Eberts, S.M., 1999; Water levels and ground-water discharge, regional aquifer system of the Midwestern Basins and Arches region, in parts of Indiana, Ohio, Illinois, and Michigan

INTRODUCTION

Aquifers in Quaternary glacial deposits and the underlying Silurian and Devonian carbonate bedrock in parts of Indiana, Ohio, Illinois, and Michigan compose the regional aquifer system under investigation as part of the Midwestern Basins and Arches Regional Aquifer System Analysis (Midwestern Basins and Arches—RASA) project of the U.S. Geological Survey (USGS). The Midwestern Basins and Arches—RASA is part of a USGS program to assess the regional hydrology, geology, and water quality of the Nation's most important aquifers (Sun, 1986). An objective specific to the Midwestern Basins and Arches—RASA project is to conceptualize and describe regional ground-water flow in the glacial-deposit and carbonate-bedrock aquifer system, including regional recharge and discharge areas and regional relations between surface and ground water (Bugliosi, 1990).

Water-level and ground-water discharge data were collected and (or) analyzed to help meet the above objective. Specifically, data from the USGS Ground-Water Site Inventory (GWSI) data base were used to determine relations between land-surface altitude and water levels in glacial-deposit aquifers. Water levels in the carbonate-bedrock aquifer were synoptically measured during July 1990, and the data were used to construct a potentiometric-surface map of the aquifer. Regional hydraulic gradients and general directions of regional flow in the carbonate-bedrock aquifer can be inferred from this map. Steady-state ground-water discharge to streams that drain the area underlain by the glacial-deposit and carbonate-bedrock aquifer system was estimated from base-flow daily values computed from streamflow records.

Water-level and ground-water-discharge data collectively form the sample information necessary to develop calibration targets for calibration of a ground-water-flow model (Anderson and Woessner, 1992). Such a ground-water-flow model of the glacial-deposit and carbonate-bedrock aquifer system was constructed to help conceptualize and describe regional ground-water flow in the aquifer system. The model was calibrated to the water-level and ground-water-discharge data presented in this atlas.

PURPOSE AND SCOPE

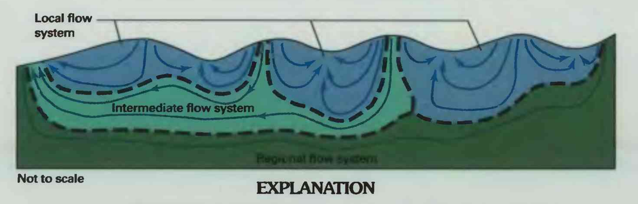
The purpose of this atlas is to present measurements of water levels and estimates of ground-water discharge to streams for the glacial-deposit and carbonate-bedrock aquifer system in the Midwestern Basins and Arches—RASA project study area. Background information and the geohydrologic setting of the study area are presented on sheet 1. Ground-water levels are summarized on sheet 2. Specifically, graphs that illustrate relations between land-surface altitude and water levels in glacial-deposit aquifers are presented. In addition, the potentiometric surface of the carbonate-bedrock aquifer, during July 1990, is illustrated on sheet 2. This potentiometric-surface map was constructed from 395 ground-water levels measured synoptically during July 1990. Thirty of the measurements were from wells that are instrumented to measure ground-water levels hourly or continuously as part of a State or USGS observation-well network. An additional 51 water levels measured in a water-bearing unit that is laterally contiguous with the carbonate-bedrock aquifer are included in the map. Ground-water discharge to streams is summarized on sheet 3. Specifically, estimates of mean ground-water discharge to selected stream reaches from a combination of local, intermediate, and regional ground-water-flow systems within the aquifer system are presented for 53 streamflow-gaging stations for long-term steady-state conditions in the aquifer system. Estimates of mean sustained ground-water discharge (discharge predominantly from relatively stable, regional and possibly intermediate ground-water-flow systems) also are presented on sheet 3. Mean stream discharge for the same period for each streamflow-gaging station is presented to serve as a frame of reference for the ground-water-discharge data.

