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 hydrologic 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.

Mark Schaefer

U.S. DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY

Mark Schaefer, Acting 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:

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<th>Multiply inch-pound units</th>
<th>To obtain metric units</th>
</tr>
</thead>
<tbody>
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</tbody>
</table>

CONVERSION FACTORS

See 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."

Hydrologic Investigations Atlas 730-D

Chapter content

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730-B           | California, Nevada |
730-C           | Arizona, Colorado, New Mexico, Utah |
730-D           | Kansas, Missouri, Nebraska |
730-E           | Oklahoma, Texas |
730-F           | Arkansas, Louisiana, Mississippi |
730-G           | Alabama, Florida, Georgia, South Carolina |
730-H           | Idaho, Oregon, Washington |
730-I           | Montana, North Dakota, South Dakota, Wyoming |
730-J           | Iowa, Michigan, Minnesota, Wisconsin |
730-K           | Illinois, Indiana, Kentucky, Ohio, Tennessee |
730-L           | Delaware, Maryland, New Jersey, North Carolina, Pennsylvania, Virginia, West Virginia |
730-M           | Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, Vermont |
730-N           | Alaska, Hawaii, Puerto Rico |
GROUND WATER ATLAS OF THE UNITED STATES

SEGMENT 3

Kansas, Missouri, and Nebraska

By James A. Miller and Cynthia L. Appel

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Cartographic design and production by Loretta J. Ulibarri, Darald L. Dunagan, and Gary D. Latzke
INTRODUCTION

The three States—Kansas, Missouri, and Nebraska—that comprise Segment 3 of this Atlas are in the central part of the United States. The major rivers that drain these States are the Platte, the Missouri, the Arkansas, and the Mississippi; the Mississippi River is the eastern boundary of the area. These rivers supply water for many uses but ground water is the source of slightly more than one-half of the total water withdrawn for all uses within the three-State area. The aquifers that contain the water consist of consolidated sedimentary rocks and unconsolidated deposits that range in age from Cenozoic through Quaternary. This chapter describes the geology and hydrology of each of the principal aquifers throughout the three-State area.

Some water enters Segment 3 as inflow from rivers and aquifers that cross the segment boundaries, but precipitation, as rain and snow, is the primary source of water within the area. Average annual precipitation (1951–80) increases from west to east and ranges from about 16 to 48 inches (fig. 1). The climate of the western one-third of Kansas and Nebraska, where the average annual precipitation generally is less than 20 inches per year, is considered to be semiarid. This area receives little precipitation chiefly because it is distant from the Gulf of Mexico, which is the principal source of moisture-laden air for the entire segment, but partly because it is located in the rain shadow of the Rocky Mountains. Average annual precipitation is greatest in southeastern Missouri.

Much of the precipitation is returned to the atmosphere by evapotranspiration, which is the combination of evaporation from the land surface and surface-water bodies, and transpiration from plants. Some of the precipitation either flows directly into streams as overland runoff or percolates into the soil and then moves downward into aquifers where it is stored for a time and subsequently released as base flow to streams. Average annual runoff, which is the total discharge into a stream from surface- and ground-water sources, ranges from about 0.2 inch in the western part of the area to about 20 inches in southeastern Missouri (fig. 2). Average annual runoff generally reflects the distribution of average annual precipitation during the same period. However, runoff is less than precipitation everywhere and ranges from less than 5 to about 20 percent of the average annual precipitation. Evapotranspiration rates are high, especially in the western one-half of the area, thus, only a small percentage of the precipitation is available to recharge aquifers in most places. Locally, however, runoff might be significantly less than shown in figure 2, and ground-water recharge, greater, especially where highly permeable rocks or deposits at the land surface allow precipitation to rapidly infiltrate. Examples of such places are the Sand Hills area of Nebraska, which is blanketed by permeable wind-blown sands, and parts of southern Missouri, where permeable limestone is at or near the land surface.

The land surface of Segment 3 generally slopes gradually from west to east. In the Great Plains Physiographic Province (fig. 3), the altitude of the flat land surface locally is about 5,000 feet above sea level in westernmost Nebraska. By contrast, in the flat Coastal Plain Physiographic Province of eastern Missouri, the altitude is about 500 feet above sea level. The land surface is gently rolling in the Central Lowland Province except where major rivers and their tributaries are deeply incised. In the Ozark Plateau Physiographic Province, rugged topography has developed where the underlying rocks have been uplifted and deeply eroded.
The numerous aquifers within Segment 3 vary in composition. Some of the aquifers are unconsolidated sand and gravel, some are semiconsolidated sediments, and some are consolidated sandstone, limestone, or dolomite. The aquifers have been defined primarily on the basis of differences in their rock types and ground-water flow systems and secondarily by the chemical quality of water they contain. Some of the aquifers are grouped into aquifer systems. An aquifer system consists of two or more aquifers that are hydraulically connected. The flow systems of the connected aquifers function similarly, and a change in conditions in one of the aquifers affects the other aquifers or aquifer systems.

Seven principal aquifers or aquifer systems are at the land surface in the three-State area. The extent of these aquifers, which primarily consist of unconsolidated deposits of late Quaternary age and are collectively called the surficial aquifer system, is shown in Figure 4. The remaining six aquifers and aquifer systems primarily consist of semiconsolidated to consolidated sedimentary rocks; Figure 5 shows where these aquifers are exposed or covered with only a thin blanket of soil and unconsolidated material. Some of the aquifers extend into the subsurface far beyond the areas where they are mapped in Figure 5. One additional aquifer system, the Western Interior Plains, is present only in the subsurface and, therefore, is not shown in the figure. This aquifer system contains saline water or brine and is not as well known as the aquifers that primarily contain freshwater. In this report, the dissolved-solids concentration in ground water is used to classify the water as fresh, saline, or brine. The concentrations used to categorize the water are as follows:

<table>
<thead>
<tr>
<th>Dissolved-solids concentration, in milligrams per liter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freshwater</td>
</tr>
<tr>
<td>Slightly saline water</td>
</tr>
<tr>
<td>Moderately saline water</td>
</tr>
<tr>
<td>Brine</td>
</tr>
</tbody>
</table>

Aquifers that are part of the surficial aquifer system are in all three States of Segment 3 (Figure 4). In this report, the surficial aquifer system is divided into the following parts: stream-valley aquifers, the Mississippi River Valley alluvial aquifer, and glacial-drift aquifers. The stream-valley aquifers are the most extensive part of the system and consist of sand and gravel deposited as alluvium in and adjacent to the channels of the larger streams in the segment. The Mississippi River Valley alluvial aquifer in southwestern Missouri also consists of alluvial sand and gravel, but these materials have been deposited as a thick, wide blanket as the channel of the Mississippi River changed its position over time. The glacial-drift aquifers consist of sand and gravel that were deposited during multiple advances of continental ice sheets from the north and northwest, primarily during the Pleistocene Epoch. Rock and soil particles were plowed from the land surface as the massive sheets of ice advanced and were transported by the ice. Some of these materials were redistributed by meltwater and were deposited in periglacial channels as stratified sand and gravel that formed productive aquifers. In contrast, poorly sorted unstratified glacial deposits of clay, silt, sand, gravel, and boulders (called till) and stratified clay and silt deposited in glacial lakes have minimal permeability. Some of the glacial-drift aquifers in eastern Nebraska, northeastern Kansas, and northem Missouri are buried beneath till or glacial-lake deposits. The High Plains aquifer (Figure 5), which is at the land surface in most of Nebraska and a large part of Kansas, is the most productive aquifer in the segment. This aquifer mostly consists of unconsolidated to consolidated sand and gravel of Quaternary and Tertiary age which were deposited as a broad, thick sheet of alluvium on a wide, gentle plain by a network of branching streams whose channels migrated across the plain. Dune sand that covers an area of about 20,000 square miles in Nebraska is part of the High Plains aquifer where the sand is saturated. Where the stream-valley aquifers overlie the High Plains, they are characterized with clay in a hydraulic connection with the Mississippi River Valley alluvial aquifer. Semiconsolidated sands of Tertiary and Cretaceous age compose the Mississippi Embayment aquifer system.

The Mississippi River Valley alluvial aquifer system is exposed at the land surface in a band that extends from south-central Kansas to northeastern Nebraska (Figure 5). This aquifer system consists of two sandstone aquifers in Cretaceous rocks, separated by a shale confining unit. Although the Great Plains aquifer system extends in the subsurface throughout Kansas and Nebraska, it contains saline water in many places northward and westward from the area it is exposed. A thick confining unit composed of Cretaceous shale, chalk, and limestone formations overlies the Great Plains aquifer system (Figures 6, 7) and separates it from the High Plains aquifer in most places. The Ozark Plateau aquifer system is exposed at the land surface in most of southern Missouri and in a small part of southwesternmost Kansas (Figure 5). This aquifer system consists of three aquifers that are separated by two confining units, all in Paleozoic rocks. The upper two aquifers are predominantly carbonate rocks, whereas the lower aquifer is predominantly sandstone. The Ozark Plateau aquifer system extends northwestern for more than 50 miles beneath a thick confining unit called the Western Interior Plains confining unit (Figure 6). This confining unit extends throughout Kansas and Nebraska and consists of poorly permeable sedimentary rocks of variable composition that range in age from Jurassic through late Mississippian.

Permeable carbonate rocks that are the subsurface equivalents of the aquifers of the Ozark Plateau aquifer system are called the Western Interior Plains aquifer system (Figure 6). Because this system is deeply buried everywhere, it contains saline water or brine and its hydrology, therefore, is not well known.

The Mississippiian aquifer in northeastern Missouri (Figure 5) is in carbonate rocks that are stratigraphically equivalent to those that compose the uppermost aquifer of the Ozark Plateau aquifer system. However, the ground-water flow systems of the two aquifers are not connected east of Boone County, Missouri, and the Mississippiian aquifer is considered to be separate from the Ozark Plateau aquifer system in this report.

The Cambrian-Ordovician aquifer is exposed in a small part of northeastern Missouri (Figure 5). This aquifer mostly consists of carbonate rocks and contains freshwater only in a band about 50 miles wide, which is parallel to and north of the Missouri River from Boone County eastward to the Mississippi River. The rocks that contain the Cambrian-Ordovician aquifer are stratigraphically equivalent to those that form part of the middle aquifer of the Ozark Plateau aquifer system. The degree to which these aquifers are hydraulically connected is not precisely known, but the two aquifers are considered to be partly continuous in this report.

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Figure 4. Coarse-grained, unconsolidated deposits, mostly of Quaternary age, compose the surficial aquifer system and provide the spring discharge to streams. Alluvium including the Mississippi River Valley alluvial aquifer (buried in some places beneath the glacial sediments) form productive aquifers. Till, loess, and fluvial deposits of glacial-lake deposits are overlain by drumlins and moraine and are considered to be part of the subsurface confining unit. Figure 5. Southwestern Missouri is under the eastward projection of the three-State area. The Cambrian-Ordovician aquifer is exposed in a small part of northeastern Missouri (fig. 6). This aquifer mostly consists of carbonate rocks and contains freshwater only in a band about 50 miles wide, which is parallel to and north of the Missouri River from Boone County eastward to the Mississippi River. The rocks that contain the Cambrian-Ordovician aquifer are stratigraphically equivalent to those that form part of the middle aquifer of the Ozark Plateau aquifer system. The degree to which these aquifers are hydraulically connected is not precisely known, but the two aquifers are considered to be partly continuous in this report.
Figure 5. The extent of six principal aquifers or aquifer systems, which are either exposed at the land surface or underlie parts of the surficial aquifer system and associated poorly permeable sediments, is mapped here. A seventh aquifer system, the Western Interior Plains, is entirely in the subsurface. Only small to moderate amounts of water can be obtained from wells completed in areas shown as confining units or having no principal aquifer.

Figure 6. Thick confining units separate the aquifer systems of Segment 3. This east-west section shows how the Creek Plains aquifer system grades westward into the Western Interior Plains aquifer system, which has been locally eroded from fault blocks in central Kansas. The line of the hydrogeologic section is shown in figure 5.
GEOLGY

The geologic and hydrogeologic nomenclature used in this report 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 names. Therefore, the nomenclature used in this report is a synthesis of that of the U.S. Geological Survey, the Kansas Geological Survey, the Missouri Department of Natural Resources, Division of Geology and Land Survey, and the Nebraska Conservation and Survey Division of the University of Nebraska. Individual sources for nomenclature are listed with each correlation chart prepared for this report.

Kansas, Missouri, and Nebraska are in part of the North American craton, which is an area that has been tectonically stable throughout most of geologic time. The area has undergone some deformation, however, as shown by faults and by upwarps and downwarps on the surface of the crystalline Precambrian rocks (fig. 8) that underlie Paleozoic and younger sedimentary rocks everywhere. Precambrian rocks are exposed only in the St. Francois Mountains of southeastern Missouri, where they are locally more than 1,000 feet above sea level; these rocks are buried to depths of as much as 6,000 feet below sea level in southwestern Kansas on the northern flank of the Anadarko Basin.

