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Potentiometric Surface of the Mississippi River Valley Alluvial Aquifer, Spring 2016

Pamphlet to accompany

Scientific Investigations Map 3439

U.S. Department of the Interior
U.S. Geological Survey

Cover. The National Aeronautics and Space Admnistration (NASA) Aqua satellite acquired this image of the Mississippi River alluvial plain on May 4, 2014. Image courtesy of the LANCE/EOSDIS Rapid Response team.

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By Virginia L. McGuire, Ronald C. Seanor, William H. Asquith, Wade H. Kress, and Kellan R. Strauch

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DAVID BERNHARDT, Secretary

U.S. Geological Survey
James F. Reilly II, Director

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- Mississippi Department of Environmental Quality: James Hoffmann, Kay Whittington, Sam Mabry, Madison Kymes, and Pat Phillips;
- U.S. Department of Agriculture, Agricultural Research Service: James Robert (JR) Rigby; and
- Yazoo Mississippi Delta Joint Water Management District: Mark Stiles (retired) and David Kelly.

Contents

Figures

Tables

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
section (640 acres or 1 square mile)	259.0	square hectometer (hm^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)

Datum

Horizontal coordinate information is referenced to the World Geodetic Survey of 1984 (WGS 84). Historical data collected and stored as North American Datum of 1927 (NAD 27) or the North American Datum of 1983 (NAD 83) have been converted to WGS 84 for use in this publication.

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88). Historical data collected and stored as National Geodetic Vertical Datum of 1929 have been converted to NAVD 88 for use in this publication.

Altitude, as used in this report, refers to distance above the vertical datum.

Abbreviations

GIS	geographic information system
MAP	Mississippi Alluvial Plain
MRVA	Mississippi River Valley alluvial
RMSE	root mean square error
USGS	U.S. Geological Survey

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Introduction

The Mississippi River Valley alluvial (MRVA) aquifer is an important surficial aquifer in the Mississippi Alluvial Plain (MAP) area. The MRVA aquifer is generally considered to be an unconfined aquifer (fig. 1; Clark and others, 2011). Groundwater withdrawal from the MRVA aquifer are primarily used for irrigation (Maupin and Barber, 2005). These groundwater withdrawals have resulted in substantial areas of water-level declines in parts of the aquifer area. Concerns about water-level declines and the sustainability of the MRVA aquifer have prompted the U.S. Geological Survey (USGS), as part of the USGS Water Availability and Use Science Program and with assistance from other Federal, State, and local agencies to undertake a regional water availability study to assess the characteristics of the MRVA aquifer, including the altitude of the MRVA aquifer surface, and to provide information to water managers to inform their decisions about resource allocations and aquifer sustainability.

The purpose of this study was to prepare and present a potentiometric surface map for the MRVA aquifer. The potentiometric surface is a contour map of groundwater-level altitudes (also known as hydraulic heads) in the MRVA aquifer, represented by the water-table elevation in the unconfined parts of the aquifers and by the elevation to which water will rise in a tightly cased well in the confined parts of the aquifer (Lohman, 1972). The potentiometric surface map characterizes pre-irrigation conditions by using groundwater-altitude data, daily mean, or daily maximum groundwater altitude from 1,108 wells generally measured generally in spring 2016 and from altitudes of the top of the water surface in rivers in the area, hereinafter referred to as "surface-water altitude," generally on April 10, 2016, from 48 streamgages in the area. The spring timeframe is after water levels have generally recovered from pumping in the previous irrigation season and before pumping begins for the 2016 irrigation season. Although the MRVA aquifer generally exhibits characteristics of unconfined conditions, where surface-water features may or may not be hydraulically connected, it also exhibits characteristics of confined or semiconfined conditions in some areas at least during part of the year; however, the location of these confined or semiconfined areas is not well understood or defined (Arthur, 1994; Kleiss and others, 2000). The term "potentiometric surface" is used in this report because it is acceptable for maps of groundwater altitude surface in unconfined, semiconfined, and confined aquifers (Lohman, 1972).

Previously published potentiometric surface maps for a large part of the MRVA aquifer include ones from water levels measured from 1953 to 1961 (Krinitzsky and Wire, 1964) and for 1964 (Boswell and others, 1968). Previously published potentiometric surface maps for parts of the MRVA aquifer include ones for the Grand Prairie region in Arkansas in 1929, 1939, and 1959 (Engler and others, 1963) and selected counties in northeast and central Arkansas in 1965 and 1966 (Albin and others, 1967; Plebuch and Hines, 1967); the entire aquifer area in Arkansas for 1972, 1980, 1983, 1984, 1985, 1986, 1987, 1989, 1992, 1994, 1996, 1998, 2000, 2002, 2004, 2006, 2008, and 2012 (Ackerman, 1989; Edds and Fitzpatrick, 1984; Plafcan and Edds, 1986; Plafcan and Fugitt, 1987; Plafcan and Remsing, 1989; Westerfield, 1990; Westerfield and Gonthier, 1993; Westerfield and Poynter, 1994; Stanton and others, 1998; Joseph, 1999; Reed, 2004; Schrader, 2001, 2006, 2008, 2010, 2015); the aquifer area in northwestern Mississippi for various years including 1976, 1980, 1981, 1982, and 1983 (Dalsin, 1978; Wasson, 1980, Darden, 1981, 1982a, 1982b, 1983; Sumner, 1984, 1985; James Hoffmann, Mississippi Department of Environmental Quality, written commun., 2018); the entire aquifer area in Missouri for 1976 (Miller and Appel, 1997); and the part of the aquifer in northeastern Louisiana for 1990 (Seanor and Smoot, 1995).