TERMINOLOGY

The water table is the upper surface of a zone of saturation where the body of ground water is not confined by an overlying impermeable zone. A potentiometric surface is an imaginary surface that represents the static head of ground water and is defined by the level to which water will rise in a tightly cased well (Ground Water Subcommittee of the Federal Interagency Advisory Committee on Water Data, 1989).

In this atlas, a semiconfined aquifer is an aquifer in which water will rise above the top of the aquifer in a tightly-cased well into a less permeable unit that leaks substantial quantities of water to the aquifer.

An aquifer system can comprise local, intermediate, and regional flow systems (fig. 1). In a local system of ground-water flow, recharge and discharge areas are adjacent to each other. In an intermediate flow system, recharge and discharge areas are separated by one or more topographic highs and lows. In a regional system, recharge areas are along ground-water divides, and discharge areas lie at the bottom of drainage basins. Regional drains are the mainstem streams within the principal drainage basins. The greatest amount of ground-water flow in an aquifer system takes place at the shallow depths of the local flow systems. Ground-water levels at shallow depths are the most affected by seasonal variations in recharge and discharge because recharge areas of the shallow flow systems make up the greatest part of the surface of a drainage basin (Toth, 1963).



EXPLANATION

Flow–system boundary — Direction of flow

Figure 1. Diagram of local, intermediate, and regional flow systems within an aquifer system.

Base flow is the component of streamflow that originates from ground-water discharge (Todd, 1980). Ground-water discharge refers to discharge to streams from a combination of local, intermediate, and regional ground-water-flow systems within an aquifer system. Sustained ground-water discharge refers to the relatively stable component of the discharge to streams and likely represents discharge predominantly from regional and possibly intermediate ground-water-flow systems within an aquifer system; that is, ground-water-flow systems that are minimally affected by variations in recharge from precipitation. In this atlas, ground-water discharge refers solely to discharge to streams and includes neither discharge to lakes or wetlands nor loss from the aquifer system by means of evapotranspiration or pumpage. Direct runoff is the part of precipitation that enters stream channels promptly after rainfall or snowmelt (Langbein and Iseri, 1960).

Long-term steady-state conditions refer to a state of dynamic equilibrium in an aquifer system in which the magnitude and direction of ground-water flow is constant over a period of years; no net change in storage in the aquifer system occurs over the long term. Ground-water levels and directions of ground-water flow can change in response to seasonal or short-term cycles of recharge and discharge during a period of long-term steady-state conditions. The long-term period referred to in this atlas is a minimum of 10 years that includes wet and dry periods.

A water year is the 12-month period from October 1 through September 30. The water year is designated by the calendar year in which it ends.

ACKNOWLEDGEMENTS

The author expresses appreciation to the ground-water staff at the Indiana and the Ohio Departments of Natural Resources for assistance in locating drillers' logs, field locating wells, and providing data from observation-network wells. In addition, the author thanks Steven D. Wilson, Illinois State Water Survey, for measuring water levels in Illinois. The cooperation of property owners who allowed access to their wells is greatly appreciated.

GEOHYDROLOGIC SETTING

The study area encompasses approximately 44,000 mi2, most of which is in the Midwestern Basins and Arches Region, as defined in Shaver (1985). The area is located along the axes of the Cincinnati, the Findlay, and the Kankakee Arches in parts of Indiana, Ohio, Illinois, and Michigan (fig. 2). Erosion has reduced these low, broad arches to a nearly flat plain. The study area generally lies between the Appalachian, the Illinois, and the Michigan (structural) Basins. The oldest bedrock units are exposed along the axis of the Cincinnati Arch in the south-central part of the study area. In general, units exposed at the bedrock surface are progressively younger with distance from the axes of the arches because the older rocks dip under the younger rocks toward the structural basins. Boundaries of the study area are coincident with surface-water bodies or with the contact between Devonian limestones and younger Devonian shales (fig. 2).

