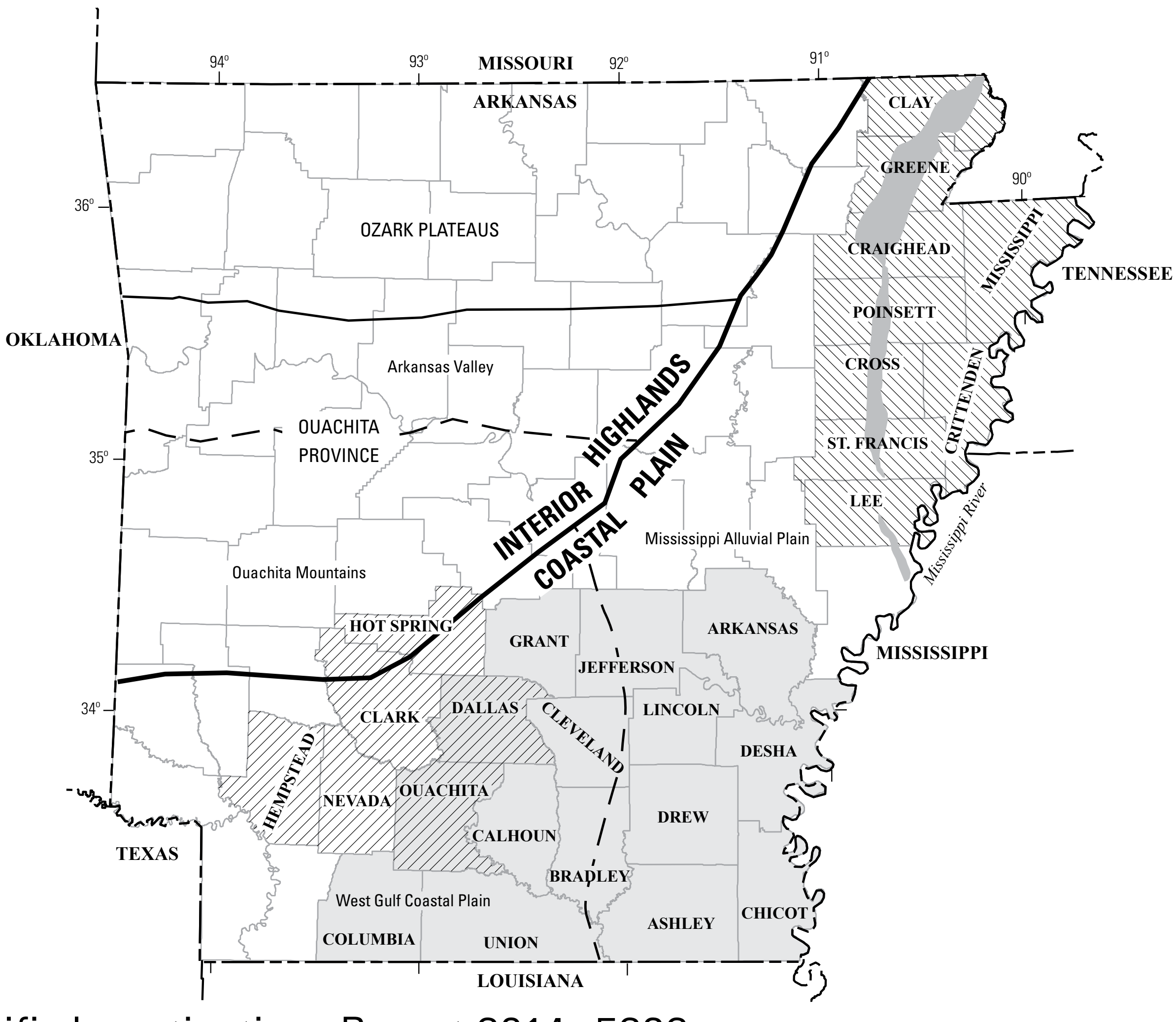
Prepared in cooperation with the Arkansas Natural Resources Commission and the Arkansas Geological Survey

Potentiometric Surfaces and Water-Level Trends in the Cockfield (Upper Claiborne) Aquifer in Southern Arkansas and the Wilcox (Lower Wilcox) Aquifer of Northeastern and Southern Arkansas, 2012



Scientific Investigations Report 2014–5232

U.S. Department of the Interior
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By Kirk D. Rodgers

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U.S. Geological Survey

U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2015

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Contents

Figures

Tables

Conversion Factors

Inch/Pound to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Flow rate	
foot per year (ft/yr)	0.3048	meter per year (m/yr)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
	Specific capacity	
gallon per minute per foot [(gal/min)/ft)]	0.2070	liter per second per meter [(L/s)/m]
	Transmissivity*	
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)

Datum

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)

Horizontal coordinate information is referenced to North American Datum of 1983 (NAD 83).

Supplemental Information

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

*Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [($ft^3/d)/ft^2$]ft. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

Potentiometric Surfaces and Water-Level Trends in the Cockfield (Upper Claiborne) Aquifer in Southern Arkansas and the Wilcox (Lower Wilcox) Aquifer of Northeastern and Southern Arkansas, 2012

By Kirk D. Rodgers

Abstract

The Cockfield aquifer, located in southern Arkansas, is composed of Eocene-age sand beds found near the base of the Cockfield Formation of Claiborne Group. The Wilcox aquifer, located in northeastern and southern Arkansas, is composed of Paleocene-age sand beds found in the middle to lower part of the Wilcox Group. The Cockfield and Wilcox aquifers are primary sources of groundwater. In 2010, withdrawals from the Cockfield aquifer in Arkansas totaled 19.2 million gallons per day (Mgal/d), and withdrawals from the Wilcox aquifer totaled 36.5 Mgal/d.

A study was conducted by the U.S. Geological Survey in cooperation with the Arkansas Natural Resources Commission and the Arkansas Geological Survey to measure water levels associated with the Cockfield aquifer and the Wilcox aquifer in northeastern and southern Arkansas. Water levels were measured at 43 wells completed in the Cockfield aquifer and 47 wells completed in the Wilcox aquifer in February and March 2012. Measurements from 2012 are presented as potentiometric-surface maps and in combination with measurements from 2006 as water-level difference maps. Trends in water-level change over time within the Cockfield and Wilcox aquifers were determined using the water-level difference maps and selected well hydrographs.

The Cockfield aquifer study area in southern Arkansas is bounded on the east by the Mississippi River and on the west by the area that contains outcrops and subcrops of the Cockfield Formation. The northern boundary of the Cockfield aquifer study area is defined by the area that contains observation wells completed in the Cockfield aquifer and the southern boundary is the Louisiana State line.

The Wilcox aquifer study area in northeastern Arkansas is bounded on the east by the Mississippi River and on the north by the Missouri State line. The southern and western boundaries are defined by areas containing observation wells completed in the Wilcox aquifer or by outcrop areas on or near Crowleys Ridge. The Wilcox aquifer study area in southern Arkansas is defined by observation wells completed in the Wilcox aquifer or by areas that contain outcrops of the Wilcox Group, or both.

The potentiometric-surface map of the Cockfield aquifer shows the regional direction of groundwater flow was generally toward the east-southeast, except in areas of intense groundwater withdrawals such as southwestern Ashley County, where groundwater flows toward the town of Crossett. The highest water-level altitude measured was 350 feet (ft) above National Geodetic Vertical Datum of 1929 (NGVD 29) in central Columbia County. The lowest water-level altitude measured was 40 ft above NGVD 29 in southeastern Lincoln County.

The water-level difference map for the Cockfield aquifer in Arkansas was constructed using 42 water-level measurements made during 2006 and 2012. The difference in water levels for the Cockfield aquifer ranged from 27.4 ft to -10.4 ft. The largest water-level rise was in Calhoun County, and the largest water-level decline was 10.4 ft in Union County. Of the 42 wells, 13 wells had a rise in water level, and the remaining 29 wells had a decline in water level.

Hydrographs for 32 wells in the Cockfield aquifer with historical water-level data were evaluated using linear regression to calculate the annual rise or decline for each well. These data were aggregated by county and statistically evaluated for the range, mean, and median of water-level change in each county. Hydrographs for Bradley, Calhoun, Chicot, Columbia, and Union Counties indicated both rising and declining water levels. The mean annual water-level rise or decline for Calhoun County was 0.00 foot per year (ft/yr) or unchanged. The mean annual water-level for Ashley, Bradley, Chicot, Cleveland, Columbia, Lincoln, and Union Counties show declines ranging from -0.02 to -1.10 ft/yr.

Two potentiometric-surface maps, one for the southern area and one for the northeastern area, were constructed to show the altitude of the water surface in the Wilcox aquifer. The direction of groundwater flow in the northeastern area was generally towards the south-southwest except for some areas

immediately adjacent to the Mississippi River where the flow was more eastward towards the river. The highest water-level altitude was 219 ft in northern Mississippi County, and the lowest water-level altitude was 123 ft near West Memphis in Crittenden County. The direction of groundwater flow in the northern part of the southern area was generally towards the southwest. The direction of groundwater flow in the southern part was in all directions because of two cones of depression and two water-level mounds. The highest water-level altitude measured was 394 ft at the center of a water-level mound in eastern Hot Spring County and a water-level mound in southwestern Hempstead County. The lowest water-level altitude measured was 145 ft at the center of the cone of depression in Clark County.

Water-level difference maps for the Wilcox aquifer in Arkansas were constructed using 47 water-level measurements made during 2006 and 2012. The difference in water levels for the Wilcox aquifer in the northeastern area ranged from 22.0 ft to -17.9 ft. The largest rise in water level occurred in Crittenden County, and the largest decline occurred in Lee County. Twenty-one wells had rising water levels, and 10 wells had declining water levels. The difference in water levels for the Wilcox aquifer in the southern area ranged from 18.1 ft to -4.2 ft. The largest rise and the largest decline in water level occurred in Nevada County. Twelve wells had rising water levels, and 4 wells had declining water levels.

Linear regression analysis of long-term hydrographs was used to determine the mean annual water-level rise and decline in the Wilcox aquifer in the northeastern and southern areas of Arkansas. In the northeastern area, the mean annual water level declined in all seven counties. The mean annual declines ranged from -0.55 ft/yr in Craighead County to -1.46 ft/yr in St. Francis County. In the southern area, the annual rise and decline calculations for wells with over 20 years of records indicate rising and declining water levels in Clark, Hot Spring, and Nevada Counties. The mean annual water level declined in all counties except Hot Spring County.

Introduction

The Cockfield aquifer (recognized nationally as the Upper Claiborne aquifer), located in southern Arkansas, is composed of Eocene-age sand beds found near the base of the Cockfield Formation of Claiborne Group. The Middle and Lower Wilcox aquifer (recognized nationally as the lower Wilcox aquifer), located in northeastern and southern Arkansas, is composed of Paleocene-age sand beds found in the lower part of the Wilcox Group. The Cockfield and Wilcox aquifers are sources of groundwater for local use. In 2010, withdrawals from the Cockfield aquifer in Arkansas totaled 19.2 million gallons per day (Mgal/d), and withdrawals from the Wilcox aquifer totaled 36.5 Mgal/d. In 2010, the Cockfield aquifer in Arkansas ranked fifth in combined usage for the State, and the Wilcox aquifer ranked third.

A study was conducted by the U.S. Geological Survey (USGS) in cooperation with the Arkansas Natural Resources Commission and the Arkansas Geological Survey to determine water levels associated with the Cockfield aquifer in southern Arkansas and the Wilcox aquifer in northeastern and southern Arkansas. In February and March 2012, water levels were measured at 43 wells completed in Cockfield aquifer and 47 wells completed in the Wilcox aquifer. These water-level measurements are presented as potentiometric-surface maps, in combination with measurements from 2006 as water-level difference maps, and in long-term hydrographs.

The study areas of the Cockfield and Wilcox aquifers are part of the Mississippi Embayment that includes much of the West Gulf Coastal Plain and the Mississippi Alluvial Plain in Arkansas (fig. 1). The Mississippi Embayment is a north-northeast trending syncline, plunging south-southwest, and is filled with Cretaceous and younger-age sediments. The study area of the Cockfield aquifer in southern Arkansas is bounded on the east by the Mississippi River and on the west by the area that contains outcrops and subcrops of the Cockfield Formation (Hosman, 1982). The northern boundary of the Cockfield aquifer study area is defined by the locations of observation wells completed in the Cockfield aquifer, and the southern boundary is the Louisiana State line (fig. 1). The Wilcox aquifer study area in northeastern Arkansas is bounded on the east by the Mississippi River and on the north by the Missouri State line. The southern and western boundaries are defined by areas containing observation wells completed in the Wilcox aquifer or by outcrop areas in or near Crowleys Ridge. Crowleys Ridge is an erosional remnant of Cretaceous- and Tertiary-age rocks that ranges from 0.5 to 12 miles (mi) wide, rises 250 to 550 feet (ft) above the surrounding Mississippi Alluvial Plain, and extends about 150 mi from southeastern Missouri to east-central Arkansas. The Wilcox aquifer study area in southern Arkansas is defined by observation wells completed in the Wilcox aquifer or by areas that contain outcrops of the Wilcox Group, or both.

This is the sixth in a series of triennial reports discussing the potentiometric surfaces of the Cockfield and Wilcox aquifers in Arkansas. Earlier reports, with water-level measurements made in 1991, 1996–97, 2000, 2003, 2006, and 2009 are reported in Westerfield (1994), Joseph (1998), Schrader and Joseph (2000), Yeatts (2004), Schrader (2007), and Pugh (2010).

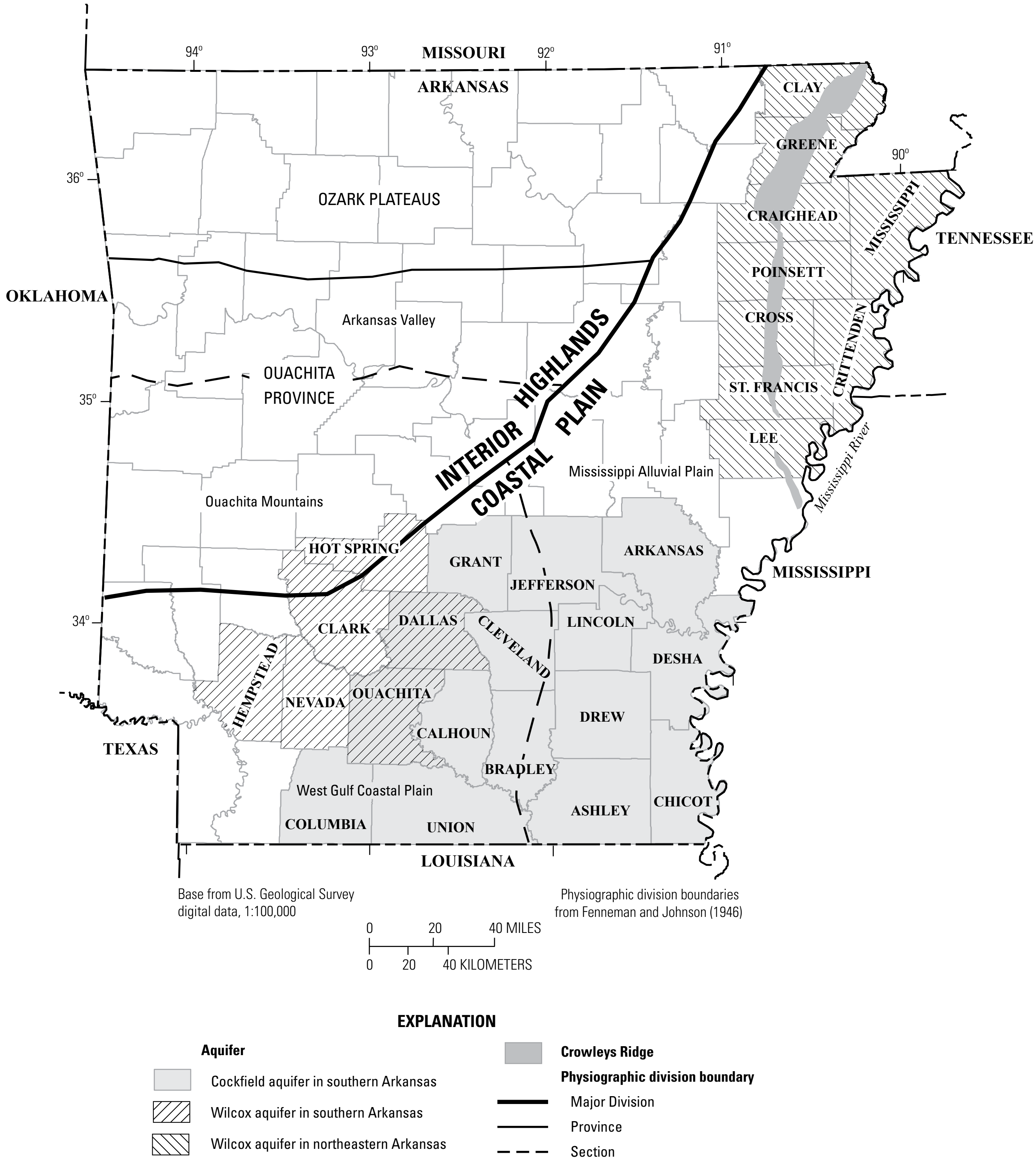


Figure 1. Location of study area of Cockfield aquifer in southern Arkansas and Wilcox aquifer in northeastern and southern Arkansas.

Methods

The well-numbering system used in this report is based on location of wells according to the Public Land Survey System used in Arkansas (U.S. Geological Survey, 2014). The component parts of a well number are the township number, the range number, the section number, three letters which indicate, respectively, the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section in which the well is located, and a sequence number. The letters are assigned counterclockwise, beginning with "A" in the northeast quarter, quarter-quarter, or quarter-quarter-quarter section in which the well is located. For example, well 01S03W04BBD16 (fig. 2) is located in Township 1 South, Range 3 West, and in the southeast quarter of the northwest quarter of the northwest quarter of section 4. This well is the 16th well in this quarter-quarter-quarter section of section 4 from which data were collected (Pugh, 2010).

The horizontal coordinate information (latitude and longitude) of a well was determined using a global positioning system, and land-surface altitude information was determined using a USGS 7.5-minute, 1:24,000 quadrangle topographic map. The horizontal coordinate information is based on the North American Datum of 1983 and is accurate to about one-tenth of a second (approximately 10–20 ft). The location of the well was then plotted on the corresponding topographic map and the land-surface altitude at that point was determined by interpolation of the topographic contours. This altitude is accurate to about one-half the contour interval of the topographic map, which is based on the National Geodetic Vertical Datum of 1929 (NGVD 29).

Water-Level Measurements

Water levels were measured by USGS personnel at public water-supply, industrial, commercial, domestic, and observation wells completed in the Cockfield or Wilcox aquifers. Measurements were made using steel or electric field tapes graduated to hundredths of a foot. The steel and electric tapes used by USGS personnel were calibrated during January 2010, prior to collecting water-level measurements. Calibration of steel and electric tapes was performed by comparing the field steel or electric tape to a standardized steel tape used only for calibration of field tapes. The water-level data are stored in the USGS National Water Information System (NWIS) (U.S. Geological Survey, 2002).

Potentiometric-surface maps for the Cockfield and Wilcox aquifers in Arkansas were constructed by plotting well positions with their respective water-level altitude using ArcGIS (Esri, 2011). The altitude of the water level in each well was determined by subtracting the measured depth to water from the land-surface altitude. The direction of groundwater flow is perpendicular to the contours in the direction of decreasing water level.

Water-level difference maps for the Cockfield and Wilcox aquifers in Arkansas were constructed using the differences between depth-to-water measurements made during 2006 and 2012. The difference in water level was calculated by subtracting the 2012 depth-to-water value from the 2006 depth-to-water value for each individual well. Positive difference values indicate a rise in water level, and negative difference values indicate a decline in water level.

Linear Regression

A linear regression analysis was used to determine the annual rise or decline of water level in selected wells using the well hydrograph. Water-level measurements made yearly during March, April, and May of the minimum 20-year period of record were used in the linear regression analysis. The equation of the regression line or line of best fit is $Y = MX + B$. The slope, M from the equation, represents the daily rise or decline in water level, B is the water level measured in feet at the y-intercept and X is the year in which the measurement was made. Five assumptions are associated with linear regression: (1) Y is linearly related to X, (2) data used to fit the linear regression are representative of data of interest, (3) variance of the residuals is constant and does not depend on X or on anything else, (4) the residuals are independent, and (5) the residuals are normally distributed. The assumption of a normal distribution is involved only when testing hypotheses, requiring the residuals from the regression equation to be normally distributed (Helsel and Hirsch, 1992). Water-level measurements collected during February and March of 2006 and 2012 were used for linear regression analysis.