Because the crystalline-rock surface slopes outward in all directions from the Chisholm Uplift and northward or southward from high areas along the Chadron Arch and the Central Kansas Uplift (fig. 8), the overlying sequence of sedimentary rocks slopes and thickens away from all these high areas. The greatest sedimentary rock accumulations are in the Salina Basin in south-central Nebraska and north-central Kansas and in the parts of the Mississippi Embayment and the Anadarko, the Denver, the Kennedy, and the Forest City Basins that are in Segment 3. For example, total sedimentary rock thickness in the southwestern part of the Nebraska panhandle and in southwestern Kansas along the Oklahoma State line is about 9,000 feet.

Numerous faults in the crystalline rocks of the three-State area are grouped mostly in or adjacent to the Central Kansas Uplift, the Nemaha Uplift, and the St. Francois Mountains. Vertical displacement across the faults varies from less than 100 to more than 2,500 feet. Displacement generally is greatest across some of the faults in the north-trending fault zone just east of the Nemaha Uplift. This fault zone and a second zone (not shown in fig. 8) that trends northeastward across the Mississippi Embayment are thought to represent zones of continental rifting that formed during Precambrian time.

Figure 7. The thick confining unit between the Great Plains and Western Interior Plains aquifer systems pinches out in north-central Nebraska where the two aquifer systems are in hydrogeologic contact. The line of the hydrogeologic section is shown in Figure 5.

Figure 8. The crystalline-rock surface slopes from high areas, such as the Chadron Arch and the Ozark and Central Kansas Uplifts, toward the Salina Basin in north-central Kansas and other basins whose centers are outside the segment.
GEOLOGY—Continued

Postdepositional erosion of the Paleozoic sedimentary sequence along most of the state boundary of the St. Francois Mountains in southeastern Missouri (fig. 9). The glacial sediments in areas of Tertiary and Quaternary sediments in western Kansas and Nebraska are not remnant of channels or water bodies removed from the St. Francois Mountains and the Ozark Plateau. These Tertiary and Quaternary sediments are mostly alluvium that was derived from erosion of the Rocky Mountains to the west of the segment.

The Ozark Plateaus rocks are exposed in southeast Missouri in an area that encircles the Precambrian core of the St. Francois Mountains. The basal Cambrian rocks in eastern Missouri are not in the area of the Rocky Mountains to the west of the segment.

The Cambrian rocks are intensely foliated and have been partially metamorphosed but they have an origin similar to the Precambrian rocks. The Cambrian system extends from its southern limit, which is continuous northward and westward through Kansas and Nebraska (fig. 13) except for a small area in northeastern Kansas where the system is missing. Two sandstone aquifers in Lower Cretaceous rocks, separated by a shale confining unit, comprise the aquifer system. An extremely thick shale confining unit underlies the aquifer system almost everywhere. Water in the Great Plains aquifer system is under confined conditions in most parts. Exceptions are where the aquifer system is exposed at the land surface or is under the influence of the High Plains aquifer; in these places, water-table conditions exist in much of the aquifer. The Ozark Plateau aquifer system extends over most of southern Missouri (fig. 14) and consists of three aquifers that are separated by two confining units, all in consolidated rocks of Paleozoic age. The uppermost aquifer is in Mississippian carbonate rocks; stratigraphically equivalent sandstone aquifers in northern Missouri are called the Wisconsinian aquifer (fig. 14). The middle aquifer of the Ozark Plateau aquifer system is in carbonate rocks of Cambrian and Ordovician age, and the lowermost aquifer in the system is in Cambrian sandstone. Sandstone aquifers are separated by two confining units, all in consolidated rocks of Paleozoic age. The uppermost aquifer is in Mississippian carbonate rocks; stratigraphically equivalent sandstone aquifers in northern Missouri are called the Wisconsinian aquifer (fig. 14).

Some of the principal aquifers and aquifer systems in Segment 3 are stacked atop others. For example, in parts of Kansas and Nebraska, the High Plains aquifer overlies the Great Plains aquifer system, which, in turn, overlies the Western Interior Plains aquifer system (fig. 17). The aquifers and aquifer systems, however, are separated by thick shale confining units in most places. Although the confining units are poorly permeable, some water is able to move vertically through them. From one aquifer to another, movement is in the direction of decreasing hydraulic head and is eastward where the confining units are thin, leaky, or both. Where confining units are absent, water moves mostly between aquifers. As an example, where stream-valley aquifers of the surficial aquifer system overlie the High Plains aquifer, no confining unit separates the aquifers, both of which consist of unconsolidated sand and gravel. The aquifers cannot be hydrologically distinguished from each other, and the stream-valley aquifers are considered to be part of the High Plains aquifer whose water is in two categories. The sequence of maps (figures 11 through 15) shows the extent of the surficial aquifer units that are underlain or are hydrologically connected in parts of it by a thick confining unit of shale.

The gray to brown sandy mud in each of the surficial aquifers is underlain by a thick shale confining unit. Marine sediments are also included in the surficial aquifer units in parts of the middle aquifer and lowermost aquifer of the Ozark Plateau aquifer system. The Surficial aquifer units are separated by two confining units, all in consolidated rocks of Paleozoic age. The uppermost aquifer is in Mississippian carbonate rocks; stratigraphically equivalent sandstone aquifers in northern Missouri are called the Wisconsinian aquifer (fig. 14).
FRESH GROUND-WATER WITHDRAWALS

Ground water is the source of water supply for more than 5 million people, or about 70 percent of the population in the three-State area (table 1). Public-water supply systems provide more than twice as much water as private (domestic) systems. Ground water supplies nearly 100 percent of the population in rural areas and is the source for many water-supply systems in small cities. About 86 percent of the population in Nebraska depends on ground water for supply.

Nearly 10 billion gallons per day was withdrawn from all the aquifers in Segment 3 during 1990 (fig. 16). About 90 percent of the total water withdrawn was used for agricultural, primarily irrigation, purposes. Withdrawals for public supply were about 6 percent of the total water withdrawn.

Total fresh ground-water withdrawals, by county, during 1990 in Kansas, Missouri, and Nebraska are shown in figure 17. Counties with the largest withdrawals are those in which agricultural irrigation is most intense. Some large cities located adjacent to major rivers (for example, St. Louis, Kansas City, and Wichita) withdraw surface water for public supply, and their effect is accordingly not indicated on the map.

The total freshwater withdrawn from each principal aquifer and aquifer system in the three-State area is shown in figure 18. About 6.91 billion gallons per day was withdrawn from the High Plains aquifer; this was about 8 times as much water as was withdrawn from the surficial aquifer systems, which is the second most used source of ground water (1.037 million gallons per day). The Osawatomie amphibian aquifer supplied water at the rate of about 330 million gallons per day and is the third largest producer. Withdrawals from the Great Plains aquifer, which is the fourth largest producer in the segment, were about 133 million gallons per day. Withdrawal rates from the Mississippi embayment aquifer system were small (95 million gallons per day) because the aquifer is limited in areal extent in Segment 3 and is overlain by the productive Mississippian River Valley alluvial aquifer.

INTRODUCTION

The surficial aquifer system in Segment 3 consists of unconsolidated sand and gravel and is divided into three parts: surficial aquifers, the Mississippi River Valley alluvial aquifer, and glacial-drift aquifers. These aquifers are hydraulically connected in some places. For example, many of the glacial-drift aquifers in northern Missouri, northeastern Kansas, and eastern Nebraska occupy ancient stream channels that have been eroded into bedrock. At locations where modern streams follow the ancient drainage patterns, the alluvial deposits of sand and gravel that compose a stream-valley aquifer may lie directly on glacial outwash that also consists of sand and gravel. Much of the sand and gravel of the stream-valley aquifers in Missouri and eastern Kansas and Nebraska has been reworked from older glacial-drift deposits and, therefore, may be difficult to distinguish from glacial outwash. Most of the water in the surficial aquifer system is under unconfined conditions.

STREAM-VALLEY AQUIFERS

The stream-valley aquifers of Segment 3 consist of narrow bands of fluvial and alluvial sediments which fill or partly fill the valleys of meandering to braided streams that have eroded shallow channels into glacial deposits, older unconsolidated alluvium, or bedrock. Where these streams cross the High Plains aquifer, the stream-valley aquifers are hydraulically connected to and are considered to be part of the underlying High Plains aquifer. Locally, the stream-valley aquifers are hydraulically connected to bedrock aquifers and, in most places, they are separated from the bedrock aquifers by poorly permeable beds of clay or shale. The extent of the stream-valley aquifers is shown in figure 19.

The unconsolidated sand and gravel deposits that compose the stream-valley aquifers are thicker, more widespread, and more productive in the valleys of the larger rivers than those of smaller streams. In Kansas, stream-valley aquifers are along the courses of the Republican, the Kansas, the Solomon, the Saline, the Hesston, the Smoky Hill, the Meramec des Cygnes, the Arkansas, and the Cimarron Rivers. In Missouri, the stream-valley aquifers along the Missouri and the Mississippi Rivers and their tributaries are important sources of freshwater for many communities and industries. Stream-valley aquifers occur along the Maouri, the Missouri, the Loup, the Platte, the Republican, and the Blue Rivers in Nebraska. No comprehensive, unified study has been done for the stream-valley aquifers; accordingly, local investigations have been selected to show their hydrology. The designated boundaries DB and D9 in figure 19 are lines of detail studies of the stream-valley aquifers, which are depicted in the following sections of this report.

The stream-valley aquifers consist mostly of sand and gravel of Holocene age but locally include sediments of Pleistocene age. The average thickness of the aquifers is about 90 to 100 feet, but locally they are as much as 160 feet thick. However, the average thickness of saturated alluvial material is less and generally ranges from 50 to 80 feet; the thicker saturated sections yield more water to wells.

Most of the water in the stream-valley aquifers is under unconfined, or water-table, conditions. Locally, where recharged aquifer sediments are capped by poorly permeable silt or clay, confined (artesian) conditions exist. The stream-valley aquifers are in direct hydraulic connection with the adjacent streams and water levels in the aquifers are, therefore, closely related to river levels (fig. 20). Aquifer and river water levels rise following precipitation events; the rise in the water level of the river precedes that in the aquifer.

EXPLANATION

Use of fresh ground-water withdrawals during 1990, in percent—Total withdrawals 9.867 million gallons per day

Public supply

Domestic and commercial

Agricultural

Industrial, mining, and thermoelectric power

Table 1. During 1990, public and domestic water-supply systems provided ground water to more than 5 million people in Kansas, Missouri, and Nebraska.

<table>
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<tr>
<th>State</th>
<th>People served (thousands)</th>
<th>State total (percent)</th>
<th>Total population (thousands)</th>
<th>Total population (percent)</th>
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<td>Missouri</td>
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<td>2,090 29  42</td>
<td>2,090 20  42</td>
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<tr>
<td>Nebraska</td>
<td>90 752</td>
<td>735 80  78</td>
<td>735 40  78</td>
<td></td>
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<tr>
<td>Total</td>
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<td>3,825 65  1,650</td>
<td>3,825 69  1,650</td>
<td></td>
</tr>
</tbody>
</table>

EXPLANATION

Fresh ground-water withdrawals during 1990, in million gallons per day

Less than 10

10 to 50

50 to 100

100 to 200

Greater than 200
Recharge to a typical stream-valley aquifer is by precipitation that falls directly on the aquifer, seepage through the beds of streams and of reservoirs and canals constructed in the streams, downward percolation of applied irrigation water (fig. 21), and ground-water flow from underlying, permeable bedrock. The aquifer discharges by leakage to streams and canals, percolation into wells, and evapotranspiration (evaporation plus transpiration by plants, especially crops during the growing season). A small amount of water is conserved by crops. Along reaches of some streams, such as the Arkansas, the Smoky Hill, and the Sickness, some of the water potentially available to recharge the aquifer from the stream is diverted by networks of canals and irrigation ditches, from which evaporation occurs. Such diversions, coupled with intense irrigation pumping from the aquifer and a resulting decrease in base flow to the stream, have severely reduced streamflow. In some cases, streams that were formerly perennial are now dry most of the year.

Figure 21. The stream-valley aquifer along the Arkansas River in Hamilton and Kearny Counties, Kansas, is underlain by thin permeable bedrock. Recharge to the aquifer is from precipitation, percolation of applied irrigation water, leakage through irrigation canal bedrock, and inflow from the bedrock. Discharge from the aquifer is by evapotranspiration (evaporation plus transpiration by plants), streamflow, subsurface use and pumping from wells.

The stream-valley aquifers are reliable sources of ground water because of the coarse-grained nature and high permeability of the aquifer materials. Yields that range from 100 to 1,000 gallons per minute commonly are reported for wells completed in these aquifers; maximum yields of more than 1,500 to 2,500 gallons per minute are reported locally in Nebraska and Missouri, respectively, and yields of as much as 3,000 gallons per minute are reported from stream-valley aquifers in Kansas. Reported transmissivity values for these aquifers, as calculated from aquifer tests, range from 600 to 80,000 square feet per day.