To best reflect hydrologic conditions in the MRVA aquifer, all groundwater altitudes used to create the 2016 potentiometric surface would have been measured in a short time frame of days or a week and there would be available data (for example, from sets of wells with short screens [for example, 5 to 10 foot (ft) screens] installed near the top, in the middle, and near the bottom of the aquifer) to indicate vertical flow components (Freeze and Cherry, 1979; Fetter, 2001). However, most wells screened in the MRVA aquifer were measured before the potentiometric surface map of the MRVA aquifer was planned and therefore the timing of each well's measurement(s) was determined by the needs and schedules of the entities doing the measurements. Also, many of the measured wells have longer screens, so their water-level measurements tend to represent an average hydraulic head in the aquifer for that location (Fetter, 2001). For this

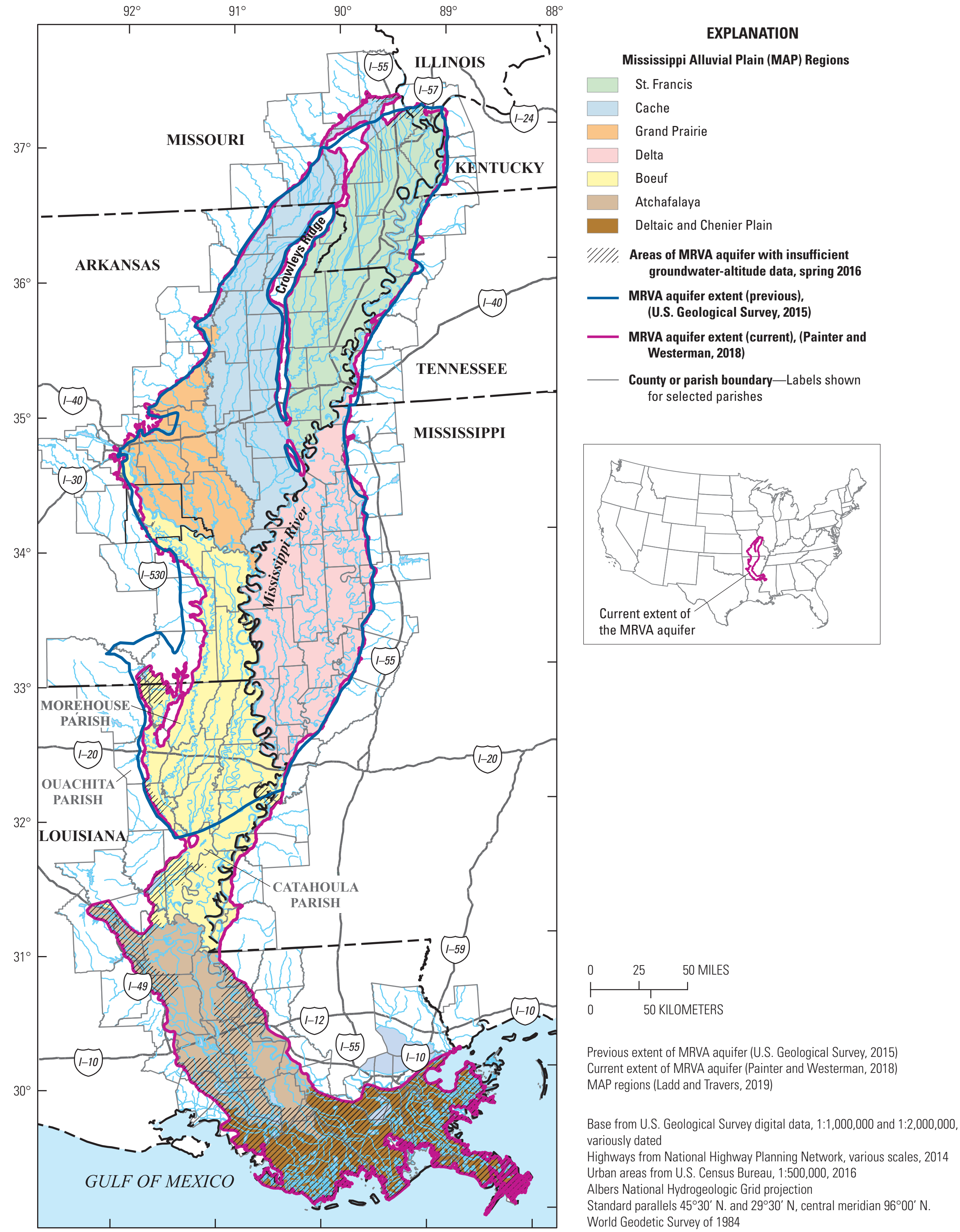


Figure 1. The previous and current extent of the Mississippi River Valley alluvial (MRVA) aquifer and areas with insufficient groundwater-altitude data to map the potentiometric surface for spring 2016.

report, recognizing the limitations of the available data, it was decided to assess all available groundwater-altitude data from wells measured from January through May 2016 for use in the potentiometric surface map of the MRVA aquifer representing spring 2016. The resultant potentiometric surface would then represent the generalized central tendency for spring 2016, but it may not be useful for some purposes, such as for calibration of a groundwater flow model for April 1 to April 15, 2016, or for some local scale assessments.

The potentiometric surface map was prepared with the understanding that when an aquifer is unconfined and hydraulically connected to surface-water features, the water table often is a "subdued reflection" of the land surface; and, where crossing surface-water bodies and sufficient groundwater- and surface-water-altitude data exist, bends upgradient or downgradient, depending on whether the surface-water body is losing or gaining water to the aquifer. When an aquifer is unconfined and not hydraulically connected to surface-water features, the water table can be a "subdued reflection" of the land surface, but the water table generally will not be affected by surface-water features. In an unconfined aquifer, the water-table altitude is equal to the hydraulic head. When an aquifer is fully or partially confined, the surface defined by groundwater altitudes in wells, tightly cased in the aquifer, is a map of its hydraulic head, which for a fully or partially confined aquifer contains both a pressure and elevation head. The potentiometric surface of a confined aquifer does not reflect the topography of the land surface and, in situations where wells are flowing, can be above the land surface; in addition, the potentiometric surface of a fully or partially confined aquifer is not affected by surface-water features, such as lakes, streams, or rivers (Fetter, 2001).

