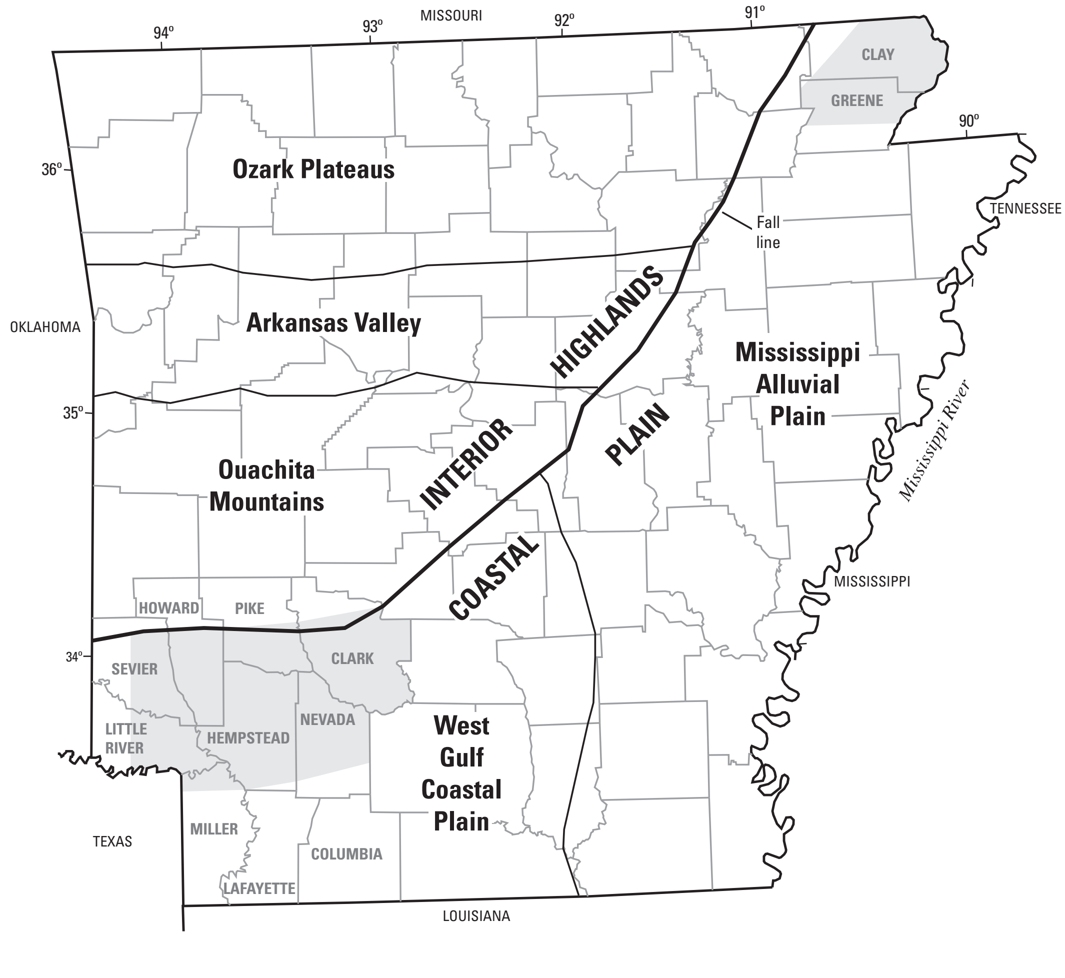
Prepared in cooperation with the Arkansas Natural Resources Commission and the Arkansas Geological Survey

Water Levels in Aquifers in the Nacatoch Sand of Southwestern and Northeastern Arkansas and the Tokio Formation of Southwestern Arkansas, Spring 2008



Scientific Investigations Report 2010–5238

U.S. Department of the Interior
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U.S. Department of the Interior
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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)
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 of 1929).

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

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

Water Levels in Aquifers in the Nacatoch Sand of Southwestern and Northeastern Arkansas and the Tokio Formation of Southwestern Arkansas, Spring 2008

By T.P. Schrader and Joshua M. Blackstock

Abstract

The Nacatoch Sand and Tokio Formation aquifers 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 61 wells completed in the Nacatoch Sand and in 50 wells completed in the Tokio Formation during spring 2008. 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 northeastern Arkansas generally is towards the southeast. A potentiometric high is located along the north and northwestern boundaries of the area.

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

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

In northeastern Arkansas, groundwater withdrawals from the Nacatoch aquifer increased by 480 percent from 1965 to 2005. In southwestern Arkansas, withdrawals from the Nacatoch aquifer and Tokio aquifer increased by 125 percent and 201 percent, respectively, from 1965 to 1980 and decreased by 93 percent and 80 percent, respectively, from 1980 to 2000. Withdrawals from Nacatoch aquifer and Tokio aquifer increased by 690 percent and 291 percent, respectively, from 2000 to 2005. Long-term hydrographs were prepared for 10 wells in the study areas. Changes in water levels in some wells may be associated with changes in withdrawals from the respective aquifers.

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 to effectively plan and manage the resource. A study was conducted by the U.S. Geological Survey 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 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 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 approximately by the Fall Line separating the Interior Highlands from the 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 area was limited to the occurrence of freshwater; the southern boundary of the area is defined by a freshwater/

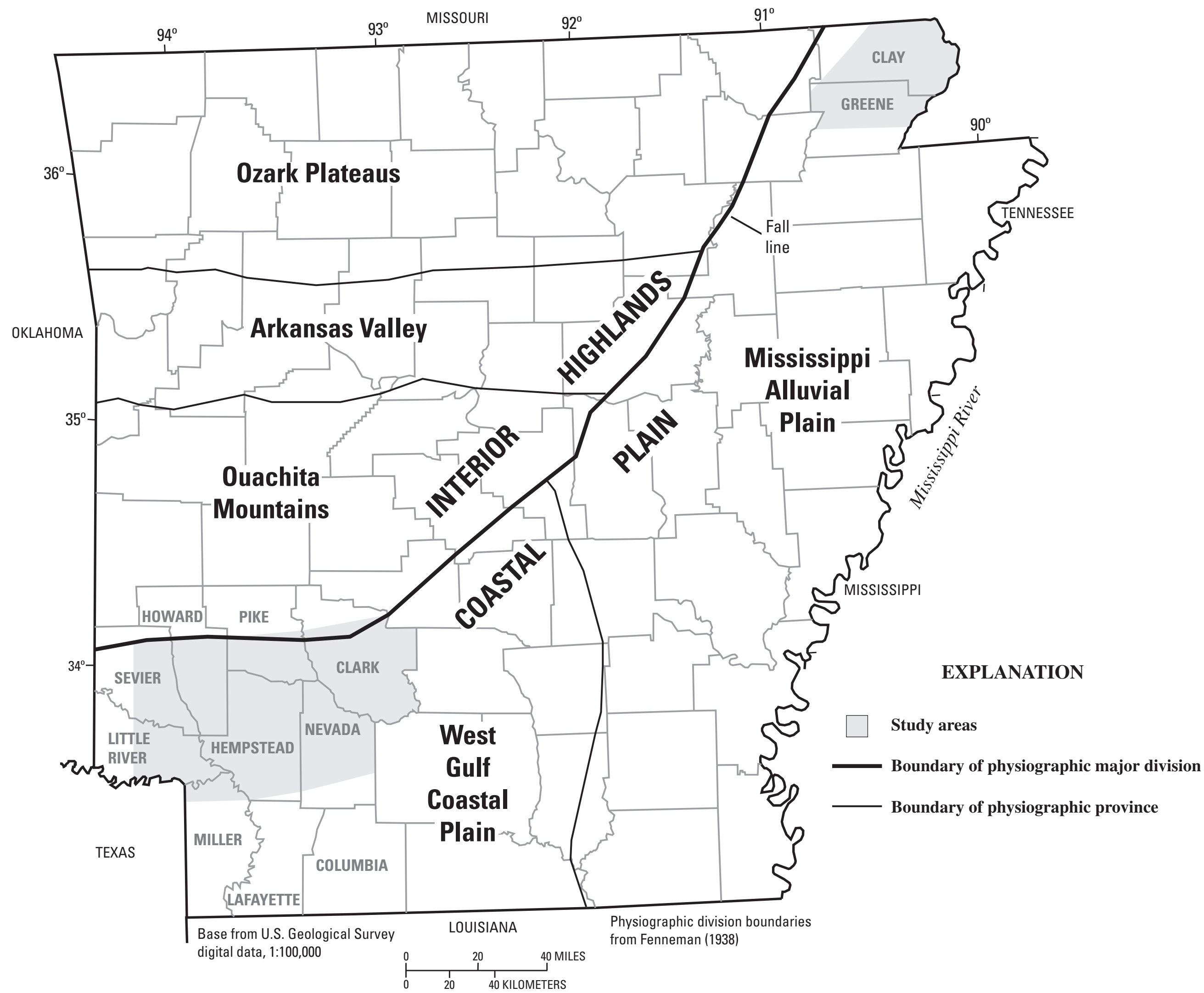


Figure 1. Location of study areas.

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 61 wells completed in the Nacatoch aquifer and in 50 wells completed in the Tokio aquifer during spring 2008. These measurements were used to construct potentiometric-surface maps. All water-level data are stored in the U.S. Geological Survey's Ground-Water Site Inventory (GWSI) data storage system (*http://waterdata.usgs.gov*). Long-term water-level hydrographs were prepared for selected wells. Withdrawal data for the aquifers in each county collected by the U.S. Geological Survey from 1965 to 2005 were related to these hydrographs.

The Tokio Formation is stratigraphically below the Nacatoch Sand and separated from it 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.

As a well is pumped, water levels decline, forming a cone of depression. 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 may account for changes shown by long-term hydrographs.

Methods

Personnel from the U.S. Geological Survey (USGS) collected water-level measurements during spring 2008 from wells screened in the Nacatoch aquifer or Tokio aquifer. 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 2008 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.

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 of 1929), was determined for each well by superposition of the wells latitude and longitude on a topographic map and is accurate to about one-half the topographic contour interval of 5 or 10 ft. Herein, all water-level and land-surface altitudes are referenced to NGVD of 1929.

The well-numbering system used in this report is based upon the location of the wells according to the Federal land survey 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 or 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.

