REVIEW OF THE HYDROLOGIC DATA-COLLECTION NETWORK IN THE ST. JOSEPH RIVER BASIN, INDIANA

By E. James Crompton, James G. Peters, Robert L. Miller, James A. Stewart, Konrad J. Banaszak, and Robert J. Shedlock

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Multiply inch-pound unit	By	To obtain metric units
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
gallon per minute (gal/min)	6.308×10^{-2}	liter per second (L/s)
million gallons per day (Mgal/d)	4.381×10^{-2}	cubic meters per second (m^3/s)
acre-feet (acre-ft)	1.233×10^{3}	cubic meters (m^3)
foot squared per day (ft^2/d)	9.290×10^{-2}	meter squared per day (m^2/d)
cubic feet per second (ft^3/s)	2.832×10^{-2}	cubic meters per second (m^3/s)
British thermal unit per minute (Btu/min)	1.757×10^{-5}	megawatt (MW)

To convert degree Fahrenheit (°F) to degree Celsius (°C)

$$(0.556)\,(°F - 32°) = °C$$

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ABSTRACT

The Indiana Department of Natural Resources considers the St. Joseph River basin a high-priority area for water-resource assessment because of rapid growth in water use during the past decade. A review of the present data-collection network for streamflow, lake, ground water, and climatic stations was done to assist the Indiana Department of Natural Resources in assessing the need for additional hydrologic monitoring. The network review included only the 1700-square-mile part of the basin in Indiana. The area is covered with glacial drift averaging from 200 to 350 feet in thickness. Extensive outwash deposits form highly productive sand and gravel aquifers and provide well-sustained streamflow. Seventy-five percent of the area is used for agriculture, and all public and private water supply is from ground water.

Currently, the streamflow network includes 11 continuous-record gaging stations and one partial-record station. Based on areal distribution, lake effect, contributing drainage area, and flow-duration ratio, six of these stations can be used to describe regional hydrology.

Gaging stations on lakes are used to collect long-term lake-level data on which to base legal lake levels, and to monitor lake-level fluctuations after legal levels are established. Of the 98 lakes for which data have been collected, 85 have had legal levels established. Using current record, legal levels could probably be established for an additional eight lakes. Existing control structures are ineffective at maintaining legal levels on at least 17 lakes during most of the year when lake levels are below the elevation of the control structure. More hydrogeologic data are needed for determining the degree to which ground water affects lake levels. Existing lake-level data might be used to evaluate the frequency and magnitude of flooding around lakes, and the effectiveness of control structures in maintaining legal levels.

The current ground-water network comprises 15 observation wells and has four purposes: (1) to determine the interaction between ground water and lakes, (2) to measure changes in ground-water levels near irrigation wells, (3) to measure water levels in wells at special purpose sites, and (4) to measure long-term changes in water levels in areas not affected by pumping. Seven wells near three lakes have provided sufficient information for correlating water levels in wells and lakes but are not adequate to quantify

the effect of ground water on lake levels due, in part, to the complex geology in the vicinity of the lakes. To establish a cause-and-effect relation between ground-water and lake levels, the network needs to be modified to provide better information about ground-water flow gradients to and from the lakes. Water levels in five observation wells located in the vicinity of intensive irrigation are not noticeably affected by seasonal withdrawals. This lack of effect is expected based on two detailed studies in the basin, which indicated that high transmissivity of the glacial aquifers and high rates of recharge can provide adequate water for current needs and substantial growth. The five observation wells probably provide adequate record for monitoring regional water levels near irrigation wells. One special-purpose well is valuable in providing water-level information in support of ground-water quality sampling. Water-level data from two long-term monitoring wells are sufficient to characterize water-level trends.

Currently, the National Weather Service operates eight climatic stations in the basin primarily to characterize regional climatic conditions and to aid in flood forecasting. The network meets network-density guidelines established by the World Meteorological Organization for collection of precipitation and evaporation data but does not meet guidelines suggested by the National Weather Service for density of precipitation gages in areas of significant convective rainfalls.

INTRODUCTION

Background

In recent years, the importance of hydrologic data in water-management-related decisions has been recognized by the Indiana Department of Natural Resources (IDNR). Work completed by the Governor's Water Resources Study Commission (GWRSC) in 1980 delineated several areas of the State where growth in water-resource development could eventually lead to water-use conflicts.

Of these areas, the part of the St. Joseph River basin that is located in Indiana (fig. 1) was selected by IDNR as a top-priority area for study. Results of studies by Purdue University for the GWRSC indicate that agricultural irrigation is extensive in this part of the State and might double by the year 2000 (Governor's Water Resource Study Commission, 1980, p. 179). Numerous natural lakes, streams, and marshes are used for recreation and wildlife habitat. Many summer homes are built in areas adjacent to the area's numerous lakes and marshes, which are sensitive to changes in streamflow and ground-water levels. The IDNR is concerned about possible effects of withdrawals for irrigation and other uses on surface- and ground-water supplies in the basin.

As a first step in preparing for increased responsibilities in water-resource management, the GWRSC and IDNR compiled much of the water-resource information available for the basin including ground-water availability, irrigational potential of soils, and ground- and surface-water withdrawals. In addition, IDNR updated water-use information, identified and mapped natural lakes and wetlands, and provided estimates of future irrigation. Beyond this preliminary work, the State was interested in evaluating the present network for collecting hydrologic data in the basin to determine whether the network will meet future needs for water-resource information.

Purpose and Scope

The purpose of this report is to review the present hydrologic data-collection network in the St. Joseph River basin and to suggest ways in which the network might be improved to meet current and anticipated needs. The review is intended as a descriptive assessment rather than a quantitative analysis of the network. Only the network in the Indiana part of the basin is discussed. The present network of U.S. Geological Survey gaging stations for streams, lakes, and ground water, as well as the climatic stations operated by the National Weather Service, is reviewed. The review considers the purposes, distribution, and effectiveness of the network. Suggestions for improving the network are based on assessments of current and future needs as identified by IDNR and the Geological Survey.

Acknowledgments

The IDNR, Division of Water, provided suggestions for the purpose and scope of the report. The Division also supplied information on lake-control structures, lakes with low-water problems, and originally designated purposes of observation wells.

BASIN DESCRIPTION

The drainage basin of the St. Joseph River covers 4,680 mi^2 (square miles) of southern Michigan and northern Indiana. The Indiana part of the basin is 1698 mi^2 in area (Hoggatt, 1975, p. 186) and includes all or part of seven counties: St. Joseph, Elkhart, Lagrange, Steuben, Dekalb, Noble, and Kosciusko (Fig. 1). For the remainder of the report, "the basin" refers only to the Indiana part of the St. Joseph River basin. (Another St. Joseph River in the Maumee River basin is not discussed in this report.)

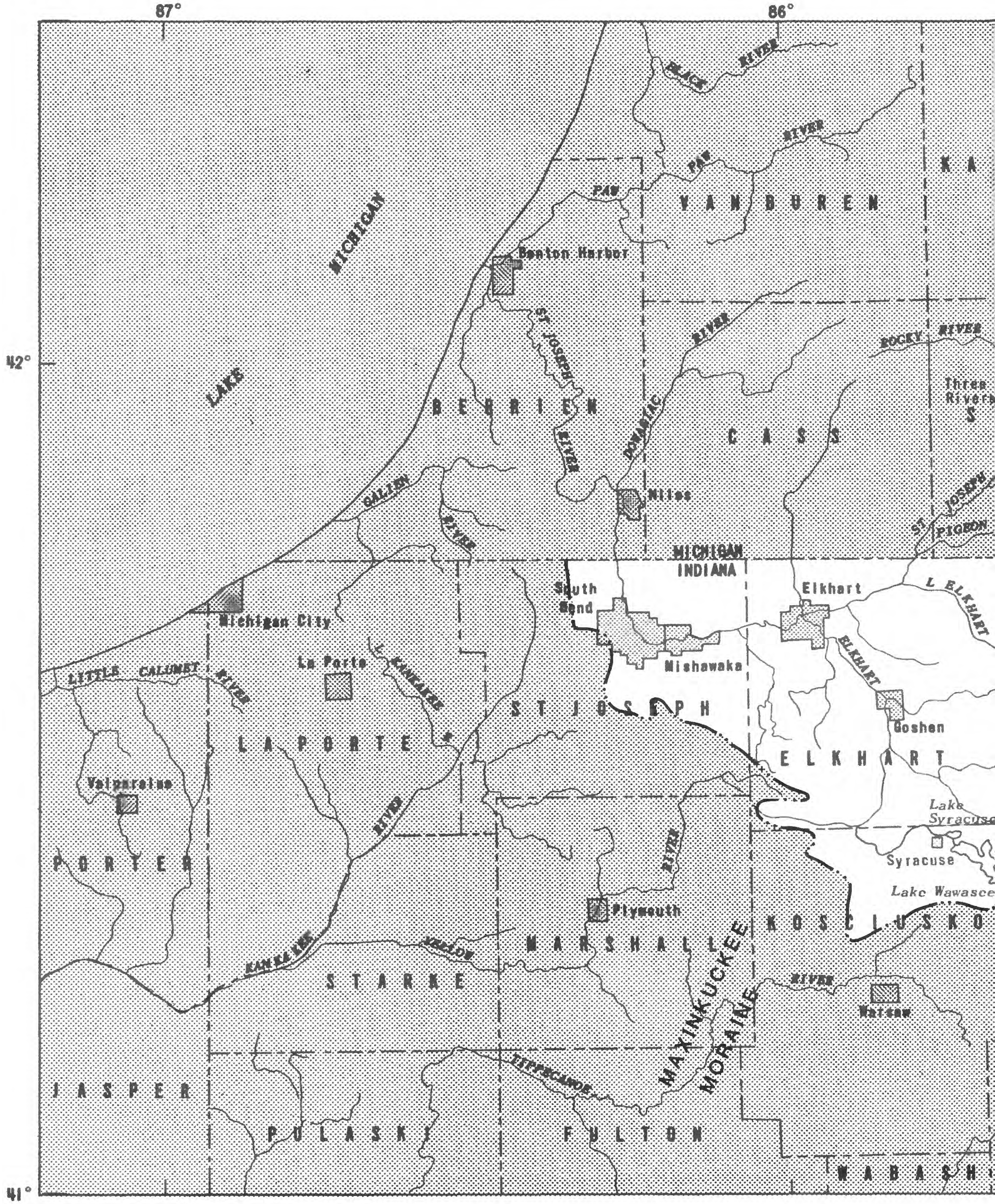
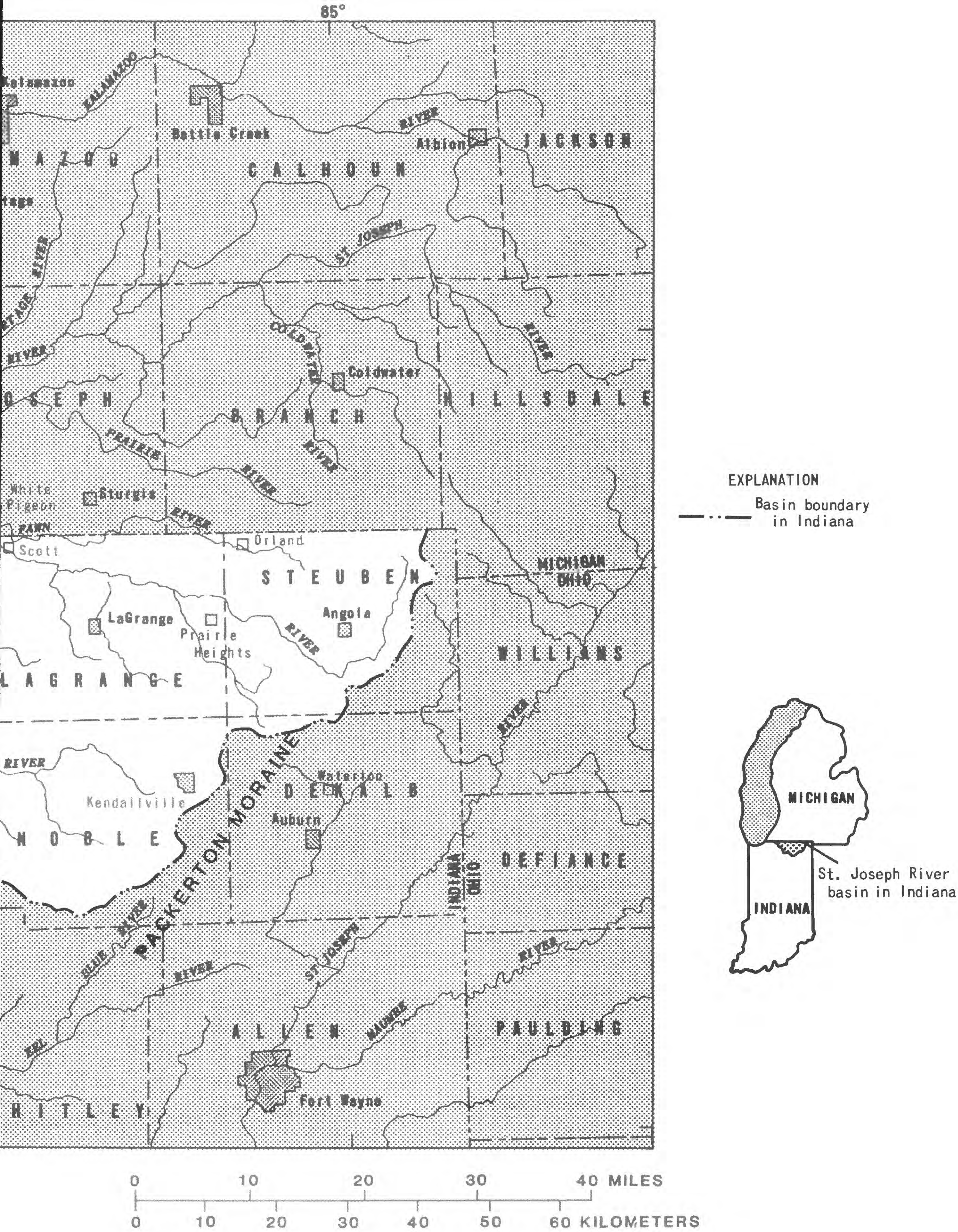


Figure 1.-- St. Joseph River basin in Indiana


85°
Kalamazoo
KALAMAZOO
Battle Creek
RIVER
Albion
JACKSON
MAZOO
CALHOUN
ST JOSEPH
COLDWATER
Coldwater
RIVER
HILLSDALE
BRANCH
PRAIRIE
RIVER
White Pigeon
Sturgis
RIVER
FAWN
Scott
Orland
STEUBEN
MICHIGAN
OHIO
LaGrange
Prairie Heights
Angola
RIVER
WILLIAMS
LAGRANGE
RIVER
RIVER
Waterloo
DEKALB
Kendallville
Auburn
NOBLE
PACKERTON MORAINE
INDIANA
OHIO
DEFIANCE
BLUE RIVER
ST JOSEPH
RIVER
RIVER
EEL
ALLEN
MAUMEE
PAULDING
Fort Wayne
WHITLEY
0 10 20 30 40 MILES
0 10 20 30 40 50 60 KILOMETERS
EXPLANATION
Basin boundary in Indiana
MICHIGAN
INDIANA
St. Joseph River basin in Indiana

Climate

Thirty years of climatic data (1951-80) from weather stations at South Bend and Goshen (fig. 1) were used to determine a climatic norm (or average) for temperature and precipitation in the basin (U.S. Department of Commerce, 1982)[1]. Average annual temperature is 49.5 °F. The average monthly temperature ranges from 23.1 °F in January to 74.0 °F in July. Precipitation average 35.8 in/yr and ranges from 1.8 in. in February to 3.8 in. in August. Potential evapotranspiration for north-central Indiana is 27 in/yr (Newman, 1981).

