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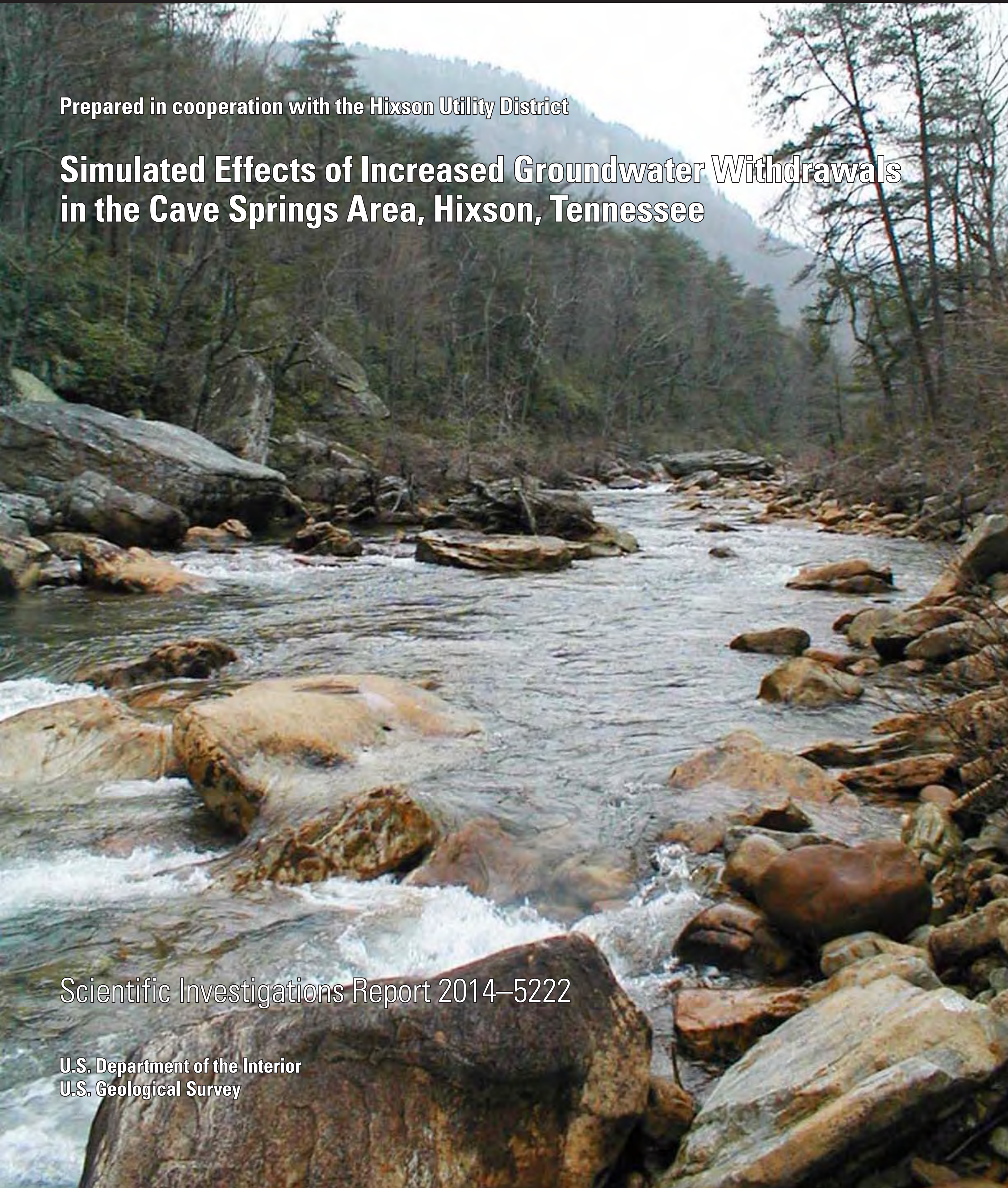

Prepared in cooperation with the Hixson Utility District

Simulated Effects of Increased Groundwater Withdrawals in the Cave Springs Area, Hixson, Tennessee

Scientific Investigations Report 2014–5222

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

Cover: North Chickamauga Creek, near the base of the Cumberland Plateau escarpment and U.S. Geological Survey streamflow gage 03566525. Photograph by C.J. Haugh, U.S. Geological Survey.

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SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2014

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
million gallons (Mgal)	3,785	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Transmissivity*	
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F-32)/1.8

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

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

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

*Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness $[(ft^3/d)/ft^2]ft$. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

Simulated Effects of Increased Groundwater Withdrawals in the Cave Springs Area, Hixson, Tennessee

By Connor J. Haugh

Abstract

Concern for future water supplies in Tennessee has grown in recent years as a result of increased awareness of competing needs, the impact of droughts, and the need for more water to support growing populations. The U.S. Geological Survey conducts investigations to improve the knowledge about interactions of geology, climate, humans, and ecosystems with the water cycle, which is critical to understanding and optimizing water availability. The Hixson Utility District in Hamilton County, Tennessee, uses groundwater resources in the Cave Springs area as a water supply, withdrawing water from two well fields located at Cave Springs and Walkers Corner. Historically, Hixson Utility District has withdrawn about 5 million gallons per day (Mgal/d) at the Cave Springs well field and between 2 and 3 Mgal/d at the Walkers Corner well field. To assess the capacity of the groundwater resources in the Cave Springs area to meet future demands, four different scenarios of increased groundwater withdrawals were analyzed using computer model simulations.

In the study area, groundwater is present in both regolith and bedrock. Groundwater flow in the regolith occurs as diffuse flow as recharge from precipitation moves through the regolith to discharge to streams and springs or to the underlying bedrock. Most of the bedrock in the study area has low primary porosity and permeability; however, fracturing and dissolution have produced substantial secondary porosity and permeability. Groundwater flow through the bedrock occurs as both diffuse and conduit flow. Recharge to the aquifer is from two distinct sources: direct infiltration of precipitation and losing streams. A major source of recharge to the aquifer that supplies Cave Springs is surface water that is lost from North Chickamauga Creek as it flows from the Cumberland Plateau onto the Newman Limestone. Average annual streamflow loss (groundwater recharge) from this reach of North Chickamauga Creek for the period November 2000 through June 2006 is about 18 cubic feet per second (ft^3/s). Groundwater leaves the aquifer as either discharge to North Chickamauga Creek, Poe Branch, and Lick Branch; discharge to Chickamauga Lake; spring flow to Cave Springs or Rogers Spring; or withdrawals at the Cave Springs or Walkers Corner well fields.

Using computer model simulations, four scenarios of increased groundwater withdrawals were analyzed. Each of these four scenarios are compared to a base-case simulation that uses groundwater withdrawal rates from 2012 of 5.1 Mgal/d from the Cave Springs well field and 2.7 Mgal/d from the Walkers Corner well field. Under scenarios A and B, pumpage is increased at Cave Springs by 2 Mgal/d and 5 Mgal/d, respectively, while pumpage at Walkers Corner remains unchanged. Under scenarios C and D, pumpage is increased at Walkers Corner by 2.6 Mgal/d and 4.5 Mgal/d, respectively, while pumpage at Cave Springs remains unchanged. The effects of the increased withdrawals were analyzed by comparing water budget changes of the groundwater discharges to Chickamauga Lake, North Chickamauga Creek, Cave Springs, Poe Branch, and Lick Branch/Rogers Spring for each of the scenarios and evaluating changes in groundwater levels at the well fields.

Under scenarios A and B, the largest change in the water budget occurs for flow to Cave Springs with decreases of 1.9 and 4.7 ft^3/s, respectively. Similarly, groundwater discharge to North Chickamauga Creek decreases by 1.0 ft^3/s and 2.6 ft^3/s, respectively. Under scenarios C and D, the largest change in the water budget occurs for flow to Chickamauga Lake with decreases of 1.3 ft^3/s and 2.3 ft^3/s, respectively. Similarly, groundwater discharge to North Chickamauga Creek decreases by 1.1 ft^3/s and 2.1 ft^3/s, respectively. Changes in groundwater levels at the well fields were also analyzed. At the Cave Springs well field, maximum declines in groundwater levels due to additional pumpage are less than 1 foot for all scenarios. Groundwater level changes at the Cave Springs well field are small due to the highly transmissive nature of the aquifer in this location. Maximum groundwater-level declines at Walkers Corner are less than 1 foot for scenarios A and B and about 52 feet and 82 feet for scenarios C and D, respectively. Under scenarios C and D, the regional potentiometric surface shows a large cone of depression centered on the Walkers Corner well field and elongated along geologic strike.

Introduction

Groundwater is an important resource throughout the Valley and Ridge Physiographic Province, which extends from Pennsylvania to Alabama. The U.S. Geological Survey (USGS) Regional Aquifer-System Analysis (RASA) study of the Valley and Ridge Physiographic Province recognized that groundwater basins in this setting are not regionally continuous; the Cave Springs area in Hamilton County, Tennessee, was selected to represent large spring basins—one of several "type-areas" designated for the RASA study (Swain and others, 1992). Concern for future water supply in Tennessee has grown in recent years as a result of increased awareness of competing needs, the impact of droughts, and the need for more water to support growing populations. Knowledge about interactions of geology, climate, human activities, and ecosystems with the water cycle is critical to understanding and optimizing water availability and is a key area of water resource research by the USGS (Evenson and other, 2013).

The sustainability of groundwater resources is a concern in many groundwater systems (Alley and others, 1999). Any amount of water pumped from the groundwater system must come from somewhere. Sources of water for increased withdrawals are removal of water that was stored in the system, more water entering the system through increased recharge, and less water leaving the system through decreased discharge (Alley and others, 1999). The removal of groundwater from storage results in lower water levels, which increases pumping costs because the vertical distance that groundwater must be lifted to land surface increases. Similarly, lower water levels may cause some wells to become dry. Less groundwater discharging to streams may affect stream water temperature and other environmental factors.

Groundwater resources in the Cave Springs area are used by the Hixson Utility District (HUD) as a source of potable water. HUD withdraws water from two well fields located at Cave Springs and Walkers Corner (fig. 1). Historically, HUD has withdrawn about 5 million gallons per day (Mgal/d) at the Cave Springs well field and between 2 and 3 Mgal/d at the Walkers Corner well field. A major source of recharge to the aquifer that supplies Cave Springs is surface water that is lost from North Chickamauga Creek as it flows off the Cumberland Plateau onto limestone in the Valley and Ridge Physiographic Province (fig. 1). The USGS, in cooperation with HUD, conducted a study during 2013 and 2014 of the local groundwater system to assess the capacity of the groundwater system to meet future demands.

