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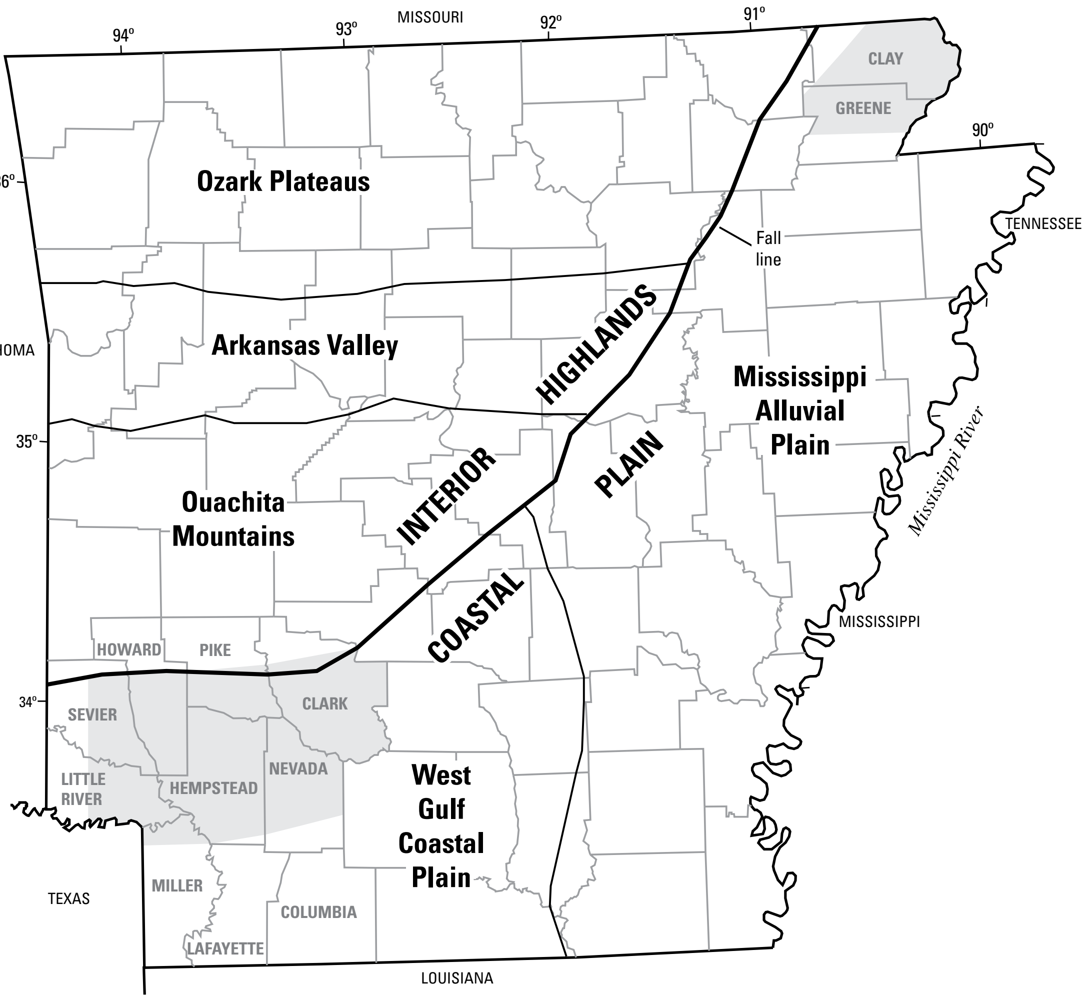
Water Levels in the Aquifers of the Nacatoch Sand of Southwestern and Northeastern Arkansas and the Tokio Formation of Southwestern Arkansas, February–March 2011



Scientific Investigations Report 2013–5130

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

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

U.S. Geological Survey
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U.S. Geological Survey, Reston, Virginia: 2013

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Contents

Figures

Tables

Conversion Factors, Vertical Datums, and Abbreviations

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)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
gallons per foot per day	0.012419	cubic meter per meter per day ($m^3/m/d$)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

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

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

Water Levels in the Aquifers of the Nacatoch Sand of Southwestern and Northeastern Arkansas and the Tokio Formation of Southwestern Arkansas, February–March 2011

By T.P. Schrader and Kirk D. Rodgers

Abstract

The aquifers in the Nacatoch Sand and Tokio Formation in southwestern Arkansas and the Nacatoch Sand in northeastern Arkansas are sources of water for industrial, public supply, domestic, and agricultural uses. Potentiometric-surface maps were constructed from water-level measurements made in 47 wells completed in the Nacatoch Sand and 45 wells completed in the Tokio Formation during February and March 2011. Aquifers in the Nacatoch Sand and Tokio Formation are hereafter referred to as the Nacatoch aquifer and the Tokio aquifer, respectively.

The direction of groundwater flow in the Nacatoch aquifer in southwestern Arkansas is towards the southeast in Hempstead, Little River, and Miller Counties and east-southeast in Clark and Nevada Counties. A potentiometric high is located within the outcrop area of north-central Hempstead County. Two cones of depression exist in the Nacatoch aquifer, one at Hope in southeastern Hempstead County and one in Clark County.

The direction of groundwater flow in the Nacatoch aquifer in northeastern Arkansas generally is towards the southeast. A potentiometric high in the study area is located along the north and northwestern boundaries of the area, but water levels may be higher outside the study area.

In northeastern Arkansas, groundwater withdrawals from the Nacatoch aquifer increased by 564 percent from 1965 to 2010. In southwestern Arkansas, groundwater withdrawals from the Nacatoch Sand increased by 125 percent from 1965 to 1980, and withdrawals decreased by 85 percent from 1980 to 2010. In southwestern Arkansas, groundwater withdrawals from the Tokio aquifer increased by 201 percent from 1965 to 1980, and withdrawals decreased by 81 percent from 1980 to 2000. Withdrawals from the Tokio aquifer increased by 291 percent from 2000 to 2005, and withdrawals decreased by 32 percent from 2005 to 2010.

The direction of groundwater flow in the Tokio aquifer in southwestern Arkansas generally is towards the south or southeast. The potentiometric high is within the outcrop area in the northern part of the area. Artesian flow exists or is inferred in southeastern Pike, northeastern Hempstead, and northwestern Nevada Counties. One apparent cone of depression might exist northwest of Hope in Hempstead County.

Introduction

Groundwater is a renewable resource important for economic growth and quality of life. Aquifers in the Nacatoch Sand and Tokio Formation in southwestern Arkansas and the Nacatoch Sand in northeastern Arkansas are sources of water for industrial, public supply, domestic, and agricultural uses. Monitoring of groundwater levels and withdrawals provides information needed to plan and manage the resource effectively. 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 provide potentiometric-surface maps and water-level hydrographs associated with aquifers in the Nacatoch Sand and Tokio Formation (hereafter referred to as the Nacatoch aquifer and Tokio aquifer, respectively) in southwestern Arkansas and the Nacatoch aquifer in northeastern Arkansas.

The study areas comprise parts of 10 counties in two areas of northeastern and southwestern Arkansas. The northeastern study area includes most of Clay and Greene Counties in the Mississippi Alluvial Plain physiographic province (fig. 1). This area is bounded on the north and east by the Missouri State line and on the west by the western extent of the Nacatoch aquifer. The southern boundary of this area was defined by the southern extent of water withdrawals from wells screened in the Nacatoch aquifer. The southwestern study area includes parts of eight counties (Clark, Hempstead, Howard, Little River, Miller, Nevada, Pike, and Sevier) in the West Gulf Coastal Plain physiographic province (fig. 1). This area is bounded on the north by the Fall Line separating the

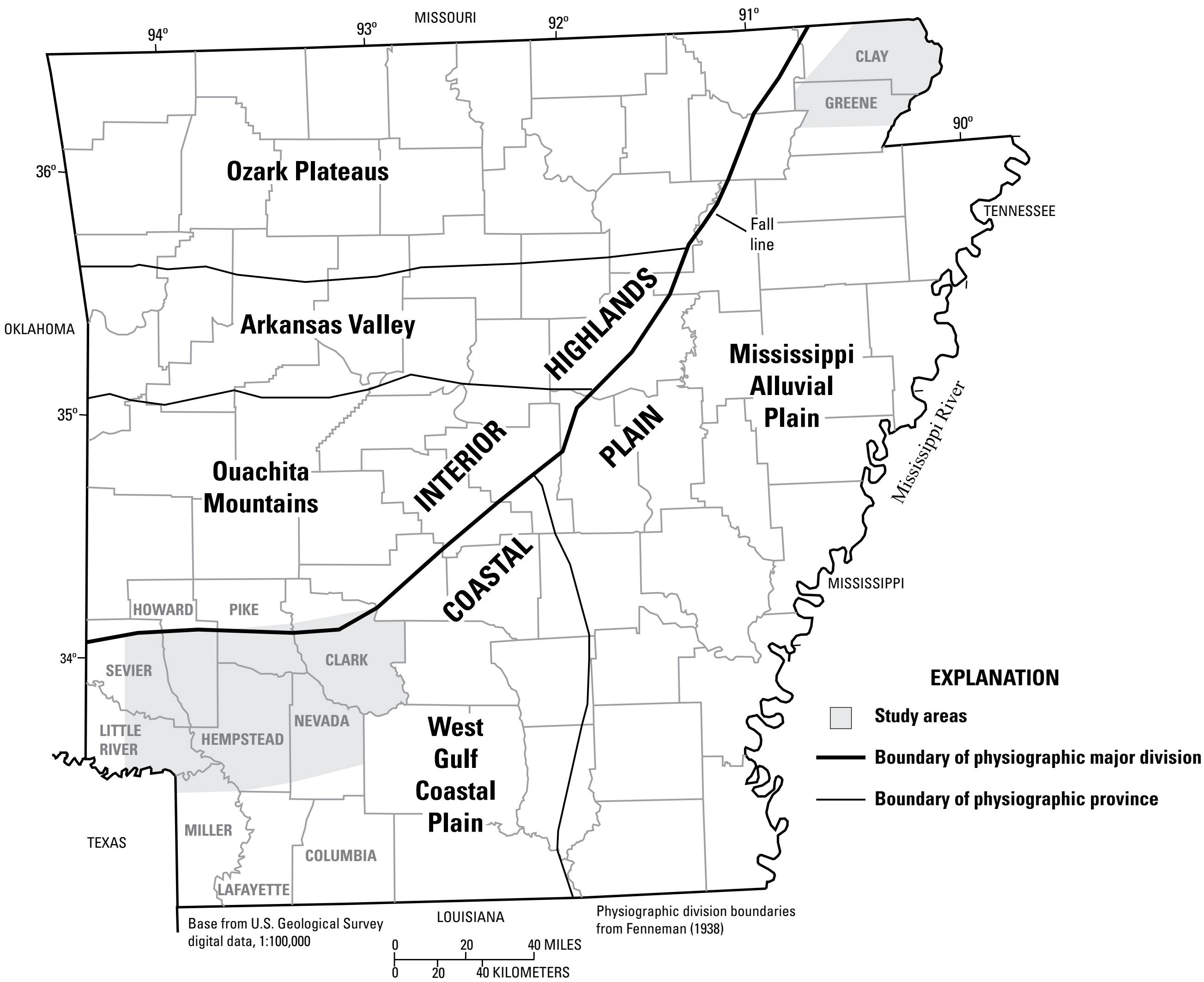

Figure 1. Location of study areas.

