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Groundwater/Surface-Water Interaction in Central Sevier County, Tennessee, October 2015–2016

Open-File Report 2017–1147

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

Cover. Whirlpool in the West Prong Little Pigeon River at Sevierville, Tennessee, downstream of the Collier Drive Bridge. Photograph by Bryon W. Fortner, Public Works Director, City of Sevierville, Tennessee, used with permission.

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RYAN K. ZINKE, Secretary

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U.S. Geological Survey, Reston, Virginia: 2017

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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)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile ($[ft^3/s]/mi^2$)	0.01093	cubic meter per second per square kilometer ($[m^3/s]/km^2$)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)

Datum

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

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

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

Abbreviations

TDEC Tennessee Department of Environment and Conservation

USGS U.S. Geological Survey

Groundwater/Surface-Water Interaction in Central Sevier County, Tennessee, October 2015–2016

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Abstract

The U.S. Geological Survey evaluated the interaction of groundwater and surface water in the central part of Sevier County, Tennessee, from October 2015 through October 2016. Stream base flow was surveyed in December 2015 and in July and October 2016 to evaluate losing and gaining stream reaches along three streams in the area. During a July 2016 synoptic survey, groundwater levels were measured in wells screened in the Cambrian-Ordovician aquifer to define the potentiometric surface in the area. The middle and lower reaches of the Little Pigeon River and the middle reaches of Middle Creek and the West Prong Little Pigeon River were gaining streams at base-flow conditions. The lower segments of the West Prong Little Pigeon River and Middle Creek were losing reaches under base-flow conditions, with substantial flow losses in the West Prong Little Pigeon River and complete subsurface diversion of flow in Middle Creek through a series of sinkholes that developed in the streambed and adjacent flood plain beginning in 2010. The potentiometric surface of the Cambrian-Ordovician aquifer showed depressed water levels in the area where loss of flow occurred in the lower reaches of West Prong Little Pigeon River and Middle Creek. Continuous dewatering activities at a rock quarry located in this area appear to have lowered groundwater levels by as much as 180 feet, which likely is the cause of flow losses observed in the two streams, and a contributing factor to the development of sinkholes at Middle Creek near Collier Drive.

Introduction

Sevier County in East Tennessee lies along the transition from the metamorphic rocks of the Blue Ridge Physiographic Province (Fenneman, 1938) to the carbonates and shale formations of the Ridge and Valley Physiographic Province (Fenneman, 1938). The variable aquifer characteristics and groundwater and surface-water interactions along this transition zone can affect the water resources and water availability to support public water supplies, domestic wells, and ecological flows. In locations where the geologic units of the Ridge and Valley are limestone or dolomite, the transition zone can be prone to sinkhole development, especially in areas where the hydrology has been altered by land-use changes, construction, or dewatering. In 2010, a series of sinkholes began forming in the channel of Middle Creek beneath and upstream from the bridge constructed in 2007 across Middle Creek on Collier Drive in Sevierville, Sevier County, Tennessee. A dye-trace investigation was conducted in 2014 by GEOServices, which identified a hydraulic connection between the sinkholes at Middle Creek and the discharge from dewatering activities at a rock quarry located about 0.5 mile northwest of the sinkholes (GEOS, 2014). After streambed stabilization measures failed to stop sinkhole formation, the Tennessee Department of Environment and Conservation (TDEC) contacted the U.S. Geological Survey (USGS) in June 2015 for assistance in evaluating potential hydrologic causes for the streambed instability. To this end, the USGS proposed a study in the central part of Sevier County consisting of stream base-flow surveys to evaluate groundwater/surface-water interaction and a synoptic survey of groundwater levels measured in wells screened in the Cambrian-Ordovician aquifer to define the potentiometric surface in the area. The geologic and hydrologic conditions encountered during construction of the Collier Drive Bridge and the stabilization efforts for the initial and ongoing sinkhole formation were not evaluated as part of this investigation. The reconnaissance of surface-water and groundwater hydrology was conducted in cooperation with the City of Sevierville and TDEC.

Purpose and Scope

This report presents the results of a study of the surface-water and groundwater hydrology along the transition from metamorphic rocks of the Blue Ridge province to the carbonate rocks of the Ridge and Valley province in central Sevier County, Tennessee, from October 2015 through October 2016.
Included in the report are discussions of (1) the results of stream base-flow surveys on specific reaches of the three primary drainages in the study area: the Little Pigeon River, the West Prong Little Pigeon River, and Middle Creek; (2) development

of a potentiometric-surface map for the Cambrian-Ordovician aquifer in the area between the West Prong Little Pigeon River and the Little Pigeon River; and (3) groundwater/surface-water interaction and the effect of dewatering on groundwater levels and streamflow in the study area. The study meets the science plan goals of the USGS Lower Mississippi-Gulf Water Science Center and the USGS Water Mission Area to support State water-resources programs through collecting, interpreting, and disseminating quality-assured, nonbiased hydrologic data to better understand the water resources of the Nation, evaluate groundwater and surface-water interaction, and provide information on environmental hazards, including land subsidence and sinkhole collapse (USGS, 2007).

Previous Investigations

The groundwater resources of East Tennessee were described by DeBuchananne and Richardson (1956). The groundwater hydrology along the transition from metamorphic rocks of the Blue Ridge Physiographic Province to carbonate rocks of the Ridge and Valley Physiographic Province and the presence of colluvial and alluvial gravel at the base of the metamorphic rocks and, in places, overlying the carbonate rocks, have been studied at several locations including Elkton, Virginia (King, 1950); the Shenandoah Valley (Yager and others, 2008); Elizabethton, Tennessee (Maclay, 1963); Gatlinburg, Tennessee (Zurawski, 1979); Erwin, Tennessee (Bradfield, 1994); Calhoun County, Alabama (Scott and others, 1987; Kidd, 2001); and as part of regional groundwater studies (Hollyday and Hileman, 1996; Hollyday and others, 1997; Swain and others, 2004).

The geology of East Tennessee, including the study area, was compiled and described by Rodgers (1953). Hamilton (1961) and King (1964) mapped parts of the study area at a scale of 1:24,000. Various sources of geologic information for East Tennessee were compiled and mapped at a scale of 1:250,000 by Hardeman and others (1966). Southworth and others (2012) compiled and updated the geology of the Great Smoky Mountains National Park region, including most of the study area, and provided a detailed summary of geologic studies conducted in the region. A generalized version of the geology presented by Southworth and others (2012) was adapted for use in this report.

The USGS has conducted multiple base-flow surveys to evaluate groundwater/surface-water interaction in Middle and East Tennessee as part of various water-resources investigations. Evaldi and Lewis (1983) conducted base-flow analysis of streams in the Sweetwater Valley, Tennessee area, as part of a groundwater availability study. Webster and Carmichael (1993) conducted a base-flow investigation of the principal streams in southeastern Hamilton County as part of a study of the groundwater hydrology of the Lower Wolftever Creek basin. Base-flow data were collected from within the Little West Fork basin at Fort Campbell Military Reservation, Tennessee and Kentucky (Ladd, 1993), and in the Bradley-Brumalow Creeks area near Arnold Air Force Base, Tennessee (Aycock and Haugh, 2001), as part of groundwater studies in these areas. Knight and Kingsbury (2007) conducted base-flow synoptic surveys of the Duck River watershed in Tennessee as part of a study to characterize the temporal and spatial variability of the various components that make up streamflow in the basin.

Sinkhole development related to dewatering, especially in karst settings, has been documented in various publications (Foose, 1953, 1969; Newton, 1976, 1987; LaMoreaux and Newton, 1986; Langer, 2001; Lolcama and others, 2002; Reeves and others, 2004). Langer (2001) published a literature review of the potential environmental impacts of quarrying stone in karst settings, including a number of cases where sinkholes formed near mines with large groundwater withdrawals. Limestone aggregate quarries have been associated with sinkhole development in karst terrain where blasting and groundwater extraction serve to reactivate and enhance karst development, and the potential for sinkhole formation can occur by any combination of processes that remove sediment and water from pre-existing caverns and focus surface water into the soil (Lolcama and others, 2002). Foose (1953, 1969) describes the impact of a mining operation near Harrisburg, Pennsylvania, and the development of a cone of depression in groundwater levels over a large area, affecting wells and spring flow, and causing the formation of about 100 sinkholes. The author states that sinkholes developed where the original water table was below the bedrock/soil contact as a consequence of flushing out underlying bedrock openings during groundwater lowering. LaMoreaux and Newton (1986) state that construction activities in an area of water-level decline can greatly increase the chances for the development of induced sinkholes. The development of sinkholes along transportation corridors and resulting from human activities in the eastern United States is described by Newton (1987).

Study Area

The study area is located in central Sevier County, Tennessee, which includes parts of the cities of Sevierville and Pigeon Forge (fig. 1), and lies within parts of the Ridge and Valley and Blue Ridge provinces. Sevier County ranked in the top 10 counties in Tennessee for percent population growth from 2010 to 2016 and ranked 11th in Tennessee in terms of net population growth for the same period with a population increase from 89,889 in 2010 to an estimated population of 96,673 in 2016 (Tennessee State Data Center, 2017). The population growth in Sevier County has resulted in new construction and infrastructure improvement. The study area includes the middle and lower reaches of the West Prong Little Pigeon River, the middle reaches of the Little Pigeon River, and all of Middle Creek, and the southernmost extent of the area lies just north of the Great Smoky Mountains National Park (fig. 1). A land-use feature present in the study area that can impact the water resources is a limestone aggregate rock quarry located in Sevierville between Middle Creek and the West Prong Little Pigeon River (fig. 1). Continuous dewatering is required for quarry operations with the water discharged into the West Prong Little Pigeon River upstream of the confluence with the Little Pigeon River.

Geology and Hydrogeology

Although highly complex, the bedrock geology within the study area can be divided into two general groups. In the northern part of the study area that lies within the Ridge and Valley province, the bedrock geology consists primarily of carbonate and shale units of Cambrian through Ordovician age, with some Mississippian age units, that generally strike northeast and dip southeast, although strike and dips vary where structural deformation of beds has occurred (fig. 2). In the southern part of the area, the bedrock geology consists primarily of structurally deformed metamorphic and crystalline rocks of Precambrian age within the Blue Ridge province.