Study Area Description

The MRVA aquifer currently (2019) is defined to be the same as the boundary of the MAP physiographic division, which encompasses a total area of approximately 43,800 square miles (mi^2) and underlies parts of seven States—Arkansas, Illinois, Kentucky, Louisiana, Mississippi, Missouri, and Tennessee (fig. 1; Painter and Westerman, 2018). The extent of the MRVA aquifer used in this report is a revision of the extent used in previous studies (fig. 1; Clark and others, 2011; Maupin and Barber, 2005; U.S. Geological Survey, 2015). The seven regions of the MRVA aquifer and MAP area are St. Francis and Cache in the north, Boeuf and Grand Prairie in the west-central area, Delta in the east central area, and Atchafalaya and Deltaic and Chenier Plain in the south (fig. 1; Ladd and Travers, 2019).

The percent of the revised MRVA aquifer area (fig. 1) underlying each State is about 34.1 percent in Arkansas, 0.3 percent in Illinois, 0.5 percent in Kentucky, 37.0 percent in Louisiana, 17.8 percent in Mississippi, 8.4 percent in Missouri, and 2.0 percent in Tennessee. The percent of revised MRVA aquifer area within each MAP region is about 12.3 percent in the Atchafalaya region, 20.9 percent in the Boeuf region, 14.4 percent in the Cache region, 16.9 percent in the Delta region, 11.2 percent in the Deltaic and Chenier Plain region, 8.0 percent in the Grand Prairie region, and 16.3 percent in the St. Francis region.

The MRVA aquifer (fig. 1) primarily underlies the Mississippi Alluvial Plain Section within the Atlantic Plain Division and Coastal Plain Province (Fenneman and Johnson, 1946; U.S. Geological Survey, 2004). The MRVA aquifer extends about 560 miles (mi) north to south from southeastern Missouri and Illinois and southwestern Kentucky to the Gulf of Mexico off Louisiana. The width of the MRVA aquifer ranges from about 35 mi in northeast Louisiana and southwest Mississippi to 134 mi in southern Louisiana. The Mississippi River is within the MRVA aquifer boundary except in southeast Louisiana, where the river is north of the aquifer boundary. Where the Mississippi River is within the MRVA aquifer boundary, the river is along the eastern boundary of the northern and southern part of the aquifer; in the central part of the MRVA aquifer, the Mississippi River curves toward the middle of the aquifer at the northwest boundary of Mississippi before curving back toward the eastern boundary of the aquifer about 50 mi south of the northeast boundary of Louisiana (fig. 1).

The MRVA aquifer consists of Quaternary-age sand, gravel, silt, and clay deposits overlying Tertiary-age units (Hosman and Weiss, 1991; Saucier, 1994; Clark and others, 2011). In some areas of the MRVA aquifer, the aquifer is overlain by Quaternary-age semi-confining or confining units of silt and clay; where present, these confining units impede recharge to the MRVA aquifer (Ackerman, 1989; Boswell and others, 1968; Kleiss and others, 2000). There are four areas within the MRVA aquifer extent where the MRVA aquifer is not present (fig. 1). The two northernmost parts of these areas are termed Crowleys Ridge, which is an erosional remnant of Tertiary-age deposits. The Crowleys Ridge areas are about 1,053 mi^2; the combined length of the two parts of Crowleys Ridge is about 185 mi and the width ranges from less than a mile to about 21 mi. Crowleys Ridge forms a physical barrier to groundwater flow in the MRVA aquifer (Schrader, 2015). The other two areas where the aquifer is not present are an upland area of about 128 mi^2 in northeastern Louisiana in the center of Morehouse Parish and the northeastern part of Ouachita Parish and an upland area of about 21 mi^2 in the north-central part of Catahoula Parish (fig. 1, Saucier, 1994).

The latest available estimate of water use in the Nation by aquifer is for the year 2000 (Maupin and Barber, 2005). Groundwater withdrawals in 2000 from wells screened in the previously mapped extent of the MRVA aquifer (fig. 1; U.S. Geological Survey, 2015) were 9,290 million gallons per day, making it the third most used aquifer in the Nation (Maupin and Barber, 2005). More than 98 percent of total withdrawals in 2000 from wells completed in the previously mapped extent of the aquifer were for irrigation. Groundwater withdrawals associated with the revised extent of the MRVA aquifer have not been determined.

Data and Methods

The 2016 potentiometric surface for this report was created by interpolating the groundwater-altitude data from wells and surface-water-altitude data from streamgages using geographic information system (GIS) software (Esri® ArcMap, version 10.5.1; Esri, 2018). The Esri® ArcMap commands are hereinafter referred to as “GIS commands” and are presented in a fixed-format font, as for example, the command “`Topo to Raster`.” The interpolated potentiometric surface was converted to a raster dataset (grid with a uniform cell size [about 0.386 mi^2] and hereinafter referred to as a “raster”); the potentiometric surface contours were derived from the raster. The point shapefiles of groundwater- and surface-water-altitude data, raster files of the potentiometric surface, and shapefile of the potentiometric surface contours are available in a companion USGS data release (McGuire and others, 2019).