Interior Highlands from the West Gulf Coastal Plain, on the west by the extent of use and the availability of wells, and on the east by the eastern borders of Clark and Nevada Counties. The southwestern study area was limited to the occurrence of freshwater where the southern boundary of the area is defined by a freshwater/saltwater interface. To the south, the groundwater is considered saline (more than 1,000 milligrams per liter of dissolved solids) and is not suitable for most uses (Boswell and others, 1965; Petersen and others, 1985).

This report presents the results of water-level measurements made in 47 wells completed in the Nacatoch aquifer and in 45 wells completed in the Tokio aquifer during February and March 2011. These measurements were used to construct potentiometric-surface maps. All water-level data are stored in the USGS Ground-Water Site Inventory (GWSI) data storage system and are available at http://waterdata.usgs.gov. Long-term water-level hydrographs were prepared for selected wells. Water-level data collected by the USGS from 1965 to 2010 were used to construct the hydrographs. The Tokio Formation is stratigraphically below the Nacatoch Sand and separated by five stratigraphic units, listed here in descending stratigraphic order: Saratoga Chalk, Marlbrook Marl, Annona Chalk, Ozan Formation, and Brownstown Marl. The Saratoga Chalk, Marlbrook Marl, and Annona Chalk are nonwater-bearing and the five-unit section can obtain a thickness of 900 feet (ft) (Petersen and others, 1985). These five units rarely are used as water sources and are not discussed in this report.

Cones of depression within a potentiometric surface are indicators of where pumping rates are exceeding the local recharge rates to the aquifer. As a well is pumped, water levels are drawn down, forming a local cone of depression. Water levels will recover over time if pumping rates do not continue to exceed the recharge rates to the aquifer. Pumping rates that exceed recharge rates for an extended period of time will cause cones of depression to enlarge. Local cones of depression can intersect and coalesce, causing a regional decrease in water levels within the aquifer. Variations in climatic conditions and resulting recharge rates can result in the natural rise or decline of water levels and could account for changes shown by long-term hydrographs.

Methods

Water-Level Measurements

Personnel from the USGS measured water levels during February and March 2011 in wells screened in the Nacatoch or Tokio aquifers. Measurements by USGS personnel were made with steel or electric tapes graduated in hundredths of a foot. The steel and electric tapes were calibrated during January 2011 prior to collecting measurements from wells. 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 (Cunningham and Schalk, 2011).

Well locations were measured using Global Positioning System receivers to acquire the horizontal coordinate information (latitude and longitude) based on the North American Datum of 1983. Land-surface altitude, feet above National Geodetic Vertical Datum of 1929 (NGVD 29), was determined for each well by superposition of the wells latitude and longitude on a USGS 7.5-minute quadrangle topographic map and is accurate to about one-half the topographic contour interval of 5 to 10 ft. Herein, all water-level and land-surface altitudes are referenced to NGVD 29.

The well-numbering system used in this report is based upon the location of the wells according to the Public Land Survey System used in Arkansas. The component parts of a well number are the township number; the range number; the section number; three letters that 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 of the well in the quarter-quarter-quarter section. The letters are assigned counterclockwise, beginning with “A” in the northeast quarter, quarter-quarter or quarter-quarter-quarter section. 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 the quarter-quarter-quarter section of section 4 from which data were collected.

Linear Regression

Two methods are used for calculating the annual rise or decline of water levels. One method is to take the difference between the final and initial water levels and divide by the period of time. This method uses two measurements, and calculated values are dependent solely on the final and initial water levels. A second method uses the linear regression of water levels and time of measurement to calculate the annual rise or decline of water levels. Linear regression is more robust because it includes all the measurements to determine the trend line, resulting in a value that is dependent on all water levels during the period of record. The slope, β (equation 1), of the line is the annual rise or decline of water levels. The intercept, β_0, is the water level in the year 1900, the origin for the graph. The predevelopment water level will not be discussed as this condition cannot be demonstrated. The equation of the regression line or line of best fit, Y = aX + b, may be written as:

$$h = \beta t + \beta_0 \tag{1}$$

where

- h is water-level altitude, in feet;
- β is the slope of the line, in feet per year;
- t is time, in years; and
- β_0 is the y-intercept or water-level altitude at time equal to 1900, in feet.

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).

Geographic Information System (GIS) Methods

Longitude and latitude of wells were obtained from the USGS National Water Information System (NWIS) and geocoded using ArcGIS (Esri, 2011). The coordinates and the measured water levels then were used to construct potentiometric maps of the Nacatoch and Tokio aquifers by interpolation. This process produces a raster image that assigns a range of values to each color in the image. The image then is converted to contour polylines using the raster to contour tool. Upon conversion, the contour polylines were corrected and refined using the PAEK (Polynomial Approximation with Exponential Kernel) method of smoothing (Bodansky and others, 2002). This 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.

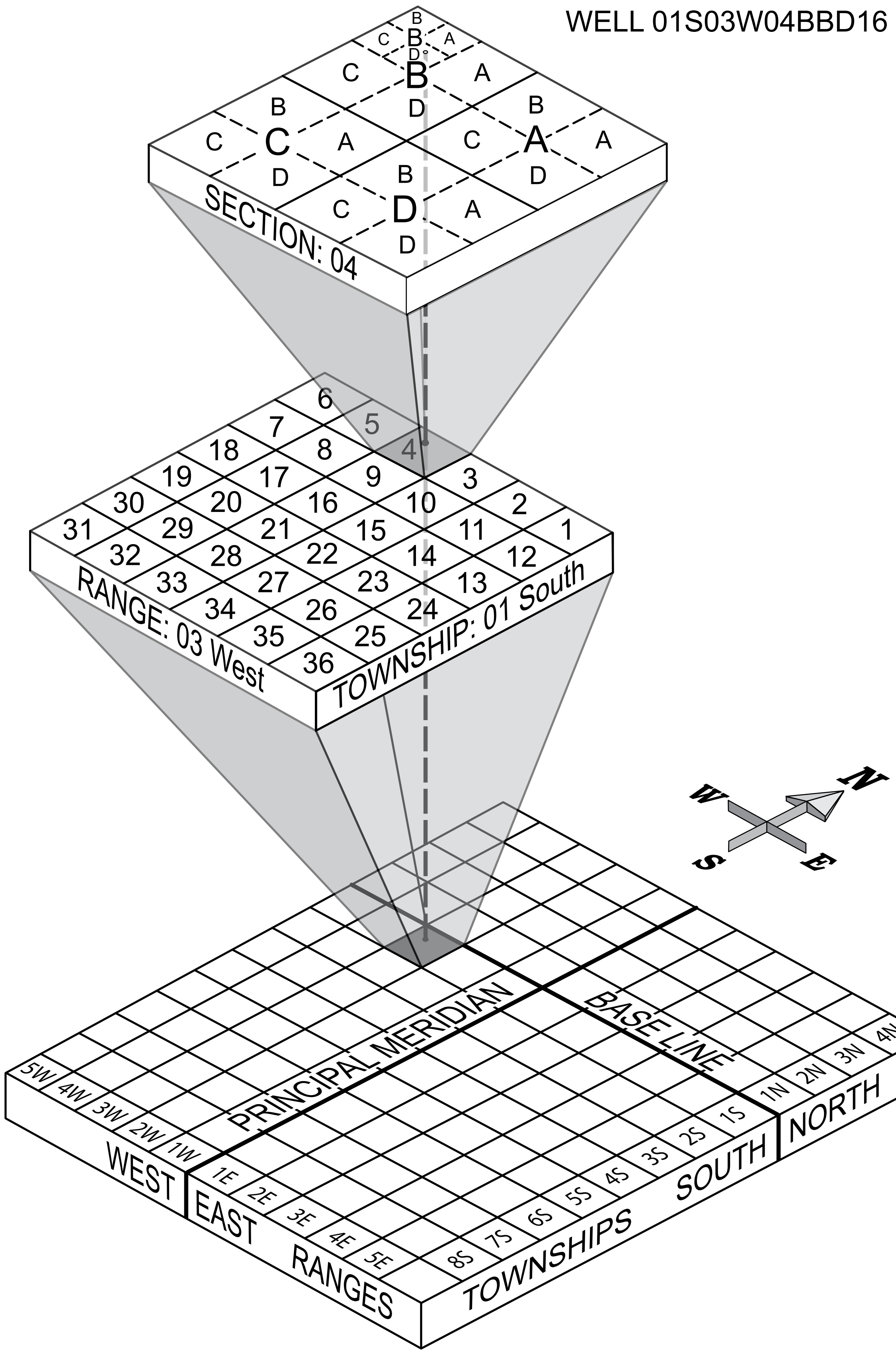

Figure 2. Diagram showing well-numbering system.

Nacatoch Sand

Hydrogeologic Setting

The Nacatoch Sand of the Navarro Group of Late Cretaceous age is underlain by the Saratoga Chalk and overlain by the Arkadelphia Marl. In the northeastern study area, the Nacatoch Sand subcrops beneath Quaternary alluvial and terrace deposits at its western extent. The altitude of the top of the Nacatoch Sand ranges from 50 to 100 ft above NGVD 29 along the western extent and dips southeasterly to 1,200 ft below NGVD 29 at the Mississippi River. Petersen and others (1985) found this unit to be approximately 100 ft in thickness at the subcrop increasing to near 600 ft at the downdip extent of the formation. In the northeastern study area, the Nacatoch Sand is composed of fine sand, interbedded clay and limestone in the lower part, increasing in grade upward to loose fine quartz sand in the upper part (Petersen and others, 1985). In western Clay and Greene Counties, the Nacatoch Sand is recharged by precipitation through the overlying alluvial and terrace deposits.

The Nacatoch Sand in the southwestern study area outcrops in a 3- to 8-mile (mi) wide belt from central Clark County southwestward towards western Hempstead County. Across Little River County, the belt subcrops beneath alluvial and terrace deposits (Boswell and others, 1965). The highest altitude of the Nacatoch Sand in the southwestern study area is approximately 300 ft above NGVD 29 in the outcrop and descends southeasterly to about 800 ft below NGVD 29 at the southern extent of the area. At the outcrop, the Nacatoch Sand is about 100 ft in thickness and has a maximum thickness of 600 ft (Petersen and others, 1985). The Nacatoch Sand in the southwestern study area is composed of three distinct units. The lower unit contains interbedded gray clay, sandy clay and marl, dark clayey fine-grained sand, and hard irregular concretionary beds with lenses of slightly glauconitic calcareous fossiliferous sand (Plebuch and Hines, 1969). The middle unit is composed of dark-green sand with coarse glauconite grains. The unit is fossiliferous where it is glauconitic and contains irregular concretionary beds (Plebuch and Hines, 1969). The upper unit consists of gray, fine-grained, unconsolidated quartz sand that is commonly crossbedded. Locally, the Nacatoch Sand has a few hard lenses and locally, is massive with beds of fossiliferous, sandy limestone. The upper unit is the primary water-bearing unit of the Nacatoch Sand (Counts and others, 1955; Plebuch and Hines, 1969; Ludwig, 1972).

