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

Potentiometric Surface of the Ozark Aquifer in Northern Arkansas, 2007

Scientific Investigations Report 2008–5137

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DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
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Plate

[In pocket]

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Conversion Factors and Datums

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
foot per second (ft/s)	0.3048	meter per second (m/s)
foot per year (ft/yr)	0.3048	meter per year (m/yr)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
million gllons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
	Slope	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)

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 of 1983).

Potentiometric Surface of the Ozark Aquifer in Northern Arkansas, 2007

By Aaron L. Pugh

Abstract

The Ozark aquifer in northern Arkansas is composed of dolomite, limestone, sandstone, and shale of Late Cambrian to Middle Devonian age, and ranges in thickness from approximately 1,100 feet to more than 4,000 feet. Hydrologically, the aquifer is complex, characterized by discrete and discontinuous flow components with large variations in permeability.

The potentiometric-surface map, based on 58 well and 5 spring water-level measurements collected in 2007 in Arkansas and Missouri, has a maximum water-level altitude measurement of 1,169 feet in Carroll County and a minimum water-level altitude measurement of 118 feet in Randolph County. Regionally, the flow within the aquifer is to the south and southeast in the eastern and central part of the study area and to the west, northwest, and north in the western part of the study area. Comparing the 2007 potentiometric-surface map with a predevelopment potentiometric-surface map indicates general agreement between the two surfaces except in the northwestern part of the study area. Potentiometric-surface differences can be attributed to withdrawals related to increasing population, changes in public-supply sources, processes or water withdrawals outside the study area, or differences in data-collection or map-construction methods.

The rapidly increasing population within the study area appears to have some effect on ground-water levels. Although, the effect appears to have been minimized by the development and use of surface-water distribution infrastructure, suggesting most of the incoming populations are fulfilling their water needs from surface-water sources. The conversion of some users from ground water to surface water may be allowing water levels in wells to recover (rise) or decline at a slower rate, such as in Benton, Carroll, and Washington Counties.

Introduction

The Ozark aquifer is the largest aquifer, both in area of outcrop and thickness, and the most important source of fresh ground water in the Ozark Plateaus physiographic province, supplying water to large areas of northern Arkansas, southern Missouri, northeastern Oklahoma, and southeastern Kansas. Understanding the changes and trends in water levels is important for continued use, planning, and management of this important natural resource.

The U.S. Geological Survey (USGS) in cooperation with the Arkansas Natural Resources Commission and the Arkansas Geological Survey conducted a study of the potentiometric surface of the Ozark aquifer within Arkansas. The study is part of an ongoing effort to monitor ground-water levels in Arkansas' major aquifers. This report presents a potentiometric-surface map of the Ozark aquifer within the Ozark Plateaus of northern Arkansas (figs. 1 and 2), representing water-level conditions for the early spring of 2007.

The study area includes 16 Arkansas counties lying completely or partially within the Ozark Plateaus of the Interior Highlands major physiographic division (Fenneman, 1938). The study area is generally bounded on the north by Missouri, on the west by Oklahoma, on the east by the Mississippi Alluvial Plain, and on the south by the Ouachita Province (fig. 1).

The potentiometric-surface map presented in this report was prepared from ground-water level data collected by the USGS during February and March of 2007 and water-level data from springs flowing from the Ozark aquifer. Additionally, streambed altitudes in areas where the aquifer is unconfined and hydraulically connected to the surface were used as bounding (maximum ground-water level) values.

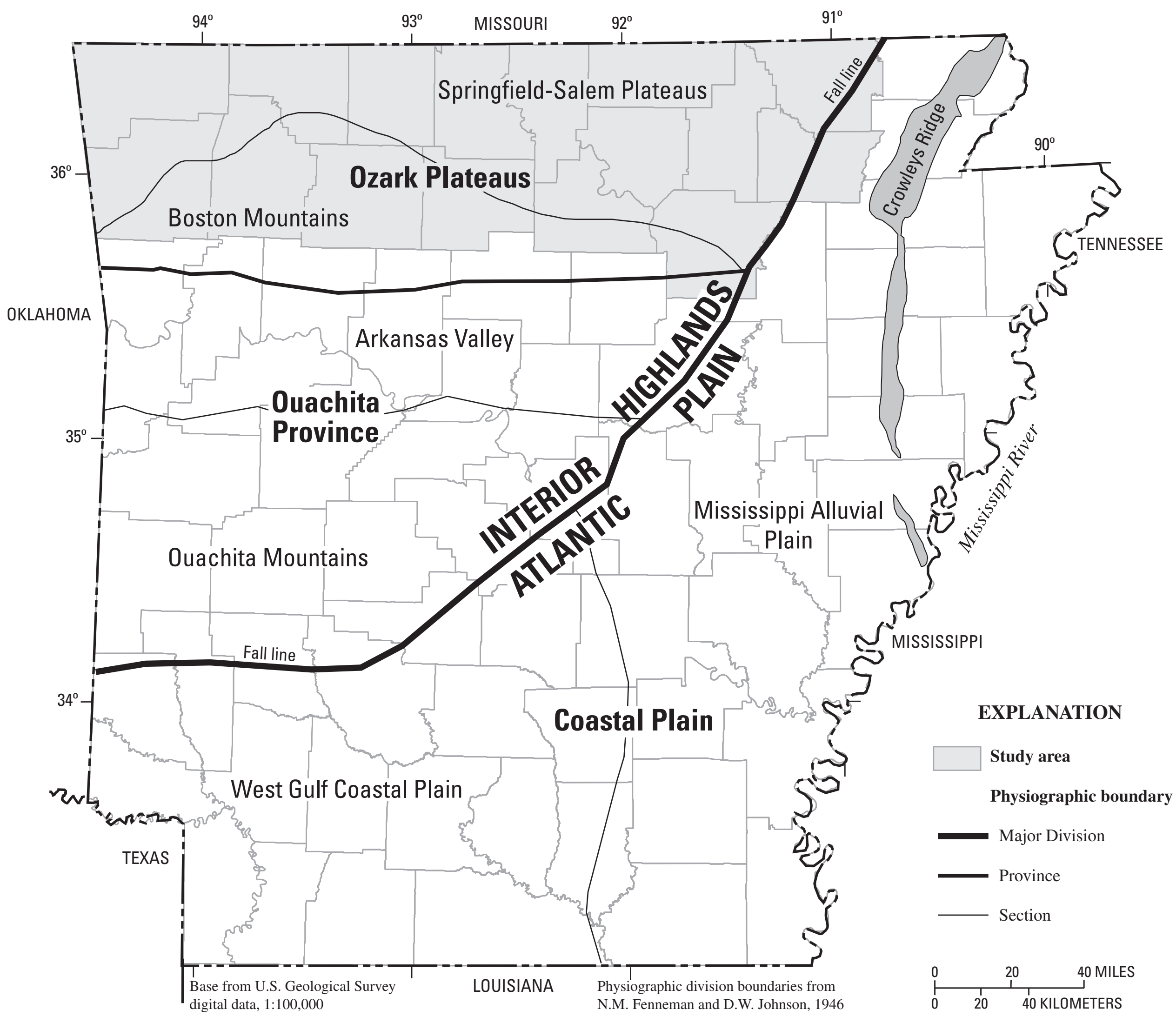

Figure 1. Location of study area.

