85	7.2	289	83.8	18.0	3.3	0.5	3.30	< 0.1	265.7	2.5	35.7	0.6	<.02	479
198	Wolcottville 2	36	10	34	86	NAT	10/77	7.1	292	82.0	21.0	5.0	<1.0	1.80	.06	276.0	4.0	13.0	0.5	<.1	469
	Wolcottville 3	36	10	34	92	NAT	10/77	7.2	296	82.0	22.0	5.0	1.0	1.50	.07	281.0	.	13.0	0.5	0.8	469
	Wolcottville 5	36	10	34	86	NAT	03/66	7.0	292	82.0	21.0	7.0	2.0	3.10	.05	297.0	3.0	11.0	0.4	0.4	308
199	USGS Howe B-44-1	38	11	15	109	HOW	12/81	7.5	292	81.0	22.0	5.8	0.9	1.10	.11	284.0	5.0	20.0	0.2	0.1	200
200	R. Miller (103)	38	11	28	69	HOW	07/85	6.1	310	89.6	21.0	2.3	0.4	0.10	< 0.1	251.3	15.7	17.0	0.2	11.9	511
201	USGS Howe B-13-2	38	11	30	164	HOW	12/81	7.5	281	78.0	21.0	6.4	1.0	0.80	.19	284.0	5.0	17.0	0.2	0.1	190
202	Pigeon R. Creek Inn Station	37	11	9	51	HOW	08/79	7.5	264	72.0	20.0	4.0	0.7	2.20	.11	246.0	5.0	25.0	0.2	0.2	273
203★	J. Flint (195)	37	11	14	124	HOW	08/85	7.3	255	67.9	20.3	8.9	0.7	1.40	< 0.1	296.1	1.9	6.8	0.7	<.02	479
204	R. Hall (104)	37	11	17	62	HOW	11/86	7.6	309	93.1	18.7	42.7	1.0	<0.10	.0	264.0	76.6	29.3	0.3	5.87	614
205	P. Herman (199)	37	11	28	76	HOW	08/85	7.3	302	83.0	22.3	2.9	0.5	1.70	<0.1	283.0	1.6	28.4	0.3	<.02	494
206	G. Bolen (105)	37	11	31	76	KEN	07/85	7.2	289	81.7	19.8	3.1	0.5	1.70	<0.1	272.1	5.7	42.3	0.3	<.02	494
207	A. Hutchen	36	11	15	28	KEN	08/63	7.3	308	84.0	24.0	2.1	0.9	0.59	.08	272.0	4.0	40.0	0.1	0.1	331
208	H.D. Kaough	36	11	15	90	KEN	07/63	7.4	330	91.0	25.0	3.4	1.1	1.50	.04	307.0	2.0	30.0	0.4	1.3	358
209	P. Iammarino (106)	36	11	16	190	KEN	07/85	7.4	271	71.8	20.0	5.6	0.7	5.00	< 0.1	303.0	0.7	7.2	0.6	<.02	490
210	R. Wolheater (107)	36	11	16	43	KEN	07/85	7.0	385	109.0	27.4	27.3	1.2	0.10	< 0.1	291.8	87.1	40.1	0.3	7.2	685
211	Lyall Elect. (144)	36	11	29	125	KEN	07/85	7.4	359	99.3	25.6	4.4	0.7	3.10	0.1	315.3	3.9	52.1	0.6	<.02	582
212★	T. Mahan (152)	36	11	35	128	KEN	07/85	7.6	216	43.6	25.3	18.9	1.0	1.80	< 0.1	279.7	11.5	2.5	1.4	<.02	467

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Location Number	Well Owner	Township (N)	Range (E)	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCO_3$	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Iron (Fe)	Manganese (Mn)	Alkalinity as $CaCO_3$	Chloride (Cl)	Sulfate (SO_4)	Fluoride (F)	Nitrate (NO_3 as N)	Total Dissolved[2] Solids (TDS)
213	J. Miller (90)	35	8	2	32	TOP	06/85	7.2	427	126.5	26.9	12.9	39.6	0.10	<0.1	306.5	28.5	63.1	0.5	30.3	810
214	E. Moser (178)	35	8	6	182	NAT	07/85	7.3	310	86.4	22.3	4.8	0.5	1.00	0.5	317.3	6.4	8.4	0.3	<.02	526
215	J. Yoder (112)	35	8	7	25	NAT	07/85	6.3	327	98.8	19.1	2.9	0.8	0.50	0.2	244.4	13.8	63.7	0.2	4.5	521
216	E. Peterson (177)	35	8	10	137	TOP	07/85	7.4	350	100.5	23.9	2.2	0.5	0.20	0.2	259.8	24.9	78.0	<.1	<.02	553
217	Monsanto Co. (60)	35	8	21	99	NAT	06/85	7.5	329	92.7	23.5	3.7	0.8	0.60	<0.1	297.5	5.8	58.6	0.4	<.02	555
218	Ligonier 1	35	8	22	130	NAT	05/77	7.8	360	99.0	27.0	4.0	1.0	1.30	.05	300.0	6.0	48.0	0.6	< 0.1	367
	Ligonier 2	35	8	22	120	NAT	02/74	7.3	362	99.0	28.0	3.0	1.0	1.70	.05	296.0	3.0	61.0	0.2	< 0.1	558
219	R. Murphy (61)	35	8	26	91	NAT	06/85	7.3	308	85.8	22.2	6.7	0.6	1.40	<0.1	305.8	10.4	27.8	0.4	<.02	530