Bedrock units throughout the study area have been altered and deformed by tectonic forces responsible for structural and geomorphic formation of the Blue Ridge and Ridge and Valley provinces. Prominent structural features in the study area include the Great Smoky fault (fig. 2), which marks the leading edge of a thrust block where bedrock units of Precambrian age have been pushed northwestward up and over rocks of Ordovician age (Southworth and others, 2012). In the central part of the study area, folding of rock units northwest of the Great Smoky fault by the advancing block formed a prominent northeast-trending anticlinal-synclinal complex (Fair Garden anticline, fig. 2), where older units of the Knox Group of Cambrian-Ordovician age are exposed along the axis of the anticline and are surrounded by progressively younger units in down-dip directions.

Surficial geology in the study area primarily consists of alluvium of Quaternary age in the valleys of the West Prong Little Pigeon River, Middle Creek, and the Little Pigeon River (fig. 2). Quaternary colluvial material weathered from the metamorphic rocks also is present in several of the smaller tributaries (fig. 2). The materials composing the alluvial and colluvial deposits primarily are weathered from the metamorphic rocks, with similar deposits described for the Gatlinburg area by Zurawski (1979).

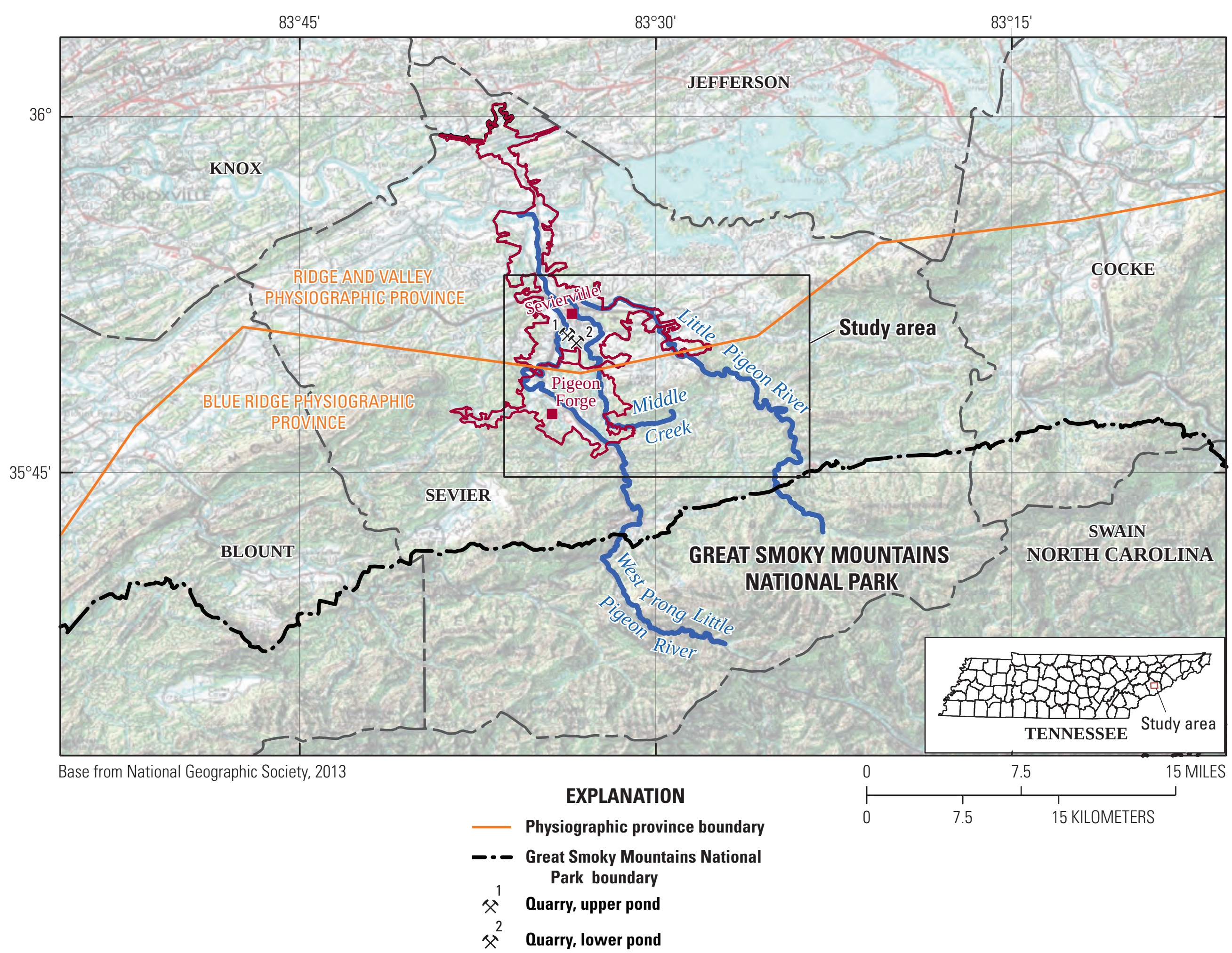


Figure 1. Location of the study area in Sevier County, Tennessee.

Bedrock units in the study area make up aquifers that can be divided into two primary groups consistent with physiography—the Cambrian through Ordovician rocks that make up the Valley and Ridge aquifers, hereafter referred to as the Cambrian-Ordovician aquifer, and Precambrian and older rocks that make up the Blue Ridge aquifers (Lloyd and Lyke, 1995). Because the primary porosity of bedrock units that make up these aquifers generally is only a few percent or less, the aquifers typically yield groundwater in small yet varying amounts depending primarily on the degree and interconnectivity of secondary porosity. Secondary porosity has been enhanced throughout the area because of the structural deformation of all rock units. Carbonate units within the Cambrian-Ordovician aquifer are karstic and presumably make up the most prolific aquifers in the study area because of the potential for these units to contain secondary openings that are dissolution-enlarged by circulating groundwater.

Aquifers in the carbonate units of the Knox Group of Cambrian-Ordovician age near Elizabethton, Tennessee, are similar to aquifers in the carbonate units near Sevierville, Tennessee. The carbonate aquifers near Elizabethton are the principal water-bearing formations in the area, and groundwater/surface-water interaction results in recharge to the aquifer during high stream stages and discharge of groundwater to the streams during low stages (Maclay, 1963). Groundwater production for industrial use near Elizabethton was about 12 million gallons per day during the 1950s, and the withdrawals were believed to be at least partially replenished by recharge from the Watauga River (Maclay, 1963).

The shale units of the Cambrian-Ordovician aquifer and the crystalline rocks of the Blue Ridge aquifers are less soluble, making them less prone to dissolution-enhanced secondary porosity. Groundwater in the metamorphic rocks in the Gatlinburg area occurs primarily in the weathered, fractured, upper part of the rocks and in gravel deposits along stream valleys (Zurawski, 1979). Therefore, wells completed in the metamorphic and crystalline rocks in the southern part of the study area typically may be expected to have lower yields than wells completed in the primarily carbonate units in the northern part of the area.

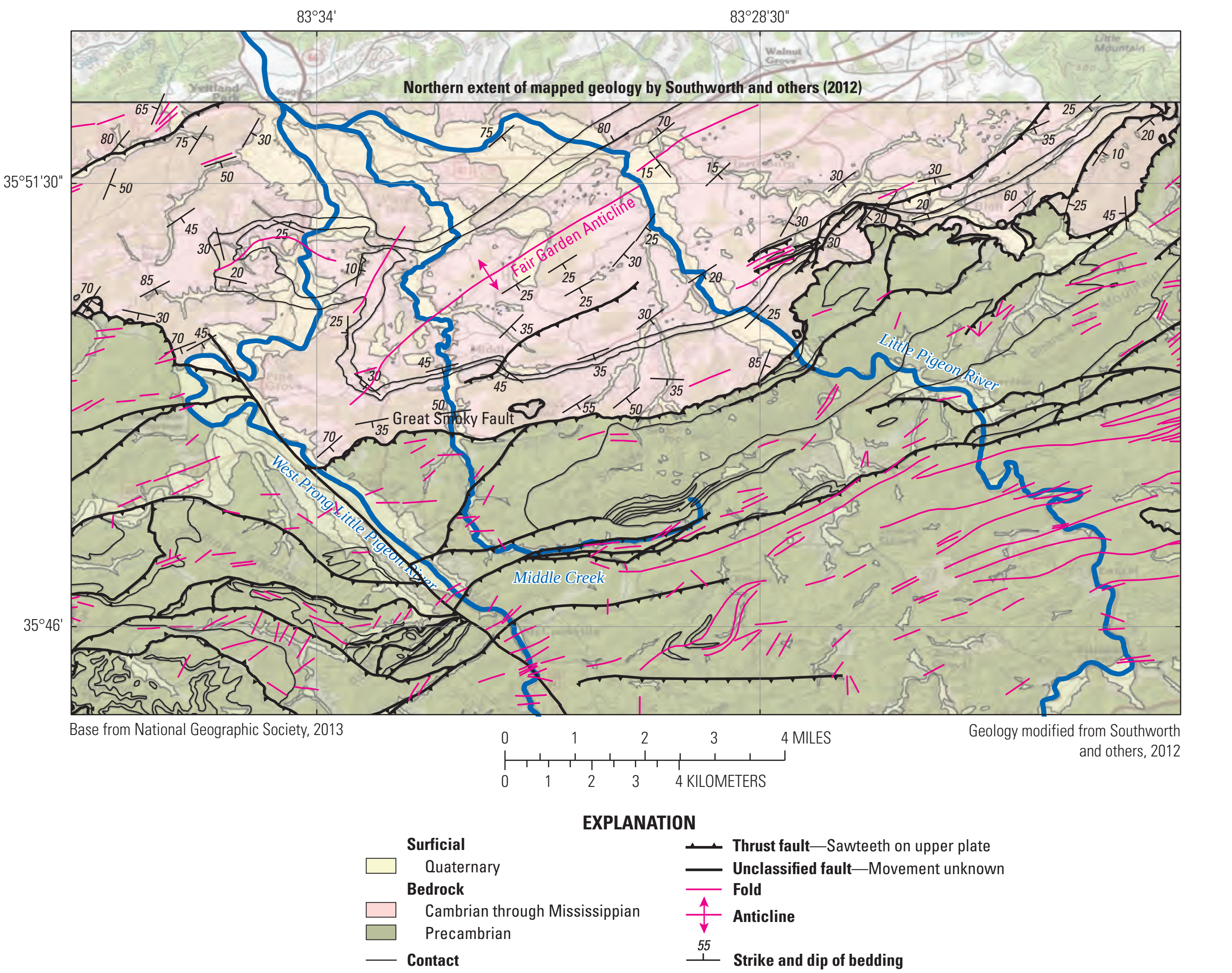


Figure 2. Generalized geology in the study area in Sevier County, Tennessee.

