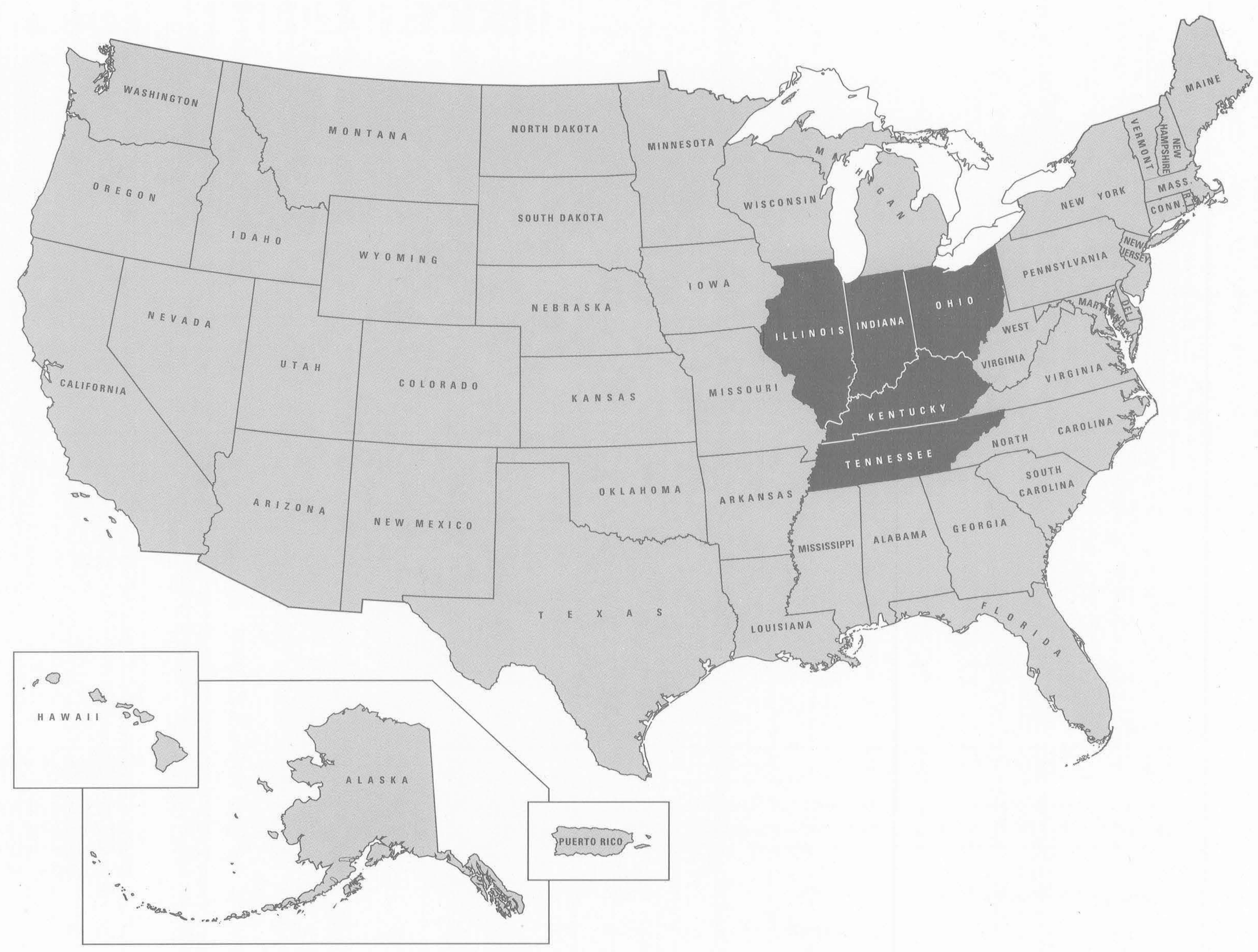
GROUND WATER ATLAS OF THE UNITED STATES

SEGMENT 10

Illinois
Indiana
Kentucky
Ohio
Tennessee



HYDROLOGIC INVESTIGATIONS ATLAS 730–K

U.S. Geological Survey

Reston, Virginia
1995

GROUND WATER ATLAS OF THE UNITED STATES
Hydrologic Investigations Atlas 730–K

FOREWORD

The Ground Water Atlas of the United States presents a comprehensive summary of the Nation's ground-water resources, and is a basic reference for the location, geography, geology, and hydrologic characteristics of the major aquifers in the Nation. The information was collected by the U.S. Geological Survey and other agencies during the course of many years of study. Results of the U.S. Geological Survey's Regional Aquifer-System Analysis Program, a systematic study of the Nation's major aquifers, were used as a major, but not exclusive, source of information for compilation of the Atlas.

The Atlas, which is designed in a graphical format that is supported by descriptive discussions, includes 13 chapters, each representing regional areas that collectively cover the 50 States and Puerto Rico. Each chapter of the Atlas presents and describes hydrogeologic and hydrologic conditions for the major aquifers in each regional area. The scale of the Atlas does not allow portrayal of minor features of the geology or hydrology of each aquifer presented, nor does it include discussion of minor aquifers. Those readers that seek detailed, local information for the aquifers will find extensive lists of references at the end of each chapter.

An introductory chapter presents an overview of ground-water conditions Nationwide and discusses the effects of human activities on water resources, including saltwater encroachment and land subsidence.

Gordon P. Eaton

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, *Secretary*

U.S. GEOLOGICAL SURVEY
Gordon P. Eaton, *Director*

CONVERSION FACTORS

For readers who prefer to use the International System (SI) units, rather than the inch-pound terms used in this report, the following conversion factors may be used:

Multiply inch-pound units	*By*	*To obtain metric units*
	Length	
inch (in)	2.54	centimeter (cm)
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 foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
billion gallons per day (Bgal/d)	3.785	million cubic meters per day (Mm^3/d)
	Transmissivity	
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)
	Temperature	
degree Celsius (°C)	9/5 (°C)+32=°F	degree Fahrenheit (°F)

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.

ATLAS ORGANIZATION

The Ground Water Atlas of the United States is divided into 14 chapters. Chapter A presents introductory material and nationwide summaries; chapters B through M describe all principal aquifers in a multistate segment of the conterminous United States; and chapter N describes all principal aquifers in Alaska, Hawaii, and Puerto Rico.

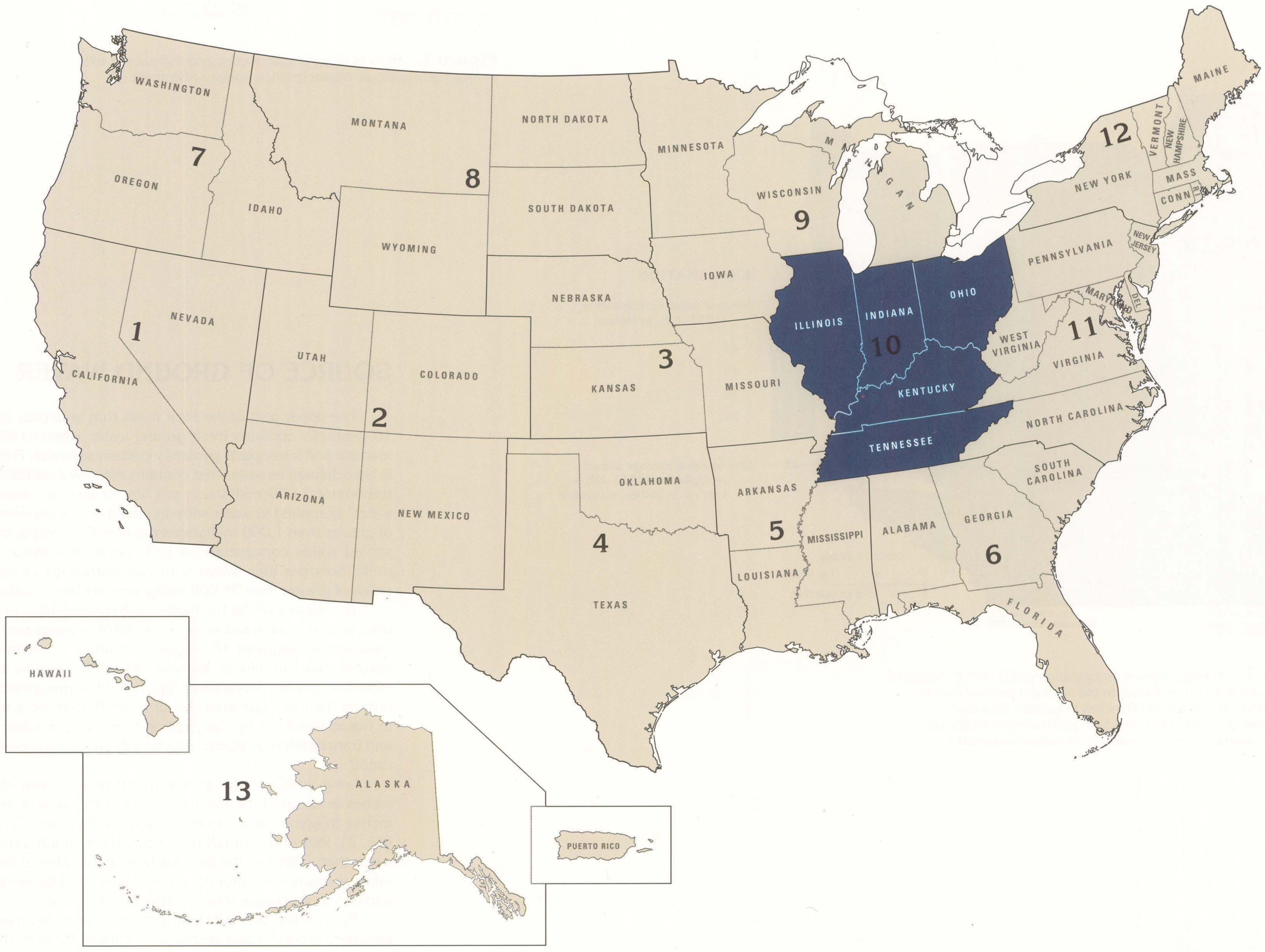
	Chapter content	*Hydrologic Atlas Chapter*
—	Introductory material and nationwide summaries	730–A
1	California, Nevada	730–B
2	Arizona, Colorado, New Mexico, Utah	730–C
3	Kansas, Missouri, Nebraska	730–D
4	Oklahoma, Texas	730–E
5	Arkansas, Louisiana, Mississippi	730–F
6	Alabama, Florida, Georgia, South Carolina	730–G
7	Idaho, Oregon, Washington	730–H
8	Montana, North Dakota, South Dakota, Wyoming	730–I
9	Iowa, Michigan, Minnesota, Wisconsin	730–J
10	Illinois, Indiana, Kentucky, Ohio, Tennessee	730–K
11	Delaware, Maryland, New Jersey, North Carolina, Pennsylvania, Virginia, West Virginia	730–L
12	Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, Vermont	730–M
13	Alaska, Hawaii, Puerto RIco	730–N

Ground Water Atlas of the United States

Segment 10

Illinois, Indiana, Kentucky, Ohio, Tennessee

By Orville B. Lloyd, Jr., and William L. Lyke



CONTENTS

Cartographic design and production by Gary D. Latzke, Bruce R. Droster, and Wendy J. Danchuk

Regional summary

INTRODUCTION

This report provides a summary of ground-water conditions and problems in Illinois, Indiana, Kentucky, Ohio, and Tennessee, which compose Segment 10 of the Ground Water Atlas of the United States, an area of about 217,000 square miles. The definition, distribution, thickness, water-yielding, and water-quality characteristics of the principal aquifers in the segment are the primary topics of this chapter. Ground-water source, occurrence, movement, use, and problems also are discussed where appropriate.

Segment 10 consists of parts of seven physiographic provinces (**fig. 1**)— the Coastal Plain, Blue Ridge, Valley and Ridge, Appalachian Plateaus, Interior Low Plateaus, Central Lowland, and Ozark Plateaus. The provinces have unique hydrogeologic characteristics that make it convenient to describe the principal aquifers in each province.

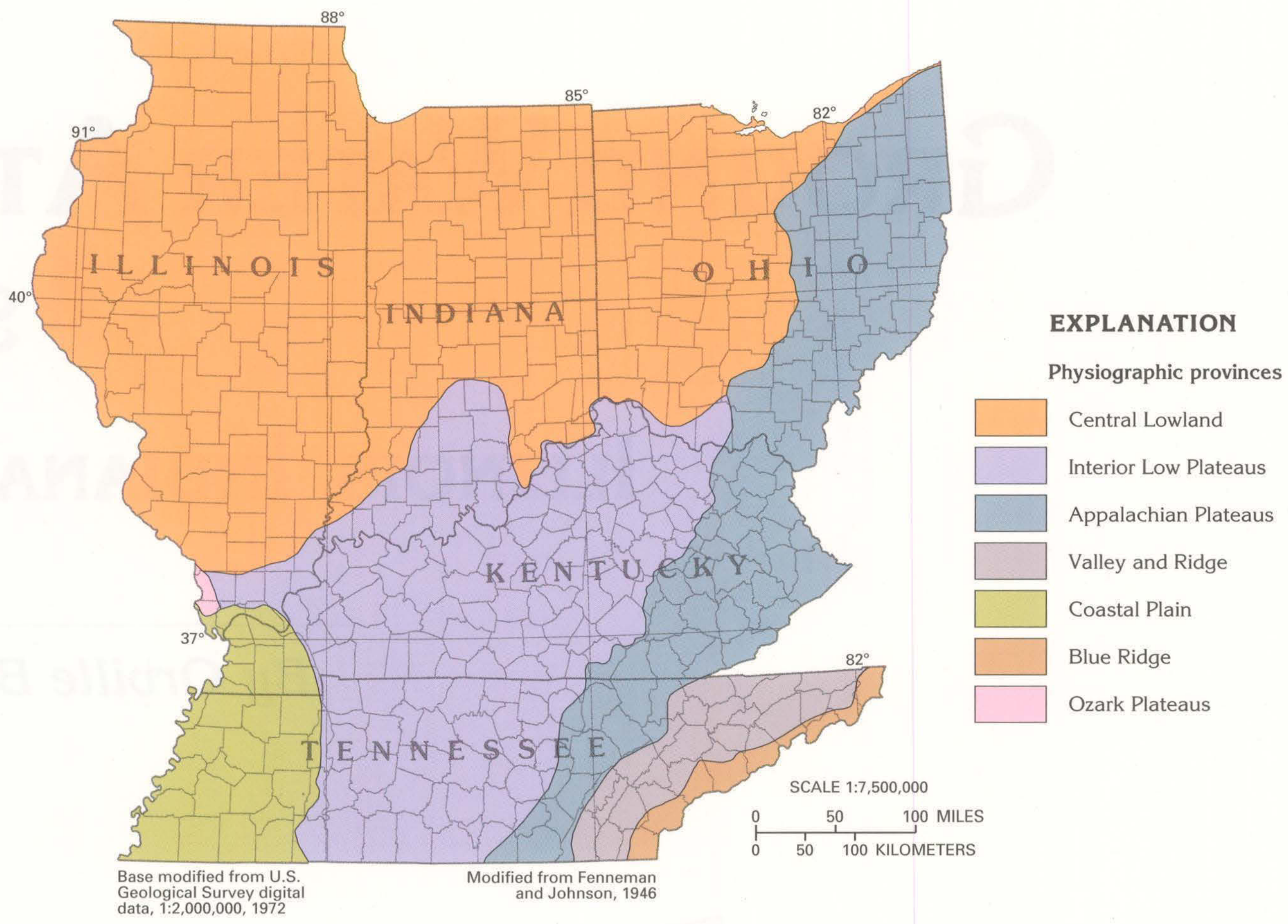


Figure 1. Parts of seven physiographic provinces, each with unique hydrogeologic characteristics, compose Segment 10.

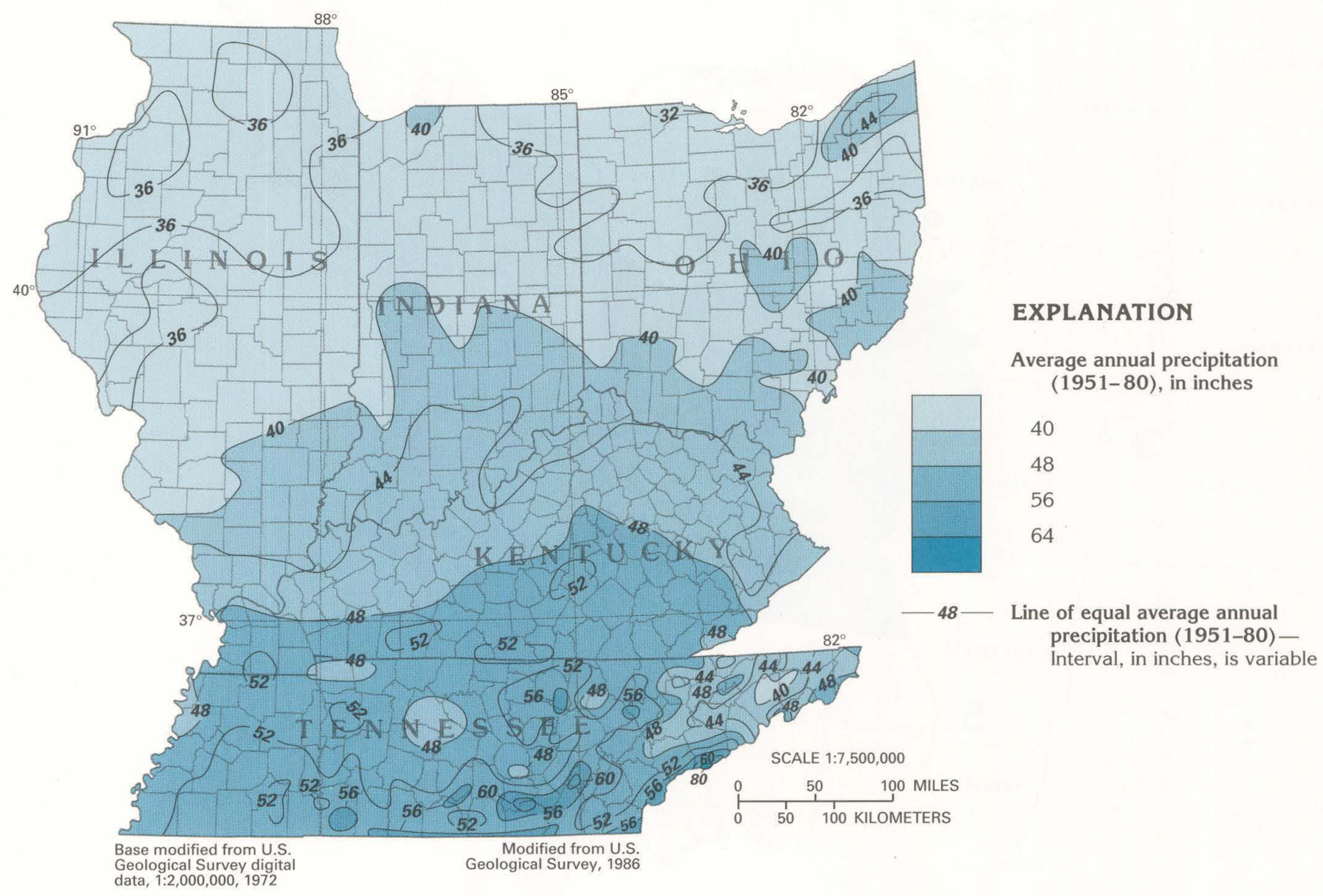


Figure 2. Average annual precipitation (1951–80) in Segment 10 ranges from about 36 inches in the northern parts of Illinois, Indiana, and Ohio to about 80 inches in eastern Tennessee. Precipitation generally increases from northwest to southeast across the segment and is greatest in mountainous areas.

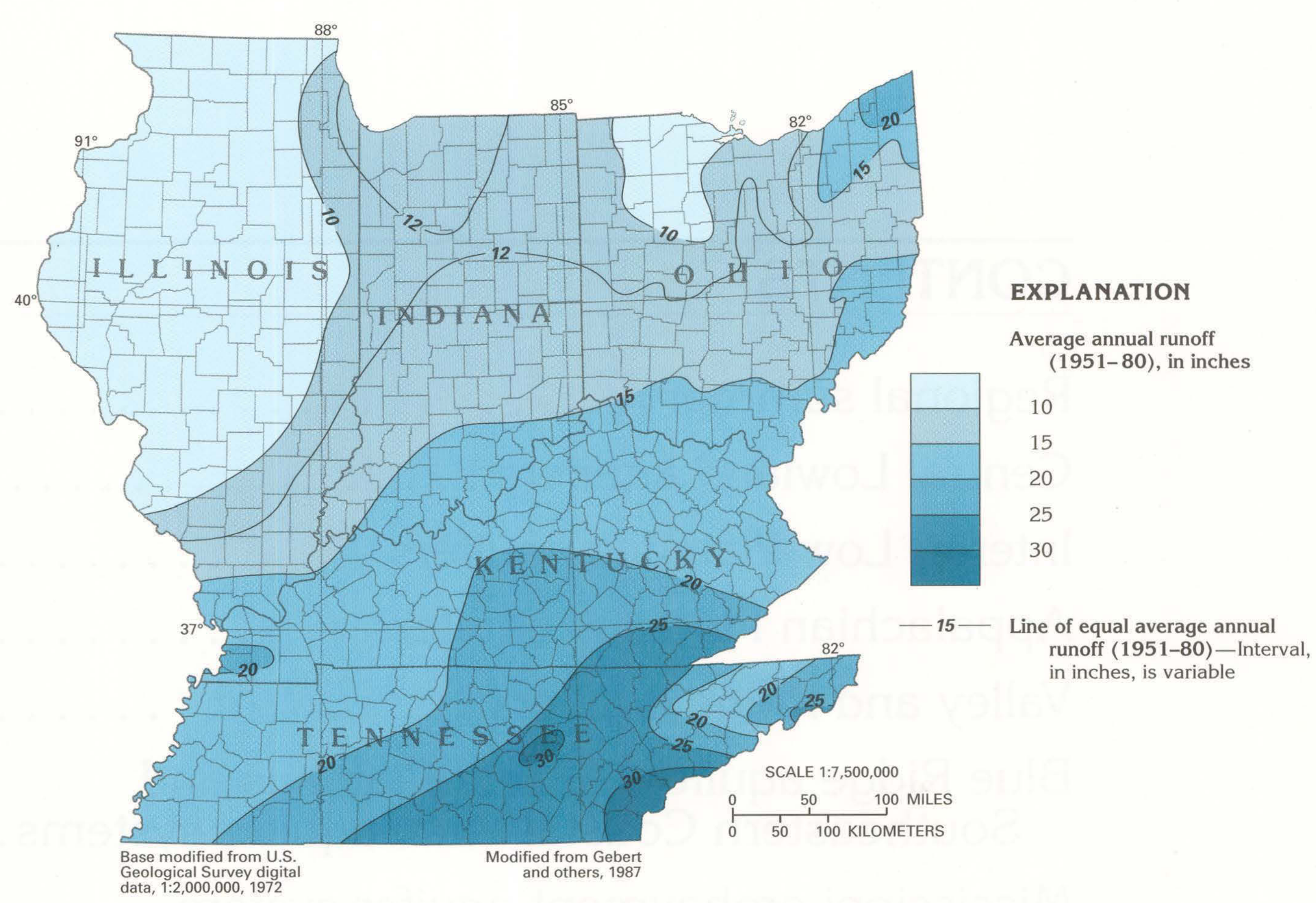


Figure 3. Average annual runoff (1951–80) in Segment 10 ranges from about 10 to 30 inches per year. Like precipitation, runoff generally increases from northwest to southeast across the segment and is greatest in the mountainous areas.

SOURCE OF GROUND WATER

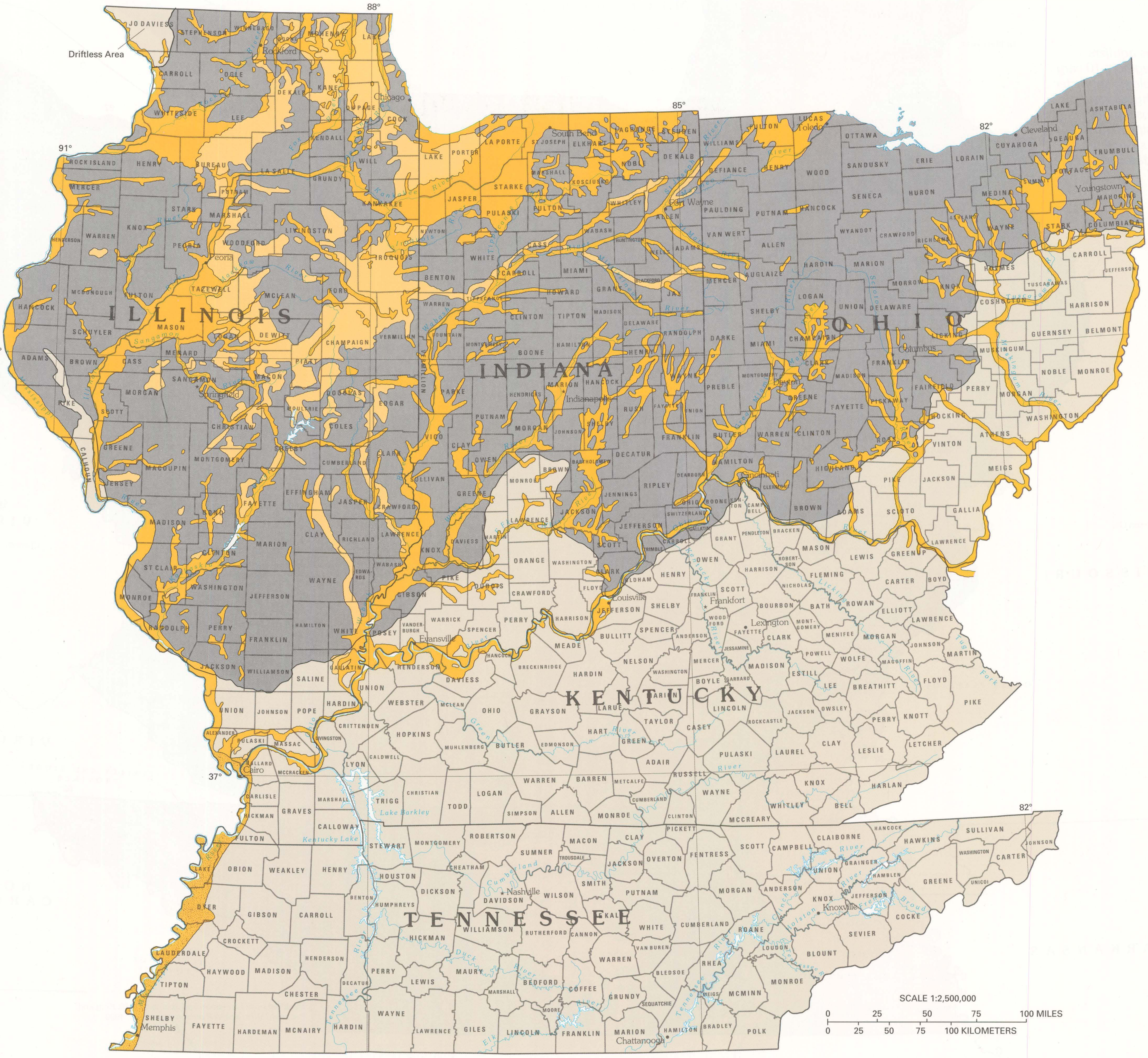
The upper part of the rock mass that underlies Segment 10 generally contains fresh ground water, whereas the intermediate and lower parts generally contain saltwater. Freshwater is here defined as water that contains dissolved-solids concentrations of 1,000 milligrams per liter or less; the term "saltwater" is applied to water with dissolved-solids concentrations of greater than 1,000 milligrams per liter. For comparison, dissolved-solids concentrations in seawater are about 35,000 milligrams per liter. Water with concentrations of dissolved solids of greater than 35,000 milligrams per liter is called brine.

The source of the freshwater in Segment 10 is precipitation, primarily rain and snow. Long-term average annual precipitation in Segment 10 ranges from about 36 inches in the northern part of Illinois, Indiana, and Ohio to more than 80 inches in eastern Tennessee (**fig. 2**). Of the precipitation that falls on the five-State area, about 50 to 70 percent is returned to the atmosphere by evaporation from surface-water bodies and transpiration by plants. Much of the remainder constitutes runoff.

Long-term average annual runoff ranges from about 10 inches in some of the northern parts of the area to about 30 inches in some parts of central and southeastern Tennessee (**fig. 3**). Part of the runoff is direct surface runoff, and part is water that infiltrates the land surface, percolates to the water table, recharges the ground-water system, and moves through aquifers to discharge into streams as base flow.

Most of the precipitation that percolates downward and becomes ground-water recharge circulates through the shallow aquifers; only a small part enters the deep aquifers. Annual ground-water recharge is estimated to range from about 1 inch in parts of Illinois where precipitation is least and the permeability of the soil and rock at the land surface is low to as much as 13 inches in parts of Tennessee where precipitation is greatest and the permeability of materials at the land surface is high.

Saltwater is present at depths of 500 feet or less in much of Segment 10, particularly in aquifers in Paleozoic rocks. The source of the saltwater is assumed to be a combination of the fresh ground water and the seawater in which the rocks were deposited or by which they were later invaded. The dissolved-solids concentration in the saltwater increases with depth and reaches brine concentration in some parts of the segment. The brine might be derived from the solution of evaporite deposits or from ionic filtration by clay or shale beds during the process of sediment compaction or both.



Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972
Albers Equal-Area Conic projection
Standard parallels 29°30' and 45°30', central meridian -96°00'

Modified from U.S. Geological Survey, 1985; Soller, 1986; and unpublished maps by David R. Soller in the files of the U.S. Geological Survey, 1988

Figure 4. Aquifers in unconsolidated sand and gravel deposits overlie aquifers in semiconsolidated and consolidated rocks in large parts of Segment 10. Most of the sand and gravel aquifers are north of Kentucky. The most productive aquifers in the unconsolidated deposits consist of coarse, well-sorted, stratified glacial deposits.

EXPLANATION

Surficial aquifer system

- Sand and gravel aquifers at or near land surface, and alluvium along streams and rivers—Patterned area shows Mississippi River Valley alluvial aquifer
- Sand and gravel aquifers buried beneath finer grained material
- Surficial deposits generally less than 100 feet thick, and the occurrence of sand and gravel aquifers difficult to locate

Southern limit of glaciation

PRINCIPAL AQUIFERS

The rocks that underlie Segment 10 are divided into the different geohydrologic units (aquifers and confining units) shown in **figures 4 and 5**. These aquifers and confining units are grouped according to the physiographic provinces shown in **figure 1** and are described in general accordance with these physiographic provinces.

Throughout Segment 10, the rocks that compose aquifers and confining units generally are divided into three types according to their degree of consolidation—the Precambrian and Paleozoic rocks are consolidated, the Cretaceous and Tertiary rocks generally are semiconsolidated, and the Quaternary deposits generally are unconsolidated. Exceptions are where carbonate cements have been dissolved from Paleozoic sandstone beds, which leaves them partly unconsolidated and friable, and where the younger unconsolidated deposits have been partly cemented or lithified. The consolidated rocks generally are covered with younger unconsolidated deposits or unconsolidated regolith derived from weathering of the consolidated rocks.

Unconsolidated, coarse-grained deposits of Quaternary age (primarily of glacial origin) compose principal aquifers that cover the Paleozoic rocks throughout most of the Central Lowland and the northern parts of the Interior Low Plateaus and Appalachian Plateaus Physiographic Provinces (**figs. 1 and 4**). Coarse-grained alluvium that has been derived from glacial material and deposited along present or buried major stream channels constitutes aquifers in the same areas. A band of alluvium parallel to the Mississippi River in westernmost Kentucky and Tennessee also composes an aquifer. Where the glacial deposits consist of coarse, well-sorted sand and gravel, they constitute some of the most productive aquifers in Segment 10. These unconsolidated deposits are collectively called the surficial aquifer system.

Semiconsolidated rocks of Cretaceous and Tertiary age compose principal aquifers in the Mississippi Embayment section of the Coastal Plain Province (**figs. 1 and 5**). Consolidated rocks of Paleozoic age compose principal aquifers in the Central Lowland, the Interior Low Plateaus, the Appalachian Plateaus, the Valley and Ridge, and the Ozark Plateaus Provinces. Consolidated rocks of Precambrian age compose principal aquifers of the Blue Ridge Province.

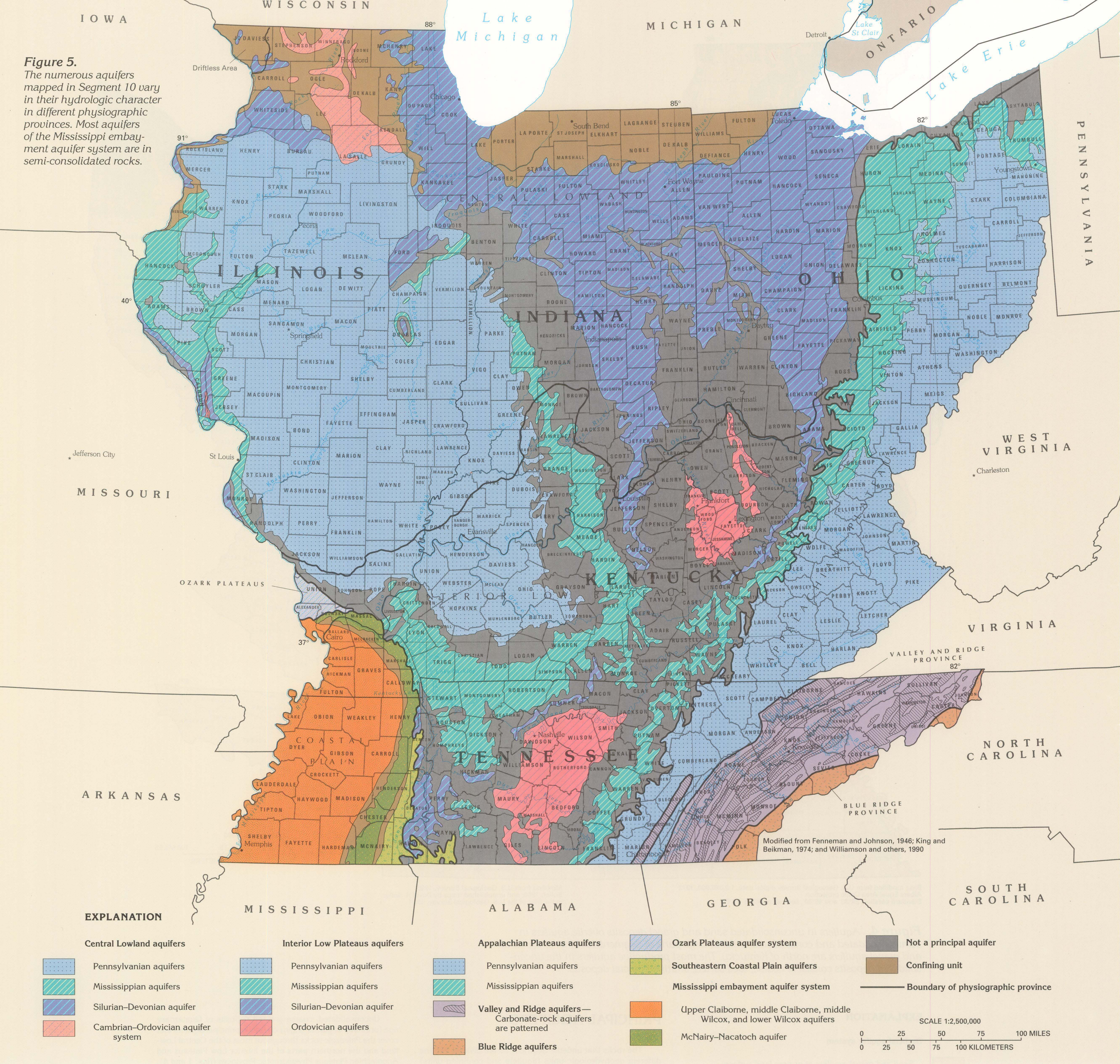
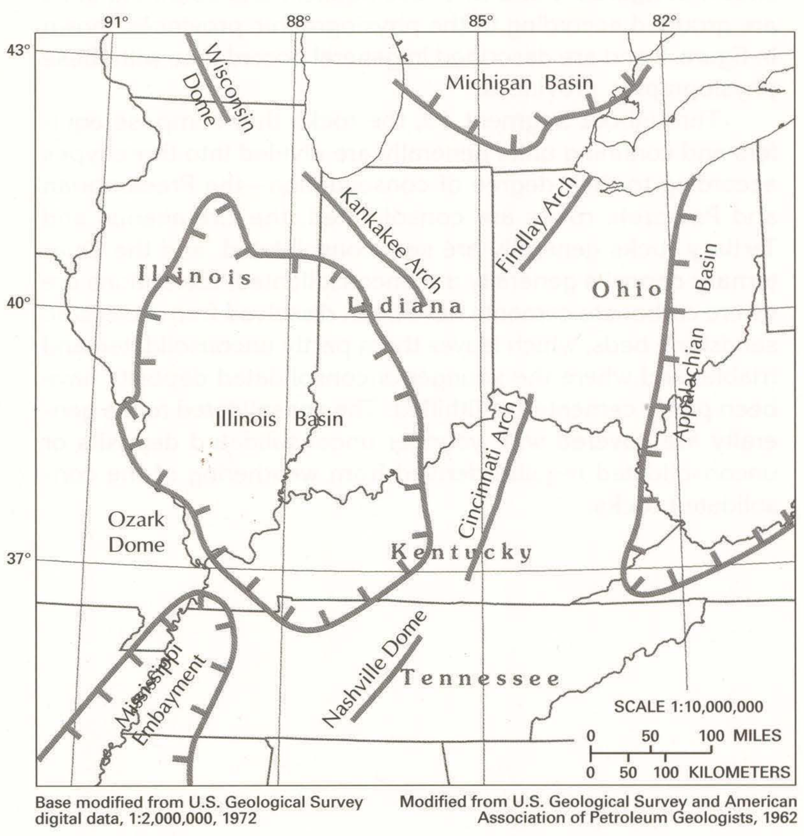


Figure 5. *The numerous aquifers mapped in Segment 10 vary in their hydrologic character in different physiographic provinces. Most aquifers of the Mississippi embayment aquifer system are in semi-consolidated rocks.*

Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972 Albers Equal-Area Conic projection
Standard parallels 29°30' and 45°30', central meridian -96°00'



EXPLANATION

Approximate location of arch and dome axis

Approximate location of basin or embayment—Hachures indicate central part of basin

Figure 6. *The arches, domes, and structural basins in Precambrian rocks and in the overlying Paleozoic sedimentary rocks of Segment 10 were created by tectonic forces. Aquifers in the Paleozoic sedimentary rocks are near the land surface over the arches and domes and are deeply buried in the structural basins.*

GEOLOGIC SETTING

To a large extent, the geology of the area controls the occurrence, movement, availability, and quality of the ground-water resources. Thus, a basic understanding of the geology is necessary to understand the ground-water hydrology.

Precambrian igneous, metamorphic, and sedimentary rocks are at the land surface in the Blue Ridge Province in eastern Tennessee. Elsewhere in Segment 10, Precambrian igneous and metamorphic rocks are buried beneath younger rocks. The top of the Precambrian rocks is about 1,000 feet below sea level in northern Illinois and is about 15,000 feet below sea level at the junction of Illinois, Indiana, and Kentucky.

A thick sequence of consolidated sedimentary rocks of Paleozoic age overlies the Precambrian rocks. These sedimentary rocks are primarily siltstone, shale, sandstone, limestone, and dolomite. Tectonic forces warped the deeply buried Precambrian rocks and created arches, domes, structural basins, and fracture systems in the overlying Paleozoic rocks (**fig. 6**). On the crests and flanks of the arches and domes, freshwater can be obtained from water-yielding rocks that are either exposed at the land surface or buried at shallow depths. The same water-yielding rocks are deeply buried in the structural basins and mostly contain saltwater or brine.

The distribution of the Paleozoic rocks in the area is controlled by the position of the arches, domes, structural basins, and associated faults. The oldest Paleozoic rocks (Cambrian) are at the land surface between northeast-trending thrust faults in the Blue Ridge and the Valley and Ridge Provinces in eastern Tennessee. Cambrian strata also subcrop below Quaternary deposits and locally crop out in a small area south of a normal fault in northern Illinois (**fig. 7**). Ordovician rocks either are at the land surface or subcrop over the arches and domes, where rocks younger than Ordovician were either eroded or never deposited. The youngest Paleozoic rocks (Pennsylvanian and Permian) are present in the areas coincident with the structural basins (**figs. 6 and 7**). Pennsylvanian strata are present in the Illinois Basin in central and southern Illinois, southwestern Indiana, and northwestern Kentucky. Pennsylvanian and Permian strata are present in the Appalachian Basin in southeastern Ohio, whereas only Pennsylvanian strata are present in the same basin in eastern Kentucky and east-central Tennessee.

The Paleozoic rocks are covered by sedimentary rocks of late Mesozoic and Cenozoic age in the Mississippi Embayment section of the Coastal Plain Province in the western parts of Kentucky and Tennessee and in southern Illinois (**figs. 1 and 7**). These Coastal Plain deposits thicken from less than 100 feet near their northern and eastern limits to about 3,000 feet at the southwestern tip of Tennessee. The deposits are primarily semiconsolidated layers of clay, silt, sand, and gravel.

In the northern part of Segment 10, the Paleozoic rocks are covered by Quaternary deposits, which consist of different combinations of clay, silt, sand, and gravel. Most of these materials were deposited by the ice of continental glaciers that covered large parts of North America during the Pleistocene Epoch or by meltwater from the ice. The southern limit of glaciation (**fig. 7**) marks the general southern extent of these deposits in Segment 10, but meltwater deposits are present south of this limit along the Ohio River and many of its tributaries.

The distribution of the different geologic units at depth is shown by the geologic sections in **figure 8**. From this perspective, the effects of arches, domes, structural basins, and associated faults on the distribution of the rocks in Segment 10 are more apparent.

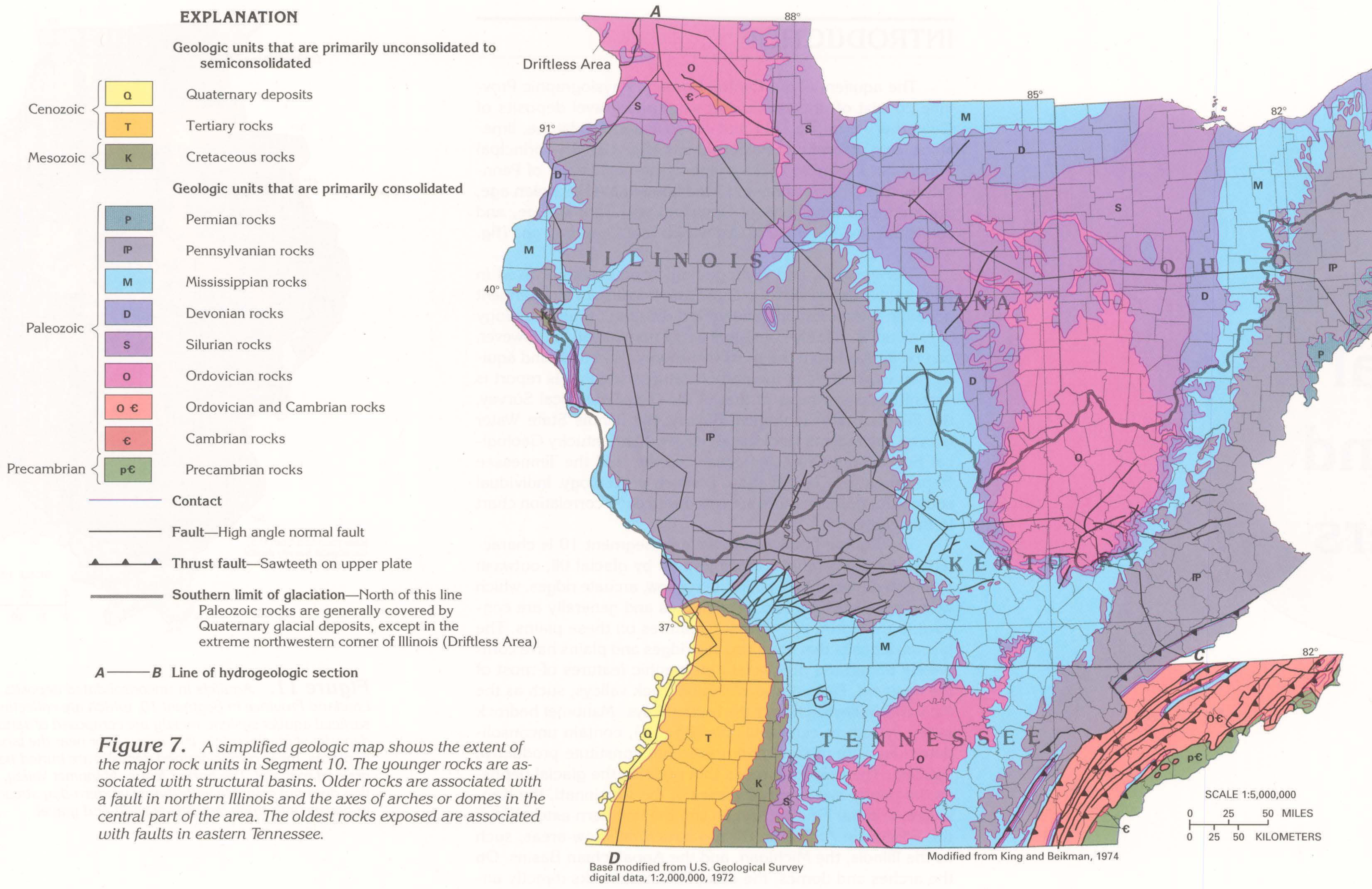


Figure 7. A simplified geologic map shows the extent of the major rock units in Segment 10. The younger rocks are associated with structural basins. Older rocks are associated with a fault in northern Illinois and the axes of arches or domes in the central part of the area. The oldest rocks exposed are associated with faults in eastern Tennessee.

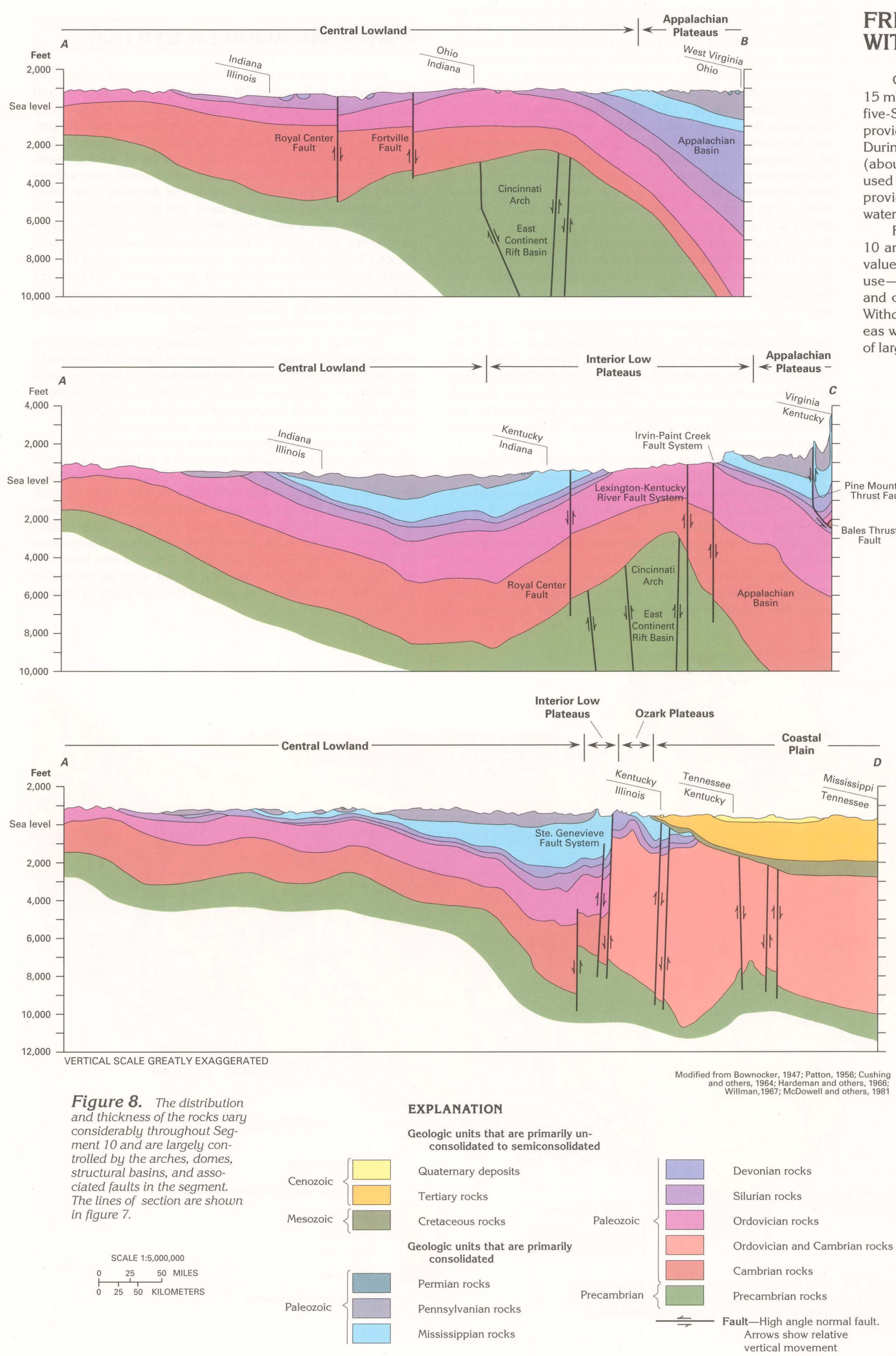


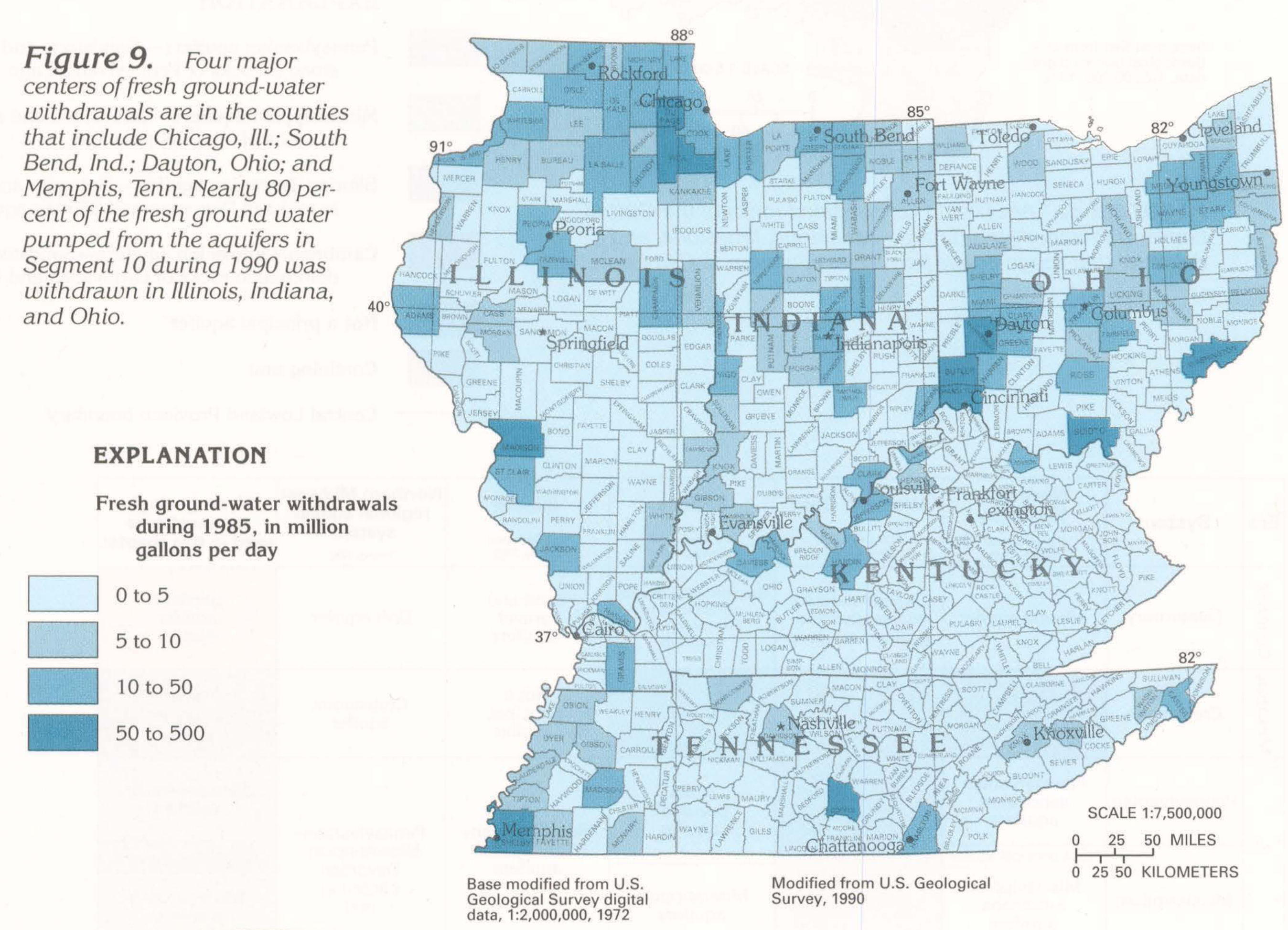
Figure 8. The distribution and thickness of the rocks vary considerably throughout Segment 10 and are largely controlled by the arches, domes, structural basins, and associated faults in the segment. The lines of section are shown in figure 7.

FRESH GROUND-WATER WITHDRAWALS

Ground water is a reliable source of freshwater for about 15 million people, or 44 percent of the total population, in the five-State area of Segment 10. Public water-supply systems provide water to twice as many people as do domestic wells. During 1985, the people of Illinois used the most ground water (about 930 million gallons per day), and those in Kentucky used the least (about 205 million gallons per day). These data provide an indication of the magnitude of the fresh ground water withdrawn by public and rural water-supply systems.

Fresh ground-water withdrawals during 1990 in Segment 10 are illustrated by county in **figure 9**. The total withdrawal values shown in **figure 9** account for all categories of water use—public supply, domestic and commercial, agricultural, and combined industrial, mining, and thermoelectric power. Withdrawals are greatest near large population centers or areas where industry is concentrated or both. Most of the areas of large withdrawals in Segment 10 are in Illinois, Indiana, and Ohio. The four largest withdrawal areas are located around Chicago, Ill., South Bend, Ind., Dayton, Ohio, and Memphis, Tenn. The rate of fresh ground-water withdrawals from the principal aquifers in Segment 10 during 1985 is shown in **figure 10**. During 1985, about 1,488 million gallons per day was withdrawn from the surficial and buried sand and gravel aquifers in deposits of Quaternary age that compose the surficial aquifer system. Most of these withdrawals were primarily along and north of the Ohio River. These aquifers supplied about 3 to 125 times as much water as other aquifers in the segment and yielded about one-half of the total fresh ground water withdrawn. Other productive aquifers or aquifer systems that supplied at least 300 million gallons per day during 1985 are the limestone and dolomite aquifers in rocks of Devonian and Silurian age (about 488 million gallons per day), the Cambrian–Ordovician aquifer system (about 396 million gallons per day), and the Mississippi embayment aquifer system (about 308 million gallons per day). The Mississippi embayment aquifer system is the principal source of fresh ground water for the westernmost parts of Kentucky and Tennessee. During 1985, the total ground water withdrawn from all the aquifers in Segment 10 was about 2,972 million gallons per day.

Figure 9. Four major centers of fresh ground-water withdrawals are in the counties that include Chicago, Ill.; South Bend, Ind.; Dayton, Ohio; and Memphis, Tenn. Nearly 80 percent of the fresh ground water pumped from the aquifers in Segment 10 during 1990 was withdrawn in Illinois, Indiana, and Ohio.



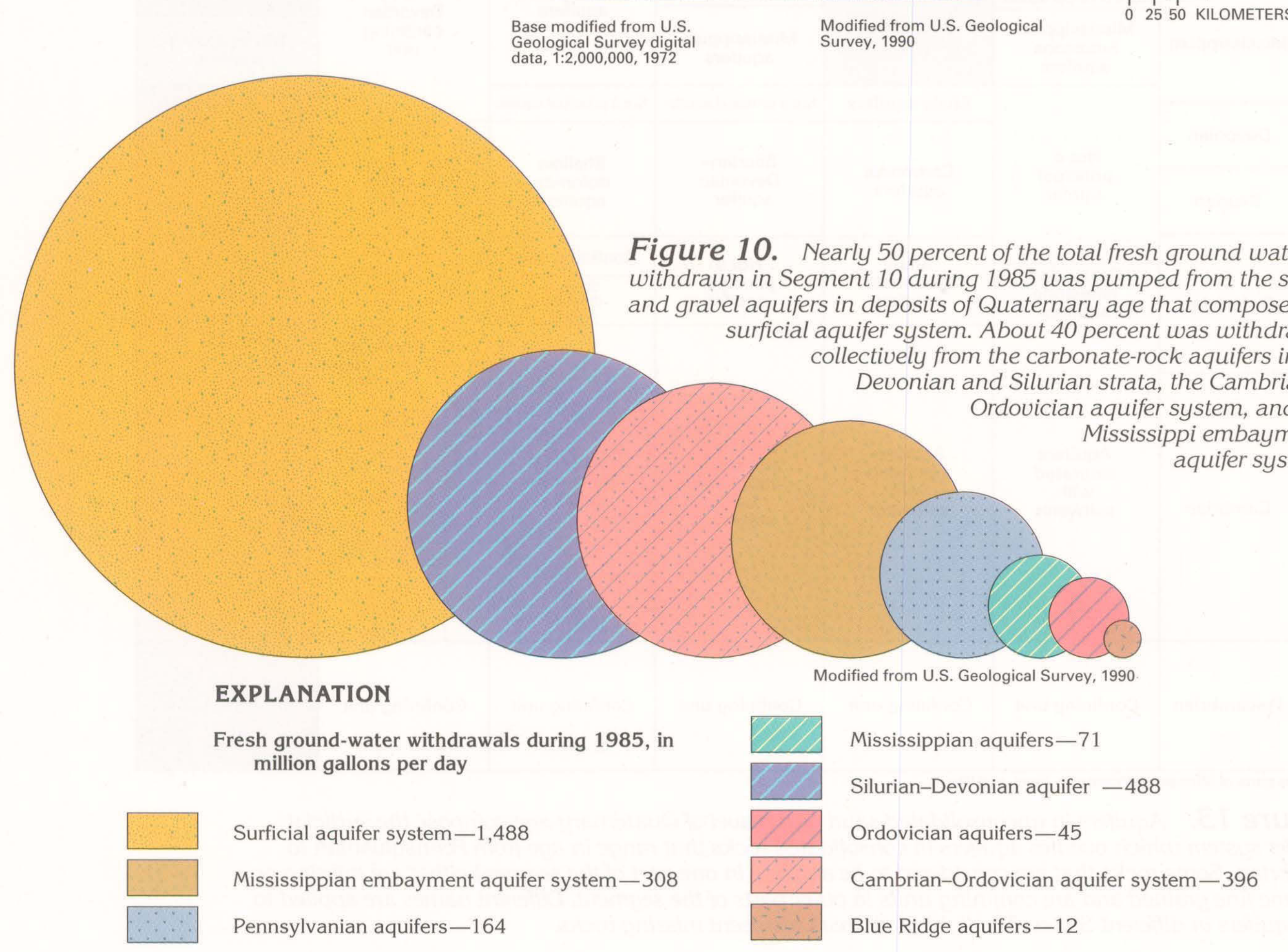


Figure 10. Nearly 50 percent of the total fresh ground water withdrawn in Segment 10 during 1985 was pumped from the sand and gravel aquifers in deposits of Quaternary age that compose the surficial aquifer system. About 40 percent was withdrawn collectively from the carbonate-rock aquifers in Devonian and Silurian strata, the Cambrian–Ordovician aquifer system, and the Mississippi embayment aquifer system.

Central Lowland aquifers

INTRODUCTION

The aquifers of the Central Lowland Physiographic Province consist of unconsolidated sand and gravel deposits of Quaternary age (**fig. 11**) and consolidated sandstone, limestone, and dolomite of Paleozoic age (**fig. 12**). The principal aquifers in Paleozoic rocks primarily are sandstone of Pennsylvanian age, limestone and sandstone of Mississippian age, dolomite and limestone of Devonian and Silurian age, and sandstone and dolomite of Ordovician and Cambrian age (**fig. 13**).

The geologic and hydrogeologic nomenclature used in this chapter differs from State to State because of independent geologic interpretations and varied distribution and lithology of rock units. A fairly consistent set of nomenclature, however, can be derived from the most commonly used rock and aquifer names. Therefore, the nomenclature used in this report is essentially a synthesis of that of the U.S. Geological Survey, the Illinois State Geological Survey, the Illinois State Water Survey, the Indiana Geological Survey, the Kentucky Geological Survey, the Ohio Geological Survey, and the Tennessee Department of Conservation, Division of Geology. Individual sources for nomenclature are listed with each correlation chart in this chapter.

The Central Lowland Province in Segment 10 is characterized by a low-relief surface formed by glacial till, outwash plains, and glacial-lake plains. Long, low, arcuate ridges, which were formed by recessional moraines and generally are concave to the north, are common features on these plains. The glacial deposits that compose the ridges and plains have completely buried the preglacial topographic features of most of the segment. Parts of the buried bedrock valleys, such as the Mahomet Valley section of the buried Teays–Mahomet bedrock valley system in central Illinois (**fig. 11**), contain unconsolidated deposits of sand and gravel that constitute productive aquifers. The Paleozoic rocks that underlie the glacial deposits dip gently away from the axes of the Cincinnati, the Kankakee, and the Findlay Arches and the southern extension of the Wisconsin Arch (**fig. 6**) into structurally low areas, such as the Illinois, the Michigan, and the Appalachian Basins. On the arches and domes, the older Paleozoic rocks directly underlie the glacial deposits near the axes of the folds; in the structural basins, the younger Paleozoic rocks are directly beneath the glacial materials near the centers of the folds.

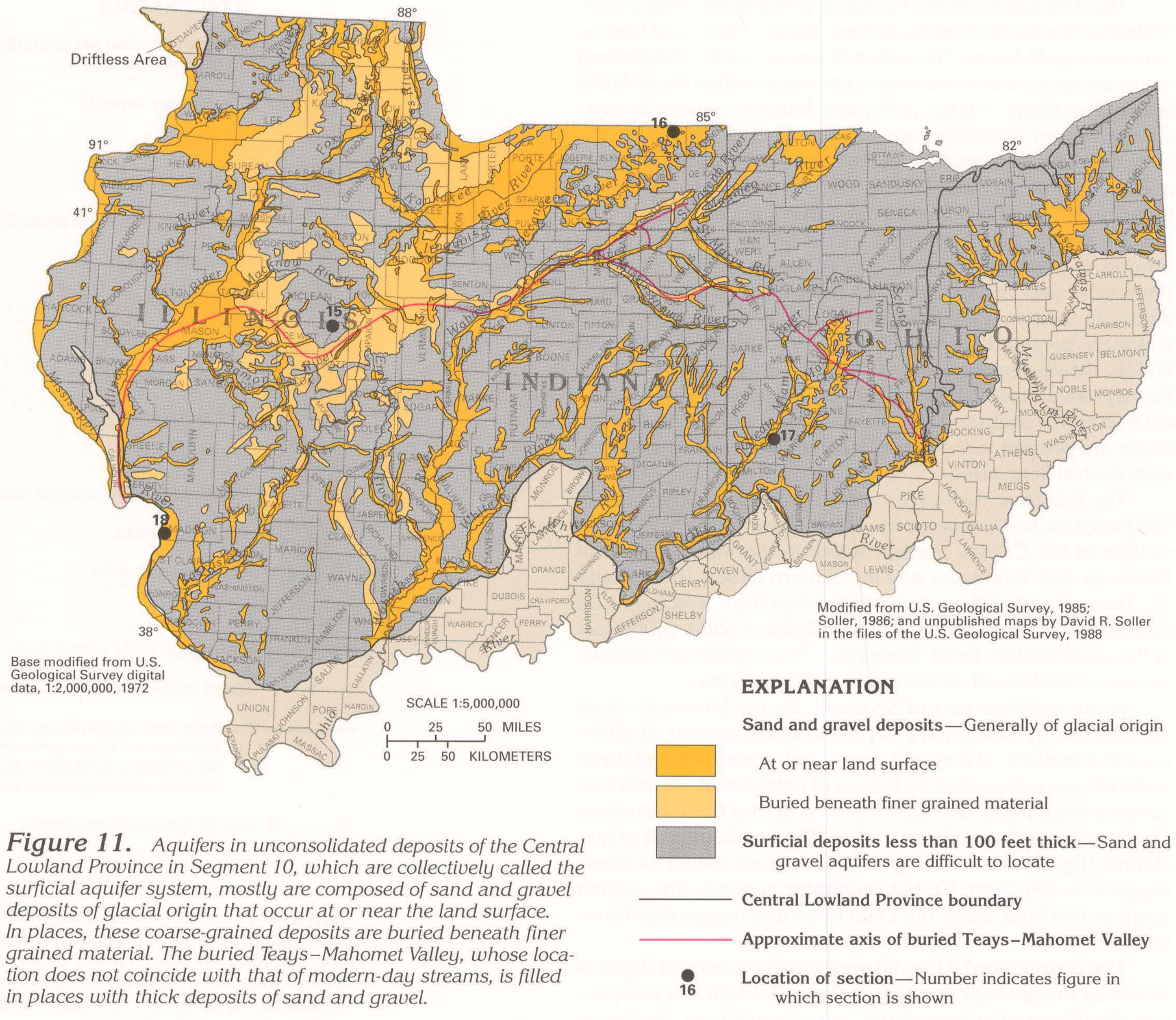


Figure 11. Aquifers in unconsolidated deposits of the Central Lowland Province in Segment 10, which are collectively called the surficial aquifer system, mostly are composed of sand and gravel deposits of glacial origin that occur at or near the land surface. In places, these coarse-grained deposits are buried beneath finer grained material. The buried Teays–Mahomet Valley, whose location does not coincide with that of modern-day streams, is filled in places with thick deposits of sand and gravel.