Geographic Information Systems

Longitudes, latitudes, and measured water-level altitudes of the Cockfield and Wilcox aquifer wells were obtained from NWIS and geocoded using ArcGIS (Esri, 2011), which is a computer-based application used to visually represent spatially based data using geographic coordinates. These data points were then interpolated using the kriging method of interpolation to construct potentiometric-surface maps of the Cockfield and Wilcox aquifers. This process produces a raster image in which each color represents a range of water-level values. The raster images were then converted to contour lines using the ArcGIS Contour tool. Upon conversion, the contour polylines were corrected and refined using the Polynomial Approximation with Exponential Kernel (PAEK) method of smoothing (Bodansky and others, 2002). The PAEK method uses a maximum allowable offset to smooth lines. PAEK is a smoothing algorithm that sets a tolerance by which lines are smoothed. A higher tolerance preserves less detail from the original interpolated contour line, and a lower tolerance preserves more detail. This method allows for the preservation of end points.

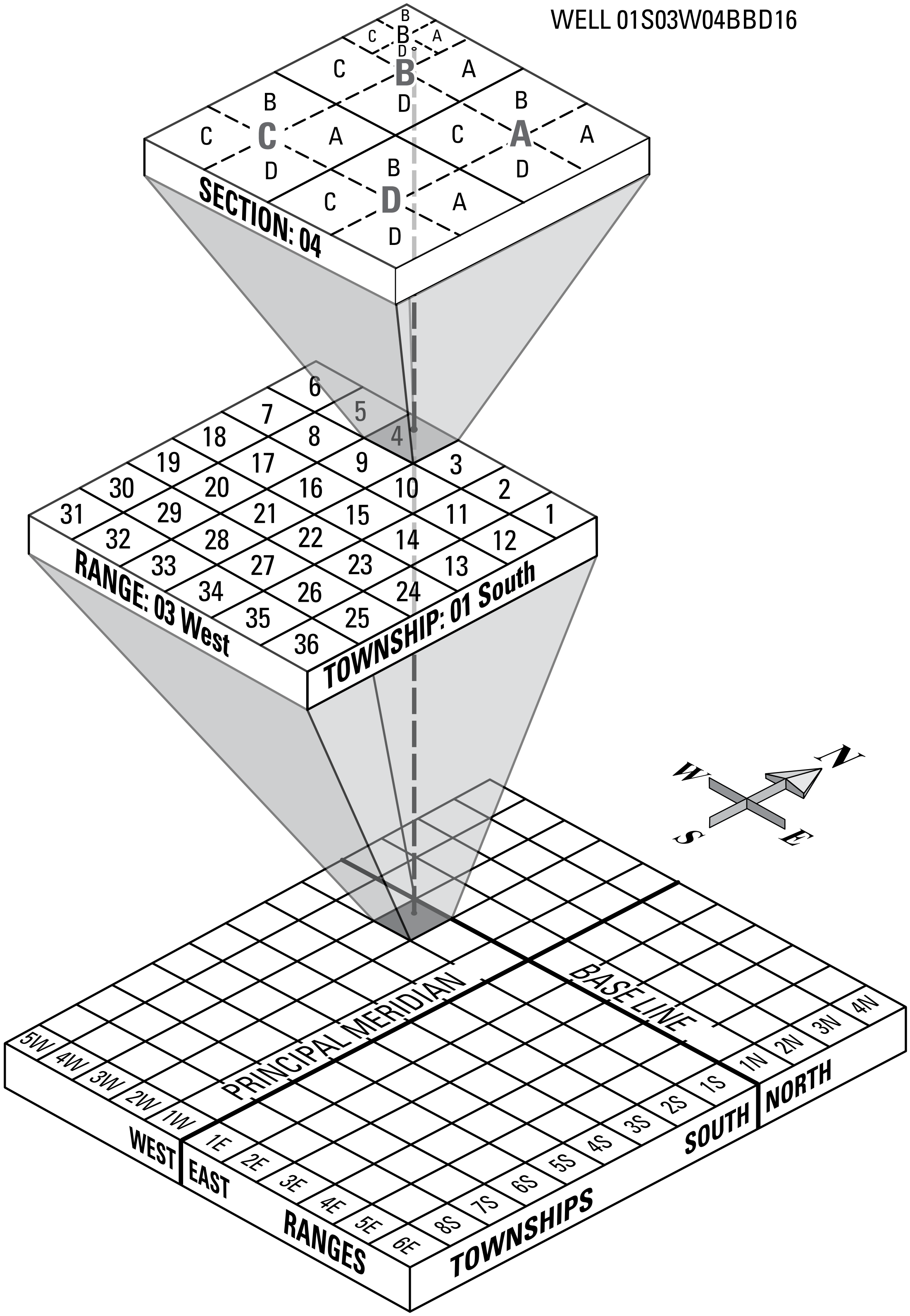


Figure 2. Well-numbering system.

Cockfield (Upper Claiborne) Aquifer

Hydrogeologic Setting

The Cockfield aquifer generally consists of discontinuous fine- to medium-grained sand units interbedded with silt, clay, and lignite of nonmarine origin. Most of the sand beds of the Cockfield aquifer are located near the base of the Cockfield Formation of Claiborne Group (hereafter referred to as Cockfield Formation) (table 1). The Cockfield Formation ranges from 100 to 400 ft thick in the outcrop areas and thickens downdip to about 625 ft in northeastern Chicot County (Onellion and Criner, 1955). The Cockfield Formation dips to the south and east towards the synclinal axis of the Mississippi Embayment (fig. 3). Thicknesses of the sand beds of the Cockfield aquifer generally range from 20 to 150 ft. Throughout the study area, the Cockfield Formation is underlain by calcareous and sandy marl, carbonaceous clay, and limestone of the Cook Mountain Formation of Claiborne Group (table 1). In much of the study area, the Cockfield Formation is overlain by silty clays of the Jackson Group.

The potentiometric surface can be near or above land surface in the confined part of the Cockfield aquifer. Sand beds at the base of the overlying Jackson Group in parts of southern Arkansas may be in hydraulic connection with the Cockfield aquifer (Ackerman, 1987). The Cockfield Formation and aquifer outcrop in Bradley, Calhoun, Cleveland, Columbia, Dallas, Grant, and Union Counties and dips to the southeast. In the subcrop area, Quaternary-age terrace deposits and alluvium overlie the Cockfield Formation. The thickness of terrace deposits may reach 40 ft, and as much as 60 ft of alluvium overlies the formation in some of the larger river valleys A generalized section of the hydrogeologic and geologic units within the Mississippi Embayment are shown in figure 3.

Most of the Cockfield aquifer recharge occurs by infiltration of rainfall on the upland outcrop areas and by inflow from the overlying alluvium or rivers that have eroded through the overburden connecting them hydrologically with the aquifer. Discharge from the aquifer is to hydrologically connected rivers in the outcrop areas, vertically to adjacent hydrogeologic units where the aquifer is confined, and to wells completed in the aquifer (Ackerman, 1987). In the outcrop areas, well depths in the aquifer are less than 200 ft and well yields are small, usually less than 30 gallons per minute (gal/min), but in areas downdip from the outcrop areas, wells screening the full thickness of the aquifer may yield from 100 to 500 gal/min (Westerfield, 1994).

Hydraulic Properties

Values for specific capacity and transmissivity vary within the Cockfield aquifer. Specific capacity values range from 0.15 gallon per minute per foot [(gal/min)ft)] to 23.7 (gal/min)/ft with a median of 0.76 (gal/min)/ft. Transmissivity values range from 325 feet squared per day (ft^2/d) to 6,280 ft^2/d with a median of 3,350 ft^2/d and a mean of 3,300 ft^2/d. Hydraulic conductivity values were not provided for any of the well tests completed in the Cockfield aquifer. An estimated hydraulic conductivity value for the Cockfield aquifer was determined by dividing the mean transmissivity value (3,300 ft^2/d) by the maximum aquifer thickness (400 ft), resulting in a value of 8.33 ft/d (Pugh, 2008).

Table 1. Hydrogeologic and geologic units within the Mississippi Embayment of Arkansas (modified from Hosman and Weiss, 1991; Hart and others, 2008).

[Dashed lines indicate the approximate location where hydrogeologic units begin and end]

<table>
<tr><th rowspan="2">Erathem</th><th rowspan="2">System</th><th rowspan="2">Series</th><th rowspan="2">Group</th><th colspan="2">Geologic unit</th><th rowspan="2" colspan="2">Hydrogeologic unit</th></tr>
<tr><th>Southern Arkansas</th><th>Northeastern Arkansas</th></tr>
<tr><td rowspan="13">Cenozoic</td><td rowspan="2">Quaternary</td><td>Holocene</td><td rowspan="2"></td><td rowspan="2" colspan="2">Alluvium and terrace deposits</td><td rowspan="2" colspan="2">Mississippi River Valley alluvial aquifer</td></tr>
<tr><td>Pleistocene</td></tr>
<tr><td rowspan="11">Tertiary</td><td>Oligocene</td><td>Vicksburg</td><td colspan="2">Not present in study areas</td><td rowspan="2" colspan="2">Vicksburg-Jackson confining unit</td></tr>
<tr><td rowspan="6">Eocene</td><td>Jackson</td><td colspan="2">Jackson Formation</td></tr>
<tr><td rowspan="5">Claiborne</td><td colspan="2">Cockfield Formation</td><td colspan="2">Upper Claiborne aquifer (Cockfield aquifer)</td></tr>
<tr><td colspan="2">Cook Mountain Formation</td><td colspan="2">Middle Claiborne confining unit</td></tr>
<tr><td>Sparta Sand</td><td rowspan="3">Memphis Sand</td><td></td><td rowspan="3">Middle Claiborne aquifer</td></tr>
<tr><td>Cane River Formation</td><td>Lower Claiborne confining unit</td></tr>
<tr><td>Carrizo Sand</td><td>Lower Claiborne aquifer</td></tr>
<tr><td rowspan="4">Upper Paleocene</td><td rowspan="3">Wilcox</td><td rowspan="3">Undifferentiated</td><td>Flour Island Formation</td><td colspan="2">Middle Wilcox aquifer</td></tr>
<tr><td>Fort Pillow Sand</td><td rowspan="2" colspan="2">Lower Wilcox aquifer</td></tr>
<tr><td>Old Breastworks Formation</td></tr>
<tr><td></td><td colspan="2">Midway Group</td><td colspan="2">Midway confining unit</td></tr>
</table>

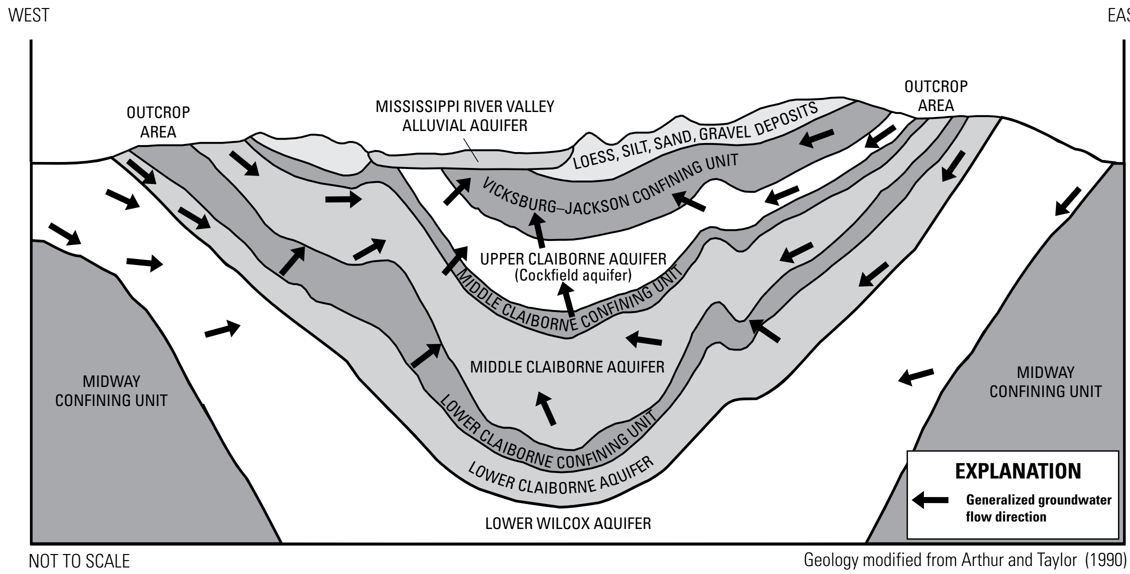


Figure 3. Generalized section of the hydrogeologic and geologic units within the Mississippi Embayment.

Water Use

Withdrawals from the Cockfield aquifer during 2010 totaled about 19.2 Mgal/d (Terrance W. Holland, U.S. Geological Survey written commun., 2013) (fig. 4). These withdrawals were primarily for industrial and public supply use, but withdrawals for agricultural, commercial, and domestic use are important locally. Withdrawals from the Cockfield aquifer rose from 1975 to 2010, with the exception of 1985. Withdrawals were 5.2 Mgal/d in 1975, 7.2 Mgal/d in 1980, 5.0 Mgal/d in 1985, 8.1 Mgal/d in 1990, 9.8 Mgal/d in 1995, 9.9 Mgal/d in 2000, and 16.1 Mgal/d in 2005 (Halberg and Johnson, 1977; Holland and Ludwig, 1981; Holland, 1987, 1993, 1999, 2004, 2007). The increase in withdrawals from the Cockfield aquifer between 2000 (9.9 Mgal/d) and 2005 (16.1 Mgal/d) are associated with increased use of water by public water-supply systems in eastern Arkansas (Holland, 2004, 2007; Pugh, 2010), and the increase in withdrawals from the aquifer between 2005 (16.1 Mgal/d) and 2010 (19.2 Mgal/d) are associated with increased industrial use of water in eastern Arkansas (Terrance W. Holland, U.S. Geological Survey written commun., 2013). Most wells completed in the study area provide small volumes of water for domestic and livestock use, but in some locations, the aquifer yields volumes large enough to supply industrial and public-supply systems.

In 2010, the State of Mississippi withdrew 22.8 Mgal/d of water from the Cockfield aquifer. Across the State line from Chicot County, Ark., the city of Greenville, Miss., withdrew 10.4 Mgal/d of water for public supply from the Cockfield aquifer in 2010 (D.E. Burt, U.S. Geological Survey, written commun., 2013). Withdrawals from the aquifer in Mississippi rose 170 percent between 1999 and 2005 (D.E. Burt, U.S. Geological Survey, written commun., 2009) and decreased by 50 percent between 2005 and 2010 (D.E. Burt, U.S.Geological Survey, written commun., 2013). The large amount of water withdrawn in Mississippi from the aquifer probably contributed to lower water levels in southeastern Arkansas (Ackerman, 1987; Joseph, 1998; Schrader and Joseph, 2000; Yeatts, 2004; Pugh, 2010).

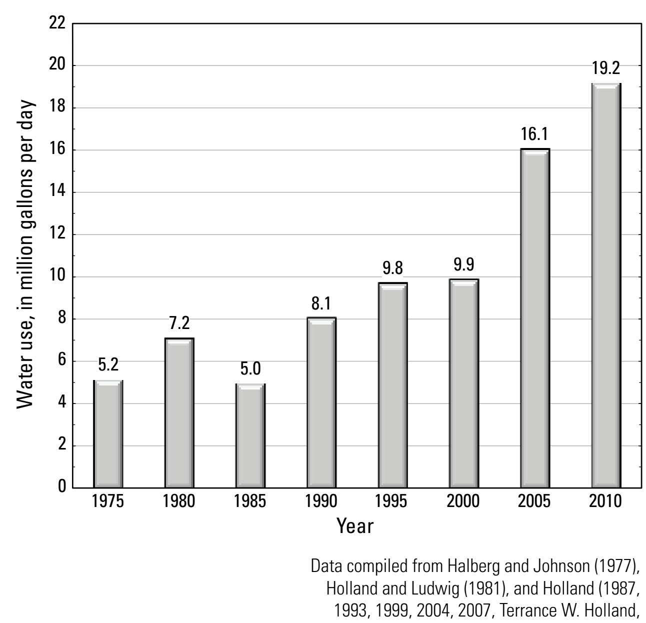


Figure 4. Water use from the Cockfield aquifer in southern Arkansas, 1975–2010.

Potentiometric Surface

The potentiometric-surface map shows the altitude of the water surface in tightly cased wells screened in the Cockfield aquifer in the study area (fig. 5). Water-level data used to construct the map are shown in appendix 1.

The potentiometric surface of the Cockfield aquifer in 2012 shows the regional direction of groundwater flow generally is towards the east-southeast, except in areas of intense groundwater withdrawals, such as southwestern Ashley County where groundwater flows toward the town of Crossett. In southern Columbia County, a trough in the potentiometic surface exists, which locally alters the flow of groundwater. This trough may indicate the formation of a cone of depression. In northeastern Drew County and northern Chicot County, groundwater flow is towards the northeast, and in southeastern Lincoln County, groundwater flow is towards the east. The highest water-level altitude measured was 350 ft above NGVD 29 in central Columbia County. This elevated water-level altitude is the result of the well being located on a higher land-surface altitude in the outcrop area. The lowest water-level altitude measured was 40 ft above NGVD 29 in southeastern Lincoln County.

Water-Level Trends

Water-Level Difference from 2006 to 2012

A water-level difference map for the Cockfield aquifer in the study area was constructed to spatially evaluate short-term (6 years) changes in water levels (fig. 6). The map was constructed using the difference between water-level measurements made in 2006 and 2012 in 42 wells (app. 2). Positive values, represented with blue, upward pointing triangles, indicate a rise in water levels between 2006 and 2012; negative values, represented with red, downward pointing triangles, indicate a decline in water levels between 2006 and 2012. The triangles are scaled in size to the relative value of rise or decline. The 2006 to 2012 water-level difference map indicates short-term changes and may not represent long-term trends.

The 2006 to 2012 difference in water levels for the Cockfield aquifer ranged from 27.4 to -10.4 ft (fig. 6). The largest water-level rise was in Calhoun County, and the largest water-level decline was in Union County (app. 2). Of the 42 wells, 13 wells had a rise in water levels, and the remaining 29 wells had a decline in water levels from 2006 to 2012. Rises in water levels occurred in Ashley, Bradley, Calhoun, Chicot, Cleveland, Columbia, Drew, and Union Counties and ranged from 27.4 ft in Calhoun County to 0.2 ft in Bradley County. Declines in water levels ranged from -0.3 ft in Calhoun and Columbia Counties to -10.4 ft in Union County, and most were less than -5.0 ft.

East of the Saline River, water levels declined in 12 of the 16 wells between 2006 and 2012. In Ashley County, 6 of the 7 wells had declines in water levels. Eleven of the 15 wells located between the Saline and Ouachita Rivers had declines in water levels, and 6 of the 11 wells west of the Ouachita River had declines in water levels for the period between 2006 and 2012.