Geology

Bedrock

The bedrock surface underlies a cover of glacial drift throughout the basin and is composed of three types of shale. In the southern part of the basin, the upper part of the bedrock is the Antrim Shale of Late Devonian age. The Ellsworth Shale in the western part is of Late Devonian and Early Mississippian age and the Coldwater Shale in the eastern part is of Early Mississippian age (Shaver, 1970). The altitude of the bedrock surface ranges from about 900 ft in Steuben County to about 400 ft in Elkhart County (N. K. Bleur, G. S. Fraser, and E. J. Hartke, Indiana Geological Survey, written commun., 1985).

Glacial Deposits

The surface features of the St. Joseph River basin result from Wisconsin glaciation and subsequent erosion of the land surface. Recessions of the Saginaw lobe of Wisconsin ice formed many morainic uplands--most notably the massive Packerton and the Maxinkuckee moraines along the southeastern and southwestern edges of the basin (fig. 1). The Packerton moraine is especially prominent, perhaps because it represents an "interlobate" moraine formed between the Saginaw and Erie lobes (Malott, 1922, p. 117).

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[1]The climatic data collected at South Bend might be affected by Lake Michigan to a greater extent than data collected in other parts of the basin. This "lake effect" probably has a larger influence on average monthly data than on average annual data.

These moraines are composed mainly of unsorted material in a clay matrix and exhibit complex knob and kettle topography. The knobs are either till and composed mainly of clay, or they are kames and composed entirely or mainly of sand and gravel. The kettles are ice-block depressions that provide basins for the numerous lakes and wetlands which distinguish this area from other parts of the State (Schneider, 1966).

The intermoraine lowlands are remnants of meltwater channels, some of which form broad valley trains and outwash plains composed of thick sand and gravel deposits.

The northwestern part of the basin is a broad, flat region known as the Kankakee lacustrine section, which extends from northeastern Illinois to south-western Michigan and lies mostly within the Kankakee River basin. The area is characterized by a thin layer of sand and numerous dunes which overlie thick sand and gravel deposits. The sand and gravel is probably associated with valley train and outwash plain further to the east and south. The sand was probably deposited during later periods of glacial recession when melt-water was partially ponded (Malott, 1922, p. 114-15).

The thickness of the glacial deposits ranges from about 30 ft (feet) near Mishawaka to more than 500 ft near Elkhart. Most of the basin is covered with deposits of 200 to 350 ft in thickness. Deposits less than 100 ft in thickness are rare (Wayne, 1956, p. 31).

Soils

The soils that developed from glacial and organic material can be divided into three general classes: clay, sand, and muck soils. The clayey soils developed on till plains and morainic uplands and are generally heavy, poorly drained loam soils with high clay and silt content; examples are the Miami and Crosier soils (Soil Conservation Service, 1973). Sandy soils developed on outwash and lacustrine sand and are generally highly permeable and droughty; examples are the Plainfield and Oshetemo soils (Soil Conservation Service, 1973). The muck soils developed in depressions associated with wetlands and peat bogs. They are very poorly drained and exemplified by the Houghton and Adrian soils (Hillis, 1980).

Topography

The topography in the basin is highly variable. The areas of valley-train and outwash-plain deposits in the western and central part are relatively flat, and local relief usually differs by less than 20 ft. Local relief in the knob and kettle areas can vary as much as 200 ft (Schneider, 1966). The altitude of the land surface ranges from 700 ft near South Bend to 1,100 ft in the eastern part.

Land Use

Nearly three-fourths of the land area in the basin (1,234 mi^2) is agricultural. About 85 percent of the agricultural land is used for growing crops--mostly corn and soybeans (Bureau of Census, 1984). The remaining one-quarter of the land area comprises forests, lakes and associated wetlands, and urban areas. The major population centers in order of decreasing size are South Bend-Mishawaka, Elkhart, Goshen, and Angola.

Hydrology

Surface Water

The headwaters of the St. Joseph River are in south-central Michigan. The river flows southwestward into Elkhart County, Indiana, and then northward into Michigan near South Bend in St. Joseph County, Indiana (fig. 1). The river discharges into Lake Michigan at Benton Harbor, Michigan. At the point where the river leaves Indiana, the total drainage area is 3662 mi^2, of which 1964 mi^2 is in Michigan (Hoggatt, 1975, p. 186). The mean annual discharge at this point is estimated to be about 3,260 ft^3/s, (cubic feet per second) based on a drainage area ratio with the gaging station at Niles, Mich., which has a mean annual discharge of 3,260 ft^3/s and a drainage area of 3,666 mi^2. The average annual runoff originating within the Indiana part of the basin is 10.8 in. (Reussow and Rohne, 1975). Major tributaries to the St. Joseph River that drain parts of Indiana are the Elkhart River, Little Elkhart River, Pigeon River and Fawn River.

Compared to streams in central and southern Indiana, streams in the St. Joseph River basin generally have higher base flows and lower flood flows per unit area of drainage. The narrower range of variability in streamflows results from two factors: (1) good hydraulic connection between highly permeable outwash aquifers and stream channels and (2) the large amount of surface-water storage from lakes and wetlands. During periods of intense precipitation or rapid snowmelt, much of the runoff is delayed by high rates of percolation into the ground-water system and by temporary surface storage. During periods of drought, this stored water is released to the stream channels. Thus, many streams in the basin provide a reliable and relatively uniform supply of water year-round.

The relative uniformity of streamflow in the basin is illustrated by the work done by Arihood and Glatfelter (1986), who estimated the flow-duration ratios for gaging stations in Indiana. The flow-duration ratio is the ratio of the discharge that is exceeded 20 percent of the time to the discharge that is exceeded 90 percent of the time. These values were determined from a flow-duration curve, which is a cumulative frequency curve that shows the percentage of time during which specified discharges were equaled or exceeded in a given period (Searcy, 1959). Searcy also states that a curve with a steep slope throughout denotes a highly variable stream whose flow is largely from direct runoff, whereas a curve with a flat slope indicates the presence of surface- or ground-water storage, which tends to equalize the flow. The lower the value of the flow-duration ratio, the flatter the slope of the flow-duration curve and the more uniform the flow. For the St. Joseph River basin, the flow-duration ratio averaged from 5 to 10, which indicates that the slope of the flow-duration curve is flat. By comparison, values for central Indiana average from 3 to 45, with a mean of 20. For southern Indiana, the flow-duration ratio is undefined, because the discharge at the 90-percent flow duration is usually zero.

More than any other area of the State, the basin is characterized by its many natural lakes of glacial origin. Schneider (1966, p. 53) indicates the lakes and peat bogs in this area may number in the thousands. Most are small, although at least 150 lakes have surface areas greater than 50 acres and (or) storage capacities of greater than 32 Mgal (million gallons) (Governor's Water Resources Study Commission, 1980, p. 191-193). Lake Wawasee in Kosciusko County is the largest lake (2,618 acres), and several lakes have maximum depths of nearly 100 ft (Indiana Stream Pollution Control Board, 1980, p. 1, 77).

Most of the lakes are along the southern and eastern parts of the basin in morainal areas. These areas are the headwaters for the major tributaries to the St. Joseph River in Indiana.

Ground Water

The St. Joseph River basin has some of the most productive aquifers in the State. The unconsolidated glacial deposits that underlie the entire basin are the major source of ground water. The most productive aquifers are in outwash plain and valley-train deposits along meltwater channels and in intermorainal lowlands. These aquifers are primarily in northern Elkhart, Lagrange, and St. Joseph counties; in northeastern Noble County; and northeastern Kosciusko County where sand and gravel deposits of 200 ft in thickness and transmissivities of 50,000 ft^2/d (feet squared per day) are common. Potential well yields range from 400 to more than 2000 gal/min (gallons per minute) (Governor's Water Resources Study Commission, 1980). Recharge to the outwash aquifers averages about 11 in/yr and can be as high as 25 in/yr (Pettijohn, 1968). Most of the recharge to the ground-water system discharges to streams and lakes and represents about 80 percent of the average annual streamflow runoff from the basin (Reussow and Rohne, 1975).

Regional (deep) ground-water flow through the unconsolidated material is toward the St. Joseph River. Flow in shallower aquifers generally is toward nearby tributaries and lakes, although variations in geology can noticeably alter ground-water flow paths locally (Bailey and others, 1985; Lindgren and others, 1985).

Water Use

All public and private drinking-water supplies in the basin obtain water from ground-water wells that tap the basin's highly productive aquifer systems. South Bend Public Utility[2], the largest single user of ground water, withdrew an average of 25 Mgal/d in 1985 (James Hebenstreit, Indiana Department of Natural Resources, Indianapolis, Indiana, oral commun., 1986). Total withdrawal by all public water supplies averaged 44 mgal/d in 1980 (Indiana Department of Natural Resources, 1982a). Private wells for domestic and livestock use withdrew an average of 15 mgal/d in 1980 (Indiana Department of Natural Resources, 1982b).

Most industries in the basin purchase water from public utilities although many of the largest industries are self-supplied. The self-supplied withdrawals are primarily from wells; however, several industries in Elkhart and St. Joseph Counties withdraw water from the St. Joseph River (Governor's Water Resources Study Commission, 1980, p. 177).

Agricultural irrigation is probably the fastest growing use of water in the basin and may be the largest consumptive use. In 1982, an estimated 41,000 acres of cropland were irrigated, which, during a year of normal precipitation, would require an estimated withdrawal of 87 mgal/d during the irrigation season (June through August). Present estimates indicate that about two-thirds of the water used for irrigation in the basin is from ground water and one-third is from surface water.

Water is used for power generation to operate coal-fired steam turbines at one facility and hydro-electric generators at four facilities. The coal-fired facility at South Bend uses about 160 mgal/d from the St. Joseph River to generate up to 250 MW (megawatts) of electricity (Governor's Water Resources Study Commission, 1980, p. 177). The four hydroelectric facilities --one each on the St. Joseph and Elkhart Rivers and two on Fawn River--have a combined capacity of 12 MW. An additional five hydroelectric plants are planned that would have a combined capacity of 4 MW (John Fisher, Lawson-Fisher Associates, oral commun., 1985).

[2]Use of the trade names and firm names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

STREAMFLOW-MONITORING NETWORK

General Description

In 1930, the State of Indiana and the U.S. Geological Survey began a cooperative program to collect streamflow data throughout the State. As part of this program, the first station within the basin was established on the Elkhart River at Goshen in 1931. Since that time, 15 continuous-record gaging stations and 15 partial-record stations were established (table 1). Currently, 11 continuous-record and one partial-record station are still in operation.

Discharge and/or stage data are collected for all stations in the streamflow network in the St. Joseph River basin. Data from these stations are published annually in "Water Resource Data for Indiana" on a water-year basis (October 1 through September 30).

The type of stations operated are classified as continuous or partial record. Continuous-record stations record stream stage using an automatic recording device. To convert continuous stage record to discharge requires development of a rating (stage-discharge relation). The rating is developed by making measurements of discharge throughout the range-in-stage at the station. Because of both natural and manmade changes to the stream channel, the stage-discharge relation is not constant. Because of this, discharge measurements are made periodically throughout the year as a basis to confirm or revise the rating.

Partial-record stations are established when only a specific type of data is needed and where continuous record of stage or discharge is not required. Partial-record stations are primarily established to provide information on floods and low-flows. At many high-flow, partial-record stations, a crest-stage gage is installed that registers the peak stage between inspections of the station (Glatfelter and others, 1985, p. 234). The location of discontinued and current continuous and partial-record stations are shown in figure 2.

Table 1.--Continuous-record and partial-record streamflow stations in the St. Joseph River basin, Indiana

[Site numbers refer to those in figure 2. CR, continuous record; CSG, crest stage gage; PRLF, partial record low-flow; HS, hydrologic systems; PD, planning and design; HF, hydrologic forecasts; RH, regional hydrology; WQ, water-quality monitoring; PO, project operation. Sources: Miller and others, 1984; and Stewart, 1983.]

Station number	Site number	Station name	County	Period of record	Total drainage area (square mile)	Type of station	Data use
04097970	A9	Lime Lake Outlet at Panama	Steuben	1969-Present	17.5	CR	HS, WQ
04098000	B4	Fawn River at Orland	Steuben	1943-47	86.4	CR	----------------
0409902050	H10	Ewing ditch near Angola	Steuben	1973-74	4.00	PRLF	----------------
0409904050	H11	Berlien ditch near Angola	Steuben	1973	3.20	PRLF	----------------
04099060	F1	Pigeon Creek tributary near Ellis	Steuben	1972,74,76-77,79-82	1.22	CSG, PRLF	----------------
04099070	G8	Pigeon Creek near Hamilton	Steuben	1979-81	43.3	PRLF	----------------
04099510	A10	Pigeon Creek near Angola	Steuben	1945-Present	106	CR	RH, PD, HF
04099610	B5	Pretty Lake Inlet near Stroh	Lagrange	1963-80	1.96	CR	RH
04099692	H12	Rowe Ditch near Howe	Lagrange	1979-81	7.52	PRFL	----------------
04099750	A2	Pigeon River near Scott	Lagrange	1968-Present	361	CR	RH
04099805	H9	Little Elkhart River near Middlebury	Elkhart	1972-79	60.6	PRFL	----------------
04099808	A11	Little Elkhart River at Middlebury	Elkhart	1979-Present	97.6	CR	RH
04099845	H2	Pine Creek near Goshen	Elkhart	1979	28.1	PRFL	----------------
04099850	A12	Pine Creek near Elkhart	Elkhart	1979-Present	31.0	CR	RH
04100000	B1	Christiana Creek at Elkhart	Elkhart	1947-52	127	CR	----------------
0410009550	H13	Dove Creek near Valentine	Lagrange	1973-74	2.20	PRLF	----------------
04100125	H5	North Branch Elkhart River near Wolcottville	Lagrange	1979-81	64.4	PRLF	----------------
04100165	F2	Wible Lake Inlet near Kendallville	Noble	1972-73,75,78-82	2.47	CSG, PRLF	----------------
04100220	B2	North Branch Elkhart River near Cosperville	Noble	1951-71	134	CR	----------------
04100222	A7	North Branch Elkhart River at Cosperville	Noble	1971-Present	142	CR	HS, HF
04100252	A8	Forker Creek near Burr Oak	Noble	1969-Present	19.2	CR	HS, WQ
04100295	A13	Rimmell Branch near Albion	Noble	1979-Present	10.7	CR	RH, WQ
04100375	H7	Solomon Creek near Syracuse	Elkhart	1974-79	33.9	PRLF	----------------
04100465	A23	Turkey Creek at Syracuse	Kosciusko	1969-Present	43.8	CR	HS
04100486	H6	Turkey Creek near Milford	Kosciusko	1979-81	75.9	PRLF	----------------
04100490	H14	Turkey Creek near New Paris	Elkhart	1960-64,66-68	169	PRLF	----------------
04100500	A6	Elkhart River at Goshen	Elkhart	1931-Present	594	CR	RH, HS, PD, PO,HF
04100800	E1	Yellow Creek at Dunlop	Elkhart	1974-Present	33.0	CSG, PRLF	RH
04101000	A1	St. Joseph River at Elkhart	Elkhart	1947-Present	3,370	CR	PD, PO, HF
04101300	H3	Judy Creek at Roseland	St. Joseph	1973-79	37.3	PRLF	----------------

Specific Data Uses

Each station in the streamflow network was established to provide data to meet some specific need--for example, to document floods, record low flows, or determine mean-daily discharge. Whatever the reason for establishing a station, data collected are often used by many Federal and State agencies, local governments, and private industry. In the St. Joseph River basin, the use of streamflow stations can be categorized into six major uses. These uses are listed in table 1 under "data use" and are defined as follows:

- Regional Hydrology: Streamflow stations that are useful in defining regional flow characteristics. Streamflow at the gaging station must be largely unaffected by manmade storage or diversion and the effects of human activities on streamflow must be limited to those caused primarily by land use. Stations on streams affected by manmade storage are included provided that the discharge from the storage facility is uncontrolled. Regional hydrology stations are useful for defining streamflow characteristics that are transferable to other unaffected sites in the region.

