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Introduction

Management of the water resources in Kansas requires information about the aquifer systems in the state, such as their vertical and lateral extent, hydraulic connection to other aquifer systems, ground-water flow directions, and variations in water quality. At present, there is a considerable amount of information available about the state's ground-water resources. However, very little of it is in electronic format.

To facilitate and enhance present and future ground-water research and management activities, the Kansas Geological Survey (KGS) and the US Geological Survey (USGS) used existing information on (1) the extent, (2) the altitude of the tops and bottoms, (3) the water-table or potentiometric surface, and (4) the water quality of the states's major aquifers to produce geographic information system (GIS) coverages of each of these parameters. The major aquifers identified in this project were the alluvial, the glacial drift, the High Plains, the Dakota (Great Plains), and the Cambro-Ordovician (Ozark) aquifers. The resulting GIS coverages are available through the Data Access and Support Center (DASC) at the KGS. This work was funded by the Kansas Water Office. The results from this project support the establishment of a state ground-water information system that is called for in the Kansas Water Plan.

KGS was responsible for generating the alluvial and the Dakota (Great Plains) aquifer coverages. The deliverables to the Kansas Water Office from KGS were the extent of the alluvial and Dakota aquifers; and the altitude of the top, and bottom, potentiometric surface, and water quality of the Dakota aquifer. Only the extent of the alluvial aquifers was produced due to insufficient information on the other parameters. In parallel, the USGS was responsible for generating the coverages for the High Plains, Cambro-Ordovician (Ozark), and glacial drift aquifers. The map coverages and the maps (included with this report) that were produced by the KGS are listed in Table 1.

The Regional Aquifer Systems of Kansas

The regional aquifer systems in Kansas that were identified are significant sources of water to users and are of wide geographic extent in Kansas. Table 2 shows the regional aquifer systems for which GIS coverages were produced and the stratigraphic units that constitute these regional aquifer systems.

Table 1. Titles of map coverages and maps produced by the KGS from this project.

Map Coverages:

- Digital Map of the Dakota Aquifer Extent in Kansas
- Digital Map of the Altitude of the Top of the Dakota Aquifer in Kansas
- Digital Map of the Altitude of the Base of the Dakota Aquifer in Kansas
- Digital Map of the Potentiometric Surface of the Dakota Aquifer in Kansas
- Digital Map of the Total Dissolved Solids Concentration of Ground Water from the Dakota Aquifer of Kansas
- Digital Map of the Alluvial Aquifer Extents in Kansas

Maps Produced:

- Top Configuration of the Dakota Aquifer (Plate A)
- Bottom Configuration of the Dakota Aquifer (Plate B)
- Potentiometric Surface of the Dakota Aquifer (Plate C)
- Total Dissolved Solids Concentration of Ground Water in the Upper Dakota Aquifer (Plate D)
- Extent of the Alluvial Aquifers in Kansas (Plate E)

The uppermost aquifer systems are the regionally unconfined alluvial valley, glacial drift, and High Plains aquifer systems (Wolf et al., 1990). These consist largely of unconsolidated Cenozoic deposits of interbedded gravel, sand, silt and clay. The saturated thickness of these deposits ranges up to more than 500 ft in parts of southwestern Kansas. The High Plains aquifer is present in much of the western two thirds of Kansas and consists of water-saturated Pliocene Ogallala Formation and associated Quaternary deposits (Stullken et al., 1985). The High Plains aquifer consists primarily of the Ogallala Formation in northwestern, west–central, and southwestern Kansas and Quaternary deposits in the Great Bend prairie south of Great Bend and in the Equus Beds region to the east. The alluvial aquifers consist of water-saturated Quaternary alluvial and contiguous terrace deposits in the river valleys of Kansas. The glacial drift aquifers consist of Pleistocene glacial till, outwash, and buried valley deposits in northeastern Kansas. The lower aquifers are generally deeper and consist of consolidated (bedrock) units. The Dakota aquifer consists of interbedded sandstone and shale of the Cretaceous Dakota, Kiowa, and Cheyenne sandstones (Macfarlane, 1993). The Dakota aquifer is referred to as the Great Plains aquifer by the US Geological Survey (Jorgensen et al., 1993). The Dakota extends westward from Washington County along the Kansas-Nebraska border and northward from Morton County along the Kansas-Colorado border and is present in 59 of the 105 Kansas counties. Its total thickness ranges up to more than 750 ft in west–central Kansas. Over most of its extent in Kansas the Dakota is overlain by a sequence of shale and chalk belonging that forms the Upper Cretaceous aquitard (Macfarlane, 1993). Near its southern extent, this sequence has been

Table 2. Stratigraphy and hydrostratigraphy of the Kansas subsurface above the Precambrian, showing the major aquifer and aquitard (confining units). Modified from Macfarlane (1993) and Jorgensen et al. (1993).

