Prepared in cooperation with the Arkansas Department of Transportation and the National Park Service

Potentiometric Surface of Groundwater-Level Altitudes Near the Planned Highway 270 Bypass, East of Hot Springs, Arkansas, July–August 2017

Pamphlet to accompany

Scientific Investigations Map 3444

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

Cover photographs: *Upper right*, Hot Springs Bypass continuous groundwater monitoring well USGS 343316092584201 02S18W18CCA1 TNC East. *Lower center*, Riffle at Gulpha Gorge above the USGS streamgage, 07358550 Gulpha Creek at Hot Springs, Arkansas. *Background*, view to the east from Hot Springs Mountain overlooking Indian Mountain and parts of the Hot Springs recharge area.

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U.S. Department of the Interior
DAVID BERNHARDT, Secretary

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Contents

Figures

Tables

Map Sheet

[Available for downloading from https://doi.org/10.3133/sim3444]

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

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

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

Abbreviations

ArDOT Arkansas Department of Transportation

DEM digital elevation model

HOSP Hot Springs National Park

USGS U.S. Geological Survey

Potentiometric Surface of Groundwater-Level Altitudes Near the Planned Highway 270 Bypass, East of Hot Springs, Arkansas, July–August 2017

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Abstract

The Ouachita Mountains aquifer system potentiometric-surface map is one component of the Hot Springs Bypass Groundwater Monitoring Project. The potentiometric-surface map provides a baseline assessment of shallow groundwater levels and flow directions before the construction of the Arkansas Department of Transportation planned extension of the Highway 270 bypass, east of Hot Springs, Arkansas. The map provides data regarding status of groundwater levels and potential effects on the recharge area in the Hot Springs National Park and to groundwater that supplies water to domestic users near the Highway 270 bypass.

Groundwater levels from 66 wells were measured in July–August 2017. Fifty nine of the 66 groundwater-level altitudes measured, along with select surface-water features and springs, were used to construct the Ouachita Mountains aquifer system potentiometric-surface map. The potentiometric surface, a two-dimensional representation, shows groundwater-level altitudes ranging from a maximum of 766 ft above the North American Vertical Datum of 1988 (NAVD 88) to a minimum of 443 ft NAVD 88. The spring altitudes on the potentiometric-surface map range from 534 ft to 927 ft above NAVD 88. The study area, located in the Ouachita Mountains physiographic section of the Ouachita physiographic province, comprises narrow valleys and high ridges of Stanley Shale, Hot Springs Sandstone, Arkansas Novaculite, Missouri Mountain-Polk Creek Shale, and Bigfork Chert. The highest groundwater-level altitudes observed were in the Hot Springs Sandstone, Arkansas Novaculite, and Missouri Mountain-Polk Creek Shale. The springs discharge in outcrop areas of the Stanley Shale, Bigfork Chert, and Arkansas novaculite. The planned Highway 270 bypass will cut across ridges and valleys comprising these formations and, very importantly, across areas with elevations above 660 ft above NAVD 88 that define the hot springs recharge zone.

This potentiometric-surface map defines the status of the shallow groundwater potentiometric surface near the Highway 270 bypass prior to initiation of construction activities. A post-construction potentiometric map is planned. It must be noted that shallow groundwater levels are also subject to climatic effects including changes in amount and timing of precipitation and changes in temperature.

Introduction

The Arkansas Department of Transportation (ArDOT) plans to construct an extension of the Highway 270 bypass east of the city of Hot Springs and Hot Springs National Park (HOSP), Garland County, Arkansas. The planned bypass extension will be approximately 5 miles long and will extend from Highway 70 to the intersection of Highway 7 and Highway 5 (fig. 1). The planned Hot Springs 270 bypass will cross the HOSP hot springs recharge area, causing concerns about how construction and the land-use and land-cover changes that may follow construction could alter recharge. In addition, local stakeholders that rely on groundwater are concerned that the construction could affect the quantity and quality of groundwater produced from domestic wells.

The U.S. Geological Survey (USGS), in cooperation with ArDOT and the National Park Service, has undertaken the Hot Springs Bypass Groundwater Monitoring Project, a study that will collect groundwater data before, during, and after highway construction to inform concerns regarding potential effects on recharge to the hot springs of HOSP and to shallow groundwater that supplies water for many homes along the highway corridor. The bypass study also provides data addressing requirements of the National Environmental Policy Act to collect hydrologic information. This study supports the USGS Science Strategy goal to serve society through water-resource monitoring, assessment, modeling, and research to provide tools that managers and policymakers can use to preserve the quality and quantity of the Nation's water resources.

An early task of the Hot Springs Bypass Groundwater Monitoring Project was collection of water-level data and construction of a potentiometric-surface map to document shallow groundwater conditions prior to the start of bypass construction. The potentiometric map presented herein is the product of that task (sheet 1). During the summer of 2017, the USGS and HOSP collected groundwater measurements from 66 wells; data from 59 of these wells were used to construct a potentiometric-surface map in the Ouachita Mountains aquifer system, herein after referred to as the Ouachita Mountains aquifer. The preconstruction potentiometric-surface map provides a baseline assessment of groundwater levels and flow directions, which will later be compared to a postconstruction potentiometric-surface map. The potentiometric surface will provide a basis of comparison for later groundwater data, elucidating groundwater-level changes, enable better understanding of groundwater flow in fractured-rock aquifer systems, and help to identify any effects of construction activities on the local aquifer system.

Hydrogeologic Setting

Local geology and hydrogeology have a strong degree of control on the potentiometric surface and groundwater flow direction in the study area. The study area is located in the Ouachita Mountains physiographic section (herein referred to as Ouachita Mountains) of the Ouachita physiographic province of the Interior Highlands (fig. 2). In the study area, strata range from Mississippian to Ordovician age (fig. 3) and consist predominantly of shale, siltstones, and quartz-rich rocks (chert, novaculite, and sandstone), with minor occurrences of carbonate and igneous rocks. The Ouachita Mountains comprise high, narrow ridges separated by narrow valleys (Kresse and others, 2014; Purdue and Miser, 1923) that were formed as rocks less resistant to weathering eroded, leaving the more resistant rocks to form the ridges. The Ouachita Mountains are divided into thirteen subsections (fig. 4): Athens Piedmont Plateau, Caddo Basin, Caddo Mountains, Cossatot Mountains, Cross Mountains, Crystal Mountains, Fourche Mountains, Mazarn Basin, Northern Mountains, Ouachita Basin, Saline Basin, Trap Mountains, and ZigZag Mountains (Chandler, 2014; Cohoon, 2013; Croneis, 1930; Foti and Bukenhofer, 1998).