- Hydrologic Systems: Streamflow stations that can be used to define current and long-term hydrologic conditions are designated as hydrologic-systems stations. Included are stations that are affected by diversions and return flows, and stations that are useful for defining the interaction of water systems.

- Planning and Design: Streamflow stations that are used for the planning and design of a specific structure or group of structures such as a dam, levee, floodwall, navigation system, water-supply diversion, hydropower plant, or water-treatment facility. The planning and design category is limited to those stations that were established for such a purpose and where this purpose is still valid.

- Project Operation: Streamflow stations that are used on an ongoing basis to assist water managers in making operational decisions such as reservoir releases, hydropower operations, or diversions. Project operation use generally implies that the data are routinely available to the operators on a real-time basis. For projects on large streams, data may only be needed every few days.

- Hydrologic Forecasts: Streamflow stations that are regularly used to provide information for hydrologic forecasting. This includes flood forecasts for a specific river reach, or periodic (daily, weekly, monthly, or seasonal) flow-volume forecast for a specific site or region. Hydrologic forecasts use generally implies that the data are routinely available to the forecasters on a real-time basis. On large streams, data may only be needed every few days.

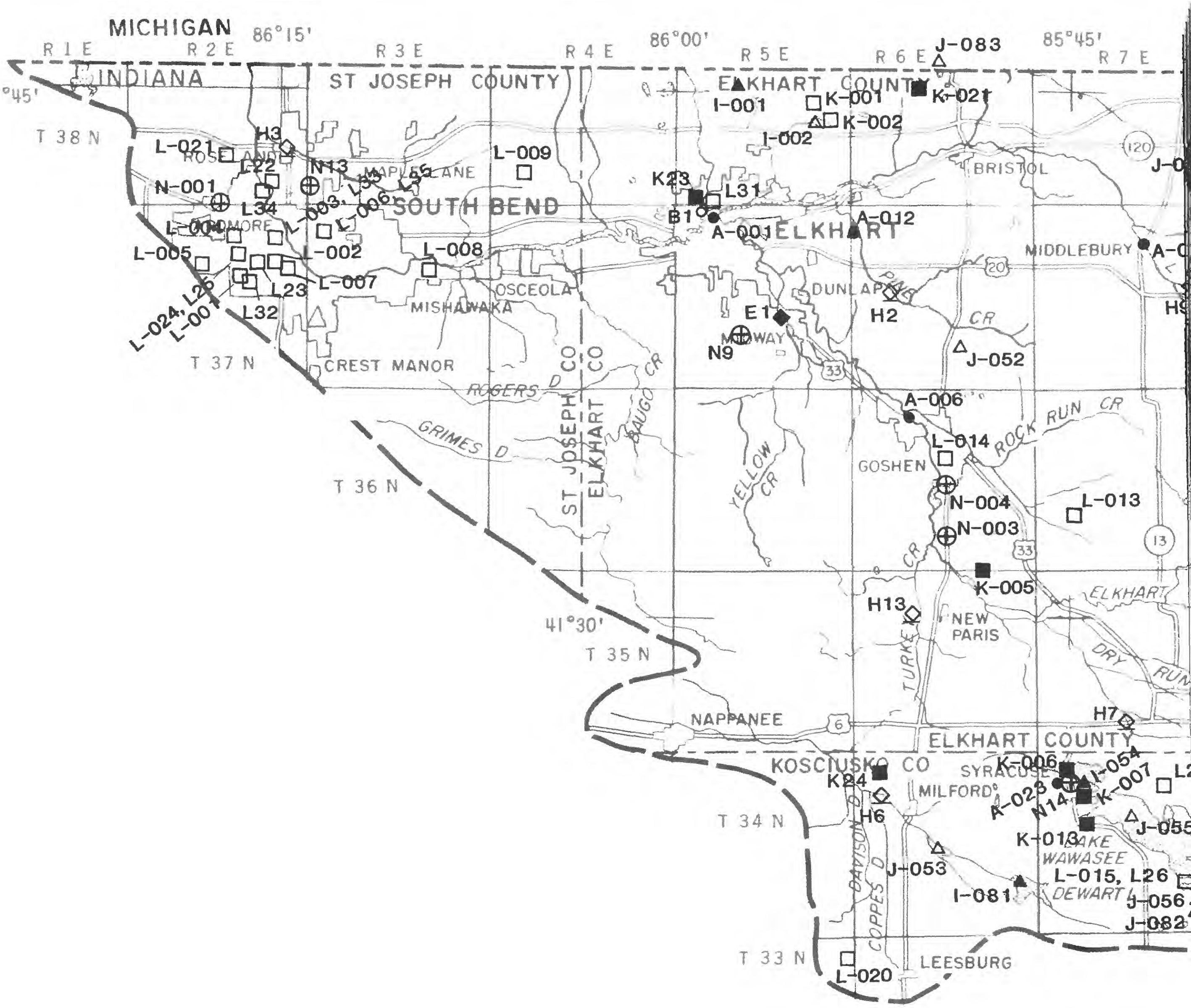
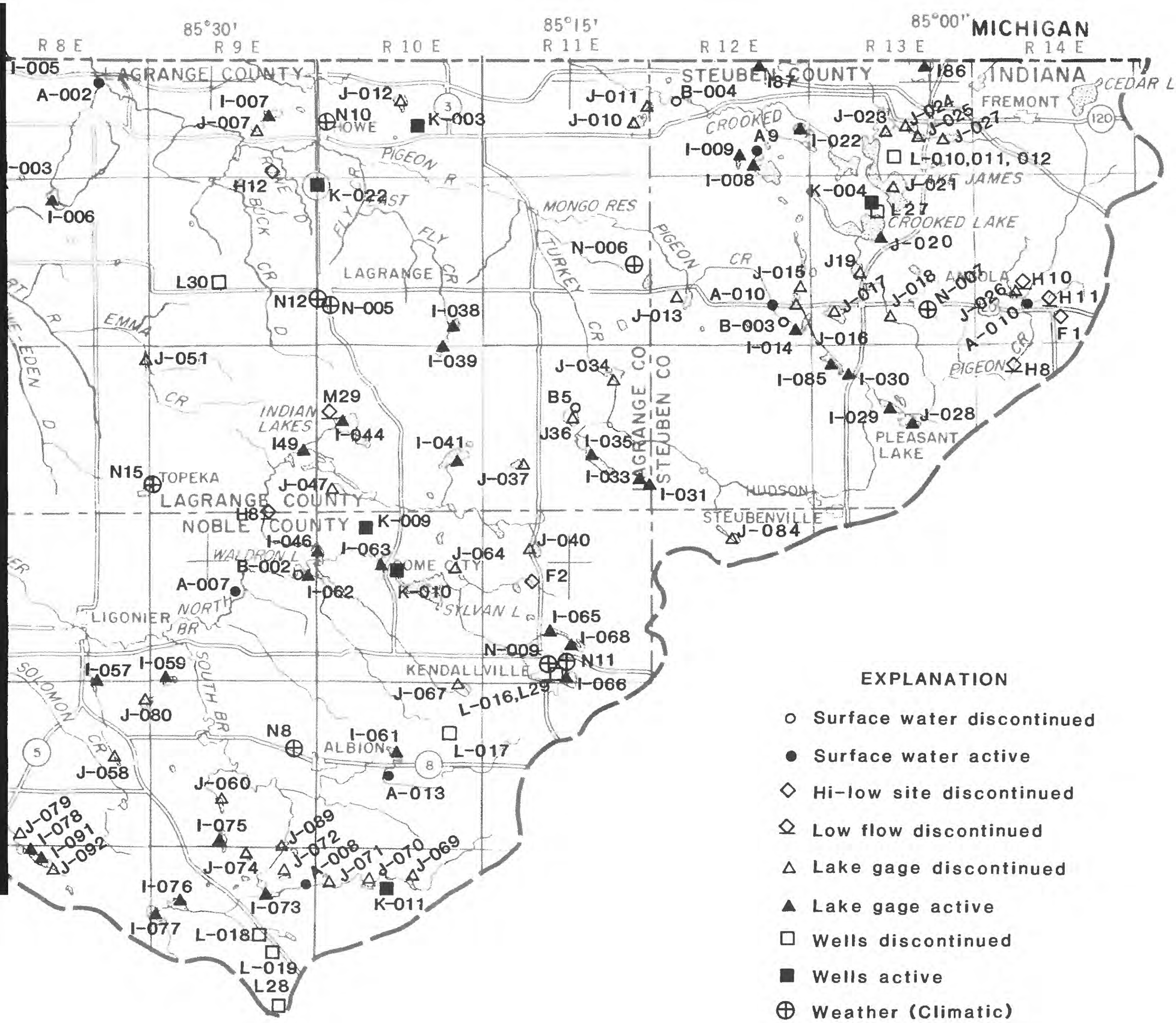


Figure 2.-- Hydrologic data-collection netwo



the St. Joseph River basin, Indiana.

- Water-Quality Monitoring: Streamflow stations where water quality or sediment transport is monitored and/or where streamflow data contribute to the interpretation of the water-quality or sediment data. These data generally are used to monitor current conditions so that trends in stream water quality can be determined.

Existing Network

The purpose of this discussion is to review the existing network of streamflow stations in the St. Joseph River basin and to offer suggestions as to how the network could be improved.

Earlier studies attempted to evaluate the statewide network of streamflow stations. In 1970, an in-depth review was made by Marie and Swisshelm (1970). The authors reviewed the purpose of each station and evaluated whether the purpose was being met. As a result of their work, two stations (North Branch Elkhart River near Cosperville, Ind., and Pigeon Creek at Hogback Lake Outlet near Angola, Ind.) in the St. Joseph River basin were relocated.

A recently completed analysis of the statewide streamflow network (Stewart and others, 1986) considered the need for each station and established the maximum efficiency in operating the network. As part of this study, a questionnaire was sent to each state and federal agency to survey their needs for streamflow data. The result of the survey indicated needs in the St. Joseph River basin for peak flow, low flow, mean-daily flow, flow duration, and real-time data. From analysis of the questionnaire, the author determined that there is sufficient justification for continuing the operation of all existing continuous-record stations in the basin.

Considering the six categories of use for a streamflow network in the St. Joseph, only those stations acceptable defining regional hydrology are reviewed. The review of these stations does not include consideration of the other five categories of use, which address specific needs. Only the user of the data can determine if the station is meeting its intended purpose regarding uses in these other five categories.

The primary purpose of the regional hydrologic network in the St. Joseph River basin is to provide estimates of flow at any point on any stream unaffected by manmade storage or diversion. Thus, the stations selected for this network should represent a wide range of factors affecting the flow regimes in the basin.

Six continuous recording stations are acceptable for defining regional hydrology in the basin. These stations are listed in table 2. The other nine stations are not acceptable because flow upstream from the stations is (or was) regulated by variable control structures or because the period of record is too short (less than 10 years) to define most streamflow characteristics. For example, at the station Elkhart River at Goshen, only the record from 1970 to the present is usable for defining regional hydrology. Prior to 1970, flow was affected by hydroelectric generating stations upstream from the gage (Nieting, J. A., Northern Indiana Public Service Company, oral commun., 1985).

Table 2.--Continuous-record stations acceptable for regional hydrology in the St. Joseph River basin, Indiana

[Site numbers refer to those in figure 2]

Site number	Station	Length of usable record (years)	Lake effect	Contributing drainage area		Calculated flow-duration ratio
				Area (square miles)	Percent of total drainage area	
A10	Pigeon Creek near Angola	40	Yes	83.5	79	8
A2	Pigeon River near Scott	17	Yes	307.	85	4
A11	Little Elkhart River at Middlebury	6	No	91.7	94	3
A12	Pine Creek near Elkhart	6	No	22.3	72	3
A13	Rimmell Branch near Albion	6	Yes	10.7	100	21
A6	Elkhart River at Goshen[1]	14	Yes	594.	100	5

[1]Flow affected by control and (or) diversion prior to water year 1971.

The factors selected as criteria for assessing the regional hydrology stations are areal distribution, lake effect, contributing drainage area, and flow-duration ratio.

Five of the six stations acceptable for regional hydrology are on streams that drain areas in the northeastern and central parts of the basin (fig. 2). The sixth stream--Rimmel Branch near Albion--drains an area along the southeastern boundary. The station on the Elkhart River at Goshen measures streamflow from much of the southern part of the basin, but stations on smaller streams in this area and in the western area are lacking.

Lakes are a dominant feature of the study area and have a strong influence on the flow characteristics. If runoff from 5 percent or greater of the drainage above the point of consideration flows through a lake the station is listed as lake affected. Of the six stations acceptable for regional hydrology, four have lake effect and two do not (table 2).

Contributing drainage area includes that part of the total drainage area that contributes directly to streamflow and it includes topographical depressions that have no surface-water drainage. Contributing drainage area has been shown to be the most important variable in predicting low flow (Arihood and Glatfelter, in press) and peak flow (Glatfelter, D. R., U.S. Geological Survey, written commun., 1985) in Indiana. For the seven stations, the range of values for contributing drainage area is from 0.64 to 594 mi^2. Three stations have values less than 50 mi^2, and four have values greater (table 2).

The flow-duration ratio used in this report is the flow at the 20-percent flow duration divided by the flow at the 90-percent flow duration. The ratio integrates the effects of various basin characteristics such as basin storage, geology, soil type, land use, and climate into one descriptive statistic and has been useful in predicting low flows at ungaged sites in Indiana (Arihood and Glatfelter, in press). A low value of the ratio indicates a flow-duration curve with a flat slope characteristic of streams with low peak flows and well-sustained low flows. Conversely, a high value of the ratio indicates a flow-duration curve with a steep slope characteristic of streams with high peak flows and reduced low flows.

Values of the flow duration ratio calculated for the seven stations acceptable for regional hydrology range from 3 to 21 (table 2) compared to values ranging from 2 to 62 for stations unaffected by flow regulation throughout the State (Arihood and Glatfelter, in press). The relatively low range of values in the basin illustrates that, in general, factors contributing to the ratio combine to produce lower peak flows and higher low flows for these streams than for streams in other parts of the State.

