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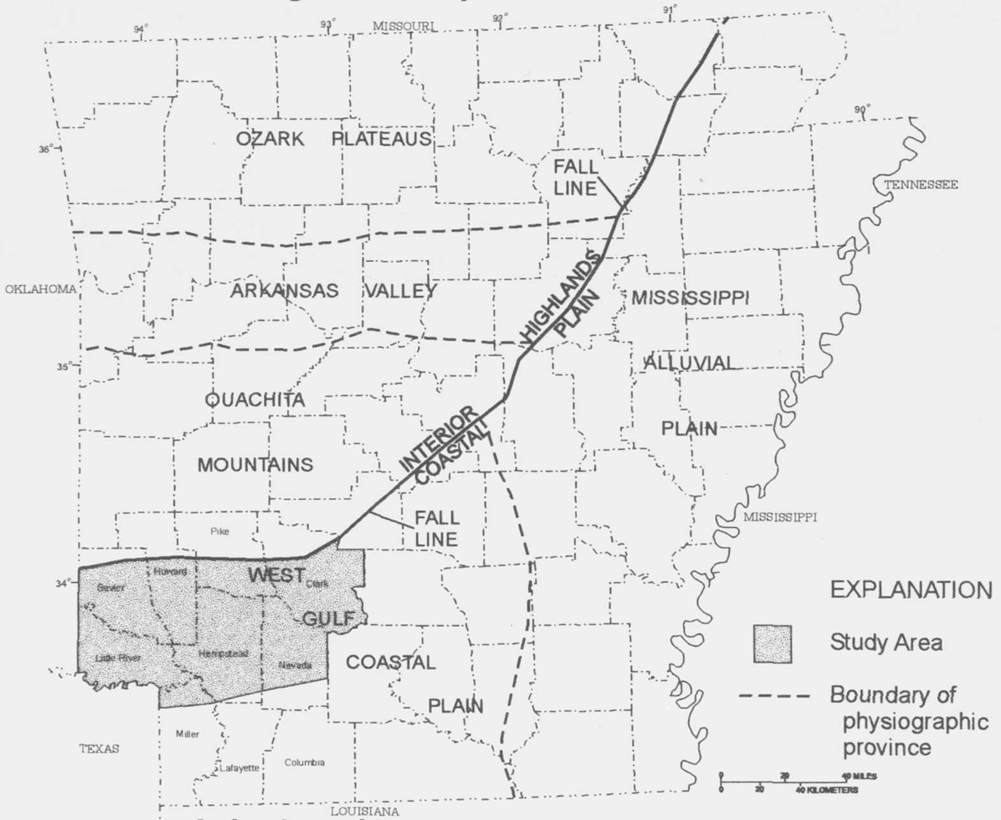
STATUS OF WATER LEVELS IN AQUIFERS IN THE NACATOCH SAND AND TOKIO FORMATION OF SOUTHWESTERN ARKANSAS, 1996

Water-Resources Investigations Report 98-4130



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

STATUS OF WATER LEVELS IN AQUIFERS IN THE NACATOCH SAND AND TOKIO FORMATION OF SOUTHWESTERN ARKANSAS, 1996

By T.P. Schrader

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 98-4130

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Arkansas Soil and Water Conservation Commission
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Little Rock, Arkansas
1998

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

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STATUS OF WATER LEVELS IN AQUIFERS IN THE NACATOCH SAND AND TOKIO FORMATION OF SOUTHWESTERN ARKANSAS, 1996

By T. P. Schrader

ABSTRACT

Aquifers in the Nacatoch Sand and Tokio Formation in southwestern Arkansas are a source of water for industrial, public supply, domestic, and agricultural uses. Water-level measurements were made in 24 wells completed in the Nacatoch Sand and 18 wells completed in the Tokio Formation from August through October 1996 to produce potentiometric-surface maps.

The direction of ground-water flow in aquifers in the Nacatoch Sand and Tokio Formation generally is to the south-southeast or southeast. Potentiometric highs for both aquifers are in the outcrop areas. The aquifer in the Tokio Formation has artesian flow in southeastern Pike, northeastern Hempstead, and northwestern Nevada Counties. One apparent cone of depression was evident within the study area in the aquifer in the Nacatoch Sand.

Withdrawals from aquifers in the Nacatoch Sand and Tokio Formation increased from 1965 to 1980 and decreased from 1980 to 1995. Long-term hydrographs were prepared for seven wells in the study area. Changes in water levels in three wells completed in the aquifer in the Nacatoch Sand and one well completed in the aquifer in the Tokio Formation might be associated with decreased withdrawals. Evidence of an association between withdrawals and water levels in three wells is not apparent.

INTRODUCTION

Ground water is a renewable resource important for economic growth and quality of life. Monitoring of ground-water levels and withdrawals provides information water managers need to effectively plan and manage the resource. A study was conducted in cooperation with the Arkansas Soil and Water Conservation Commission and the Arkansas Geological Commission to provide potentiometric surfaces and water-level hydrographs associated with aquifers in the Nacatoch Sand and Tokio Formation (hereinafter referred to as the Nacatoch aquifer and Tokio aquifer, respectively) in southwestern Arkansas. The Nacatoch and Tokio aquifers are sources of water for industrial, public- supply, domestic, and agricultural use within the West Gulf Coastal Plain in southwestern Arkansas.

The Nacatoch aquifer is stratigraphically above the Tokio aquifer. The top of the Nacatoch aquifer has an altitude of about 300 feet (ft) above sea level[1] in the outcrop and descends to about 800 ft below sea level at the southern boundary of the study area. The top of the Tokio aquifer has an altitude of about 300 ft above sea level in the outcrop and descends to about 1,800 ft below sea level at the southern boundary of the study area. Five stratigraphic units separate the Nacatoch aquifer from the Tokio aquifer, listed here in descending stratigraphic order: Saratoga Chalk, Marlbrook Marl, Annona Chalk, Ozan Formation, and Brownstown Marl. In the study area, these five units are rarely used as a water source and are not discussed in this report.

[1]In this report, sea level refers to the National Geodetic Vertical Datum of 1992—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929

Cones of depression within a potentiometric surface are indicators of pumping rates that 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 within the aquifer. Water levels will recover in a short period of time if pumping rates cease to exceed the recharge rates to the aquifer. Pumping rates that exceed recharge rates for an extended period of time will cause radial growth in cones of depression. Local cones of depression can intersect and coalesce, causing a regional drop in water levels within the aquifer. Variations in climatic conditions and, thus, recharge, can result in the rise or decline of water levels and could account for changes shown by long-term hydrographs.

The study area spans eight counties (Clark, Hempstead, Howard, Little River, Miller, Nevada, Pike, and Sevier) in the West Gulf Coastal Plain physiographic province (fig.1). The area is bounded on the north by the Fall Line separating the Interior Highlands from the Coastal Plain, on the west by Oklahoma and Texas, and on the east by the eastern borders of Clark and Nevada Counties. The study area was limited to the freshwater zone. The southern boundary of the study area is defined by a freshwater/saltwater interface. To the south, the water in the aquifers is not suitable for most uses based on the concentrations of dissolved solids and salinity (Boswell and others, 1965; Petersen and others, 1985).