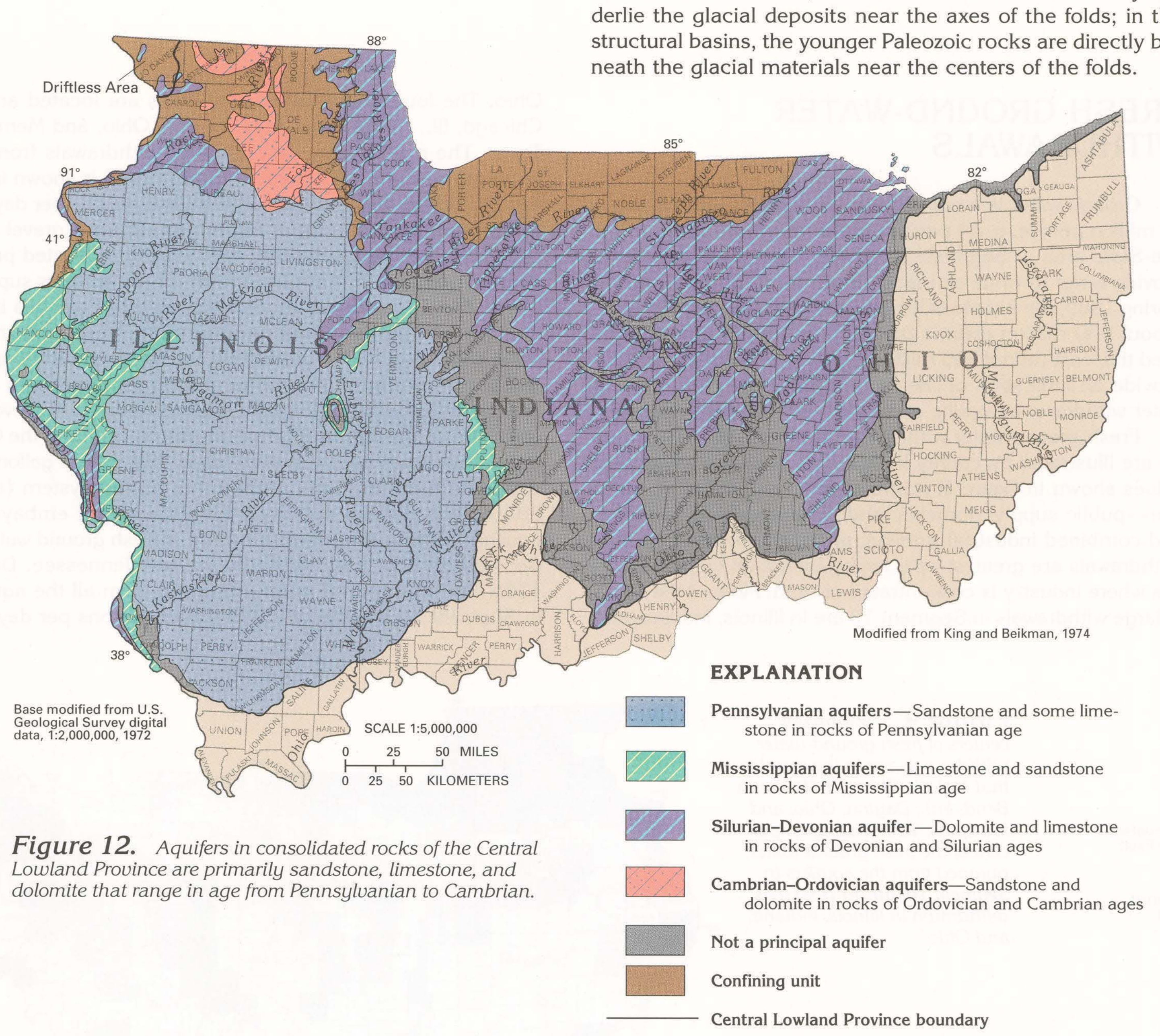


Figure 12. Aquifers in consolidated rocks of the Central Lowland Province are primarily sandstone, limestone, and dolomite that range in age from Pennsylvanian to Cambrian.

The depth to which freshwater circulates in the consolidated rocks depends on a number of factors, including the permeability of the aquifers in the consolidated rocks, and on the number, thickness, and permeability of confining units that are present in the consolidated rocks and in the overlying unconsolidated deposits. For example, the freshwater flow system is deep in northern Illinois where the aquifers in consolidated rocks of Ordovician and Cambrian age transmit water from aquifer outcrop and shallow subcrop areas in central Wisconsin to depths of about 2,000 feet in the Chicago, Ill., area. A freshwater flow system also exists in the aquifers in dolomite and limestone of Devonian and Silurian age in the eastern part of the segment in Indiana and Ohio. In contrast, the aquifers in limestone and sandstone of Mississippian age are saturated with saltwater in Illinois and Indiana, except in areas where these rocks crop out. The aquifers in Mississippian rocks in Illinois and Indiana mostly are overlain by Pennsylvanian rocks that are interlayered shale, siltstone, sandstone, limestone, and coal. The interlayered shale and siltstone form confining units that impede the downward movement of the freshwater and the flushing of saltwater from the underlying aquifers in Mississippian rocks.

Unconsolidated glacial deposits of Quaternary age overlie the consolidated Paleozoic rocks throughout most of the Central Lowland Province in Segment 10. However, Silurian and Ordovician rocks are at the land surface in the Driftless Area in northwestern Illinois, and rocks of Pennsylvanian through Ordovician age are at the land surface along the boundary between the Central Lowland and the Ozark Plateaus Provinces in southwestern Illinois.

The unconsolidated Quaternary deposits are saturated with freshwater throughout the segment. The water moves through the void spaces between the mineral grains and rock particles that constitute the deposits. The upper part of the consolidated Paleozoic rocks that underlie the Quaternary deposits also is saturated with freshwater, which moves through primary pore spaces in some of the sandstone units and secondary openings, such as fractures and bedding planes, in all the consolidated rocks. In limestone and dolomite, these secondary openings are often enlarged by the dissolution of the carbonate rocks. As a consequence of this enlargement, the limestone and dolomite form the most productive aquifers in consolidated rocks in the segment.

SURFICIAL AQUIFER SYSTEM

Some of the most productive aquifers in the Central Lowland Province in Segment 10 consist of Quaternary sand and gravel deposits (**fig. 11**). These deposits, which are collectively called the surficial aquifer system, supply more than 50 percent of the fresh ground water withdrawn in the segment. The Quaternary deposits primarily are material of glacial origin. Even the Holocene alluvium present in some river valleys mostly is derived from reworked glacial deposits. The different combinations of clay, silt, sand, and gravel that compose the glacial material were deposited during at least three stages of advance and retreat of the ice. In places where they were directly emplaced by the ice, these deposits, called till, are poorly sorted mixtures of clay, silt, sand, gravel, and boulders and generally are not productive aquifers. In other places, sediments deposited by glacial meltwater consist of coarse sand and gravel that are productive aquifers.

The range in thickness of the Quaternary deposits in the northern part of Segment 10 is shown in **figure 14**. The thickness of the deposits ranges from less than 100 feet in most of the segment to between 400 and 600 feet in buried bedrock valleys. The thickest deposits are mostly in west-central Ohio, northeastern Indiana, and northern and central Illinois.

Most of the principal sand and gravel deposits that are known to constitute aquifers are shown in **figure 11**. These coarse-grained deposits have been divided into two categories: deposits that are at or near land surface and those that are buried beneath fine-grained material. Sand and gravel deposits at or near land surface mostly are in the present river valleys and upland areas. Those deposits buried beneath fine-grained material are in former river valleys (valleys cut into bedrock) that have been filled with glacial material, such as the buried Teays–Mahomet Valley that extends through parts of Illinois, Indiana, and Ohio.

Era	System	Northern Kentucky (U.S. Geological Survey, 1985)	Western Ohio (U.S. Geological Survey, 1985)	Indiana (U.S. Geological Survey, 1985)	Illinois (U.S. Geological Survey, 1985)	Northern Midwest regional aquifer system[1] (Young, 1992)		Hydrogeologic nomenclature used in this chapter	
Cenozoic	Quaternary	Alluvial aquifer	Unconsolidated, coarse-and fine-grained aquifers	Glaciofluvial, glacial outwash, and Wisconsin till aquifers	Sand and gravel aquifers	Drift aquifer		Surficial aquifer system	
Mesozoic	Cretaceous				Not a principal aquifer	Cretaceous aquifer		Not a principal aquifer	
Paleozoic	Pennsylvanian	Pennsylvanian sandstone aquifers		Not a principal aquifer	Pennsylvanian–Mississippian aquifers	Pennsylvanian–Mississippian–Devonian confining unit		Pennsylvanian aquifers	
	Mississippian	Not a principal aquifer						Not a principal aquifer	
		Mississippian limestone aquifers		Mississippian aquifers				Mississippian aquifers	
	Devonian	Not a principal aquifer	Shale aquifers	Not a principal aquifer	Not a principal aquifer			Not a principal aquifer	
	Silurian		Carbonate aquifers	Silurian–Devonian aquifer	Shallow dolomite aquifers	Silurian–Devonian aquifer		Silurian–Devonian aquifer	
	Ordovician		Shaly carbonate aquifers	Not a principal aquifer	Confining units	Cambrian–Ordovician aquifer system	Maquoketa confining unit	Not a principal aquifer	
		Ordovician limestone aquifers			Shallow dolomite aquifer				
		Aquifers saturated with saltwater	Aquifers saturated with saltwater	Aquifers primarily saturated with saltwater	Cambrian–Ordovician aquifer		St. Peter–Prairie du Chien–Jordan aquifer	Cambrian–Ordovician aquifer system	Sandstone and dolomite aquifers of Ordovician age
	Cambrian						St. Lawrence–Franconia confining unit		Sandstone and dolomite aquifers of Cambrian age
							Ironton–Galesville aquifer		
							Eau Claire confining unit		
							Mount Simon aquifer		
Middle Proterozoic	Precambrian	Confining unit	Confining unit	Confining unit	Confining unit	Confining unit		Confining unit	

[1]Includes parts of Minnesota, Wisconsin, Iowa, and Illinois.

Figure 13. Aquifers in unconsolidated sand and gravel of Quaternary age compose the surficial aquifer system which overlies aquifers in consolidated rocks that range in age from Pennsylvanian to Cambrian. Some rocks that are considered to be aquifers in one part of the segment either are missing or become fine grained and are confining units in other parts of the segment. Different names are applied to the aquifers in different States. The light gray areas represent missing rocks.

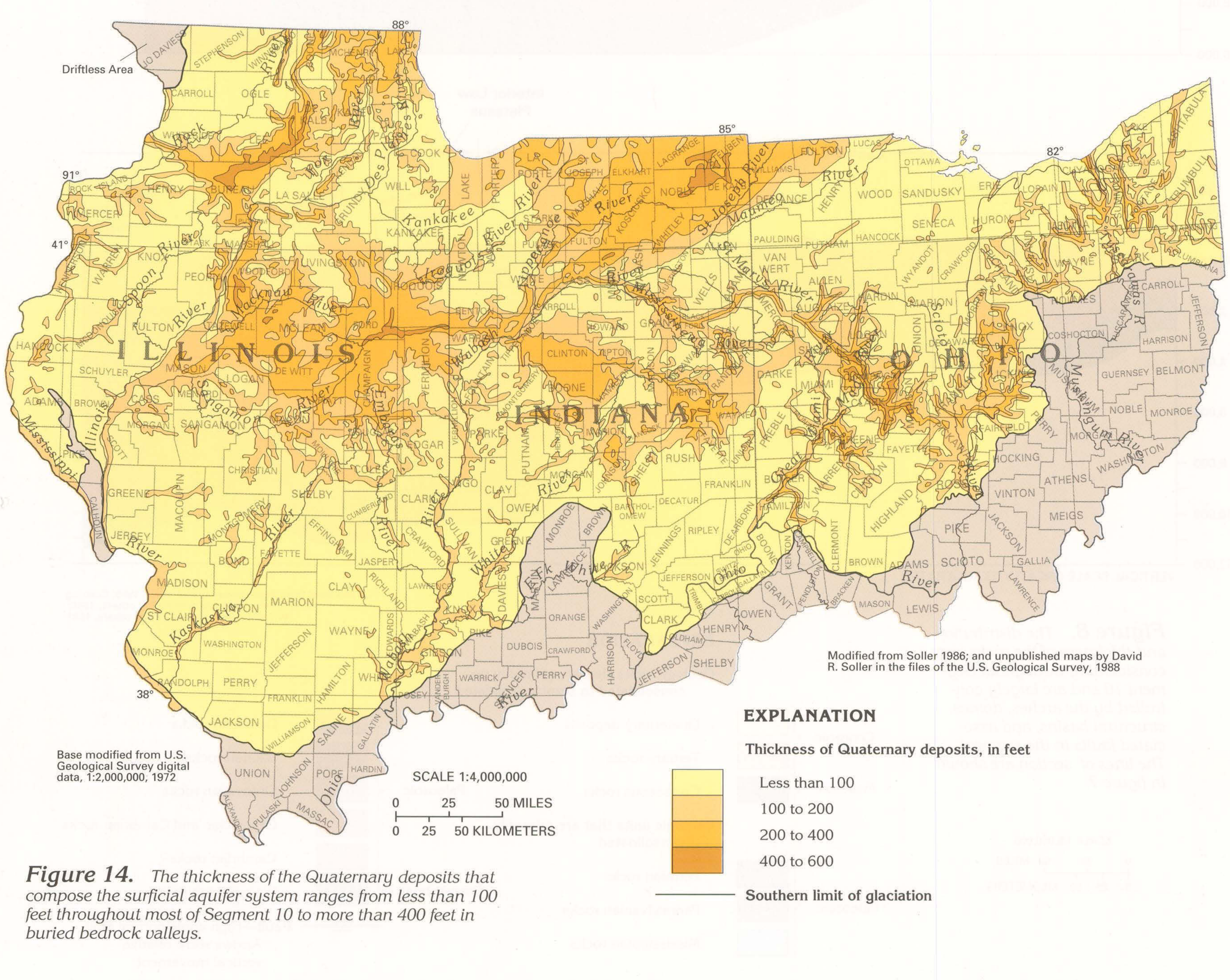


Figure 14. The thickness of the Quaternary deposits that compose the surficial aquifer system ranges from less than 100 feet throughout most of Segment 10 to more than 400 feet in buried bedrock valleys.

Hydrogeologic Setting

The lateral extent, thickness, and hydraulic characteristics of each of the numerous sand and gravel aquifers and clay and silt confining units that make up the surficial aquifer system are difficult to map at a regional scale because the distribution of the sediments is extremely complex. Consequently, examples from different areas within the Central Lowland Province in Segment 10 are used to illustrate the similarities and differences in the hydrology of these deposits.

The sand and gravel aquifers of the surficial aquifer system are present in different hydrogeologic settings. Aquifers that consist of glacial deposits are in buried river valleys, such as the Mahomet Valley in central Illinois (**fig. 15**); glacial outwash plains, such as the one in northern Lagrange County, Ind. (**fig. 16**); and ancestral river valleys, such as the one along the Great Miami River in Butler County, Ohio (**fig. 17**). The thick Quaternary sand and gravel deposits along the Mississippi River near East St. Louis, St. Clair County, Ill. (**fig. 18**), represent alluvium deposited by the ancestral Mississippi River. Much of this alluvium consists of eroded and reworked glacial deposits.

The occurrence and movement of the ground water is somewhat different in the four hydrogeologic settings shown in **figures 15 through 18**. In the buried bedrock valley setting (**fig. 15**), the shallow sand and gravel aquifers are isolated from direct recharge and discharge by overlying clay and silt deposits that compose local confining units. Under natural conditions, most of the water that recharges these shallow aquifers moves along short flow paths and discharges to local streams. The remainder of the water circulates into the deeper sand and gravel that fills the buried Mahomet Valley. Where wells withdraw water from the deeper sand and gravel aquifers, more of the recharge water is drawn into the deeper deposits. Water is transmitted rapidly to wells completed in the shallow, isolated sand and gravel aquifers, but the long-term yield of the wells is limited by the volume of recharge that passes through the surrounding clay and silt deposits. Small volumes of water might flow from bedrock into the sand and gravel aquifers.

In the glacial outwash plain setting (**fig. 16**), the sand and gravel aquifers commonly are at the land surface and receive recharge directly from precipitation. Under natural conditions, water in the upper part of the glacial deposits discharges to local streams, lakes, or wetlands; however, water in the deeper parts of the sand and gravel deposits flows beneath local streams and lakes and discharges to larger streams that are regional drains. Large yields are possible from wells completed in the glacial outwash aquifers, particularly where the aquifers have a direct hydraulic connection to streams and lakes and the wells are located near these surface-water bodies.

Parts of the hydrogeologic setting in **figure 17** are similar to the settings illustrated by **figures 15 and 16**. The upper sand and gravel aquifer in **figure 17*A*** is recharged directly by precipitation and has a direct hydraulic connection to the Great Miami River, similar to the aquifer–lake connection shown in **figure 16**. This direct connection increases the potential for large volumes of recharge to move toward nearby pumping wells. The recharge is obtained partly by induced infiltration of water from the river. The deeper buried sand and gravel aquifers shown in **figure 17*B*** are isolated from direct recharge and discharge by overlying clay and silt confining layers, a situation similar to that shown in **figure 15**.

The sand and gravel deposits in the Mississippi River Valley (**fig. 18**) are somewhat isolated from direct recharge but have a direct hydraulic connection to the river. Under natural conditions, recharge percolates downward through clay and silt confining units and then mostly moves through the sand and gravel deposits to discharge at the river. Wells near the river capture some of the flow and also might obtain some water by induced infiltration of water from the river.

Published reports on the sand and gravel deposits of the surficial aquifer system indicate that individual units range from less than 1 to about 300 feet in thickness. The thickest aquifers shown in this chapter are in the glacial outwash plain (**fig. 16**) in northern Lagrange County, Ind., and in the buried Mahomet Valley in central Illinois.

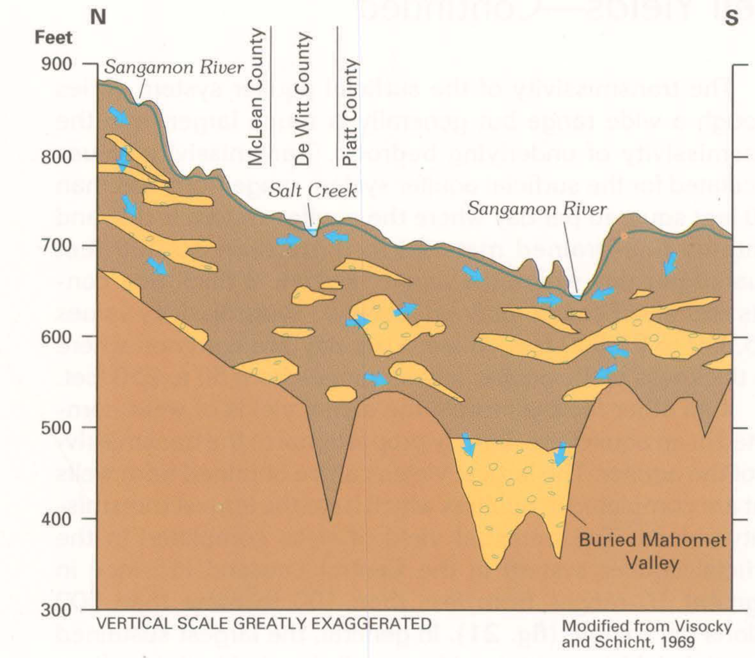


Figure 15. *A number of sand and gravel aquifers, which appear to be isolated in the subsurface, are present in central Illinois. Individual aquifers have been reported to be as much as 150 feet thick in parts of the buried Mahomet Valley, which is incised in the bedrock. The location of McLean, De Witt and Piatt Counties are shown in figure 11.*

EXPLANATION

Sand and gravel aquifers

Generally clay and silt

Bedrock

Water table

Direction of ground-water movement

0 5 10 MILES

0 5 10 KILOMETERS

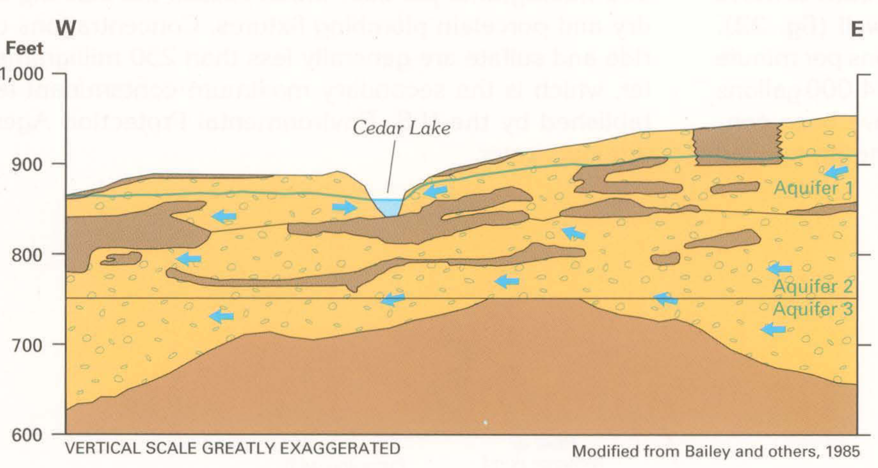


Figure 16. *Sand and gravel aquifers receive recharge at the land surface in the glacial outwash plain of Lagrange County in northern Indiana. The interconnected aquifers have a thickness of about 300 feet in the eastern part of the section. The location of the section is shown in figure 11.*

EXPLANATION

Sand and gravel aquifers

Generally clay and silt

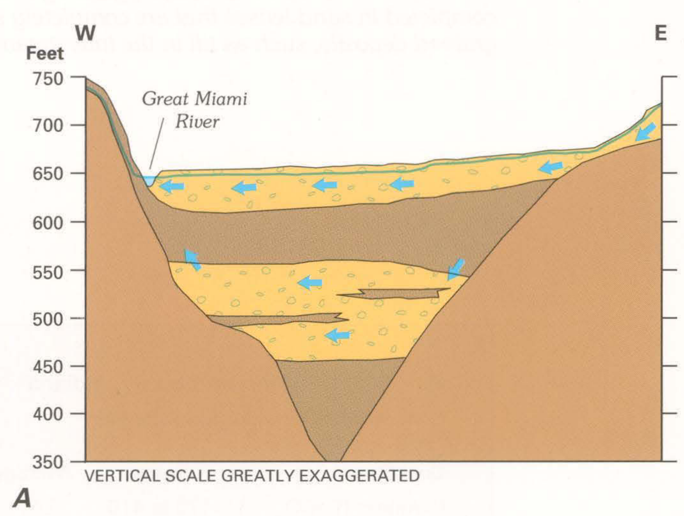
Bedrock

Water table

Direction of ground-water movement

0 1 2 MILES

0 1 2 KILOMETERS



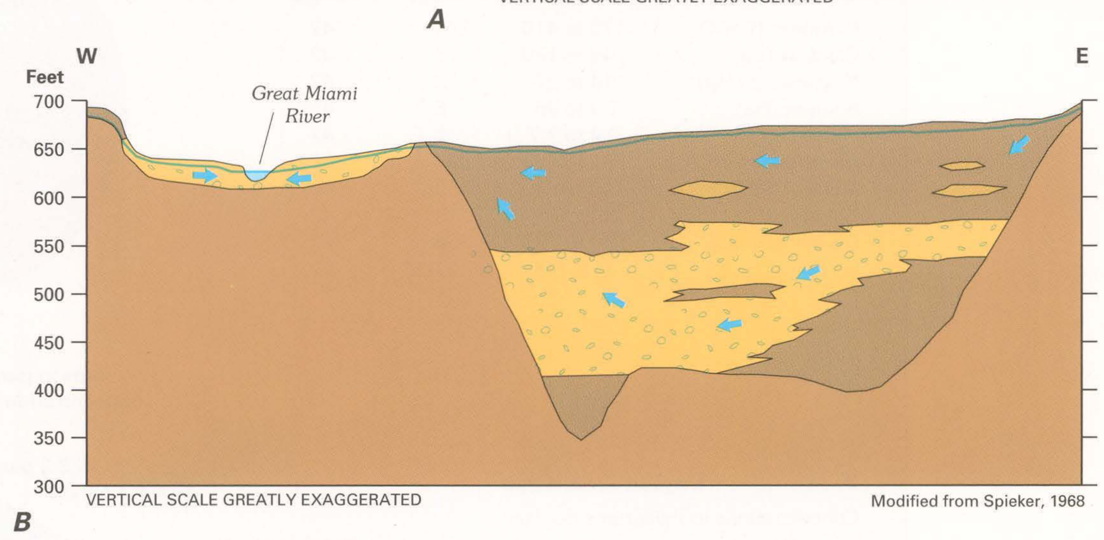


Figure 17. *Two separate aquifers, which range from 50 to 100 feet thick, are present in northeastern Butler County, Ohio, where the present and ancestral courses of the Great Miami River coincide (A). Where the courses diverge (B), only one aquifer might be present. The locations of the sections are shown in figure 11.*

EXPLANATION

Sand and gravel aquifers

Generally clay and silt

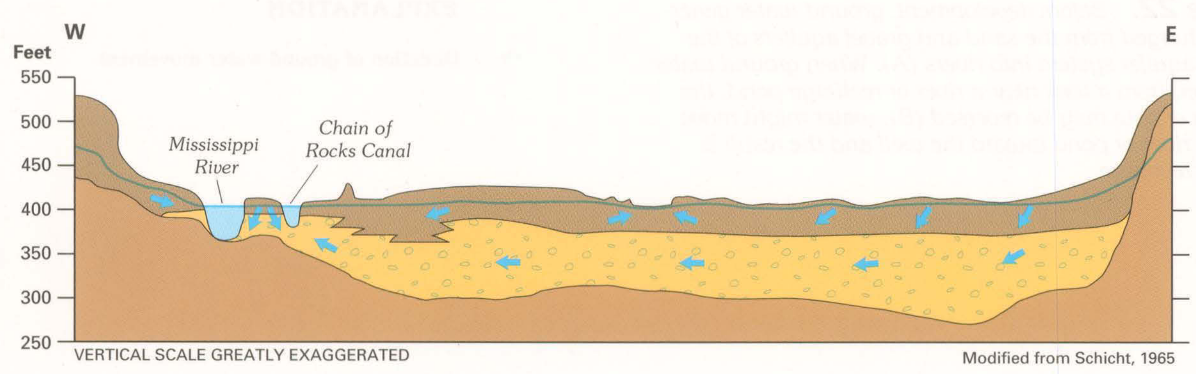
Bedrock

Water table

Direction of ground-water movement—Major direction of ground-water movement is toward the south (perpendicular to the section)

0 1500 3000 FEET

0 500 1000 METERS



0 1 2 MILES

0 1 2 KILOMETERS

Figure 18. *The thickest stream valley alluvial aquifer is present in the Mississippi River Valley at East St. Louis, Ill. The aquifer is about 100 feet thick and is hydraulically connected to the Chain of Rocks Canal and the Mississippi River. The location of the section is shown in figure 11.*

EXPLANATION

Sand and gravel aquifers

Generally clay and silt

Bedrock

Water table

Direction of ground-water movement

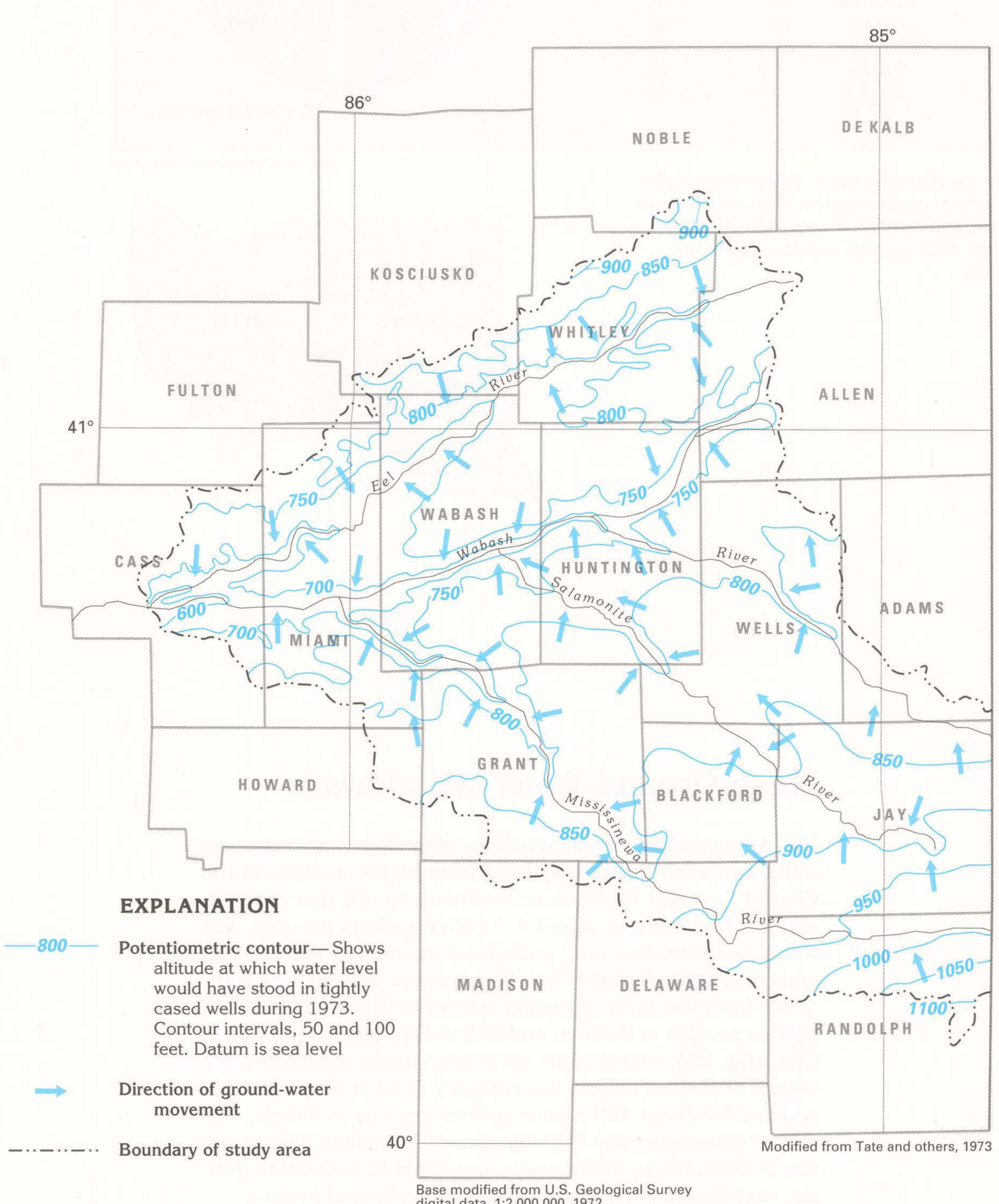
Generalized Ground-Water Movement

Although ground water in the surficial aquifer system is under water-table, or unconfined, conditions in many places, artesian, or confined, conditions exist in places where interbedded clay or silt compose local confining units. Together, water-table and artesian water levels compose the potentiometric surface of an aquifer. The difference in the altitude of the potentiometric surface over a unit horizontal distance is called the hydraulic gradient. Ground water moves through an aquifer in a direction generally parallel to the hydraulic gradient. The movement generally is perpendicular to the lines of equal altitude of the potentiometric surface.

A local example of the configuration of the potentiometric surface of the surficial aquifer system and its relation to interstream recharge areas and stream-valley discharge areas is shown in **figure 19**. In this example, the altitude of the potentiometric surface in the upper part of the Wabash River Basin in northeastern Indiana ranges from less than 600 to more than 1,100 feet above sea level. The regional hydraulic gradient in the basin is about 5 feet per mile, whereas local gradients are as much as 50 feet per mile. The direction of ground-water movement shown in **figure 19** is typical of that in the surficial aquifer system throughout the segment. Most of the water moves through the aquifer along short flow paths toward local streams where it is discharged to the streams as base flow. Some of the water follows longer flow paths in the deeper parts of the aquifer system and discharges to larger streams.

Aquifer Hydraulic Characteristics and Well Yields

In parts of central and southern Ohio, the buried Teays Valley is filled with laminated clay and silt that are not aquifer material. Further to the north and west, in the upper part of the Wabash River Basin in Indiana, the valley is filled partly with sand and gravel. In western Indiana and central Illinois, sand and gravel aquifers have been mapped in and along the buried Teays–Mahomet Valley (**fig. 11**). These coarse, permeable materials allow water to move through the sediments with little resistance to flow. The capacity of an aquifer to transmit water is known as transmissivity, which is a way of measuring the relative ease with which water moves through the aquifer. Transmissivity values for the permeable sediments in the buried Teays Valley in the upper Wabash River Basin range from 3,000 to about 40,000 feet squared per day (**fig. 20**). The water moves more readily through the aquifer where the transmissivity is greatest.

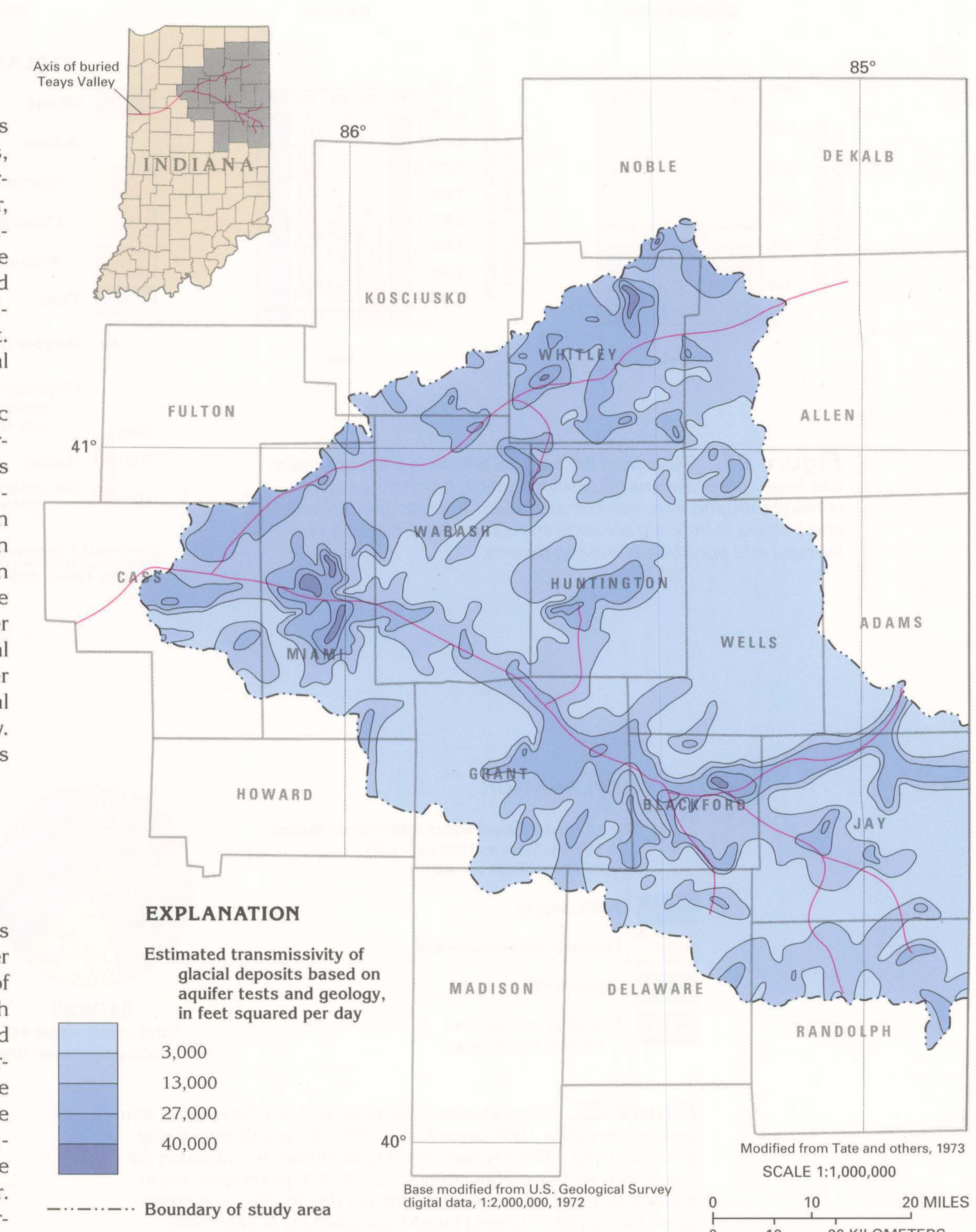


SCALE 1:1,000,000

0 10 20 MILES

0 10 20 KILOMETERS

Figure 19. *The altitude of the potentiometric surface of the surficial aquifer system in the upper part of the Wabash River Basin, Ind., reflects the land-surface altitude. The gradient of the potentiometric surface ranges from about 5 to about 50 feet per mile. In general, the ground water moves toward and discharges to local streams.*



SCALE 1:1,000,000

0 10 20 MILES

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Figure 20. *Glacial deposits that compose the surficial aquifer system have high values of transmissivity in places along the axis of the buried Teays Valley in the upper Wabash River Basin. These deposits have the potential to yield large volumes of water to wells.*

Aquifer Hydraulic Characteristics and Well Yields—Continued

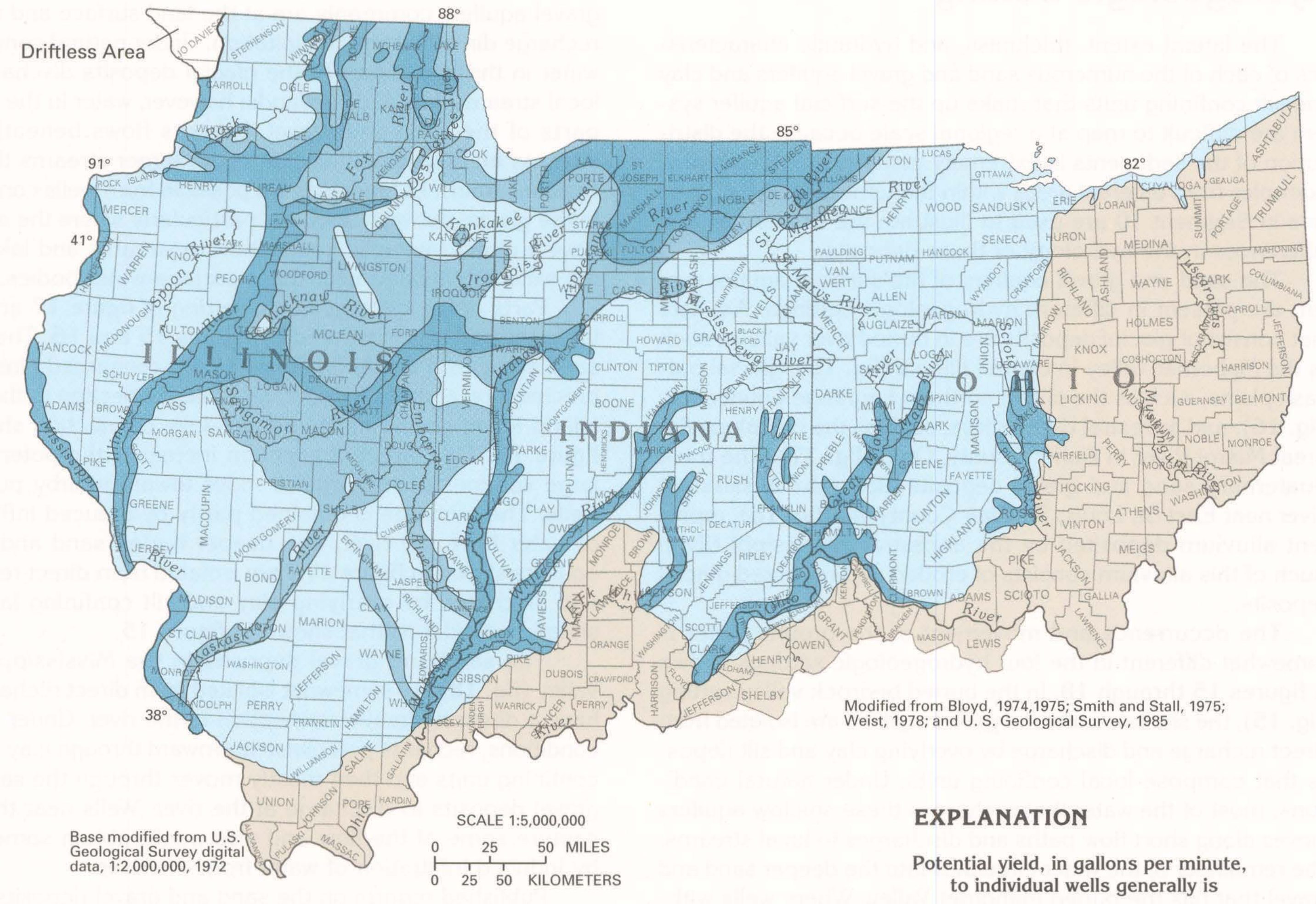
The transmissivity of the surficial aquifer system varies through a wide range but generally is much larger than the transmissivity of underlying bedrock. Transmissivity values calculated for the surficial aquifer system range from less than 500 feet squared per day where the aquifer system is thin and contains fine-grained material to more than 50,000 feet squared per day where the aquifer system is thick and consists entirely of coarse-grained material. Transmissivity values of 5,000 to 25,000 feet squared per day are common where the thickness of the aquifer system ranges from 50 to 250 feet.

If all other factors remain the same, yields of wells completed in an aquifer are directly proportional to the transmissivity of the aquifer. The largest yields can be obtained from wells that are completed in aquifers which have the largest transmissivity values. The potential yield of wells completed in the surficial aquifer system in the Central Lowland Province in Segment 10 ranges from less than 100 to more than 500 gallons per minute (**fig. 21**). In general, the largest sustained potential yields are obtained from wells located in river valleys where the aquifers and the river are hydraulically connected. Under such conditions, large withdrawals from a well near a river will cause the water level in the well to decline until it is below river level. The gradient created will induce water to move from the river into the aquifer and toward the well (**fig. 22**). Under these conditions, well yields of 2,000 gallons per minute are common, and maximum yields might exceed 4,000 gallons per minute. In some places, recharge ponds have been constructed to capture and impound surface water. The impounded water percolates downward to recharge the surficial aquifer system and subsequently moves into nearby pumping wells.

Ground-Water Quality

The quality of water in the sand and gravel aquifers of the surficial aquifer system is similar throughout Illinois, Indiana, and Ohio. The quality of the ground water is such that the water generally is adequate or can be treated and made adequate for most uses. However, in some places in Illinois and Ohio, nitrate concentrations are larger than the maximum contaminant level of 10 milligrams per liter established by the U.S. Environmental Protection Agency for drinking water. These large nitrate concentrations are possibly due to contamination of the ground water by fertilizer or by septic tank effluent.

Water in the surficial aquifer system typically is a calcium magnesium bicarbonate type, is hard, and has large concentrations of iron (**fig. 23**). The water typically has a neutral pH. Concentrations of dissolved solids mostly range between about 250 and 750 milligrams per liter with a median concentration that approaches 500 milligrams per liter, which is the secondary maximum contaminant level recommended for drinking water by the U.S. Environmental Protection Agency (**fig. 24**). Median hardness concentrations, which are expressed as calcium carbonate, generally exceed 300 milligrams per liter. Most of the water contains iron concentrations of greater than 300 micrograms per liter, which causes the staining of laundry and porcelain plumbing fixtures. Concentrations of chloride and sulfate are generally less than 250 milligrams per liter, which is the secondary maximum contaminant level established by the U.S. Environmental Protection Agency for drinking water.



EXPLANATION

Potential yield, in gallons per minute, to individual wells generally is

- Less than 100
- 100 to 500
- Greater than 500

Figure 21. The largest well yields (more than 500 gallons per minute) in the Central Lowland Province in Segment 10 are from wells completed in coarse sand and gravel aquifers along major streams and rivers and in outwash plains, such as the one in northern Indiana. The smallest well yields (less than 100 gallons per minute) from the surficial aquifer system generally are from wells completed in sand lenses that are completely surrounded by fine-grained deposits, such as till in the interstream areas.

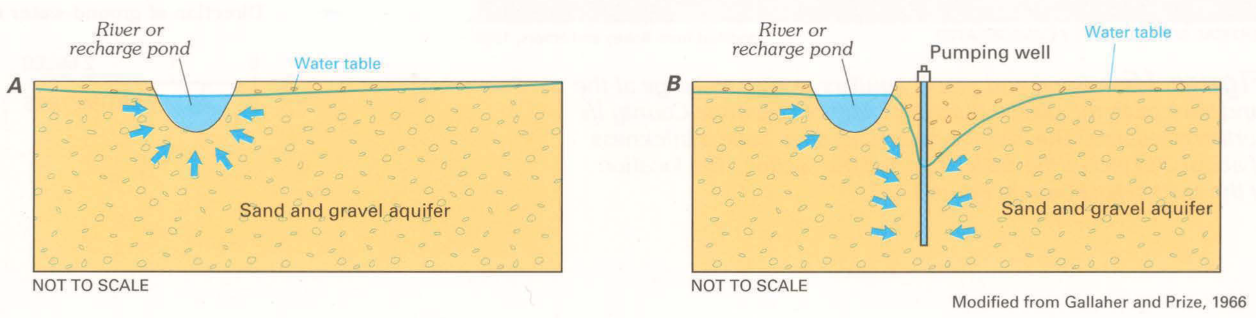


Figure 22. Before development, ground water generally discharged from the sand and gravel aquifers of the surficial aquifer system into rivers (A). When ground water is pumped from a well near a river or recharge pond, the direction of flow may be reversed (B); water might move from the river or pond toward the well and the result is induced recharge.

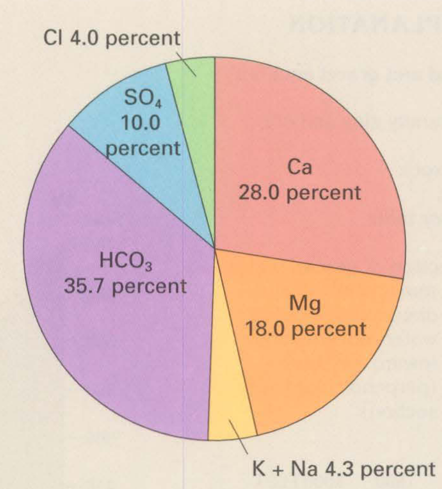
EXPLANATION

→ Direction of ground-water movement

A. Morgan County, Indiana

Concentrations in milligrams per liter

Constituent	Range	Average	Number of samples
Hardness ($CaCO_3$)	170 to 410	280	42
Calcium (Ca)	49 to 120	75	42
Magnesium (Mg)	14 to 27	22	42
Sodium (Na)	2.9 to 26	6.2	42
Potassium (K)	0.4 to 3.7	1.1	42
Bicarbonate (HCO_3)	195 to 488	293	97
Sulfate (SO_4)	0.6 to 63	32	42
Chloride (Cl)	3.1 to 43	13	42
Dissolved solids	250 to 524	366	42
Iron (Fe)	0 to 6.5	0.03	97

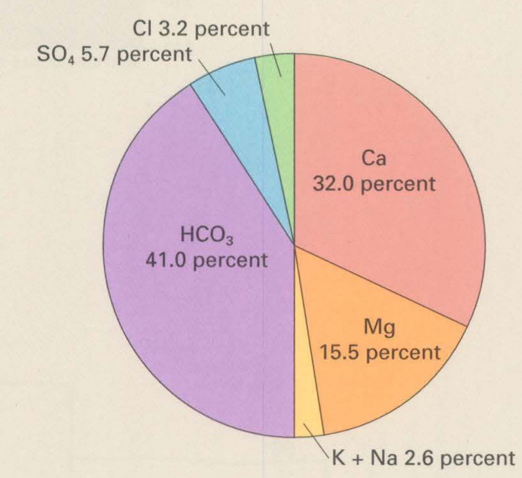


Values in percent of average major ion concentration, in milliequivalents per liter

B. Dayton area, Ohio

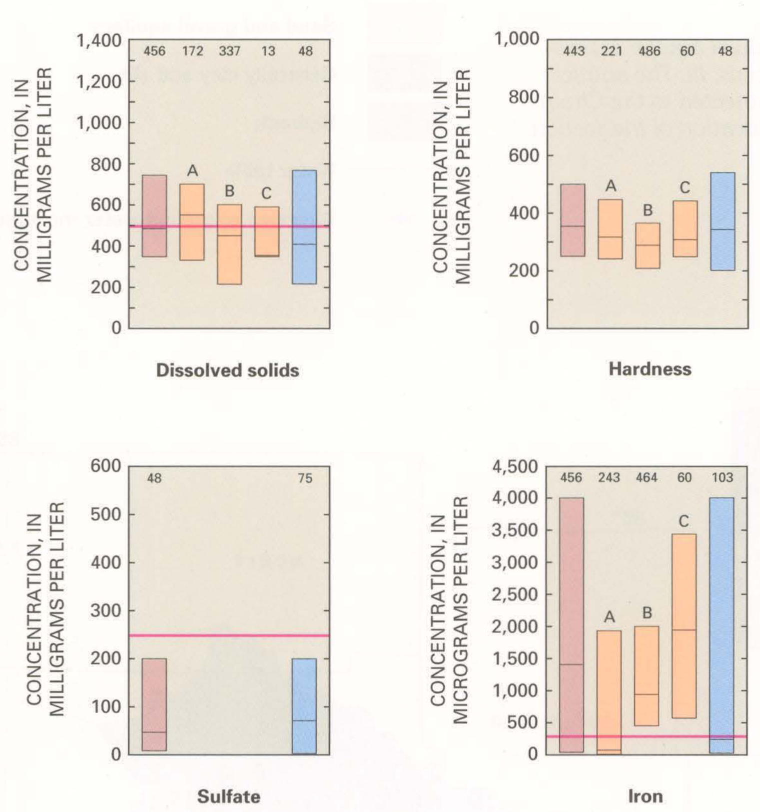
Concentrations in milligrams per liter

Constituent	Range	Average	Number of samples
Hardness ($CaCO_3$)	269 to 516	386	44
Calcium (Ca)	60 to 135	95	44
Magnesium (Mg)	29 to 57	37	44
Sodium (Na)	3.6 to 39	15	44
Potassium (K)	0.7 to 4.5	1.9	44
Bicarbonate (HCO_3)	268 to 470	366	44
Sulfate (SO_4)	21 to 189	80	44
Chloride (Cl)	1.2 to 60	23	44
Dissolved solids	274 to 651	458	44
Nitrate (NO_3)	0 to 30	3.8	44
Iron (Fe)	0 to 3.5	0.66	44



Data from Norris and Spieker, 1966

Figure 23. The quality of water is similar from wells completed in the surficial aquifer system in river valleys in Indiana and Ohio (shown) and in Illinois (not shown). Calcium, magnesium, bicarbonate, and locally sulfate are the dominant ions.



EXPLANATION

- Illinois
- Indiana
  - A Glaciofluvial deposits
  - B Outwash deposits
  - C Wisconsin till deposits
- Ohio

48 Number of analyses

Percentile—Percentage of analyses equal to or less than indicated values

90th, 50th, 10th — Median; Secondary maximum contaminant level

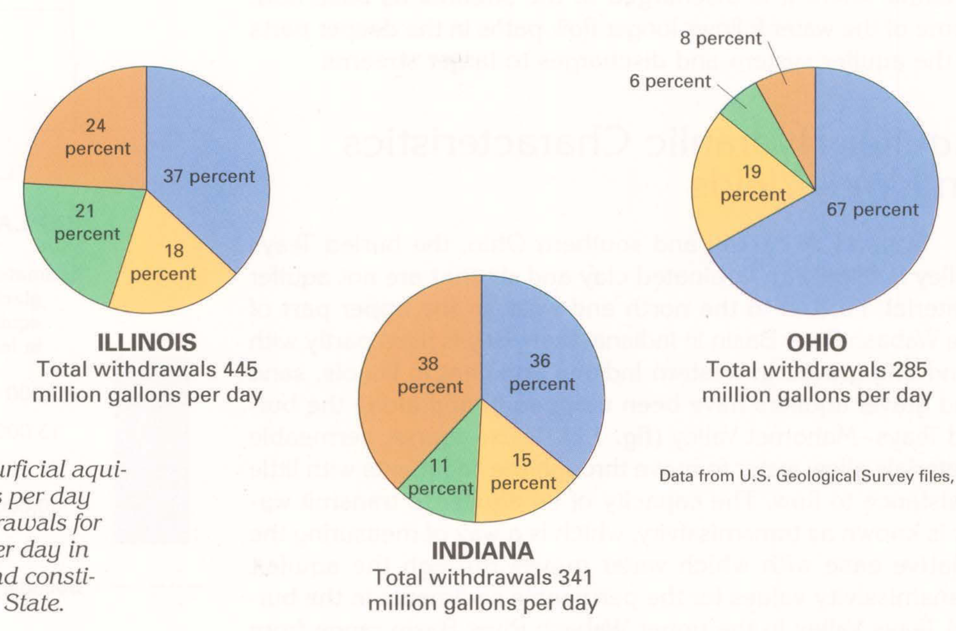
Data from U.S. Geological Survey files, 1988; Contaminant level from U. S. Environmental Protection Agency, 1986

Figure 24. Water from the surficial aquifer system generally has large concentrations of dissolved solids, hardness-causing constituents, and iron. Iron concentrations in water from Illinois and Indiana commonly are large enough to cause staining of laundry and porcelain plumbing fixtures.

EXPLANATION

Use of fresh ground-water withdrawals during 1985—Total withdrawals 1,071 million gallons per day

- Public supply
- Domestic and commercial
- Agricultural
- Industrial, mining, and thermoelectric power



Data from U.S. Geological Survey files, 1990

Figure 25. Ground-water withdrawals from the surficial aquifer system during 1985 ranged from 285 million gallons per day in Ohio to 445 million gallons per day in Illinois. Withdrawals for public supply ranged from about 123 million gallons per day in Indiana to about 191 million gallons per day in Ohio and constituted the largest or second largest use category in each State.

Fresh Ground-Water Withdrawals

Approximately 2 billion gallons of fresh ground water was withdrawn each day during 1985 from all the aquifers in the Central Lowland Province in Segment 10. Of this amount, about 53 percent, or about 1.1 billion gallons per day, was withdrawn from the sand and gravel aquifers of the surficial aquifer system. About 445 million gallons per day was withdrawn from the surficial aquifer system in Illinois, 341 million gallons per day in Indiana, and 285 million gallons per day in Ohio (**fig. 25**). Withdrawals for public supply constituted the largest or second largest use category in each State, and accounted for about 165 million gallons per day in Illinois, 123 million gallons per day in Indiana, and 191 million gallons per day in Ohio. Large withdrawals were made for industrial, mining, and thermoelectric power use in Illinois and Indiana.

PENNSYLVANIAN AQUIFERS

Hydrogeologic Setting

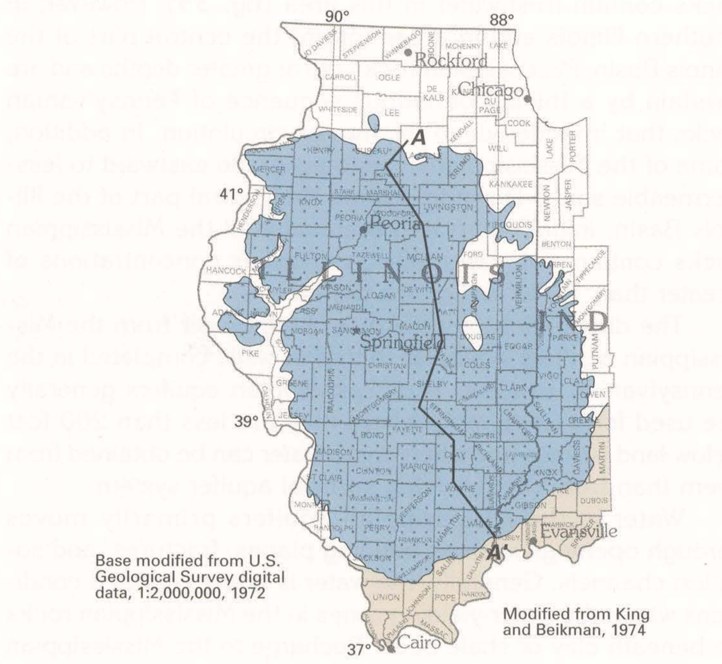
Sandstone and limestone beds of Pennsylvanian age that are aquifers in the Central Lowland Province in Segment 10 lie beneath the surficial aquifer system in parts of Illinois and Indiana (**fig. 26**). The Pennsylvanian sandstones and limestones are parts of repeating sequences of beds deposited during multiple sedimentary cycles. An ideal complete cycle consists of the following sequence of beds, listed from bottom to top: basal sandstone, sandy shale, limestone, underclay, coal, gray shale, limestone, black platy shale, limestone, and silty gray shale that contains iron concretions (**fig. 27**). The bottom five beds in the ideal sequence (including the coal) were deposited in a nonmarine environment. As the sea encroached upon the land, the upper five beds were deposited in a marine or marginal marine environment. Multiples of all or parts of this sequence were deposited by repeated advances and retreats of the sea. The main body of the sea was about as far west of Segment 10 during Pennsylvanian time as the present location of the State of Kansas. Sheetlike and channel-fill sandstones at the bases of the sedimentary sequences are some of the most productive aquifers in Pennsylvanian rocks. However, a zone of fractures, joints, and bedding plains commonly occurs in the upper parts of exposed Pennsylvanian rocks, and these openings yield water to wells regardless of rock type.

Small to moderate supplies of water are obtained from the Pennsylvanian aquifers in places where little water is available from the overlying Quaternary deposits of the surficial aquifer system. These conditions might exist where the Quaternary deposits are thin or fine grained or both. The Pennsylvanian aquifers commonly are used for water supplies in areas where they are buried beneath less than 100 feet of Quaternary deposits (**fig. 28**).

Most of the water in the Pennsylvanian aquifers is under confined conditions because the aquifers commonly are interbedded with siltstone, shale, and clay and are overlain by Quaternary deposits that contain clay beds. The water primarily moves through secondary openings, such as fractures and joints or local solution channels in limestones. Recharge to the Pennsylvanian aquifers takes place through the overlying Quaternary deposits. The large volumes of water stored in the surficial aquifer system serve to replenish ground water withdrawn from wells completed in the Pennsylvanian aquifers. In some places, such as river valleys, water levels in the Pennsylvanian aquifers are higher than those in the overlying surficial aquifer system, and ground water moves from the Pennsylvanian aquifers to the surficial aquifer system.

The thickness of Pennsylvanian rocks that is saturated with freshwater ranges from less than 100 feet to more than 300 feet (**fig. 29**). The thickest parts of the freshwater-yielding Pennsylvanian rocks are in central and southeastern Illinois and southwestern Indiana. Nearly the entire thickness of Pennsylvanian rocks contains freshwater in the north-central part of Illinois (**fig. 30**). Toward the south, the depth to saltwater decreases, and the Pennsylvanian rocks thicken. Near the southern limit of the area, only the upper 10 percent of the Pennsylvanian rocks contains freshwater.

The sandstones and limestones that are the most productive aquifers in the Pennsylvanian rocks have a distinct stratigraphic (vertical) and areal distribution. Sandstones are the predominant aquifers in the lower parts of the sequence of Pennsylvanian rocks, whereas limestones are the predominant aquifers in the middle and upper parts of the sequence (**fig. 31**). The sandstone aquifers are saturated with freshwater only in peripheral parts of the area underlain by the Pennsylvanian rocks; elsewhere, they contain saltwater. Some of the limestones and shales of the middle and upper parts of the sequence grade into sandstones and silty sandstones in southeastern Illinois. Because these sandstones and silty sandstones commonly are channel-fill deposits, they are sinuous, thin, and discontinuous and might be difficult to locate.



EXPLANATION

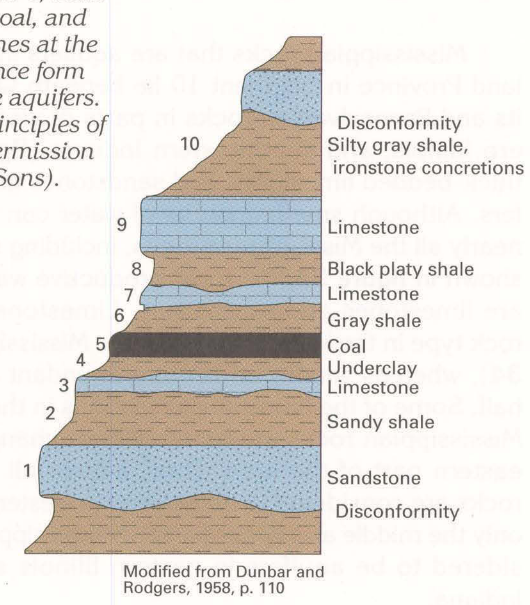
Pennsylvanian aquifers—Sandstone and some limestone in rocks of Pennsylvanian age

A——A' Line of hydrogeologic section

SCALE 1:7,500,000
0 25 50 MILES
0 25 50 KILOMETERS

Figure 26. *Pennsylvanian rocks that are aquifers in the Central Lowland Province in Segment 10 are extensive in Illinois and Indiana. The aquifers in Pennsylvanian rocks lie beneath the Quaternary deposits of the surficial aquifer system.*

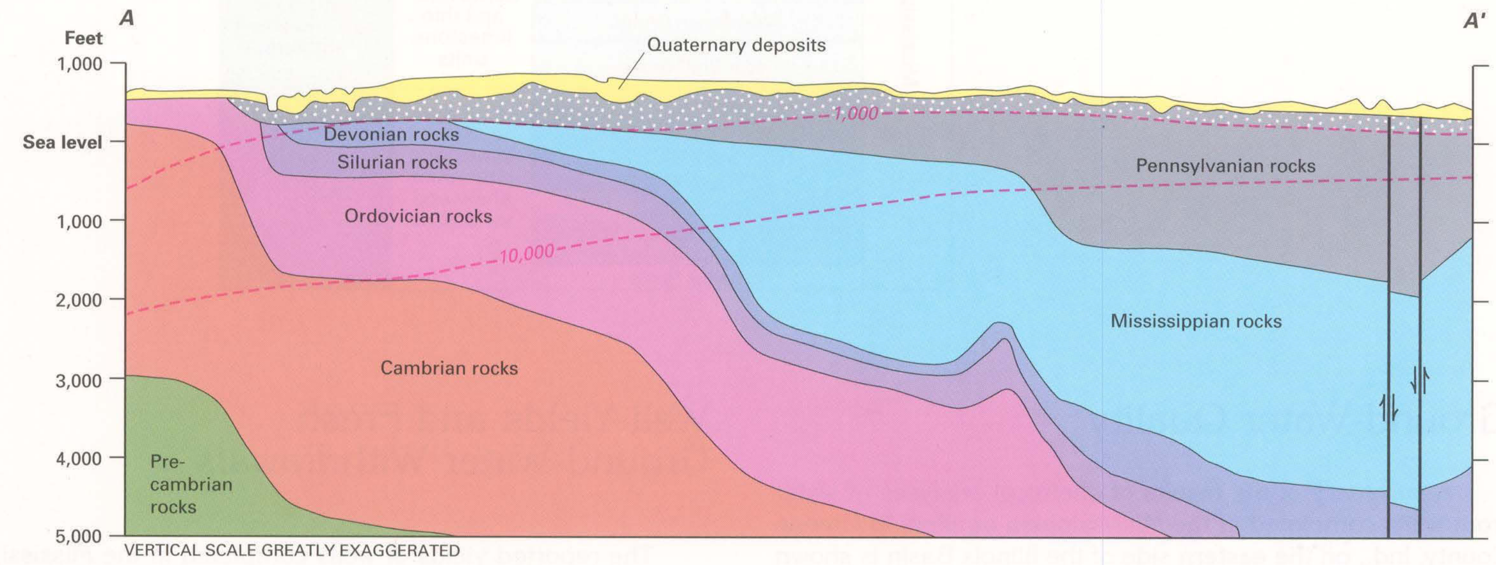
Figure 27. *A typical sequence of beds deposited during a sedimentary cycle in the Pennsylvanian rocks of Illinois consists of about 10 beds of sandstone, shale, clay, coal, and limestone. Sandstones at the base of each sequence form the most productive aquifers. (Reprinted from "Principles of Stratigraphy" by permission of John Wiley and Sons).*



EXPLANATION

Aquifer

Confining unit



SCALE 1:2,500,000
0 20 MILES
0 20 KILOMETERS

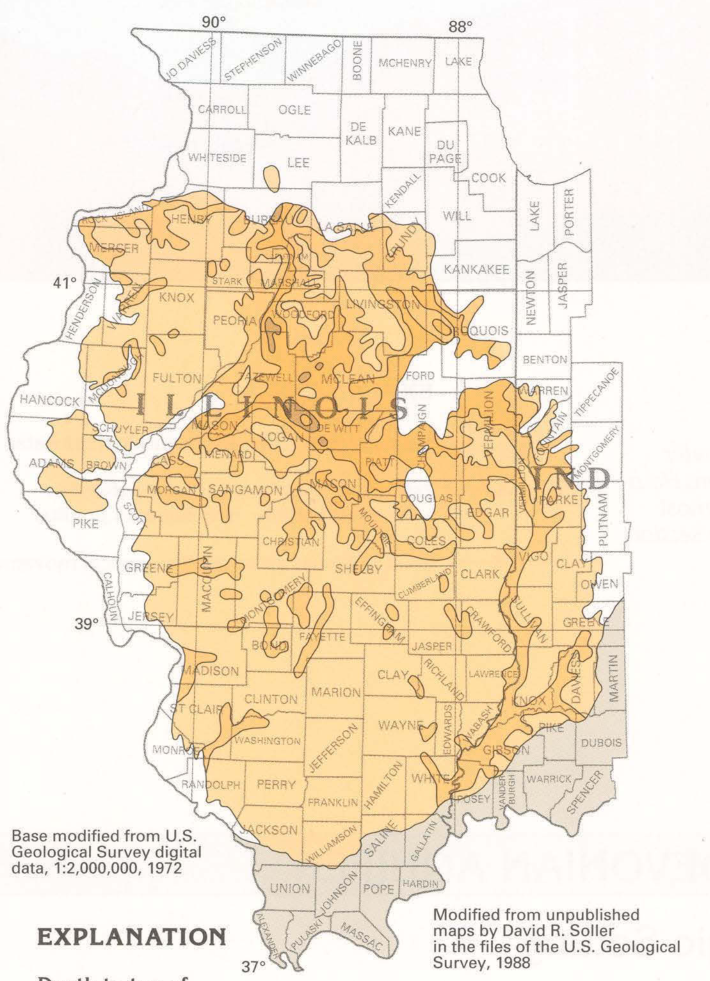
EXPLANATION

Pennsylvanian rocks that contain freshwater

- - 1,000 - - Estimated line of equal concentration of dissolved-solids, in milligrams per liter

Fault—Arrows show relative vertical movement

Figure 30. *The thickness of Pennsylvanian rocks increases from north to south. However, the thickness of freshwater in these rocks generally decreases from south to north. The line of the section is shown in figure 26.*



Modified from unpublished maps by David R. Soller in the files of the U.S. Geological Survey, 1988

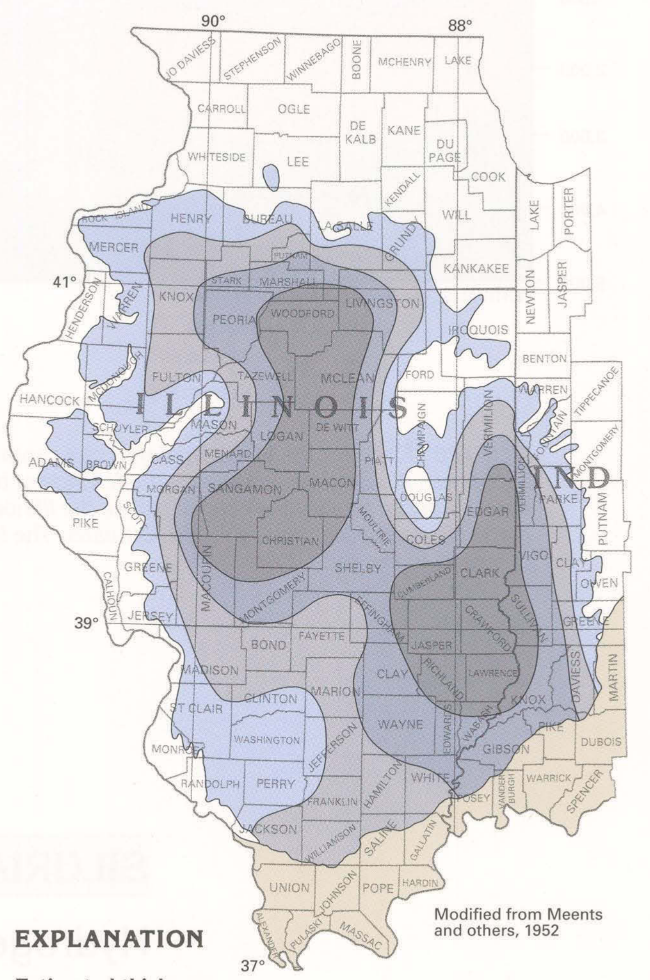
EXPLANATION

Depth to top of Pennsylvanian rocks, in feet

- Less than 100
- 100 to 200
- 200 to 400
- 400 to 600

SCALE 1:5,000,000
0 25 50 MILES
0 25 50 KILOMETERS

Figure 28. *The depth to the top of the Pennsylvanian rocks ranges from less than 100 feet to about 600 feet below land surface. These rocks generally are deeper where the valleys eroded into them are filled with Quaternary deposits.*



Modified from Meents and others, 1952

EXPLANATION

Estimated thickness of Pennsylvanian rocks that contain freshwater, in feet

- Less than 100
- 100 to 200
- 200 to 300
- 300 to 400

SCALE 1:5,000,000
0 25 50 MILES
0 25 50 KILOMETERS

Figure 29. *The thickest sections of Pennsylvanian rocks that contain freshwater are in central and southeastern Illinois.*

Figure 31. *Several geologic formations of Pennsylvanian age are aquifers in the Central Lowland Province of Segment 10. The aquifers in the lower and middle parts of the sequence are mostly sandstones; aquifers in the upper part are mostly limestones.*

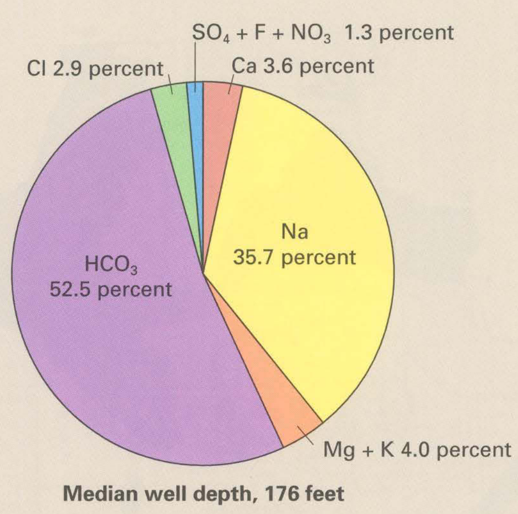
System	Geologic unit		Lithology	Hydrogeologic unit
Pennsylvanian	McLeansboro Group	Mattoon Formation	Shaly sandstone, sandy shale, and limestone	Limestone and sandstone aquifers
		Bond Formation	Limestone and minor shale	
		Modesto Formation	Limestone, shale, minor coal, and sandstone	
	Kewanee Group	Carbondale Formation	Coal, shale, minor limestone, and sandstone	Confining unit with minor sandstone aquifers
		Spoon Formation	Shale, coal, and minor sandstone	
	McCormick Group	Abbott Formation	Sandy shale, shaly sandstone, sandstone, and coal	Sandstone aquifers
		Caseyville Formation	Sandstone, shaly sandstone, and sandy shale	

Clay and Vigo Counties, Indiana

Concentrations in milligrams per liter

Constituent	Range	Median	Number of samples
Hardness ($CaCO_3$)	4 to 422	61	14
Calcium (Ca)	0.2 to 98	13	14
Magnesium (Mg)	0.7 to 43	7	14
Sodium (Na)	11 to 1,470	137	14
Potassium (K)	0.4 to 4.3	2.1	14
Bicarbonate (HCO_3)	21 to 1,540	540	14
Sulfate (SO_4)	0.8 to 82	8.4	14
Chloride (Cl)	2 to 1,400	17	14
Fluoride (F)	0.1 to 15	1	14
Dissolved solids	106 to 3,360	539	14
Nitrate (NO_3)	0 to 18	0.4	14
Iron (Fe)	0.02 to 37	0.28	14

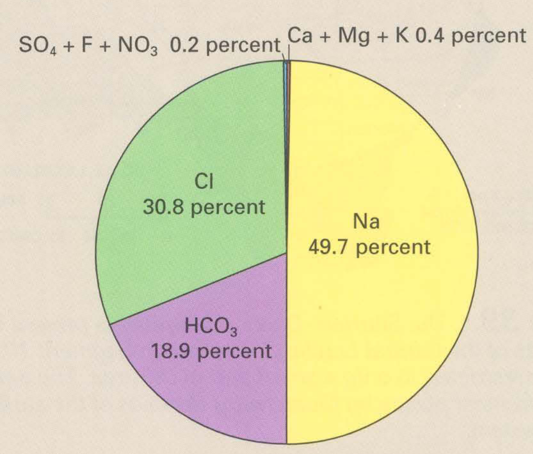
A.