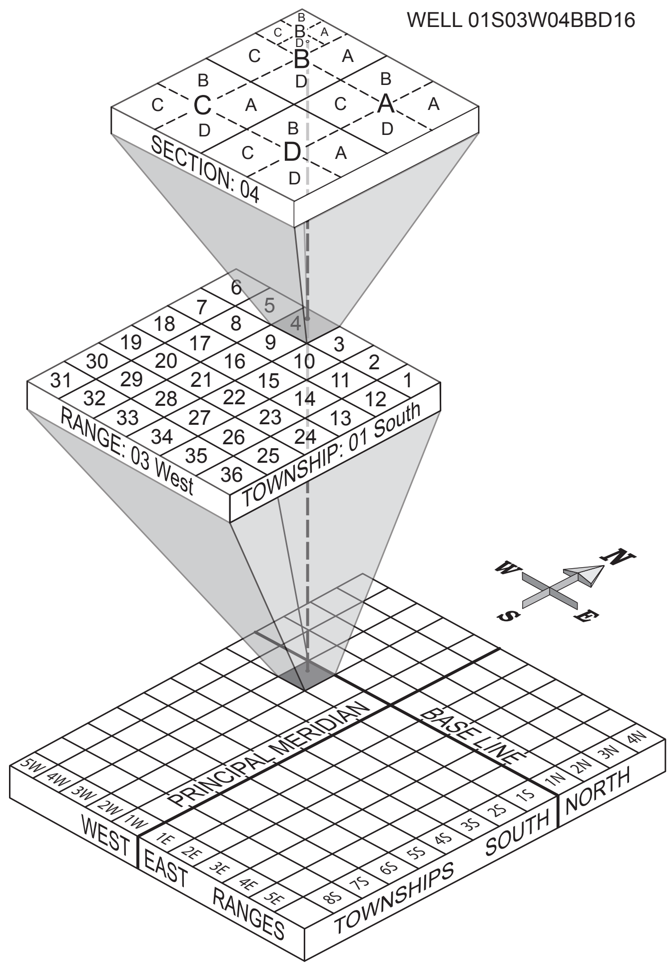


Figure 2. Well-numbering system.

Nacatoch Sand

Hydrogeologic Setting

The Nacatoch Sand of Late Cretaceous age is underlain by the Saratoga Chalk and overlain by the Arkadelphia Marl. In the northeastern area, the Nacatoch Sand subcrops beneath Quaternary alluvial and terrace deposits along the western boundary. The top of the Nacatoch Sand has an altitude of about 50 to 100 ft above NGVD of 1929 along the western boundary, dips toward the southeast, and descends to about 1,200 ft below NGVD of 1929 at the Mississippi River. This unit is about 100 ft thick near the subcrop and attains a maximum thickness of about 600 ft downdip (Petersen and others, 1985).

The Nacatoch Sand in the northeastern area consists of interbedded clay, limestone, and fine sand in the lower part, grading upward to loose fine quartz sand in the upper part (Petersen and others, 1985). The Nacatoch aquifer receives recharge from precipitation through the overlying alluvium and terrace deposits in western Clay and Greene Counties.

In the southwestern area, the Nacatoch Sand outcrops in a belt 3 to 8 miles (mi) wide extending from central Clark County southwestward to western Hempstead County. The belt continues westward as a subcrop below Quaternary alluvial and terrace deposits across Little River County (Boswell and others, 1965). The top of the Nacatoch Sand has an altitude of about 300 ft above NGVD of 1929 in the outcrop, dips towards the southeast, and descends to about 800 ft below NGVD of 1929 at the southern boundary of the area. The Nacatoch Sand is about 100 ft thick near the outcrop and attains a maximum thickness of 600 ft (Petersen and others, 1985).

The Nacatoch Sand in the southwestern area consists of three distinct units. The upper unit is composed of unconsolidated, gray, fine-grained quartz sand that commonly is crossbedded. Locally, the sand is massive and contains a few hard lenses and beds of fossiliferous sandy limestone. This upper sand unit is the main water-bearing unit of the Nacatoch Sand. The middle unit consists of a dark-green sand that contains coarse grains of glauconite and weathers to lighter shades of green. This unit generally is fossiliferous where it is glauconitic. The lower unit consists of interbedded gray clay, sandy clay and marl, dark clay-rich fine-grained sand, and hard irregular concretionary beds (Counts and others, 1955; Plebuch and Hines, 1969).

In the southwestern area, the Nacatoch aquifer receives recharge from precipitation in its outcrop areas in Clark, Nevada, and Hempstead Counties and through the overlying alluvium and terrace deposits in Little River County and in northeastern Texas. The Nacatoch aquifer is used in northeastern Greene County, Clay County, southern Clark County, northwestern Nevada County, central Hempstead County, northern Miller County, and southeastern Little River County. Flowing artesian wells produce yields of 1 or 2 gallons per minute (gal/min) in the lowest stream valleys in Clark and Nevada Counties. Wells in Hempstead County and western Nevada County produce yields of 150 to 300 gal/min. In the southwestern area, downdip about 2 to 20 mi southeast of the outcrop area, groundwater generally is excessively saline for most uses. Well yields in Miller County, eastern Nevada County, and Clark County generally are small, and the water may contain considerable chloride (Counts and others, 1955). Aquifer tests of wells completed in the Nacatoch aquifer at Hope and Prescott show a transmissivity of 3,600 gallons per day per foot (gal/d/ft) (Ludwig, 1972).

Water Use

Total withdrawals from the Nacatoch aquifer in the northeastern area were 0.25 million gallons per day (Mgal/d) in 1965 and increased to 2.21 Mgal/d in 1990, an increase of 784 percent during the 25-year period (fig. 3). The majority of these withdrawals occurred in Clay County and were 0.25 Mgal/d in 1965 and increased to 1.98 Mgal/d in 1990, an increase of 692 percent. Withdrawals in Greene County were 0.00 Mgal/d in 1965 and increased to 0.23 Mgal/d in 1990. The total amount of withdrawals in the northeastern area in 2005 was 1.45 Mgal/d, a decrease of 34 percent from 1990. This trend is explained by the decrease in withdrawals from Clay County from 1.98 Mgal/d in 1990 to 0.97 Mgal/d in 2005. However, withdrawals have increased in Greene County from 0.23 Mgal/d in 1990 to 0.48 Mgal/d in 2005, an increase of 200 percent. From 1965 to 2005, withdrawals from the Nacatoch aquifer increased by 480 percent. Withdrawals in Clay County have increased from 0.25 Mgal/d in 1965 to 0.97

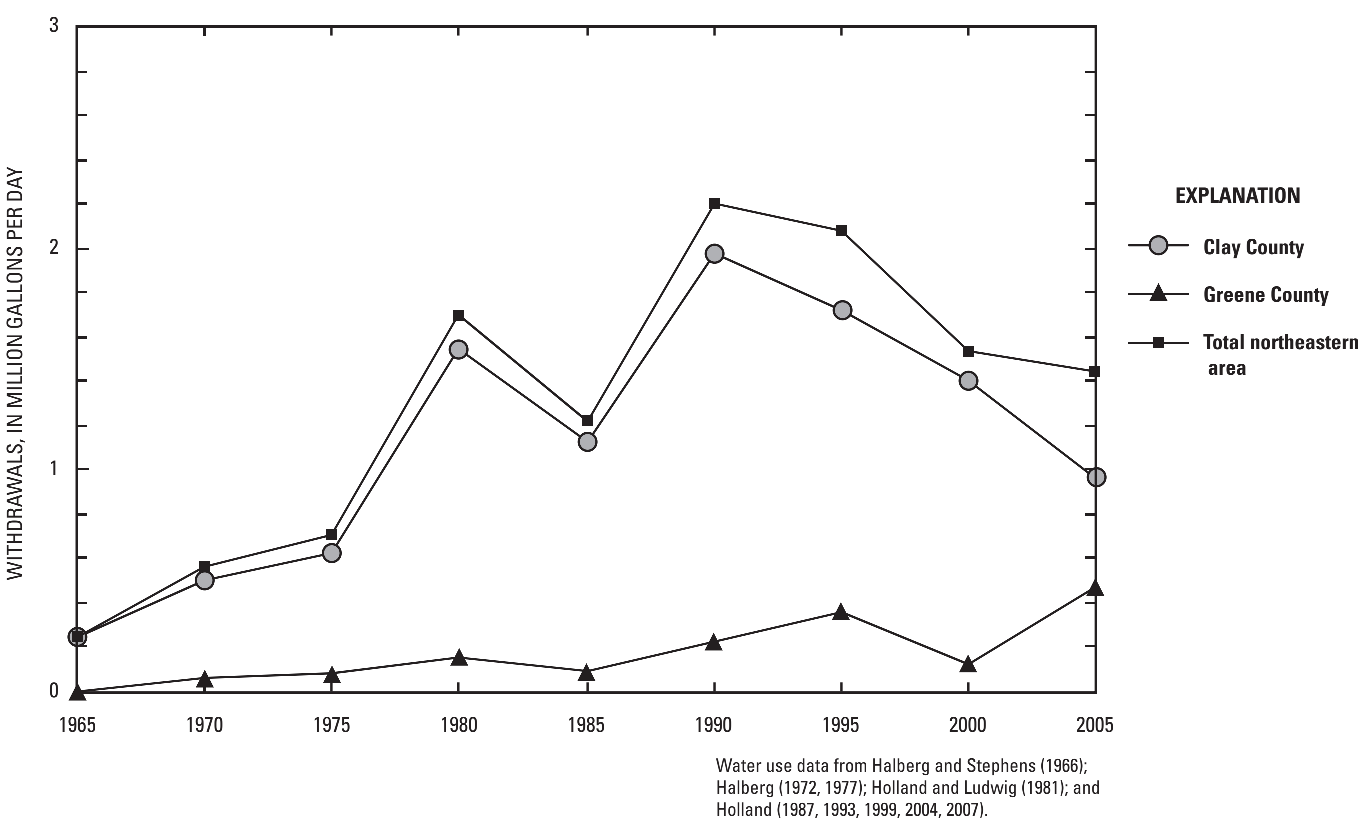


Figure 3. Withdrawals for the Nacatoch aquifer for the northeastern area in Arkansas.

Mgal/d in 2005, an increase of 288 percent. Withdrawals in Greene County have increased from 0.06 Mgal/d in 1970 to 0.48 Mgal/d in 2005, an increase of 700 percent (Halberg and Stephens, 1966; Holland and Ludwig, 1981; Holland, 1987, 1993, 1999, 2004, 2007).

