Introduction

The Ozark aquifer, within the Ozark Plateaus aquifer system (herein referred to as the "Ozark system"), is the primary groundwater source in the Ozark Plateaus physiographic province (herein referred to as the "Ozark Plateaus") of Arkansas, Kansas, Missouri, and Oklahoma (fig. 1) (Fenneman, 1938; Fenneman and Johnson, 1946). Groundwater from the Ozark system has historically been an important part of the water resource base, and groundwater availability is a concern in some areas; dependence on the Ozark aquifer as a water supply has caused evolving localized issues. The construction of a regional potentiometric-surface map of the Ozark aquifer is needed to aid assessment of current and future groundwater use and availability. The regional potentiometric-surface mapping is part of the U.S. Geological Survey (USGS) Groundwater Resources Program initiative (http://water.usgs.gov/ogw/gwrp/activities/regional.html) and the Ozark system groundwater availability project (http://ar.water.usgs.gov/ozarks), which seeks to quantify current groundwater resources, evaluate changes in these resources over time, and provide the information needed to simulate system response to future human-related and environmental stresses.

The Ozark groundwater availability project objectives include assessing (1) growing demands for groundwater and associated declines in groundwater levels as agricultural, industrial, and public supply pumping increases to address needs (Emmett and others, 1978a; Richards and Mugel, 2008); (2) regional climate variability and pumping effects on groundwater and surface-water flow paths (Imes and Emmett, 1994; Macfarlane and Hathaway, 1987); (3) effects of a gradual shift to a greater surface-water dependence in some areas (Kresse and others, 2014); and (4) shale-gas production requiring groundwater and surface water for hydraulic fracturing (Kresse and others, 2012; U.S. Environmental Protection Agency, 2010). Data compiled and used to construct the regional Ozark aquifer potentiometric surface will aid in the assessment of those objectives.

The purpose of this report is to document a regional potentiometric surface of the Ozark aquifer representing synoptic conditions from November 2014 through January 2015. The potentiometric surface can be used to evaluate groundwater-level changes, provide calibration and simulation targets for the Ozark system regional groundwater flow model, and provide comprehensive data to the Ozark system groundwater availability project. A regional potentiometric map of the Ozark aquifer has not been completed since the detailed hydrologic studies of the Ozark Plateaus aquifer system investigated by Imes and Emmett (1994) (figs. 28 and 40), as part of the 1981 Central Midwest Regional Aquifer-System Analysis (Jorgensen and Signor, 1981) of the 1978–96 USGS Regional Aquifer-System Analysis Program, approximated a predevelopment surface (Gillip and others, 2008). The regional potentiometric surface for this report shows large-scale groundwater-level characteristics, but the regional potentiometric surface does not show smaller, local-scale detail, such as localized cones of depression that may be indicative of evolving local issues. The regional map does not invalidate previous local-scale observations and efforts, as the scope of this regional study did not include the extensive measurements required to delineate local-scale depressions. The potentiometric surface, however, shows regionally important details such as water-level patterns highlighting the intimate connection between surface water and groundwater across large areas and regional groundwater-flow directions. For information on local-scale conditions, the reader is referred to studies that include finer scale water-level-measurement data for the study area (Aley, 1988; Czarnecki and others, 2009, 2014; Dintelmann and others, 2006; Emmett and others, 1978b; Gillip and others, 2008; Imes, 1989a, 1989b, 1990, 1991; Imes and Emmett, 1994; Imes and Kleeschulte, 1995; Imes and others, 2007; Juracek and Hansen, 1996; Kleeschulte, 2001, 2006; Macfarlane and Hathaway, 1987; Mugel and Imes, 2003; Mugel and others, 2009; Pugh, 1998, 2008; Richards, 2010; Richards and Mugel, 2008; Schrader, 2001, 2005, 2015; Steinkamp, 1987; Vandike, 1992).