Bedrock units within the study area include interbedded Ordovician shales and limestones, Devonian and Silurian limestones and dolomites, and Mississippian and Devonian shales (fig. 2). These bedrock units are directly overlain by Quaternary glacial deposits throughout most of the study area (fig. 3); glacial deposits deeply bury numerous ancient valleys on the bedrock surface. Glacial deposits range in thickness from 0 to 400 ft (Gray, 1983; Soller, 1986) and include ground- and end-moraine deposits, lacustrine sediments, outwash sediments, and small amounts of ice-contact stratified drift (Flint, 1959).

The study area has a humid temperate climate; mean annual precipitation computed from stations with at least 50 years of data ranges from 33 to 43 in. (E. F. Bugliosi, 1999) (fig. 4). Parts of the following three major river systems drain the study area: the Ohio, the St. Lawrence, and the Upper Mississippi (fig. 4).

The water table in the study area generally is within Quaternary alluvium or glacial deposits. Glacial-deposit aquifers typically comprise sands and gravels in areally extensive outwash deposits or in thin, discontinuous intratill lenses. The aquifers are most commonly unconfined where outwash sediments are present along the regional drains. Glacial-deposit aquifers may be locally semiconfined or confined by till. The productivity of glacial-deposit aquifers is vertically and horizontally variable over small distances because of variations in the composition, continuity, and structure of the deposits (Strobel, 1990).

Water in the underlying carbonate-bedrock aquifer is primarily present in fractures, bedding joints, and other openings within the rock. The carbonate-bedrock aquifer ranges in thickness from 0 to 750 ft and thickens from the crests of the arches into the adjacent structural basins (Norris and Fidler, 1973; Rupp, 1991). Interfaces between freshwater (less than 10,000 mg/L dissolved solids; U.S. Environmental Protection Agency, 1984) and saltwater in the carbonate bedrock are present within the structural basins and define the lateral extent of the carbonate-bedrock aquifer. Freshwater has been found in Devonian and Silurian carbonate bedrock within the Illinois Basin as far as 70 mi west of where the carbonate bedrock is exposed at the bedrock surface (Rupp and Pennington, 1987; D.J. Schnoebelen, U.S. Geological Survey, written commun., 1991) (fig. 2). Dissolved-solids concentration of water in the carbonate bedrock is greater than 10,000 mg/L in some areas within 5 mi north of the northern limit of its subcrop (D.J. Schnoebelen, U.S. Geological Survey, written commun., 1991). The carbonate bedrock contains water with a dissolved-solids concentration of greater than 50,000 mg/L in some areas within 30 mi east of the eastern limit of its subcrop (L.L. Lesney, U.S. Geological Survey, written commun., 1991). At the regional scale, the carbonate-bedrock aquifer is semiconfined by glacial deposits where the aquifer is exposed at the bedrock surface (aquifer subcrop) and unconfined where it is exposed at the land surface (aquifer outcrop). The aquifer is confined by Devonian shales elsewhere in the Midwestern Basins and Arches Region. The productivity of the carbonate-bedrock aquifer varies with the concentration of openings within the rock. Although some units or zones within the semiconfined carbonate-bedrock aquifer are more or less productive than others, the carbonate-bedrock aquifer is thought to function as a single hydrologic unit at a regional scale. Few wells tap the carbonate-bedrock aquifer where it dips beneath the Devonian shales because shallower freshwater sources are available.