ERA	SYSTEM	ROCK STRATIGRAPHIC UNITS	HYDROSTRATIGRAPHIC UNITS: Western and Central Kansas		HYDROSTRATIGRAPHIC UNITS: Southeastern Kansas	
Cenozoic	Quaternary	Unconsolidated Sediments	Alluvial Valley Aquifers		Alluvial Valley Aquifers	
	Tertiary	Ogallala Formation	High Plains Aquifer System			
Mesozoic	Cretaceous	Colorado Group	Upper Cretaceous Aquitard			
		Dakota Formation	Upper Dakota Aquifer	Dakota Aquifer System		
		Kiowa Formation Cheyenne Sandstone	Kiowa Shale Aquitard			
			Lower Dakota Aquifer			
	Jurassic/Triassic	Morrison Formation Dockum Group	Upper Permian-Pennsylvanian Aquitard			
Paleozoic	Permian					
		Cedar Hills Sandstone	Cedar Hills Sandstone Aquifer			
			Lower Permian-Pennsylvanian Aquitard			
	Pennsylvanian				Lower Permian-Pennsylvanian Aquitard	
	Mississippian		Upper Western Interior Plains Aquifer System	Western Interior Plains Aquifer System	Springfield Plateau Aquifer	Ozark Plateaus Aquifer System
		Northview Shale Compton Limestone			Ozark Confining Unit	
	Devonian	Chattanooga Shale	Confining Unit			
	Silurian/ Ordovician		Lower Western Interior Plains Aquifer System		Ozark Aquifer	
		Derby-Doe Run Dolomite Davis Formation			St. Francois Confining Unit	
	Cambrian	Reagan Sandstone			St. Francois Aquifer	
Pre-Cambrian			Basement Confining Unit			

removed by erosion and Dakota directly underlies and is hydraulically connected to the High Plains aquifer. Near its central Kansas extent stream erosion has removed the overlying aquitard and the Dakota crops out at the surface.

The Cambro-Ordovician aquifer (Macfarlane and Hathaway, 1987) is locally referred to as the "Roubidoux" and constitutes the lower part of the Ozark aquifer (Jorgensen et al., 1993). This deep aquifer system consists of limestone, dolomite, and sandstone of the Ordovician Cotter Dolomite, Jefferson City Dolomite, Roubidoux Sandstone, and Gasconade Dolomite; and the Cambrian Eminence Dolomite, Bonneterre Dolomite, and Reagan Sandstone. The Mississippian aquifer (Macfarlane and Hathaway, 1987) is composed of Mississippian limestones and cherty limestones and is a part of the upper unit of the Ozark aquifer (Jorgensen et al., 1993). In parts southeastern Kansas these aquifer units are separated by shaley strata belonging to the Northview Shale, Compton Limestone, and Chattanooga Shale. The total thickness of the Ozark aquifer in southeastern Kansas ranges in thickness from 700 ft to 1,200 ft (Jorgensen et al., 1993). The Ozark aquifer system in southeastern Kansas is overlain by Pennsylvanian shales, sandstones, and limestones that form the Western Interior Plains confining system (Jorgensen et al., 1993).

Methods Used to Generate the Dakota and the Alluvial Aquifer Coverages

Aquifer extents were taken from the Geologic Map of Kansas (Ross, 1991; scale 1:500,000) and from Wade (1992; scale 1:24,000) where the aquifers crop out at the surface. Only the aquifer extent coverage was prepared for the alluvial aquifers. For the Dakota aquifer, its extent is also inferred from subsurface mapping which was made from gamma-ray logs of boreholes drilled for oil and gas exploration and production and from test holes (Macfarlane et al., 1990; scale 1:1,000,000 and Macfarlane et al., 1993; scale 1:500,000). The boundary separating the outcrop/subcrop region of the Dakota aquifer from the region where the Dakota is overlain by the Upper Cretaceous aquitard was taken directly from the Geologic Map of Kansas (Ross, 1991; scale 1:500,000) and from Wade (1992; scale 1:24,000) where the aquitard crops out at the surface or was inferred from subsurface mapping using the gamma-ray logs.