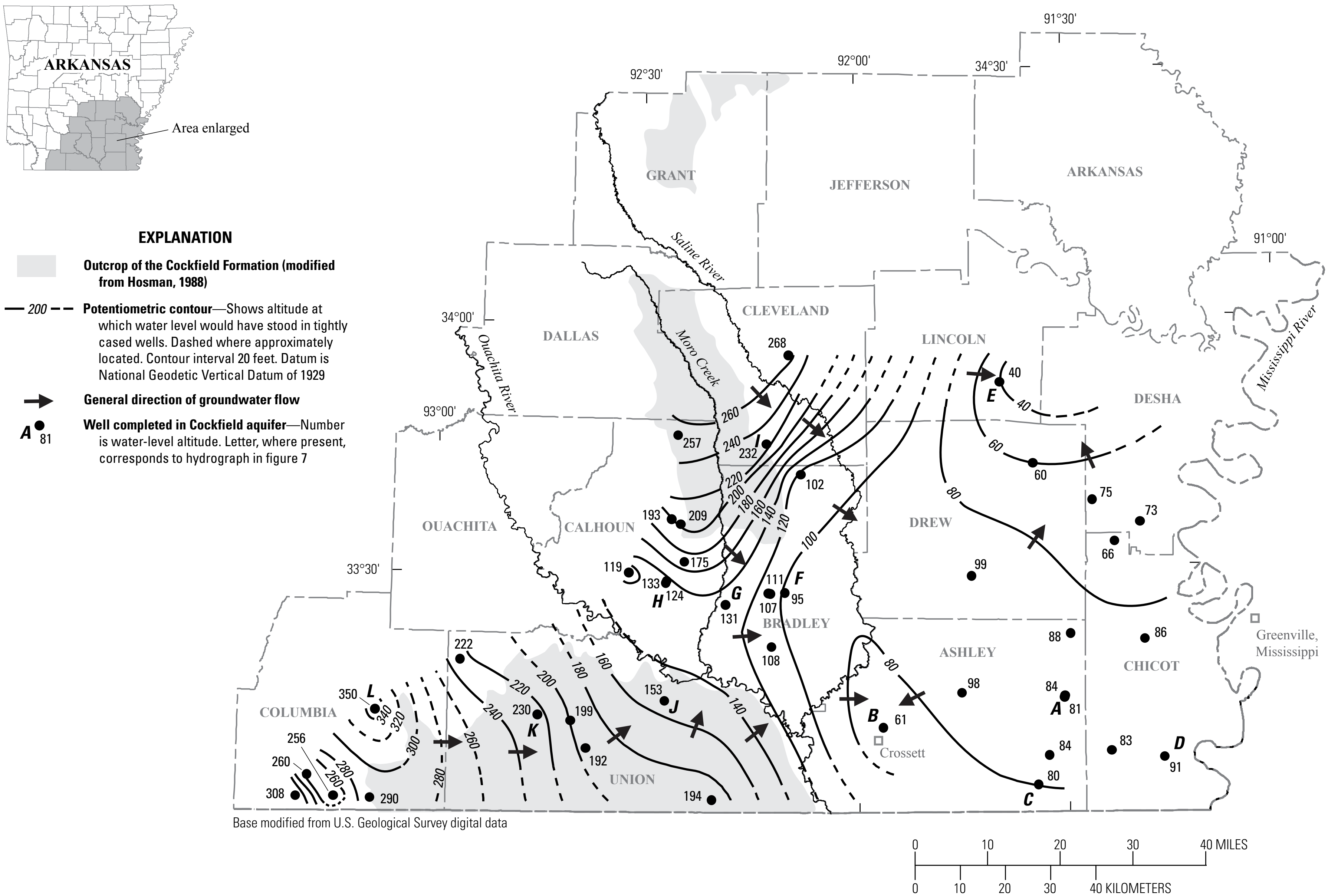


Figure 5. Potentiometric surface of the Cockfield aquifer in southern Arkansas, 2012.

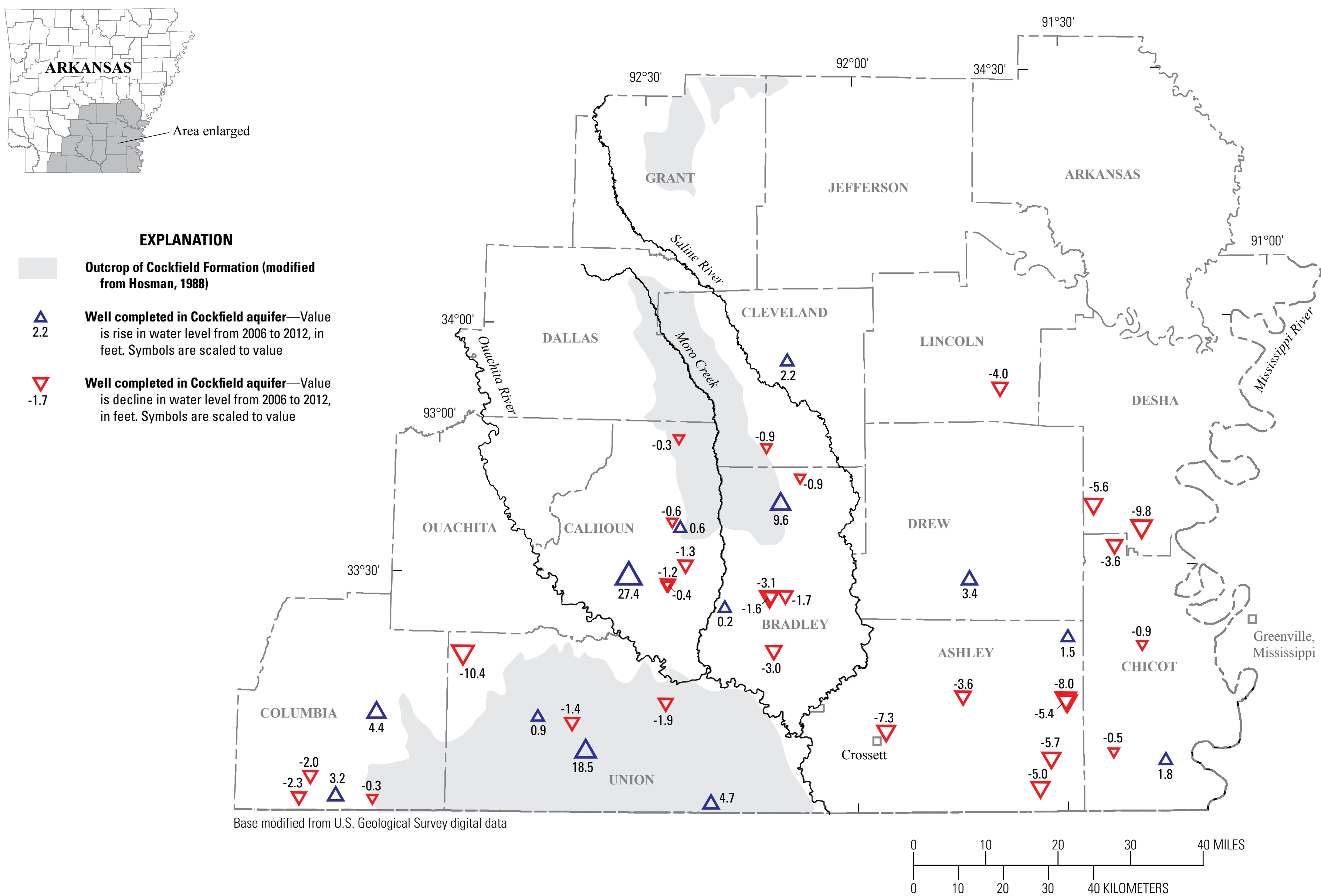


Figure 6. Water-level difference for the Cockfield aquifer in southern Arkansas, 2006–12.

Long-Term Hydrographs

Two methods were used to evaluate long-term water-level trends for the Cockfield aquifer in Arkansas. The first method was to use the hydrograph for a well with a minimum of 20 years of record and plot the water levels in relation to time. Hydrographs of selected wells are shown in figure 7*A*–*L*. The selected well locations are plotted on figure 5. The second method evaluated the annual rise or decline in water levels over a 20-year or more period through 2012, using the line of best fit (Y = MX + B) and residual (R^2). The coefficient of determination (R^2) is a measure of how close the data are to the line of best fit.

Hydrographs for 32 wells with historical water-level data in the Cockfield aquifer with a minimum of 20 years of water-level data were constructed and evaluated. The annual rise or decline in water levels was aggregated by county. The values for the range, mean, and median of water-level change were computed for each county (table 2).

Analysis of selected hydrographs is divided into three geographic regions: the area east of the Saline River (Ashley, Chicot, Desha, Drew, Lincoln, and part of Cleveland Counties), the area between the Saline and Ouachita Rivers (Bradley, Calhoun, and part of Cleveland Counties), and the area west of the Ouachita River (Columbia and Union Counties). The area east of the Saline River is confined by the overlying Jackson Group. The central area between the Saline and Ouachita Rivers is a mixed area, the northern part is an outcrop area, the eastern part is confined by the Jackson Group, and the southern part underlies Quaternary-age terrace deposits. The area west of the Ouachita River is in an outcrop area with overlying Quaternary-age terrace deposits.

Hydrographs for wells located in Ashley, Chicot, and Lincoln Counties, east of the Saline River and screened within the confined part of the Cockfield aquifer, are shown in figures 7*A*–*E*. These hydrographs indicate changes in water levels ranging from a rise of approximately 0.5 ft (well 18S02W25ABB3, fig. 7*D*) to a decline of approximately 57 ft (well 10S05W06CAC1, fig. 7*E*) over the period of record.

Hydrographs for wells located in Bradley, Calhoun, and part of Cleveland Counties, the area between the Saline and Ouachita Rivers, are shown in figures 7*F*–*I*. These wells are screened in confined and unconfined areas of the Cockfield aquifer. The hydrographs indicate rises and declines in water levels ranging from a decline of approximately 23 ft (well 14S10W31DBA1, fig 7*F*) to a rise of approximately 1 ft (well 15S12W11CAB1, fig. 7*G*) over the period of record.

Hydrographs for wells located in Union and Columbia Counties, the area west of the Ouachita River, are shown in figures 7*J*–*L*. The hydrographs indicate rises and declines over the period of record from a decline of approximately 5 ft (well 17S16W33BBA2, fig. 7*K*) to a rise of approximately 2 ft (well 17S13W17DDC1, fig. 7*J*).

Hydrographs for the 32 wells with historical water-level data were evaluated using linear regression to calculate the annual rise or decline for each well, and the data were aggregated by county and statistically evaluated for the range, mean, and median of water-level change in each county (table 2). Cleveland and Lincoln Counties had only one well with a minimum of 20 years of record. Annual rise or decline calculations associated with wells with more than 20 years of record in Ashley and Chicot Counties indicated a decline in water levels. Bradley, Calhoun, Columbia, and Union Counties indicate rising and declining water levels. The mean annual water-level rise or decline for Calhoun County was 0.00 ft/yr or unchanged. The mean annual water-level data for Ashley, Bradley, Chicot, Cleveland, Columbia, Lincoln, and Union Counties show declines ranging from -0.02 to -1.10 ft/yr.

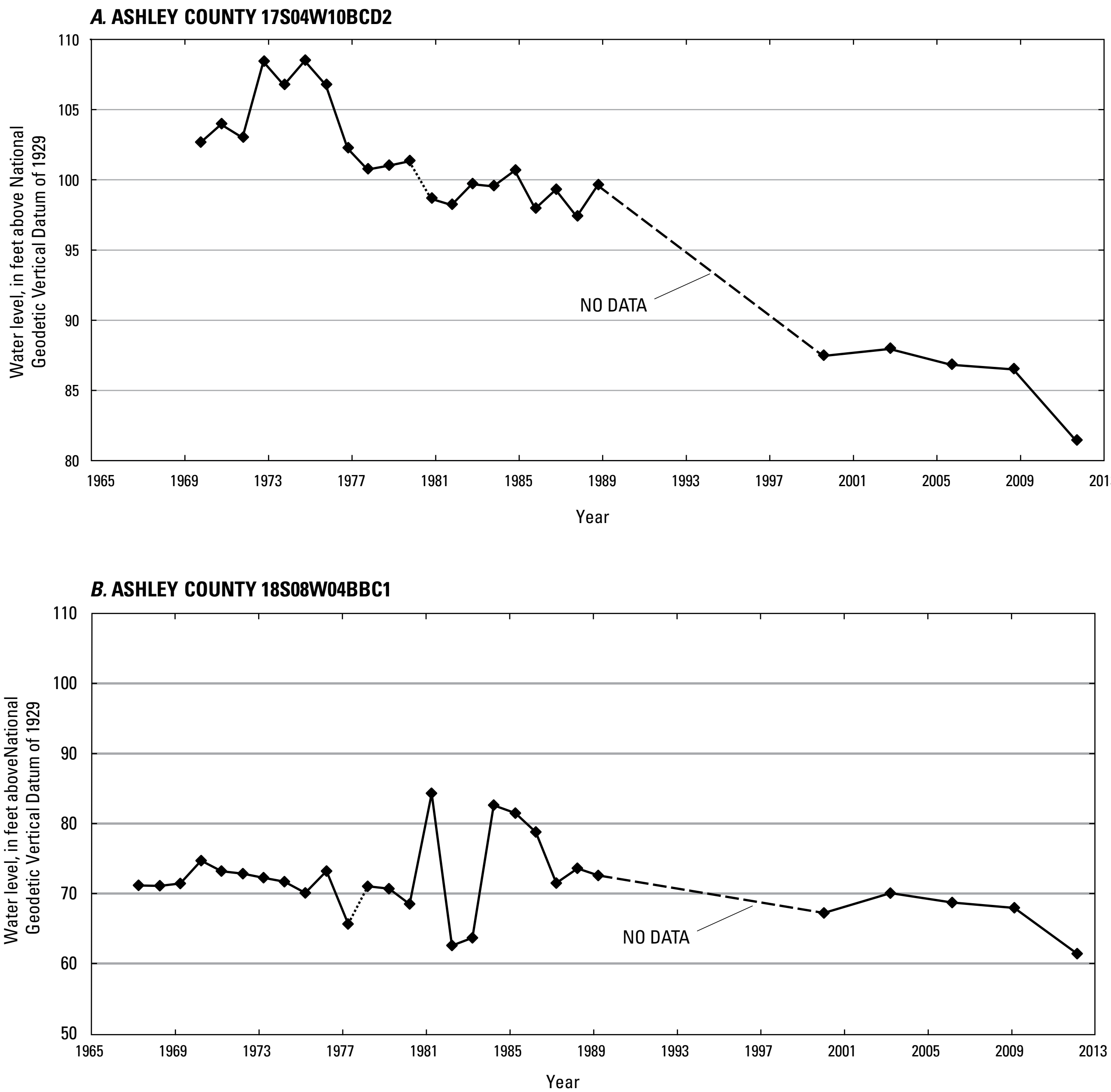
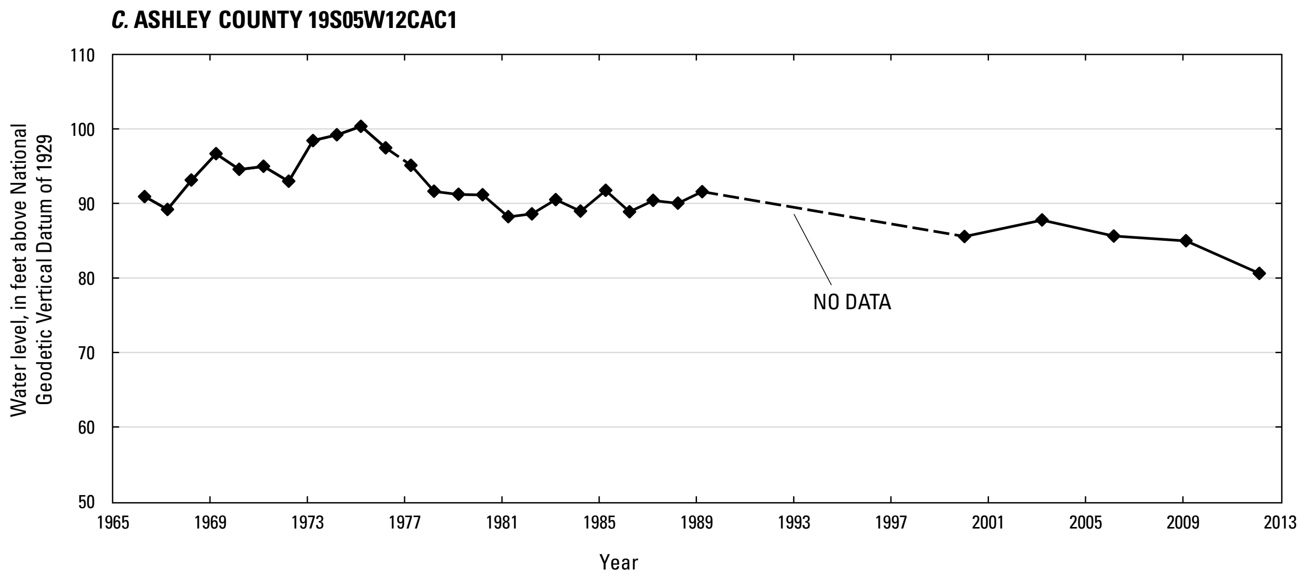


Figure 7. Water-level hydrographs for selected wells completed in the Cockfield aquifer in southern Arkansas.



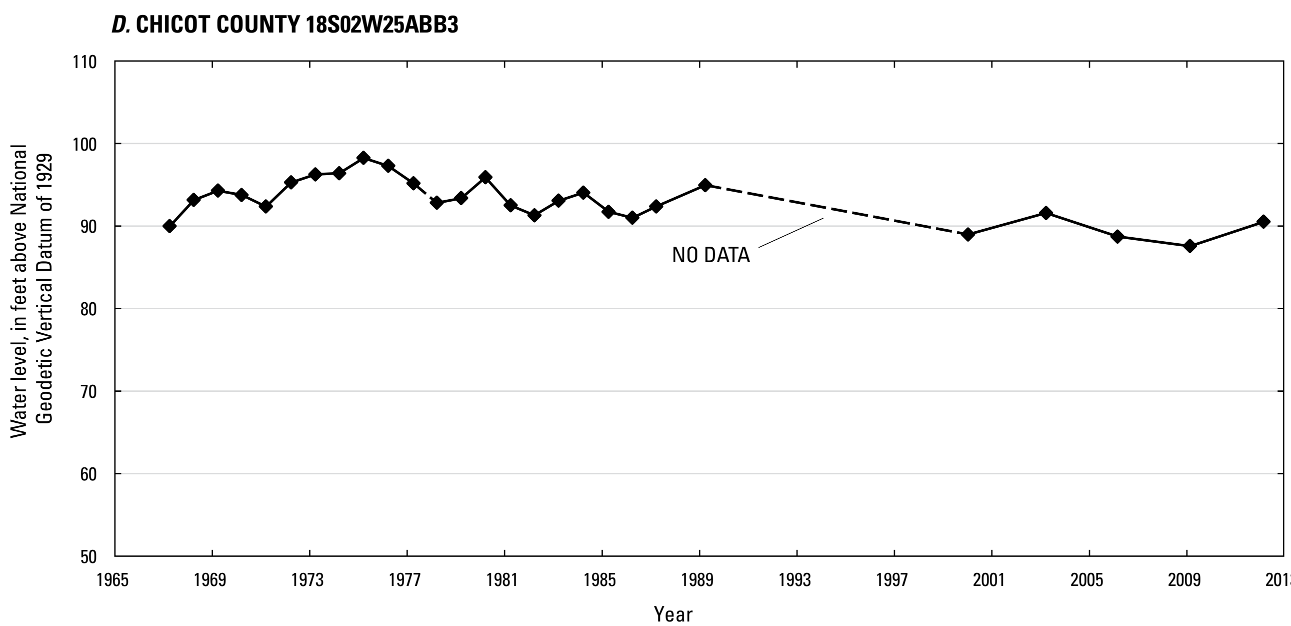
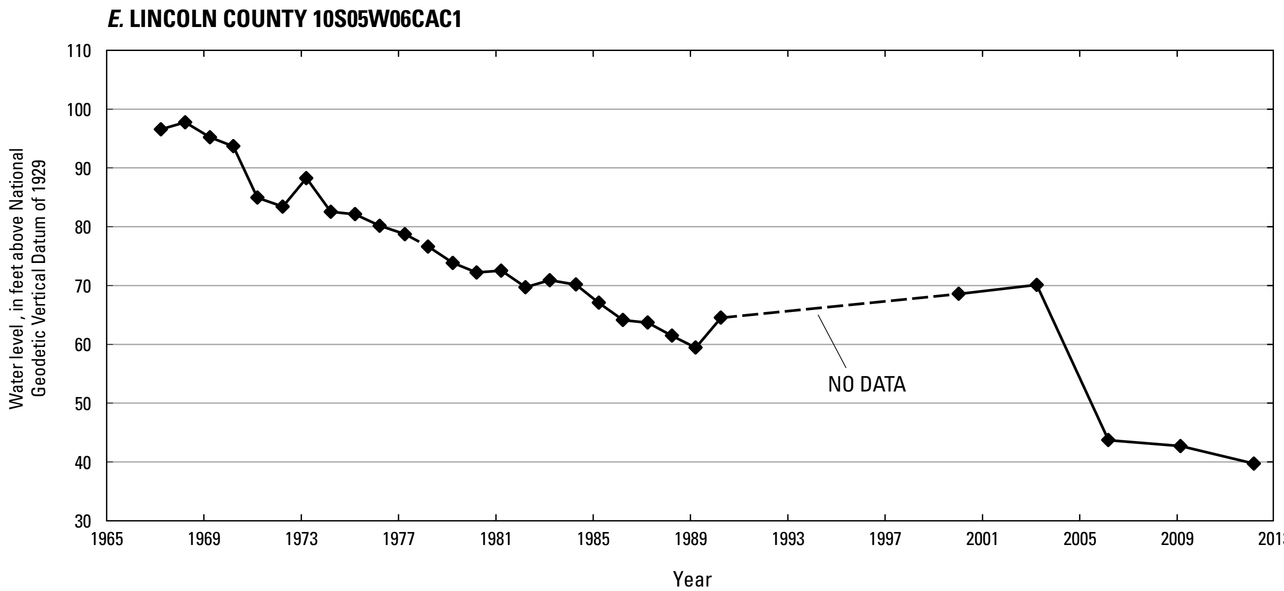