Withdrawals from the Nacatoch aquifer in the southwestern area were 2.11 Mgal/d in 1965 and increased by 125 percent to 4.75 Mgal/d in 1980 (fig. 4). During this period, the largest withdrawals occurred in Hempstead County where withdrawals increased from 1.12 Mgal/d in 1965 to 1.98 Mgal/d in 1980, an increase of 77 percent. Withdrawals in Clark County increased from 0.44 Mgal/d in 1965 to 1.73 Mgal/d in 1980, an increase of 293 percent. Withdrawals in Howard, Little River, Miller, and Nevada County were 0.00, 0.20, 0.14, and 0.21 Mgal/d, respectively, in 1965. In 1980, Howard and Nevada County withdrawals increased to 0.24 and 0.68 Mgal/d, respectively. However, withdrawals in Little River and Miller County decreased to 0.06 Mgal/d. Withdrawals from the Nacatoch aquifer in this area were 0.32 Mgal/d in 2000, a decrease of 93 percent from 1980. In 2000, withdrawals in Clark, Hempstead, and Miller County decreased to 0.02, 0.27, and 0.03 Mgal/d, respectively. Withdrawals in Howard, Little River, and Nevada County decreased to 0.00 Mgal/d in 2000. The sharp decrease in withdrawal rates is explained by public water supplies in the southwestern area converting to a surface-water source and relying less on groundwater sources (Halberg and Stephens, 1966; Holland and Ludwig, 1981; Holland, 1987, 1993, 1999, 2004). However, in 2005, groundwater withdrawals increased to 2.53 Mgal/d. Withdrawals increased in Clark, Hempstead, and Nevada County. Withdrawals in Clark and Nevada County increased to 0.43 and 0.18 Mgal/d, respectively, in 2005. In Hempstead County, withdrawals increased from 0.27 in 2000 to 1.92 Mgal/d in 2005, an increase of 711 percent (Holland, 2007).

Potentiometric Surface

Water-level measurements in 61 wells during spring 2008 were used to construct potentiometric-surface maps for the Nacatoch aquifer (figs. 5 and 6; table 1). The potentiometric surface was mapped by calculating the altitude of the water levels (table 1) and is represented by contour lines of equal water-level altitude value. The general direction of groundwater flow is perpendicular to the contour lines in the direction of downward hydraulic gradient.

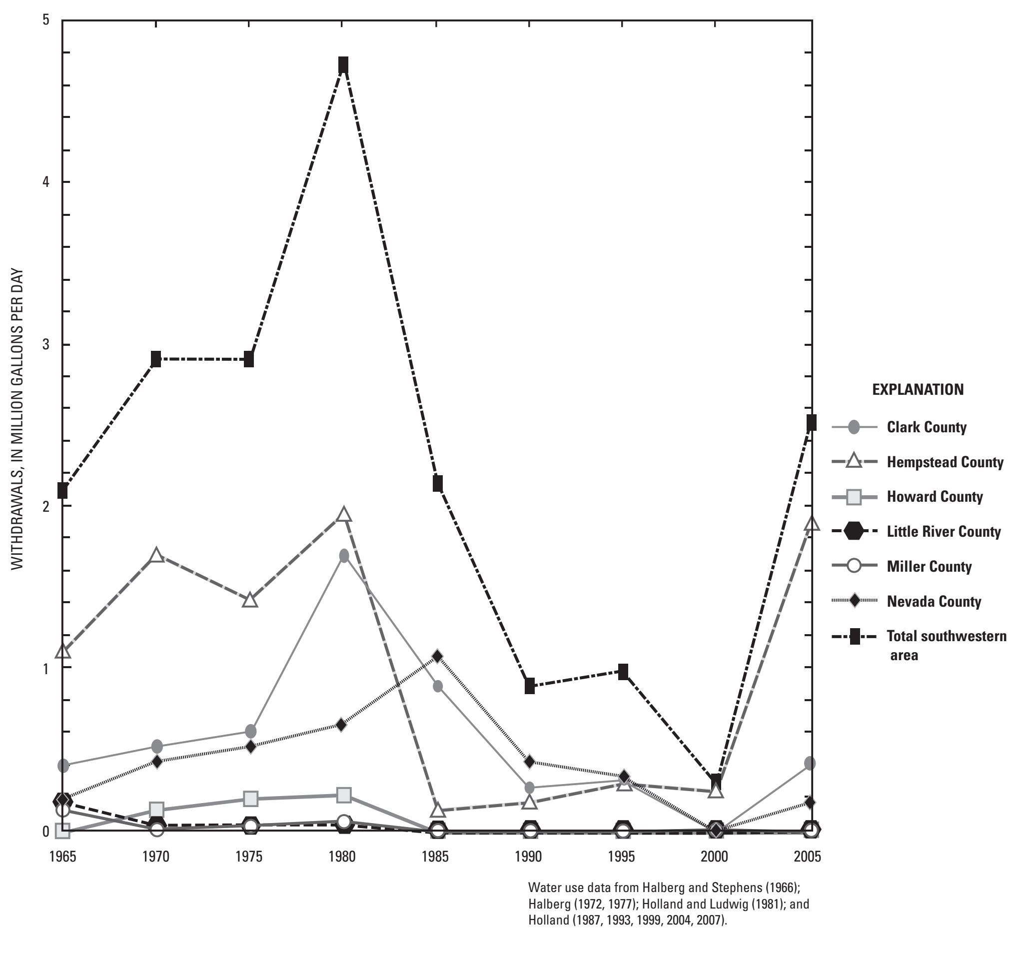


Figure 4. Withdrawals for the Nacatoch aquifer for the southwestern area in Arkansas.

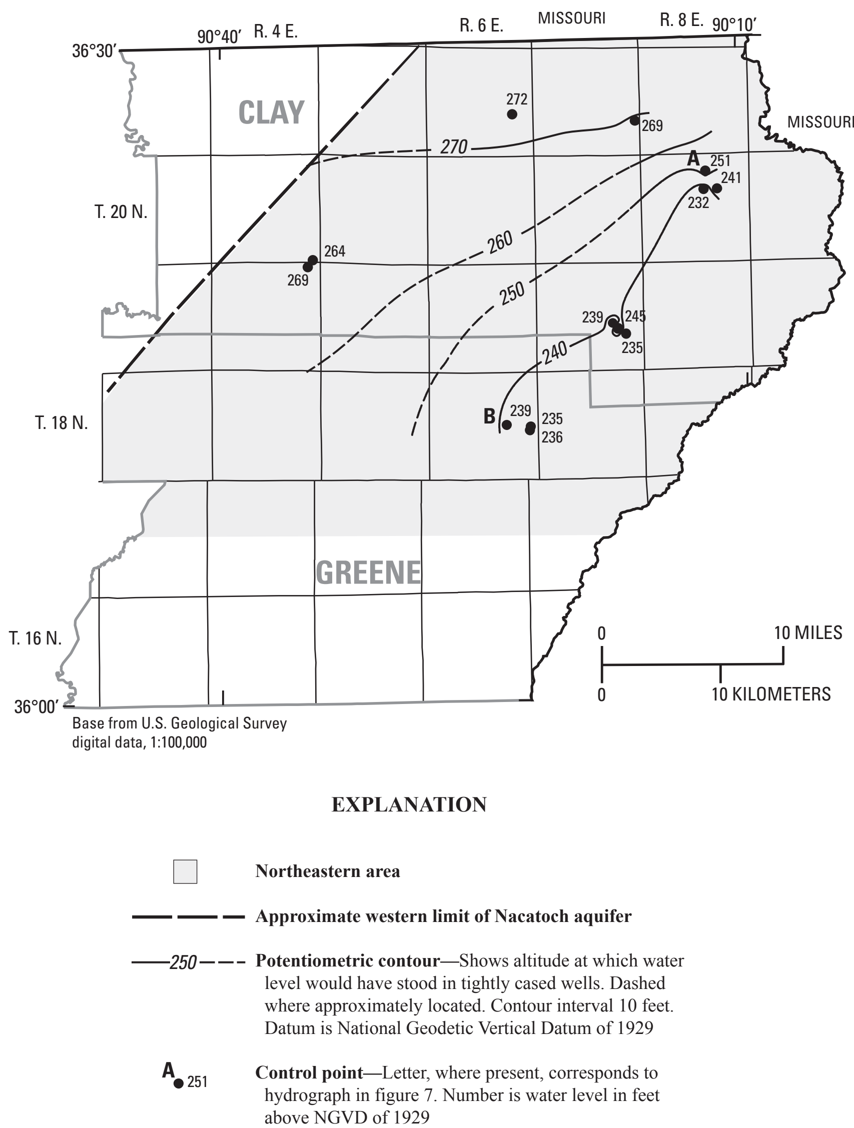
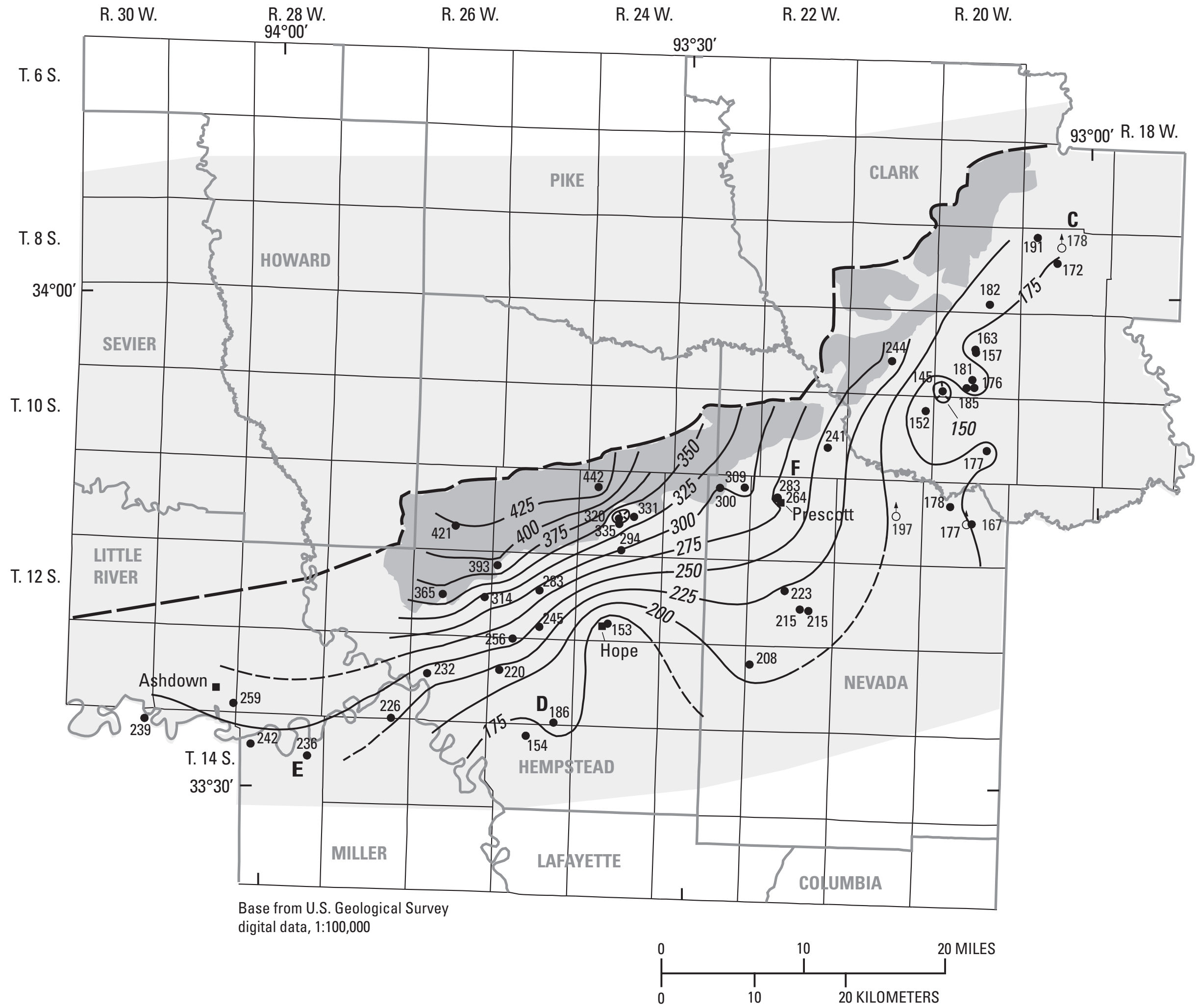


Figure 5. Potentiometric surface of the Nacatoch aquifer, northeastern Arkansas, spring 2008.