The study area is in the ZigZag Mountains subsection of the Ouachita Mountains and is bounded to the south by Highway 70, to the north by Highway 7 and Highway 5 (fig. 5). The ZigZag Mountains are a belt 6 to 8 miles wide and are named for the zigzag ridge pattern formed by truncation of parallel, plunging anticlines and synclines (Purdue and Miser, 1923). These anticlines and synclines of the ZigZag Mountains are divided into smaller, named mountains. The smaller named mountains that are included in this study area are Indian Mountain, Grapevine Mountain, and an unnamed mountain between Indian and Grapevine Mountains (fig. 5). The planned Highway 270 bypass cuts across the ridges of Indian Mountain and the unnamed mountain and valleys of eroded rock. The bypass is also planned to cross the following geologic formations: Stanley Shale, Hot Springs Sandstone, Arkansas Novaculite, Missouri Mountain-Polk Creek Shale, and Bigfork Chert. The resistant, ridge-forming Hot Springs Sandstone, Arkansas Novaculite, and Bigfork Chert are the primary formations conveying recharge to the hot springs. The Stanley Shale and, to a lesser extent, the Missouri Mountain-Polk Creek Shale crop out in the valleys (fig. 6).

Pervasive fracturing associated with the Ouachita orogeny constitutes the most abundant form of porosity in rocks at the near surface and has resulted in a high degree of hydraulic connectivity between formations, effectively forming a single surficial aquifer across the region (Kresse and others, 2014). In this report these formations collectively will be referred to as one regional hydrogeologic unit: the Ouachita Mountains aquifer (fig. 3). In the Ouachita Mountains aquifer, topography, structure and secondary porosity influence groundwater availability and flow. Kresse and Hays (2009) observed that shallow groundwater flow paths were confined by topographic boundaries resulting in short flow paths from elevated areas to valley floors and that flow was controlled by secondary-porosity features. Secondary porosity, void space created after the rock was formed, such as joints, fractures, and separation along bedding planes (Kresse and Hays, 2009), in the Bigfork Chert, Arkansas Novaculite, and Hot Springs Sandstone has made these the primary recharge formations for the Ouachita Mountains aquifer system due to the brittle nature and extreme fracturing of the chert, novaculite, and sandstone (Albin, 1965; Bedinger and others, 1979; Halberg and others, 1968; Kresse and Hays, 2009; Purdue, 1910; Purdue and Miser, 1923). Researchers have identified the Bigfork Chert as the most productive water-bearing formation in the region (Albin, 1965; Cole and Morris, 1986; Halberg and others, 1968; Kresse and Hays, 2009; Kresse and others, 2014; Stone and Bush, 1984). Because of the pervasive fracturing and high degree of connectivity across these strata in the shallow subsurface, the shallow aquifer is generally under unconfined conditions, although local permeability contrasts do create zones of partial confinement as well as perched zones.

The hot springs of HOSP receive recharge from the weathering-resistant, highly fractured, quartz-rich Bigfork Chert, Arkansas Novaculite, and Hot Springs Sandstone where these formations lie above elevations of approximately 660 feet (ft) and are exposed on the eroded anticlinal limbs in hydraulic communication with the hot springs. These characteristics validate concerns over potential effects on the hot springs from highway construction. Construction will involve blasting, change of land cover, and installation of engineered drainage. Whereas blasting effects have been shown to be limited in areal extent (Lane and others, 1996), land-cover changes above 660 ft and drainage of surface water and shallow groundwater from elevations above 660 ft to below 660 ft would result in lower groundwater levels in the recharge area, potentially decreasing hot spring flow.

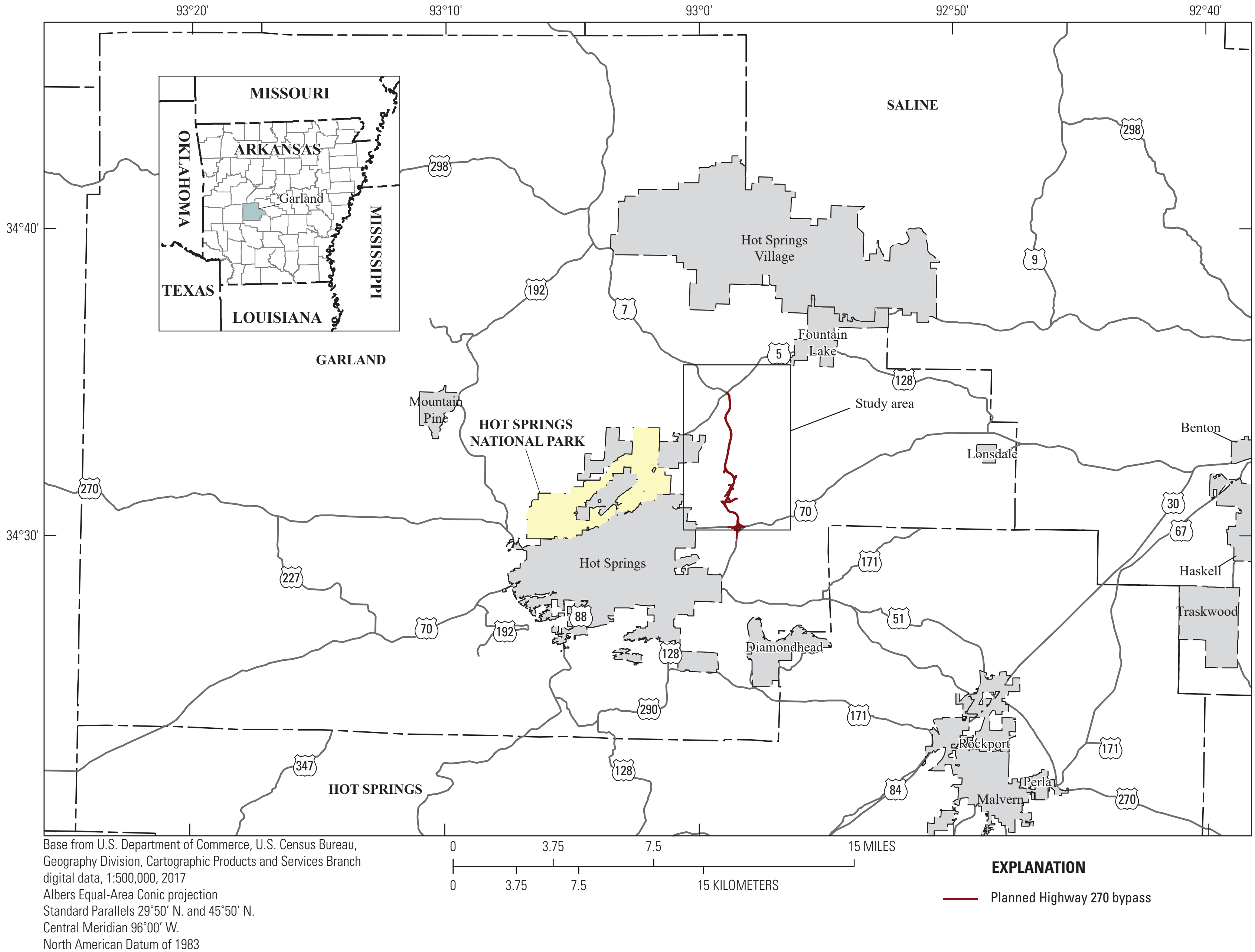


Figure 1. Location of the study area near the planned Highway 270 bypass, east of Hot Springs, Arkansas.