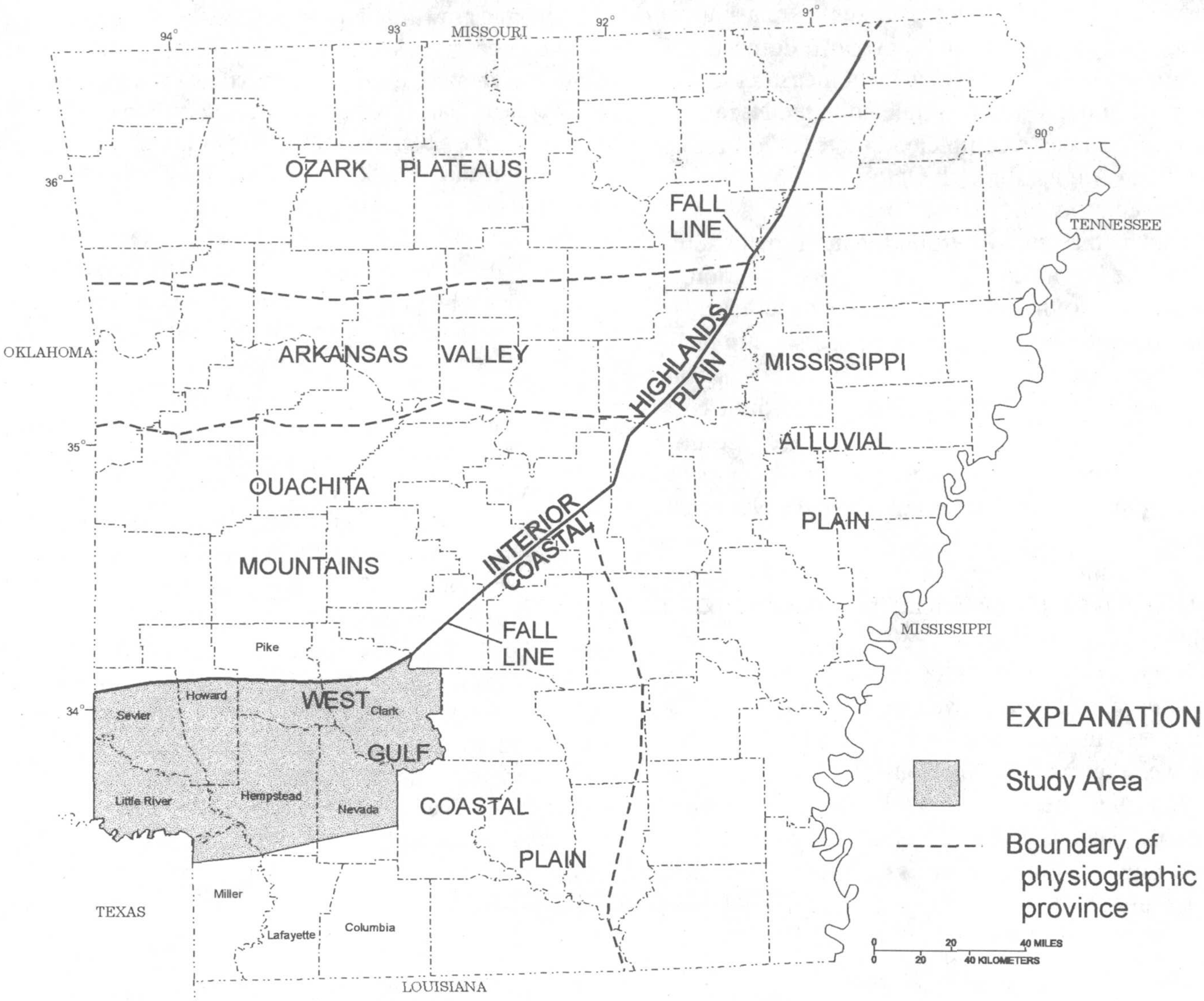


Figure 1. Location of study area.

This report presents results of the study. Water-level measurements used to construct the potentiometric surfaces were made in 24 wells completed in the Nacatoch aquifer and in 18 wells completed in the Tokio aquifer during August through October of 1996. All water-level data are stored in the U.S. Geological Survey's Ground-Water Site Inventory (GWSI) data storage system. Long-term water-level hydrographs were prepared for selected wells. County withdrawal data collected by the U.S. Geological Survey from 1965 to 1995 were related to these hydrographs.

NACATOCH SAND

Hydrogeologic Setting

The Nacatoch Sand of Cretaceous age is underlain by the Saratoga Chalk and overlain by the Arkadelphia Marl. The Nacatoch Sand outcrops in a belt 3 to 8 miles (mi) wide extending from central Clark County southwestward to the western edge of Hempstead County (fig. 2). The belt continues westward as a subcrop below Quaternary alluvial and terrace deposits across Little River County (Boswell and others, 1965). The Nacatoch Sand is about 100 ft thick near the outcrop and attains a maximum thickness of 600 ft downdip. The unit dips toward the southeast (Petersen and others, 1985).

The Nacatoch Sand consists of three distinct units. The lower unit consists of interbedded gray clay, sandy clay and marl, dark clay-rich fine-grained sand, and hard irregular concretionary beds. 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 upper unit is composed of unconsolidated, gray, fine-grained quartz sand that commonly is cross bedded. Locally the sand is massive and contains a few hard lenses and beds of fossiliferous sandy limestone. This upper sand unit contains the primary aquifer of the Nacatoch Sand (Counts and others, 1955; Plebuch and Hines, 1969).

The general direction of ground-water flow in the Nacatoch aquifer is to the south-southeast. The direction of ground-water flow may be influenced by several geologic features. The Nacatoch aquifer receives recharge from precipitation in its outcrop areas in Hempstead, Nevada, and Clark Counties and through the overlying alluvium and terrace deposits in Little River County, Arkansas, and northeastern Texas. The direction of flow might be affected by the increase in clay content in the downdip direction and by a fault system trending northeastward from northeastern Texas across Miller, Lafayette, and Nevada Counties in Arkansas. The pattern of flow is altered by pumpage of water from the aquifer at Hope, in Hempstead County, where water levels have declined from an altitude of 185 ft above sea level in 1942 to 145 ft in 1969. The ground water flows toward the southeast on the west side of Hope and toward the southwest on the east side of Hope (Boswell and others, 1965; Ludwig, 1972).

The Nacatoch aquifer yields water to wells in southwestern Clark county, northern Nevada County, central Hempstead County, northern Miller County, and southeastern Little River County. Flowing 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. Downdip 2 to 20 mi from the outcrop area, the water generally is too salty for most uses. In Miller County, eastern Nevada County, and Clark County yields are generally smaller and the water may contain considerable chloride (Counts and others, 1955). Aquifer tests made using 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 withdrawn from the Nacatoch aquifer was estimated to be 2.11 million gallons per day (Mgal/d) in 1965 and increased to 4.75 Mgal/d in 1980. Water withdrawn from the Nacatoch aquifer was estimated to be 1.02 Mgal/d in 1995, a decrease of 78 percent from 1980 (Halberg and Stephens, 1966; Holland and Ludwig, 1981; T.W. Holland, U.S. Geological Survey, written commun., 1995).