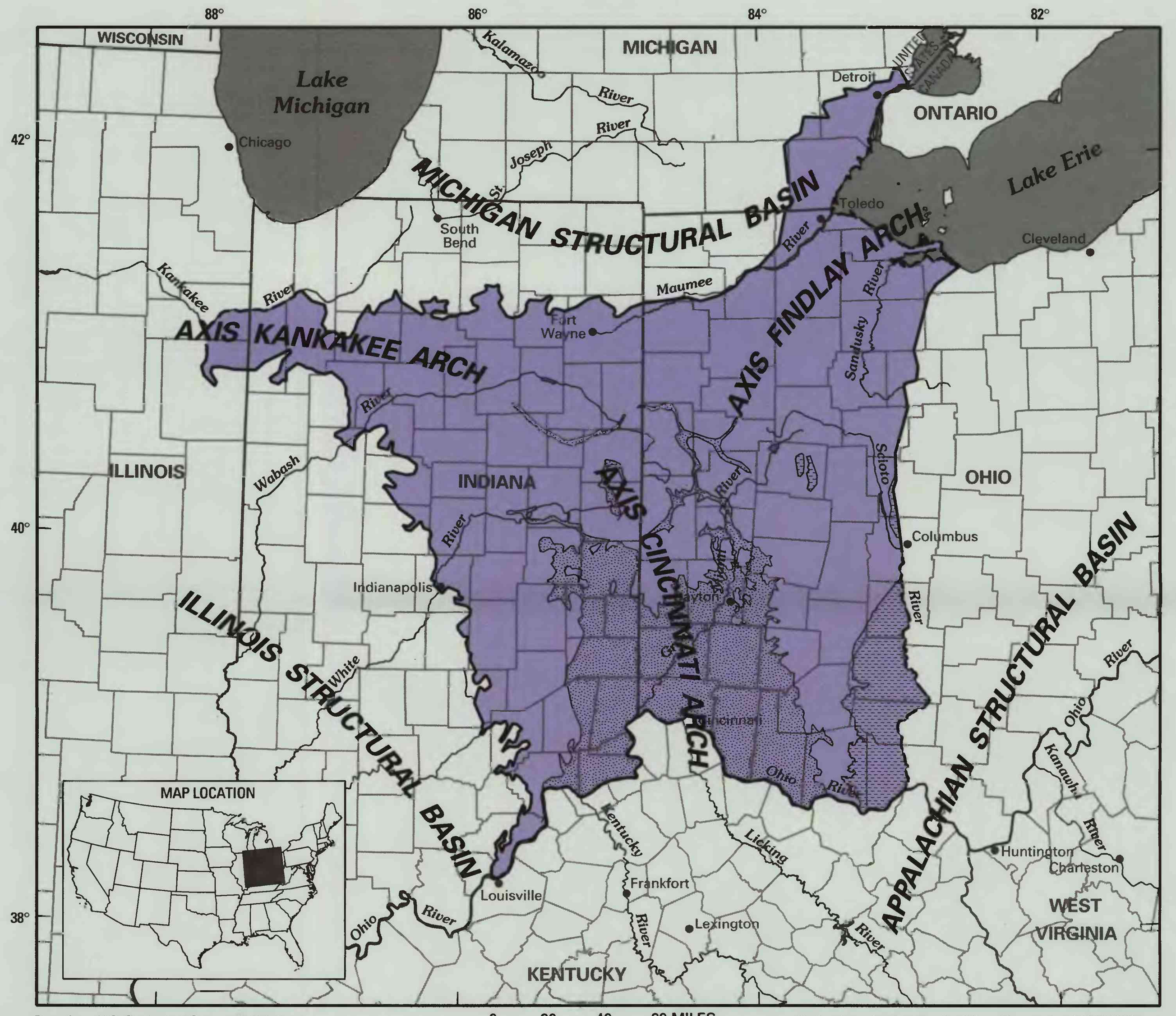
The carbonate-bedrock aquifer is confined below by interbedded Ordovician shales and limestones. Although the Ordovician rocks directly underlie the aquifer throughout most of the study area, they are laterally contiguous with the aquifer along the axis of the Cincinnati Arch in the south-central part of the study area where the Ordovician rocks are exposed at the bedrock surface (fig. 2). The contact between Silurian and Ordovician rocks, where it is exposed at the bedrock surface, has been described throughout the literature as a spring horizon. The role of the Ordovician shale along this contact was summarized succinctly by Norris and others (1950, p. 23), "The chief importance of the impervious Ordovician shale with respect to ground water is that it deflects the water to the surface as springs." The interbedded Ordovician shales and limestones are used as a source of water, however, in the south-central part of the study area, where they are exposed at the bedrock surface and other aquifers are absent. Weathering has increased secondary porosity and has allowed for water circulation to increase at shallow depths in the Ordovician rocks within this area. Yields from wells completed in the Ordovician shales and limestones in the south-central part of the study area are typically less than 10 gal/min, drawdowns are commonly extreme, and dry holes are common (Indiana Department of Natural Resources, 1988). In this atlas, Ordovician rocks exposed at the bedrock surface (fig. 2) are referred to as the "upper weathered zone water-bearing unit." The upper weathered zone water-bearing unit within the Ordovician rocks is not considered to be an aquifer.