The chemical quality of the water in the stream-valley aquifers generally is suitable for most uses. Typically, the water is hard and a calcium bicarbonate type. Dissolved solids concentrations generally are less than 500 milligrams per liter but locally are as much as 7,000 milligrams per liter; the larger concentrations reflect an influx of water with large chloride or sulfate concentrations from underlying aquifers or from irrigation return flow. Large iron concentrations are common.

Arkansas River Valley, Southwestern Kansas

The stream-valley aquifer that borders the Arkansas River in southwestern Kansas (area A in fig. 19) has been studied along a 48-mile reach of the river between the Colorado- Kansas State line and a geologic structure called the Bear Creek Spillway. This reach has been studied for some time because of the collapse of bedrock following dissolution of underlying salt beds. East of this zone the stream-valley aquifer is hydrologically connected to the High Plains aquifer and is, therefore, considered to be part of it. The stream-valley aquifer shown in figure 22 primarily comprises alluvial sand and gravel that fill a valley which is as much as 5 miles wide and has been eroded into poorly permeable Cretaceous bedrock. The sand and gravel range in thickness from 0 to 125 feet and generally are thickest near the center of the valley; however, the saturated thickness of this permeable material is less than 75 feet except in small areas (fig. 23). Well yields are directly proportional to saturated thickness. Where the saturated thickness is 25 feet or less, well yields are between 100 and 500 gallons per minute, but where saturated thickness is 75 feet or more, yields that range from 1,000 to 3,000 gallons per minute have been reported.

Figure 25. Water levels in wells completed in the stream-valley aquifer declined during the 1970s in response to decreases in precipitation and to the discharge of the Arkansas River from Colorado and an increase in ground-water withdrawals.

The Arkansas River and the stream-valley aquifer are hydraulically connected and water moves freely from the aquifer into the stream or from the stream into the aquifier, depending upon the relative position of the water levels in the stream and aquifer. The flow of the Arkansas River is impounded by the John Martin Reservoir in Colorado, about 35 miles upstream from the Colorado-Kansas State line, and water is released from the reservoir during the growing season to supply downstream irrigation ditches and canals. Beginning about 1970, the flow of the river was insufficient to meet irrigation needs along the Kansas reach of the river (fig. 24), partly because of increased diversions upstream. The river was a perennial stream throughout the studied 48-mile reach until about 1975 but was dry most of the year east of (downstream from) Kendall from 1975 through 1980. Accordingly, farmers who used ditch irrigation changed from surface water to ground water as a source of irrigation supply, this change, coupled with increased development, caused withdrawals from the stream-valley aquifer to more than triple between 1975, when about 20,000 acre-feet per year was pumped, and 1979, when withdrawals were about 65,000 acre-feet per year. One acre-foot is the volume of water that will cover 1 acre of land to a depth of 1 foot, or 43,560 cubic feet of water. The combination of decreased streamflow from Colorado, less-than-normal precipitation, and increased pumping caused water levels in the aquifer to decline 4 feet in the western part of Hamilton County (fig. 25) and more than 25 feet in Kearny County.

Water in the stream-valley aquifer moves from west to east (fig. 26) and follows the eastward slope of the topography of the valley floor. Movement of the water in the aquifer is nearly parallel to streamflow. In places, the altitude of the water table is below the altitude of the stream, and the contours show a slight "v" that points in a downstream direction (fig. 26). In other places, the contours "v" slightly upstream (for example, near Mayfield), which reflects a change in the water table or aquifer location. The lack of sharp, well-defined "v" points on the contours indicates good hydraulic connection between the stream and the aquifer. The depth to the water table also is shown in figure 26. The water table is nearest to land surface near the river and is deepest near the edge of the valley.

Water levels in the stream-valley aquifer and in the streams adjacent to it can change seasonally in response to pumping from the aquifer. The effects of pumping are summarized in figure 27. Before pumping began, the water table in the aquifer was above the water level in the stream, and the aquifer discharged to the stream as shown in figure 27A. Wells installed to provide irrigation supplies can greatly lower the water table in the aquifer, especially during the summer, when crop growth rate is highest and water demands are greatest. At such times, ground-water movement can be reversed from that before pumping began (fig. 27B), and water can move from the stream to recharge the aquifer. When irrigation pumping ceases during the water months, movement of water from the aquifer to the stream is reversed; however, water levels may not recover fully to those before pumping began. If pumping is greatly increased (fig. 27C), however, the regional water table may decline to a level below that observed; the stream will flow only after periods of heavy rainfall and will lose water to the aquifer during all seasons. This condition exists along some reaches of the Arkansas River in Kansas.

The hydrographs in figure 28 show the response of the water level in a well 100 feet from the Arkansas River near Kendall to changes in the river stage. From 1970 through 1981, the water level in the aquifer near the river was generally above or at the river stage. When the river is a flooding stream here and contributes water to the aquifer. The hydrograph shows that the river ceased to flow for several months during 1979, 1980, and 1981. Thus, the aquifer received no recharge from the stream.
The stream-valley aquifer along parts of the Smoky Hill, the Saline, and the Solomon Rivers (area D9 in fig. 19) ranges in width from about 3 to 5 miles (fig. 29). The lower two-thirds of the aquifer generally consists of coarse-grained alluvial deposits, whereas the upper third is finer-grained material. The uplands adjacent to the rivers are underlain by sandstone, shale, and limestone of Cretaceous to Permian age (fig. 29), all of which are less permeable than the alluvium. Locally, the stream-valley aquifer is bordered by Quaternary dune sands and poorly sorted terrace deposits that are mostly unconsolidated and not part of the stream-valley aquifer. Shale beds underlie the stream-valley aquifer and form a confining unit that separates the aquifer from permeable beds in the Hutchinson Salt Member of the Wellington Formation of Permian age. Wells completed in the coarse-grained, lower part of the stream-valley aquifer commonly yield from 200 to 900 gallons per minute. Transmissivity values determined from aquifer tests in this part of the aquifer range from 8,000 to 13,000 feet squared per day. The water in the aquifer generally is unconfined. The stream-valley aquifer is in direct hydraulic contact with the three rivers and discharges water to them.

The stream-valley aquifer mostly contains freshwater in its upper 35 to 50 feet in the area shown in figure 29. Below the freshwater from Salina westward, the aquifer contains saline water, some of which discharges to some of the reaches of the rivers. During a period of stable base flow in 1976-77, the chloride concentration in water from the Smoky Hill River increased about 800 milligrams per liter in the reach of the river between New Cambria and Sand Springs. In the same period, an increase in chloride concentration of about 550 milligrams per liter was observed in water from the Smoky Hill River in the reach between Niles and Solomon. Chloride concentrations as large as 35,000 milligrams per liter have been reported in water from the lower part of the stream-valley aquifer. Withdrawals from the aquifer in this part of central Kansas are small because of the poor quality of the water.

The source of the saline water and brine in the stream-valley aquifer is the Hutchinson Salt Member of the Wellington Formation (fig. 30). Fresh groundwater from the alluvial aquifer has been incised into bedrock and averages about 500 feet in thickness but is locally as much as 1,000 feet thick. The saturated thickness of the aquifer averages about 90 feet. Groundwater flow in the stream-valley aquifer moves eastward, in the direction of flow of the river. During a period of stable base flow in 1976-77, the water table in the stream-valley aquifer, April, 1977. Pulsed-when approach these areas, the water table is at least 150 feet below mean sea level.

The flow of water from the stream-valley aquifer moves eastward to the river, creating confined conditions. Sandstone, limestone, dolomite, and shale are prominent in the upper part of the aquifer and locally create confined conditions. Sandstone, limestone, dolomite, and shale of Permian and Mississippian age locally contain the bedrock that underlies the stream-valley aquifer in western Kansas. From the Howard-Boone County line eastward, the bedrock consists of Ordovician limestone and dolomite. In upland areas, glacial deposits overlie the bedrock and locally are hydraulically connected to the stream-valley aquifer.

The alluvial material of the stream-valley aquifer averages about 90 feet in thickness but is locally as much as 160 feet thick. The saturated thickness of the aquifer averages about 80 feet. Reported yields of wells completed in the aquifer range from less than 100 to about 3,000 gallons per minute. Recharge to the stream-valley aquifer is by infiltration of precipitation, seepage of water from the Missouri River to the aquifer during periods of high streamflow, and inflow from bedrock aquifers. Discharge from the aquifer is by evapotranspiration, withdrawals by wells, and seepage to the Missouri River during periods of low streamflow. The general direction of water movement in the stream-valley aquifer is downstream and toward the river (fig. 34). Water in the stream-valley aquifer is a calcium bicarbonate type and is characterized by excessive iron content and hardness; in many places, the water is softened before use. Dissolved solids concentrations in water from the aquifer range from about 250 to 1,500 milligrams per liter and are largest in areas where saline water leaks upward from bedrock and is diluted by mixing with freshwater.

**Missouri River Valley, Missouri**

Alluvial deposits along the Missouri River form an important stream-valley aquifer from the Iowa-Missouri State line to the junction of the Missouri and the Mississippi Rivers (fig. 30), small areas of similar deposits in eastern Nebraska compose local aquifers. The deposits partly fill an entrenched bedrock valley that ranges from about 2 to 10 miles wide. In many places in northern Missouri, the bedrock contains slightly saline water, and the stream-valley aquifers, along with aquifers in glacial drift, are the only sources of fresh groundwater. The part of the stream-valley aquifer along the Missouri River between St. Charles and Jefferson City, Missouri (area D9 in fig. 19) is described below.

The stream-valley aquifer consists of sand, silt, gravel, and sandstone and locally contains saline water. The line of the hydrogeologic section shown in figure 34.

**EXPLANATION**

- **Missouri River stream-valley aquifer**
  - Water-table contacts—Shows altitude of water table in stream-valley aquifer, April, 1977. Pulsed-when approach these areas, the water table is at least 150 feet below mean sea level.
  - Potentiometric surface—Shows altitude of potentiometric surface of the Wellington aquifer, April, 1977. Contour interval 10 feet, Datum is mean sea level.
  - Direction of flow—Direction of flow of the Missouri River, April, 1977.
  - Saline water
  - Brine

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**EXPLANATION**

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  - Water-table contacts—Shows altitude of water table in stream-valley aquifer, April, 1977. Pulsed-when approach these areas, the water table is at least 150 feet below mean sea level.
  - Potentiometric surface—Shows altitude of potentiometric surface of the Wellington aquifer, April, 1977. Contour interval 10 feet, Datum is mean sea level.
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  - Saline water
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During 1990, an average of about 147 million gallons of water per day was withdrawn from the stream-valley aquifer (fig. 35). About 45 percent of this amount, or about 66 million gallons per day, was used for public supply. Industrial, mining, and thermoelectric power withdrawals amounted to about 48 million gallons per day, and agricultural withdrawals were about 24 million gallons per day. The remainder of the water withdrawn (about 9 million gallons per day) was used for domestic and commercial purposes.

The Mississippi River Valley alluvial aquifer, which is in parts of seven States, is the major source of water for the area (fig. 36). The chemical quality of the water in the Mississippi River Valley alluvial aquifer generally meets the standards recommended for public water supplies by the U.S. Environmental Protection Agency. Locally, excessive concentrations of iron and manganese have been reported. Iron concentrations in water from the aquifer locally are as much as 30 milligrams per liter and average about 4.3 milligrams per liter; manganese concentrations locally are as much as 2.0 milligrams per liter and average 0.66 milligrams per liter. The water is a calcium-magnesium bicarbonate type, generally hard, and has small dissolved solids concentrations (averaging 240 milligrams per liter). Locally, the water in the aquifer contains traces of pesticides and nutrients as a result of downstream leaching of irrigation water from fields that have been treated with chemicals for insect control or with fertilizer.

Withdrawals of freshwater from the Mississippi River Valley alluvial aquifer totaled 129 million gallons per day during 1990 (fig. 41). About 92 million gallons per day was withdrawn for agricultural purposes, which is the principal water use. About 23 million gallons per day was withdrawn for public supply, and about 10 million gallons per day was pumped for industrial, mining, and thermoelectric power uses. Withdrawals for domestic and commercial uses were about 5 million gallons per day.
GLACIAL-DRIFT AQUIFERS

The maximum southern extent of glacial ice and glacial-drift deposits was about the present location of the Missouri River in Missouri and just south of the Kansas River in northeastern Kansas. The glacial deposits in Segment 3 are pre-Illinoian and, thus, are older than deposits in States to the north and east of the segment. Some of the drift in Segment 3 might be of late Pleistocene age, whereas most glacial deposits in North America are considered to be Pleistocene. Although deposits of glacial drift extend over wide areas, most were laid down directly by the ice; are fine-grained, poorly sorted, or both; and, therefore, yield only small amounts of water to wells. The thickness of glacial drift generally is 100 to 200 feet but locally is greater than 300 feet in eastern Missouri and 400 feet in western Missouri and northeastern Kansas. In southeastern Nebraska, local drift thicknesses of more than 250 feet have been reported. Meltwater created an extensive stream network in front of the advancing ice (fig. 42), and the streams deposited gravel, sand, and finer sediments as alluvium along the courses of preglacial bedrock valleys.