Potentiometric Surface

The potentiometric surface for the Nacatoch aquifer shows the altitude that water would have stood in tightly cased wells screened in the aquifer (fig. 2). Water levels measured in 24 wells from August through October 1996 were used to construct the map (table 1). The surface is mapped by determining the altitude of the water levels and is represented on the map by contours that connect points of equal value. The general direction of ground-water flow is perpendicular to the contours in the direction of downward hydraulic gradient.

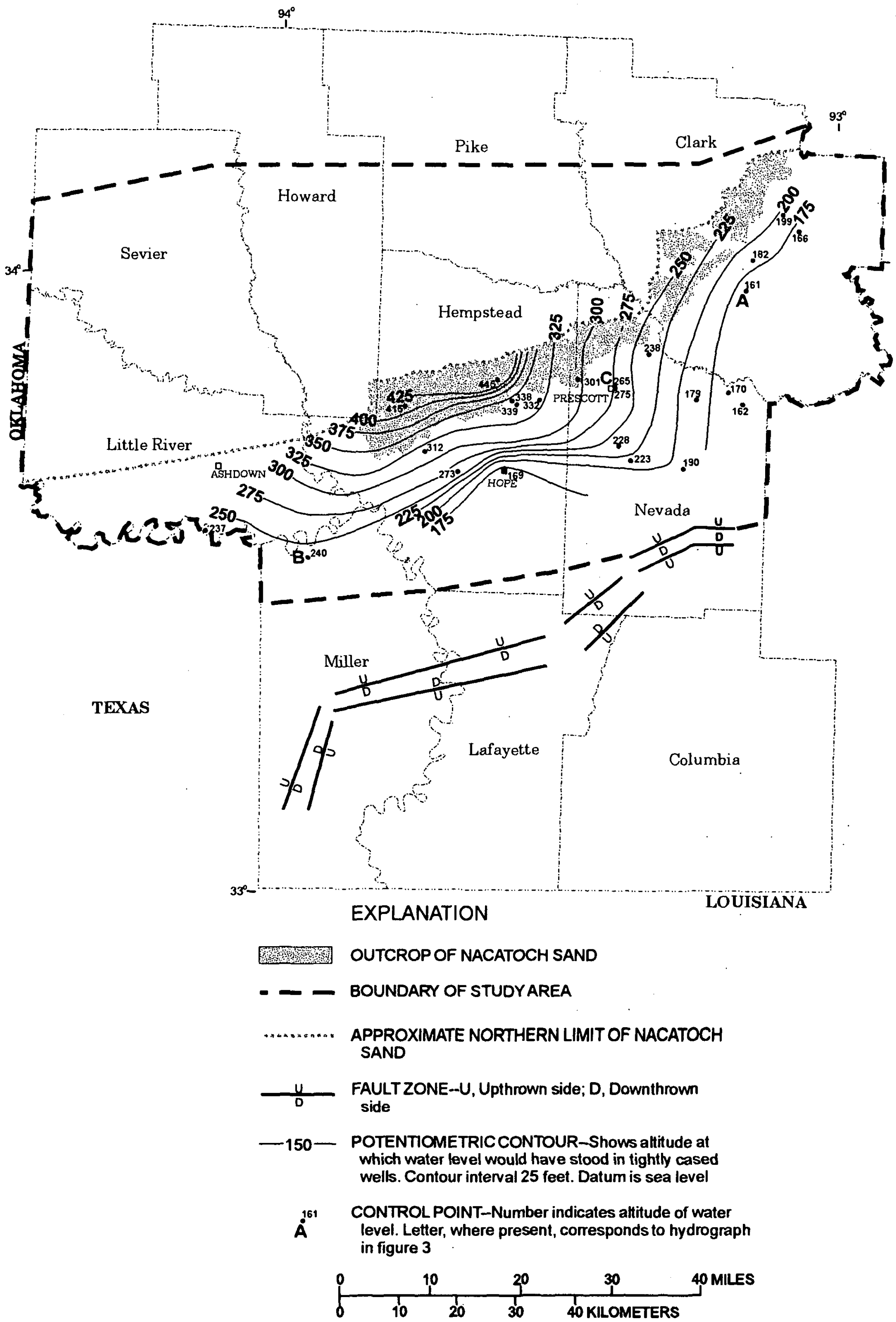


Figure 2. Potentiometric surface of wells completed in the Nacatoch aquifer, southwestern Arkansas, August-October 1996.

Table 1. Water-level measurements and well information for selected wells completed in the Nacatoch aquifer

Local well number	Latitude	Longitude	Water level altitude (feet above sea level)	Depth to water level (feet below land-surface datum)	Land-surface altitude (feet above sea level)	Date of measurement
			Clark County			
08S19W06DCA1	340359	0930432	199	71.07	270	09-06-96
08S19W16CAB1	340225	0930246	166	6.92	173	08-29-96
08S20W34DAB1	335753	0930745	182	18.33	200	08-16-96
09S20W16DDC1	335656	0930840	161	72.18	233	08-16-96
			Hempstead County			
11S24W08BDB1	334834	0933625	445	25.28	470	08-06-96
11S24W21ADD1	334641	0933447	338	62.81	401	09-12-96
11S24W21DDD1	334618	0933446	339	32.09	371	09-12-96
11S24W22ADD1	334643	0933142	332	33.10	365	09-12-96
11S26W27BDD1	334605	0934645	415	15.45	430	10-08-96
12S24W28CDC1	334009	0933539	169	183.58	353	08-06-96
12S25W34BAC1	334002	0934051	273	46.96	320	10-08-96
12S26W24ABC1	334152	0934430	312	3.07	315	08-08-96
			Little River County			
14S30W01DAA1	333420	0940849	237	45.34	282	10-09-96
			Miller County			
14S28W13CCB1	333200	0935725	240	25.74	266	08-28-96
			Nevada County			
10S22W23DCB1	335105	0931935	238	3.81	242	08-21-96
11S20W08DCD1	334726	0931042	170	10.29	180	10-08-96
11S20W15CDC1	334622	0930904	162	12.73	175	08-20-96
11S21W14CAB1	334646	0931411	179	.99	180	10-08-96
11S22W08DAC2	334759	0932313	265	41.48	306	08-21-96
11S22W08DDB4	334756	0932318	275	31.39	306	10-08-96
11S23W03DCD1	334840	0932726	301	79.36	380	10-08-96
12S21W27BAC1	334022	0931537	190	9.51	200	08-20-96
12S22W09CDD1	334230	0932249	228	.51	229	10-08-96
12S22W22ACD1	334107	0932132	223	122.03	345	10-08-96

In the study area the direction of ground-water flow in the Nacatoch aquifer generally is to the south-southeast. The potentiometric high is located within the outcrop area in the central part of the study area. The highest water-level altitude measured was about 445 ft in northeastern Hempstead County. The lowest water-level altitude measured was about 161 ft in eastern Clark County.

A cone of depression might exist at Hope in Hempstead County. Historical water levels indicate a decline from 185 ft above sea level in 1942 to 145 ft in 1969 (Ludwig, 1972). The northern half of an apparent cone of depression at Hope is shown on figure 2. Data in the Nacatoch aquifer were not available south of Hope. Reports indicate that the water level has recovered 24 ft to an altitude of 169 ft above sea level from 1969 to 1996 in this cone of depression. No other cones of depression were evident in the Nacatoch aquifer (Counts and others, 1955; Ludwig, 1972).