Methods

Personnel from the USGS collected water-level measurements during February and March 2007 from wells screened in and springs flowing from the Ozark aquifer. Well water-level measurements were made to the nearest 0.01 foot (ft) and were collected using steel or electric tapes from a measuring point of a known altitude. The steel and electric tapes were calibrated during January 2007. Spring water levels were considered to be the land-surface altitudes at which water from the Ozark aquifer emanated.

Well and spring locations were measured using a Global Positioning System receiver to acquire the horizontal coordinate information, latitude and longitude, based on the North American Datum of 1983. The latitude and longitude of the well or spring location was transferred to the appropriate 7.5-minute USGS topographic quadrangle map and the altitude (National Geodetic Vertical datum of 1929 (NGVD of 1929)) determined. Well and spring horizontal locations are accurate to +/- 10 ft and the altitude of the land surface at this location also is accurate to +/- 10 ft.

Where the Ozark aquifer is unconfined, land-surface contours and stream altitudes from a 1:500,000 scale topographic map of Arkansas (U.S. Geological Survey, 1990) were considered in the construction of the potentiometric-surface map to prevent contours from crossing streams at inappropriate locations, and to reflect the general land-surface topography where appropriate.

Hydrographs with least squares linear regression trend lines were constructed for wells open to the Ozark aquifer with a minimum of 30 years of ground-water level measurements. Least squares linear regression trend lines are a mathematical method of organizing data by plotting the data graphically and drawing a best fit straight trend line through the data by minimizing the sum of the squares of the offsets (residuals) (McCuen, 1985). The equation of the trend line is represented by:

$$y = a + bx$$

where

- y is the dependant variable (water-surface elevation, in feet)
- a is the y intercept value (value of y at $x = 0$)
- b is the slope of the trend line (annual rise or decline in water level, in feet per year) and
- x is the independent variable (time, in years).

Aquifer Description

The Ozark Plateaus aquifer system (fig. 2) in and adjacent to the Ozark Plateaus is divided into five hydrogeologic units based on relative rock permeability and well yields.

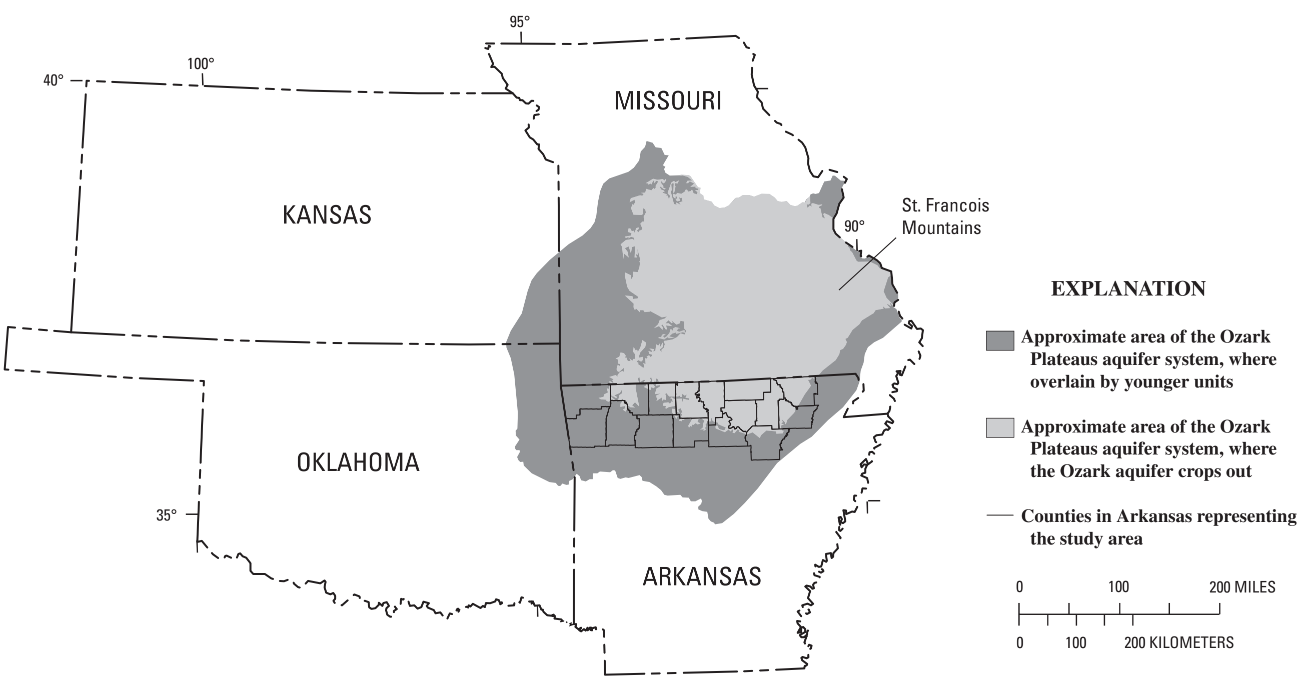

Figure 2. Location of Ozark Plateaus aquifer system.

These units crop out in a concentric pattern centered on the St. Francois Mountains of southeastern Missouri and dip to the southeast and south in northeastern Arkansas and to the south and southwest in north-central and northwestern Arkansas. The boundaries between these hydrogeologic units do not always conform to geologic time divisions or formation boundaries, but were chosen to delineate groups of rocks having similar hydrologic properties. These hydrogeologic units consist of rocks that range in age from Cambrian to Devonian and are the St. Francois aquifer, St. Francois confining unit, Ozark aquifer, Ozark confining unit, and Springfield Plateau aquifer (Imes and Emmett, 1994). The St. Francois aquifer and St. Francois confining unit underlie the Ozark aquifer. The Ozark confining unit overlies the Ozark aquifer and the Springfield Plateau aquifer overlies the Ozark confining unit.

The Ozark aquifer in Arkansas is composed of dolomite, limestone, sandstone, and shale of Upper Cambrian to Middle Devonian age (table 1) and ranges in thickness from approximately 1,100 ft in the northwestern corner of the State to more than 4,000 ft in the west-central part of the State (Imes, 1990). Most wells completed in the Ozark aquifer yield between 50 and 100 gallons per minute (gal/min) although some wells may yield as much as 600 gal/min (Imes and Emmett, 1994; Adamski and others, 1995).

The Ozark aquifer is underlain by the St. Francois confining unit (the uppermost geologic unit of which is the Doe Run Dolomite; table 1). The Ozark aquifer is exposed in much of southern and central Missouri and north-central Arkansas (fig. 2) where uplift of the Ozark Dome and erosion of younger rocks has formed a deeply dissected, rugged topography that is the primary recharge area of the aquifer. The aquifer is overlain by the Ozark confining unit mainly in the southern and western part of the study area (table 1). Within the Mississippi Alluvial Plain, east and southeast of the outcrop area (figs. 1 and 2), thick deposits of Cretaceous-, Tertiary-, and Quaternary-age sediments unconformably overlay the Ordovician-age rocks of the Ozark aquifer. Within this part of the Mississippi Alluvial Plain, major rivers receive substantial discharge from the adjacent Ozark aquifer (Mesko and Imes, 1995).