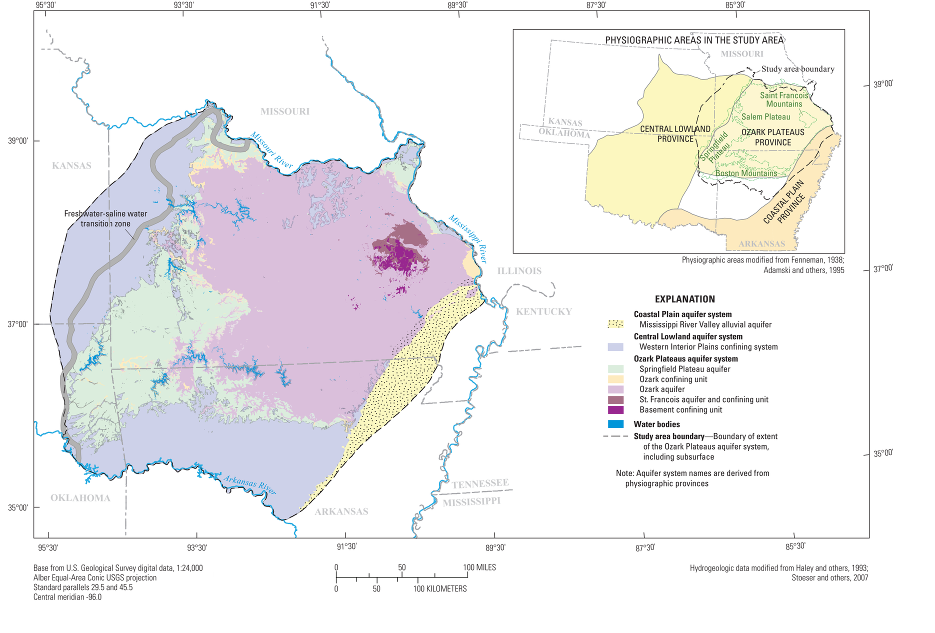

Figure 1. Study area map showing surficial extent of aquifers and confining units of the Ozark Plateaus aquifer system, which compose the physiographic province and regions.

Hydrogeologic Setting

Hydrogeologic units and geology of the study area have been studied extensively (Adamski and others, 1995; Banner and others, 1989; Ethington and others, 2012; Harrison and McDowell, 2003; Harrison and others, 2002; Hudson, 2000; Hudson and others, 2006; Hudson and Turner, 2007, 2009, 2014; Imes, 1989b, 1989c, 1990; Imes and Emmett, 1994; Jorgenson and others, 1993; Kleeschulte and Seeger, 2003; Kresse and others, 2014; McDowell and others, 2000; Miller and Appel, 1997; Mugel and Imes, 2003; Orndorff, 2003; Orndorff and Harrison, 2001; Smith and Imes, 1991; Turner and Hudson, 2010; Weary, 2015; Weary and McDowell, 2006; Weary and others, 2013, 2015; Weary and Schindler, 2004; Weems, 2002; Whitfield and others, 1994). In this report, hydrogeologic characteristics are briefly discussed, and geologic units of the Ozark aquifer follow naming conventions used in Missouri. Figure 2 lists the stratigraphically equivalent geologic units names for Arkansas, Kansas, and Oklahoma, and the units are divided into the upper, middle, and lower Ozark aquifer (Imes and Emmett, 1994). Figure 1 shows aquifers and confining units, which compose the physiographic province and sections in the study area. The reader should note that aquifer systems in figure 1 refer to a "heterogeneous body of intercalated permeable and poorly permeable material that functions regionally as a water-yielding hydraulic unit; it comprises two or more permeable beds (aquifers) separated at least locally by confining units that impede groundwater movement but do not greatly affect the regional hydraulic continuity of the system" (Poland and others, 1972). Aquifers and confining units are named for province and its subdivisions; nomenclature associated with the correlation of hydrogeologic formations will have the designation of aquifer or aquifer system implied for any formation or group of formations for this report.

The study area is bounded to the north by the Missouri River, to the south by the Arkansas River and Boston Mountains of the Ozark Plateaus, to the west by a freshwater-saline water transition zone along the Central Lowland-Ozark Plateaus province boundaries, and to the east by the Mississippi River and Mississippi River Valley alluvial aquifer of the Coastal Plain province (fig. 1). The Ozark system is primarily located in the physiographic province, Ozark Plateaus, which comprises three physiographic sections: Salem Plateau, Springfield Plateau, and the Boston Mountains (fig. 1). The Ozark system is divided into five hydrogeologic units (youngest to oldest) (fig. 2): Springfield Plateau aquifer, Ozark confining unit, Ozark aquifer, St. Francois confining unit, and St. Francois aquifer (Imes and Emmett, 1994). The Ozark system is geologically complex and includes Cambrian- to Mississippian-age strata. The Ozark system aquifers, comprising carbonate karst and granular-media strata, are bound by confining layers of variable extent and competency. The Ozark system aquifers have experienced fracturing, faulting, and extensive dissolution of soluble rocks that have modified primary rock properties and the ability to convey and store water. For the carbonate units, fracturing and faulting provided initial pathways for dissolution and karst development, resulting in intimate connection of groundwater with surface water across large areas.