EXPLANATION

Southwestern area

Outcrop of Nacatoch Sand

Approximate northern limit of Nacatoch aquifer

250 **Potentiometric contour**—Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Hachures indicate depression. Contour interval 25 feet. Datum is National Geodetic Vertical Datum of 1929

D 186 **Control point**—Letter, where present, corresponds to hydrograph in figure 7. Number is water level in feet above NGVD of 1929

197 **Flowing artesian well**—Number is water level in feet above NGVD of 1929

Figure 6. Potentiometric surface of the Nacatoch aquifer, southwestern Arkansas, spring 2008.

Table 1. Water-level data collected during spring 2008 from wells completed in the Nacatoch Sand.

[NGVD of 1929, 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 of 1929)	Depth to water (feet below land surface)	Land-surface datum (feet above NGVD of 1929)	Date of measurement
			Clark			
08S19W06DCB1	340359	930433	191	78.98	270	2/28/2008
08S19W09ACC1	340323	930228	178	-0.85	177	2/28/2008
08S19W16CAB1	340226	930247	172	0.78	173	2/28/2008
08S20W34DAB1	335954	930744	182	18.47	200	2/28/2008
09S20W16DBD1	335708	930847	163	77.83	241	2/28/2008
09S20W16DDC1	335657	930845	157	75.93	233	2/28/2008
09S20W28DCB1	335516	930901	185	16.93	202	2/28/2008
09S20W31CAD1	335435	931111	145	114.39	259	2/28/2008
09S20W33ABD1	335447	930852	176	33.33	209	2/28/2008
09S20W33BCD2	335446	930926	181	26.22	207	2/28/2008
09S21W21DAD1	335625	931453	244	100.76	345	2/28/2008
10S20W22DCB1	335054	930757	177	83.18	260	2/28/2008
10S21W12BAB1	335321	931225	152	69.26	221	2/28/2008
			Clay			
19N04E01BDB1	361910	903560	269	11.33	280	3/03/2008
19N07E23BAC1	361602	901748	239	82.64	322	303/2008
19N07E23DBC1	361549	901730	245	37.68	283	3/03/2008
19N07E26AAA1	361532	901703	235	41.18	276	3/03/2008
20N04E36DCC1	361929	903542	264	15.24	279	3/03/2008
20N08E10ABC1	362313	901202	251	88.97	340	3/03/2008
20N08E14BAB2	362227	901120	241	44.63	286	3/03/2008
20N08E15BAA1	362224	901208	232	148.86	381	3/03/2008
21N06E23DAC1	362619	902329	272	28.02	300	3/03/2008
21N07E25AAC1	362550	901607	269	72.77	342	3/03/2008
			Greene			
18N06E14CCD1	361115	902420	239	48.12	287	3/04/2008
18N06E24ABB2	361112	902256	235	34.69	270	3/04/2008
18N06E24BDA1	361058	902300	236	39.84	276	3/04/2008
			Hempstead			
11S24W08BDB1	334837	933619	442	28.18	470	2/26/2008
11S24W21ADD1	334641	933449	320	50.29	370	2/26/2008
11S24W21DDD1	334621	933447	335	35.97	371	2/26/2008
11S24W22ADD1	334647	933343	331	34.13	365	2/26/2008
11S24W34CBC1	334444	933438	294	26.28	320	2/26/2008
11S26W27BDD1	334611	934645	421	9.16	430	2/25/2008
12S24W28CDC1	334012	933536	153	200.18	353	2/22/2008
12S25W07ABB1	334346	934340	393	42.14	435	2/25/2008
12S25W15DBC1	334214	934036	283	28.17	311	2/22/2008

Table 1. Water-level data collected during spring 2008 from wells completed in the Nacatoch Sand.—Continued

[NGVD of 1929, 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 of 1929)	Depth to water (feet below land surface)	Land-surface datum (feet above NGVD of 1929)	Date of measurement
Hempstead—Continued						
12S25W34BAC1	334002	934055	245	74.80	320	2/26/2008
12S26W21AAC1	334158	934739	365	32.66	398	2/21/2008
12S26W24ABC1	334159	934438	314	0.72	315	2/21/2008
13S25W05ABD1	333915	934232	256	26.23	282	2/22/2008
13S25W18AAB1	333740	934332	220	62.99	283	2/22/2008
13S25W35DDC1	333406	933931	186	187.49	373	2/26/2008
13S26W17DDB1	333705	934845	232	58.57	291	2/21/2008
14S25W04DDD1	333317	934132	154	105.94	260	2/26/2008
Little River						
13S28W31BCC1	333509	940251	259	51.81	311	2/19/2008
14S30W01DAA1	333426	940904	239	43.32	282	2/19/2008
Miller						
14S27W02AAB1	333419	935121	226	29.23	255	2/20/2008
14S28W13CCB1	333158	935727	236	29.53	266	2/20/2008
14S28W17BBC1	333240	940134	242	28.42	270	2/20/2008
Nevada						
10S22W23DCB1	335105	931935	241	0.66	242	2/27/2008
11S20W08DCD1	334727	931037	178	3.18	181	2/27/2008
11S20W15CDC1	334622	930905	167	8.12	175	2/27/2008
11S20W22AAA1	334624	930926	177	-1.76	175	2/27/2008
11S21W14CAB1	334652	931434	197	-1.20	196	2/27/2008
11S22W08DAC2	334760	932314	264	41.70	306	2/26/2008
11S22W08DDB4	334757	932314	283	22.92	306	2/26/2008
11S23W03DCD1	334840	932726	300	85.28	385	2/26/2008
11S23W12ABB1	334837	932541	309	72.40	381	2/26/2008
12S22W09CDD1	334230	932250	223	6.37	229	2/27/2008
12S22W22ACD1	334108	932135	215	126.93	342	2/27/2008
12S22W23CBA1	334102	932057	215	114.00	329	2/27/2008
13S22W07BDC1	333744	932514	208	135.48	343	2/27/2008

In the southwestern area, the direction of groundwater flow in the Nacatoch aquifer is generally towards the south-southeast in Little River, Miller, and Hempstead Counties and to the east-southeast in Nevada and Clark Counties (fig. 6). This direction of flow may be affected by the increase in clay content in the downdip direction (Boswell and others, 1965). The highest water-level altitude measured was 442 ft in the outcrop area of north-central Hempstead County. The lowest water-level altitude measured was about 145 ft in Clark County.

Three depressions exist in the southwestern area. The largest depression exists at Hope in Hempstead County (fig. 6). Historical water levels indicate a decline of 40 ft from an altitude of 185 ft in 1942 to 145 ft in 1969 (Ludwig, 1972). The water-level altitude in January 2002 was 119 ft (Schrader and Scheiderer, 2004). This depression alters local groundwater-flow directions from the regional direction, with groundwater flowing towards Hope from the west, north, and northeast directions. A comparison with the 2002 potentiometric-surface maps (Schrader and Scheiderer, 2004) for the Nacatoch aquifer exhibits a substantial rise in water level at Hope from 119 ft to 153 ft in 2000. Small depressions exist in southern Clark County and northeastern Hempstead County. The water level in the depression in southern Clark County has declined about 1 ft from 146 ft in 2005 to 145 ft in 2008. The water level in the depression in northeastern Hempstead County has declined 1 ft from 321 in 2005 to 320 ft in 2008. The rest of the southwestern and northeastern areas have minor variations in water level when compared to the 2005 maps.

Long-Term Water-Level Changes

Hydrographs from wells completed in the Nacatoch aquifer with long-term (minimum of 20 years) water-level measurements were constructed (two in the northeastern area and four in the southwestern area). A minimum 20-year period was used to minimize the effect of short-term variations in climate and localized pumping rates on water levels in a single well.

Two long-term hydrographs are associated with two wells (sites A and B, fig. 7) located in the northeastern area (fig. 5). Water levels in both of these wells have an annual decline of about 1.2 ft/yr. In Clay County, well 20N08E10ABC1 consistently showed declines in water level from 1965 to 1990. These declines may be associated with increased withdrawals in Clay County during this period from 0.25 Mgal/d in 1965 to 1.98 Mgal/d in 1990. However, water levels since 1998 have been relatively stable, which may also be associated with withdrawals. Since 1990, withdrawals in Clay County have decreased from 1.98 Mgal/d in 1990 to 0.97 Mgal/d in 2005, a decrease of 51 percent (Halberg and Stephens, 1966; Holland, 1993, 2007; Schrader, 2007). In Greene County, water levels in well 18N06E14CCD1 show an overall decline from 1977 until 1990. Water levels have been relatively stable since then. Overall declines in both wells may be associated with withdrawals from the Nacatoch aquifer in the northeastern area from 1965 to 2005 with the majority of withdrawals occurring in Clay County (fig. 3). However, relatively stable water levels in Clay County from 1990 to 2005 may also be associated with decreased withdrawals.

Four wells with historical water-level measurements (sites C-F; fig. 7) are located in the southwestern area (fig. 6). One well is located in each of the following four counties: Clark, Hempstead, Miller, and Nevada Counties. Water-level rise and decline varied by county.

Water levels in well 08S19W09ACC1 (site C, figs. 6 and 7) declined from about 186 ft above NGVD of 1929 in 1962 to about 178 ft in 2008, an annual decline of about 0.2 ft/yr. The consistent decline in water level does not reflect the changes associated with water use from the Nacatoch aquifer in Clark County.

Water levels in well 13S25W35DDC1 (site D, figs. 6 and 7) declined from 188 ft in 1975 to 175 ft in 1979. Water use from the Nacatoch aquifer in Hempstead County increased from 1.44 Mgal/d in 1975 to 1.98 Mgal/d in 1980 (Halberg, 1977; Holland and Ludwig, 1981), an increase of 72 percent (fig. 4). Water use declined from 1.98 Mgal/d in 1980 to 0.15 Mgal/d in 1985. From 1979 to 1999, a general rise in water level was observed, but from 1999 to 2002, a sharp decrease in water level occurred. From 2005 to 2008, a small decrease in water level occurred. Water-use rates from the Nacatoch aquifer increased from 0.32 Mgal/d in 2000 to 2.53 Mgal/d in 2005, an increase of about 690 percent (Holland, 1987, 1999, 2004, 2007). These fluctuations in water level can be explained by corresponding changes in water use from the Nacatoch aquifer in Hempstead County.