In order for the regional hydrology network to adequately define the flow regime in the basin, the gaging stations in the network need to be at sites that represent the general hydrologic characteristics of ungaged streams. For the purposes of this report, ungaged streams are those with drainage areas greater than 5 mi^2 and with less than 50 percent of the drainage area gaged. The authors have identified 66 ungaged streams in the basin (table 3). These are streams for which flow characteristics might be estimated using data from the regional hydrology gaging stations. Thus, comparison between the characteristics of the ungaged streams and those of the regional hydrology stations is useful in evaluating the regional hydrology network.

Lake effect is a factor that influences flow for 42 percent of the ungaged streams and two-thirds of the regional hydrology stations.

The range of contributing drainage areas for the regional hydrology stations is 10.7 to 594 mi^2 (table 2) compared to a range of 4.36 to 183 mi^2 (table 3) for ungaged streams. Regional hydrology stations with contributing drainage areas of about 5, 50, and 200 mi^2 are not included in the network.

In terms of flow-duration ratio, the regional hydrology stations adequately represent the ungaged streams. Values of flow-duration ratio for ungaged streams were estimated by regionalization methods described by Arihood and Glatfelter (in press). For ungaged streams, ratio values range from 3 to 10 (table 3) compared to values ranging from 3 to 21 for the regional hydrology stations (table 2).

Table 3.--Ungaged streams in the St. Joseph River basin, Indiana

[---, value has not been determined; USGS, U.S. Geological Survey]

Stream and location	County	Total drainage area (square miles)	Contributing drainage area (square miles)	Lake effect	Estimated flow-duration ratio
Trout Creek at mouth	Elkhart	28.2	----	No	5
Rowe Eden ditch at mouth	Elkhart	30.2	30.2	No	5
Mather ditch at mouth	Elkhart	12.6	12.6	Yes	5
Washington Township ditch at mouth	Elkhart	14.6	----	No	5
Sheep Creek at mouth	Elkhart	9.8	9.8	No	5
Puterbaugh Creek at mouth	Elkhart	16.3	----	Yes	5
Osolo Township ditch at mouth	Elkhart	11.5	11.5	Yes	5
Christiana Creek at mouth[1]	Elkhart	128	128	No	5
Philips ditch at mouth	Elkhart	5.85	5.65	No	10
Stony ditch at mouth	Elkhart	20.3	18.1	No	5-10
Dry Run at mouth	Elkhart	6.4	6.4	No	5
Meyer ditch at mouth	Elkhart	9.02	9.02	No	5
Hire ditch at mouth	Elkhart	5.51	5.51	No	5
Solomon Creek at mouth	Elkhart	45.9	42.3	No	5
Whetten ditch at mouth	Elkhart	5.77	5.77	No	5
Dausman ditch at mouth	Elkhart	12.2	12.2	No	5-10
Swoveland ditch at mouth	Elkhart	9.08	9.08	No	5-10
Turkey Creek at mouth[2]	Elkhart	183	183	Yes	5-10
Boyer ditch at mouth	Elkhart	6.00	6.00	No	10
Hoover ditch at mouth	Elkhart	10.3	9.6	No	10
Horn ditch at mouth	Elkhart	14.9	14.9	No	5-10
Rock Run Creek at mouth	Elkhart	43.5	43.5	No	5-10
Leedy ditch at mouth	Elkhart	9.56	9.56	No	5
Cobus Creek at mouth	Elkhart	33.6	30.0	No	5
Billman ditch at mouth	Elkhart	5.11	5.11	No	10
Grimes ditch at mouth	Elkhart	20.2	20.2	No	10
Township ditch at mouth	Elkhart	10.2	10.2	No	10
Rogers ditch at mouth	Elkhart	9.47	9.47	No	10
Fawn River at Indiana-Michigan State Line[3]	Lagrange	193	157	No	5
Turkey Creek at inlet to Mongo Reservoir[4]	Lagrange	64.3	62.8	Yes	5

Table 3.--Ungaged streams in the St. Joseph River basin, Indiana--Continued

Stream and location	County	Total drainage area (square miles)	Contributing drainage area (square miles)	Lake effect	Estimated flow-duration ratio
East Fly Creek at mouth	Lagrange	24.2	24.2	Yes	5
Fly Creek at mouth	Lagrange	43.3	41.7	Yes	5
Rowe ditch at mouth	Lagrange	7.52	7.52	No	5
East Buck Creek ditch at inlet to Buck Creek	Lagrange	18.7	18.7	Yes	5
Buck Creek at inlet into Pigeon Lake	Lagrange	25.7	24.7	Yes	5
Van Natta ditch at mouth	Lagrange	7.33	7.33	No	5
Page ditch at mouth	Lagrange	19.7	16.9	Yes	5
Hostetler ditch at mouth	Lagrange	9.5	9.5	No	5
Bontrager ditch at mouth	Lagrange	34.3	34.3	Yes	5-10
Adams Lake outlet at mouth	Lagrange	6.93	6.93	Yes	5-10
Little Elkhart Creek at inlet to Whitmer Lake	Lagrange	31.7	31.7	Yes	10
Oliver Lake outlet at mouth	Lagrange	15.1	15.1	Yes	5-10
Crooked Creek above Tamarack Lake outlet	Steuben	57.5	51.3	Yes	5-10
Mud Creek at mouth	Steuben	5.31	5.31	No	10
Mud Lake at outlet	Steuben	14.2	14.2	Yes	10
Mud Creek at inlet into Big Turkey Lake	Steuben	7.08	7.08	Yes	5-10
Tamarack Lake at outlet	Noble	19.4	19.4	Yes	10
Waterhouse Lake at outlet	Noble	5.79	5.79	Yes	10
Oviatt ditch at mouth	Noble	9.33	9.33	Yes	10
Middle Branch Elkhart River at mouth	Noble	37.3	37.3	Yes	10
Clock Creek at inlet into Turkey Lake	Noble	15.6	15.6	Yes	10
Dry Run at mouth	Noble	7.56	7.56	Yes	10
Huston ditch at mouth	Noble	8.09	8.09	No	5-10
Winebrenner ditch at mouth	Noble	6.74	6.74	No	10
Carol Creek at inlet into Muncie Lake	Noble	18.5	18.5	Yes	10
Croft Creek at mouth[5]	Noble	24.9	24.9	Yes	10
Long ditch at mouth	Noble	5.85	5.85	No	10
Lower Long Lake outlet at mouth	Noble	5.31	5.31	Yes	10
South Branch Elkhart River at mouth[6]	Noble	114	114	Yes	5-10
Sparta Lake ditch at mouth	Noble	5.56	4.36	Yes	5

Table 3.--Ungaged streams in the St. Joseph River basin, Indiana--Continued

Stream and location	County	Total drainage area (square miles)	Contributing drainage area (square miles)	Lake effect	Estimated flow-duration ratio
Turkey Creek at inlet into Lake Wawasee	Kosciusko	15.9	15.9	Yes	5
Wabee Lake outlet at mouth	Kosciusko	15.9	12.7	Yes	5
Coppes ditch at mouth	Kosciusko	21.4	21.4	No	5
Omar-Neff ditch at mouth	Kosciusko	11.5	11.5	No	10
Berlin Court ditch at mouth	Kosciusko	18.6	18.6	No	10
Baugo Creek at mouth	St. Joseph	79.9	79.9	No	5-10
Eller Ditch at mouth	St. Joseph	7.44	7.44	No	5-10
Willow Creek at mouth	St. Joseph	7.80	7.80	No	5
Judy Creek at mouth	St. Joseph	37.7	29.7	No	3-5

[1]USGS gage upstream at Christiana Creek at Elkhart (discontinued).
[2]USGS gage upstream at Turkey Creek at Syracuse.
[3]USGS gage upstream at Fawn River at Orland (discontinued).
[4]USGS gage upstream at Pretty Lake Inlet near Stroh (discontinued).
[5]USGS gage upstream at Rimmell Branch near Albion.
[6]USGS gage upstream at Rimmell Branch near Albion and Forker Creek near Burr Oak.

Suggested Improvements

The areal distribution of the six regional hydrology stations provides adequate coverage for the northern and eastern parts of the basin. Additional stations in the southern and western parts would improve coverage for those areas.

The distribution of stations between those affected and those unaffected by lakes adequately represents the basin. Any additional stations added to the network should maintain this distribution.

The network could be improved by adding stations with contributing drainage areas of about 5, 50, and 200 mi^2.

It is commonly possible to select gaging sites that serve more than one purpose. Of the six stations acceptable for regional hydrologic-data collection, three are multipurpose stations (table 1). When selecting sites for continuous-record stations for any purpose, the factors contributing to acceptable regional-hydrology stations also should be considered. If acceptable, these stations could be used not only to calculate streamflow statistics for the stream on which they are located, but also to estimate flow characteristics for other streams with similar drainage. This practice greatly extends the usefulness of the record.

Partial-record stations might be more desirable than continuous-record stations if only limited information, such as flood frequency and (or) low-flow frequency, is needed. Compared to continuous-record stations, partial record stations cost about one-sixth as much to install and operate (Glatfelter, D. R., U.S. Geological Survey, oral commun., 1985).

Where real-time data are needed, gaging stations can be equipped with telecommunications equipment. This equipment provides stage information by direct telephone access or by satellite communication with a computer.

LAKE-LEVEL MONITORING NETWORK

Description

In 1943, the Geological Survey, in cooperation with the Indiana Department of Conservation (now IDNR), began to monitor lake levels on six lakes in the basin. By 1950, the number of lakes being monitored increased to 49 primarily in response to a State law mandating the Department of Conservation to establish legal levels for all lakes in the State. The established level is based on an average of the high and low levels over the period for which lake data are available. To date, lake-level data have been collected for 98 lakes (table 4 and figure 2). The current network comprises 32 continuous-record gaging stations, which monitor lake levels on 52 lakes.

Table 4.--Lakes of record in the St. Joseph River basin, Indiana

[Site numbers refer to those in figure 2. -----, value has not been determined; +, depth contour map is available for sale by Indiana Department of Natural Resources, State Office Building, Indianapolis, Indiana; -, depth contour map is not available.]

Station number	Site number	Lake	County	Drainage area (square miles)	Surface area (acres)	Established level[1]	Capacity (acre-feet)	Contour map available	Period of record
04097520	I87	Lake Pleasant near Nevada Mills	Steuben	3.18	424	-----	3,490	+	1954-69, 1976-Present
04097550	I86	Lake George at Jamestown	Steuben	[2]14.7	488	985.28	-----	-	1946-Present
04097596	J27	Marsh Lake near Fremont	Steuben	14.9	-----	-----	-----	-	1967-69
04097600	J25	Little Otter Lake near Fremont	Steuben	15.7	34	965.18	740	+	1946-53
04097640	J24	Big Otter Lake near Fremont	Steuben	21.3	69	964.96	1,780	+	1946-53
04097650	J23	Snow Lake at Lake James	Steuben	[2]40.2	310	964.96	7,998	+	1943-49
04097660	J21	Lake James at Lake James	Steuben	[2]47.8	1,034	964.96	33,585	+	1943-49
04097680	I22	Jimmerson Lake at Nevada Mills[3]	Steuben	[2]51.6	434	964.66	4,394	+	1946-Present
04097780	J19	Loon Lake near Angola	Steuben	2.13	138	1,011.98	630	+	1954-66
04097850	I20	Crooked Lake at Crooked Lake	Steuben	10.4	828	988.17	10,555	+	1946-Present
04097950	I8	Lake Gage at Panama	Steuben	[2]17.3	332	954.25	10,140	+	1946-Present
04097960	I9	Lime Lake at Panama	Steuben	[2]17.5	57	954.25	427	+	1946-Present
04098100	J10	Wall Lake near Orland	Lagrange	1.61	141	942.25	1,640	+	1953-54
04098110	J11	Mud Lake near Orland	Steuben	1.85	25	939.01	-----	-	1956-67
04098300	J12	Cedar Lake near Ontario	Lagrange	1.60	120	871.90	1,020	+	1948-51
04099050	J26	Pigeon Lake near Angola	Steuben	[2]35.2	61	988.24	930	+	1954-63
04099100	J18	Fox Lake near Angola	Steuben	[2]1.25	142	1,018.83	3,150	+	1946-53
04099190	J28	Pleasant Lake at Pleasant Lake	Steuben	[2]1.12	53	963.52	1,190	+	1946-66
04099200	I29	Long Lake at Moonlight	Steuben	[2]67.9	92	-----	1,540	+	1946-Present
04099250	I30	Bower Lake near Pleasant Lake	Steuben	[2]84.6	25	948.50	280	+	1946-71, 1976-Present
04099260	I85	Golden Lake near Pleasant Lake[4]	Steuben	[2]88.8	119	948.50	1,810	+	1946-71, 1976-Present
04099400	J17	Silver Lake near Angola	Steuben	[2]3.79	238	959.40	2,540	+	1945-53
04099430	J16	Bass Lake near Angola	Steuben	[2].39	61	979.68	450	+	1954-66
04099440	J15	Howard Lake near Angola	Steuben	[2]3.90	27	977.34	130	+	1954-63
04099500	I14	Hogback Lake near Angola	Steuben	[2]103	146	948.50	1,450	+	1946-Present
04099520	J13	Otter Lake near Flint	Steuben	[2]6.91	118	934.15	1,960	+	1954-66
04099540	J84	Story Lake near Hudson	DeKalb	3.16	77	942.20	1,020	+	1946, 1954-66
04099560	J32	Big Turkey Lake at Stroh	Lagrange	35.8	450	926.61	7,300	+	1945-66
04099575	I31	McClish Lake near Helmer[5]	Lagrange	1.28	35	951.09	1,210	+	1951-74, 1976-Present
04099580	I33	Lake-of-the-Woods near Helmer	Lagrange	5.25	136	951.09	5,470	+	1951-74, 1976-Present