The Ozark aquifer lies between the Springfield Plateau and St. Francois aquifers (fig. 2) in the Ozark system and is the largest and most important aquifer of the region; many public and private supplies depend entirely upon the Ozark aquifer because of the productivity and widespread availability of the aquifer (Vandike, 1992). The Ozark aquifer has been separated into upper, middle, and lower Ozark aquifer hydrogeologic units (fig. 2) as part of the USGS Groundwater Resources Program initiative, based upon previously compiled data on the geologic characteristics and hydrologic properties of the rocks and modified from Imes and Emmett (1994); however, groundwater-level measurements collected for this map did not distinguish among upper, middle, and lower units because of completion practices typical of the region and lack of sufficiently detailed completion information for many wells. The upper Ozark aquifer is carbonate dominated, comprising Devonian-, Silurian-, and Ordovician-age rocks. The middle Ozark aquifer comprises the Cotter Dolomite and Jefferson City Dolomite of Ordovician age. The lower Ozark aquifer includes Ordovician-age (Roubidoux Formation, Gasconade Dolomite, and Van Buren Formation-Gunter Sandstone Member) and Cambrian-age (Eminence Dolomite and Potosi Dolomite) hydrogeologic units.

The Ozark aquifer is generally under unconfined conditions where it crops out across the Salem Plateau section (Miller and Appel, 1997); in the Saint Francois Mountains (fig. 1), the aquifer has been removed by erosion. The Ozark aquifer is generally under confined conditions across the Springfield Plateau (fig. 1), where the aquifer is overlain by the Ozark confining unit, which in turn is overlain by the Springfield Plateau aquifer. The middle Ozark aquifer does have limited exposures along river valleys in McDonald, Lawrence, Dade, and St. Clair Counties in Missouri, as well as in Madison and Benton Counties in Arkansas. Recharge to the Ozark aquifer, where unconfined, is primarily by infiltration of rainfall, and where confined, recharge originates from downgradient flow from outcrop areas of the Ozark aquifer and leakage from the Springfield Plateau aquifer (Kresse and others, 2014).

To the west of the Salem-Springfield Plateaus and south of the Boston Mountains lies the Western Interior Plains confining system within the Central Lowland-Ozark Plateaus provinces. The Western Interior Plains confining system overlies the Ozark system and the Western Interior Plains aquifer system and consists of a thick sequence of Pennsylvanian sedimentary rocks of low permeability. Groundwater discharged from the Western Interior Plains aquifer system is slightly saline (around 1,000 milligrams per liter or more dissolved solids) because of leakage from saline formations, particularly from the Permian strata of the Western Interior Plains aquifer system (Banner and others, 1989; Imes, 1985; Imes and Emmett, 1994). The Western Interior Plains aquifer system merges into the freshwater-saline water transition zone where flow gradients induce a vertical component of flow resulting in discharge into streams as base flow and into alluvial deposits in stream valleys (Miller and Appel, 1997).

Recharge in the higher altitude water-level areas (indicated by blue shading on the potentiometric-surface map, fig. 3), where the Ozark aquifer is exposed is generally by direct recharge from precipitation. Short, shallow flow paths are important in outcrop areas of the Ozark aquifer where precipitation quickly infiltrates into the subsurface and groundwater moves quickly to deeply incised streams in these high-relief, upland areas (Adamski and others, 1995; Kresse and others, 2014). Because of the rapid recharge and drainage occurring in these unconfined, upland areas of the Ozark aquifer, highly variable groundwater-gradient reversals are common (Aley, 1988; Kresse and others, 2014); hence, regional flow is controlled by regional topographic highs, and shallower, shorter local flow systems controlled by local topography are superimposed on this larger framework. Water discharged from the Ozark aquifer moves into the streams, springs, and karst features, such as dissolution-enlarged fractures, bedding planes, and caves, located along flow paths.

Figure 2. Stratigraphic units and regional geohydrologic units (modified from Imes and Emmett, 1994).