Long-Term Water-Level Changes

Three hydrographs from selected wells completed in the Nacatoch aquifer display long-term (minimum of 25 years), water-level altitudes (fig. 3). Water levels in well 09S20W16DDC1 (site A, fig. 2), declined from about 184 ft above sea level in 1975 to about 144 ft in 1981, which is a decline of 6.7 feet per year (ft/yr). From 1981 to 1996, a general rise in water level to 161 ft was observed, which is approximately a 1.1 ft/yr rise. The rise in water levels might be associated with the decreased withdrawal from the Nacatoch aquifer in Clark County (table 2).

Water levels in well 14S28W13CCB1 (site B, fig. 2) ranged from a minimum of about 234 ft to a maximum of about 249 ft in the mid-1960's. The time of maximum estimated withdrawals for Miller County, 0.14 Mgal/d (in 1965), roughly corresponds to the time of minimum water level. From 1965 to 1980, the water-level data show limited variability; possibly a reflection of the decreased withdrawals from the Nacatoch aquifer in Miller County. After 1980 water levels rose about 4 ft and might be associated with the minimal withdrawal from the Nacatoch aquifer in Miller County (table 2).

Water levels in well 11S22W08DAC2 (site C, fig. 2) rose from about 179 ft in 1985 to about 267 ft in 1990, an average rise of about 17.6 ft/yr. This rise might be associated with a decrease of about 60 percent in withdrawals from the Nacatoch aquifer in Nevada County from 1.11 Mgal/d in 1985 to 0.44 Mgal/d in 1990.

Although water levels in these three wells might be associated with changes in withdrawals, other factors also may affect water levels. Water levels may be affected by local factors such as pumpage changes, climatic variations, or changes in leakage to and from overlying and underlying rock units.

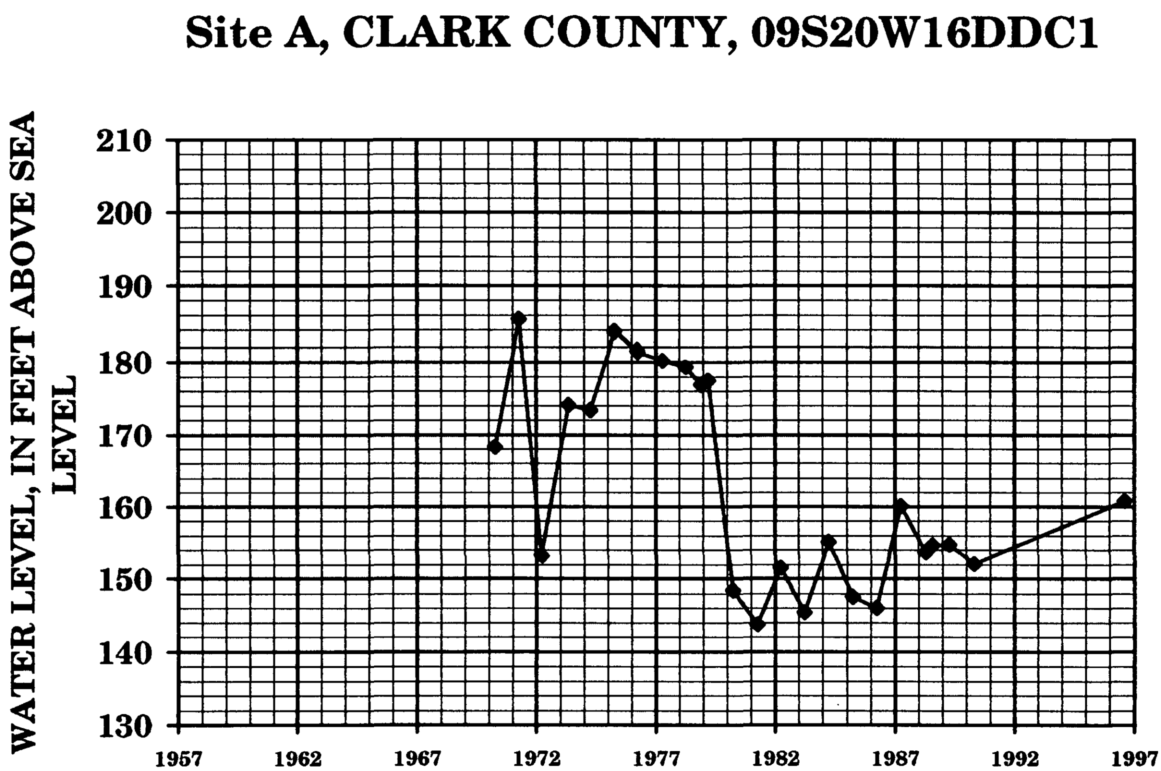
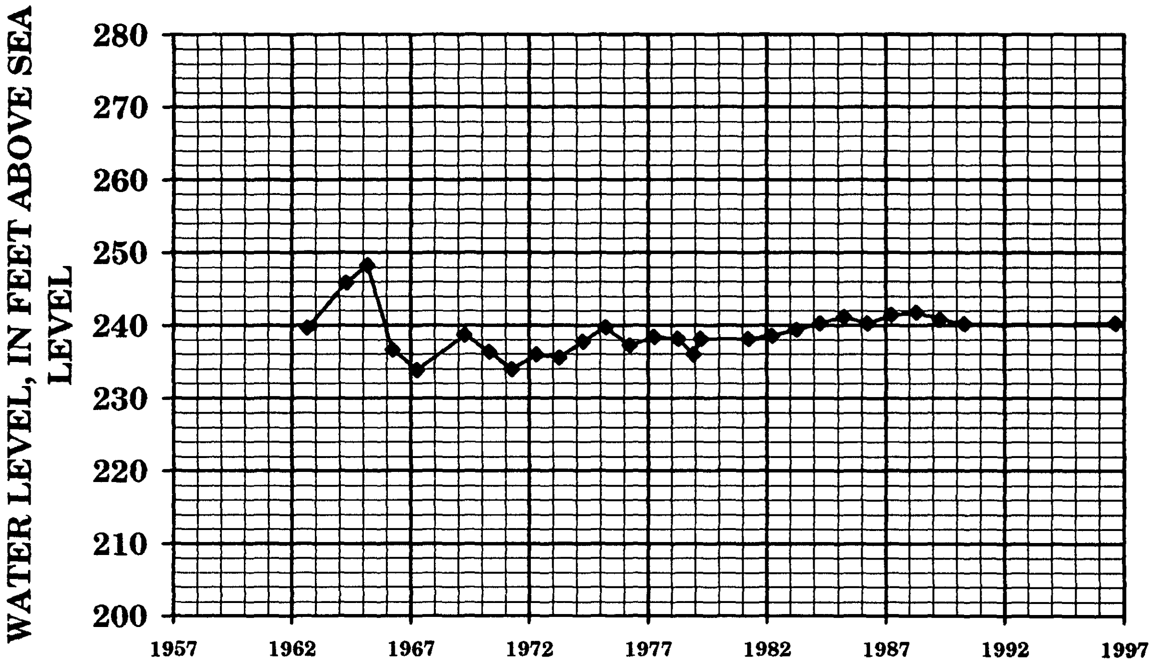


Figure 3. Water-level altitudes for selected wells completed in the Nacatoch aquifer (page 1 of 2).