Purpose and Scope

This repost presents results of an investigation of the Cave Springs area groundwater system. The report includes a general description of the hydrogeology of the study area, an analysis of recharge to the aquifer from streamflow loss from North Chickamauga Creek, and results of computer model simulations of four scenarios of increased groundwater withdrawals from two well fields: Cave Springs and Walkers Corner. The information provided through this investigation will assist the USGS in better defining the complex interaction of geology, groundwater and surface-water hydrology, and human interaction in the study area. The Water Science Strategy (Evenson and others, 2013) for the USGS identifies several key research areas that will benefit from this investigation, including:

- Knowledge about interactions of geology, climate, humans, and ecosystems with the water cycle, which is critical to understanding and optimizing water availability;
- Continued research on natural and human-related processes affecting water quantity and quality, including the ability of natural systems to tolerate or remediate human impacts;
- Integration of water use with its information on the rest of the water cycle; and
- Characterizing and predicting water availability at the spatial and temporal scales needed to understand and manage water resources.

Previous Studies

The geology and hydrologic resources of the Valley and Ridge Physiographic Province and the Cave Springs area have been the subjects of previous studies. Rodgers (1953) compiled and described the geology of East Tennessee, and Swingle and others (1964) mapped the geology and summarized the mineral resources of the area. The geology of Hamilton County was described by the Tennessee Department of Conservation, Division of Geology (1979); the hydrology of the Cave Springs area by Bradfield (1992); the hydrogeology of the Cave Springs groundwater basin by Pavlicek (1996); and groundwater flow simulation of the Cave Springs area by Haugh (2002). The groundwater resources of East Tennessee were described by DeBuchananne and Richardson (1956); 84 springs in East Tennessee were analyzed in terms of magnitude and variability of discharge by Sun and others (1963). Hollyday and Smith (1990) analyzed discharge data from 171 large springs, predominantly within the Valley and Ridge Physiographic Province, and Swain and others (1991) recognized Cave Springs as a type-area representative of large spring basins in the Valley and Ridge Physiographic Province. Much of the background information presented in this report is reprinted from Haugh (2002), which contains a more detailed description of the study area and documentation of the groundwater-flow model used in this study.

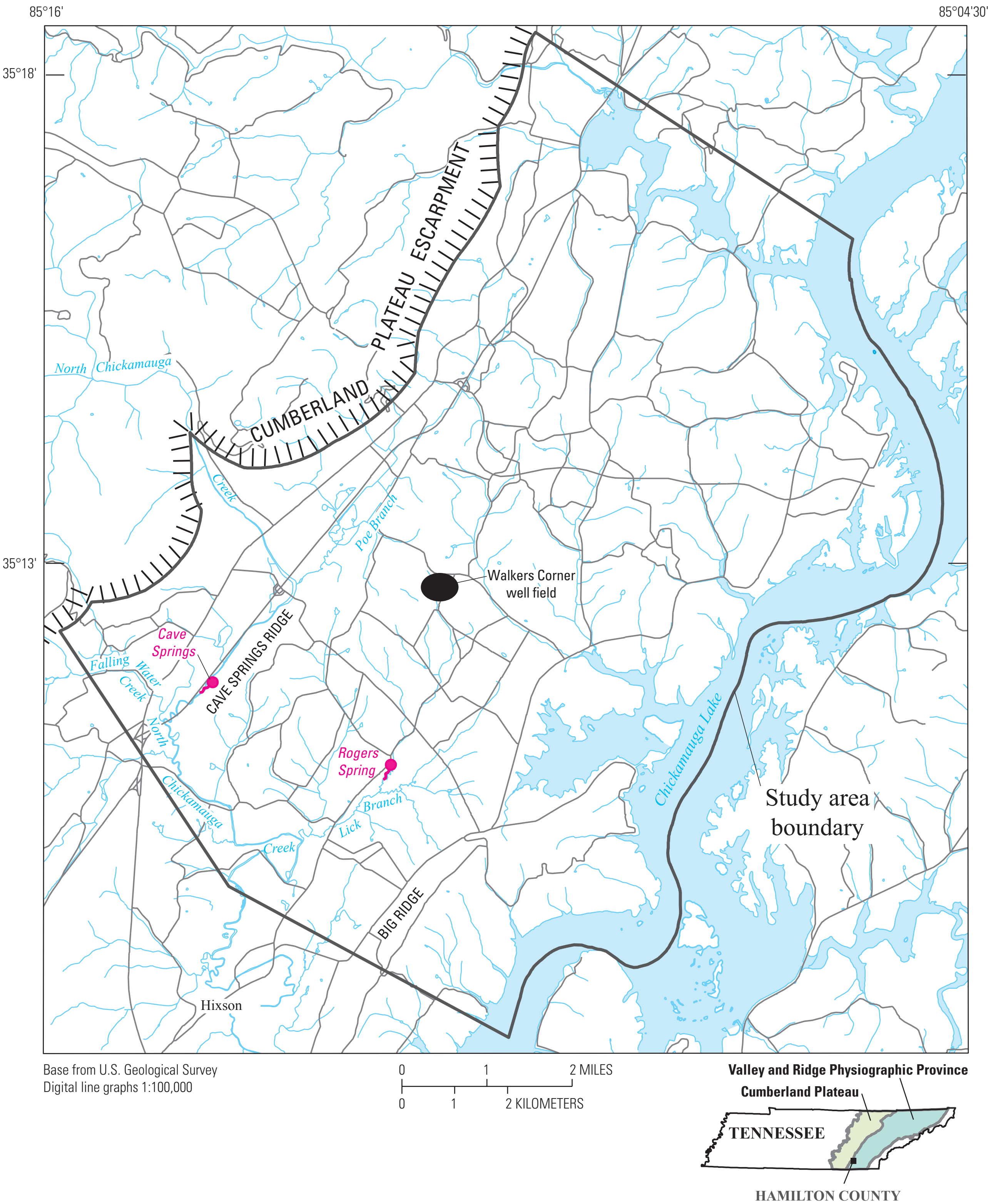


Figure 1. Physiographic and cultural features in the study area, Hixson, Tennessee.

Descriptions of Study Area

The study area (fig. 1) is located in the rolling terrain of the Valley and Ridge Physiographic Province of East Tennessee, which consists of alternating valleys and ridges that trend northeast. Land-surface altitudes in the study area range from about 650 feet (ft), where North Chickamauga Creek leaves the study area, to more than 1,000 ft along the north end of Cave Springs Ridge. The study area includes about 60 square miles of Hamilton County and is bounded on the northeast and southeast by Chickamauga Lake, an impoundment of the Tennessee River, and on the west by the Cumberland Plateau. Land-surface altitudes just west of the study area on the Cumberland Plateau rise to over 1,800 ft. The main streams in the study area are North Chickamauga Creek and its tributaries, Poe Branch and Lick Branch.

Most of the study area is underlain by folded limestone and dolomite ranging in age from Cambrian to Mississippian (Miller, 1974). The primary formations exposed at land surface in the study area, listed from oldest to youngest, include the Copper Ridge Dolomite, the Knox Group (Ordovician formations), the Chickamauga Limestone, and the Newman Limestone (fig. 2). These formations generally dip towards the southeast at approximately 20 degrees. Rocks exposed along the northwestern side of the study area boundary include Pennsylvanian-age shales and sandstones of the Cumberland Plateau (fig. 3). A thick mantle of regolith, composed of insoluble chert and clay residuum formed from in-situ chemical weathering of carbonate bedrock, covers most of the study area. In the flood plain of North Chickamauga Creek, the regolith also contains coarse-grained alluvium, consisting of gravel, cobbles, and boulders eroded from the siliciclastic rocks of the Cumberland Plateau.

Groundwater

Groundwater is present in both regolith and bedrock. Groundwater flow in the regolith occurs as diffuse flow as recharge from precipitation moves through the regolith to discharge to streams and springs or to the underlying bedrock. The regolith, where thicker than 50 ft, functions as a storage reservoir for recharge to the underlying bedrock (Swain and others, 1991). Most of the bedrock in the study area has low primary porosity and permeability; however, fracturing and dissolution have produced substantial secondary porosity and permeability (Swain and others, 1991). Groundwater flow through the bedrock occurs as both diffuse and conduit flow.

Water levels observed in wells from both well fields exhibit normal seasonal variations and appear to be in equilibrium with current pumping rates. Water rights to Cave Springs were acquired by HUD in 1952; however, groundwater-level data from the well field were not available until 1987. At Cave Springs, groundwater levels in well Hm:N-035 (USGS station number 351148085135301) vary seasonally, between 37 and 58 ft below land surface for the period of record (1987 to 2014) and, although there is much missing record, the data show no long-term declines (fig. 4). At Walkers Corner, measured groundwater levels declined about 20 to 30 ft between 1996 (when withdrawals from the Walkers Corner well field began) and 2000 (fig. 5). Since 2000, both normal seasonal and annual variations are present in the water levels, but no continuing decline is observed, indicating that groundwater levels are in equilibrium with current pumping rates (fig. 5).

Recharge

In the study area, recharge occurs from precipitation dispersed throughout the study area and from losing streams. Average annual recharge estimates for the Hixson, Tennessee area, based on hydrograph separation and water budgets as summarized by Haugh (2002), range from 10.5 inches per year (in/yr) to 15.0 in/yr. In a computer flow model, recharge from direct infiltration of precipitation was divided into two zones—the Cave Springs Ridge area and all other areas—with calibrated recharge values of 20 in/yr and 8 in/yr, respectively (Haugh, 2002). Previous studies identified a losing reach of North Chickamauga Creek upstream of the mouth of Poe Branch (Lowery and others, 1989; Pavlicek, 1996) and recognized this reach as an important source of concentrated recharge to the groundwater system and Cave Springs (Haugh, 2002), but data quantifying the amount of water lost from the creek that recharged the aquifer were limited.

Based on this information, additional streamflow data were collected between 2000 and 2006 to further investigate and quantify recharge from North Chickamauga Creek streamflow loss. Data collection included a series of discharge measurements focusing on North Chickamauga Creek upstream of the mouth of Poe Branch (table 1; fig. 6). The extent of the losing reach of North Chickamauga Creek was defined with a series of streamflow measurements made during low base-flow conditions on October 12, 2000, and during high base-flow conditions on April 26, 2001 (fig. 7). Streamflow losses during low and high base flow were 2 and 40 ft^3/s, respectively. The losing stream reach begins near site 12 (fig. 6) at the base of the Cumberland Plateau escarpment where North Chickamauga Creek flows eastward from the sandstone of the Cumberland Plateau and onto the Newman Limestone. The primary factors creating this losing reach are the altitude of the streambed relative to the water table and the presence of the Newman Limestone, which contains dissolution-enlarged fractures that can easily transmit water (Bradfield, 1992; Haugh, 2002). The downstream end of the losing reach is located near the mouth of Poe Branch where North Chickamauga Creek turns to the southwest and flows parallel to Cave Springs Ridge. Two continuous streamflow gages, 03566525 (site 12, fig. 6 and table 1) and 0356653019 (site 15, fig. 6 and table 1), were established near the upstream and downstream ends, respectively, of the losing reach. Both streamflow gages operated from November 2000 through June 2006. In July 2006, the downstream gage (0356653019) was discontinued, but the upstream gage (03566525) continued to operate until July 2012.