Recharge of the Nacatoch aquifer in the southwestern area occurs by precipitation in the outcrop areas of Clark, Hempstead, and Nevada Counties and through the overlying alluvium and terrace deposits in Little River County and northeastern Texas. The Nacatoch aquifer supplies water to northeastern Clay and Greene Counties, southern Clark County, central Hempstead County, southeastern Little River County, northern Miller County, and northwestern Nevada County.

In the valleys of Clark and Nevada Counties, artesian wells yield 1 to 2 gallons per minute (gal/min). Wells yield 150 to 300 gal/min in Hempstead and western Nevada Counties. In the southwestern area, 2 to 20 miles southeast of the outcrop, groundwater can be saline. Groundwater flow in the Nacatoch Sand is generally to the southeast. In Clark, Miller, and Nevada Counties, well yields are low and may contain substantial concentrations of chloride (Counts and others, 1955).

Estimated withdrawals from the northeastern study area of the Nacatoch Sand from 1965 to 2010 rose 564 percent from 0.25 million gallons per day (Mgal/d) to 1.66 Mgal/d with a maximum usage in 1990 of 2.21 Mgal/d (fig. 3). From 1990 to 2010, withdrawal rates decreased by 25 percent from 2.21 Mgal/d to 1.66 Mgal/d (Holland, 1993, 1999, 2004, 2007; Terrance W. Holland, U.S. Geological Survey, written commun., 2013).

Withdrawals from the southwestern study area of the Nacatoch Sand were estimated to be 2.11 Mgal/d in 1965 and increased by 125 percent in 1980 to 4.75 Mgal/d (fig. 4). From 1980 to 2010, withdrawals decreased by 85 percent. This decrease has been attributed to public water supplies converting to surface-water sources and relying less on groundwater sources (Halberg and Stephens, 1966; Halberg, 1972, 1977; Holland and Ludwig, 1981; Holland, 1987, 1993, 1999, 2004, 2007; Terrance W. Holland, U.S. Geological Survey, written commun., 2013).

Potentiometric Surface

Potentiometric-surface maps of the Nacatoch aquifer were constructed using measurements from 47 wells collected during February and March 2011 (figs. 5 and 6; table 1). Water-level altitudes were calculated (table 1) and used to map the potentiometric surface, which is represented by contour lines showing water-level altitudes of equal value (figs. 5 and 6). Groundwater flow, in general, is perpendicular to contour lines in the direction of downward hydraulic gradient.

In the northeastern Nacatoch study area (fig. 5), groundwater-flow direction is towards the southeast. A potentiometric high of 271 ft above NGVD 29 is located along the northern border of the study area in Clay County. The lowest water-level altitude of 233 ft was measured in northeastern Greene County.

Groundwater-flow direction in the southwestern Nacatoch study area (fig. 6) is towards the southeast in Hempstead, Little River, and Miller Counties and east-southeast in Clark and Nevada Counties. An increase in the clay content in the direction of the downdip may affect the direction of groundwater flow (Boswell and others, 1965). The highest water-level altitude of 443 ft was measured in the outcrop area of north-central Hempstead County. The lowest water-level altitude of 143 ft was found near Hope in southern Hempstead County and probably is associated with pumping in the area.

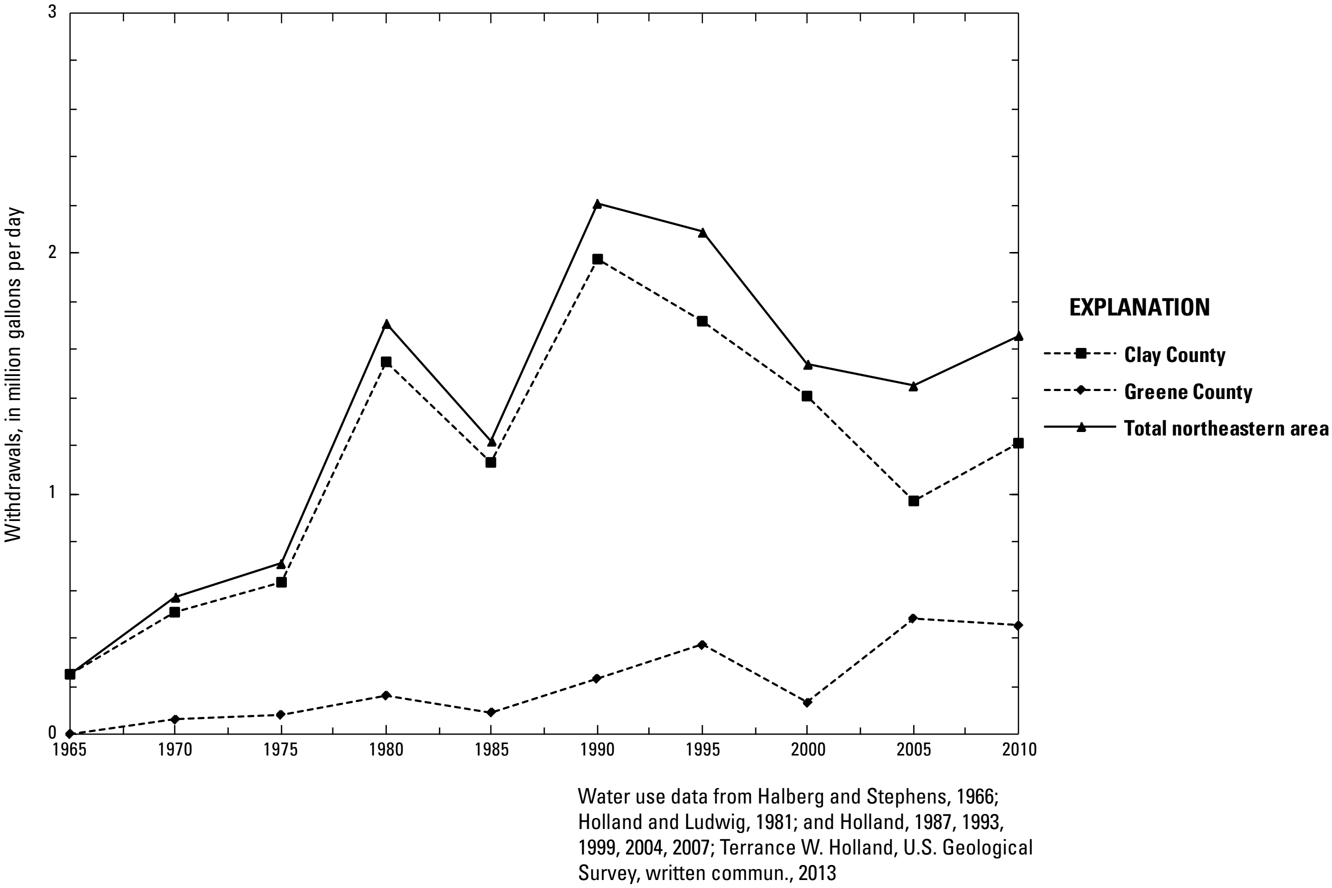

Figure 3. Estimated withdrawals by county from the Nacatoch aquifer for the northeastern study area.

A cone of depression exists in Hempstead County at Hope. Historical water levels decreased 40 ft from 185 ft in 1942 to 145 ft in 1969 (Ludwig, 1972). In January of 2002, the water-level altitude was 119 ft (Schrader and Scheiderer, 2004). This depression alters local groundwater flow from the regional direction, with groundwater flowing towards Hope from the west, north, and northeast directions (Schrader, 2007). Another cone of depression exists in Clark County. Water levels in the cone of depression have risen from 146 ft in 2002 to 152 ft in 2011. Minor variations are seen in the water levels in the remaining southwest and northeast study areas when compared to those published in previous studies.

Long-Term Water-Level Changes

Six hydrographs (two in the northeastern study area and four in the southwestern study area) from wells completed in the Nacatoch Sand with long-term water-level measurements (minimum of 20 years) were constructed. Annual decline or rise in feet per year (ft/yr) for water levels for each well was determined using linear regression. A 20-year minimum period reduces the effect of short-term localized pumping rates and variations in climate on water levels in a single well.

Evaluation of long-term data indicates declining water levels in the northeastern study area (fig. 7). Clay County well 21N06E23DAC1 (Site A) shows an average annual decrease of 0.51 ft/yr. Clay County well 20N08E10ABC1 (Site B) shows an average annual decrease of 1.06 ft/yr. This decline could be associated with increased withdrawals from 0.25 Mgal/d in 1965 to 1.98 Mgal/d in 1990 (Holland, 1993, 1999, 2004, 2007; Terrance W. Holland, U.S. Geological Survey, written commun., 2013), a 692-percent increase (fig. 3). The withdrawal rate in Clay County decreased by 39 percent (fig. 3) from 1.98 Mgal/d in 1990 to 1.21 Mgal/d in 2010 (Holland, 1993, 1999, 2004, 2007; Terrance W. Holland, U.S. Geological Survey, written commun., 2013). The decrease in water level shows no apparent relation to withdrawals, however, it could be caused by water leakage to underlying rock units or from climatic variations.

Hydrographs from four wells having historical water-level measurements in the southwestern study area are shown in figure 7 (sites C–F).The water-level hydrograph for Clark County well 08S19W09ACC1 (Site C, fig. 7) shows an annual decrease of 0.18 ft/yr. Water level overall has decreased from 185.91 ft in 1963 to 177.30 ft in 2011. Estimated withdrawals