Figure 7. Water-level hydrographs for selected wells completed in the Cockfield aquifer in southern Arkansas.—Continued



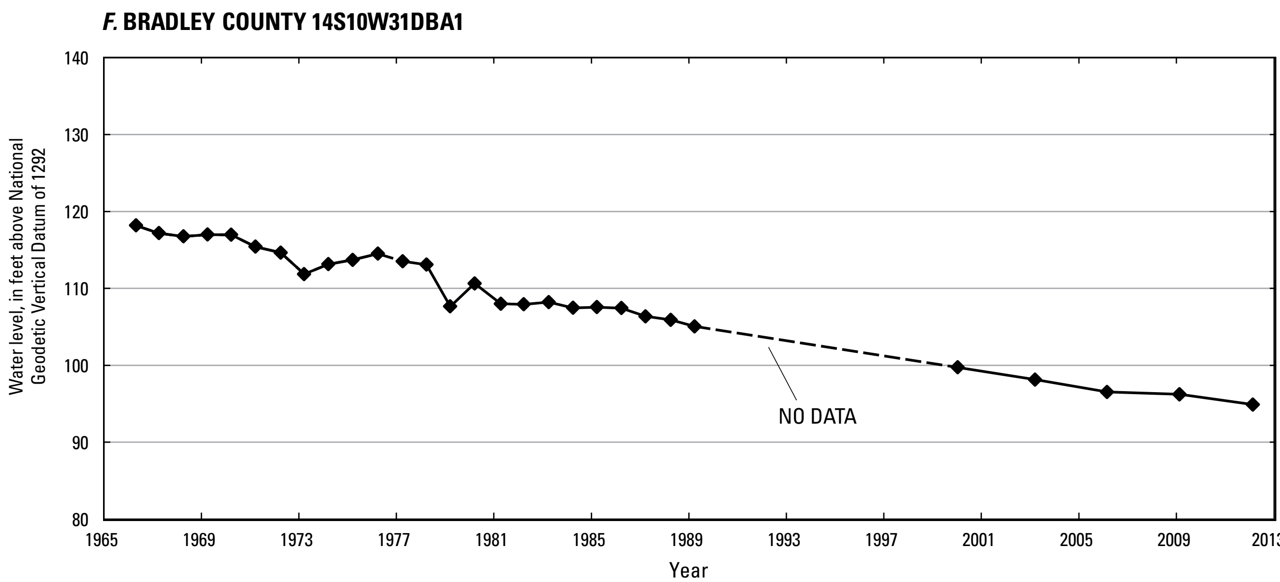
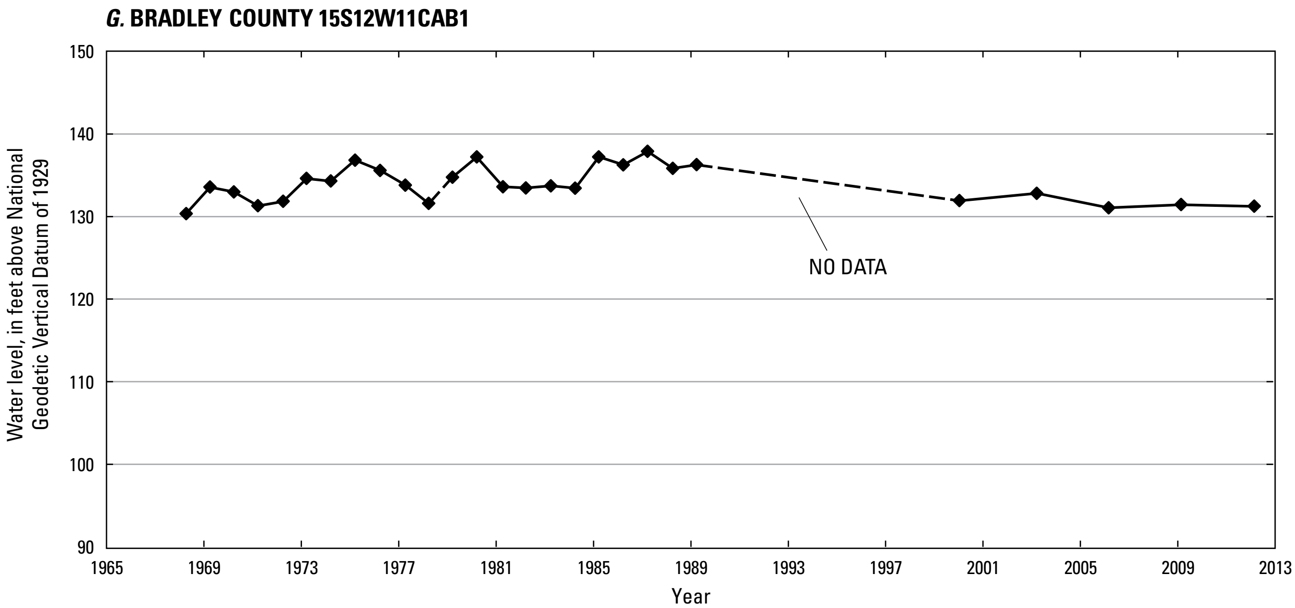


Figure 7. Water-level hydrographs for selected wells completed in the Cockfield aquifer in southern Arkansas.—Continued



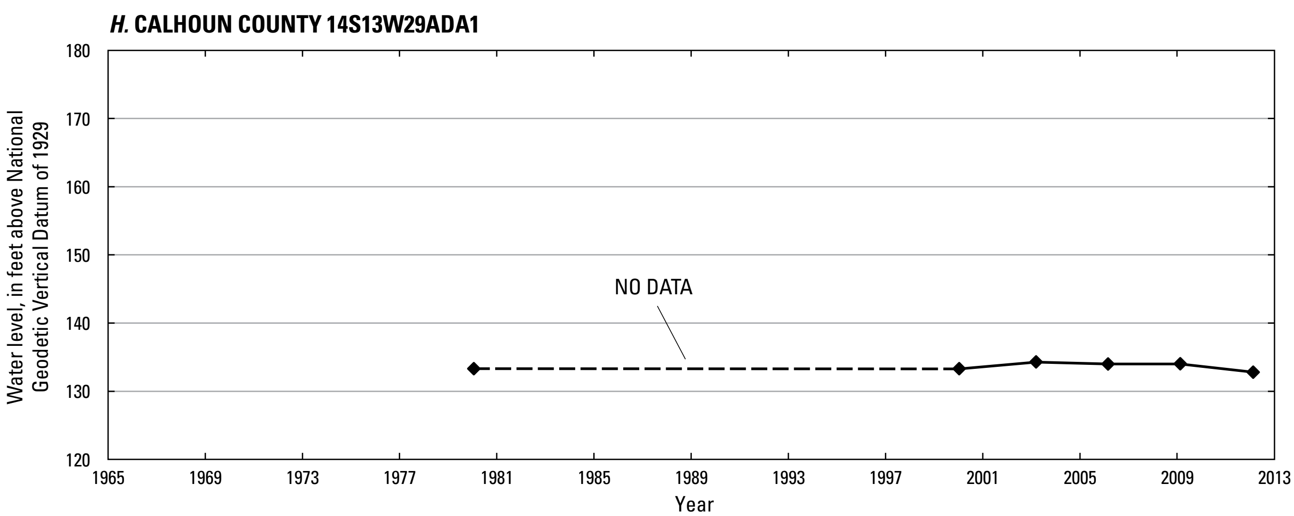
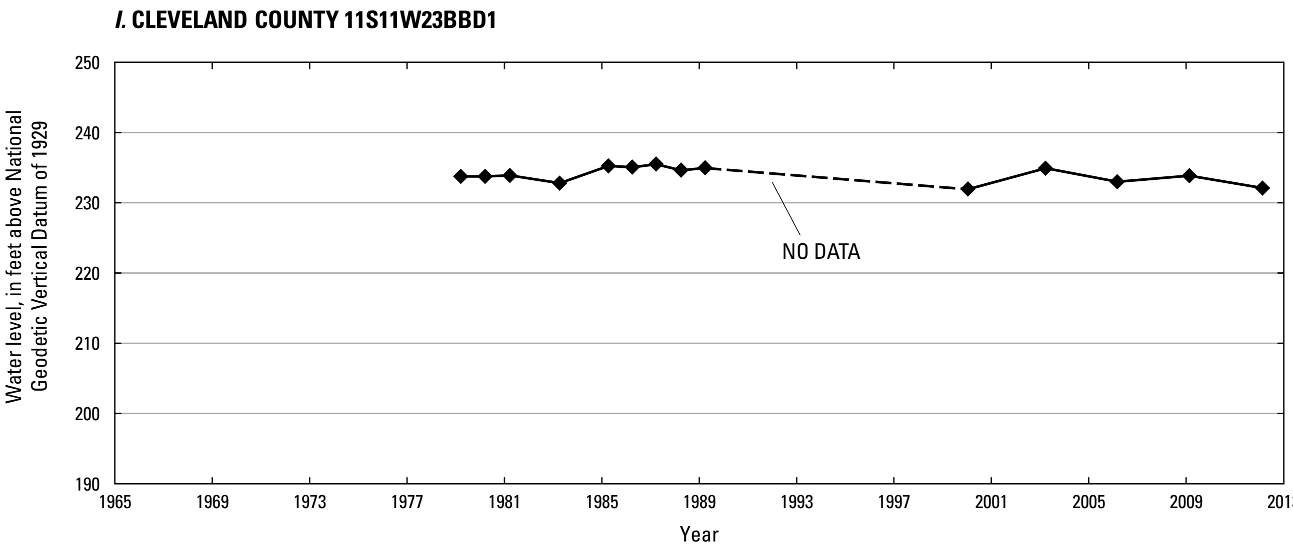


Figure 7. Water-level hydrographs for selected wells completed in the Cockfield aquifer in southern Arkansas.—Continued



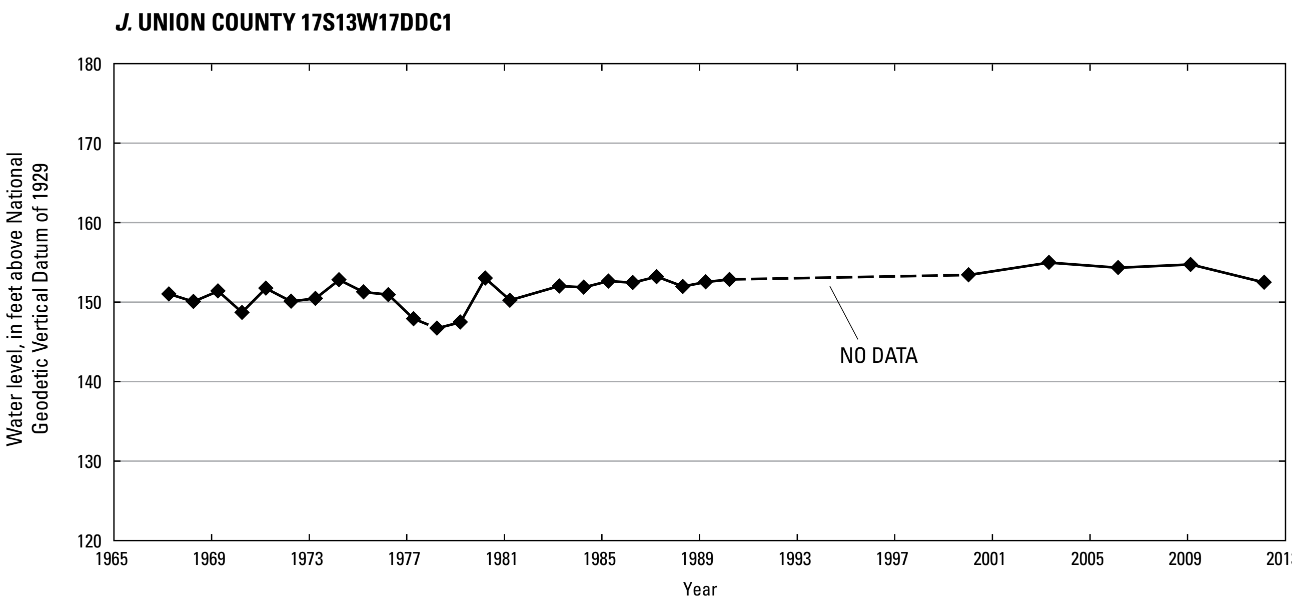
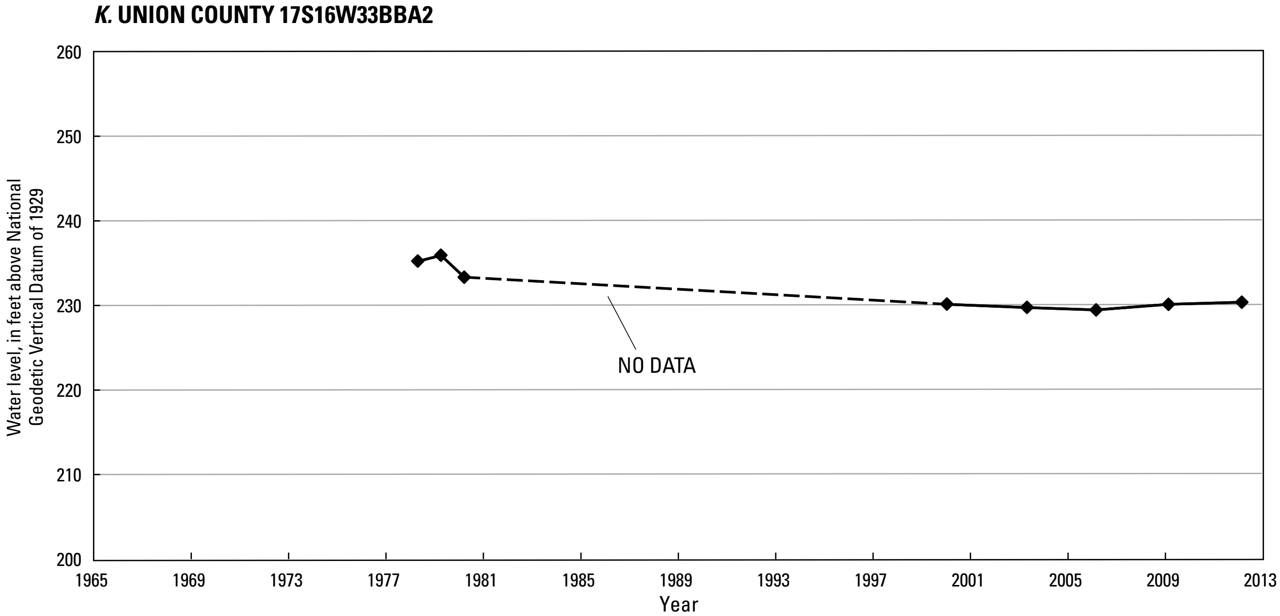


Figure 7. Water-level hydrographs for selected wells completed in the Cockfield aquifer in southern Arkansas.—Continued



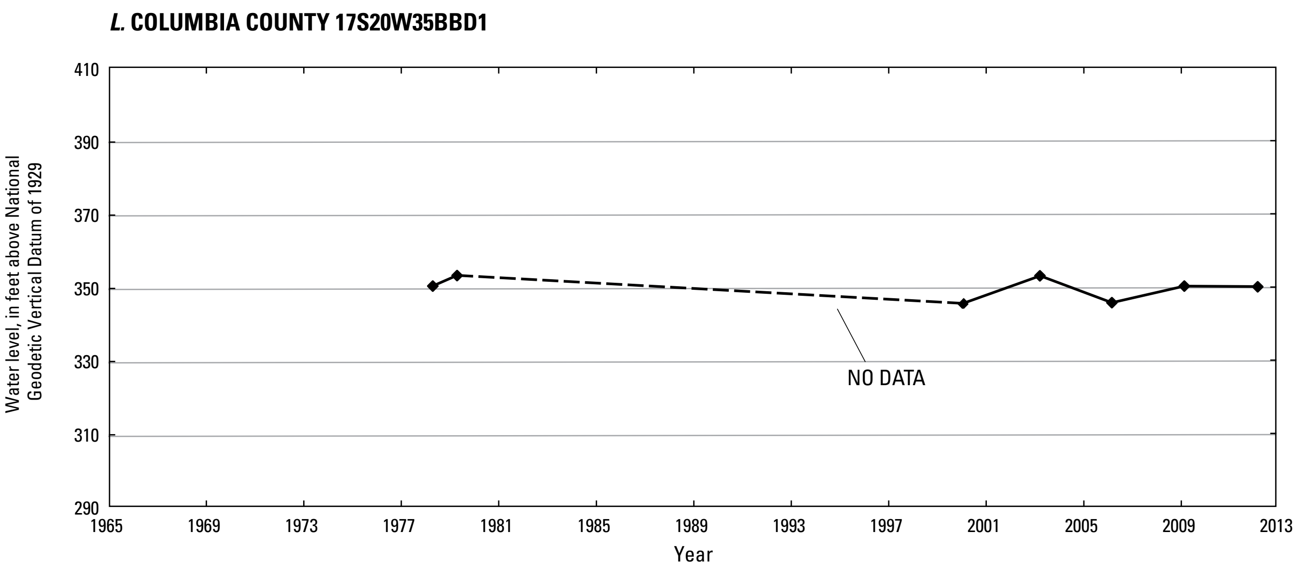


Figure 7. Water-level hydrographs for selected wells completed in the Cockfield aquifer in southern Arkansas.—Continued

Table 2. Range, mean, and median of annual rise or decline in water level by county for wells with 20 or more years of record completed in the Cockfield aquifer in Arkansas.

[Annual rise or decline in water level for each well is calculated using linear regression; negative value indicates decline; positive value indicates rise; R^2, coefficient of determination]

County	Number of wells	Range of values of annual rise (+) or decline (-) in water level (feet/year)	Mean annual rise (+) or decline (-) in water level (feet/year)	Median annual rise (+) or decline (-) in water level (feet/year)	Range of R^2 values for trend lines
Ashley	6	-0.55 to -0.11	-0.32	-0.31	0.08 to 0.90
Bradley	4	-0.51 to 0.40	-0.04	-0.03	0.04 to 0.97
Calhoun	6	-0.11 to 0.22	0.00	-0.01	0.07 to 0.70
Chicot	3	-0.33 to -0.11	-0.19	-0.15	0.40 to 0.70
Cleveland	1	-0.04	-0.04	-0.04	0.16
Columbia	5	-0.11 to 0.04	-0.02	0.01	0.01 to 0.26
Lincoln	1	-1.10	-1.10	-1.10	0.84
Union	6	-0.18 to 0.11	-0.03	-0.02	0.001 to 0.85

Wilcox (Lower Wilcox) Aquifer

Hydrogeologic Setting

The Wilcox aquifer, in northeastern and southern Arkansas, is composed of the Wilcox Group and is distributed throughout the Mississippi Embayment. The Wilcox Group is part of a syncline approximately centered beneath the Mississippi River that plunges to the south-southeast (fig. 3). In the northeast part of Arkansas, the Wilcox Group is composed of three units: the Flour Island Formation, the Fort Pillow Sand, and the Old Breastworks Formation; in southern Arkansas, the formation is undifferentiated (table 1). In central Arkansas, the Wilcox aquifer is not extensively used, and water-level data are not sufficient to determine potentiometric surfaces. Because of the discontinuous nature of water-level data, the potentiometric-surface map of the Wilcox aquifer is divided into two areas—one in northeastern Arkansas and the second in southern Arkansas.

The Wilcox Group is composed of thin interbedded layers of lignitic sand and clays in most of the northeastern area. The Wilcox Group crops out at or near Crowleys Ridge in Clay, Craighead, and Greene Counties (Broom and Lyford, 1981). East of Crowleys Ridge, the Wilcox Group (including the Fort Pillow Sand and the Old Breastworks Formation) contains a sand bed 200 ft or more in thickness (Petersen and others, 1985) in the middle to lower part of the unit which is referred to as the “1,400-foot sand” (Ryling, 1960; Plebuch, 1961) or the “lower Wilcox aquifer” (Hosman and others, 1968).

In northeastern Arkansas, the Wilcox aquifer is overlain by a clay bed of the Wilcox Group and is underlain by a clay bed of the Wilcox Group or the Midway Group. Part of the Wilcox aquifer, within Crowleys Ridge, is perched and hydrologically separated from the aquifer in the surrounding Mississippi Alluvial Plain (fig. 1) (Petersen and others, 1985).

The Wilcox Group is composed of interbedded layers of clay, sandy clay, sand, and lignite in the southern area. The Wilcox Group overlies the Midway Group and underlies Quaternary-age terrace deposits and alluvium or crops out. The outcrop is generally thin and discontinuous over large areas. Downslope from the outcrop, the Wilcox Group becomes thicker, ranging from a few feet in the outcrop areas to about 750 ft at the center of the syncline (Albin, 1964).