Site B, MILLER COUNTY, 14S28W13CCB1



Site C, NEVADA COUNTY, 11S22W08DAC2

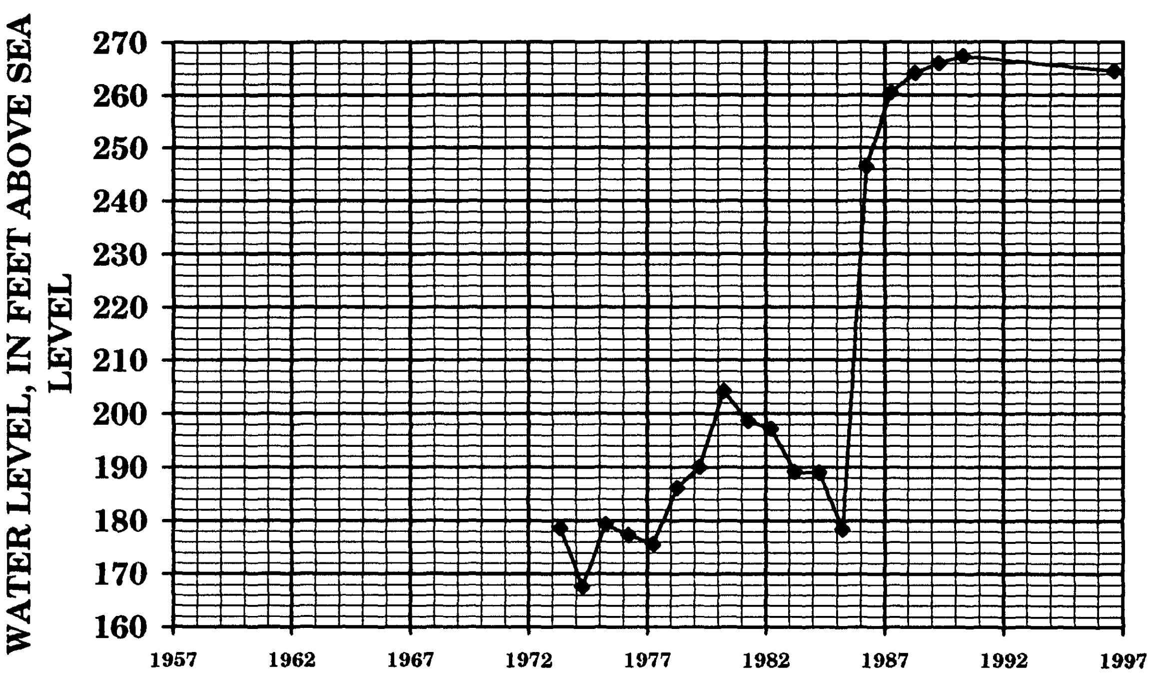


Figure 3. Water-level altitudes for selected wells completed in the Nacatoch aquifer (page 2 of 2).

Table 2. Estimated withdrawal rates by county from the Nacatoch aquifer

[Units are million gallons per day. Data from T.W. Holland, U.S. Geological Survey, written commun., 1997; Holland, 1993; Holland, 1987; Holland and Ludwig, 1981; Halberg, 1977; Halberg, 1972; Halberg and Stephens, 1966]

County	Estimated withdrawal rate						
	1965	1970	1975	1980	1985	1990	1995
Clark	0.44	0.55	0.64	1.73	0.91	0.29	0.34
Hempstead	1.12	1.72	1.44	1.98	0.15	0.20	0.32
Howard	0.00	0.14	0.22	0.24	0.00	0.00	0.00
Little River	0.20	0.04	0.04	0.06	0.00	0.00	0.00
Miller	0.14	0.03	0.04	0.06	0.00	0.00	0.00
Nevada	0.21	0.45	0.55	0.68	1.11	0.44	0.36
Total	2.11	2.93	2.93	4.75	2.17	0.93	1.02

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 Lower Cretaceous age in Pike, Nevada, Miller, and most of Hempstead Counties (Petersen and others, 1985); and the Woodbine Formation of Upper Cretaceous age in Little River, Sevier, Howard, and northwestern Hempstead Counties (Boswell and others, 1965). The Tokio Formation crops out in a southwest to northeast trending mile-wide band in west-central Clark County just south of the Fall Line (fig. 4). The outcrop attains a maximum width of about 10 miles in Howard County and continues southwest into Sevier County approximately 8 miles. In this area, the Tokio Formation is overlain in several places by terrace deposits and Quaternary alluvium. The unit crops out again in northwestern Little River County. The unit ranges in thickness from about 50 to more than 300 ft 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 aquifer receives recharge from precipitation where it outcrops or is overlain by permeable alluvial and terrace deposits. Salinity increases in the direction of ground-water flow to the south-southeast. The aquifer yields freshwater to within a few miles north of Ashdown in Little River County. The water in the Tokio aquifer becomes slightly to moderately saline downdip (southeast) from near Prescott to the fault zone trending across Nevada County. Except in its outcrop area, water in the Tokio aquifer is under artesian conditions (Petersen and others, 1985).

The Tokio aquifer yields water to wells in southern Pike County, northern Nevada County, northern and central Hempstead County, southern Howard County, and southeastern Sevier County. Wells tapping the aquifer range in depth from a few feet near the outcrop 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). Records indicate that water levels in the aquifer did not decline appreciably from 1950 to 1968, and that water levels have not been greatly affected by withdrawal of water at Hope and Prescott (Ludwig, 1972). Estimates of water withdrawn from the Tokio aquifer increased from 2.0 Mgal/d in