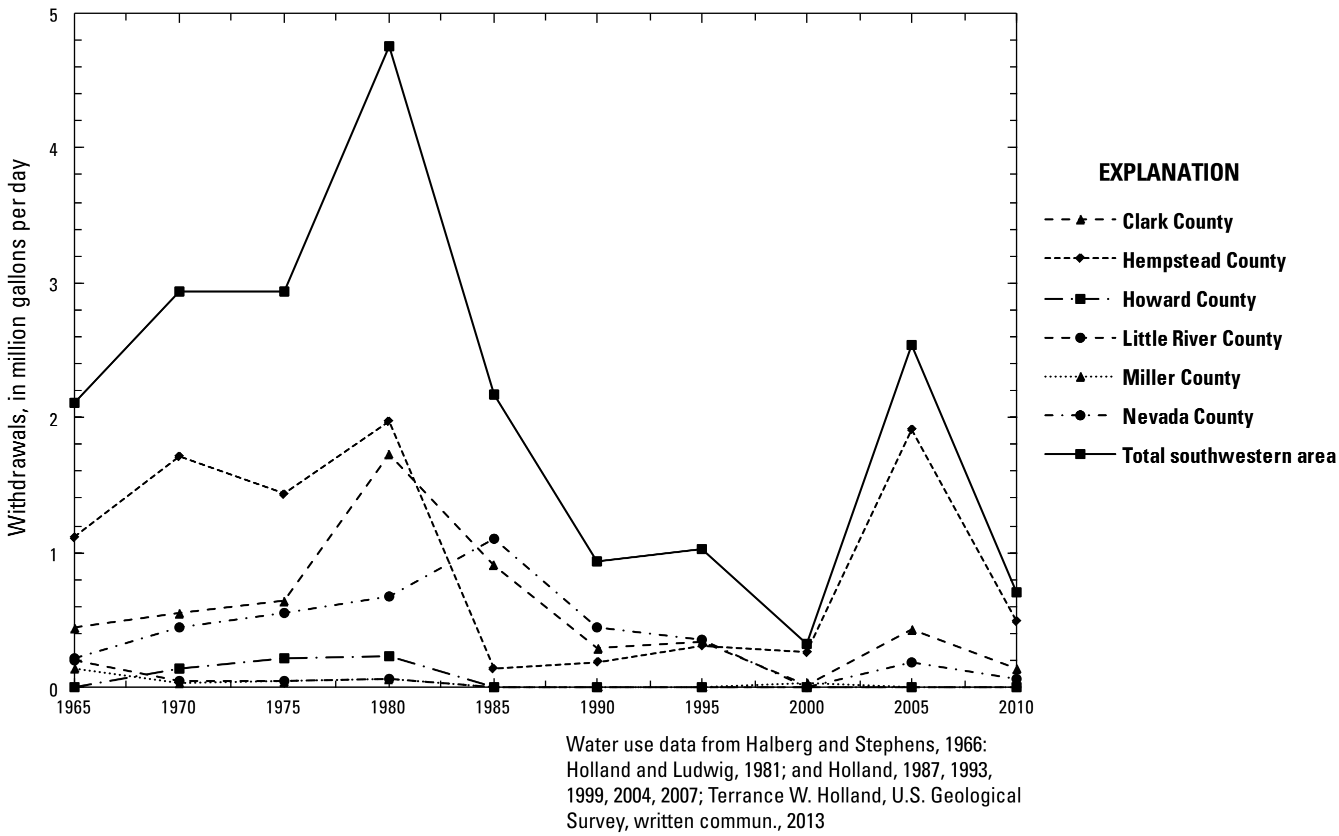

Figure 4. Estimated withdrawals from the Nacatoch aquifer for the southwestern study area.

from Clark County vary over this time period. Between 1990 and 1995, withdrawal rates increased slightly from 0.29 Mgal/d to 0.34 Mgal/d; from 1995 to 2000, the rate of withdrawal decreased to 0.02 Mgal/d. This may be associated with a decrease in pumping rates. Between 2000 and 2005, withdrawal rates increased from 0.02 Mgal/d to 0.43 Mgal/d; in 2010, withdrawal rates decreased to 0.14 Mgal/d. (fig. 4; Holland, 1993, 1999, 2004, 2007; Terrance W. Holland, U.S. Geological Survey, written commun., 2013).

The water-level hydrograph for Hempstead County well 13S25W35DDC1 (Site D, fig. 7) shows an annual increase of 0.15 ft/yr. From 1975 to 1979, water level decreased from 187.74 ft to 175.11 ft. During this time period, withdrawals increased from 1.44 Mgal/d in 1975 to 1.98 Mgal/d in 1980 (Halberg, 1977; Holland and Ludwig, 1981). From 1979 to 1999, the water level increased from 175 ft to 220 ft. From 1980 to 1985, withdrawal estimates decreased by 92 percent, from 1.98 Mgal/d to 0.15 Mgal/d (Holland, 1987). Withdrawal estimates increased slightly from 0.15 Mgal/d in 1985 to 0.32 Mgal/d in 1995 then decreased to 0.27 Mgal/d in 2000. Between 2000 and 2005, withdrawal estimates increased by 611 percent from 0.27 Mgal/d to 1.92 Mgal/d. Overall withdrawal estimates for Hempstead County between 2005 and 2010 decreased by 1.42 Mgal from 1.92 Mgal/d in 2005 to 0.50 Mgal/d in 2010 (Holland, 2007; T.W. Holland, U.S. Geological Survey, written commun., 2013), a 74-percent decrease in withdrawals.

The water-level hydrograph for Miller County well 14S28W13CCB1 (Site E, fig. 7) shows an annual increase of 0.07 ft/yr from 1966 to 2011. Water levels have remained relatively stable since 1966. Withdrawal estimates from Miller County have not changed since 2005 (Holland, 2007; Terrance W. Holland, U.S. Geological Survey, written commun., 2013).

The water-level hydrograph for Nevada County well 11S22W08DAC2 (Site F, fig. 7) shows that between 1985 and 1988, water levels increased 88.84 ft. Water use decreased from 1.11 Mgal/d to 0.44 Mgal/d between 1985 and 1990 (Holland, 1987, 1993). The increase in water level may be associated with decreased pumping rates. Water level has not changed appreciably since 1990. Although water levels in these six wells may be associated with changes in water use, they also may be affected by climatic variations or changes in leakage to and from overlying and underlying rock units (Schrader, 2007).

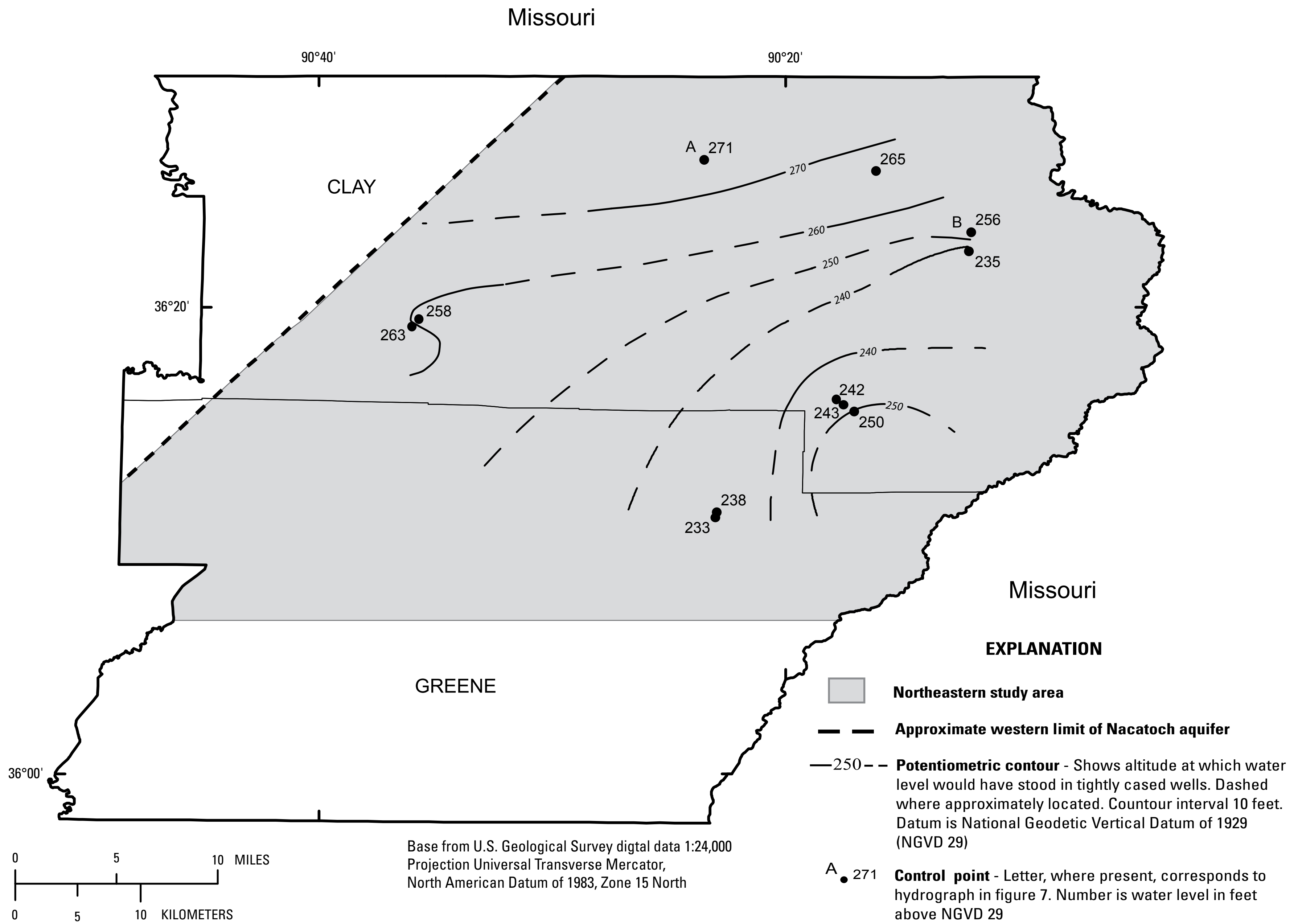

Figure 5. Potentiometric surface of the Nacatoch aquifer, northeastern Arkansas, February and March 2011.

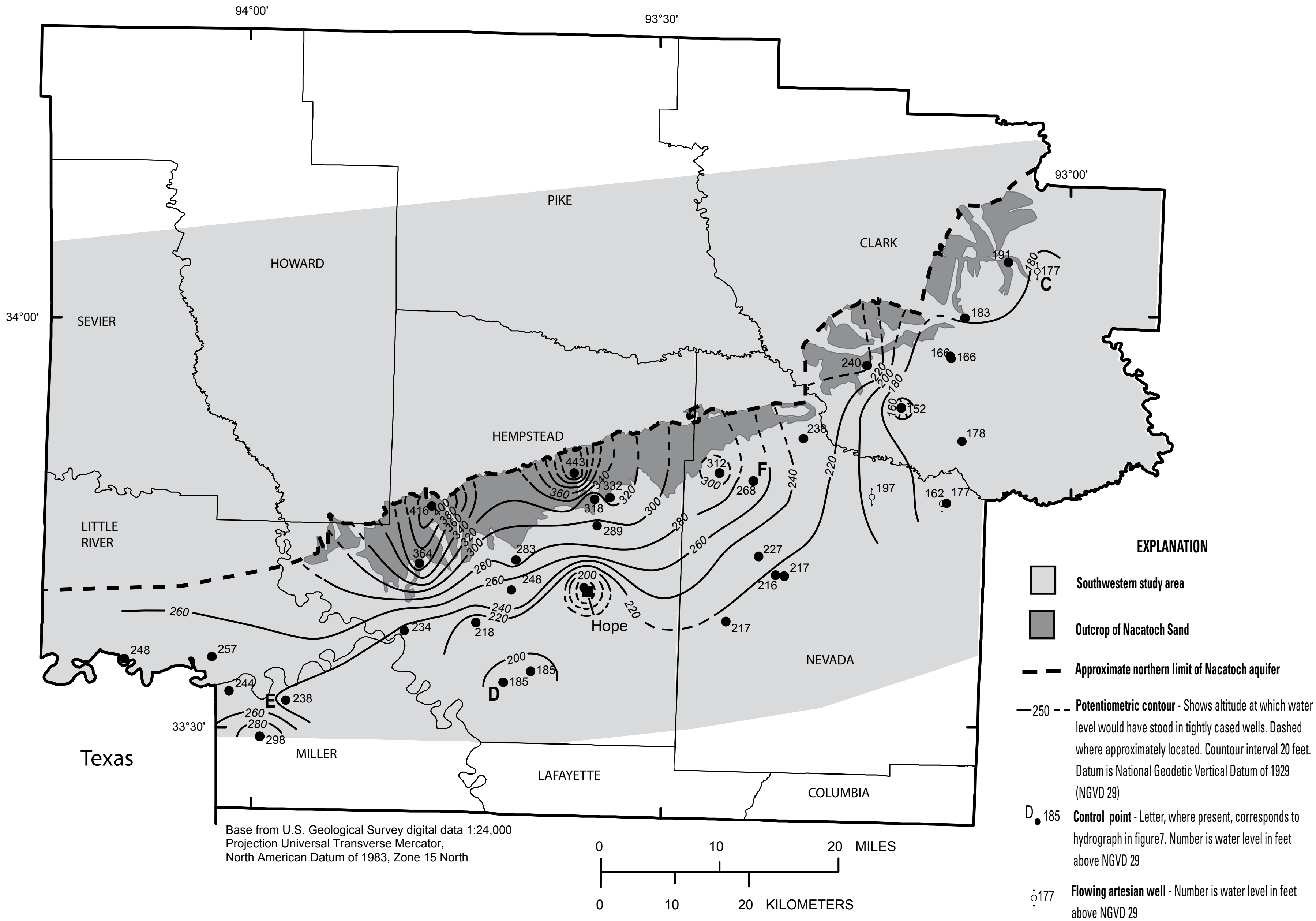

Figure 6. Potentiometric surface of the Nacatoch aquifer, southwestern Arkansas, February and March 2011.