Median well depth, 176 feet

Values in percent of median major ion concentration, in milliequivalents per liter

B.



Median well depth, 241 feet

Figure 32. *Water from the Pennsylvanian aquifers can change rapidly from a sodium bicarbonate type to a sodium chloride type with an increase in depth of only a few feet.*

Data from Cable and others, 1971

Ground-Water Quality

The quality of water obtained from the upper parts of the Pennsylvanian aquifers generally is similar throughout the area. However, pronounced water-quality changes occur with depth. Because the water-yielding sandstones and limestones are thin and are interlayered with thin, low-permeability deposits, such as shale and coal, the water withdrawn from these aquifers tends to be a composite water type, which reflects interaction of the ground water with several rock types that contain different minerals. Dissolved-solids concentrations in water from the Pennsylvanian aquifers increase with increasing depth, but in the freshwater parts of the aquifers, the water is softened somewhat by ion exchange between the water and minerals in the shales and clays. Typically, the water from the freshwater parts of the Pennsylvanian aquifers is moderately hard and is a sodium bicarbonate type with a median dissolved-solids concentration that is slightly greater than 500 milligrams per liter (**fig. 32*A***). The increase in concentration of dissolved solids with increasing depth primarily is due to increases in the concentrations of sodium and chloride in the water. These constituents are present in the saltwater and brine in the deep parts of the Pennsylvanian aquifers.

Mixing of freshwater with the saltwater results in a water that is a sodium chloride type, such as the water represented by **figure 32*B***. The change in water from a sodium bicarbonate type to a sodium chloride type, accompanied by a large increase in dissolved-solids concentrations, takes place with small changes in depth. Concentrations of calcium, magnesium, and bicarbonate are larger in water from the shallower parts of the Pennsylvanian aquifers. Large concentrations of fluoride (as much as 15 milligrams per liter) locally are present. In some instances, the fluoride content of the water is great enough to mottle the teeth of persons who drink it on a continual basis.

Well Yields and Fresh Ground-Water Withdrawals

Yields of wells completed in the Pennsylvanian aquifers have been reported to range from less than 1 to about 100 gallons per minute. The average well yield is about 10 gallons per minute.

Fresh ground-water withdrawals from the Pennsylvanian aquifers are relatively small. Withdrawals from these aquifers during 1985 were less than 4 percent of the total withdrawals in Illinois and less than 1 percent of the total withdrawals in Indiana.

MISSISSIPPIAN AQUIFERS

Hydrogeologic Setting

Mississippian rocks that are aquifers in the Central Lowland Province in Segment 10 lie beneath Quaternary deposits and Pennsylvanian rocks in parts of western Illinois, eastern Illinois, and southwestern Indiana (**fig. 33**). Generally, thick-bedded limestones and sandstones constitute the aquifers. Although small amounts of water can be obtained from nearly all the Mississippian rocks, including shale, in the areas shown in **figure 33**, the most productive water-yielding rocks are limestones and sandstones. Limestone is the dominant rock type in the lower one-half of the Mississippian section (**fig. 34**), whereas sandstone is more abundant in the upper one-half. Some of the limestone formations in the lower part of the Mississippian rocks in western Illinois change to shale in the eastern part of the area. Thus, almost all the Mississippian rocks are considered to be aquifers in western Illinois, whereas only the middle and upper parts of Mississippian rocks are considered to be aquifers in eastern Illinois and southwestern Indiana.

Freshwater circulates to depths greater than 1,000 feet below sea level in west-central Illinois; consequently, all the Mississippian rocks that are directly overlain by Quaternary deposits and some that are directly overlain by Pennsylvanian rocks contain freshwater in this area (**fig. 35**). However, in southern Illinois and in areas toward the central part of the Illinois Basin, Mississippian rocks are at greater depths and are overlain by a thick, continuous sequence of Pennsylvanian rocks that impedes deep freshwater circulation. In addition, some of the Mississippian limestones grade eastward to less-permeable shale. Downdip toward the central part of the Illinois Basin, initially part and eventually all the Mississippian rocks contain water with dissolved-solids concentrations of greater than 1,000 milligrams per liter.

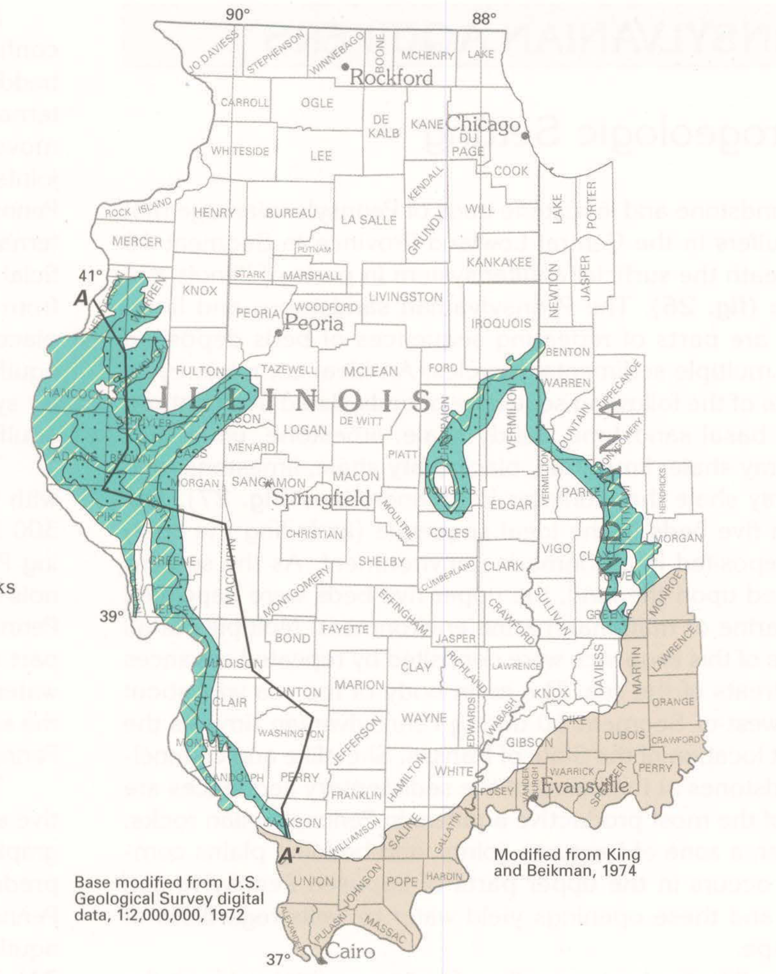
The distribution of wells that obtain water from the Mississippian aquifers is similar to that of wells completed in the Pennsylvanian aquifers. The Mississippian aquifers generally are used for water supply where they are less than 200 feet below land surface and where more water can be obtained from them than from the overlying surficial aquifer system.

Water in the Mississippian aquifers primarily moves through openings such as bedding planes, fractures, and solution channels. Generally, the water is under confined conditions where the water-yielding zones in the Mississippian rocks lie beneath clay or shale beds. Recharge to the Mississippian aquifers occurs primarily by water that percolates downward through the overlying Quaternary deposits and Pennsylvanian rocks. Water discharges to these younger rocks in places where the water level in the Mississippian aquifers is higher than that in the overlying aquifers. Water stored in the overlying rocks, especially the Quaternary deposits, serves to replenish ground water withdrawn from the Mississippian aquifers.

Figure 34. Limestones and sandstones constitute the Mississippian aquifers. Aquifers in the lower part of the section are primarily limestone; aquifers in the upper part of the section are mostly sandstone. Geologic units that compose aquifers are shown in blue.

System	Geologic unit	Lithology	Hydrogeologic unit
Mississippian	Grove Church Shale	Sandstone, shale, and thin limestone units	Primarily sandstone aquifers
	Kinkaid Limestone		
	Degonia Sandstone		
	Clore Formation		
	Palestine Sandstone		
	Menard Limestone		
	Waltersburg Formation		
	Vienna Limestone		
	Tar Springs Sandstone		
	Okaw Group	Sandstone and thin limestone units	Sandstone and limestone aquifers
	West Baden Group		
	Cedar Bluff Group		
	Aux Vases Sandstone	Limestone with minor shale and sandstone	Primarily limestone aquifers
	Ste. Genevieve Limestone		
	St. Louis Limestone		
	Salem Limestone		
	Warsaw Limestone / Shale		
	Burlington and Keokuk Limestones		
	Chouteau Limestone		
	Hannibal Shale		

Figure 33. Mississippian rocks are mostly overlain by Quaternary deposits and Pennsylvanian rocks and yield freshwater to wells in two areas. In western Illinois, almost all the Mississippian rocks are aquifers; in east-central Illinois and southwestern Indiana, only the middle and upper parts of these rocks are aquifers.



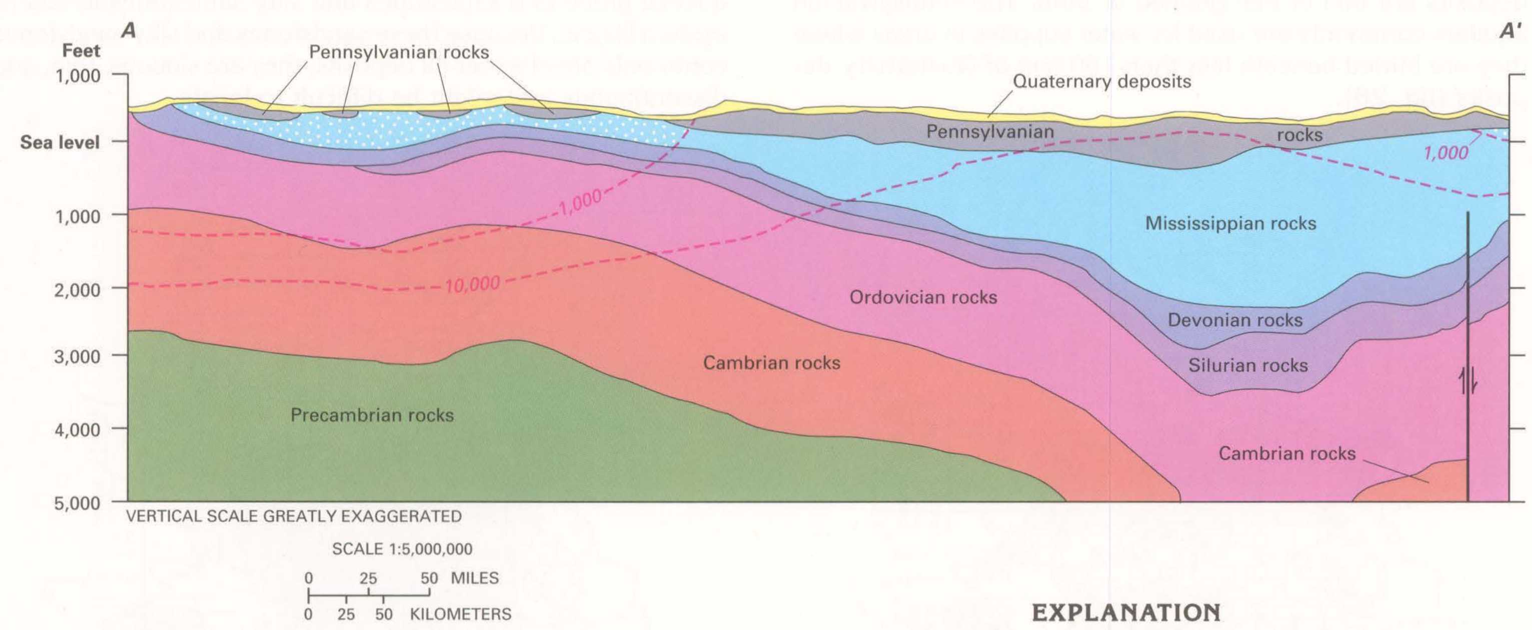


Figure 35. All the Mississippian rocks contain freshwater in western Illinois, represented by the left side of this section. However, downdip toward the central part of the Illinois Basin, most of the Mississippian rocks contain saltwater. The line of the section is shown in figure 33.

EXPLANATION

Mississippian rocks that contain freshwater

--1,000-- Estimated line of equal dissolved-solids concentration, in milligrams per liter

Fault—Arrows show relative vertical movement

Ground-Water Quality

A summary of the results of chemical analyses of water from wells completed in the Mississippian aquifers in Greene County, Ind., on the eastern side of the Illinois Basin is shown in **figure 36**. The water is moderately hard and is a sodium calcium bicarbonate type. Water from wells deeper than 200 feet in Greene County can have concentrations of sulfate and chloride that exceed 250 milligrams per liter and dissolved solids that exceed 500 milligrams per liter. Sparse data indicate that water from the Mississippian aquifers in western Illinois is very hard, which reflects the predominance of limestone in this area. Slightly acidic ground water partially dissolves the limestone, thus increasing the concentration of calcium and magnesium ions (primary hardness-causing constituents) in the water.

Water quality and well-depth data from the Mississippian and the Pennsylvanian aquifers in Greene and Sullivan Counties, Ind., indicate that small increases in well depth are accompanied by large increases in dissolved-solids concentrations (**fig. 37**). Wells shallower than 160 feet yield water that contains less than 500 milligrams per liter dissolved solids; water from deeper wells has dissolved-solids concentrations as large as 3,400 milligrams per liter. At shallow depths, the water generally is hard and is a calcium bicarbonate type or a calcium sodium bicarbonate type, whereas water from deep wells in the Mississippian aquifers might be a sodium chloride type.

Well Yields and Fresh Ground-Water Withdrawals

The reported yields of wells completed in the Mississippian aquifers range from less than 1 to more than 100 gallons per minute; the average well yield is about 10 gallons per minute. Properly completed and developed wells commonly yield from 20 to 30 gallons per minute. The largest volumes of water are obtained from wells that penetrate large openings in the rocks, such as bedding planes, fractures, and solution openings.

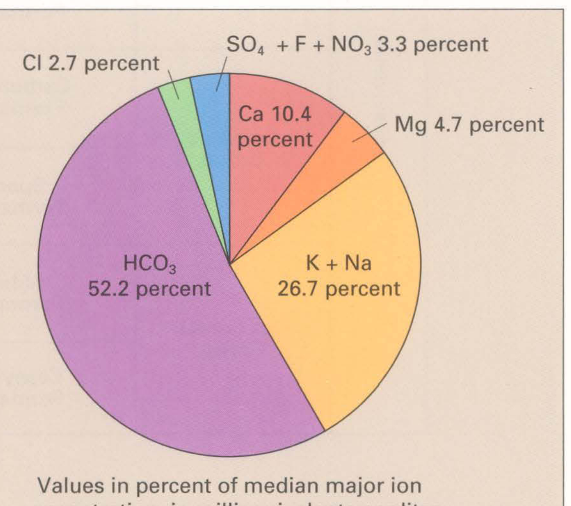
The specific capacity (well yield divided by water-level drawdown during pumping) of wells completed in the Mississippian aquifers generally ranges from 0.03 to 9 gallons per minute per foot of water-level drawdown (**fig. 38**). The specific capacity generally is greater for some Mississippian formations than others. Wells completed in the Keokuk and the Burlington Limestones generally have the largest specific capacities, and those completed in the Ste. Genevieve, the St. Louis, and the Salem Limestones and the shale and limestone of the Warsaw Formation generally have the smallest specific capacities.

Fresh ground-water withdrawals from the Mississippian aquifers during 1985 were less than 3 percent of the total ground water withdrawn in Illinois. Withdrawals from Mississippian aquifers in Indiana during the same period were less than 1 percent of the total ground water withdrawn.

Greene County, Indiana

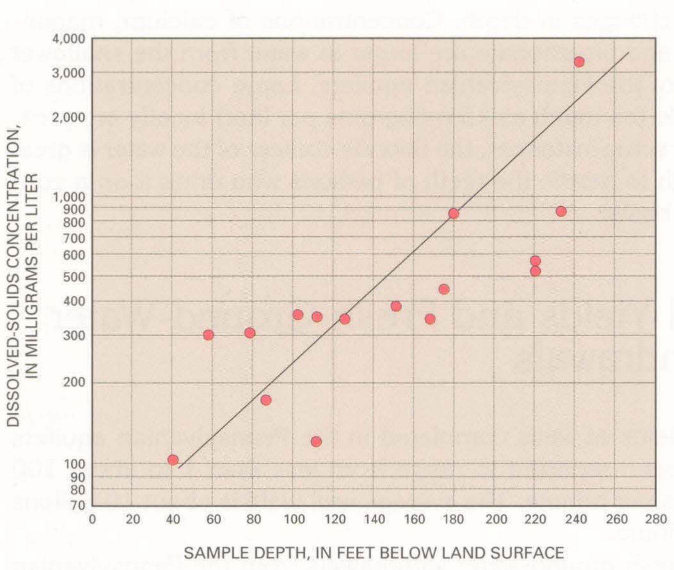
Concentrations in milligrams per liter

Constituent	Range	Median	Number of samples
Hardness ($CaCO_3$)	6 to 272	78	10
Calcium (Ca)	0.8 to 63	24	10
Magnesium (Mg)	0.5 to 31	6.6	10
Sodium (Na)	2.8 to 754	70	10
Potassium (K)	0.6 to 3.3	1.1	10
Bicarbonate (HCO_3)	53 to 811	367	10
Sulfate (SO_4)	1.2 to 315	17	10
Chloride (Cl)	1.5 to 700	11	10
Fluoride (F)	0.1 to 4.5	0.25	10
Dissolved solids	85 to 1,880	332	10
Nitrate (NO_3)	0 to 18	1.6	10
Iron (Fe)	0.04 to 1.0	0.14	10



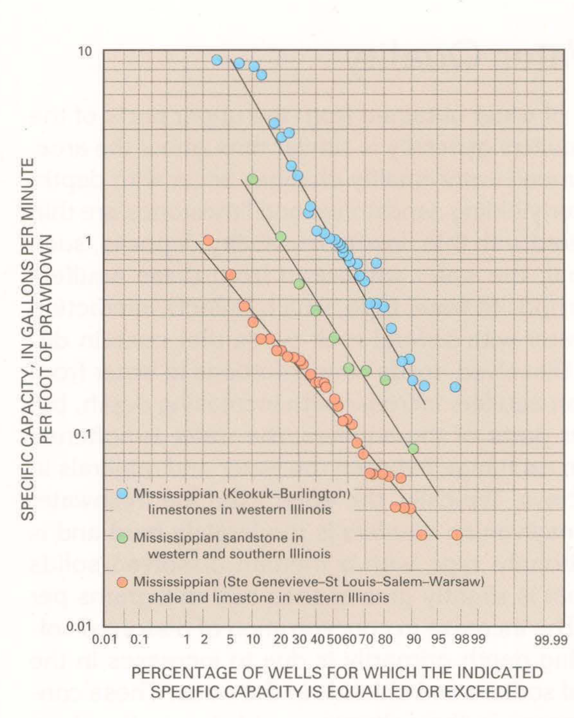
Modified from Cable and Robison, 1973

Figure 36. Water from the Mississippian aquifers in Greene County, Ind., is a sodium calcium bicarbonate type. Water that contains dissolved-solids concentrations of 1,800 milligrams per liter is reported from wells about 250 feet deep completed in the Mississippian aquifers.



Modified from Wangsness and others, 1983

Figure 37. Dissolved-solids concentrations in water from wells completed in the Mississippian and the Pennsylvanian aquifers in Greene and Sullivan Counties, Ind., increase as well depth increases.



Modified from Csallany, 1966

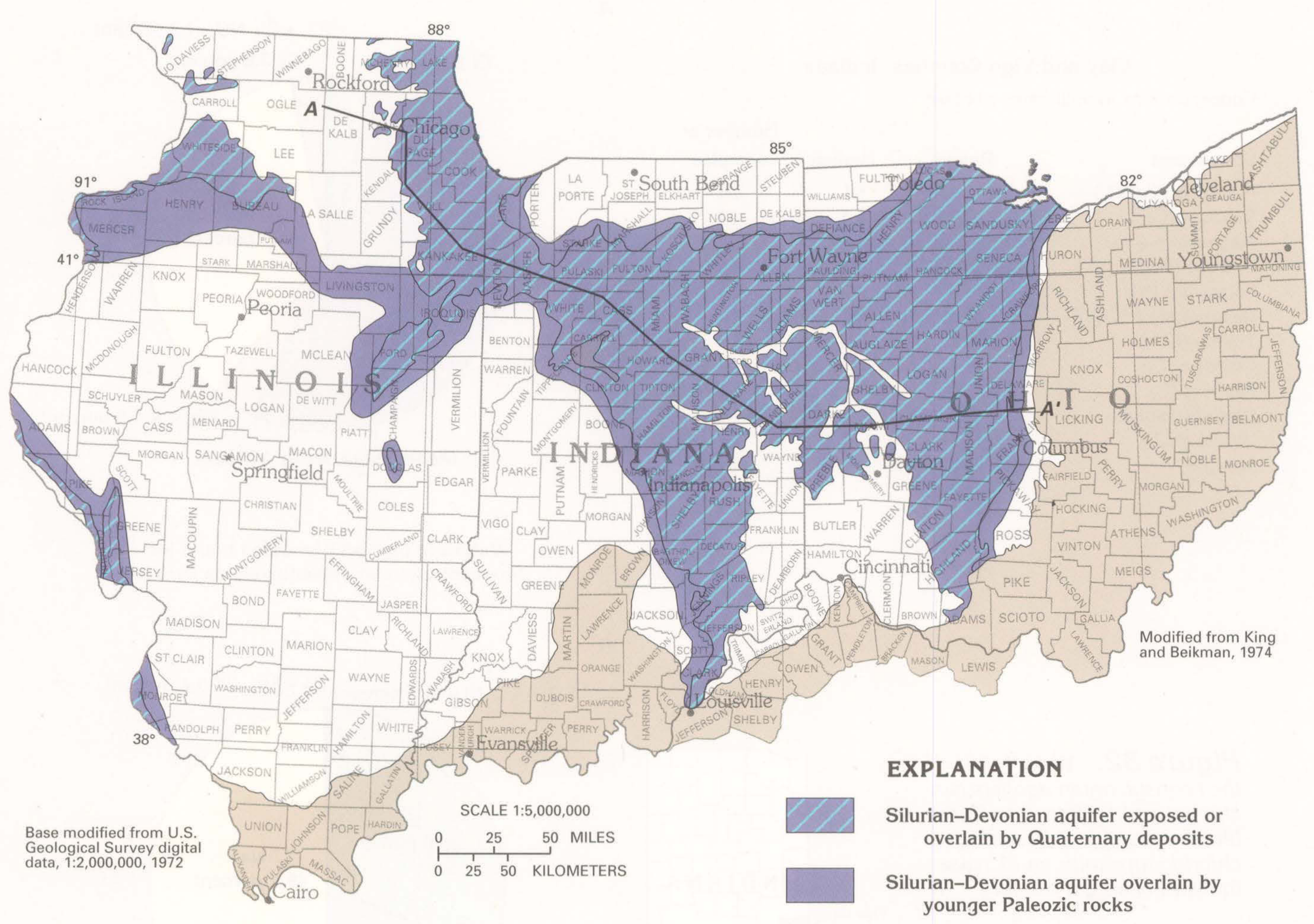
Figure 38. Specific capacities of wells completed in the Keokuk and the Burlington Limestones generally are larger than those for wells completed in other Mississippian formations.

SILURIAN–DEVONIAN AQUIFER

Hydrogeologic Setting

Dolomites and limestones of Silurian and Devonian age constitute one of the principal consolidated-rock aquifers throughout a large area in the Central Lowland Province in Segment 10 (**fig. 39**). The Silurian–Devonian aquifer lies beneath Upper Devonian shales, Mississippian rocks, or Quaternary deposits and is present from central Ohio across Indiana into northern and western Illinois.

The Silurian–Devonian aquifer has been referred to by a number of different names. It is known as the carbonate aquifer in Ohio, the Silurian–Devonian aquifers in Indiana, and the upper part of the shallow dolomite aquifer in Illinois. The aquifer was designated the "Silurian–Devonian aquifer" by a regional aquifer study that encompassed northern Illinois, Iowa, Wisconsin, and Minnesota. Because the name "Silurian–Devonian aquifer" has been applied regionally, this name is used in this chapter.



EXPLANATION

Silurian–Devonian aquifer exposed or overlain by Quaternary deposits

Silurian–Devonian aquifer overlain by younger Paleozoic rocks

A——A' Line of hydrogeologic section

Figure 39. The Silurian–Devonian aquifer is present throughout large parts of the Central Lowland Province in Segment 10. Devonian rocks are restricted to only a small part of the area. The aquifer is overlain in most places by Quaternary deposits of the surficial aquifer system.

Hydrogeologic Setting—Continued

The Devonian rocks are less important hydrologically than the Silurian rocks because much of the lower part of the section of Devonian rocks has been removed from most of the area by erosion (**fig. 40**). Consequently, the Devonian parts of the aquifer are mainly in narrow bands in Ohio, Indiana, and eastern Illinois. Only in a small area in northwestern Indiana do Devonian carbonate rocks completely cover the freshwater-yielding Silurian carbonate rocks.

In northern Illinois, freshwater is present at depths greater than 1,000 feet below sea level, which is much deeper than the bottom of the Silurian–Devonian aquifer (**fig. 41**). However, to the south and east (throughout most of the area shown in color in **figure 39**), the Silurian–Devonian aquifer generally contains freshwater where the aquifer is between land surface and about 500 feet below land surface. The base of freshwater approximately coincides with the base of the aquifer in most places. The underlying Upper Ordovician shales impede the downward movement of freshwater. The Silurian–Devonian aquifer contains freshwater for only a short distance from where it is overlain by Upper Devonian shales in Ohio, Indiana, and eastern Illinois. These overlying shales impede the downward movement of freshwater into the aquifer. In western and northwestern Illinois where the Silurian–Devonian aquifer is covered by Mississippian rocks, the extent of freshwater beneath the younger rocks is greater.

Most of the freshwater part of the Silurian–Devonian aquifer is directly overlain by unconsolidated deposits of Quaternary age that compose the surficial aquifer system. The thickness of the Quaternary deposits and, consequently, the depth to the top of the Silurian–Devonian aquifer range from less than 100 feet to more than 400 feet below land surface in the area. The Silurian–Devonian aquifer is most commonly used for water supply where it is overlain by less than 200 feet of Quaternary deposits.

Ground water generally is under confined conditions in the Silurian–Devonian aquifer. The water moves through fractures, bedding planes, and solution cavities in the dolomites and limestones. The Silurian–Devonian aquifer is recharged from the overlying surficial aquifer system in areas where water levels in the surficial aquifer system are higher than those in the Silurian–Devonian aquifer. Locally, where the water-level differences are reversed, water discharges to the surficial aquifer system from the Silurian–Devonian aquifer. The water stored in the surficial aquifer system serves to replenish the water withdrawn from wells that are completed in the underlying Silurian–Devonian aquifer.

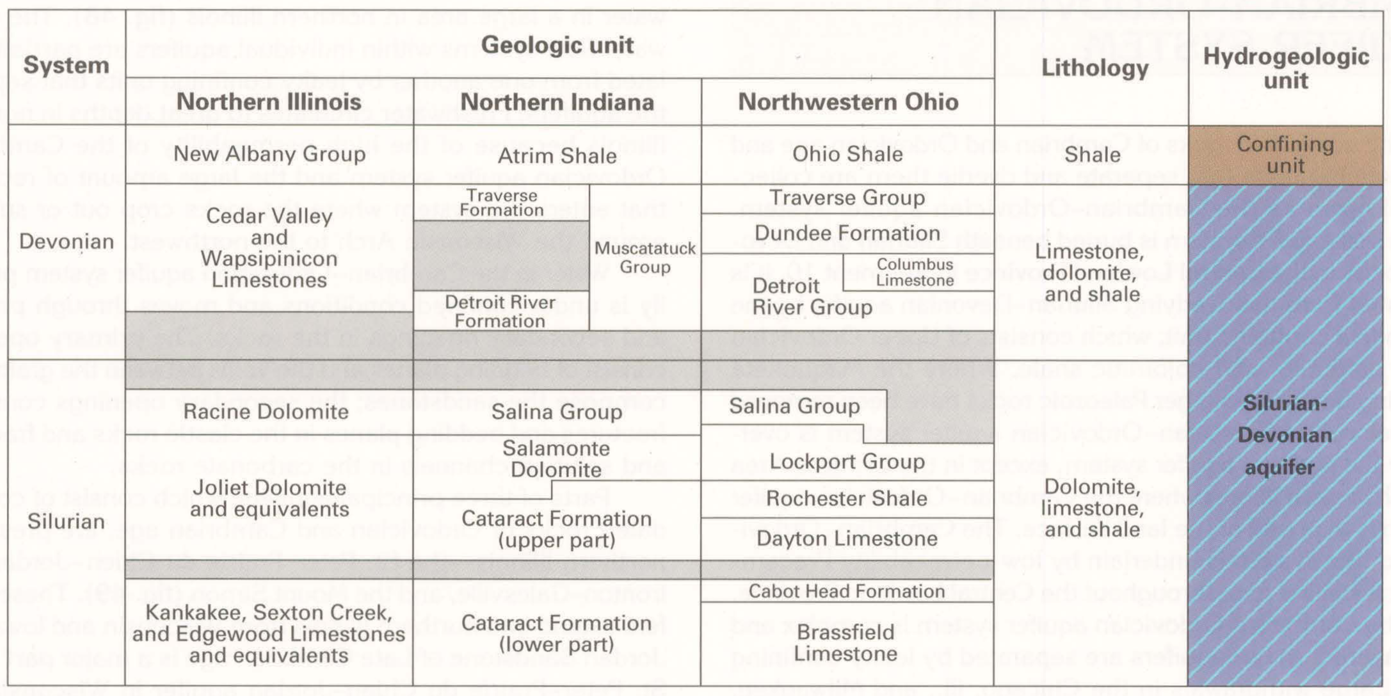


Figure 40. *Several geologic formations that consist of dolomite and limestone compose the Silurian–Devonian aquifer. The gray areas represent missing rocks.*

Figure 41. *The Silurian–Devonian aquifer contains freshwater where the aquifer is less than 500 feet below land surface. The line of the section is shown in figure 39.*

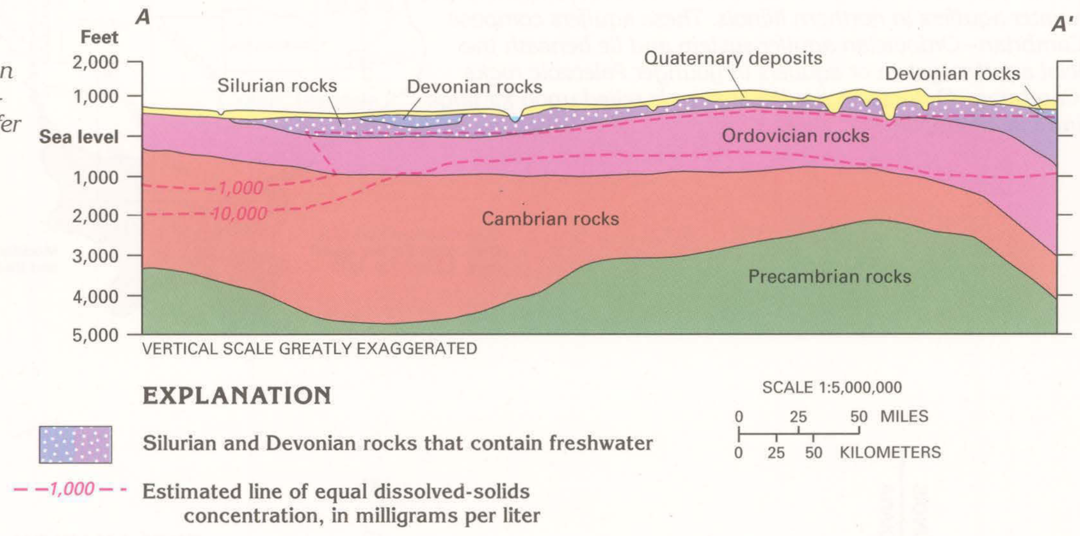


Figure 42. *Large yields are possible from wells completed in the Silurian–Devonian aquifer along and on the flanks of the Findlay Arch in Ohio. Yields of wells in the southern one-half of the large yield area average about 600 gallons per minute.*

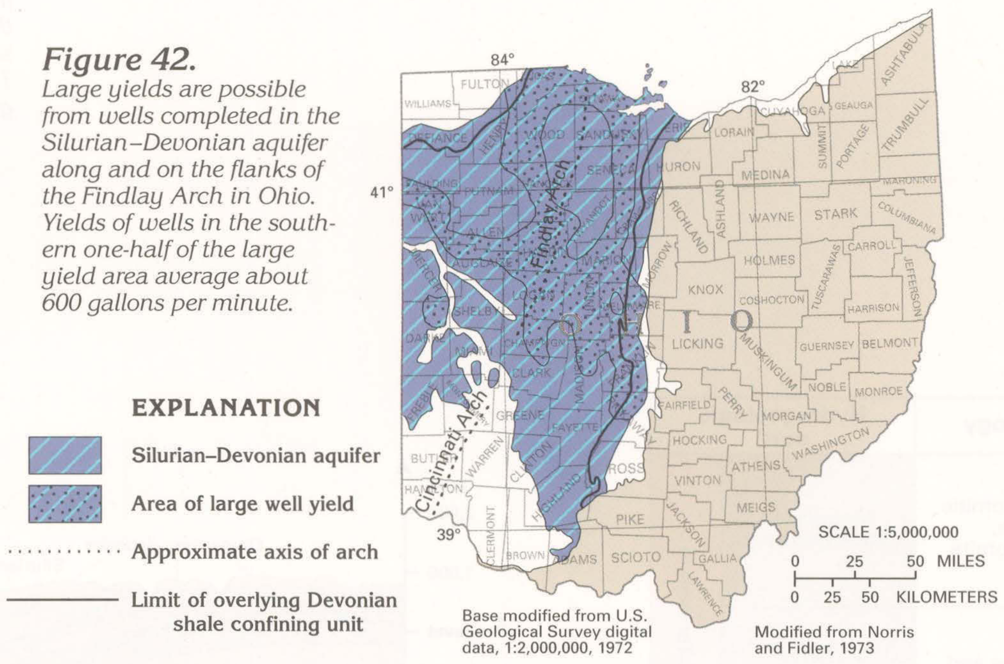
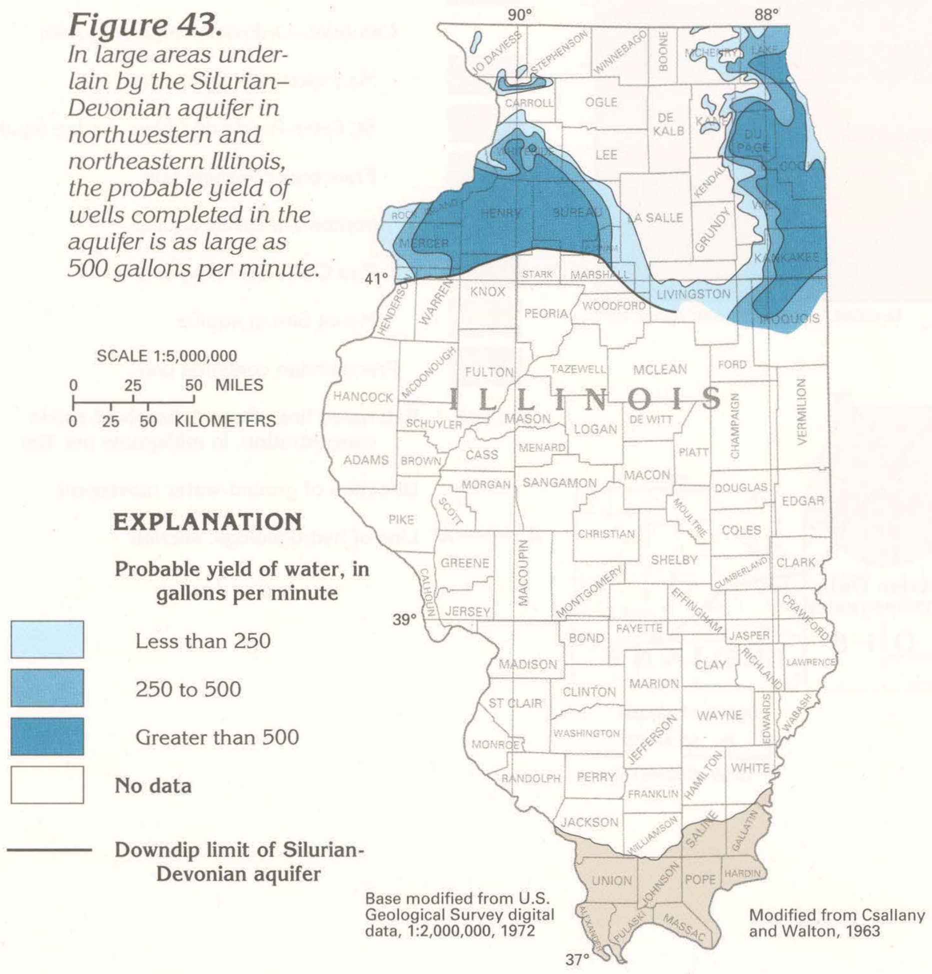


Figure 43. *In large areas underlain by the Silurian–Devonian aquifer in northwestern and northeastern Illinois, the probable yield of wells completed in the aquifer is as large as 500 gallons per minute.*



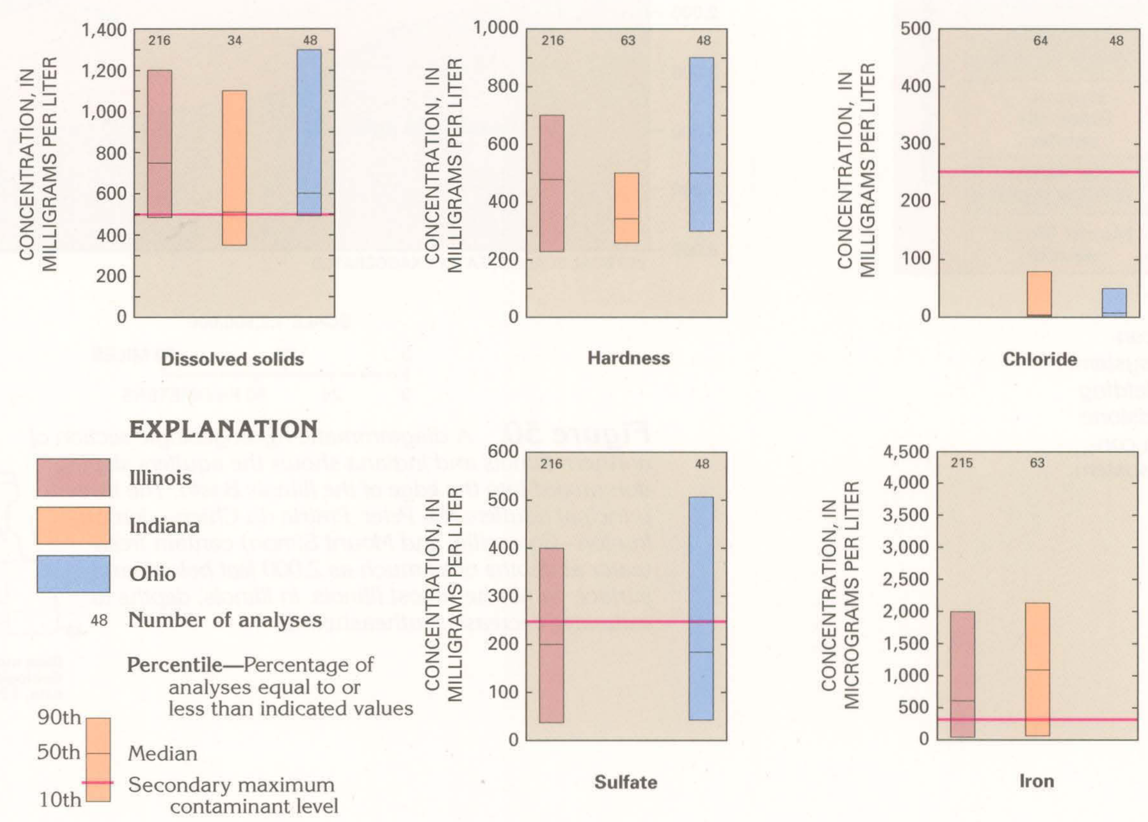
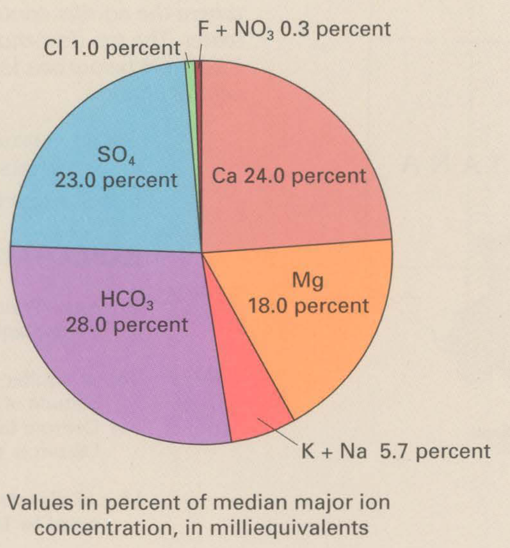


Figure 44. *Water from the Silurian–Devonian aquifer generally has large concentrations of dissolved solids. The water commonly contains concentrations of dissolved solids, sulfate, and iron that exceed the secondary maximum contaminant levels established for drinking water by the U.S. Environmental Protection Agency.*

Southwestern Ohio

Concentrations in milligrams per liter

Constituent	Range	Median	Number of samples
Hardness ($CaCO_3$)	340 to 2,200	710	15
Calcium (Ca)	82 to 640	110	15
Magnesium (Mg)	33 to 200	49	15
Sodium (Na)	4.8 to 56	27	15
Potassium (K)	1.3 to 14	3.7	15
Bicarbonate (HCO_3)	320 to 454	388	15
Sulfate (SO_4)	16 to 1,750	250	15
Chloride (Cl)	2 to 85	8	15
Fluoride (F)	0.5 to 2.2	1.1	15
Dissolved solids	349 to 3,070	710	15
Nitrate (NO_3)	0 to 0.2	0.1	15
Iron (Fe)	0.02 to 29	1.2	15



Modified from Norris and Fidler, 1973

Figure 45. *The quality of water from wells in the Silurian–Devonian aquifer in west-central Ohio is typical of that for the entire aquifer. Calcium, magnesium, bicarbonate, and sulfate are the dominant ions in the water.*

Figure 46. *Calcium magnesium bicarbonate water is present in recharge areas and calcium magnesium sulfate water is present in discharge areas of the Silurian–Devonian aquifer in western Ohio.*

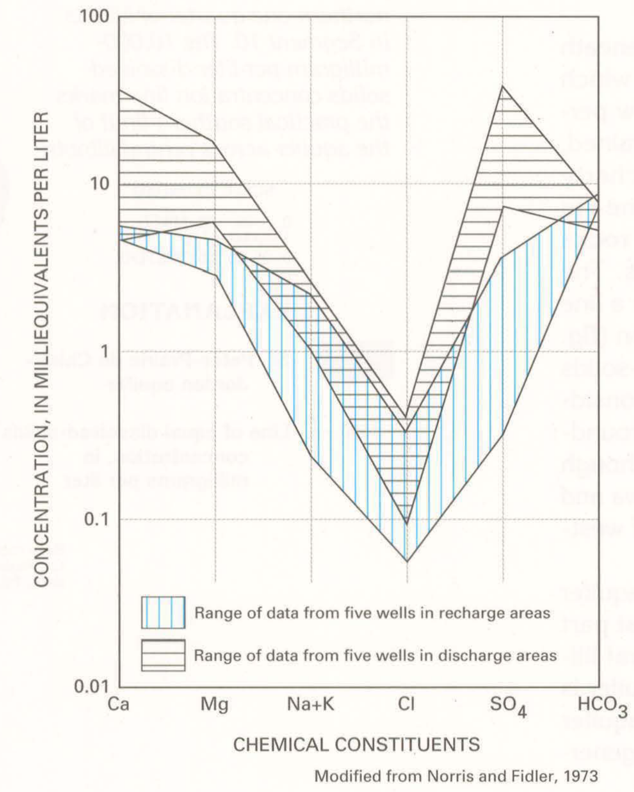
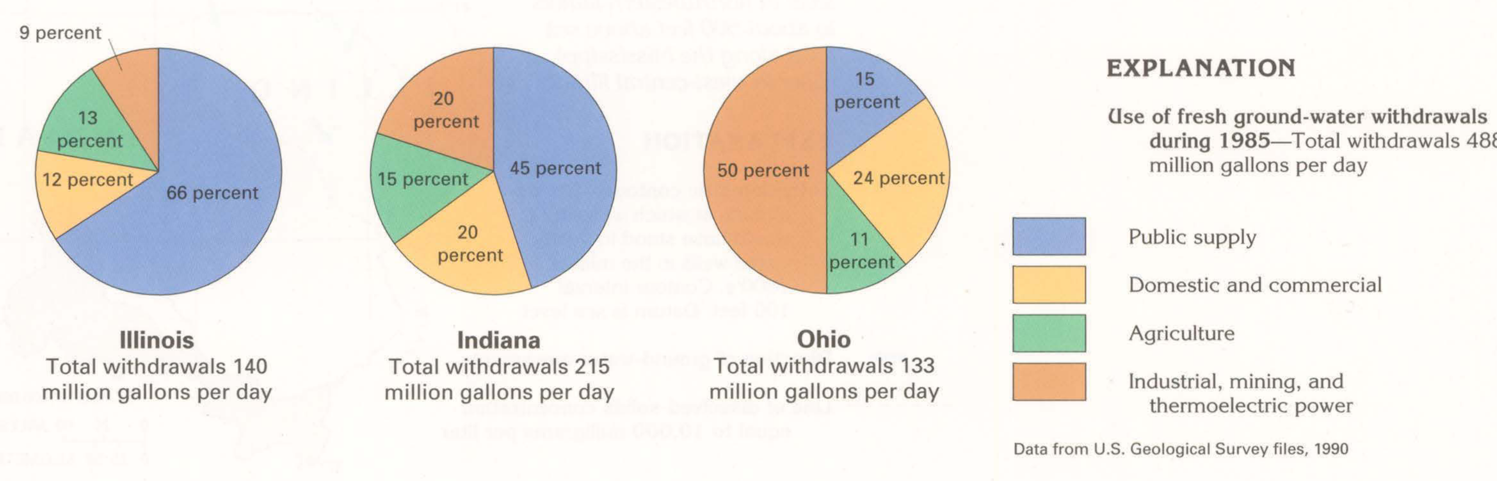


Figure 47. *Fresh ground-water withdrawals from the Silurian–Devonian aquifer during 1985 ranged from about 133 million gallons per day in Ohio to about 215 million gallons per day in Indiana. Withdrawals for public supply were the largest use category in Illinois and Indiana; industrial, mining, and thermoelectric power was the largest use category in Ohio.*



Well Yields

The yields of wells completed in the Silurian–Devonian aquifer range from less than 5 to more than 1,000 gallons per minute. Yields of 5 to 15 gallons per minute can be obtained from most wells completed in the aquifer throughout the area shown in **figure 39**. Large well yields are possible locally in Illinois, Indiana, and Ohio, but the largest well yields, more than 1,500 gallons per minute, are reported from northern Illinois.

Large well yields in Ohio are possible in the west-central and northwestern parts of the State (**fig. 42**). Middle and Upper Silurian dolomites are the major water-yielding rocks in this area due to the dissolving action of slightly acidic recharge water on these carbonate rocks where they are exposed or thinly covered along the flanks and part of the axis of the Findlay Arch. The specific capacities of large-diameter test wells were used to define the areas of large yield shown in **figure 42**. The specific capacities of these wells range from 5 to 106 gallons per minute per foot of water-level drawdown, and average about 30 gallons per minute per foot of drawdown. The average yield for wells located in the southern one-half of the area of large yield is about 600 gallons per minute and the average yield for wells in the remainder of the large-yield area is about 450 gallons per minute. Specific capacities of large-diameter test wells located outside the area of large yield shown in **figure 42** range from less than 0.5 to 5 gallons per minute per foot of water-level drawdown and average about 2.2 gallons per minute per foot of drawdown. The yield of these wells ranges from about 160 to 260 gallons per minute.

The estimated yield of wells completed in the Silurian–Devonian aquifer in northern Illinois is shown in **figure 43**. Well yields in the area are highly variable and might be 1 gallon per minute or less. However, analysis of specific-capacity data for wells in the area indicates that well yields of 250 gallons per minute or more are probable throughout most of the area, and well yields of 500 gallons per minute are probable in large parts of northeastern and northwestern Illinois. The wells with large yields generally are completed in the upper one-third of Silurian rocks. Larger yields also coincide with places where the bedrock surface is locally at higher altitudes than surrounding areas and where the Silurian rocks are overlain by Quaternary sand and gravel deposits.

Ground-Water Quality

The chemical quality of water from the freshwater parts of the Silurian–Devonian aquifer generally is adequate or can be treated and made adequate, for most purposes. Concentrations of dissolved solids and iron exceeded secondary maximum contaminant levels established by the U.S. Environmental Protection Agency in more than 50 percent of the studied samples (**fig. 44**). In addition, the water is hard, and sulfate concentrations exceed 250 milligrams per liter in many samples. Generally, chloride concentrations are less than 250 milligrams per liter where the aquifer is directly overlain by the surficial aquifer system. However, chloride concentrations might be greater than 250 milligrams per liter downdip, particularly where the aquifer is overlain by Devonian, Mississippian, or Pennsylvanian shales, which impede deep freshwater circulation.

An example of the major dissolved constituents in water from the Silurian–Devonian aquifer is shown in **figure 45**. In samples from western Ohio, calcium, magnesium, bicarbonate, and sulfate are the most common ions. The large concentrations of calcium and magnesium probably are derived primarily from the dolomite (calcium magnesium carbonate) through which the water moves. The water is a calcium magnesium bicarbonate type in recharge areas and a calcium magnesium sulfate type in discharge areas (**fig. 46**).

Fresh Ground-Water Withdrawals

Total fresh ground-water withdrawals from the Silurian–Devonian aquifer in Illinois, Indiana, and Ohio were about 488 million gallons per day during 1985. About 95 percent of this water was withdrawn from wells completed in the aquifer in the Central Lowland Physiographic Province. The remainder came from wells located in southernmost Illinois and Ohio in the Interior Low Plateaus Province. Water withdrawn from the Silurian–Devonian aquifer was about 21 percent of the total ground water withdrawn for all three States during 1985. The withdrawals from the Silurian–Devonian aquifer were about 15 percent of the total ground water withdrawn in Illinois, 18 percent in Ohio, and 34 percent in Indiana.

The volume of water withdrawn for some of the groundwater use categories changes significantly from State to State (**fig. 47**). Ground-water withdrawals from the Silurian–Devonian aquifer for public supply during 1985 were about 92 million gallons per day in Illinois, 97 million gallons per day in Indiana, and 20 million gallons per day in Ohio. Public supply was the largest use category in Illinois and Indiana. In Ohio, about 67 million gallons per day were withdrawn for industrial, mining, and thermoelectric power use, the largest use category in the State.

CAMBRIAN–ORDOVICIAN AQUIFER SYSTEM

The aquifers in rocks of Cambrian and Ordovician age and the confining units that separate and overlie them are collectively known as the Cambrian–Ordovician aquifer system. Where this aquifer system is buried beneath Silurian and Devonian rocks in the Central Lowland Province in Segment 10, it is separated from the overlying Silurian–Devonian aquifer by the Maquoketa confining unit, which consists of Upper Ordovician shale, dolomite, and dolomitic shale. Where the Maquoketa confining unit and younger Paleozoic rocks have been removed by erosion, the Cambrian–Ordovician aquifer system is overlain by the surficial aquifer system, except in the Driftless Area in northwestern Illinois where the Cambrian–Ordovician aquifer system is exposed at the land surface. The Cambrian–Ordovician aquifer system is underlain by low-permeability Precambrian crystalline rock throughout the Central Lowland Province.

The Cambrian–Ordovician aquifer system is complex and multilayered; major aquifers are separated by leaky confining units. Large withdrawals in the Chicago, Ill., and Milwaukee, Wis., areas have created deep, extensive cones of depression in the potentiometric surface of the aquifer system. The Cambrian–Ordovician aquifer system is a major source of water supply in Segment 9 and is discussed in greater detail in the chapter of this Atlas that describes that segment.

The Cambrian–Ordovician aquifer system contains freshwater in a large area in northern Illinois (**fig. 48**). The freshwater flow systems within individual aquifers are partially isolated from one another by leaky confining units that separate the aquifers. Freshwater circulates to great depths in northern Illinois because of the high permeability of the Cambrian–Ordovician aquifer system and the large amount of recharge that enters the system where the rocks crop out or subcrop around the Wisconsin Arch to the northwest.

Water in the Cambrian–Ordovician aquifer system primarily is under confined conditions and moves through primary and secondary openings in the rocks. The primary openings consist of bedding planes and the voids between the grains that compose the sandstones; the secondary openings consist of fractures and bedding planes in the clastic rocks and fractures and solution channels in the carbonate rocks.

Parts of three principal aquifers, which consist of consolidated rocks of Ordovician and Cambrian age, are present in northern Illinois—the St. Peter–Prairie du Chien–Jordan, the Ironton–Galesville, and the Mount Simon (**fig. 49**). These aquifers extend into northern Illinois from Wisconsin and Iowa. The Jordan Sandstone of Late Cambrian age is a major part of the St. Peter–Prairie du Chien–Jordan aquifer in Wisconsin and Iowa, but in Segment 10, this sandstone is part of the aquifer only in western Illinois. The relations among the three principal aquifers and their associated overlying and underlying confining units are shown in a hydrogeologic section from Stephenson County, Ill., to Howard County, Ind. (**fig. 50**).

EXPLANATION

- Extent of overlying Pennsylvanian aquifers
- Extent of overlying Silurian-Devonian aquifer
- Cambrian-Ordovician aquifer system
- Confining unit
- Southern limit of freshwater in the St. Peter Sandstone with dissolved-solids concentrations of 1,000 milligrams per liter or less
- U / D Sandwich Fault—U, upthrown side, D, downthrown side
- Southern limit of Driftless Area

SCALE 1:4,000,000

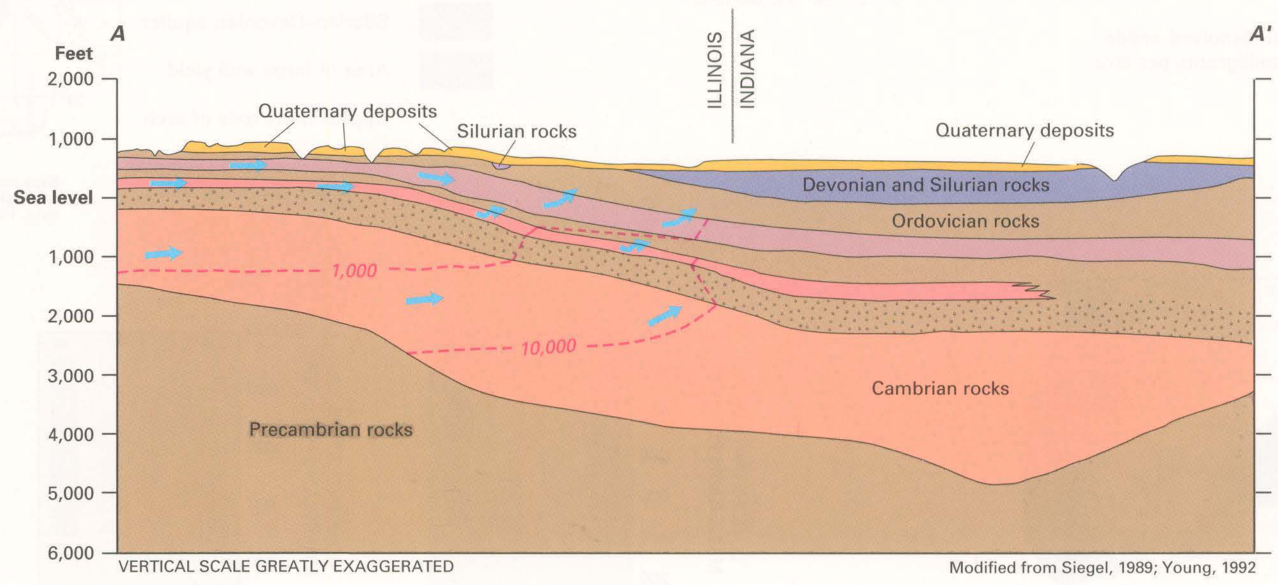
0 50 100 MILES
0 50 100 KILOMETERS

Figure 48. *Several Cambrian and Ordovician formations are freshwater aquifers in northern Illinois. These aquifers compose the Cambrian–Ordovician aquifer system and lie beneath the surficial aquifer system or aquifers in younger Paleozoic rocks. The Cambrian–Ordovician aquifer system is relied upon for large ground-water supplies.*

System	Geologic unit		Lithology	Hydrogeologic unit[1]	
Ordovician	Maquoketa Group		Shale, dolomitic shale, and dolomite	Maquoketa confining unit	Cambrian–Ordovician aquifer system
	Galena Group				
	Platteville Group				
	Ancell Group	Glenwood Formation	Sandstone and dolomite	St. Peter–Prairie du Chien–Jordan aquifer	
		St. Peter Sandstone			
	Prairie du Chien Group				
Cambrian	Jordan Sandstone and Eminence Dolomite				
	Potosi Dolomite		Dolomite and shale	Franconia confining unit	
	Franconia Formation				
	Ironton Sandstone		Sandstone	Ironton–Galesville aquifer	
	Galesville Sandstone				
	Eau Claire Formation		Siltstone and shale	Eau Claire confining unit	
	Mount Simon Sandstone		Sandstone	Mount Simon aquifer	

[1]Modified from Young, 1992.

Figure 49. *Three aquifers, which are separated by confining units, compose the Cambrian–Ordovician aquifer system. The aquifers consist of sandstones, except for the water-yielding beds in the Prairie du Chien Group, which consist of sandstone and dolomite beds. The Maquoketa confining unit, which consists mostly of shale, is the uppermost part of the aquifer system.*



EXPLANATION

Hydrogeologic unit

- Surficial aquifer system
- Silurian–Devonian aquifer
- Cambrian–Ordovician aquifer system
  - Maquoketa confining unit
  - St. Peter–Prairie du Chien–Jordan aquifer
  - Franconia confining unit
  - Ironton–Galesville aquifer
  - Eau Claire confining unit
  - Mount Simon aquifer
- Precambrian confining unit
- –1,000– Estimated line of equal dissolved-solids concentration, in milligrams per liter
- Direction of ground-water movement
- A——A' Line of hydrogeologic section

SCALE 1:2,500,000

0 25 50 MILES
0 25 50 KILOMETERS

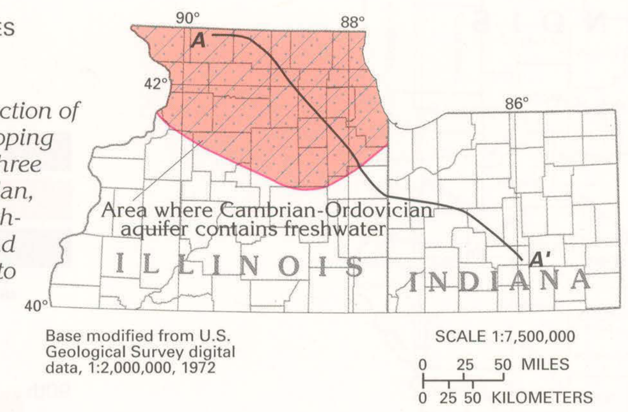


Figure 50. *A diagrammatic hydrogeologic section of northern Illinois and Indiana shows the aquifers sloping downward into the edge of the Illinois Basin. The three principal aquifers (St. Peter–Prairie du Chien–Jordan, Ironton–Galesville, and Mount Simon) contain freshwater at depths of as much as 2,000 feet below land surface in northernmost Illinois. In Illinois, depths to saltwater decrease southeastward.*

St. Peter–Prairie du Chien–Jordan Aquifer

The St. Peter–Prairie du Chien–Jordan aquifer lies beneath the Maquoketa, the Galena, and the Platteville Groups, which primarily are shale, dolomitic shale, and dolomite of low permeability. The aquifer consists of the fine- to medium-grained, well-sorted, friable St. Peter Sandstone; the sandy, cherty dolomites of the Prairie du Chien Group; and the fine- to coarse-grained, dolomitic Jordan Sandstone. These rocks contain freshwater in the northern one-fourth of Illinois. The practical southern boundary of the aquifer is marked by a line that traverses the State in a northeast–southwest direction (**fig. 51**) and represents water in the aquifer with dissolved-solids concentrations of 10,000 milligrams per liter. This is considered to be the practical limit of the aquifer because ground-water movement downgradient of the line is minimal. Although the Jordan Sandstone is a major part of the aquifer in Iowa and Wisconsin, the Jordan is present in only a small part of western Illinois in Segment 10.