Major division	Province	Section
Atlantic Plain	Coastal Plain	Mississippi Alluvial Plain
		West Gulf Coastal Plain
Interior Highlands	Ozark Plateaus	Springfield-Salem plateaus
		Boston Mountains
	Ouachita Province	Arkansas Valley
		Ouachita Mountains

Figure 2. Physiographic divisions of Arkansas. Modified from Fenneman (1917 and 1928).

Time-stratigraphic unit: Era	Time-stratigraphic unit: System	Formation		Maximum thickness in Hot Springs area, in feet	Topography	Regional hydrogeologic unit[1]
Paleozoic	Mississippian	Stanley Shale		8,500	Broad valleys with low ridges and hills	Ouachita Mountains aquifer
		Hot Springs Sandstone		150	Steep slopes, or narrow, sharp crested ridges	
	Mississippian Devonian	Arkansas Novaculite		650	High ridges and steep slopes	
	Silurian Ordovician	Missouri Mountain-Polk Creek Shale[1] Blaylock Sandstone[2] Polk Creek Shale[2]	Undifferentiated	195	Steep slopes, or narrow valleys	
	Ordovician	Bigfork Chert		700	Steep-sided low ridges and round knobs	

[1]Modified from Renken (1998).

[2]In the study area the Blacklock Sandstone is not exposed, and the Missouri Mountain and Polk Creek shale beds are undifferentiated.

Figure 3. Stratigraphic column and correlated hydrogeologic units of the Ouachita Mountains physiographic section, Arkansas. Modified from Bedinger and others (1979); Kresse and Hays (2009, table 1); Kresse and others (2014, table 4); Purdue and Miser (1923, table 1).