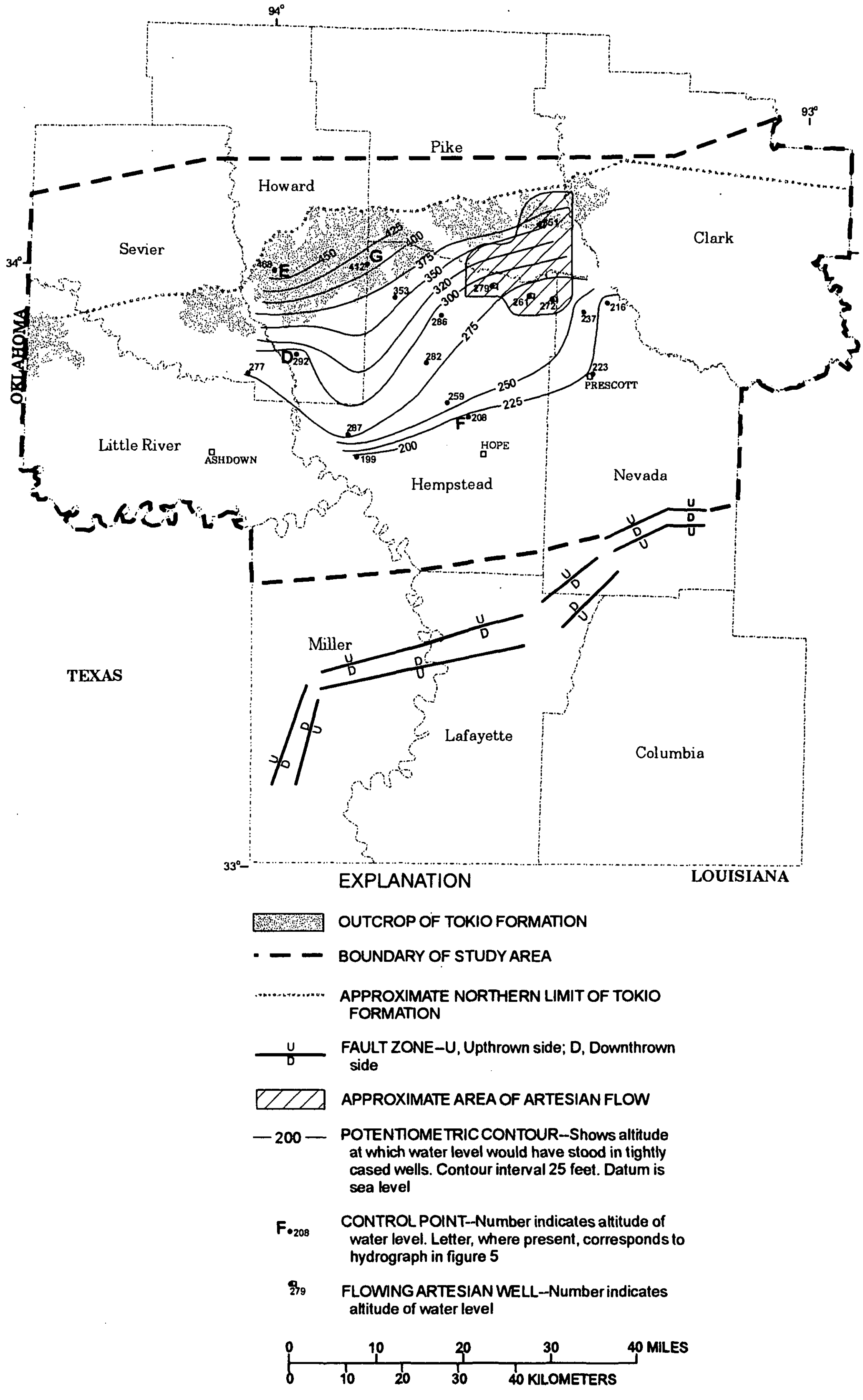


Figure 4. Potentiometric surface of wells completed in the Tokio aquifer, southwestern Arkansas, August-October 1996.

1965 to 6.02 Mgal/d in 1980. Water withdrawn from the Tokio aquifer was estimated to be 2.23 Mgal/d in 1995, a decrease of 63 percent from 1980 (Halberg and Stephens, 1966; Holland and Ludwig, 1981; T.W. Holland, U.S. Geological Survey, written commun., 1995).

Potentiometric Surface

The potentiometric surface for the Tokio aquifer shows the altitude that water would have stood in tightly cased wells screened in the aquifer (fig. 4). Water-level measurements in 18 wells from August through October 1996 were used to construct the map (table 3). The surface is mapped by determining the altitude of the water levels and is represented on the map by contours that connect points of equal value. The general direction of ground-water flow is perpendicular to the contours in the direction of downward hydraulic gradient.

In the study area, the direction of ground-water flow in the Tokio aquifer is generally to the southeast. The potentiometric high is within the outcrop area in the northern part of the study area. The highest water-level altitude measured was about 468 ft in Howard County. The lowest water-level altitude measured was about 199 ft in Hempstead County. An area of artesian flow exists in southeastern Pike, northeastern Hempstead, and northwestern Nevada Counties, as evidenced by the four wells with water-level altitudes above the land surface. Cones of depression were not evident within the study area.

Table 3. Water-level measurements and well information for selected wells completed in the Tokio aquifer

Local well number	Latitude	Longitude	Water level altitude (feet above sea level)	Depth to water level (feet below land-surface datum)	Land-surface altitude (feet above sea level)	Date of measurement
			Hempstead County			
09S23W33CDA1	335457	0932802	272	-1.70	270	08-07-96
09S24W28ACC1	335616	0933549	279	-1.50	277	08-07-96
09S24W36ADD1	335520	0933041	261	-1.01	260	10-09-96
09S26W18CBB1	335819	0934925	412	13.11	425	08-07-96
10S25W09CDB1	335329	0934049	286	75.08	361	09-12-96
10S26W03BBB1	335508	0934613	353	31.40	384	08-07-96
11S25W08BAA1	334856	0934232	282	112.97	395	09-11-96
12S24W06CDC1	334345	0933737	208	147.50	355	08-06-96
12S27W04BBC1	334447	0934002	259	176.19	435	08-08-96
12S27W23BDA1	334202	0935134	287	97.66	385	08-08-96
12S27W36DBC1	333954	0935034	199	62.44	261	09-04-96
			Howard County			
09S28W20DAC1	335740	0940013	468	12.13	480	08-27-96
11S28W02CDA1	334938	0935738	292	17.12	309	08-27-96
			Nevada County			
09S22W33DCC1	335441	0932137	216	8.58	225	08-21-96
10S23W12AAA1	335350	0932422	237	18.87	256	10-09-96
11S22W08DAC1	334757	0932315	223	81.82	305	08-21-96
			Pike County			
08S23W09ADC1	340213	0932930	351	-.90	350	09-04-96
			Sevier County			
11S29W13CCD1	334750	0940313	277	83.42	360	09-04-96

Long-Term Water-Level Changes

Four hydrographs from selected wells completed in the Tokio aquifer display long-term (minimum of 25 years) water-level changes. Two hydrographs are shown for wells located in Howard County and two hydrographs are shown for wells located in Hempstead County (fig. 5).

The two hydrographs from wells in Howard County show small variations in water levels. In well 11S28W02CDA1 (site D, fig. 4), water levels fluctuated between about 282 ft and about 293 ft above sea level over a 31-year period. Water levels in well 09S28W20DAC1 (site E, fig. 4) ranged from about 461 ft to about 478 ft over a 40-year period. There does not appear to be an association between water levels in these two wells and withdrawal estimates for Howard County or the study area (table 4). Primary factors in the variation in water levels in this well might be local in extent (resulting from local pumpage changes), result from climatic variations, or changes in leakage to and from overlying and underlying rock units.