The top of the St. Peter–Prairie du Chien–Jordan aquifer is more than 500 feet above sea level in the northernmost part of Illinois and about 2,500 feet below sea level in central Illinois (**fig. 52**). The average altitude of the top of the aquifer is about 250 feet above sea level in the area where the aquifer contains freshwater. The slope of the top of the aquifer generally is southward into the Illinois Basin.

The St. Peter–Prairie du Chien–Jordan aquifer is about 250 feet thick along the northern boundary of Illinois and about 1,250 feet thick in west-central Illinois. The thickness averages about 400 feet in the area where the aquifer contains freshwater. The aquifer is thinnest in northern Illinois where the rocks of the Prairie du Chien Group were completely eroded away before the deposition of the St. Peter Sandstone.

Before substantial volumes of ground water were withdrawn from the Cambrian–Ordovician aquifer system, water levels in the St. Peter–Prairie du Chien–Jordan aquifer are estimated to have ranged from more than 900 feet above sea level in parts of northern Illinois to about 500 feet above sea level along the Mississippi River in west-central Illinois (**fig. 53**). The direction of ground-water movement, as shown by the arrows on **figure 53**, was from upland recharge areas toward discharge areas at major streams and Lake Michigan.

Figure 51. *The St. Peter–Prairie du Chien–Jordan aquifer contains freshwater in the northern one-quarter of Illinois in Segment 10. The 10,000-milligram-per-liter dissolved-solids concentration line marks the practical southern limit of the aquifer across central Illinois.*

SCALE 1:7,500,000

0 25 50 MILES
0 25 50 KILOMETERS

EXPLANATION

- St. Peter–Prairie du Chien–Jordan aquifer
- –1,000– Line of equal dissolved-solids concentration, in milligrams per liter

Figure 52. *The altitude of the top of the St. Peter–Prairie du Chien–Jordan aquifer averages about 250 feet above sea level in the northern one-quarter of Illinois where the aquifer contains freshwater. The top descends to about 2,500 feet below sea level in central Illinois.*

SCALE 1:7,500,000

0 25 50 MILES
0 25 50 KILOMETERS

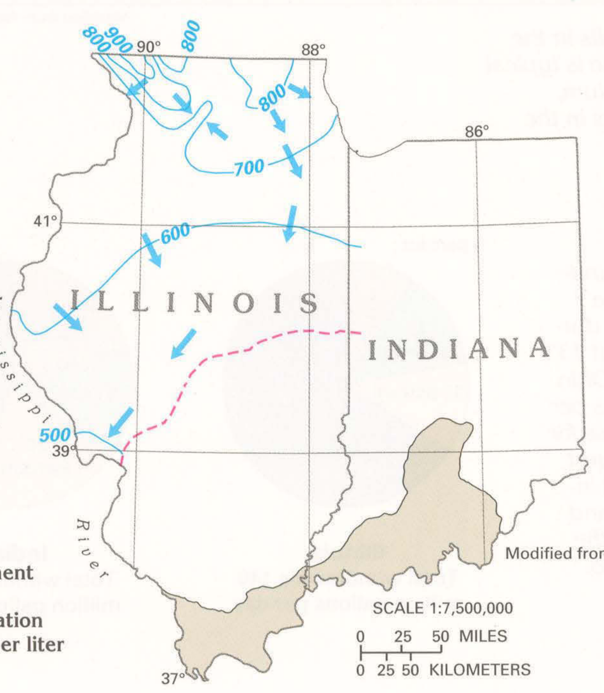
EXPLANATION

- St. Peter–Prairie du Chien–Jordan aquifer
- —500— Top of aquifer contour—Shows altitude of top of aquifer. Contour interval 500 feet. Datum is sea level
- Line of dissolved-solids concentration equal to 10,000 milligrams per liter

Figure 53. *During the middle 1800's, the estimated potentiometric surface of the St. Peter–Prairie du Chien–Jordan aquifer ranged from more than 900 feet above sea level in northwestern Illinois to about 500 feet above sea level along the Mississippi River in west-central Illinois.*

EXPLANATION

- —700— Potentiometric contour—Shows altitude at which water level would have stood in tightly cased wells in the middle 1800's. Contour interval 100 feet. Datum is sea level
- Direction of ground-water movement
- Line of dissolved-solids concentration equal to 10,000 milligrams per liter



Ironton–Galesville Aquifer

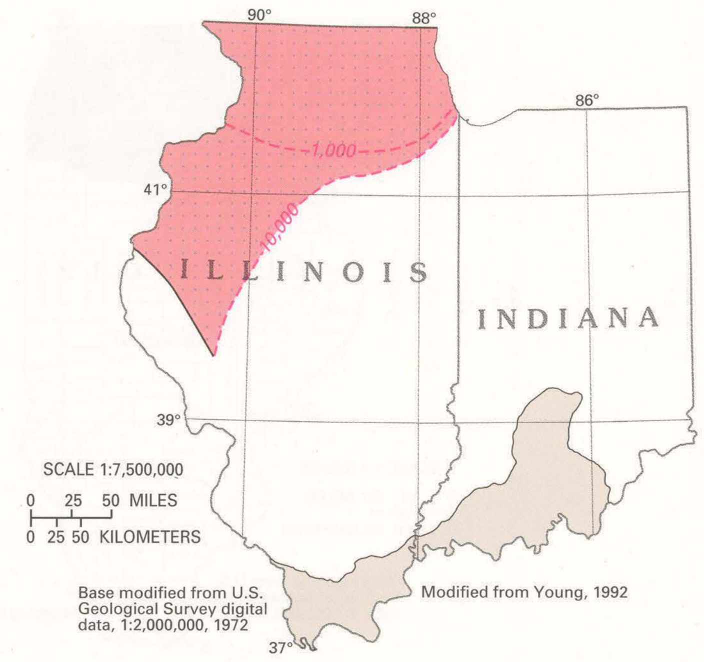
The Ironton–Galesville aquifer is separated from the overlying St. Peter–Prairie du Chien–Jordan aquifer by dolomite and poorly sorted, fine-grained clastic rocks of the Franconia Formation and the Potosi Dolomite (**fig. 49**). These low-permeability rocks are collectively known as the Franconia confining unit in northern Illinois.

The Ironton–Galesville aquifer consists of the Ironton and the Galesville Sandstones of Cambrian age. These units are lithologically similar and generally consist of fine- to coarse-grained quartzose sandstone. They compose the most productive aquifer of the Cambrian–Ordovician aquifer system in northeastern Illinois and yield much of the ground water withdrawn in the Chicago area.

The sandstones of the Ironton–Galesville aquifer were not deposited to the southwest of a line that marks the limit of the aquifer in west-central Illinois (**fig. 54**). In central and eastern Illinois, the line that represents water in the aquifer that contains dissolved-solids concentrations of 10,000 milligrams per liter marks the practical limit of the aquifer.

The top of the Ironton–Galesville aquifer slopes from about 250 feet above sea level in northernmost Illinois to about 2,500 feet below sea level in the west-central part of the State (**fig. 55**). The average altitude of the top of the aquifer in Illinois is about 1,000 feet below sea level. The thickness of the aquifer ranges from more than 200 feet southwest of Chicago to zero at the depositional limit. The average thickness of the aquifer is about 150 feet in northern Illinois.

Estimated water levels (hydraulic head) for the Ironton–Galesville aquifer before the development of substantial ground-water supplies from the Cambrian–Ordovician aquifer system are shown in **figure 56**. Water levels were about 800 feet above sea level along the northern border of Illinois and less than 700 feet above sea level in the southern part of the area. Water levels were slightly higher in the Ironton–Galesville aquifer than those in the deeper Mount Simon aquifer along the Illinois–Wisconsin State line. Ground-water flow in the Ironton–Galesville aquifer generally was southward toward the Illinois Basin from recharge areas in Wisconsin.



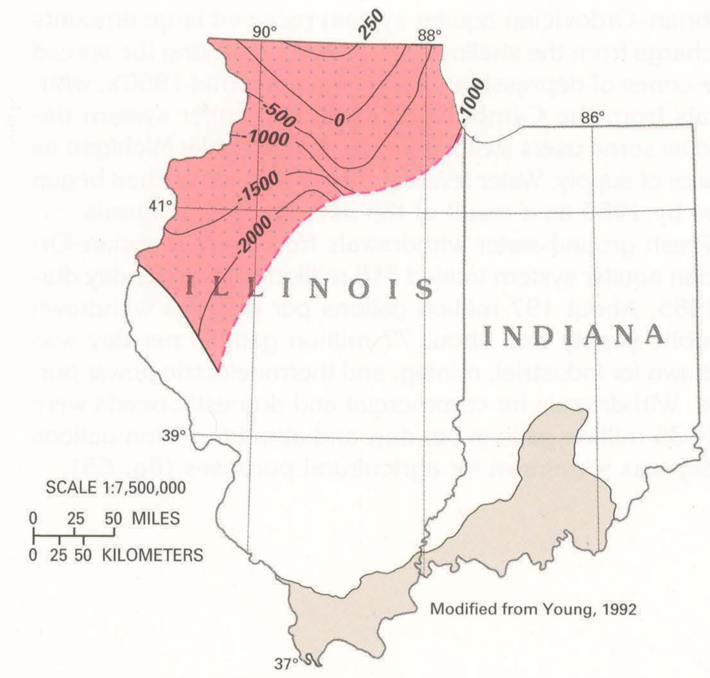
EXPLANATION

Ironton–Galesville aquifer

-1,000- Line of equal dissolved-solids concentration, in milligrams per liter

Erosional boundary of aquifer

Figure 54. The Ironton–Galesville aquifer contains freshwater in the northern one-quarter of Illinois. The 10,000-milligram-per-liter dissolved-solids concentration line marks the practical southeastern limit of the aquifer.



EXPLANATION

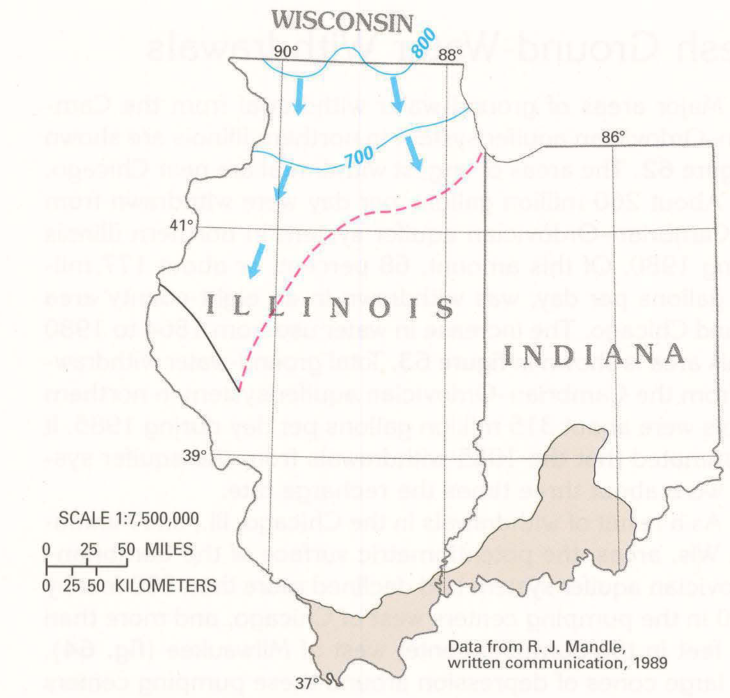
Ironton–Galesville aquifer

-1000 — Top-of-aquifer contour—Shows altitude of top of aquifer. Contour interval, in feet, is variable. Datum is sea level

Line of dissolved-solids concentration equal to 10,000 milligrams per liter

Erosional boundary of aquifer

Figure 55. The top of the Ironton–Galesville aquifer ranges from about 250 feet above sea level in northernmost Illinois to about 2,500 feet below sea level in west-central Illinois.



EXPLANATION

—700— Potentiometric contour—Shows altitude at which water level would have stood in tightly cased wells in the middle 1800's. Contour interval 100 feet. Datum is sea level

Line of dissolved-solids concentration equal to 10,000 milligrams per liter

Erosional boundary of aquifer

Direction of ground-water movement

Figure 56. During the middle 1800's, it is estimated that the potentiometric surface of the Ironton–Galesville aquifer ranged from about 800 feet above sea level along the northern border of Illinois to less than 700 feet above sea level toward the south. Ground water flowed from areas of high water levels (hydraulic head) in the north to areas of lower water levels in the south.

Mount Simon Aquifer

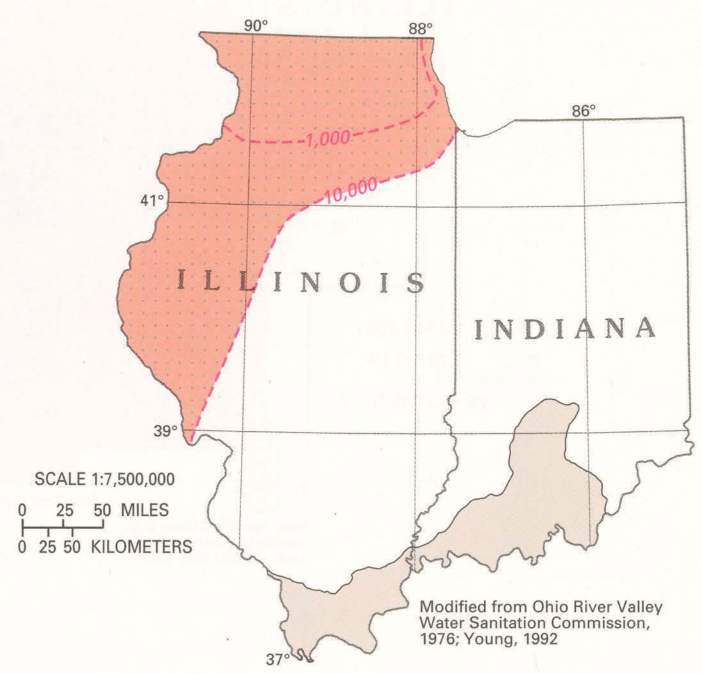
The Mount Simon aquifer underlies the northern part of Illinois and the northwestern part of Indiana in Segment 10. It is separated from the Ironton–Galesville aquifer by low-permeability siltstones and shales of the Eau Claire Formation. These low-permeability rocks are known as the Eau Claire confining unit (**fig. 49**).

The Mount Simon aquifer consists of sandstone that contains water with a wide range of concentrations of dissolved solids (**fig. 57**). In Segment 10, only the upper part of the aquifer in northern Illinois contains freshwater. Dissolved-solids concentrations increase with depth (**fig. 50**) and toward the south and east. The line that shows dissolved-solids concentrations of 10,000 milligrams per liter on **figure 57** marks the practical southern limit of the aquifer.

The top of the Mount Simon aquifer ranges from slightly above sea level to more than 2,000 feet below sea level (**fig. 58**). The depth to the top of the aquifer decreases toward the north; the aquifer crops out on the flanks of the Wisconsin Arch in Wisconsin. The average depth to the top of the aquifer in northern Illinois is about 800 feet below sea level.

The thickness of the Mount Simon aquifer in northern Illinois ranges from slightly less than 1,000 feet in northernmost Illinois to more than 2,500 feet southwest of Chicago. The average thickness is between 1,500 and 2,000 feet. The Mount Simon aquifer is by far the thickest aquifer in the Cambrian–Ordovician aquifer system in Segment 10.

Estimated hydraulic heads (water levels) in the Mount Simon aquifer before substantial ground-water supplies were developed from the Cambrian–Ordovician aquifer system in northern Illinois are shown in **figure 59**. The predevelopment potentiometric surface is estimated to have been more than 800 feet above sea level northwest of Chicago and less than 700 above sea level to the east, south, and west. Ground-water movement was away from the high hydraulic heads (high water levels) toward lower heads (lower water levels) present along major rivers and Lake Michigan.

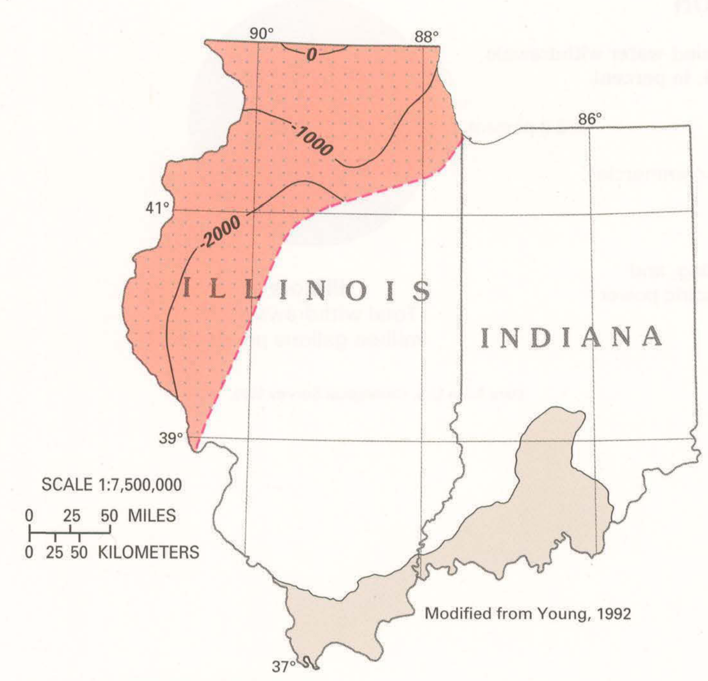


EXPLANATION

Mount Simon aquifer

-1,000- Line of equal dissolved-solids concentration, in milligrams per liter

Figure 57. Dissolved-solids concentrations are less than 1,000 milligrams per liter in water from the top of the Mount Simon aquifer in northern Illinois. The water becomes much more saline a short distance to the south and with increasing depth in the aquifer.



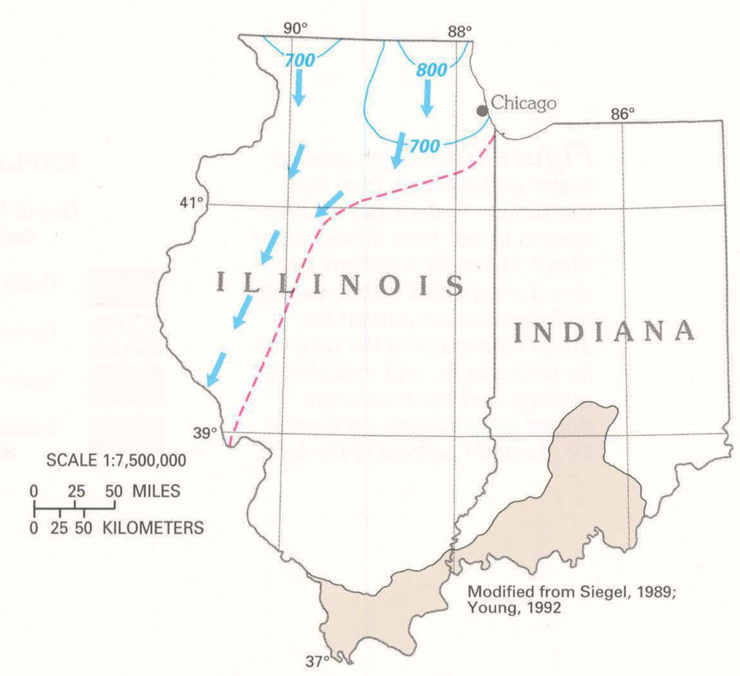
EXPLANATION

Mount Simon aquifer

-1000 — Top-of-aquifer contour—Shows altitude of top of Mount Simon aquifer. Contour interval 1,000 feet. Datum is sea level

Line of dissolved-solids concentration equal to 10,000 milligrams per liter

Figure 58. The top of the Mount Simon aquifer ranges from just above sea level in northernmost Illinois to more than 2,000 feet below sea level along the southern limit of the aquifer.



EXPLANATION

—700— Potentiometric contour—Shows altitude at which water level would have stood in tightly cased wells in the middle 1800's. Contour interval 100 feet. Datum is sea level

Line of dissolved-solids concentration equal to 10,000 milligrams per liter

Direction of ground-water movement

Figure 59. Hydraulic heads (water levels) in the Mount Simon aquifer are estimated to have been higher than 800 feet above sea level in northeastern Illinois in the middle 1800's. Ground water flowed toward the east, south, and west, where the hydraulic heads were lower.

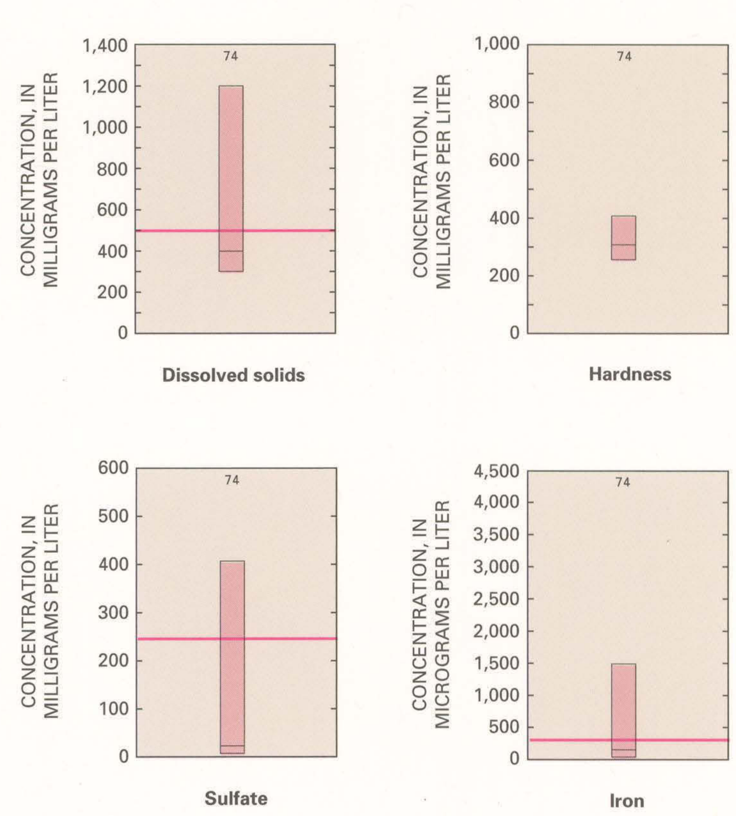
Ground-Water Quality

Most of the data on the quality of water from the Cambrian–Ordovician aquifer system in northern Illinois are from wells that are open to more than one aquifer in the system. Thus, the data represent the average quality of water from the entire system. The quality of water from the Cambrian–Ordovician aquifer system in northern Illinois generally is suitable for most uses. However, the water commonly is hard and might contain concentrations of dissolved solids, sulfate, and iron that exceed secondary maximum contaminant levels established by the U.S. Environmental Protection Agency for drinking water (**fig. 60**).

Water from 74 wells completed in the Cambrian–Ordovician aquifer system in northern Illinois had concentrations of dissolved solids that ranged from about 260 to 1,180 milligrams per liter, concentrations of hardness-causing constituents that ranged from about 250 to 420 milligrams per liter, sulfate concentrations that ranged from less than 10 (detection limit) to about 400 milligrams per liter, and iron concentrations that ranged from less than 50 (detection limit) to about 2,000 micrograms per liter (**fig. 60**).

The composite water that represents the Cambrian–Ordovician aquifer system is a calcium magnesium bicarbonate type in northern Illinois (**fig. 61**). Toward the south where the aquifers are deeply buried, the water changes to a calcium magnesium bicarbonate chloride type; to the southwest, it changes to a sodium bicarbonate chloride type as it moves down the hydraulic gradient. Still further downgradient, the water changes to a sodium chloride type. Sulfate is one of the dominant dissolved constituents of the water in the aquifer system in a small part of west-central Illinois.

Figure 60. Freshwater from the Cambrian–Ordovician aquifer system generally is hard; concentrations of iron commonly exceed that recommended for drinking water.



EXPLANATION

74 Number of analyses

Percentile—Percentage of analyses equal to or less than indicated values

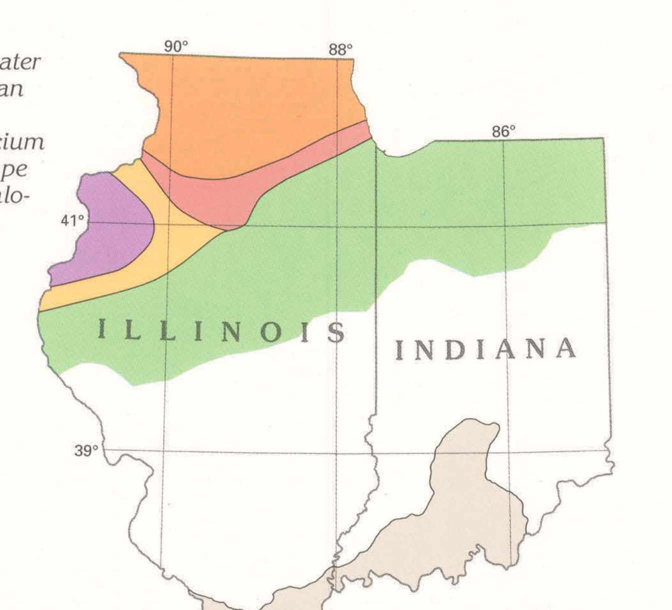
90th

50th Median

10th Secondary maximum contaminant level

Data from U.S. Geological Survey files, 1988; Contaminant level from U. S. Environmental Protection Agency, 1986

Figure 61. Ground water in the Cambrian–Ordovician aquifer system in northern Illinois changes from a calcium magnesium bicarbonate type in the north to a sodium chloride type toward the south.



EXPLANATION

Water type

Calcium magnesium bicarbonate

Calcium magnesium bicarbonate chloride

Sodium calcium sulfate bicarbonate

Sodium bicarbonate chloride

Sodium chloride

Fresh Ground-Water Withdrawals

Major areas of ground-water withdrawal from the Cambrian–Ordovician aquifer system in northern Illinois are shown in **figure 62**. The areas of largest withdrawal are near Chicago.

About 260 million gallons per day were withdrawn from the Cambrian–Ordovician aquifer system in northern Illinois during 1980. Of this amount, 68 percent, or about 177 million gallons per day, was withdrawn in an eight-county area around Chicago. The increase in water use from 1864 to 1980 in this area is shown in **figure 63**. Total ground-water withdrawals from the Cambrian–Ordovician aquifer system in northern Illinois were about 315 million gallons per day during 1985. It is estimated that the 1985 withdrawals from the aquifer system were about three times the recharge rate.

As a result of withdrawals in the Chicago, Ill., and Milwaukee, Wis. areas, the potentiometric surface of the Cambrian–Ordovician aquifer system had declined more than 800 feet by 1980 in the pumping centers west of Chicago, and more than 300 feet in the pumping center west of Milwaukee (**fig. 64**). The large cones of depression around these pumping centers spread westward and northwestward to areas where the Maquoketa confining unit is absent. Where this confining unit has been removed by erosion, the upper part of the Cambrian–Ordovician aquifer system is in direct contact with the overlying surficial aquifer system in north-central Illinois and southeastern Wisconsin. Where the two systems are in contact, the Cambrian–Ordovician aquifer system received large amounts of recharge from the shallower system, thus limiting the spread of the cones of depression. Beginning in the mid-1980's, withdrawals from the Cambrian–Ordovician aquifer system declined as some users switched to water from Lake Michigan as a source of supply. Water levels in the aquifer system had begun to rise by 1985 as a result of the decreased withdrawals.

Fresh ground-water withdrawals from the Cambrian–Ordovician aquifer system totaled 315 million gallons per day during 1985. About 197 million gallons per day was withdrawn for public supply and about 77 million gallons per day was withdrawn for industrial, mining, and thermoelectric power purposes. Withdrawals for commercial and domestic needs were nearly 35 million gallons per day, and about 6 million gallons per day was withdrawn for agricultural purposes (**fig. 65**).

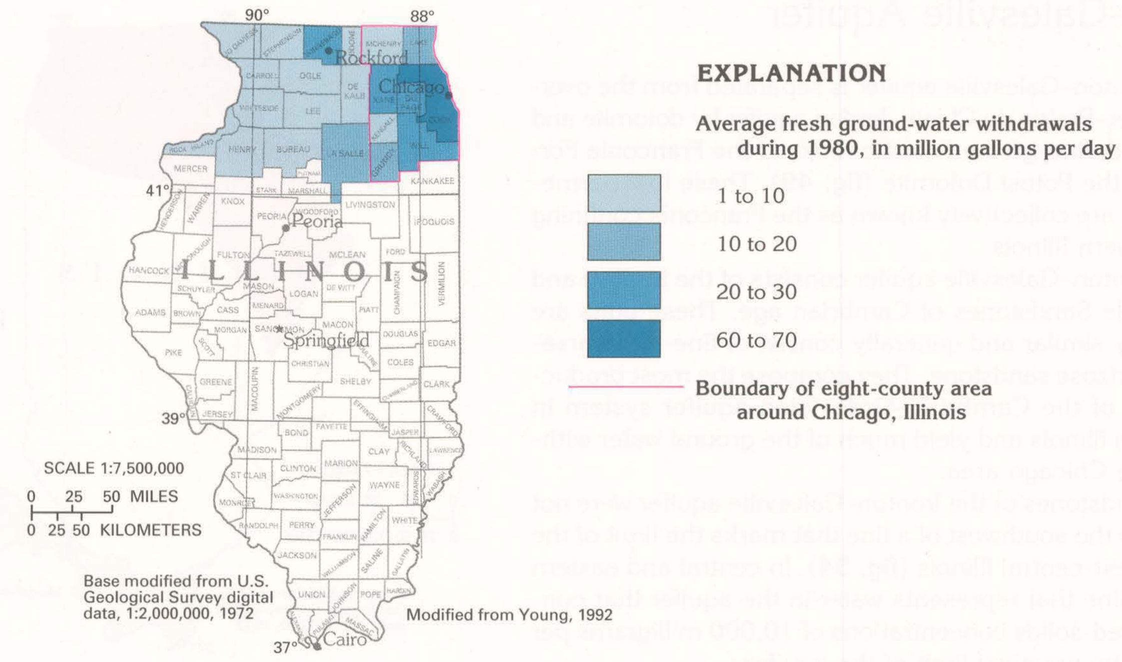


Figure 62. *The Cambrian–Ordovician aquifer system is relied on for large ground-water supplies in northern Illinois. During 1980, average ground-water withdrawals were about 177 million gallons per day in an eight-county area around Chicago. Of this amount, about 68 million gallons per day was withdrawn in Cook County, which includes Chicago.*

Figure 63. *Average fresh ground-water withdrawals from the Cambrian–Ordovician aquifer system in the eight-county area around Chicago increased from about 0.2 million gallons per day during 1864 to about 177 million gallons per day during 1980.*

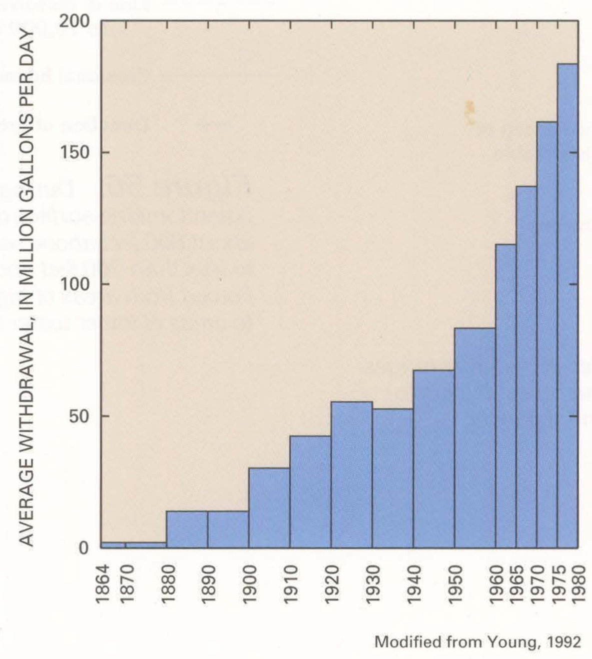


Figure 64. *As a result of large ground-water withdrawals from the Cambrian–Ordovician aquifer system from 1864 to 1980, the potentiometric surface of the aquifer system declined more than 800 feet around pumping centers west of Chicago and more than 300 feet around the pumping center west of Milwaukee, Wis. In the areas where declines were caused by these withdrawals, ground water flowed from all directions toward the pumping centers.*

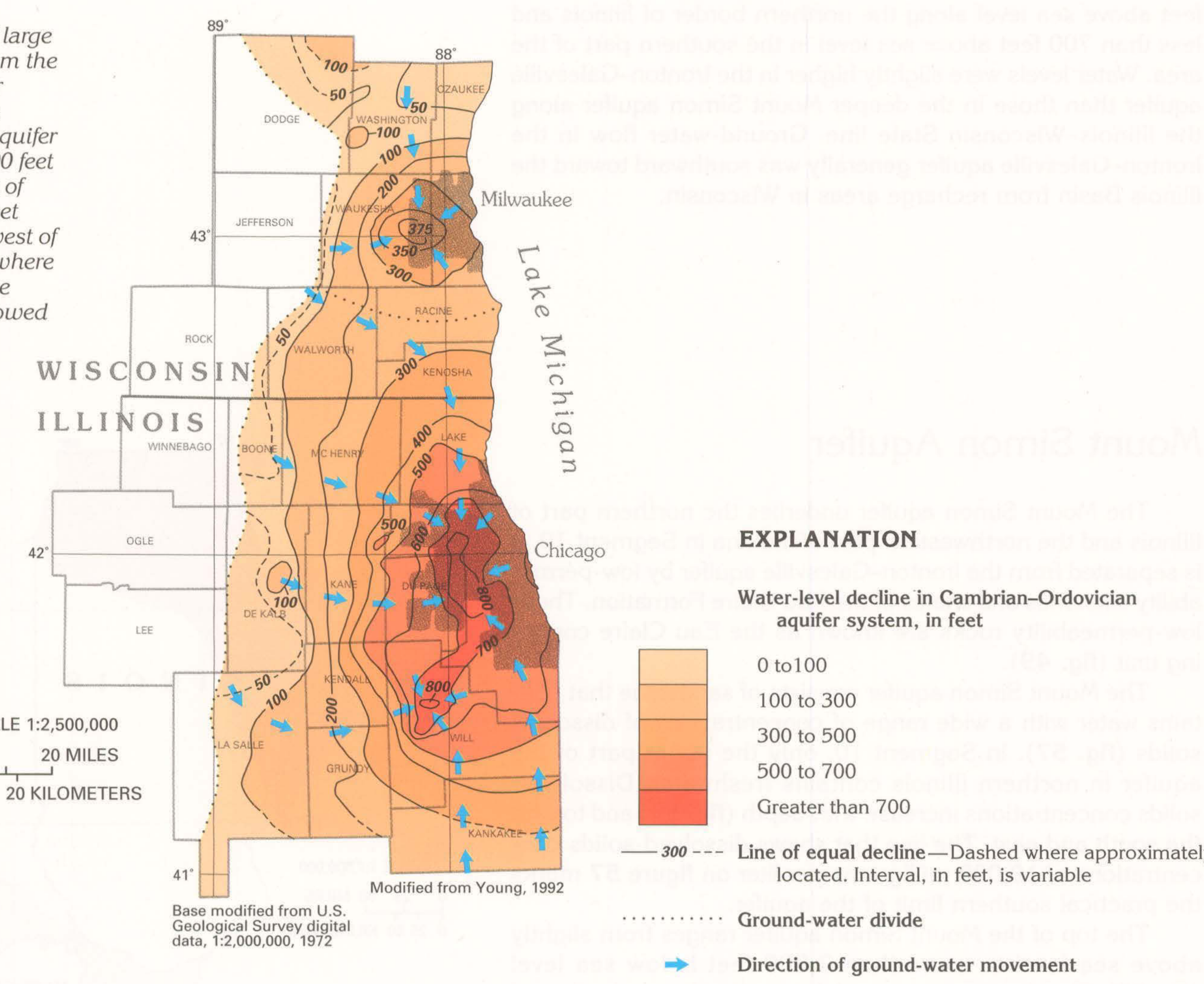
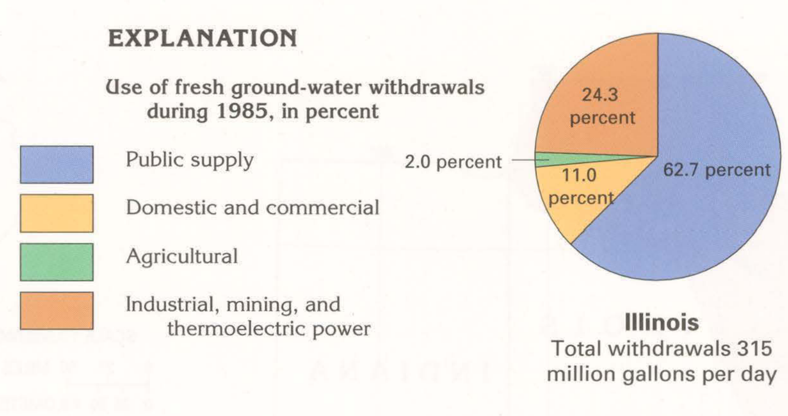


Figure 65. *Fresh ground-water withdrawals from the Cambrian–Ordovician aquifer system in northern Illinois were about 315 million gallons per day during 1985. Public-supply withdrawals accounted for about 63 percent of the total water withdrawn, and industrial, mining, and thermoelectric power withdrawals accounted for about 24 percent of the total.*

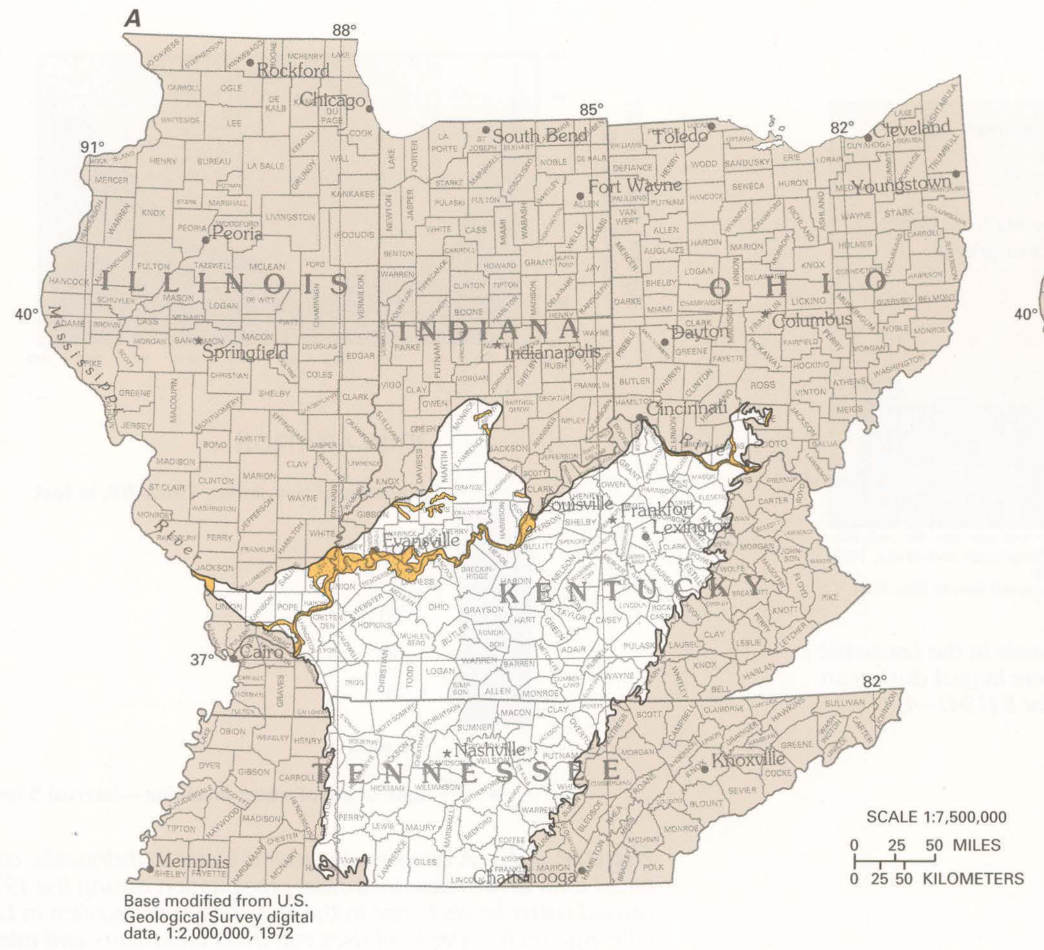


Interior Low Plateaus aquifers

INTRODUCTION

The Interior Low Plateaus aquifers in Segment 10 consist of the same two general categories of rocks as those in the Central Lowland Province—unconsolidated sand and gravel deposits of Quaternary age that compose the surficial aquifer system and consolidated limestone, dolomite, and sandstone of Paleozoic age (**figs. 66 and 67**). The surficial aquifer system is present only along the Ohio River Valley and a few of its tributaries in the northern part of the Interior Low Plateaus Province (**fig. 66*A***), in contrast with the large areal extent of the aquifer system in the Central Lowland Province. The principal aquifers in Paleozoic rocks are sandstone and limestone aquifers in rocks of Pennsylvanian age, limestone aquifers in rocks of Mississippian age, and limestone and dolomite aquifers in rocks of Devonian, Silurian, and Ordovician age (**figs. 66*B* and 67**).

The major hydrogeologic difference between the Interior Low Plateaus and the Central Lowland Provinces is the restricted distribution of the Quaternary deposits of the surficial aquifer system and the consequent exposure of the Paleozoic rocks throughout most of the Interior Low Plateaus. As a result, recharge to and discharge from the aquifers in rocks of Paleozoic age take place directly in the Interior Low Plateaus Province, whereas they take place mostly through the Quaternary deposits in the Central Lowland Province. Precipitation is the primary source of recharge in the Interior Low Plateaus Province. Most of the precipitation becomes overland runoff to streams, but some percolates downward through soil and residuum to the underlying bedrock. Some water is stored in and moves through intergranular pore spaces in the soil, residuum, and unconsolidated deposits of Quaternary age. In the consolidated rocks, however, most of the water moves through and is discharged from secondary openings, such as joints, fractures, bedding planes, and solution openings. As a result, ground-water discharge from springs is common throughout the Interior Low Plateaus Province in Segment 10.



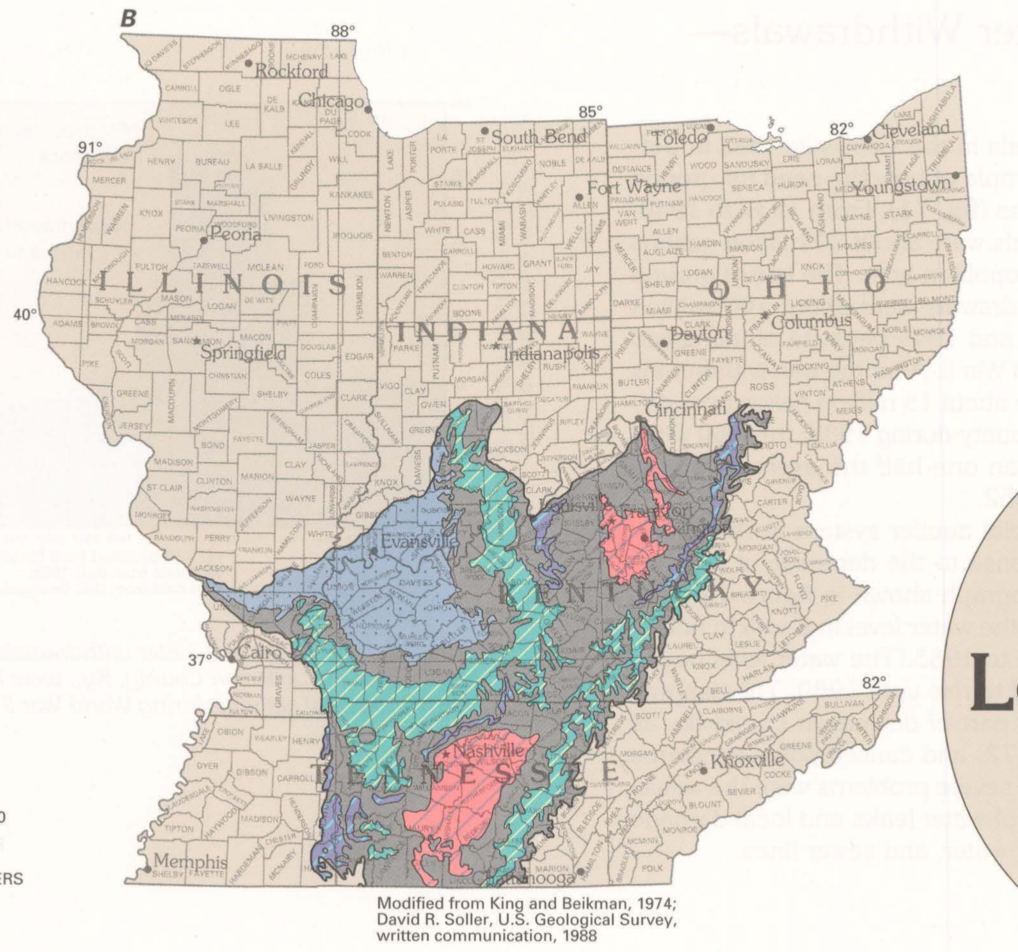


Figure 66 *The surficial aquifer system consists of sand and gravel deposits of Quaternary age located primarily along the Ohio River (A). Aquifers in consolidated rocks that range in age from Ordovician to Pennsylvanian extend over large parts of the Interior Low Plateaus Province (B).*

EXPLANATION

Interior Low Plateaus aquifers

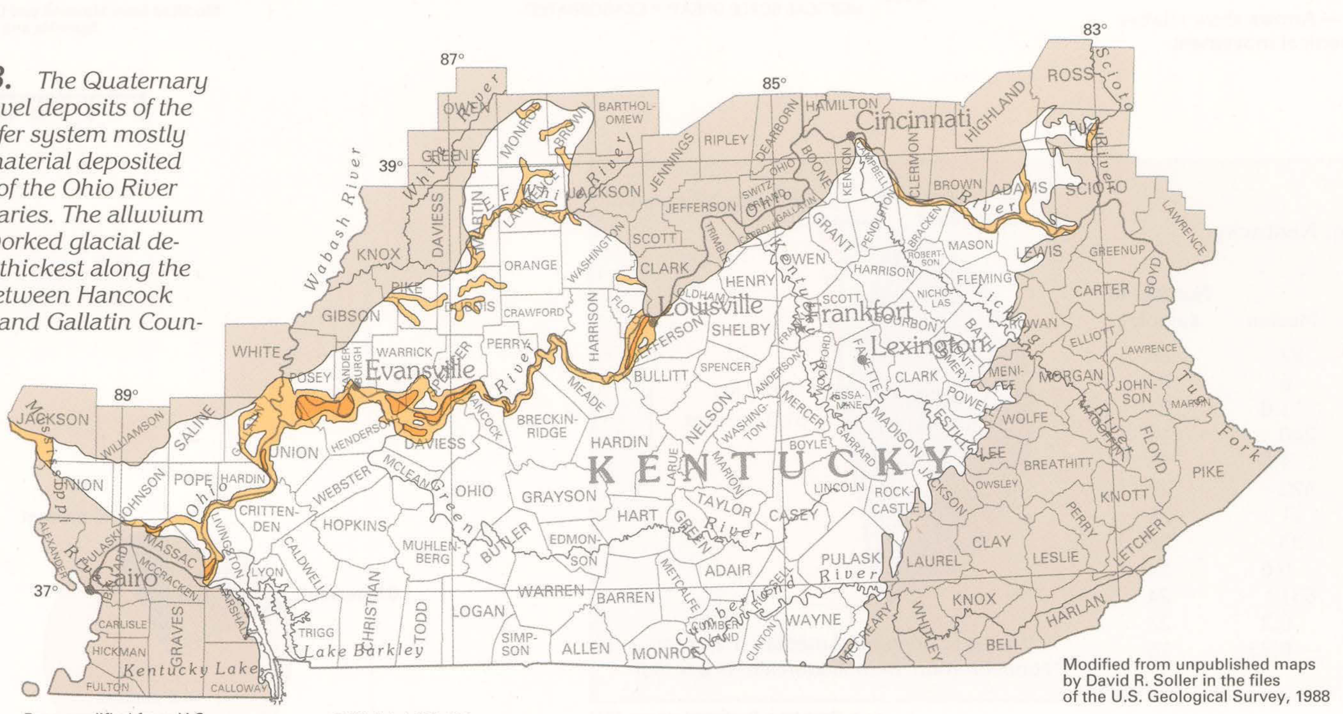
- Surficial aquifer system
- Pennsylvanian aquifers
- Mississippian aquifers
- Silurian–Devonian aquifer
- Ordovician aquifers
- **Not a principal aquifer**
- **Interior Low Plateaus Province boundary**

Era	System	Southern Illinois	Southwestern Indiana	Central and Western Kentucky	Southern Ohio	Central Tennessee	Hydrogeologic nomenclature used in this report
Cenozoic	Quaternary	Sand and gravel aquifers	Glaciofluvial aquifer	Alluvial aquifer	Unconsolidated coarse-grained aquifer		Surficial aquifer system
Paleozoic	Pennsylvanian	Pennsylvanian–Mississippian aquifers	Not a principal aquifer	Pennsylvanian sandstone aquifers	Not a principal aquifer		Pennsylvanian aquifers
	Mississippian		Mississippian aquifers	Mississippian limestone aquifers		Mississippian carbonate aquifers[2]	Mississippian aquifers
	Devonian	Shallow dolomite aquifer		Ordovician limestone aquifers[1]	Carbonate aquifers		Silurian-Devonian aquifer
	Silurian						
	Ordovician	Not a principal aquifer	Not a principal aquifer		Not a principal aquifer	Ordovician carbonate aquifer	Ordovician aquifers
	Cambrian			Not a principal aquifer		Knox aquifer	Not a principal aquifer
Middle Proterozoic	Precambrian	Confining unit	Confining unit	Confining unit	Confining unit	Confining unit	Confining unit

[1]Minor Silurian-Devonian aquifers included with Ordovician limestone aquifers.
[2]Silurian-Devonian aquifers included with Mississippian carbonate aquifers.

Figure 67. *Sand and gravel of alluvial origin compose the surficial aquifer system. Aquifers in consolidated rocks of Paleozoic age are mostly limestone and dolomite, but the Pennsylvanian aquifers consist of sandstone with some limestone. The light gray areas represent missing rocks.*

Figure 68. *The Quaternary sand and gravel deposits of the surficial aquifer system mostly are alluvial material deposited in the valley of the Ohio River and its tributaries. The alluvium mostly is reworked glacial deposits and is thickest along the Ohio River between Hancock County, Ky., and Gallatin County, Ill.*



EXPLANATION

Thickness of Quaternary deposits, in feet

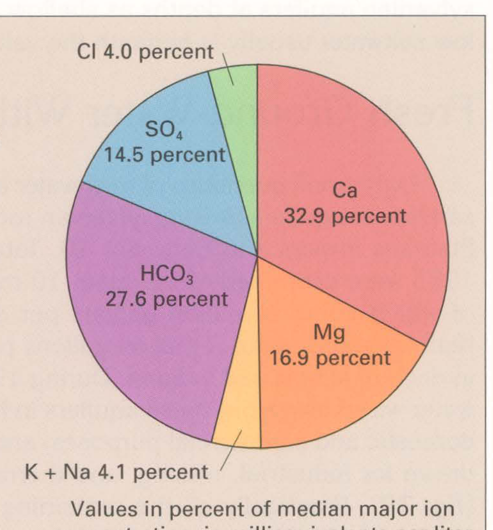
- Less than 100
- 100 to 200

Figure 69. *Ground water from wells completed in the surficial aquifer system in the Louisville, Ky., area typically is hard and is a calcium magnesium bicarbonate sulfate type.*

Louisville, Kentucky

Concentrations in milligrams per liter

Constituent	Range	Median	Number of samples
Hardness ($CaCO_3$)	149 to 1,727	515	72
Calcium (Ca)	44 to 341	164	59
Magnesium (Mg)	9.5 to 234	51	61
Sodium (Na)	3.7 to 149	22	59
Potassium (K)	0.8 to 12	3.2	61
Bicarbonate (HCO_3)	105 to 600	418	63
Sulfate (SO_4)	18 to 1,359	173	61
Chloride (Cl)	3.5 to 500	35	65
Fluoride (F)	0 to 0.6	0.1	66
Dissolved solids	222 to 2,358	960	45
Nitrate (NO_3)	0 to 62	0.4	60
Iron (Fe)	0.02 to 14	2.6	62



Values in percent of median major ion concentration, in milliequivalents per liter

Data from Faust and others, 1980

SURFICIAL AQUIFER SYSTEM

The sand and gravel deposits of Quaternary age along the Ohio River compose the principal aquifers in unconsolidated rocks in the Interior Low Plateaus Province in Segment 10. These aquifers, which are collectively called the surficial aquifer system, consist primarily of alluvium reworked from the Quaternary glacial sand and gravel deposits of the surficial aquifer system in the Central Lowland Province to the north.

The distribution and approximate thickness of the Quaternary deposits in the Interior Low Plateaus Province are shown in **figure 68**. Typically, the lower two-thirds or more of the alluvial deposits consists of coarse sand and gravel that directly overlie bedrock. These coarse-grained sediments form the principal aquifers in unconsolidated rocks. The upper part of the alluvial deposits consists of fine sand, silt, and clay. All or part of these fine-grained sediments may be unsaturated.

The saturated thickness of the Quaternary deposits increases from east to west along the Ohio River. In Kentucky, the saturated thickness is about 35 feet in Lewis County, about 80 feet around Louisville in Jefferson County, and about 110 feet in Henderson County. If all other factors remain the same, then the amount of water an aquifer will yield increases in direct proportion to the saturated thickness of the aquifer.

Aquifer Characteristics and Well Yields

Aquifer-test data from Kentucky indicate that median values of transmissivity for different areas of the surficial aquifer system along the Ohio River range from about 4,400 to 28,000 feet squared per day. The greater the transmissivity, the more readily water can move through the aquifer system. The median specific capacities reported for 173 wells completed in different areas of the surficial aquifer system along the Ohio River in Kentucky range from about 14 to 110 gallons per minute per foot of water-level drawdown. These data indicate that large yields can be expected from wells completed in the sand and gravel aquifers, particularly where the saturated deposits are coarse grained and thick. It is common for wells near the Ohio River to have sustained yields of 1,000 gallons per minute if they are completed in coarse-grained, well-sorted, thick alluvial deposits that are hydraulically connected to the river.

Ground-Water Quality

Chemical analyses of water from selected wells completed in the surficial aquifer system in the Louisville, Ky., area are shown in **figure 69**. These data are examples of the chemical characteristics of water from the sand and gravel aquifers in the Interior Low Plateaus Province.

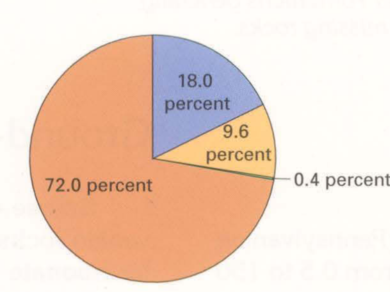
The water typically is hard and is a calcium magnesium bicarbonate sulfate type (**fig. 69**) with large concentrations of iron. Large dissolved-solids concentrations (exceeding 500 milligrams per liter) and large iron concentrations (exceeding 0.3 milligram per liter) are common problems. Dissolved-solids concentrations in water from wells in the Louisville area range from about 220 to about 2,360 milligrams per liter with a median of 960 milligrams per liter.

The distance of wells from rivers and streams and the type of underlying bedrock affect the chemical characteristics of the water from wells completed in the surficial aquifer system. Concentrations of dissolved solids, hardness-causing constituents (calcium and magnesium in particular), and, in some cases, sulfate are likely to be larger in water from wells in areas underlain by limestone and smaller in water from wells near rivers and streams. The larger concentrations of these constituents might result from mixing of the water in the surficial aquifer system with more highly mineralized water that is discharged from the underlying limestone into the sand and gravel aquifers. The smaller concentrations might result from the mixing of ground water with less mineralized river water that recharges the aquifer system near pumping wells.

Fresh Ground-Water Withdrawals

During 1985, about 113 million gallons per day was withdrawn from wells completed in the surficial aquifer system in the Interior Low Plateaus Province in Segment 10. Most of the withdrawals were along the Ohio River in Kentucky. The 113 million gallons withdrawn from this aquifer is about 55 percent of the total fresh ground water withdrawn in Kentucky during 1985. Almost three-fourths of the water withdrawn from the surficial aquifer system during 1985 was used for industrial, mining, and thermoelectric power purposes (**fig. 70**). Withdrawals for public supply were the second largest use category.

Figure 70. *During 1985, fresh ground-water withdrawals from the surficial aquifer system in Kentucky for industrial, mining, and thermoelectric power uses were about 81 million gallons per day.*



Kentucky
Total withdrawals 113 million gallons per day

EXPLANATION

Use of fresh ground-water withdrawals during 1985, in percent

- Public supply
- Domestic and commercial
- Agricultural
- Industrial, mining, and thermoelectric power

Data from U.S. Geological Survey files, 1990

Fresh Ground-Water Withdrawals—Continued

The history of withdrawals in the Louisville area in Jefferson County, Ky., is an example of how the need for ground water can change through time (**fig. 71**). From 1937 to 1940, fresh ground-water withdrawals were about 40 million gallons per day in the Louisville metropolitan area. The use of ground water rose sharply until withdrawals were about 100 million gallons per day during 1943 and 1944 because of increased industrial activity during World War II. After the war, withdrawals declined to the point that only about 15 million gallons per day was withdrawn in Jefferson County during 1985; the total withdrawal that year was less than one-half the average annual withdrawals from 1946 to 1952.

Water levels in the surficial aquifer system in the Louisville area have risen in response to the decrease in ground-water withdrawals. The hydrograph shown in **figure 72** illustrates the decline and rise of the water level in a well in northeastern Louisville from 1937 to 1983. The water level began to rise in 1962 and continued to rise until 1980. The rise was more than 50 feet in a small part of downtown Louisville, as shown by the map in **figure 72**, and caused some problems in the area. Perhaps the most severe problems were the weakening of basements because of water leaks and local damage to underground gas, electric, water, and sewer lines.

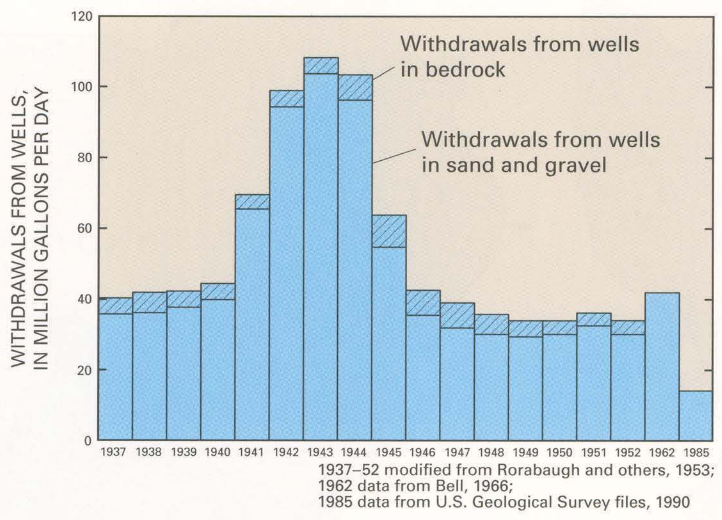
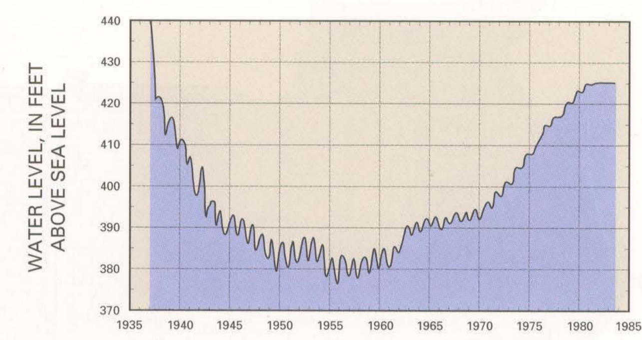
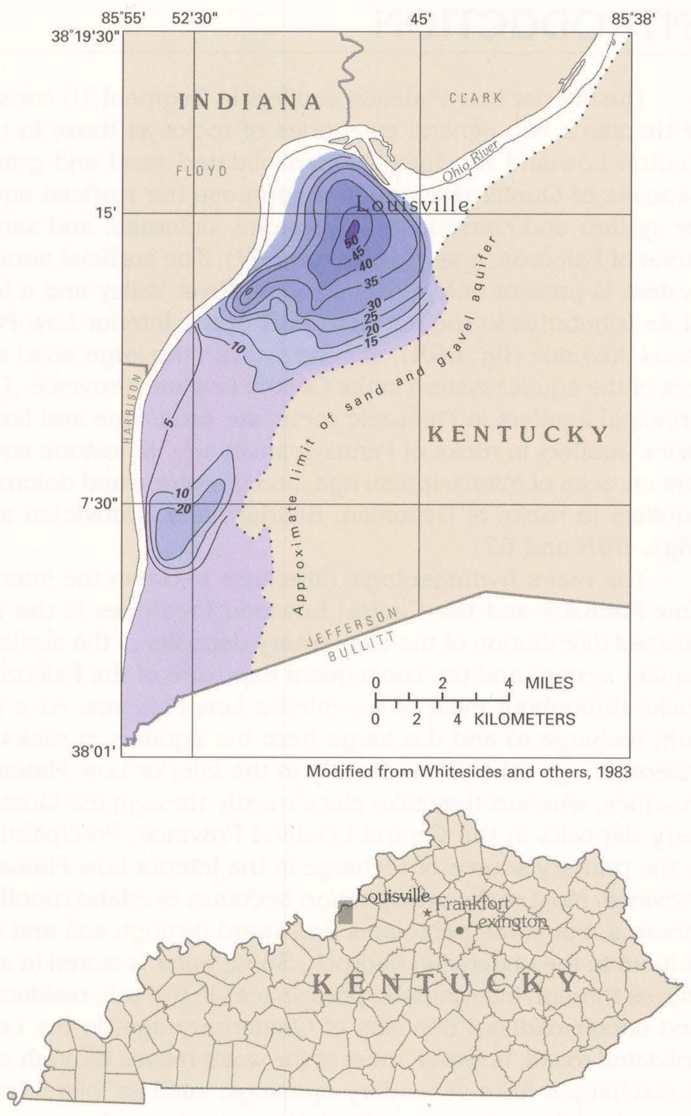


Figure 71. *Fresh ground-water withdrawals in the Louisville metropolitan area in Jefferson County, Ky., were largest during an increase of industrial activity during World War II (1941–45).*





EXPLANATION

Water-level rise during 1962–82, in feet

- 10
- 20
- 30
- 40
- 50
- No data

—30— Line of equal water-level rise—Interval 5 feet

Figure 72. *A decrease in ground-water withdrawals, combined with an increase in annual precipitation during the 1970's, caused water levels to rise in the surficial aquifer system in Louisville, Ky. Such water-level rises can flood basements and interfere with utility services and maintenance.*

PENNSYLVANIAN AQUIFERS

Hydrogeologic Setting

Sandstones of Pennsylvanian age are the principal aquifers in consolidated rocks throughout most of the northwestern part of the Interior Low Plateaus Province in Segment 10. These sandstones are present in the northwestern part of Kentucky (known as the Western Coal Field), southwestern Indiana, and part of the southern tip of Illinois (**fig. 73**). Where present, these sandstones are used as a source of water except where they are overlain by Quaternary sand and gravel aquifers of the surficial aquifer system in the valleys of the Ohio River and its tributaries.

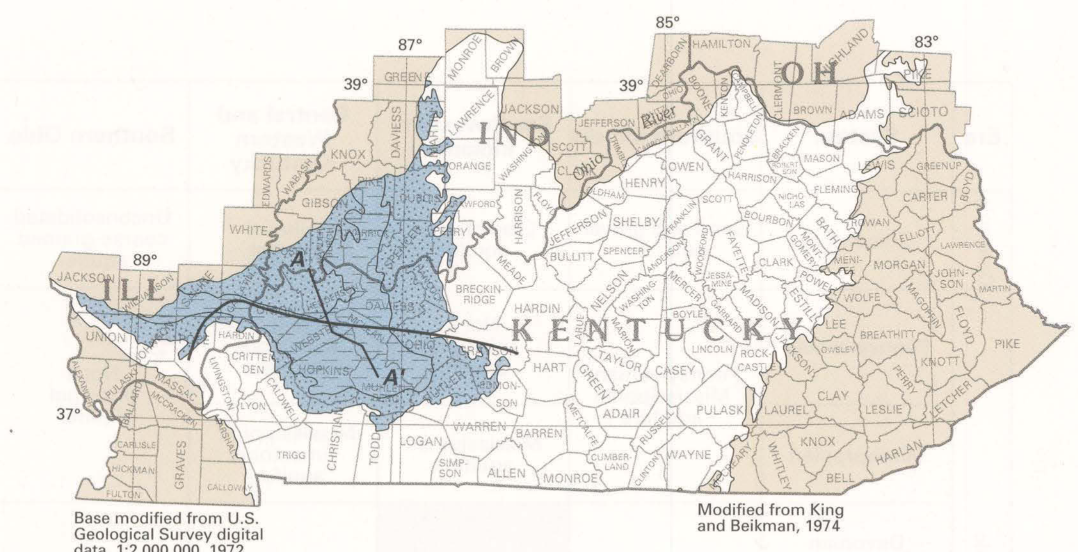
The Pennsylvanian rocks are folded into a syncline (**fig. 74**) that plunges to the north and northwest into the Illinois Basin. Sandstones of the Caseyville and the Tradewater Formations are at land surface on the periphery of the area as shown in **figure 73** and dip beneath younger Pennsylvanian rocks in the central part of the area. The rocks are offset by several nearly vertical faults that trend east to west and might act as conduits for or barriers to ground-water movement.

The Pennsylvanian sandstones, like those in the Central Lowland Province, are part of repeating sequences of coal-bearing rocks deposited during sedimentary cycles. An ideal complete cycle consists of the following sequence of beds, listed from bottom to top: basal sandstone, sandy shale, limestone, underclay, coal, gray shale, limestone, black platy shale, limestone, and silty gray shale with iron concretions. Most of the sandstones are in the upper and lower parts of the Pennsylvanian rocks (**fig. 75**). The sandstones mostly are channel-fill deposits and are separated by sequences of shale, coal, and limestone. Sandstones are more common north of the Rough Creek Fault System than south of it, and shale, sandy shale, and limestone are more common south of the fault system than to the north.