The hydrogeology of the Ozark aquifer is complex, consisting of a combination of discrete and discontinuous flow components resulting from spatial variations in regolith thickness, faults, the presence of chert nodules, lithology, and cementation. Primary porosity and permeability are low for most rock units of the aquifer, although secondary permeability resulting from fracturing, bedding planes, and dissolution of the carbonate rocks is spatially variable and ranges from moderate to large (Adamski, 1996). Hydraulic conductivity ranges from 1×10^{-8} feet per second (ft/s) to more than 1×10^{-3} ft/s (Imes and Emmett, 1994). The principal recharge area for the aquifer is in central and south-central Missouri and north-central Arkansas, where the aquifer is hydraulically connected to the surface and the potentiometric surface mimics the land-surface topography.

Beneath the Mississippi Alluvial Plain (fig. 1), the rocks composing the Ozark aquifer dip at about 45 feet per mile (ft/mi) to the southeast. In the northern part of the study area, the regional dip is about 26 ft/mi southward, increasing to 175 ft/mi or more at the southern boundary of the Ozark Plateaus (Imes, 1990). The depth of the Ozark aquifer increases to more than 4,000 ft below land surface in the southern part of the study area. In this area, water quality is affected by increasing amounts of dissolved solids, fluoride, sulfide, and radium as water moves downdip, away from recharge areas (Imes and Emmett, 1994). The combination of greater depth and poorer water quality limits the viability of the Ozark aquifer as an economic source of water in the southernmost part of the study area.

Potentiometric Surface

The potentiometric-surface map (plate 1) indicates the altitude to which water would stand in wells completed in the Ozark aquifer. The potentiometric surface was contoured using the 2007 water-level data from 58 wells and 5 springs (table 2). Additional bounding values from land-surface contours and stream altitudes were used where the Ozark aquifer is exposed at the surface.

The potentiometric-surface map is intended to show the general configuration of the potentiometric surface. The Ozark aquifer covers a large area in Arkansas and has variable thickness and hydrologic properties. Water-level data distribution is sparse in some areas. The potentiometric-surface map should not be used to estimate exact water-level altitude or depth to water at any given location.

The extent of the potentiometric-surface map presented on plate 1 covers approximately half the area of the Ozark Plateaus in Arkansas (fig. 1). In the southern part of the study area the aquifer is not a viable source of water because of great depths and poor water quality (Imes and Emmett, 1994). Few water wells have been constructed in this part of the study area, consequently, no data are available for contouring purposes.

The potentiometric-surface map depicts the general direction of ground-water flow within the Ozark aquifer, with ground-water movement perpendicular to the contours in the direction of the hydraulic gradient. The direction of regional ground-water flow generally is to the south and southeast in the eastern and central part of the study area and to the west, northwest, and north in the western part of the study area, but has greater variability in areas where the unconfined part of the aquifer is hydraulically connected to the surface. In these areas, the flow direction is affected more by local topography (flowing from high altitudes toward stream valleys).

The 2007 water-level data indicates the highest water-level altitude is 1,169 ft above NGVD of 1929 in Carroll County. Water-level altitudes of less than 400 ft above NGVD of 1929 are mapped along the eastern and southeastern part of the study area in Independence, Lawrence, Randolph, and Sharp Counties. The lowest measured water level of 118 ft

Table 1. Stratigraphic column with descriptions of lithologic and hydrogeologic properties of the Ozark aquifer and adjacent confining units within Arkansas (modified from Lamonds, 1972; Imes, 1990; Imes and Smith, 1990).

ERA	PERIOD	GEOLOGIC UNIT	HYDROGEOLOGIC UNIT	LITHOLOGY	THICKNESS (feet)	HYDROGEOLOGY
Paleozoic	Devonian	Chattanooga Shale	Ozark confining unit	Shale unit that crops out in a narrow band that outlines the Ozark aquifer and is missing where the Ozark aquifer is exposed at the surface.	0 - 200	Unit is relatively impermeable because of large shale content.
		Clifty Limestone	Ozark aquifer	Chert with lenses of limestone, dolomite, and cherty sandstone.	0 - 250	The residual cherty rubble, weathered from cherty limestone and sandstone of the unit, may yield 2 to 5 gallons per minute.
		Penters Chert				
	Silurian	Lafferty Limestone		Limestone, dolomite, sandstone, and minor amounts of shale	0 - 2,000	The limestones and dolomites commonly yield 5 to 10 gallons per minute from solution channels, bedding planes, and fractures. Similar yields may be obtained from the sandstone where it is porous or fractured. These units contain many springs. Yields from springs and some wells may exceed 50 gallons per minute.
		St. Clair Limestone				
		Brassfield Limestone				
	Ordovician	Cason Shale				
		Fernvale Limestone				
		Kimmswick Limestone				
		Plattin Limestone				
		Joachim Dolomite				
		St. Peter Sandstone				
		Everton Formation				
		Smithville Formation		Dolomite, dolomitic limestone, and minor amounts of sandstone and shale.	100 - 1,000	The solution channels and fractures in the dolomite and dolomitic limestone commonly yield 5 to 10 gallons per minute. Wells that tap large solution channels may yield more than 50 gallons per minute, but large yields are uncommon. These units yield water to several large springs.
		Powell Dolomite				
		Cotter Dolomite				
		Jefferson City Dolomite				
		Roubidoux Formation		Sandstone and sandy dolomite. Not exposed in Arkansas.	100 - 250	Yields of as much as 450 gallons per minute may be obtained from some wells, but yields are highly variable and generally average less than 150 gallons per minute.
		Gasconade Dolomite		Dolomite, sandy dolomite, and sandstone. Not exposed in Arkansas.	350 - 650	The most productive water-bearing part of this unit is the Van Buren Formation. Wells that tap into the Van Buren Formation commonly yield 150 to 300 gallons per minute and may yield as much as 500 gallons per minute.
		Gunter Sandstone member of the Van Buren Formation				
	Cambrian	Eminence Dolomite				
		Potosi Dolomite				
		Doe Run Dolomite	St. Francois confining unit	Shale and shaley dolomite, siltstone, and limestone conglomerate. Shales present both as distinct beds and disseminated throughout dolomite matrix. Not exposed in Arkansas.	0 - 750	Permeability is minimal to moderate. Unit is more permeable where transected by fault and fracture zones.
		Derby Dolomite				
		Davis Formation				

Table 2. Information pertaining to measured wells and springs in the Ozark aquifer in northwestern Arkansas and south-central Missouri, 2007.