Water levels in well 14S28W13CCB1 (site E, figs. 6 and 7) ranged from 248 ft to 236 ft from 1962 to 2008. Withdrawals in Miller County were less than 0.10 Mgal/d from 1970 through 2005 (fig. 4). Water-level changes in this well cannot be attributed to a specific factor.

Water levels in well 11S22W08DAC2 (site F, figs. 6 and 7), increased from about 179 ft in 1985 to about 267 ft in 1990, an average rise of about 17.6 ft/yr in the 5-year period (Schrader, 2007). This increase in water levels occurred when the withdrawal rates from the Nacatoch aquifer in Nevada County decreased from 1.11 Mgal/d in 1985 to 0.44 Mgal/d in 1990 (Holland, 1987, 1993), a decrease of about 60 percent (fig. 4). Water levels declined 2 ft from about 266 in 2005 to 264 in 2008.

Although water levels in these six wells located in the northeastern and southwestern areas may be associated with changes in water use, including localized withdrawals that are not apparent in the county totals, other factors also may affect water levels such as climatic variations or changes in leakage to and from overlying and underlying rock units.

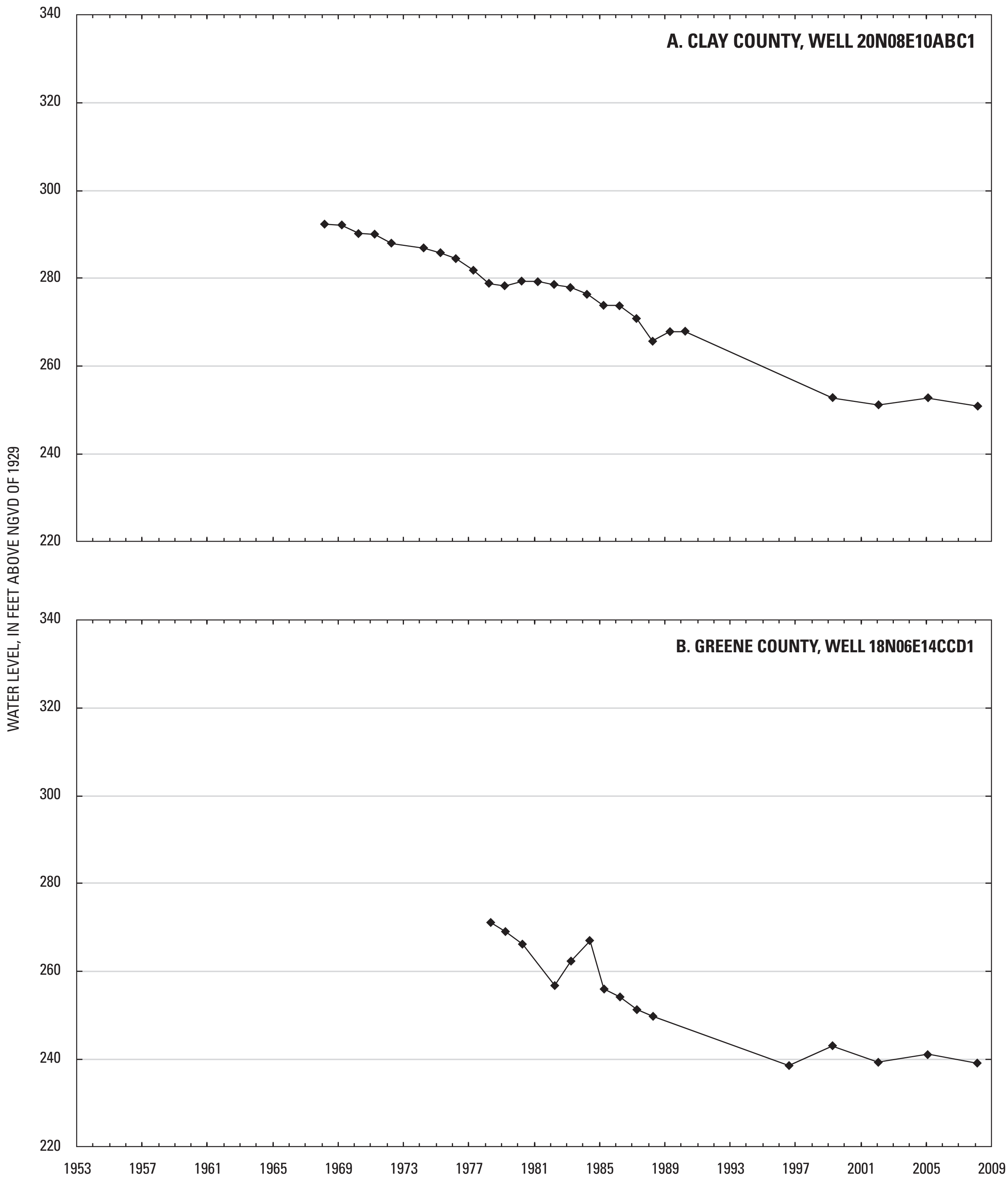


Figure 7. Water-level hydrographs for selected wells completed in the Nacatoch aquifer.

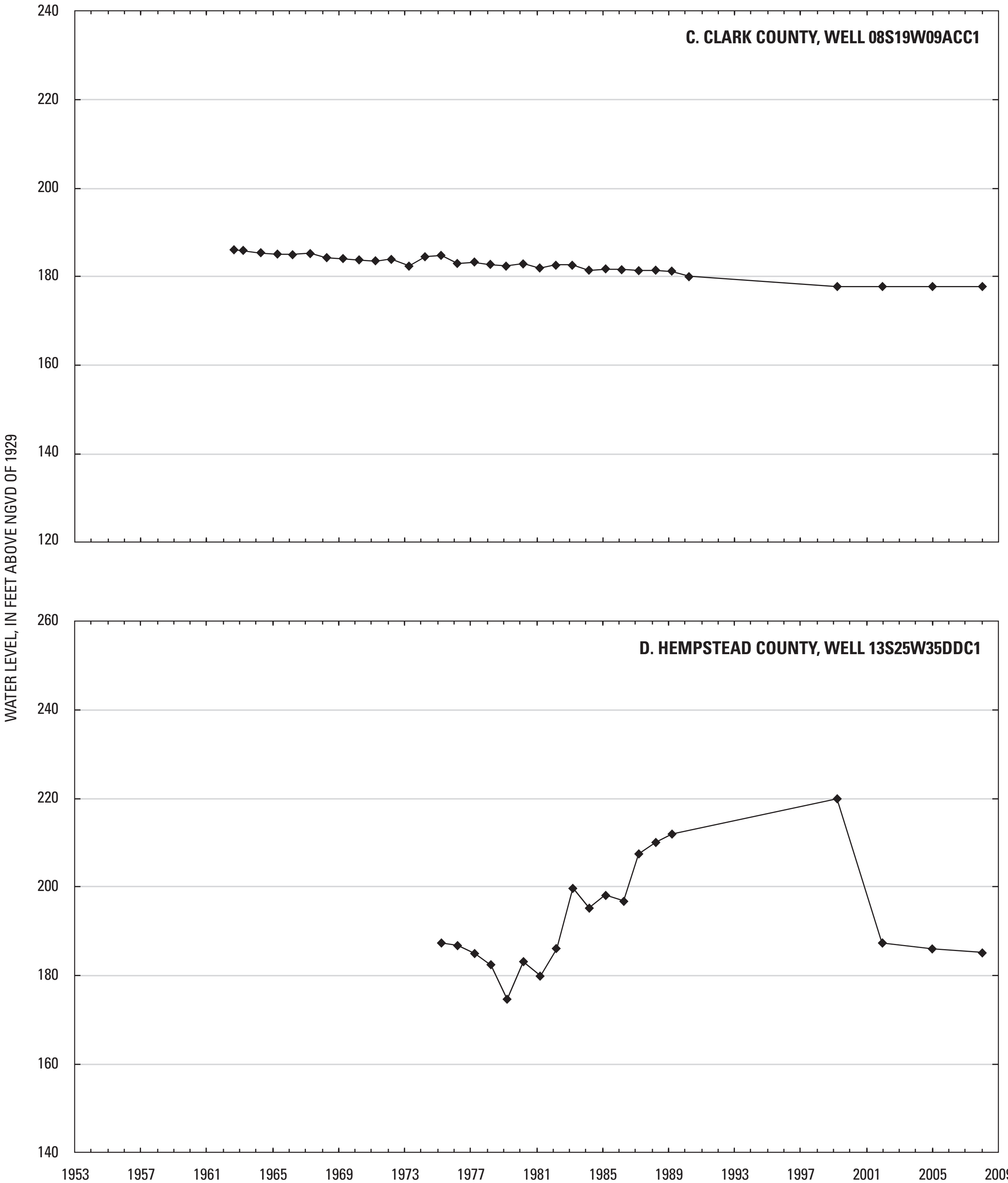


Figure 7. Water-level hydrographs for selected wells completed in the Nacatoch aquifer.—Continued