CONVERSION FACTORS, VERTICAL DATUM, AND CHEMICAL CONCENTRATION

Multiply inch-pound unit	By	To obtain metric unit
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow	
cubic feet per second (ft^3/s)	28.32	liters per second (L/s)
gallons per minute (gal/min)	630.9	liters per second (L/s)

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

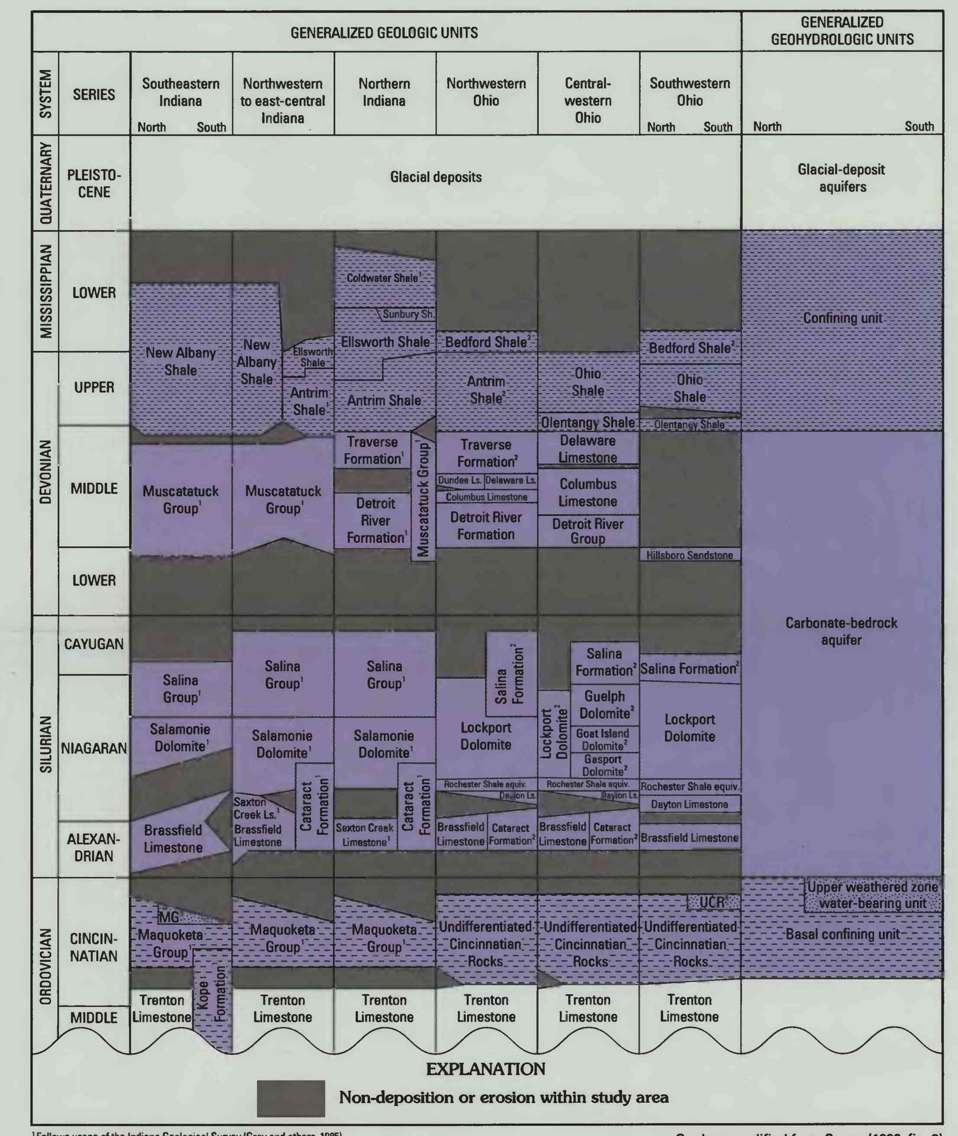
Chemical concentration: Concentrations of dissolved solids are given in milligrams per liter (mg/L), which is a unit expressing the concentration of chemical constituents as mass (milligrams) of solute per unit volume (liter) of water.