[Blue lines mark boundaries between hydrogeologic units. Shading represents divisions between the upper (green), middle (red), and lower (blue), Ozark aquifer. Modified from Imes and Emmett, 1994 (table 1)]

Era	System	Southeastern Missouri	Southwestern Missouri	Southeastern Kansas	Northeastern Oklahoma	Northern Arkansas	Hydrogeologic unit	Hydrogeologic system
Paleozoic	Pennsylvanian	Pleasanton Formation[1], Marmaton Group[1], Cherokee Shale[1]	Kansas City Group, Pleasanton Formation, Marmaton Group, Cherokee Shale	Kansas City Group, Pleasanton Formation, Marmaton Group, Cherokee Group	Marmaton Group, Cabaniss Group, Krebs Group, Atoka Formation, Bloyd Shale, Hale Formation	McAlester Formation, Hartshorne Sandstone, Atoka Formation, Bloyd Shale, Hale Formation		Western Interior Plains confining system[2]
	Mississippian	Vienna Limestone[1], Tar Springs Sandstone[1], Glen Dean Limestone[1], Hardinsburg Sandstone[1], Golconda Formation[1], Cypress Formation[1], Paint Creek Formation[1], Yankeetown Sandstone[1], Renault Formation[1], Aux Vases Sandstone[1], Ste. Genevieve Limestone[1], St. Louis Limestone[1]	Fayetteville Shale, Batesville Sandstone, Hindsville Limestone, Carterville Formation, St. Louis Limestone	St. Louis Limestone	Pitkin Limestone, Fayetteville Shale, Batesville Sandstone, Hindsville Limestone, Moorefield Formation	Pitkin Limestone, Fayetteville Shale, Batesville Sandstone, Moorefield Formation		
	Mississippian	Salem Limestone[3], Warsaw Limestone[3], Keokuk Limestone[3], Burlington Limestone[3], Fern Glen Limestone[3]	Salem Limestone, Warsaw Limestone, Keokuk Limestone, Burlington Limestone, Elsey Formation, Reeds Spring Formation, Pierson Formation	Salem Limestone, Warsaw Limestone, Keokuk Limestone, Burlington Limestone, Fern Glen Limestone	Keokuk Limestone, Boone Formation, Reeds Spring Member, St. Joe Limestone Member	Boone Formation, Reeds Spring Member, St. Joe Limestone Member	Springfield Plateau aquifer	Ozark Plateaus aquifer system[5]
	Mississippian / Devonian	Chouteau Limestone, Hannibal Shale, Bachelor Formation[4], Bushberg Sandstone, Glen Park Limestone, Chattanooga Shale	Northview Shale, Sedalia Limestone, Compton Limestone, Chattanooga Shale	Chouteau Limestone, Chattanooga Shale	Northview Equivalent, Compton Equivalent, Woodford Chert, Chattanooga Shale	Chattanooga Shale	Ozark confining unit	
	Devonian	St. Laurent Limestone, Grand Tower Limestone, Clear Creek Chert, Little Saline Limestone, Bailey Limestone	Callaway Formation, Fortune Formation[4]		Sallisaw Formation, Frisco Limestone	Clifty Limestone, Penters Chert	Ozark aquifer, upper	
	Silurian	Bainbridge Limestone, Sexton Creek Limestone[4]			St. Clair Limestone	Lafferty Limestone, St. Clair Limestone, Brassfield Limestone	Ozark aquifer, upper	
	Ordovician	Girardeau Limestone, Orchard Creek Shale, Thebes Sandstone, Maquoketa Shale, Cape Limestone[4], Kimmswick Limestone, Decorah Formation, Plattin Limestone, Rock Levee Formation[4], Joachim Dolomite, Dutchtown Formation[4], St. Peter Sandstone, Everton Formation, Smithville Formation, Powell Dolomite	Kimmswick Limestone, Plattin Limestone, Joachim Dolomite, St. Peter Sandstone, Everton Formation, Smithville Formation, Powell Dolomite		Sylvan Shale, Fernvale Limestone, Viola Limestone, Fite Limestone, Tyner Formation, Burgen Sandstone, Smithville Equivalent, Powell Dolomite	Cason Shale, Fernvale Limestone, Kimmswick Limestone, Plattin Limestone, Joachim Dolomite, St. Peter Sandstone, Everton Formation, Smithville Formation, Powell Dolomite	Ozark aquifer, upper	
	Ordovician	Cotter Dolomite, Jefferson City Dolomite	Cotter Dolomite, Jefferson City Dolomite	Cotter Dolomite, Jefferson City Dolomite	Cotter Dolomite, Jefferson City Dolomite	Cotter Dolomite, Jefferson City Dolomite	Ozark aquifer, middle	
	Ordovician	Roubidoux Formation, Gasconade Dolomite, Van Buren Formation, Gunter Sandstone Member	Roubidoux Formation, Gasconade Dolomite, Van Buren Formation, Gunter Sandstone Member	Roubidoux Formation, Gasconade Dolomite, Van Buren Formation, Gunter Sandstone Member	Roubidoux Formation, Gasconade Dolomite, Van Buren Formation, Gunter Sandstone Member	Roubidoux Formation, Gasconade Dolomite, Van Buren Formation, Gunter Sandstone Member	Ozark aquifer, lower	
	Cambrian	Eminence Dolomite, Potosi Dolomite	Eminence Dolomite, Potosi Dolomite	Eminence Dolomite, Potosi Dolomite	Eminence Dolomite, Potosi Dolomite	Eminence Dolomite, Potosi Dolomite	Ozark aquifer, lower	
	Cambrian	Doe Run Dolomite, Derby Dolomite, Davis Formation	Doe Run Dolomite, Derby Dolomite, Davis Formation	Doe Run Dolomite, Derby Dolomite, Davis Formation	Doe Run Dolomite, Derby Dolomite, Davis Formation	Doe Run Dolomite, Derby Dolomite, Davis Formation	St. Francois confining unit	
	Cambrian	Bonneterre Formation[6], Reagan Sandstone, Lamotte Sandstone	Bonneterre Dolomite, Reagan Sandstone, Lamotte Sandstone	Bonneterre Dolomite[6], Reagan Sandstone, Lamotte Sandstone	Bonneterre Equivalent, Reagan Sandstone, Lamotte Sandstone	Bonneterre Dolomite, Reagan Sandstone, Lamotte Sandstone	St. Francois aquifer	
		PRECAMBRIAN IGNEOUS AND METAMORPHIC ROCKS					Basement confining unit	