Table 1. Water-level data collected during February and March 2011 from wells completed in the Nacatoch aquifer.

[NGVD 29, National Geodetic Vertical Datum of 1929; horizontal datum is North American Datum of 1983]

Station name	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Water-level altitude (feet above NGVD 29)	Depth to water (feet below land surface)	Land-surface datum (feet above NGVD 29)	Date of measurement
			Clark County			
08S19W06DCB1	340359	930433	191	79.21	270	03/04/2011
08S19W09ACC1	340323	930228	177	-0.30	177	03/04/2011
08S20W34DAB1	335954	930744	183	17.24	200	03/03/2011
09S20W16DBD1	335708	930847	166	74.84	241	03/03/2011
09S20W16DDC1	335657	930845	166	66.78	233	03/03/2011
09S21W21DAD1	335625	931453	240	105.39	345	03/03/2011
10S20W22DCB1	335054	930757	178	81.54	260	03/02/2011
10S21W12BAB1	335321	931225	152	68.53	221	03/02/2011
			Clay County			
19N04E01BDB1	361910	903560	263	16.93	280	03/07/2011
19N07E23BAC1	361602	901748	242	80.43	322	03/08/2011
19N07E23DBC1	361549	901730	243	40.24	283	03/08/2011
19N07E26AAA1	361532	901703	250	26.18	276	03/08/2011
20N04E36DCC1	361929	903542	258	21.35	279	03/07/2011
20N08E10ABC1	362313	901202	256	84.24	340	03/08/2011
20N08E15BAA1	362224	901208	235	145.90	381	03/07/2011
21N06E23DAC1	362619	902329	271	28.61	300	03/07/2011
21N07E25AAC1	362550	901607	265	76.77	342	03/07/2011
			Greene County			
18N06E24ABB2	361112	902256	238	32.06	270	03/08/2011
18N06E24BDA1	361058	902300	233	42.74	276	03/08/2011
			Hempstead County			
11S24W08BDB1	334837	933619	443	26.95	470	03/01/2011
11S24W21ADD1	334641	933449	318	52.34	370	03/01/2011
11S24W22ADD1	334647	933343	332	33.29	365	03/01/2011
11S24W34CBC1	334444	933438	289	31.50	320	03/01/2011
11S26W27BDD1	334611	934645	416	13.74	430	03/01/2011
12S24W28CDC1	334012	933536	143	209.53	353	03/01/2011
12S25W15DBC1	334214	934036	283	27.52	311	02/28/2011
12S25W34BAC1	334002	934055	248	71.86	320	02/28/2011
12S26W21AAC1	334158	934739	364	33.57	398	02/24/2011
13S25W18AAB1	333740	934332	218	64.74	283	02/25/2011
13S25W35DDC1	333406	933931	185	188.17	373	03/01/2011
13S26W17DDB1	333705	934845	234	57.49	291	02/28/2011
14S25W04DDD1	333317	934132	185	75.34	260	03/01/2011
			Little River County			
13S28W31BCC1	333509	940251	257	53.51	311	02/22/2011
14S30W01DAA1	333426	940904	248	33.70	282	02/22/2011

Table 1. Water-level data collected during February and March 2011 from wells completed in the Nacatoch aquifer.—Continued

[NGVD 29, National Geodetic Vertical Datum of 1929; horizontal datum is North American Datum of 1983]

Station name	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Water-level altitude (feet above NGVD 29)	Depth to water (feet below land surface)	Land-surface datum (feet above NGVD 29)	Date of measurement
Miller County						
14S28W13CCB1	333158	935727	238	28.41	266	02/23/2011
14S28W17BBC1	333240	940134	244	26.38	270	02/22/2011
14S28W34CDC1	332919	935920	298	6.60	298	02/23/2011
Nevada County						
10S22W23DCB1	335105	931935	238	4.47	242	03/01/2011
11S20W15CDC1	334622	930905	162	13.06	175	03/01/2011
11S20W22AAA1	334624	930926	177	-2.05	175	03/01/2011
11S21W14CAB1	334652	931434	197	-1.10	196	03/01/2011
11S22W08DAC2	334760	932314	268	37.75	306	03/02/2011
11S23W12ABB1	334837	932541	312	69.01	381	03/02/2011
12S22W09CDD1	334230	932250	227	2.27	229	03/01/2011
12S22W22ACD1	334108	932135	216	126.07	342	03/01/2011
12S22W23CBA1	334102	932057	217	112.43	329	03/02/2011
13S22W07BDC1	333744	932514	217	126.32	343	03/02/2011

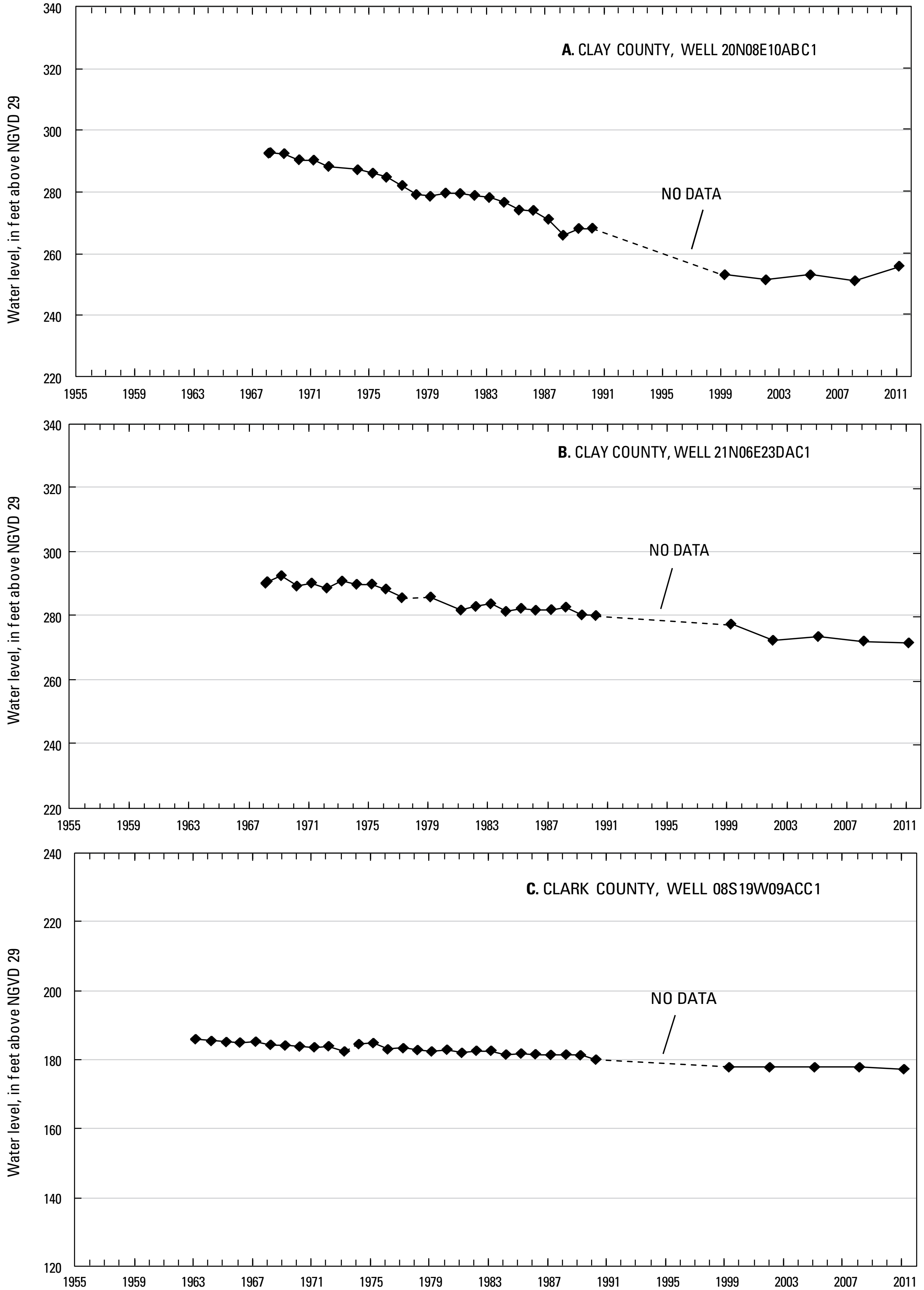

Figure 7. Water levels for selected wells completed in the Nacatoch aquifer.

