APPENDIX F

REFERENCE SHEETS AND EXCERPTS FROM THE GROUND WATER ATLAS OF THE UNITED STATES – HA 730-D

USGS

GROUND WATER ATLAS of the UNITED STATES
Kansas, Missouri, and Nebraska
HA 730-D

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REGIONAL SUMMARY

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 Niobrara, the Platte, the Kansas, the Arkansas, and the Missouri; 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rivers supply water for many uses but ground water is the source of slightly more than one-half of the total water withdrawn for all uses within the three-State area.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 Cambrian 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 35 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 windblown 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 Plateaus Physiographic Province, rugged topography has developed where the underlying rocks have been uplifted and deeply eroded.

AREAL DISTRIBUTION OF AQUIFERS

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 aquifer or aquifers.

Seven principal aquifers or aquifer systems are at the land surface in the three-State area. The extent of those 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:

Dissolved-solids concentration, in milligrams per liter

Freshwater	less than 1,000
Slightly saline water	1,000 to 3.000
Moderately saline water	3,000 to 10,000
Very saline water	10,000 to 35,000
Brine	Greater than 35,000

Aquifers that are part of the surficial aquifer system are in all three States of Segment 3 (fig. 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 southeastern 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 planed 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 preglacial 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 northern Missouri are buried beneath till or glacial-lake deposits.

The High Plains aquifer (fig. 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 to 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 aquifer, they are connected hydraulically to the aquifer and are considered to be part of it.

The Mississippi embayment aquifer system in southeastern Missouri underlies and is in hydraulic connection with the Mississippi River Valley alluvial aquifer. Semiconsolidated sands of Tertiary and Cretaceous age compose the Mississippi embayment aquifer system.

The Great Plains aquifer system is exposed at the land surface in a band that extends from south-central Kansas to northeastern Nebraska (fig. 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 where it is exposed. A thick confining unit composed of Cretaceous shale, chalk, and limestone formations overlies the Great Plains aquifer system (fig. 6 and fig. 7) and separates it from the High Plains aquifer in most places.

The Ozark Plateaus aquifer system is exposed at the land surface in most of southern Missouri and in a small part of southeasternmost Kansas (fig. 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 Plateaus aquifer system extends northwestward for more than 50 miles beneath a thick confining unit called the Western Interior Plains confining unit (fig. 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 equi-valents of the aquifers of the Ozark Plateaus aquifer system are called the Western Interior Plains aquifer system (fig. 6). Because this system is deeply buried everywhere, it contains saline water or brine and its hydrology, therefore, is not well known.

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

The Cambrian-Ordovician aquifer is exposed in a small part of northeastern Missouri (fig. 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 Plateaus 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.

GEOLOGY

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 Ozark Uplift and northward or southwestward 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.

Postdepositional erosion of the Paleozoic sedimentary-rock sequence from eastern Missouri to central Kansas and eastern Nebraska has beveled off some of the rocks. As a consequence, progressively younger rocks are exposed to the west and northwest of the Precambrian core of the St. Francois Mountains in southeastern Missouri (fig. 9). The glacial sediments that cover bedrock strata in eastern Nebraska, northeastern Kansas, and northern Missouri are not shown in figure 9, and stream-valley deposits are shown only along the major streams; the total extent of these deposits in Segment 3 is the same as that shown in figure 4. The widespread areas of Tertiary and Quaternary sediments in western Kansas and Nebraska are not related to erosion or beveling of rocks away from the St. Francois Mountains and the Ozark Uplift. These Tertiary and Quaternary sediments are mostly alluvium that was derived from erosion of the Rocky Mountains to the west of the segment.

Cambrian rocks are exposed in southeastern Missouri in an area that encircles the Precambrian core of the St. Francois Mountains. The basal Cambrian rocks are sandstones, and the upper parts of the Cambrian sequence are mostly dolomite.

Ordovician rocks are exposed in a large area in southern Missouri and in smaller areas in northeastern and southeast-ern Missouri. The thick sequence of Ordovician strata mostly consists of dolomite and limestone interbedded with minor sandstone and shale and has been divided into a large number of geologic formations.

Silurian rocks consist of a thin sequence of dolomite and limestone and are exposed only locally in southeastern and northeastern Missouri near the Mississippi River. Some studies have postulated that the Silurian Period was characterized by extensive uplift and erosion in the area of Segment 3.

Devonian rocks are exposed in scattered areas of southern, southeastern, and northern Missouri. Like the Silurian strata, Devonian rocks are thin. The lower and middle parts of the Devonian sequence are mostly limestone interbedded with minor sandstone and chert, whereas the upper part is mostly widespread shale.