Recharge to the Wilcox aquifer in the northeastern area occurs through infiltration of precipitation in outcrop areas along the western side of Crowleys Ridge. Discharge occurs mainly through well withdrawals (Westerfield, 1994). The depth of wells in this area ranged from 462 ft in Greene County to 1,885 ft in Lee County. Well yield ranged from 100 to 2,000 gal/min (Schrader and Joseph, 2000).

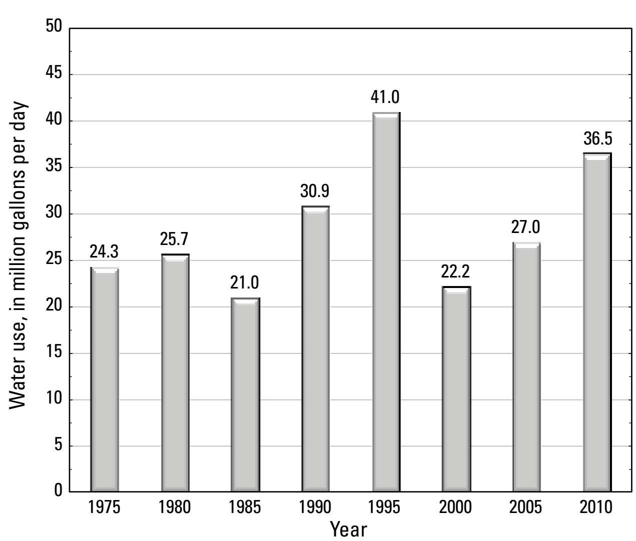
Recharge to the Wilcox aquifer in the southern area occurs through infiltration of precipitation in outcrop areas and inflow from overlying alluvial and terrace deposits. Discharge occurs from flows into overlying formations, into streams in the outcrop area, and to wells (Westerfield, 1994). Well depths ranged from 14 ft within the recharge area in Hempstead County to 533 ft in Ouachita County. Well yields ranged from 10 to 100 gal/min (Schrader and Joseph, 2000).

Hydraulic Properties

Values for specific capacity and transmissivity vary within the Wilcox aquifer. Pugh (2008) reported the following values based on multiple-well aquifer tests and single-well pump tests. Specific capacity values ranged from 0.25 (gal/min)/ft to 641 (gal/min)/ft with a median of 21.1 (gal/min)/ft. Transmissivity values ranged from 30 ft^2/d to 32,000 ft^2/d with a median of 8,170 ft^2/d and a mean of 10,700 ft^2/d. Hydraulic conductivity values could not be determined based on well tests completed in the Wilcox aquifer. Pugh (2008) calculated an estimated hydraulic conductivity value of 9.7 ft/d for the Wilcox aquifer by dividing the mean transmissivity value (10,700 ft^2/d) by the maximum aquifer thickness (1,100 ft).

Water Use

The majority of water withdrawals from the Wilcox aquifer were for industrial and public supply. Withdrawals for agricultural, commercial, and domestic use were less than those for industrial and public supply but important locally. Reported withdrawals from the Wilcox aquifer in Arkansas totaled 36.5 Mgal/d during 2010 (fig. 8), most of which occurred in the northeastern study area (Terrance W. Holland, U.S. Geological Survey, written commun., 2012). Withdrawals from 1975 through 2005 remained relatively constant, between 21.0 Mgal/d and 27.0 Mgal/d, with the exception of 1990 and 1995 when 30.9 Mgal/d and 41.0 Mgal/d were withdrawn, respectively. The rise in water use from 1990 to 1995 was attributed to withdrawals by a power generation plant that was operating during this time period (Terrance W. Holland, U.S. Geological Survey written commun., 2009). The rise in water use from 2005 to 2010 was attributed to increased withdrawals for industry, irrigation, and public supply (Aaron L. Pugh, U.S. Geological Survey written commun., 2014). In the northeastern area, the majority of water withdrawn from the Wilcox aquifer was for public supply. The aquifer is also an important source of water locally for agricultural, commercial, and domestic use. In the southern area, the majority of water withdrawn from the aquifer was for domestic use.



Data compiled from Halberg and Johnson (1977), Holland and Ludwig (1981), and Holland (1987, 1993, 1999, 2004, 2007, Terrance W. Holland, U.S. Geological Survey, written commun., 2010)

Figure 8. Water use from the Wilcox aquifer in Arkansas, 1975–2010.

Potentiometric Surface

Two potentiometric-surface maps, one for the northeastern area and one for the southern area, show the altitude of the water surface in the Wilcox aquifer (figs. 9 and 10). The maps were constructed using water-level data collected in February and March 2012 from 47 wells; 31 wells in the northeastern area (app. 3) and 16 wells in the southern area (app. 4).

The direction of groundwater flow in the Wilcox aquifer in the northeastern area in 2012 (fig. 9) was towards the south-southwest except for some areas immediately adjacent to the Mississippi River where the flow was more eastward towards the river. Groundwater withdrawals have altered the direction of flow near West Memphis (Joseph, 1998). The highest water-level altitude was 219 ft in northern Mississippi County, and the lowest water-level altitude was 123 ft near West Memphis in Crittenden County. In Greene County, a water-level altitude of 182 ft was measured near Crowleys Ridge. Within Crowleys Ridge, the waters of the Wilcox aquifer are perched at higher altitudes than the surrounding Mississippi Alluvial Plain and have too few control points for contouring.

The direction of groundwater flow in the southern area (fig. 10) was generally towards the southwest in the northern part. The direction of groundwater flow in the southern part was in all directions because of two cones of depression and two water-level mounds. The cones of depression are located in southeastern Clark County and central Nevada County, and the water-level mounds are located in Hot Spring County and Hempstead County (fig. 10). The water-level mounds are the result of the higher land-surface altitudes in the outcrop area. Groundwater flow toward the cone of depression in southeastern Clark County was generally from the north, south, and west; water flows toward the cone of depression in Nevada County from all directions. Groundwater flow from the water-level mound in eastern Hot Spring County was generally to the north, south, and east; groundwater flows from the water-level mound in southern Hempstead County to the south, east, and west. The highest water-level altitude measured was 394 ft at the centers of the water-level mounds in eastern Hot Spring County and southwestern Hempstead County. The lowest water-level altitude measured was 145 ft at the center of the cone of depression in Clark County.

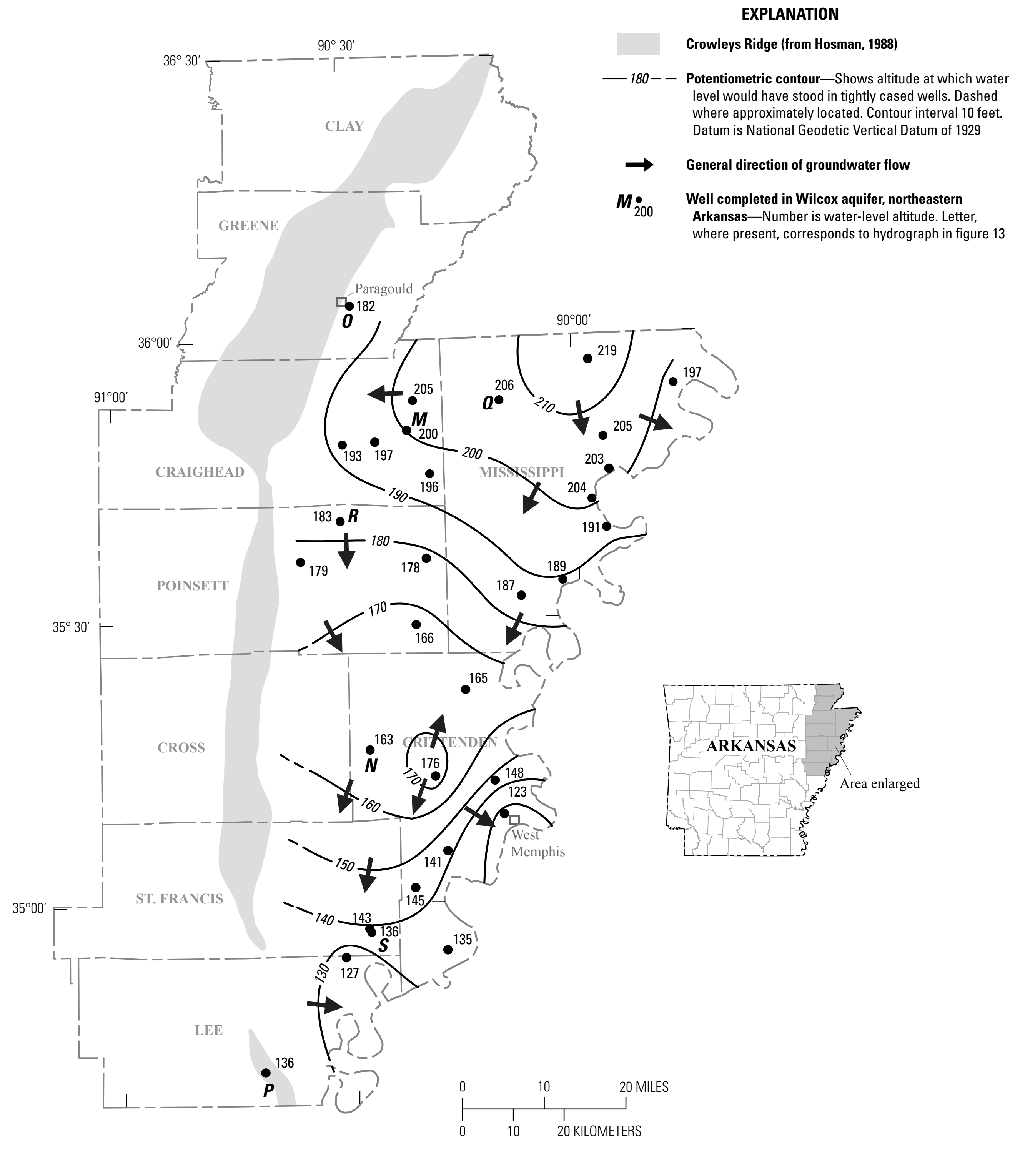


Figure 9. Potentiometric surface of the Wilcox aquifer in northeastern Arkansas, 2012.

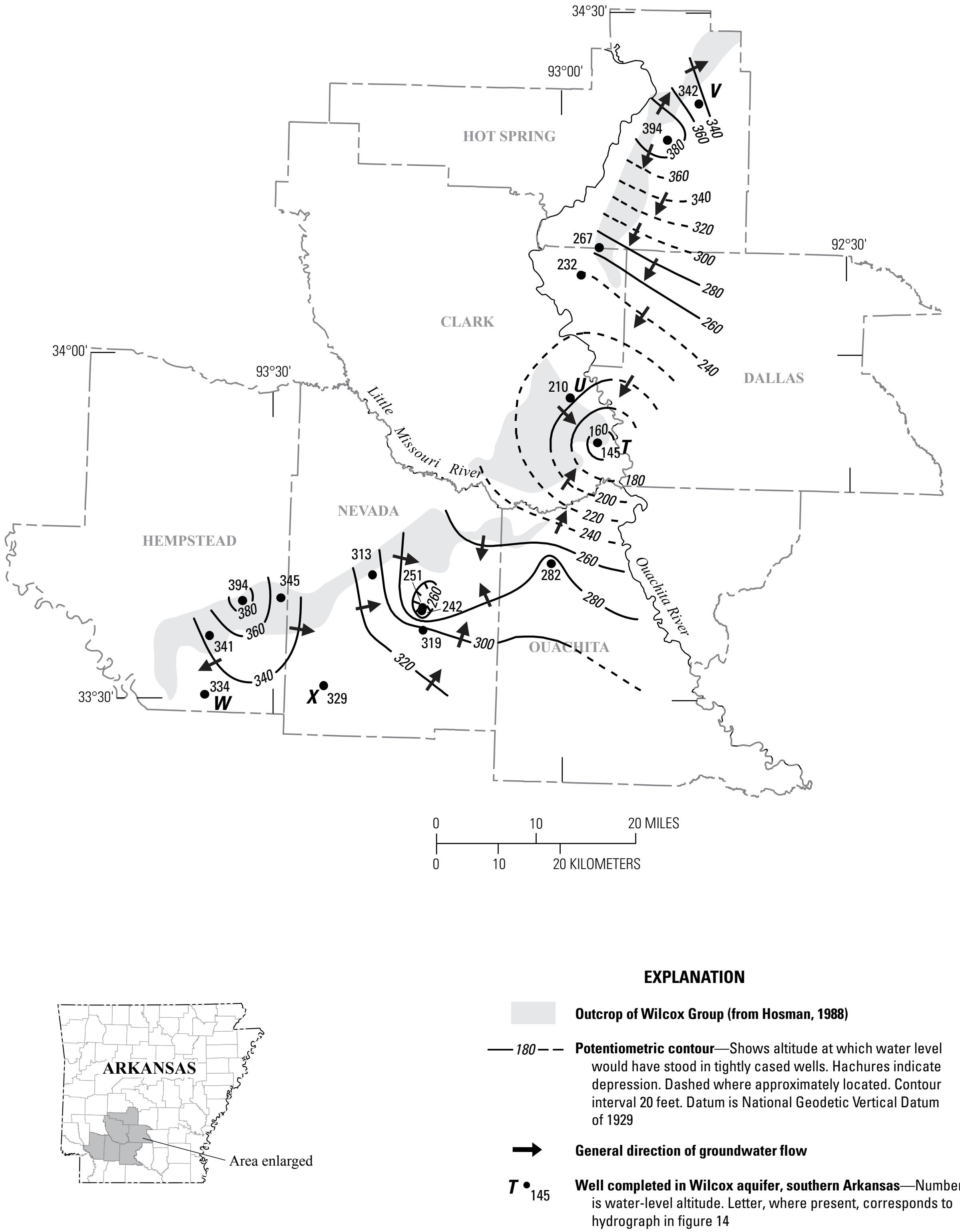


Figure 10. Potentiometric surface of the Wilcox aquifer in southern Arkansas, 2012.

Water-Level Trends

Water-Level Difference from 2006 to 2012

Water-level difference maps (figs. 11 and 12) for the Wilcox aquifer in Arkansas were constructed using 47 water-level measurements made during 2006 and 2012. Difference values were obtained from water levels measured in 31 wells in the northeastern area of the Wilcox aquifer and 16 wells measured in the southern area.

The 2006 to 2012 difference in water levels for the Wilcox aquifer in the northeastern area (fig. 11, app. 5) ranged from 22.0 to -17.9 ft. The largest rise in water levels occurred in Crittenden County, and the largest decline was in Lee County. Twenty-one wells in the northeastern area had rising water levels, and 10 wells had declining water levels. Wells in the northern part of this area had rising water levels, and wells in the southern part had declining water levels. In the central part of the area, water levels in all wells measured in Craighead County rose, and water levels rose in all but one well in Poinsett County and one well in Mississippi County. Water levels in wells in Crittenden County rose and declined. All water levels in wells measured in Lee and St. Francis Counties declined.

The 2006 to 2012 difference in water levels for the Wilcox aquifer in the southern area (fig. 12, app. 6) ranged from 18.1 to -4.2 ft. The largest rise and the largest decline in water levels occurred in Nevada County. Water-levels rose in 12 wells in the southern area and declined in 4 wells. Water levels in wells in the northern area rose and declined in wells in the central part of the area (Clark County). Water levels in wells in the southern part of the area rose and declined.

Long-Term Hydrographs

Hydrographs for 12 wells with a minimum of 20 years of record (7 wells in the northeastern area and 5 wells in the southern area) were used to evaluate long-term trends of the Wilcox aquifer. The well locations for the corresponding hydrographs are plotted on figures 9 and 10 and designated by the letters M–X positioned next to the well. These hydrographs are shown on figure 13 (northeastern, area) and figure 14 (southern area). Hydrographs for 36 wells (24 wells in the northeastern area of the Wilcox aquifer and 12 wells in the southern area) were used to calculate the annual rise or decline in water levels over a period of 20 or more years using linear regression. The annual rise or decline in water levels was aggregated by county, and values for the range, mean, and median of water-level change were computed for each county (table 3). The summary for Greene, Lee, and St. Francis Counties was for a single well.

Selected hydrographs for the northeastern area (figs. 13*M*–*S*) all show declining water levels. Water-level changes in selected wells ranged from a decline of approximately 23 ft in well 14N07E17DCB1 (fig. 7*M*) in Craighead County to a decline of approximately 60 ft in well 04N06E21BAD2 (fig. 7*S*) in St. Francis County. Hydrographs in the southern area (figs. 14*T*–*X*) show rising and declining water levels. Water-level changes in selected wells ranged from a decline of approximately 20 ft in well 10S18W10DDB1 (fig. 7*T*) in Clark County to a rise of approximately 14 ft in well 14S22W19AAA1 (fig. 7*X*) in Nevada County.

Linear regression analysis of long-term hydrographs was used to determine the mean annual water-level rise and decline in the Wilcox aquifer in the northeastern and southern areas of Arkansas. In the northeastern area, the mean annual water level declined in all seven counties. The mean annual declines ranged from -0.55 ft/yr in Craighead County to -1.46 ft/yr in St. Francis County. Greene, Lee, and St. Francis Counties had only one well with a minimum of 20 years of record.

In the southern area, the annual rise or decline calculations for wells with over 20 years of record indicate rising and declining water levels in Clark, Hot Spring, and Nevada Counties. The mean annual water level declined in all counties except Hot Spring County.

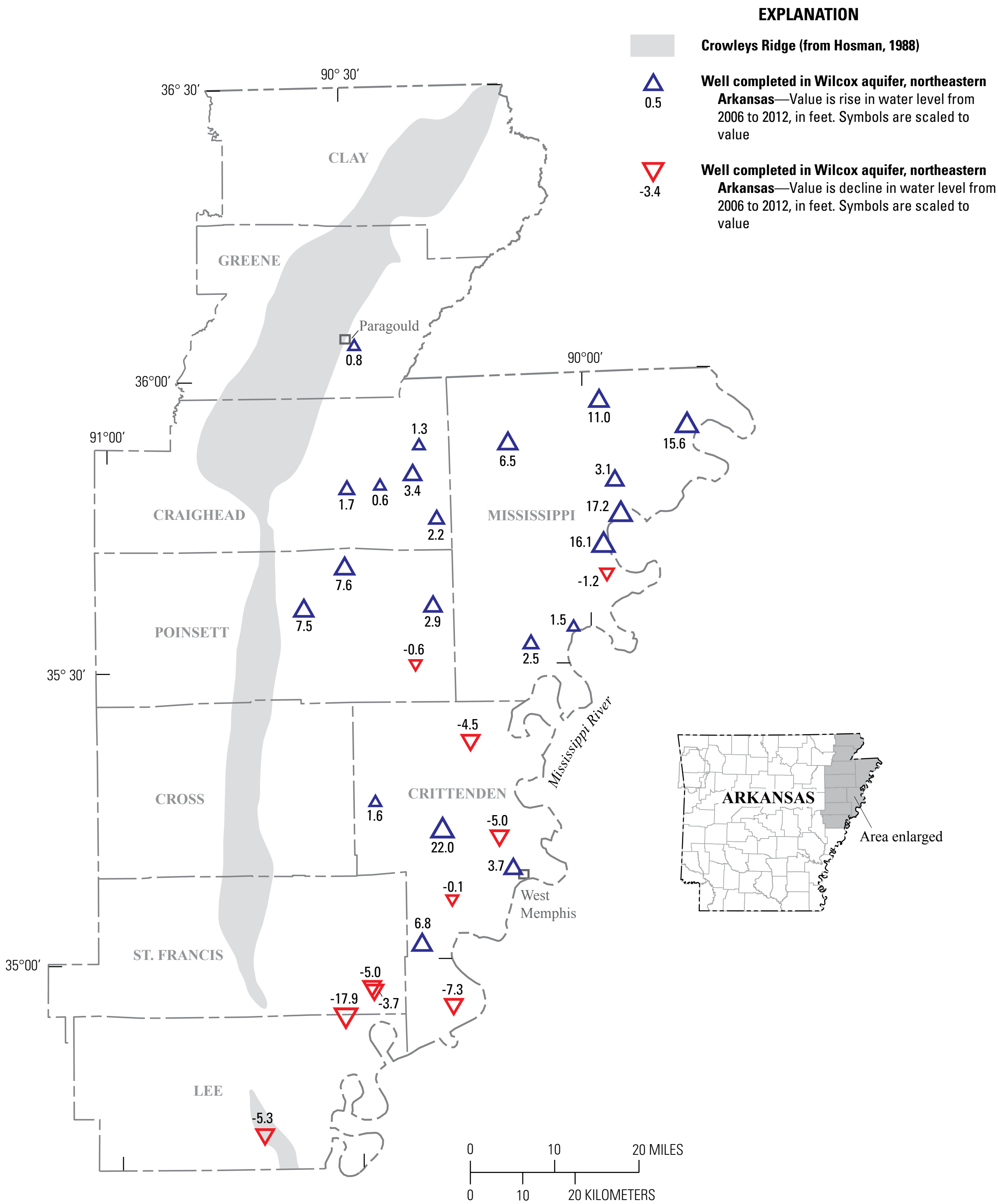


Figure 11. Water-level difference for the Wilcox aquifer in northeastern Arkansas, 2006–12.