Complex interbedding of fine- and coarse-grained material is characteristic of the glacial deposits (fig. 43). The lensoid shape of some of the beds is the result of meandering of the meltwater streams across their valley floors and of periodic changes in stream-channel locations. However, in parts of Missouri, the glacial-drift aquifers are not complexly interbedded. For example, in the Grand River Valley of Daviess County, Missouri, the basal part of the deposits that fill glacial stream channels is coarse grained, and the upper part generally consists of poorly permeable silt, clay, or till (fig. 44). Such aquifers are called buried channel or buried valley aquifers and contain water under confined or semiconfined conditions. Flat all the drift consists of sand and gravel. (shown in figures 43 and 44), and not all is saturated. Water generally is obtained from sand beds that range from 20 to 40 feet in thickness.

Yields of wells completed in the glacial-drift aquifers are generally suitable for most uses. The water is hard and commonly is a calcium bicarbonate type although in many places in Missouri and locally in Kansas, it is a sodium sulfate type. Dissolved solids concentrations in water from these aquifers usually are less than 500 milligrams per liter but exceed 2,150 milligrams per liter in places. Sulfate concentrations ordinarily are 250 milligrams per liter or less except locally in Kansas and in Missouri; concentrations of sulfate as great as 2,150 milligrams per liter have been reported in Missouri. The source of the sulfate is dissolution of gypsum in the underlying bedrock. The hydraulic head in the glacial-drift aquifers is, therefore, a composite surface and shows the general configuration of water levels. The influence of topography on water levels in these aquifers is shown by a map of their potentiometric surface in Missouri (fig. 45). Topographically high areas in Clinton and Sullivan Counties, for example, stand out clearly. The low water levels parallel the courses of the Missouri and the Mississippi Rivers and some of their tributaries show that the aquifer discharges water to these streams.

The complex interbedding of permeable and poorly permeable sediments in the glacial-drift aquifers results in a large number of local confining units. Accordingly, water in these aquifers is under unconfined conditions in some places and confined conditions in other places. Where several sand and clay beds are stacked, water levels in each of the stacked sand beds may be different. The potentiometric surface of the glacial-drift aquifer is, therefore, a composite surface and shows the general configuration of water levels. The influence of topography on water levels in these aquifers is shown by a map of their potentiometric surface in Missouri (fig. 45). Topographically high areas in Clinton and Sullivan Counties, for example, stand out clearly. The low water levels parallel the courses of the Missouri and the Mississippi Rivers and some of their tributaries show that the aquifer discharges water to these streams.

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HYDROGEOLOGIC UNITS

The High Plains aquifer consists of all or parts of several geologic units of Quaternary and Tertiary age. The stratigraphic column in figure 48 shows the formation of the non-marine, continental rock type, thickness, and age of the geologic units that compose the aquifer. The Brule Formation is the upper unit of the White River Group and is a primarily massive siltstone with beds and channel deposits of sandstone. Locally, the Brule includes lenticular beds of volcanic ash, siltstone, and sandstone. The Brule underlies much of western Nebraska and is included in the aquifer only where it has been fractured or where the formation contains solution openings. Such secondary porosity and permeability are developed only where the Brule crops out or is near the land surface. Such secondary porosity and permeability are developed only where the Brule crops out or is near the land surface.

The Ogallala consists of unconsolidated gravel, sand, silt, and clay. Locally, it also includes calcite, which is a hard deposit of calcium carbonate. These Quaternary deposits are highly porous and, therefore, quickly absorb rainfall that recharges the High Plains aquifer. The Ogallala provides water for irrigation and other purposes. Where the Ogallala is unsaturated, groundwater moves freely between the aquifer and the streams. Where the Ogallala is saturated, groundwater is in hydraulic connection with the aquifer. Because the silt is angular and highly porous, the lens will maintain a vertical flow where it is exposed in meadows or stream banks.

Unconsolidated deposits of Quaternary age overlie the Ogallala Formation. These Quaternary deposits consist of sand, gravel, silt, and clay, much of which is reworked material from previous erosion surfaces. Some of these unconsolidated deposits are saturated, such as in southwestern Nebraska and southern Kansas, where they are part of the Ogallala aquifer. Figure 49 shows the Ogallala Formation in those areas.

The Ogallala Formation is the geologic unit that includes the High Plains aquifer and is at the land surface throughout most of the extent of the aquifer. The Ogallala consists of unconsolidated gravel, sand, silt, and clay. It also includes calcite, which is a hard deposit of calcium carbonate. These Quaternary deposits are highly porous and, therefore, quickly absorb rainfall that recharges the High Plains aquifer. The Ogallala provides water for irrigation and other purposes. Where the Ogallala is unsaturated, groundwater moves freely between the aquifer and the streams. Where the Ogallala is saturated, groundwater is in hydraulic connection with the aquifer. Because the silt is angular and highly porous, the lens will maintain a vertical flow where it is exposed in meadows or stream banks.

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Depth to Water

The depth to water in a particular area is the distance between the water table and the land surface. The water table is the level at which the water in an aquifer is at or near atmospheric pressure, and it is typically indicated by a contour line on a map. The depth to water can vary significantly within an aquifer, and it can be influenced by factors such as recharge, evapotranspiration, and pumping.

Ground-Water Flow

Water in the High Plains aquifer generally flows from west to east, or perpendicular to the regional water table declivities. The flow path is often influenced by surface features such as streams and rivers. In some areas, water may flow downward from the aquifer into the bedrock. Recharge to the High Plains aquifer can occur from surface water, infiltration of streamflow, and precipitation through dune sands. The amount and types of vegetation, the slope of the land, and the hydraulic properties of the aquifer also play a role in the flow of water through the aquifer.

Saturated Thickness and Well Yield

The saturated thickness of an aquifer is the vertical distance between the water table and the base of the aquifer, and it is a measure of the amount of water that can be stored in an aquifer. The saturated thickness can be affected by factors such as geology, topography, and land use.

Challenges in the saturated thickness of the High Plains aquifer have resulted from ground-water development. Saturated thicknesses have decreased in most places (fig. 57), but in two areas in south-central Nebraska, recharge to the aquifer from surface water recharge combined with downward leak of water from canals and reservoirs has increased saturated thickness. In large areas in southwestern Kansas, large-scale irrigation development has decreased the saturated thickness of the aquifer more than 25 percent.
GROUND-WATER DEVELOPMENT AND WATER-LEVEL FLUCTUATIONS

Development of the High Plains aquifer began in the late 1800's, when windmills were used as a source of power to pump water from scattered irrigation wells. Spurred by the drought of the 1930's, ground-water irrigation expanded rapidly. Development of the High Plains aquifer generally began in Texas, adjacent parts of New Mexico, and in major stream valleys in other States in the 1930's. Widespread development progressed to Oklahoma and Kansas in the 1940's and extended to Colorado, Nebraska, and Wyoming in the 1950's; the aquifer has undergone little development in South Dakota.

In 1949, the total acreage irrigated by ground water in the High Plains was slightly more than 2 million acres (fig. 59), most of which was in Texas. The number of acres irrigated in Kansas and Nebraska expanded greatly in the late 1950's in response to a drought. The amount of irrigated acreage in those States continued to increase until 1978, by which time nearly 170,000 irrigation wells had been completed in the High Plains aquifer, about 23,000 of these wells were in Kansas, and nearly 58,000 were in Nebraska. Collectively, irrigation wells in eight States pumped about 23 million acre-feet of water from the High Plains aquifer in 1978 to irrigate about 13 million acres. In 1978, water from the High Plains aquifer was used to irrigate about 4.5 million acres in Nebraska and more than 2 million acres in Kansas. The large increase in the number of wells drilled for irrigation between 1952 and 1978 was partially a result of the development of center-pivot irrigation systems during the 1960's. Center-pivot systems, such as those shown from an aerial view in figure 60, are supplied by irrigation wells and have the water-distribution pipes mounted on a wheeled boom that rotates in a circle around the center of the irrigated area. Such systems make it possible to irrigate the rolling terrain of the High Plains. In Nebraska alone, the number of center-pivot irrigation systems increased from about 8,000 in 1972 to more than 27,000 by the end of 1984 (fig. 61).

As the number of irrigation wells increased, the percentage of land that was irrigated also increased. In 1949, the 5 percent or less of land that was irrigated in most of Nebraska and Kansas (fig. 62A) was mostly along rivers or valleys. By 1964, the percentage of irrigated land had increased, and much of the irrigated land was in upland areas (fig. 62B). By 1978, the percentage of irrigated land had greatly increased (fig. 62C) as more upland areas were irrigated.

As development of the High Plains aquifer became more extensive, water levels in the aquifer began to decline in some locations. Well yields decreased in some planes as a result of the water-level declines. The cost of pumping increased as water levels declined because pumps were set deeper and more energy was required to lift water to an increased distance. The cost of the energy used to pump the water also increased. This increased cost for obtaining irrigation water decreased the profit in growing crops that require irrigation in parts of the High Plains area.

Average annual withdrawals of water from the High Plains aquifer are generally much larger than recharge to the aquifer from precipitation. In places where recharge rates are high, the demand for irrigation water could be as low as twice the average annual recharge; where recharge rates are low, the demand could be more than 100 times the recharge. The quantity of water removed from storage from the entire aquifer between predonation conditions and 1980 is estimated to be about 166 million acre-feet, of which about 27 million acre-feet was withdrawn in Kansas. No significant quantity of water has been removed from storage in Nebraska. By 1980, withdrawals of water from the High Plains aquifer had resulted in water-level declines of more than 100 feet in parts of southwestern Kansas (fig. 63). Development of the aquifer in this area began in the 1950's, which is earlier than in most other places in Kansas. Generally, the later the development of the aquifer begins in a region and the less intense the development has been, the smaller the water-level decline in that area. Water-level rises shown in parts of southern Nebraska are a response to increased recharge of the aquifer by infiltration of surface water applied for irrigation.

GROUND-WATER QUALITY

The chemical quality of water in the High Plains aquifer is affected by many factors. These factors include the chemical composition of surface-water materials, the introduction of dissolved-solids concentrations in ground water in areas where the water discharges by evapotranspiration, and the composition of water that recharges the aquifer. Ground water generally contains smaller concentrations of dissolved minerals near recharge areas where the residence time of the water in the aquifer has been short, and, thus, dissolution of aquifer minerals has been less. The water generally is more mineralized near discharge areas because residence time has been longer and more dissolution of minerals has taken place.

The dissolved-solids concentrations in ground water in a general indicator of the chemical quality of the water. Dissolved-solids concentrations in water from the High Plains aquifer are less than 500 milligrams per liter in most of Kansas and Nebraska (fig. 64), but locally exceed 1,000 milligrams per liter in both States. The limit of dissolved solids recommended by the U.S. Environmental Protection Agency for drinking water is 500 milligrams per liter. Most crops can tolerate water in which the dissolved-solids concentration is 500 milligrams per liter or less. In places with well-drained soils, many types of crops can tolerate water with a dissolved-solids concentration of between 500 and 1,500 milligrams per liter. In southwestern and south-central Kansas, the High Plains aquifer overlies a Permian bedrock that contains bedded salt. Where circulating ground water has dissolved some of this salt and the mineralized water has subsequently moved up into the High Plains aquifer, the dissolved-solids concentration of the water in the High Plains aquifer is greatly increased. Also, dissolved-solids concentrations generally are greater near streams where water from the High Plains aquifers discharges.

Ground water near the streams is shallow enough to be transmitted by plants or to be evaporated directly from the soil. Concentrations of dissolved solids in the ground water are increased by the evapotranspiration process. Rates of transpiration are greatest where deep-rooted phreatophytes, such as sedge, cottonwood, willow, and salt cedar, grow.
Excursive concentrations of sodium in water adversely affect plant growth and soil properties, and constitute salinity hazards that may limit irrigation development. Sodium that has been concentrated in the soil by evapotranspiration and irrigation exchange decreases soil permeability and permeability. Areas of high or very high sodium hazard occur in parts of Kansas. Sodium hazard is evaluated by the sodium adsorption ratio, which relates the concentration of sodium to calcium plus magnesium; if this ratio is high, then the sodium can affect any clay in the soil and thus affect soil structure. Sodium concentrations in water from the High Plains aquifer in Kansas and Nebraska are shown in Figure 68. Concentrations are less than 25 milligrams per liter in most of Nebraska and northern Kansas. Concentrations are greatest in southeastern Kansas where evapotranspiration rates are high and in southwestern Kansas where the High Plains aquifer overlies Permian bedrock that contains saline water derived from partial dissolution of salt beds. Sodium concentrations are increased along the Platte and the Republican Rivers where evapotranspiration rates into the river are high. Salinity and sodium hazards generally are low in Nebraska where the High Plains aquifer primarily consists of sand and gravel, which contain few sodium-bearing minerals. Excursive fluviatile concentrations are a widespread problem in water from the High Plains aquifer. Some of the fluviatile sodium is derived from dissolution of fluviatile-bearing minerals in parts of the aquifer that contain sand and gravel, such as the Ogallala Formation. Extremely large concentrations (2-5 milligrams per liter) of fluoride are found where the aquifer contains sodium deposits or where it is underlain by rocks of Cretaceous age. Large concentrations of fluoride in drinking water cause staining of teeth, but fluoride is not a concern in irrigation water.