Methods

Streamflow measurements for the stream base-flow surveys on specific reaches of the Little Pigeon River, the West Prong Little Pigeon River, and Middle Creek were made by wading the streams and measuring discharge using handheld acoustic Doppler velocimeters (Nolan and Shields, 2000). These flow values were compared to the USGS continuous streamgage on the Little Pigeon River at Sevierville, TN (station number 03470000) located just downstream of the confluence of the West Prong Little Pigeon River and the Little Pigeon River. The streamgage was used to determine when base-flow conditions were occurring so that the streamflow mostly comprised groundwater discharge to the streams.

A reconnaissance was conducted to locate wells in the Cambrian-Ordovician aquifer where water-level data could be collected. Water-level measurements were made in 34 wells during July 19–26, 2016, coincident with the second streamflow survey. Groundwater levels and well depths were measured at domestic wells and observation wells using either electric tape or steel tape and chalk methods (Cunningham and Schalk, 2011). Information on the groundwater and surface-water sites, water-level measurements, and streamflow data included in this report are available through the USGS National Water Information System (NWIS) database (U.S. Geological Survey, 2017c).

A preliminary potentiometric-surface map of the water-level altitude data was prepared in ArcGIS (Esri, 2015) using the groundwater levels measured in July 2016 by applying a regularized spline interpolation method with a weight of 0.1 and a 12-point neighborhood to the input data, followed by contouring of the interpolated surface. Only the groundwater-level data from the well measurements were used in the interpolation process. No supplemental surface-water altitude data were used to develop the surface. The surface was then contoured and the contours were adjusted to more closely honor the well control and topography, particularly in the stream valleys. Parts of some contours then were dashed to show the inferred groundwater altitudes in areas away from well control.

Stream Base Flow

Two stream base-flow surveys were conducted during this study. A preliminary survey was conducted in December 2015, and an expanded survey was conducted in July 2016. Both surveys were completed during base-flow conditions, where the recession of flow was relatively steady to ensure minimal change of streamflow over the measurement periods (fig. 3). Continuous streamflow data collected at the USGS streamgage on the Little Pigeon River at Sevierville, TN (station number 03470000; fig. 4) (U.S. Geological Survey, 2017b) were used during the evaluation of streamflow conditions in the area prior to and during the surveys to determine base-flow conditions, and general changes in streamflow during the surveys.

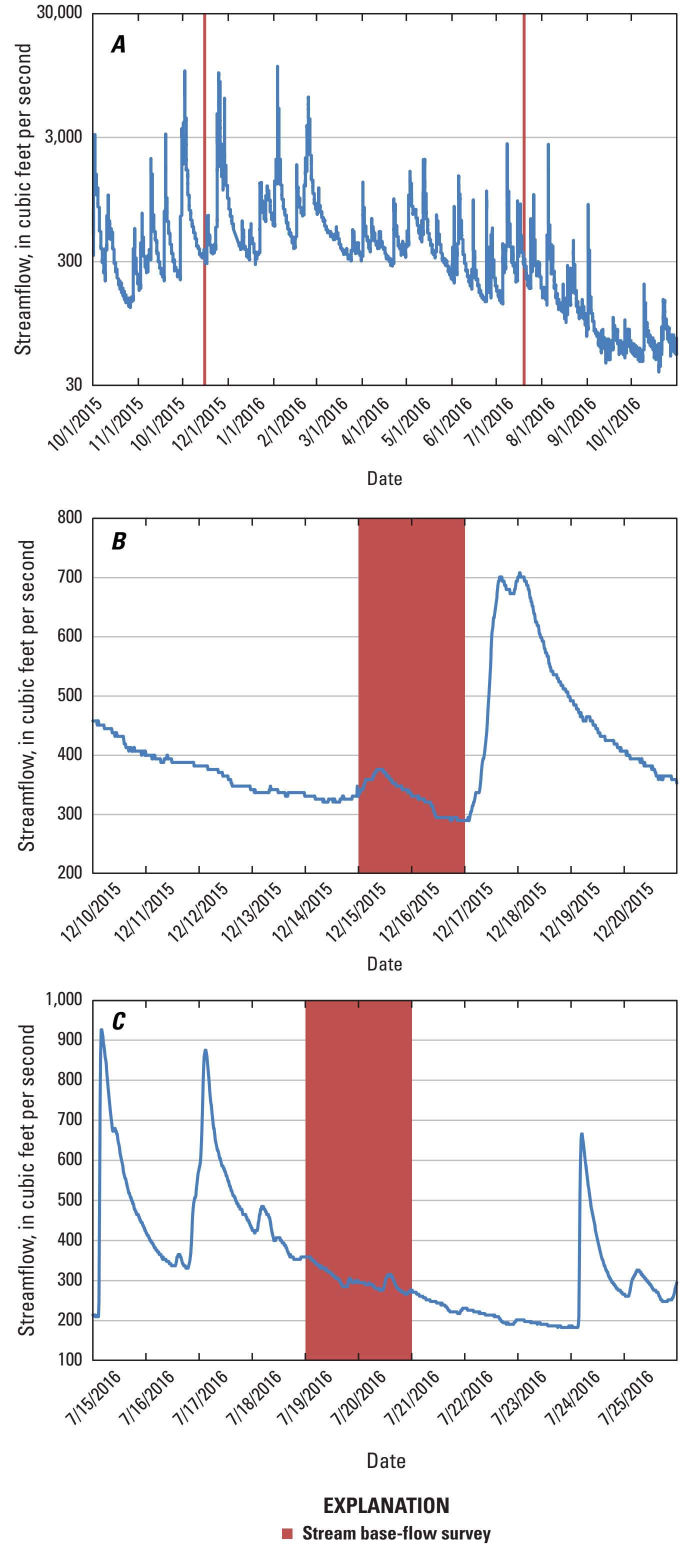


Figure 3. Hydrographs showing streamflow in the Little Pigeon River at Sevierville, TN (USGS streamgage 03470000), and periods of streamflow surveys for (*A*) October 1, 2015, through October 31, 2016; (*B*) December 10–20, 2015; and (*C*) July 15–25, 2016. [Streamflow data from U.S. Geological Survey (2017b)]

During December 15–16, 2015, streamflow measurements were made at 15 locations along the West Prong Little Pigeon River, Middle Creek, and Little Pigeon River (table 1; fig. 4). An instantaneous streamflow value recorded at the Little Pigeon River at Sevierville, TN streamgage (03470000) at 0000 (midnight) on December 16, 2015, was included in the measurement dataset as an additional control point. Flow in the measured streams generally was characteristic of base-flow conditions on the basis of streamflow data from the Little Pigeon River streamgage (fig. 3*A*, *B*). Data from the streamgage show that an increase in streamflow of about 45 cubic feet per second (ft^3/s) occurred in the first half of the day on December 15, 2015, and a decrease in streamflow of about 20 ft^3/s occurred near midday on December 16, 2015 (fig. 3*B*). Because there is no record of significant rainfall in the study area for several days prior to or during this survey and because no changes in inputs or withdrawals of this magnitude on any of the streams upstream of the gage are known (the highest flow measured in Middle Creek was well below the changes recorded at the gage), the causes of the observed changes in streamflow and whether or not corresponding changes in flow in the West Prong Little Pigeon River occurred cannot be determined.

During July 19–20, 2016, streamflow measurements were made at 30 locations along the West Prong Little Pigeon River, Middle Creek, and Little Pigeon River (table 2; fig. 5). An instantaneous streamflow value recorded at the Little Pigeon River at Sevierville, TN streamgage (03470000) at 0000 on July 20, 2016, was included in the measurement dataset as an additional control point. Flow in the measured streams generally was characteristic of base-flow conditions on the basis of streamflow data from the Little Pigeon River streamgage (fig. 3*C*). Data from the streamgage show that a decrease in streamflow of about 20 ft^3/s occurred in the second half of the day on July 19, 2016, and an increase in streamflow of about 40 ft^3/s occurred near midday on July 20, 2016 (fig. 3*C*). Because there is no record of significant rainfall in the study area for several days prior to or during this survey and because no changes in inputs or withdrawals of this magnitude on any of the streams at locations upstream of the gage are known (the highest flow measured in Middle Creek was well below the changes recorded at the gage), the causes of the observed changes in streamflow or whether or not corresponding changes in flow in the West Prong Little Pigeon River occurred cannot be determined.

The recorded streamflow at the USGS streamgage on the Little Pigeon River (03470000) was lower during the July survey (295 ft^3/s at 0000 on July 20, 2016) than the December survey (331 ft^3/s at 0000 on December 16, 2015; U.S. Geological Survey, 2017b); however, higher flow conditions were observed at the streamflow-measurement locations along the Little Pigeon River during July than December (figs. 4 and 5; tables 1 and 2). Higher flow in the Little Pigeon River in July likely resulted from local rainfall in the basin prior to the survey. The higher flow in the Little Pigeon River was offset by lower flow in the West Prong Little Pigeon River during July, which resulted in overall lower flow at the streamgage on the Little Pigeon River (fig. 5).

Streamflow data collected during the surveys were evaluated to identify losing and gaining stream reaches and to compare unit-streamflow values, in cubic feet per second per square mile, for measurement sites underlain by units that make up the Cambrian-Ordovician aquifer and the Blue Ridge aquifers. Flow generally increased in a downstream direction in the upper and middle reaches of the three streams during both surveys, with the highest unit-streamflow values generally occurring at measurement locations underlain by rock units that make up the Blue Ridge aquifers (tables 1 and 2). Flow in the Little Pigeon River was higher during the July 2016 measurements, whereas flow in the West Prong Little Pigeon River and Middle Creek was higher during the December 2015 measurements (figs. 3–5; tables 1 and 2).

Losing stream reaches were identified along the West Prong Little Pigeon River and Middle Creek in the northwestern part of the study area during both measurement surveys (figs. 4 and 5). During the December 2015 survey, flow along a downstream reach of the West Prong Little Pigeon River decreased by more than 20 ft^3/s, then increased at the next measurement location downstream of this reach (fig. 4 and table 1, sites 5, 4, and 2). During the same survey, flow in an intermediate reach of Middle Creek decreased by more than 3 ft^3/s (fig. 4 and table 1, sites 27 and 23). In July 2016, losses of approximately the same magnitude were observed along the losing reaches in both streams, with Middle Creek going dry (fig. 5 and table 2). Additional sites measured downstream of the losing reach of Middle Creek in July 2016 showed only minimal gain in flow prior to the confluence of the stream with the Little Pigeon River (fig. 5 and table 2).