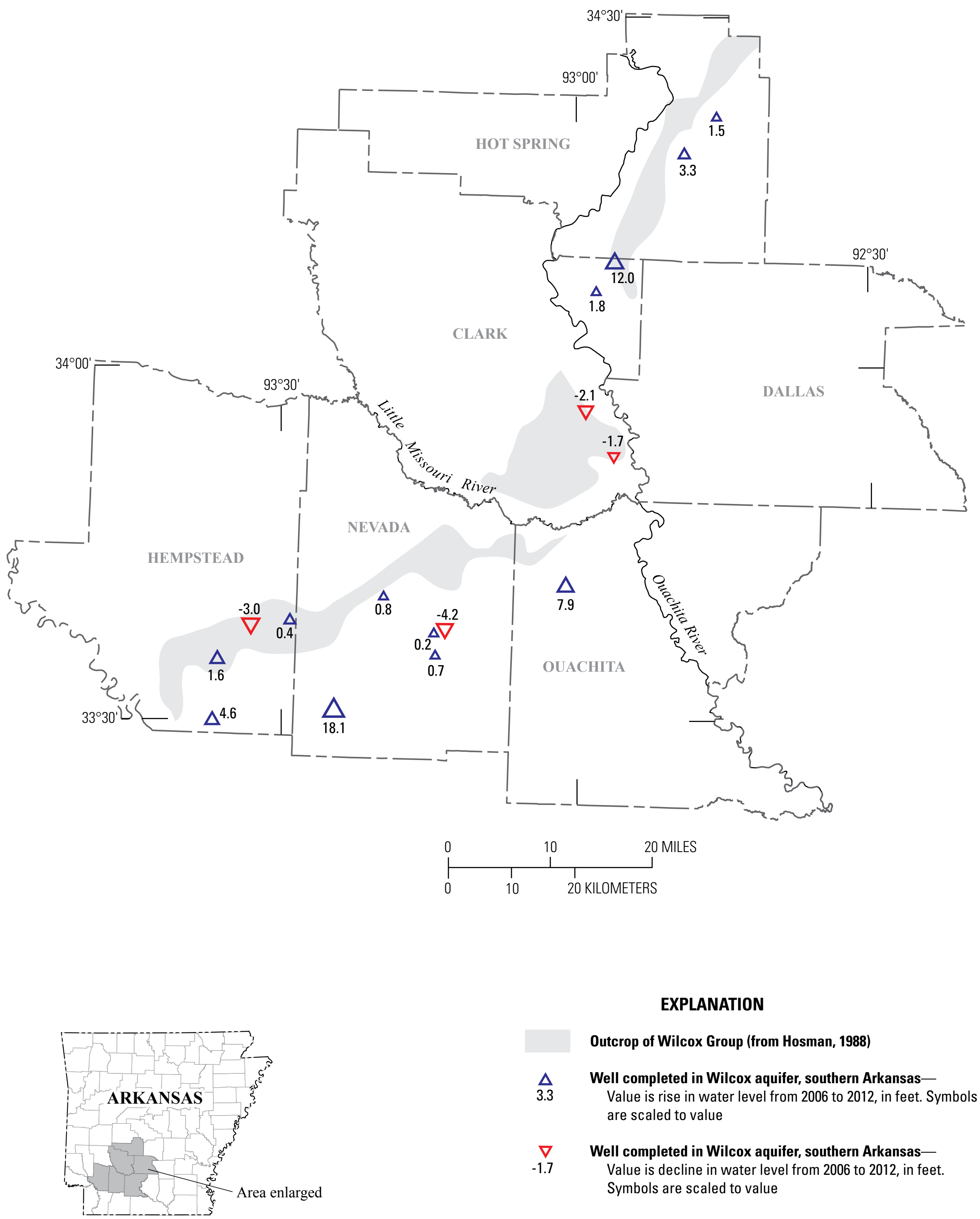
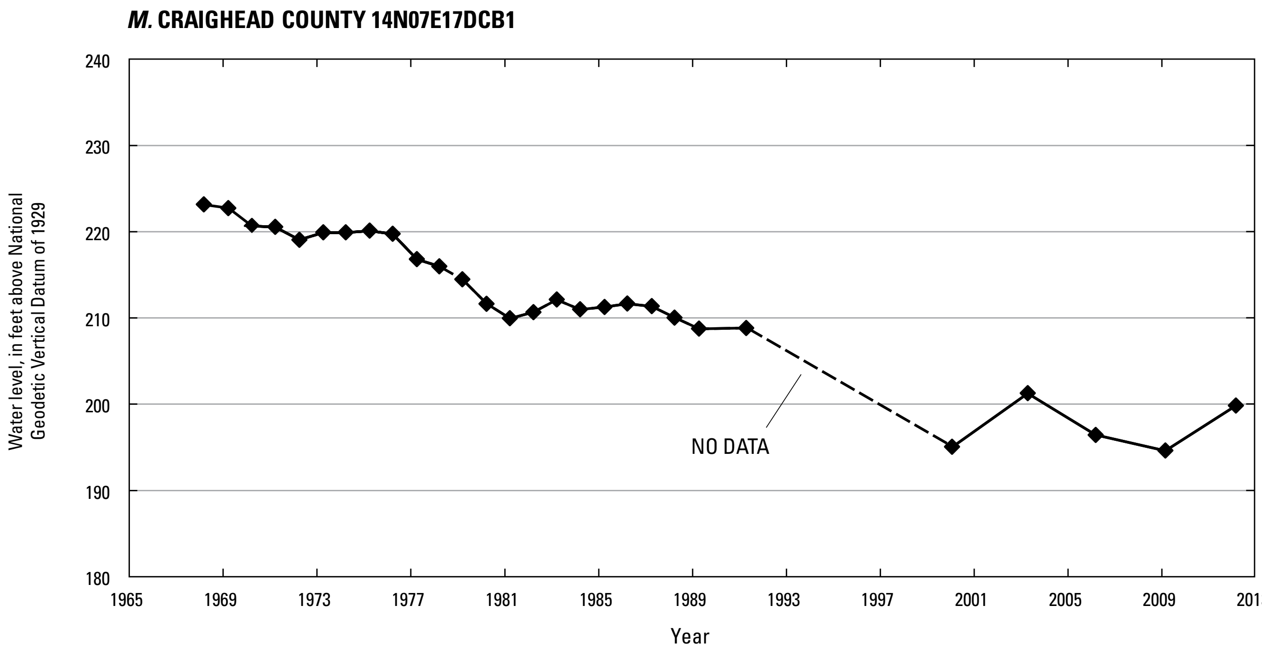


Figure 12. Water-level difference for the Wilcox aquifer in southern Arkansas, 2006–12.



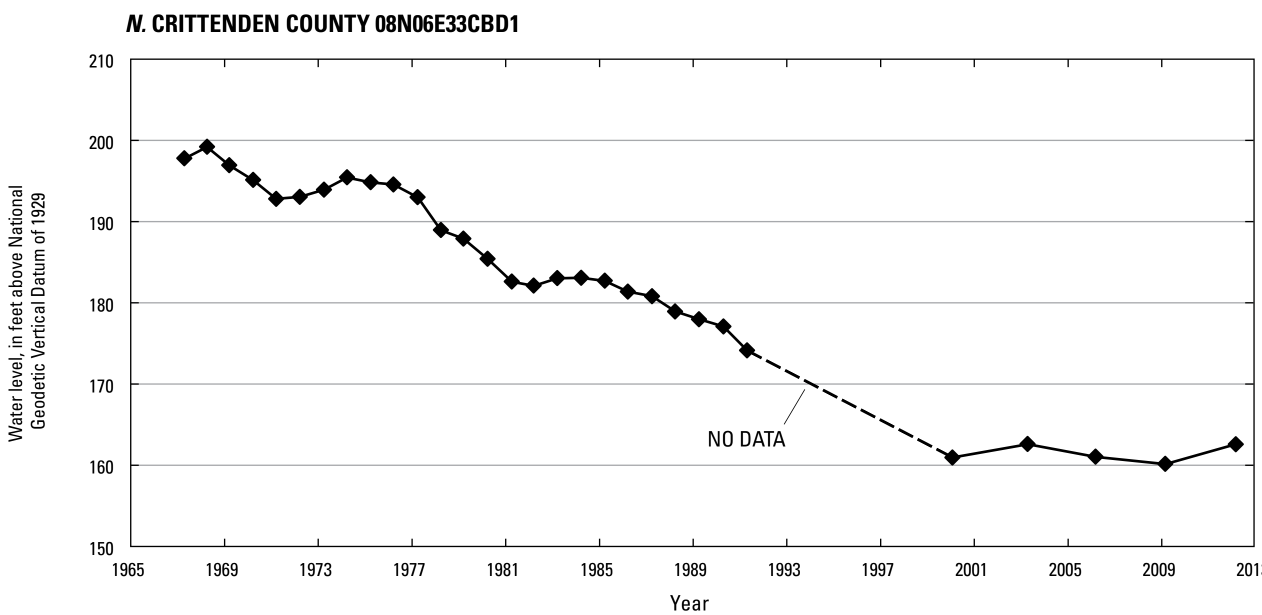
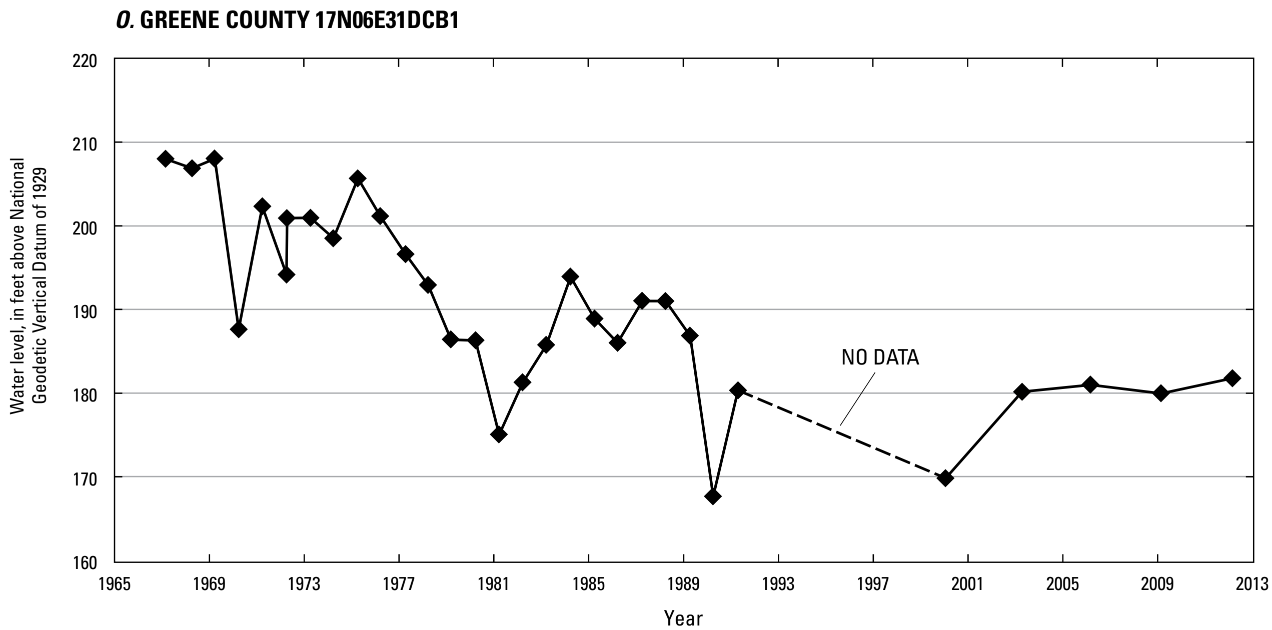


Figure 13. Water-level hydrographs for selected wells completed in the Wilcox aquifer in northeastern Arkansas.



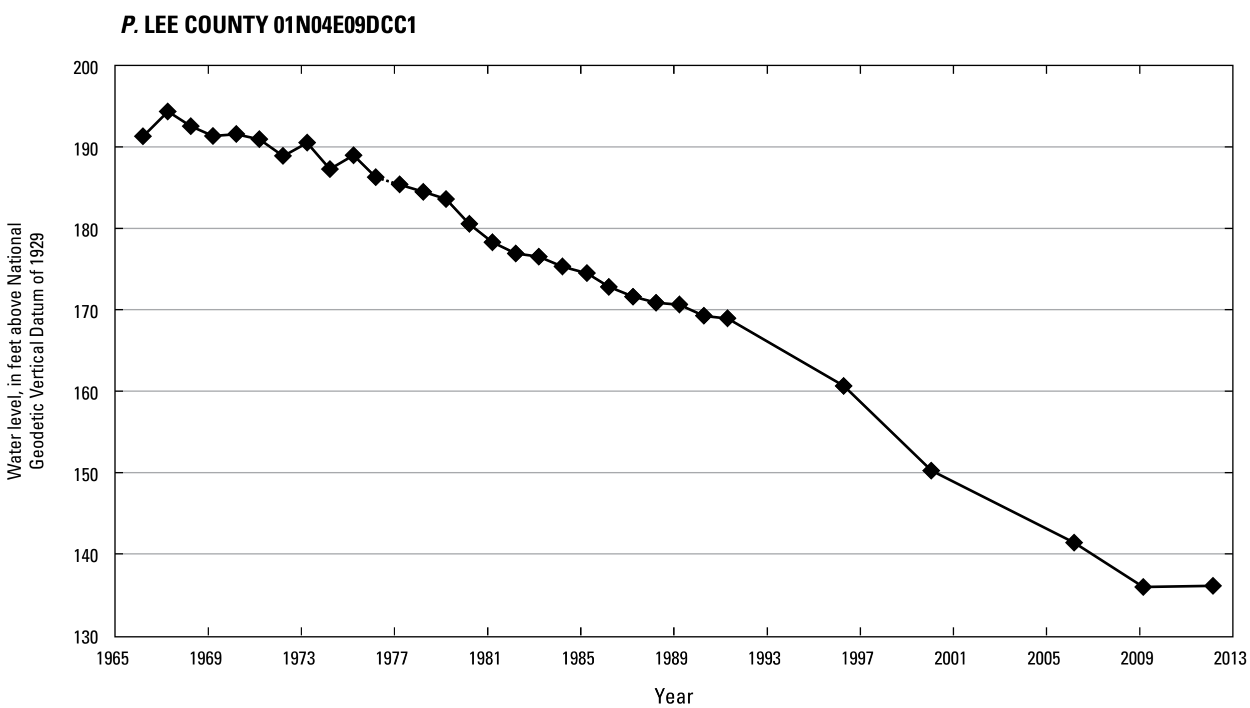
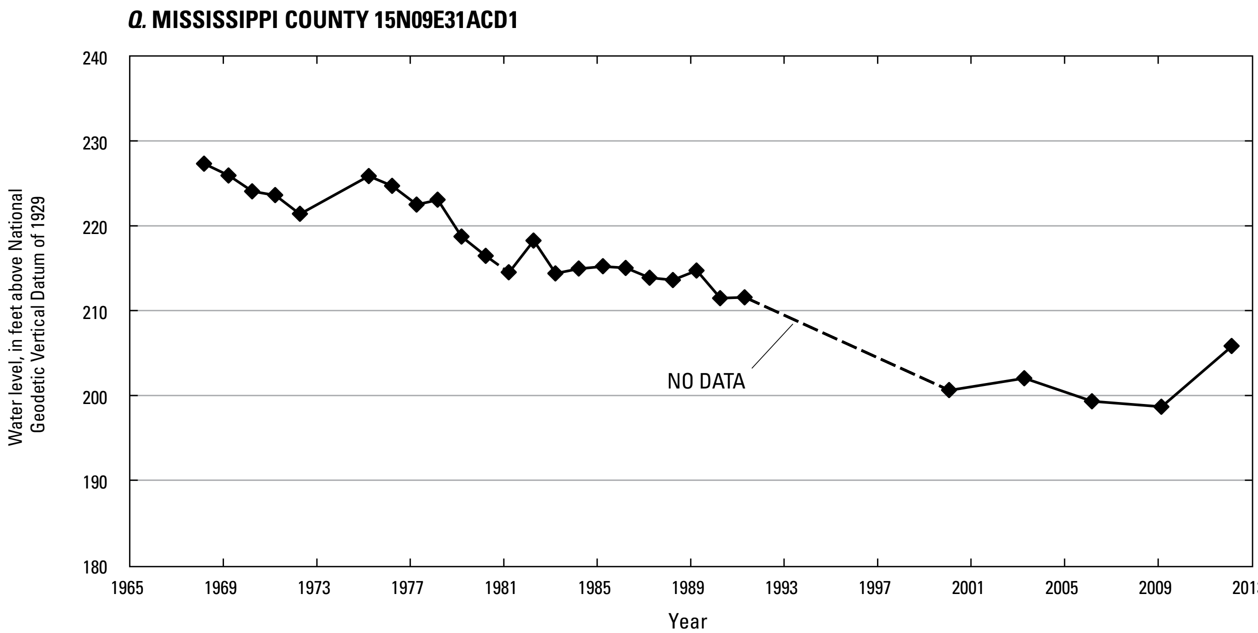


Figure 13. Water-level hydrographs for selected wells completed in the Wilcox aquifer in northeastern Arkansas.—Continued



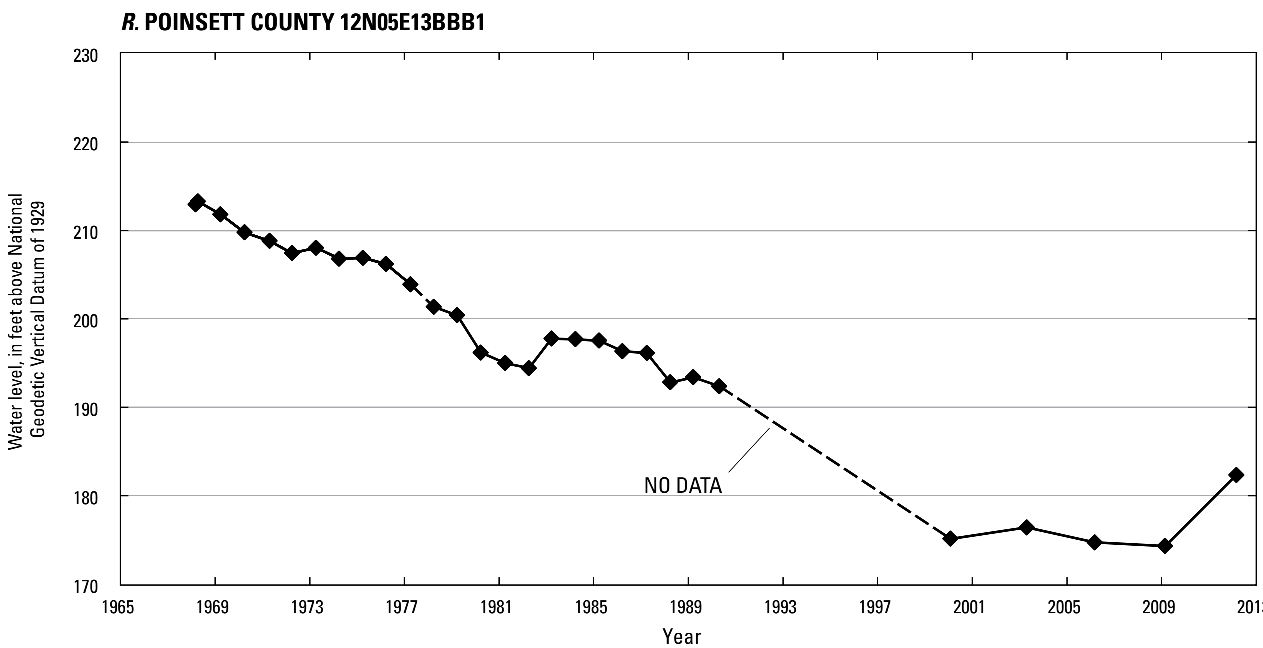


Figure 13. Water-level hydrographs for selected wells completed in the Wilcox aquifer in northeastern Arkansas.—Continued