Table 4.--Lakes of record in the St. Joseph River basin, Indiana--Continued

Station number	Site number	Lake	County	Drainage area (square miles)	Surface area (acres)	Established level[1]	Capacity (acre-feet)	Contour map available	Period of record
04099600	I35	Big Long Lake near Stroh	Lagrange	4.77	388	956.2	-----	-	1954-Present
04099620	J36	Pretty Lake near Stroh	Lagrange	2.89	184	965.50	4,720	+	1949-53, 1963-65
04099640	J34	Little Turkey Lake at Elmira	Lagrange	56.5	135	925.72	1,550	+	1945-66
04099660	I39	Royer Lake near Plato[6]	Lagrange	4.69	69	936.50	1,630	+	1952-Present
04099670	I38	Fish Lake near Plato	Lagrange	[2]10.6	100	936.50	4,050	+	1945-Present
04099700	I7	North Twin Lake near Howe	Lagrange	1.54	135	843.56	2,120	+	1953-Present
04099710	J7	South Twin Lake near Howe[7]	Lagrange	2.22	116	843.56	3,600	+	1953-70
04099740	I6	Shipshewana Lake near Shipshewana	Lagrange	[2]6.74	202	852.04	1,350	+	1951-Present
04099760	I5	Fish Lake near Scott	Lagrange	[2]6.21	139	814.42	2,560	+	1954-73, 1976-Present
04099780	I4	Stone Lake near Scott	Lagrange	1.51	152	818.76	2,060	+	1954-73, 1976-Present
04099800	J51	Emma Lake near Emma	Lagrange	13.6	42	880.87	700	+	1954-66
04099810	I3	Cass Lake near Shipshewana	Lagrange	.68	89	-----	873	+	1970-Present
04099820	J1	Hunter Lake near Middlebury	Elkhart	.51	99	856.90	1,120	+	1946-53
04099840	J52	Wolf Lake near Goshen	Elkhart	[2]1.29	100	813.00	-----	-	1947-57
04099860	I2	Heaton Lake near Elkhart	Elkhart	9.33	87	767.30	640	+	1946-53, 1969-74, 1976-Present
04099880	I1	Simonton Lake near Elkhart	Elkhart	7.44	303	772.19	1,560	+	1946-Present
04099950	J83	Indiana Lake near Bristol	Elkhart	.62	122	759.73	3,400	+	1946-53
04100010	J40	Cree Lake near Kendallville	Noble	4.85	58	945.23	910	+	1949-66
04100020	J37	Blackman Lake near Wolcottville	Lagrange	.98	67	974.20	1,210	+	1953-59
04100030	I41	Adams Lake near Wolcottville	Lagrange	5.62	308	953.59	7,690	+	1946-Present
04100040	J47	Atwood Lake near Wolcottville	Lagrange	1.23	170	899.99	1,560	+	1948-53
04100050	I49	Witmer Lake near Wolcottville[8]	Lagrange	36.1	204	897.36	7,040	+	1945-Present
04100060	I49	Westler Lake near Wolcottville[8]	Lagrange	37.8	88	897.36	1,770	+	1945-Present
04100070	I49	Dallas Lake near Wolcottville[8]	Lagraage	39.8	283	897.36	9,970	+	1945-Present
04100080	I44	Martin Lake near Valentine[9]	Lagrange	4.93	26	899.45	890	+	1945-Present
04100090	I44	Olin Lake near Valentine[9]	Lagrange	5.81	103	899.45	9,180	+	1945-Present
04100100	I44	Oliver Lake near Valentine	Lagrange	11.1	362	899.45	15,358	+	1945-Present
04100110	I49	Hackenburg Lake near Wolcottville	Lagrange	55.4	42	897.36	510	+	1945-Present
04100120	I49	Messick Lake near Wolcottville[8]	Lagrange	56.4	68	897.36	1,450	+	1945-Present
04100130	I46	Jones Lake near Cosperville[10,11]	Noble	70.3	114	885.55	960	+	1948-Present
04100140	I66	Bixler Lake at Kendallville	Noble	5.28	120	963.65	2,090	+	1945-Present
04100150	I68	Round Lake at Kendallville[12]	Noble	3.47	99	954.50	2,140	+	1954-Present
04100160	I65	Little Long Lake at Kendallville	Noble	4.55	71	954.50	1,750	+	1954-Present

Table 4.--Lakes of record in the St. Joseph River basin, Indiana--Continued

Station number	Site number	Lake	County	Drainage area (square miles)	Surface area (acres)	Established level[1]	Capacity (acre feet)	Contour map available	Period of record
04100170	J64	Latta Lake near Rome City	Noble	2.52	42	918.71	900	+	1954-66
04100180	I63	Sylvan Lake at Rome City	Noble	33.8	669	916.20	5,986	+	1943-Present
04100190	J67	Sackrider Lake near Kendallville	Noble	1.43	33	-----	740	+	1954-63
04100200	I62	Tamarack Lake near Cosperville[10]	Noble	15.9	50	885.55	880	+	1948-Present
04100210	I62	Steinbarger Lake near Cosperville[10]	Noble	24.3	73	885.55	1,590	+	1948-Present
04100220	I62	Waldron Lake near Cosperville	Noble	134	216	885.55	3,120	+	1948-Present
04100230	J69	Long Lake near Burr Oak	Noble	12.0	40	895.82	630	+	1954-71
04100240	J70	Sand Lake near Burr Oak	Noble	14.9	47	893.56	1,270	+	1946-51
04100250	J71	River Lake near Burr Oak	Noble	18.6	24	-----	380	+	1954-65
04100258	I77	High Lake near Wolflake	Noble	4.43	123	896.35	1,240	+	1961-Present
04100260	I76	Bear Lake near Wolflake	Noble	6.98	136	894.60	3,030	+	1943-Present
04100280	I73	Muncie Lake near Burr Oak	Noble	42.8	47	-----	580	+	1954-Present
04100290	J72	Silver Lake near Wolflake	Noble	.28	34	-----	220	+	1953-63
04100300	I61	Skinner Lake near Albion	Noble	14.0	125	927.74	1,750	+	1945-72, 1977-Present
04100310	J74	Pleasant Lake near Wolflake	Noble	.29	20	-----	540	+	1952-53
04100320	I75	Upper Long Lake near Wolflake	Noble	2.08	86	891.19	1,900	+	1956-Present
04100330	J60	Lower Long Lake near Albion	Noble	4.35	66	889.81	1,560	+	1946-52
04100340	J80	Eagle Lake near Kimmel	Noble	3.22	81	-----	1,050	+	1946-48
04100350	I59	Diamond Lake near Wawaka	Noble	4.80	105	-----	2,580	+	1946-Present
04100360	J58	Sparta Lake at Kimmel	Noble	.69	31	888.50	170	+	1946-51
04100370	I57	Engle Lake near Ligonier	Noble	4.19	48	-----	670	+	1956-71,1977-Present
04100380	I78	Harper Lake near Washington Center	Noble	2.76	11	878.25	160	+	1946-Present
04100390	I78	Knapp Lake near Washington Center[13]	Noble	6.02	88	878.25	3,040	+	1946-Present
04100400	I78	Moss Lake near Washington Center[13]	Noble	6.12	9	878.25	80	+	1946-Present
04100410	I78	Hindman Lake near Washington Center[13]	Noble	8.66	13	878.25	140	+	1946-Present
04100420	J79	Gordy Lake near Cromwell[14]	Noble	9.40	31	876.68	680	+	1953-66
04100425	J79	Rider Lake near Cromwell[14]	Noble	10.9	5	876.68	30	+	1953-66
04100430	J79	Duely Lake near Cromwell[14,15]	Noble	11.2	21	876.68	180	+	1953-66
04100440	J79	Village Lake near Cromwell	Noble	12.0	12	876.68	160	+	1953-66
04100446	J82	Flatbelly Lake near Syracuse	Kosciusko	4.66	326	-----	-----	-	1964-69

Table 4.--Lakes of record in the St. Joseph River basin, Indiana--Continued

Station number	Site number	Lake	County	Drainage area (square miles)	Surface area (acres)	Established level[1]	Capacity (acre feet)	Contour map available	Period of record
04100448	J56	Papakeechie Lake near Syracuse	Kosciusko	5.52	300	-----	-----	-	1964-69
04100450	J55	Wawasee Lake at Wawasee	Kosciusko	36.9	3,060	858.89	67,210	+	1943-66
04100460	I54	Syracuse Lake at Syracuse	Kosciusko	38.2	414	858.87	5,360	+	1943-Present
04100470	I81	Dewart Lake near Leesburg	Kosciusko	[2]8.05	551	867.70	9,000	+	1945-Present
04100480	J53	Wabee Lake near Milford	Kosciusko	[2]14.6	187	829.79	4,750	+	1946-53

[1]Elevation, in feet, above mean sea level.
[2]Contains drainage area (5 percent or greater) that does not contribute directly to surface-water runoff.
[3]Formerly published as Jimerson Lake at Nevada Mills.
[4]Data collected at Bower Lake near Pleasant Lake.
[5]Data collected at Lake-of-the-Woods near Helmer.
[6]Data collected at Fish Lake near Plate.
[7]Data collected at North Twin Lake near Howe.
[8]Data collected at Hackenburg Lake near Wolcottville.
[9]Data collected at Oliver Lake near Valentine.
[10]Data collected at Waldron Lake near Cosperville.
[11]Formerly published as Sanford Lake near Cosperville.
[12]Data collected at Little Long Lake at Kendallville.
[13]Data collected at Knapp Lake near Washington Center.
[14]Data collected at Village Lake near Cromwell.
[15]Formerly published at Duley Lake near Cromwell, and Druely Lake near Cromwell, and Druley Lake near Cromwell.

Existing Network

The network has two purposes. The first is to collect data on lakes without established levels so that a legal level can be established. The second is to provide long-term monitoring of lakes with established levels.

In fulfilling the first purpose, legal levels have been established for 85 of the 98 lakes for which data have been collected. Of the remaining 13, 8 have 10 years or more of data. The other five have less than 10 years of data and are not currently being monitored.

The second purpose of the network -- to monitor levels in lakes with legal levels -- provides a way to monitor the fluctuations above and below the legal level. Fluctuations can be a problem especially where lakes are surrounded by farmland or by seasonal or permanent communities. A relatively small rise in lake levels, generally occurring in the spring, can cause local flooding where relief is flat and surface drainage is poor. During late summer and autumn, lower lake levels increase hazards for boating and other recreational activities.

In an attempt to control lake levels, IDNR maintains 43 control structures that affect the levels of 56 lakes of record (table 5). The effectiveness of these structures depends on the factors that influence the water budgets of lakes. Components of a lake budget include precipitation, evapotranspiration, surface-water inflow and outflow, ground-water inflow and outflow, and change in lake storage. Of these components, surface-water inflow and outflow and change in lake storage are most affected by control structures--that is, control structures are most effective for lakes with substantial surface-water inflow and outflow. For many lakes in the basin, especially those in permeable outwash deposits with little or no surface water flux, ground water may represent the largest component of inflow and outflow. For these lakes, control structures are less effective especially during periods when the elevation of the water table surrounding the lake is lower than the elevation of the crest of the control structure.

Heaton Lake near Elkhart (fig. 3), site number 12 (fig. 2), provides an example of a lake for which ground water probably accounts for a major part of the water budget. The lake drains 9.33 mi^2 and has a maximum depth of 22 ft. Outflow from the lake is controlled by a fixed-crest concrete weir. The surficial geology of the area indicates the lake is developed in highly permeable outwash deposits (Kirshner and McCarta, 1974). Observation wells Elkhart-5 and Elkhart-6 near the lake are finished in surficial outwash at depths of 13 ft and 22 ft below land surface. A comparison of hydrographs for the two wells with a hydrograph of the lake for 1979 to 1983 indicates a good hydraulic connection between the lake and surrounding outwash aquifer (fig. 4). An analysis of lake level data by Paul Chester (Indiana Department of Natural Resoures, Division of Water, written commun., 1981) showed that water levels in Heaton Lake are at least one foot below the elevation of the weir more than 50 percent of the time. Chester's work indicates that, in addition to Heaton Lake, at least 14 other lakes have water levels below the elevation of the control structure more than half of the time (table 6).

Table 5.--Surface-water inflow and outflow conditions and type of outflow control for lakes of record in the St. Joseph River basin, Indiana

[Site numbers refer to those in figure 2; UNS, unnamed stream]

Station number	Site number	Lake	County	Surface-water inflow[1]	Surface-water outflow[1] and [type of outflow control][2]
04097520	I87	Lake Pleasant near Nevada Mills	Steuben	None	UNS [natural]
04097550	I86	Lake George at Jamestown	Steuben	UNS--outlet from Silver Lake	Crooked Creek [variable]
04097596	J27	Marsh Lake near Fremont	Steuben	UNS--outlet from Sisters Lake; 3 UNS	Follette Creek [natural]
04097600	J25	Little Otter Lake near Fremont	Steuben	Follette Creek--outlet from Marsh Lake and Green Lake	Big Otter Lake [natural]
04097640	J24	Big Otter Lake near Fremont	Steuben	Little Otter Lake; 1 UNS	Follette Creek [natural]
04097650	J23	Snow Lake at Lake James	Steuben	Follette Creek--outlet from Big Otter Lake; Crooked Creek--outlet from Mud Lake; 1 UNS	Lake James [fixed-indirect]
04097660	J21	Lake James at Lake James	Steuben	Snow Lake; 2 UNS	Jimmerson Lake [fixed-indirect]
04097680	I22	Jimmerson Lake at Nevada Mills	Steuben	Lake James	Crooked Creek [fixed]
04097780	I19	Loon Lake near Angola	Steuben	UNS--outlet from Buck Lake	UNS [natural]
04097850	I20	Crooked Lake at Crooked Lake	Steuben	2 UNS--outlets from Center Lake and Loon Lake; 1 UNS	UNS [variable]
04097950	I8	Lake Gage at Panama	Steuben	UNS--outlet from Crooked Lake	Lime Lake [variable]
04097960	I9	Lime Lake at Panama	Steuben	Lake Gage	UNS [variable]
04098100	J10	Wall Lake near Orland	Lagrange	None	Wetland [fixed]
04098110	J11	Mud Lake near Orland	Steuben	None	Wetland [fixed]
04098300	J12	Cedar Lake near Ontario	Lagrange	UNS--outlet from Duff Lake	UNS [fixed]
04099050	J26	Pigeon Lake near Angola	Steuben	Pigeon Creek; Ewing ditch	Pigeon Creek [natural]
04099100	J18	Fox Lake near Angola	Steuben	None	UNS [variable]
04099190	J28	Pleasant Lake at Pleasant Lake	Steuben	None	None
04099200	J29	Long Lake at Moonlight	Steuben	Pigeon Creek	Pigeon Creek [natural]
04099250	I30	Bower Lake near Pleasant Lake	Steuben	Pigeon Creek--outlet from Long Lake	Golden Lake [natural]
04099260	I85	Golden Lake near Pleasant Lake	Steuben	Pigeon Creek--outlet from Bower Lake; UNS--outlet from Tamarack Lake; 1 UNS	Pigeon Creek [natural]
04099400	J17	Silver Lake near Angola	Steuben	None	UNS [fixed]
04099430	J16	Bass Lake near Angola	Steuben	None	None
04099440	J15	Howard Lake near Angola	Steuben	None	None
04099500	I14	Hogback Lake near Angola	Steuben	Pigeon Creek--outlet from Golden Lake; UNS--outlet from Silver Lake; 1 UNS	Pigeon Creek [natural]
04099520	J13	Otter Lake near Flint	Steuben	UNS--outlet from Gravel Lake	Pigeon Creek [variable]
04099540	J84	Story Lake near Hudson	DeKalb	None	UNS [natural]
04099560	J32	Big Turkey Lake at Stroh	Lagrange	Turkey Creek; Mud Creek--outlet from Henry Lake; UNS--outlet from unnamed lake	Turkey Creek [fixed]
04099575	I31	McClish Lake near Helmer	Lagrange	None	Lake-of-the-Woods [fixed-indirect]

Table 5.--Surface-water inflow and outflow conditions and type of outflow control for lakes of record in the St. Joseph River basin, Indiana--Continued