Location Number	Well Owner	Township (N)	Range (E)	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCO_3$	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Iron (Fe)	Manganese (Mn)	Alkalinity as $CaCO_3$	Chloride (Cl)	Sulfate (SO_4)	Fluoride (F)	Nitrate (NO_3 as N)	Total Dissolved[2] Solids (TDS)
220	G. Guyos (62)	35	8	28	87	NAT	06/85	7.3	364	104.0	25.2	5.8	2.6	0.40	0.1	268.7	29.2	96.4	0.2	<.02	595
221★	M. Moser (63)	35	8	30	62	NAT	06/85	7.3	284	81.0	19.4	3.5	0.7	0.90	<0.1	248.2	12.5	57.0	0.3	<.02	484
222	T. Wigent (89)	35	8	36	85	NAT	06/85	7.0	380	107.5	26.9	4.1	1.0	0.70	<0.1	274.2	27.5	91.2	0.4	<.02	598
223#	W. Noble School 1	34	8	3	115	NAT	09/84	7.5	.	.	.	3.0		5.40	.06	256.0	.	67.0	.	.	.
#	W. Noble School 2	34	8	3	127	NAT	06/75	7.4	330	.	.	.		0.25	<.1	270.0	4.0	.	.		313
#	W. Noble School	34	8	3	132	NAT	06/75	7.4	335	.	.			1.87	<.1	255.0	4.0	.	.		306
224	H. Alfrey (179)	34	8	5	148	STJ	07/85	7.4	298	83.6	21.2	4.5	0.5	1.40	<0.1	298.7	6.2	9.0	0.3	<.02	499
225	H. Alfrey (180)	34	8	5	75	STJ	07/85	7.2	397	112.1	27.6	4.6	0.6	2.00	0.1	291.1	12.4	111.0	<.1	.6	634
226	Cromwell 1	34	8	16	112	NAT	06/79	7.6	316	88.0	23.0	3.0	0.8	2.50	.06	286.0	<5.0	44.0	0.3	<.1	337
	Cromwell 2	34	8	16	118	NAT	06/79	7.6	322	90.0	24.0	3.0	0.8	2.30	.05	276.0	<5.0	55.0	0.3	.1	346
227	R. Reasoner (88)	34	8	26	82	NAT	06/85	6.8	371	107.0	21.3	3.4	0.8	8.80	0.2	295.7	4.9	75.0	0.6	<.02	590
228	NIPSCO (125)	35	9	2	43	NAT	07/85	7.3	312	90.6	19.8	5.1	0.4	2.20	<0.1	227.2	14.3	94.1	0.5	<.02	510
229	M. Kendall (118)	35	9	13	95	NAT	07/85	7.5	217	60.5	15.4	11.8	0.7	1.60	<0.1	255.6	1.4	<.1	0.8	<.02	413
230	Wawaka Church (187)	35	9	27	26	NAT	08/85	7.4	309	86.3	22.2	4.4	0.5	1.40	<0.1	271.4	4.2	40.6	0.4	<.02	499
231	J. Rosenogle (186)	35	9	33	90	NAT	08/85	7.4	255	68.3	19.9	7.8	0.5	1.20	<0.1	268.9	2.5	2.7	0.7	<.02	442
232	W. Phares (185)	34	9	6	205	NAT	08/85	7.2	289	78.4	22.2	8.7	0.7	0.90	<0.1	312.3	4.0	2.2	0.4	<.02	508
233	E. Peffer (114)	34	9	10	64	NAT	07/85	7.3	315	86.2	22.7	7.0	0.8	3.60	<0.1	265.7	6.8	60.9	0.5	<.02	519
234	H. Koenig (191)	34	9	12	131	NAT	08/85	7.4	340	96.0	23.6	3.0	0.7	1.80	0.1	266.4	7.9	60.0	0.2	<.02	525
235	M. Richman (115)	34	9	14	123	NAT	07/85	7.2	372	103.5	25.9	3.9	0.7	3.90	<0.1	296.6	9.5	86.1	0.4	<.02	603
236	J. Marsh (142)	34	9	19	147	NAT	07/85	7.2	333	95.3	22.2	2.7	0.8	2.00	0.1	267.8	4.5	56.8	0.3	<.02	515
237	Albion 1	34	9	24	98	NAT	10/77	7.2	326	82.0	29.0	11.0	2.0	2.10	.02	302.0	6.0	24.0	0.9	.2	338
	Albion 2	34	9	24	110	NAT	10/77	7.3	274	70.0	24.0	18.0	2.0	1.70	.04	298.0	<.1	4.0	1.0	.3	300
238	J. Steffe (141)	34	9	31	68	STJ	07/85	7.2	388	110.0	26.8	10.6	1.2	1.90	<0.1	317.3	15.0	100.0	0.2	<.02	658
239	T. Bortner (188)	34	9	33	66	NAT	08/85	7.2	356	98.8	25.5	2.6	0.9	2.20	<0.1	310.8	4.3	41.8	0.5	<.02	564
240	H. Staller (189)	34	9	34	45	NAT	08/85	7.0	513	141.7	36.6	4.5	0.8	4.60	0.2	374.3	13.6	117.0	0.3	<.02	784
241	J. Carson (140)	33	9	9	80	STJ	07/85	7.1	407	117.0	25.6	28.2	2.6	5.40	0.2	337.4	73.8	62.2	0.3	<.02	732
242-	Cp. Lutherhaven (190)	33	9	11	94/117	STJ	08/85	7.6	260	58.5	27.3	18.0	1.3	0.80	<0.1	296.1	3.2	5.2	1.2	<.02	491
243	M. Rowland (138)	33	9	12	48	NAT	07/85	7.0	344	104.0	18.6	2.0	0.7	4.30	0.2	340.9	2.7	41.5	0.5	<.02	595
244★	C. Shively (139)	33	9	21	176	NAT	07/85	7.5	243	65.8	18.5	7.2	0.7	1.40	<0.1	289.3	0.7	<0.1	0.8	<.02	458
245	B. Parks (151)	35	10	1	63	KEN	07/85	7.1	369	102.9	26.1	3.4	0.7	2.50	0.2	275.2	10.0	71.9	0.3	<.02	559
246	Fidler Inc. (109)	35	10	3	190	NAT	07/85	7.1	273	78.6	18.4	3.4	2.6	0.40	<0.1	278.0	1.3	22.5	0.5	<.02	472