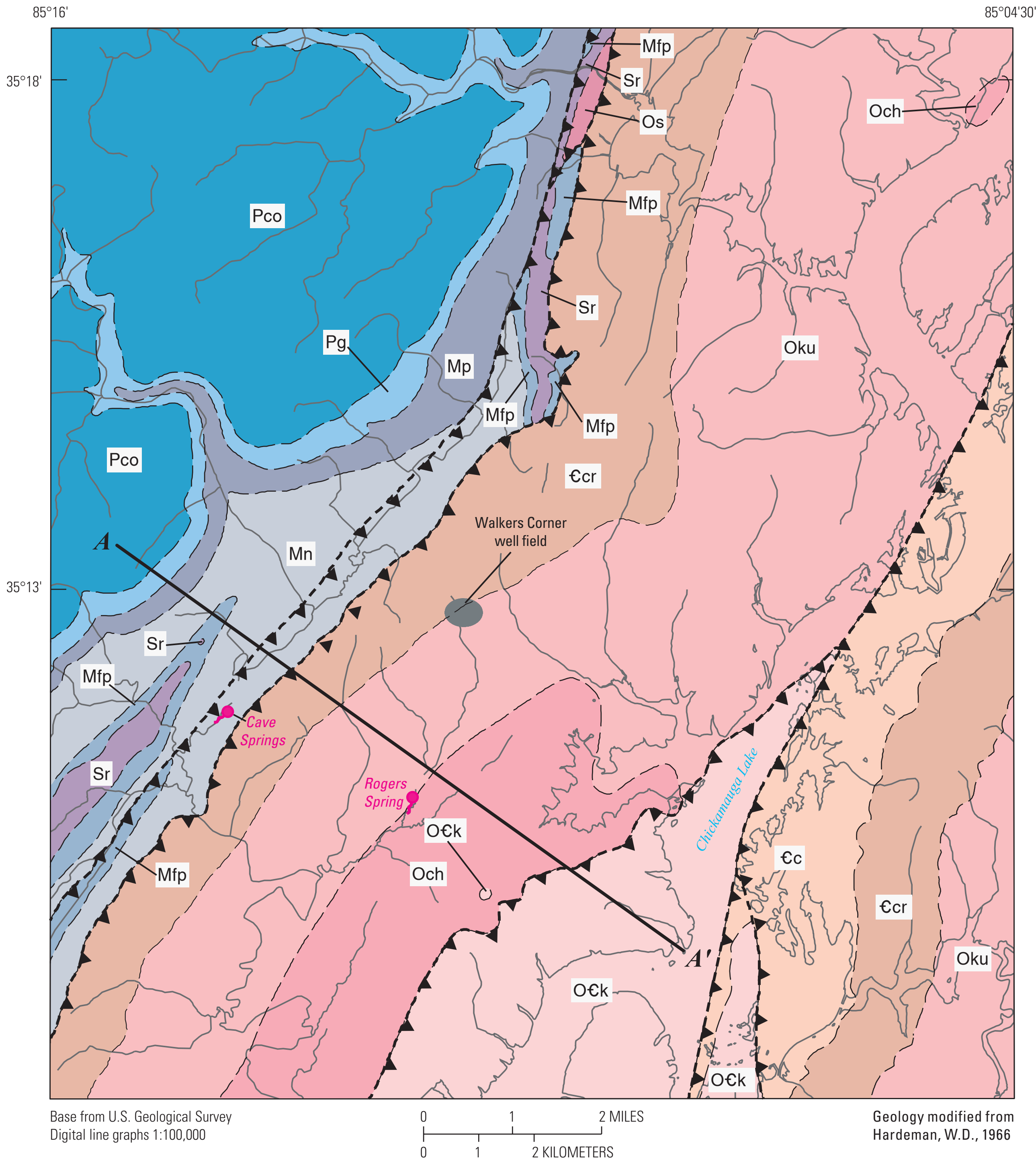


Figure 2. Geology of the Hixson, Tennessee area.