Mississippian rocks crop out in a wide to narrow band that extends from southwestern Missouri to just north of the Missouri River in central Missouri and as a second, less extensive band in northeastern Missouri parallel to the Mississippi River. Mississippian strata in Segment 3 are mostly limestone (commonly cherty) but include some beds of sandstone and shale. Outliers of Mississippian rocks in southern Missouri show that these beds extended over a much larger area before most were removed by erosion.

Pennsylvanian strata crop out in large areas of eastern Kansas and western Missouri. These rocks are covered with glacial drift to the west and north of the Missouri River where they are mapped in figure 9 as the shallowest bedrock. Pennsylvanian rocks consist of shale, sandstone, limestone, and some coal beds and were deposited in a series of sedimentary cycles, each of which represents a transgression and regression of the Pennsylvanian sea. Each cycle, known as a cyclo-them (fig. 10), begins and ends with nonmarine shale deposits; intervening marine limestone and shale were deposited in shallow to deep water. The thick Pennsylvanian section has been divided into a large number of geologic formations, especially in Kansas where 49 formations are recognized in exposed Pennsylvanian strata and several additional formations are delineated in the subsurface. Outliers of Pennsylvanian rocks in east-central Missouri show that before they were partly eroded, these strata covered a much greater area than at present.

Permian rocks are exposed in a wide to narrow band that extends from south-central Kansas to southeastern Nebraska. Permian rocks primarily consist of shale and sandstone but also contain beds of halite (rock salt), gypsum, anhydrite, and minor limestone. Cyclic deposition is characteristic of Permian strata, but the cycles are not as numerous as those of the Pennsylvanian rocks.

Triassic and Jurassic rocks are present in the subsurface of western Kansas and Nebraska. These rocks mostly are shale, siltstone, and dolomite, but some Jurassic sandstone beds locally yield small amounts of water. Triassic and Jurassic rocks are not shown in figure 9.

Cretaceous rocks are exposed in large areas of central Kansas and eastern Nebraska and smaller areas in southeastern Missouri and western Kansas and Nebraska. Cretaceous strata in Nebraska and Kansas consist largely of shale, but prominent, widespread sandstones are in the lower part of the Cretaceous section, and equally widespread limestone and chalk units are in the upper part. Semiconsolidated sand and clay form the Cretaceous beds of Missouri.

Tertiary and Quaternary deposits are the most widespread geologic unit in Segment 3 and are especially prominent in Kansas and Nebraska. They are characterized mainly by unconsolidated sand and gravel, but locally include beds of sandstone, siltstone, silt, and clay. The Quaternary and Tertiary deposits mapped along the major stream courses in the segment consist primarily of unconsolidated sand and gravel. In the Missouri bootheel, Tertiary beds consist of unconsolidated to semiconsolidated clay and sand overlain by unconsolidated Quaternary sand and gravel.

VERTICAL SEQUENCE OF AQUIFERS

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. 7); 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 easiest where the confining units are thin, leaky, or both.

Where confining units are absent, water moves readily 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 hydraulically distinguished from each other, and the stream-valley aquifers are considered to be part of the High Plains aquifer where the two are in contact.

The sequence of maps (figures 11 through 15) shows the extent of each aquifer or aquifer system. Comparison of the maps shows the places where aquifers are stacked upon each other. The vertical sequence is different from area to area, and no single location contains all the aquifers.

The uppermost aquifers in the segment are in unconsolidated sand and gravel of the surficial aquifer system (fig. 11). This system has been subdivided into three parts (stream-valley alluvial aquifers, Mississippi River Valley alluvial aquifer, glacial-drift aquifers), primarily on the basis of differences in the origin and geometry of the permeable material that composes the aquifers. The aquifers primarily contain water under unconfined (water-table) conditions and mostly consist of sediments of Quaternary age.

The High Plains aquifer (fig. 12) underlies part of the surficial aquifer in Nebraska and Kansas. No confining unit separates the two aquifers. The principal geologic unit in the High Plains aquifer in Nebraska and western Kansas is the Ogallala Formation, which mostly consists of unconsolidated sand and gravel; locally, the High Plains aquifer is called the Ogallala aquifer. In south-central Kansas, the aquifer comprises mostly Quaternary sediments. Although clay beds create local confined conditions, most of the water in the aquifer is unconfined. The High Plains aquifer is an extremely important source of water, primarily for irrigated agriculture, in Segment 3.