Table 1. Streamflow measurements at three streams in Sevier County, Tennessee, December 15–16, 2015.

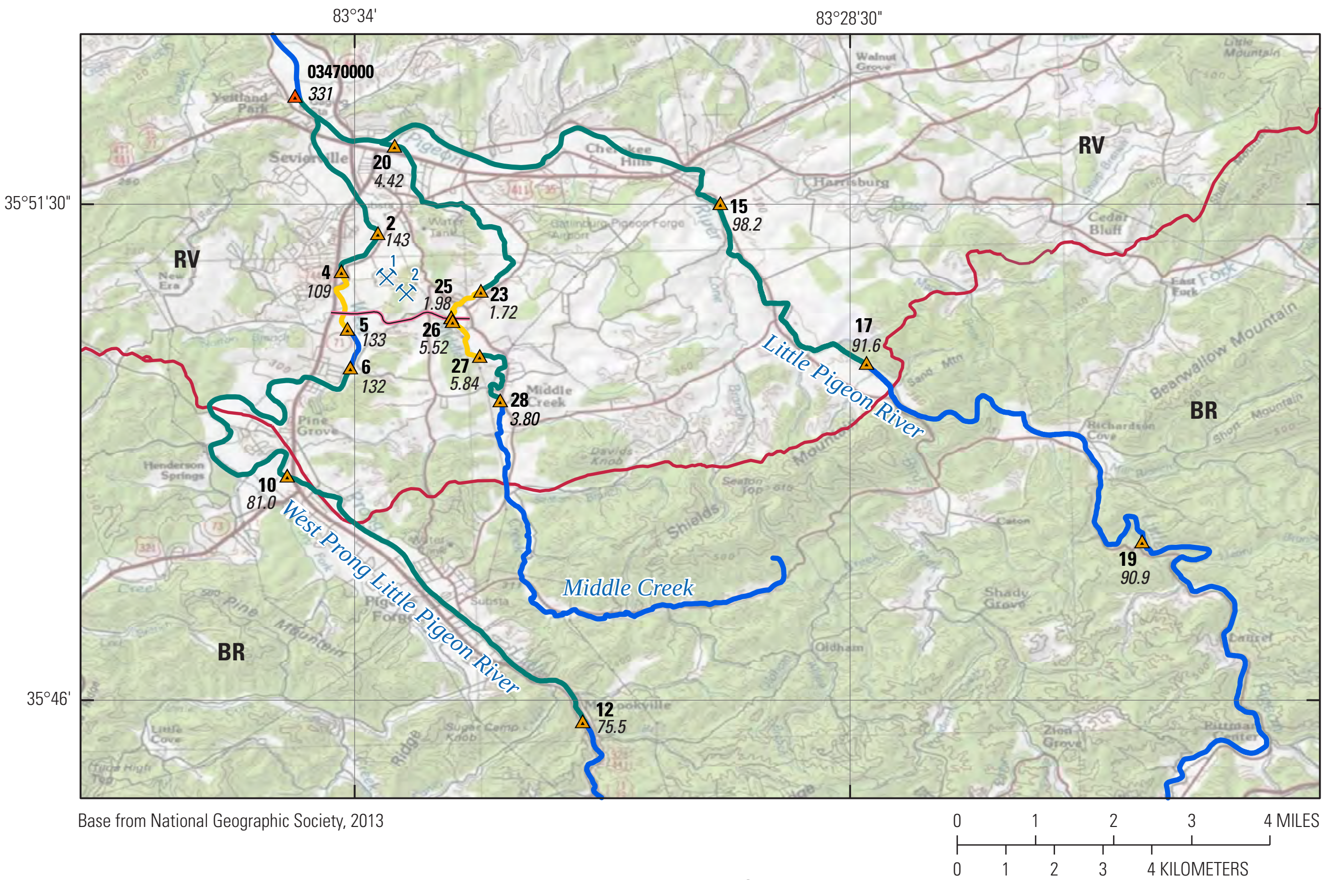
[no., number; STAID, U.S. Geological Survey station number; C-O, Cambrian-Ordovician; BR, Blue Ridge; M/D/Y, month, day, year; Q1, first set of streamflow measurements for study; ft3/s, cubic feet per second; $(ft^3/s)/mi^2$, cubic feet per second per square mile; DA, drainage area (from U.S. Geological Survey, 2017a); mi^2, square miles; Est., estimated; Dr., Drive; HWY, highway; Rt, Route; TN, Tennessee; Cr, Creek; nr, near; Blvd, boulevard]

Site no. (fig. 4)	STAID	Stream	Aquifer	Q1 date (M/D/Y)	Q1 time	Q1 (ft^3/s)	Q1, unit streamflow [$(ft^3/s)/mi^2$]	Est. river mile	Latitude	Longitude	DA (mi^2)	Description
2	03469800	West Prong Little Pigeon River	C-O	12/15/15	13:56	143	0.96	1.72	35.85305	–83.5623667	149.2	West Prong Little Pigeon River above Island at Sevierville, TN
4	03469775	West Prong Little Pigeon River	C-O	12/15/15	13:41	109	0.73	2.35	35.84597	–83.5691100	148.4	West Prong Little Pigeon River Below Park Road Bridge at Sevierville, TN
5	03469750	West Prong Little Pigeon River	C-O	12/15/15	10:41	133	0.91	3.26	35.83532	–83.5679900	145.9	West Prong Little Pigeon River at Collier Drive Bridge at Pigeon Forge, TN
6	03469700	West Prong Little Pigeon River	C-O	12/15/15	11:04	132	0.91	3.78	35.82821	–83.5674500	144.8	West Prong Little Pigeon River at Canton Road at Pigeon Forge, TN
10	03469550	West Prong Little Pigeon River	BR/C-O	12/15/15	15:54	81.0	1.05	8.61	35.8082	–83.5791000	76.8	West Prong Little Pigeon River below HWY 441 Bridge at Pigeon Forge, TN
12	03469430	West Prong Little Pigeon River	BR	12/15/15	16:17	75.5	1.08	13.20	35.7628	–83.5245000	70.0	West Prong Little Pigeon River above Pigeon Forge, TN
15	03469128	Little Pigeon River	C-O	12/16/15	14:28	98.2	0.90	10.00	35.85858	–83.4990000	108.7	Little Pigeon River above Old Newport Hwy Bridge at Sevierville, TN
17	03469124	Little Pigeon River	C-O	12/16/15	12:40	91.6	0.90	13.09	35.82903	–83.4720090	101.3	Little Pigeon River above Clark Branch, near Caton, TN
19	03469123	Little Pigeon River	BR	12/16/15	9:04	90.9	1.18	18.65	35.79604	–83.4210410	77.3	Little Pigeon River below Grant Road Bridge near Caton, TN

Table 1. Streamflow measurements at three streams in Sevier County, Tennessee, December 15–16, 2015.—Continued

[no., number; STAID, U.S. Geological Survey station number; C-O, Cambrian-Ordovician; BR, Blue Ridge; M/D/Y, month, day, year; Q1, first set of streamflow measurements for study; ft3/s, cubic feet per second; $(ft^3/s)/mi^2$, cubic feet per second per square mile; DA, drainage area (from U.S. Geological Survey, 2017a); mi^2, square miles; Est., estimated; Dr., Drive; HWY, highway; Rt, Route; TN, Tennessee; Cr, Creek; nr, near; Blvd, boulevard]

Site no. (fig. 4)	STAID	Stream	Aquifer	Q1 date (M/D/Y)	Q1 time	Q1 (ft^3/s)	Q1, unit streamflow [$(ft^3/s)/mi^2$]	Est. river mile	Latitude	Longitude	DA (mi^2)	Description
20	03469198	Middle Creek	C-O	12/16/15	19:38	4.42	0.29	0.16	35.86919	–83.5593000	15.2	Middle Creek at River Place Bridge at Sevierville, TN
23	03469194	Middle Creek	C-O	12/16/15	14:27	1.72	0.15	3.01	35.84238	–83.5433283	11.5	Middle Creek at Rt 449 near Middle Creek Road at Pigeon Forge, TN
25	03469192	Middle Creek	C-O	12/16/15	11:19	1.98	0.18	3.55	35.83747	–83.5488117	11.1	Middle Creek Below Collier Dr Bridge at Pigeon Forge, TN
26	03469190	Middle Creek	C-O	12/16/15	10:26	5.52	0.50	3.60	35.83678	–83.5485433	11.0	Middle Creek above Collier Dr Bridge at Pigeon Forge, TN
27	03469189	Middle Creek	C-O	12/16/15	8:30	5.84	0.56	4.23	35.83035	–83.5435100	10.34	Middle Creek at Rt 449 at Pigeon Forge, TN
28	03469187	Middle Creek	C-O	12/16/15	9:25	3.80	0.42	5.31	35.82213	–83.5397350	8.99	Middle Creek at Middle Cr. United Methodist Church at Pigeon Forge, TN



EXPLANATION

- 12 / 75.5 — Streamflow measurement site, number, and streamflow value, in cubic feet per second (see table 1)
- 03470000 / 331 — Streamflow gage at Little Pigeon River, station number, and streamflow value, in cubic feet per second
- 1 — Quarry, upper pond
- 2 — Quarry, lower pond
- Collier Drive
- Gaining reach: Increase in measured streamflow between sites is greater than 5 percent
- Losing reach: Decrease in measured streamflow between sites is greater than 5 percent
- Increase or decrease in measured streamflow between sites is less than 5 percent
- Trace of Great Smoky fault separating the Blue Ridge (BR) and Ridge and Valley (RV) Physiographic Provinces

Figure 4. Streamflow measurement locations and streamflow values, Sevier County, Tennessee, December 15–16, 2015. [See table 1 for site information.]

Table 2. Streamflow measurements at three streams in Sevier County, Tennessee, July and October 2016.