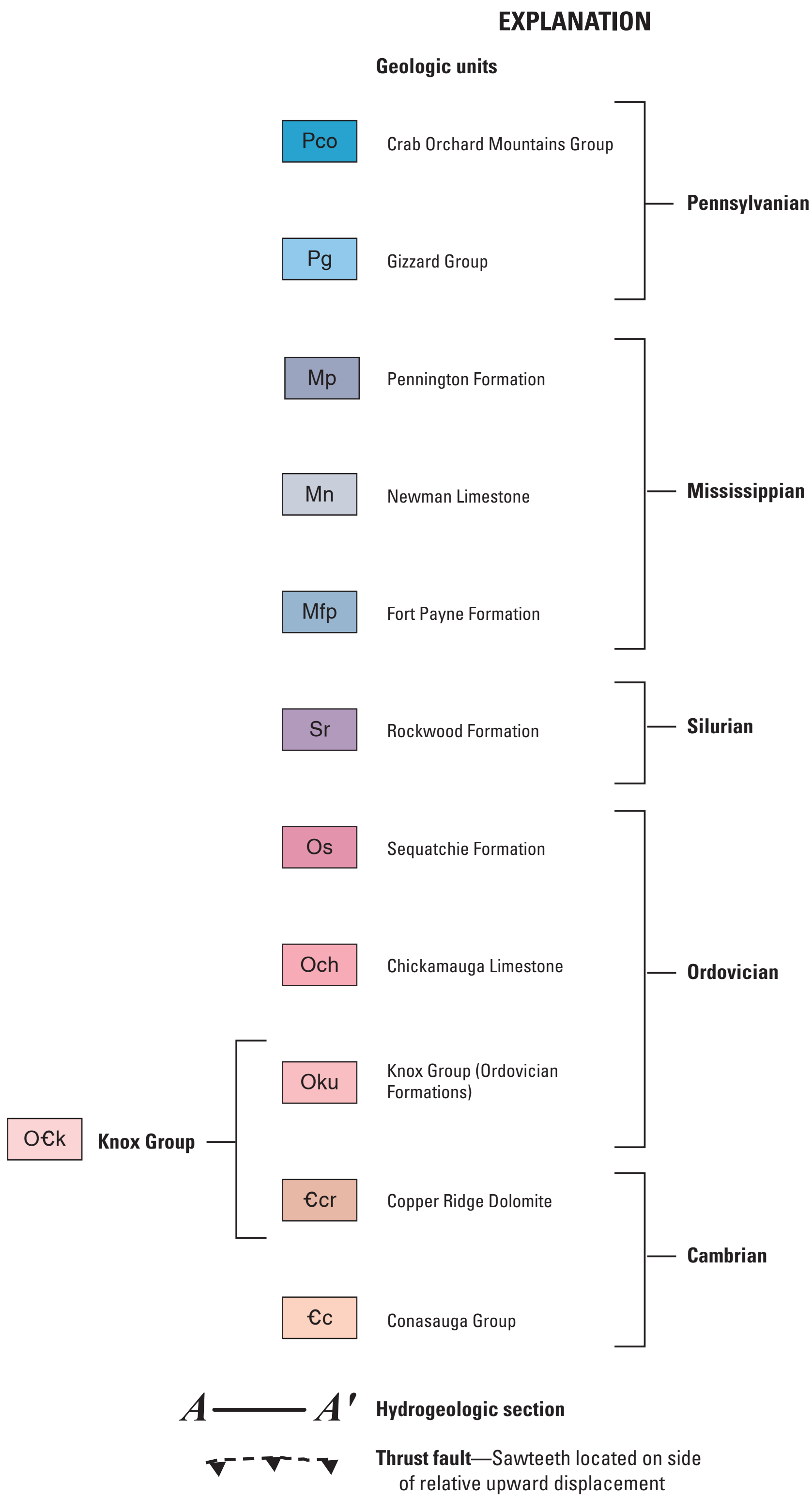


Figure 2. Geology of the Hixson, Tennessee area.—Continued

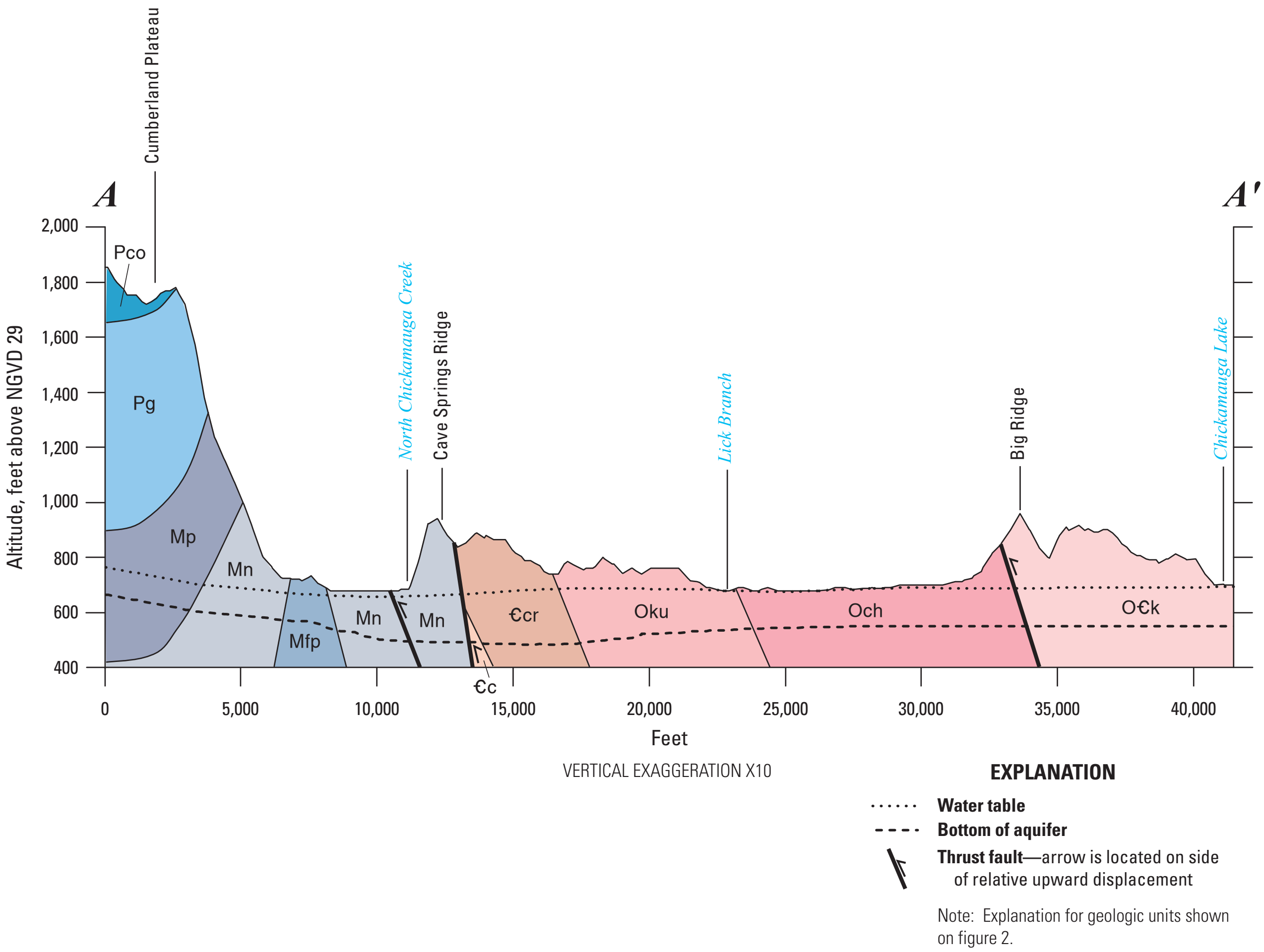


Figure 3. Hydrogeologic cross section through the Hixson, Tennessee area.

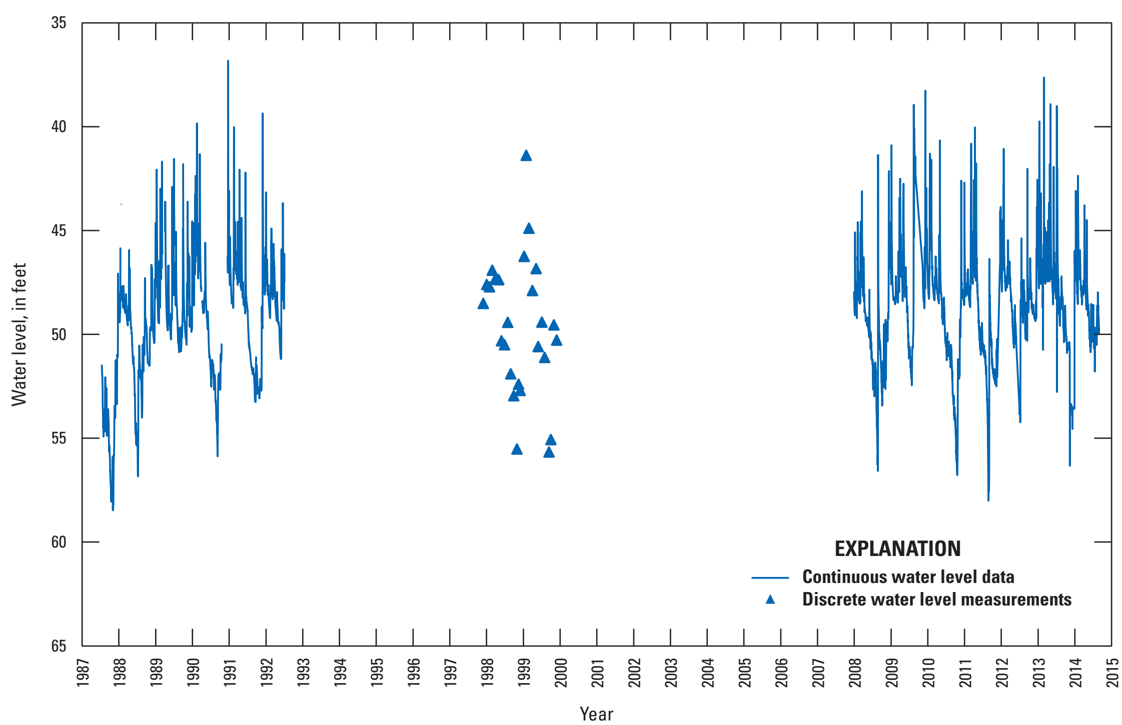


Figure 4. Water levels at Cave Springs in well Hm:N-035 (USGS station number 351148085135301).

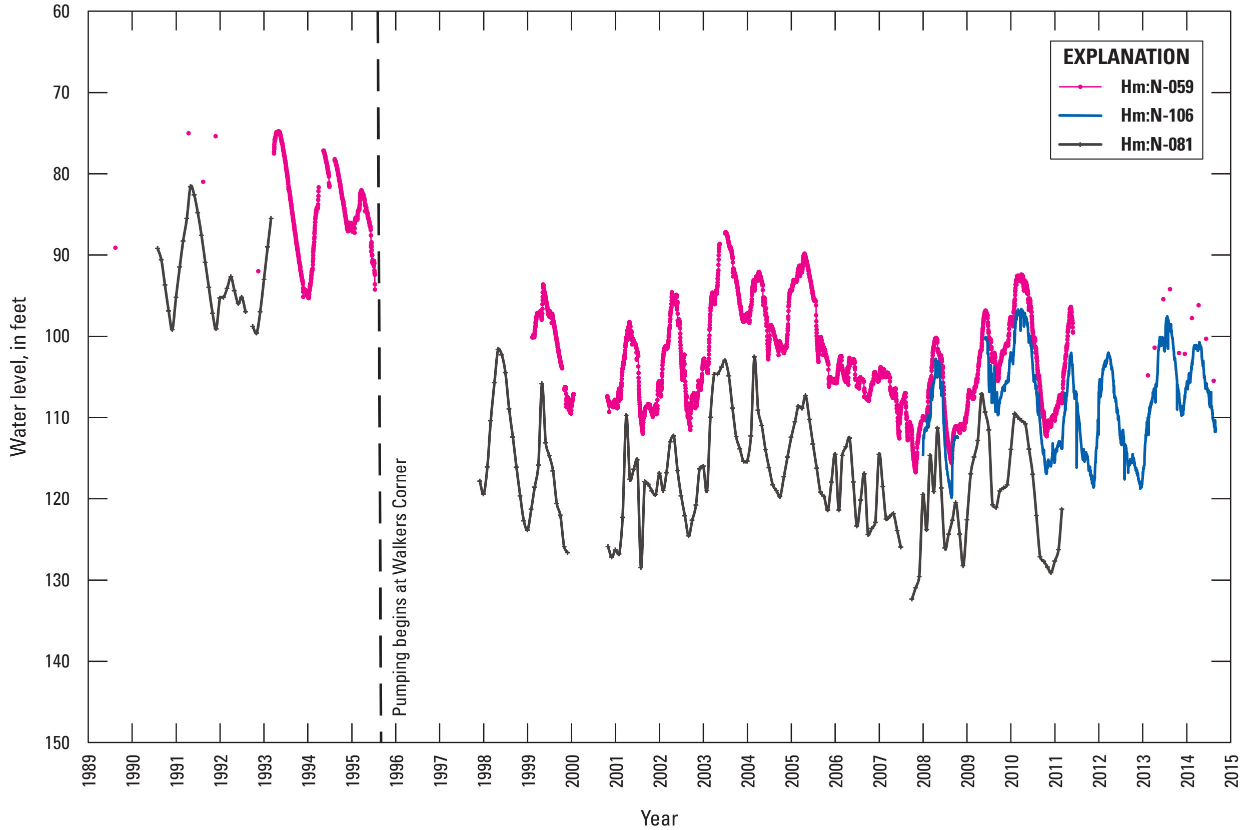


Figure 5. Water levels at Walkers Corner in wells Hm:N-059 (USGS station number 351249085110101), Hm:N-081 (USGS station number 351252085110001), and Hm:N-106 (USGS station number 351251085110001).

Table 1. Stream-discharge data at select stations in the North Chickamauga Creek area, October 12, 2000, and April 26, 2001.

[ft^3/s, cubic square foot per second; mi^2, square mile; --, no data]

Site number	Station number	Site name	River mile	10/12/00 discharge (ft3/s)	4/26/01 discharge (ft^3/s)	Drainage area (mi^2)
1	03566511	North Chickamauga Creek above Cain Creeknear Point Ridge, Tenn.	24.2	0.7	11.9	19.89
2	035665115	Cain Creek near North Chickamauga Creek near Point Ridge, Tenn.	--	0.3	13.2	21.80
3	035665117	North Chickamauga Creek below Cain Creek, Tenn.	24	1.0	25.1	41.69
4	03566512	North Chickamauga Creek above Cooper Creek near Redbird Point, Tenn.	22.6	0.8	24.5	43.14
5	035665125	Cooper Creek near North Chickamauga Creek near Redbird Point, Tenn.	--	0	4.4	8.47
6	03566514	North Chickamauga Creek below Stevenson Branch near Redbird Point, Tenn.	21.9	0.8	32.3	53.15
7	03566515	Boston Branch at North Chickamauga Creek, Tenn.	--	--	1.5	1.37
8	03566516	North Chickamauga Creek below Boston Branch, Tenn.	20.7	1.1	33.3	58.43
9	03566520	North Chickamauga Creek near unnamed tributary near Huckleberry, Tenn.	20.2	1.8	30.7	58.96
10	03566522	North Chickamauga Creek near Huckleberry, Tenn.	19.6	1.2	35.6	59.59
11	03566524	North Chickamauga Creek near Hogskin Branch, Tenn.	19.1	2.0	45.8	60.21
12	03566525	North Chickamauga Creek near Montlake, Tenn.	18.8	--	56.3	60.55
13	03566528	North Chickamauga Creek near Montlake near Daisy, Tenn.	18.6	1.2	40.8	60.99
14	03566530	North Chickamauga Creek near Daisy, Tenn.	17.3	0	34.4	62.63
15	0356653019	North Chickamauga Creek at Hwy 27 near Daisy, Tenn.	16.7	0	17.1	63.61
16	035665348	Poe Branch at Mile Straight, Tenn.	--	0	1.3	9.81
17	03566535	North Chickamauga Creek at Mile Straight, Tenn.	16.6	0	20.3	74.00