Location Number	Well Owner	Township (N)	Range (E)	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCO_3$	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Iron (Fe)	Manganese (Mn)	Alkalinity as $CaCO_3$	Chloride (Cl)	Sulfate (SO_4)	Fluoride (F)	Nitrate (NO_3 as N)	Total Dissolved[2] Solids (TDS)
247	J. McCormick (110)	35	10	5	131	NAT	07/85	7.2	278	77.5	19.4	5.5	0.7	2.40	<0.1	306.7	0.7	< 0.1	0.6	<.02	490
248	J. Bidwell (193)	35	10	8	129	NAT	08/85	7.5	275	77.5	19.1	2.5	0.5	1.60	<0.1	250.2	1.1	26.6	0.2	<.02	442
249	Gene Stratton Porter	35	10	22	30	KEN	11/79	7.6	288	74.0	25.0	9.0	1.2	6.30	.05	284.0	3.0	9.0	0.6	0.2	475
250	Sharon Ranly (197)	35	10	23	51	KEN	08/85	7.3	300	84.0	21.4	1.4	0.7	1.10	0.1	262.8	1.4	30.8	<.1	<.02	468
251	R. Wysong (194)	35	10	25	87	KEN	08/85	7.3	337	89.4	25.7	4.4	0.8	4.20	<0.1	318.2	2.1	27.0	0.6	<.02	552
252	F. Weber (117)	35	10	29	50	NAT	07/85	7.3	286	86.4	15.9	2.6	1.2	2.70	0.1	222.6	8.6	60.2	0.3	<.02	452
253	Max Bruce	35	10	29	64	NAT	12/79	6.9	434	124.0	30.0	10.0	2.0	8.80	.31	352.0	23.0	69.0	0.1	0.1	478
254-	Lyall Elec. Co. (126)	35	10	35	138/125	KEN	07/85	7.3	291	78.0	22.4	7.5	0.8	2.40	<0.1	314.6	2.4	13.3	0.8	<.02	521
255	T. Trowbridge (128)	34	10	1	75	KEN	07/85	7.1	423	120.0	28.5	5.3	0.8	3.10	0.2	310.7	7.9	117.0	0.3	<.02	668
256	R. Bauman (127)	34	10	2	115	KEN	07/85	7.1	443	125.3	30.2	3.6	0.8	3.00	0.1	314.6	9.6	134.0	0.4	<.02	696
257	Larry Ober (116)	34	10	8	105	NAT	07/85	7.4	307	76.9	26.8	10.1	1.0	2.50	<0.1	328.0	1.5	10.4	1.0	<.02	543
258	James Shrock (132)	34	10	16	80	KEN	07/85	7.1	358	104.0	21.4	8.0	0.8	5.80	<0.1	319.9	5.0	70.9	0.7	<.02	617
259★	A. Bauman (133)	34	10	13	212	KEN	07/85	7.6	180	42.9	17.0	42.1	0.8	1.40	<0.1	299.3	2.6	<.1	1.2	<.02	479
260★	B. Bower (130)	34	10	28	150	KEN	07/85	7.6	191	50.0	15.5	20.5	0.7	1.50	<0.1	288.4	1.1	5.8	1.0	<.02	457
261★	H. Hickman (137)	34	10	32	112	NAT	07/85	7.3	335	74.0	35.0	12.6	1.3	2.30	<0.1	402.9	0.8	12.0	1.2	<.02	642
262★	R. Foster (131)	34	10	35	240	KEN	07/85	7.8	213	50.5	20.1	21.8	0.9	2.40	<0.1	292.4	0.8	<.1	1.2	<.02	463
263	Chain-O-Lakes Saddle Barn	33	10	5	75	NAT	10/78	7.4	296	68.0	31.0	18.0	2.0	0.50	0.2	316.0	1.0	8.0	1.1	0.1	516
264	Chain-O-Lakes Norman Lake	33	10	6	98	NAT	10/78	7.3	260	65.0	24.0	17.0	2.0	1.70	.02	284.0	2.0	9.0	1.0	0.1	291
265	Chain-O-Lakes Campground	33	10	9	175	KEN	10/78	7.2	414	118.0	28.0	3.0	1.0	3.20	.05	312.0	4.0	92.0	0.4	0.1	437
315	USGS obs 8	33	10	9	149	KEN	06/67	7.7	359	101.0	26.0	3.3	1.2	1.70	0.0	297.0	3.0	61.0	0.4	0.2	392
266	C. Rensberger (108)	35	11	8	90	KEN	07/85	7.2	284	76.0	21.9	9.5	0.9	2.30	<0.1	299.3	6.0	12.3	0.8	<.02	504
267	D. DeGroff (196)	35	11	15	95	KEN	08/85	7.0	445	122.3	33.6	1.6	0.8	0.60	0.1	341.4	5.5	94.7	<.1	<.02	681
268★	R. Burkley (135)	35	11	20	320	KEN	07/85	7.5	252	67.3	19.7	9.5	0.8	1.40	<0.1	298.5	0.8	5.0	1.0	<.02	480
269★	W. Sexton (136)	35	11	28	215	KEN	07/85	7.2	262	71.1	19.4	11.2	0.9	2.40	<0.1	314.6	0.7	5.1	0.9	<.02	506
270	R. Muesing (143)	35	11	27	116	KEN	07/85	7.6	347	94.0	25.3	5.6	0.7	4.10	0.1	320.8	2.2	44.3	0.7	<.02	577
271+	R. Strater (129)	35	11	30	118	KEN	07/85	7.2	3	0.7	0.4	149.7	0.4	<0.10	<0.1	313.8	1.0	33.0	0.5	<.02	576
272	Kendallville 6	35	11	34	215	KEN	06/82	7.6	316	87.0	24.0	6.0	1	1.70	0.0	313.0	2.0	7.0	0.3	0	511
273	H. Walburn (134)	34	11	8	112	KEN	07/85	7.5	300	76.2	25.6	8.0	0.9	2.30	<0.1	296.3	1.5	21.3	1.1	<.02	508
274	W. Short (184)	34	11	10	260	KEN	07/85	7.5	274	70.2	23.7	16.9	0.8	0.70	0.1	318.8	3.5	1.2	0.8	<.02	517