Station number	Site number	Lake	County	Surface-water inflow[1]	Surface-water outflow[1] and [type of outflow control][2]
04099580	I33	Lake-of-the-Woods near Helmer	Lagrange	Outlet from McClish Lake; outlet from Spectacle Lake	UNS [fixed]
04099600	I35	Big Long Lake near Stroh	Lagrange	UNS	UNS [fixed]
04099620	J36	Pretty Lake near Stroh	Lagrange	None	UNS [variable]
04099640	J34	Little Turkey Lake at Elmira	Lagrange	Turkey Creek; UNS--outlet from Mud Lake and Pretty Lake	Turkey Creek [fixed]
04099660	I39	Royer Lake near Plato	Lagrange	UNS	UNS--inlet to Fish Lake [natural]
04099670	I38	Fish Lake near Plato	Lagrange	UNS--outlet from Royer Lake; UNS--outlet from Grass Lake	Fly Creek [Natural]
04099700	I7	North Twin Lake near Howe	Lagrange	UNS--outlet from Still Lake	South Twin Lake [fixed-indirect]
04099710	J7	South Twin Lake near Howe	Lagrange	North Twin Lake	UNS [fixed]
04099740	I6	Shipshewana Lake near Shipshewana	Lagrange	UNS--outlet from Cotton Lake	Page ditch [fixed]
04099760	I5	Fish Lake near Scott	Lagrange	UNS	UNS [variable]
04099780	I4	Stone Lake near Scott	Lagrange	None	Wetland [fixed]
04099800	J51	Emma Lake near Emma	Lagrange	UNS	Bontrager ditch [natural]
04099810	I3	Cass Lake near Shipshewana	Lagrange	None	UNS [fixed]
04099820	J1	Hunter Lake near Middlebury	Elkhart	None	East Lake ditch [natural]
04099840	J52	Wolf Lake near Goshen	Elkhart	None	UNS [natural]
04099860	I2	Heaton Lake near Elkhart	Elkhart	UNS	Puterbaugh Creek [fixed]
04099880	I1	Simonton Lake near Elkhart	Elkhart	None	None
04099950	J83	Indiana Lake near Bristol	Elkhart	None	UNS [natural]
04100010	J40	Cree Lake near Kendallville	Noble	UNS--outlet from Schockopee Lake	Little Elkhart River [fixed]
04100020	J37	Blackman Lake near Wolcottville	Lagrange	None	UNS [variable]
04100030	J41	Adams Lake near Wolcottville	Lagrange	None	UNS [fixed]
04100040	J47	Atwood Lake near Wolcottville	Lagrange	None	UNS [natural]
04100050	I49	Witmer Lake near Wolcottville	Lagrange	Little Elkhart Creek; UNS--outlet from Atwood Lake; 2 UNS	Westler Lake [variable-indirect]
04100060	I49	Westler Lake near Wolcottville	Lagrange	Witmer Lake	Dallas Lake [variable-indirect]
04100070	I49	Dallas Lake near Wolcottville	Lagrange	Westler Lake	Hackenburg Lake [variable-indirect]
04100080	I44	Martin Lake near Valentine	Lagrange	UNS--outlet from Smith hole; 2 UNS	Olin Lake [variable-indirect]
04100090	I44	Olin Lake near Valentine	Lagrange	Martin Lake	Oliver Lake [variable-indirect]
04100100	I44	Oliver Lake near Valentine	Lagrange	Olin Lake; Dove Creek; 1 UNS	Oliver Lake Outlet [variable]
04100110	I49	Hackenburg Lake near Wolcottville	Lagrange	Dallas Lake; Oliver Lake Outlet	Messick Lake [variable]
04100120	I49	Messick Lake near Wolcottville	Lagrange	Hackenburg Lake	North Branch Elkhart River [variable]
04100130	I46	Jones Lake near Cosperville	Noble	North Branch Elkhart River; 2 UNS	Waldron Lake; North Branch Elkhart [variable-indirect]
04100140	I66	Bixler Lake at Kendallville	Noble	None	Bixler Lake ditch [variable]

Table 5.--Surface-water inflow and outflow conditions and type of outflow control for lakes of record in the St. Joseph River basin, Indiana--Continued

Station number	Site number	Lake	County	Surface-water inflow[1]	Surface-water outflow[1] and [type of outflow control][2]
04100150	I68	Round Lake at Kendallville	Noble	UNS--outlet from Little Whitford Lake	Little Long Lake [fixed-indirect]
04100160	I65	Little Long Lake at Kendallville	Noble	UNS--outlet from Round Lake	Waterhouse ditch [fixed]
04100170	J64	Latta Lake near Rome City	Noble	UNS--outlet from Grannis Lake	UNS [fixed]
04100180	I63	Sylvan Lake at Rome City	Noble	Oviatt ditch--outlet from Latta Lake and Wible Lake; Henderson Lake ditch--outlet from Henderson Lake	Little Lake [variable]
04100190	J67	Sackrider Lake near Kendallville	Noble	None	UNS [natural]
04100200	I62	Tamarack Lake near Cosperville	Noble	Clock Creek	Steinbarger Lake [variable-indirect
04100210	I62	Steinbarger Lake near Cosperville	Noble	Tamarack Lake; Dry Run	Waldron Lake [variable-indirect]
04100220	I62	Waldron Lake near Cosperville	Noble	Steinbarger Lake	North Branch Elkhart River [variable]
04100230	J69	Long Lake near Burr Oak	Noble	Thuma Stream	UNS [natural]
04100240	J70	Sand Lake near Burr Oak	Noble	UNS--outlet from Long Lake	UNS [natural]
04100250	J71	River Lake near Burr Oak	Noble	UNS--outlet from Mud Lake	UNS [natural]
04100258	J77	High Lake near Wolflake	Noble	None	UNS [fixed]
04100260	I76	Bear Lake near Wolflake	Noble	UNS--outlet from High Lake; UNS--outlet from Wolf Lake	Wetlands [fixed]
04100280	I73	Muncie Lake near Burr Oak	Noble	Forker Creek; Carrol Creek; Brown ditch	Williams Lake [natural]
04100290	J72	Silver Lake near Wolflake	Noble	None	UNS--inlet to Pretty Lake [natural]
04100300	I61	Skinner Lake near Albion	Noble	Rimmell Branch; UNS--outlet from Sweet Lake	Croft ditch [fixed]
04100310	J74	Pleasant Lake near Wolflake	Noble	None	None
04100320	I75	Upper Long Lake near Wolflake	Noble	UNS	UNS--inlet to Dollar Lake [natural]
04100330	J60	Lower Long Lake near Albion	Noble	UNS--outlet from Upper Long Lake; UNS--outlet from Russell Lake	UNS [fixed]
04100340	J80	Eagle Lake near Kimmel	Noble	UNS	UNS [fixed]
04100350	I59	Diamond Lake near Wawaka	Noble	UNS--outlet from Eagle Lake; UNS	UNS [natural]
04100360	J58	Sparta Lake at Kimmel	Noble	None	Sparta Lake ditch [natural]
04100370	I57	Engle Lake near Ligonier	Noble	Sparta Lake ditch	Sparta Lake ditch [natural]
04100380	J78	Harper Lake near Washington Center	Noble	Little Bause Lake; UNS	Knapp Lake [natural]
04100390	I78	Knapp Lake near Washington Center	Noble	Harper Lake; Little Knapp Lake	Moss Lake [natural]
04100400	I78	Moss Lake near Washington Center	Noble	Knapp Lake	Hindman Lake [natural]

Table 5.--Surface-water inflow and outflow conditions and type of outflow control for lakes of record in the St. Joseph River basin, Indiana--Continued

Station number	Site number	Lake	County	Surface-water inflow[1]	Surface-water outflow[1] and [type of outflow control][2]
04100410	I78	Hindman Lake near Washington Center	Noble	Moss Lake; UNS	UNS [natural]
04100420	J79	Gordy Lake near Cromwell	Noble	UNS--outlet from Hindman Lake	Rider Lake [natural]
04100425	J79	Rider Lake near Cromwell	Noble	Gordy Lake	Duely Lake [natural]
04100430	J79	Duely Lake near Cromwell	Noble	Rider Lake	Village Lake [natural]
04100440	J79	Village Lake near Cromwell	Noble	Duely Lake; 1 UNS	Turkey Creek [natural]
04100446	J82	Flatbelly Lake near Syracuse	Kosciusko	None	Papakeechie Lake [variable]
04100448	J56	Papakeechie Lake near Syracuse	Kosciusko	UNS--outlet from Spear Lake	Wawasee Lake [fixed]
04100450	J55	Wawasee Lake at Wawasee	Kosciusko	Turkey Creek; Dillion Creek; Papakeechie Lake; 2 UNS	Syracuse Lake [variable]
04100460	I54	Syracuse Lake at Syracuse	Kosciusko	Wawasee Lake; 1 UNS	Turkey Creek [variable]
04100470	I81	Dewart Lake near Leesburg	Kosciusko	Westlake ditch	Hammond ditch [fixed]
04100480	J53	Wabee Lake near Milford	Kosciusko	Hammond ditch; 1 UNS	UNS [natural]

[1] Source of data is U.S. Geological Survey 7.5 min. topographic maps. Data not verified by field observation.
[2] Source of data is Indiana Department of Natural Resources, Division of Water.

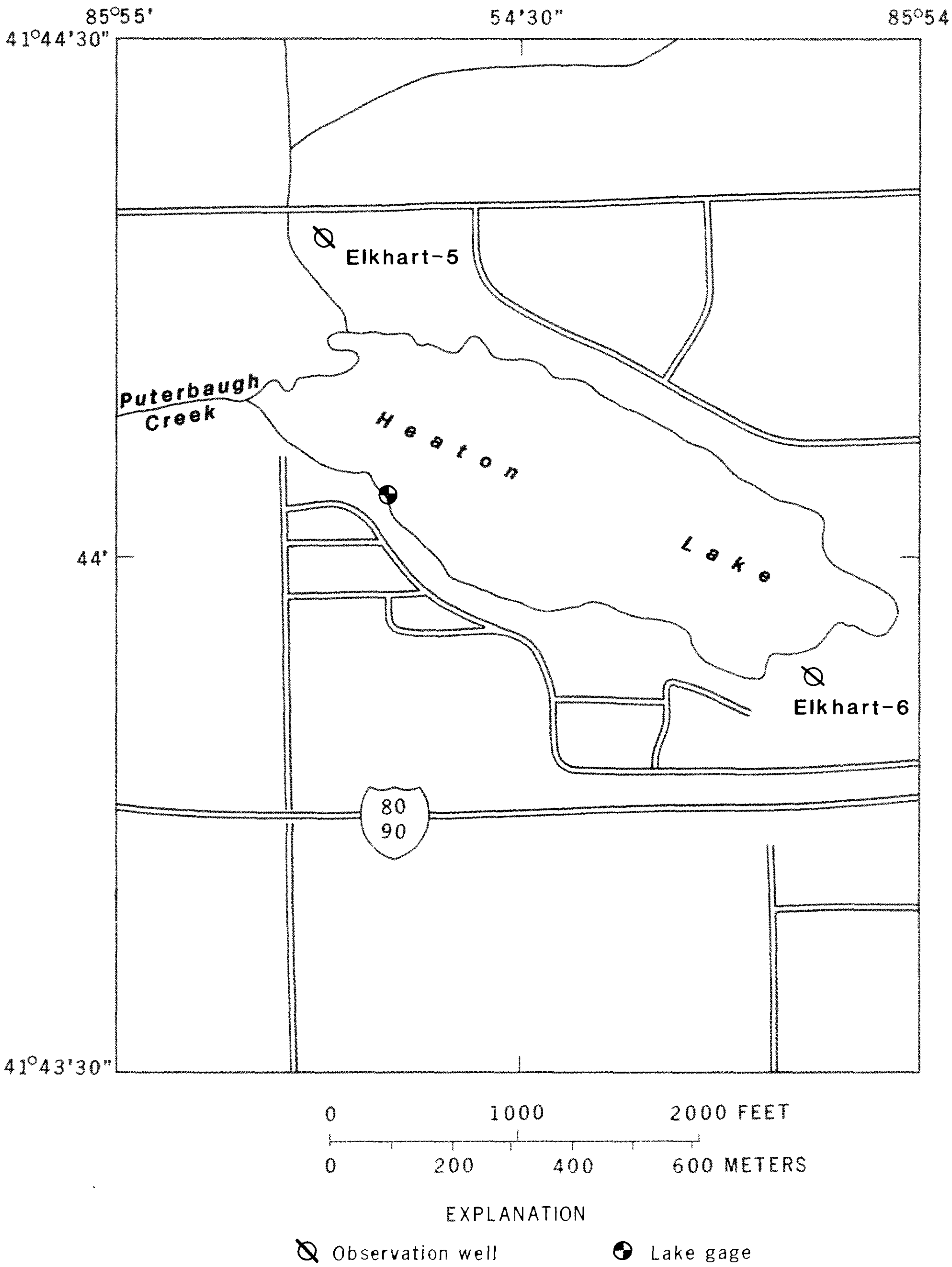


Figure 3.-- Location of observation wells Elkhart-5 and Elkhart-6 relative to Heaton Lake.

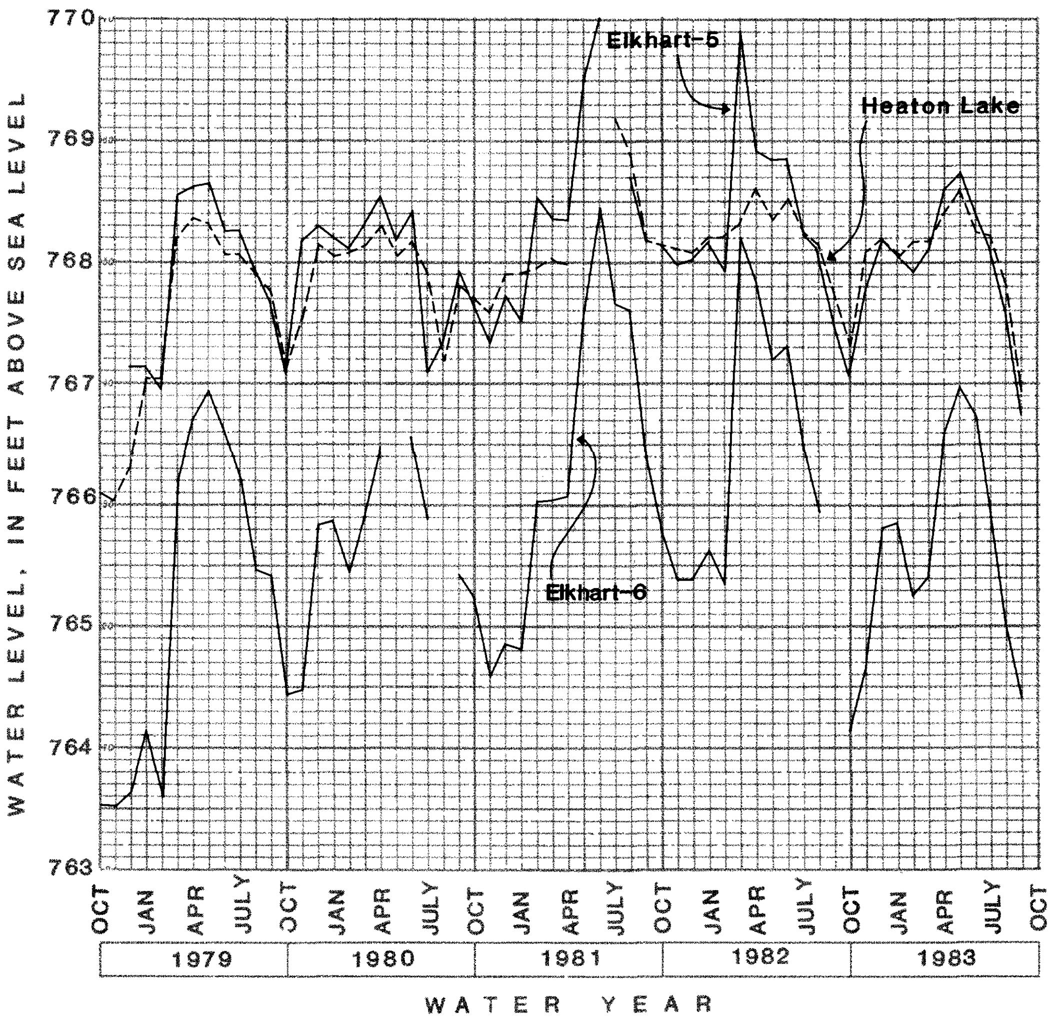


Figure 4.-- Maximum monthly water levels in Heaton Lake and in observation wells Elkhart-5 and Elkhart-6, 1979-83 water years.