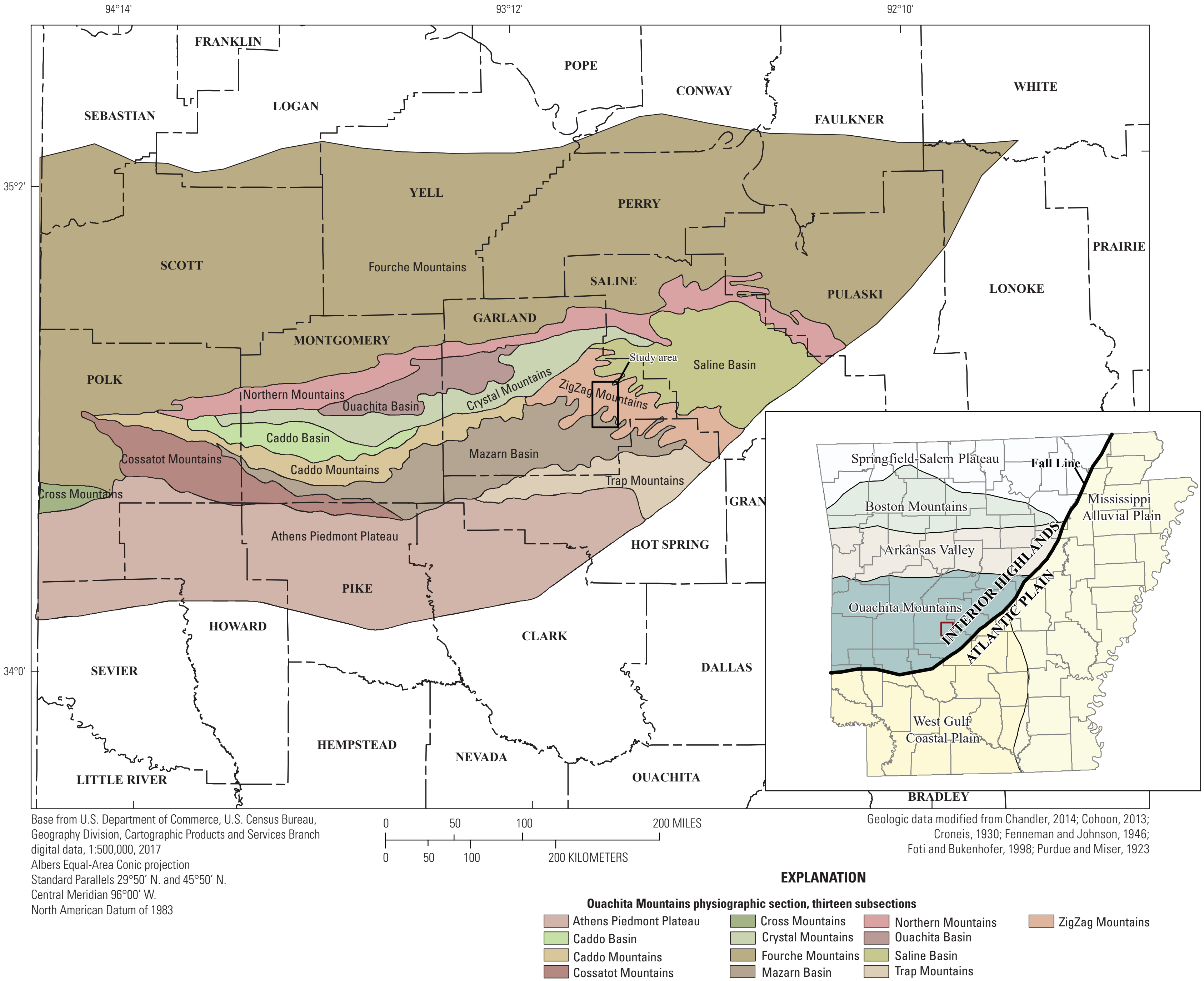
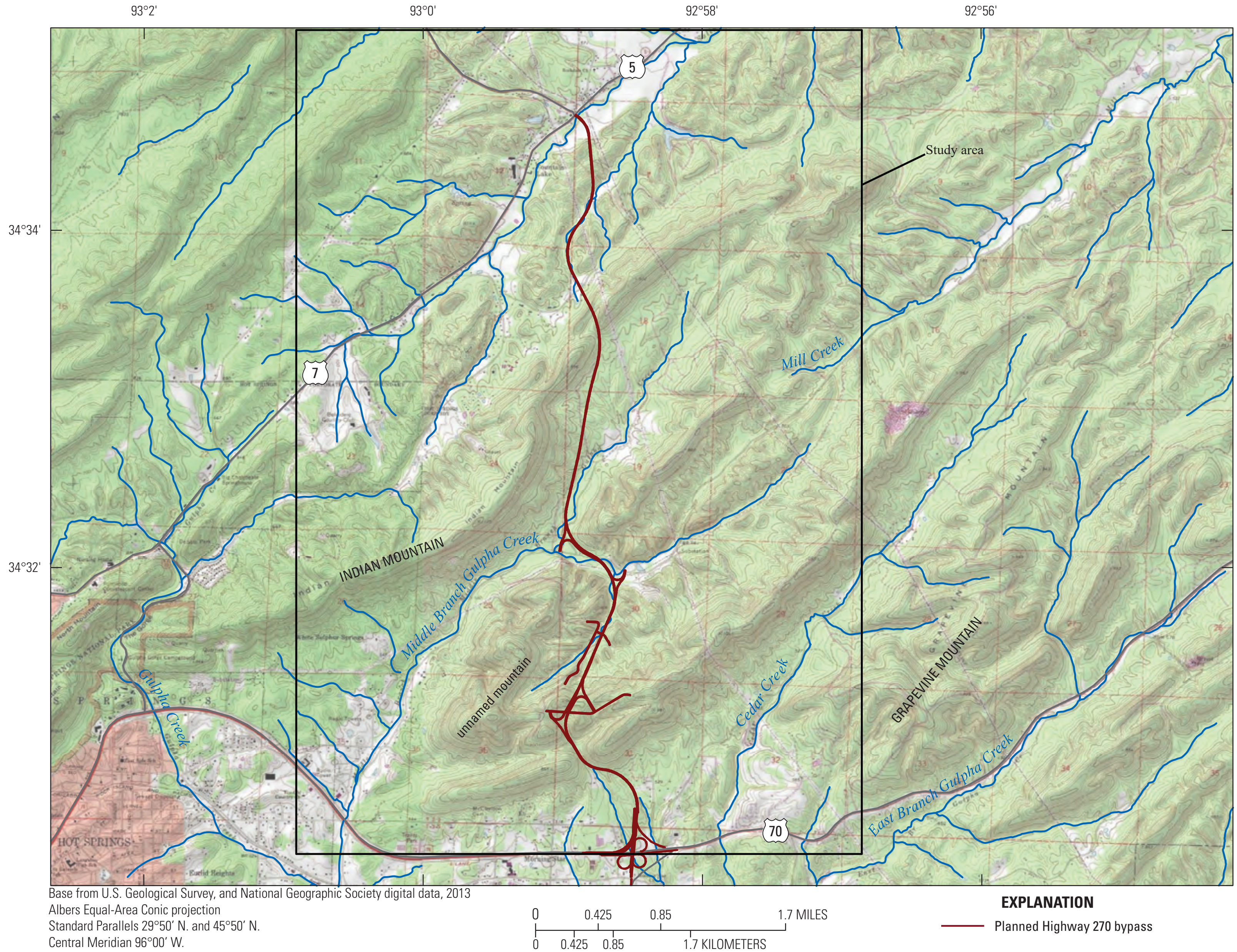
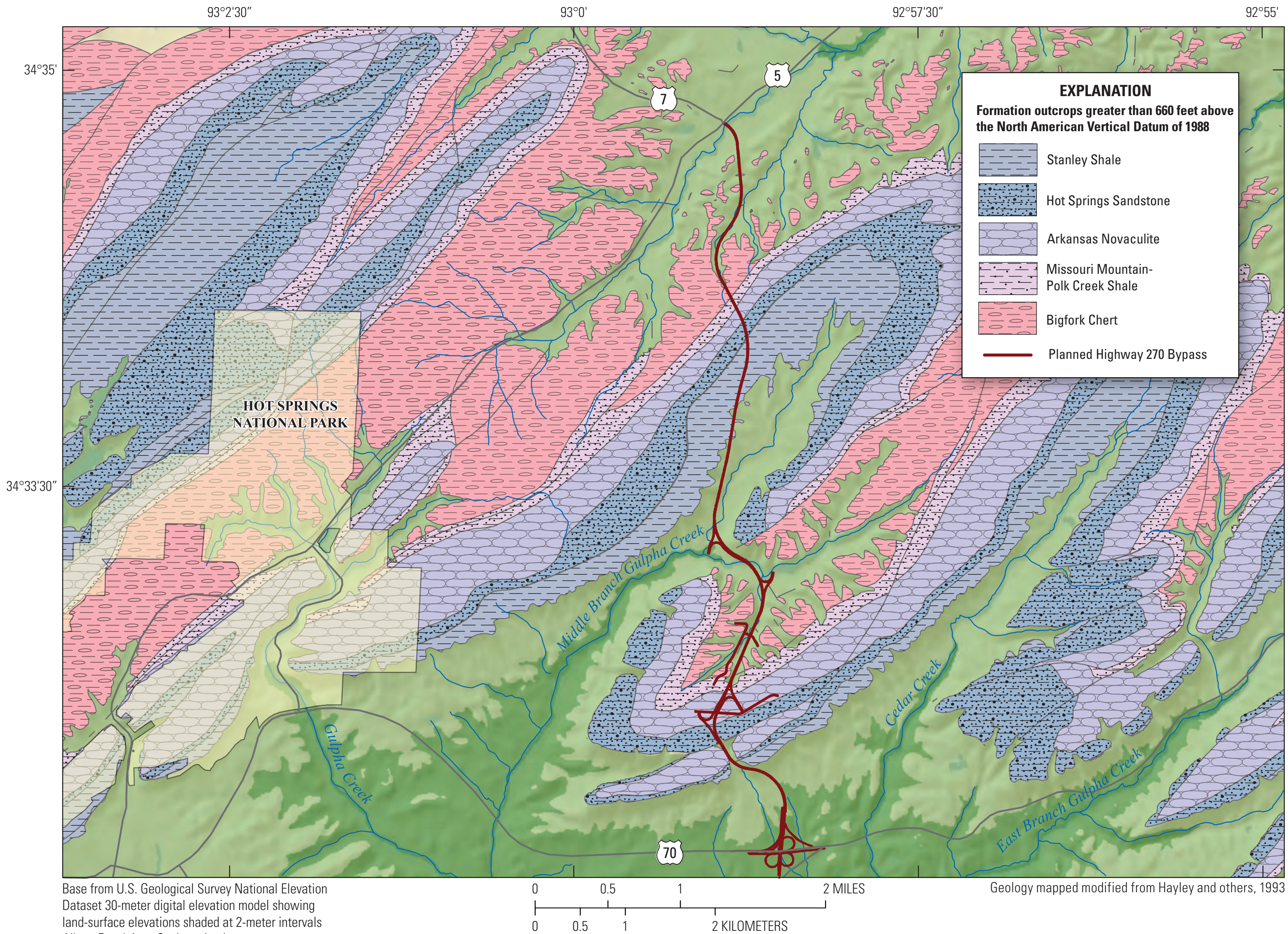