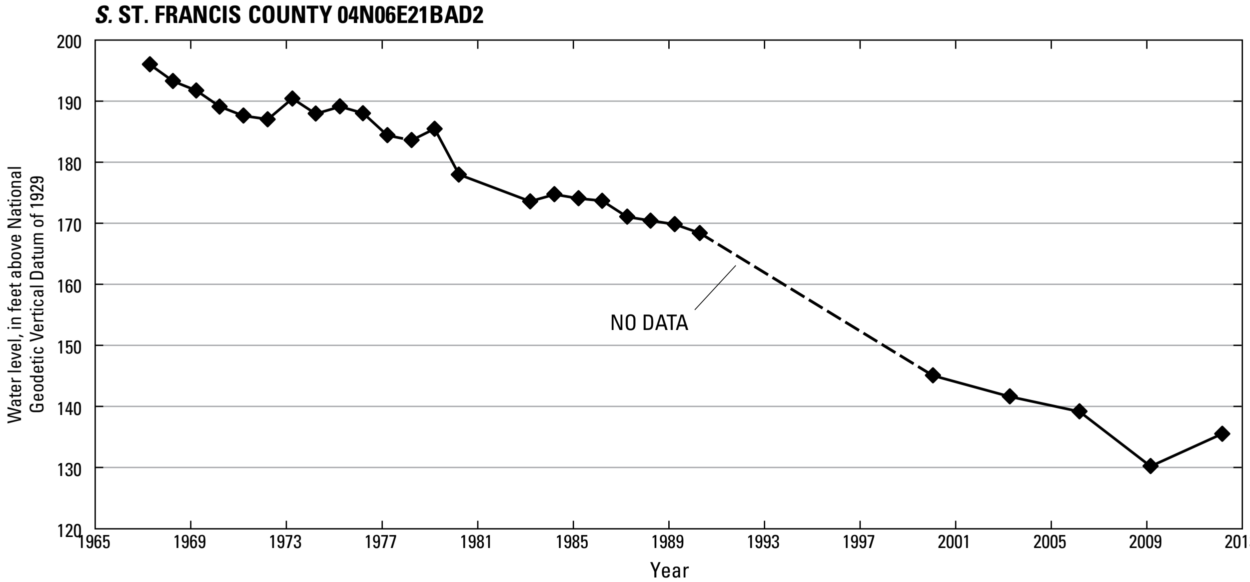
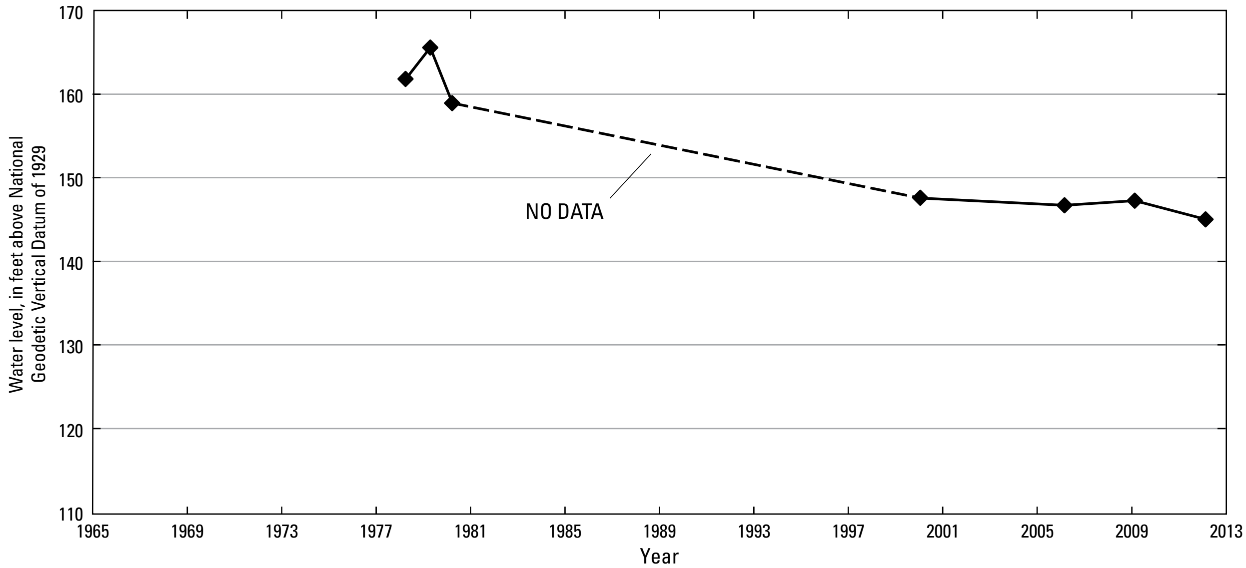


Figure 13. Water-level hydrographs for selected wells completed in the Wilcox aquifer in northeastern Arkansas.—Continued

T. **CLARK COUNTY 10S18W10DDB1**



U. **CLARK COUNTY 09S18W20CBB1**

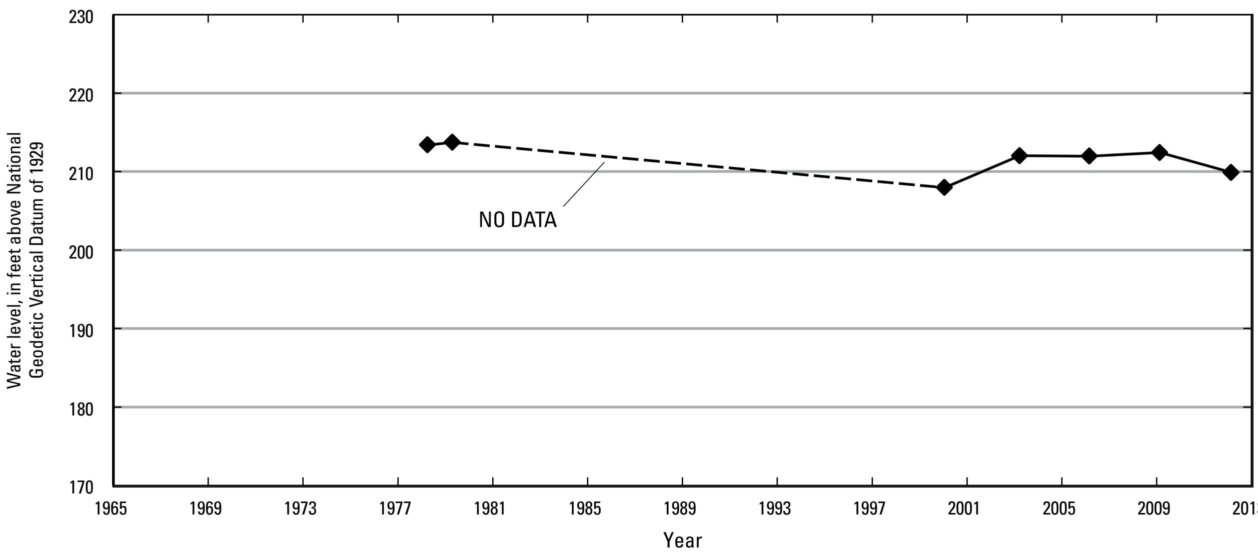
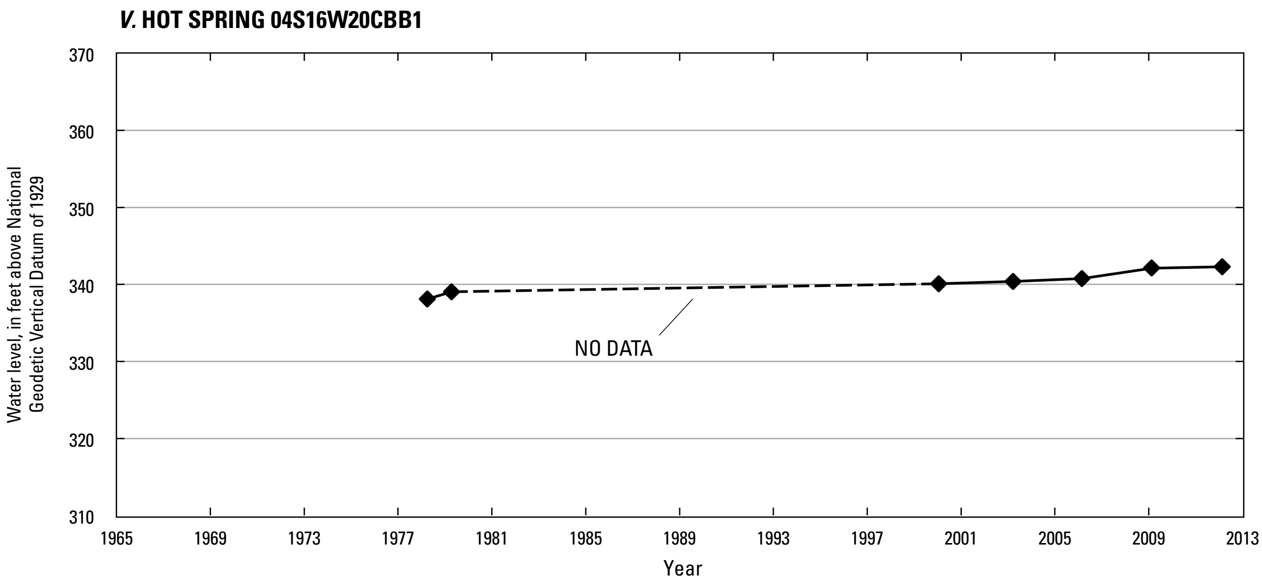


Figure 14. Water-level hydrographs for selected wells completed in the Wilcox aquifer in southern Arkansas.



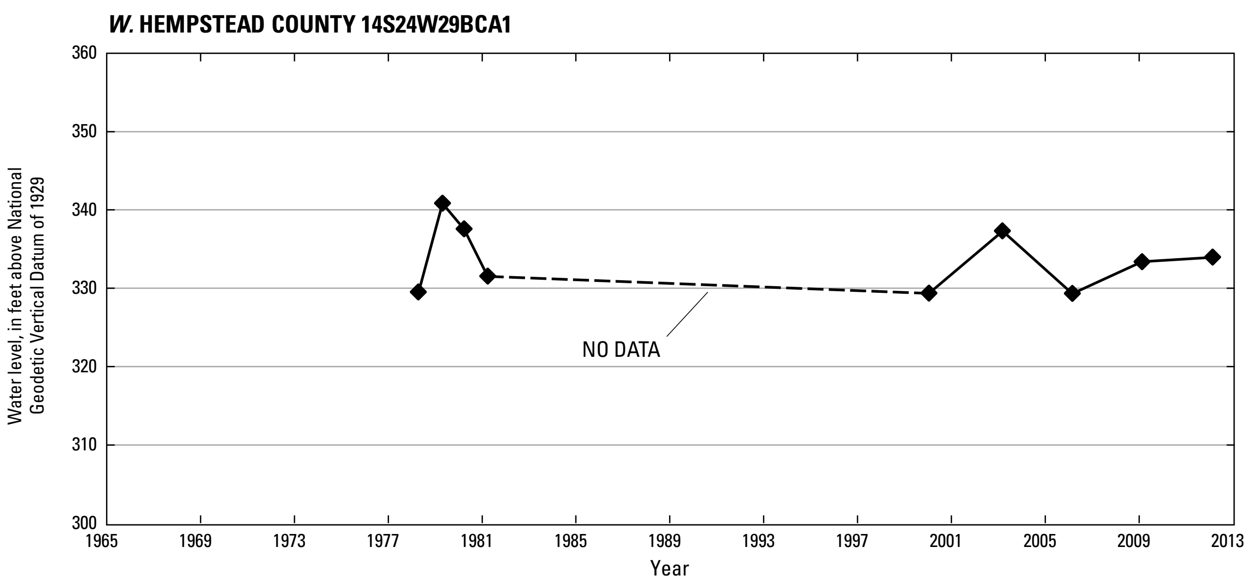


Figure 14. Water-level hydrographs for selected wells completed in the Wilcox aquifer in southern Arkansas.—Continued

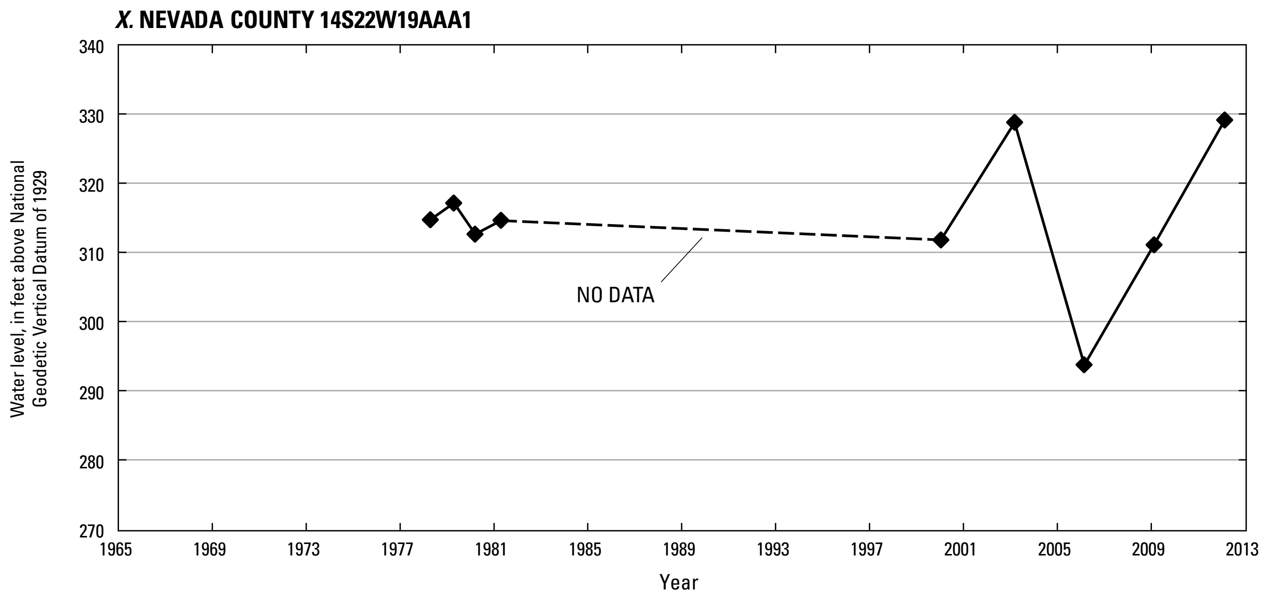


Figure 14. Water-level hydrographs for selected wells completed in the Wilcox aquifer in southern Arkansas.—Continued

Table 3. Range, mean, and median of annual rise or decline in water level by county for wells with 20 or more years of record completed in the Wilcox aquifer in Arkansas.

[Annual rise or decline in water level for each well is calculated using linear regression; negative value indicates decline; positive value indicates rise; R^2, coefficient of determination]

County	Number of wells	Range of values of annual rise (+) or decline (-) in water level (feet/year)	Mean annual rise (+) or decline (-) in water level (feet/year)	Median annual rise (+) or decline (-) in water level (feet/year)	Range of R^2 values for trend lines
Northeastern area					
Craighead	4	-0.66 to -0.43	-0.55	-0.55	0.67 to 0.92
Crittenden	8	-1.57 to -0.88	-1.15	-1.11	0.78 to 0.98
Greene	1	-0.66	-0.66	-0.66	0.54
Lee	1	-1.31	-1.31	-1.31	0.97
Mississippi	6	-0.95 to -0.55	-0.73	-0.68	0.70 to 0.91
Poinsett	3	-0.91 to -0.80	-0.85	-0.84	0.76 to 0.93
St. Francis	1	-1.46	-1.46	-1.46	0.97
Southern area					
Clark	3	-0.55 to 0.18	-0.15	-0.07	0.30 to 0.97
Hempstead	3	-0.62 to -0.07	-0.26	-0.07	0.05 to 0.67
Hot Spring	2	-0.01 to 0.11	0.05	0.05	0.01 to 0.88
Nevada	4	-0.11 to 0.03	-0.03	-0.04	0.00 to 0.16

Summary

The Cockfield aquifer located in southern Arkansas is composed of Eocene-age sand beds found near the base of the Cockfield Formation of Claiborne Group. The Wilcox aquifer located in northeastern and southern Arkansas, is composed of Paleocene-age sand beds found in the middle to lower part of the Wilcox Group. The Cockfield and Wilcox aquifers are primary sources of groundwater. In 2010, withdrawals from the Cockfield aquifer in Arkansas totaled 19.2 (Mgal/d) and withdrawals from the Wilcox aquifer totaled 36.5 Mgal/d.

Water levels were measured at 43 wells completed in the Cockfield aquifer and 47 wells completed in the Wilcox aquifer in February and March 2012. Measurements from 2012 are presented as potentiometric-surface maps and in combination with measurements from 2006 as water-level difference maps. Trends in water-level change over time within the Cockfield and Wilcox aquifers were determined using the water-level difference maps and selected well hydrographs. Hydrogaphs for selected wells were constructed using 20 or more years of historical water-level data.

The Cockfield aquifer study area in southern Arkansas is bounded on the east by the Mississippi River and on the west by the area that contains outcrops and subcrops of the Cockfield Formation. The northern boundary of the Cockfield aquifer study area is defined by the area that contains observation wells completed in the Cockfield aquifer and the southern boundary is the Louisiana State line. The Wilcox aquifer study area in northeastern Arkansas is bounded on the east by the Mississippi River and on the north by the Missouri State line. The southern and western boundaries are defined by areas containing observation wells completed in the Wilcox aquifer or by outcrop areas on or near Crowleys Ridge. The Wilcox aquifer study area in southern Arkansas is defined by observation wells completed in the Wilcox aquifer or by areas that contain outcrops of the Wilcox Group, or both.

The potentiometric surface of the Cockfield aquifer shows the regional direction of groundwater flow was generally toward the east-southeast, except in areas of intense groundwater withdrawals such as southwestern Ashley County, where groundwater flows toward the town of Crossett. In southern Columbia County, a trough in the potentiometic surface exists, which locally alters the flow of groundwater. The highest water-level altitude measured was 350 feet (ft) above National Geodetic Vertical Datum of 1929 (NGVD 29) in central Columbia County. The lowest water-level altitude measured was 40 ft above NGVD 29 in southeastern Lincoln County.

The 2006 to 2012 difference in water levels for the Cockfield aquifer ranged from 27.4 to -10.4 ft. The largest water-level rise was in Calhoun County, and the largest water-level decline was in Union County. Of the 42 wells, 13 wells had a rise in water levels, and the remaining 29 wells had a decline in water levels from 2006 to 2012.

Analysis of selected hydrographs was divided into three geographic regions: the area east of the Saline River (Ashley, Chicot, Desha, Drew, Lincoln, and part of Cleveland Counties), the area between the Saline and Ouachita Rivers (Bradley, Calhoun, and part of Cleveland Counties), and the area west of the Ouachita River (Columbia and Union Counties). Hydrographs for wells located east of the Saline River and screened within the confined part of the Cockfield aquifer indicated changes in water levels that range from a rise of approximately 0.5 ft to a decline of approximately 57 ft over the period of record.

Hydrographs for wells located in the area between the Saline and Ouachita Rivers were screened in confined and unconfined areas of the Cockfield aquifer. The hydrographs indicate rises and declines in water levels that ranged from a rise of approximately 1 ft to a decline of approximately 23 ft over the period of record. Hydrographs for wells located in the area west of the Ouachita River indicated rises and declines in water levels that ranged from a rise of approximately 2 ft to a decline of approximately 5 ft over the period of record.

Hydrographs for the 32 wells with historical water-level data in the Cockfield aquifer were evaluated using linear regression to calculate the annual rise or decline for each well and the data were aggregated by county and statistically evaluated for the range, mean, and median of water-level change in each county. Bradley, Calhoun, Columbia, and Union Counties indicate rising and declining water levels. The mean annual water-level rise or decline for Calhoun County was 0.00 ft/yr or unchanged. The mean annual water-level data for Ashley, Bradley, Chicot, Cleveland, Columbia, Lincoln, and Union Counties show declines ranging from -0.02 to -1.10 ft/yr.

Two potentiometric-surface maps, one for the northeastern area and one for the southern area, were constructed to show the altitude of the water surface in the Wilcox aquifer. The maps were constructed using water-level data collected in February and March 2012 from 47 wells; 31 wells in the northeastern area and 16 wells in the southern area. The direction of groundwater flow in the northeastern area was generally towards the south-southwest except for some areas immediately adjacent to the Mississippi River where the flow was more eastward towards the river. The highest water-level altitude was 219 ft in northern Mississippi County, and the lowest water-level altitude was 123 ft near West Memphis in Crittenden County. In Greene County, a water-level altitude of 182 ft was measured near Crowleys Ridge. Within Crowleys Ridge, water levels in the Wilcox aquifer were perched at higher water-level altitudes than the aquifer in the surrounding Mississippi Alluvial Plain. The direction of groundwater flow in the southern area was generally towards the southwest in the northern part. The direction of groundwater flow in the southern part was in all directions because of two cones of depression and two water-level mounds. The water-level mounds are the result of the higher land-surface altitudes in the outcrop area. The highest water-level altitude measured was 394 ft at the center of the water-level mounds in eastern Hot Spring County and southwestern Hempstead County. The lowest water-level altitude measured was 145 ft at the center of the cone of depression in Clark County.