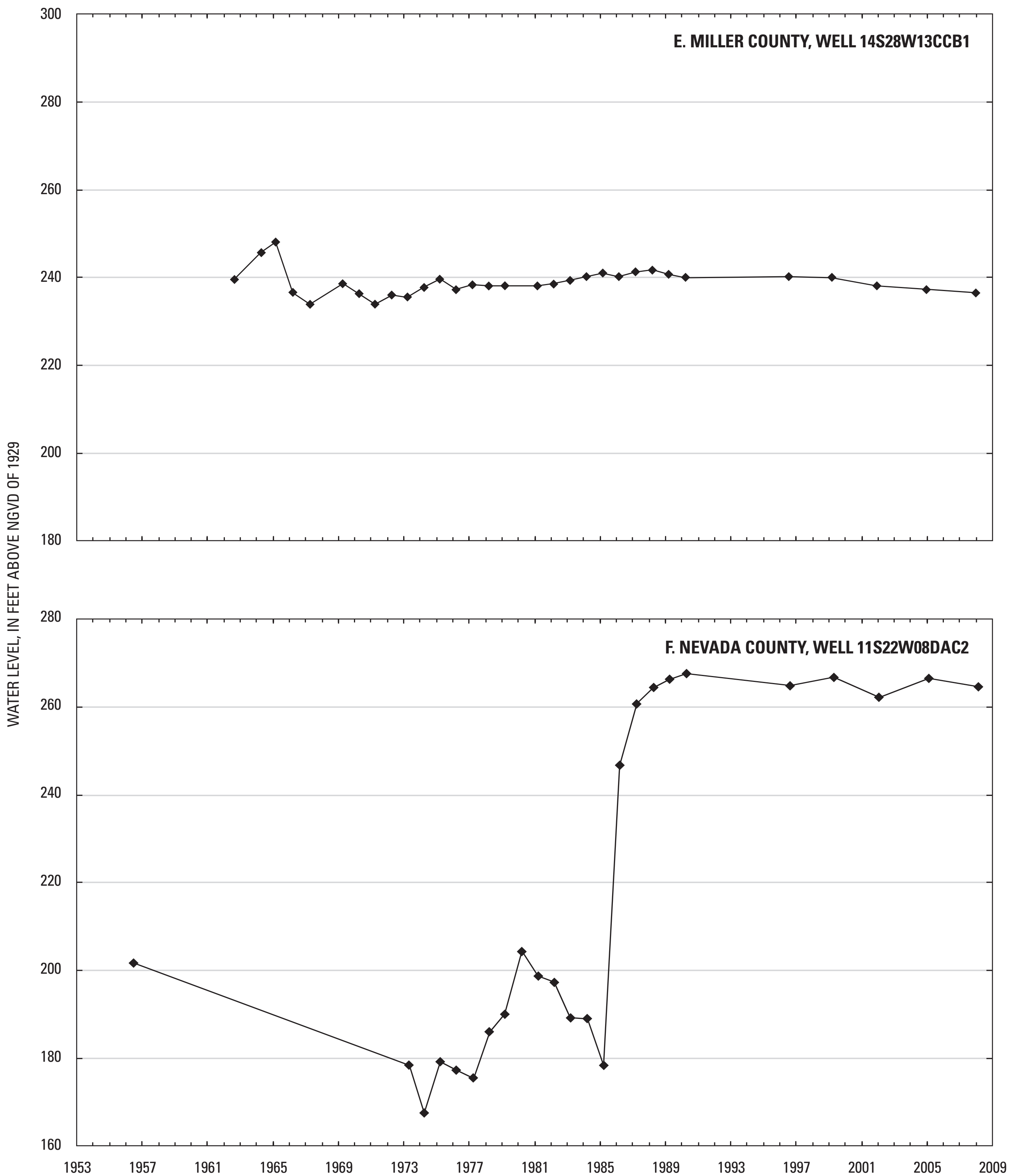


Figure 7. Water-level hydrographs for selected wells completed in the Nacatoch aquifer.—Continued

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 eastern 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, crossbedded 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 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 yields freshwater to within a few miles north of Ashdown in Little River County (fig. 9) and becomes slightly to moderately saline downdip (southeast) from near Prescott to the fault zone trending 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. Wells flowing 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).

Water Use

Water withdrawn from the Tokio aquifer increased by 201 percent from 2.0 Mgal/d in 1965 to 6.02 Mgal/d in 1980 (fig. 8). Water withdrawn from the Tokio aquifer was 1.17 Mgal/d in 2000, a decrease of 80 percent from 1980. Water withdrawn from the Tokio aquifer was 4.58 Mgal/d in 2005, an increase of 291 percent from 2000 (Halberg and Stephens, 1966; Holland and Ludwig, 1981; Holland, 1999, 2004, 2007).

Water-use data for the Tokio aquifer by county is variable, with increases or decreases occurring over 5- to 20-year periods. Water withdrawals in Hempstead County increased by 348 percent from 0.67 Mgal/d in 1965 to 3.0 Mgal/d in 1980 (fig. 8). Water withdrawn in Hempstead County was 0.76 Mgal/d in 2000, a decrease of 75 percent from 1980. Water withdrawn increased to 2.10 Mgal/d in 2005, an increase of 213 percent from 2000. By county, Hempstead County was the largest user of water from the Tokio aquifer in 2005. In Sevier County, water withdrawals were 0.15 Mgal/d in 1965, increasing to 1.15 Mgal/d in 1990, an increase of 667 percent from 1965. From 1990 to 2000, water withdrawn in Sevier County decreased to 0.30 Mgal/d in 2000, a decrease of 74 percent from 1990. Water withdrawn in 2005 was 1.73 Mgal/d, an increase of 477 percent from 2000. In Howard County, water withdrawals were 0.69 Mgal/d in 1965, increasing to 1.11 Mgal/d in 1980, an increase of 61 percent from 1965. Water withdrawals decreased to 0.14 Mgal/d in 1985 and to less than 0.1 Mgal/d in 1990, 1995, and 2000. In 2005, water withdrawals increased to 0.50 Mgal/d in Howard County. In Nevada County, water withdrawals were 0.37 Mgal/d in 1965, increasing to 0.68 Mgal/d in 1980, an increase of 84 percent from 1965. Water withdrawals decreased to less than 0.1 Mgal/d in 1990, 1995, 2000, and 2005. In Pike County, water withdrawals were 0.12 Mgal/d in 1965, increasing to 0.82 Mgal/d in 1980, an increase of 583 percent from 1965. Water withdrawals decreased to less than 0.1 Mgal/d in 1990, 1995, 2000, and 2005. Water withdrawls in Clark, Little River, and Miller Counties were less than 0.1 Mgal/d from 1965 through 2005 (Halberg and Stephens, 1966; Holland and Ludwig, 1981; Holland, 1999, 2004, 2007).

Potentiometric Surface

The potentiometric-surface map for the Tokio aquifer shows the altitude that water would have stood in tightly cased wells screened in the aquifer (fig. 9). Water-level measurements (table 2) in 50 wells during spring 2008 were used to construct the map. The surface was mapped by determining the altitude of the water levels and is represented on the map by contour lines that connect points of equal value. The general direction of groundwater flow is perpendicular to the contours 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-surface high is within the outcrop area in the northwestern part of the southwestern area. The highest water-level altitude measured was 488 ft above NGVD of 1929 in the outcrop area of Howard County. The lowest water-level altitude measured was 129 ft above NGVD of 1929 about 5 mi northwest of Hope in Hempstead County.

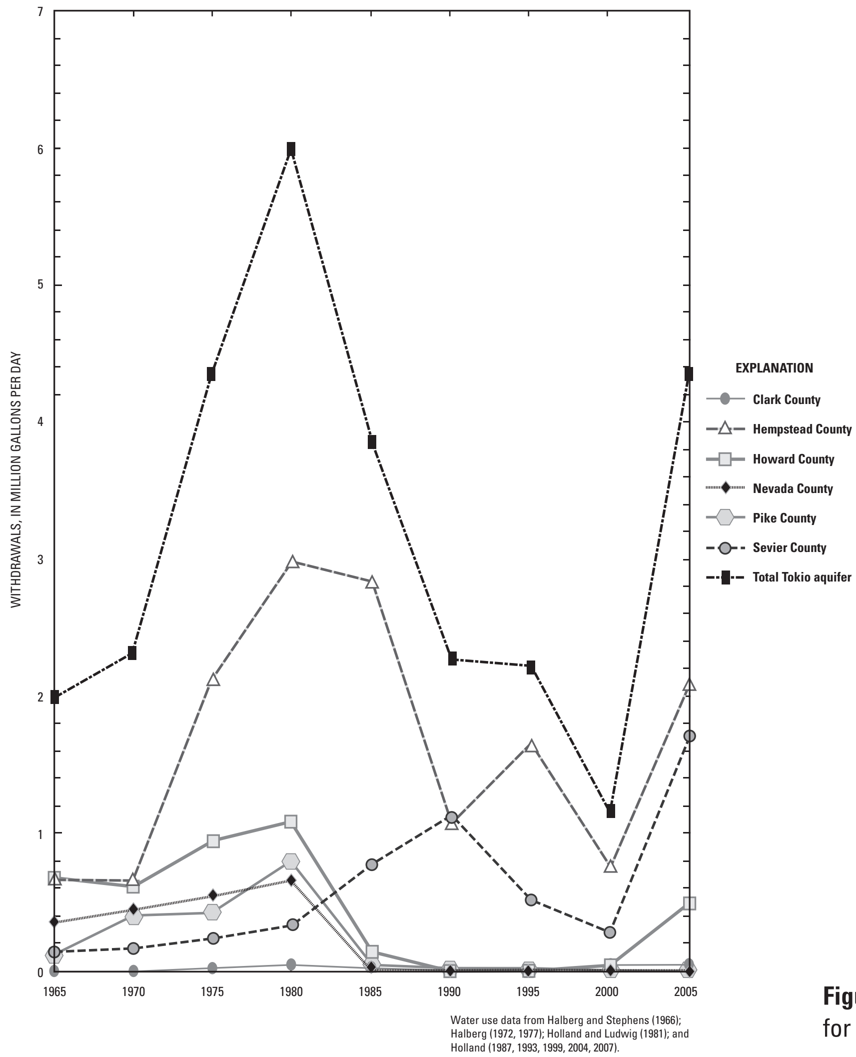


Figure 8. Withdrawals for the Tokio aquifer for the southwestern area in Arkansas.

An area of artesian flow exists in southeastern Pike, northeastern Hempstead, and northwestern Nevada Counties as evidenced by eight flowing artesian wells (fig. 9).

A cone of depression may exist about 5 mi northwest of Hope. The northern half of an apparent cone of depression northwest of Hope is shown on figure 9. Water-level data in the Tokio aquifer were not available south of this area. No other cones of depression were evident in the Tokio aquifer. A comparison of the 2008 map with the 2002 and 1999 potentiometric-surface maps for the Tokio aquifer shows one substantial change; the 300-foot contour is positioned further north in Howard County. The change in this contour is the result of the addition of the measurement at well 10S27W02ACD1, which had not been collected prior to 2005.

Long-Term Water-Level Changes

Four hydrographs from wells completed in the Tokio aquifer have long-term (minimum of 20 years) water-level altitudes (fig. 10). Two wells are located in Hempstead County (sites G and H) and the other two wells are located in Howard (site I) and Nevada (site J) Counties (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.

The two hydrographs in Hempstead County show differences between water-level trends over long periods. In well 09S23W33CDA1 (site G, figs. 9 and 10), water levels generally declined from 1958 to 2008. Water levels in well 12S24W06DAD1 (site H, figs. 9 and 10) fluctuated through a range in altitude of about 276 to about 132 ft over a 37-year period. Water levels generally declined from 1971 to 1979, generally rose from 1979 to 1989, then declined from 1989 to 1999. The average annual decline in water level at well 12S24W06DAD1 from 1971 to 2008 was 3.8 ft/yr. Water withdrawals in Hempstead County increased from 0.67 Mgal/d in 1965 to 3.0 Mgal/d in 1980, then decreased to 0.76 Mgal/d in 2000. Water withdrawn increased to 2.10 Mgal/d in 2005. The decline and rise in water levels in well 12S24W06DAD1 may be associated with the fluctuating withdrawals from the Tokio aquifer in Hempstead County, whereas water levels in well 09S23W33CDA1 do not appear to have a similar association.