[NA, not applicable; Aquifer code designations are: 364STPR, St. Peter Sandstone; 364EVRN, Everton Formation; 368PWLL, Powell Dolomite; 367CTTR, Cotter Dolomite; 368JFRC, Jefferson City Dolomite; 367RBDX, Roubidoux Formation, 367GNTR, Gunter Sandstone member of the Van Buren Formation; 367POTS, Potosi Dolomite; NGVD of 1929, National Geodetic Vertical Datum of 1929; Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD83)]

Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Local well number	Land- surface altitude (feet above NGVD of 1929)	Well depth (feet below land-surface altitude)	Aquifer code of formation at depth of well	Water- level altitude (feet above NGVD of 1929)	Depth to water (feet)	Date of measurement
				Arkansas				
				Baxter County				
361610	921143	19N11W31DAA1	640	193	367CTTR	556	83.62	3/08/2007
361714	923026	19N14W29DBC1	720	1,625	367GNTR	662	58.39	3/08/2007
362114	921423	20N11W35CCA1	600	295	367CTTR	568	32.24	2/22/2007
362309	921419	20N12W23CBA1	600	550	367RBDX	515	85.46	2/22/2007
362431	921912	20N13W13ABD1	620	209	367CTTR	552	67.63	3/8/2007
362435	922026	20N13W14ABC1	580	493	367CTTR	551	29.03	2/22/2007
362700	921558	21N12W33ACB1	610	500	367RBDX	579	31.47	2/22/2007
				Benton County				
362004	935553	19N28W11BAD1	1,260	1,030	367RBDX	1,074	185.97	2/26/2007
361954	940618	19N29W07DAA1	1,210	1,659	367GNTR	1,069	140.92	2/26/2007
362456	942723	20N33W14ACD1	1,185	1,600	367GNTR	765	419.66	2/26/2007
362512	942720	20N33W14DBC1	1,230	1,614	367GNTR	802	427.77	2/26/2007
362417	943607	20N34W21ABD1	1,022	380	364EVRN	995	26.98	2/26/2007
362636	940138	21N29W35DDB2	1,405	1,769	367GNTR	1,056	348.82	2/26/2007
				Boone County				
361150	930258	18N19W19BCC1	1,150	1,649	367GNTR	912	238.18	2/28/2007
361022	930050	18N19W33BBB1	1,300	2,055	367GNTR	668	632.00	2/28/2007
362703	925503	21N18W20CCD1	880	1,415	371POTS	640	240.00	2/27/2007
				Carroll County				
362022	932604	19N23W04BAC1	1,365	1,587	367RBDX	1,169	195.97	2/27/2007
361918	932633	19N23W08ADD1	1,355	2,300	367GNTR	1,108	247.31	2/27/2007
362340	934458	20N26W16DCA1	1,198	1,332	367GNTR	1,061	137.38	2/27/2007
362313	934253	20N26W23ACA1	1,335	1,713	371POTS	1,047	287.85	2/27/2007
362939	934412	21N26W10CDC1	1,090	1,122	367GNTR	929	161.14	2/27/2007
362921	934641	21N26W17BCC1	1,010	1,058	367RBDX	981	29.21	2/27/2007
				Fulton County				
361707	913831	19N06W20DCA1	825	158	367CTTR	733	92.03	3/08/2007
361728	913503	19N06W23AAD1	680	1,630	367GNTR	474	205.88	3/08/2007
362210	914923	20N08W27ABD1	662	1,282	367GNTR	658	4.40	3/01/2007

Table 2. Information pertaining to measured wells and springs in the Ozark aquifer in northwestern Arkansas and south-central Missouri, 2007.—Continued

[NA, not applicable; Aquifer code designations are: 364STPR, St. Peter Sandstone; 364EVRN, Everton Formation; 368PWLL, Powell Dolomite; 367CTTR, Cotter Dolomite; 368JFRC, Jefferson City Dolomite; 367RBDX, Roubidoux Formation, 367GNTR, Gunter Sandstone member of the Van Buren Formation; 367POTS, Potosi Dolomite; NGVD of 1929, National Geodetic Vertical Datum of 1929; Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD83)]

Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Local well number	Land- surface altitude (feet above NGVD of 1929)	Well depth (feet below land-surface altitude)	Aquifer code of formation at depth of well	Water- level altitude (feet above NGVD of 1929)	Depth to water (feet)	Date of measurement
				Fulton County (Spring)				
361908	913431	19N06W12BDAA1SP	400	NA	367CTTR	400	0.00	2/22/2007
				Independence County (Spring)				
354949	913959	14N06W29BCC1SP	340	NA	367CTTR	340	0.00	3/07/2007
				Izard County				
360753	920626	17N11W13AAD1	538	1,729	367RBDX	490	47.69	3/01/2007
361323	915549	18N09W15BCB1	742	600	367CTTR	650	92.14	3/01/2007
				Marion County				
361748	923222	19N15W14BAA2	640		367CTTR	626	14.11	2/23/2007
361634	923527	19N15W20ACC1	684	900	367RBDX	581	102.60	2/23/2007
361442	924124	19N16W33CCB1	841	753	367RBDX	565	276.35	2/23/2007
361512	925050	19N18W36BDC1	755	1,392	367RBDX	716	38.82	2/28/2007
362452	923951	20N16W03BBA1	900	600	368JFRC	764	136.38	2/22/2007
362225	924919	20N17W19ABC1	862	180	367CTTR	841	20.71	2/23/2007
				Newton County				
360014	931130	16N21W34ABC1	870	190	364EVRN	809	60.56	3/09/2007
				Randolph County				
361350	910944	18N02W02CAC1	361	128	368JFRC	308	53.32	3/07/2007
362440	905351	20N02E06AAC1	485	900	367RBDX	118	366.97	3/07/2007
362249	910959	20N02W15DAD1	440	170	367CTTR	414	26.21	3/07/2007
				Searcy County				
355126	923401	14N15W15AAC1	1,060	3,534	367GNTR	706	354.28	2/28/2007
355520	923718	15N15W19CDD1	1,100	550	364EVRN	774	325.75	2/28/2007
355750	924133	15N16W09BBA1	925	950	368PWLL	724	201.32	2/28/2007
355416	924025	15N16W34BAD1	1,000	485	364PLTN	817	183.01	2/28/2007
355819	924450	15N17W01CBA1	986	1,320	368PWLL	825	161.36	2/28/2007
355935	923919	16N16W35BAB1	980	550	364EVRN	587	393.03	2/28/2007
				Sharp County				
355812	913318	15N05W06DDD1	645	482	364EVRN	540	104.73	3/07/2007
360233	913338	16N05W06DCC1	450	1,110	367RBDX	406	43.54	3/07/2007
360023	913654	16N06W27ACC1	650	1,000	367CTTR	554	95.83	3/07/2007
360818	912804	17N05W12BDC1	417	425	367CTTR	357	60.42	3/07/2007
360604	913854	17N06W29ABC1	525	900	367CTTR	441	83.60	3/7/2007
361325	913638	18N06W10CBC1	625	1,525	367GNTR	483	141.79	3/7/2007

Table 2. Information pertaining to measured wells and springs in the Ozark aquifer in northwestern Arkansas and south-central Missouri, 2007.—Continued