Figure 4. Extent of the 13 subsections of the Ouachita Mountains physiographic section of the Interior Highlands in Arkansas.



Base from U.S. Geological Survey, and National Geographic Society digital data, 2013
Albers Equal-Area Conic projection
Standard Parallels 29°50′ N. and 45°50′ N.
Central Meridian 96°00′ W.
North American Datum of 1983

Figure 5. ZigZag Mountains and smaller ranges of the ZigZag Mountains in the study area.



Base from U.S. Geological Survey National Elevation Dataset 30-meter digital elevation model showing land-surface elevations shaded at 2-meter intervals
Albers Equal-Area Conic projection
Standard Parallels 29°50′ N. and 45°50′ N.
Central Meridian 96°00′ W.
North American Datum of 1983

Geology mapped modified from Hayley and others, 1993

Figure 6. Surficial extent of formations and geologic structures in the study area.

Methods

The potentiometric surface of the Ouachita Mountains aquifer (sheet 1) is a two-dimensional representation of groundwater flow in the area and represents synoptic conditions during summer 2017. The groundwater altitudes used to construct the potentiometric contours represent altitudes at which water levels would have stood in tightly cased wells and should not be used to determine absolute water-level altitudes or depth to water at any given location because of the study area’s complex structural geology and small-scale variable hydrologic properties not accommodated by measurement density.

Water levels were measured in 66 wells between July 10 and August 28, 2017. Of the 66 measured water levels, 59 measurements made between July 24 and August 28, 2017, met data representativeness and quality-assurance constraints and were used to construct the potentiometric surface. Well locations were selected from three sources—previously reported sites (Kresse and Hays, 2009), site reconnaissance, and driller’s logs obtained through the Arkansas Natural Resources Commission driller database (U.S. Geological Survey and Arkansas Natural Resources Commission, 1996). The collected data and formation thicknesses from Kresse and Hays (2009) (fig. 3) were also used to determine in which of the formations each of the 20 wells was completed. Of the 59 wells measured, 12 were assigned as completed in the Bigfork Chert, 6 in the Missouri Mountain-Polk Creek Shale, 3 in the Arkansas Novaculite, 2 in the Hot Springs Sandstone, and 36 in the Stanley Shale.

Well depths were available for 39 of the 59 wells measured, and depths ranged from 40 to 1,000 ft (table 1). Well 343049092582201, a flowing artesian well with a depth to water of −0.54 ft and a 1,000-ft depth, was considerably deeper than other wells inventoried; therefore, this well was excluded from the potentiometric map. Depths for wells used in the construction of the potentiometric-surface map ranged from 40 to 390 ft with a mean well depth of 160 ft. The 20 wells with no recorded depths were assumed to be completed in the surficial aquifer and were assumed to be completed in the outcropping formation around the well site. These assumptions are based on the well depth range of 40 to 390 ft and data from Kresse and Hays (2009) indicating that 83 percent of domestic wells measured in the study area were less than 200 ft in depth and that the remaining 17 percent were less than 400 ft in depth. The 59 water-level measurements were referenced to a land-surface datum and were converted to water-level altitude by subtracting the well land-surface elevation from measured water-level depths. Measured groundwater data are available from the USGS National Water Information System (U.S. Geological Survey, 2018). In addition to the groundwater-level measurement data, altitudes of selected streams and altitudes of 18 spring emergences located throughout the study area were used in construction of the potentiometric-surface map. Surface-water features and springs represent the intersection of the groundwater table with land surface. Major streams and creeks were selected in the study area from the USGS National Hydrography Dataset (U.S. Geological Survey, 2017). Springs were selected from the previously published report by Kresse and Hays (2009) and site reconnaissance. Surface-water features and spring altitudes were calculated from 10-meter digital elevation model (DEM) data (U.S. Geological Survey, 2015, 2016). All well, stream, and spring locations were plotted by using ArcMap 10.5 (Esri, 2018).

After data were collected, processed, and plotted, a potentiometric surface was generated by using the interpolation method Topo to Raster in ArcMap 10.5 (Esri, 2017a). This tool is specifically designed for the creation of hydrologically correct DEMs while imposing constraints that ensure a connected drainage structure and a correct representation of the surface from the provided contour data (Esri, 2017a). Once the raster surface was created, 50-ft-interval contours were generated by using Contour (Spatial Analyst), a spatial analyst tool (available through the ArcGIS 3D Analyst toolbox) that creates a line-feature class of contours (isolines) from the raster surface (Esri, 2017b). The topo to raster and contouring done by ArcMap 10.5 is a rapid way to interpolate data, but computer programs do not account for hydrologic connections between groundwater and surface water. For this reason, contours were manually adjusted based on topographic influence, a comparison with the potentiometric-surface data from Kresse and Hays (2009), and well-point water-level altitudes to more accurately represent the potentiometric surface.

The complete dataset containing the hydrogeologic framework shapefiles and potentiometric surface shapefiles of well points, spring points, and contours for the study area is available from Nottmeier and Hays (2019). This dataset supports the findings in this report.

Table 1. Wells used to construct potentiometric surface, July–August 2017, in Garland County, Hot Springs, Arkansas.