The generally shallow depth of water in the High Plains aquifer makes water in the aquifer susceptible to contamination. Application of fertilizers and organic pesticides to cropland has greatly increased since the 1960s, thus increasing the availability and the amount of potential contaminants available. Increased concentrations of sodium, alkalinity, nitrate, and fluoride (a herbicide) have been found in water that underlies areas of irrigated cropland in Nebraska and Kansas. Of 132 wells sampled during 1984-85 in Nebraska, measurable concentrations (greater than 0.04 milligram per liter) of the herbicide atrazine were found in water that underlies rangefeed in a small part of the Great Bend area of the Kansas River Basin in Kansas.

**FRESH GROUND-WATER WITHDRAWALS**

Withdrawals of fresh ground water from the High Plains aquifer in Segment 3 during 1990 totaled 8,181 million gallons per day (fig. 65). Of this amount, 4,596 million gallons per day was withdrawn in Nebraska. About 97 percent of the total withdrawals, or about 7,900 million gallons per day, was used for agricultural, primarily irrigation, purposes. About 260 million gallons per day was pumped for public supply. Domestic and commercial withdrawals were about 40 million gallons per day, and industrial, mining, and other commercial water uses also were about 40 million gallons per day.

**INTRODUCTION**

The Mississippi embayment aquifer system in Segment 3 is in southeastern Missouri (fig. 67) on the western side of the Mississippi Embayment section of the Coastal Plain Physiographic Province. The aquifers that compose the Mississippi embayment aquifer system are unconsolidated to semi-consolidated sands that range in age from Eocene to Late Cretaceous. The Mississippi embayment aquifer system extends over large areas in Arkansas, Louisiana, and Mississippi and smaller areas in Alabama, Florida, Illinois, Kentucky, Missouri, and Tennessee (fig. 67). The aquifer system is unusual in its areal extent in Segment 3 of this Atlas and is discussed in greater detail in chapter F which describes that segment. Little freshwater is withdrawn from the Mississippi embayment aquifer system in Missouri because it is overlain in most places by the productive Mississippi River Valley alluvial aquifer.

**HYDROGEOLOGIC UNITS**

The six aquifers and two confining units that compose the Mississippi embayment aquifer system in Missourisubcrop as narrow bands (fig. 68) beneath the Mississippi River Valley alluvial aquifer. Five of the aquifers of the Mississippi embayment aquifer system are shown in order beneath the aquifer sequence. These are the upper Claiborne aquifer, the middle Claiborne aquifer, the lower Claiborne upper Wilcox aquifer, the middle Wilcox aquifer, and the lower Wilcox aquifer. The clayey middle Claiborne confining unit separates the upper Claiborne and middle Claiborne aquifers. The McNairy-Papachoc aquifer, deepest aquifer in the system, is in sand of Cretaceous age and underlies thick clay of the Mississippian confining unit. Clayey silt of the Vicksburg-Jackson confining unit overlies the aquifer system locally in an area adjacent to Tennessee.

Sodium in some of the aquifers in the Mississippi embayment aquifer system is not separated by regional confining units, they can be defined on the basis of changes in lithology and hydraulic head (water level) between aquifers. The vertical movement of water between the middle Claiborne through lower Wilcox aquifers is restricted by interbedded fine-grained sediments within the aquifers. In contrast, the middle Claiborne and Mississippian confining units more effectively retard the vertical movement of water between aquifers.

The extensive, massive water-yielding sands of the aquifer system slope and thicken in Missouri toward the axis of the Mississippi Embayment. The clayey middle Claiborne confining unit has been chosen to illustrate the aquifer system because it extends over a wide area and has been penetrated by numerous wells. The top of the lower Wilcox aquifer is about 200 feet above sea level at its updip limit but shallows to more than 1,000 feet below sea level in southeastern Pemiscot County (fig. 70). On the opposite (Tennessee) side of the Embayment, the top of the aquifer is shallower. The aquifer, thus, has a troughlike shape, as do the aquifers that overlie and underlie it.

The lower Wilcox aquifer thicknesses from a featheredge at its northeastern limit to more than 300 feet in southeastern Pemiscot County. The top of the aquifer slopes to more than 1,000 feet below sea level in western Pemiscot County.

**GROUND-WATER FLOW**

Because the Mississippi embayment aquifer system in Missouri is covered by the Mississippi River Valley alluvial aquifer in most places, the aquifer system is recharged mostly by downward leakage of water from the alluvial aquifer. Water enters the lower Wilcox aquifer in a band where sands of the aquifer are in hydraulic contact with those of the overlying Mississippi River Valley alluvial aquifer (fig. 72). Water from the lower Wilcox aquifer then moves southeastward down the dip of the sand bed in the lower Wilcox aquifer. The lower Wilcox aquifer also moves westward and southwestward from aquifer outcrop areas in Tennessee and Kentucky. Because the lower Wilcox aquifer is deeply buried, this water moves under the Mississippi River without discharging to the river. Water discharges from the aquifer by upward leakage to shallower aquifers in Arkansas.

**GROUND-WATER QUALITY**

The chemical quality of freshwater in the aquifers of the Mississippi embayment aquifer system in Missouri is suitable for most uses. The water is fresh except locally in the McNairy-Papachoc aquifer, which is the deepest aquifer of the system (fig. 73). Dissolved-solids concentrations in water from this aquifer locally exceed 2,000 milligrams per liter in New Madrid and Stoddard Counties and exceed 1,000 milligrams per liter in an area of about 400 square miles. Water in this area is a sodium chloride type and probably has entered the McNairy-Papachoc aquifer by upward leakage from underlying saline salt rocks that locally contain saline water. Water in shallower aquifers of the Mississippi embayment aquifer system is fresher than that in the McNairy-Papachoc aquifer.

Water in the aquifers of the Mississippi embayment aquifer system is a calcium magnesium bicarbonate type in aquifer-recharge areas. As the water moves down the hydraulic gradient, it changes to a sodium bicarbonate type and locally changes to a calcium bicarbonate type as it discharges to the Mississippi River Valley alluvial aquifer. Downgradient parts of the aquifers.

**FRESH GROUND-WATER WITHDRAWALS**

About 95 million gallons per day of freshwater was pumped from the aquifers of the Mississippi embayment aquifer system in Missouri during 1990. Most of the water was withdrawn for agricultural, primarily irrigation, use. Because the Mississippi River Valley alluvial aquifer in most places is a thin, productive aquifer, larger amounts of water are withdrawn from it than from the deeper Mississippi embayment aquifer system.
INTRODUCTION

The Great Plains aquifer system underlies most of Nebraska, about one-half of Kansas, the eastern one-third of Colorado, and small parts of New Mexico, Oklahoma, Texas, South Dakota, and Wyoming (fig. 74). The rocks that compose the aquifer system extend northward into Segment 8 of this Atlas, where they mostly contain saline water, and equivalent rocks extend still further northward into western Canada. The aquifer system has been studied in detail, however, only in the area shown in figure 74, where it extends for about 170,000 square miles. Although the Great Plains aquifer system is extensive in Segment 2 of this Atlas, it contains primarily saline water there, along with some brine, oil, and gas, and is accordingly not discussed in detail in the chapter which describes that segment. The maps and descriptions presented in this chapter apply to the parts of the aquifer system that are in Kansas and Nebraska.

The Great Plains aquifer system is named for the Great Plains Physiographic Province, which is a vast, rolling plain that slopes eastward for several hundred miles from the front of the Rocky Mountains. The water-yielding rocks of the aquifer system are sandstone; confining units in the system consist of siltstone and shale. Water has been produced from the uppermost part of the aquifer system for many years; more than 1,000 flowing wells were reported to be tapping water from the aquifer in 1905. In the early 1900s, the uppermost aquifer of the system was named the Dakota aquifer and was described as a classic artesian system. More recent studies have shown that the flow system of this aquifer is more complex than was originally thought. Likewise, the stratigraphy of the rocks that form the aquifer is complex. It is now known to be an over-simplification to refer to the aquifer simply as the "Dakota aquifer," and it has accordingly been renamed.

HYDROGEOLOGIC UNITS

The rocks that contain the Great Plains aquifer system were deposited during the lower part of the Cretaceous Period and reflect transgressions and regressions of the Cretaceous sea. The thickness of the basin part of the aquifer system varies because of the relief of the pre-Cretaceous erosional surface. Local stratigraphy is complex because numerous oscillations of the sea resulted in repeated, rapid shifts from marine to marginal marine to nonmarine depositional environments. These environmental changes are reflected in abrupt changes in the texture of the sediments. Sand bodies are typically thin, lenticular, or sinusoid. There are, however, thick, more continuous sand bodies that were deposited in deltaic, shoreline, or fluvial environments.

Regionally, the Great Plains aquifer system is characterized by two sandstone aquifers separated by a shale confining unit (fig. 75). The aquifer system contains more geologic formations and is more complex in southwestern Nebraska, where it is extremely thick, than to the east in Nebraska and Kansas, where it is thinner. In places, both aquifers are subdivided by shale beds that form local confining units. The Great Plains confining system, which consists mostly of thick layers of Upper Cretaceous shale, overlie the Great Plains aquifer systems. The aquifer system is confined below by a thick sequence of shale, limestone, sandstone, and anhydrite beds of Jurassic to Late-Miocene ages. This underlying sequence of confining beds is called the Western Interior Plains confining system.

The upper aquifer of the Great Plains aquifer system is called the Dakota aquifer. This aquifer was formerly called the Dakota aquifer from the Dakota Sandstone, which is a prominent part of the aquifer. The Maha is the best known and most used part of the aquifer system. The correlation chart (fig. 75) shows the different usage of the term "Dakota" in different places throughout the extent of the aquifer system. In eastern Nebraska and Kansas, the name "Dakota Formation" applies only to the upper part of the system. In southwestern Nebraska, the Dakota is considered to be a stratigraphic group that includes all Lower Cretaceous rocks and the lower part of Upper Cretaceous rocks, and consists of four sandstone aquifers and three confining units. In Kansas, the term "Dakota aquifer" refers to the entire Great Plains aquifer system. Because of the multiple meanings of the term "Dakota" as applied to either geologic units or hydrogeologic units, confusion is avoided by assigning a new name, the "Maha aquifer," to the upper aquifer. Likewise, it is inexact to apply the formerly used name "Cheyenne Sandstone aquifer" to the lower aquifer of the Great Plains aquifer system. Accordingly, this lower aquifer has been renamed the "Apishapa aquifers." The Maha aquifer is separated from the Apishapa aquifers in most places by the Apishapa confining unit, which consists of the Niobrara and the Skull Creek Shales.

The Maha and the Apishapa aquifers consist of locally cemented, medium- to fine-grained sandstone. The Apishapa confining unit that separates the aquifers consists of slightly permeable shale. The Maha aquifer is more extensive than the Apishapa aquifer (fig. 76), where the Apishapa confining unit pinches out, the two aquifers are in direct contact and are considered to be part of the Maha aquifer (fig. 77). In western Nebraska, both aquifers are downwarped to depths of more than 5,000 feet below land surface in part of the Denver Basin (fig. 78), where parts of the Great Plains aquifer system contain brine, oil, and gas. In eastern Nebraska and most of Kansas, the aquifer system is buried to depths of 1,000 feet or less below land surface.

The Maha aquifer is much thicker than the Apishapa aquifer in most places. The thickness of the Maha aquifer generally is more than 1,000 feet below land surface. In part of the Denver Basin, however, the aquifer system is as deep as 10,000 feet below land surface and locally contains oil and gas. Most of the freshwater is withdrawn from the aquifer system where the overlying rocks are thin.
GROUND-WATER FLOW

The regional movement of water in the Great Plains aquifer system in Segment 3 can be inferred from a map of the potentiometric surface of the aquifer system (fig. 81). Water levels in the aquifer system are highest in southwestern Kansas and southwestern Nebraska. Water moves generally eastward and northward from recharge areas in southwestern Colorado toward discharge areas in central Kansas, eastern Nebraska, and along the Platte River in northeastern Nebraska. In its central parts, the aquifer system typically is overlain by a thick confining system, and the hydraulic gradient is flat. Water in the aquifer system in these places moves sluggishly. Near the eastern limit of the aquifer system, the hydraulic gradient becomes steeper, which indicates a more dynamic ground-water flow system.

Much of the recharge to the aquifer system is from precipitation that falls directly on aquifer outcrop areas in southeastern Colorado and northeastern Nebraska. Some recharge, however, enters the aquifer system as downward leakage through the overlying Great Plains confining system. The High Plains aquifer overlies this confining system, and the hydraulic gradient is downward from the High Plains aquifer to the Great Plains aquifer system in most places (fig. 82). For example, in the southwestern part of the Nebraska panhandle, the water table in the High Plains aquifer is more than 2,500 feet higher than the hydraulic head in the Great Plains aquifer system. In many places near the eastern limit of the Great Plains aquifer system, however, water levels in the High Plains aquifer and the Great Plains aquifer system are about equal. Locally, the hydraulic gradient is reversed, and discharge takes place by upward leakage from the Great Plains aquifer system to the High Plains aquifer. Most discharge from the Great Plains aquifer system is by upward leakage, but some discharge is as base flow to streams in aquifer outcrop areas.