[no., number; STAID, U.S. Geological Survey station number; C-O, Cambrian-Ordovician; BR, Blue Ridge; M/D/Y, month, day, year; Q2, second set of flow measurements for study; ft³/s, cubic feet per second; (ft³/s)/mi², cubic feet per second per square mile; DA, drainage area (U.S. Geological Survey, 2017a); mi², square miles; Est., estimated; Dr, Drive; HWY, highway; Rt, Route; TN, Tennessee; nr, near; Blvd, boulevard; –, no data]

Site no. (fig. 5)	STAID	Stream	Aquifer	Q2 date (M/D/Y)	Q2 time	Q2 (ft³/s)	Q2, unit streamflow [(ft³/s)/mi²]	Est. river mile	Latitude	Longitude	DA (mi²)	Description
1	03469900	West Prong Little Pigeon River	C-O	7/20/16	9:36	66.5	0.44	0.20	35.871060	–83.574300	150.7	West Prong Little Pigeon River at 411 Bridge, TN
2	03469800	West Prong Little Pigeon River	C-O	7/20/16	11:48	71.6	0.48	1.72	35.853050	–83.562367	149.2	West Prong Little Pigeon River above Island at Sevierville, TN
3	03469778	West Prong Little Pigeon River	C-O	7/20/16	16:00	43.7	0.29	1.95	35.849050	–83.564700	148.6	West Prong Little Pigeon River near entrance to Vulcan Quarry at Sevierville, TN
4	03469775	West Prong Little Pigeon River	C-O	7/20/16	14:21	38.6	0.26	2.35	35.845970	–83.569110	148.4	West Prong Little Pigeon River Below Park Road Bridge at Sevierville, TN
5	03469750	West Prong Little Pigeon River	C-O	7/20/16	14:13	58.9	0.40	3.26	35.835320	–83.567990	145.9	West Prong Little Pigeon at Collier Drive Bridge at Pigeon Forge, TN
6	03469700	West Prong Little Pigeon River	C-O	7/20/16	9:22	60.0	0.41	3.78	35.828213	–83.567450	144.8	West Prong Little Pigeon at Caton Road at Pigeon Forge, TN
7	034696800	West Prong Little Pigeon River	C-O	7/20/16	11:03	59.4	0.41	4.70	35.825776	–83.578529	143.5	West Prong Little Pigeon River off of Apple Valley Road, Sevierville, TN
8	03469660	West Prong Little Pigeon River	C-O	7/20/16	12:28	57.8	0.40	5.28	35.820340	–83.579640	143.1	West Prong Little Pigeon River at Music Road, Pigeon Forge, TN
9	03469640	West Prong Little Pigeon River	BR	7/20/16	12:15	60.8	0.43	7.20	35.812850	–83.5933861	141.4	West Prong Little Pigeon River off Battle Hill Road Ab Big Island, Pigeon Forge, TN
10	03469550	West Prong Little Pigeon River	BR/ C-O	7/20/16	7:18	45.6	0.59	8.61	35.808200	–83.579100	76.8	West Prong Little Pigeon River below HWY 441 Bridge at Pigeon Forge, TN

Table 2. Streamflow measurements at three streams in Sevier County, Tennessee, July and October 2016.—Continued

[no., number; STAID, U.S. Geological Survey station number; C-O, Cambrian-Ordovician; BR, Blue Ridge; M/D/Y, month, day, year; Q2, second set of flow measurements for study; ft^3/s, cubic feet per second; $(ft^3/s)/mi^2$, cubic feet per second per square mile; DA, drainage area (U.S. Geological Survey, 2017a); mi^2, square miles; Est., estimated; Dr, Drive; HWY, highway; Rt, Route; TN, Tennessee; nr, near; Blvd, boulevard; –, no data]

Site no. (fig. 5)	STAID	Stream	Aquifer	Q2 date (M/D/Y)	Q2 time	Q2 (ft^3/s)	Q2, unit streamflow [$(ft^3/s)/mi^2$]	Est. river mile	Latitude	Longitude	DA (mi^2)	Description
11	03469469	West Prong Little Pigeon River	BR	7/20/16	10:46	57.0	0.75	10.0	35.796388	–83.561389	75.9	West Prong Little Pigeon River at Jake Thomas Blvd Bridge, Pigeon Forge, TN
12	03469430	West Prong Little Pigeon River	BR	7/20/16	9:40	58.3	0.83	13.2	35.762800	–83.524500	70.0	West Prong Little Pigeon River above Pigeon Forge, TN
13	03469177	Little Pigeon River	C-O	7/19/16	10:10	211	1.14	6.57	35.867638	–83.545975	184.4	Little Pigeon River at Robert Henderson Rd Bridge at intersection with River Road, Sevierville, TN
14	03469173	Little Pigeon River	C-O	7/19/16	14:00	222	1.23	7.95	35.871944	–83.526389	181.0	Little Pigeon off Robert Henderson Rd upstream of Witt Hollow Road, Sevierville, TN
15	03469128	Little Pigeon River	C-O	7/19/16	15:48	183	1.68	10.0	35.858580	–83.499000	108.7	Little Pigeon River above Old Newport Hwy Bridge at Sevierville, TN
16	03469125	Little Pigeon River	C-O	7/19/16	9:00	187	1.81	11.6	35.840110	–83.488710	103.1	Little Pigeon Pittman Center road bridge nr Red Bank Road, Sevierville, TN
17	03469124	Little Pigeon River	C-O	7/19/16	13:30	193	1.90	13.1	35.829026	–83.472009	101.3	Little Pigeon River above Clark Branch nr Caton, TN
18	034691234	Little Pigeon River	BR	7/19/16	16:30	183	2.25	15.9	35.8157638	–83.4379861	81.2	Little Pigeon nr Richardson Cove Road Bridge and Maples Branch Road, Sevierville, TN
19	03469123	Little Pigeon River	BR	7/19/16	10:00	175	2.26	18.7	35.796040	–83.421041	77.3	Little Pigeon River below Grant Road Bridge, near Caton, TN

Table 2. Streamflow measurements at three streams in Sevier County, Tennessee, July and October 2016.—Continued

[no., number; STAID, U.S. Geological Survey station number; C-O, Cambrian-Ordovician; BR, Blue Ridge; M/D/Y, month, day, year; Q2, second set of flow measurements for study; ft^3/s, cubic feet per second; $(ft^3/s)/mi^2$, cubic feet per second per square mile; DA, drainage area (U.S. Geological Survey, 2017a); mi^2, square miles; Est., estimated; Dr, Drive; HWY, highway; Rt, Route; TN, Tennessee; nr, near; Blvd, boulevard; –, no data]

Site no. (fig. 5)	STAID	Stream	Aquifer	Q2 date (M/D/Y)	Q2 time	Q2 (ft^3/s)	Q2, unit streamflow [$(ft^3/s)/mi^2$]	Est. river mile	Latitude	Longitude	DA (mi^2)	Description
20	03469198	Middle Creek	C-O	7/19/16	13:56	0.25	0.02	0.16	35.869190	–83.559300	15.2	Middle Creek at River Place Bridge at Sevierville, TN
21	034691946	Middle Creek	C-O	7/19/16	16:42	0.22	0.02	1.56	35.857380	–83.545240	14.3	Middle Creek below Veterans Blvd.
22	034691942	Middle Creek	C-O	7/19/16	13:26	0.28	0.02	2.05	35.853090	–83.539640	14.0	Middle Creek at Blanton Dr Bridge
23	03469194	Middle Creek	C-O	7/19/16	12:50	0.01	0.00	3.01	35.842383	–83.5433283	11.5	Middle Creek at Rt 449 near Middle Creek Road at Pigeon Forge, TN
24	03469193	Middle Creek	C-O	7/19/16	8:45	0	0.00	3.18	35.840846	–83.5461080	11.2	Middle Creek below East Ridge Road, Sevierville, TN
25	03469192	Middle Creek	C-O	7/19/16	7:45	0	0.00	3.55	35.837467	–83.5488116	11.1	Middle Creek below Collier Dr Bridge at Pigeon Forge, TN
26	03469190	Middle Creek	C-O	7/19/16	11:41	2.27	0.21	3.60	35.836783	–83.5485433	11.0	Middle Creek above Collier Dr Bridge at Pigeon Forge, TN
27	03469189	Middle Creek	C-O	7/19/16	10:16	2.41	0.23	4.23	35.830350	–83.543510	10.4	Middle Creek at Rt 449 at Pigeon Forge, TN
28	03469187	Middle Creek	C-O	7/19/16	9:18	1.82	0.20	5.31	35.822130	–83.539735	8.99	Middle Creek at Middle Creek United Methodist Church at Pigeon Forge, TN
29	03469185	Middle Creek	BR	7/19/16	9:57	1.08	0.19	6.65	35.804470	–83.538560	5.45	Middle Creek on Middle Creek Rd nr McCarter Hollow
30	03469182	Middle Creek	BR	7/19/16	11:33	0.56	0.17	8.68	35.782770	–83.527800	3.24	Middle Creek at Millers Way Bridge
G	03469758	West Prong Little Pigeon River	C-O	10/19/16	–	20.4	0.14	–	35.83934	–83.5684	145.9	25 feet upstream from observed whirlpool at Sevierville, TN
F	03469759	West Prong Little Pigeon River	C-O	10/19/16	–	12.6	0.09	–	35.83959	–83.5685	145.91	downstream from observed whirlpool above Norton Branch at Sevierville, TN

Table 2. Streamflow measurements at three streams in Sevier County, Tennessee, July and October 2016.—Continued

[no., number; STAID, U.S. Geological Survey station number; C-O, Cambrian-Ordovician; BR, Blue Ridge; M/D/Y, month, day, year; Q2, second set of flow measurements for study; ft^3/s, cubic feet per second; $(ft^3/s)/mi^2$, cubic feet per second per square mile; DA, drainage area (U.S. Geological Survey, 2017a); mi^2, square miles; Est., estimated; Dr, Drive; HWY, highway; Rt, Route; TN, Tennessee; nr, near; Blvd, boulevard; –, no data]

Site no. (fig. 5)	STAID	Stream	Aquifer	Q2 date (M/D/Y)	Q2 time	Q2 (ft^3/s)	Q2, unit streamflow [$(ft^3/s)/mi^2$]	Est. river mile	Latitude	Longitude	DA (mi^2)	Description
H	03469757	West Prong Little Pigeon River	C-O	10/20/16	–	20.1	0.14	–	35.83928	–83.5684	145.9	50 feet upstream from observed whirlpool at Sevierville, TN
E	03469760	West Prong Little Pigeon River	C-O	10/20/16	–	12.8	0.09	–	35.83967	–83.5686	148.04	downstream from observed whirlpool below Norton Branch at Sevierville, TN
J	03469756	West Prong Little Pigeon River	C-O	10/20/16	–	21.8	0.15	–	35.83919	– 83.5684	145.89	100 feet upstream from observed whirlpool at Sevierville, TN