Base from U.S. Geological Survey digital data, 1:2,000,000, 1972

0 20 40 60 MILES
0 20 40 60 KILOMETERS

Bedrock geology generalized from Bownocker (1920), Willman and others (1967), Burger and others (1971), Gray and others (1972), Johnson and Keller (1972), and Gray and others (1987)



[1] Follows usage of the Indiana Geological Survey (Gray and others, 1985)
[2] Follows usage of the Ohio Geological Suvery (Hull, 1990; Larsen 1991)
[3] Maquoketa Group
[4] Undifferentiated Cincinnatian rocks

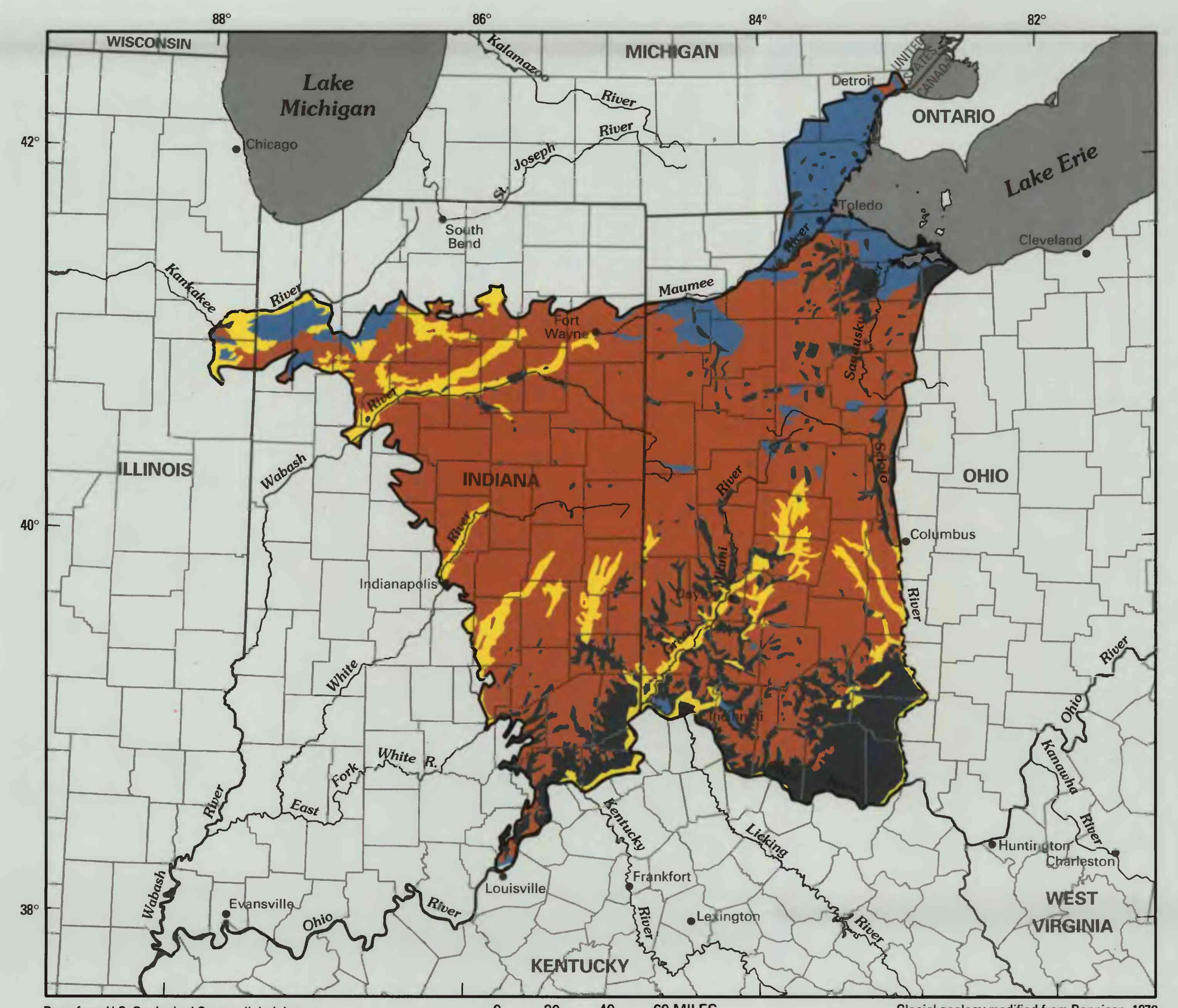
Geology modified from Casey (1992, fig. 3)