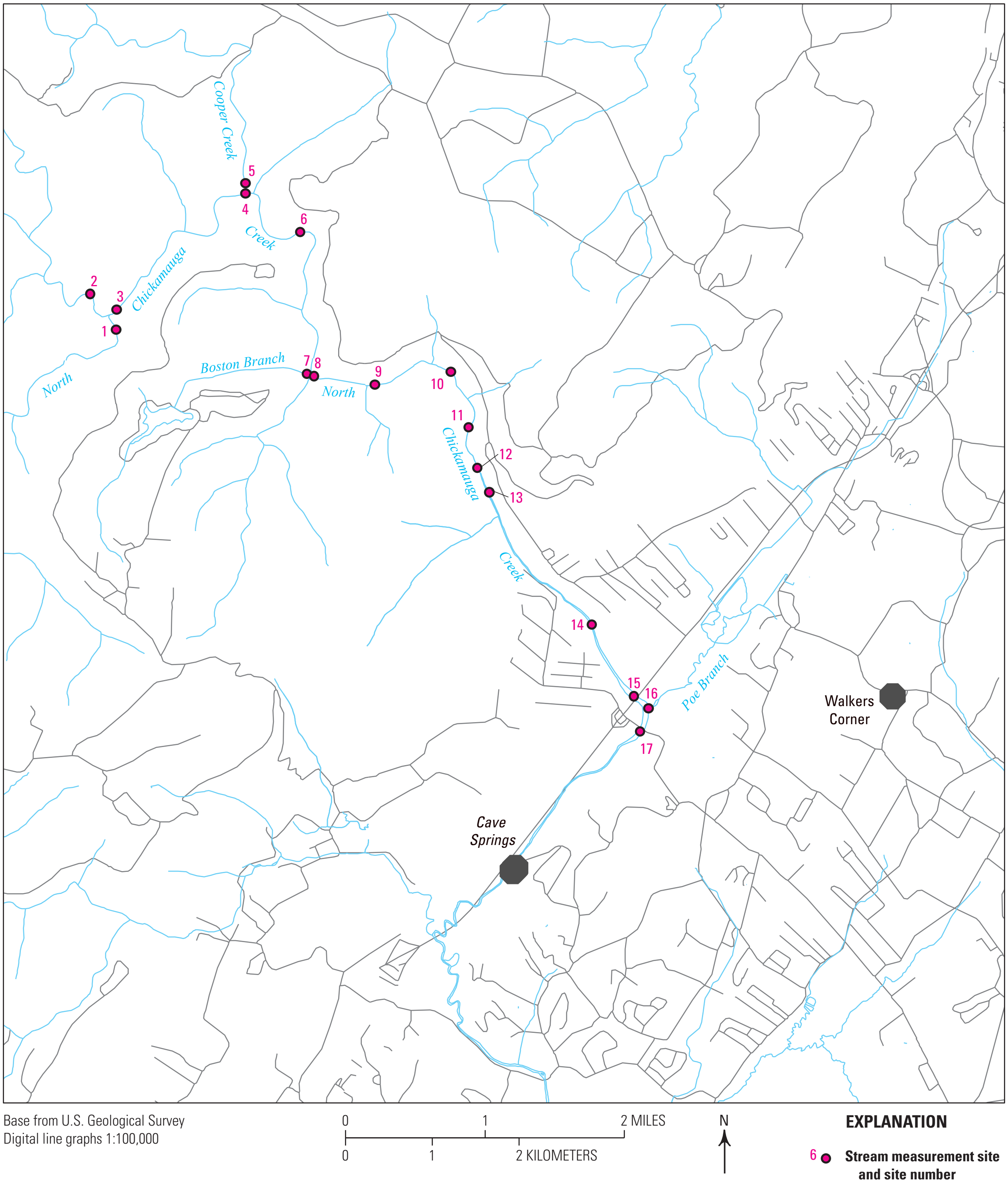


Figure 6. Location of streamflow measurement sites in the North Chickamauga Creek area.

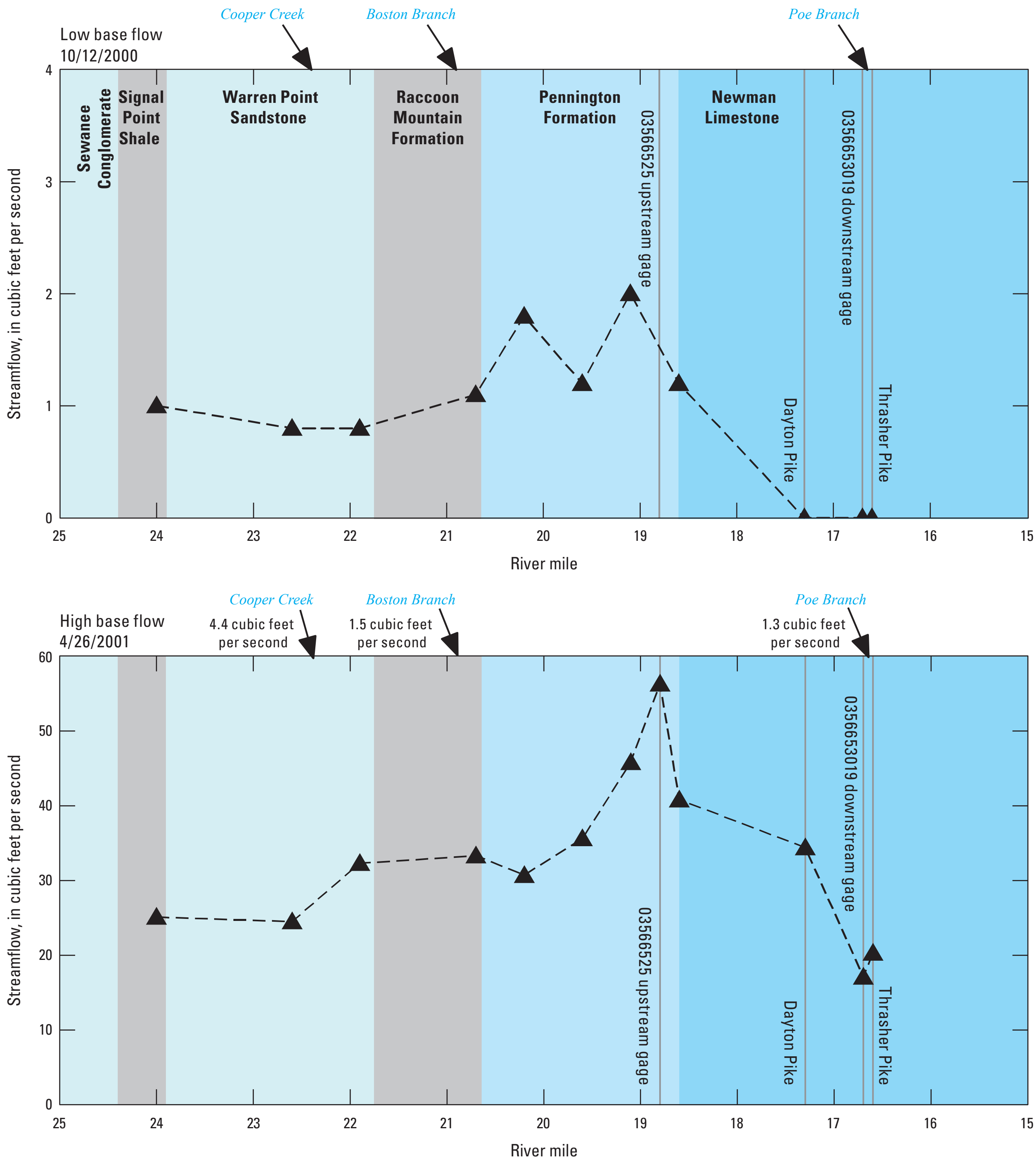


Figure 7. Graph showing streamflow versus river mile in the North Chickamauga Creek area, October 12, 2000, and April 26, 2001.

Continuous streamflow data collected from November 2000 through June 2006 show that when flow at the upstream gage is about 20 ft^3/s or less, all streamflow sinks into the subsurface before reaching the downstream gage. Flow duration curves for this period show that the downstream gage has flow greater than zero 67 percent of the time and, therefore, no flow 33 percent of the time or about 120 days a year, while the upstream gage has flow greater than zero more than 99 percent of the time and, therefore, no flow less than 1 percent of the time (fig. 8). The downstream gage had no flow for 165 days during a relatively dry year in 2001 (fig. 9) and had no flow for 82 days during a relatively wet year in 2003 (fig. 10). Average annual streamflow loss calculated by subtracting the daily mean streamflow from the upstream and downstream gages for the period November 2000 through June 2006 is about 18 ft^3/s. The results of a flow-path analysis from a groundwater model and a water budget analysis indicate that this streamflow loss is a major source of recharge to Cave Springs and the Cave Springs well field, accounting for about 70 percent of the total water discharged at Cave Springs and withdrawn at the Cave Springs well field (Haugh, 2004).

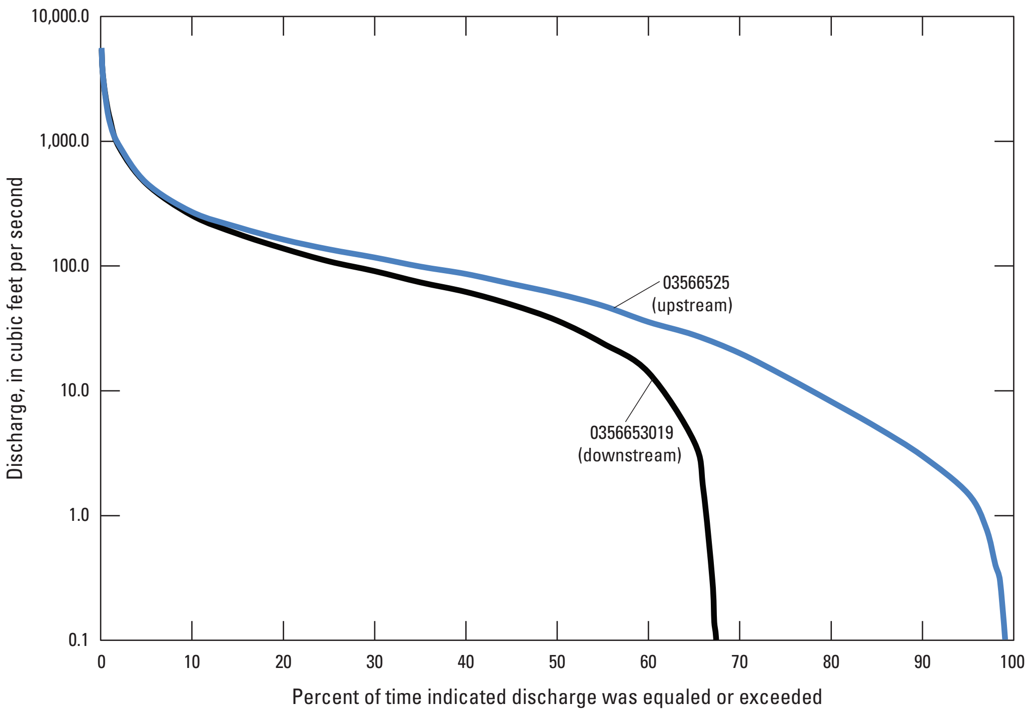


Figure 8. Graph showing flow duration curves for North Chickamauga Creek gages 03566525 (upstream) and 0356653019 (downstream).