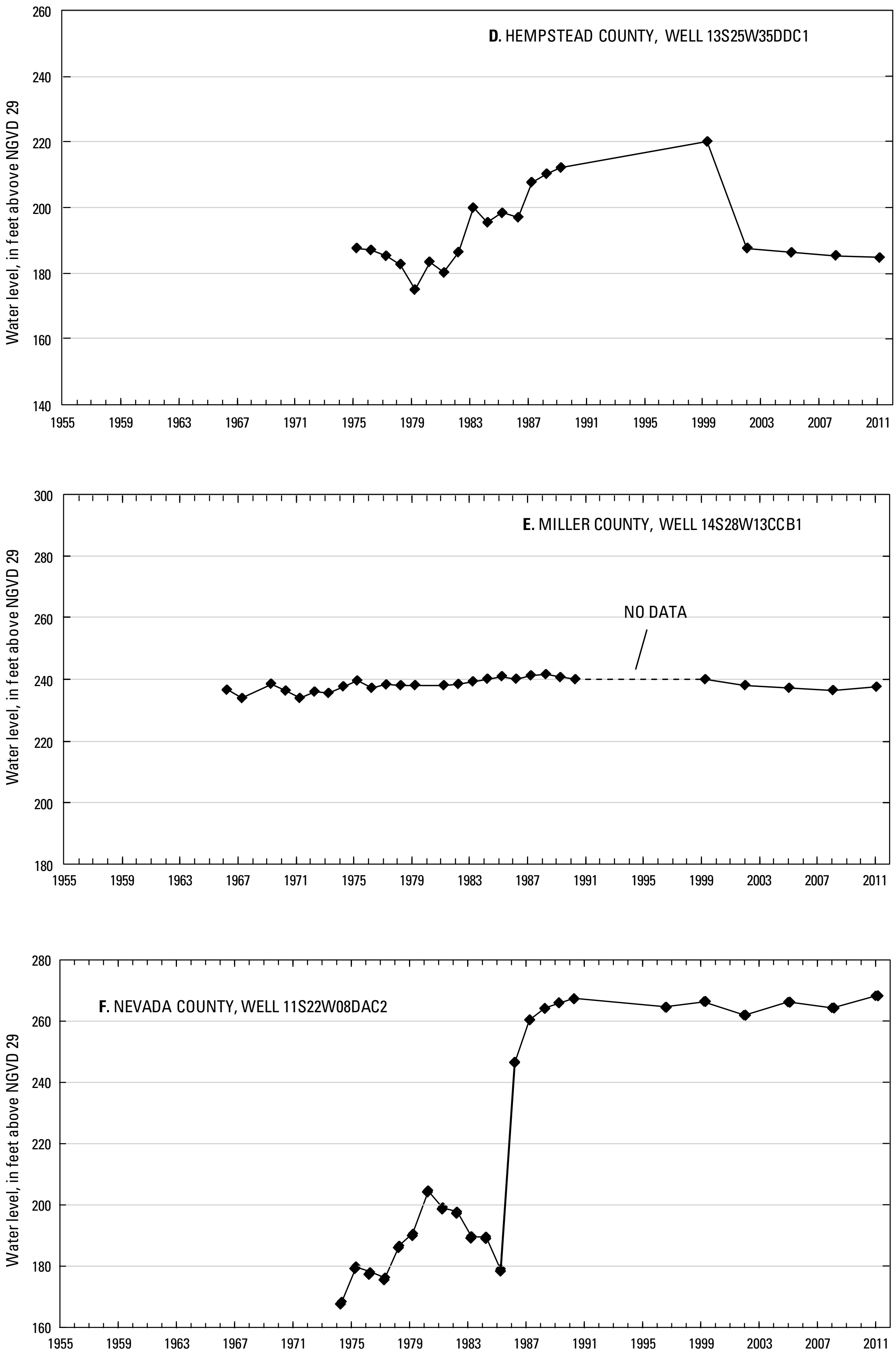

Figure 7. Water levels for selected wells completed in the Nacatoch aquifer.—Continued

Tokio Formation

Hydrogeologic Setting

The Tokio Formation of Cretaceous age underlies the Brownstown Marl and overlies consolidated rocks of Mississippian and Pennsylvanian age in Clark and northeastern Nevada Counties (Plebuch and Hines, 1969); the Trinity Group of Early Cretaceous age in Pike, Nevada, Miller, and most of Hempstead Counties (Petersen and others, 1985); and the Woodbine Formation of Late Cretaceous age in Little River, Sevier, Howard, and northwestern Hempstead Counties (Boswell and others, 1965). The Tokio Formation outcrops in a southwest-to-northeast trending band from east Sevier County to west-central Clark County. The outcrop attains a maximum width of about 10 mi in Howard County and extends approximately 8 mi to the southwest into Sevier County. In this area, the Tokio Formation is overlain in several places by terrace deposits of Quaternary alluvium. The unit also outcrops in northwestern Little River County, west of the southwestern area. The unit ranges in thickness from about 50 ft to more than 300 ft, dips towards the southeast, and is composed of discontinuous, interbedded gray clay and poorly sorted, cross-bedded quartz sands, lignite, and a prevalent basal gravel (Counts and others, 1955; Boswell and others, 1965; Plebuch and Hines, 1969; Petersen and others; 1985). The Tokio Formation does not occur in the northeastern study area.

The Tokio aquifer receives recharge from precipitation where it outcrops or is overlain by permeable alluvial and terrace deposits. Salinity increases downdip to the south-southeast. The Tokio aquifer becomes slightly to moderately saline downdip (southeast) from near Prescott across Nevada County (Petersen and others, 1985).

The Tokio aquifer yields potable water to wells in eastern Little River County, southeastern Sevier County, southern Howard and Pike Counties, western Clark County, northern and central Hempstead County, and northwestern Nevada County. Wells penetrating the Tokio aquifer range in depth from a few feet in the outcrop area to about 1,200 ft at Hope and Prescott (Ludwig, 1972). Wells in central Hempstead County yield up to 300 gal/min. Artesian wells producing as much as 90 gal/min occur in the bottom-land areas adjacent to streams (Counts and others, 1955). Historic records indicate that water levels in the aquifer did not decline appreciably from 1950 to 1968, and that water levels had not been greatly affected by withdrawal of water at Hope and Prescott during this period (Ludwig, 1972). Estimates of water withdrawn from the Tokio aquifer increased by 201 percent from 2.00 Mgal/d in 1965 to 6.02 Mgal/d in 1980 (fig. 8). Water withdrawn from the Tokio aquifer was estimated to be

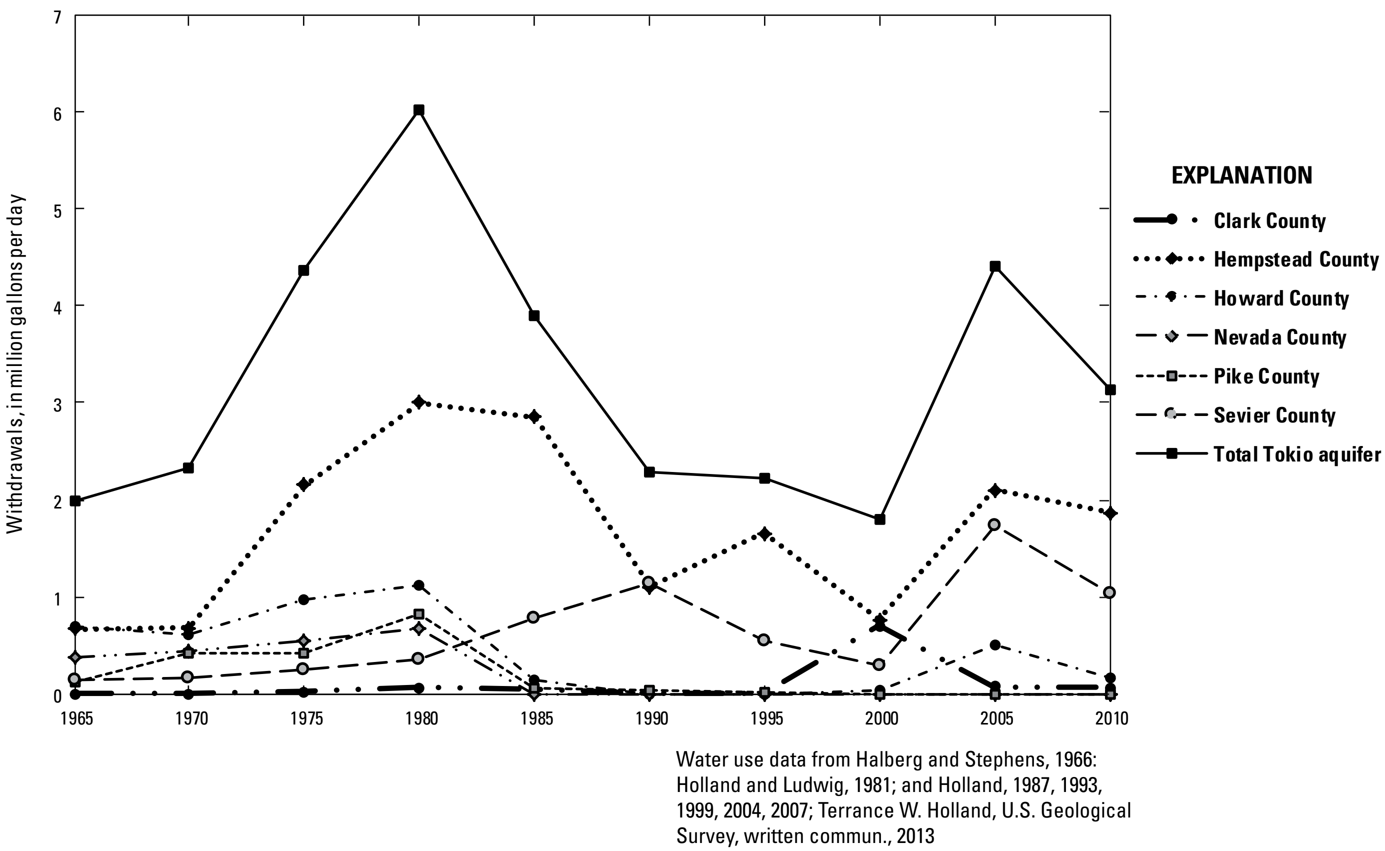

Figure 8. Estimated withdrawals by county from the Tokio aquifer for the southwestern study area.

1.17 Mgal/d in 2000, a decrease of 81 percent from 1980. Water withdrawn from the Tokio aquifer was estimated to be 4.58 Mgal/d in 2005, an increase of 291 percent from 2000. Water withdrawn from the Tokio aquifer was estimated to be 3.13 Mgal/d in 2010, a decrease of 32 percent from 2005 (Halberg and Stephens, 1966; Holland and Ludwig, 1981; Holland, 1999, 2004, 2007; Terrance W. Holland, U.S. Geological Survey, written commun., 2013).

Potentiometric Surface

Potentiometric-surface maps of the Tokio aquifer were constructed using measurements from 45 wells collected during February and March 2011 (fig. 9; table 2). Water-level altitudes were calculated (table 2) and used to map the potentiometric surface, which is represented by contour lines showing water-level altitudes of equal value (fig. 9). Groundwater flow, in general, is perpendicular to contour lines in the direction of downward hydraulic gradient.

In the southwestern area, the direction of groundwater flow in the Tokio aquifer generally is towards the south or southeast. The potentiometric high is within the outcrop area in the northwestern part of the southwestern area. The highest water-level altitude measured was 491 ft above NGVD 29 in Howard County. The lowest water-level altitude measured was 124 ft above NGVD 29 about 5 mi northwest of Hope in Hempstead County. An area of artesian flow exists or is inferred in southeastern Pike, northeastern Hempstead, and northwestern Nevada Counties as evidenced by eight flowing artesian wells.

A cone of depression may exist about 5 mi northwest of Hope. The northern one-half of this apparent cone of depression is shown on figure 9. Water-level data in the Tokio aquifer were not available south of Hope. There is a cone of depression in southern Howard County. This is the first documentation of a cone of depression in this area. A comparison of the 2011 map with the 2002 and 1999 potentiometric-surface maps for the Tokio aquifer shows one substantial change; the 300-ft contour is positioned further north in Howard County. The change in this contour is because of the measurement at well 10S27W02ACD1, which had not been measured prior to 2005.