[NA, not applicable; Aquifer code designations are: 364STPR, St. Peter Sandstone; 364EVRN, Everton Formation; 368PWLL, Powell Dolomite; 367CTTR, Cotter Dolomite; 368JFRC, Jefferson City Dolomite; 367RBDX, Roubidoux Formation, 367GNTR, Gunter Sandstone member of the Van Buren Formation; 367POTS, Potosi Dolomite; NGVD of 1929, National Geodetic Vertical Datum of 1929; Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD83)]

Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Local well number	Land- surface altitude (feet above NGVD of 1929)	Well depth (feet below land-surface altitude)	Aquifer code of formation at depth of well	Water- level altitude (feet above NGVD of 1929)	Depth to water (feet)	Date of measurement
				Sharp County—Continued				
361813	912337	19N04W15BAA1	584	611	367RBDX	530	53.63	3/7/2007
				Sharp County (Springs)				
360228	913211	16N05W17AABA1SP	495	NA	364STPR	495	0.00	3/7/2007
360325	913631	16N06W10AAA1SP	435	NA	364EVRN	435	0.00	3/7/2007
360325	913648	16N06W10ABBA1SP	455	NA	364EVRN	455	0.00	3/7/2007
				Stone County				
355805	921352	15N12W02BCA1	980	3,420	367GNTR	748	232.10	3/8/2007
355806	922402	15N13W06AC1	1,123	3,105	367RBDX	631	492.09	3/8/2007
				Washington County				
355903	941807	15N31W17BBD1	1,195	2,097	367GNTR	1,156	38.78	2/26/2007
355652	941858	15N31W30CAD1	1,165	2,485	367GNTR	1,145	19.81	2/26/2007
360509	942242	16N32W09ABD1	1,135	1,815	367GNTR	989	146.13	2/26/2007
				Missouri				
				Ozark County				
363206	923609	21N15W03BAB1	805	550	367GSCD	665	140.35	2/21/2007
				Taney County				
363640	930554	23N20W27CCC1	763	350	367RBDX	671	91.72	3/8/2007
363603	930601	23N20W33ADD1	705	410	367RBDX	658	47.42	2/21/2007

above NGVD of 1929 was measured in eastern Randolph County.

In most of the study area, the general level and shape of the potentiometric surface has changed little since predevelopment or as mapped in previously published USGS reports in 1995 (Pugh, 1998), 2001 (Schrader, 2001), and 2004 (Schrader, 2005). A comparison of the predevelopment potentiometric surface (Imes, 1990) and the 2007 potentiometric surface indicates general agreement between the two surfaces with the exception of parts of Benton, Carroll, and Washington Counties. In northwestern Benton County, water levels have declined and the direction of flow has changed from westward during predevelopment times to northwestward in 2007. In northeastern Benton and northwestern Carroll Counties, water levels have declined although the direction of flow is still to the north. In northwestern Washington County, water levels have declined and the direction of flow is northwestward, matching the predevelopment direction of flow. The potentiometric surface in 2007 is similar to the potentiometric surface in 1995 (Pugh, 1998), 2001 (Schrader, 2001), and 2004 (Schrader, 2005). Potentiometric-surface differences can be attributed to differences in hydrologic stresses (withdrawals related to changing population, differences in withdrawals for agricultural uses, or withdrawal conditions just prior to a water-level measurement) or data-collection and map-construction methods (time of year or number of water-level measurements and locations of water-level measurements used to construct maps representing different years).

Population and Water Use

The population of the 16 counties in northern Arkansas that compose the study area has increased steadily since 1960 (fig. 3). From 1960 through 2000 the population in the state of Arkansas has increased 50 percent while counties in the study area increased 147 percent. The largest increase in population was in the counties bordering Missouri and Oklahoma including: Washington (183 percent), Benton (323 percent), Carroll (125 percent), Boone (111 percent), Marion (167 percent), Baxter (286 percent), and Sharp (171 percent). Lawrence and Searcy Counties experienced the smallest increases in population, 3 and 2 percent respectively (U.S. Census Bureau, 2008).

Estimated total ground-water use for the Ozark aquifer in Arkansas has increased slightly for the period from 1960 through 2005, while estimated total surface-water use has increased dramatically for the same time period for the study area (fig. 3). Estimated ground-water use from the Ozark aquifer in Arkansas increased from 19.66 million gallons per day (Mgal/d) in 1960 to 24.15 Mgal/d in 2005 or approximately a 23 percent increase. Ground-water use peaked in 1975 at 38.29 Mgal/d. Estimated surface-water use for the study area increased from 21.26 Mgal/d in 1960 to 598.56 Mgal/d in 2005 or approximately a 2,715 percent increase. For the period from 1960 to 1985, estimated surface-water use increased from 21.26 Mgal/d to 79.36 Mgal/d or approximately a 273 percent increase. In 1990, estimated surface-water use was 592.76 Mgal/d or approximately a 647 percent increase from 1985. For the period from 1990 through 2005, the estimated surface-water use increased from 592.76 Mgal/d to 598.56 Mgal/d, or approximately a 1 percent increase. (Stephens and Halberg, 1961; Halberg and Stephens, 1966; Halberg, 1972, 1977; Holland and Ludwig, 1981; Holland, 1987, 1993, 1999, 2004, 2007).

The large jump in estimated surface-water use between 1985 and 1990 mainly is attributed to the commissioning of the Flint Creek Power Plant and Beaver Water District distribution system becoming operational and beginning to report water use in 1990. The Flint Creek Power Plant became operational in 1978 (Electric Cooperatives of Arkansas, 2008) and uses approximately 320 Mgal/d (T.W. Holland, U.S. Geological Survey, written commun., 2008) for cooling. The Beaver Water District became operational in 1973 providing approximately 40 Mgal/d to municipal public-supply systems in Benton, Carroll, and Washington Counties (T.W. Holland, U.S. Geological Survey, written commun., 2008). Water use for these and other similar facilities across the State began reporting water use in 1990 when the Arkansas Natural Resources Commission began collecting water-use data from these facilities.

The large increase in population within the study area is not reflected by a similar increase in ground-water use from the Ozark aquifer. While the population for the study area increased 147 percent from 1960 to 2000, the ground-water use from the Ozark aquifer only increased 23 percent from 1960 to 2005. The relatively small increase in ground-water use, when compared to the increase in population, is attributed to the completion of Beaver Reservoir in 1966, and the subsequent creation of Beaver Water Districts and other surface water supply systems meeting the water needs of the rapidly increasing population.