The Great Plains aquifer system is mostly confined above by the Great Plains confining system and below by the Western Interior Plains confining system. Movement of water through the confined parts of the aquifer system is very slow and is estimated to be 10 feet per year or less. Flow is more rapid in places where the aquifer system crops out or the overlying confining system is thin. The presence of oil, gas, and brine in deeply buried parts of the aquifer system, such as the Denver Basin, indicates that the water in such places is virtually stagnant.

Most of the data available for the water-yielding capability of the Great Plains aquifer system are from the Maha aquifer. Sparse data from the deeper Apishapa aquifer indicate that the two aquifers have similar hydraulic properties, which show similar trends. Most of the porosity in the aquifer system is intergranular; that is, it consists of pore spaces between individual sand grains. Joints, fractures, and bedding planes exist locally in the sandstones, but most of the water moves through the intergranular pore spaces. Sandstone porosity in the Great Plains aquifer system generally decreases as the depth of burial of the aquifer system increases because the sandstone has compacted where it is buried beneath thousands of feet of overlying rocks. The compaction has reduced the percentage of pore space in the sandstone from more than 30 percent where overlying rocks are thin to less than 10 percent where the aquifer system is deeply buried. This reduction in pore space not only reduces the capacity of the aquifer to store water, but also its capability to transmit water.

Transmissivity, or the capacity of an aquifer or aquifer system to transmit water, is one way to measure the ease with which ground water moves. The greater the transmissivity of an aquifer, the more readily water moves through it, and the greater the chances of obtaining large well yields from the aquifer. The distribution of the estimated transmissivity of the Maha aquifer is shown in figure 83. The transmissivity of the aquifer is greater in its eastern parts, and the larger transmissivity values (1,000 to more than 10,000 feet squared per day) coincide with places where the aquifer is thickest. The transmissivity values in western Nebraska locally are less than 100 feet squared per day in thin, aquifer multiplied and compacted in part of the Denver Basin. Reported yields of wells completed in the Maha aquifer in eastern Nebraska and central Kansas commonly exceed 50 gallons per minute and locally are as much as 1,000 gallons per minute. These large-yield areas coincide with places where the transmissivity of the aquifer is high.
GROUND-WATER QUALITY

The chemical character of water in the Great Plains aquifer system is determined by many factors. Some of or all the following factors determine the ground-water chemistry: the mineral content of the soil or aquifer material through which the water has passed, the rate of movement of the water, the length of time the water remains in the aquifer; the chemistry of water trapped during sediment deposition; diagenesis, or the chemical and physical changes that take place in aquifer sediments after they are deposited; and mixing of the water with water in adjacent hydrologic units or from the land surface.

Concentrations of dissolved solids in water from the Maha aquifer are mapped in Figure 84. The aquifer contains fresh-water only near its southern and eastern margins and in a small area in northwestern Nebraska. These are places where the overlying confining unit is thick and represent areas of aquifer recharge or discharge; the flow system is accordingly dynamic, and mineralized water can be readily flushed from the aquifer. Also, the quartz sand that composes most of the aquifer is not readily dissolved; this condition leads to small dissolved-solids concentrations in the ground water.

Water that contains dissolved-solids concentrations of between 1,000 and 10,000 milligrams per liter is considered to be slightly to moderately saline. Such water is characteristic of much of the Great Plains aquifer system and results from incomplete flushing of highly mineralized water by a sluggish flow system. Some of the mineralized water has leaked upward from underlying Permian rocks that contain halite and evaporite minerals. Concentrations of dissolved solids that range from 10,000 to about 20,000 milligrams per liter are common in water from the central and east-central parts of the aquifer. Concentrations of this magnitude can result from the combination of incomplete flushing and the upward migration of highly mineralized water from underlying Permian rocks.

Ground water can be classified into hydrochemical facies on the basis of the dominant cations and anions in the water. To demonstrate the classification used, a sodium chloride water is one in which sodium ions account for more than 50 percent of the total cations in the water, and chloride ions account for more than 50 percent of the total anions. The distribution of hydrochemical facies in water from the Great Plains aquifer system is shown in Figure 85. In many artesian flow systems, the water changes progressively from a calcium bicarbonate type in upgradient recharge areas to a sodium chloride type in deep, confined parts of the flow system. This is not the case with the Great Plains aquifer system because the distribution of hydrochemical facies is more complex (fig. 85). Calcium bicarbonate type water mostly is in a narrow band along the eastern and southern limits of the aquifer system. Where the aquifer system is confined, it mostly contains sodium bicarbonate or sodium chloride type waters. These hydrochemical facies are in places where mineralized water in the aquifer system has not been completely flushed by circulating fresh-water and where underlying saline water leaks upward faster than it can be flushed. Some of the sodium bicarbonate water may be the result of ion exchange of calcium for sodium on the surface of clay or other sodium-rich minerals. The leakage is thought to take place along fractures and faults. In summary, incomplete flushing, slow circulation through most of the aquifer system, rock-water interaction within the aquifer system, and mixing of highly mineralized waters from adjacent rocks are the processes that produce the observed distribution of hydrochemical facies.

FRESH GROUND-WATER WITHDRAWALS

Freshwater is withdrawn from the Great Plains aquifer system in Kansas and Nebraska mostly along the southern and eastern margins of the aquifer. These are the parts of the aquifer system that are nearest to land surface and contain most of the freshwater. Although development of the aquifer system began in the early 1900's and moderate amounts of water were withdrawn from the aquifer system during the 1940's and the 1950's, it was not until the 1960's that withdrawals were significant (fig. 86). Estimated withdrawals from the aquifer system in Kansas and Nebraska during the 1970's were at a rate of about 350,000 acre-feet per year, which is almost eight times the rate of withdrawal during the 1950's. The distribution of withdrawals has changed with time. During the 1950's, withdrawals in Kansas and Nebraska were about equal; during the 1960's, however, withdrawals increased greatly in Nebraska, while withdrawals in Kansas remained about the same as in the 1950's. During the 1970's, withdrawals increased greatly in both States.

Total fresh ground-water withdrawals from the Great Plains aquifer system in Kansas and Nebraska were about 17 million gallons per day during 1990 (fig. 87). About 73 percent of the total was water withdrawn, or 867 million gallons per day, was used for agricultural purposes, primarily irrigation. About 17 million gallons per day was for water withdrawal, mostly for municipal purposes, and the same amount was withdrawn for domestic and commercial purposes. About 2 million gallons per day was pumped for industrial, mining, and thermoelectric power use.

Figure 84. Freshwater occurs only along the eastern and southern margins of the Maha aquifer and in a small area in northwestern Nebraska. These are places where the overlying confining unit is thick and represent areas of aquifer recharge or discharge; the flow system is accordingly dynamic, and mineralized water can be readily flushed from the aquifer. Also, the quartz sand that composes most of the aquifer is not readily dissolved; this condition leads to small dissolved-solids concentrations in the ground water.

Figure 85. Water in the Great Plains aquifer system is mostly a sodium bicarbonate or sodium chloride type where the system is confined and a calcium bicarbonate type where it is unconfined. The water type mapped mostly reflects circulation of water in the aquifer system. The water changes progressively from a calcium bicarbonate type in upgradient recharge areas to a sodium chloride type in deep, confined parts of the flow system. This is not the case with the Great Plains aquifer system because the distribution of hydrochemical facies is more complex (fig. 85). Calcium bicarbonate type water mostly is in a narrow band along the eastern and southern limits of the aquifer system. Where the aquifer system is confined, it mostly contains sodium bicarbonate or sodium chloride type waters. These hydrochemical facies are in places where mineralized water in the aquifer system has not been completely flushed by circulating fresh-water and where underlying saline water leaks upward faster than it can be flushed. Some of the sodium bicarbonate water may be the result of ion exchange of calcium for sodium on the surface of clay or other sodium-rich minerals. The leakage is thought to take place along fractures and faults. In summary, incomplete flushing, slow circulation through most of the aquifer system, rock-water interaction within the aquifer system, and mixing of highly mineralized waters from adjacent rocks are the processes that produce the observed distribution of hydrochemical facies.

Figure 86. Rates of withdrawal of freshwater from the aquifer system in Kansas and Nebraska increased greatly during the 1960's and the 1970's. Withdrawals in Kansas were much greater than those in Nebraska during these two decades.

Figure 87. Most of the water withdrawn from the aquifer system during 1990 was used for agricultural purposes, primarily irrigation.
INTRODUCTION

The Ozark Plateaus aquifer system contains most of the freshwater in the aquifers that consist of Mississippian and older rocks in Segment 3. The aquifer system underlies most of southern Missouri and a small part of extreme southwestern Kansas in this segment; it also underlies a large area in northeastern Arkansas and a small part of northeastern Oklahoma (fig. 88). The Arkansas part of the aquifer system is discussed in detail in the chapter of this Atlas that describes Segment 5, and the Oklahoma part is discussed briefly in the chapter that describes Segment 4.

Bocks equivalent to parts of the Ozark Plateaus aquifer system locally contain freshwater in parts of northeastern Missouri and are called the Mississippian and the Cambrian-Ordovician aquifers. Equivalent carbonate rocks to the west and northwest that contain saline water or brine have been named the "Western Interior Plains aquifer system" (fig. 89). The water-yielding rocks in the Ozark Plateaus aquifer system and equivalent beds are mostly limestones and dolomites, but some sandstones are productive aquifers. Confining units within the aquifer system and its equivalents are shale or dolomite. The lithology of the individual aquifers and confining units and their hydraulic character are consistent over large areas.

Ground water in the aquifer system locally moves from topographically high recharge areas to surface streams. Regional movement is northwestern, southward, and southwesterly from a high area on the topographic surface in central Missouri. Some of the drainages in the Springfield aquifer, by contrast, the aquifer and the Cambrian-Ordovician aquifer appear to be hydraulically connected, at least in part.

Figure 89. The major aquifers and confining units of the Ozark Plateaus aquifer system that grade upward into equivalent hydrogeologic units of the Western Interior Plains aquifer system and have stratigraphic equivalents in northern Missouri are shown. The Springfield aquifer is shown as a base flow at shallow level, and the deeper aquifers are shown discharging water to surface streams.

Figure 90. Water in the lower part of the Ozark Plateaus aquifer moves northward, southward, and southwesterly from a high area on the topographic surface in central Missouri. The Springfield aquifer moves mostly upward across the thick, effective Western Interior Plains confining unit, and equivalent aquifers in Nebraska and Kansas. The flow direction changes vertically upward as it moves to higher aquifers in this transition zone in eastern Kansas and central Missouri.

Figure 91. The water-yielding rocks of both aquifer systems are shown as base flow at shallow level, and the deeper aquifers are shown discharging water to surface streams.

Figure 92. The Ozark Plateaus aquifer system contains freshwater in the Missouri River valley alluvial aquifer system. Water in the freshwater portion of the Missouri aquifer is slightly saline to brackish. The freshwater portion of the Missouri aquifer system is shown. This basin area of vigorous ground water circulation, and the more highly mineralized saltwater is in places where ground water movement is also of significance.

Figure 93. Several geologic formations, mostly of Mississippian, Ordovician, and Pennsylvanian age, underlie the Aquifer system. Confining units between the aquifers are mostly limestones and dolomites, but some sandstones are productive aquifers. Confining units within the aquifer system and its equivalents are shale or dolomite. The lithology of the individual aquifers and confining units and their hydraulic character are consistent over large areas.

Figure 88. The Ozark Plateaus aquifer system extends over most of southern Missouri and smaller parts of adjacent States. An equivalent aquifer system to the west, the Western Interior Plains aquifer system, contains saline water in the Springfield aquifer of southern Missouri, which is part of the Cambrian-Ordovician aquifer system. The unsaturated zone moves westward into equivalent hydrogeologic units.

Figure 95. This idealized hydrogeologic section in central Kansas and Nebraska indicates that the rocks of the Western Interior Plains aquifer system are considered to be hydraulically connected in places. Upper Devonian and Lower Mississippian rocks compose a confining unit in the Western Interior Plains aquifer system. The aquifiers with the highest dissolved solids concentrations are shown in this diagram. The line of equal dissolved-solids concentrations, in milligrams per liter, is shown in the diagram. The scale bar represents five million gallons per day.

RELATION TO ADJACENT AQUIFERS AND AQUIFER SYSTEMS

The Ozark Plateaus aquifer system consists of three aquifers that are separated by two confining units (fig. 89), all of which grade laterally westward into equivalent hydrogeologic units that are called the Lower Mississippian and the Upper Devonian aquifers of northern Missouri. The Springfield aquifer is fresh to slightly saline. The freshwater portion of the Missouri aquifer is shown as base flow at shallow level, and the deeper aquifers are shown discharging water to surface streams.