Location Number	Well Owner	Township (N)	Range (E)	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCO_3$	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Iron (Fe)	Manganese (Mn)	Alkalinity as $CaCO_3$	Chloride (Cl)	Sulfate (SO_4)	Fluoride (F)	Nitrate (NO_3 as N)	Total Dissolved[2] Solids (TDS)
	STEUBEN COUNTY																				
275#	Fawn River Hatchery	38	12	20	108	HOW	10/77	7.5	294	.	.	7.0		1.00	0.14	280.0	4.0	17.0	0.3	<.1	360
276	Orland 2 (198)	38	12	29	97	HOW	08/85	7.4	283	81.9	18.7	2.2	0.5	0.90	0.2	245.2	4.5	36.1	<.1	<.02	451
277	H. Smith (121)	37	12	33	123	KEN	07/85	7.2	322	91.8	22.4	4.5	0.7	0.20	<0.1	270.9	9.1	57.0	0.7	1.5	530
278	T. Gose (122)	36	12	6	100	KEN	07/85	7.3	372	99.0	28.9	4.2	1.0	3.20	<0.1	331.2	2.4	71.8	0.8	<.02	623
279	A. Perrine (123)	36	12	7	238	KEN	07/85	7.7	287	71.8	22.7	12.7	0.9	8.00	<0.1	318.1	4.7	2.0	0.8	<.02	522
280	F. Walter (169)	36	12	11	160	KEN	07/85	7.2	304	71.4	29.8	16.6	1.0	2.00	<0.1	341.9	3.9	9.8	1.4	<.02	566
281	S. Ringler (170)	36	12	14	79	KEN	07/85	7.1	408	106.3	32.6	7.5	0.8	4.60	0.1	345.4	21.8	60.3	0.9	<.02	665
282	E.R. Oetling (183)	36	12	20	148	KEN	07/85	7.4	294	78.8	23.3	7.8	0.7	0.80	<0.1	305.7	2.7	4.5	0.6	<.02	502
283	G. Anderson (124)	36	12	29	292	KEN	07/85	7.4	276	74.0	21.5	7.8	0.8	1.60	<0.1	306.8	1.5	7.7	0.8	<.02	499
284	R. Lochamire (145)	36	12	33	114	KEN	07/85	7.3	345	92.9	26.0	6.5	0.7	3.00	<0.1	344.9	3.1	38.3	0.6	<.02	601
285	J. Flaugh (146)	36	12	33	70	KEN	07/85	7.6	272	73.5	20.8	7.8	0.6	1.70	0.1	282.7	1.7	2.4	0.7	<.02	464
286	C. Tompkins (172)	36	12	36	93	KEN	07/85	7.3	272	67.5	24.4	10.4	0.8	1.80	<0.1	282.2	4.7	26.3	1.0	<.02	492
287	Pokagon Boys Camp	38	13	33	150	HOW	08/79	7.5	298	78.0	25.0	7.0	1.1	1.50	.11	300.0	5.0	12.0	0.4	0.3	497
288	Pokagon Shelter Area	38	13	33	60	HOW	08/79	7.5	295	78.0	24.0	9.0	1.2	1.30	.10	296.0	5.0	11.0	0.4	0.3	492
289	Pokagon-Potawatomi Inn South	38	13	34	87	HOW	11/83	7.6	339	94.0	26.0	8.0	1.4	2.00	.06	287.0	24.0	23.0	0.3	3.2	545
	Pokagon-Potawatomi Inn Old	38	13	34	80	HOW	11/83	7.4	313	82.0	26.0	8.0	2.0	2.00	.05	294.0	15.0	23.0	0.2	0.2	517
290	Roy Reed (162)	37	13	19	99	HOW	07/85	7.4	244	68.2	16.9	2.7	0.5	2.20	<0.1	225.1	9.7	27.6	0.6	<.02	409
291	Angola 3	37	13	26	149	KEN	01/75	7.7	370	99.0	30.0	7.0	2.0	2.30	.1	328.0	8.0	40.0	0.6	0.1	589
	#Angola 6	37	13	26	130	KEN	01/48	7.7	.	.	.	.		2.00	0.0	296.0	.	.	0.3	0.0	.
	Angola 7	37	13	26	143	KEN	04/54	7.5	433	109.0	39.0	9.0	1.0	1.30	.1	340.0	18.0	79.0	0.3	0.0	460
	Angola 8	37	13	26	145	KEN	03/74	7.4	338	96.0	24.0	26.0	3.0	0.92	.24	306.0	32.0	33.0	0.6	<.1	589
	Angola 9 (200)	37	13	26	111	KEN	08/85	6.9	576	157.5	42.4	14.1	2.2	4.70	0.2	398.3	56.8	128.0	0.3	<.02	899
292	N. Brady (163)	36	13	4	120	KEN	07/85	7.2	308	80.8	24.6	8.1	0.8	2.40	<0.1	316.3	12.5	21.0	0.9	<.02	547
293★	Favorite Farms (166)	36	13	8	93	KEN	07/85	7.0	29	6.4	3.1	186.1	2.4	0.20	<0.1	319.3	29.5	139.0	0.2	<.02	761
	Favorite Farms (167)	36	13	8	70	KEN	07/85	7.0	463	133.0	30.5	7.2	1.2	2.70	0.2	333.3	25.5	144.0	<.1	<.02	755
294	H. Hinen (168)	36	13	8	235	HOW	07/85	7.3	288	72.3	24.9	19.4	0.9	3.00	0.1	309.8	18.6	6.6	0.7	<.02	535

Location Number	Well Owner	Township (N)	Range (E)	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCO_3$	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Iron (Fe)	Manganese (Mn)	Alkalinity as $CaCO_3$	Chloride (Cl)	Sulfate (SO_4)	Fluoride (F)	Nitrate (NO_3 as N)	Total Dissolved[2] Solids (TDS)
295	L. Gilbert (164)	36	13	15	115	HOW	07/85	6.9	436	131.2	24.9	13.9	2.2	2.90	0.2	305.3	35.2	121.0	0.3	<.02	708
296	F. Murden (165)	36	13	29	135	KEN	07/85	7.2	303	79.4	23.9	8.1	0.7	3.40	< 0.1	307.3	12.6	8.4	0.6	<.02	521
297	B. Kuckuck (171)	36	13	30	84	KEN	07/85	7.1	389	93.7	36.0	10.5	1.1	4.00	< 0.1	382.0	15.6	20.4	0.9	<.02	661
298	Ashley 1	35	13	6	120	KEN	04/79	7.4	356	98.0	27.0	8.0	2.0	8.50	.11	300.0	13.0	52.0	0.6	<0.1	575
299	Ashley 2	36	13	31	138	KEN	04/79	7.5	306	84.0	23.0	6.0	1.0	4.30	0.04	304.0	4.0	12.0	0.4	<0.1	506
300	L. Penner (153)	38	14	13	93	KEN	07/85	8.9	249	67.4	19.0	12.5	0.7	1.20	0.5	289.2	13.3	0.6	0.7	<.02	478
301	Steve Gard (160)	38	14	19	192	KEN	07/85	7.1	331	91.7	24.4	5.9	0.8	0.30	0.4	335.8	19.8	9.6	0.4	<.02	572
302	D. Schaeffer (182)	38	14	19	107	KEN	07/85	7.3	340	94.6	24.9	3.2	0.7	0.30	0.5	326.9	8.0	23.8	.1	<.02	562
303★	D. Becher (159)	38	14	27	52	KEN	07/85	7.2	362	102.7	23.5	2.2	0.6	4.90	0.1	279.2	21.4	78.3	0.4	<.02	579
304	Fremont 1	38	14	28	110	KEN	02/58	7.5	524	141.0	42.0	34.0	6.0	0.50	0.1	398.0	68.0	118.0	0.0	0.3	649
	Fremont 2	38	14	28	110	KEN	03/66	6.8	556	158.0	39.9	88.0	5.0	1.40	.1	385.0	194.0	75.0	0.0	.2	791
305	Fremont Sewage Treatment	38	14	30	160	KEN	04/82	8.1	394	125.0	20.0	27.0	2.3	0.07	0.04	297.0	75.0	46.0	0.2	1.4	660
306	IN Toll Rd. Ser. 8	38	14	30	51	KEN	11/73	7.8	442	122.0	33.0	21.0	3.0	0.20	0.06	342.0	60.0	58.0	0.2	<.1	714
307★	D. Smith (158)	38	14	32	93	KEN	07/85	7.5	221	43.2	27.1	19.7	1.3	1.00	<0.1	297.2	10.0	6.0	1.6	<.02	503
308	D. Nedele (157)	37	14	4	77	KEN	07/85	7.2	381	107.1	26.2	6.3	0.6	3.30	0.1	298.2	25.1	79.3	0.6	<.02	620
309	B. Shultz (156)	37	14	18	117	KEN	07/85	7.4	259	54.9	28.9	17.7	1.0	1.70	<0.1	296.2	11.2	7.0	1.7	<.02	507
310★	P. Gordon (154)	37	14	27	185	KEN	07/85	7.5	219	49.9	22.4	27.3	1.0	1.00	<0.1	273.7	27.7	1.9	1.1	<.02	477
311	R. Condon (155)	37	14	30	60	KEN	07/85	7.0	425	115.1	31.7	4.6	1.1	3.60	0.2	346.4	21.5	79.6	0.7	< .02	688