Water-level difference maps for the Wilcox aquifer in Arkansas were constructed using 47 water-level measurements made during 2006 and 2012. Difference values were obtained from water levels measured in 31 wells in the northeastern area of the Wilcox aquifer and 16 wells measured in the southern area. The difference in water levels for the Wilcox aquifer in the northeastern area ranged from 22.0 ft to -17.9 ft. The largest rise in water levels occurred in Crittenden County, and the largest decline was in Lee County. Twenty-one wells had rising water levels, and 10 wells had declining water levels. The difference in water levels for the Wilcox aquifer in the southern area ranged from 18.1 ft to -4.2 ft. The largest rise and the largest decline in water levels occurred in Nevada County. Twelve wells had rising water levels, and 4 wells had declining water levels.

Hydrographs for the northeastern area showed declining water levels. Water-level changes in selected wells ranged from a decline of approximately 23 ft to a decline of approximately 60 ft. Hydrographs in the southern area showed declining and rising water levels. Water-level changes in selected wells ranged from a rise of approximately 14 ft to a decline of approximately 20 ft.

Linear regression analysis of long-term hydrographs was used to determine the mean annual water-level rise and decline in the Wilcox aquifer in the northeastern area and southern area of Arkansas. In the northeastern area, the mean annual water level declined in all seven counties. The mean annual declines ranged from -0.55 ft/yr in Craighead County to -1.46 ft/yr in St. Francis County.

In the southern area, the annual rise or decline calculations for wells with over 20 years of record indicated rising and declining water levels in Clark, Hot Spring, and Nevada Counties. The mean annual water level declined in all counties except Hot Spring County.

This is the sixth in a series of triennial reports discussing the potentiometric surfaces of the Cockfield and Wilcox aquifers. This report and the previous five reports were prepared in cooperation with the Arkansas Natural Resources Commission and the Arkansas Geological Survey.

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Appendixes

Appendix 1. Water-level data collected during February 2012 from wells completed in the Cockfield aquifer in southern Arkansas.

[Horizontal datum is North America Datum of 1983; NGVD 29, National Geodetic Vertical Datum of 1929; Letters in parentheses correspond to well locations in figure 5 and well hydrographs in figure 7; --, missing data]

Station name	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Water-level altitude (feet above NGVD 29)	Depth to water (feet below land-surface datum)	Land-surface datum (feet above NGVD 29)	Well depth (feet)	Date of measure-ment
			Ashley County				
15S04W26CBC1	332144	912932	88	40.36	128	409	2/24/2012
17S04W10BCD2 (A)	331417	913030	81	43.58	125	340	2/24/2012
17S04W10CBA1	331406	913033	84	41.34	125	360	2/24/2012
17S06W07ADA1	331442	914510	98	76.43	174	426	2/24/2012
18S04W19DAA2	330710	913247	83	32.61	116	356	2/24/2012
18S08W04BBC1 (B)	331038	915627	61	87.62	149	314	2/24/2012
19S05W12CAC1 (C)	330336	913425	81	34.40	115	320	2/24/2012
			Bradley County				
12S10W10BCA1	334108	920807	102	125.02	227	425	2/23/2012
12S10W30CAC1	333815	921046	238	2.07	240	58	2/23/2012
14S10W31DBA1 (F)	332658	921025	95	98.12	193	349	2/23/2012
14S11W35CAB1	332656	921251	111	79.03	190	320	2/23/2012
14S11W35DAC1	332650	921233	107	67.32	174	345	2/23/2012
15S12W11CAB1 (G)	332536	921858	131	23.76	155	225	2/23/2012
16S11W11ACA1	332027	921223	109	32.39	141	140	2/23/2012
			Calhoun County				
11S13W15BBC1	334560	922534	257	53.44	310	70	2/23/2012
13S13W09CBD1	333555	922638	193	38.63	323	147	2/23/2012
13S13W15DBA1	333517	922520	209	22.78	232	122	2/23/2012
14S13W11CAC1	333045	922451	175	29.89	205	105	2/22/2012
14S13W29ADA1 (H)	332829	922722	133	27.22	160	81	2/22/2012
14S13W29DAC1	332815	922729	124	14.69	139	–	2/22/2012
14S14W21ACB1	332931	923249	119	12.87	132	160	2/22/2012
			Chicot County				
13S03W26BBB1	333247	912301	66	72.96	139	442	2/27/2012
16S02W04BAC1	332027	911857	86	38.98	125	330	2/27/2012
18S02W25ABB3 (D)	330640	911541	91	44.48	135	322	2/27/2012
18S03W14CCC1	330731	912319	83	15.32	98	320	2/27/2012
			Cleveland County				
09S10W17CDD1	335534	920942	268	2.49	270	361	2/23/2012
11S11W23BBD1 (I)	334449	921258	232	42.93	275	148	2/23/2012
			Columbia County				
17S20W35BBD1 (L)	331313	930914	350	10.52	361	–	2/22/2012
19S20W34ADC1	330233	930958	290	22.71	313	40	2/22/2012
19S21W17CBB1	330520	931857	260	46.16	306	55	2/22/2012
19S21W35ADC1	330247	931513	256	0.37	256	30	2/22/2012
19S22W36DBB1	330245	932034	308	43.43	351	69	2/22/2012
			Desha County				
12S03W30ADC1	333747	912611	75	78.54	153	280	2/27/2012
13S02W08CAA1	333504	911921	73	74.29	147	515	2/27/2012

Appendix 1. Water-level data collected during February 2012 from wells completed in the Cockfield aquifer in southern Arkansas.—Continued

[Horizontal datum is North America Datum of 1983; NGVD 29, National Geodetic Vertical Datum of 1929; Letters in parentheses correspond to well locations in figure 5 and well hydrographs in figure 7; --, missing data]

Station name	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Water-level altitude (feet above NGVD 29)	Depth to water (feet below land-surface datum)	Land-surface datum (feet above NGVD 29)	Well depth (feet)	Date of measure-ment
Drew County							
14S06W21BDC1	332846	914339	99	117.19	216	–	2/24/2012
11S05W35DDB1	334216	913438	60	119.60	180	500	2/27/2012
Lincoln County							
10S05W06CAC1 (E)	335204	913918	40	130.29	170	550	2/27/2012
Union County							
16S18W22DCD1	331913	925704	222	25.15	247	36	2/22/2012
17S13W17DDC1 (J)	331402	922746	153	40.52	193	24	2/22/2012
17S15W31DCA2	331144	924116	199	54.41	253	110	2/22/2012
17S16W33BBA2 (K)	331229	924601	230	24.63	255	31	2/22/2012
18S15W21DAC1	330824	923909	192	7.65	200	40	2/22/2012
19S12W28CBA1	330207	922109	194	6.02	200	25	2/22/2012

Appendix 2. Difference in depth to water from 2006 to 2012 in the Cockfield aquifer in southern Arkansas.

[Horizontal datum is North American Datum of 1983; Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929; positive differences in depth to water indicate a rise in water levels from 2006 to 2012 whereas negative values indicate a decline in water levels from 2006 to 2012]

Station name	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	2006 depth to water (feet below land-surface datum)	2012 depth to water (feet below land-surface datum)	Difference in water level from 2006 to 2012 (feet)
Ashley County					
15S04W26CBC1	332144	912932	41.88	40.36	1.5
17S04W10BCD2	331417	913030	38.18	43.58	-5.4
17S04W10CBA1	331406	913033	33.30	41.34	-8.0
17S06W07ADA1	331442	914510	72.85	76.43	-3.6
18S04W19DAA2	330710	913247	26.89	32.61	-5.7
18S08W04BBC1	331038	915627	80.30	87.62	-7.3
19S05W12CAC1	330336	913425	29.38	34.40	-5.0
Bradley County					
12S10W10BCA1	334108	920807	124.15	125.02	-0.9
12S10W30CAC1	333815	921046	11.66	2.07	9.6
14S10W31DBA1	332658	921025	96.47	98.12	-1.7
14S11W35CAB1	332656	921251	75.89	79.03	-3.1
14S11W35DAC1	332650	921233	65.68	67.32	-1.6
15S12W11CAB1	332536	921858	23.94	23.76	0.2
16S11W11ACA1	332027	921223	29.36	32.39	-3.0
Calhoun County					
11S13W15BBC1	334560	922534	53.18	53.44	-0.3
13S13W09CBD1	333555	922638	38.03	38.63	-0.6
13S13W15DBA1	333517	922520	23.40	22.78	0.6
14S13W11CAC1	333045	922451	28.55	29.89	-1.3
14S13W29ADA1	332829	922722	26.02	27.22	-1.2
14S13W29DAC1	332815	922729	14.24	14.69	-0.4
14S14W21ACB1	332931	923249	40.27	12.87	27.4
Chicot County					
13S03W26BBB1	333247	912301	69.34	72.96	-3.6
16S02W04BAC1	332027	911857	38.07	38.98	-0.9
18S02W25ABB3	330640	911541	46.27	44.48	1.8
18S03W14CCC1	330731	912319	14.86	15.32	-0.5
Cleveland County					
09S10W17CDD1	335534	920942	4.73	2.49	2.2
11S11W23BBD1	334449	921258	42.03	42.93	-0.9
Columbia County					
17S20W35BBD1	331313	930914	14.91	10.52	4.4
19S20W34ADC1	330233	930958	22.37	22.71	-0.3
19S21W17CBB1	330520	931857	44.12	46.16	-2.0
19S21W35ADC1	330247	931513	3.54	0.37	3.2
19S22W36DBB1	330245	932034	41.15	43.43	-2.3

Appendix 2. Difference in depth to water from 2006 to 2012 in the Cockfield aquifer in southern Arkansas.—Continued

[Horizontal datum is North American Datum of 1983;Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929; positive differences in depth to water indicate a rise in water levels from 2006 to 2012 whereas negative values indicate a decline in water levels from 2006 to 2012]

Station name	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	2006 depth to water (feet below land-surface datum)	2012 depth to water (feet below land-surface datum)	Difference in water level from 2006 to 2012 (feet)
Desha County					
12S03W30ADC1	333747	912611	72.99	78.54	-5.6
13S02W08CAA1	333504	911921	64.48	74.29	-9.8
Drew County					
14S06W21BDC1	332846	914339	120.62	117.19	3.4
Lincoln County					
10S05W06CAC1	335204	913918	126.3	130.29	-4.0
Union County					
16S18W22DCD1	331913	925704	14.71	25.15	-10.4
17S13W17DDC1	331402	922746	38.67	40.52	-1.9
17S15W31DCA2	331144	924116	52.99	54.41	-1.4
17S16W33BBA2	331229	924601	25.54	24.63	0.9
18S15W21DAC1	330824	923909	26.13	7.65	18.5
19S12W28CBA1	330207	922109	10.73	6.02	4.7

Appendix 3. Water-level data collected during February and March 2012 from wells completed in the Wilcox aquifer in northeastern Arkansas.

[Horizontal datum is North America Datum of 1983; NGVD 29, National Geodetic Vertical Datum of 1929; Letters in parentheses correspond to well locations in figure 9 and well hydrographs in figure 13]

Station name	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Water-level altitude (feet above NGVD 29)	Depth to water (feet below land-surface datum)	Land-surface datum (feet above NGVD 29)	Well depth (feet)	Date of measure-ment
			Craighead County				
13N07E14BBA2	354526	901911	196	24.72	221	1,028	2/29/2012
14N05E25DCB1	354843	903029	193	40.52	233	890	2/29/2012
14N06E27ACB2	354858	902613	197	30.39	227	999	2/29/2012
14N07E17DCB1 (M)	355008	902202	200	32.17	232	1,070	2/29/2012
15N07E33BAD1	355315	902107	205	26.68	232	1,034	2/29/2012
			Crittenden County				
04N07E36ADB1	345449	901828	135	66.38	201	1,638	2/28/2012
05N07E29ACC1	350129	902225	145	54.77	200	1,700	2/28/2012
06N07E01ABB1	350520	901807	141	66.16	207	1,541	2/28/2012
06N09E07CAC1	350907	901042	123	86.72	210	1,470	2/28/2012
07N07E14CCC1	351318	901930	176	46.91	223	1,584	2/28/2012
07N08E24CAB1	351238	901148	148	73.36	221	1,540	2/28/2012
08N06E33CBD1 (N)	351614	902752	163	52.41	215	1,750	2/28/2012
09N08E29ADD1	352225	901516	165	60.57	225	1,564	2/28/2012
			Greene County				
17N06E31DCB1 (O)	360328	902902	182	103.23	285	462	2/29/2012
			Lee County				
01N04E09DCC1 (P)	344209	904220	136	67.93	204	1,885	2/28/2012
03N05E01BAB1	345413	903136	127	69.06	196	1,702	2/28/2012
			Mississippi County				
11N09E33AAB1	353214	900739	187	49.77	237	1,560	3/1/2012
11N10E20ADA1	353349	900213	189	45.57	235	1,417	3/1/2012
12N11E17CDD1	353917	895618	191	54.02	245	1,500	3/1/2012
13N11E08DDA1	354528	895547	203	41.82	245	1,445	3/1/2012
13N11E31CCCC1	354221	895807	204	37.37	241	1,500	3/1/2012
14N11E20CCA1	354859	895626	205	34.77	240	1,518	3/1/2012
15N09E31ACD1 (Q)	355306	900952	206	34.19	240	1,158	2/29/2012
15N10E01ADC1	355712	895806	219	28.96	248	1,350	2/29/2012
15N12E23DBC1	355426	894701	197	41.03	238	1,491	3/1/2012
			Poinsett County				
10N07E16CBB2	352925	902129	166	51.60	218	1,500	3/1/2012
11N05E06CCD1	353622	903618	179	35.21	214	992	3/2/2012
11N07E03BDD1	353629	901955	178	38.15	216	1,456	3/2/2012
12N05E13BBB1 (R)	354038	903059	183	39.66	222	1,071	3/2/2012
			St. Francis County				
04N06E16CCB1	345712	902830	143	59.35	202	1,615	2/28/2012
04N06E21BAD2 (S)	345649	902815	136	65.48	201	1,740	2/28/2012

Appendix 4. Water-level data collected during February and March 2012 from wells completed in the Wilcox aquifer in southern Arkansas.

[Horizontal datum is North America Datum of 1983; NGVD 29, National Geodetic Vertical Datum of 1929; Letters in parentheses correspond to well locations in figure 10 and well hydrographs in figure 14; --, missing data]

Station name	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Water-level altitude (feet above NGVD 29)	Depth to water (feet below land-surface datum)	Land-surface datum (feet above NGVD 29)	Well depth (feet)	Date of measurement
Clark County							
07S18W03BBD1	340917	925604	267	2.75	270	47	2/21/2012
07S18W20ABB2	340652	925757	232	9.86	242	19	2/21/2012
09S18W20CBB1 (U)	335611	925905	210	20.10	230	26	2/22/2012
10S18W10DDB1 (T)	335216	925613	145	49.99	195	215	2/21/2012
Hempstead County							
13S23W04BDD1	333842	932911	345	4.51	350	14	2/21/2012
13S24W02DCA2	333829	933311	394	51.92	446	63	2/21/2012
13S24W29ACC1	333524	933635	341	29.98	371	60	2/21/2012
14S24W29BCA1 (W)	333017	933704	334	21.04	355	31	2/21/2012
Hot Springs County							
04S16W20CBB1 (V)	342144	924532	342	2.73	345	18	2/21/2012
05S17W10AAC1	341836	924853	394	15.57	410	26	2/21/2012
Nevada County							
12S22W24CDA1	334046	931941	313	31.21	344	41	2/21/2012
13S21W02DCC1	333754	931426	251	63.53	315	240	2/21/2012
13S21W11BDA1	333738	931432	242	25.91	268	–	2/21/2012
13S21W23ABC1	333556	931423	319	42.56	362	47	2/21/2012
14S22W19AAA1 (X)	333105	932443	329	7.92	337	75	2/21/2012
Ouachita County							
12S19W11DCD1	334144	930105	282	5.92	288	533	2/21/2012

Appendix 5. Difference in depth to water from 2006 to 2012 in the Wilcox aquifer in northeastern Arkansas.

[Horizontal datum is North American Datum of 1983; Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929; positive differences in depth to water indicate a rise in water levels from 2006 to 2012 whereas negative values indicate a decline in water levels from 2006 to 2012]

Station name	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	2006 depth to water (feet below land-surface datum)	2012 depth to water (feet below land-surface datum)	Difference in water level from 2006 to 2012 (feet)
Craighead County					
13N07E14BBA2	354526	901911	26.89	24.72	2.2
14N05E25DCB1	354843	903029	42.24	40.52	1.7
14N06E27ACB2	354858	902613	30.98	30.39	0.6
14N07E17DCB1	355008	902202	35.57	32.17	3.4
15N07E33BAD1	355315	902107	28.00	26.68	1.3
Crittenden County					
04N07E36ADB1	345449	901828	59.09	66.38	-7.3
05N07E29ACC1	350129	902225	61.52	54.77	6.8
06N07E01ABB1	350520	901807	66.06	66.16	-0.1
06N09E07CAC1	350907	901042	90.44	86.72	3.7
07N07E14CCC1	351318	901930	68.93	46.91	22.0
07N08E24CAB1	351238	901148	68.37	73.36	-5.0
08N06E33CBD1	351614	902752	53.96	52.41	1.6
09N08E29ADD1	352225	901516	56.03	60.57	-4.5
Greene County					
17N06E31DCB1	360328	902902	104.00	103.23	0.8
Lee County					
01N04E09DCC1	344209	904220	62.62	67.93	-5.3
03N05E01BAB1	345413	903136	51.18	69.06	-17.9
Mississippi County					
11N09E33AAB1	353214	900739	52.29	49.77	2.5
11N10E20ADA1	353349	900213	47.07	45.57	1.5
12N11E17CDD1	353917	895618	52.79	54.02	-1.2
13N11E08DDA1	354528	895547	59.03	41.82	17.2
13N11E31CCCC1	354221	895807	53.51	37.37	16.1
14N11E20CCA1	354859	895626	37.88	34.77	3.1
15N09E31ACD1	355306	900952	40.69	34.19	6.5
15N10E01ADC1	355712	895806	39.93	28.96	11.0
15N12E23DBC1	355426	894701	56.59	41.03	15.6
Poinsett County					
10N07E16CBB2	352925	902129	51.03	51.60	-0.6
11N05E06CCD1	353622	903618	42.72	35.21	7.5
11N07E03BDD1	353629	901955	41.03	38.15	2.9
12N05E13BBB1	354038	903059	47.28	39.66	7.6
St. Francis County					
04N06E16CCB1	345712	902830	54.36	59.35	-5.0
04N06E21BAD2	345649	902815	61.81	65.48	-3.7

Appendix 6. Difference in depth to water from 2006 to 2012 in the Wilcox aquifer in southern Arkansas.

[Horizontal datum is North American Datum of 1983; Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929; positive differences in depth to water indicate a rise in water levels from 2006 to 2012, whereas negative values indicate a decline in water levels from 2006 to 2012]

Station name	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	2006 depth to water (feet below land-surface datum)	2012 depth to water (feet below land-surface datum)	Difference in water level from 2006 to 2012 (feet)
Clark County					
07S18W03BBD1	340917	925604	14.72	2.75	12.0
07S18W20ABB2	340652	925757	11.63	9.86	1.8
09S18W20CBB1	335611	925905	18.03	20.10	-2.1
10S18W10DDB1	335216	925613	48.31	49.99	-1.7
Hempstead County					
13S23W04BDD1	333842	932911	4.91	4.51	0.4
13S24W02DCA2	333829	933311	48.9	51.92	-3.0
13S24W29ACC1	333524	933635	31.6	29.98	1.6
14S24W29BCA1	333017	933704	25.68	21.04	4.6
Hot Springs County					
04S16W20CBB1	342144	924532	4.25	2.73	1.5
05S17W10AAC1	341836	924853	18.85	15.57	3.3
Nevada County					
12S22W24CDA1	334046	931941	32.01	31.21	0.8
13S21W02DCC1	333754	931426	59.31	63.53	-4.2
13S21W11BDA1	333738	931432	26.07	25.91	0.2
13S21W23ABC1	333556	931423	43.28	42.56	0.7
14S22W19AAA1	333105	932443	26.03	7.92	18.1
Ouachita County					
12S19W11DCD1	334144	930105	13.82	5.92	7.9

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