Water-Level Data

Groundwater-altitude data were compiled by the USGS (table 1; McGuire and others, 2019) from 1,168 wells completed in the MRVA aquifer and measured during January through May 2016. The wells were measured as part of their regular water-level monitoring program by the Arkansas Natural Resources Commission, Arkansas Department of Health, Arkansas Geological Survey, Illinois Department of Agriculture, Illinois State Water Survey, Louisiana Department of Natural Resources, Louisiana Department of Transportation and Development, Mississippi Department of Environmental Quality, Missouri Department of Natural Resources, Yazoo Mississippi Delta Joint Water Management District, U.S. Department of Agriculture (USDA) Natural Resources Conservation Service, and USGS, or were measured by drillers in Missouri. The groundwater altitude in wells that were manually measured one or more times and are not driller-measured, are hereinafter referred to as “manually measured.” The groundwater altitude in wells that were measured continually for all or part of the time period, are hereinafter referred to as “continually measured.” The groundwater altitude in wells measured by drillers in Missouri during well construction are hereinafter referred to as “driller-measured.” The manually, continuously, and driller-measured water levels were stored in the USGS National Water Information System database (U.S. Geological Survey, 2018) or in a USGS data release (McGuire and others, 2019) as depth to water from land surface. For the manually and driller-measured wells, the land-surface altitude, in feet, and associated vertical datum (National Geodetic Vertical Datum of 1929 [NGVD 29] or North American Vertical Datum of 1988 [NAVD 88]) were retrieved or determined for each well. If the stored land-surface altitude datum was NGVD 29, the land-surface altitude was converted to NAVD 88 using the National Geodetic Survey’s VERTCON computer program (Miller, 1999), and the groundwater altitude with respect to the NAVD 88 was calculated for each well by subtracting depth to water from land-surface altitude. For the continually measured well, the daily mean or maximum groundwater altitude was retrieved and, if necessary, converted to NAVD 88 using National Geodetic Survey’s VERTCON computer program (Miller, 1999).

The accuracy of groundwater altitudes from manually and continually measured wells are assumed to be to the hundredths of a foot. The accuracy of the groundwater altitudes from the driller-measured wells are assumed to be 1 to 2 ft because drilling and development activities could affect the measurement and because little documentation was provided about the measurement details (David Smith, USGS Central Midwest Water Science Center, written commun., August 2018).

The 977 manually measured wells were measured one time for about 97 percent of the wells and two or three times for about 3 percent of the wells. There were 18 continuously measured wells in operation for all or part of the time from January to May 2016; a manual measurement was used for one of the continuously measured wells because continuous measurements were not available for this well in early April and a manual measurement was available. There was only one measurement available for each of the 173 driller-measured wells. The groundwater-altitude value for each of the wells was assessed for suitability prior to inclusion in the 2016 potentiometric surface map. The objective of the groundwater-altitude review was to identify and exclude groundwater-altitude values that appeared to be affected by current or recent pumping or were substantially different from the groundwater altitudes in nearby wells, possibly because of local or seasonal conditions. Other considerations for rejecting a well’s groundwater altitude were apparent discrepancies between the spatial location of the well and the well’s legal description or identifier and suspected inaccuracy in the land-surface altitude value.

For manually measured wells with one measurement and driller-measured wells, the only available measurement was selected as the groundwater altitude to consider for use to create the potentiometric surface map. For the manually measured wells with more than one measurement, generally the maximum (highest) groundwater altitude for each well was selected; the difference between the maximum and minimum groundwater altitude values ranged from 0.22 to 12.64 ft, with a median difference of 2.14 ft. For the wells measured continuously, the daily mean or maximum (highest) groundwater altitudes in April and May 2016, were reviewed and one value for each well was selected from April 7 to May 12, 2016; the difference between the maximum and minimum groundwater altitude values of the daily maximum or daily mean from April 1 through May 31, 2016, ranged from 0.46 to 22.80 ft, with a median difference of 1.91 ft.

Groundwater-altitude values from 962 manually measured wells, 17 continuously measured wells, and 129 driller-measured wells were used to create the 2016

Table 1. Total number of wells that were completed in the Mississippi River Valley alluvial (MRVA) aquifer and measured manually one or more times or continually from January through May 2016, and the subset of these wells whose groundwater-altitude data were used to generate the potentiometric surface map for the MRVA aquifer, spring 2016, by Mississippi Alluvial Plain (MAP) region (Ladd and Travers, 2019).

[--, no data]

MAP Region	Total number of wells in ground-water-monitoring networks, which were measured manually, pre-irrigation season, 2016	Total number of wells in ground-water-monitoring networks, which were mea-sured continually, pre-irrigation season, 2016	Total number of wells in Missouri measured by drillers after well installation, pre-irrigation season, 2016	Number of wells in groundwater-monitoring networks, which were measured manually and used in potentiometric surface map, spring 2016	Number of wells in groundwater-monitoring networks, which were measured continually and used in potentiometric surface map, spring 2016	Number of wells in Missouri measured by drillers after well installation, which were used in potentiometric surface map, spring 2016	Total number of wells used to generate the potentiometric surface map, spring 2016
St. Francis	110	5	128	110	5	92	207
Cache	177	7	45	176	7	37	220
Boeuf	103	1	--	99	1	--	100
Grand Prairie	108	4	--	103	4	--	107
Delta	477	1	--	472	--	--	472
Atchafalaya	2	--	--	2	--	--	2
Deltaic and Chenier Plain	--	--	--	--	--	--	--
Mississippi River Valley alluvial aquifer (total)	977	18	173	962	17	129	1,108

potentiometric surface map (table 1; McGuire and others, 2019). The distribution of the selected wells and the measurement month for the selected groundwater altitude are shown in figure 2, which indicates that if only wells measured in a short timeframe, such as during April 2016, were used to create the 2016 potentiometric surface map, there would be larger areas with no groundwater-altitude data. The measurement month associated with the groundwater-altitude value used for the manually measured wells was January for 3 wells, February for 6 wells, March for 205 wells, April for 649 wells, and May for 99 wells; the median measurement date for all manually measured water levels was April 6, 2016. The measurement month associated with the daily mean groundwater-altitude value used for the continually measured wells was April for 13 wells and May for 4 wells; the median measurement date for all continually measured water levels was April 10, 2016. The measurement month for the driller-measured wells was January for 3 wells, February for 12 wells, March for 41 wells, April for 35 wells, and May for 38 wells; the median measurement date for the driller-measured water levels was April 6, 2016 (fig. 2; table 2).