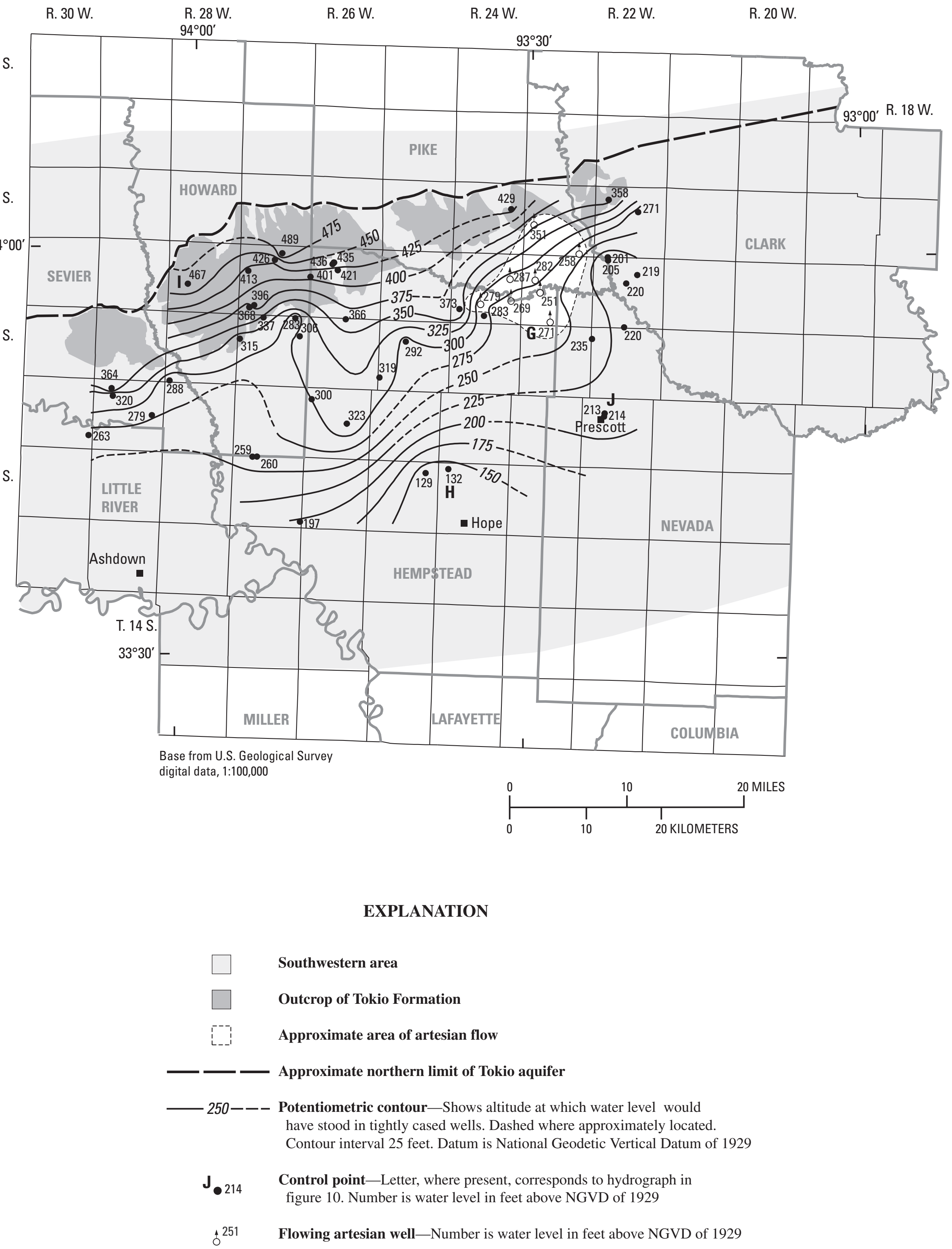


Figure 9. Potentiometric surface of the Tokio aquifer, southwestern Arkansas, spring 2008.

Table 2. Water-level data collected during spring 2008 from wells completed in the Tokio Formation.

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

Station name	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Water-level altitude (feet above NGVD of 1929)	Depth to water (feet below land surface)	Land-surface datum (feet above NGVD of 1929)	Date of measurement
Clark County						
08S22W05CCC1	340408	932256	358	31.63	390	2/27/2008
08S22W15ABB2	340313	932018	271	53.59	325	2/27/2008
09S22W05BBB1	335951	932259	205	107.18	312	2/28/2008
09S22W05BCA1	335936	932257	201	33.60	235	2/28/2008
09S22W10DBA1	335832	932022	219	142.93	362	2/27/2008
09S22W16ACA1	335754	932120	220	13.23	233	2/27/2008
Hempstead County						
09S23W20BDA1	335710	932859	251	-1.23	250	2/21/2008
09S23W33CDA1	335457	932802	271	-0.95	270	2/21/2008
09S24W25BBB1	335633	933132	269	-0.50	268	2/21/2008
09S24W28ACC1	335617	933415	279	-2.11	277	2/21/2008
09S24W30DCC1	335556	933607	373	17.04	390	2/21/2008
09S24W33ADC1	335526	933356	283	45.87	329	2/21/2008
09S26W08ADA2	335920	934717	435	2.53	438	2/21/2008
09S26W08ADD1	335918	934717	436	0.73	437	2/21/2008
09S26W09CDC1	335846	934656	421	3.89	425	2/21/2008
09S26W18CBB1	335815	934921	401	23.54	425	2/21/2008
10S25W09CDB1	335329	934052	292	69.48	361	2/21/2008
10S25W30CCD1	335048	934310	319	69.32	388	2/21/2008
10S26W03BBA1	335507	934612	366	1.18	367	2/25/2008
11S26W08BBB1	334909	934903	300	71.58	372	2/25/2008
11S26W23BBB1	334720	934602	323	95.74	419	2/25/2008
12S24W06DAD1	334360	933701	132	222.56	355	2/25/2008
12S25W02DDD1	334341	933902	129	237.92	367	2/22/2008
12S27W04BBC1	334450	935358	260	174.83	435	2/25/2008
12S27W05AAC1	334449	935421	259	176.22	435	2/25/2008
12S27W36DBC1	333958	935024	197	63.61	261	2/21/2008
Howard County						
09S27W03DBD1	340000	935153	488	73.52	562	2/20/2008
09S27W10BCB1	335930	935232	426	108.06	534	2/20/2008
09S27W18ADB1	335840	935453	413	78.62	492	2/20/2008
09S27W32BDB1	335606	935424	396	54.57	451	2/20/2008
09S27W32BDB2	335606	935424	368	81.58	450	2/20/2008
09S28W20DAC1	335740	940014	467	12.64	480	2/20/2008
10S27W02ACD1	335454	935056	283	75.49	358	2/20/2008
10S27W04BBD1	335512	935330	337	55.48	392	2/20/2008
10S27W12CAB1	335356	935021	306	76.98	383	2/20/2008
10S27W18BAC1	335336	935535	315	106.87	422	2/20/2008

Table 2. Water-level data collected during spring 2008 from wells completed in the Tokio Formation.—Continued

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

Station name	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Water-level altitude (feet above NGVD of 1929)	Depth to water (feet below land surface)	Land-surface datum (feet above NGVD of 1929)	Date of measurement
Little River County						
11S30W25DDC1	334618	940852	263	22.16	285	2/19/2008
Nevada County						
09S22W33DCC1	335437	932130	220	5.47	225	2/26/2008
10S23W12AAA1	335345	932421	235	21.14	256	2/26/2008
11S22W08DAC1	334758	932315	213	92.17	305	2/26/2008
11S22W08DAC8	334757	932312	214	91.47	305	2/26/2008
Pike County						
08S23W19ADC1	340213	932931	351	-1.01	350	2/20/2008
08S23W35DCA1	340004	932530	258	-1.15	257	2/20/2008
08S24W14AAC1	340324	933134	429	94.41	523	2/20/2008
09S23W17BBC2	335804	932925	282	-1.83	280	2/20/2008
09S24W14AAD1	335810	933139	287	-1.63	285	2/20/2008
Sevier County						
10S28W31DCC1	335026	940145	288	41.84	330	2/19/2008
11S29W05DCA1	334949	940653	364	116.33	480	2/19/2008
11S29W08DBB1	334907	940704	320	144.83	465	2/19/2008
11S29W13CCD1	334750	940317	279	81.42	360	2/19/2008

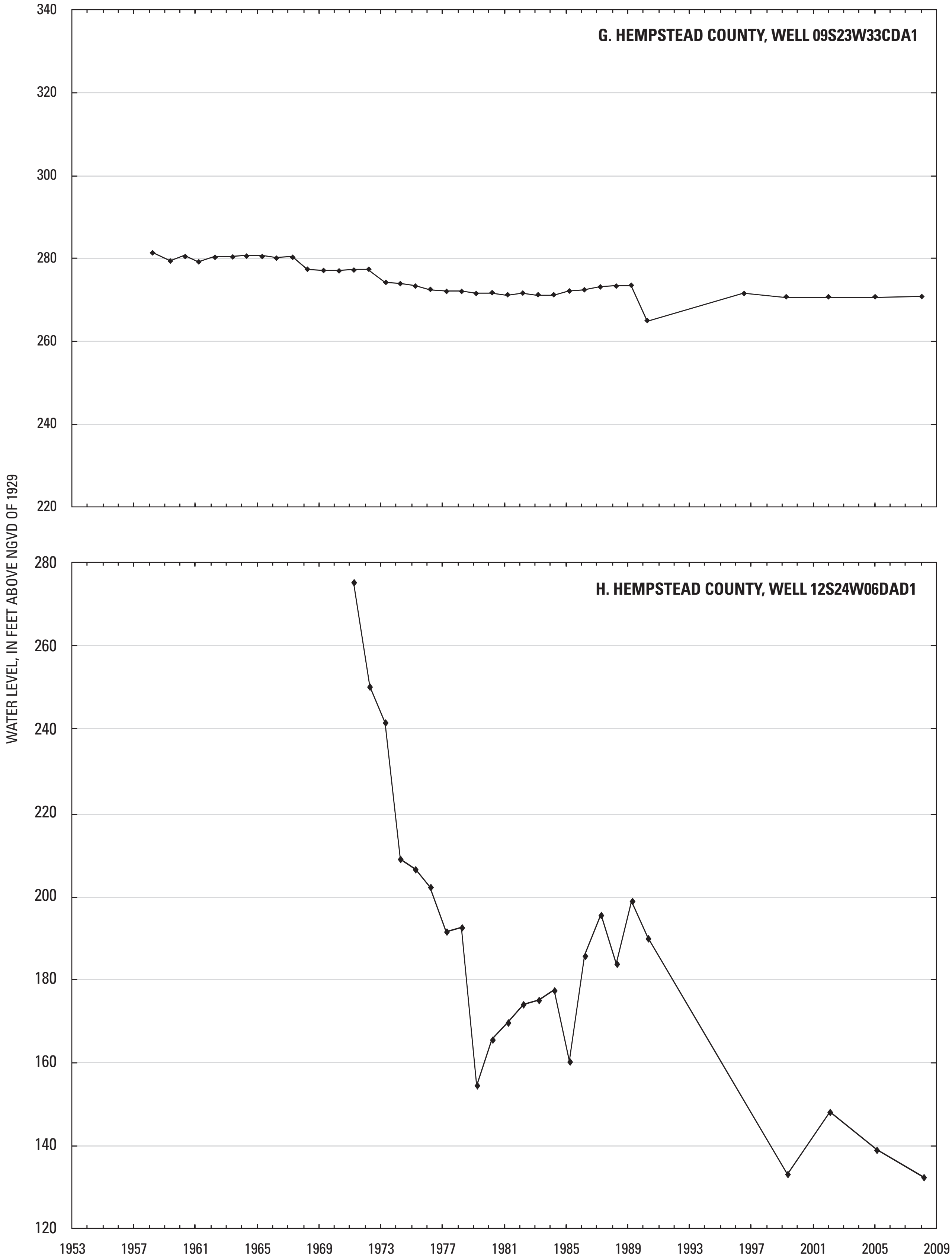


Figure 10. Water-level hydrographs for selected wells completed in the Tokio aquifer.