Appendix 15. Recommended water quality standards and remarks for selected chemical constituents

Constituent	U.S. EPA's Recommended concentration limit, mg/l	Remarks
Total Dissolved Solids (TDS)	500[1]	Water with concentrations greater than 500 mg/l may have a disagreeable taste. High values (>1000 mg/l) my accelerate corrosion of well screens, pumps and casings and cause foaming and scaling in boilers.
Iron (Fe)	.3[1]	Concentrations exceeding .3 mg/l cause staining of laundry, utensils and fixtures and may impart a metallic taste. Values above .5 mg/l may cause well screens to become encrusted. Large quantities stimulate the growth of iron bacteria.
Manganese (Mn)	.05[1]	Manganese and iron have similar characteristics. Concentrations above .2 mg/l discolors food during cooking and stains laundry utensils and fixtures black. Food and water my have a metallic taste at amounts above .5 mg/l. Amounts as low as .1 mg/l stimulate growth of certain bacteria. Mn tends to precipitate at concentratins above .05 mg/l and may form a filter clogging sludge or slime.
Chloride (Cl)	250[1]	Concentrations in excess of 250 mg/l in combination with high sodium may impart a salty taste. Amounts above 1000 mg/l may be physiologically unsafe. Large amounts may accelerate corrosion.
Sulfate (SO_4)	250[1]	Concentrations greater than 500 mg/l in combination with ions (expecially sodium and magnesium) can impart odors and a medicinal or bitter taste to water. Amounts above 600 mg/l have a laxative effect for people unaccustomed to sulfate-rich water.
Nitrate (NO_3 as N)	10[2]	Concentrations above 20 mg/l impart a bitter taste to drinking water. Concentrations greater than 10 mg/l causes infant methemoglobinema, a disease characterized by cyanosis or a bluish coloration of the skin.
Fluoride (F)	1.4-2.4[2]	Fluoride concentrations ranging from about .9 mg/l to 1.7 mg/l help prevent tooth decay. Amounts above recommended concentration limits may cause mottled teeth. Serious mottling of teeth and skeletal defects can occur with concentrations above 6.0 mg/l. (Limit varies on basis of climate (temperature) and intake amount.)

[1]U.S. EPA National Secondary Drinking Water Regulations, 1979b.
[2]U.S. EPA National Interim Primary Drinking Water Regulations, 1979a.
Other references: Hunn and Rosenshein, 1969; GWRSC, 1980; Lehr and others, 1980; Todd, 1980.

Appendix 16. Public Water Supply Projections

The projections of future water withdrawals in the St. Joseph River basin were developed using the methodology of the Governor's Water Resource Study Commission report (1980). Appendix One of that report describes the methodology used to project future water withdrawals.

While the Governor's study published water use projections for regions, the St. Joseph basin covers only portions of regions 2 and 3a, and a very small part of Region 3b. Therefore, some recalculations were necessary to make water use projections on a county basis, or in some cases, only that part of the county that lay within the basin. In addition, projections were based upon historical data through the year 1980.

Future projections of withdrawals were computed by multiplying the projected per capita usage (gallons per person per day) by the projected population served for the year in question. Both the projected per capita usage and the projected population served were for only that part of each county in the basin.

As part of the Governor's study, an analysis was undertaken of the service characteristics of 17 counties across the state. It was found that the percent of population served remained stable over the study period in most counties. In a few counties where there was as abundance of ground water, the percent served was declining. In a few more counties, the percent served was increasing.