[USGS, U.S. Geological Survey; NAVD 88, North American Vertical Datum of 1988; --, indicates no data available. Dates are presented in month/day/year format]

Well number (see sheet 1)	USGS station number	Formation[1]	Well depth (feet)	Altitude of land surface (feet above NAVD 88)	Date of measure-ment	Depth to water level (feet below land sur-face)	Water-lev-el altitude (feet above NAVD 88)
1	343023092584801	Stanley Shale	253	528	7/26/2017	12.74	515
2	343029092593001	Stanley Shale	130	503	7/24/2017	14.76	488
3	343047092571101	Stanley Shale	165	585	7/24/2017	17.55	567
4	343047092571201	Stanley Shale	220	599	8/1/2017	29.06	570
5	343051092575401	Stanley Shale	300	542	7/25/2017	25.11	517
6	343056093001701	Stanley Shale	74	454	7/26/2017	10.96	443
7	343150092594901	Stanley Shale	130	592	7/26/2017	24.03	568
8	343153092582401	Bigfork Chert	120	586	7/25/2017	5.72	580
9	343229092585201	Stanley Shale	120	555	7/26/2017	5.30	550
10	343230093000701	Missouri Mountain-Polk Creek Shale	150	794	7/24/2017	33.65	760
11	343257092593601	Missouri Mountain-Polk Creek Shale	--	759	7/24/2017	36.84	722
12	343304092593501	Bigfork Chert	106	731	7/24/2017	49.17	682
13	343305092593501	Bigfork Chert	89	714	7/24/2017	33.05	681
14	343330092591101	Bigfork Chert	50	671	7/24/2017	27.00	644
15	343102092590701	Hot Springs Sandstone	288	941	7/28/2017	223.52	717
16	343103092581101	Stanley Shale	165	658	7/28/2017	57.28	601
17	343052092575301	Stanley Shale	300	544	7/25/2017	29.20	515
18	343052092575601	Stanley Shale	--	549	7/25/2017	27.09	522
19	343254092593701	Missouri Mountain-Polk Creek Shale	--	793	7/24/2017	59.42	734
20	343340092584901	Bigfork Chert	150	693	7/24/2017	12.93	680
21	343350092584101	Bigfork Chert	100	674	7/24/2017	10.71	663
22	343032092592501	Stanley Shale	50	549	7/25/2017	10.79	538
23	343031092592401	Stanley Shale	40	557	7/25/2017	2.65	554
24	343029092591801	Stanley Shale	--	542	7/25/2017	12.90	529
25	343137092585401	Bigfork Chert	205	708	7/25/2017	129.79	578
26	343042092581001	Stanley Shale	--	532	7/26/2017	21.57	510
27	343043092574901	Stanley Shale	--	545	7/26/2017	61.7	483
28	343116092573101	Stanley Shale	--	537	7/26/2017	14.32	523
29	343124093000101	Stanley Shale	100	470	7/26/2017	4.15	466
30	343329092584901	Arkansas Novaculite	81	817	8/28/2017	76.15	741
31	343216092590201	Stanley Shale	105	573	7/24/2017	27.34	546
32	343221092590101	Stanley Shale	--	581	7/24/2017	0.94	580
33	343235092584701	Stanley Shale	105	565	7/24/2017	-0.28	565
34	343130092582801	Missouri Mountain-Polk Creek Shale	208	688	7/25/2017	35.23	653

Table 1. Wells used to construct potentiometric surface, July–August 2017, in Garland County, Hot Springs, Arkansas.—Continued

[USGS, U.S. Geological Survey; NAVD 88, North American Vertical Datum of 1988; --, indicates no data available. Dates are presented in month/day/year format]

Well number (see sheet 1)	USGS station number	Formation[1]	Well depth (feet)	Altitude of land surface (feet above NAVD 88)	Date of measurement	Depth to water level (feet below land surface)	Water-level altitude (feet above NAVD 88)
35	343111093000801	Stanley Shale	300	461	7/27/2017	4.16	457
36	343128092595901	Stanley Shale	--	470	7/27/2017	12.56	457
37	343421092592601	Bigfork Chert	180	653	7/27/2017	41.44	612
38	343447092594601	Stanley Shale	--	656	7/27/2017	32.05	624
39	343210092590201	Stanley Shale	--	541	7/25/2017	25.34	516
40	343334092590101	Bigfork Chert	150	694	7/24/2017	37.41	657
41	343350092584201	Bigfork Chert	--	666	7/24/2017	22.36	644
42	343233093000801	Missouri Mountain-Polk Creek Shale	--	777	7/24/2017	14.25	763
43	343228093000801	Missouri Mountain-Polk Creek Shale	--	809	7/24/2017	43.26	766
44	343232092585801	Stanley Shale	145	660	7/25/2017	44.96	615
45	343210092591201	Stanley Shale	125	558	7/24/2017	30.81	527
46	343217092591201	Stanley Shale	130	616	7/24/2017	13.62	602
47	343259092581501	Stanley Shale	--	681	7/26/2017	8.74	672
48	343137092584101	Bigfork Chert	--	601	7/25/2017	3.62	597
49	343135092583601	Bigfork Chert	208	749	7/25/2017	138.72	610
50	343043092584601	Stanley Shale	--	590	7/26/2017	21.15	569
51	343044092584601	Stanley Shale	--	585	7/26/2017	19.63	565
52	343049092582401	Stanley Shale	45	564	7/26/2017	15.70	548
53	[2]343049092582201	Stanley Shale	1,000	556	7/26/2017	-0.54	557
54	343052092582601	Stanley Shale	--	590	7/26/2017	19.98	570
55	343039092582301	Stanley Shale	105	519	7/26/2017	27.45	492
56	343151092594601	Stanley Shale	160	574	7/26/2017	10.15	564
57	343105092585201	Hot Springs Sandstone	325	889	7/27/2017	174.31	715
58	343111092584601	Arkansas Novaculite	--	882	7/27/2017	123.88	758
59	343115092590101	Arkansas Novaculite	390	864	7/27/2017	175.68	688

[1]Formations collectively are referred to as one regional hydrogeologic unit: Ouachita Mountains aquifer.

[2]Water-level data from this station were not used to construct the potentiometric surface.

Table 2. Springs used to construct potentiometric surface, July–August 2017, in Garland County, Hot Springs, Arkansas.

[USGS, U.S. Geological Survey; NAVD 88, North American Vertical Datum of 1988]

Spring number (see sheet 1)	USGS station number	Formation[1]	Altitude of land surface[2] (feet above NAVD 88)
1	343033092584601	Stanley Shale	637
2	343057092572101	Stanley Shale	569
3	343105092572001	Stanley Shale	576
4	343126092582601	Arkansas Novaculite	720
5	343128092581901	Arkansas Novaculite	729
6	343134092580501	Arkansas Novaculite	927
7	343155092583301	Bigfork Chert	561
8	343157092583701	Bigfork Chert	551
9	343158092585501	Bigfork Chert	592
10	343209092583101	Bigfork Chert	626
11	343211092582301	Bigfork Chert	632
12	343218092585501	Stanley Shale	534
13	343104092585801	Arkansas Novaculite	705
14	343302092581201	Stanley Shale	683
15	343222092590001	Stanley Shale	570
16	343221092590601	Stanley Shale	636
17	343213092590801	Stanley Shale	570
18	343149092594801	Stanley Shale	592

[1]Formations collectively are referred to as one regional hydrogeologic unit: Ouachita Mountains aquifer.