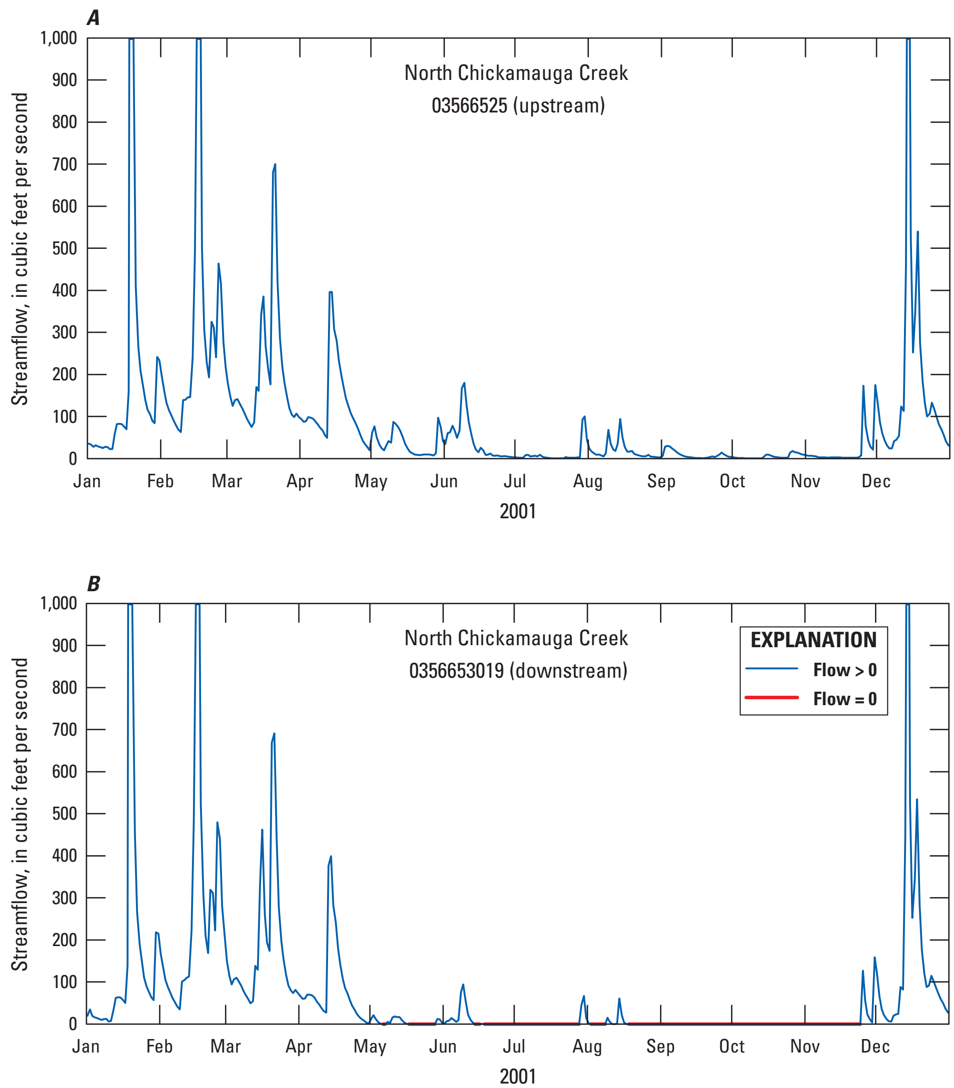


Figure 9. Graph showing daily mean streamflow North Chickamauga Creek gages; (*A*), 03566525 (upstream) and (*B*), 0356653019 (downstream) for 2001.

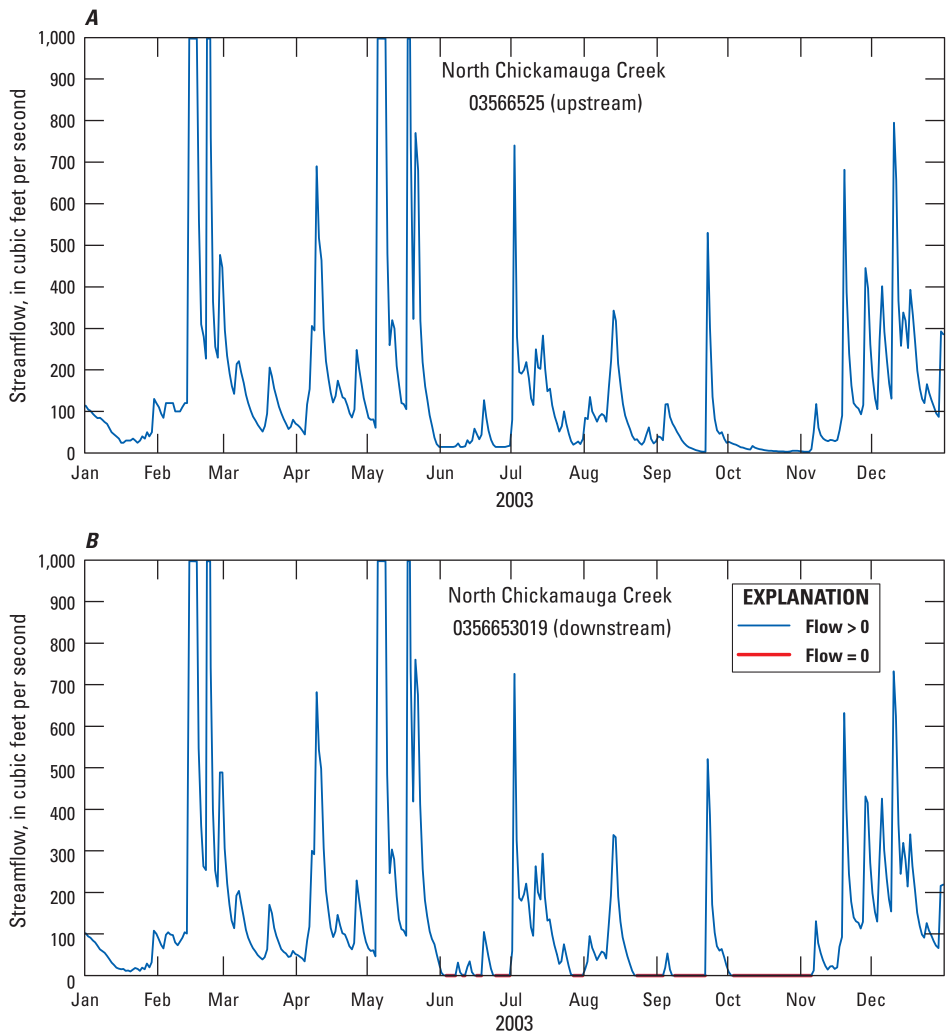


Figure 10. Graph showing daily mean streamflow North Chickamauga Creek gages; (*A*), 03566525 (upstream) and (*B*), 0356653019 (downstream) for 2003.

Flow Model

A steady-state groundwater-flow model for the Cave Springs area was constructed and calibrated in a previous study (Haugh, 2002). The flow model contains two layers; layer 1 corresponds to the saturated regolith and layer 2 corresponds to the bedrock. The model grid is made up of 131 columns and 96 rows. The smallest grid cells, located near Cave Springs and the Walkers Corner well fields, are about 150 by 150 ft, and the largest grid cells, located near the model boundaries, are about 800 by 800 ft (see fig. 16 in Haugh, 2002). The model grid is oriented so that the grid is aligned parallel to the strike of the bedrock.

Modeled recharge is from two distinct sources: direct infiltration of precipitation and losing streams. Groundwater leaves the aquifer as either discharge to the simulated stream reaches of North Chickamauga Creek, Poe Branch, and Lick Branch; discharge to Chickamauga Lake; spring flow to Cave Springs or Rogers Spring; or withdrawals at Cave Springs or Walkers Corner well fields.

Simulated steady-state water levels using 2012 withdrawal amounts show the highest water level in the center of the study area, just north of Walkers Corner and to the northwest along the escarpment of the Cumberland Plateau (fig. 11). Gradients indicate groundwater flows radially outward from the center of the study area towards Chickamauga Lake, Lick Branch, Poe Branch, and North Chickamauga Creek. Low gradients trend along the axis of the North Chickamauga Creek and Poe Branch valley. A cone of depression is evident at the Walkers Corner well field.

Simulated Effects of Groundwater Withdrawals

Sources of water to pumping wells are reductions in aquifer storage, increases in the rates of recharge (inflow) to an aquifer, and decreases in the rates of discharge (outflow) from an aquifer (Barlow and Leake, 2012). Initially, most water is derived from aquifer storage until the pumping stress reaches an equilibrium or steady-state condition with the aquifer. Under steady-state conditions, the only sources of water are increases in the rates of recharge to an aquifer and decreases in the rates of discharge from an aquifer. In the steady-state model used for this study, the rates of recharge from both precipitation and the losing stream reach are set at the calibrated values, so the only source of water to the pumped wells is the overall decrease in the rate of discharge from the aquifer. Therefore, the steady-state model simulated the maximum expected changes in groundwater discharges.

Four different scenarios of increased groundwater withdrawals were analyzed using steady-state computer model simulations and were compared to a base-case simulation. The base-case simulation used withdrawal amounts from 2012 with pumpage from the Cave Springs well field at 5.1 Mgal/d and Walkers Corner well field at 2.7 Mgal/d for total withdrawal of 7.8 Mgal/d (Hixson Utility District, written commun., 2013). Pumpage amounts for the four scenarios are summarized in table 2. Under scenarios A and B, pumpage at the Cave Springs well field is increased by 2 Mgal/d and 5 Mgal/d, respectively, with pumpage at Walkers Corner well field unchanged. The increases of 2 Mgal/d and 5 Mgal/d are based on estimates of future demands from the Cave Springs well field provided by HUD. Under scenarios C and D, pumpage at Walkers Corner well field is increased by 2.6 Mgal/d and 4.5 Mgal/d, respectively, with pumpage at the Cave Springs well field unchanged. The increase of 2.6 Mgal/d in scenario C assumes a third well is added at Walkers Corner well field and the two existing wells are pumped near capacity. The increase of 4.5 Mgal/d in scenario D assumes two additional wells at Walkers Corner well field and the two existing wells are pumped near capacity. Each scenario was assessed by comparing changes, relative to the base scenario, in groundwater levels at the well fields and groundwater discharges to Chickamauga Lake, North Chickamauga Creek, Cave Springs, Poe Branch, and Lick Branch/Rogers Spring.