Part of the precipitation that falls on the exposed Pennsylvanian rocks percolates downward to the water table to recharge the aquifers in these rocks. The water then moves through the aquifers from areas of higher hydraulic head (high water levels), such as uplands and interstream areas, to discharge at areas of lower hydraulic head (low water levels), such as streams and springs. The water primarily moves through fractures and bedding planes in the rocks. The general direction of regional ground-water movement is toward the Ohio River and its tributaries. Most of the ground water moves along short flow paths through the shallow parts of the zone of saturation to discharge at nearby streams. Some water discharges to springs and wells.

In most places, the freshwater–saltwater interface in the Pennsylvanian aquifer is at depths of less than 500 feet below land surface. The deepest occurrence of freshwater in these aquifers is in Hopkins and Muhlenberg Counties, Ky. Here, freshwater is present more than 400 feet below sea level, or more than 1,000 feet below land surface. The origin of this deep freshwater is unknown.

Figure 73. *Sandstones that form the principal aquifers in the Pennsylvanian rocks underlie northwestern Kentucky and adjacent parts of Indiana and Illinois.*



SCALE 1:5,000,000

0 25 50 MILES

0 25 50 KILOMETERS

EXPLANATION

Pennsylvanian aquifers

- Generally sandstone
- Generally shale

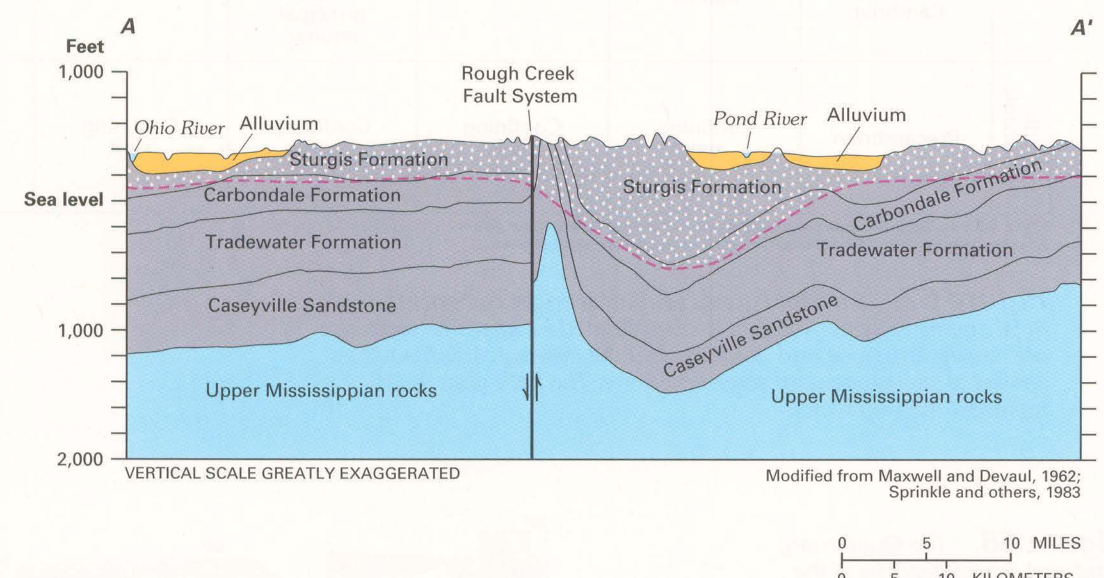
—— Rough Creek Fault System—Approximately located

A——A' Line of hydrogeologic section

Figure 74. *Pennsylvanian rocks are offset by faults in some places and are folded in other places. The depth to water with a dissolved-solids concentration of 1,000 milligrams per liter averages less than 500 feet but can be as great as 1,000 feet. The line of the section is shown in figure 73.*

EXPLANATION

- Pennsylvanian rocks that contain freshwater
- - - - Estimated line of dissolved-solids concentration equal to 1,000 milligrams per liter
- Fault—Arrows show relative vertical movement



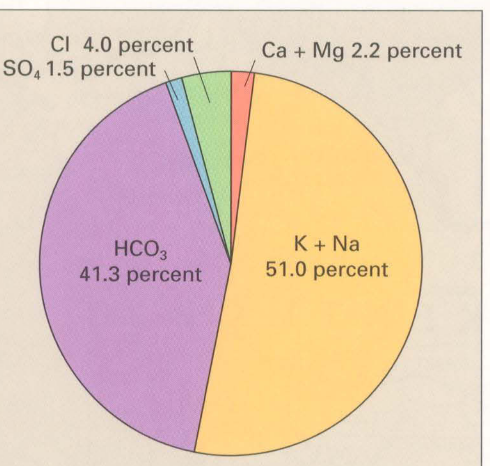
System	Series	Geologic unit: North of Rough Creek Fault System	Geologic unit: South of Rough Creek Fault System	Lithology: North of Rough Creek Fault System	Lithology: South of Rough Creek Fault System	Hydrogeologic unit: North of Rough Creek Fault System	Hydrogeologic unit: South of Rough Creek Fault System
Pennsylvanian	Upper	Sturgis Formation	Sturgis Formation	Shaly sandstone, sandy shale, and limestone	Shale, sandy shale, and minor limestone	Limestone and sandstone aquifers	Confining unit with minor limestone aquifers
	Middle	Carbondale Formation		Shale, coal, minor sandstone, and limestone		Confining unit with minor sandstone, limestone, and coal aquifers	
		Tradewater Formation		Shaly sandstone, sandy shale, sandstone, minor limestone, and coal		Sandstone aquifers	
	Lower	Caseyville Formation		Sandstone, shaly sandstone, and sandy shale			

Figure 75. *Most of the sandstone aquifers are in the Caseyville and the Tradewater Formations south of the Rough Creek Fault System and in the Sturgis Formation north of the fault system. The aquifers in the Caseyville and the Tradewater Formations generally contain saltwater. The gray areas represent missing rocks.*

Western coal field region, Kentucky

Concentrations in milligrams per liter

Constituent	Range	Median	Number of samples
Hardness ($CaCO_3$)	2 to 215	22	26
Calcium (Ca)	1.1 to 52	6	21
Magnesium (Mg)	0 to 11	1.8	21
Sodium (Na)	11 to 1,350	240	19
Potassium (K)	0.6 to 8.6	1.6	18
Bicarbonate (HCO_3)	156 to 1,400	522	26
Sulfate (SO_4)	0.3 to 109	11	26
Chloride (Cl)	0.4 to 1,720	33	26
Fluoride (F)	0 to 4.2	0.6	24
Dissolved solids	186 to 3,710	631	24
Nitrate (NO_3)	0 to 1.8	0.2	22
Iron (Fe)	0.01 to 7.9	0.23	25



Values in percent of median major ion concentration, in milliequivalents per liter

Data from Davis and others, 1974

Figure 76. *Water from the sandstone aquifers in Lower Pennsylvanian rocks typically is soft and is a sodium bicarbonate type. Dissolved-solids concentrations locally exceed 500 milligrams per liter.*

Aquifer Characteristics and Well Yields

Limited data from wells completed in the Pennsylvanian aquifers in Kentucky indicate well yields range from 0.5 to 150 gallons per minute and average about 25 gallons per minute. The median well yield is 9 gallons per minute.

Large water-level declines might result from small to moderate ground-water withdrawals in some of the Pennsylvanian aquifers. Such declines are most probable in aquifers that have low permeability, small areal extent, and limited recharge. Water levels in the sandstone aquifers that lie at depths of greater than 500 feet below land surface and that are completely surrounded by rocks of low permeability are the most likely to show large declines. Typically, large water-level declines are accompanied by high costs of the energy used to pump the water.

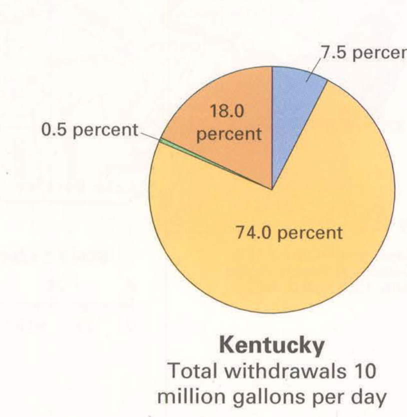
Ground-Water Quality

Sparse data indicate that the aquifers in Upper Pennsylvanian rocks contain hard water that is a calcium magnesium bicarbonate type. The calcium and magnesium in the water probably are derived from the partial dissolution of limestone beds or carbonate cements in sandstone beds.

The quality of the ground water from the sandstone aquifer in Lower Pennsylvanian rocks in the Interior Low Plateaus generally is suitable for most uses. The water typically is soft and is a sodium bicarbonate type (**fig. 76**). In places, the water contains concentrations of iron that exceed 0.3 milligram per liter. Water from wells deeper than 500 feet might contain concentrations of chloride that exceed 250 milligrams per liter. In places, dissolved-solids concentrations exceed 500 milligrams per liter. Saltwater locally is present in the Pennsylvanian aquifers at depths as shallow as 100 feet. The shallow saltwater usually is beneath the valleys of major streams.

Fresh Ground-Water Withdrawals

Only small quantities of freshwater are withdrawn from the sandstone aquifers in Pennsylvanian rocks in the Interior Low Plateaus Province in Segment 10. Total withdrawals during 1985 were estimated to be about 10 million gallons per day, of which about 6 million gallons per day was withdrawn in Kentucky and about 2 million gallons per day was withdrawn in each of Illinois and Indiana. During 1985, 74 percent of the water withdrawn from these aquifers in Kentucky was used for domestic and commercial purposes, and 18 percent was withdrawn for industrial, mining, and thermoelectric power uses (**fig. 77**). Practically all the remaining withdrawals were for public supply.



Kentucky

Total withdrawals 10 million gallons per day

EXPLANATION

Use of fresh ground-water withdrawals during 1985, in percent

- Public supply
- Domestic and commercial
- Agricultural
- Industrial, mining, and thermoelectric power

Data from U.S. Geological Survey files, 1990

Figure 77. *Domestic and commercial withdrawals, together with withdrawals for industrial, mining, and thermoelectric power uses, accounted for 92 percent of the ground water withdrawn from sandstone aquifers in Pennsylvanian rocks in Kentucky during 1985.*

MISSISSIPPIAN AQUIFERS

Hydrogeologic Setting

A large part of the Interior Low Plateaus Province in Segment 10 is underlain by limestone aquifers in Mississippian rocks (**fig. 78**). These aquifers have been called the Mississippian Plateau aquifers in Kentucky and the Highland Rim aquifer system in Tennessee. They are present in limestone that is either flat lying or gently dipping and are capped by a layer of regolith that varies greatly in thickness. In general, the limestone aquifers that yield the largest quantities of water to wells and springs are the Upper Mississippian Monteagle, the Ste. Genevieve, and the St. Louis Limestones (**fig. 79**). Where the Monteagle, the Ste. Genevieve, and the St. Louis are thin or missing, such as in the southwestern part of central Tennessee, the Warsaw Limestone along with chert and limestone beds of the Fort Payne Formation are the principal aquifers.

In most places, the Mississippian aquifers are covered by regolith, which mostly consists of weathered material, or residuum (**fig. 80**). This material consists of clay, silt, sand, and pebble-sized particles of limestone or chert, which are derived mostly from weathering of the underlying bedrock. In the southwestern part of central Tennessee, the regolith might consist mostly of chert left from the weathering of the Fort Payne Formation. Where thick and saturated, this chert rubble constitutes a productive local aquifer. The regolith can store large quantities of water that subsequently percolate slowly downward to recharge aquifers in the underlying consolidated rock. The regolith is as thick as 150 feet in several places in the Interior Low Plateaus Province in Tennessee.

The conceptual flow system in the Mississippian aquifers is shown in **figure 80**. Precipitation infiltrates the land surface and percolates downward to the water table, which marks the top of the zone of saturation. The water moves through intergranular spaces in the unconsolidated material of the regolith. However, in the underlying limestone bedrock, the water moves through zones of secondary permeability created by dissolution enlargement of bedding planes and fractures by the slightly acidic water. The solution openings store and transmit most of the water that moves through the limestone and discharges to streams, springs, and wells. Little water passes through the blocks of limestone between the bedding planes and fractures.

Freshwater circulates through the limestone aquifers to depths as great as 500 feet below land surface (**fig. 81**). However, most of the circulation is at depths of less than 300 feet. All other factors being equal, the freshwater circulation is deepest where the local topographic relief and attendant hydraulic gradients are greatest. For example, the depth to water with 10,000 milligrams per liter dissolved solids in the Mississippian aquifers is greatest near the escarpment between the Appalachian Plateaus and the Interior Low Plateaus Provinces near the right end of the section shown in **figure 81**.

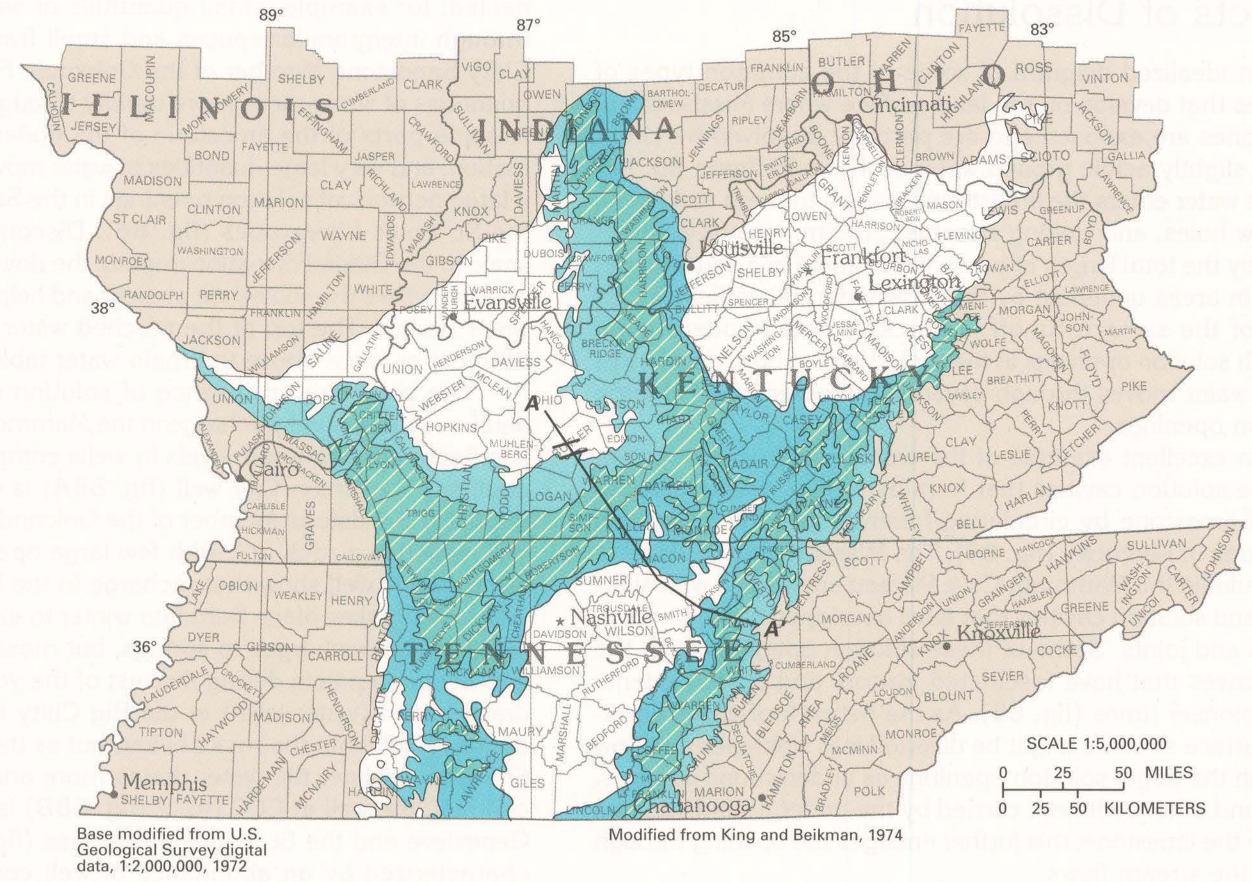


Figure 78. Rocks of Mississippian age underlie a large part of the Interior Low Plateaus Province in Segment 10. The principal aquifers in these rocks primarily are in the Upper Mississippian limestones.

System	Series	West-central Kentucky, southern Illinois, southern Indiana: Geologic unit	Lithology	Hydrogeologic unit	West-central Tennessee: Geologic unit	Lithology	Hydrogeologic unit	East-central Kentucky and East-central Tennessee: Geologic unit	Lithology	Hydrogeologic unit
Mississippian	Upper	Grove Church Shale	Interlayered limestone, sandstone, and shale	Local limestone and sandstone aquifers				Pennington Formation	Primarily shale	Confining unit; local sandstone aquifers
		Kinkaid Limestone								
		Buffalo Wallow Formation								
		Tar Springs Sandstone								
		Glen Dean Limestone						Bangor Limestone		
		Hardinsburg Sandstone							Limestone	Limestone aquifers
		Golconda Formation						Newman Limestone: Hartselle Formation		
		Girkin Limestone: Cypress Sandstone					Primarily limestone aquifers	Newman Limestone: Monteagle Limestone		
		Girkin Limestone: Paint Creek Formation				Limestone and sandstone				
		Girkin Limestone: Bethel Sandstone			Monteagle Limestone					
		Girkin Limestone: Paoli and Renault Limestones		Limestone aquifers						
		Ste. Genevieve Limestone	Limestone and local sandstone		Ste. Genevieve Limestone	Limestone		Newman Limestone: Ste. Genevieve Limestone		
		St. Louis Limestone			St. Louis Limestone			Newman Limestone: St. Louis Limestone		
		Salem Limestone			Warsaw Limestone			Warsaw Limestone		
		Warsaw Limestone								
		Fort Payne Formation	Chert and limestone		Fort Payne Formation	Chert and limestone		Fort Payne Formation		
	Lower	Burlington Limestone; Keokuk Limestone; Chouteau and Rockford Limestones; New Providence Formation	Limestone and shale	Local limestone aquifers in western part of area						
			Shale	Confining unit	Chattanooga Shale	Shale	Confining unit	Chattanooga Shale	Shale	Confining unit

Figure 79. The most productive Mississippian aquifers comprise the Monteagle, the Ste. Genevieve, the St. Louis, and the Warsaw Limestones and the Fort Payne Formation. Most of the other Mississippian formations consist of fine-grained clastic rocks. Geologic units that compose aquifers are shown in blue.

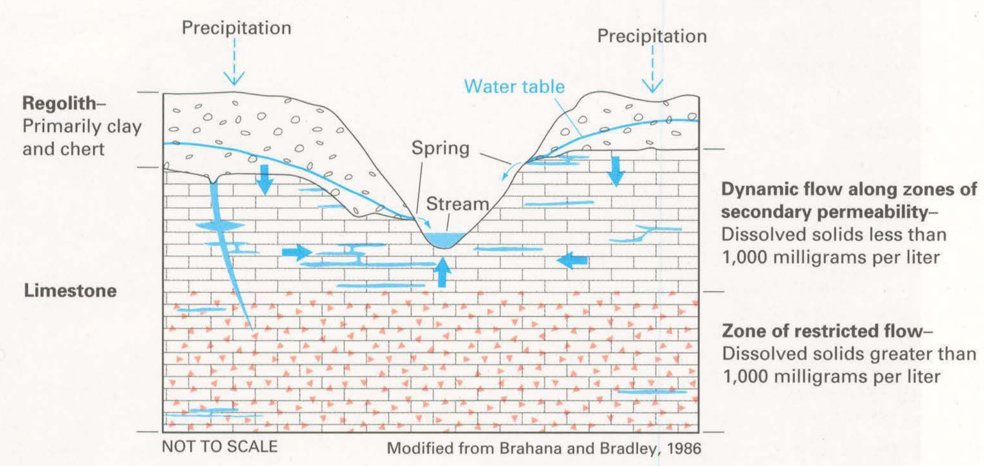


Figure 80. In general, regolith that consists mostly of unconsolidated residuum overlies the consolidated limestone in the area. Ground water percolates downward through the unconsolidated regolith and then moves through fractures, bedding planes, and solution openings in the limestone to eventually discharge to springs and streams.

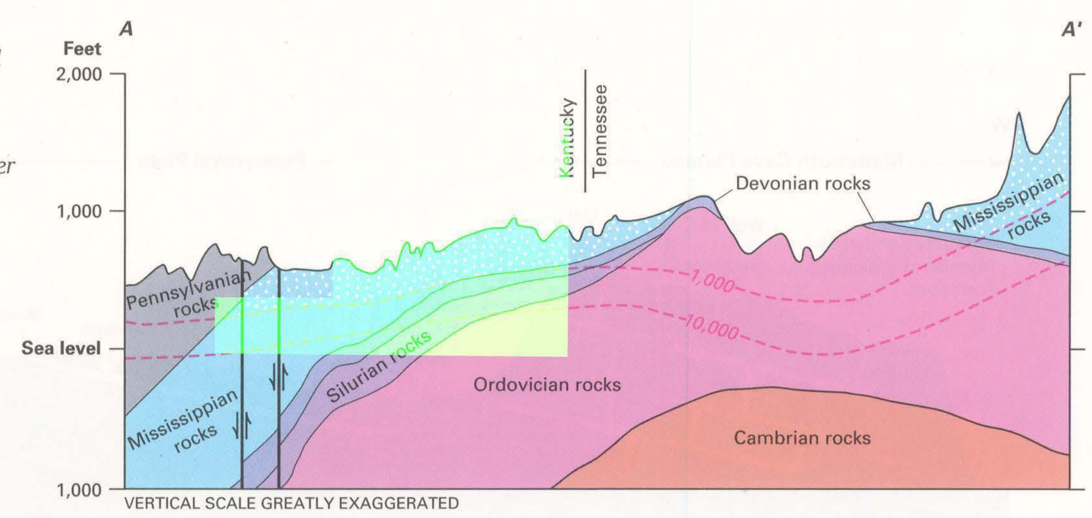


Figure 81. Fresh ground water circulates to depths as great as 500 feet below land surface in the Mississippian aquifers. Most of the freshwater circulation is at depths of less than 300 feet. The line of the section is shown in figure 78.

Figure 82. The altitude of the potentiometric surface of the Mississippian aquifers in western Kentucky ranges from less than 400 to about 900 feet above sea level. Most ground-water flow is local and discharges to the many springs in the area.

SCALE 1:1,500,000
0 20 40 MILES
0 20 40 KILOMETERS

The altitude and configuration of the potentiometric surface and the general direction of ground-water movement in the Mississippian aquifers (the Ste. Genevieve and the St. Louis Limestones) in western Kentucky are shown in **figure 82**. The altitude of the potentiometric surface ranges from less than 400 feet above sea level in the west to more than 900 feet above sea level in three small areas in the east. However, little, if any, regional ground-water flow occurs. Most of the flow is local, toward springs and the few streams that drain the area. An escarpment that bounds the aquifer on the north is aptly named the "Dripping Springs Escarpment" because of the many small seeps and springs that discharge water along it.

Water in the Mississippian aquifers generally moves in a direction perpendicular to the potentiometric contours, as shown by the arrows in **figure 82**. However, the water locally moves along fractures and bedding planes that might be nearly perpendicular to one another. Consequently, the arrows that show ground-water flow direction indicate only the general direction of water movement in a complex flow system that has many local horizontal and vertical components.

Effects of Dissolution

An idealized diagram of some of the common types of features that develop on the land surface where Mississippian limestones are exposed and are partially dissolved by circulating, slightly acidic ground water is shown in **figure 83**. Recharge water enters the limestone aquifers through sinkholes, swallow holes, and sinking streams. Stream density, as measured by the total length of perennial streams in a square mile, is low in areas underlain by the limestone; this indicates that most of the surface runoff is quickly routed underground through solution openings in the rocks. In the subsurface, most of the water moves through caverns and other types of large solution openings.

An excellent example of the extent and interconnection of large solution cavities that form as a result of the dissolution of limestone by circulating freshwater is the Mammoth Cave area in Kentucky (**fig. 84**). The Mississippian limestones that underlie the Mammoth Cave Plateau are riddled with sinkholes and solution cavities that have developed along bedding planes and joints. Some of these solution openings form the large caves that have fascinated visitors and area residents since pioneer times (**fig. 85**). As the network of caves develops, surface streams might be diverted into sinkholes and flow through the larger solution openings as underground streams. Sand and other sediment carried by the underground streams abrade the limestone; this further enlarges the opening through which the stream flows.

The solution openings in the limestone are so well developed in the Mammoth Cave area that most surface runoff enters the rocks through sinkholes and moves through solution cavities to springs (**fig. 86**). Accordingly, surface streams in the area are few. Most of the water moves rapidly downward through enlarged, well-connected solution openings to the main water table and then moves laterally to discharge from springs into the Green River. Some of the solution openings are large enough to contain underground streams, such as Echo River (**fig. 87**). However, some of the water moves more slowly through openings that are small and poorly interconnected; for example, small quantities of water move slowly through intergranular spaces and small fractures in the Big Clifty Sandstone Member of the Golconda Formation. Larger quantities of water move more rapidly through small openings in some parts of the limestone of the underlying Girkin Formation, and very large quantities of water move rapidly through a large network of solution openings in the Ste. Genevieve and the St. Louis Limestones (**fig. 86**). Discontinuous layers of shale in the Girkin Formation impede the downward movement of water where the shales are present and help support perched water bodies. The top of the perched water bodies might be 300 feet or more above the main water table.

The presence or absence of solution openings affects aquifer recharge and discharge in the Mammoth Cave area and is reflected by the water levels in wells completed in different aquifers. The Union City well (**fig. 88*A***) is completed in the Big Clifty Sandstone Member of the Golconda Formation (**fig. 86**), which is a rock unit with few large openings. The water levels in this well show that recharge to the Big Clifty is rapid and mostly takes place from late winter to early spring. Some of the water discharges to springs, but most drains gradually into deeper aquifers during the rest of the year. When the hydraulic head (water level) in the Big Clifty is high, the water drains rapidly into the rocks below, but as the water level continues to decline, the water drains more and more slowly. In contrast, the well at CCC No. 2 (**fig. 88*B***) is open to the Ste. Genevieve and the St. Louis Limestones (**fig. 86**), which are characterized by an abundance of well-connected solution openings. The water level in these rocks can fluctuate rapidly depending on antecedent conditions, the season of the year, and local precipitation. The water level in the well at CCC No. 2 showed almost no change during dry weather and after light summer rains; however, following periods of greater-than-normal precipitation (**fig. 88*C***), the water level rose sharply. This water-level response indicates that the well at CCC No. 2 is open to solution openings in the limestone. These openings allow rapid recharge to and equally rapid discharge from the aquifer during and immediately following periods of intense precipitation.

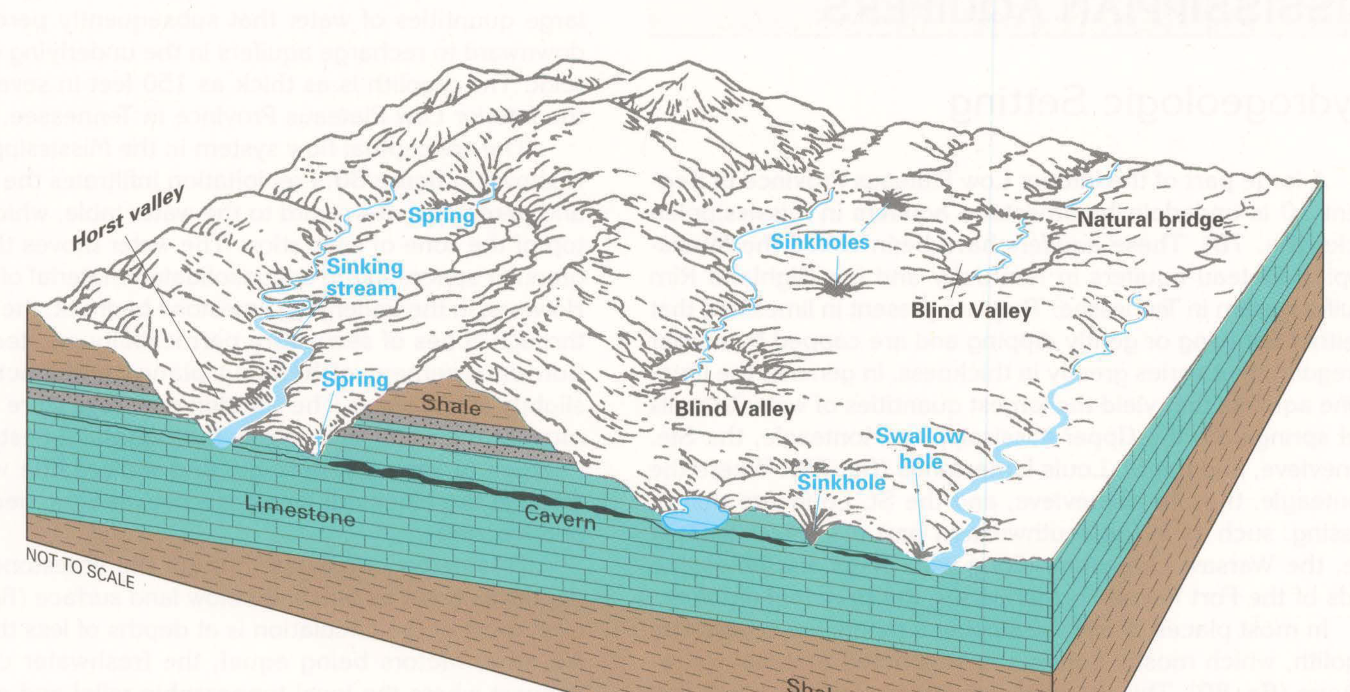
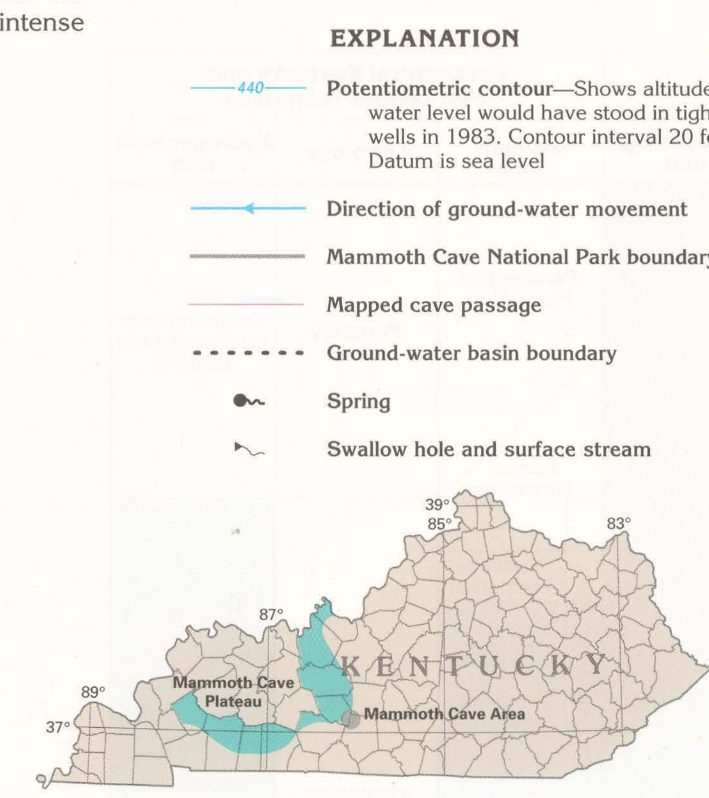


Figure 83. *The dissolution of limestone forms characteristic land-surface features, such as sinkholes, swallow holes, sinking streams, and springs, shown in this idealized diagram. In areas underlain by the Mississippian aquifers, few streams are present because most of the precipitation is quickly routed into and through solution openings in the rocks.*

Modified from McGregor and Rarick, 1962



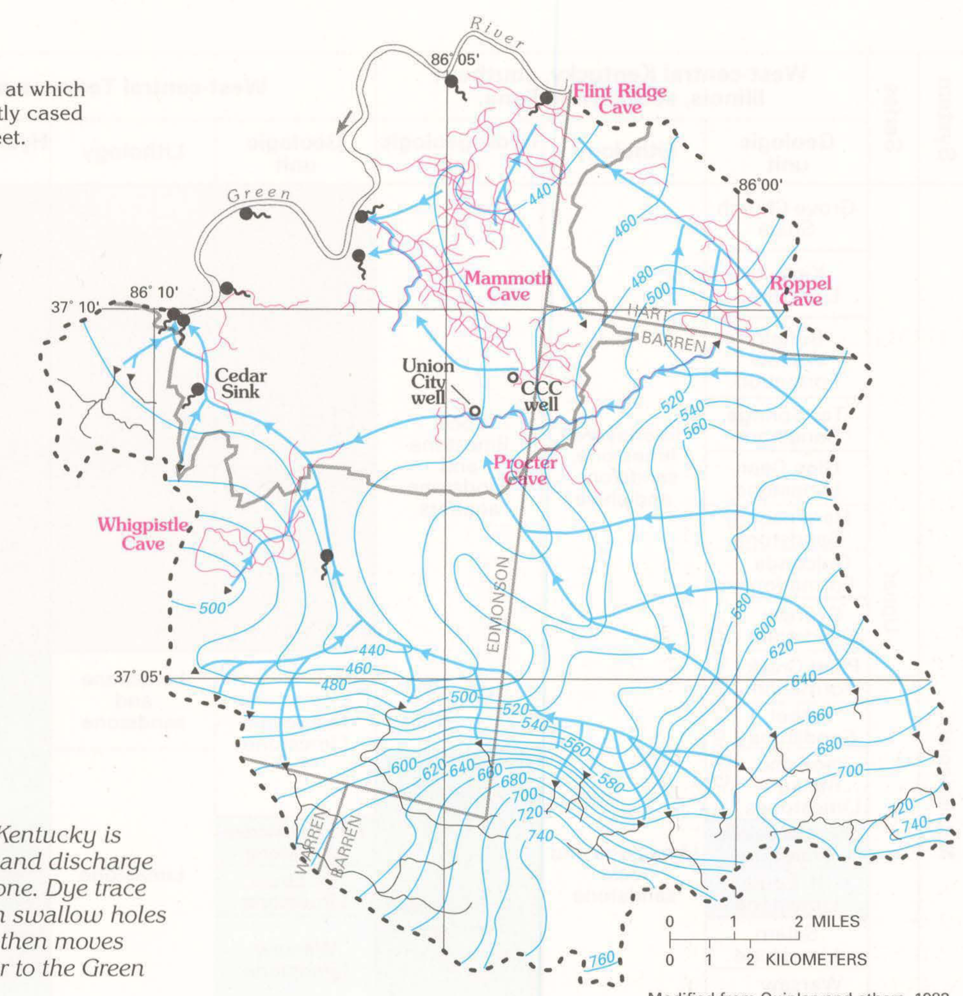


Figure 84. *The Mammoth Cave area in central Kentucky is one place where ground-water recharge, movement, and discharge have been studied in relation to dissolution of limestone. Dye trace studies show that water enters the limestone through swallow holes that capture most of the surface drainage. The water then moves through cave systems until it discharges to springs or to the Green River.*

Modified from Quinlan and others, 1983

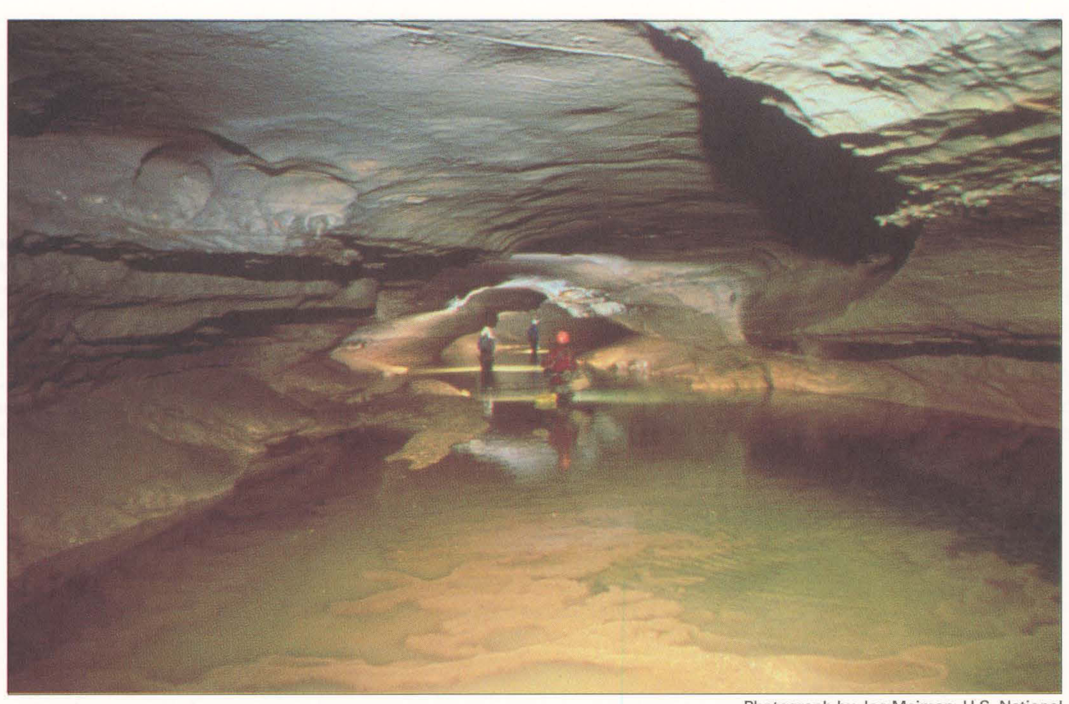
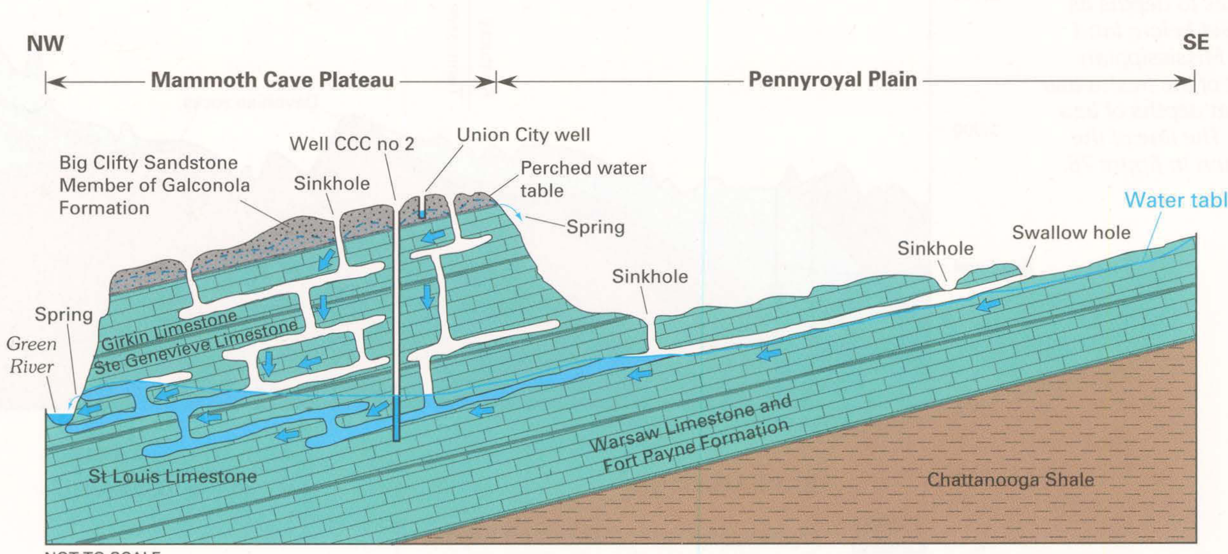


Figure 85. *Where the solution openings in limestone are large and well connected, they might form networks of caves, such as Mammoth Cave. The openings can be enlarged at the bottom as the limestone is eroded by sediment-laden streams flowing through them.*

Photograph by Joe Meiman, U.S. National Park Service, Mammoth Cave, Ky.



Modified from Brown, 1966; Quinlan and others, 1983

Figure 86. *The Ste. Genevieve and the St. Louis Limestones that underlie the Mammoth Cave Plateau contain a well-developed network of solution openings. These openings were formed by dissolution of the limestones as ground water moved along bedding planes and fractures from recharge areas to points of discharge.*

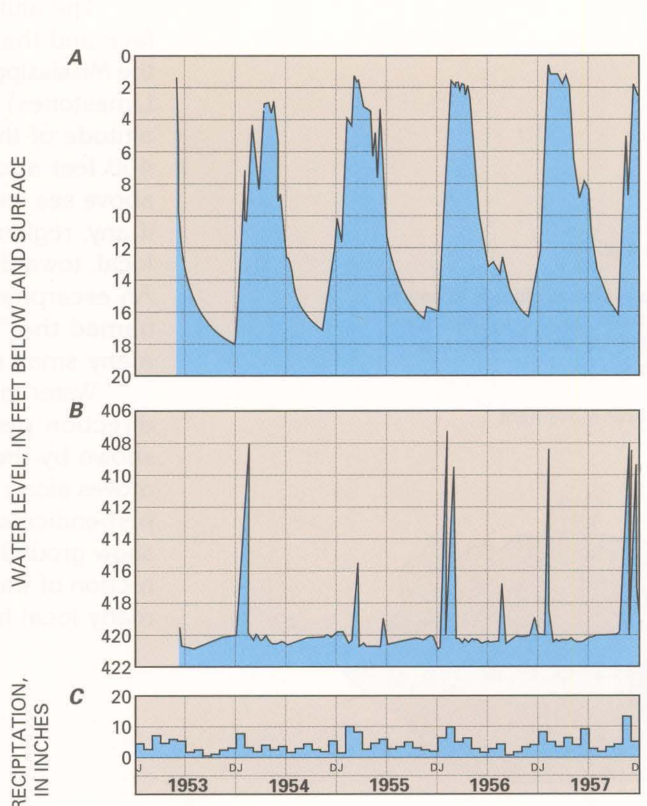
EXPLANATION

Direction of ground-water movement

Figure 87. *The Echo River flows through one of the larger solution openings in the network of caverns that composes Mammoth Cave.*

Photograph by Joe Meiman, U.S. National Park Service, Mammoth Cave, Ky.

Figure 88. *Water levels in wells completed in different geologic formations in Mississippian rocks respond differently to recharge. Changes in the water level in the Union City well (A), completed in the Big Clifty Sandstone Member of the Golconda Formation, show that this unit is recharged rapidly and drained slowly. In contrast, fluctuations in the water level in a well at CCC No. 2 (B), which is open to the Ste. Genevieve and the St. Louis Limestones, show that recharge to and discharge from these limestone aquifers occurs rapidly in response to greater-than-normal precipitation (C). This indicates direct hydraulic connection between the land surface and the aquifer through large solution openings in the limestone.*



Modified from Brown, 1966

Aquifer Characteristics, Yields of Wells, and Discharges of Springs

The hydraulic characteristics of the Mississippian aquifers vary greatly over short distances. For example, the ability of limestone with large, interconnected solution openings to transmit and yield water is several orders of magnitude greater than that of the almost impermeable blocks of limestone between solution openings, fractures, and bedding planes. These large differences are reflected in the yield and specific capacity of wells completed in the limestone aquifers and the discharges of springs that issue from these aquifers.

The data in **table 1** indicate that the yields of wells completed in the Mississippian aquifers vary greatly. Well yields commonly range from 2 to 50 gallons per minute, and reported maximum yields range from about 100 gallons per minute in Indiana to 1,000 gallons per minute in Illinois. Wells that penetrate large, saturated solution openings may yield several thousands of gallons per minute. However, such openings constitute only a small part of the rock and might be difficult to locate.

Table 1. *Yields of wells completed in the Mississippian aquifers commonly range from 2 to 50 gallons per minute and locally exceed 1,000 gallons per minute*

[Data source: U.S. Geological Survey, 1985]

State	Yield of wells completed in Mississippian aquifers (gallons per minute)	
	Common range	May exceed
Illinois	5 to 25	1,000
Indiana	2 to 25	100
Kentucky	2 to 10	500
Tennessee	5 to 50	400

Aquifer Characteristics, Yields of Wells, and Discharges of Springs—Continued

The discharges of 31 selected springs that issue from Mississippian aquifers in the western part of the Interior Low Plateaus Province in Tennessee range from about 3 to 1,100 gallons per minute, with a median discharge of about 200 gallons per minute (**fig. 89**). These springs issue mainly from the Warsaw Limestone and the Fort Payne Formation, and those that discharge several hundred gallons per minute or more are equally distributed between the Warsaw and the Fort Payne. These data indicate that discharge can vary from spring to spring.

The distribution of discharges for six large springs in Kentucky is shown in **figure 90**. These springs issue primarily from the St. Louis Limestone. These discharges, which were measured from 1951 to 1960, indicate the variability from spring to spring and through time at a given spring. The difference between the high and low discharges measured at a spring varies by a factor of about 5 to about 200. Knowledge of such discharge variability is important when planning the use of springs for water supply. Discharges of the springs shown in **figure 90*B*** are more variable than those of the springs shown in **figure 90*A***.

Figure 89. *The discharges of 31 selected springs that issue from Mississippian aquifers in Dickson, Humphreys, and Lawrence Counties, Tenn., range from about 3 to 1,100 gallons per minute.*

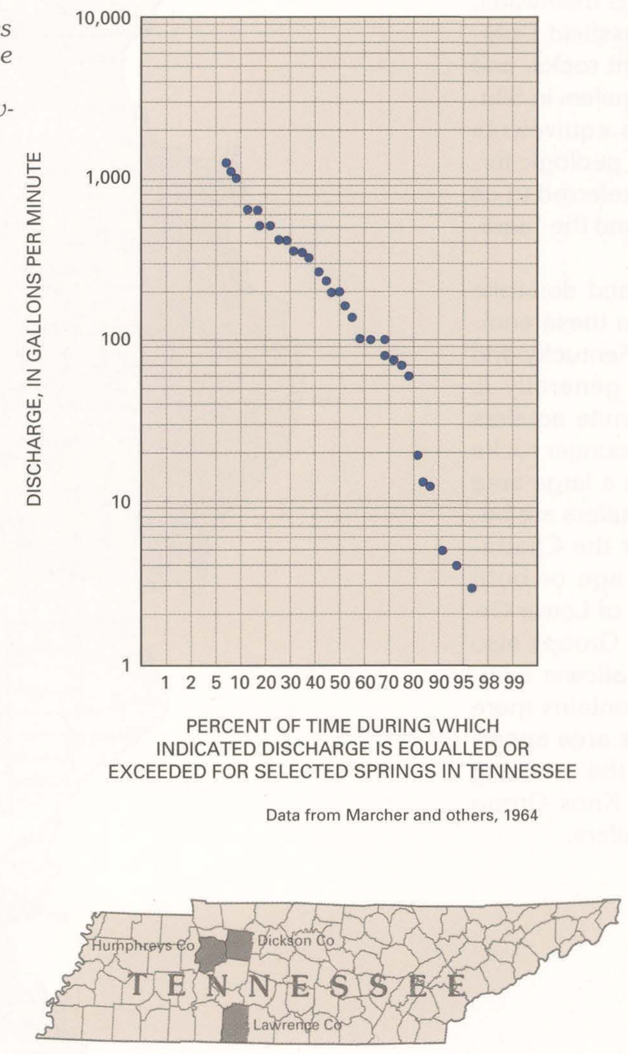
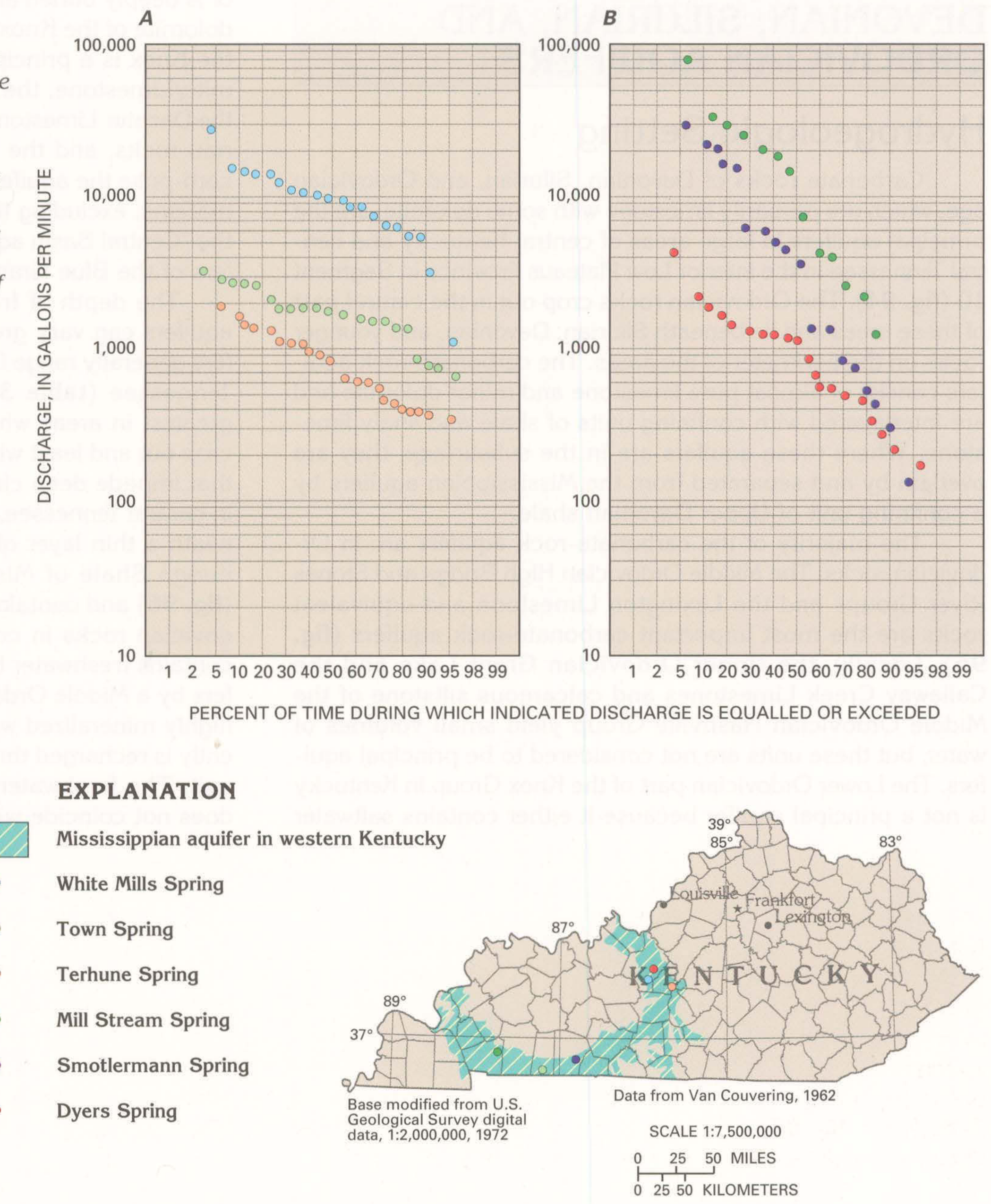


Figure 90. *The discharge from six large springs that issue from Mississippian aquifers in Kentucky varied greatly from 1951 to 1960. Discharges of three of the springs (A) ranged over only about one order of magnitude, whereas discharge of the other three (B) ranged over as much as three orders of magnitude.*



Ground-Water Quality

The quality of water in the Mississippian aquifers in Kentucky is somewhat different from that in Tennessee (**fig. 91**). The range of concentrations and the median concentration of dissolved solids, iron, and the median hardness are greater for water from these aquifers in Kentucky than in Tennessee. However, median concentrations of dissolved solids and iron in both States are less than the secondary maximum contaminant levels for drinking water established by the U.S. Environmental Protection Agency. The quality of the water generally is adequate, or it can be treated and made adequate for most uses.

Water-quality data from wells and springs in the Mississippian aquifers in Kentucky indicate that the water is either a calcium magnesium bicarbonate type or a calcium bicarbonate type. The water type changes slightly as the proportion of magnesium and sulfate vary. Chemical analyses of water from wells and springs in the St. Louis Limestone were selected to represent the quality of water in the Mississippian aquifers in Kentucky (**fig. 92**). Water from wells (**fig. 92*A***) has a larger proportion of magnesium and sulfate and a slightly larger proportion of chloride than that from springs (**fig. 92*B***). Sparse data from wells and springs in Tennessee indicate that the quality of the water in the Mississippian aquifers is similar to that of Mississippian aquifer spring water in Kentucky.

Water with the large concentrations of sulfate is from wells that penetrate anhydrite and gypsum beds in the deeper parts of the Mississippian aquifers in Kentucky. The water moves slowly and follows long flow paths in the deep parts of the aquifers; therefore, the water is in contact with the aquifer minerals for a long time and dissolves much material. In contrast, water that discharges from springs and water from wells that penetrate only shallow parts of the aquifers have smaller concentrations of dissolved solids because the water has moved only short distances or has had limited residence time in the aquifers and thus has had little opportunity to dissolve minerals.

Contaminated and turbid water are problems that can plague the users of water from wells and springs in limestone aquifers. Sinkholes are sometimes used to dispose of solid and liquid wastes. Water that recharges limestone aquifers through waste-filled sinkholes can transport contaminants into the aquifer, and the contaminated water can spread rapidly through a system of interconnected solution openings until it reaches wells or springs. Solution features, such as swallow holes, in streambeds allow sediment-laden storm runoff to enter the aquifers directly. Turbid water also can be caused by pumping of large-capacity wells, which results in the rapid movement of water through solution openings lined with silt or clay. Contamination and turbidity problems can become worse during periods of prolonged, intense rainfall.

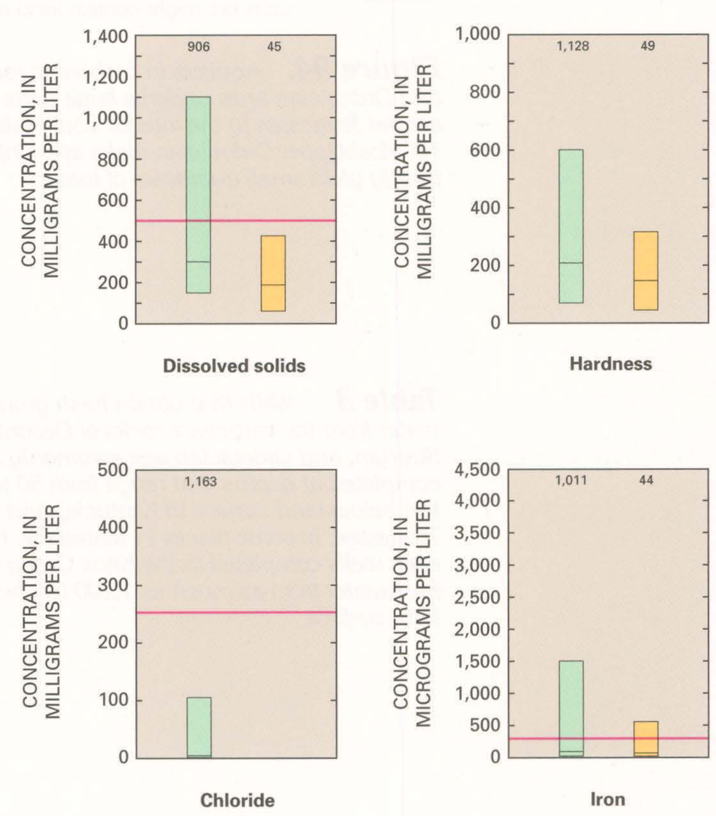
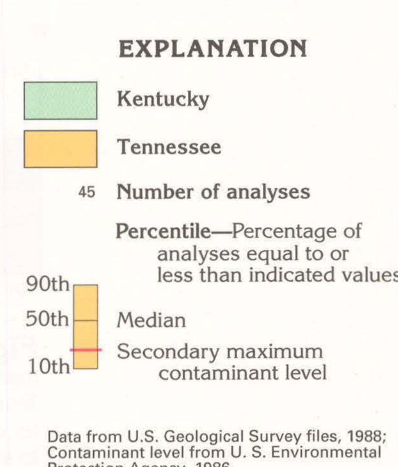


Figure 91. *Water from the Mississippian aquifers in Kentucky and Tennessee is hard and contains large concentrations of iron in some samples. Dissolved-solids concentrations generally are larger in water from the aquifers in Kentucky than from those in Tennessee.*

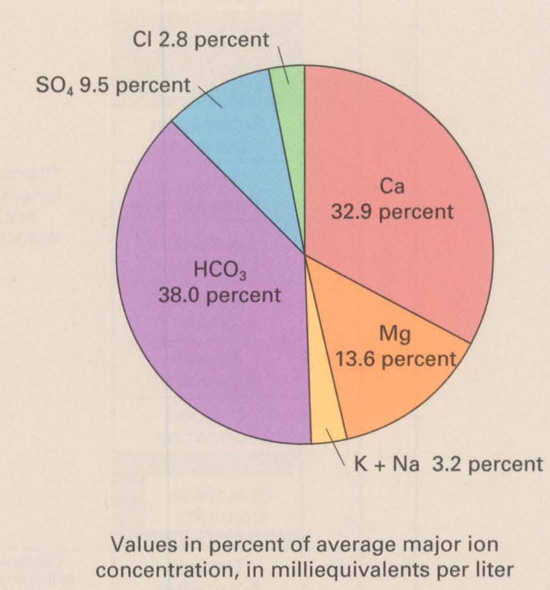


St. Louis Limestone in Kentucky

Concentrations in milligrams per liter, unless otherwise specified

A. Water from wells

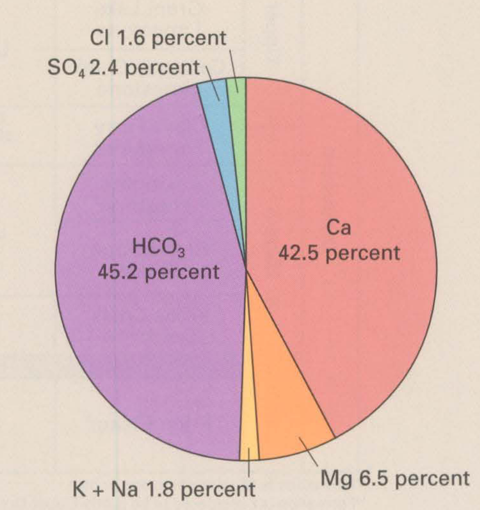
Constituent	Range	Median	Number of samples
Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	147 to 1,335	579	99
Calcium (Ca)	16 to 212	72	99
Magnesium (Mg)	1 to 62	18	99
Sodium (Na)	0.8 to 96	7.2	99
Potassium (K)	0 to 29	1.3	99
Bicarbonate (HCO_3)	58 to 398	253	99
Sulfate (SO_4)	0 to 527	50	99
Chloride (Cl)	0.3 to 270	11	99
Silica (SiO_2)	0 to 17	3.2	99



Values in percent of average major ion concentration, in milliequivalents per liter

B. Water from springs

Constituent	Range	Median	Number of samples
Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	410 to 485	442	6
Calcium (Ca)	66 to 87	76	6
Magnesium (Mg)	5.8 to 9.9	7	6
Sodium (Na)	2.4 to 5.1	3.1	6
Potassium (K)	1.1 to 1.7	1.3	6
Bicarbonate (HCO_3)	220 to 268	246	6
Sulfate (SO_4)	7 to 14	10	6
Chloride (Cl)	4.1 to 6.2	5	6
Silica (SiO_2)	9.9 to 11	11	6



Data from Plebuch and others, 1985

Figure 92. *Water from selected wells completed in the Mississippian aquifer in Kentucky is a calcium magnesium bicarbonate type (A). Water from springs that issue from the aquifer is a calcium bicarbonate type (B).*

Fresh Ground-Water Withdrawals

Total fresh ground-water withdrawals during 1985 from the Mississippian aquifers in the Interior Low Plateaus part of Segment 10 were about 64 million gallons per day (**table 2**). No 1985 withdrawal data were available for the Mississippian aquifers in Illinois; therefore, 1980 withdrawals were used for tabulation. About 80 percent of the total withdrawals were in Tennessee and Kentucky where the Mississippian aquifers are most areally extensive. Ground-water withdrawals in Tennessee and Kentucky were primarily for public supply and domestic and commercial uses (**fig. 93**). These use categories accounted for about 73 percent of the total withdrawals in Tennessee and about 92 percent in Kentucky during 1985. The remaining withdrawals were for agricultural and industrial and mining purposes. No water was withdrawn from the Mississippian aquifers in Tennessee and Kentucky for thermoelectric power use during 1985.

Table 2. *The Mississippian aquifers are an important source of fresh ground water in the Interior Low Plateaus part of segment 10. About one-half of the water withdrawn from these aquifers was used in Tennessee and about one-quarter was used in Kentucky*

[Data source: a, withdrawals during 1980 in Illinois, Kirk and others, 1982; b, withdrawals during 1985 in Indiana, Kentucky, and Tennessee, U.S. Geological Survey, 1990]

State	Ground-water withdrawals from limestone aquifers in Mississippian rocks (estimated to nearest million gallon per day)
Illinois	9a
Indiana	4b
Kentucky	18b
Tennessee	33b
Total	64

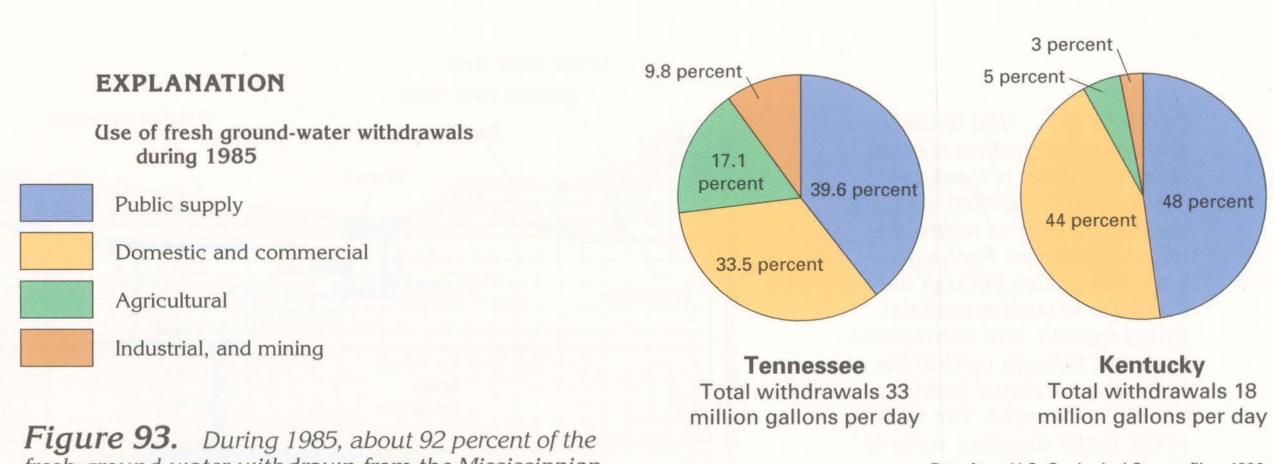


Figure 93. *During 1985, about 92 percent of the fresh ground water withdrawn from the Mississippian aquifers was used for public supply and for commercial and domestic purposes in Kentucky. About 73 percent of the water withdrawn from these aquifers in Tennessee was used for the same purposes. Much more water was withdrawn for agricultural and for industrial and mining uses in Tennessee than in Kentucky during 1985.*

DEVONIAN, SILURIAN, AND ORDOVICIAN AQUIFERS

Hydrogeologic Setting

Carbonate rocks of Devonian, Silurian, and Ordovician age, which are primarily limestone with some dolomite, are the principal aquifers in large areas of central Kentucky and central Tennessee in the Interior Low Plateaus Province in Segment 10 (**fig. 94**). The Ordovician rocks crop out in the central part of these areas and lie beneath Silurian, Devonian, and younger rocks on the perimeter of the areas. The carbonate-rock aquifers consist of almost pure limestone and minor dolomite and are interlayered with confining units of shale and shaly limestone. Where these aquifers are in the subsurface, they are overlain by and separated from the Mississippian aquifers by a confining unit of Upper Devonian shale.

The majority of the carbonate-rock aquifers are in Ordovician rocks. The Middle Ordovician High Bridge and Stones River Groups and the Lexington Limestone and equivalent rocks are the most important carbonate-rock aquifers (**fig. 95**). Locally, the Upper Ordovician Grant Lake and the Callaway Creek Limestones and calcareous siltstone of the Middle Ordovician Nashville Group yield small volumes of water, but these units are not considered to be principal aquifers. The Lower Ordovician part of the Knox Group in Kentucky is not a principal aquifer because it either contains saltwater or is deeply buried and yields little freshwater. However, where dolomite of the Knox Group in Tennessee contains freshwater, the Knox is a principal aquifer. The Silurian Brassfield Dolomite/Limestone, the Wayne Group and equivalent rocks, and the Decatur Limestone are the most productive aquifers in Silurian rocks, and the Peagram Formation and its equivalents com-pose the aquifers in Devonian rocks. These geologic formations, excluding the Knox Group, have been referred to as the "Central Basin aquifer system" in Tennessee and the "aquifers of the Blue Grass region" in Kentucky.

The depth of freshwater in the limestone and dolomite aquifers can vary greatly, but wells completed in these aquifers generally range from 50 to 200 feet deep in Kentucky and Tennessee (**table 3**). The depth to saltwater generally is greatest in areas where the limestone and dolomite aquifers crop out and least where they are covered with younger rocks that impede deep circulation of ground water. In a large area in central Tennessee, the upper parts of these aquifers are beneath a thin layer of Mississippian limestone or the Chattanooga Shale of Mississippian and Devonian age or both (**fig. 96**) and contain freshwater. The upper part of Lower Ordovician rocks in central Tennessee (the Knox Group) also contains freshwater but is separated from the shallower aquifers by a Middle Ordovician confining unit that contains more highly mineralized water. The Knox Group in this area apparently is recharged through fractures that transect the confining unit. The freshwater–saltwater interface in the Knox Group does not coincide with that in the shallower aquifers.