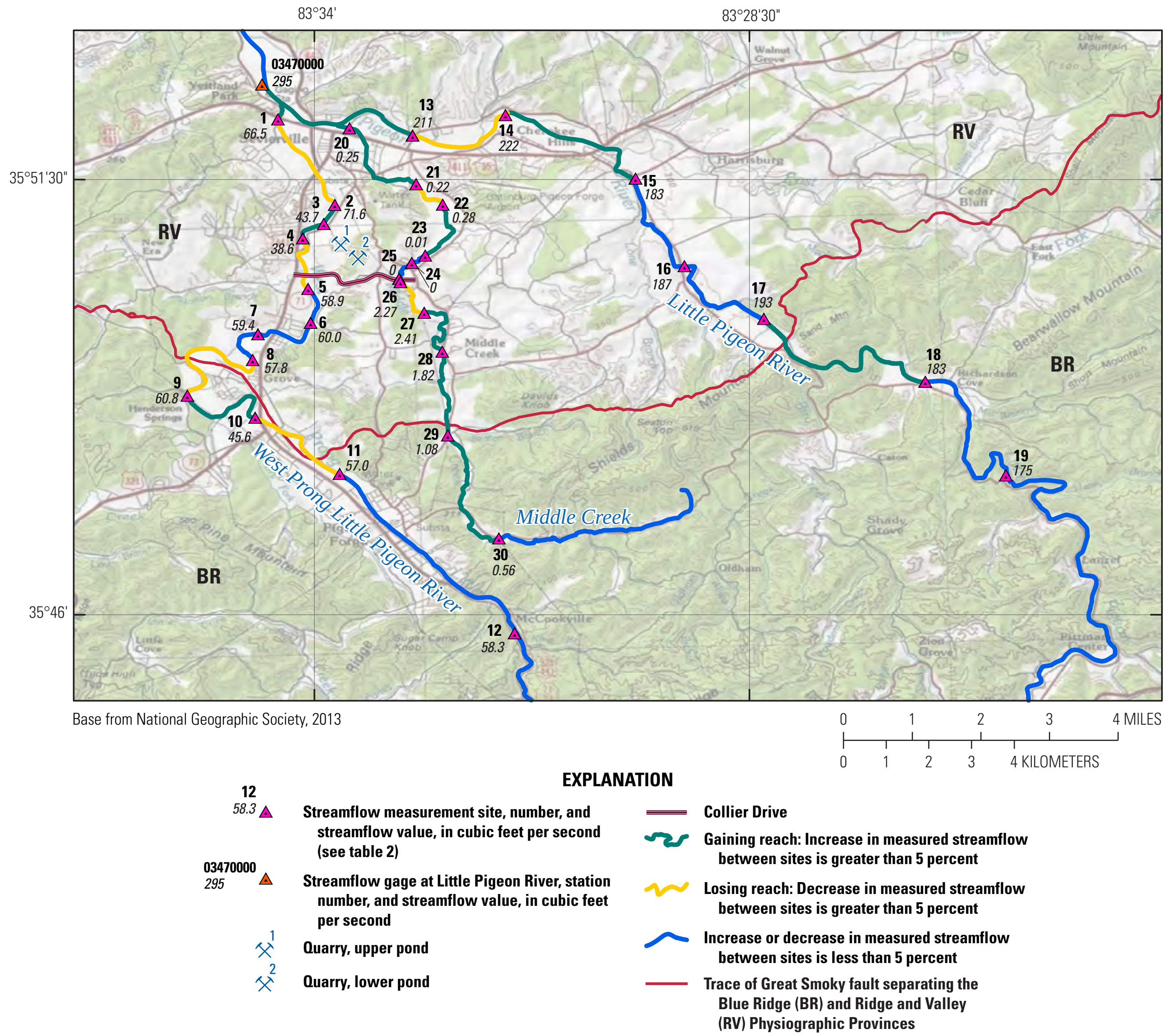


Figure 5. Streamflow measurement locations and streamflow values, Sevier County, Tennessee, July 19–20, 2016. [See table 2 for site information.]

A rock quarry is located between the West Prong Little Pigeon River and Middle Creek adjacent to the losing reaches of these streams (figs. 4 and 5). Ponds that have formed in excavation pits are continuously dewatered by pumping for quarrying operations, and the pumped water is released back to the West Prong Little Pigeon River near the northwestern property boundary, just upstream of measurement Site 2 (figs. 4 and 5). Water-surface altitudes in the southeastern-most (lower) pond are maintained at about 750 feet (ft; altitude on September 8, 2016, was 754 ft; John Thomas, Vulcan Materials Company, written commun., January 25, 2017). Based on stream water-surface altitudes estimated from the Pigeon Forge, TN 1:24,000 topographic map (Tennessee Valley Authority, 1956) of approximately 900–910 ft and 940–950 ft above the National Geodetic Vertical Datum of 1929 (NGVD 29) in the losing reaches of the West Prong Little Pigeon River and Middle Creek, respectively, about 150–200 ft of downward vertical head difference occurs between the streams and the lower quarry pond. Such large gradients likely are the cause of the streamflow losses observed during the measurement surveys along the West Prong Little Pigeon River and Middle Creek. The company operating the quarry reportedly has indicated that the water pumped from the excavation pits consists of lost flow from the West Prong Little Pigeon River (Ronnie Bowers, Tennessee Department of Environment and Conservation, oral commun., 2015).

In October 2016, a small whirlpool was identified and reported to the City of Sevierville in the West Prong Little Pigeon River downstream of the Collier Drive Bridge and about mid-way between streamflow measurement locations 4 and 5 (fig. 6). A series of discharge measurements made at one location immediately upstream and another immediately downstream of the feature on October 19 and 20, 2016, indicated that flow was about 20.4 ft^3/s upstream and 12.6 ft^3/s downstream on October 19 (fig. 6, locations G and F), and about 20.1 ft^3/s upstream and 12.8 ft^3/s downstream on October 20, 2016 (fig. 6, locations H and E). A second upstream discharge measurement was made a few hundred feet upstream of the whirlpool feature on October 20, just upstream of the location of a second smaller apparent whirlpool where loss of flow in the river also was indicated (fig. 6, location J). Discharge at this location was 21.8 ft^3/s, indicating an additional loss of flow of about 1.7 ft^3/s between this location and the measurement location just upstream of the main whirlpool feature.

As part of the survey on October 20, a reconnaissance was conducted along an approximate 1,200-ft-long reach of the West Prong Little Pigeon River downstream of the main whirlpool. Other locations in the streambed and bank were identified along this reach that also appeared to be potential flow-loss sites. Farther downstream, an estimated 300-ft-long reach located upstream of a low-head dam and just upstream of measurement location 4 (fig. 6) was found to be dry, indicating that the river lost about 13 ft^3/s between the main whirlpool and the point where the stream went dry and a total of about 22 ft^3/s along the entire surveyed reach. It should be noted that moderate to severe drought conditions experienced in the study area for several weeks prior to identification of the whirlpool resulted in abnormally low stage and discharge in the West Prong Little Pigeon River and so the whirlpool(s) probably would not have been visible under higher flow conditions.

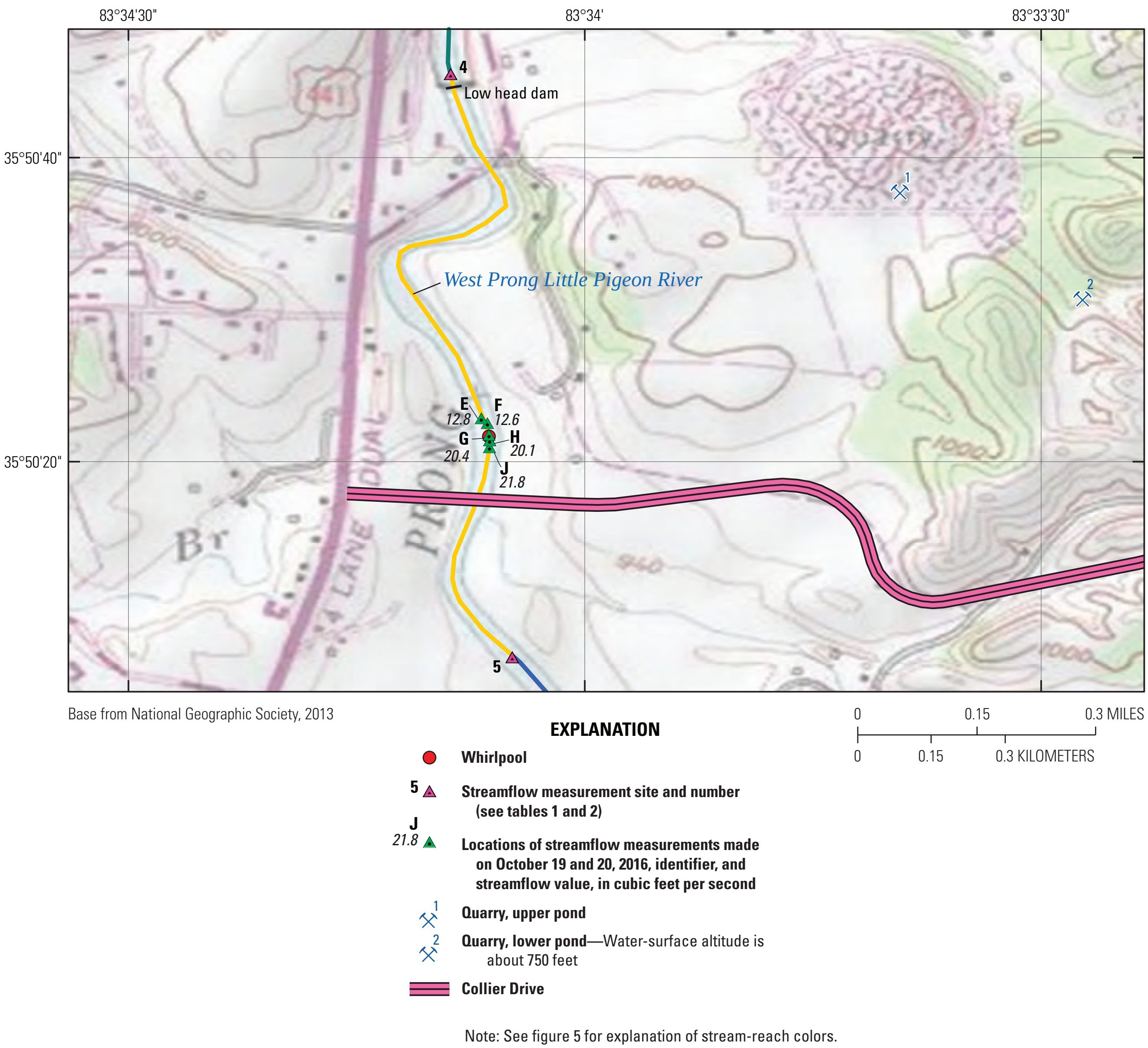


Figure 6. Streamflow measurement locations on the West Prong Little Pigeon River near two whirlpools and the measured streamflow values, Sevier County, Tennessee, October 19–20, 2016.