Daily mean surface-water-altitude data were assembled for 94 streamgages routinely operated by the U.S. Army Corps of Engineers and USGS in the MRVA aquifer area (table 3; U.S. Army Corps of Engineers, 2018; U.S. Geological Survey, 2018; McGuire and others, 2019). For this study, the gage altitude, in feet; the associated vertical datum (NGVD 29 or NAVD 88); and the mean river stage on April 10, 2016, were retrieved for each streamgage. If the vertical datum associated with the gage altitude was NGVD 29, the gage altitude was converted to NAVD 88 using National Geodetic Survey's VERTCON program (Miller, 1999) for possible use to create the potentiometric surface map.

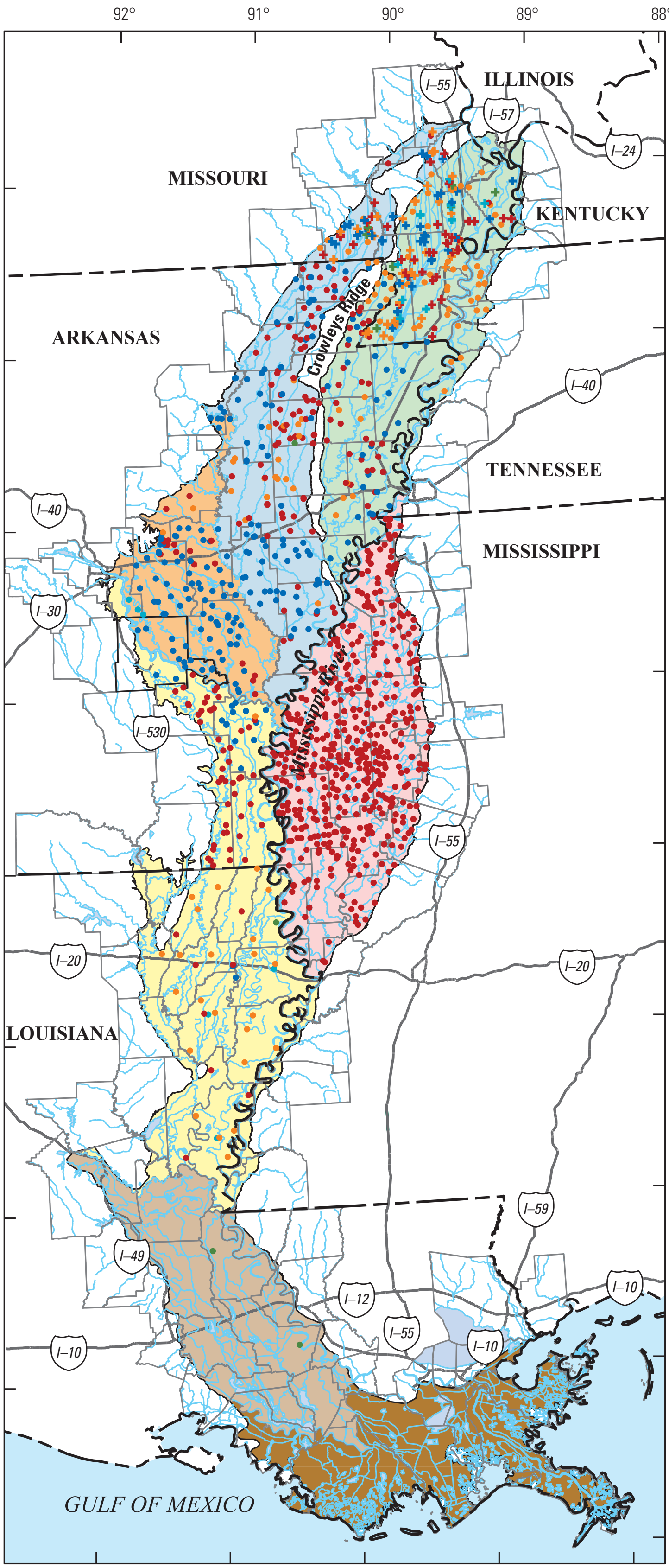
Of the 94 streamgages considered for use in the potentiometric surface map (table 3), 30 were in areas with little or no groundwater data (defined as no groundwater data within 12.4 mi of the center of the cell that contains the streamgages); 5 did not have surface-water-altitude data in early April 2016; and 11 had surface-water-altitude that was much higher than the nearby wells screened in the MRVA aquifer, likely either because the surface-water altitude was affected by precipitation events or the MRVA aquifer is not connected to the surface water at these locations. There were 48 streamgages in areas with nearby groundwater-altitude data for 2016 used to create the 2016 potentiometric surface (table 3). The surface-water-altitude values were considered to be approximations of the groundwater altitude because the altitude where the groundwater and surface are connected likely is below the surface-water altitude and above the altitude of the river bottom.

The groundwater-altitude data were organized into two files and the surface-water-altitude data were organized into one file (McGuire and others, 2019). Two fields were added to each groundwater- and surface-water-altitude record in each file—the "USE_2016" and "USECMT2016" fields. The "USE_2016" field was assigned a positive value for records with a water-level altitude that was used in the creation of the potentiometric surface map and a negative value for records that were excluded. The "USECMT2016" field is populated for records where the "USE_2016" field is negative and provides an explanation for why the water level was not used for the 2016 potentiometric surface map.