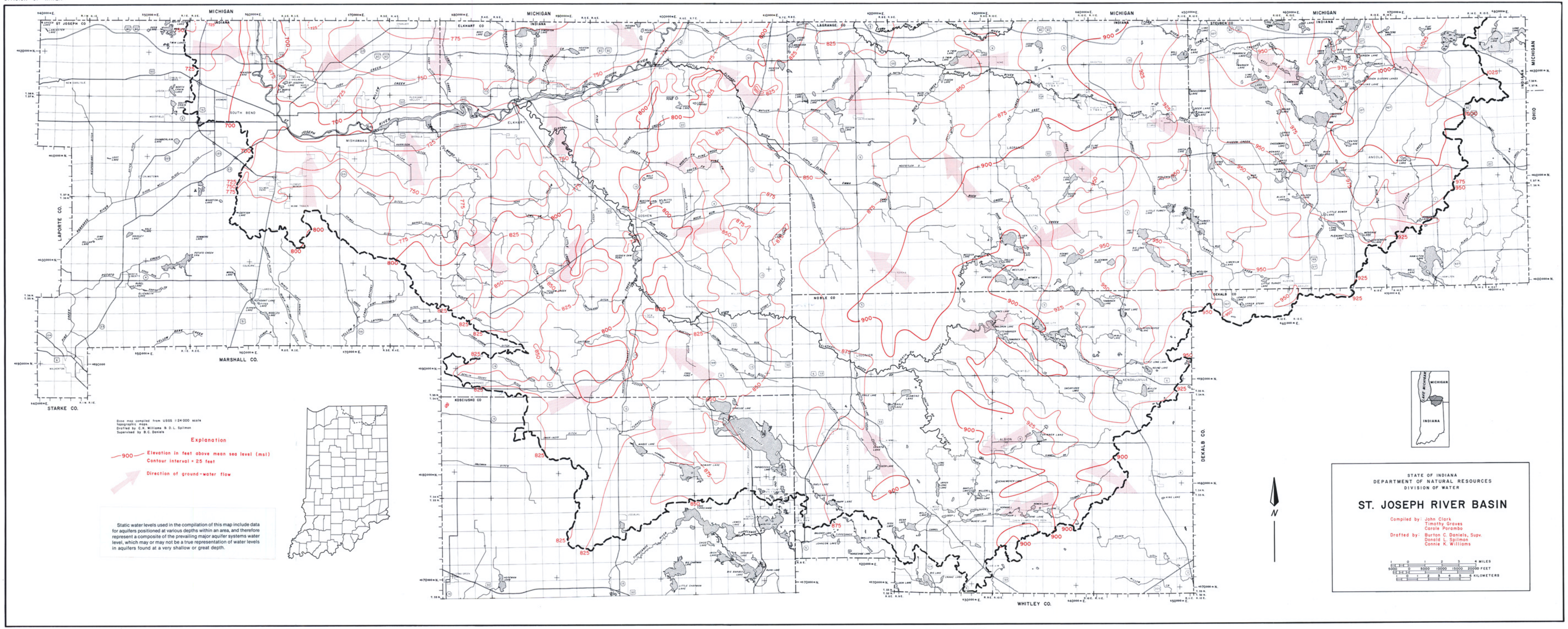
In counties where percent served was declining, the trend line of the percent served decreased about seven percent over 25 years from the year 1975 to the year 2000. The Governor's study used a decrease in percent served of 1 percent from 1975 to 1980, a decrease of 3 percent from 1980 to 1990 and another decrease of 3 percent from 1990 to 2000. Since this report has data for 1980, water use projections were made only for 1990 and 2000. However, the 3 percent decreases from 1980 to 1990 and 1990 to 2000 were still used to compute the percent served.

All counties in the St. Joseph basin had decreasing percent served except LaGrange and St. Joseph counties whose percent served remained unchanged.

The projected population served for 1990 or 2000 was determined by multiplying the projected county population in the basin by the projected percent served.

The projected per capita usages for the years 1990 and 2000 were developed from historical data. First, a least-squares-error linear equation was fit through historical data of public utilities serving more than 1000 persons in each county or that part of a county that lay within the basin. The data covered a period from 1950 through 1980. Next, the 1980 per capita usage water calculated for all utilities, that is, utilities serving populations greater than 1000 as well as utilities serving populations less than 1000. Finally, the 1990 per capita usage was then calculated by multiplying the slope of the least squares line by 10 and adding this number to the 1980 per capita usage. The 2000 per capita usage was calculated by multiplying the slope of the least squares line by 10 and adding this number to the 1990 per capita projection.

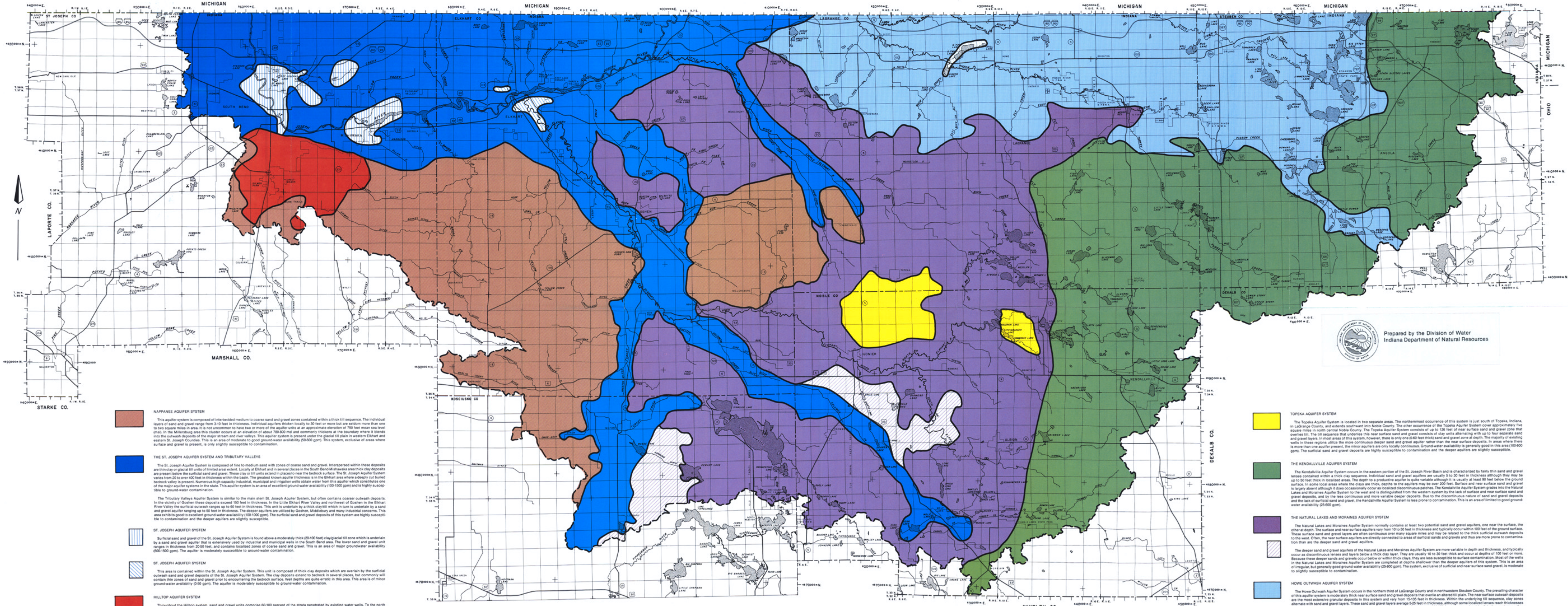
The results of the computations of projected water withdrawals are shown in the text under the topic of public water supplies.