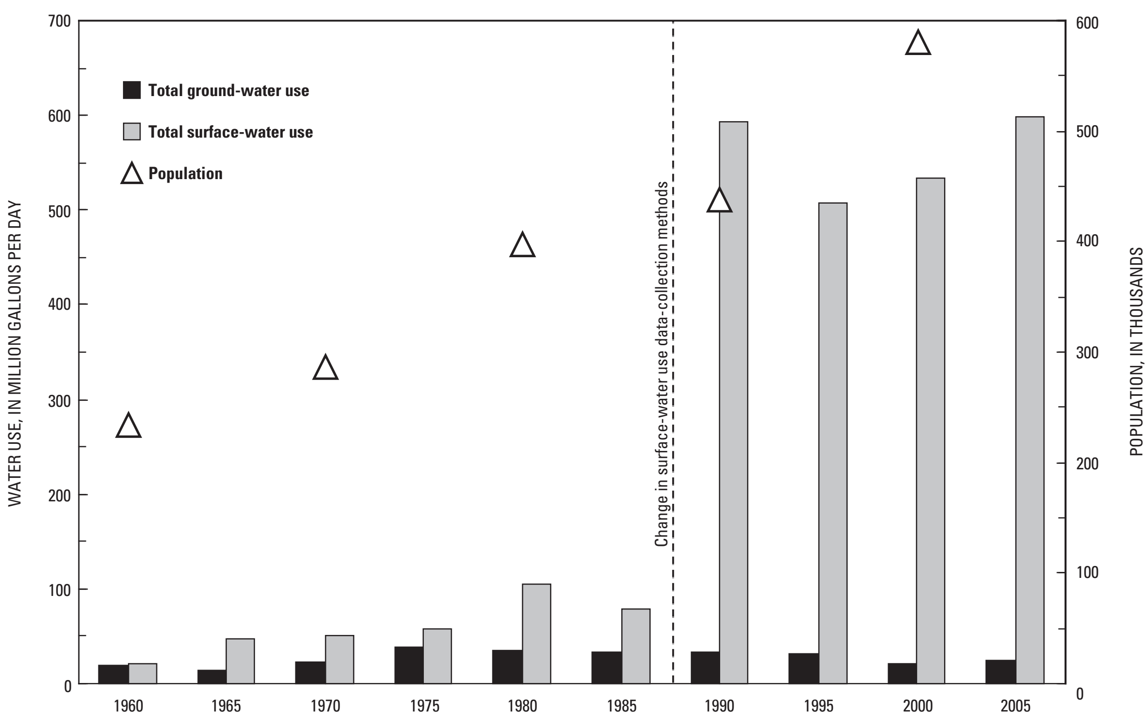

Figure 3. Total estimated ground- and surface-water use and population for the study area in northern Arkansas, 1960-2005.

Long-Term Hydrograph Trends

Hydrographs with regression trend lines were constructed for wells open to the Ozark aquifer with a minimum of 30 years of ground-water level measurements. Twenty-four hydrographs from 12 wells are presented in figure 4 and were selected to provide a relatively even distribution, geographically, across the study area. The minimum 30-year period of record was used to evaluate long-term trends not dominated by variations in climate or localized pumping rates on water levels in a single well. Trend lines using least squares linear regression were calculated for two 20-year trend periods, the first from 1967 to 1987 and the second from 1987 to 2007, to determine the slope in feet per year of water levels in each well. The slope of the trend line represents the typical annual decline or rise in water level over the trend period (20 years). A statistical summary of the number of wells with 30 or more years of data, the range of the annual rise or decline in water levels, and the mean and the median value for each county in the study area are presented in table 3. Negative trend slope values denote a decline in water level.

Water-level trends in the Ozark aquifer were divided into two 20-year trend periods (table 3), 1967-1987 and 1987-2007, to appraise the change in ground-water level trends (fig. 3). Of the 55 wells measured in the Arkansas part of the Ozark aquifer in 2007, 22 of the wells have long-term records of 30 or more years. Out of the 16 counties in the study area, 10 counties have one or more wells with long-term records. Carroll (five wells), Sharp (three wells), and Washington (three wells) Counties have three or more wells with long-term records. Baxter, Independence, Lawrence, Madison, Randolph, and Searcy Counties have no wells with long-term records.

Ground-water level trends for the period from 1967 through 1987 show mean annual water levels rising in six counties: Carroll, Fulton, Marion, Newton, Sharp and Stone. Mean annual rises ranged between 1.91 ft/yr in Marion County and 0.01 ft/yr in Newton County. Mean annual declines in water-levels for the same period (1967-1987) occurred in four counties: Benton, Boone, Izard, and Washington. Mean annual declines ranged between -6.20 ft/yr in Boone County and -0.12 ft/yr in Washington County.

Table 3. Statistical summary of annual rise/decline in water level for two 20-year trend periods (1967-1987 and 1987-2007) by county for wells in the Ozark aquifer of Arkansas.

[no wells with 30 or more years of data in Baxter, Independence, Lawrence, Madison, Randolph, and Searcy Counties]

County	Number of wells with 30 or more years of data	20-Year trend (1967-1987)					20-Year trend (1987-2007)				
		Range or value of average rise/decline in water level (feet/year)			Mean annual rise/decline in water level (feet/year)	Median annual rise/decline in water level (feet/year)	Range or value of average rise/decline in water level (feet/year)			Mean annual rise/decline in water level (feet/year)	Median annual rise/decline in water level (feet/year)
Benton	2	-8.86	to	-0.85	-4.86	-4.86	-1.12	to	-0.29	-0.70	-0.70
Boone	2	-7.62	to	-4.78	-6.20	-6.20	-1.12	to	-1.09	-1.10	-1.10
Carroll	5	-1.18	to	7.80	1.43	0.18	-0.50	to	3.35	1.06	0.84
Fulton	2	1.30	to	1.35	1.33	1.33	-0.33	to	-0.07	-0.20	-0.20
Izard	1		-1.23		-1.23			-1.00		-1.00	
Marion	2	0.46	to	3.36	1.91	1.91	-3.26	to	-0.59	-1.92	-1.92
Newton	1	0.014			0.014		0.22			0.22	
Sharp	3	0.002	to	0.37	0.12	0.004	-0.18	to	-0.03	-0.08	-0.04
Stone	1		0.048		0.048			0.63		0.63	
Washington	3	-0.25	to	0.03	-0.12	-0.13	-0.09	to	0.28	0.07	0.03