Table 2. Summary statistics for water-level measurement dates of water levels used in the spring 2016 potentiometric surface map for wells that were completed in the Mississippi River Valley alluvial aquifer and measured manually one or more times or continually as part of groundwater monitoring networks or measured by drillers from January through May 2016, by Mississippi Alluvial Plain (MAP) region (Ladd and Travers, 2019).

[Minimum, maximum, and median columns are shown in YYYYMMDD format; YYYY, year; MM, month; DD, day; --, no data]

MAP Region	Summary statistics for water-level measurement dates of water levels used in the potentiometric surface map, Mississippi River alluvial aquifer, spring 2016											
	Manually measured wells in groundwater monitoring networks			Continuously measured wells in groundwater-monitoring networks			Driller-measured wells			All wells		
	Minimum	Maximum	Median	Minimum	Maximum	Median	Minimum	Maximum	Median	Minimum	Maximum	Median
St. Francis	20160314	20160512	20160427	20160427	20160525	20160428	20160105	20160530	20160412	20160105	20160530	20160425
Cache	20160308	20160513	20160405	20160127	20160531	20160507	20160301	20160523	20160404	20160127	20160531	20160405
Boeuf	20160105	20160518	20160412	20160507	20160507	20160507	--	--	--	20160105	20160518	20160412
Grand Prairie	20160229	20160505	20160316	20160407	20160507	20160411	--	--	--	20160229	20160507	20160316
Delta	20160401	20160430	20160406	--	--	--	--	--	--	20160401	20160430	20160406
Atchafalaya	20160104	20160105	20160104	--	--	--	--	--	--	20160104	20160105	20160104
Deltaic and Chenier Plain	--	--	--	--	--	--	--	--	--	--	--	--
Mississippi River Valley alluvial aquifer	20160104	20160518	20160406	20160127	20160531	20160502	20160105	20160530	20160406	20160104	20160531	20160406



EXPLANATION

Mississippi Alluvial Plain (MAP) Regions
- St. Francis
- Cache
- Grand Prairie
- Delta
- Boeuf
- Atchafalaya
- Deltaic and Chenier Plain

County or parish boundary

Measured wells in groundwater-monitoring networks

Water-level measurement month
- January 2016
- February 2016
- March 2016
- April 2016
- May 2016

Driller-measured wells

Water-level measurement month
- January 2016
- February 2016
- March 2016
- April 2016
- May 2016

0 25 50 MILES

0 50 KILOMETERS

Current extent of MRVA aquifer (Painter and Westerman, 2018) MAP regions (Ladd and Travers, 2019)

Base from U.S. Geological Survey digital data, 1:1,000,000 and 1:2,000,000, variously dated
Highways from National Highway Planning Network, various scales, 2014
Urban areas from U.S. Census Bureau, 1:500,000, 2016
Albers National Hydrogeologic Grid projection
Standard parallels 45°30′ N. and 29°30′ N, central meridian 96°00′ N.
World Geodetic Survey of 1984

Figure 2. Location of wells with a water level used to create the potentiometric surface map of the Mississippi River Alluvial (MRVA) aquifer, spring 2016, and the measurement month for the selected water level.

Table 3. Total number of streamgages in the Mississippi Alluvial Plain (MAP) with surface-water-altitude values from surface-water monitoring networks, in operation for all or part of the time from January through May 2016, and number of streamgages with surface-water-altitude values generally for April 10, 2016, and used to generate the potentiometric surface map for spring 2016 in the Mississippi River Valley alluvial aquifer by MAP region (Ladd and Travers, 2019).

[--, no data]

MAP Region	Number of streamgaging stations with surface-water altitude values for all or part of the time period from January to May 2016	Number of surface-water altitude values generally for April 10, 2016, and used to generate the potentiometric surface map of 2016
St. Francis	5	5
Cache	11	7
Boeuf	20	15
Grand Prairie	1	--
Delta	13	8
Atchafalaya	21	13
Deltaic and Chenier Plain	23	--
Mississippi River Valley alluvial aquifer (total)	94	48

Characterizing the 2016 Potentiometric Surface Raster and Contours

The potentiometric surface raster and contours were generated using a series of GIS commands and three source files of groundwater- and surface-water-altitude data from January to May 2016 (McGuire and others, 2019). For each source file, only the groundwater- and surface-altitude data with a value greater than zero for the field attribute “USE_2016” were used to generate the potentiometric surface for 2016. The resultant spatial files are in Albers equal-area conic projection in meters with respect to the World Geodetic Survey of 1984 (WGS 84) horizontal datum and the potentiometric surface altitude is expressed relative to NAVD 88 vertical datum. The rasters have a cell size of 1,000 meters and are aligned with the National Hydrologic Grid (Clark and others, 2018).

The steps used to generate the potentiometric surface for 2016 can be divided into three workflows: data preparation and other activities prior to analysis, analysis, and final map preparation. These workflows are described in detail in the process steps within the metadata files for the raster and contours of the potentiometric surface (McGuire and others, 2019) and briefly described below:

- Description of the data preparation and other activities prior to analysis workflow:
  - The sparse groundwater-altitude data for 2016 in Louisiana was assessed separately with groundwater- and surface-water-altitude data for 2018 to determine if surface-water-altitude data for 2016 could be used to estimate groundwater altitude in the 2016 potentiometric surface map. The 2018 groundwater data considered were for USGS station numbers equal to USGS 300619091053701, USGS 300645091085301, USGS 302528091543101, USGS 302827091301201, USGS 302934091571001, and USGS 303310091493401; the 2018 streamgage data considered were for USGS station numbers equal to USGS 07380400, USGS 07380401, USGS 07380500, USGS 07384400, USGS 07386600, USGS 07386850, USGS 301655091440800, USGS 302020091435700, and USGS 302320091465900 (U.S. Geological Survey, 2018). Because of this evaluation, 2016 surface-water-altitude data from these streamgages were used as the estimated groundwater altitude at those locations in the 2016 potentiometric surface map (McGuire and others, 2019).
  - Areas of the aquifer with little groundwater-altitude data were identified using the GIS “`Euclidean Distance`” command. These areas with little groundwater-altitude data for 2016 were defined as cells that were generally about 12.4 mi or more from the center of the cell to the nearest well with a groundwater altitude, which was used in the 2016 potentiometric surface map. The areas with little groundwater-altitude data for 2016 were a total of about 8,500 mi^2, or about 19 percent of the MRVA aquifer area. About 81 percent of the aquifer area were assumed to have sufficient groundwater data for 2016 to create a potentiometric surface map for spring 2016.

- Description of the analysis workflow:
  - The interpolations to create rasters of the potentiometric surface for the two aquifer sections were done using the GIS command "`Topo to Raster`." The input data included the following:
    - Groundwater altitudes from subsets of the two files of groundwater altitude data and surface-water altitude from a subset of the streamgage file, where the "USE_2016" field was greater than zero;
    - The MRVA aquifer boundary in two sections—one on the east side of Crowleys Ridge and the other on the west side of Crowleys Ridge (combined with the remaining aquifer area); and
    - For all interpolations after the initial run, potentiometric surface contours were had been manually modified to guide the interpolation, especially in areas with little data or in areas near streams.
    - The potentiometric surfaces for the two sections were combined using the GIS "`merge`" command, and contours of the merged potentiometric surface were created using the GIS "`contour`" commands.
  - In March 2018, a collaborator with considerable knowledge about the MRVA aquifer in Mississippi manually contoured the potentiometric surface in Mississippi and provided feedback on potential location and land-surface altitude problems associated with the manually measured groundwater-altitude data (James Hoffmann, Mississippi Department of Environmental Quality, written commun., March 2018). If the data problems could not be resolved, the "USE_2016" field was set to a negative value. In addition, the manual contours were georeferenced and digitized, and the manually modified contours generated in the prior process step were updated using the contours drawn by the collaborator (James Hoffmann, Mississippi Department of Environmental Quality, written commun., March 2018) and the updated groundwater-altitude values and locations as guides.
  - The potentiometric surface raster, which was output from the interpolation process, was compared to a raster of the aquifer base (Saucier, 1994; Wilson and Hosman, 1987; Hart and others, 2008; James Hoffmann, Mississippi Department of Environmental Quality, written commun., February 2018; Joseph Richards, U.S. Geological Survey, written commun., March 2018; Wacaster and others, 2018) to identify where the input potentiometric surface raster was below the aquifer-base raster. The input potentiometric surface raster was below the aquifer-base raster in about 1 percent of the aquifer area, all in the northwestern part of the aquifer in southeastern Missouri. No changes were made to the input potentiometric surface raster as a result of this comparison because there were groundwater-altitude data for nine wells screened in the MRVA aquifer in these areas. The well identification (also termed site-badge) codes for these wells are USGS:364529089550501, MO000:517234, MO000:517231, MO000:517233, MO000:304550, MO000:506283, MO000:304521, MO000:517195, and MO000:506299 (McGuire and others, 2019).
  - This workflow was repeated as often as necessary until the potentiometric surface was finalized.
- Description of the map preparation workflow:
  - Lines perpendicular to the potentiometric surface contours were generated at selected locations and added to the potentiometric surface map, with arrow heads indicating flow direction.
  - A total of five potentiometric maps were created—one for the entire MRVA aquifer, and one each for the St. Francis and Cache MAP regions in the north, Boeuf and Grand Prairie MAP regions in the west-central area, Delta MAP region in the east-central area, and Atchafalaya and Deltaic and Chenier Plain MAP regions in the south. The map of the entire MRVA area is presented at a scale of 1:1,325,000 and shows the labeled contours and unlabeled control point values. The four maps of 1 or 2 MAP regions are presented at a reduced, scale of 1:625,000 to allow for the display of control point values.

The interpolation process, which was used to generate the rasters, can result in cell values for cells collocated with a measured well that are generally similar to, but commonly not equal to, the corresponding groundwater- and surface-water-altitude values based on measurements. This difference is partly because the cell values represent the value for the cell area, and the measured values are values at specific locations within the area represented by the cell.

To assess the uncertainty in the final contours, the water-level altitude for all values considered in the potentiometric surface map and for all values used to generate the potentiometric-surface raster were compared to the final potentiometric-surface raster value in the cell where the well or streamgage is located (McGuire and others, 2019). The root mean square error (RMSE) and bias were calculated for the difference between the manually or driller measured water-level altitude and the value extracted from the potentiometric-surface raster generated using the contours (Helsel and Hirsch, 2002).

Potentiometric Surface, Spring 2016

Based on water-level altitude values from 1,108 wells and 48 streamgages, the 2016 potentiometric contours ranged from 10 to 340 ft above NAVD 88, and the regional direction of groundwater flow was to the south-southwest, except in areas of groundwater-altitude depressions (sheet 1), where groundwater flowed into the depression, and near rivers, where flow was generally parallel to the rivers. However, in some areas, flow was from the aquifer into the river or from the river into the aquifer. The lowest measured groundwater altitude was 22.51 ft in Iberville Parish, La., and the highest was 339.87 ft in Bollinger County, Mo.; the lowest measured surface-water altitude was 3.39 ft in Lafayette Parish, La., and the highest was 348.60 ft in Bollinger County, Mo. (McGuire and others, 2019). Based on groundwater- and surface-water-altitude measurements from January to May 2016, the MRVA aquifer is connected to surface-water features in some areas and disconnected in other areas at least during part of the year; however, the extent of these areas degree of connectivity cannot be derived from these data.