Table 6.--Lakes with water levels below the elevation of the control structure more than 50 percent of the time.

[Information provided by Indiana Department of Natural Resources, Division of Water]

Lake	County	Lake	County
Bear Lake near Wolflake	Noble	Little Long Lake at Kendallville	Noble
Big Long Lake near Stroh	Lagrange	Little Turkey Lake at Elmira	Lagrange
Bixler Lake at Kendalville	Noble	Mud Lake near Orland	Steuben
Blackman Lake near Wolcottville	Lagrange	Pretty Lake near Stroh	Lagrange
Fish Lake near Scott	Lagrange	Skinner Lake near Albion	Noble
Heaton Lake near Elkhart	Elkhart	South Twin near Howe	Lagrange
Latta Lake near Rome City	Noble	Syracuse Lake at Syracuse	Kosciusko
		Wawasee Lake at Wawasee	Koscuisko

The causes of low lake levels are likely to be different among the lakes, but a knowledge of their water budgets would certainly be needed to identify the causes. Presumably, rates of precipitation and evapotranspiration are similar among all lakes in the basin, and surface water inflow and outflow are relatively easy to measure. However, the ground-water component of lake budgets can be highly variable from one lake to another and is usually the most difficult component to estimate. Existing information on glacial geology and ground-water flow is not adequate to evaluate the ground water component for lakes in the basin. This subject is discussed in more detail in the section "Ground-water-level monitoring network" (page 35).

Suggested Improvements

Assessment of the monitoring network for lake levels suggests several types of analyses that could be done with existing data to improve current knowledge of the lakes in the basin.

An analysis of lake-level frequency using long-term lake-level records could provide information on the magnitude and frequency of flooding.

A comparison of the fluctuations in lake levels before and after the installation of control structures could be used to evaluate the effectiveness of the structures in maintaining legal levels during drought periods.

For lakes with water levels frequently below the elevation of the crest, a review of pre-structure water levels and a preliminary water budget analysis would be useful in re-evaluating the elevation of crest. By including information on hydrogeology, ground-water flow to and from the lake could be evaluated. This analysis would also be useful during planning stages for anticipated control structures.

Legal levels could be established for lakes with adequate data.

GROUND-WATER-LEVEL MONITORING NETWORK

Description

In 1935, the Geological Survey and the Indiana Department of Conservation (now IDNR) began a cooperative program to monitor water levels in 87 wells in the northern part of the State. Seven of these wells were in the basin (table 7). From 1944 to 1947, 21 wells were added to the basin network. Of these, 17 were in St. Joseph County, and were used to monitor changes in water levels in the vicinity of South Bend (fig. 2). By the mid 1950's many of these wells were discontinued because of the close similarity of their water level patterns.

Currently, the network in the basin comprises 15 observation wells with water-level recorders (table 7). The data are collected for four purposes:

- To determine the interaction between ground water and lakes.
- To measure changes in ground-water levels near high-production irrigation wells.
- To measure changes in water-levels at special purpose (small area) sites.
- To measure long-term changes in water levels in areas not affected by pumping.

Table 7.--Observation wells in the St. Joseph River basin, Indiana

[Site numbers refers to those in figure 2. ---, value was not determined]

Station number	Site number	Well	Elevation (feet above mean sea level)	Screened interval (feet below land surface)	Period of record	Purpose
414145085583401	L31	Elkhart 1	---	---	1935-45	none
413246085445601	L13	Elkhart 2	---	---	1945-52	none
413428085493701	L14	Elkhart 3	---	---	1950-71	none
413121085481301	K5	Elkhart 4	818	58-60	1966-Present	Irrigation
414419085544601	K1	Elkhart 5	771	11-13	1976-Present	Lake
414351085540401	K2	Elkhart 6	774	20-22	1976-Present	Lake
414514085505001	K21	Elkhart 7	781	56-61	1981-Present	Irrigation
414446086002501	K23	Elkhart 8	763.36	70-80	1983-Present	Special purpose
412236085401401	L26	Kosciusko 1	---	---	1937-41	none
412237085401401	L15	Kosciusko 2	---	---	1938-66	none
412007085531001	L20	Kosciusko 3	---	---	1945-52	none
412500085384501	K8	Kosciusko 5	870	11-13	1976-Present	Lake
412554085450001	K6	Kosciusko 6	870	20-23	1978-Present	Lake
412510085442801	K7	Kosciusko 7	870	21-24	1978-Present	Lake
412404085442501	K13	Kosciusko 8	863	24-27	1978-Present	Lake
412556085513401	K24	Kosciusko 9	830.90	99-102	1982-Present	Irrigation
413830085285701	L30	Lagrange 1	---	---	1945-46	none
414318085200601	K3	Lagrange 2	910	80-86	1980-Present	Irrigation
414158085253401	K22	Lagrange 3	870	35-40	1981-Present	Irrigation
412629085150801	L16	Noble 1	---	---	1935-46	none
411558085255801	L28	Noble 2	---	---	1935-44	none
411800085265201	L18	Noble 3	---	---	1935-47	none
412434085185801	L17	Noble 5	---	---	1942-52	none
412626085150801	L29	Noble 6	---	---	1946-66	none
411740085263701	L19	Noble 7	---	---	1947-52	none
411922085221801	K11	Noble 8	928	146-148	1966-71 and 1974-Present	Long-term trend
413106085232701	K9	Noble 9	930	39-42	1976-Present	Long-term trend
412948085223401	K10	Noble 10	920	21-24	1978-Present	Lake
413956086092801	L8	St. Joseph 1	---	---	1935-52	none
414023086170001	L24	St. Joseph 4	---	---	1944-52	none

Table 7.--Observation wells in the St. Joseph River basin, Indiana--Continued

Station number	Site number	Well	Elevation (feet above mean sea level)	Screened interval (feet below land surface)	Period of Record	Purpose
414027086170001	L25	St. Joseph 5	---	---	1944-52	none
414038086150501	L3	St. Joseph 6	---	---	1944-53	none
414106086173701	L4	St. Joseph 8	---	---	1944-53	none
413927086170301	L1	St. Joseph 9	---	---	1945-70	none
414000086150501	L7	St. Joseph 10	---	---	1945-47	none
413932086171901	L23	St. Joseph 11	---	---	1945-49	none
413954086160401	L5	St. Joseph 12	---	---	1945-50	none
414216086082001	L9	St. Joseph 14	---	---	1945-47	none
414317086171401	L21	St. Joseph 15	---	---	1945-47	none
414220086154301	L22	St. Joseph 16	---	---	1945-59	none
414033086130501	L6	St. Joseph 17	---	---	1945-62	none
413910086161701	L32	St. Joseph 20	---	---	1945-47	none
414023086151001	L33	St. Joseph 21	---	---	1945-70	none
414023086151002	L2	St. Joseph 22	---	---	1946-52	none
414153086160201	L34	St. Joseph 87	---	---	1945	none
414052086124201	L35	St. Joseph 88	---	---	1945	none
414236085014601	L10	Steuben 1	---	---	1935-66	none
414237085014201	L11	Steuben 2	---	---	1935-52	none
414236085014602	L12	Steuben 3	---	---	1955-71	none
414108085025101	L27	Steuben 4	---	---	1976-79	none
414109085025701	L4	Steuben 5	---	---	1979-82	none

Existing Network

In 1976, the ground-water network in the State was reviewed by Marie (1976). His suggestions for modifying the network included (1) installing observation wells in areas with special ground-water problems or potential problems, (2) ensuring that the type of record being collected on each well is consistent with its purpose, (3) determining the accuracy requirements for data of all the wells in the network, and (4) periodically re-evaluating the network to ensure that the State's objectives remain valid and that the network is adequately meeting those objectives. Marie also proposed seven well classifications for grouping the wells in the network:

(1) Long-term trend (continuous monitoring)
(2) Long-term trend (periodical monitoring)
(3) Short-term unaffected by pumpage
(4) Short-term affected by pumpage
(5) Project
(6) Current-purpose
(7) Discontinued

Water levels from seven wells near three gaged lakes have been monitored since 1978 in an attempt to draw inferences about the effect of ground-water on lake levels (table 8). Comparisons of water levels in the wells and nearby lakes have been useful in observing correlations between fluctuations in the water table and lake levels (see section "Lake-level Monitoring Network"). However, the wells have not provided quantitative information on cause-and-effect relations between ground-water flow and lake levels, because the number and (or) location of the wells is not adequate to define the water-table configuration in the vicinity of the lakes.

Moreover, recent hydrogeologic studies demonstrate that the relations between ground water and lakes are much more complex than was assumed when the network was installed. Hypothetical lake and ground-water systems have been simulated by Winter (1976) and McBride and Pfaunkuch (1975), and real lake and ground-water systems have been simulated by Larson and others (1975), Munter (1979), Siegel and Winter (1980), and Winter and Carr (1980). These studies demonstrate that ground-water flow near and below lakes as well as between lakes in multiple-lake settings, such as those found in the St. Joseph River basin, can be influenced by depth of the lake(s), the local water-table configuration, and the heterogeneity and anisotropy of the underlying aquifer system. Seigel (1981, 1983) has shown these factors also to be important for ground-water flow near wetlands. These steady-state model studies of lakes and wetlands show that the scale of ground-water flow paths toward and away from lakes is controlled by these factors and varies considerably from one hydrogeologic setting to another.

Agricultural irrigation has become the major consumptive use of water in the basin and may double by the year 2000 (Governor's Water Resource Study Commission, 1980, p. 482). The authors estimate that at least two-thirds of the water used for irrigation is from ground-water withdrawals.

Table 8.--Active observation wells near lakes in the St. Joseph River basin, Indiana

Well	Lake
Elkhart 5	Heaton Lake
Elkhart 6	Heaton Lake
Noble 10	Sylvan Lake
Kosciusko 6	Syracuse Lake
Kosciusko 7	Syracuse Lake
Kosciusko 8	Syracuse Lake

Five observation wells are located in four areas of intensive irrigation to monitor water levels year-round. Elkhart-4 is south of Goshen, Elkhart-7 is north of Elkhart, Kosciusko-9 is north of Milford, and Lagrange 2 and 3 are east and south of Howe (fig. 2). At least three high-production wells for irrigation are within a 1-mile radius of each of the observation wells.

Hydrographs of maximum daily water levels for five wells closely resemble each other. The hydrographs of well Elkhart-4 for the 1967 and 1983 growing season (April through September) provides an example (fig. 5). The hydrograph of well Elkhart-8 (located away from irrigation pumping) for the same 6-month period in 1983 is provided for comparison. The three hydrographs are all remarkably similar. Any effects of irrigation pumping (June through August) on the water levels of well Elkhart-4 or on the water levels of the four other observation wells near irrigation are not apparent from the water-level records collected to date.

The reasons for the apparent lack of effect of irrigation on ground-water levels, are the relatively high transmissivity (5,000 to 16,000 ft^2/d) of the glacial aquifers, the relatively high rates (10 inches/year) of recharge, and the relatively small demand (compared to supply) placed on the system. Imbrigiotta and Martin (1981) studied the northwestern corner of Elkhart County and noted high transmissivity and recharge for outwash aquifers. These factors were explored more fully by Bailey and others (1985) and Lindgren and others (1985) for two irrigation areas near Milford and Howe.

One observation well, Elkhart-8, was installed to monitor ground-water levels at a special-purpose site. This well was installed in 1983 to continuously monitor water levels in an outwash aquifer near Elkhart. The well provides information in support of a ground-water quality monitoring program by the City of Elkhart. Data from the well are used to characterize long-term water-level trends and identify appropriate times for sampling. Elkhart-8 is expected to provide valuable information for the water-quality sampling program for the foreseeable future.

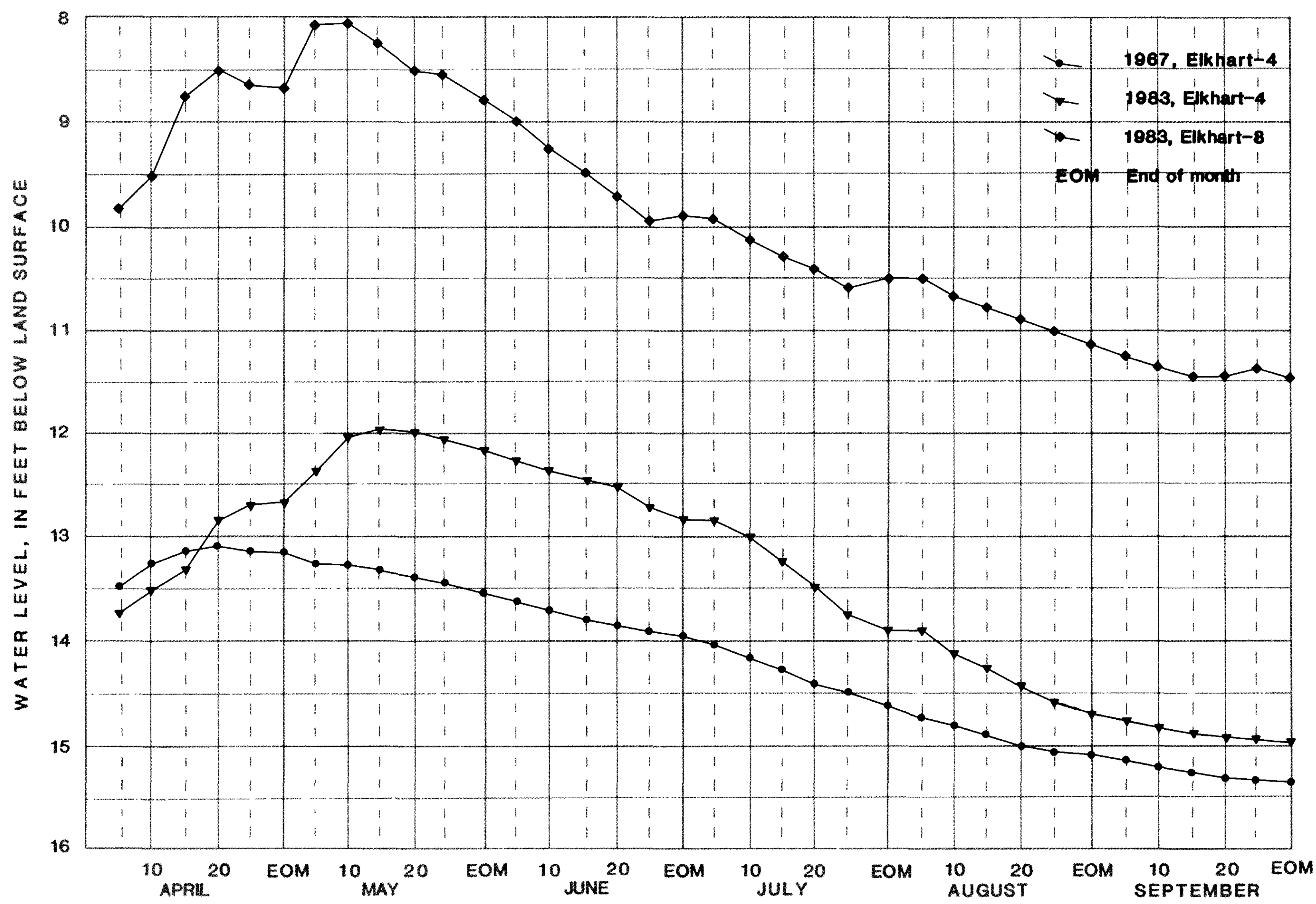


Figure 5.- Maximum daily water levels in observation well Elkhart-4, April through September , 1967 and 1983, and in observation well Elkhart-8, April through September 1983.