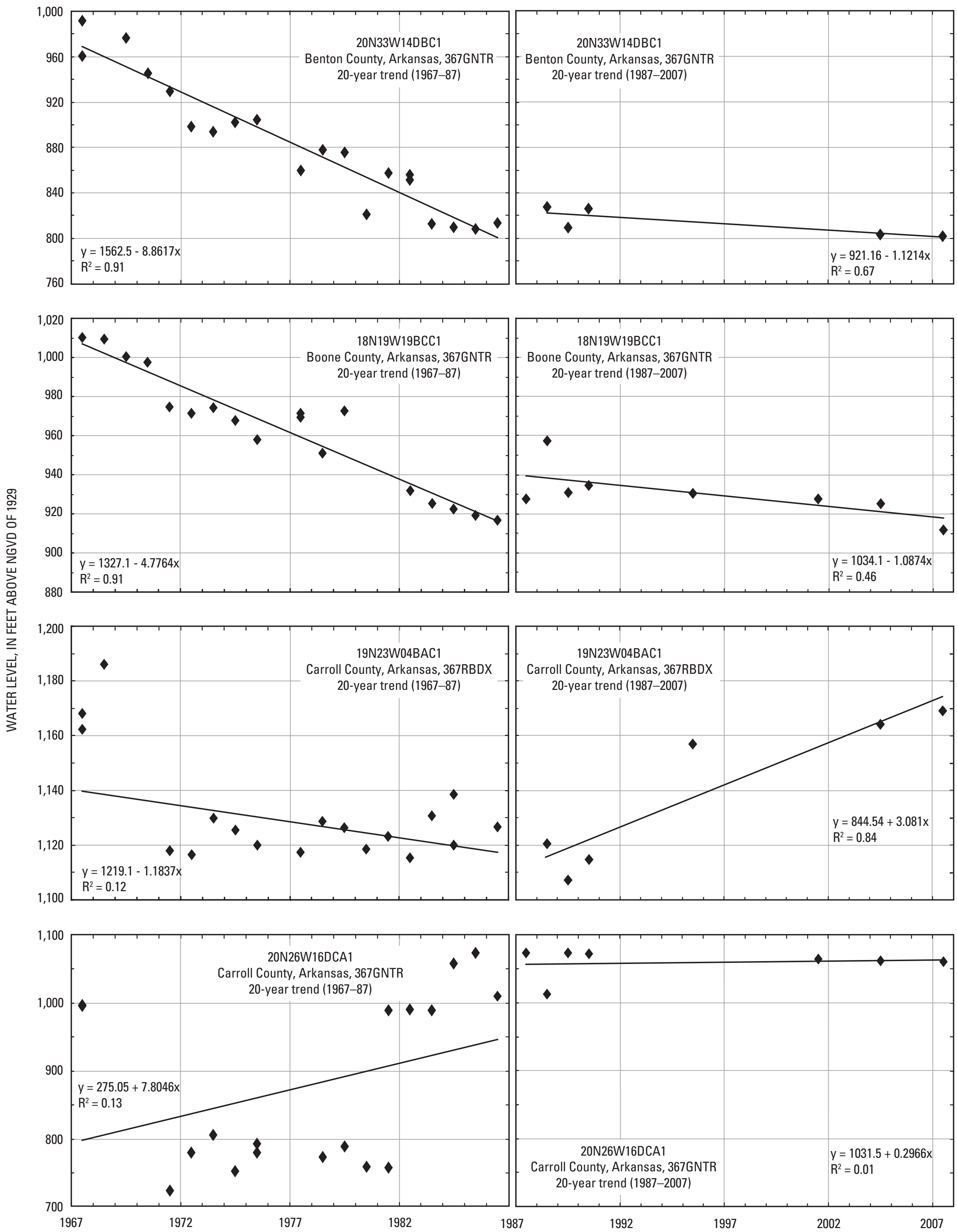

Figure 4. Water-level hydrographs and trends for selected wells completed in the Ozark aquifer in Arkansas.

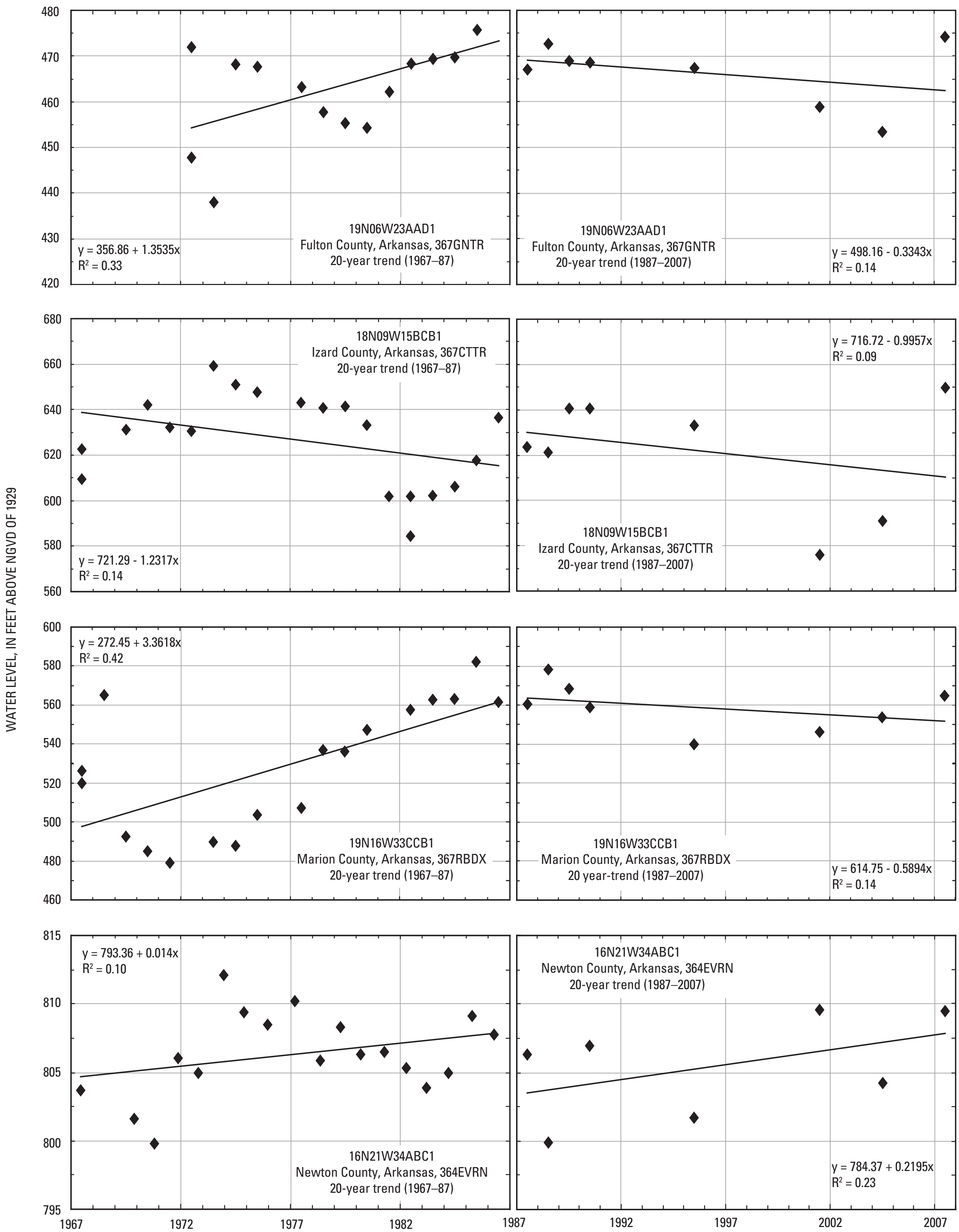

Figure 4. Water-level hydrographs and trends for selected wells completed in the Ozark aquifer in Arkansas.—Continued