The Mississippi embayment aquifer system (fig. 13) underlies part of the surficial aquifer system in the bootheel and adjacent counties of Missouri. No confining unit separates the two aquifer systems. Unconsolidated to semiconsolidated sand aquifers, separated by clayey confining units, compose the Mississippi embayment aquifer system.

The Great Plains aquifer system extends from its southern and eastern limits continuously northward and westward through Kansas and Nebraska (fig. 13) except for a small area in northwestern Nebraska where the system is missing. Two sandstone aquifers in Lower Cretaceous rocks, separated by a shale confining unit, compose 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 places. Exceptions are where the aquifer system is exposed at the land surface or is directly overlain by the High Plains aquifer; in these places, water-table conditions exist in much of the aquifer.

The Ozark Plateaus 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 carbonate rocks in northern Missouri are called the Mississippian aquifer (fig. 14). The middle aquifer of the Ozark Plateaus aquifer system is in carbonate rocks of Cambrian and Ordovician age, and the lowermost aquifer in the system is in Cambrian sandstones. The confining units that separate the aquifers are dolomite and shale. Water in the aquifers of the Ozark Plateaus aquifer system and the Mississippian aquifer is unconfined in and just downgradient from aquifer outcrop areas but is confined elsewhere. Water is confined in the Mississippian aquifer in most places by poorly permeable Pennsylvanian strata that overlie the aquifer. A thick shale confining unit overlies the Ozark Plateaus aquifer system westward from western Missouri and southeasternmost Kansas. This confining unit is exceedingly thick and poorly permeable. Water-yielding rocks beneath the confining unit compose the Western Interior Plains aquifer system (fig. 14) in Paleozoic rocks that are lateral equivalents of the aquifers of the Ozark Plateaus aquifer system. The Western Interior Plains aquifer system is entirely in the subsurface and contains slightly saline water or brine that is under confined conditions everywhere. The Ozark Plateaus and the Western Interior Plains aquifer systems directly overlie poorly permeable crystalline rocks, whereas the Mississippian aquifer is underlain by a confining unit of shale and carbonate rocks.

The Cambrian-Ordovician aquifer in northern Missouri (fig. 15) consists of several water-yielding beds of sandstone and dolomite. Some of the permeable strata in this aquifer are equivalent to parts of the middle aquifer of the Ozark Plateaus aquifer system, but the Missouri River is a discharge area for both aquifers and, thus, hydraulically separates them in some places. Water in the Cambrian-Ordovician aquifer is confined in most places. The aquifer is underlain by a confining unit of Cambrian shale, dolomite, and limestone.

FRESH GROUND-WATER WITHDRAWALS

Ground water is the source of water supply for more than 5 million people, or almost 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) sys-tems. 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 of 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, Missouri) 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 8,191 million 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 system, which is the second most used source of ground water (1,037 million gallons per day). The Ozark Plateaus aquifer system 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 Mississippi River Valley alluvial aquifer.

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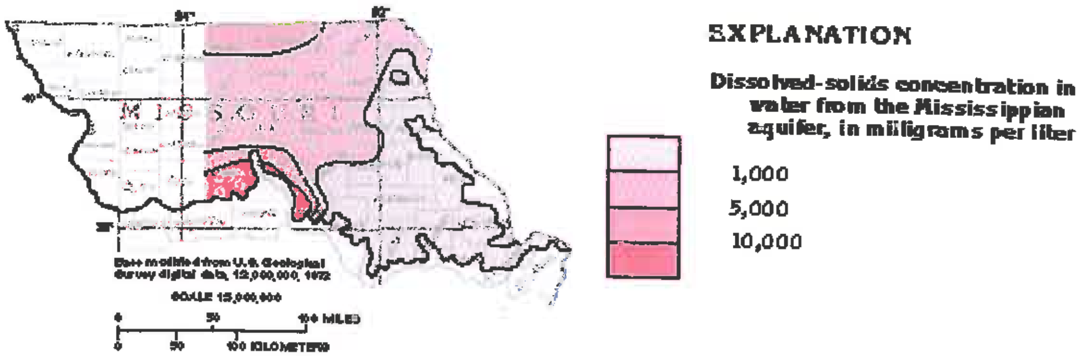

Modified from Imes, J.L., 1985, The ground-water flow system in northern Missouri with emphasis on the Cambrian–Ordovician aquifer: U.S. Geological Survey Professional Paper 1305, 61 p.

Figure 117. The Mississippian aquifer contains freshwater only in its eastern one-third. The area of water that contains more than 10,000 milligrams per liter of dissolved solids is the result of upward leakage of saline water from deeper aquifers.