Long-Term Water-Level Changes

Two hydrographs from wells completed in the Tokio aquifer have long-term (minimum of 20 years) water-level altitudes (fig. 10). The two wells are located in Hempstead County (sites G and H; fig. 9). The minimum 20-year period is used to decrease the effect of short-term variations in climate and localized pumping rates on water levels in a single well.

Water-level trends vary in different parts of Hempstead County. In well 09S23W33CDA1 (site G, figs. 9 and 10), in northern Hempstead County, water levels generally declined about 0.26 ft/yr from 1958 to 2008. Water levels in well 12S24W06DAD1 (site H, figs. 9 and 10), in central Hempstead County, fluctuated through a range of about 275.60 to about 123.80 ft over a 39-year period, although water-level rises are seen from 1979 to 1989 and 1999 to 2002. The annual decline in water levels at well 12S24W06DAD1 from 1971 to 2011 was 3.70 ft/yr. The decline and rise in water levels in well 12S24W06DAD1 may be associated with the fluctuating withdrawals from the Tokio aquifer in Hempstead County, while water levels in well 09S23W33CDA1 do not appear to have a similar association. Although water levels in these two wells may be associated with changes in water use, other factors may affect water levels such as climatic variations or changes in leakage to and from overlying and underlying rock units.

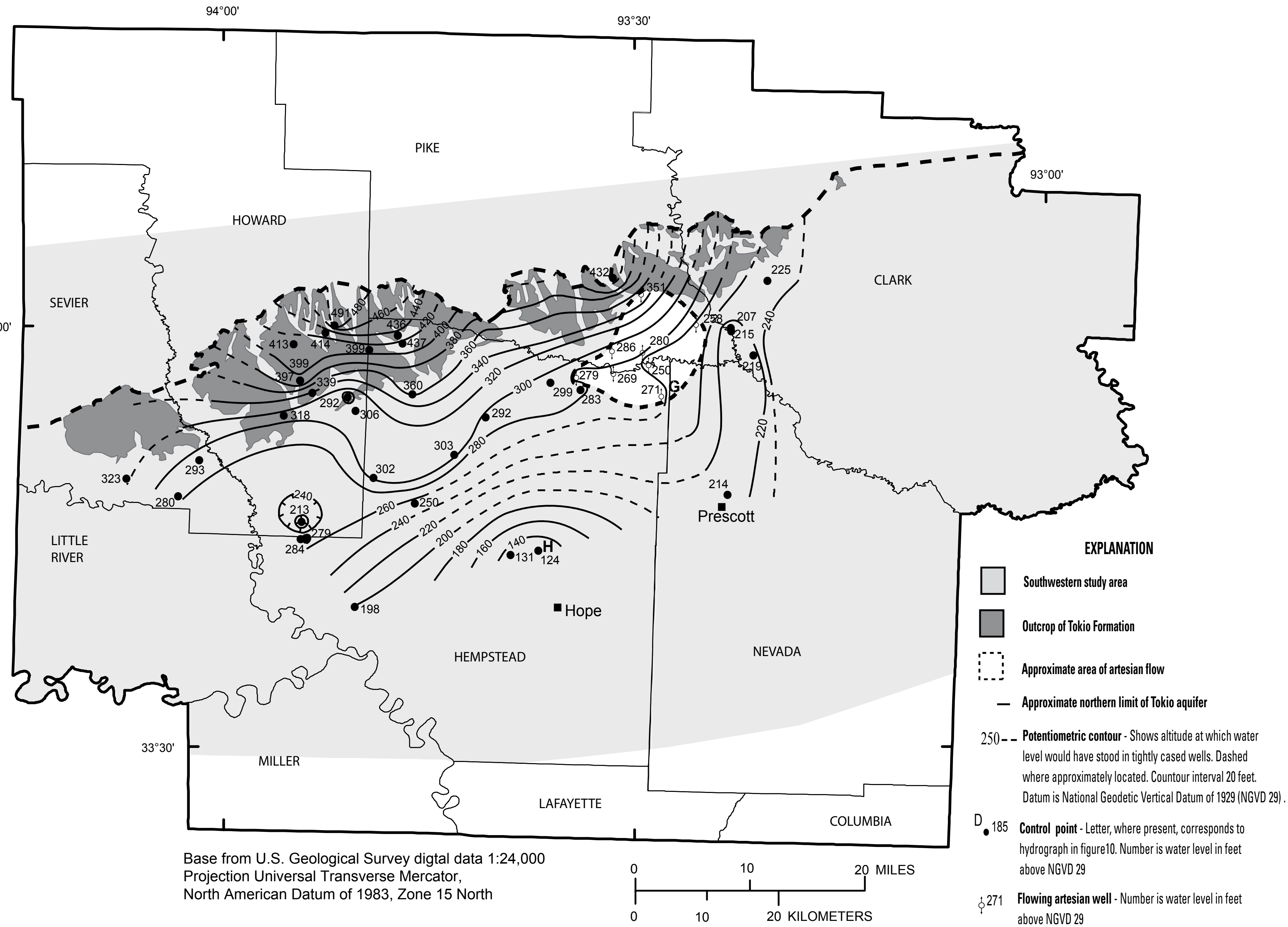

Figure 9. Potentiometric surface of the Tokio aquifer, southwestern Arkansas, February and March 2011.

Table 2. Water-level data collected during February and March 2011 from wells completed in the Tokio aquifer.

[NGVD 29, National Geodetic Vertical Datum of 1929; Horizontal Datum is North American Datum of 1983; a negative or zero depth to water indicates a flowing artesian well]

Station name	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Water-level altitude (feet above NGVD 29)	Depth to water (feet below land surface)	Land-surface datum (feet above NGVD 29)	Date of measurement
Clark County						
08S22W15ABB2	340313	932018	225	100.00	325	03/03/2011
09S22W05BBB1	335951	932259	215	97.00	312	03/03/2011
09S22W05BCA1	335936	932257	207	28.00	235	03/03/2011
09S22W10DBA1	335832	932022	260	102.00	362	03/03/2011
09S22W16ACA1	335754	932120	219	14.00	233	03/03/2011
Hempstead County						
09S23W20BDA1	335710	932859	250	0.00	250	02/24/2011
09S23W33CDA1	335457	932802	271	-0.92	270	02/24/2011
09S24W25BBB1	335633	933132	269	-0.50	268	02/24/2011
09S24W28ACC1	335617	933415	279	-2.11	277	02/24/2011
09S24W30DCC1	335556	933607	299	91.13	390	02/24/2011
09S24W33ADC1	335526	933356	283	46.06	329	02/24/2011
09S26W08ADA2	335920	934717	437	0.94	438	02/25/2011
09S26W08ADD1	335918	934717	436	0.80	437	02/25/2011
09S26W09CDC1	335846	934656	420	5.08	425	02/25/2011
09S26W18CBB1	335815	934921	399	25.73	425	02/25/2011
10S25W09CDB1	335329	934052	292	69.17	361	02/24/2011
10S25W30CCD1	335048	934310	303	85.27	388	03/01/2011
10S26W03BBA1	335507	934612	360	7.29	367	03/01/2011
11S26W08BBB1	334909	934903	302	69.70	372	03/01/2011
11S26W23BBB1	334720	934602	250	169.09	419	03/01/2011
12S24W06DAD1	334360	933701	124	231.22	355	03/01/2011
12S25W02DDD1	334341	933902	131	235.68	367	03/01/2011
12S27W04BBC1	334450	935358	284	151.38	435	03/01/2011
12S27W05AAC1	334449	935421	279	156.16	435	03/01/2011
12S27W36DBC1	333958	935024	198	62.94	261	02/24/2011
Howard County						
09S27W03DBD1	340000	935153	491	70.60	562	02/23/2011
09S27W10BCB1	335930	935232	414	120.09	534	02/23/2011
09S27W18ADB1	335840	935453	413	78.59	492	02/23/2011
09S27W32BDB1	335606	935424	397	54.47	451	02/23/2011
09S27W32BDB2	335606	935424	399	50.96	450	02/23/2011
10S27W02ACD1	335454	935056	292	65.73	358	02/23/2011
10S27W04BBD1	335512	935330	339	53.00	392	02/23/2011
10S27W12CAB1	335356	935021	306	77.15	383	02/23/2011
10S27W18BAC1	335336	935535	318	103.86	422	02/23/2011
11S27W21CDA1	334603	935418	213	67.02	280	02/23/2011

Table 2. Water-level data collected during February and March 2011 from wells completed in the Tokio aquifer.—Continued

[NGVD 29, National Geodetic Vertical Datum of 1929; Horizontal Datum is North American Datum of 1983; a negative or zero depth to water indicates a flowing artesian well]

Station name	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Water-level altitude (feet above NGVD 29)	Depth to water (feet below land surface)	Land-surface datum (feet above NGVD 29)	Date of measurement
			Nevada County			
11S22W08DAC8	334757	932312	214	91.37	305	03/02/2011
12S21W28ADA1	334015	931559	260	5.46	265	03/02/2011
			Pike County			
08S23W19ADC1	340213	932931	351	-0.81	350	02/23/2011
08S23W35DCA1	340004	932530	258	-1.15	257	02/23/2011
08S24W14AAC1	340324	933134	432	90.98	523	02/24/2011
09S23W17BBC2	335804	932925	280	-0.20	280	02/24/2011
09S24W14AAD1	335810	933139	286	-1.20	285	02/24/2011
			Sevier County			
10S28W31DCC1	335026	940145	293	36.85	330	02/22/2011
11S29W08DBB1	334907	940704	323	141.90	465	02/22/2011
11S29W13CCD1	334750	940317	280	80.45	360	02/22/2011