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The aquifers in the Ozark Plateau aquifer system have been named for geographic or physiographic features (fig. 94). From shallowest to deepest, the three aquifers are the Springfield Plateau aquifer, which is named for a physiographic feature in western Missouri; and the St. Francois aquifer, which was named for the St. Francois Mountains in southeastern Missouri. Confining units in the system are named the same as the aquifers they surround; for example, the St. Francois aquifer is overlain by the St. Francois confining unit.

The aquifers and confining units of the Ozark Plateau aquifer system are exposed as a sequence of concentric bands that are centered around the Precambrian rocks that are exposed in the St. Francois Mountains (fig. 95). These Precambrian igneous and metamorphic rocks form the basement confining unit, which is the lower confining unit of the Ozark Plateau aquifer system. Exposures of the St. Francois aquifer surround this confining unit and are, in turn, surrounded by a band of the overlying St. Francois confining unit. The rocks that compose the Ozark aquifer crop out over more than one-half of southern Missouri and in a large part of northern Arkansas. The thick, widespread Ozark aquifer is by far the most important aquifer of the Ozark Plateau aquifer system; the equivalent Cambrian-Ordovician aquifer north of the Missouri River is also an important source of water. The thin Ozark confining unit overlies and crops out as a narrow band that separates the Ozark aquifer from the overlying Springfield Plateau aquifer. A thick sequence of rocks with minimal permeability, which is called the Western Interior Plains confining system, overlies and effectively confines the Springfield Plateau aquifer west of the outcrop area of the aquifer. The Osaka Plateau aquifer system is covered in southwestern Missouri by Mississippian and younger rocks and deposits that are part of the Mississippian embayment aquifer system or the Mississippi River alluvial aquifer. Variations in the thickness and extent of the aquifers and confining units of the Ozark Plateau aquifer system and their equivalents are shown in figure 96. The thickness of the Springfield Plateau aquifer is uniform slightly to the west of its outcrop area, but the equivalent upper aquifer unit of the Western Interior Plains aquifer system thins westward where it is covered by the Western Interior Plains confining system. The Osaka aquifer thickens gradually westward and is more than 1,000 feet thick in central Missouri; the aquifer thins more rapidly to the east of the St. Francois Mountains. The thickness of the St. Francois aquifer varies greatly because the rocks that compose this aquifer were deposited on an irregular erosional surface that was developed on Precambrian rocks of the basement confining unit. The thickness of the St. Francois and the Osaka confining units does not vary as much as that of the aquifers that they separate.

The Ozark Plateau aquifer is the uppermost aquifer of the Ozark Plateau aquifer system and consists almost entirely of limestone of Mississippian age. The thickest and most productive water-yielding geologic formations included in the aquifer are the Burlington and the Kentuck Limestones (fig. 93). Most of the water from the Springfield Plateau aquifer generally drains through these openings has dissolved part of the limestone and has resulted in a network of solution channels. This dissolution activity is reflected at the land surface by springs, caves, and sinkholes, and by sparse surface drainage. These features are characteristic of a type of topography called karst topography, which commonly is developed in areas underlain by limestone.

Recharge to the Springfield Plateau aquifer is mostly from precipitation on outcrop areas of the aquifer. After the recharge water percolates downward to the water table, most of it moves laterally along short flow paths to discharge as base flow to nearby streams. Some of the water follows flow paths of intermediate length and discharges to large streams, and a small part of the recharge moves laterally into confined parts of the aquifer. A small amount of recharge to the Springfield Plateau aquifer is by upward leakage of water from the deeper Ozark aquifer in places where the hydraulic head of the Ozark aquifer is greater than that of the Springfield Plateau aquifer. In much of the outcrop area of the Springfield Plateau aquifer, however, water levels in this aquifer are higher than those in the Ozark aquifer, and water leaks downward to recharge the Ozark aquifer. Most of the dissolved solids in the recharge to the Springfield Plateau aquifer are dissolved in the groundwater that flows through the Ozark confining unit that separates the Springfield Plateau aquifer from the overlying confining units. A map of the estimated potentiometric surface of the Springfield Plateau aquifer and the thickness of the confining units that compose this aquifer were used to calculate that the water in the aquifer moved mostly from local recharge areas to nearby surface drains. The configuration of the potentiometric surface is consistent generally with the configuration of the flow of water between and through the confining units, and the surface contours are smoother and only reflect the influence of large streams. The regional movement of water in the aquifer is westward.

The chemical quality of water in the Springfield Plateau aquifer generally is suitable for most uses where the aquifer is unconfined or where the confining unit that overlies the aquifer is thin. The water commonly is a calcium bicarbonate type and is moderately hard. Dissolved-solids concentrations in water from the aquifer generally are less than 1,000 milligrams per liter except where the aquifer is confined (fig. 99). Dissolved-solids concentrations increase rapidly downstream where the aquifer becomes confined. Concentrations of sulfates, generally are small in water from the aquifer except in the Tri-State lead-zinc mining district of southeastern Missouri, southwestern Kansas, and northeastern Oklahoma where concentrations of more than 500 milligrams per liter are reported near some mining areas. These large concentrations result from leaching of the sulfide minerals that contain the lead and zinc.

Most of the water withdrawn from the Springfield Plateau aquifer is used for domestic and stock-watering supplies. Yields of wells completed in the aquifer generally are less than 20 gallons per minute.

The Ozark confining unit underlies the Springfield Plateau aquifer and hydraulically separates this aquifer from the deeper Ozark aquifer. The Ozark confining unit consists mostly of shale but locally includes limestone of minimal permeability. The confining unit generally is less than 100 feet thick except in small areas. Where the shale component of the confining unit is greater, the confining unit can more effectively retard the vertical movement of water between the Springfield Plateau and the Ozark aquifers. North of the Missouri River, rocks equivalent to the Ozark confining unit separate the Mississippian and the Cambrian-Ordovician aquifers.

Ozark aquifer

The Ozark aquifer is the middle aquifer of the Ozark Plateau aquifer system and consists of numerous geologic formations that are part of the province and its subdivisions. The rocks of the aquifer are mostly dolomite and limestone, but some beds of sandstone, chert, and shale are included in it. The Ozark aquifer is the primary source of water in the Ozark Plateau Physiographic Province from which it is named. The Ozark aquifer provides water for municipal, industrial, and domestic supplies. The water-yielding formations that compose the Ozark aquifer are the Upper Cambrian Potomac Dolomite, the Lower Ordovician Garonnda Dolomite, and the Erubus Formation. The Potomac Dolomite is the most permeable of these three formations. North of the Potomac River, rocks that are equivalent to the Ozark aquifer are called the Cambrian-Ordovician aquifers. Like the Ozark aquifer, the Cambrian-Ordovician aquifers are made up of carbonate rocks; however, it also includes beds of sandstone and shale. The Upper Cambrian Potomac and the Erubus formations are the main water-yielding formations in the Cambrian-Ordovician aquifers, but the Lower Ordovician Garonnda Dolomite and locally the Middle Ordovician St. Peter Sandstone are important sources of water. Most wells completed in the Cambrian-Ordovician aquifers are open to more than one water-yielding unit. The Ozark and the Cambrian-Ordovician aquifers are mapped together in this report.

This idealized hydrogeologic section in south-central Missouri shows the thickness of the confining units that separate the aquifers. The Springfield Plateau aquifer is the uppermost aquifer of the Ozark Plateau aquifer system; the equivalent Cambrian-Ordovician aquifer north of the Missouri River is also an important source of water. The thin Ozark confining unit overlies and crops out as a narrow band that separates the Ozark aquifer from the overlying Springfield Plateau aquifer. A thick sequence of rocks with minimal permeability, which is called the Western Interior Plains confining system, overlies and effectively confines the Springfield Plateau aquifer west of the outcrop area of the aquifer. The Osaka Plateau aquifer system is covered in southwestern Missouri by Mississippian and younger rocks and deposits that are part of the Mississippian embayment aquifer system or the Mississippi River alluvial aquifer. Variations in the thickness and extent of the aquifers and confining units of the Ozark Plateau aquifer system and their equivalents are shown in figure 96. The thickness of the Springfield Plateau aquifer is uniform slightly to the west of its outcrop area, but the equivalent upper aquifer unit of the Western Interior Plains aquifer system thins westward where it is covered by the Western Interior Plains confining system. The Osaka aquifer thickens gradually westward and is more than 1,000 feet thick in central Missouri; the aquifer thins more rapidly to the east of the St. Francois Mountains. The thickness of the St. Francois aquifer varies greatly because the rocks that compose this aquifer were deposited on an irregular erosional surface that was developed on Precambrian rocks of the basement confining unit. The thickness of the St. Francois and the Osaka confining units does not vary as much as that of the aquifers that they separate.
The Ozark aquifer underlies most of Missouri south of the Missouri River, and the Cambrian-Ordovician aquifer underlies the eastern one-half of Missouri north of that river (fig. 100). The Ozark aquifer is less than 1,000 feet thick throughout the Salem Plateau but thickens to more than 3,000 feet in southeastern Missouri just north and east of the Bootheel. The Ozark aquifer pinches out against the flanks of the St. Francois Mountains, and its thickness is irregular where it has been eroded against canyons, valleys, and other types of solution features characteristic of karst topography that have developed on the carbonate-rock units that compose the aquifer. North of the Missouri River, the thickness of the Cambrian-Ordovician aquifer averages about 1,200 feet but is locally greater than 1,700 feet. Carbonate rocks equivalent to the Cambrian-Ordovician aquifer in northwestern Missouri are deeply buried and contain only saline water.

Recharge to the Ozark aquifer is mostly from precipitation on aquifer outcrop areas. Small volumes of water recharge the aquifer by downward leakage from the shallow Springfield Plateau aquifer. Most ground-water flow in the shallow part of the Ozark aquifer moves from topographically high recharge areas along short flow paths to discharge as base flow to nearby streams. The shallow flow system is accordingly controlled mostly by topography. The ground water mostly occurs in and moves through fractures and bedding planes in carbonate rocks. These openings have been enlarged by dissolution of the carbonate rocks and have been reported at depths of as great as 1,500 feet below land surface. Where sinkholes have formed from dissolution of the carbonate rocks, water that runs over the land surface may enter the sinkholes and large volumes of recharge can enter the aquifer in this manner. Recharge to the equivalent Cambrian-Ordovician aquifer likewise is mostly from precipitation on aquifer outcrop areas, but small amounts of recharge enter this aquifer by downward leakage of water from the overlying Mississippian aquifer.

Discharge from the Ozark and the Cambrian-Ordovician aquifers is mostly to streams in aquifer outcrop areas. Some water follows flow paths of intermediate length and discharges to regional streams, such as the Missouri and the Mississippi Rivers. A small volume of water leaks upward from the aquifer and locally discharges to the overlying Springfield Plateau aquifer. In southeastern Missouri, a small volume of water discharges from the Ozark aquifer to the Mississippi River valley, which discharges through a large karst depression. A map of the potentiometric surface of the Ozark and the Cambrian-Ordovician aquifers before development of the aquifers begins (fig. 101) can be used to show the regional direction of ground-water movement in the aquifers. Water in the Ozark aquifer generally moved northward, westward, and southwestward from high areas on the potentiometric surface in south-central Missouri; some of the water moved toward the Mississippi and the Missouri Rivers. In the Cambrian-Ordovician aquifer, water moved along a gentle gradient from a high area in the potentiometric surface in central Missouri toward these same rivers. Movement of water in both aquifers at present is similar to movement before development except that very local near well fields where the direction of ground-water flow is toward the pumping wells.

Water movement is under unconfined conditions in the Ozark aquifer is mostly under confined conditions in the Cambrian-Ordovician aquifer. When the water is unconfined, water levels in the aquifer respond rapidly to changes in precipitation. For example, figure 100 shows changing groundwater levels in a well completed in the Potosi Dolomite (part of the Ozark aquifer) at West Plains in central Howell County, Missouri. Although this well is more than 1,300 feet deep, water-level rises of as much as 140 feet were recorded soon after several inches of precipitation fell. Solution openings in the carbonate rocks that compose the aquifer allow large volumes of water to enter the aquifer quickly, which accounts for the rapid rise in the water level. A sinkhole over one such solution opening in West Plains collapsed in 1978 (fig. 103). This sinkhole formed in a municipal sewage lagoon and allowed raw sewage to enter the aquifer quickly and directly. Within a few days after the sinkhole collapsed, raw sewage was detected in nearby streams, and eventually large volumes of sewage were detected in a large spring 36 miles southwest of West Plains.

In most places, water in the Ozark aquifer is not highly mineralized, and the chemical quality of the water is suitable for most uses. Dissolved-solids concentrations in water from the Ozark and the Cambrian-Ordovician aquifers are mapped in figure 104. Concentrations in the Ozark aquifer are less than 1,000 milligrams per liter except in the westward parts of the aquifer and locally near the Missouri River. In contrast, the equivalent Cambrian-Ordovician aquifer contains fresh water only in a small area in the southern part of the aquifer. In both the St. Francois aquifer and the Cambrian-Ordovician aquifers, calcium bicarbonate type but locally is a sodium bicarbonate type. Chloride and sulfate concentrations are less than 10 milligrams per liter in most places and the water is hard to moderately hard.