Under scenarios A and B, where pumpage is increased in wells at Cave Springs, the change in water level is small due to the highly transmissive nature of the aquifer at this location. The maximum water-level change for scenario A is –0.33 ft (fig. 12) and for scenario B is –0.82 ft (fig. 13). The largest change in the water budget occurs for groundwater flow to Cave Springs with decreases of 1.9 and 4.7 ft^3/s, respectively, for scenarios A and B. Similarly, groundwater discharge to North Chickamauga Creek decreases by 1.0 and 2.6 ft^3/s, respectively, for scenarios A and B. Groundwater discharge to Chickamauga Lake and Lick Branch is unchanged (table 3). Increases in pumpage at Cave Springs may induce more water to recharge the aquifer along the losing reach of North Chickamauga Creek where it flows from the Cumberland Plateau onto the Newman Limestone. If this occurs, the actual decrease in groundwater discharge at Cave Springs and North Chickamauga Creek would be reduced by the amount of additional recharge.

Under scenario C, where pumpage is increased at Walkers Corner from 2.7 Mgal/d to 5.3 Mgal/d, the maximum water-level change is –51.2 ft (fig. 14). Under scenario C, the regional potentiometric surface is similar to the base case, but shows a larger cone of depression centered on the Walkers Corner well field and elongated along geologic strike. The highest water levels are in the center of the study area just north of Walkers Corner and to the northwest along the escarpment of the Cumberland Plateau (fig. 15). The largest change in the water budget occurs for groundwater flow to Chickamauga Lake with a decrease of 1.3 ft^3/s. Similarly, groundwater discharge to North Chickamauga Creek decreases by 1.1 ft^3/s for scenario C (table 4).

Under scenario D, where pumpage is increased at Walkers Corner from 2.7 Mgal/d to 7.2 Mgal/d, the maximum water-level change is –81.9 ft (fig. 16). Under scenario D, the regional potentiometric surface shows a large cone of depression centered on the Walkers Corner well field and elongated along geologic strike. The highest water levels are in the center of the study area, just north of Walkers Corner and to the northwest along the escarpment of the Cumberland Plateau (fig. 17).

The largest change in the water budget occurs for groundwater flow to Chickamauga Lake with a decrease of 2.3 ft^3/s for scenario D. Similarly, groundwater discharge to North Chickamauga Creek decreases by 2.1 ft^3/s (table 4).

Models, by their very nature, are simplifications of the natural system. Factors that affect how well a model represents the natural system include the model scale, inaccuracies in estimating hydraulic properties, inaccurate or poorly defined boundary conditions, and the accuracy of pumping, water-level, and streamflow data. The limitations of the model used for these simulations are documented in Haugh (2002). The limitations most relevant to the simulations in this report include: (1) data to determine stream base flow is limited to a few miscellaneous measurements with the exceptions of 5 years of continuous record at Cave Springs and the continuous gages that define the losing reach of North Chickamuaga Creek; (2) ground water discharge to Chickamauga Lake cannot be measured in the field but accounts for about 20 percent of the water budget; and (3) additional production wells simulated in the report are assumed to be similar to existing production wells, but actual well characterisitics may be different due to variations in hydraulic properties within the aquifer. Uncertainty in the recharge flux from the losing reach of North Chickamauga Creek has improved with the additional streamflow data presented in this report. Finally, scenarios in this report simulate the maximum expected changes in groundwater discharges; since the rates of recharge from both precipitation and the losing stream reach are set at the calibrated values, the only source of water to the pumped wells is a decrease in the rate of discharge from the aquifer. Increases in pumpage at Cave Springs may induce more water to recharge the aquifer along the losing reach of North Chickamauga Creek where it flows from the Cumberland Plateau onto the Newman Limestone. If this occurs, the actual decrease in groundwater discharge at Cave Springs would be reduced by the amount of additional recharge.

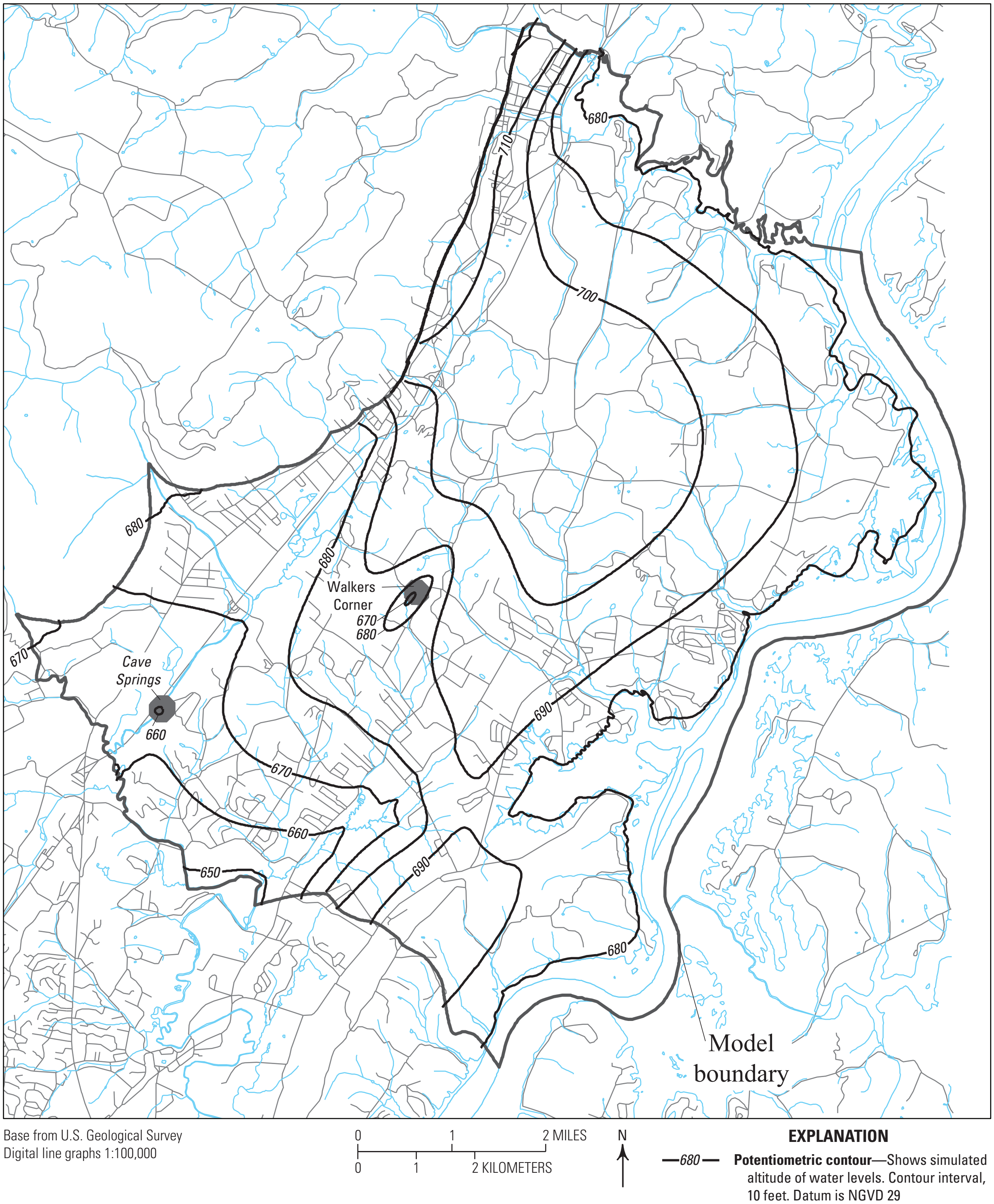


Figure 11. Simulated steady-state water levels under 2012 pumping conditions.

Table 2. Groundwater withdrawal rates for base case and scenarios for model simulation.

	Pumpage, in million gallons per day		
	Cave Springs	**Walkers Corner**	**Total**
Base case	5.1	2.7	7.8
Scenario A	7.1	2.7	9.8
Scenario B	10.1	2.7	12.8
Scenario C	5.1	5.3	10.4
Scenario D	5.1	7.2	12.3

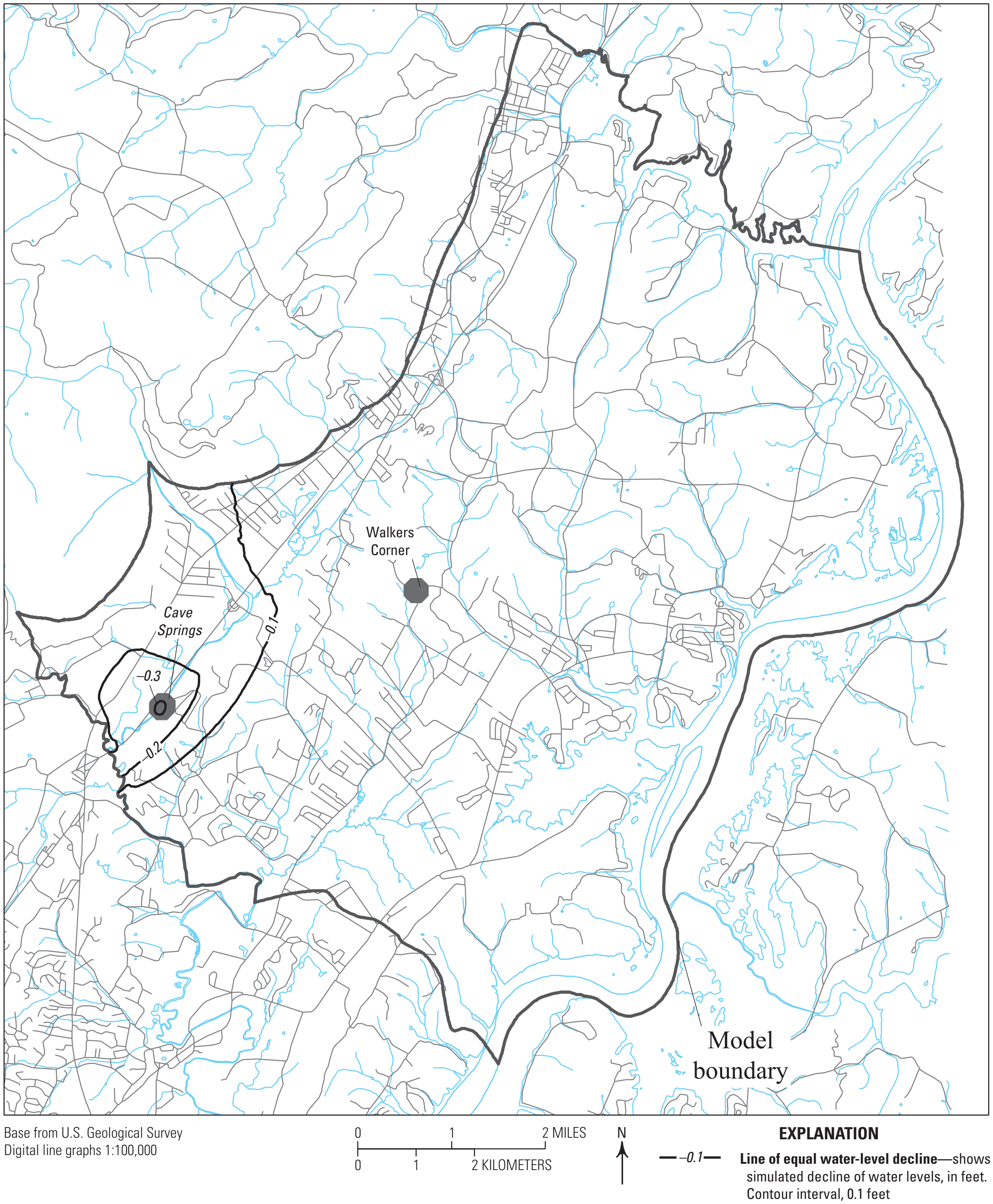


Figure 12. Simulated groundwater-level change from pumpage under scenario A.