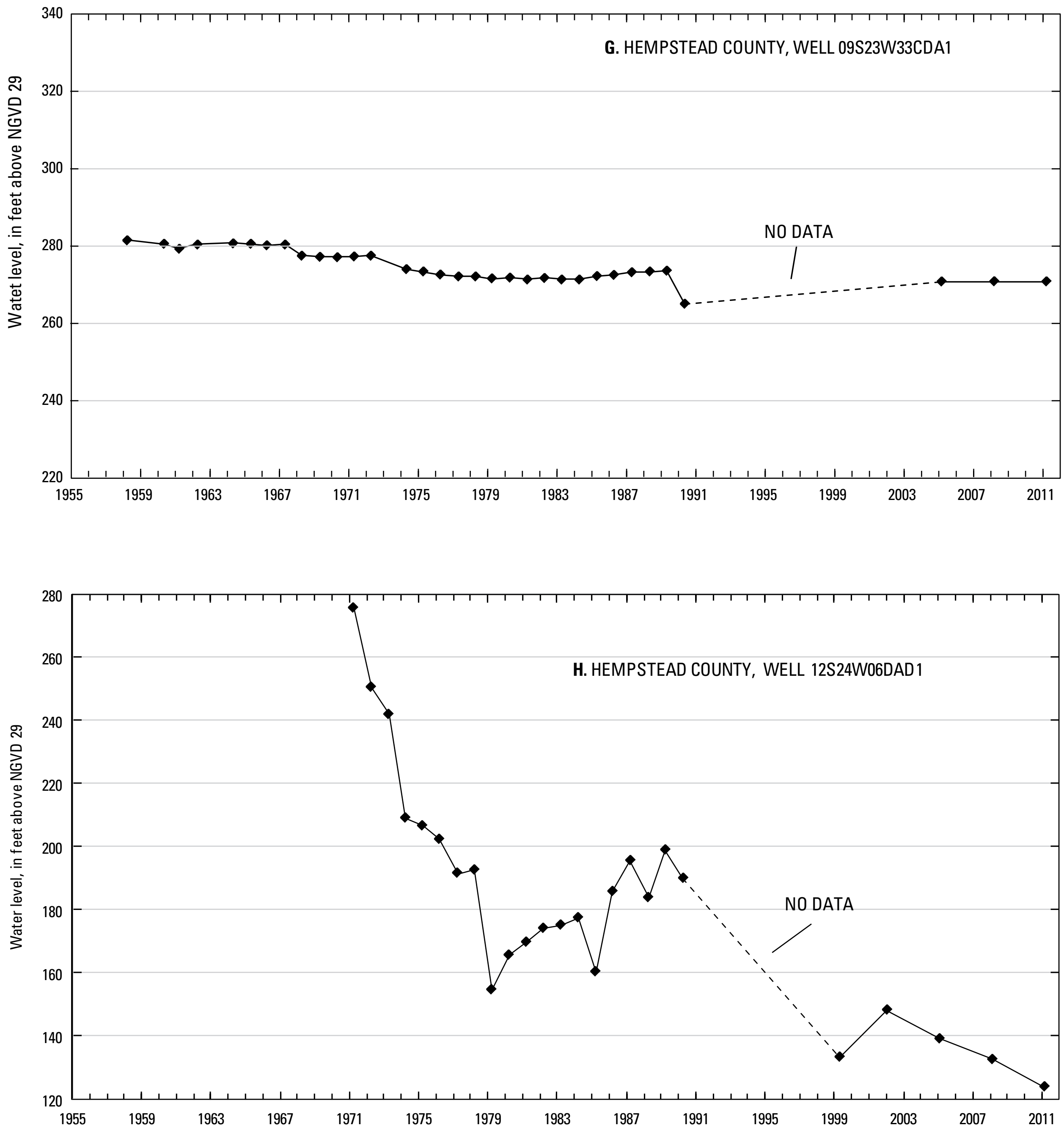

Figure 10. Water level for selected wells completed in the Tokio aquifer.

Summary

Aquifers in the Nacatoch Sand and Tokio Formation in southwestern Arkansas and the Nacatoch Sand in northeastern Arkansas are sources of water for industrial, public supply, domestic, and agricultural uses. A study was conducted by the U.S. Geological Survey in 2011 in cooperation with the Arkansas Natural Resources Commission and the Arkansas Geological Survey to provide potentiometric-surface maps and water-level hydrographs associated with aquifers in the Nacatoch Sand and Tokio Formation (hereafter referred to as the Nacatoch aquifer and Tokio aquifer, respectively) in southwestern Arkansas and the Nacatoch aquifer in northeastern Arkansas.

Potentiometric-surface maps were constructed from water-level measurements made in 47 wells completed in the Nacatoch aquifer and in 45 wells completed in the Tokio aquifer during February and March 2011. In northeastern

Arkansas, groundwater withdrawals from the Nacatoch aquifer increased by 564 percent from 1965 to 2010. In southwestern Arkansas, groundwater withdrawals from the Nacatoch aquifer increased by 125 percent from 1965 to 1980. From 1980 to 2010, withdrawals decreased by 85 percent. In southwestern Arkansas, groundwater withdrawals from the Tokio aquifer increased by 201 percent from 1965 to 1980. From 1980 to 2000, withdrawals decreased by 81 percent. From 2000 to 2005, withdrawals from the Tokio aquifer increased by 291 percent. From 2005 to 2010, withdrawals from the Tokio aquifer decreased by 32 percent.

In the northeastern Nacatoch study area, groundwater-flow direction is towards the southeast. A potentiometric high of 271 feet (ft) above the National Geodetic Vertical Datum of 1929 (NGVD 29) is located along the northern border of Clay County. The lowest water-level altitude (233 ft above NGVD 29) was measured in northeastern Greene County.

Groundwater-flow direction in the southwestern Nacatoch study area is towards the southeast in Hempstead, Little River, and Miller Counties and towards the east-southeast in Clark and Nevada Counties. An increase in the clay content in the direction of the downdip may affect the direction of groundwater flow. The highest water-level altitude (443 ft above NGVD 29) was measured in the outcrop area of north-central Hempstead County. The lowest water-level altitude (143 ft above NGVD 29) was measured near Hope in southern Hempstead County.

Two cones of depression exist in the southwestern Nacatoch aquifer study area—in Hempstead County at Hope (143 ft above NGVD 29) and in Clark County (152 ft above NGVD 29). The depression at Hope alters local groundwater-flow directions from the regional direction, with groundwater flowing towards Hope from the west, north, and northeast directions.

Six hydrographs (two in the northeastern study area and four in the southwestern study area) from wells completed in the Nacatoch aquifer displaying long-term water-level measurements (minimum of 20 years) were constructed. The hydrographs for Clay County wells 20N08E10ABC1 and 21N06E23DAC1 show an average annual decrease of 1.06 and 0.51 feet per year (ft/yr), respectively. The water-level hydrograph for Clark County well 08S19W09ACC1 has remained relatively stable over the 20-year period with an annual decrease of 0.18 ft/yr. The hydrograph for Hempstead County well 13S25W35DDC1 shows an annual increase of 0.15 ft/yr. The water-level hydrograph for Miller County well 14S28W13CCB1 has remained essentially unchanged over the minimum 20-year period. The water-level hydrograph for Nevada County well 11S22W08DAC2 shows that between 1985 and 1988, water levels increased 88.84 ft. Although water levels in these six wells may be associated with changes in water use, they also may be affected by climatic variations or changes in leakage to and from overlying and underlying rock units.

In the southwestern area, the direction of groundwater flow in the Tokio aquifer generally is towards the south or southeast. The potentiometric high is within the outcrop area in the northwestern part of the southwestern area. The highest water-level altitude measured was 491 ft above NGVD 29 in Howard County. The lowest water-level altitude measured was 124 ft above NGVD 29 about 5 miles northwest of Hope in Hempstead County. An area of artesian flow exists or is inferred in southeastern Pike, northeastern Hempstead, and northwestern Nevada Counties as evidenced by eight flowing artesian wells.

Two hydrographs from wells completed in the Tokio aquifer have long-term (minimum of 20 years) water-level altitudes. The two wells are located in Hempstead County, and the hydrographs show differences between water-level trends over long periods. In well 09S23W33CDA1, water levels generally declined about 0.26 ft/yr from 1958 to 2008. Water levels in well 12S24W06DAD1 fluctuated from a range of about 276 to about 132 ft over a 39-year period. Water levels generally declined from 1971 to 1979, generally rose from 1979 to 1989, then declined from 1989 to 1999. The annual decline in water level at well 12S24W06DAD1 from 1971 to 2011 was 3.70 ft/yr. The decline and rise in water levels in well 12S24W06DAD1 may be associated with the fluctuating withdrawals from the Tokio aquifer in Hempstead County, while water levels in well 09S23W33CDA1 do not appear to have a similar association.

References

Bodansky, E., Gribov, A., and Pilouk, M., 2002, Smoothing and compression of lines obtained by raster-to-vector conversion: Lecture Notes in Computer Science Volume 2390, Springer Publishing Co., p. 256–265.

Boswell, E.H., Moore, G.K., MacCary, L.M., and others, 1965, Cretaceous aquifers in the Mississippi Embayment: U.S. Geological Survey Professional Paper 448–C, 37 p.

Counts, H.B., Tait, D.B., Klein, Howard, and Billingsley, G.A., 1955, Ground-water resources in a part of southwestern Arkansas: U.S. Geological Survey Water Resources Circular No. 2, 35 p.

Cunningham, W.L., and Schalk, C.W., comps., 2011, Groundwater technical procedures of the U.S. Geological Survey: U.S. Geological Survey Techniques and Methods 1-A1, 151 p. (Available only online at http://pubs.usgs.gov/tm/1a1/.)

Esri, 2011, ArcGIS desktop—Release 10: Redlands, California, Environmental Systems Research Institute.

Fenneman, N.M., 1931, Physiography of western United States: New York, McGraw-Hill Book Co., Inc., 689 p.

Fenneman, N.M., 1938, Physiography of western United States: New York, McGraw-Hill Book Co., 689 p.

Halberg, H.N., 1972, Use of water in Arkansas, 1970: Arkansas Geological Commission Water Resources Summary Number 7, 17 p.

Halberg, H.N., 1977, Use of water in Arkansas, 1975: Arkansas Geological Commission Water Resources Summary Number 9, 28 p.

Halberg, H.N., and Stephens, J.W., 1966, Use of water in Arkansas, 1965: Arkansas Geological Commission Water Resources Summary Number 5, 12 p.

Holland, T.W., 2004, Estimated water use in Arkansas, 2000: U.S. Geological Survey Scientific Investigations Report 2004–5230, 31 p.

Holland, T.W., 2007, Estimated water use in Arkansas, 2005: U.S. Geological Survey Scientific Investigations Report 2004–5230, 31 p.

Holland, T.W., 1987, Use of water in Arkansas, 1985: Arkansas Geological Commission Water Resources Summary Number 14, 30 p.

Holland, T.W., 1993, Use of water in Arkansas, 1990: U.S. Geological Survey Open-File Report 93–48, pamphlet.

Holland, T.W., 1999, Water use in Arkansas, 1995: U.S. Geological Survey Open-File Report 99–188, 1 sheet.

Holland, T.W., and Ludwig, A.H., 1981, Use of water in Arkansas, 1980: Arkansas Geological Commission Water Resources Summary Number 14, 30 p.

Ludwig, A.H., 1972, Water resources of Hempstead, Lafayette, Little River, Miller, and Nevada Counties, Arkansas: U.S. Geological Survey Water-Supply Paper 1998, 41 p.

Petersen, J.C., Broom, M.E., and Bush, W.V., 1985, Geohydrologic units of the Gulf Coastal Plain in Arkansas: U.S. Geological Survey Water-Resources Investigations Report 85–4116, 20 p.

Plebuch, R.O., and Hines, M.S., 1969, Water resources of Clark, Cleveland, and Dallas Counties, Arkansas: U.S. Geological Survey Water-Supply Paper 1879–A, 32 p.

Schrader, T.P., 1999, Status of water levels in aquifers in the Nacatoch Sand of southwestern and northeastern Arkansas and Tokio Formation of southwestern Arkansas, 1999: U.S. Geological Survey Water-Resource Investigations Report 99–4208A, 23 p.

Schrader, T.P., 2007, Status of water levels in aquifers in the Nacatoch Sand of southwestern and northeastern Arkansas and Tokio Formation of southwestern Arkansas, February 2005: U.S. Geological Survey Water-Scientific Investigations Report 07–5024, 21 p.

Schrader, T.P., and Scheiderer, R.M., 2004, Status of water levels in aquifers in the Nacatoch Sand of southwestern and northeastern Arkansas and Tokio Formation of southwestern Arkansas, 2002: U.S. Geological Survey Water-Resources Investigations Report 03–4284, 24 p.

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