The thickness of the Missouri aquitard is very variable because the sedimentary rocks that compose the aquitard are deposited on an irregular erosional surface. The aquifer is thickest in central and eastern Missouri.
ST. FRANCIS AQUIFER—Continued

Water is withdrawn from the St. Francis aquifer only where the aquifer crops out or is buried to shallow depths. Little is known, therefore, about the regional ground-water flow system or the chemical quality of the water in the aquifer. Sparse water-level data (fig. 107) indicate that flow in the aquifer in near-outcrop areas primarily is controlled by topography. Water enters the aquifer as recharge from precipitation that falls on topographically high outcrop areas. Most of the water moves along short flow paths and discharges as base flow to nearby streams. A small volume of water moves along slightly longer flow paths into confined parts of the aquifer and discharges to shallower aquifers by upward leakage.

The chemical quality of the water in the St. Francis aquifer and near the aquifer outcrop areas generally is suitable for most uses. The water is a calcium-magnesium bicarbonate type with dissolved-solids concentrations reported to range between 200 and 400 milligrams per liter. Chloride concentrations in the water generally are less than 60 milligrams per liter, and sulfate concentrations are 150 milligrams per liter or less. Freshwater has been reported from the St. Francis aquifer as far west as Jasper and Petticoat, Missouri, which indicates a regional ground-water flow system in the aquifer.

SOLUTION FEATURES

Carbonate rocks, such as the limestone and dolomite that make up a large part of the Ozark Plateau aquifer system, are readily dissolved where they are exposed at the land surface or covered by a thin layer of soil. Small amounts of carbon dioxide are absorbed by precipitation that falls through the atmosphere. When the precipitation falls on the soil and percolates down through it to the water table, additional carbon dioxide is absorbed from decomposing organic matter in the soil. This absorption creates a weak carbonic acid, which partially dissolves the carbonate rocks. Initially, most of the rock material is dissolved along existing joints in the rock, such as joints and bedding planes. As the openings are enlarged, pieces of the carbonate rock are able to move upward through the aquifer; thus, the dissolution process and enlargement of the openings is accelerated. In some places, the openings are enlarged until streams flow in them and sediment transported in the streams moves part of the rocks. If dissolution proceeds long enough, karst topography, which is characterized by caves, sinkholes, and springs, develops on the carbonate rocks.

![Figure 107. Water in the St. Francis aquifer generally moves along short flow paths from high altitudes on the pedimental surface to nearby streams where it discharges as base flow.](image1)

![Figure 108. Reversable sinkholes, such as this one, which is called Oval Sink and is located near Springfield, Missouri, allows surface runoff to enter carbonate-rock aquifers directly during most seasons. Water fills the sinkhole and then drains into the aquifer through the sinkhole and the stream and discharges at the water table in the Ozark Plateau aquifer. Such sinkholes are shown as sinkholes.](image2)

Sinkholes

Sinkholes are closed, usually circular depressions in the land surface. Sinkholes form by dissolution of bedrock and are common where carbonate rocks are at or near land surface. Voids develop where part of the carbonate rock is dissolved and the subsequent collapse of overlying material creates a sinkhole. Many sinkholes form slowly and expand gradually. Sudden collapse of surface material into a sinkhole sometimes occurs as a result of a natural decline of ground-water levels or human activities, such as the diversion of surface water, withdrawal of ground water, or construction of surface water impoundments on former streams on the land surface. Such sudden collapse is called catastrophic collapse and can result in severe damage to property or endanger human or animal life.

All or part of the flow of small streams might enter a sinkhole. Sinkholes commonly are connected to a subsurface network of caves, pipes, and other types of solution openings, all of which channel large volumes of ground water. Thus, sinkholes have important effects on ground and surface water. Large sinkholes may be occupied by ponds or lakes. Some sinkholes, such as the one shown in figure 108, are reversable; that is, water may flow into the sinkhole at times and out of it at other times. Such a sinkhole is called an estavelle. The relation of the water table to flow into and out of a reversable sinkhole is shown by the diagram in figure 109. During periods of normal or less-than-normal precipitation, water levels in the aquifer are low, and surface water enters the aquifer quickly and directly through the estavelles (fig. 109A). However, flow can be reversed (fig. 109B), and an estavelle can function as a spring when water levels in the aquifer rise during periods of excessive precipitation. As water levels continue to rise (fig. 109C), flow can be reversed in additional estavelles.

Sinkholes are abundant to common in much of the area where the carbonate rocks that compose the Ozark Plateau aquifer system are at or near the land surface (fig. 110). Most of the areas where more than 10 sinkholes per 100 square miles have been mapped are underlain by the St. Francis aquifer (compare figs. 95 and 110). Most sinkholes that have formed by sudden collapse are in the area underlain by the Ozark aquifer. However, a large area of abundant sinkholes near Springfield, Missouri, and smaller, isolated areas of abundant sinkholes to the north and west of Springfield are underlain by the Springfield Plateau aquifer.

Springs

Springs are openings through which ground water discharges to the land surface. The sizes of the springs and the volume of water they discharge vary. Some springs are small seeps where only small volumes of water issue slowly from the aquifer; others, such as Mamasc Spring in Missouri (fig. 111A), are large enough to form the headwaters of streams. Following heavy rains in the catchment area of the spring, a bubbling can develop on the surface of a stream where the spring discharges through the streambed (fig. 111B). Although springs may discharge from an aquifer that contains water under unconfined, or water-table, conditions, such springs tend to be small, their discharge vary greatly, and their flow tend to cease during periods of low rainfall. In contrast, springs that issue from aquifers that contain water under confined conditions tend to be unaffected by seasonal variations in precipitation because the movement of such springs is limited by a large replenishment area, in some cases as large as several tens or hundreds of square miles. Springs are common in areas of karst topography, such as that which has developed on the carbonate rocks of the Ozark and the Springfield Plateau aquifers.

Missouri has eight first-order springs, or springs that have a flow that is greater than or equal to 100 cubic feet per second. The location of these springs is shown in figure 112, along with the location of smaller springs. All first-order springs and most of the smaller springs mapped issue from the Ozark aquifer (compare figs. 95 and 112). Some springs, however, issue from the Springfield Plateau and the Cambrian Ordovician aquifers. The springs are fed by conduits that developed by partial dissolution of the limestone and dolomite that compose the aquifers. Fractures and joints in the carbonate rocks also channel water to the springs. Water from many springs is used to supply fish hatcheries, and some springs are used as a partial source of municipal water supply. The chemical quality of spring water usually is suitable for most purposes, but the water is susceptible to contamination because in many places, the springs are connected to sinkholes by networks of solution openings. Thus, any contaminants that enter the aquifer can quickly be transported to a spring, as in the case of the sewage lagoon at West Plains, Missouri, discussed previously.

FRESH GROUND-WATER WITHDRAWALS

Total fresh-ground-water withdrawals from the Ozark Plateau aquifer system during 1990 were 330 million gallons per day, 8 million gallons per day of which was withdrawn in Kansas. About 139 million gallons per day was withdrawn for industrial, mining, and thermoelectric power uses. Withdrawal for agricultural purposes, the principal use (fig. 113), is about 88 million gallons per day for public supply, and about 32 million gallons per day was withdrawn for industrial, mining, and thermoelectric power uses. Withdrawals for domestic and commercial supplies were about 50 million gallons per day.
The Mississippian aquifer is the uppermost aquifer in Paleozoic rocks in northern Missouri. The aquifer extends over all of Missouri north of the Missouri River (fig. 114) except for small areas near the Mississippi and the Missouri rivers where the rocks that compose the aquifer have been removed by erosion. Stratigraphically equivalent rocks south of the Missouri River are considered to be part of the Springfield Plateau aquifer, which is the uppermost aquifer of the Ozark Plateau aquifer system. The Mississippian and the Springfield Plateau aquifers possibly are hydraulically connected in the Saline-Chariton-Howard-Cooper County area but are hydraulically separate elsewhere. Because this connection is poorly known, the aquifers are considered to have separate ground-water flow systems in this report.

The Mississippian aquifer is so named because it consists of Cambrian-Ordovician rocks that are younger than the basal Mississippian. The formation consists of crystalline limestone and yield water primarily from solution cavities. In most places, the aquifer is overlain by a confining unit of Pennsylvanian shale and sandstone and is everywhere underlain by a confining unit of Mississippian shale. The thickness of the Mississippian aquifer averages about 200 feet but locally exceeds 400 feet in northeastern Missouri (fig. 115). The aquifer is thickest in part of the Forest City Basin, which is a structural downwarp that extends northward into Iowa, and is thinnest near the Mississippi and the Missouri Rivers where it has been dissected or partially removed by erosion.

Ground-water movement in the Mississippian aquifer can be inferred from a map of the potentiometric surface of the aquifer (fig. 116). The map was prepared by using the earliest water levels available for wells completed in the aquifer, in order to represent conditions before the aquifer was developed. Recharge to the aquifer is mostly from precipitation that falls on areas where the aquifer is exposed at the land surface or is overlain by a thin blanket of younger rocks or glacial deposits, or both. Locally, the Mississippian aquifer receives some recharge by vertical leakage from the underlying glacial drift aquifers or the deeper Cambrian-Ordovician aquifer where the hydraulic head in the Mississippian aquifer is less than that of the adjacent aquifers. Most of the water in the Mississippian aquifer moves along flow paths that are of short or intermediate length from the three high areas on the potentiometric surface toward small to large streams, into which it discharges as base flow (fig. 116). The irregular shape of the potentiometric surface largely reflects the topography of the area.

The chemical quality of the water in the Mississippian aquifer varies considerably. The aquifer contains freshwater only in the eastern one-third of its extent (fig. 117); elsewhere, it contains slightly saline water, slightly saline water, or saline water. Dissolved-solids concentrations of greater than 10,000 milligrams per liter. This very saline water is thought to have entered the Mississippian aquifer either by upward leakage from the underlying Cambrian-Ordovician aquifer or by the discharge of eastward-moving saline water from the upper aquifer unit of the Western Interior Plains aquifer system.

The Western Interior Plains aquifer system underlies most of Kansas, the eastern and southern parts of Nebraska, and a small area in western-central Missouri (fig. 118). The aquifer system consists of water-yielding dolomite, limestone, and sandstone that are stratigraphically equivalent to aquifers of the Ozark Plateau aquifer system. However, in contrast to the Ozark Plateau system, the Western Interior Plains aquifer system contains no freshwater.

The Western Interior Plains aquifer system consists of lower aquifer units in rocks of Ordovician and Cambrian age, a middle confining unit of Mississippian and Devonian age, and an upper aquifer unit of Mississippian limestone. The thickness of the aquifer system (including the confining unit) ranges from less than 500 feet to more than 3,000 feet in Segment 3 (fig. 119). The aquifer system is thin or absent on structural uplifts and is thickest in downwarps. For example, the thick area in southeastern Kansas is on the northern flank of the Aradarka Basin, and the thick area along the Missouri River is on the southern flank of the Forest City Basin. The aquifer system is thin or missing in western Nebraska and central Kansas atop the Chautauqua and the Cambridge Arch and the central Kansas uplift and is locally thin or absent in eastern Kansas on the Osage Uplift.

Regional ground-water movement in the aquifer system is southeastward to eastward. Much of the water discharges from the aquifer system in the transition zone between the Western Interior Plains and the Ozark Plateau aquifer systems. The location of this transition zone and the merging of ground-water flow in these two aquifer systems are discussed in the section of this report that describes the relation of the Ozark Plateau aquifer system to adjacent aquifers. Saline ground water from the Western Interior Plains aquifer system discharges to springs and streams in Henry and Saline Counties, Missouri. Water is thought to move very slowly through the aquifer system.

Dissolved-solids concentrations of water in the Western Interior Plains aquifer system are greater than 1,000 milligrams per liter everywhere. In thick, deeply buried parts of the aquifer system, dissolved-solids concentrations of more than 200,000 milligrams per liter have been reported. The large concentrations are due, in part, to the slow movement of ground water in the aquifer system. The slower the water moves, the longer it is in contact with aquifer minerals and the more mineral material it is able to dissolve.

Little water is withdrawn from the Western Interior Plains aquifer system because the aquifer system is deeply buried and contains highly mineralized water. Locally, deeply buried parts of the aquifer system contain oil and gas, and some brine that is a by-product of hydrocarbon production is injected into disposal wells, which are completed in permeable parts of the system.

The water in the Mississippian aquifer moves locally from recharge areas that are high on the potentiometric surface toward streams where it discharges as base flow. No regional direction of flow can be defined for the aquifer.
References

Regional summary


Arkansas Geological Survey, 1970a, Reconnaissance of the ground-water resources of the Mississippi River alluvium between Miami and Fort Smith, Arkansas: Water-Resources Investigations Report 70-12, 119 p.