Potentiometric-Surface Map

A reconnaissance was conducted during the spring and early summer of 2016 to locate wells where water-level depth measurements could be made. A total of 41 wells were identified, of which 34 were measurable during the synoptic survey of groundwater levels conducted during July 19–26, 2016, coincident with the second streamflow survey. The water-level data were used to prepare a map of the potentiometric surface of the Cambrian-Ordovician aquifer for use in comparison with the locations of losing and gaining reaches of the three surveyed streams.

Water levels ranged from a high of about 1,072 ft above NGVD 29 in the southwestern part of the study area to a low of about 897 ft in the northwestern part of the study area (fig. 7; table 3). In the eastern, south-central, and southwestern parts of the area, the potentiometric surface generally mimics land surface with higher groundwater altitudes beneath the ridges and lower groundwater altitudes in the valleys of the Little Pigeon River, Middle Creek, and West Prong Little Pigeon River, indicating groundwater gradients towards these streams. General increases in streamflow in downstream directions that were observed during the December and July streamflow surveys also indicate that groundwater contributes flow to the stream reaches in these areas (fig. 7).

In the northwestern part of the study area, the potentiometric surface is depressed beneath parts of the West Prong Little Pigeon River and Middle Creek surface-water basins. The deepest part of the depression, where water-level altitudes are less than 900 ft above NGVD 29, is centered in the area just east of the West Prong Little Pigeon River, west of Middle Creek, and north of Collier Drive (fig. 7). The western and northern flanks of the depression are not strictly defined because no wells were measured west of the West Prong Little Pigeon River. However, the inferred locations and orientations of the 900- and 925-ft contours shown on the potentiometric map that lie to the southeast of the West Prong Little Pigeon River in the area of depressed water levels and an estimated base-flow water-surface altitude of about 900 ft above NGVD 29 in the stream along this reach support the finding of an approximate 30-percent reduction (loss) in flow along the reach from the July 2016 streamflow data. In the southeastern part of the depression area, the potentiometric map indicates that water levels rise gradually to the east-southeast toward the reach of Middle Creek where sinkholes have developed in the streambed and alluvial plain at and upstream of the bridge crossing the creek along Collier Drive (fig. 7).

Water levels at well numbers 35 and 40 define the 900-ft altitude contour that denotes the deepest part of the potentiometric depression (fig. 7). The altitudes of the bottom depths of both of these wells are higher than the approximate 750-ft water-surface altitude in the lower pond at the quarry. The land-surface altitude of well 35 is 991 ft, and its depth is 230 ft (bottom at an altitude of 761 ft). The land-surface altitude of well 40 is 947 ft, and its depth is 125 ft (bottom at an altitude of 822 ft). Based on the southeastern trend of the long axis of the interpreted depression, it appears that these wells may lie normal to a major trend in bedrock permeability in the area. This inferred bedrock permeability anisotropy in the depression area is supported by water-level altitudes in the two wells that are considerably higher than the altitude of the water surface in the lower quarry pond, although the water-level altitude in well 35 may in part be maintained by the West Prong Little Pigeon River. The permeability anisotropy also is inferred by the presence of a several-foot-wide, linear joint-like feature observed in the top of bedrock exposed in a large sinkhole that developed in the channel of Middle Creek in August 2011. The linear feature reportedly had a general northwest-southeast orientation and was large enough to convey all flow lost from Middle Creek in an apparent northwesterly direction (Ronnie Bowers, Tennessee Department of Environment and Conservation, oral commun., 2011).

Groundwater and Surface-Water Interaction

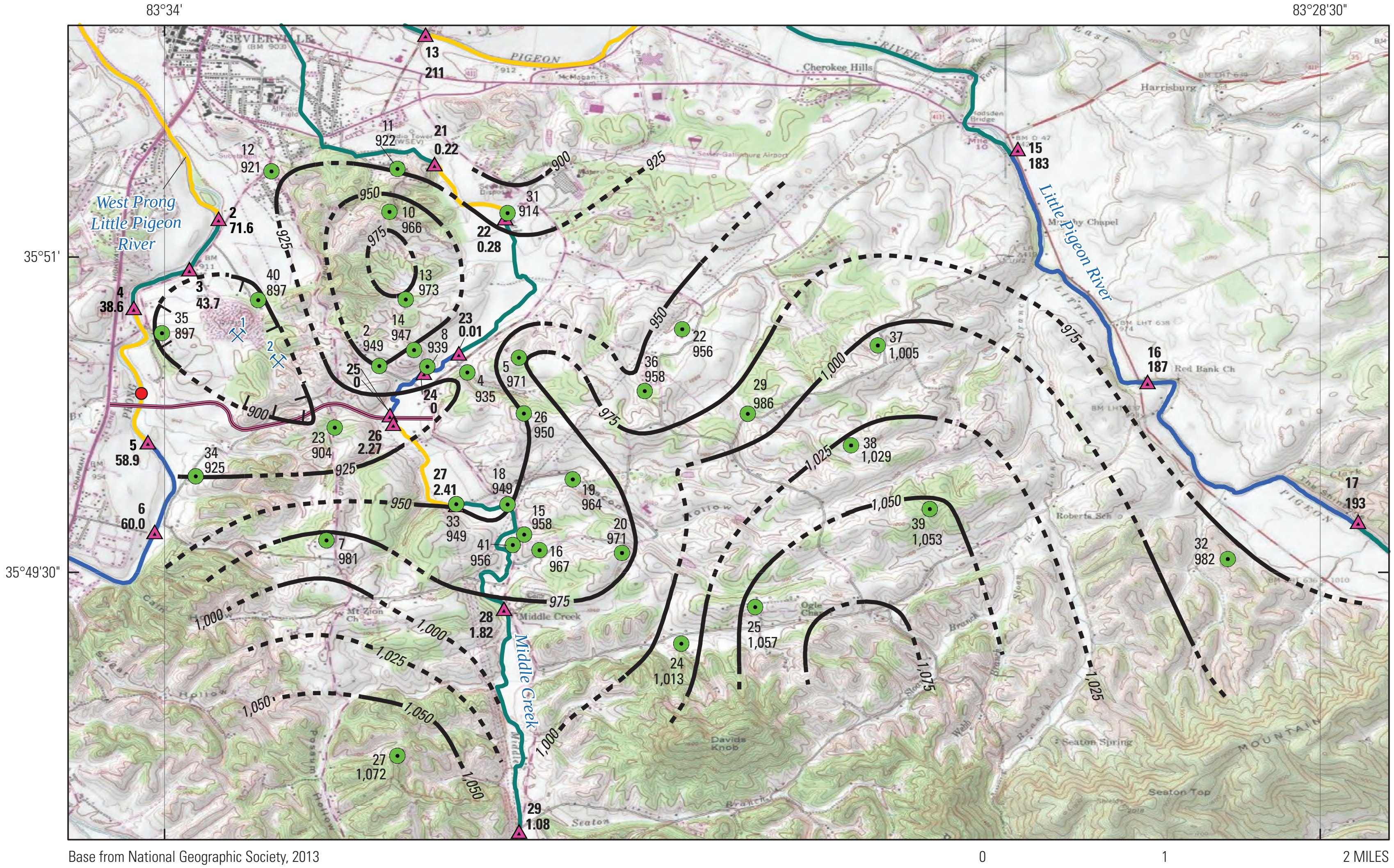
The groundwater and surface water of the Sevierville study area are controlled by the underlying geology and are affected locally by dewatering for the quarry operation. In a natural, undisturbed setting, the potentiometric surface of an aquifer is a subdued replica of land surface with groundwater flow from upland areas to springs and streams, and the aquifer contributes groundwater discharge to maintain the surface-water base flow (Winter and others, 1999). Streamflow measurements made during the December 2015 high base-flow period generally indicate this same pattern with generally increasing streamflow in a downstream direction along West Prong Little Pigeon River, Middle Creek, and Little Pigeon River. However, variations in streamflow relative to the underlying geology and the transition from the Blue Ridge to Ridge and Valley provinces were noted during the streamflow surveys.

During the December 2015 and July 2016 surveys, the Little Pigeon River and West Prong Little Pigeon River had increases in flow from the Blue Ridge to the Ridge and Valley provinces, with a large increase in flow (81 to 132 ft^3/s) in the West Prong Little Pigeon River across and downstream from a section of the Great Smoky fault zone (fig. 2) in December 2015 (fig. 4 and table 1, sites 10 and 6). During the December survey, flow in the Little Pigeon River increased from 91.6 to 98.2 ft^3/s between two sites located on the Ridge and Valley carbonate rocks (fig. 4 and table 1, sites 17 and 15). During the July survey, flow increased along the Little Pigeon River in the Blue Ridge setting and then decreased from 193 to 183 ft^3/s in the Ridge and Valley carbonate rocks (fig. 5 and table 2, sites 17 and 15). Flow along the West Prong Little Pigeon River was variable during the July survey with small changes measured within the fault zone, and an increase in flow from 45.6 to about 60 ft^3/s measured downstream of the fault zone (fig. 5, sites 10 and 5–9).

Table 3. Wells and water-level measurements in Sevier County, Tennessee, July 19–26, 2016.