[1]Geologic unit in southeastern Missouri that is stratigraphically equivalent to geologic units in the Western Interior Plains confining system but not part of the confining system.
[2]The Western Interior Plains confining system also includes younger sediments west of the study area.
[3]Geologic unit in southeastern Missouri that is stratigraphically equivalent to geologic units in the Springfield Plateau aquifer but not part of the aquifer.
[4]Unit follows usage of the Missouri Division of Geology and Land Survey.
[5]The Western Interior Plains aquifer system deeply buried in the western part of the study area included, where permeable carbonate rocks in the subsurface are equivalents of the aquifers of the Ozark Plateaus aquifer system (Miller and Appel, 1997).
[6]Unit follows usage of the National Geologic Map Database.

Methods

The regional Ozark aquifer potentiometric-surface map shows the altitude at which the water level would have risen in tightly cased wells and represents conditions during the period from November 2014 through January 2015 (fig. 3). Water levels were measured during this period to ensure that wells had adequate time to recover from previous summer pumping and prior to the start of the 2015 summer pumping season. Groundwater-level data from 178 wells cased completely in and open to the Ozark aquifer are available from the USGS National Water Information System (NWIS; data available at http://waterdata.usgs.gov/nwis). Groundwater wells were determined to be completed within Ozark aquifer geologic units (fig. 2) by evaluating lithology from geophysical logs, groundwater driller logs, total depth, casing depth, publications, and available historical groundwater-level data. Groundwater-level data were collected for Arkansas, Kansas, and Missouri; however, groundwater-level data were not collected for Oklahoma because of the local practice of completing wells in both the Springfield Plateau and Ozark aquifers and a lack of completion data to indicate wells that were completed solely in the Ozark aquifer.

Streams and springs in the study area represent the intersection of the groundwater table with land surface; these features were used in the construction of the potentiometric-surface map. In Arkansas and Missouri, where the Ozark aquifer crops out, altitudes of select gaining stream reaches, compiled from previous reports on gaining and losing streams (data available at http://dx.doi.org/10.5066/F7W9577Q) and select springs (data available at ftp://msdis.missouri.edu/pub/Inland_Water_Resources/MO_2010_Springs_shp.zip), were calculated from 10-meter digital elevation data (Knierim and others, 2015; Missouri Department of Natural Resources and others, 2010).

Representative and uniform data distribution is important when developing a potentiometric-surface map; therefore, a spatial analysis of sites in a geographic information system by using data from the USGS NWIS, Missouri Spatial Data Information Service, and Missouri Department of Natural Resources (MODNR) was conducted to identify areas with sparse data. Kansas groundwater-level measurements were collected from observation wells by the Kansas Department of Agriculture–Division of Water Resources personnel.