The RMSE for the difference between the measured water-level altitude for the 16 manually measured and 44 driller measured wells that were not used in the potentiometric surface map was 40 ft and 24 ft, respectively. The RMSE for the difference between the measured water-level altitude for the 1,108 manually and driller measured wells that were used in the potentiometric surface map, was 2 ft with a bias of −0.34 ft.

The 2016 potentiometric contours in the Cache region-ranged from 120 to 340 ft and show a large depression in the lower half of the Cache region (sheet 2). The lowest measured groundwater altitude was 116.21 ft in a depression in Poinsett County, Ark., and the highest measured groundwater altitude was 339.87 ft in Bollinger County, Mo.; the lowest measured surface-water altitude was 174.56 ft in Prairie County, Ark., and the highest was 348.60 ft in Bollinger County, Mo. (McGuire and others, 2019). Flow in the Cache region generally is to the south-southwest or into the depression in the southern part of the region.

The 2016 potentiometric contours in the St Francis region ranged from 170 to 310 ft (sheet 2). The lowest measured groundwater altitude was 160.61 ft in Saint Francis County, Ark., and the highest measured groundwater altitude was 313.98 ft in Mississippi County, Mo.; the lowest measured surface-water altitude was 273.43 ft in New Madrid County, Mo., and the highest was 298.07 ft in Alexander County, Ill. (McGuire and others, 2019). Flow in the St. Francis region generally is to the south-southwest.

The 2016 potentiometric contours in the Boeuf region ranged from 30 to greater than 220 ft (sheet 3). The lowest measured groundwater altitude was 35.25 ft in Concordia Parish, La., and the highest measured groundwater altitude was 181.95 ft in Jefferson County, Ark.; the lowest measured surface-water altitude was 31.51 ft in Concordia Parish, La., and the highest was 231.09 ft in Pulaski County, Ark. (McGuire and others, 2019). Flow in the Boeuf region generally is to the southeast and southwest.

The 2016 potentiometric contours in the Grand Prairie region range from 80 to 220 ft; there is a large depression in the potentiometric surface within the region (sheet 3). The lowest measured groundwater altitude was 72.08 ft in Arkansas County, Ark., and the highest measured groundwater altitude was 228.33 ft in Lonoke County, Ark. (McGuire and others, 2019). Flow in the Grand Prairie region generally is into the depression that encompasses most of the region.

The 2016 potentiometric contours in the Delta region range from 60 to 200 ft; there is a large depression in the potentiometric surface within central part of the region (sheet 4). The lowest measured groundwater altitude was 57.96 ft in Sunflower County, Miss., and the highest measured groundwater altitude was 199.39 ft in DeSoto County, Miss.; the lowest measured surface-water altitude was 84.40 ft in Warren County, Miss., and the highest was 200.02 ft in Shelby County, Tenn., (McGuire and others, 2019). Flow in the Delta region generally is into the large depression and toward the south.

For most of the Atchafalaya region and all of the Deltaic and Chenier Plain region, potentiometric contours for spring 2016 could not be created because there were no groundwater-altitude data (sheet 5). In the part of the Atchafalaya region included in the 2016 potentiometric surface map, potentiometric contours ranged from 10 to 30 ft (sheet 5). The lowest measured groundwater altitude was 22.51 ft in Iberville Parish, La., and the highest measured groundwater altitude was 24.48 ft in Pointe Coupee Parish, La.; the lowest measured surface-water altitude was 3.39 ft in Lafayette Parish, La., and the highest was 28.57 ft in Avoyelles Parish, La. (McGuire and others, 2019). Groundwater flow in the mapped area is generally toward the south and southwest.

Summary

A potentiometric surface map for spring 2016 was created for the Mississippi River Valley alluvial (MRVA) aquifer using available groundwater-altitude data from 1,108 wells completed in the MRVA aquifer and from the altitude of the top of the water surface in area rivers from 48 streamgages. Personnel from the Arkansas Natural Resources Commission, Arkansas Department of Health, Arkansas Geological Survey, Illinois Department of Agriculture, Illinois State Water Survey, Louisiana Department of Natural Resources, Louisiana Department of Transportation and Development, Mississippi Department of Environmental Quality, Missouri Department of Natural Resources, Yazoo Mississippi Delta Joint Water Management District, U.S. Department of Agriculture Natural Resources Conservation Service, U.S. Geological Survey (USGS), and drillers in Missouri routinely collect groundwater-level data from wells screened in the MRVA aquifer. The USGS and the U.S. Army Corps of Engineers routinely collect data on river stage and discharge for the rivers overlying the MRVA aquifer area. The potentiometric surface map for 2016 was created utilizing existing groundwater and surface-water altitudes to support investigations to characterize the MRVA aquifer as part of the USGS Water Availability and Use Science Program.

Sufficient data exist to map the potentiometric surface of the MRVA aquifer for spring 2016 for about 81 percent of the aquifer area. The lowest measured groundwater altitude was 22.51 feet (ft) in Iberville Parish, La., and the highest was 339.87 ft in Bollinger County, Mo.; the lowest measured surface-water altitude was 3.39 ft in Lafayette Parish, La., and the highest was 348.60 ft in Bollinger County, Mo. The potentiometric contours ranged from 10 to 340 ft above North American Vertical Datum of 1988. The regional direction of groundwater flow was generally to the south-southwest, except in areas of groundwater-altitude depressions, where groundwater flowed into the depression, and near rivers, where flow can be from aquifer to the river or from the river into the aquifer. There are large depressions in the potentiometric surface in the lower half of the Cache region and in most of the Grand Prairie and Delta regions.

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