[no., number; M/D/Y, month, day, year; D; domestic well; #, well is not used; O, observation well; DTWBLS, depth to water below land surface; >, greater than; –, no data; Dry, no water in well; ~, approximately; water-level data for measured wells are available through the USGS National Water Information System Web interface (U.S. Geological Survey, 2017c)]

Well no. (fig. 7)	Station no.	Latitude	Longitude	Date (M/D/Y)	Well type	DTWBLS (feet)	Land surface altitude (feet)	Water-level altitude (feet)	Measured well depth (feet)	Reported well depth (feet)
2	355029083325901	35.84135	–83.5496	7/19/16	D#	22.9	972	949	>190	–
4	355027083323301	35.84084	–83.5426	7/20/16	D#	17.3	952	935	60.5	108
5	355031083321901	35.842	–83.5385	7/20/16	D	111.8	1,082	971	–	465
7	354939083331401	35.82753	–83.5538	7/19/16	D	149.3	1,130	981	–	–
8	355029083324501	35.8413	–83.5458	7/19/16	D	16.4	955	939	–	–
10	355113083325601	35.85359	–83.5488	7/20/16	D	132.6	1,099	966	198	–
11	355125083325401	35.85698	–83.5482	7/20/16	D#	49.2	971	922	76.2	–
12	355124083333001	35.85679	–83.5582	7/20/16	D#	14.1	935	921	19.1	–
13	355048083325101	35.84663	–83.5475	7/19/16	D#	55.3	1,028	973	152	–
14	355033083324901	35.84261	–83.5469	7/20/16	D#	70.7	1,018	947	170	–
15	354941083321701	35.82799	–83.5381	7/19/16	D#	27.3	985	958	222	–
16	354936083321301	35.82676	–83.5369	7/20/16	D	41.4	1,008	967	–	–
18	354949083322201	35.83039	–83.5395	7/19/16	D#	10.7	960	949	120	–
19	354957083320501	35.83236	–83.5343	7/19/16	D#	8.3	972	964	52	–
20	354936083394101	35.82655	–83.5304	7/20/16	D	154.1	1,125	971	>300	–
22	355039083313201	35.84428	–83.5256	7/19/16	D	54.9	1,011	956	–	268
23	355011083331201	35.83649	–83.5532	7/19/16	D#	108.4	1,013	904	–	~100
24	354910083313301	35.81934	–83.5257	7/19/16	D#	26.0	1,039	1,013	76.9	–
25	354920083311101	35.82225	–83.5198	7/19/16	D #	69.0	1,126	1,057	103.5	150
26	355015083321801	35.83759	–83.5382	7/19/16	D	153.7	1,104	950	>300	–
27	354838083325401	35.81047	–83.5482	7/20/16	D#	151.7	1,223	1,072	–	–
29	355015083311301	35.83757	–83.5204	7/19/16	D	47.6	1,034	986	190	–
30	355014083325501	35.83708	–83.5485	7/20/16	O	Dry	974	Dry	25.1	–
31	355113083322201	35.85348	–83.5394	7/20/16	O	9.7	924	914	17.4	–
32	354934083285701	35.82604	–83.4823	7/19/16	D	116.4	1,099	982	180	–
33	354950083323701	35.83041	–83.5435	7/20/16	O	5.8	955	949	8.8	–
34	354957083335101	35.8326	–83.5642	7/20/16	D	22.5	947	925	104	–
35	355038083340101	35.84394	–83.5669	7/20/16	O	89.4	986	897	–	230
36	355022083314301	35.83939	–83.5286	7/19/16	D	98.9	1,057	958	–	364
37	355035083303601	35.84298	–83.5101	7/21/16	D	105.0	1,110	1,005	–	124
38	355006083304401	35.83506	–83.5122	7/21/16	D	104.3	1,134	1,029	–	465
39	354948083202201	35.83002	–83.506	7/21/16	D#	136.1	1,189	1,053	216	–
40	355048083333301	35.84658	–83.5592	7/26/16	D#	46.6	944	897	78.3	125
41	354938083322001	35.82716	–83.539	7/21/16	D#	26.7	983	956	190	–



EXPLANATION

- Whirlpool
- 24 / 1,013 — **Well location, number, and water-level altitude, in feet (see table 3)**
- 28 / 1.82 — **Surface-water site, number, and streamflow value, in cubic feet per second (see table 2)**
- **Collier Drive**
- 1,075 — **Potentiometric contour**—Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Hachure indicates depression. Contour interval is 25 feet. Datum is National Geodetic Vertical Datum of 1929 (NGVD 29)
- 1 — **Quarry, upper pond**
- 2 — **Quarry, lower pond**—Water-surface altitude is about 750 feet

Note: See figure 5 for explanation of stream-reach colors.

Figure 7. Potentiometric-surface map showing well control and surface-water measurement locations and streamflow values, Sevier County, Tennessee, July 19–26, 2016. [Water-level data from U.S. Geological Survey (2017c).]

During high and low base-flow conditions, streamflow along reaches of West Prong Little Pigeon River and Middle Creek decreased by 20 to 24 ft^3/s and 2 to 4 ft^3/s, respectively. The observed losing reaches on Middle Creek and West Prong Little Pigeon River and the depressed potentiometric surface in part of the study area both indicate the hydrologic effects of the quarry dewatering operation.

The depression in the potentiometric surface is centered on the rock quarry and appears to result from ongoing dewatering operations at the facility. The potentiometric depression likely also is the cause for streamflow losses in the area as evidenced by (1) the measured decrease in streamflow from 58.9 to 38.6 ft^3/s between sites 5 and 4 and 58.9 to 43.7 ft^3/s between sites 5 and 3 on the West Prong Little Pigeon River near the quarry in July 2016 (fig. 5 and table 2), and (2) the decrease in flow related to the whirlpool(s) and other downstream flow-loss locations from about 20 ft^3/s to zero observed in October 2016 (fig. 6). In addition to the apparent inducing of streamflow losses in the West Prong Little Pigeon River, the potentiometric data and streamflow data for Middle Creek indicate that the effects of dewatering extend at least three-quarters of a mile to the southeast of the lower quarry pond, including the area where sinkholes have developed in the vicinity of the Collier Drive Bridge over Middle Creek. During the July 2016 streamflow survey, all flow in Middle Creek was captured and diverted to the subsurface by the sinkholes, with dry or deficit flow conditions downstream from the sinkholes to the mouth of the stream at its confluence with the Little Pigeon River (figs. 5 and 7 and table 2). A shallow (25-ft-deep) piezometer installed to the top of bedrock in the right bank of Middle Creek just upstream of the Collier Drive Bridge was dry during the well-measurement survey and is reported to contain water only when the stage of Middle Creek exceeds about 943 ft above NGVD 29 (Environmental Management and Engineering, Inc., written commun., May 1, 2013). The lower groundwater levels likely are a contributing factor to the formation of sinkholes near the Collier Drive Bridge at Middle Creek. The continued loss of flow in Middle Creek to the existing sinkholes has contributed to the ongoing development and expansion of sinkholes near the bridge.

Summary and Conclusions

The data collected as part of this investigation document the groundwater conditions and streamflow changes in the area of a series of sinkholes that continue to form in the streambed and flood plain of Middle Creek at the Collier Drive Bridge. The bridge was completed in 2007, and sinkholes were first observed in 2010. Streamflow data were evaluated to identify losing and gaining stream reaches and to compare unit-streamflow values for measurement sites underlain by bedrock units that make up the Cambrian-Ordovician aquifer and the Blue Ridge aquifers. In general, unit discharge is greater in the Blue Ridge aquifers. The Little Pigeon River and West Prong Little Pigeon River increased in flow from the Blue Ridge to the Ridge and Valley Physiographic Provinces, with a large increase in flow in the West Prong Little Pigeon River across and downstream of a section of the Great Smoky fault zone. Both streamflow surveys showed flow between two streamflow measurement sites along a downstream reach of the West Prong Little Pigeon River adjacent to the quarry decreased by more than 20 ft^3/s, and flow in an intermediate reach of Middle Creek decreased by more than 3 ft^3/s. In July 2016, Middle Creek went dry at the Collier Drive Bridge as flow was lost to a series of sinkholes upstream of the bridge. In October 2016, during very low-flow conditions, a whirlpool and other potential flow-loss locations were identified in the West Prong Little Pigeon River downstream of Collier Drive. Streamflow measurements and a reconnaissance of the stream channel conducted downstream of Collier Drive at the time the whirlpool was identified indicate a flow loss of about 22 ft^3/s along the entire surveyed reach.

A rock quarry located between the West Prong Little Pigeon River and Middle Creek is adjacent to the losing lower reaches of these streams and is continuously dewatered for quarrying operations. Water-surface altitudes between the lower pond in the quarry and nearby segments of the West Prong Little Pigeon River and Middle Creek indicate that about 150 to 200 ft of downward vertical head difference occurs between the streams and the pond. Such large gradients likely are the cause of the streamflow losses observed along the West Prong Little Pigeon River and Middle Creek during the measurement surveys. The lowered groundwater levels resulting from the dewatering likely are a contributing factor in the development of the sinkholes near the Collier Drive Bridge at Middle Creek.

A map of the potentiometric surface of the Cambrian-Ordovician aquifer was developed from water levels measured in 34 wells. In the eastern, south-central, and southwestern parts of the area, the potentiometric surface indicates that groundwater gradients towards these streams are responsible for the observed gains in flow along the streams. In the northwestern part of the area, the potentiometric surface is depressed beneath parts of the West Prong Little Pigeon River and Middle Creek surface-water basins, and likely is the cause of flow losses observed along the lower reaches of these streams during both streamflow surveys. The deepest part of the depression, where water-level altitudes are less than 900 ft, is centered on the rock quarry in the area just east of the West Prong Little Pigeon River, west of Middle Creek, and north of Collier Drive. The groundwater-level data further indicate that the water levels remain depressed but rise gradually to the southeast through the area where sinkholes have developed in the streambed and alluvial plain of Middle Creek. Water levels in two wells located along the northeastern and southwestern flanks of the depression and a major northwest-trending linear joint-like feature exposed in bedrock in a sinkhole that opened in the streambed of Middle Creek in 2011 appear to indicate permeability anisotropy in bedrock in the area where water levels are depressed.

The investigation in Sevier County provided additional data to evaluate the change in streamflow and the groundwater/surface-water interaction that occur along the boundary between the metamorphic rocks of the Blue Ridge province and the carbonate formations of the Ridge and Valley province. The investigation determined that groundwater levels in a part of the study area have been lowered as a result of dewatering for operation of the rock quarry. Streamflow in Middle Creek and the West Prong Pigeon River decreased in areas of depressed groundwater levels. The lower groundwater levels likely are a contributing factor to the formation of sinkholes near the Collier Drive Bridge at Middle Creek. The continued loss of flow in Middle Creek to the existing sinkholes has contributed to the ongoing development and expansion of these features near the bridge.

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