Groundwater levels were measured by using a calibrated, graduated steel tape and an electric water-level indicator or by making an air-pressure gage measurement. Calibrated tapes are accurate to within 0.01 foot (ft), but the accuracy of air-pressure gage measurements ranges from 1 to 10 ft (Garber and Koopman, 1968; Gillip and others, 2008). Field-collected groundwater levels are subject to potential measurement errors including nonrepresentative water-level measurements possibly caused by recent or nearby pumping, inaccurate airline measurement or inaccurate airline length reported, and nonavailability and inaccuracy of well-construction information. Well-construction information was collected from well owners or from posted information at well sites. To reduce possible errors or data inconsistencies, all field sheets and water-level collection software data files were reviewed for accurate well location, altitudes, and construction information. Well driller logs, State and Federal agency well databases, and aerial photographs were used to check for accuracy and consistency. To verify field measurements, historical water-level data and recent well driller logs from each State, which include static groundwater-level measurements obtained during well installation, were reviewed and compared to groundwater levels measured for this study. Groundwater-level measurements were converted from depth below land surface, in feet, to groundwater-level altitude, in feet. Well altitudes, used to calculate groundwater-level altitudes, originally reported with respect to the National Geodetic Vertical Datum of 1929 (NGVD 29), were converted to the North American Vertical Datum of 1988 (NAVD 88), for consistency.

After collecting and processing the data, a potentiometric surface was generated by using the interpolation method TopotoRaster in ArcMap. This tool is specifically designed for the creation of hydrologically correct digital elevation models while imposing constraints that ensure a connected drainage structure and a correct representation of the surface from the provided contour data (Esri, 2011). Once the raster surface was created, 100-ft contours were generated by using Contour (Spatial Analyst), which is a spatial analyst tool (available through ArcGIS Spatial Analyst Toolbox) that creates a line-feature class of contours (isolines) from the raster surface (Esri, 2008). Contours were manually adjusted based on topographical influence, a comparison with the regional map of Imes and Emmett (1994), and data point water-level altitudes to more accurately represent the potentiometric surface.