The digital map of the altitude of the Dakota aquifer top and bottom in Kansas were based on contour maps of the top configuration of the Dakota Formation, the Morrison Formation, and the Permian System in Kansas (Macfarlane et al., 1990; scale 1:100,000) and top configuration of the upper Dakota aquifer (Dakota Formation), the Kiowa shale aquitard and the lower Dakota aquifer (Longford Member and Cheyenne Sandstone), the Morrison-Dockum aquifer, the Permian-Pennsylvanian aquitard, and the Cedar Hills Sandstone aquifer in southwestern Kansas (Macfarlane et al., 1993). Contours for the north-central Kansas area were adjusted using information from Chu (1995, 1:500,000). A contour interval of 100 ft was selected for both coverages because some of the sources used to generate this coverage mapped the elevation of the top and bottom at a 100 ft contour interval. These maps were derived from analysis of gamma-ray logs and of drillers' logs of oil and gas exploration and production wells. These maps were used to delineate the top of the confined Dakota aquifer and in central Kansas, the altitude of the aquifer top beneath the alluvium of the major streams crossing the Dakota aquifer outcrop area.

The contour maps were supplemented with data for the altitude of the bedrock surface beneath the High Plains aquifer in Southwest Kansas Groundwater Management District No. 3 (Watts and Stullken, 1985) and the Big Bend Groundwater Management District No. 5 (Sophocleous et al., 1993). In these districts the Dakota aquifer subcrops beneath the High Plains aquifer and data used to derive these maps comes primarily from drillers' logs of water wells. The altitude of the top of Dakota aquifer is not shown in central Kansas where the Dakota aquifer outcrops or is covered by thin alluvium or terrace deposits. In this part of the state the altitude of the top is considered to be equivalent to the land surface elevation or at a depth of less than 50 ft. below the surface in river valleys.

The digital map of the potentiometric surface of the Dakota aquifer in Kansas is based on a contour map of the pre-development potentiometric surface of the Dakota aquifer in Kansas by Macfarlane et al. (1990; scale 1:1,000,000). No additional data were used to supplement the pre-development data due to the limited use of the aquifer over most of Kansas and the 100-foot contour interval of the original map. The original map was produced using data from the Central Midwest Regional Aquifer Systems Analysis Program (CMRASA) project files (US Geological Survey, Lawrence, Kansas) and supplemented by data from the Dakota Aquifer Program (Kansas Geological Survey, Lawrence, Kansas). The point data were digitized into ARC/INFO and posted on a paper copy of a 1:500,000- scale base map of Kansas showing the extent of the Dakota aquifer, and then manually contoured. The resulting contour map was compared with a contour map of the potentiometric surface of the Dakota aquifer in eastern Colorado (Robson and Banta, 1987). The Kansas map was manually digitized into ARC/INFO in the Lambert Conformal Conic Projection.

The digital map of the concentration in mg/L of total dissolved solids (TDS) in ground water from the Dakota aquifer in Kansas is for the upper Dakota aquifer in Kansas (Whittemore et al., 1995; scale 1:100,000). This map was produced primarily using chemical analyses of water samples from the Dakota aquifer contained in the KWATCHEM database maintained by the Dakota Aquifer Program at the Kansas Geological Survey, Lawrence, Kansas. The data source was supplemented by total dissolved solids concentration values derived from the analysis of geophysical logs of oil and gas production and exploration boreholes in northwest Kansas (Boeken, 1995). Geographic coordinates for the sample locations were extracted from the digital database and posted using ARC/INFO on a paper copy of a 1:500,000 scale base map of Kansas showing the extent of the Dakota aquifer, and manually contoured. The contour map of dissolved solids concentrations was manually digitized into ARC/INFO in the Lambert Conformal Conic Projection. The contour interval selected to produce this map is irregular.

The maps were produced using ArcInfo Version 7.0.3 software by Environmental Systems Research Institute, Incorporated. Each map is projected using the Lambert Conformal Conic Projection with first and second standard parallels at 33 and 45 degrees with a central meridian at -98 degrees 15 minutes and a latitude of origin at 36 degrees. These parameters conform to the state of Kansas standard projection. Length units are in meters. Data digitized into ARC/INFO had an root mean square error of 0.09 in at the original scale of the map or about 120 m on the ground. This is within the suggested National Map Accuracy Standards of the USGS of 0.02 in (Nebert, 1989).