COMPOSITE PIEZOMETRIC SURFACE MAP FOR UNCONSOLIDATED AQUIFERS

STATE OF INDIANA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATER

Plate 2



AQUIFER DESIGNATION MAP

NAPPANEE AQUIFER SYSTEM

This aquifer system is composed of interbedded medium to coarse sand and gravel zones contained within a thick till sequence. The individual layers of sand and gravel range from 3-10 feet in thickness. Individual aquifers thicken locally to 30 feet or more but are seldom more than one to two square miles in area. It is not uncommon to have two or more of the aquifer units at an approximate elevation of 750 feet mean sea level (msl). In the Millersburg area this cluster occurs at an elevation of about 780-800 msl and commonly thickens at the boundary where it blends into the outwash deposits of the major stream and river valleys. This aquifer system is present under the glacial till plain in western Elkhart and eastern St. Joseph Counties. This is an area of moderate to good ground-water availability (50-600 gpm). This system, exclusive of areas where surface and gravel is present, is only slightly susceptible to contamination.

THE ST. JOSEPH AQUIFER SYSTEM AND TRIBUTARY VALLEYS

The St. Joseph Aquifer System is composed of fine to medium sand with zones of coarse sand and gravel. Interspersed within these deposits are thin clay or glacial till units of limited areal extent. Locally at Elkhart and in several places in the South Bend-Mishawaka area thick clay deposits are present below the surficial sand and gravel. These clay or till units extend in places to near the bedrock surface. The St. Joseph Aquifer System varies from 20 to over 400 feet in thickness within the basin. The greatest known aquifer thickness is in the Elkhart area where a deeply cut buried bedrock valley is present. Numerous high capacity industrial, municipal and irrigation wells obtain water from this aquifer which constitutes one of the major aquifer systems in the state. This aquifer system is an area of excellent ground-water availability (100-1500 gpm) and is highly susceptible to ground-water contamination.

The Tributary Valleys Aquifer System is similar to the main stem St. Joseph Aquifer System, but often contains coarser outwash deposits. In the vicinity of Goshen these deposits exceed 150 feet in thickness. In the Little Elkhart River Valley and northwest of Goshen in the Elkhart River Valley the surficial outwash ranges up to 60 feet in thickness. This unit is underlain by a thick clay/till which in turn is underlain by a sand and gravel aquifer ranging up to 50 feet in thickness. The deeper aquifers are utilized by Goshen, Middlebury and many industrial concerns. This area exhibits good to excellent ground-water availability (100-1000 gpm). The surficial sand and gravel deposits of this system are highly susceptible to contamination and the deeper aquifers are slightly susceptible.

ST. JOSEPH AQUIFER SYSTEM

Surficial sand and gravel of the St. Joseph Aquifer System is found above a moderately thick (20-100 feet) clay/glacial till zone which is underlain by a sand and gravel aquifer that is extensively used by industrial and municipal wells in the South Bend area. The lower sand and gravel unit ranges in thickness from 20-50 feet, and contains localized zones of coarse sand and gravel. This is an area of major groundwater availability (500-1500 gpm). The aquifer is moderately susceotible to ground-water contamination.

ST. JOSEPH AQUIFER SYSTEM

This area is contained within the St. Joseph Aquifer System. This unit is composed of thick clay deposits which are overlain by the surficial outwash sand and gravel deposits of the St. Joseph Aquifer System. The clay deposits extend to bedrock in several places, but commonly will contain thin zones of sand and gravel prior to encountering the bedrock surface. Well depths are quite erratic in this area. This area is of minor ground-water availablity (0-50 gpm). The aquifer is moderately susceptible to ground-water contamination.

HILLTOP AQUIFER SYSTEM

Throughout the Hilltop system, sand and gravel units comprise 60-100 percent of the strata penetrated by existing water wells. To the north the St. Joseph Aquifer System (outwash valley) forms a distinct topographic contrast with the Hilltop Aquifer which occurs at a higher elevation. The south, east and west boundaries of the Hilltop Aquifer represent a gradational change from the sand/gravel rich Hilltop system deposits, to clay/till rich deposits typical of the Nappannee System. A poorly defined band surficial sand and gravel, often more than 100 feet thick, extends north-south through the middle of the system. Clay/till units thicken to the east and west; however, they seldom exceed 40 feet in thickness. Many wells located in the northern third of the system are completed in a 10-30 foot thick sand and gravel unit found at an elevation of 720-690 feet - virtually matching the elevation range of the St. Joseph surficial sand and gravel complex immediately to the north. Continuity of the various units becomes more erratic southward. Wells in the south half of the system are typcially completed in thick sand and gravel units ranging in elevation from approximatly 750-670 feet. This is an area of moderate ground-water availability (25-150 gpm). The aquifer is susceptible to ground-water contamination.

TOPEKA AQUIFER SYSTEM

The Topeka Aquifer System is located in two separate areas. The northernmost occurrence of this system is just south of Topeka, Indiana, in LaGrange County, and extends southward into Noble County. The other occurrence of the Topeka Aquifer System cover approximately five square miles in north central Noble County. The Topeka Aquifer System consists of up to 126 feet of near surface sand and gravel zone that overlies till. The till sequence that underlies this near surface sand and gravel consists of clay units alternating with up to four separate sand and gravel layers. In most areas of this system, however, there is only one (0-60 feet thick) sand and gravel zone at depth. The majority of existing wells in these regions utilize the more continuous deeper sand and gravel aquifer rather than the near surface deposits. In areas where there is more than one aquifer present, the minor aquifers are only locally continuous. Ground-water availability is generally good in this area (100-600 gpm). The surficial sand and gravel deposits are highly susceptible to contamination and the deeper aquifers are slightly susceptible.

THE KENDALLVILLE AQUIFER SYSTEM

The Kendallville Aquifer System occurs in the eastern portion of the St. Joseph River Basin and is characterized by fairly thin sand and gravel lenses contained within a thick clay sequence. Individual sand and gravel aquifers are usually 5 to 30 feet in thickness although they may be up to 50 feet thick in localized areas. The depth to a productive aquifer is quite variable although it is usually at least 90 feet below the ground surface. In some local areas where the clays are thick, depths to the aquifers may be over 200 feet. Surface and near surface sand and gravel is largely absent although it does occassionally occur as localized discontinuous patches. The Kendallville Aquifer System grades into the Natural Lakes and Moraines Aquifer System to the west and is distinguished from the western system by the lack of surface and near surface sand and gravel deposits, and by the less continuous and more variable deeper deposits. Due to the discontinuous nature of sand and gravel deposits and the lack of surficial sand and gravel, the Kendallville Aquifer System is less prone to contamination. This is an area of limited to good ground-water availability (25-600 gpm).