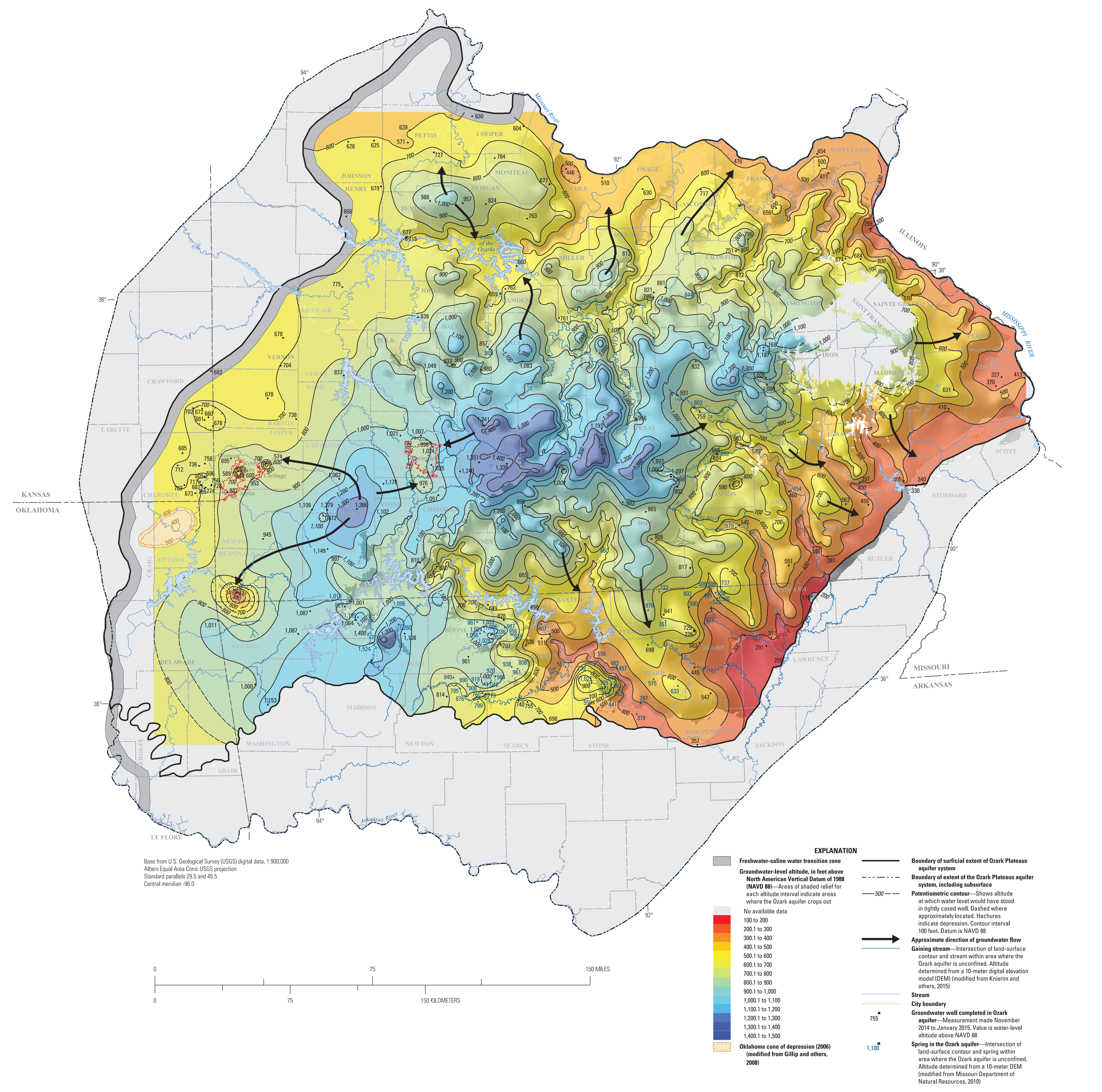

Figure 3 Regional potentiometric surface for the Ozark aquifer from November 2014 through January 2015.

Potentiometric Surface

The potentiometric-surface map of the Ozark aquifer is a two-dimensional depiction of a three-dimensional view of the surface. The groundwater altitudes used in the map construction represent altitudes at which the water level would have stood in a tightly cased well; the map should not be used to determine the absolute water-level altitude or depth to water at any given location because of the variable geology and hydrologic properties of the study area and because of the changing nature of water levels through time. The potentiometric surface indicates the general direction of groundwater flow; under isotropic conditions, groundwater flow is perpendicular to the lines of equal hydraulic head and in the direction of hydrologic gradient.

The Ozark aquifer is unconfined across more than 50 percent of the potentiometric map area, and groundwater flow is predominantly driven by topography. A radial flow pattern moving north from the central Ozarks towards the Missouri River, west towards the freshwater-saline water transition zone, east towards the Mississippi River and Mississippi River Valley alluvial aquifer, and south towards the Arkansas River is a key characteristic of the flow system (fig. 3). A well in Lawrence County, Mo., with a maximum groundwater-level altitude of 1,366 ft, located in a topographic high, and a well in Randolph County, Ark., with a minimum groundwater-level altitude of 178 ft, located in a topographic low, are examples of how groundwater flow in the Ozark aquifer is driven by hydraulic head. Topographic control of flow and the connection between groundwater and surface water are illustrated where contours crossing streams form a "V" pointing towards higher altitudes where water from the aquifer is discharging into the streams. Streams, incised in lower altitude valleys, across the study area have V-shaped contours that point towards the lower altitudes, indicating reaches where streams act as discharge points for the Ozark aquifer. This pattern of V-shaped contours is well illustrated in lower water-level altitude areas along streams such as the Big Piney River, Current River, Eleven Point River, Gasconade River, Jacks Fork River, and Roubidoux Creek in the north-central part of the study area, west of the Saint Francois Mountains (fig. 3).

Within the limitations of the regional-scale dataset, the groundwater-flow directions show good agreement with previously constructed, local- and regional-scale Ozark aquifer potentiometric maps (Imes and Emmett, 1994; Richards and Mugel, 2008; Schrader, 2015). Differences in these potentiometric surfaces may be ascribed to the size of the mapped area (regional or local scales), number of wells that were measured (data density), and timing (such as the season, year, decade) of measurements. On the regional potentiometric surface in the southwestern part of the study area in Jasper and McDonald Counties, Mo., groundwater declines are evident when compared to the predevelopment potentiometric-surface map by Imes and Emmett (1994). Groundwater-level altitudes in Kansas range from a low of 596 ft to a high of 805 ft in Cherokee County, Kans., and from a low of 660 ft to a high of 702 ft in the southeastern corner of Crawford County, Kans. While the southeastern corner of Crawford County, Kans., does show a slight decline (42 ft difference between the low and high groundwater-level altitudes), smaller scale cones of depression are not evident because of the large scale of the regional potentiometric surface. In Oklahoma (Gillip and others, 2008) and in Springfield, Greene County, Mo. (Richards and Mugel, 2008), two cones of depression on a local scale are displayed to compare with the current regional potentiometric surface and to highlight the historical importance of groundwater-level declines in these areas. Past water-level measurement data and resulting previously constructed, local-scale potentiometric maps detail water-level declines and the formation of cones of depression in southeastern Kansas (Cherokee and Crawford Counties), Missouri (Barry, Barton, Cedar, Dade, Greene, Jasper, Lawrence, McDonald, and Newton Counties), and northwestern Oklahoma (Craig and Ottawa Counties) (Czarnecki and others, 2009; Czarnecki and others, 2014; Gillip and others, 2008; Richards, 2010; Richards and Mugel, 2008).