Although a total of six map coverages were created, only five plates appear in this report since the Dakota extent is used as backdrop for the other four Dakota maps. The DOCUMENT macro in the Arc Macro Language (version 7.04) from the USGS Water Resources Division and the US Environmental Protection Agency (version 2.02) was used to improve the utility and understanding of the map coverages. This macro effectively stores metadata entered by the map author(s) in the ARC/INFO export files intended for distribution, so that potential users have access to fairly detailed information about the features depicted in each coverage along with the methods used to produce them as well as their intended and appropriate use.

Narrative Description of the Parameters Portrayed on Each of the Dakota Aquifer Coverages

The Dakota aquifer extent coverage shows the outcrop/subcrop belt where the Dakota is at the surface or is overlain by younger Cenozoic deposits and the confined part where the Dakota is overlain by the Upper Cretaceous aquitard. The irregular nature of the boundary between these two regions in central and parts of southwestern Kansas indicates stream incision where the aquitard has been removed by erosion.

The top of the confined aquifer is defined as the contact between the Graneros Shale and the underlying Dakota Formation where the Upper Cretaceous aquitard has not been removed by erosion (Macfarlane et al., 1990). The coverage showing the altitude of the top of the Dakota aquifer indicates that the aquifer top dips to the north over most of Kansas. In southwestern Kansas, the top of the Dakota aquifer dips more strongly in a northeasterly direction along the eastern limb of the Las Animas arch and the Sierra Grande uplift. In the outcrop/subcrop belt the top of the unconfined aquifer is the base of the overlying Cenozoic deposits or land surface. In this part of the aquifer the irregular nature of the top surface reflects Cenozoic erosion prior to the deposition of the Ogallala Formation. The elevation of the top of the aquifer is lowest in the Salina basin along the northern border and in the northwestern corner of Kansas.

The coverage showing the altitude of the bottom of the Dakota reflects the erosional topography developed on top of Permian and Jurassic strata in Kansas and regional dip of the Cretaceous section to the north (Hamilton, 1994). The base of the Dakota aquifer is defined as the base of the Cretaceous System and is lowest in elevation in the Salina basin along the northern border and in the northwestern corner of Kansas and highest in southwestern Kansas. In southwestern Kansas the base of the Dakota aquifer dips moderately to the northeast on the eastern limb of the Las Animas arch and the Sierra Grande uplift. Stream incision into lower units is shown in Scott, Lane, Gove, Logan, and Thomas counties in northwestern and west–central Kansas. The northwesterly dip of the base near the outcrop/subcrop belt in Washington, Cloud, and Republic counties reflects the structure along the western side of the Nemaha uplift.

The Dakota aquifer potentiometric surface coverage shows the variation in hydraulic head within the aquifer. Most of the data used to map the potentiometric surface are from the upper Dakota aquifer. The map generally indicates northeastward flow of ground water within the upper Dakota from a regional recharge area in southeastern Colorado and toward regional discharge areas in the river valleys of north–central Kansas. Modeling studies reported in Macfarlane, 1993; Macfarlane and Smith, 1994; and Smith and Macfarlane, 1994) indicate that a regional flow system dominates the Dakota aquifer in most of Kansas. However, nearer the outcrop/subcrop belt in south–central and north–central Kansas, local flow systems begin to dominate the flow pattern. This suggests that the Dakota potentiometric surface only shows the apparent flow pattern in this part of the aquifer.

The coverage showing the distribution of TDS concentrations in ground waters of the Dakota aquifer reflects the flushing of saline ground water from the Dakota by freshwater recharge, remnant salinity within the aquifer, and the upward migration of salinity from Permian in central Kansas (Whittemore and Fabryka-Martin, 1992; Macfarlane, 1995; Davisson et al., 1995; Smith, 1995). The map may not reflect the average TDS concentrations throughout the aquifer, especially where there has been significant upward migration of saltwater from the underlying Permian.

Extent of the Kansas Alluvial Aquifers Coverage

The coverage showing the extent of the alluvial aquifers in Kansas shows that these aquifers consist of primarily Quaternary alluvium and dune sand. Dune sands are a more common component of the alluvial deposits in the Arkansas River basin than in the Kansas River basin. The Quaternary alluvium is divided in pre-Kansan and post-Kansan alluvium. Pre-Kansan alluvium consists primarily of terrace deposits that are contiguous with the other alluvial deposits within the valley. Pre-Kansan deposits are quite extensive in the Smoky Hill, Pawnee, and Arkansas River valleys. Post Kansan alluvium consists primarily of the alluvial deposits within the active meander belt of the stream and are usually capped by Recent deposits.

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