EXPLANATION

Bedrock units included in investigation

- **Mississippian and Devonian shales**—Confining unit
- **Devonian and Silurian limestones and dolomites**—Carbonate-bedrock aquifer
- **Interbedded Ordovician shales and limestones**—Upper weathered zone water-bearing unit
- **Interbedded Ordovician shales and limestones**—Basal confining unit
- **Study-area boundary**—Solid where coincident with the contact between Devonian limestones and younger Devonian shales. Dashed where coincident with surface-water body

Figure 2. Location of study area, structural elements, and bedrock geology within the study area.



Base from U.S. Geological Survey digital data, 1:2,000,000, 1972

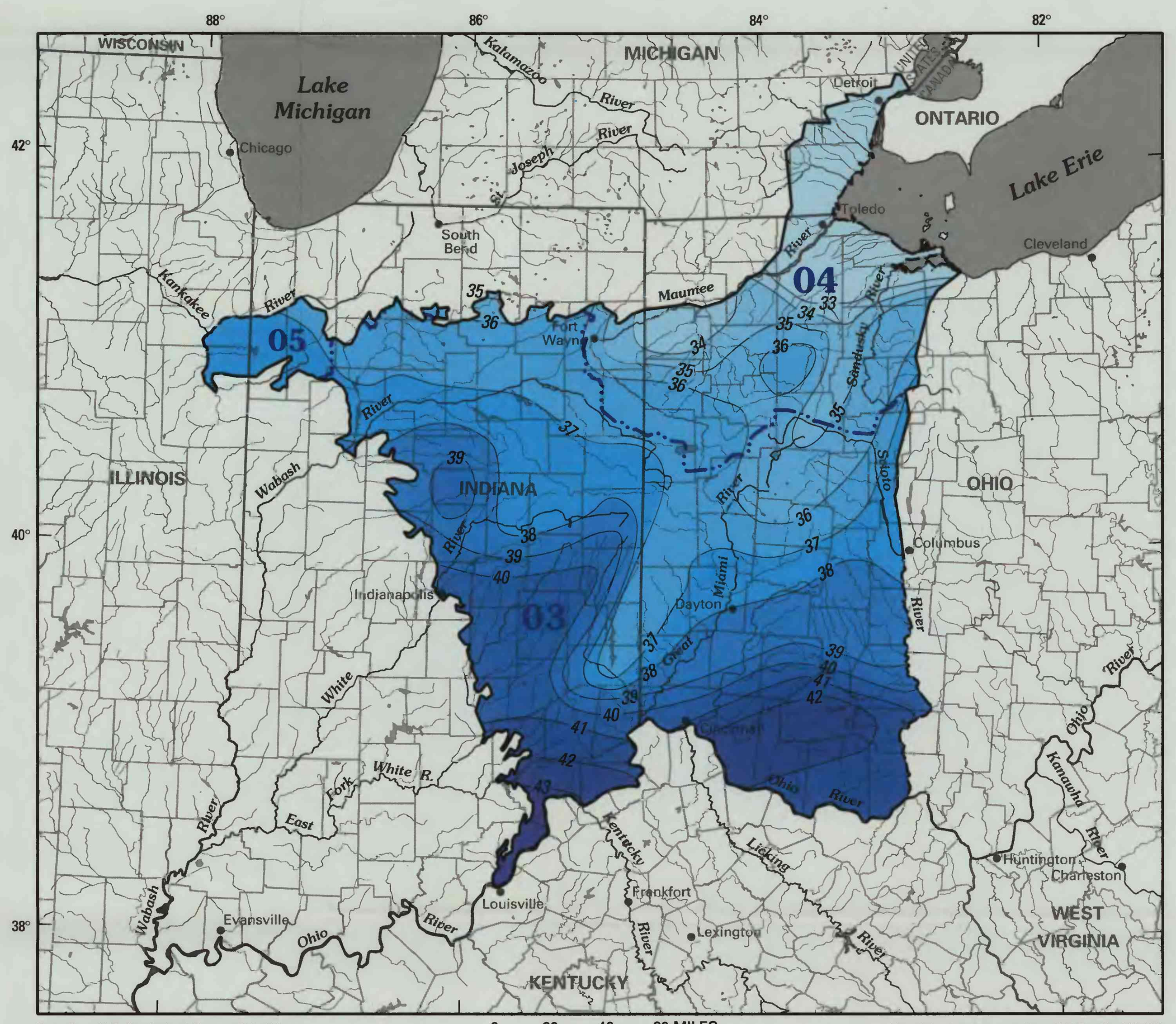
0 20 40 60 MILES
0 20 40 60 KILOMETERS

Glacial geology modified from Bennison, 1978

EXPLANATION

- Ground- and end-moraine deposits
- Lacustrine sediments
- Outwash sediments and ice-contact stratified drift
- Glacial deposits absent
- **Study-area boundary**—Solid where coincident with the contact between Devonian limestones and younger Devonian shales. Dashed where coincident with surface-water body

Figure 3. Generalized glacial geology within the study area.



Base from U.S. Geological Survey digital data, 1:2,000,000, 1972

0 20 40 60 MILES
0 20 40 60 KILOMETERS

Precipitation contours from E.F. Bugliosi (1999)
Basin boundaries from The National Atlas of the United States, Hydrologic Units map, 1:3,500,000, 1998

EXPLANATION

- **Equal mean annual precipitation, in inches**—Interval is 1 inch. Darker blues indicate higher precipitation
- 03 **Boundary of of major river basin**—Number indicates basin; 03, Ohio River Basin; 04, St. Lawrence River Basin; 05, Upper Mississippi River Basin
- **Study-area boundary**—Solid where coincident with the contact between Devonian limestones and younger Devonian shales. Dashed where coincident with surface-water body

Figure 4. Mean annual precipitation for stations with at least 50 years of data, and location of major drainage basins within the study area.

INTERIOR—GEOLOGICAL SURVEY, RESTON, VIRGINIA—2000

WATER LEVELS AND GROUND-WATER DISCHARGE, REGIONAL AQUIFER SYSTEM OF THE MIDWESTERN BASINS AND ARCHES REGION, IN PARTS OF INDIANA, OHIO, ILLINOIS, AND MICHIGAN

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