Two observation wells (Noble-9 and Noble-8) were installed to monitor long-term changes in water levels in areas not affected by pumping. Noble 9 is located at an intrabasin, surface-water divide. This well was installed to evaluate water-level changes in a natural lakes area. The pattern of the hydrograph (fig. 6) is similar to the patterns for other observations wells in the basin, but the magnitude of the fluctuations (up to 8 ft) is much greater than it is for the other wells. The large fluctuations probably result from the position of the well on a ground-water divide--an area that would be subject to large water-table fluctuations during and following recharge events.

Noble 8 is screened in a deep, confined aquifer. The fluctuations in water levels in the aquifer are small compared to fluctuations in the other wells (fig. 6). The small fluctuations probably result from the well tapping a regional flow system which would be subject to small variations in recharge and discharge. It is doubtful that either Noble 9 or Noble 8 will provide additional useful information unless increased water withdrawal is anticipated nearby or other objectives for the wells can be identified.

Suggested Improvements

The purposes of the ground-water network have evolved from general monitoring of background water levels to addressing several more specific objectives. The eight wells near lakes have provided sufficient information on the degree of similarity between fluctuations in ground-water levels and nearby lake levels. If more quantitative analysis of interaction between ground water and lakes is needed, the present network needs modification.

A minimum of two and preferably more closely spaced wells along a line perpendicular to the lake's shoreline could provide useful information about the water-table configuration from which inferences about ground-water flow to the lake could be drawn. At many of the lakes in the basin, several nests of wells screened at different vertical intervals may be necessary to provide a preliminary understanding of the interactions of the lake with the surrounding ground-water system. Without these improvements, the present network will probably provide no additional useful hydrologic data for either water management or scientific study, and could be considered for abandonment.

The five wells near irrigation withdrawals show no effect from pumping. Recent studies in the irrigation areas near Milford and Howe conclude that withdrawals for irrigation would have to increase several fold before water levels would be significantly affected. The observation wells appear to adequately represent water levels in their respective areas and may be useful in monitoring effects from future water-use development.

Another area that could be considered for monitoring of the effects of large withdrawals is the South Bend and Mishawaka municipal well fields, which represent the largest ground-water withdrawal in the basin. More than 30 Mgal/d were withdrawn from the municipal wells in 1978 (Governor's Water Resource Study Commission, 1980). The effect of large-scale, year-round pumping on ground-water levels in that area is not known.

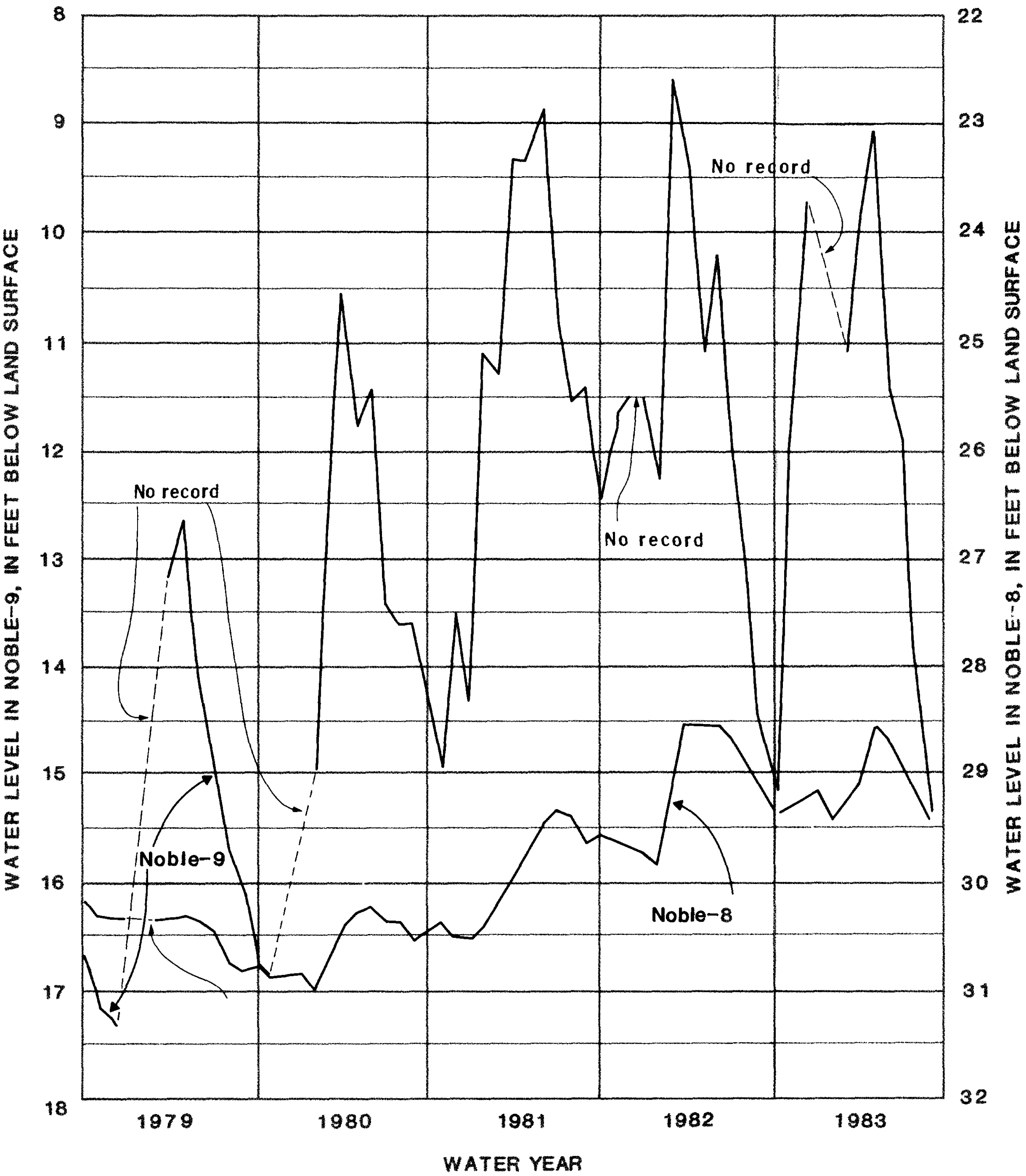


Figure 6.– Maximum monthly water levels in observation wells Noble-8 and Noble-9, 1979-83 water years.

Perhaps the greatest needs for ground-water information in the basin are a delineation of the major aquifer systems and a better understanding of ground-water flow patterns. These needs are not easily met because of the complexity of the hydrogeologic environment, as was discovered in the studies near Howe and Milford. However, when changes are planned to the present network obtaining this information would be helpful, in assessing potential effects of ground water contamination, or in evaluating water-resources in the basin.

CLIMATIC-CONDITIONS MONITORING NETWORK

Climatic data are needed to provide estimates of several components of the hydrologic cycle. Measurements of temperature, humidity, precipitation, and evaporation are used in computing runoff, recharge, and potential evapotranspiration.

Description

Since 1892, climatic data have been collected at as many as 16 stations throughout the basin (fig. 2). The period of record and type of data collected at each station are listed in table 9. At present, the National Weather Service (NWS) maintains six stations for which data are published. The longest continuous record (90 years) of climatic data has been collected at South Bend, which is one of three first order (complete) weather stations in the state. Currently, precipitation data are collected at all six stations. Prairie Heights is the only station where evaporation data are collected. Climatic summaries from the National Climatic Data Center, Ashville, N.C., are on file at IDNR Division of Water. Additional data for Indiana are available from the National Weather Service Office at Purdue University.

Three purposes are defined for NWS climatic stations:

(A) Climatic-network stations are index stations collecting long term data that represent climatic conditions over broad areas of uniform terrain and climate. At least one climatic-network station is established every 625 mi^2 throughout the U.S. (Bernard Spitler, National Weather Service, Kansas City, Missouri, oral commun., 1985).

(B) Hydrologic-network stations are part of the flood-forecasting program of the National Weather Service. Precipitation events at these stations are reported immediately to regional flood-forecasting centers for use in flood prediction. Climatic-network stations and hydrologic-network stations are considered permanent and are rarely changed.

(C) Special-use stations fulfill a variety of local meteorological functions usually related to agriculture.

The purposes of the active climatic stations in the basin for which data are published are listed in table 9.

In addition to these six stations, NWS operates two stations for which data are not published. One at Ligonier is a hydrologic-network station and collects precipitation data. The other at Waterford Mills is a special-use station and collects data for agricultural purposes.

Table 9.--Climatic stations in the St. Joseph River basin, Indiana

[Site numbers refer to those in figure 2. A, climatic network; B, hydrologic network; C, special use; E, evaporation; P, precipitation; T, temperature; ---, discontinued station. Sources: annual summaries Climatological Data 1930-83, NOAA, National Oceanic and Atmospheric Administration, National Climatic Center, Ashville, N. C.]

Site number	Station	Period of record	Type of data	Type of station
N8	Albion 5E	1927-72	T,P	---
N7	Angola	1899-Present	T,P	A,B
N9	Elkhart	1951-78	P	---
N4	Goshen College	1925-Present	T,P	A,B
N3	Goshen Airport	1942-61	P	---
N10	Howe Military Academy	1906-51	T,P	---
N11	Kendallville	1947-72	T,P	---
		1951-72	E	---
N9	Kendallville 2	1940-Present	P	A
N12	Lagrange	1941-62	P	---
N5	Lagrange sewage plant	1962-Present	T,P	A,B
N16	Ligonier[1]	1974-Present	P	B
N13	Notre Dame Moreau Seminary	1912-51	T,P	---
N6	Prairie Heights	1973-Present	T,P,E,H	C
N1	South Bend	1894-Present	T,P,H	A,B
N14	Syracuse	1895-1907	P	---
N15	Topeka	1892-1905	P	---
N17	Waterford Mills[1]	1966-Present	T,P,H	C

[1]Data not published for these stations.

Existing Network

The World Meteorological Organization (WMO) has established guidelines for the density of climatic stations collecting precipitation and evaporation data. Guidelines for station density are based on a classification system using climate and terrain. Under this system, the climate in northern Indiana is temperate, and the terrain is flat. The recommended gaging density for this classification and the current density in the basin are presented in table 10. The NWS advises an increased density (50 mi^2 per station) for precipitation gages in areas such as the St. Joseph River basin, where 30 percent or more of the annual precipitation is in the form of rainfall from convective storms (Albert Schipe, National Weather Service, Indianapolis, oral commun., 1986). The present density for precipitation gages in the basin is about 300 mi^2 per station if only the six active stations with published data are considered or about 200 mi^2 per station if all eight active stations are considered.

Table 10.--Recommended density and current density for precipitation and evaporation stations in the St. Joseph River basin, Indiana

Type of station	Recommended density[1] (square miles per station)	Current density (square miles per station)
Precipitation	250-350	300
Evaporation	19,000	10,000

[1] Source: World Meteorological Organization (1974)

Suggested Improvements

The eight NSW climatic stations currently operating within the basin are used to define regional patterns and provide information for flood forecasting. The density of the network meets or exceeds the guidelines developed by WMO for precipitation and evaporation data. However, because most of the summer precipitation in the basin is from convective storms, which often have a small spatial distribution, a greater density for precipitation gages might be needed to measure rainfall adequately throughout the basin.

SUMMARY

This report was written as part of a basin assessment being done by the IDNR. Data-collection stations operated cooperatively by the Geological Survey and IDNR for streams, lakes, and ground water were reviewed. Additionally, the network of climatic stations operated by the National Weather Service was described briefly. The review of these stations was mainly descriptive, not quantitative, and included the purposes and distribution of the stations, discussion of how well the stations meet their purposes, and suggestions as to how the network might be improved.

Streamflow data have been collected at 30 stations in the basin since the cooperative program between the State and the Geological Survey began in 1930. Currently, data are being collected at 11 continuous-record stations and one partial-record station. Six continuous-record stations are suitable for use as regional-hydrology stations because flows are not affected by variable control structures or diversions. These stations adequately represent the hydrology of the basin in terms of areal distribution, lake effect, and flow duration.

The lake network began in 1943 and since then lake-level data have been collected on 98 lakes. Legal lake levels have been established for 85 of these lakes. Control structures are used to help maintain legal levels on 56 lakes. On as many as 17 lakes, lake levels are below the crest of the control structure most of the time. In these cases, the structures are not the primary control of lake levels. More information about the ground-water components of flow to and from lakes would be helpful in evaluating the factors affecting water levels during periods of drought. Existing lake-level data could be analyzed (1) to estimate the magnitude and frequency of flooding around lakes, (2) to evaluate the effectiveness of operators of variable-crest control structures, and (3) to re-evaluate the established level of lakes with levels frequently above or below the legal level. Additional hydrogeologic data would be needed to estimate water budgets for lakes and to evaluate the effectiveness of control structures for lakes with large ground-water components.

The cooperative ground-water program between the Geological Survey and the Department of Conservation (now INDR) was begun in 1935. Currently the basin network comprises 15 wells monitored for four purposes: (1) to determine interaction between ground-water and lakes, (2) to measure changes in ground-water levels near irrigation wells, (3) to measure changes in ground-water levels at special purpose sites, and (4) to measure long-term changes in water levels in areas not affected by pumpage. The network does not provide sufficient data for quantifying lake and ground-water interactions because the number and spacing of observation wells is not adequate to define ground-water flow in the complex hydrogeologic setting around the lakes. The well network near lakes should be expanded or discontinued. Water levels in five observation wells near irrigation wells are not noticeably affected by seasonal pumping. The lack of apparent effect is expected based on two detailed studies, Bailey and others (1985) and Lindgren and others (1985), which indicated that high transmissivity of the outwash aquifer, and high rates of recharge can

provide adequate water for current needs and substantial growth. The observation wells probably provide a good record of regional water levels for areas of intensive irrigation in the basin. Two long-term monitoring wells have provided sufficient information on aquifers they were designed to monitor. Unless other purposes for these wells are identified, they could be discontinued. Water levels in a special-purpose well are measured as part of a local ground-water-quality monitoring program that is expected to continue indefinitely. Additional hydrogeologic information is needed to better delineate the aquifer systems and ground-water flow paths in the basin.

Currently, NWS operates eight climatic data stations in the basin. These stations are used to characterize climatic conditions regionally, provide real-time precipitation data for flood forecasting, and fulfill certain local use purposes. The network meets or exceeds guidelines established by WMO for the distribution of precipitation and evaporation stations but does not meet guidelines suggested by NWS for precipitation gages in areas of significant convective rainfall.

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