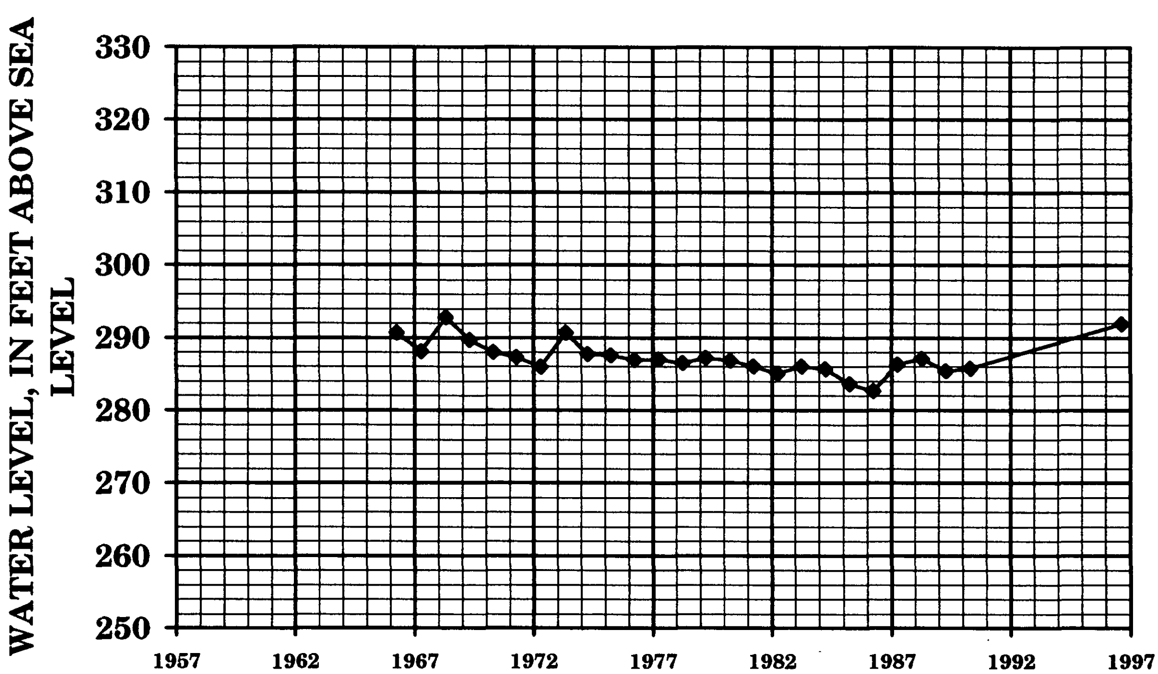
The two hydrographs from wells in Hempstead County show vast differences between water-level trends over long periods. In well 12S24W06CDC1 (site F, fig. 4), water levels fluctuated between about 159 ft and about 258 ft above sea level over a 25-year period. The water level generally declined from about 258 ft in 1972 to about 166 ft in 1979, an average decline of about 13.1 ft/yr. From 1981 to 1996, the water level generally rose from about 166 ft to about 208 ft, an average rise of about 2.8 ft/yr. The changes in water levels in this well might be associated with decreased withdrawals (table 4) in Hempstead County from the Tokio aquifer. Hempstead County had an increase in withdrawals from the Tokio aquifer from 0.67 Mgal/d in 1965 to 3.00 Mgal/d in 1980. Withdrawals decreased to 1.66 Mgal/d in 1995. Water levels in well 09S26W18CBB1 (site G, fig. 4) showed little fluctuation and ranged from about 399 ft to about 414 ft over a 40-year period. There does not appear to be an association between water levels in this well and estimated withdrawals for Hempstead County. These data indicate that withdrawal patterns in Hempstead County were not uniform, resulting in greater drawdown in localized areas. Primary factors in the variation in water levels in this well might be local in extent (resulting from local pumpage changes), result from climatic variations, or changes in leakage to and from overlying and underlying rock units.

Table 4. Estimated withdrawal rates by county from the Tokio aquifer

[Units are million gallons per day. Data from T.W. Holland, U.S. Geological Survey, written commun., 1997; Holland, 1993; Holland, 1987; Holland and Ludwig, 1981; Halberg, 1977; Halberg, 1972; Halberg and Stephens, 1966]

County	Estimated withdrawal rate						
	1965	1970	1975	1980	1985	1990	1995
Clark	0.00	0.00	0.02	0.06	0.04	0.01	0.01
Hempstead	0.67	0.68	2.15	3.00	2.86	1.10	1.66
Howard	0.69	0.62	0.97	1.11	0.14	0.00	0.00
Little River	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Miller	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nevada	0.37	0.47	0.55	0.68	0.00	0.00	0.00
Pike	0.12	0.41	0.43	0.82	0.06	0.03	0.02
Sevier	0.15	0.17	0.25	0.35	0.79	1.15	0.54
Total	2.00	2.35	4.37	6.02	3.89	2.29	2.23

Site D, HOWARD COUNTY, 11S28W02CDA1



Site E, HOWARD COUNTY, 09S28W20DAC1

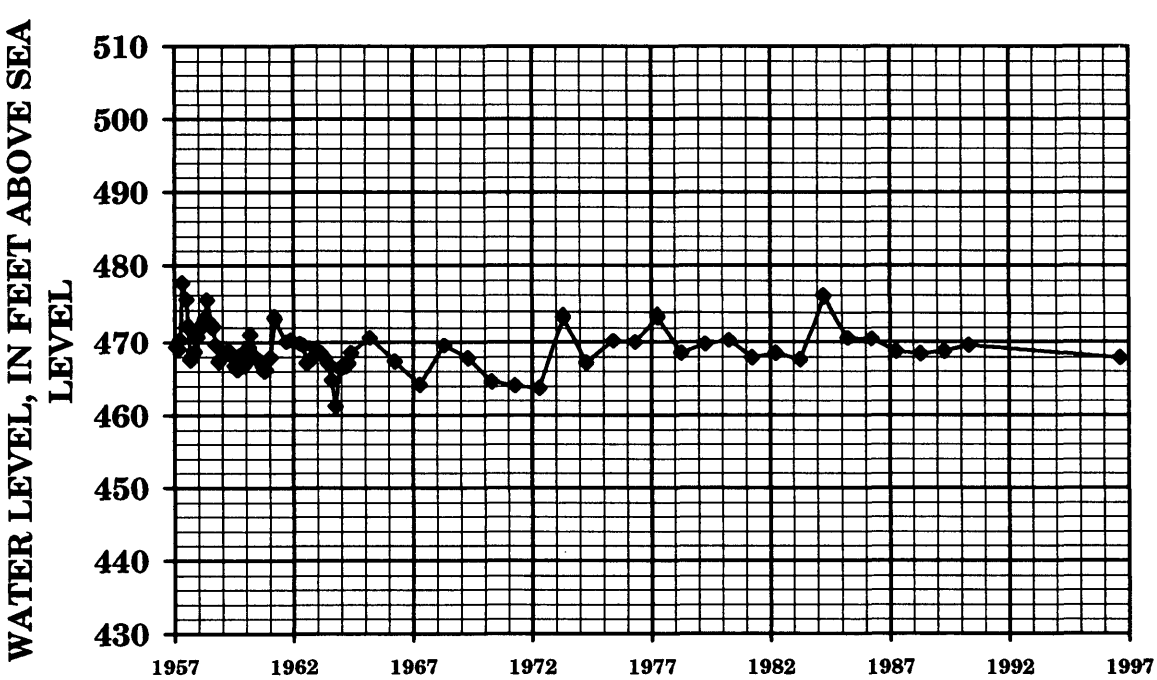
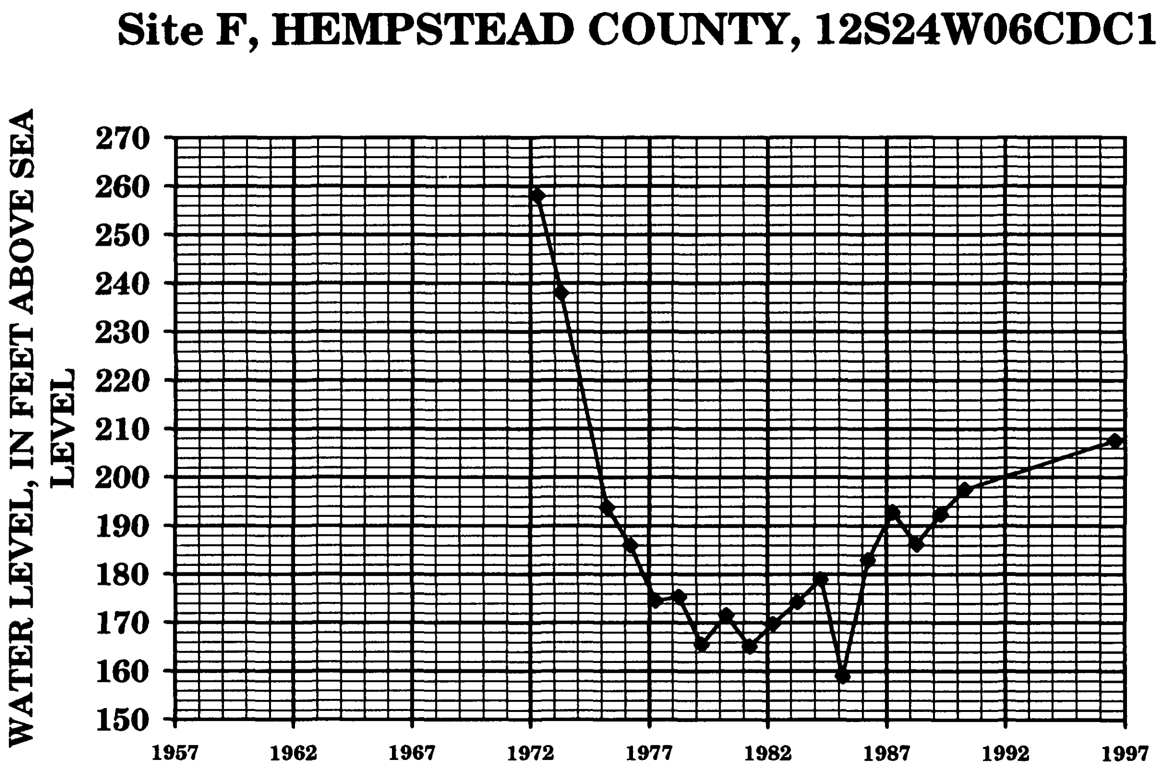