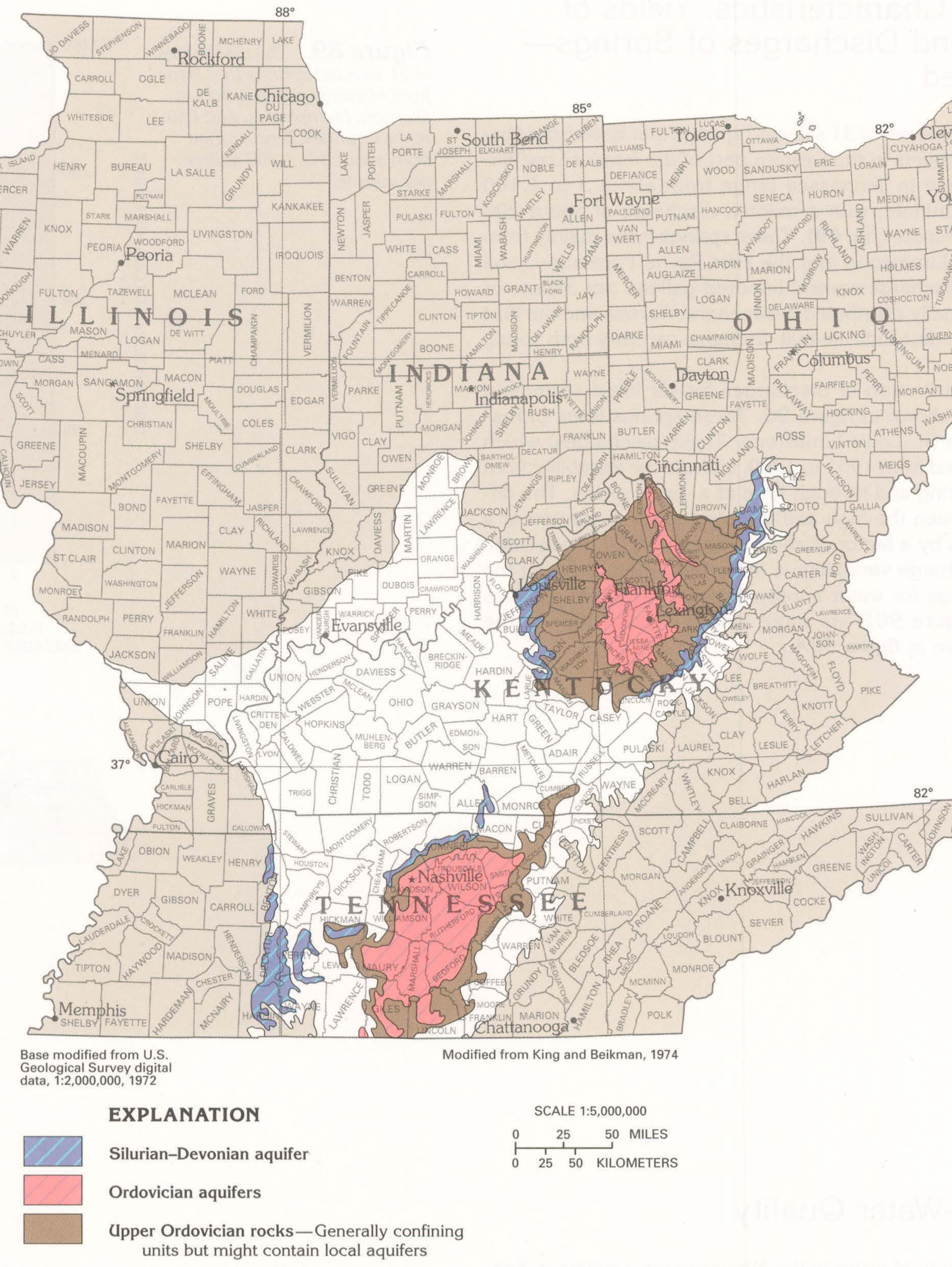


Figure 94. *Aquifers in carbonate rocks of Devonian, Silurian, and Ordovician ages underlie large parts of central Kentucky and central Tennessee in the Interior Low Plateaus Province in Segment 10. Most Upper Ordovician rocks are confining units, but some locally yield small quantities of water.*

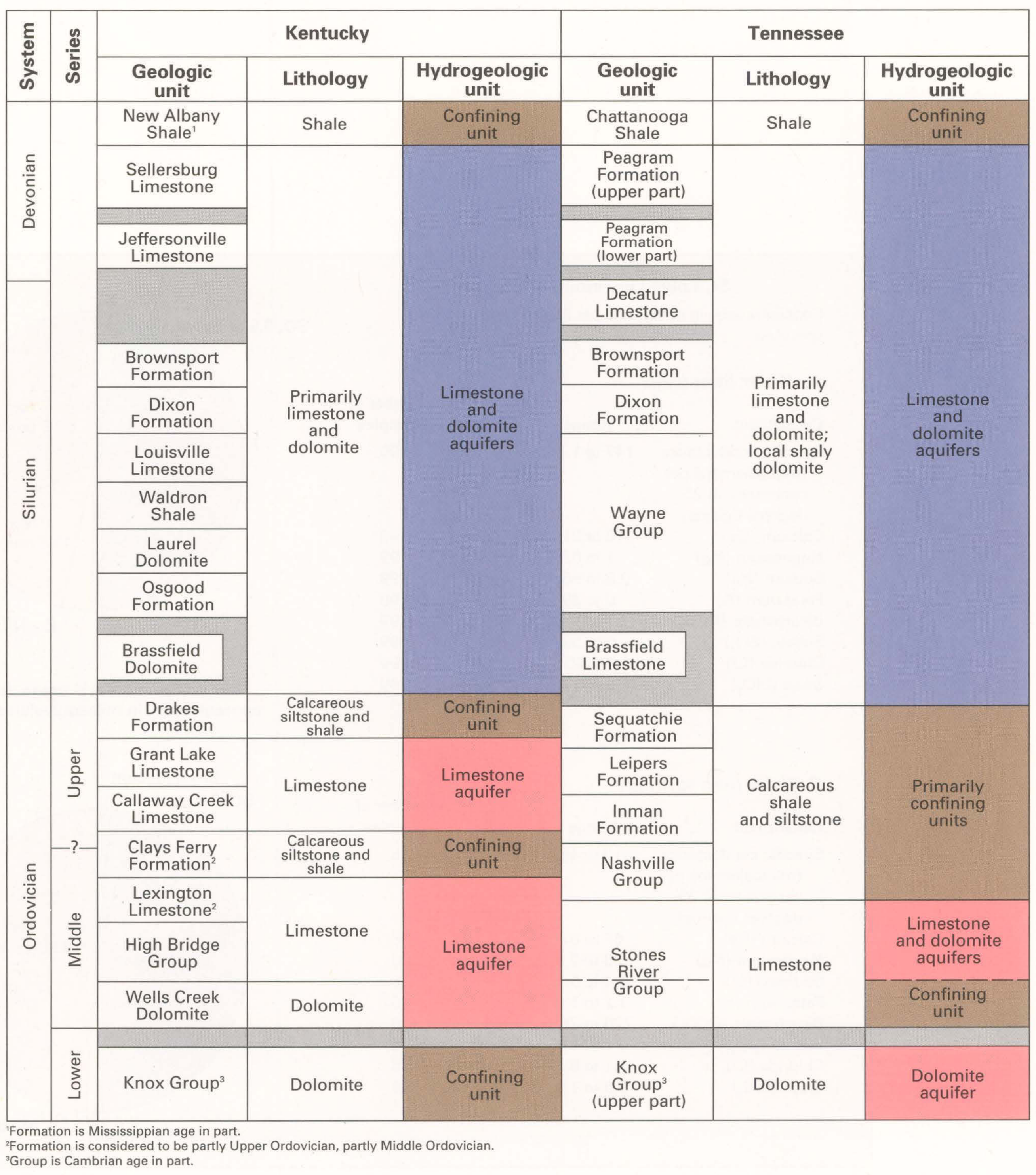


Figure 95. *The carbonate-rock aquifers consist of a number of limestone and dolomite formations that range in age from Devonian to Ordovician. The gray areas represent missing rocks.*

Table 3. *Wells that obtain fresh ground water from the carbonate rocks of Devonian, Silurian, and Ordovician age commonly are completed at depths that range from 50 to 200 feet below land surface in Kentucky and Tennessee. In some places in Tennessee, however, wells completed in the Knox Group obtain freshwater from as much as 1,200 feet below land surface*

[Data source: U.S. Geological Survey, 1985]

State and aquifer	Well depth below land surface (feet) Common range	May exceed
Kentucky (Ordovician limestone and dolomite)	50 to 200	300
Tennessee (Ordovician limestone and dolomite)	50 to 150	200
(Knox Group)	700 to 1,200	1,400

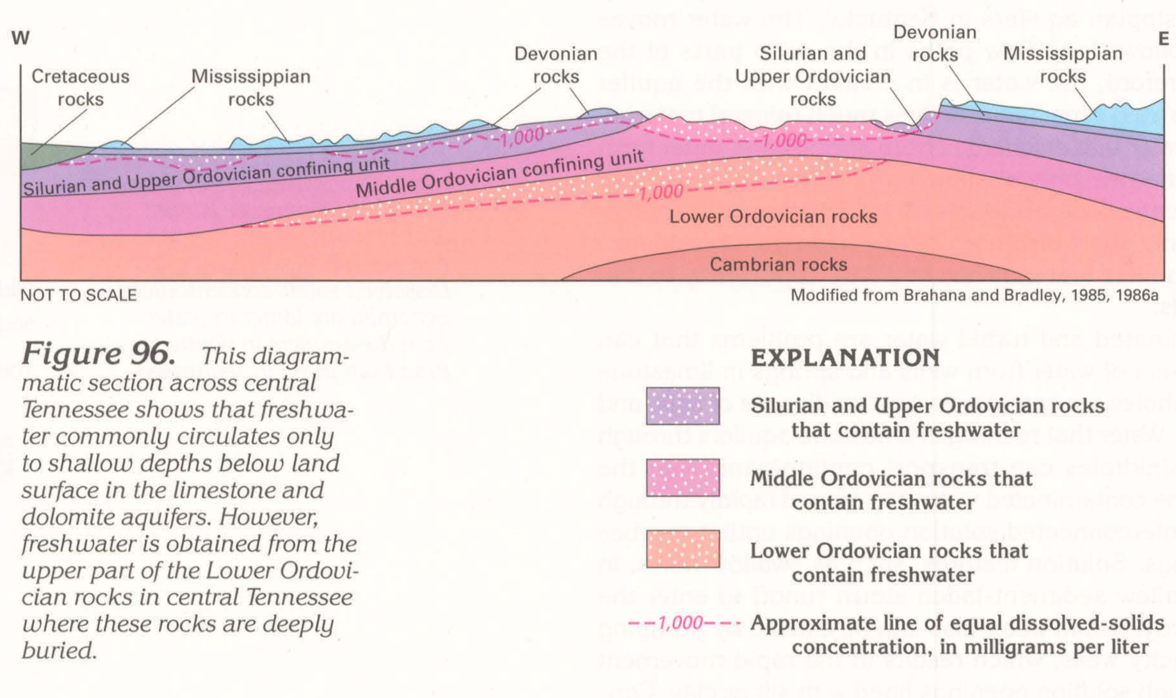


Figure 96. *This diagrammatic section across central Tennessee shows that freshwater commonly circulates only to shallow depths below land surface in the limestone and dolomite aquifers. However, freshwater is obtained from the upper part of the Lower Ordovician rocks in central Tennessee where these rocks are deeply buried.*

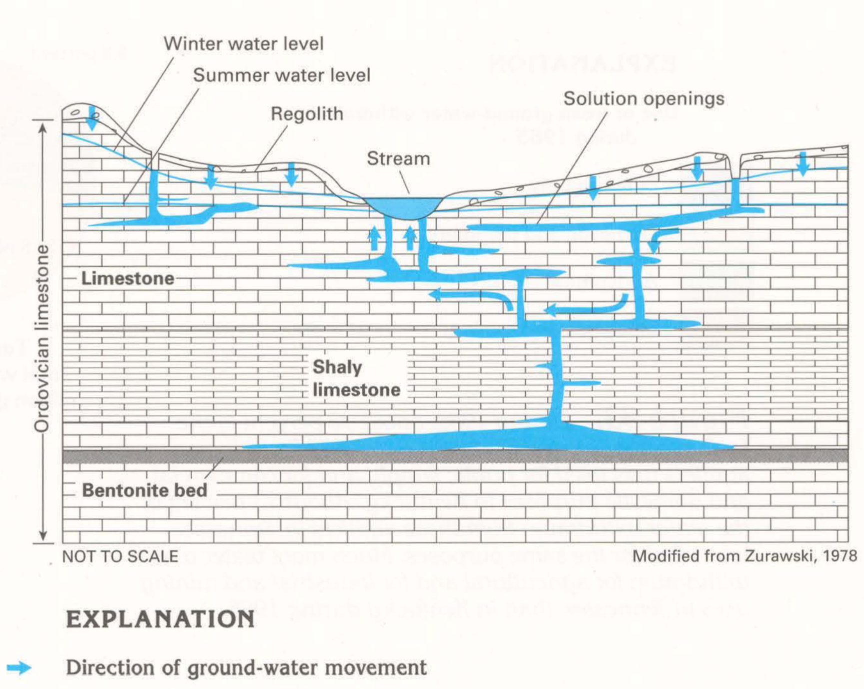


Figure 97. *The limestone and dolomite aquifers contain small quantities of insoluble material and, therefore, produce only a thin layer of residuum when weathered. Recharge water percolates through the thin layer of surface material, called regolith, and subsequently moves through vertical fractures and horizontal bedding planes in the rocks. The slightly acidic water dissolves some of the limestone and dolomite as it moves to streams and other areas of discharge, such as springs and wells. The vertical movement of the recharge water and, therefore, the depth of development of solution openings, are restricted by zones of low permeability.*

The occurrence and movement of ground water in the limestone and dolomite aquifers in Devonian, Silurian, and Ordovician rocks are much like those in the Mississippian aquifers. However, because the Devonian, Silurian, and Ordovician rocks generally contain small quantities of insoluble material, the aquifers in these rocks generally are covered in outcrop areas by a much thinner layer of regolith than are the Mississippian aquifers. The slightly acidic precipitation that falls on aquifer outcrop areas infiltrates the land surface and percolates downward to the water table. In the subsurface, the slightly acidic water forms solution openings as it moves along fractures and bedding planes and dissolves part of the limestone and dolomite of the Devonian, Silurian, and Ordovician rocks. Dissolution is less advanced in these aquifers, and caves are fewer than in the Mississippian aquifers. Ground water in the limestone and dolomite aquifers is almost exclusively stored in and moves through solution openings (**fig. 97**). Insignificant quantities of ground water are stored in and move through the almost impermeable blocks of limestone between the solution openings, bedding planes, and fractures. The distribution of solution openings is complex and difficult to map, but most openings are in the zone of dynamic freshwater circulation between land surface and depths from 200 to 400 feet below land surface. The volume of solution openings in the Ordovician limestones is estimated to be less than 0.5 percent of the total rock volume.

Confining units, such as beds of shaly limestone and bentonite, affect the depth to which freshwater circulates (**fig. 97**). Thin bentonite zones, which consist of clay particles that expand or swell when they become wet, form layers of low permeability that effectively impede the vertical movement of ground water. For example, in areas where the bentonite layers are continuous, the downward movement of ground water is restricted. This restriction isolates the ground water below the bentonite from the zone of dynamic circulation above the bentonite. In areas where the bentonite zones are breached by vertical fractures or have been eroded by stream valleys, ground water below the bentonite is more readily recharged or discharged and is part of the zone of dynamic freshwater circulation. In such places, solution-enlarged openings will develop beneath the bentonite.

Ground water in the limestone and dolomite aquifers moves from upland recharge areas where water-level altitudes are high to low-lying discharge areas where they are low. Most of the discharge areas are located along streams. In Kentucky, the streams that receive discharge from the carbonate-rock aquifers generally drain to the north and northwest into the Ohio River. Areas underlain by the freshwater-yielding limestone and dolomite aquifers in Tennessee are drained by the Cumberland and the Tennessee Rivers.

Yield of Wells and Discharges of Springs

The yields of wells completed in the limestone and dolomite aquifers in rocks of Devonian, Silurian, and Ordovician age vary considerably throughout the area. This variability is caused primarily by large variations in hydraulic properties over short distances in the aquifers. The yields of wells completed in the carbonate-rock aquifers in Kentucky and Tennessee commonly range from 2 to 20 gallons per minute and can exceed 300 gallons per minute (**table 4**). Yields reported from 8,000 wells, drilled primarily to supply water for households and completed in limestone aquifers in Ordovician rocks in Tennessee, indicate that more than 90 percent of the wells obtained a supply of ground water adequate for domestic use; 70 percent had yields of more than 3 gallons per minute, 8 percent had yields of more than 25 gallons per minute, and slightly less than 1 percent had yields of 50 gallons per minute or more. The maximum well yield was 600 gallons per minute. About 90 percent of the wells that had yields of more than 25 gallons per minute were located in flat-bottomed valleys underlain by depressions in the carbonate bedrock.

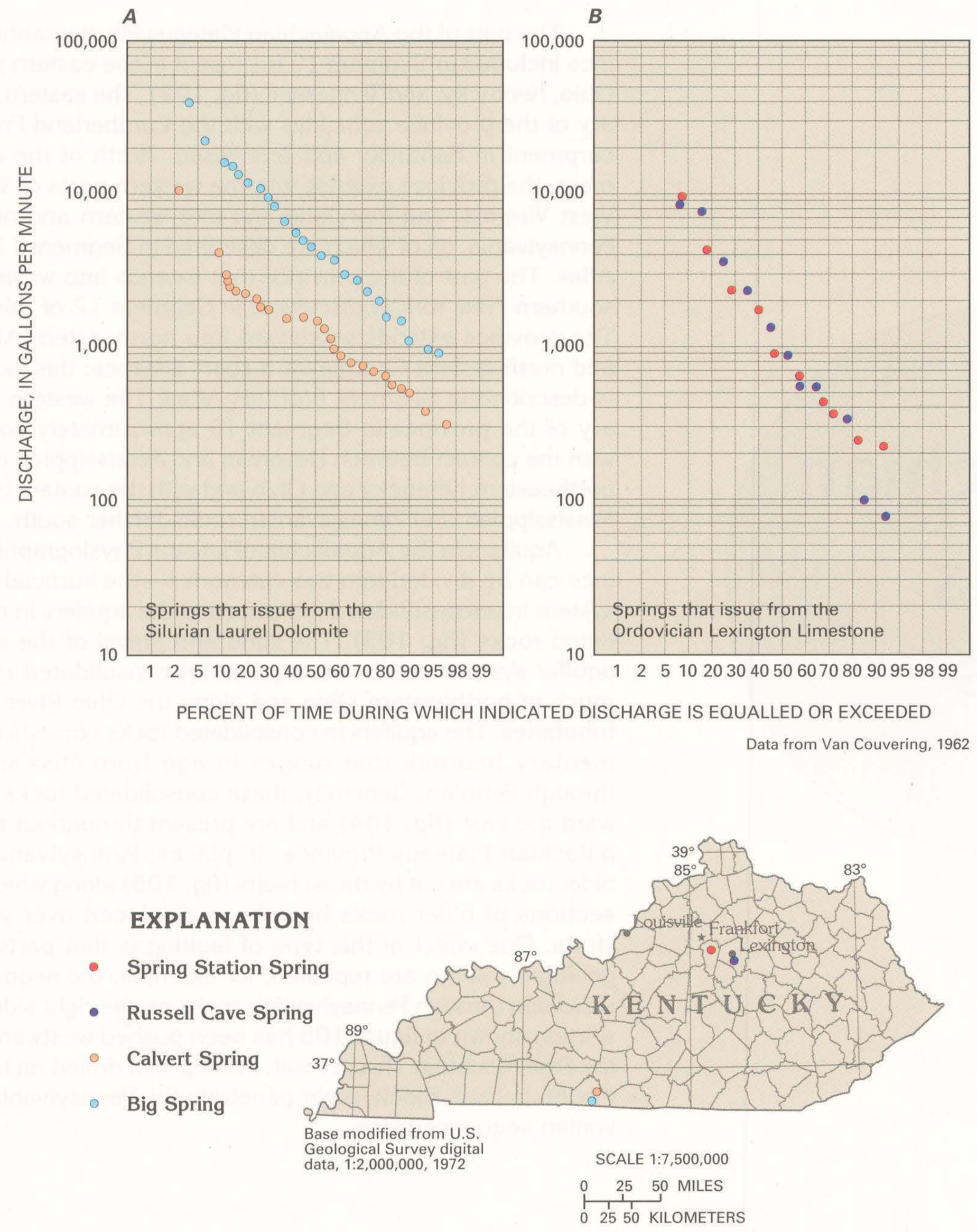
Spring discharge also is extremely variable. Discharges reported for 89 springs that issue from aquifers in the Silurian and Ordovician rocks in the south-central part of Tennessee range over more than four orders of magnitude (from 0.1 to about 2,500 gallons per minute) with a median discharge of about 6 gallons per minute. From 1951 to 1960, the reported discharge of four large springs that issue from these aquifers in Kentucky ranged over more than three orders of magnitude (**fig. 98**). Two of the springs issue from aquifers in Silurian rocks (**fig. 98*A***) and had discharges that ranged from 300 to 40,000 gallons per minute. The other two springs issue from aquifers in Ordovician rocks (**fig. 98*B***) and had discharges that ranged from 75 to 9,500 gallons per minute. These data indicate that discharge can vary greatly at a spring from season to season and from year to year.

Table 4. *Yields of wells completed in the limestone and dolomite aquifers in Ordovician rocks in Kentucky and Tennessee commonly range between 2 and 20 gallons per minute and might exceed 300 gallons per minute*

[Data source: U.S. Geological Survey, 1985]

State	Yield of wells in limestone and dolomite aquifers in Ordovician rocks (gallons per minute) Common range	May exceed
Kentucky	2 to 10	300
Tennessee		
(Aquifers in middle Ordovician rocks)	5 to 20	300
(Knox group)	1 to 10	20

Figure 98. *The discharge of two large springs that issue from aquifers in the Silurian rocks in Kentucky (A) generally is greater and varies less than the discharge of two large springs that issue from aquifers in Ordovician rocks in that State (B). The discharges of these springs range over three orders of magnitude.*



Ground-Water Quality

The quality of the water in the limestone and dolomite aquifers in Ordovician rocks in Kentucky and Tennessee is shown in **figure 99**; sparse data indicate that the quality of water in the Devonian and Silurian carbonate-rock aquifers is similar. The range and median concentrations of dissolved solids, hardness, and iron are larger in Kentucky than in Tennessee. However, the median concentrations for the constituents shown generally are equal to or less than the secondary maximum contaminant levels for drinking water established by the U.S. Environmental Protection Agency. The quality of the water generally is adequate, or it can be treated and made adequate for most uses.

The water from Ordovician aquifers in Kentucky is a hard, calcium magnesium bicarbonate type (**fig. 100**). The abundance of these dominant ions results primarily from dissolution of the carbonate rocks as slightly acidic recharge water moves through the aquifers.

The quality of the water from wells completed in the Ordovician aquifer in Kentucky (**fig. 100*A***) and from springs that issue from the same aquifer (**fig. 100*B***) is similar. The concentrations of constituents in the Devonian and Silurian aquifers probably are similar to those in water from the Ordovician aquifers. Dissolved-solids concentrations generally are larger in water from wells than from springs (**fig. 100**). In addition, the water from wells contains larger concentrations of chloride, sodium, and potassium than the spring water.

As with the Mississippian aquifers, contaminated and turbid waters are common problems for the users of water from the limestone and dolomite aquifers in Devonian, Silurian, and Ordovician rocks in Kentucky and Tennessee. The thin soil and residuum and the presence of solution features, such as sinkholes, swallow holes, and solution-enlarged fractures, allow water from the land surface to recharge the aquifer directly and rapidly. Contaminated and sediment-laden waters can then spread rapidly through the system of interconnected solution openings to eventually reach wells and springs.

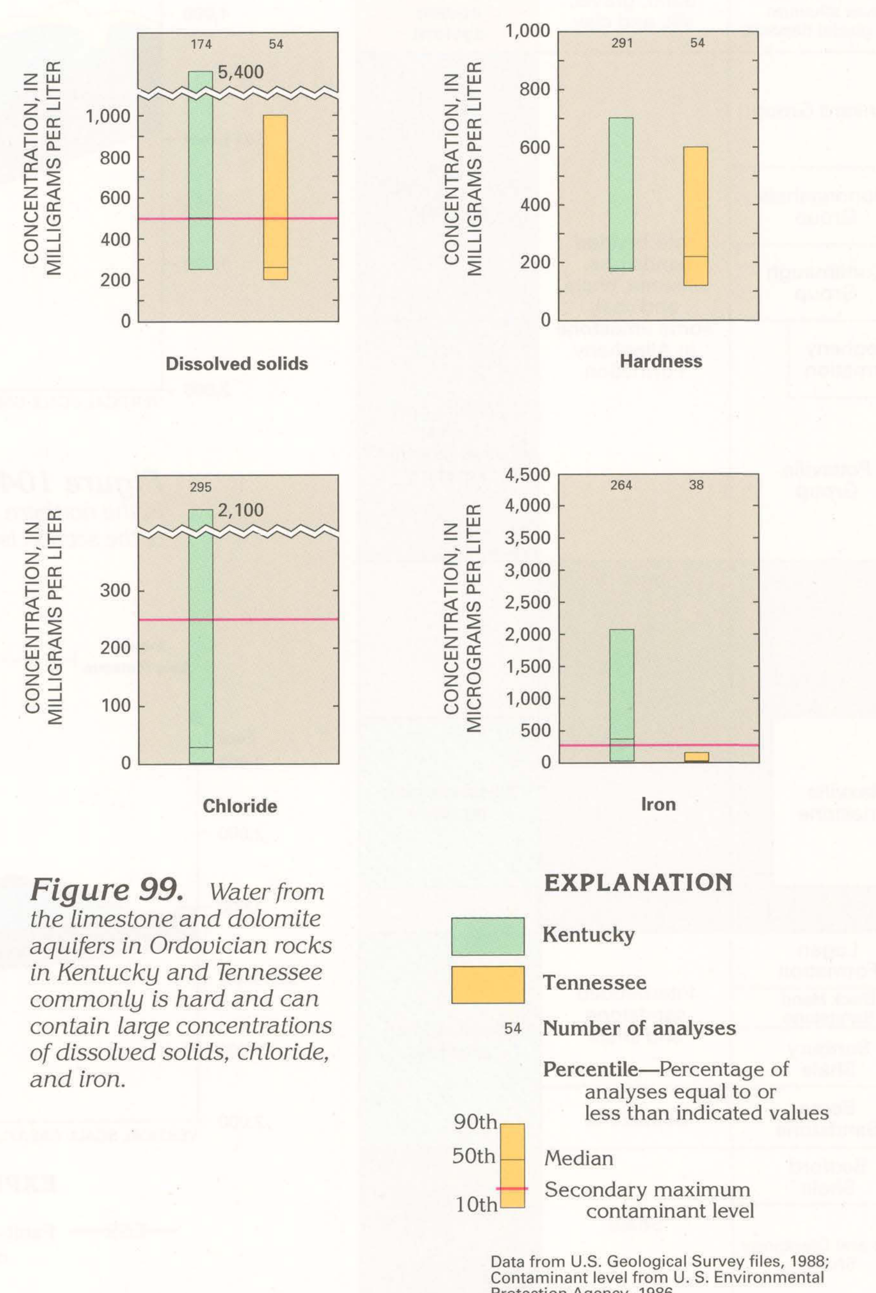


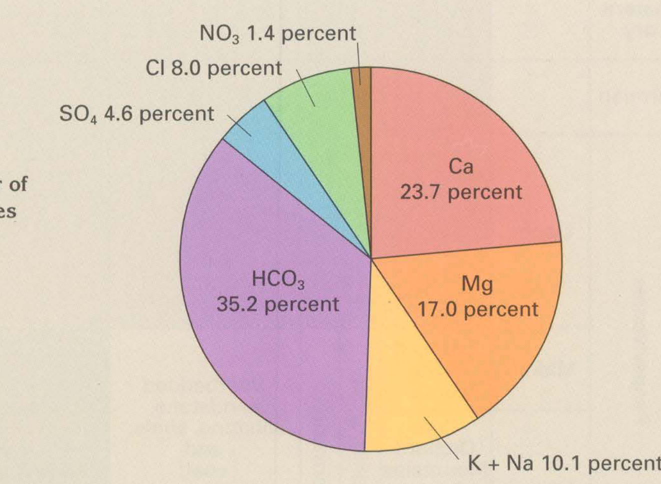
Figure 99. *Water from the limestone and dolomite aquifers in Ordovician rocks in Kentucky and Tennessee commonly is hard and can contain large concentrations of dissolved solids, chloride, and iron.*

Ordovician aquifers in Kentucky

Concentrations in milligrams per liter

A. Water from wells

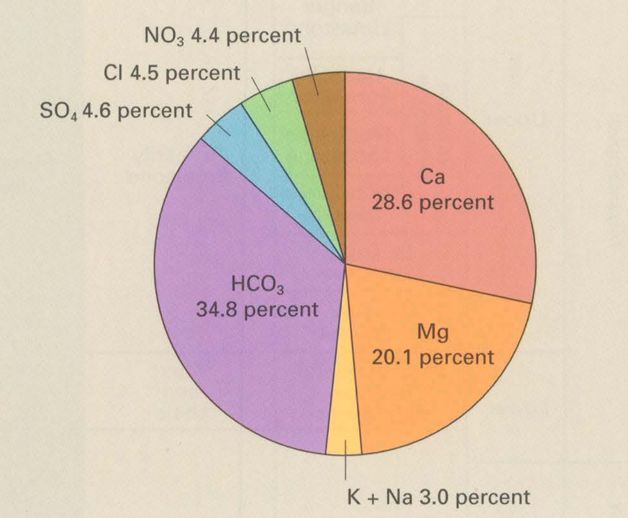
Constituent	Range	Median	Number of samples
Calcium (Ca)	46 to 117	69	23
Magnesium (Mg)	7.3 to 38	30	23
Sodium (Na)	3.5 to 230	32	22
Potassium (K)	0.7 to 15	3	22
Bicarbonate (HCO_3)	82 to 716	311	81
Sulfate (SO_4)	1 to 1,290	32	81
Chloride (Cl)	1.8 to 14,000	41	81
Dissolved solids	183 to 795	530	23
Nitrate (NO_3)	0.01 to 55	12.4	74



Values in percent of median major ion concentrations, in milliequivalents per liter

B. Water from springs

Constituent	Range	Median	Number of samples
Calcium (Ca)	30 to 90	54	11
Magnesium (Mg)	2.4 to 38	23	11
Sodium (Na)	1.6 to 8.0	5.9	10
Potassium (K)	0.5 to 2.4	0.6	10
Bicarbonate (HCO_3)	102 to 474	201	39
Sulfate (SO_4)	1.7 to 670	21	39
Chloride (Cl)	1.6 to 6,500	15	39
Dissolved solids	153 to 335	248	10
Nitrate (NO_3)	1.6 to 43	19	27



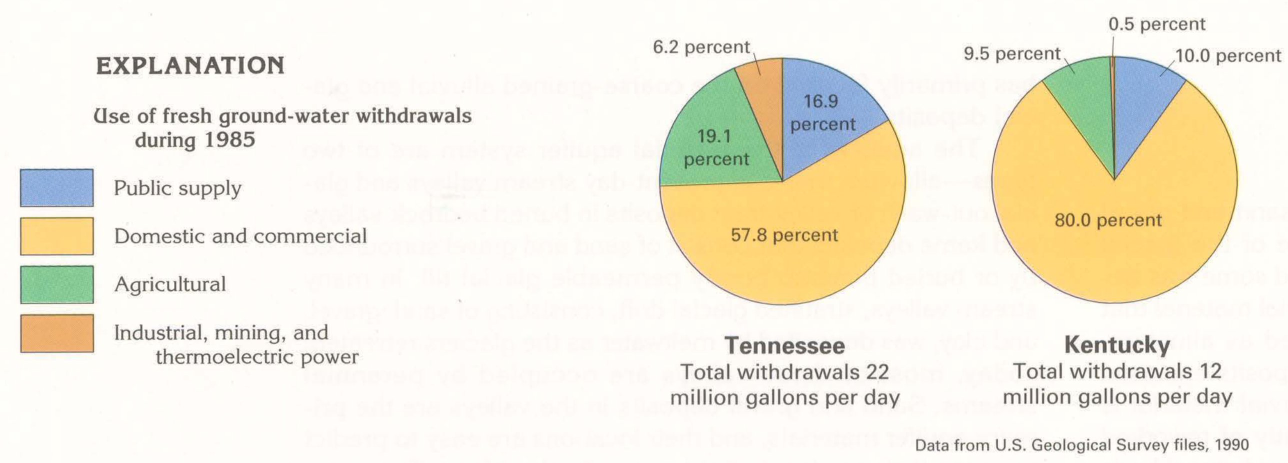
Data from Palmquist and Hall, 1961

Figure 100. *Well and spring waters from the Ordovician aquifers in Kentucky are a calcium magnesium bicarbonate type. The quality of the water in the Devonian and Silurian aquifers probably is similar to that in the Ordovician aquifers. Water from wells generally contains larger concentrations of dissolved solids than the spring water.*

Fresh Ground-Water Withdrawals

More fresh ground water is withdrawn from the limestone and dolomite aquifers in Devonian, Silurian, and Ordovician rocks in Tennessee than in Kentucky. About 22 million gallons per day were withdrawn from these aquifers in Tennessee and about 12 million gallons per day were withdrawn in Kentucky during 1985 (**fig. 101**). During the same year, about 93 percent of the ground water withdrawn in Tennessee (about 21 million gallons per day) and about 99 percent of that withdrawn in Kentucky (nearly 12 million gallons per day) were pumped for public-supply, domestic and commercial, and agricultural uses. Most of the withdrawals in both States were for domestic and commercial purposes. Withdrawals for domestic and commercial uses during 1985 amounted to about 13 million gallons per day in Tennessee and about 10 million gallons per day in Kentucky. Public-supply withdrawals were about 4 million gallons per day in Tennessee and about 1 million gallons per day in Kentucky. Withdrawals for agricultural purposes during 1985 amounted to about 4 million gallons per day in Tennessee and about 1 million gallons per day in Kentucky. The remainder of the withdrawals during 1985 were for industrial and mining uses and were greater than 1 million gallons per day in Tennessee but less than 100,000 gallons per day in Kentucky. No water was withdrawn for thermoelectric power purposes in either State.

Figure 101. *During 1985, total fresh ground-water withdrawals from the limestone and dolomite aquifers in Devonian, Silurian, and Ordovician rocks in the Interior Low Plateaus Province of Segment 10 were about 34 million gallons per day. Withdrawals in Tennessee were nearly twice those in Kentucky. Most of the withdrawals were for domestic and commercial uses.*



Appalachian Plateaus aquifers

INTRODUCTION

The part of the Appalachian Plateaus Physiographic Province included in Segment 10 is present in the eastern parts of Ohio, Kentucky, and Tennessee (**fig. 102**). The eastern boundary of the province coincides with the Cumberland Front Escarpment in Kentucky and Tennessee. North of the escarpment, the province extends into the western parts of Virginia, West Virginia, and Maryland and into western and northern Pennsylvania, all of which are described in Segment 11 of this Atlas. The part of the province that extends into western and southern New York is discussed in Segment 12 of this Atlas. The province extends southward into northeastern Alabama and northwestern Georgia for a short distance; this extension is described in Segment 6 of this Atlas. The western boundary of the province in Segment 10 approximately coincides with the contact between Devonian and Mississippian rocks in northeastern Kentucky and Ohio and with the contact between Mississippian and Pennsylvanian rocks farther south.

Aquifers in the Appalachian Plateaus Physiographic Province can be divided into two categories—the surficial aquifer system in unconsolidated deposits and the aquifers in consolidated rocks (**fig. 103**). The sand and gravel of the surficial aquifer system overlie the aquifers in consolidated rocks in much of northeastern Ohio and along the Ohio River and its tributaries. The aquifers in consolidated rocks consists of sedimentary bedrock that ranges in age from Mississippian through Permian. Generally, these consolidated rocks dip toward the east (**fig. 104**) and are present throughout the Appalachian Plateaus Province. In places, Pennsylvanian and older rocks are cut by thrust faults (**fig. 105**) along which thick sections of older rocks have been displaced over younger strata. One effect of this type of faulting is that parts of the geologic column are repeated; for example, the sequence of Devonian through Pennsylvanian rocks on the right side of the section shown in **figure 105** has been pushed westward along the Pine Mountain Thrust Fault. A deep well drilled on the Pine Mountain Fault Block might penetrate the Pennsylvanian–Devonian sequence twice.

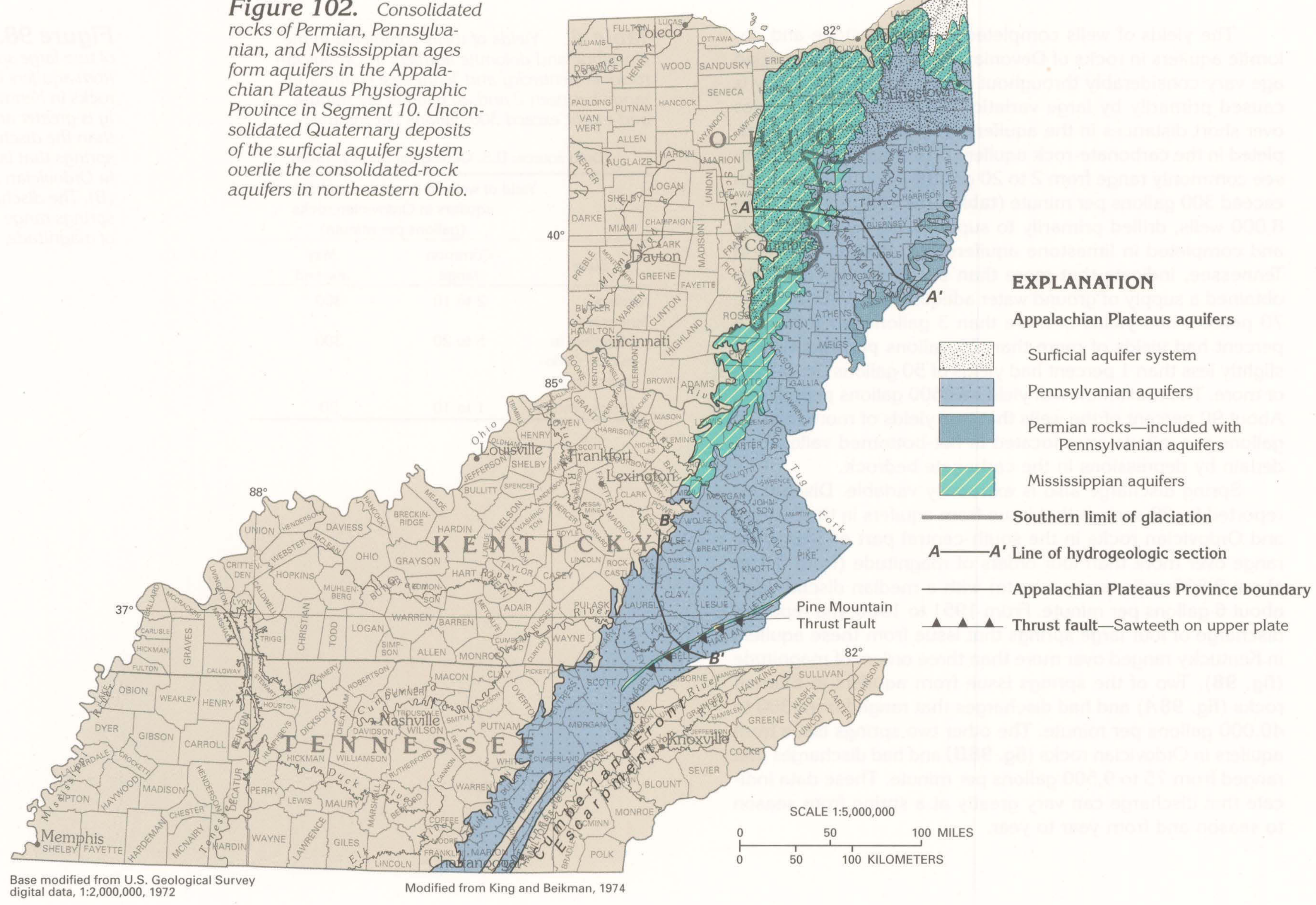


Figure 102. *Consolidated rocks of Permian, Pennsylvanian, and Mississippian ages form aquifers in the Appalachian Plateaus Physiographic Province in Segment 10. Unconsolidated Quaternary deposits of the surficial aquifer system overlie the consolidated-rock aquifers in northeastern Ohio.*

System	Series	Tennessee: Geologic unit	Tennessee: Lithology	Tennessee: Hydrogeologic unit	Kentucky: Geologic unit	Kentucky: Lithology	Kentucky: Hydrogeologic unit	Ohio: Geologic unit	Ohio: Lithology	Ohio: Hydrogeologic unit
Quaternary					Undifferentiated river alluvium	Sand, gravel, silt, and clay	Surficial aquifer system	Undifferentiated river alluvium and glacial deposits	Sand, gravel, silt, and clay	Surficial aquifer system
Permian								Dunkard Group[1]	Interbedded sandstone, siltstone, shale, and coal; some limestone in Allegheny Formation	Upper Pennsylvanian aquifers
Pennsylvanian	Upper				Monongahela Group	Primarily shale	Upper Pennsylvanian aquifers	Monongahela Group		
					Conemaugh Group			Conemaugh Group		
	Middle	Crooked Fork Group (Breathitt Group; Lee Formation)	Interbedded sandstone, siltstone, shale, and coal; minor conglomerate	Middle and Lower Pennsylvanian aquifers	Breathitt Formation; Lee Formation	Interbedded sandstone, siltstone, shale, and coal; minor conglomerate in Lee Formation	Middle and Lower Pennsylvanian aquifers	Allegheny Formation		Middle and Lower Pennsylvanian aquifers
	Lower	Crab Orchard Mountains Group; Gizzard Group						Pottsville Group		
Mississippian	Upper	Pennington Formation	Shale	Confining unit	Pennington Formation	Shale	Confining unit			
		Newman Limestone: Bangor Limestone; Hartselle Formation; Monteagle Limestone; Ste. Genevieve Limestone	Primarily limestone	Mississippian aquifers	Slade Formation; Ste. Genevieve Member; St. Louis Member	Primarily limestone	Mississippian aquifers	Maxville Limestone		Mississippian aquifers
		St. Louis Limestone								
		Warsaw Limestone			Borden Formation	Shale		Logan Formation	Interbedded sandstone and shale	Mississippian aquifers
	Lower	Fort Payne and Grainger Formations	Chert and shale	Confining unit				Black Hand Sandstone		
					Sunbury Shale			Sunbury Shale		
		Chattanooga Shale	Shale		Berea Sandstone	Sandstone		Berea Sandstone	Sandstone	
Devonian					Ohio, New Albany[2] and Olentangy Shales	Shale	Confining unit	Bedford Shale; Ohio and Olentangy Shales	Shale	Confining unit

[1]Permian rocks included in Upper Pennsylvanian aquifers in this report.
[2]New Albany Shale is partly Mississippian age.

Data from Patchen and others, 1985a,b

Figure 103. *The principal aquifers in the Appalachian Plateaus Physiographic Province in Segment 10 can be divided into two categories—the surficial aquifer system in unconsolidated deposits of Quaternary age and the aquifers in consolidated rocks of Mississippian through Permian age. The gray areas represent missing rocks.*

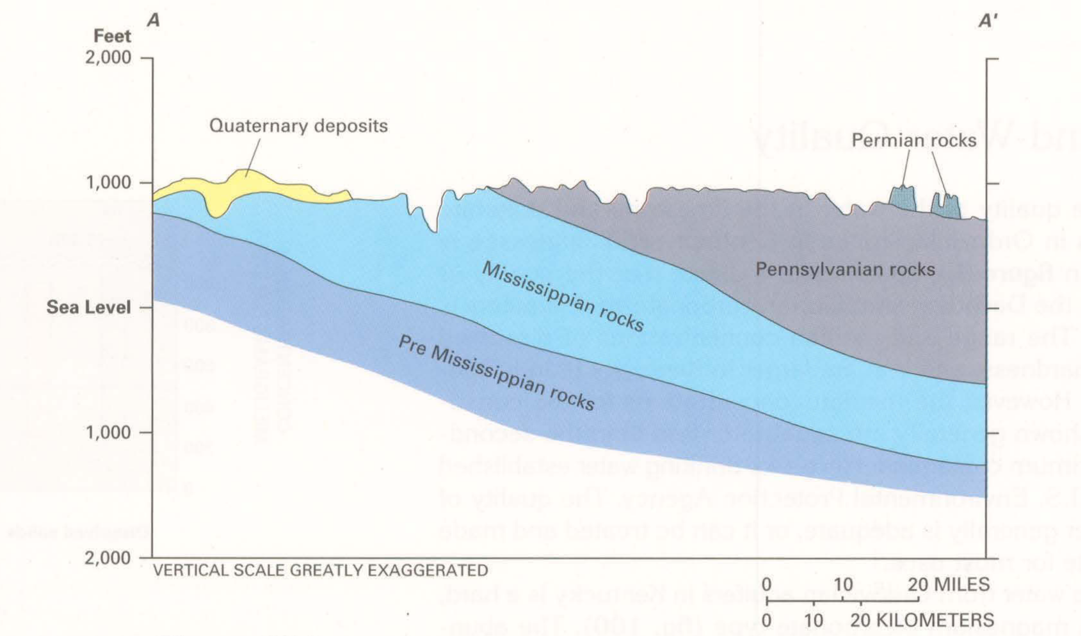


Figure 104. *Generally, the Paleozoic rocks dip toward the east in the northern part of the Appalachian Plateaus Province. The line of the section is shown in figure 102.*

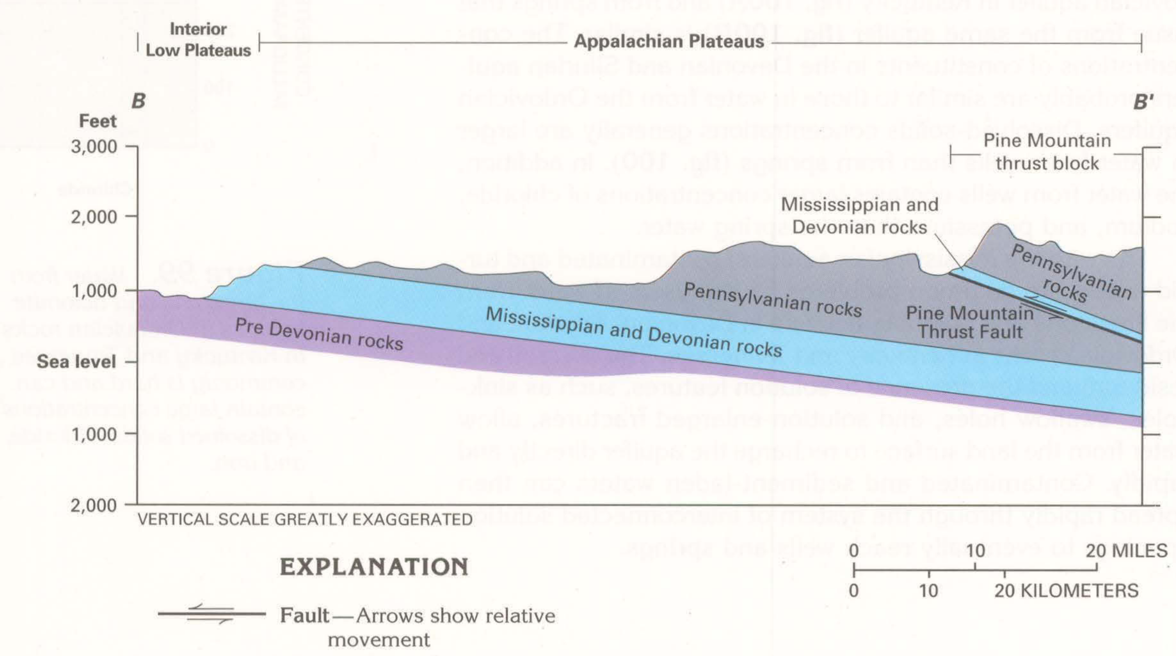


Figure 105. *Movement along faults such as the Pine Mountain Thrust Fault has emplaced older rocks atop younger ones in some of the southern parts of the Appalachian Plateaus Province. Such movement can cause parts of the geologic section to be repeated. The line of the section is shown in figure 102.*

HYDROGEOLOGIC UNITS

Surficial Aquifer System

The surficial aquifer system consists of sand and gravel deposits of glacial and alluvial origin. Some of the glacial material was deposited directly by the ice, and some was deposited by meltwater. The coarse-grained glacial material that constitutes productive aquifers was deposited as alluvium, which filled bedrock valleys, and as kame deposits enclosed within or buried beneath glacial till. The alluvial material is along present-day streams and consists mostly of reworked glacial deposits. Aquifers that consist of sand and gravel beds in the glacial and alluvial deposits are locally present throughout eastern Ohio and in northeastern Kentucky along the Ohio River (**fig. 106**). Wells completed in the sand and gravel deposits, which are highly permeable, yield more water than wells completed in any of the other aquifers in the Appalachian Plateaus Province. As a result, ground-water development in Ohio has primarily focused on the coarse-grained alluvial and glacial deposits.

The aquifers of the surficial aquifer system are of two types—alluvium that is in present-day stream valleys and glacial out-wash or valley-train deposits in buried bedrock valleys and kame deposits that consist of sand and gravel surrounded by or buried beneath poorly permeable glacial till. In many stream valleys, stratified glacial drift, consisting of sand, gravel, and clay, was deposited by meltwater as the glaciers retreated. Today, most of these valleys are occupied by perennial streams. Sand and gravel deposits in the valleys are the primary aquifer materials, and their locations are easy to predict because they are located at or near land surface. These deposits commonly range from 25 to 200 feet in thickness but may exceed 300 feet in large stream valleys. The kame deposits cover the northern Ohio part of the Appalachian Plateaus Province (**fig. 106**). Fine-grained glacial till might enclose or cover these local, lens-shaped sand and gravel aquifers, thus making the aquifers difficult to locate.

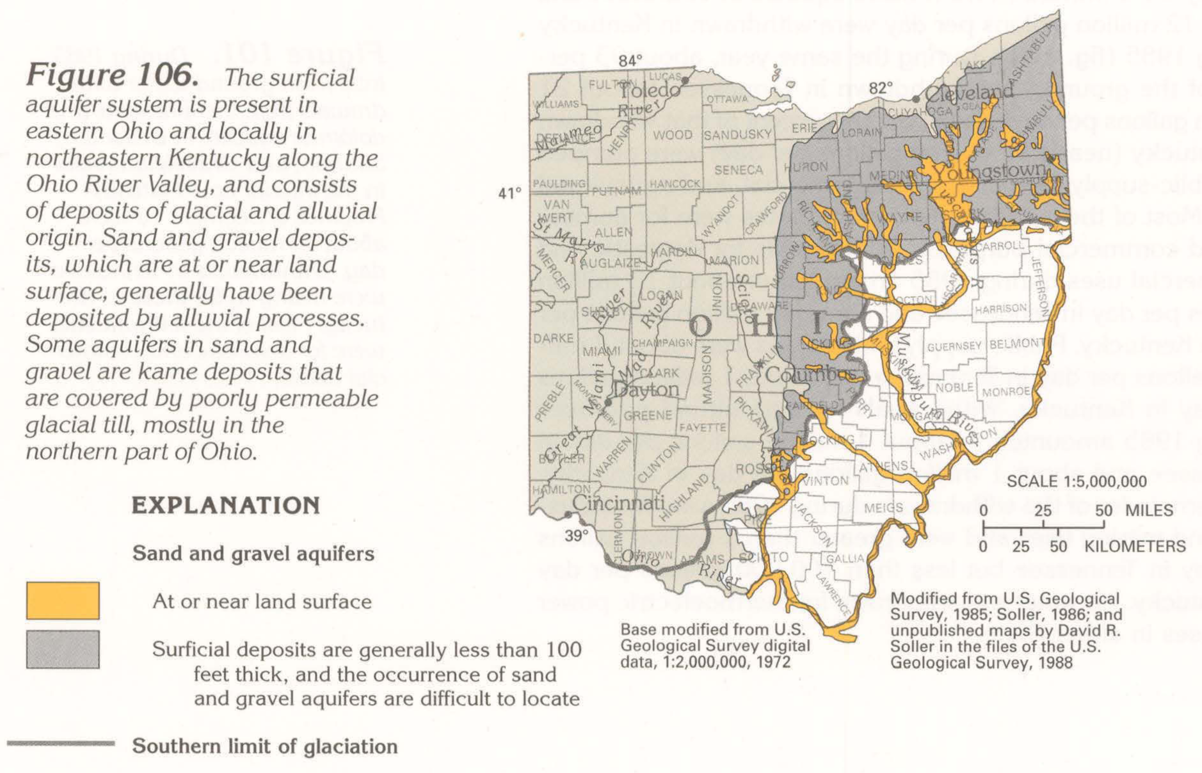


Figure 106. *The surficial aquifer system is present in eastern Ohio and locally in northeastern Kentucky along the Ohio River Valley, and consists of deposits of glacial and alluvial origin. Sand and gravel deposits, which are at or near land surface, generally have been deposited by alluvial processes. Some aquifers in sand and gravel are kame deposits that are covered by poorly permeable glacial till, mostly in the northern part of Ohio.*

Pennsylvanian Aquifers

Pennsylvanian aquifers in the Appalachian Plateaus Province mostly consist of sandstone and limestone that are parts of repeating sequences of beds deposited during multiple sedimentary cycles. A complete, ideal cycle consists of the following sequence of beds, listed from bottom to top: underclay, coal, gray shale or black platy shale, freshwater limestone, and sandstone or silty shale. Not all the beds listed are present in each cycle. The sandstones and limestones are the most productive aquifers. Sandstone aquifers also are present in rocks of Permian age. In the following description, rocks of Pennsylvanian age are grouped into Upper Pennsylvanian aquifers and Middle and Lower Pennsylvanian aquifers; water-yielding rocks of Permian age are discussed with the Upper Pennsylvanian aquifers.

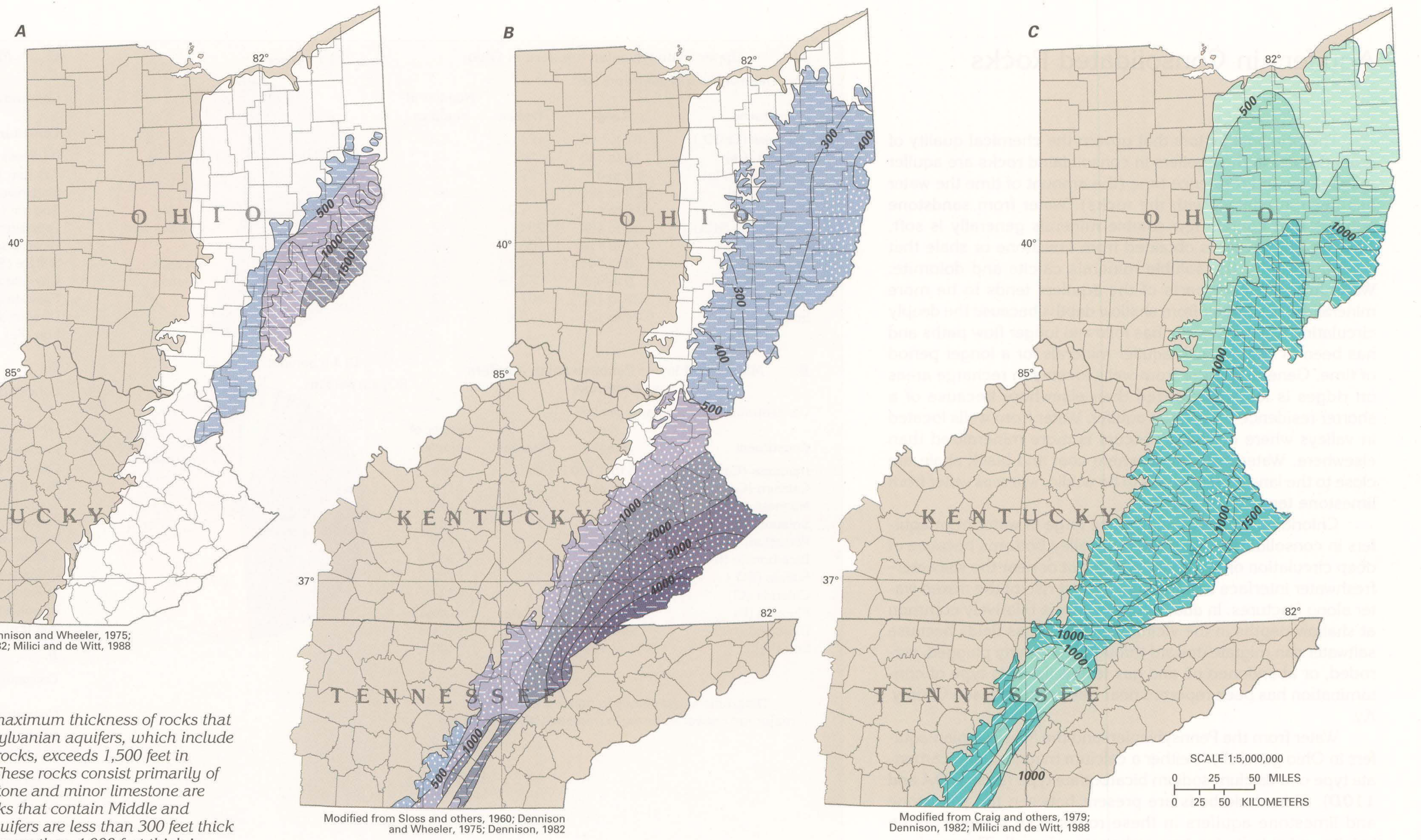
Upper Pennsylvanian aquifers mostly are present in the Pennsylvanian Monongahela and Conemaugh Groups but also can include sandstones of the Dunkard Group of Pennsylvanian and Permian age (**fig. 103**). Strata that contain these aquifers are present in southeastern Ohio and a small part of northeastern Kentucky (**fig. 107*A***). In southeastern Ohio, Upper Pennsylvanian rocks are primarily interbedded sandstone, siltstone, and shale with minor coal; they grade to shale and siltstone in northeastern Kentucky. The dominant lithology is shale, although some limestone beds are present in the Monongahela Group. Together, the Monongehela and the Conemaugh Groups average about 1,000 feet in thickness. These rocks thicken slightly toward the southeast and exceed 1,500 feet in thickness along the Ohio River in Belmont, Monroe, and Washington Counties, Ohio, where they include the Dunkard Group.

Middle and Lower Pennsylvanian aquifers crop out throughout most of the Appalachian Plateaus Province in Segment 10 and are the most widespread source of ground water in the province. Shale with interbedded sandstone is the dominant lithology of Middle and Lower Pennsylvanian rocks in the northern part of the province, whereas sandstone is dominant in the south (**fig. 107*B***). Rocks that compose the Middle and Lower Pennsylvanian aquifers include the Allegheny Formation and the Pottsville Group in Ohio, the Breathitt and the Lee Formations in Kentucky, and several equivalent formations in Tennessee (**fig. 103**). The Allegheny Formation and the Pottsville Group are primarily interbedded sandstone, siltstone, and shale but contain economically important beds of coal. An average of about 40 percent of the total thickness of the Pottsville Group is sandstone. In Kentucky, the Breathitt Formation is primarily interbedded sandstone, siltstone, and shale, whereas the Lee Formation is predominantly sandstone with some conglomerate. Beds of sandstone in the Breathitt Formation are typically from 30 to 120 feet thick and compose about 50 percent of the total thickness of the formation. About 80 percent of the total thickness of the Lee Formation consists of beds of sandstone and conglomerate. Middle and Lower Pennsylvanian rocks in Tennessee are predominately interbedded conglomerate and sandstone with some siltstone, shale, and coal beds. The primary water-yielding units are sandstone and conglomerate beds in the Crab Orchard Mountains Group; some conglomerate beds in this group locally are 200 feet thick, whereas sandstone beds in the group range from 100 to 300 feet thick and are locally conglomeratic.

Mississippian Aquifers

Mississippian aquifers in the Appalachian Plateaus Province in Segment 10 consist mostly of limestone and sandstone. Fractured chert of the Fort Payne Formation in Tennessee locally forms an aquifer. Shale is more abundant in Mississippian strata in Ohio and Kentucky than sandstone and limestone, whereas limestone is more prevalent in Tennessee (**fig. 107*C***). The Mississippian aquifers are exposed at land surface along and east of the western boundary of the Appalachian Plateaus Province in Ohio and northern Kentucky and locally in southeastern Kentucky and northeastern Tennessee along the Pine Mountain Thrust Fault.

The Black Hand and the Berea Sandstones (**fig. 103**) are the primary Mississippian aquifers in Ohio. Although the Berea is Devonian age in part, it is included in the Mississippian aquifers in this chapter. The thickness of the Black Hand locally exceeds 600 feet and that of the Berea locally exceeds 100 feet. The Berea Sandstone also is a productive aquifer in northern Kentucky. The Ste. Genevieve and the St. Louis Members of the Slade Formation are productive aquifers in central and southern Kentucky, particularly in stream valleys where they are covered only by a thin layer of Pennsylvanian rocks and unconsolidated alluvial deposits. In Tennessee, the Monteagle, the St. Louis, the Warsaw, and the Newman Limestones, as well as the Fort Payne and the Grainger Formations, compose productive Mississippian aquifers.



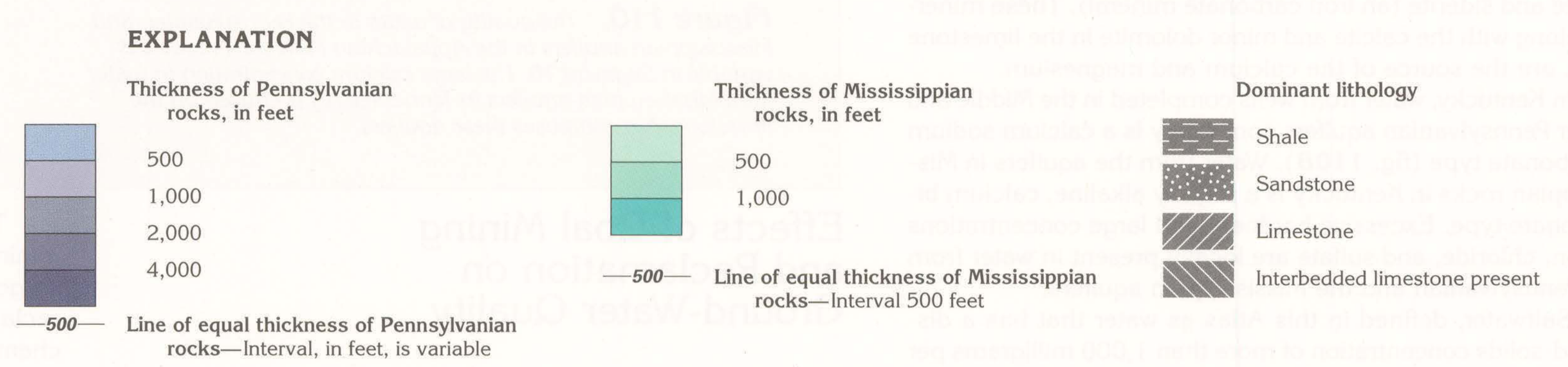


Figure 107. *The maximum thickness of rocks that contain the Upper Pennsylvanian aquifers, which include water-yielding Permian rocks, exceeds 1,500 feet in southeastern Ohio (A). These rocks consist primarily of shale, but beds of sandstone and minor limestone are productive aquifers. Rocks that contain Middle and Lower Pennsylvanian aquifers are less than 300 feet thick in parts of Ohio but are more than 4,000 feet thick in southeastern Kentucky and northeastern Tennessee (B). Sandstone and conglomerate compose more than 50 percent of Lower Pennsylvanian rocks in southeastern Ohio and in most of Kentucky and Tennessee. Rocks that contain Mississippian aquifers are about 500 feet thick in Ohio and more than 1,500 feet thick in eastern Kentucky (C). Shale composes more than 50 percent of the Mississippian rocks in Ohio and Kentucky, whereas limestone is the dominant rock type in Tennessee. Interbedded limestone is present in the rocks that compose the Upper Pennsylvanian and Mississippian aquifers.*

GROUND-WATER OCCURRENCE AND MOVEMENT

Surficial Aquifer System

Sand and gravel aquifers of the surficial aquifer system in Ohio are the most productive aquifers in the Appalachian Plateaus Province in Segment 10 because the aquifers are highly permeable and easily recharged. Generally, these aquifers are either exposed at land surface or buried at shallow depths and thus are directly recharged by precipitation. In many places, the aquifers are hydraulically connected to streams, which provide recharge to the aquifers near places where wells that withdraw water from an aquifer have lowered the water level in the aquifer below that of the stream. Well yields in sand and gravel deposits commonly range from 100 to 500 gallons per minute but might exceed 2,000 gallons per minute (**table 5**).

Aquifers that consist of fine sand and silt also are common in Ohio but generally are less permeable than aquifers that consist of coarse sand and gravel. Yields of wells completed in these finer grained aquifers commonly range from 25 to 50 gallons per minute. Generally, these aquifers are present in the fill of abandoned stream valleys and as lenses within layers of glacial till; therefore, the aquifers typically are not in direct hydraulic connection with streams.

Aquifers in Consolidated Rocks

Aquifers in consolidated rocks are an important source of ground water, especially where wells penetrate fractures that store and transmit water, where sandstone beds are hydraulically interconnected, near outcrop areas where recharge is direct and drilling depths are minimal, and in stream valleys where alluvial deposits that overlie the consolidated rocks store recharge and subsequently slowly release water to the aquifers. The aquifers in consolidated rocks are directly recharged by precipitation where they are exposed at land surface (**fig. 108**). However, low-permeability layers of underclay beneath coal beds retard downward movement of the water and might create perched water-table conditions above the main water table. The perched water discharges mainly to springs; the main water table discharges to streams, as well as springs. Water in deep artesian aquifers might be part of a regional flow system with a different flow direction than the shallower ground-water flow systems.

Water in the consolidated-rock aquifers of the Appalachian Plateaus Province is primarily in fractures in sandstones and shales and in fractures or bedding planes enlarged by dissolution in limestones. Fractured coal beds also yield water in some places. Because these consolidated rocks have little or no intergranular permeability, fractures store and transmit most of the ground water. The fractures generally are at shallow depths; most are a few tens to a few hundreds of feet below land surface. These fractures commonly form where erosion has removed overlying rocks, thus relieving vertical compressional stress and along the crest of anticlinal folds. The number of fractures and the width of individual fractures generally decrease as depth increases. Although fractures are present throughout the consolidated rocks of the Appalachian Plateaus, aquifer characteristics of the rocks and well yields are variable because the effective permeability of the rocks is dependent, for the most part, upon the number of fractures and how well the fractures are interconnected. Low intergranular permeability, coupled with the decrease in the size and number of fractures as depth increases, restricts the regional flow of water and creates conditions in which well yields generally are small.