THE NATURAL LAKES AND MORAINES AQUIFER SYSTEM

The Natural Lakes and Moraines Aquifer System normally contains at least two potential sand and gravel aquifers, one near the surface, the other at depth. The surface and near surface aquifers vary from 10 to 50 feet in thickness and typically occur within 100 feet of the ground surface. These surface sand and gravel layers are often continuous over many square miles and may be related to the thick surficial outwash deposits to the west. Often, the near surface aquifers are directly connected to areas of surficial sands and gravels and thus are more prone to contamination than are the deeper sand and gravel aquifers.

The deeper sand and gravel aquifers of the Natural Lakes and Moraines Aquifer System are more variable in depth and thickness, and typically occur as discontinuous lenses and layers below a thick clay layer. They are usually 10 to 30 feet thick and occur at depths of 100 feet or more. Because these deeper sands and gravels occur below or within thick clays, they are less susceptible to surface contamination. Most of the wells in the Natural Lakes and Moraines Aquifer System are completed at depths shallower than the deeper aquifers of this system. This is an area of irregular, but generally good ground water availability (25-800 gpm). The system, exclusive of surficial and near surface sand gravel, is moderate to slightly susceptible to contamination.

HOWE OUTWASH AQUIFER SYSTEM

The Howe Outwash Aquifer System occurs in the northern third of LaGrange County and in northwestern Steuben County. The prevailing character of this aquifer system is moderately thick near surface sand and gravel deposits that overlie an altered till plain. The near surface outwash deposits are the most extensive granular deposits in this system and vary from 15-135 feet in thickness. Within the underlying till sequence, clay zones alternate with sand and gravel layers. These sand and gravel layers average 5-25 feet in thickness, although some localized lenses reach thicknesses of 100 feet. The tops of the sand and gravel lenses characterisitically occur between 800-850 feet mean sea level (msl) in the western portion of this aquifer system. This system typically occurs at progressively higher elevations to the east, two or more sand and gravel deposits often occur at depth within the till sequence, but are only continuous locally. This is an area of good to excellent ground-water availability (100-1000 gpm). The surficial deposits are highly susceptible to contamination and the deeper sand and gravels are moderately so.

An anomaly in the Hower Aquifer System is present around Pigeon Lake, North and South Twin Lakes, and Still Lake west of Howe. Surrounding this group of lakes is an unexpectedly thick clay sequence within the aquifer system. Surficially, this region is similar to the remainder of the Howe Aquifer system in that it is underlain by sand & gravel. However, below this upper zone, the lake area contains clay layers ranging from 25 to 180 feet in thickness, which is much greater than the depth in the Howe System. This is an area of moderate ground-water availability (5-100 gpm). This system, exclusive of the surficial sand and gravel, is only slightly susceptible to contamination.

Prepared by the Division of Water
Indiana Department of Natural Resources

Base map compiled from USGS 1:24000 scale topographic maps.
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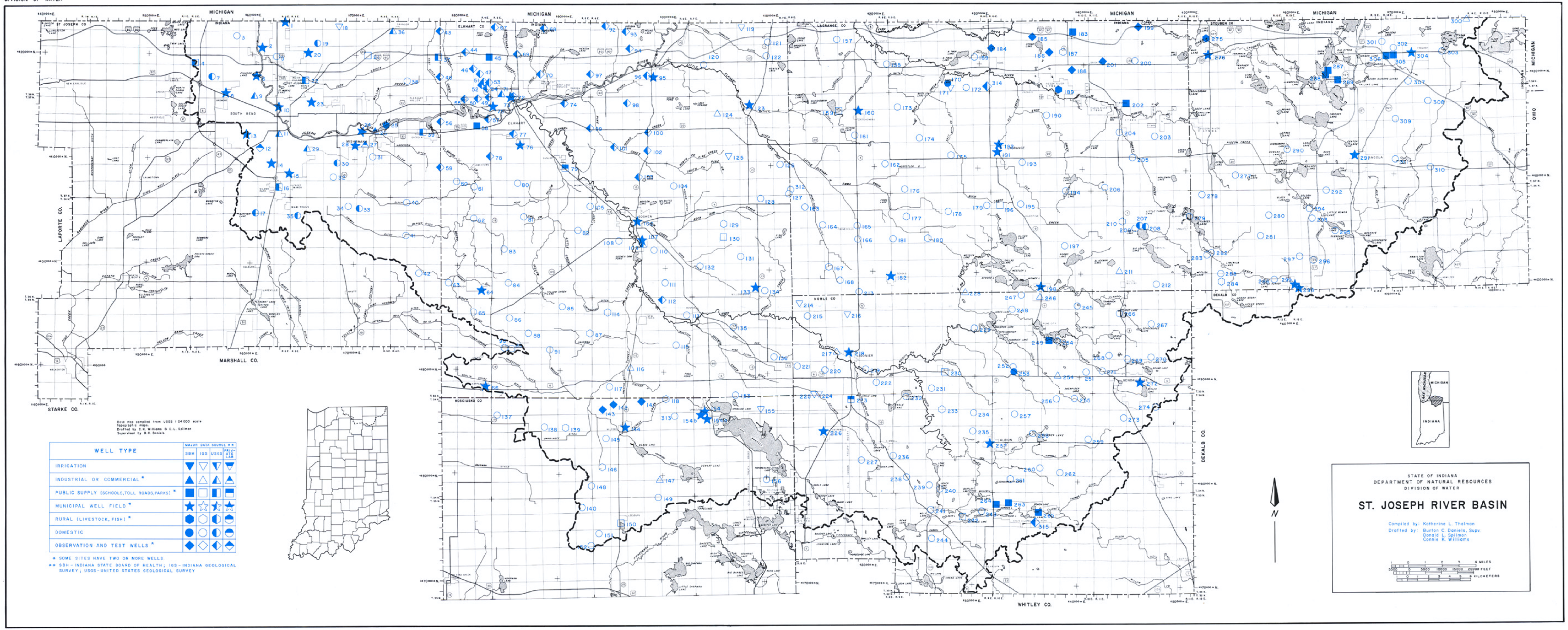

GROUND-WATER QUALITY SAMPLING LOCATIONS