Figure 5. Water-level altitudes for selected wells completed in the Tokio aquifer (page 1 of 2).



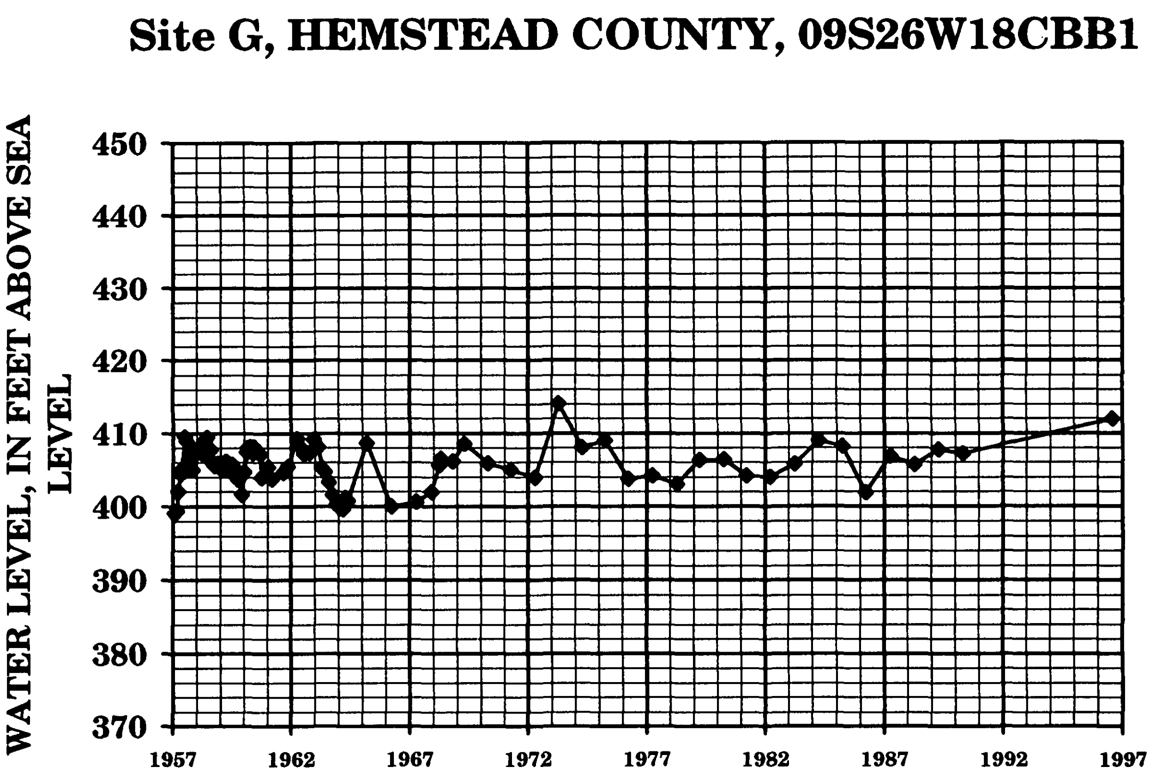


Figure 5. Water-level altitudes for selected wells completed in the Tokio aquifer (page 2 of 2).

SUMMARY

Aquifers in the Nacatoch Sand and Tokio Formation in southwestern Arkansas are a source of water for industrial, public supply, domestic, and agricultural uses. Water-level measurements were made in 24 wells completed in the Nacatoch aquifer and 18 wells completed in the Tokio aquifer from August through October of 1996 to produce potentiometric-surface maps. Withdrawals from aquifers in the Nacatoch Sand and Tokio Formation increased from 1965 to 1980 and decreased from 1980 to 1995.

The direction of ground-water flow in the Nacatoch aquifer generally is to the south-southeast. The potentiometric high is located within the outcrop area. One cone of depression was evident at Hope in Hempstead County. Reports indicate that the water level has recovered 24 ft from 1969 to 1996 in this cone of depression.

Water levels in three wells in Clark, Miller, and Nevada Counties rose during a period of decreased withdrawal from the Nacatoch aquifer. Water withdrawn from the Nacatoch aquifer was estimated to be 1.02 Mgal/d in 1995, a decrease of 78 percent from 4.75 Mgal/d in 1980.

The direction of ground-water flow in the Tokio aquifer is generally to the southeast. The potentiometric high is located within the outcrop area. An area of artesian flow exists in southeastern Pike, northeastern Hempstead, and northwestern Nevada Counties. Cones of depression were not evident in the Tokio aquifer within the study area.

Hydrographs of one of four wells completed in the Tokio aquifer showed a rise in water levels during a period of decreased withdrawals from the aquifer. Water withdrawn from the Tokio aquifer was estimated to be 2.23 Mgal/d in 1995, a decrease of 63 percent from 6.02 Mgal/d in 1980. Water levels in one well in Hempstead County might be associated with decreased withdrawals. Three hydrographs show no apparent association between water-level changes in wells completed in the Tokio aquifer and withdrawals. The variation in water levels in these wells could result from differences in localized withdrawals, climatic variations, or leakage of water from overlying and underlying rock formations.

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