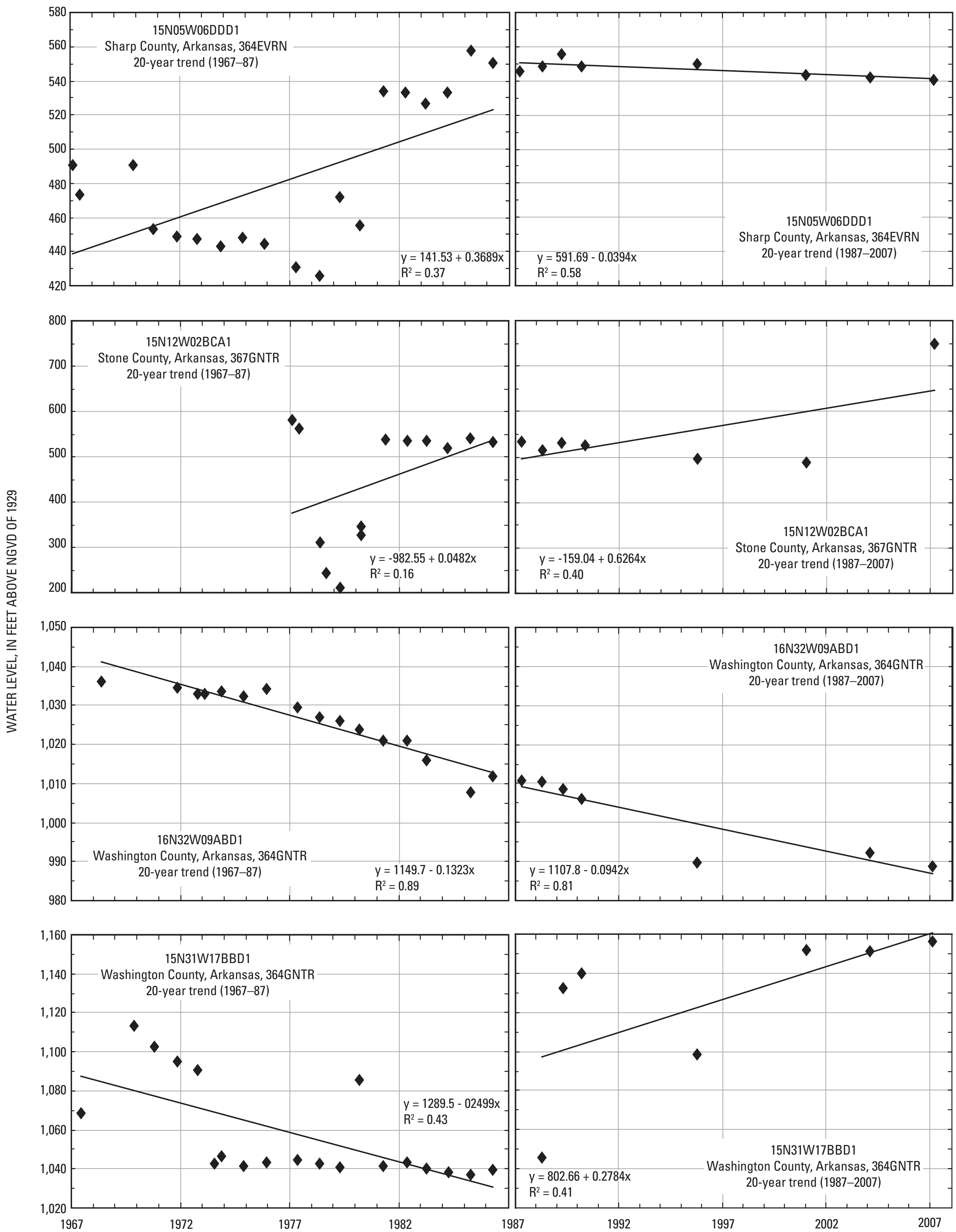

Figure 4. Water-level hydrographs and trends for selected wells completed in the Ozark aquifer in Arkansas.—Continued

For the period from 1987 through 2007, mean annual water-levels rose in only four counties: Carroll, Newton, Stone, and Washington. Mean annual rises ranged from 0.07 ft/yr in Washington County to 1.06 ft/yr in Carroll County. Mean annual declines, for the same period (1987-2007) occurred in six counties: Benton, Boone, Fulton, Izard, Marion, and Sharp. Mean annual declines ranged from -1.92 ft/yr in Marion County to -0.20 ft/yr in Fulton County.

Examining how mean annual water-level trends have changed from the first period (1967-1987) to the second period (1987-2007) provides mixed results. Benton, Boone, and Izard Counties experienced declining mean annual water levels for both periods; although, the rate of decline decreased from the first period to the second period in all three counties. Carroll, Newton, and Stone Counties experienced rising mean annual water levels for both periods. In Newton and Stone Counties, the rate of rising mean annual water levels increased during the second period; while in Carroll County, the rate of rising mean annual water levels decreased during the second period. Fulton, Marion, and Sharp Counties experienced rising mean annual water levels for the first period and declining mean annual water levels during the second period. Washington County experienced declining mean annual water levels during the first period and rising mean annual water levels during the second period.

An examination of water-use and population data and hydrograph trends over time provides some insight into changing water levels in the Ozark aquifer. The rapidly increasing population within the study area appears to have some effect on ground-water levels. Although, the effect may have been minimized by the development and use of surface-water distribution infrastructure, suggesting most of the incoming populations are fulfilling their water needs from surface-water sources. The conversion of some users from ground water to surface water may be allowing water levels in wells to recover (rise) or decline at a slower rate, such as in Benton, Carroll, and Washington Counties. Water levels in wells continue to decline at locations where the users have not converted to surface water, such as in Marion and Sharp Counties.

Summary

During February and March 2007, ground-water levels from 58 wells and 5 springs in the Ozark aquifer in northern Arkansas and southern Missouri were measured by the U.S. Geological Survey in cooperation with the Arkansas Natural Resources Commission and the Arkansas Geological Survey. A potentiometric-surface map of the Arkansas part of the Ozark aquifer was constructed. The Ozark aquifer in northern Arkansas is composed of dolomite, limestone, sandstone, and shale of Upper Cambrian to Middle Devonian age, which dips to the south and southeast away from the St. Francois Mountains of southeastern Missouri. The aquifer is complex, characterized by discrete hydrogeologic units with large variations in permeability. The principal recharge area for the aquifer is in southern and central Missouri and north-central Arkansas where the aquifer is hydraulically connected to the surface.

A potentiometric-surface map of the Ozark aquifer in northern Arkansas for 2007 indicates the maximum measured water-level altitude is 1,169 ft in Carroll County and the minimum measured water-level altitude is 118 ft in Randolph County. The direction of regional ground-water flow generally is to the south and southeast in the eastern and central part of the study area and to the west, northwest, and north in the western part of the study area, but has greater variability in areas where the unconfined part of the aquifer is hydraulically connected to the surface. In these areas, the flow direction is affected more by local topography (flowing from high altitudes toward stream valleys). The 2007 potentiometric-surface map is generally similar in shape to a predevelopment potentiometric-surface map except in Benton, Carroll, and Washington Counties in northwestern Arkansas. Potentiometric-surface differences can be attributed to differences in hydrologic stresses (withdrawals related to changing population, differences in withdrawals for agricultural uses, or withdrawal conditions just prior to a water-level measurement) or data-collection and map-construction methods (time of year or different numbers and locations of water-level measurements used to construct maps representing different years).

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