[2]Spring altitudes calculated from 10-meter digital elevation model data (U.S. Geological Survey, 2015; U.S. Geological Survey, 2016).

Potentiometric Surface and Groundwater Flow

Depth to water in the study area ranged from -0.54 ft above the land surface to 223.52 ft below the land surface (bls). The mean depth to water in 36 wells completed in the Stanley Shale was 19 ft, with a maximum depth to water of 62 ft bls and minimum depth to water level of −0.28 ft bls. The mean depth to water in the 12 wells completed in the Bigfork Chert was 43 ft bls, with a maximum depth to water of 139 ft bls and a minimum depth to water of 4 ft bls. Kresse and Hays (2009) reported a mean depth to water of 75 ft bls in 11 wells completed in the Bigfork Chert.

Shallow groundwater flow in the study area is driven by topographic gradient, and as a result, potentiometric-level altitudes are a subdued reflection of ground-surface elevations. The maximum groundwater-level altitude recorded for a well was 766 ft above the North American Vertical Datum of 1988 (NAVD 88) at well number 43 (associated with a topographic high) and a minimum groundwater-level altitude of 443 ft above NAVD 88 at well number 6 (associated with a topographic low) (table 1; sheet 1). The highest groundwater-level altitudes in the study area were observed in Arkansas Novaculite, Hot Springs Sandstone, and Missouri Mountain-Polk Creek Shale outcrop areas. The weathering-resistant nature of the Arkansas Novaculite and Hot Springs Sandstone results in these rocks holding up some of the highest land-surface elevations in the area and creates rugged terrain. As the water moves through the system, groundwater flows from the topographic highs downgradient in various directions towards the topographic lows underlain by the Stanley Shale, Missouri Mountain-Polk Creek Shale, and less-resistant sections of the Bigfork Chert.

As shallow groundwater in the study area moves downgradient, water discharges at cold springs from fractures, bedding contacts, or other permeability contrasts. The altitudes of springs used in construction of the potentiometric surface range from 534 to 927 ft above NAVD 88 (table 2; sheet 1). This study used data from only five springs in the Bigfork Chert and four springs in the Arkansas Novaculite. Of the 18 springs used to construct the potentiometric-surface map for this study, 9 emerged from the Stanley Shale. The shale formations have been characterized as having lower permeability, porosity, and storage, resulting in uneven distribution of recharge, rapidly filled fractures, and greater increase in water levels and flow gradients during rain events (Bedinger and others, 1979; Kresse and Hays, 2009). Shallow groundwater not discharged to springs continues to flow towards valleys of Bigfork Chert and Stanley Shale and then to discharge into streams.

Rainfall is the ultimate source of recharge for the shallow and the deep groundwater systems, which are extensively connected in the origins of the flow paths. Precipitation infiltrates into the highly permeable Arkansas Novaculite, Hot Springs Sandstone, and Bigfork Chert in the topographically high areas, recharging the shallow groundwater aquifer as well as providing recharge for the long and deep flow path to the hot springs of HOSP. High storage and permeability in the Arkansas Novaculite and Bigfork Chert allow rapid recharge from rain events and a movement of water through fractures (Kresse and Hays, 2009). Indian Mountain, the limb of the plunging anticline which the northern part of the Highway 270 bypass is planned to cross, is an important hot springs recharge zone above the elevation of 660 ft (figs. 5 and 6). Precipitation also infiltrates the highly fractured and weathered shale units, such as the Stanley Shale, which predominantly outcrop at lower elevations; however, pressure-head requirements mandate that this recharge input from lower elevations will not be part of the hot springs flow path but will rather be of more importance to the shallow groundwater system. As such, water recharging the system infiltrates and moves along groundwater flow paths with residence times from days to thousands of years. Groundwater picks up heat due to the local geothermal gradient as it moves deeper and along longer flow paths. The hot springs of HOSP flows upward along faults connected to the surface to eventually resurge on the nose of a thrust-faulted, plunging anticline (Kresse and Hays, 2009). The longer residence times are found in deeper parts of the flow system with long flow paths and deeper waters moving upward from depth along the thrust faults to discharge at the hot springs of HOSP.

Summary

The Hot Springs 270 bypass is planned to cross the Hot Springs National Park (HOSP) hot springs recharge zone and an area where shallow groundwater is important for domestic water supply; stakeholders have concerns as to how construction may alter land cover, topography, and drainage, thus possibly affecting recharge and shallow groundwater. A potentiometric-surface map has been constructed to provide a baseline, preconstruction assessment of current groundwater levels and flow directions that can be used to compare and assess groundwater-level altitudes (and potential changes) after highway construction.

Shallow groundwater in the study area resides in the Ouachita Mountains aquifer, which is composed of highly fractured, consolidated rocks. Water-level data show strong topographic control—the shallow-groundwater potentiometric surface presents a subdued reflection of topography with groundwater from higher hydraulic head on ridges held up by Arkansas Novaculite and Hot Springs Sandstone moving towards lower hydraulic head in valleys of Bigfork Chert and Stanley Shale along fractures, joints, and bedding planes in weathered bedrock. The highest groundwater-level altitudes in the study area were observed in Arkansas Novaculite, Hot Springs Sandstone, and Missouri Mountain-Polk Creek Shale outcrop areas. The maximum potentiometric-surface altitude of 927 feet (ft) is associated with a topographic high, and the minimum potentiometric-surface altitude of 443 ft is associated with a topographic low.

Elevations above 660 ft above NAVD 88 define the hot springs recharge zone. Groundwater recharge that is not rapidly discharged to springs and streams along short flow paths, moves deeper, along much longer flow paths, to pick up heat on the local geothermal gradient. Eventually the groundwater intercepts and flows upward along faults connected to the surface and emerges at the hot springs discharge area. Residence time along the deeper, longer flow path is on the order of thousands of years.

References

Albin, D.R., 1965, Water-resources reconnaissance of the Ouachita Mountains, Arkansas: United States. Government Printing Office, Water Supply Paper 1809-J, accessed March 18, 2018, at http://pubs.er.usgs.gov/publication/wsp1809J.

Bedinger, M.S., Pearson, F.J., Jr., Reed, J.E., Sniegocki, R.T., and Stone, C.G., 1979, The waters of Hot Springs National Park, Arkansas—Their nature and origin: U.S. Geological Survey Professional Paper 1044–C, accessed January 5, 2018, at http://pubs.er.usgs.gov/publication/pp1044C.