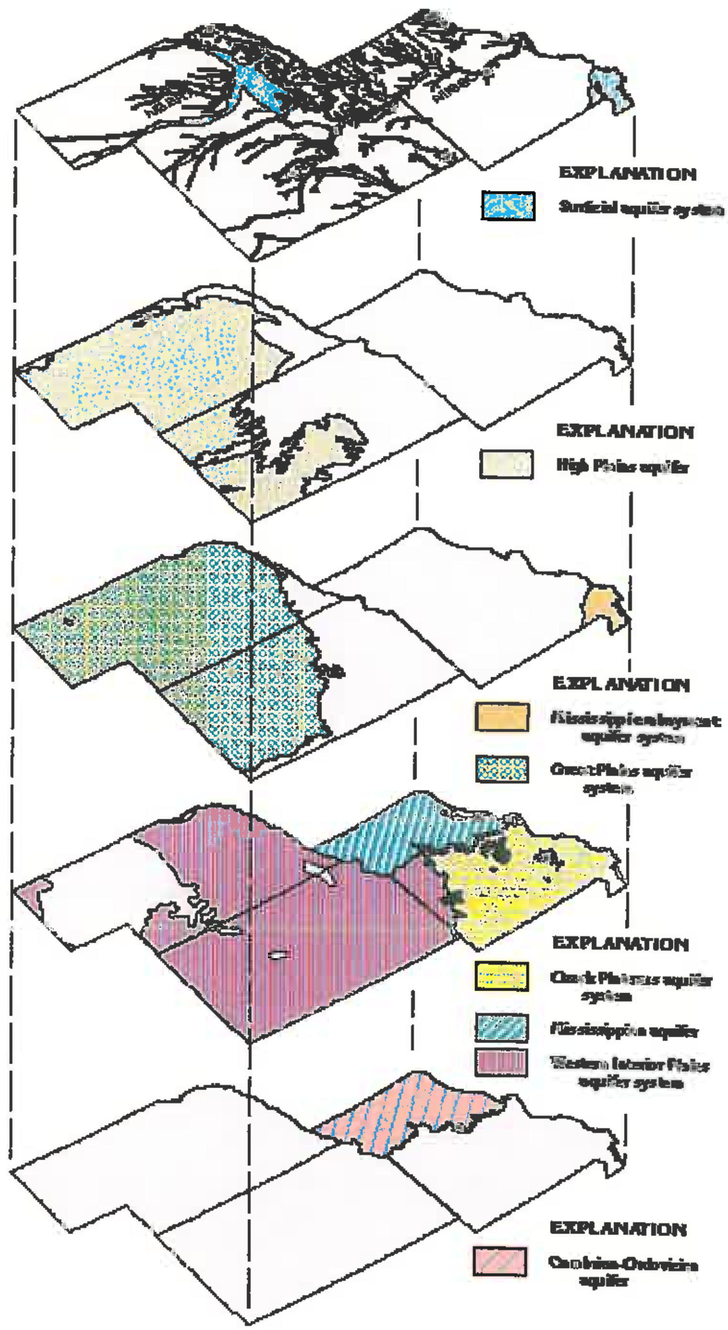

Figure 11. The surficial aquifer system consists of stream-valley aquifers along major drainages, the Mississippi River Valley alluvial aquifer in the Missouri bootheel, and glacial-drift aquifers in northern Missouri, eastern Nebraska, and northeastern Kansas. All three aquifers consist of unconsolidated deposits of sand and gravel.

Figure 12. The High Plains aquifer primarily consists of unconsolidated sand and gravel of the Ogallala Formation in Nebraska and western Kansas and of Quaternary beds in south-central Kansas. The aquifer underlies and is hydraulically con-nected to parts of the surficial aquifer system in Kansas and Nebraska.

Figure 13. The Mississippi embayment aquifer system directly underlies and is hydraulically con-nected to the surficial aquifer system in southeastern Missouri. The Great Plains aquifer system in Kansas and Nebraska underlies much of the High Plains aquifer and is separated from parts of it by a thick confining unit of shale.

Figure 14. The Ozark Plateaus aquifer system in southern Missouri is a large freshwater system in Paleozoic rocks. Equivalent rocks of the Western Interior Plains aquifer system, however, contain no fresh- water. The Mississippian aquifer of northern Missouri is in rocks equivalent to those of the upper part of the Ozark Plateaus aquifer system but has little or no hydraulic connection to that system.

Figure 15. The Cambrian–Ordovician aquifer consists of dolomite and sandstone beds equivalent to part of the Ozark Plateaus aquifer system but is hydraulically separate from that system in some places. The aquifer is overlain and underlain by confining units.