The population increase, growing demand for water, and water-quality issues in southwestern Missouri are causing communities such as in Jasper and McDonald Counties, Mo., to assess the Ozark aquifer and its ability to sustain long-term population growth (Czarnecki and others, 2009; Gillip and others, 2008; Wittman and others, 2003). Low groundwater-level altitudes of 574 ft measured in an observation well northeast of Carthage, Jasper County, Mo., and 589 ft in a well in Webb City, Jasper County, Mo., indicate local groundwater-level declines (Wittman and others, 2003). Conversely, a well in Oronogo, Mo., located north of Webb City, had a groundwater-level altitude of 895 ft, and an observation well southwest of Carthage, Mo., had a groundwater-level altitude of 953 ft; these communities reported no groundwater declines according to Wittman and others (2003). The contrast in relatively high and low groundwater levels over short distances emphasizes the local influence of pumping from the Ozark aquifer. In areas where the Ozark aquifer is confined, groundwater levels respond differently to water withdrawals compared to groundwater levels in unconfined areas of the aquifer. Water-level declines induced by a given amount of pumping are greater in confined areas as compared to unconfined areas because water is yielded primarily by the compressibility of the rock matrix rather than by dewatering of the saturated porosity. Additionally, for wells where water withdrawals are high and the aquifer has low transmissivity and storage, longer recovery periods and more expansive cones of depression may be expected.

South of Jasper County, Mo., groundwater declines can be seen in the town of Noel, McDonald County, Mo., in an observation well with a groundwater-level altitude of 349 ft that lies in a distinct cone of depression. When the well for the town of Noel was drilled in 1936, it was a flowing artesian well, but by 1962, water levels had declined to 48 ft below land surface (Missouri Department of Natural Resources, 2015). The groundwater-level measurement made for this study in late 2014 to early 2015 indicates that water levels in Noel, Mo., have declined 116 ft since 2006. The MODNR reported that the potentiometric surface has declined more than 400 ft since 1936 when the well was drilled. In contrast, the water-level altitude measured in a well in Benton County, Ark., approximately 20 miles southwest of Noel, Mo., is 1,011 ft, a difference in the water-level altitude of 662 ft. While the potentiometric surface does indicate considerable groundwater declines in northwestern Arkansas as a result of the cone of depression or in comparison with the Imes and Emmet (1994) map, declines have been noted over time in areas of development and population growth for individual wells in Benton, Carroll, and Washington Counties, Ark. (Czarnecki and others, 2014; Kresse and others, 2014); however, groundwater use from the Ozark aquifer in northwestern Arkansas has decreased, and surface water for public-supply use has increased as more communities convert to surface-water use because of issues arising over groundwater quantity and quality (Kresse and others, 2014).

Acknowledgments

The author would like to thank the USGS Groundwater Resources Program for providing funding to conduct this study. The author would like to also thank all public and private landowners who provided information and access to their water wells for groundwater-level measurements. Thanks also are extended to Joseph Richards with the USGS for providing expertise, suggestions, and information and to David "Charlie" Smith, Jarrett Ellis, Gregory Johnson, and Joshua Blackstock with the USGS for measuring groundwater levels in Missouri and Arkansas. Cristi Hansen with the USGS and Caleb Fabrycky with the Kansas Department of Agriculture–Division of Water Resources provided groundwater levels at real-time observation wells in Kansas.

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2015

For sale by U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225, 1–888–ASK–USGS

Digital files available at http://dx.doi.org/10.3133/sim3348

Suggested citation: Nottmeier, A.M., 2015, Regional potentiometric surface of the Ozark aquifer in Arkansas, Kansas, Missouri, and Oklahoma, November 2014–January 2015: U.S. Geological Survey Scientific Investigations Map 3348, 1 sheet, http://dx.doi.org/10.3133/sim3348.

ISSN 2329-132X (online)
http://dx.doi.org/10.3133/sim3348