Sandstone, limestone, and conglomerate are the dominant water-yielding rocks that compose Upper Pennsylvanian aquifers, but beds of fractured coal locally provide small supplies of water. Individual sandstone beds in Upper Pennsylvanian rocks generally are of limited areal extent and are isolated from other sandstone beds. The discontinuous occurrence and the generally fine-grained texture of the unfractured rocks and sparse fracture openings combine to impede the flow of ground water. Ground water in these aquifers generally moves from recharge areas downgradient to discharge at streams, wells, and coal mines. Perched water tables above clay layers that underlie coal beds in the upland areas give rise to springs along valley walls (**fig. 108**). Well yields from Upper Pennsylvanian aquifers commonly range between 1 and 20 gallons per minute in Ohio (**table 5**).

Middle and Lower Pennsylvanian rocks generally contain more sandstone and conglomerate than Upper Pennsylvanian rocks. Some of the Middle and Lower Pennsylvanian sandstone and conglomerate beds are regionally extensive and contain well-developed fracture systems. These fractures increase the overall yield of Middle and Lower Pennsylvanian aquifers compared to Upper Pennsylvanian aquifers (**table 5**). Perched water tables can occur above underclays in Middle and Lower Pennsylvanian aquifers but are less common than in Upper Pennsylvanian aquifers. In Kentucky and Tennessee, sandstone and conglomerate in Middle and Lower Pennsylvanian rocks tend to be thickly bedded or massive, and extend over large areas. Well yields from Middle and Lower Pennsylvanian aquifers only range from 1 to 25 gallons per minute in Ohio but range from 5 to 50 gallons per minute in Tennessee.

Mississippian aquifers are mostly in limestones, except in Ohio where they are mostly in sandstones. Slightly acidic water that moves along fractures, bedding planes, and other primary openings in limestone dissolves part of the limestone and enlarges the original openings (**fig. 109**). The maximum reported yields of wells completed in these aquifers are highly variable; wells that penetrate solution openings in the limestone have large yields (**table 5**). In Ohio, withdrawals from Mississippian aquifers can induce recharge from the directly overlying surficial aquifer system. In these areas, yields of wells completed in the Mississippian aquifers can be greater than elsewhere. Mississippian aquifers also are an important source of water in stream valleys where the overlying Pennsylvanian rocks are thin or absent. In stream valleys, recharge from alluvial valley fill tends to increase yields of wells completed in the underlying Mississippian aquifers. In Tennessee and Kentucky, springs can discharge from valley walls at the contact between Pennsylvanian and Mississippian rocks (**fig. 109**). Water percolates downward through the Pennsylvanian sandstones and then flows laterally along the contact with less-permeable Mississippian shale to emerge as springs along the valley walls.

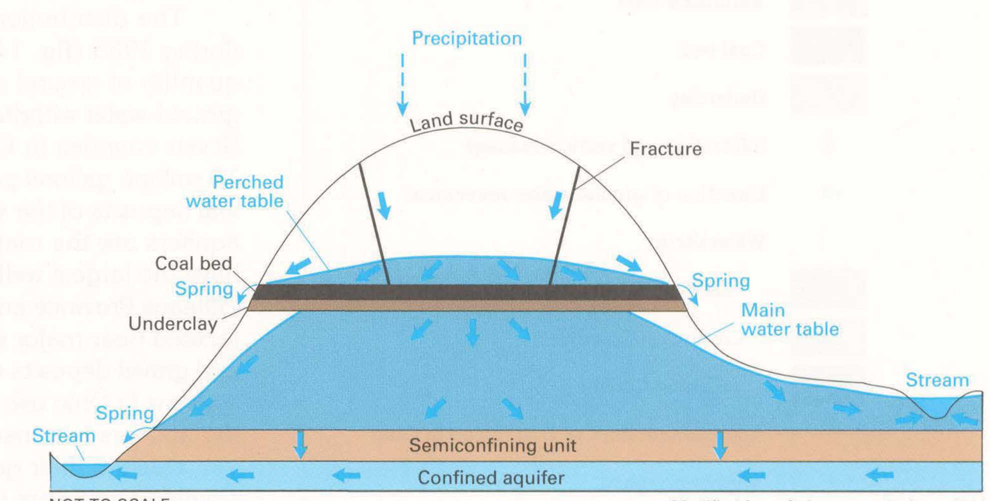


Figure 108. *Aquifers in consolidated rocks are directly recharged by precipitation where they are exposed at the land surface. Water enters the aquifers primarily through fractures, which store and transmit the water. The fractures decrease in width and number with depth. In Pennsylvanian rocks in the Appalachian Plateaus Province, underclay beneath coal beds creates perched water tables, which result in springs that issue from valley walls. Water percolates slowly downward through the underclay to reach the main water table.*

EXPLANATION

Direction of ground-water movement

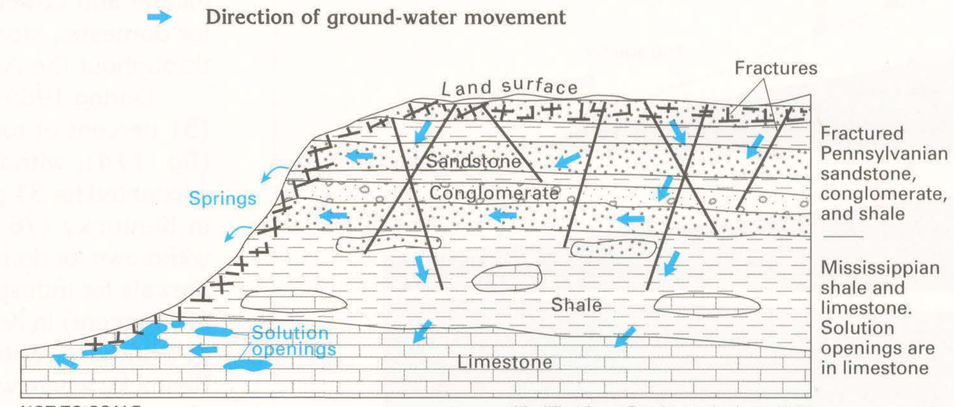


Figure 109. *Water moves primarily through fractures in aquifers in Pennsylvanian and Mississippian sandstone, conglomerate, and limestone in the Appalachian Plateaus Province. Dissolution of limestone along openings, such as fractures and bedding planes, increases the size of the openings. Fractures in shale confining units allow water to move rapidly downward through the confining units. Shallow near-surface fractures yield the most water to wells.*

Table 5. *The range of yields of wells completed in the surficial aquifer system, particularly in coarse sand and gravel, greatly exceeds that of wells completed in aquifers in consolidated rocks*

[Data source: Gaydos and others, 1982; Kiesler and others, 1983; Quinones and others, 1981; and U.S. Geological Survey, 1985. ND, no data; NP, not present]

Aquifer or aquifer system	Well characteristics											
	Ohio				Kentucky				Tennessee			
	Depth (feet)		Yield (gallons per minute)		Depth (feet)		Yield (gallons per minute)		Depth (feet)		Yield (gallons per minute)	
	Common range	May exceed	Common range	May exceed	Common range	May exceed	Common range	May exceed	Common range	May exceed	Common range	May exceed
Surficial aquifer system:												
Sand and gravel	25 to 200	300	100 to 500	2,000	ND	ND	ND	ND	NP	NP	NP	NP
Fine-grained sand	25 to 200	300	25 to 50	100	NP	NP	NP	NP	NP	NP	NP	NP
Aquifers in consolidated rocks:												
Upper Pennsylvanian aquifers	25 to 100	300	1 to 20	45	ND	ND	ND	ND	NP	NP	NP	NP
Middle and Lower Pennsylvanian aquifers	25 to 300	400	1 to 25	100	75 to 200	400	1 to 50	200	100 to 200	250	5 to 50	200
Mississippian aquifers	25 to 300	400	5 to 25	250	100 to 300	500	1 to 40	50	50 to 200	250	5 to 50	400

GROUND-WATER QUALITY

The quality of ground water from the aquifers in the Appalachian Plateaus Province in Segment 10 generally is suitable, with minimal treatment for most uses. Chlorination is usually the only treatment required to make the water suitable for drinking. Locally, excessive concentrations of iron or sulfate may be present. Water from the surficial aquifer system and the aquifers in consolidated rocks may be locally contaminated by saltwater present at shallow depths or by human activities, such as the disposal of wastes or development of the coal, oil, and gas resources of the area.

Surficial Aquifer System

Water from the surficial aquifer system in the Appalachian Plateaus Province in Ohio is predominantly a calcium bicarbonate type. The water generally has larger concentrations of dissolved solids, chloride, and sulfate and is harder than water from the aquifers in consolidated rocks in the same area (**table 6**). Iron concentrations also tend to be larger in water from the surficial aquifer system and generally increase with depth.

Table 6. *Concentrations of selected water-quality properties and constituents are larger in water from the surficial aquifer system than in water from aquifers in consolidated rocks from Ohio*

[Data source: U.S.Geological Survey, 1988. Values are median concentrations, in milligrams per liter]

Property or constituent	Surficial aquifer system	Aquifers in consolidated rocks
Hardness ($CaCO_3$)	337	216
Sulfate (SO_4)	76	36
Chloride (Cl)	31	10
Dissolved solids	413	322

Aquifers in Consolidated Rocks

The principal factors that govern the chemical quality of ground water in the aquifers in consolidated rocks are aquifer mineralogy and residence time (the amount of time the water has been in contact with the rocks). Water from sandstone aquifers that contain few soluble minerals generally is soft, whereas hard water is obtained from limestone or shale that contain more of the soluble minerals calcite and dolomite. Water in the deeper parts of the aquifers tends to be more mineralized than water from shallow depths because the deeply circulating water generally has followed longer flow paths and has been in contact with aquifer minerals for a longer period of time. Generally, water from wells located in recharge areas on ridges is less mineralized than elsewhere because of a shorter residence time in the aquifer. Water from wells located in valleys where discharge occurs is more mineralized than elsewhere. Water from areas where coal and black shale are close to the land surface tends to be acidic, whereas water from limestone tends to be alkaline.

Chloride concentrations can be large in water from aquifers in consolidated rocks beneath valley bottoms because of deep circulation of the water to zones at or near the saltwater–freshwater interface and the subsequent rise of the mixed water along fractures. In addition, saltwater is relatively common at shallow depths in the vicinity of oil and gas fields because saltwater can migrate upward through improperly plugged, corroded, or abandoned oil and gas test wells. This type of contamination has been reported near Keaton in Johnson County, Ky.

Water from the Pennsylvanian and the Mississippian aquifers in Ohio generally is either a calcium magnesium bicarbonate type or a calcium sodium bicarbonate type (**figs. 110*A* and 110*D***). Thin shale beds are present between the sandstone and limestone aquifers in these rocks. The shales contain calcite and siderite (an iron carbonate mineral). These minerals, along with the calcite and minor dolomite in the limestone beds, are the source of the calcium and magnesium.

In Kentucky, water from wells completed in the Middle and Lower Pennsylvanian aquifers commonly is a calcium sodium bicarbonate type (**fig. 110*B***). Water from the aquifers in Mississippian rocks in Kentucky is a slightly alkaline, calcium bicarbonate type. Excessive hardness and large concentrations of iron, chloride, and sulfate are locally present in water from the Pennsylvanian and the Mississippian aquifers.

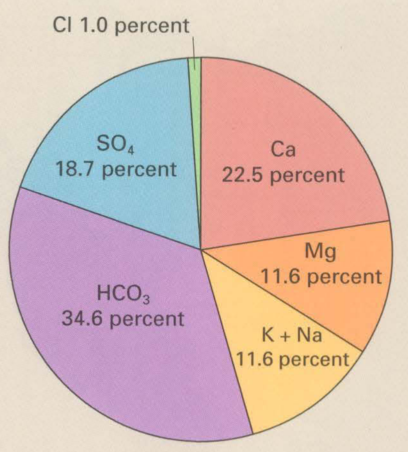
Saltwater, defined in this Atlas as water that has a dissolved-solids concentration of more than 1,000 milligrams per liter, generally is at depths greater than 300 feet below land surface in Kentucky. However, saltwater is at depths of less than 100 feet below land surface in valleys of large rivers and their principal tributaries. Locally, however, freshwater is reported to be present at great depths in areas in Kentucky adjacent to major faults; for example, chloride concentrations of only 2 milligrams per liter were present in water from two wells reported to be 1,500 feet deep in Bell County, Ky. Freshwater probably circulated to this depth in fractures or steeply dipping bedding planes associated with the Pine Mountain Thrust Fault.

Sparse data indicate that water from Pennsylvanian aquifers in Tennessee ranges from soft to hard, is a mixed type (no anion or cation is dominant), and contains small concentrations of dissolved solids (**fig. 110*C***). In contrast, water from Mississippian aquifers, which are mostly limestone, generally is a calcium bicarbonate type (**fig. 110*E***) and is harder and more mineralized than water from Middle and Lower Pennsylvanian aquifers. Large concentrations of sulfate locally are present in water from wells completed in Mississippian rocks.

A. **Upper Pennsylvanian aquifers in Ohio**

Concentrations in milligrams per liter

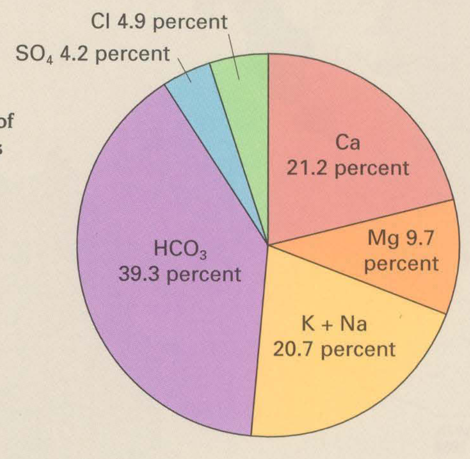
Constituent	Range	Median	Number of samples
Hardness ($CaCO_3$)	62 to 568	194	12
Calcium (Ca)	14 to 143	54	12
Magnesium (Mg)	6.8 to 60	17	12
Sodium (Na)	4.8 to 396	32	12
Potassium (K)	0.6 to 4.1	1.2	7
Bicarbonate (HCO_3)	50 to 484	254	12
Sulfate (SO_4)	13 to 470	108	12
Chloride (Cl)	0 to 348	4.1	12
Fluoride (F)	0 to 0.9	0.15	12
Dissolved solids	128 to 1,177	407	12
Iron (Fe)	0.04 to 12	0.6	12



B. **Middle and lower Pennsylvanian aquifers in Kentucky**

Concentrations in milligrams per liter

Constituent	Range	Median	Number of samples
Hardness ($CaCO_3$)	3 to 2,190	96	185
Calcium (Ca)	2.4 to 248	27	118
Magnesium (Mg)	0.5 to 177	7.5	117
Sodium (Na)	1.5 to 742	29	121
Potassium (K)	0.5 to 22	2.4	116
Bicarbonate (HCO_3)	0 to 537	153	102
Sulfate (SO_4)	0.1 to 2,749	13	185
Chloride (Cl)	1 to 2,450	11	238
Fluoride (F)	no data	no data	no data
Dissolved solids	no data	no data	no data
Iron (Fe)	0.01 to 157	1	100

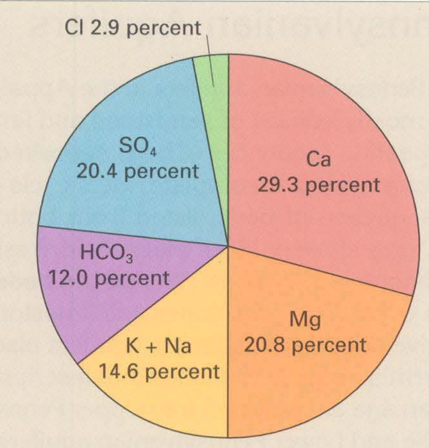


Diagrams show values in percent of median major ion concentrations, in milliequivalents per liter

C. **Middle and lower Pennsylvanian aquifers in Tennessee**

Concentrations in milligrams per liter

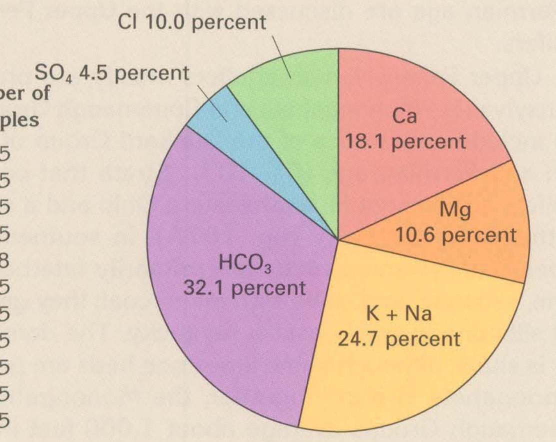
Constituent	Range	Median	Number of samples
Hardness ($CaCO_3$)	5 to 374	20	30
Calcium (Ca)	6.5 to 43	16	3
Magnesium (Mg)	2.4 to 65	6.9	3
Sodium (Na)	3.4 to 82	8.1	3
Potassium (K)	1.9 to 3.4	1.9	3
Bicarbonate (HCO_3)	4 to 272	20	30
Sulfate (SO_4)	4 to 166	27	4
Chloride (Cl)	0.4 to 40	3	29
Fluoride (F)	no data	no data	no data
Dissolved solids	56 to 109	no data	2
Iron (Fe)	no data	no data	no data



D. **Mississippian aquifers in Ohio**

Concentrations in milligrams per liter

Constituent	Range	Median	Number of samples
Hardness ($CaCO_3$)	24 to 952	206	15
Calcium (Ca)	7 to 243	56	15
Magnesium (Mg)	1.4 to 84	20	15
Sodium (Na)	2 to 626	84	15
Potassium (K)	1.3 to 6.2	3.2	8
Bicarbonate (HCO_3)	130 to 567	301	15
Sulfate (SO_4)	1.2 to 592	34	15
Chloride (Cl)	0 to 950	55	15
Fluoride (F)	0 to 1.5	0.2	15
Dissolved solids	236 to 1,330	575	15
Iron (Fe)	0.04 to 12	0.6	15



E. **Mississippian aquifers in Tennessee**

Concentrations in milligrams per liter

Constituent	Range	Median	Number of samples
Hardness ($CaCO_3$)	6 to 81,000	120	238
Calcium (Ca)	1.6 to 610	44.5	99
Magnesium (Mg)	0.3 to 210	6.8	99
Sodium (Na)	1 to 1,400	3.1	82
Potassium (K)	0 to 65	1.2	80
Bicarbonate (HCO_3)	0 to 1,190	118	239
Sulfate (SO_4)	0 to 3,600	9	86
Chloride (Cl)	2.1 to 38,000	4.2	237
Fluoride (F)	no data	no data	no data
Dissolved solids	47 to 6,000	160	55
Iron (Fe)	0 to 18	0.1	97

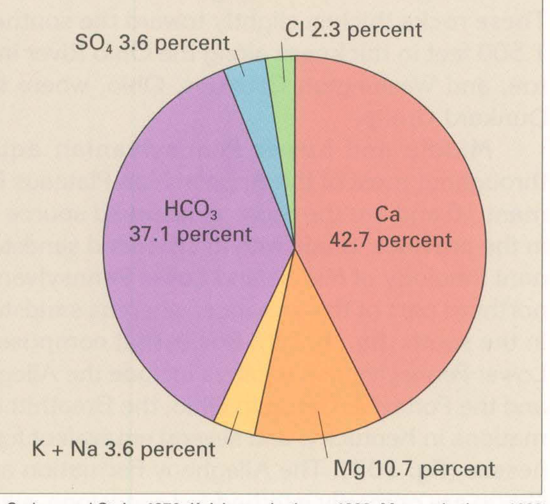


Figure 110. The quality of water in the Pennsylvanian and Mississippian aquifers in the Appalachian Plateaus Province is variable in Segment 10. The large calcium concentration in water from Mississippian aquifers in Tennessee (E) is caused by the limestone that composes these aquifers.

Data from Sedam and Stein, 1970; Keisler and others, 1983; May and others, 1983

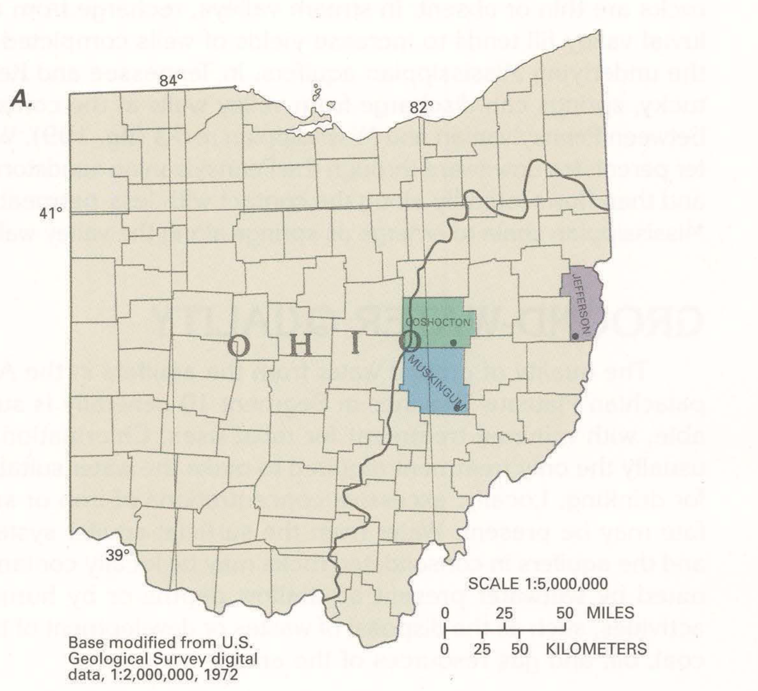
Effects of Coal Mining and Reclamation on Ground-Water Quality

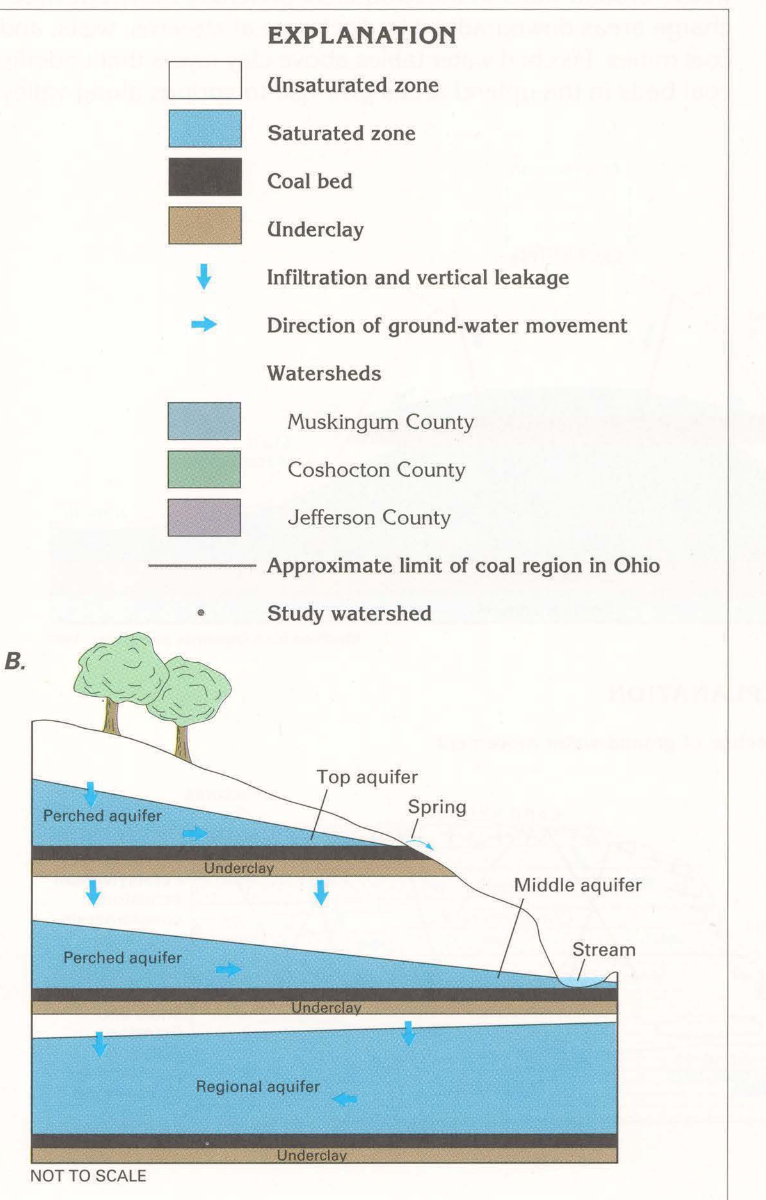
Surface coal mining and reclamation activities can affect the quality of ground water. Changes in ground-water quality that can occur as a result of mining and reclamation are characterized below for three small watersheds in eastern Ohio (**fig. 111*A***).

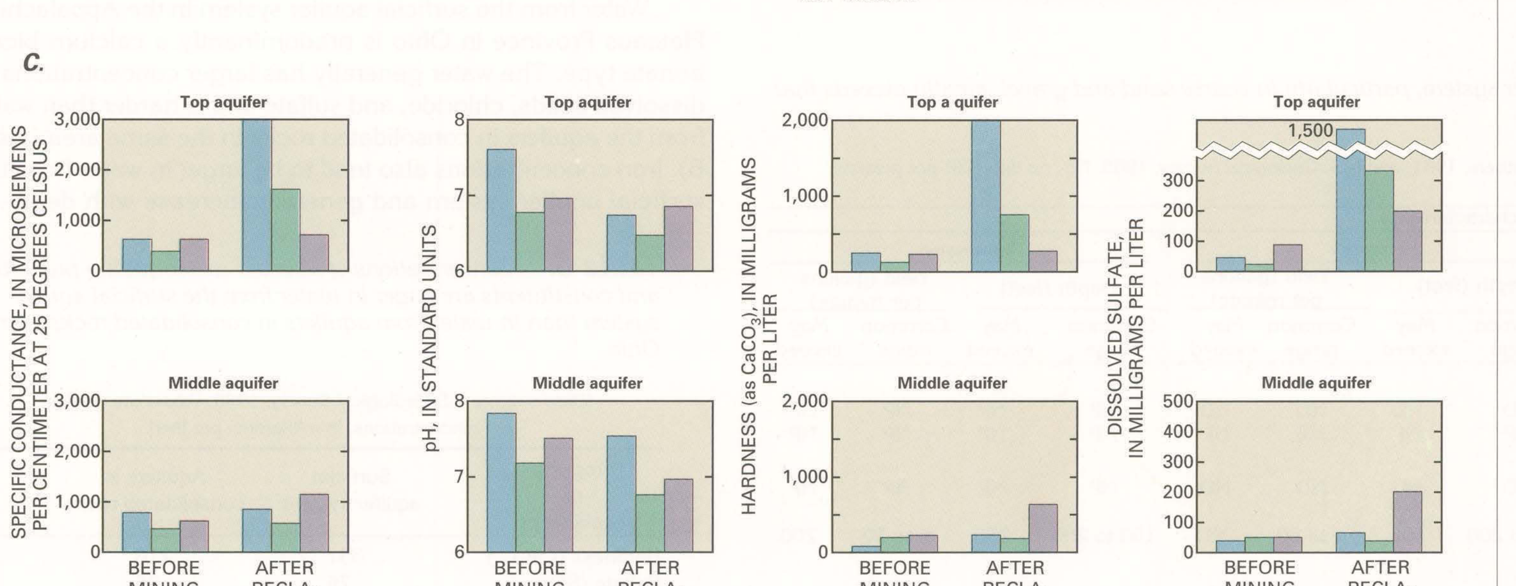
The ground-water flow system in coal mining areas generally is controlled by underclays that typically are present beneath each of several coal beds (**fig. 111*B***). These underclays impede the vertical flow of water to underlying aquifers, thereby creating one or more perched aquifers. In the example shown in **figure 111*B***, two perched aquifers overlie a regional aquifer in which the direction of ground-water movement is different from that in the perched aquifers. Water moves laterally along the top of the underclays and discharges as springs or seeps where the clay crops out in valley walls. In this example, during surface mining of the uppermost coal, the aquifer material and the coal bed overlying the shallowest underclay is removed and replaced with broken waste rock (spoil material) as part of the reclamation process.

The quality of the water in the aquifers can be altered by mining activity. In this example, water in the top aquifer undergoes many water-quality changes as a result of mining and reclamation. Water in the middle aquifer undergoes some chemical changes, and water in the deeper, regional aquifer undergoes no significant water-quality changes. Water in the top aquifer generally changed from a calcium bicarbonate type to a calcium sulfate type. Hardness, specific conductance (an indirect measure of the concentration of dissolved solids), and sulfate in water from the top aquifer increased after reclamation (**fig. 111*C***). Changes in the chemical quality of the water from the middle aquifer are less pronounced, and no significant changes occur in the quality of water from the regional aquifer. Chemical changes that result from mining can be quite different in other places from those shown in this example. The exact changes also depend on the chemical composition of the coal and the spoil material.

Figure 111. Ground-water quality can be affected by surface mining and reclamation activities. In three study watersheds in the coal region of Ohio (A), underclays create perched aquifers (B). The median values of selected chemical properties and constituents in water from the perched aquifers change following mining and reclamation activities (C).







Modified from Eberle and Razem, 1985

FRESH GROUND-WATER WITHDRAWALS

Ground water is an important source of freshwater in the Appalachian Plateaus Province of Segment 10. Ohio withdrew the largest quantity of ground water during 1985—about eight times the quantity withdrawn by Kentucky and Tennessee combined (**fig. 112**). However, surface-water use greatly exceeded ground-water use in all three States.

The distribution of ground-water withdrawals by county during 1985 (**fig. 113**) shows that Ohio withdrew the largest quantity of ground water and had the most counties in which ground-water withdrawals exceeded surface-water withdrawals. Seven counties in Ohio that had withdrawals of greater than 10 million gallons per day are located where glacial and alluvial deposits of the surficial aquifer system are present. These aquifers are the major sources of ground water because they have the largest well yields of any aquifers in the Appalachian Plateaus Province and because many of Ohio's urban areas are located near major streams whose valleys are filled with sand and gravel deposits of the surficial aquifer system. Many water systems in Ohio use water from the surficial aquifer system and the aquifers in consolidated rocks for their freshwater supply.

Despite their generally lower yields, the aquifers in consolidated rocks are important sources of water. In Ohio, Upper Pennsylvanian aquifers provide domestic supplies, and Mississippian aquifers provide domestic and small public supplies. Middle and Lower Pennsylvanian aquifers are used primarily for domestic, stock, and small public and industrial supplies throughout the Appalachian Plateaus Province.

During 1985, most of the ground water withdrawn in Ohio (51 percent of total withdrawals) was used for public supply (**fig. 114**); withdrawals for domestic and commercial uses accounted for 31 percent. In contrast, most of the ground water in Kentucky (76 percent) and Tennessee (52 percent) was withdrawn for domestic and commercial uses, followed by withdrawals for industrial, mining, and thermoelectric power uses (14 percent) in Kentucky and public-supply uses (37 percent) in Tennessee. Water needs of industry are apparent in Ohio and Kentucky where withdrawals for industrial, mining, and thermoelectric power uses made up a significant percentage of the total ground water withdrawn.

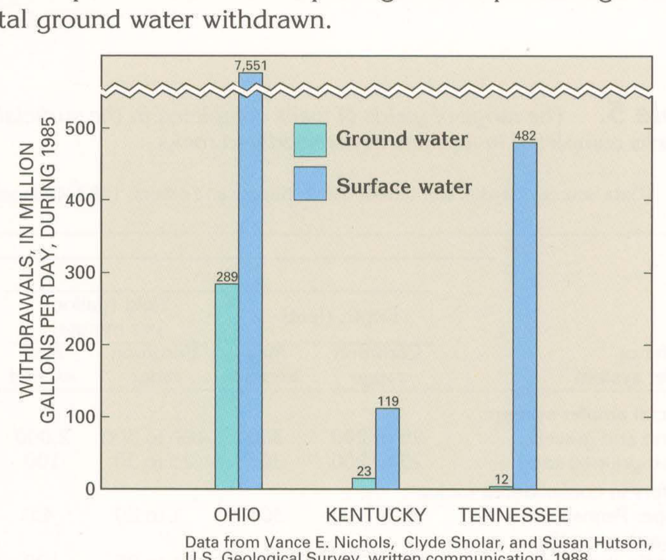
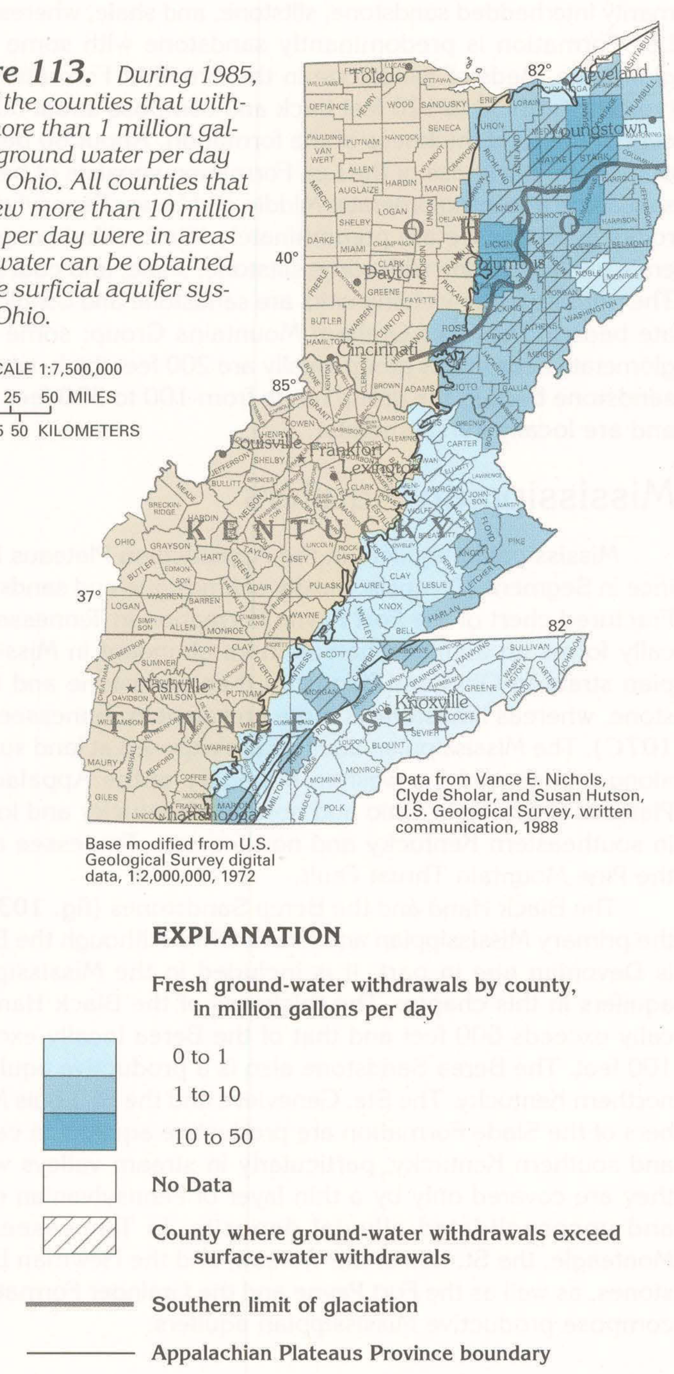


Figure 112. During 1985, surface water was the major source of freshwater in the Appalachian Plateaus Province in Ohio, Kentucky, and Tennessee. Ground-water withdrawals in Ohio were about eight times those of Kentucky and Tennessee combined.

Figure 113. During 1985, most of the counties that withdrew more than 1 million gallons of ground water per day were in Ohio. All counties that withdrew more than 10 million gallons per day were in areas where water can be obtained from the surficial aquifer system in Ohio.



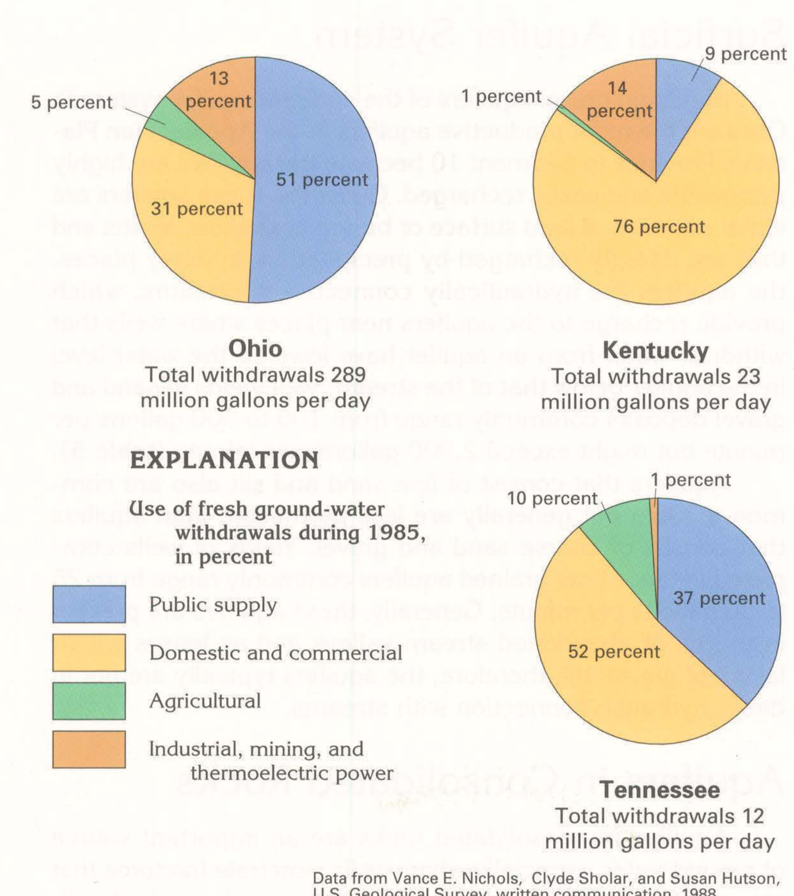


Figure 114. Most ground water withdrawn in Ohio during 1985 was used for public supply. In Kentucky and Tennessee, most of the water withdrawn during the same period was used for domestic and commercial supplies.

Valley and Ridge aquifers

INTRODUCTION

The Valley and Ridge Physiographic Province is characterized by a sequence of folded and faulted, northeast-trending Paleozoic sedimentary rocks that form a series of alternating valleys and ridges that extend from Alabama and Georgia to New York. The province is more areally extensive in Segment 11 than in Segment 10; therefore, the aquifers in the province are discussed in greater detail in that Atlas Chapter. The Valley and Ridge Province in the eastern part of Tennessee in Segment 10 (**fig. 115**) is underlain by rocks that are primarily Cambrian and Ordovician in age. Minor Silurian, Devonian, and Mississippian rocks also are present in the province. Soluble carbonate rocks and some easily eroded shales underlie the valleys in the province, and more erosion-resistant siltstone, sandstone, and some cherty dolomite underlie ridges.

The arrangement of the northeast-trending valleys and ridges and the broad expanse of the Cambrian and the Ordovician rocks in eastern Tennessee are the result of a combination of folding, thrust faulting, and erosion. Compressive forces from the southeast have caused these rocks to yield, first by folding and subsequently by repeatedly breaking along a series of thrust faults as shown in **figure 116**. The result of the faulting is that geologic formations can be repeated several times across the faults; for example, the carbonate-rock aquifers in the Chickamauga, the Knox, and the Conasauga Groups are repeated across the thrust faults shown in **figure 116**. In eastern Tennessee, the thrust faults are closely spaced and are more responsible than the folds for the present distribution of the rocks. Following the folding and thrusting, erosion produced the sequence of ridges and valleys on the present land surface.

The general hydrogeologic characteristics of the entire Valley and Ridge Province are fairly consistent. However, unique characteristics can be attributed to local differences in rock type and geologic structure.

HYDROGEOLOGIC UNITS

The principal aquifers in the Valley and Ridge Province of Segment 10 consist of carbonate rocks that are Cambrian, Ordovician, and Mississippian in age (**fig. 117**). These aquifers, which are typically present in valleys and rarely present on broad, dissected ridges, underlie more than one-half of the Valley and Ridge Province in Tennessee (**fig. 115**). Most of the carbonate-rock aquifers are directly connected to sources of recharge, such as rivers or lakes, and solution activity has enlarged the original openings in the carbonate rocks. Other types of rocks in the province can yield large quantities of water to wells where they are fractured or contain solution openings or are directly hydraulically connected to sources of recharge.

System	Geologic unit			Predominant lithology
Mississippian	Pennington Formation			Shale and siltstone
Mississippian	Newman Limestone	Greasy Cove Formation		Limestone and calcareous shale
Mississippian	Fort Payne Formation	Grainger Formation		Cherty limestone and dolomite, shale, and siltstone
Devonian	Chattanooga Shale			Black shale
Silurian	Rockwood Formation			Shale
Silurian	Clinch Sandstone			Sandstone
Ordovician	Sequatchie Formation			Shaly limestone
Ordovician	Chickamauga Group: Reedsville Shale			Shale
Ordovician	Chickamauga Group: Unnamed limestone unit			Shaly limestone
Ordovician	Chickamauga Group: Moccasin Formation	Bays Formation		Calcareous shale, shale, and siltstone
Ordovician	Chickamauga Group: Ottosee Shale			Shale
Ordovician	Chickamauga Group: Holston Formation			Limestone
Ordovician	Chickamauga Group: Lenoir Limestone	Athens Shale	Sevier Shale	Limestone and shale
Ordovician	Knox Group: Mascot Dolomite / Kingsport Formation	Newala Formation equivalent		Cherty dolomite and limestone
Ordovician	Knox Group: Longview Dolomite			Dolomite
Ordovician	Knox Group: Chepultepec Dolomite			Cherty dolomite
Cambrian	Knox Group: Copper Ridge Dolomite			Cherty dolomite
Cambrian	Conasauga Group: Maynardville Limestone			Limestone
Cambrian	Conasauga Group	Honaker Dolomite		Dolomite, shale, and limestone
Cambrian	Rome Formation			Sandstone, shale and siltstone
Cambrian	Shady Dolomite			Dolomite
Cambrian	Chilhowee Group			Quartzite, shale, and sandstone

Modified from Hardeman and others, 1966

Figure 117. *The carbonate rock units shown in color constitute the principal aquifers in the Valley and Ridge Province in eastern Tennessee. Most of these aquifers are in Cambrian and Ordovician rocks.*

GROUND-WATER MOVEMENT

Ground water in the Valley and Ridge aquifers primarily is stored in and moves through fractures, bedding planes, and solution openings in the rocks. These types of openings are secondary features that developed after the rocks were deposited and lithified. Little primary porosity and permeability remain in these rocks after the process of lithification. Some ground water moves through primary pore spaces between the particles that constitute the alluvium along streams and the residuum of weathered material that overlies most of the rocks in the area.

In the carbonate rocks, the fractures and bedding planes have been enlarged by dissolution of part of the rocks. Slightly acidic water, especially that circulating in the upper 200 to 300 feet of the zone of saturation, dissolves some of the calcite and dolomite that compose the principal aquifers. Most of this dissolution takes place along fractures and bedding planes where the largest volumes of acidic ground water flow.

Ground-water movement in the Valley and Ridge Province in eastern Tennessee is localized, in part, by the repeating lithology created by thrust faulting and, in part, by streams. Major streams are parallel to the northeast-trending valleys and ridges, and tributary streams are perpendicular to the valleys and ridges. Older rocks (primarily the Conasauga Group and the Rome Formation) have been displaced upward over the top of younger rocks (the Chickamauga and the Knox Groups) along thrust fault planes (**fig. 118**) thus forming a repeating sequence of permeable and less permeable hydrogeologic units. The repeating sequence, coupled with the stream network, divides the area into a series of adjacent, isolated, shallow ground-water flow systems. Within these local flow systems, most of the ground-water movement takes place within 300 feet of land surface. In recharge areas, most of the ground water flows across the strike of the rocks. The water moves from the ridges where the water levels are high toward lower water levels adjacent to major streams that flow parallel to the long axes of the valleys (**fig. 118**). Most of the ground water is discharged directly to local springs or streams, but some of it moves along the strike of the rocks, following highly permeable fractures, bedding planes, and solution zones to finally discharge at more distant springs or streams. Although fracture zones locally are present in the clastic rocks, the highly permeable zones, which are primarily present in the carbonate rocks, act as collectors and conduits for the water.

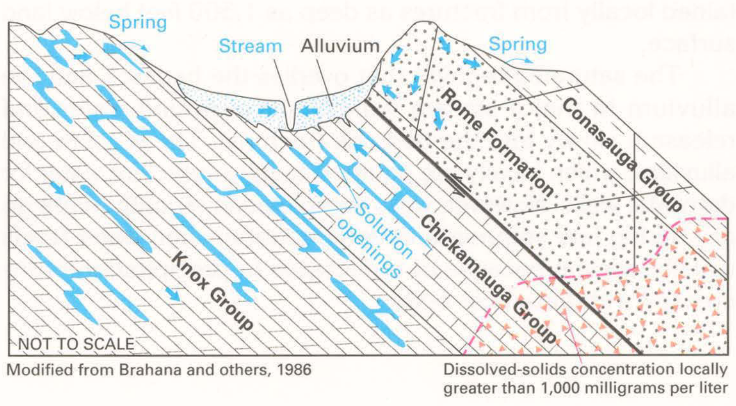


Figure 118. *Ground water moves downward through interstitial pore spaces in residuum and alluvium into the consolidated rocks where it moves along fractures, bedding planes, and solution openings. The general direction of flow is from ridges toward springs and streams in the valleys.*

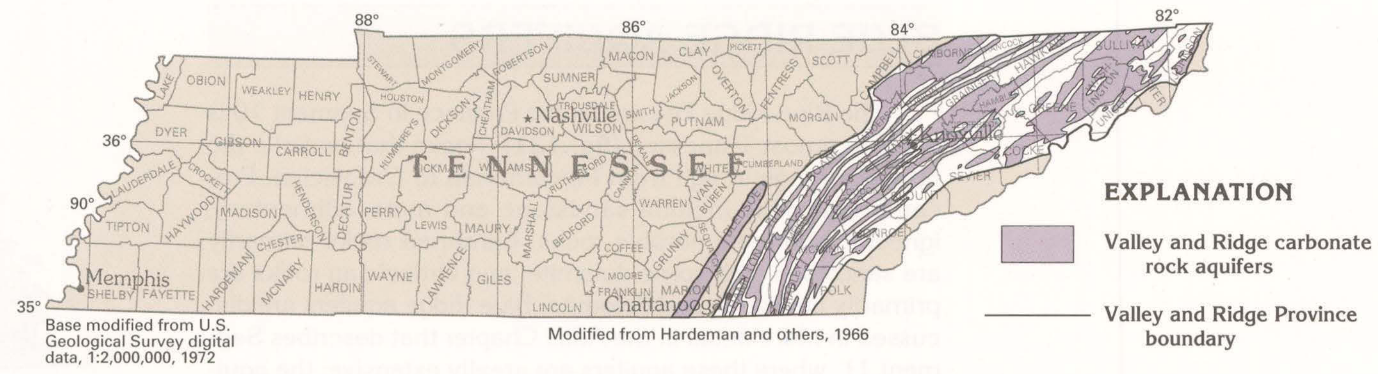


Figure 115. *The Valley and Ridge aquifers in Segment 10 are in eastern Tennessee. The isolated area west of the main body of the aquifers is the Sequatchie Valley, which has the same rocks and similar structures as the Valley and Ridge Physiographic Province.*

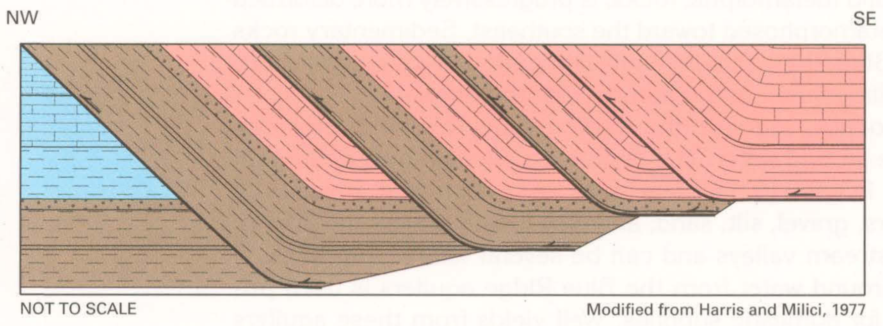


Figure 116. *The sequence of Cambrian and Ordovician formations that includes some of the carbonate-rock aquifers in the Valley and Ridge Province is repeated several times by thrust faults in eastern Tennessee. The Rome Formation, which is a confining unit, also is repeated. This repetition, combined with topography, results in many local ground-water flow systems.*

WELL YIELDS AND SPRING DISCHARGE

Yields of wells completed in the principal Valley and Ridge aquifers range from about 1 to 2,500 gallons per minute (**table 7**). The largest yields (2,500 gallons per minute) are reported for wells completed in the Honaker Dolomite of the Conasauga Group. Large yields also are reported for wells completed in limestone or dolomite of the middle and lower parts of the Chickamauga Group, the Knox Group, and the Shady Dolomite (all about 500 gallons per minute). The median yields of wells completed in the principal aquifers range from about 11 to 350 gallons per minute; the largest median yields are for wells in the Shady Dolomite (350 gallons per minute), the middle part of the Conasauga Group (100 gallons per minute), and the Newman Limestone (55 gallons per minute).

The discharges of springs that issue from the principal Valley and Ridge aquifers in eastern Tennessee vary greatly; measured discharges range from about 1 to 5,000 gallons per minute (**table 7**). The largest springs issue from the Newman Limestone and the Lenoir Limestone of the Chickamauga Group. Springs that issue from the Knox Group discharge as much as 4,000 gallons per minute. The median discharges of springs that issue from the principal aquifers range from 20 to 175 gallons per minute. The largest median discharges are from springs that issue from the Shady Dolomite (175 gallons per minute), the Knox Group (50 gallons per minute), and the upper part of the Conasauga Group (40 gallons per minute). Many springs discharge as much as 10 times more water during periods of abundant rainfall than during extended periods of little or no rainfall.

Table 7. *Yields of wells completed in the principal Valley and Ridge aquifers range from about 1 to 2,500 gallons per minute. The discharge of springs that issue from these aquifers ranges from about 1 to 5,000 gallons per minute*

[Data source: DeBuchananne and Richardson, 1956]

Aquifer and geologic unit	Well yield: Range	Well yield: Median	Well yield: Number of wells	Spring discharge: Range	Spring discharge: Median	Spring discharge: Number of springs
Mississippian aquifers:						
Newman Limestone	10 to 225	55	9	5 to 5,000	20	14
Fort Payne Formation	10 to 100	25	3	20 to 150	25	3
Ordovician aquifers:						
Lower and middle Chickamauga Group	2 to 500	15	111	1 to 5,000	20	141
Ordovician and Cambrian aquifers:						
Knox Group	1 to 500	11	204	1 to 4,000	50	435
Cambrian aquifers:						
Upper Conasauga Group	3 to 400	15	14	2 to 1,000	40	43
Middle Conasauga Group	3 to 2,500	100	23	1 to 1,000	20	60
Shady Dolomite	100 to 500	350	3	2 to 2,000	175	10

Yield or discharge (gallons per minute)

GROUND-WATER QUALITY

The chemical quality of water in the freshwater parts of the Valley and Ridge aquifers is similar for shallow wells and springs (**fig. 119**). The water is hard, is a calcium magnesium bicarbonate type, and typically has a dissolved-solids concentration of 170 milligrams per liter or less. The ranges of concentrations are thought to be indicators of the depth and rate at which ground water flows through the carbonate-rock aquifers. In general, the smaller values for a constituent represent water that is moving rapidly along shallow, short flow paths from recharge areas to points of discharge. This water has been in the aquifers for a short time and has accordingly dissolved only small quantities of aquifer material. Conversely, the larger values represent water that is moving more slowly along deep, long flow paths. Such water has been in contact with aquifer minerals for a longer time and thus has had greater opportunity to dissolve the minerals. Also, water that moves into deeper parts of the aquifers can mix with saltwater that might be present at depth.

In places where the residuum that overlies the carbonate rocks is thin, the Valley and Ridge aquifers are susceptible to contamination by human activities. The complex network of fractures, bedding planes, and solution openings developed in the carbonate rocks allows rapid local ground-water movement. The natural ground-water quality is subject to degradation in places where landfills and other waste-disposal sites, underground storage tanks, and septic tank systems are located.

Mississippian, Ordovician, and Cambrian aquifers in Tennessee

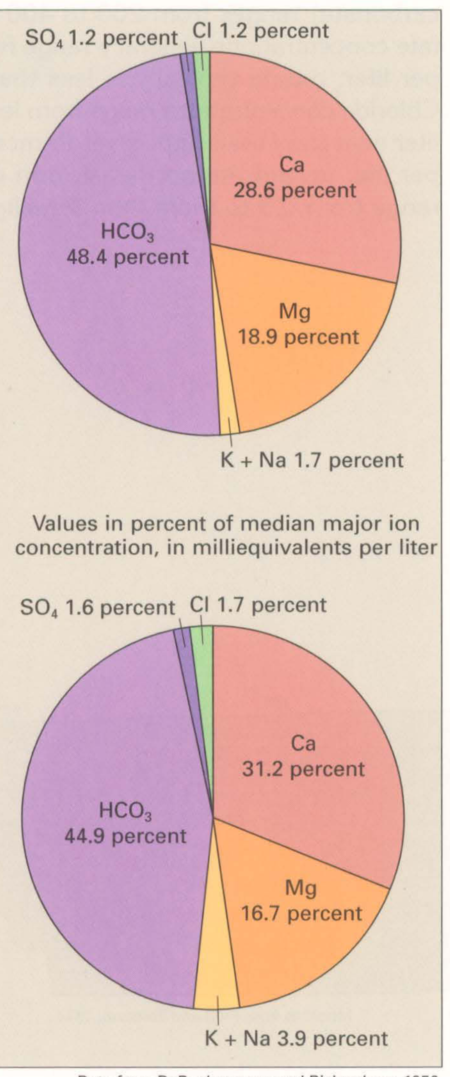
Concentrations in milligrams per liter

A. Water from wells

Constituent	Range	Median	Number of samples
Hardness ($CaCO_3$)	5 to 475	150	148
Calcium (Ca)	2 to 140	40	140
Magnesium (Mg)	1 to 75	13	137
Sodium (Na) and potassium (K)	1 to 100	6	107
Bicarbonate (HCO_3)	6 to 500	175	149
Sulfate (SO_4)	1 to 99	5	144
Chloride (Cl)	1 to 680	4	146
Dissolved solids	15 to 1,700	170	150
Nitrate (NO_3)	1 to 40	5	60
Iron (Fe)	0.01 to 28	0.07	146

B. Water from springs

Constituent	Range	Median	Number of samples
Hardness ($CaCO_3$)	15 to 275	135	72
Calcium (Ca)	12 to 70	30	82
Magnesium (Mg)	2 to 33	12	86
Sodium (Na) and potassium (K)	1 to 54	2	57
Bicarbonate (HCO_3)	20 to 300	155	77
Sulfate (SO_4)	1 to 95	3	81
Chloride (Cl)	1 to 14	2	81
Dissolved solids	25 to 300	150	78
Nitrate (NO_3)	1 to 14	3	43
Iron (Fe)	0.01 to 9	0.07	77



Data from DeBuchananne and Richardson, 1956

Figure 119. *Water quality is similar for wells (A) and springs (B) in the principal Valley and Ridge aquifers. The water typically is a calcium magnesium bicarbonate type.*

FRESH GROUND-WATER WITHDRAWALS

Fresh ground-water withdrawals from the aquifers in the Valley and Ridge Province in eastern Tennessee were about 82 million gallons per day during 1985 (**fig. 120**). This amount constitutes about 16 percent of the ground water used in the State. About 31 million gallons per day was withdrawn for public supply, and about 20 million gallons per day was withdrawn for industrial, mining, and thermoelectric power purposes. About 19 million gallons per day was withdrawn for domestic and commercial supplies, and about 12 million gallons per day was withdrawn for agricultural use.

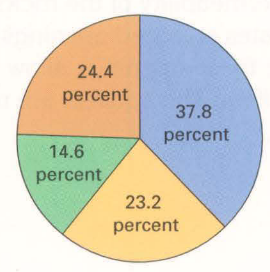


Figure 120. *Fresh ground-water withdrawals from the Valley and Ridge aquifers in Tennessee were about 82 million gallons per day during 1985. More water was withdrawn for public supply than for any other use.*

Blue Ridge, Ozark Plateaus, and Southeastern Coastal Plain aquifers

BLUE RIDGE AQUIFERS

The Blue Ridge Physiographic Province in Segment 10 is in easternmost Tennessee (**fig. 121**). Rocks that underlie the province range in age from Precambrian to Ordovician. Precambrian rocks include sandstone and metasedimentary, igneous, and metamorphic rocks. Cambrian rocks primarily are sandstone with some dolomite, and Ordovician rocks are primarily limestone and dolomite. Blue Ridge aquifers are discussed in more detail in the Atlas Chapter that describes Segment 11, where these aquifers are areally extensive; the aquifers are discussed briefly in the Chapters that describe Segments 6 and 12, where these aquifers locally are present.

Ground water in the Blue Ridge Physiographic Province generally is present in fractured bedrock. The bedrock, which consists of sedimentary, metasedimentary, and crystalline igneous and metamorphic rocks, is progressively more deformed and metamorphosed toward the southeast. Sedimentary rocks in the Blue Ridge Province primarily are well-cemented sandstone, limestone, and dolomite with minor shale.

Locally, regolith and stream-valley alluvium also can provide ground water. The bedrock is overlain by regolith that ranges from 1 to 150 feet thick. Alluvium that consists of boulders, gravel, silt, sand, and clay locally covers the floor of major stream valleys and can be several tens of feet thick.

Ground water from the Blue Ridge aquifers is used primarily for domestic supplies. Well yields from these aquifers are adequate for domestic, livestock, and small public supplies. The specific capacities of 13 wells finished in sandstone and phyllite in Great Smoky Mountains National Park, Tenn., range from 0.04 to 13 gallons per minute per foot of drawdown with a median of 0.57 gallon per minute per foot of drawdown. The yield of these wells ranges from less than 1 to about 125 gallons per minute with a median of 6 gallons per minute. Wells completed in Cambrian and Precambrian sandstone, metamorphic rocks, and crystalline rocks rarely have large yields, unless a well is open to major fracture zones.

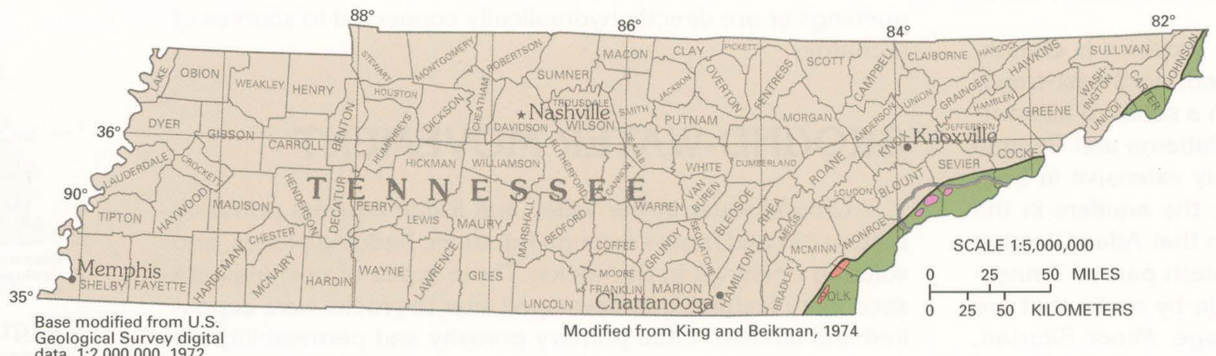
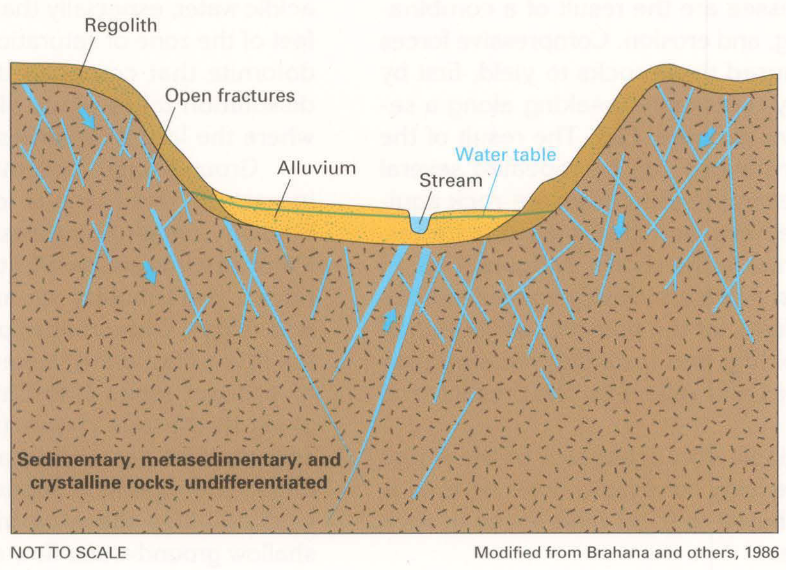


Figure 121. The Blue Ridge Physiographic Province in Segment 10 is in easternmost Tennessee. Rocks of Precambrian age underlie most of the province, but rocks of Cambrian and Ordovician age are locally present.

Figure 122. Most of the available water in the Blue Ridge aquifers is in fractures within a few hundred feet of land surface. The weight of the overlying rock tends to keep these fractures closed at depth; thus, regional ground-water flow is not significant.



GROUND-WATER OCCURRENCE

Ground-water occurrence in the Blue Ridge aquifers is determined by the number, size, and degree of interconnection of fractures. Rocks in the Blue Ridge Province generally are massive and have little or no primary porosity. The rocks generally are nonporous and impermeable except within a few hundred feet of land surface where fractures (present in all rock types) provide secondary permeability (**fig. 122**). Fractures are less common at depth and, therefore, regional ground-water flow is not significant. Most of the water available from these fractures is within about 300 feet of land surface. However, sparse data indicate that fresh ground water can be obtained locally from fractures as deep as 1,500 feet below land surface.

The saturated regolith that overlies the bedrock and the alluvium in major stream valleys store ground water and release it slowly into the bedrock fractures. The regolith and alluvium, which locally are aquifers, supply sufficient water for domestic wells. However, wells completed in regolith might go dry during late summer and early autumn when water levels usually decline because of a decrease in precipitation or increased withdrawals or both.

Ground-water circulation in the Blue Ridge aquifers is localized. Most of the ground water moves along short, shallow flow paths. Precipitation recharges the regolith and alluvium and then percolates downward into the bedrock aquifers. Discharge is to seeps and springs, as base flow to streams and rivers, and as withdrawals from wells. The amount of ground-water discharge to streams and rivers ranges between 400,000 and 800,000 gallons per day per square mile of area and averages about 600,000 gallons per day per square mile of area throughout the Blue Ridge. This large rate of discharge is controlled primarily by large quantities of precipitation and large infiltration rates.

GROUND-WATER QUALITY

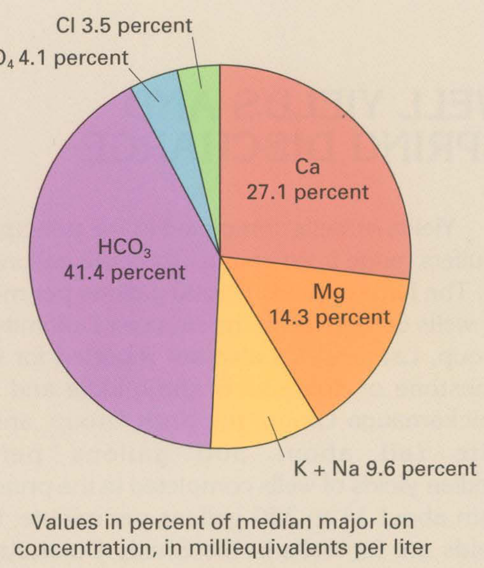
The chemical quality of the water in the Blue Ridge aquifers generally is suitable for most uses. Water from wells completed in sandstone aquifers (**fig. 123**) typically is a calcium magnesium bicarbonate type. Dissolved-solids concentrations are less than 300 milligrams per liter. Water from wells completed in crystalline rocks of Precambrian age has a smaller dissolved-solids concentration and is softer than water from wells completed in sandstone aquifers.

Figure 123. Ground water from sandstones of Precambrian and Cambrian age is a calcium magnesium bicarbonate type, with small concentrations of dissolved solids.

Cambrian and Precambrian sandstones in Tennessee

Concentrations in milligrams per liter

Constituent	Range	Median	Number of samples
Hardness ($CaCO_3$)	6.8 to 172	76	11
Calcium (Ca)	1 to 49	17	11
Magnesium (Mg)	0.3 to 15	5.5	11
Sodium (Na) and potassium (K)	2.8 to 58	7.2	11
Bicarbonate (HCO_3)	13 to 155	79	11
Sulfate (SO_4)	1 to 96	6	11
Chloride (Cl)	1.5 to 26	4	11
Dissolved solids	19 to 297	109	11



Values in percent of median major ion concentration, in milliequivalents per liter

Data from DeBuchananne and Richardson, 1956

OZARK PLATEAUS AQUIFER SYSTEM

Because only a small part of the Ozark Plateaus aquifer system is within Segment 10 (**fig. 124**), the aquifer system is only briefly summarized here. A complete description of the geology, hydrology, and water-quality of the aquifer system is presented in the Chapter of this Atlas that describes Segment 3.

The principal aquifers in consolidated rocks of the Ozark Plateaus aquifer system consist of limestone and minor dolomite of Mississippian through Ordovician age. Unconsolidated sand and gravel aquifers in Quaternary deposits overlie the aquifers in consolidated rocks along the Mississippi River and its tributaries.

Water in the limestone and dolomite aquifers of the Ozark Plateaus aquifer system primarily is stored in and moves through fractures and bedding planes because of the low primary porosity and permeability of the rocks. Dissolution of the carbonate rocks creates enlarged openings along the fractures and bedding planes; these openings allow water to move rapidly through the aquifers. The aquifers are recharged by downward leakage through overlying sand and gravel deposits and directly through fractures, sinkholes, and swallow holes where the aquifers crop out. Springs are common points of discharge for the limestone and dolomite aquifers.

Yields of wells completed in the Ozark Plateaus aquifer system in Illinois generally are less than 25 gallons per minute but might be several hundred gallons per minute where well withdrawals induce additional recharge from nearby springs or streams. Yields of wells completed in the consolidated rocks that contain some sand and shale commonly are less than those of wells completed in limestone and dolomite.