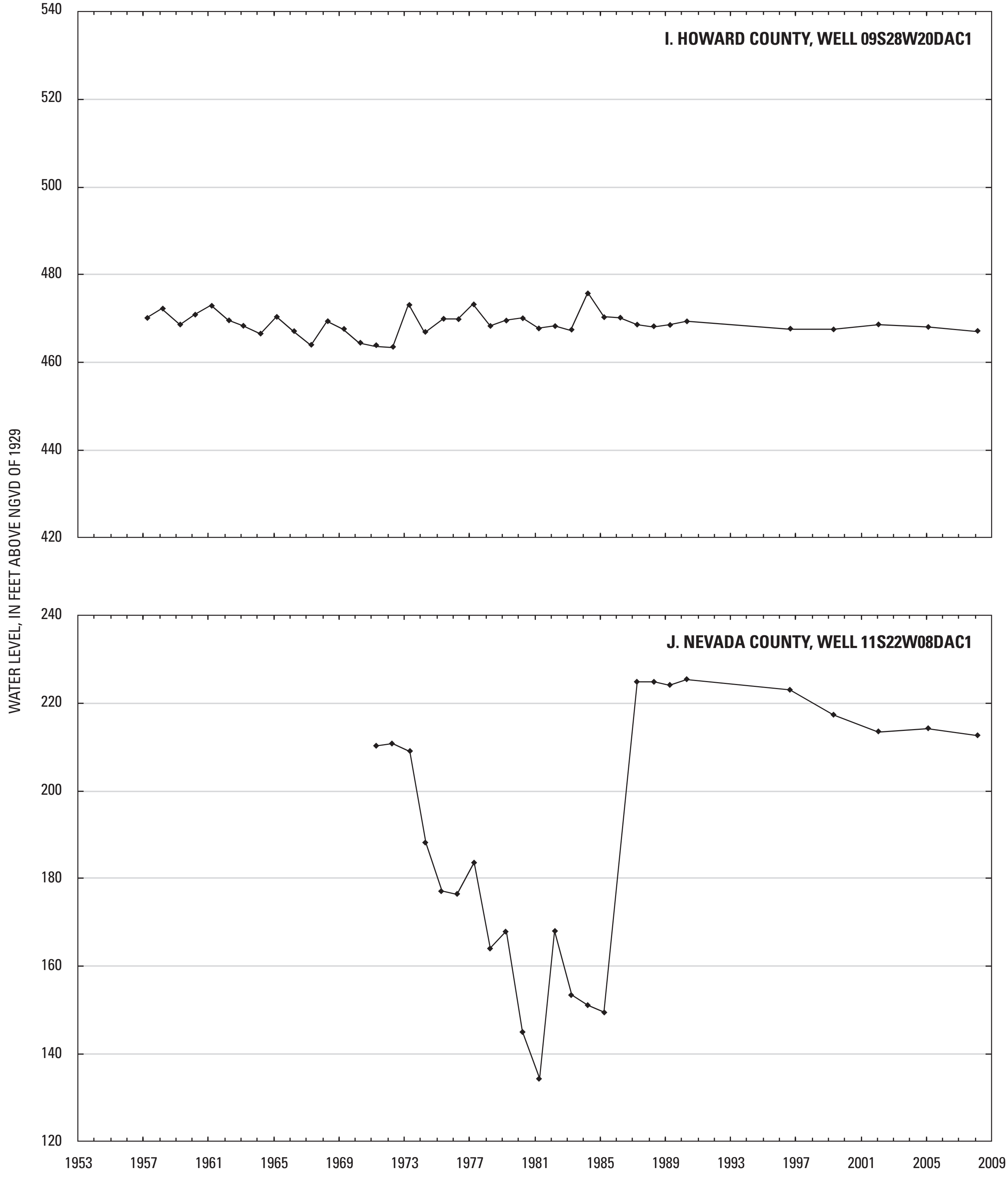


Figure 10. Water-level hydrographs for selected wells completed in the Tokio aquifer.—Continued

In Howard County, water levels in well 09S28W20DAC1 (site I, figs. 9 and 10) range from about 476 ft to about 464 ft over a 51-year period from 1957 to 2008. No substantial rises or declines in water levels were observed. In Howard County, water withdrawals were 0.69 Mgal/d in 1965, increasing to 1.11 Mgal/d in 1980. Water withdrawals decreased to 0.14 Mgal/d in 1985 and less than 0.1 Mgal/d in 1990, 1995, and 2000. In 2005, water withdrawals increased to 0.50 Mgal/d in Howard County. There does not appear to be any association between water levels in this well and withdrawals from the Tokio aquifer (fig. 8).

In Nevada County, water levels in well 11S22W08DAC1 (site J, figs. 9 and 10) declined from about 211 ft in 1972 to about 150 ft in 1985, with a minimum of 135 ft in 1981. This is an annual decline of about 4.7 ft/yr. Water withdrawals from the Tokio aquifer for Nevada County increased from 0.37 Mgal/d in 1965 to 0.68 Mgal/d in 1980 (fig. 8). From 1985 to 1987, a rise in water level to about 225 ft was observed, which is an approximately 37.5 ft/yr rise. From 1998 to 2008, there was a decline in water level from about 225 ft to about 213 ft, respectively. Water withdrawals from Nevada County decreased to less than 0.10 Mgal/d by 1985 and continued at this rate through 1990, 2000, and 2005. The decline and rise in water levels may be associated with the increased and decreased withdrawals from the Tokio aquifer.

Although water levels in these four wells may be associated with changes in water use, other factors also may affect water levels such as climatic variations or changes in leakage to and from overlying and underlying rock units.

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 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 61 wells completed in the Nacatoch Sand and 50 wells completed in the Tokio Formation during spring 2008. In northeastern Arkansas, withdrawals from the Nacatoch aquifer increased by 480 percent from 1965 to 2005. In southwestern Arkansas, withdrawals from the Nacatoch and Tokio aquifers increased by 125 percent and 201 percent, respectively, from 1965 to 1980 and decreased by 93 percent and 80 percent, respectively, from 1980 to 2000. Withdrawals from Nacatoch aquifer and Tokio aquifer increased by 690 percent and 291 percent, respectively, from 2000 to 2005.

The direction of groundwater flow in the northeastern area of the Nacatoch aquifer generally is towards the southeast. The highest water level measured is located in northern Clay County along the north and northwestern boundary of this area. The lowest water level measured is located in eastern Clay County.

The direction of groundwater flow in the southwestern area of the Nacatoch aquifer is towards the south-southeast in Little River, Miller, and Hempstead Counties and to the east-southeast in Nevada and Clark Counties. The highest water level measured is located in the outcrop area in north-central Hempstead County. A depression exists at Hope in Hempstead County. Small depressions exist in southern Clark County and northeastern Hempstead County.

In the northeastern area of the Nacatoch aquifer, water levels in two wells declined during a period of increased withdrawals from the Nacatoch aquifer. Water levels in these wells have an annual decline of about 1.2 ft/yr. The Clay County well consistently showed declines in water level from 1965 to 1990. These declines may be associated with increased withdrawals in Clay County during this period. However, water levels since 1998 have been relatively stable. Withdrawals in Clay County have decreased from 1.98 Mgal/d in 1990 to 0.97 Mgal/d in 2005. The Greene County well shows an overall decline from 1977 until 1990. Water levels have been relatively stable since then.

In the southwestern area of the Nacatoch aquifer, the sharp decrease in withdrawal rates is explained by public water supplies in the southwestern area converting to surface water and relying less on groundwater sources. Four wells with historical measurements are located in the southwestern area. Water levels in the Hempstead County well show a decline from 1975 to 1979, a general rise from 1979 to 1999, a sharp decrease from 1999 to 2002, and a small decrease from 2005 to 2008. These fluctuations in water level can be explained by changes in water use. Water levels in the Nevada County well show an increase from 1985 to 1990, an average rise of about 17.6 ft/yr. This increase in water levels occurred when the withdrawal rates from the Nacatoch aquifer in Nevada County decreased from 1985 to 1990. Water levels declined from 2005 to 2008. Water levels in the Clark and Miller County wells do not reflect the changes associated with water use. The variation in water levels in these six wells located in the northeastern and southwestern areas could result from differences in localized withdrawals, climatic variations, or leakage of water from overlying and underlying rock units.

The direction of groundwater flow in the Tokio aquifer generally is towards the south or southeast. The highest water level measured is located where the aquifer outcrops in the northwestern part of the study area. An area of artesian flow exists in southeastern Pike, northeastern Hempstead, and northwestern Nevada Counties. A cone of depression may exist about 5 miles northwest of Hope in Hempstead County.

The hydrographs of two of four wells completed in the Tokio aquifer showed a decline and a rise in water levels

during a period of increased, then decreased withdrawals from the Tokio aquifer. Water levels in the two wells in Hempstead County show differences between water-level trends over long periods. In well 09S23W33CDA1, water levels generally declined from 1958 to 2008. Water levels in well 12S24W06DAD1 fluctuated over a 37-year period. Water levels generally declined from 1971 to 1979, generally rose from 1979 to 1989, then declined from 1989 to 1999. The decline and rise in water levels in well 12S24W06DAD1 may be associated with the fluctuating withdrawals from the Tokio aquifer in Hempstead County, whereas water levels in well 09S23W33CDA1 do not appear to have a similar association. In the Howard County well there does not appear to be any association between water levels in this well and withdrawals from the Tokio aquifer. Water levels in the Nevada County well declined from 1972 to 1985 and rose from 1985 to 1987. The decline and rise in water levels may be associated with the increased and decreased withdrawals from the Tokio aquifer.

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