Chandler, A., 2014, Physiographic Provinces of Arkansas: Arkansas Geological Survey, accessed March 21, 2018, at http://www.geology.ar.gov/pdf/Physiographic_Regions_Poster.pdf.

Cohoon, R.R., 2013, Geologic Roadguide to the Scenic 7 Byway: Arkansas Geological Survey 01, 123 p., accessed March 21, 2018, at http://www.geology.ar.gov/pdf/RGS-01%20Ouachita%20Mountains.pdf.

Cole, E.F., and Morris, E.E., 1986, Quality of water resources of the Ouachita National Forest, Arkansas: Water-Resources Investigations Report 86–4166, accessed March 22, 2018, at http://pubs.er.usgs.gov/publication/wri864166.

Croneis, C., 1930, Geology of the Arkansas Paleozoic area: with special reference to oil and gas possibilities: Bulletin, Arkansas Geological Survey, Little Rock, Arkansas, 457 p.

Esri, 2017a, How Topo to Raster works—Help | ArcGIS Desktop, accessed December 5, 2017, at ArcGIS Pro at http://pro.arcgis.com/en/pro-app/tool-reference/3d-analyst/how-topo-to-raster-works.htm.

Esri, 2017b Contour—Help | ArcGIS Desktop, accessed December 5, 2017, at ArcGIS Pro Raster Surface toolset at http://pro.arcgis.com/en/pro-app/tool-reference/3d-analyst/contour.htm.

Esri, 2018, ArcGIS Desktop 10.5, accessed March 13, 2018, at ArcGIS Desktop at https://desktop.arcgis.com/en/.

Fenneman, N.M., 1917, Physiographic Subdivision of the United States: Proceedings of the National Academy of Sciences of the United States of America, v. 3, no. 1, p. 17–22.

Fenneman, N.M., 1928, Physiographic Divisions of the United States: Annals of the Association of American Geographers, v. 18, no. 4, p. 261.

Fenneman, F., and Johnson, D.W., 1946, Physical Divisions of the United States, scale 1:7,000,000.

Foti, T.L., and Bukenhofer, G.A., 1998, Description of the Sections and Subsections of the Interior Highlands of Arkansas and Oklahoma: v. 52, p. 11.

Halberg, H.N., Bryant, C.T., and Hines, M.S., 1968, Water resources of Grant and Hot Spring Counties, Arkansas: U.S. Geological Survey Water Supply Paper 1857, accessed March 22, 2018, at http://pubs.er.usgs.gov/publication/wsp1857.

Haley, B.R., Glick, E.E., Bush, W.V., Clardy, B.F., Stone, C.G., Woodward, M.B., and Zachry, D.L., 1993, Geologic map of Arkansas, scale 1:500,000.

Kresse, T.M., and Hays, P.D., 2009, Geochemistry, comparative analysis, and physical and chemical characteristics of the thermal waters east of Hot Springs National Park, Arkansas, 2006–09: U.S. Geological Survey Scientific Investigations Report 2009–5263, 48 p., accessed November 28, 2017, at https://pubs.usgs.gov/sir/2009/5263/.

Kresse, T.M., Hays, P.D., Merriman, K.R., Gillip, J.A., Fugitt, D.T., Spellman, J.L., Nottmeier, A.M., Westerman, D.A., Blackstock, J.M., and Battreal, J.L., 2014, Aquifers of Arkansas—Protection, management, and hydrologic and geochemical characteristics of groundwater resources in Arkansas: U.S. Geological Survey Scientific Investigations Report 2014–5149, 334 p., accessed at http://dx.doi.org/10.3133/sir20145149.

Lane, J.W., Haeni, F.P., Soloyanis, S., Placzek, G., Williams, J.H., Johnson, C.D., Buursink, M.L., Joesten, P.K., and Knutson, K.D., 1996, Geophysical characterization of a fractured-bedrock aquifer and blast-fractured contaminant-recovery trench, *in* Symposium on the Application of Geophysics to Engineering and Environmental Problems 1996: Environment and Engineering Geophysical Society, p. 429–441.

Nottmeier, A.M., and Hays, P.D., 2019, Datasets of the potentiometric surface of groundwater-level altitudes near the planned Highway 270 bypass, east of Hot Springs, Arkansas, July–August 2017: U.S. Geological Survey data release, https://doi.org/10.5066/F7TD9WK0.

Purdue, A.H., 1910, The collecting area of the waters of the Hot Springs, Hot Springs, Arkansas: The Journal of Geology, v. 18, no. 3, p. 279–285.

Purdue, A.H., and Miser, H.D., 1923, Description of the Hot Springs District: Folios of the Geologic Atlas 215, 12 p., accessed January 5, 2018, at http://pubs.er.usgs.gov/publication/gf215.

Renken, R.A., 1998, Ground water atlas of the United States—Segment 5, Arkansas, Louisiana, Mississippi: U.S. Geological Survey Hydrologic Atlas 730–F, 28 p., accessed March 22, 2018, at https://pubs.usgs.gov/ha/ha730/ch_f/.

Stone, C.G., and Bush, W.V., 1984, General geology and mineral resources of the Caddo River watershed: Arkansas Geological Commission 29, 32 p., accessed March 22, 2018, at http://geology.arkansas.gov/info_circulars/ic29.htm.

U.S. Geological Survey, 2015, USGS NED 1 arc-second n35w094 1 x 1 degree ArcGrid 2015, accessed December 5, 2017, at The National Map: Elevation, at https://nationalmap.gov/elevation.html.

U.S. Geological Survey, 2016, USGS NED 1 arc-second n35w093 1 x 1 degree ArcGrid 2016, accessed December 5, 2017, at The National Map: Elevation, at https://nationalmap.gov/elevation.html.

U.S. Geological Survey, 2017, USGS National Hydrography Dataset (NHD) Best Resolution 20170831 for State or Territory File GDB 10.1 Model Version 2.2.1: ScienceBase Catalog, accessed November 28, 2017, at https://www.sciencebase.gov/catalog/item/581d79c4e4b0dee4cc8e7a41.

U.S. Geological Survey, 2018, USGS water data for the Nation: U.S. Geological Survey National Water Information System database, accessed July 1, 2017, at http://dx.doi.org/10.5066/F7P55KJN.

U.S. Geological Survey and Arkansas Natural Resources Commission, 1996, Water Well Construction Reports, accessed December 19, 2018, at https://www.usgs.gov/software/water-well-construction-reports.

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