Water from wells completed in the Ozark Plateaus aquifer system is hard and is a calcium magnesium bicarbonate type. Dissolved-solids concentrations generally range from 350 to 1,000 milligrams per liter and increase toward the northeast as the aquifers dip into the Illinois Basin. Hardness (as calcium carbonate) ranges from 200 to 400 milligrams per liter; sulfate concentrations generally range from 25 to 125 milligrams per liter; nitrate typically is less than 5 milligrams per liter. Chloride concentrations range from less than 50 milligrams per liter near the Mississippi River to more than 1,000 milligrams per liter toward the northeast. Iron concentrations generally range from 0.3 to more than 5 milligrams per liter.

Figure 124. A small part of the consolidated rocks that compose the Ozark Plateaus aquifer system is present in the southwestern part of Illinois in Segment 10. These rocks consists primarily of limestone and dolomite of Mississippian through Ordovician age.

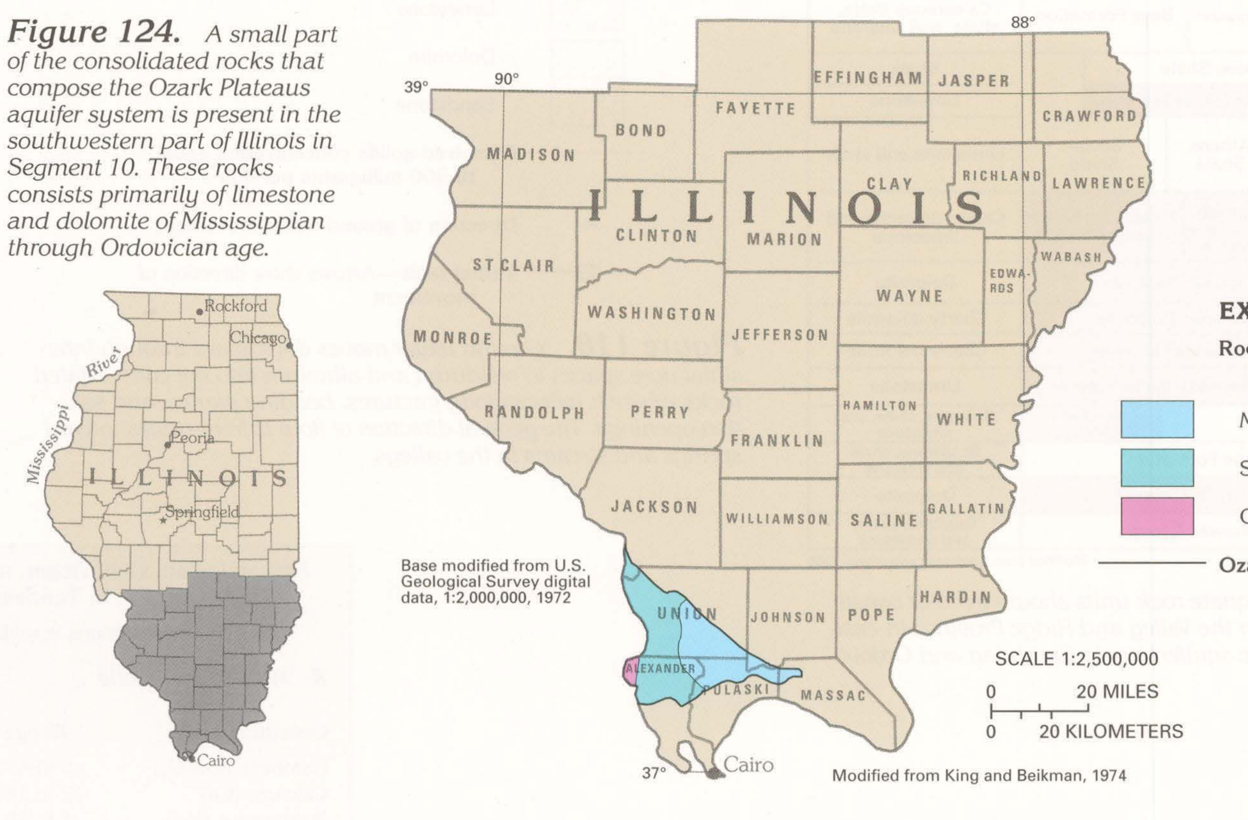
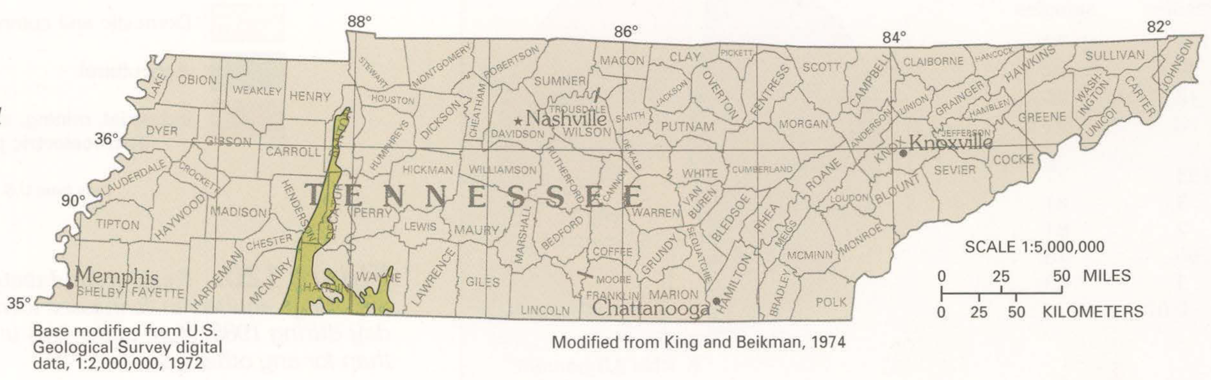


Figure 125. Semiconsolidated clastic sediments of the Southeastern Coastal Plain aquifer system underlie a small area in western Tennessee. Although the aquifer system is thin, sand beds of the system provide a limited quantity of water to wells.



SOUTHEASTERN COASTAL PLAIN AQUIFER SYSTEM

The part of the Southeastern Coastal Plain aquifer system within Segment 10 is restricted to small areas in portions of six counties in western Tennessee (**fig. 125**) The aquifer system extends into Segments 5 and 6, and is discussed in detail in the chapter of this Atlas that describes the aquifers in Segment 6, where the aquifer system is most extensive.

The Southeastern Coastal Plain aquifer system is divided into four regional aquifers, which consist mostly of semiconsolidated sand, separated by three regional confining units of clay, mudstone, and chalk. Only the lowermost regional aquifer, called the Black Warrior River aquifer, and its overlying confining unit are present in Tennessee. The Black Warrior River aquifer consists of Late Cretaceous sands of fluvial and deltaic origin, interbedded with clay and minor gravel. The geologic units that compose the aquifer are primarily the Tuscaloosa and the Eutaw Formations and the Coffee Sand.

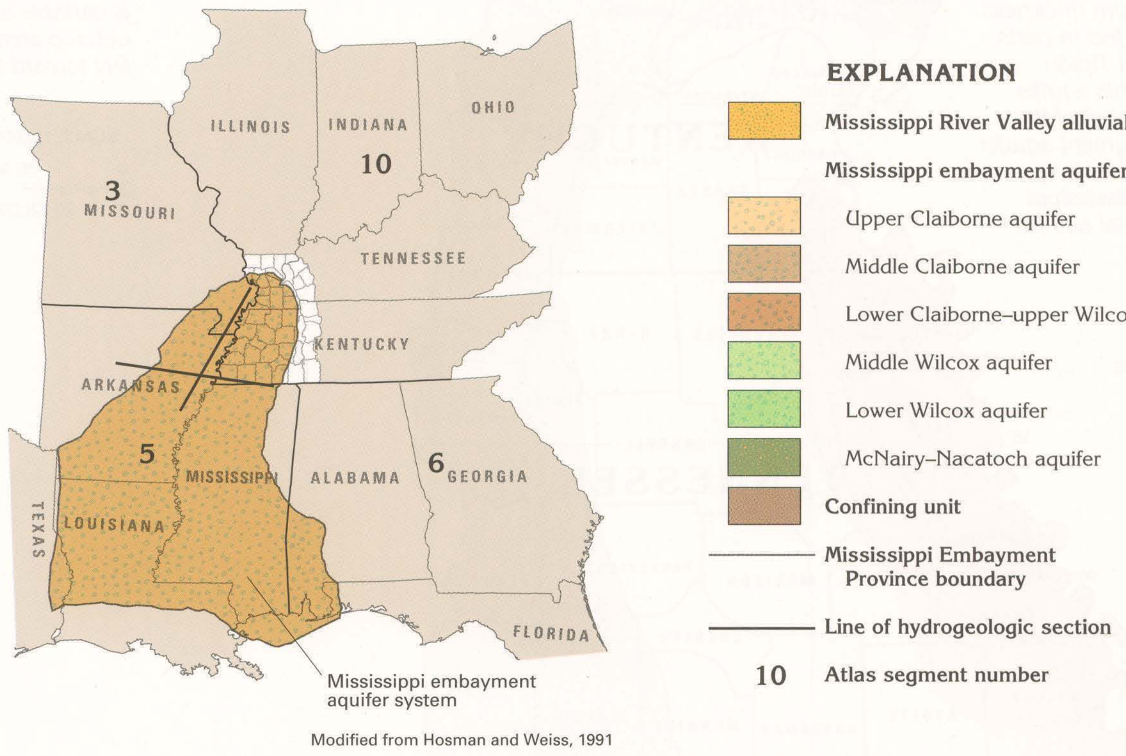
Water enters the Black Warrior River aquifer in upland recharge areas and moves westward and southwestward, down the dip of the sand beds, to discharge to streams. A small amount of the water moves into deep, confined parts of the aquifer. The water is stored in and moves through intergranular pore spaces. Water generally is present under unconfined conditions in and near aquifer recharge areas except where lenses of clay form local confining beds.

Although the Black Warrior River aquifer is moderately permeable, the aquifer is thin, and its transmissivity is accordingly moderate. Estimated transmissivity values for the part of the aquifer in Tennessee are 5,000 feet squared per day or less. Yields of wells completed in the aquifer generally are less than 50 gallons per minute, but, locally, yields of as much as 300 gallons per minute have been reported.

Water from the Black Warrior River aquifer is hard to moderately hard and is a calcium bicarbonate type. Dissolved-solids concentrations in water from the aquifer are small because the silica minerals that compose the aquifer do not readily dissolve. Locally, objectionable concentrations of iron have been reported.

INTRODUCTION

The aquifers that compose the Mississippi embayment aquifer system (**fig. 126**) are located in the southwestern part of Segment 10 on the eastern side of the Mississippi Embayment section of the Coastal Plain Physiographic Province. These aquifers consist of unconsolidated to semiconsolidated sediments that range in age from Late Cretaceous through late Eocene. They are a major source of freshwater, whereas consolidated rocks of Ordovician through Precambrian age that underlie these aquifers contain saltwater. The Mississippi embayment aquifer system is present in parts of Alabama, Arkansas, Florida, Illinois, Kentucky, Louisiana, Mississippi, Missouri, and Tennessee. It is areally extensive in Segment 5 and is discussed in greater detail in the Atlas Chapter describing that segment.



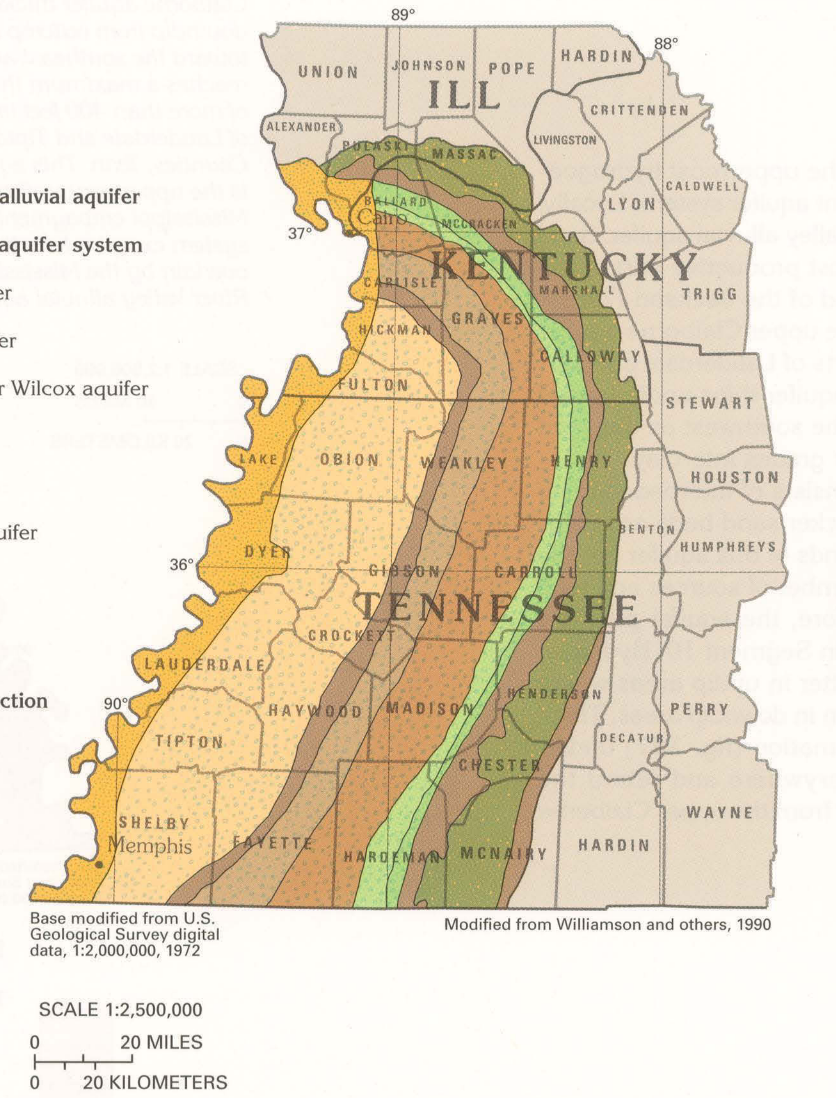


Figure 126. *The aquifers and confining units of the Mississippi embayment aquifer system crop out in a sequence of arcuate bands in westernmost Kentucky and Tennessee and in southernmost Illinois. The aquifers are exposed on the east flank of the Mississippi Embayment, which is a large structural downwarp in the Coastal Plain Physiographic Province.*

HYDROGEOLOGIC UNITS

Six aquifers and two confining units compose the Mississippi embayment aquifer system in Segment 10 (**fig. 127**). The Mississippi River Valley alluvial aquifer, which consists of sediments of Quaternary age, is present in a narrow band along the Mississippi River (**fig. 126**); it overlies the Mississippi embayment aquifer system and is in hydraulic contact with the system. East of this band, the five aquifers in Tertiary rocks that compose the Mississippi embayment aquifer system cover a wide part of the Coastal Plain of Kentucky and Tennessee. In descending order, these aquifers are the upper Claiborne aquifer (which is underlain by the middle Claiborne confining unit), the middle Claiborne aquifer, the lower Claiborne–upper Wilcox aquifer, the middle Wilcox aquifer, and the lower Wilcox aquifer. The McNairy–Nacatoch aquifer, which lies beneath the Midway confining unit, consists of sediments of Cretaceous age and occurs as a band at or near the eastern edge of the Coastal Plain Province in Illinois, Kentucky, and Tennessee.

The aquifers in the Mississippi embayment aquifer system are defined on the basis of changes in lithology and hydraulic head (water level) between aquifers. Some of these aquifers are separated by areally extensive confining units—the middle Claiborne and the Midway confining units (**fig. 127**)—that consist of fine-grained sediments that restrict the vertical movement of water between aquifers. Other aquifers that are not separated by confining units contain interbedded fine-grained sediments that restrict vertical flow within and between the aquifers.

Extensive and massive beds of sand characterize the Mississippi embayment aquifer system. These beds thin and pinch out along the updip limit of the Mississippi Embayment. Aquifers in the Mississippi embayment aquifer system thicken toward the center of the embayment (**fig. 128**) and toward the southwest parallel to the axis of the embayment (**fig. 129**). Although the McNairy–Nacatoch aquifer is present throughout the part of the Mississippi Embayment that is within Segment 10, it pinches out toward the southwest. The Mississippi embayment aquifer system overlies consolidated sedimentary rocks of Paleozoic age or clay and chalk of Cretaceous age that are much less permeable than the sediments of the aquifer system.

The tops of the aquifers in Tertiary and Cretaceous rocks slope toward the axis of the Mississippi Embayment; for example, the top of the lower Wilcox aquifer (**fig. 130**) is at an altitude of about 300 feet along much of the area where the aquifer crops out. Near the center of the Mississippi Embayment, however, the top of the aquifer is more than 1,000 feet below sea level. The troughlike configuration of the aquifers generally is more evident for the deeper aquifers than for the shallower ones (**fig. 128**).

Mississippi River Valley Alluvial Aquifer

The Mississippi River Valley alluvial aquifer is present only along the Mississippi River in Segment 10. The alluvial aquifer consists primarily of Quaternary sediments that range from clay to coarse gravel. The sediments commonly grade downward from fine sand, silt, or clay at the top to coarse sand or gravel at the base. These sediments reach a maximum thickness of about 100 feet and have a total thickness of sand and gravel of about 80 feet in northwestern Tennessee and western Kentucky.

The Mississippi River Valley alluvial aquifer is capable of sustaining well yields of several thousand gallons per minute because it is hydraulically connected to the Mississippi River. Thus, recharge may be induced from the river to the aquifer in places where pumping wells located near the river have lowered the water level in the aquifer below that of the river. However, this aquifer is not a major source of ground water in Segment 10 because of its small areal extent. Where the alluvial aquifer covers aquifers in Tertiary rocks, there is direct hydraulic connection between the alluvial aquifer and the underlying aquifers.

System	Series	Geologic unit: Illinois	Geologic unit: Kentucky	Geologic unit: Tennessee	General lithology	Hydrogeologic unit[1]	
Quaternary	Holocene and Pleistocene	Alluvium and terrace deposits	Alluvium and loess deposits	Alluvium and loess deposits	Sand, gravel, and loess	Mississippi River Valley alluvial aquifer	
Tertiary	Eocene	(gray area)	Jackson Formation	Jackson Formation	Sand, silt, and clay	Upper Claiborne aquifer	Mississippi embayment aquifer system
			Claiborne Group: Cockfield Formation	Claiborne Group: Cockfield Formation			
			Claiborne Group: Cook Mountain Formation	Claiborne Group: Cook Mountain Formation	Clay and silt	Middle Claiborne confining unit	
			Claiborne Group: Sparta Sand	Claiborne Group: Memphis Sand		Middle Claiborne aquifer	
			Claiborne Group: Tallahatta Formation		Sand and minor clay. Some lignite	Lower Claiborne–upper Wilcox aquifer	
		Wilcox Formation	Wilcox Formation	Wilcox Group: Flour Island Formation			
	Paleocene			Wilcox Group: Fort Pillow Sand		Middle Wilcox aquifer	
				Wilcox Group: Old Breastworks Formation		Lower Wilcox aquifer	
		Midway Group: Porters Creek Clay	Midway Group: Porters Creek Clay	Midway Group: Porters Creek Clay	Clay and minor sand	Midway confining unit	
		Midway Group: Clayton Formation	Midway Group: Clayton Formation	Midway Group: Clayton Formation			
Cretaceous	Upper	McNairy Sand	McNairy Sand	McNairy Sand	Sand	McNairy–Nacatoch aquifer	
		Nacatoch Sand	Nacatoch Sand	Nacatoch Sand			

[1]Hydrogeologic unit names apply to the entire Mississippi embayment aquifer system. Local names may differ.

Data from Brahana and others, 1986; Hosman and Weiss, 1991; Parks and Carmichael, 1990; Williamson and others, 1990

Figure 127. *Geologic units that range in age from Late Cretaceous to late Eocene are separated into regional aquifers and confining units that compose the Mississippi embayment aquifer system. Not all the aquifers are separated by confining units; rather, fine-grained material in the lower parts of some aquifers restricts vertical ground-water movement. The gray area represents missing rocks.*

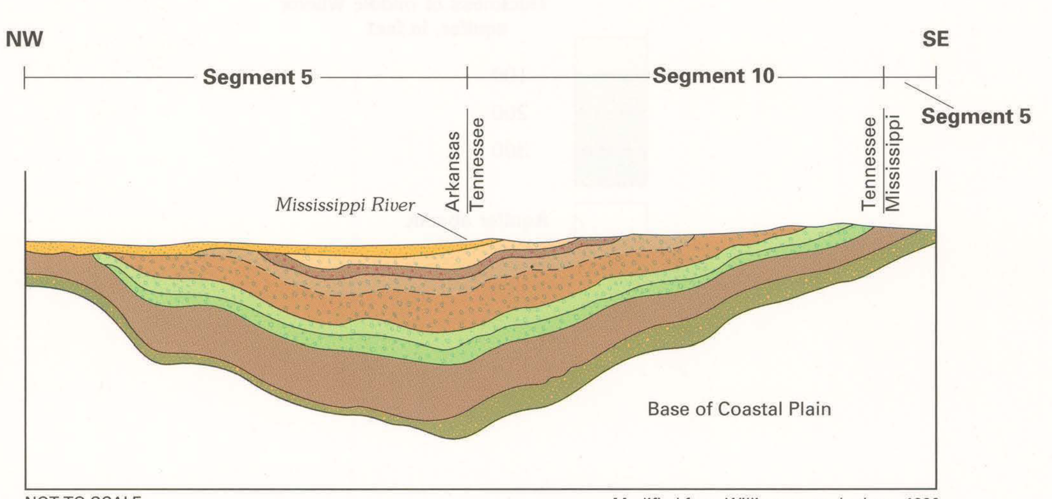
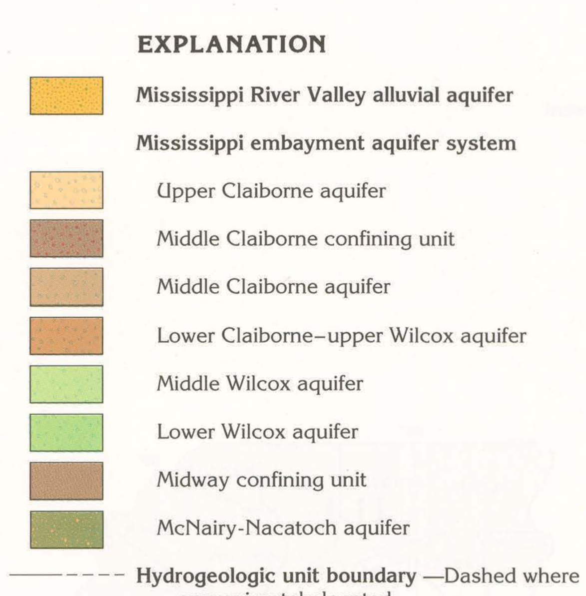


Figure 128. *The Mississippi embayment aquifer system in Kentucky and Tennessee thickens toward the west; the thickest part underlies the Mississippi River. The aquifers in rocks of Cretaceous and Tertiary age are exposed at land surface in most of Tennessee but are covered by Quaternary sediments that compose the Mississippi River Valley alluvial aquifer in westernmost Tennessee and in Arkansas. The approximate location of of this generalized section is shown in figure 126.*



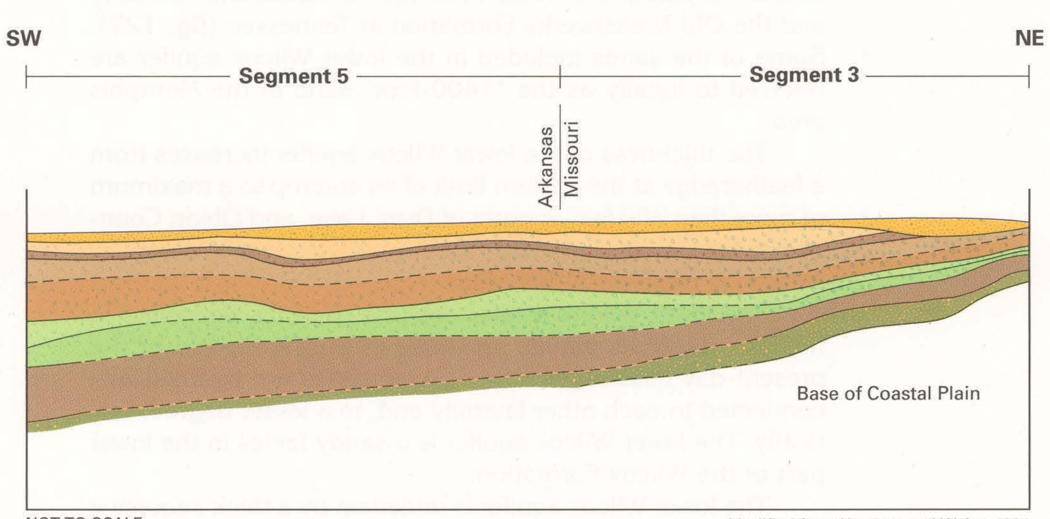
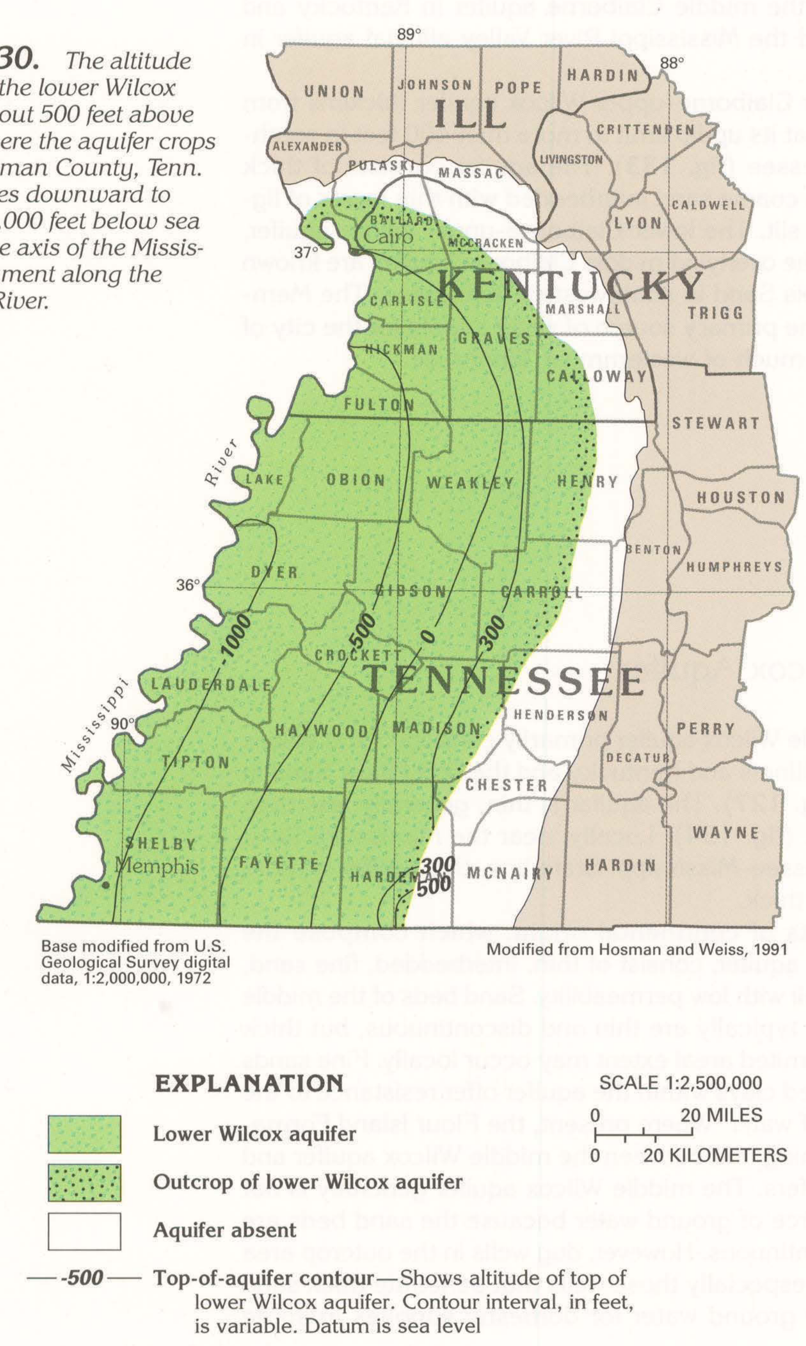


Figure 129. *The Mississippi embayment aquifer system thickens toward the southwest. The McNairy–Nacatoch aquifer, which is present throughout the part of the Mississippi Embayment that is within Segment 10, pinches out toward the southwest. The approximate location of the line of this generalized section is shown in figure 126.*

Figure 130. *The altitude of the top of the lower Wilcox aquifer is about 500 feet above sea level where the aquifer crops out in Hardeman County, Tenn. The top slopes downward to more than 1,000 feet below sea level near the axis of the Mississippi Embayment along the Mississippi River.*



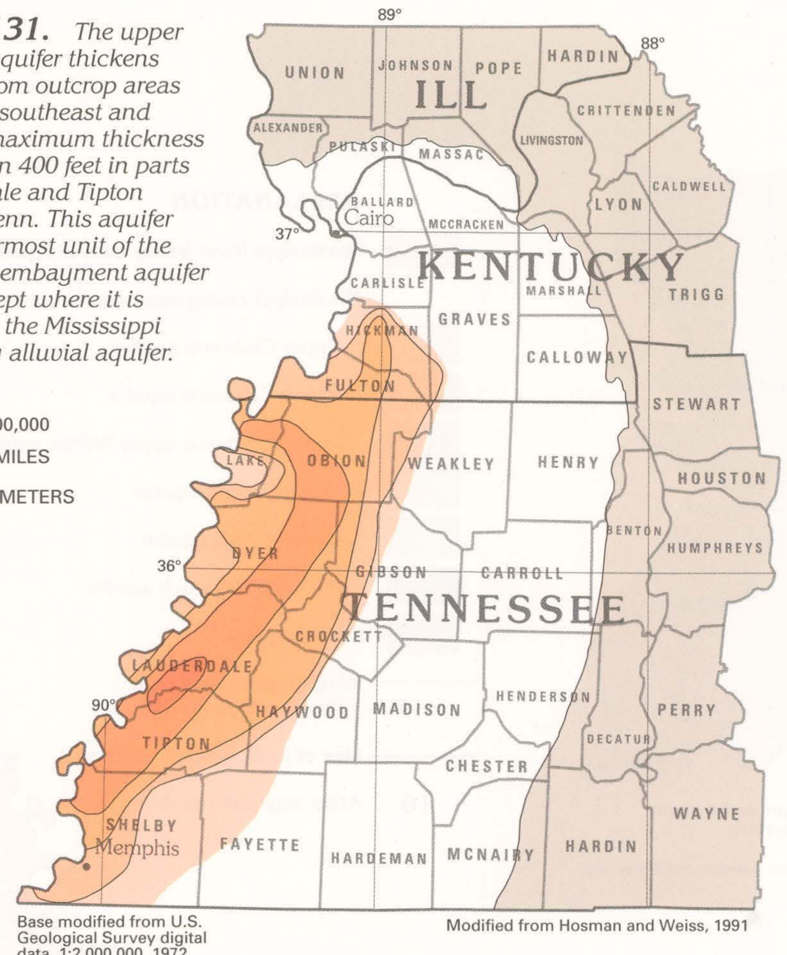
Mississippi Embayment Aquifer System

Upper Claiborne Aquifer

The upper Claiborne aquifer is the uppermost hydrogeologic unit of the Mississippi embayment aquifer system. Locally, it is overlain by the Mississippi River Valley alluvial aquifer. Sand of the Cockfield Formation is the most productive part of the upper Claiborne aquifer; locally, sand of the Jackson Formation also is productive (**fig. 127**). The upper Claiborne aquifer thickens to more than 400 feet in parts of Lauderdale and Tipton Counties, Tenn. (**fig. 131**). The aquifer thins updip toward outcrop areas and downdip toward the southwest as the sand that composes the aquifer gradually grades into clay.

The upper Claiborne aquifer consists of interbedded fine sand, silt, clay, and some lignite; thicker sand beds are common near the base of the aquifer. Sands of this aquifer are the result of fluvial deposition from a number of sources and tend to be of limited areal extent. Therefore, the aquifer provides only small supplies of ground water in Segment 10. Hydraulic connection between the sands is better in updip areas where intervening clay layers are thinner than in downdip areas. Thick clay beds of the Cook Mountain Formation (**fig. 127**) underlie the upper Claiborne aquifer everywhere and retard the downward movement of ground water from the upper Claiborne aquifer to deeper aquifers.

Figure 131. *The upper Claiborne aquifer thickens downdip from outcrop areas toward the southeast and reaches a maximum thickness of more than 400 feet in parts of Lauderdale and Tipton Counties, Tenn. This aquifer is the uppermost unit of the Mississippi embayment aquifer system except where it is overlain by the Mississippi River Valley alluvial aquifer.*



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

Modified from Hosman and Weiss, 1991

EXPLANATION

Thickness of upper Claiborne aquifer, in feet

- 100
- 200
- 300
- 400
- Aquifer absent

Figure 132. *The middle Claiborne aquifer is a major source of water in Segment 10. The thickness of this aquifer is variable and increases from outcrop areas to more than 200 feet toward the southwest.*

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

Modified from Williamson and others, 1990

EXPLANATION

Thickness of middle Claiborne aquifer, in feet

- Less than 200
- Greater than 200
- Aquifer absent

Middle Claiborne Aquifer

The middle Claiborne aquifer is a major source of ground water in the Mississippi embayment aquifer system in Segment 10. This aquifer primarily consists of the Sparta Sand in Kentucky (**fig. 127**) and the upper part of the Memphis Sand in Tennessee. The lower part of the Memphis Sand is considered to be part of the regional lower Claiborne–upper Wilcox aquifer. The middle Claiborne aquifer includes sands of the Tallahatta Formation in Kentucky.

The thickness of the middle Claiborne aquifer is variable (**fig. 132**). Sands of the middle Claiborne aquifer are derived from continental sources and are thick and massive with few or no clay layers. Therefore, these sands are hydraulically well connected, which allows large quantities of water to be withdrawn from the aquifer.

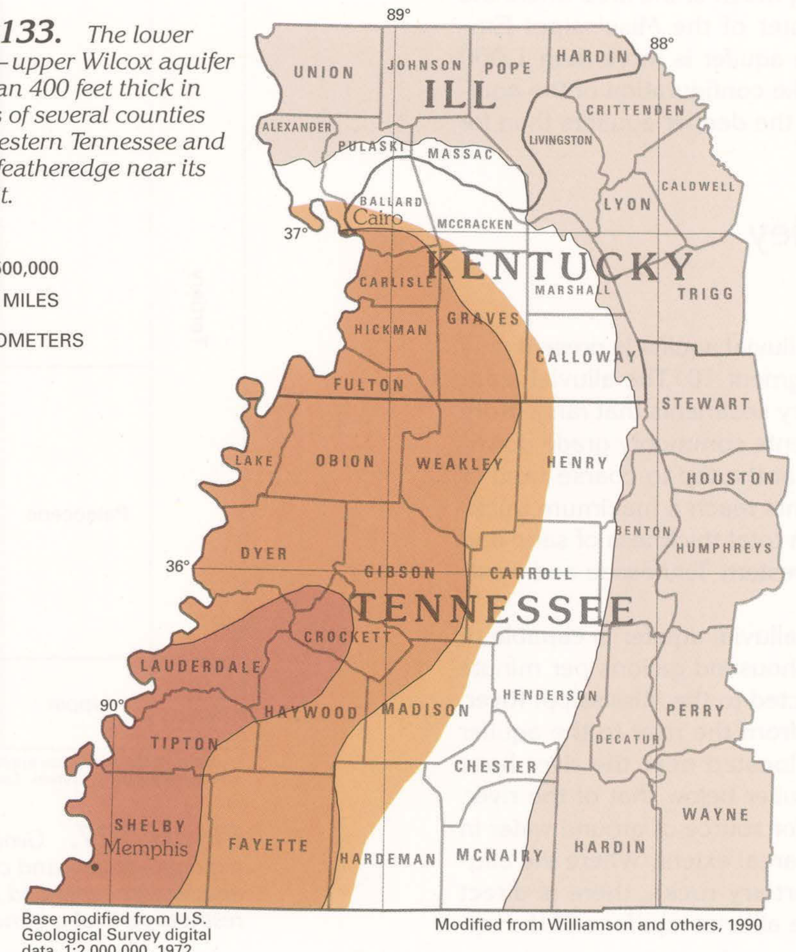
The middle Claiborne aquifer is in direct hydraulic connection with the underlying lower Claiborne–upper Wilcox aquifer in Tennessee and Kentucky. No confining unit separates the aquifers in these States. Farther downdip, however, an effective confining unit called the lower Claiborne confining unit retards the vertical movement of the water between these two aquifers. Because the lower Claiborne confining unit is extensive in Segment 5, it is discussed in more detail in the Atlas Chapter which describes that segment.

Lower Claiborne–Upper Wilcox Aquifer

The lower Claiborne–upper Wilcox aquifer in Illinois and Kentucky consists of the upper part of the Wilcox Formation (**fig. 127**). In Tennessee, the aquifer consists of the lower part of the Memphis Sand. The Flour Island Formation in Tennessee is consists of silt and clay and forms a local confining unit that separates the lower Claiborne–upper Wilcox aquifer from the underlying middle Wilcox aquifer. The lower Claiborne–upper Wilcox aquifer is directly overlain by and is hydraulically connected to the middle Claiborne aquifer in Kentucky and Tennessee and the Mississippi River Valley alluvial aquifer in Illinois.

The lower Claiborne–upper Wilcox aquifer thickens from a featheredge at its updip limit to more than 400 feet in southwestern Tennessee (**fig. 133**). The aquifer consists of thick beds of fine to coarse sand interbedded with thin layers of lignite, clay, and silt. The lower Claiborne–upper Wilcox aquifer, coupled with the overlying middle Claiborne aquifer, are known as the Memphis Sand in southwestern Tennessee. The Memphis Sand is the primary source of water supply for the city of Memphis and much of westernmost Tennessee.

Figure 133. *The lower Claiborne–upper Wilcox aquifer is more than 400 feet thick in large parts of several counties in southwestern Tennessee and thins to a featheredge near its updip limit.*



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

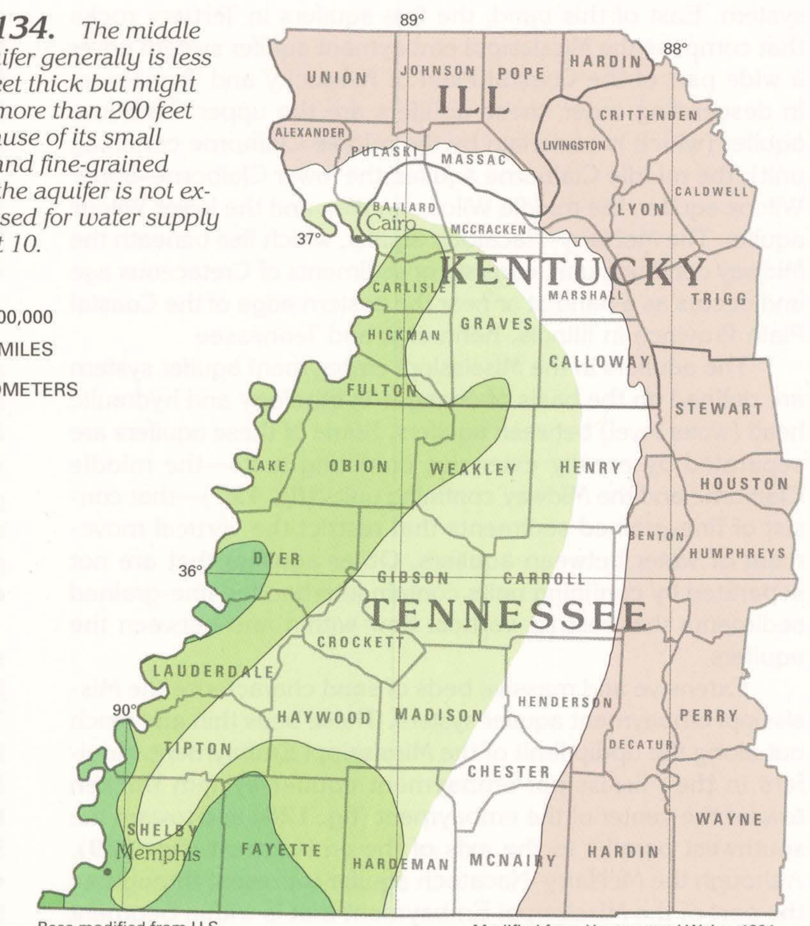
Modified from Williamson and others, 1990

EXPLANATION

Thickness of lower Claiborne–upper Wilcox aquifer, in feet

- 200
- 400
- Aquifer absent

Figure 134. *The middle Wilcox aquifer generally is less than 100 feet thick but might locally be more than 200 feet thick. Because of its small thickness and fine-grained character, the aquifer is not extensively used for water supply in Segment 10.*



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

Modified from Hosman and Weiss, 1991

EXPLANATION

Thickness of middle Wilcox aquifer, in feet

- 100
- 200
- 300
- Aquifer absent

Middle Wilcox Aquifer

The middle Wilcox aquifer primarily consists of the Wilcox Formation in Illinois and Kentucky and the Fort Pillow Sand in Tennessee (**fig. 127**). The aquifer is thin, generally less than 200 feet thick (**fig. 134**). Locally, near the Mississippi River and the Tennessee–Mississippi State line, the aquifer is more than 200 feet thick.

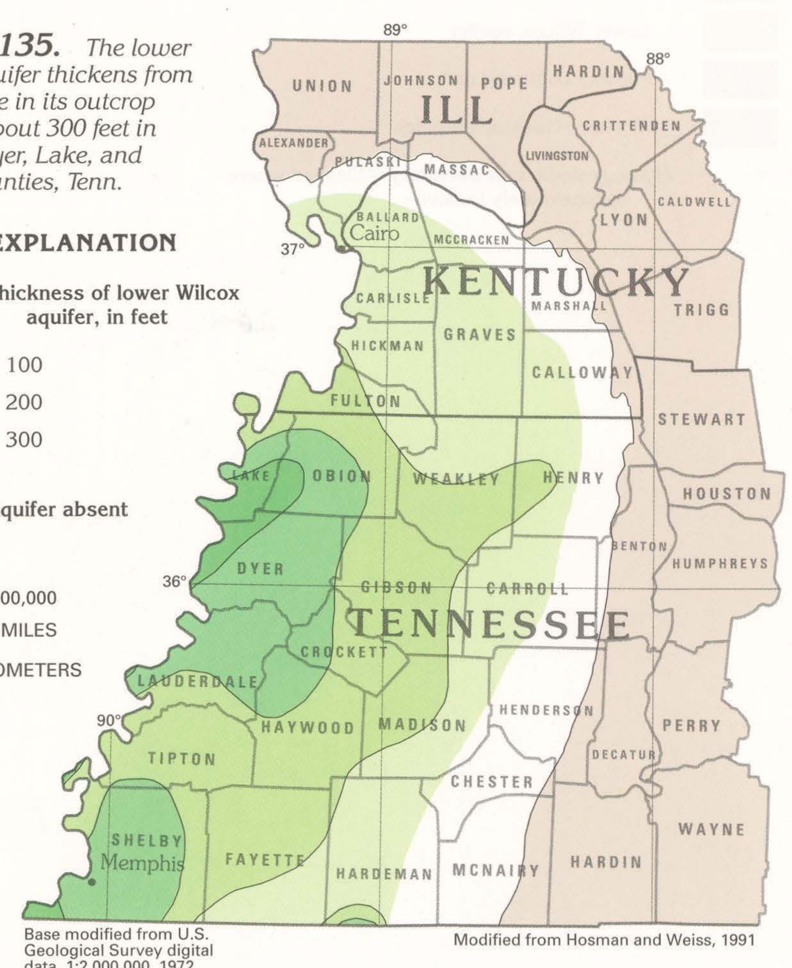
Sediments of continental origin, which compose the middle Wilcox aquifer, consist of thin, interbedded, fine sand, silt, and clay, all with low permeability. Sand beds of the middle Wilcox aquifer typically are thin and discontinuous, but thick sand beds of limited areal extent may occur locally. Fine sands and interbedded clays within the aquifer offer resistance to the vertical flow of water. Where present, the Flour Island Formation is a confining unit between the middle Wilcox aquifer and overlying aquifers. The middle Wilcox aquifer generally is not used as a source of ground water because the sand beds are thin and discontinuous. However, dug wells in the outcrop area of the aquifer, especially those wells that penetrate thick sand beds, provide ground water for domestic supplies in some areas.

Figure 135. *The lower Wilcox aquifer thickens from a thin edge in its outcrop areas to about 300 feet in parts of Dyer, Lake, and Obion Counties, Tenn.*

EXPLANATION

Thickness of lower Wilcox aquifer, in feet

- 100
- 200
- 300
- Aquifer absent



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

Modified from Hosman and Weiss, 1991

Lower Wilcox Aquifer

The lower Wilcox aquifer directly underlies the middle Wilcox aquifer and is the lowermost aquifer in Tertiary rocks in the Mississippi embayment aquifer system. This aquifer consists of part of the Wilcox Formation in Illinois and Kentucky and the Old Breastworks Formation in Tennessee (**fig. 127**). Some of the sands included in the lower Wilcox aquifer are referred to locally as the "1400-foot" sand in the Memphis area.

The thickness of the lower Wilcox aquifer increases from a featheredge at the eastern limit of its outcrop to a maximum of more than 300 feet in parts of Dyer, Lake, and Obion Counties in Tennessee (**fig. 135**). Total sand thickness in the aquifer also is greatest in this area.

The lower Wilcox aquifer consists of sands deposited in fluvial conditions similar to those in the floodplain of the present-day Mississippi River. These sands are hydraulically connected to each other laterally and, to a lesser degree, vertically. The lower Wilcox aquifer is a sandy facies in the lower part of the Wilcox Formation.

The lower Wilcox aquifer is underlain by a thick sequence of marine clay beds known as the Midway confining unit (**fig. 127**). This confining unit hydraulically separates the lower Wilcox aquifer from underlying aquifers in Cretaceous rocks, except locally where the confining unit is thin.

McNairy–Nacatoch Aquifer

The McNairy–Nacatoch aquifer is in Upper Cretaceous rocks and is the lowermost hydrogeologic unit included in the Mississippi embayment aquifer system (**fig. 127**). The McNairy–Nacatoch aquifer is included in the aquifer system because of the local hydraulic connection between this aquifer and the overlying aquifers in Tertiary rocks in the northern part of the Mississippi Embayment where the Midway confining unit is thin. However, the McNairy–Nacatoch aquifer appears to be hydraulically separated from the overlying aquifers throughout most of the Mississippi Embayment. The McNairy–Nacatoch aquifer primarily consists of the McNairy Sand in Segment 10 but also includes the Nacatoch Sand. Other underlying sands of Late Cretaceous age, including the Coffee Sand and sand beds in the Demopolis, the Eutaw, and the Tuscaloosa Formations, are discontinuous in Segment 10. The McNairy–Nacatoch aquifer thickens from less than 50 feet near its updip limit to a maximum of more than 400 feet (**fig. 136**). Sand in the McNairy–Nacatoch aquifer is present as a single thick bed or as two or more thick sand beds separated by thin clay or marl layers. The sand facies locally is overlain by clay and marl of Late Cretaceous age, which, in turn, are overlain by clays of the Midway confining unit. The clean, fine sands change laterally to clay, marl, and limestone toward the southwest and are accompanied by calcareous cementation that fills the pore space between sand grains and greatly reduces the permeability of the sand. This abrupt facies change is in Mississippi, south of Segment 10.

Figure 136. *The McNairy–Nacatoch aquifer thins toward its outcrop area from a maximum thickness of more than 400 feet in western Tennessee. Facies change to clay and other low-permeability materials is responsible for the aquifer thinning to the south and southwest.*

SCALE 1:2,500,000
0 20 MILES
0 20 KILOMETERS

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

Modified from Hosman and Weiss, 1991

EXPLANATION

Thickness of McNairy–Nacatoch aquifer, in feet
200
400

Aquifer absent

—400— **Line of equal thickness of McNairy–Nacatoch aquifer**—Interval 50 feet

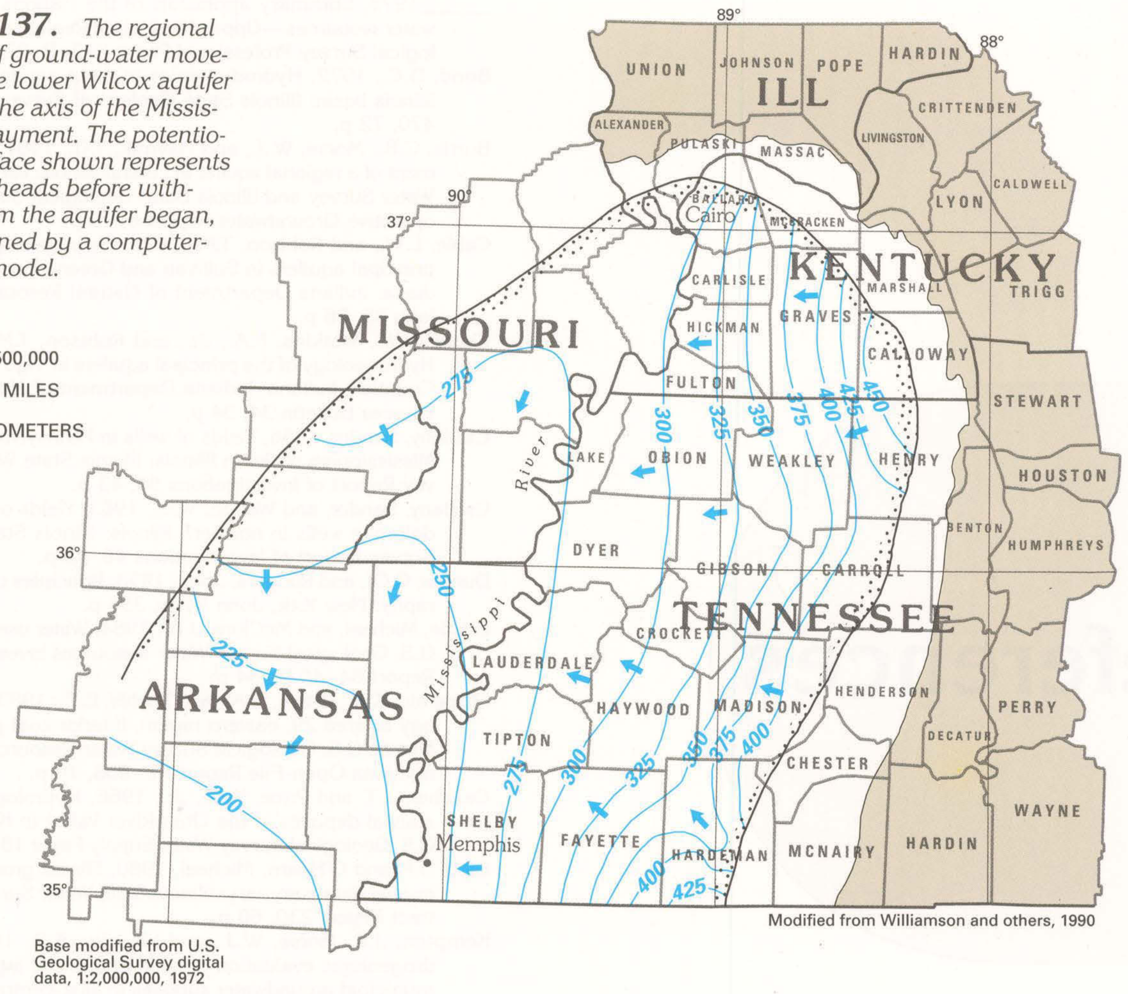


Figure 137. *The regional direction of ground-water movement in the lower Wilcox aquifer is toward the axis of the Mississippi Embayment. The potentiometric surface shown represents hydraulic heads before withdrawal from the aquifer began, as determined by a computerized flow model.*

SCALE 1:2,500,000
0 20 MILES
0 20 KILOMETERS

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

Modified from Williamson and others, 1990

EXPLANATION

Outcrop of lower Wilcox aquifer

—400— **Potentiometric contour**—Shows altitude at which water level would have stood in tightly cased wells before development. Contour interval 25 feet. Datum is sea level

Direction of ground-water movement

Approximate limit of aquifer

Ground-Water Movement

The principal aquifers in the Mississippi embayment aquifer system that are used for water supply in Segment 10 are the middle Claiborne, the lower Wilcox, and the McNairy–Nacatoch aquifers. The middle Claiborne and the lower Wilcox aquifers are recharged by precipitation on aquifer outcrop areas and by downward leakage from overlying aquifers. Because the outcrop area of the lower Wilcox aquifer is small, the primary source of recharge to this aquifer is downward leakage. Most recharge to the McNairy–Nacatoch aquifer is from precipitation on outcrop areas; a small quantity of recharge is by upward leakage from underlying aquifers. Discharge from all aquifers in the system is mainly to streams in outcrop areas or to the Mississippi River Valley alluvial aquifer where the alluvial aquifer is present; some discharge is to wells. In the deeper, confined parts of the aquifers, upward leakage to shallower aquifers occurs.

Regional ground-water movement in the aquifers of the Mississippi embayment aquifer system generally is from aquifer outcrop areas toward the axis of the Mississippi Embayment. The potentiometric surface of the lower Wilcox aquifer (**fig. 137**) is representative of the configuration of hydraulic heads in these aquifers. Water enters the aquifers at the updip, higher altitude outcrop areas and moves down the dip of the aquifers. In the example shown in **figure 137**, water also enters the lower Wilcox aquifer in subcrop areas in Missouri and Arkansas by downward leakage from shallower aquifers. The general direction of movement of the water is toward the Mississippi River and subsequently to the southwest along the axis of the Mississippi Embayment. Ultimately, the water discharges by upward leakage to shallower aquifers in downdip areas.

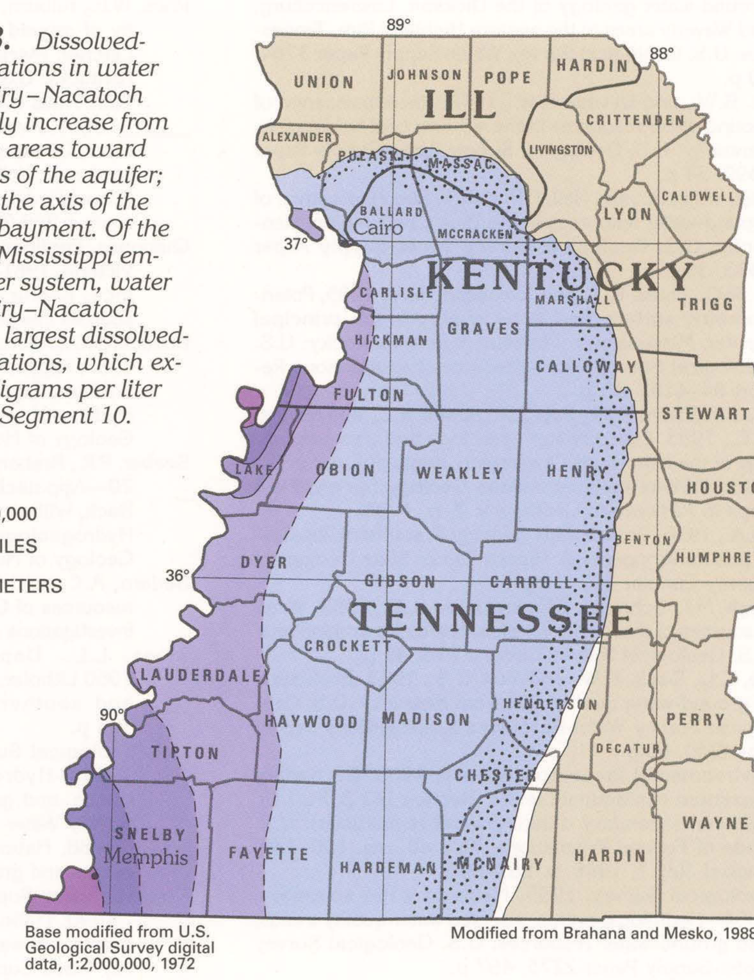


Figure 138. *Dissolved-solids concentrations in water from the McNairy–Nacatoch aquifer generally increase from aquifer outcrop areas toward the deeper parts of the aquifer; that is, toward the axis of the Mississippi Embayment. Of the aquifers in the Mississippi embayment aquifer system, water from the McNairy–Nacatoch aquifer has the largest dissolved-solids concentrations, which exceed 1,000 milligrams per liter in two parts of Segment 10.*

SCALE 1:2,500,000
0 20 MILES
0 20 KILOMETERS

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

Modified from Brahana and Mesko, 1988

EXPLANATION

Dissolved-solids concentration, in milligrams per liter—Lines dashed where approximately located
250
500
750
1,000

Outcrop of McNairy–Nacatoch aquifer

Aquifer absent

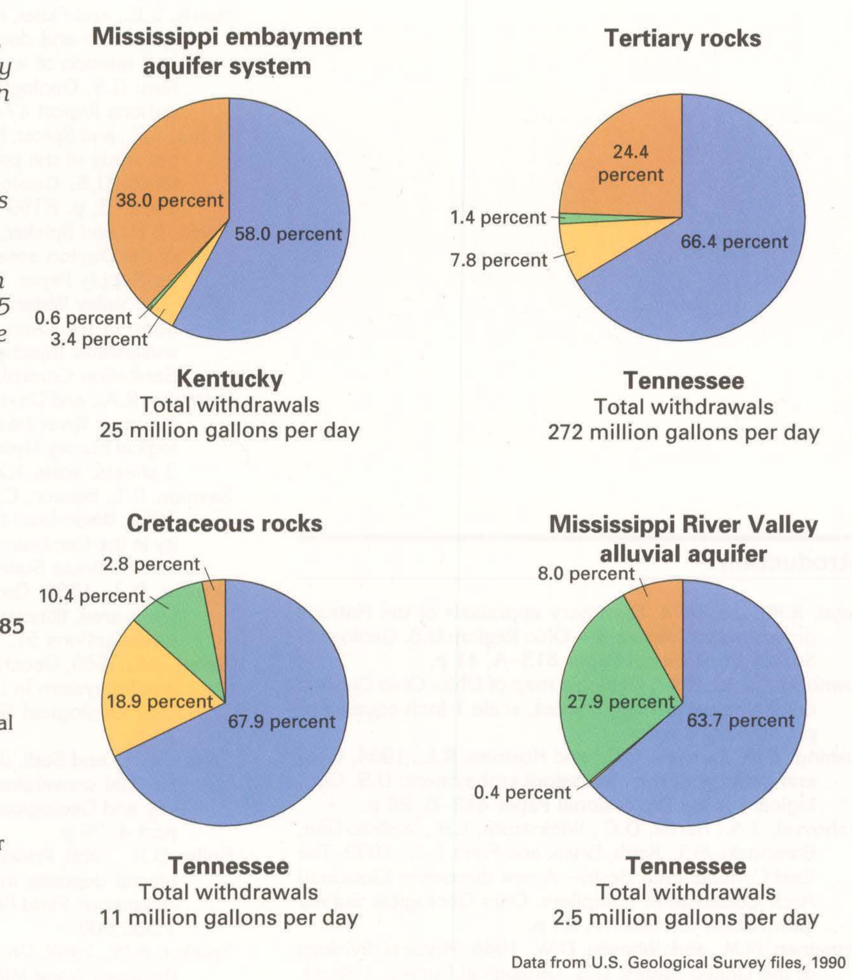


Figure 139. *During 1985, about 25 million gallons per day was withdrawn from aquifers in the Mississippi embayment aquifer system in Kentucky. In Tennessee during 1985, about 272 million gallons per day was withdrawn from the aquifers in Tertiary rocks, about 11 million gallons per day from aquifers in Cretaceous rocks, and about 2.5 million gallons per day from the Mississippi River Valley alluvial aquifer.*

EXPLANATION

Use of fresh ground-water withdrawals during 1985

Public supply

Domestic and commercial

Agricultural

Industrial, mining, and thermoelectric power

Data from U.S. Geological Survey files, 1990

HYDRAULIC CHARACTERISTICS OF PRINCIPAL AQUIFERS

Yields from the Mississippi embayment aquifer system in Segment 10 tend to be greater for wells completed in the aquifers in Tertiary rocks than for those completed in the McNairy–Nacatoch aquifer. In Tennessee, wells completed in the middle Claiborne and the lower Wilcox aquifers commonly yield from 200 to 1,000 gallons per minute, but yields might locally exceed 2,000 gallons per minute. Wells completed in the McNairy–Nacatoch aquifer commonly yield from 50 to 500 gallons per minute, but yields might exceed 1,000 gallons per minute. Yields for wells completed in these aquifers in Kentucky are smaller. Wells completed in the middle Claiborne and the lower Wilcox aquifers in Kentucky yield from 5 to 100 gallons per minute, and wells completed in the McNairy–Nactoch aquifer in Kentucky yield from 5 to 25 gallons per minute.

Transmissivity is a measure of the ease with which water can move through an aquifer. The larger the transmissivity, the more readily water can move through the aquifer. The middle Claiborne aquifer in Segment 10 has an average transmissivity of about 29,000 feet squared per day, as indicated by 80 aquifer tests. The lower Wilcox aquifer in this segment has an average transmissivity of about 13,000 feet squared per day, as indicated by 24 aquifer tests. The McNairy–Nactoch aquifer has an average transmissivity of about 4,000 feet squared per day, as indicated by two aquifer tests.

GROUND-WATER QUALITY

The chemical quality of water from the aquifers in the Mississippi embayment aquifer system generally is suitable for most uses. The areal distribution of constituents in the water differs within individual aquifers, as well as between aquifers. Water in these aquifers is soft to moderately hard and is usually a calcium bicarbonate type in aquifer outcrop areas. As the water moves deeper into the aquifers, it becomes a sodium bicarbonate type. Iron, fluoride, and sulfate concentrations typically are small in water from all the aquifers.

Dissolved-solids concentrations usually are less than 250 milligrams per liter in water from most of the aquifers in the Mississippi embayment aquifer system. However, dissolved-solids concentrations increase as the water moves along flow paths into deeper parts of the aquifers. A map of dissolved-solids concentrations in water from the McNairy–Nacatoch aquifer (**fig. 138**) shows such an increase. Locally, dissolved-solids concentrations in water from this aquifer exceed 1,000 milligrams per liter.

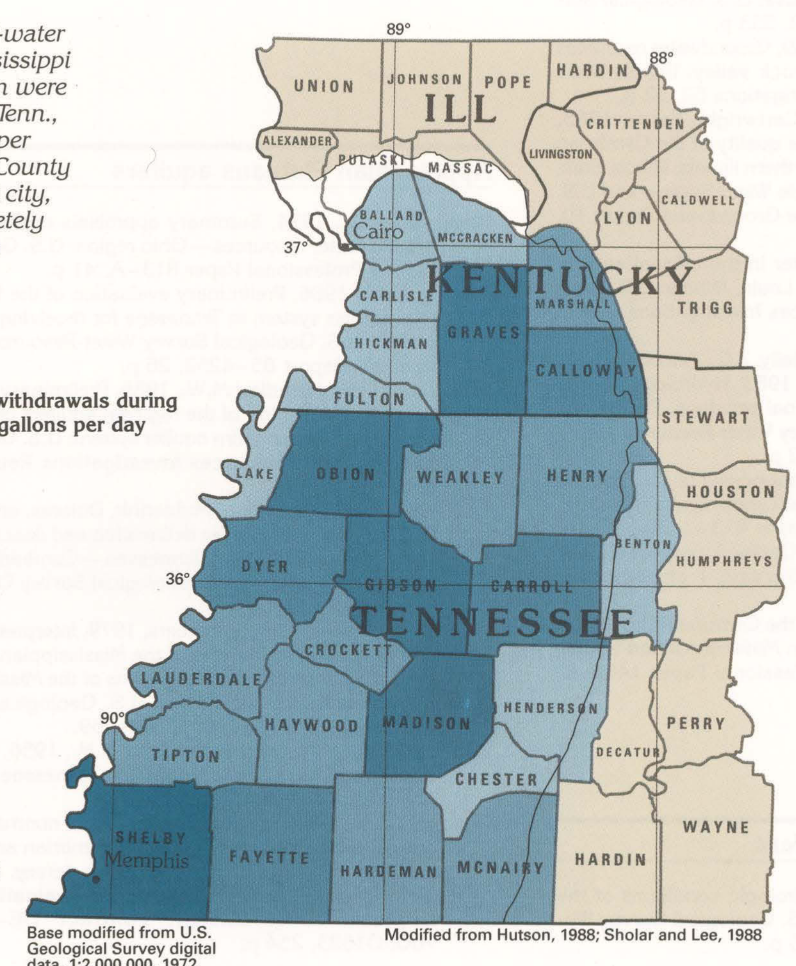


Figure 140. *Ground-water withdrawals from the Mississippi embayment aquifer system were largest in Shelby County, Tenn., about 196 million gallons per day during 1985. Shelby County includes the State's largest city, Memphis, which is completely supplied by ground water.*

EXPLANATION

Fresh ground-water withdrawals during 1985, in million gallons per day
0 to 2
2 to 5
5 to 9
9 to 16
Greater than 16
No data

SCALE 1:2,500,000
0 20 MILES
0 20 KILOMETERS

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

Modified from Hutson, 1988; Sholar and Lee, 1988

FRESH GROUND-WATER WITHDRAWALS

Total ground-water withdrawals from the aquifers of the Mississippi embayment aquifer system in Kentucky and Tennessee were about 311 million gallons per day during 1985. Most of this water, about 272 million gallons per day, or about 87 percent of the total, was withdrawn from aquifers in the Tertiary rocks in Tennessee (**fig. 139**). The Memphis, Tenn., area, which is totally supplied by ground water, accounted for withdrawals of about 196 million gallons per day. In comparison, only about 11 million gallons per day was withdrawn from the aquifers in Cretaceous rocks in Tennessee, and about 25 million gallons per day was withdrawn from the entire aquifer system in Kentucky. In Kentucky, about 70 percent of this water was supplied by aquifers in Tertiary rocks and about 30 percent by aquifers in Cretaceous rocks. About 2.5 million gallons per day was withdrawn from the Mississippi River Valley alluvial aquifer in Tennessee during 1985.

Ground water is the major source of water for public supply throughout the Coastal Plain Province in Segment 10. During 1985, withdrawals for public supply and for industrial, commercial, and thermoelectric power uses accounted for more than 90 percent of the ground water withdrawn from the aquifers in Tertiary and Cretaceous rocks in Kentucky and the aquifers in Tertiary rocks in Tennessee. Public-supply withdrawals accounted for about 65 to 70 percent of the water withdrawn from all the aquifers in the Mississippi embayment aquifer system in Tennessee.

Shelby County, Tenn., which includes the city of Memphis, withdrew about 196 million gallons per day of freshwater during 1985. As shown in **figure 140**, withdrawals in other counties in the Coastal Plain Province in Segment 10 were much smaller.

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