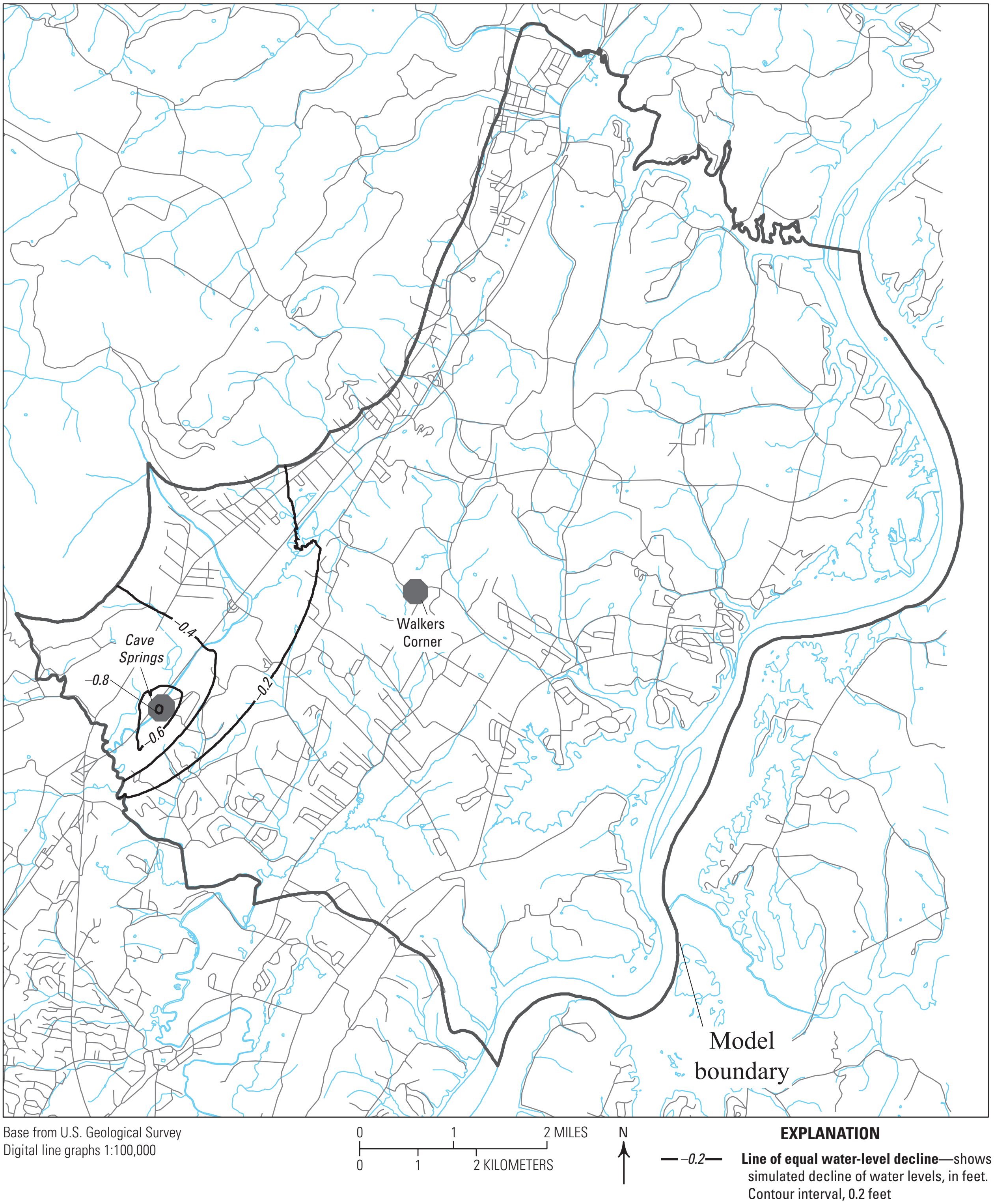


Figure 13. Simulated groundwater-level change from pumpage under scenario B.

Table 3. Simulated groundwater discharges and withdrawals for scenarios A and B.

[Groundwater withdrawal amounts are shown here in ft³/s. To convert ft³/s to Mgal/d, multiple by 0.65. Mgal/d, million gallons per day; ft³/s, cubic foot per second]

	Base case	Scenario A: Increase pumping in the Cave Springs well field by 2 Mgal/d			Scenario B: Increase pumping in the Cave Springs well field by 5 Mgal/d		
	Discharge, in ft^3/s	Discharge, in ft^3/s	Change from base case, in ft^3/s	Percent change from base case, in ft^3/s	Discharge, in ft^3/s	Change from base case, in ft^3/s	Percent change from base case, in ft^3/s
Groundwater discharge							
Chickamauga Lake	18.3	18.3	0.0	0	18.3	0.0	0
Poe Branch	3.6	3.4	–0.2	–6	3.1	–0.5	–14
Cave Springs	16.0	14.1	–1.9	–12	11.3	–4.7	–29
North Chickamauga Creek	33.6	32.6	–1.0	–3	31.0	–2.6	–8
Lick Branch and Rogers Spring	2.9	2.9	0.0	0	2.9	0.0	0
Groundwater withdrawal							
Wells at Cave Springs	7.8	10.9	3.1	40	15.6	7.8	100
Wells at Walkers Corner	4.2	4.2	0	0	4.2	0.0	0
Total from wells	12.0	15.1	3.1	26	19.8	7.8	65

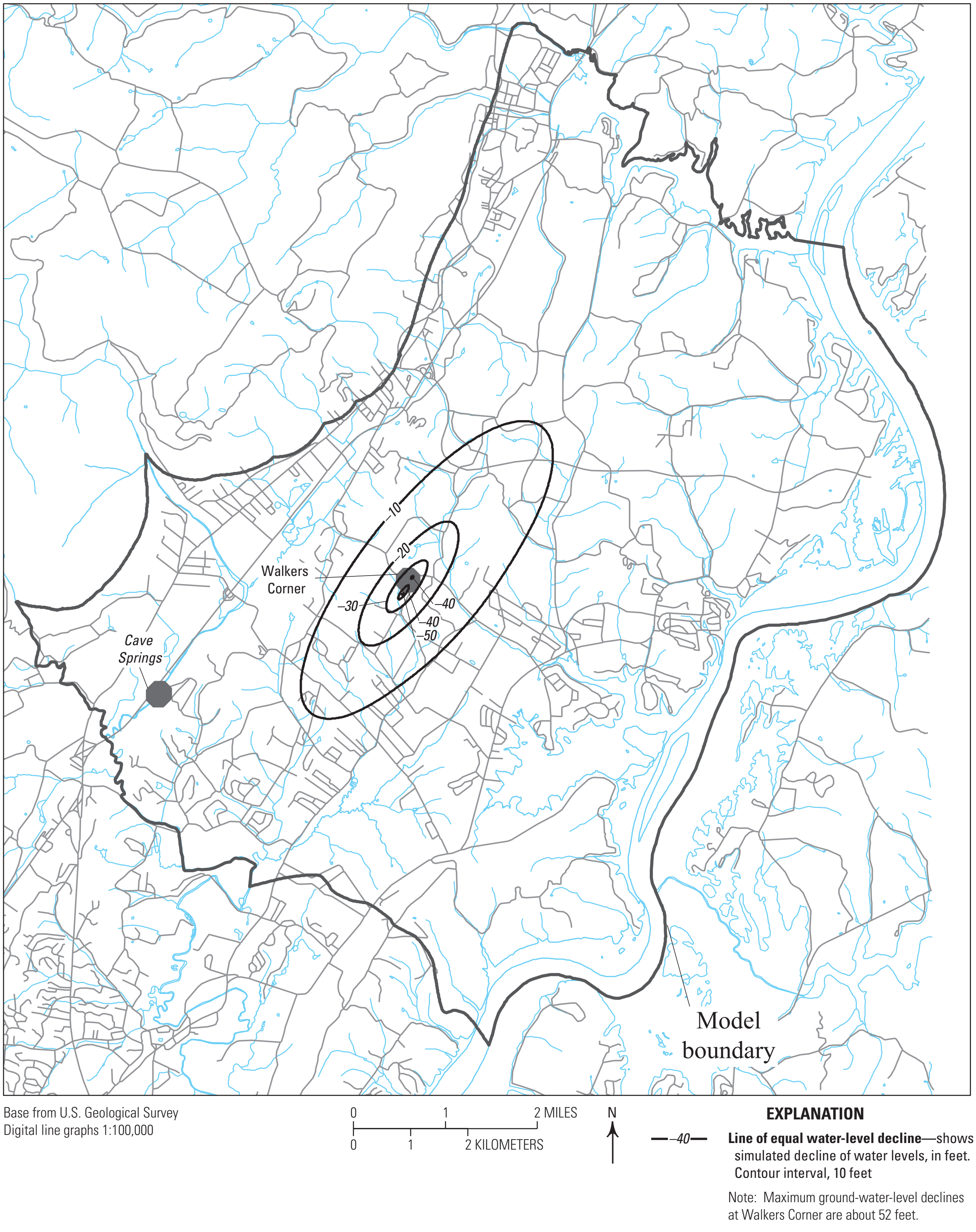


Figure 14. Simulated groundwater-level change from pumpage under scenario C.

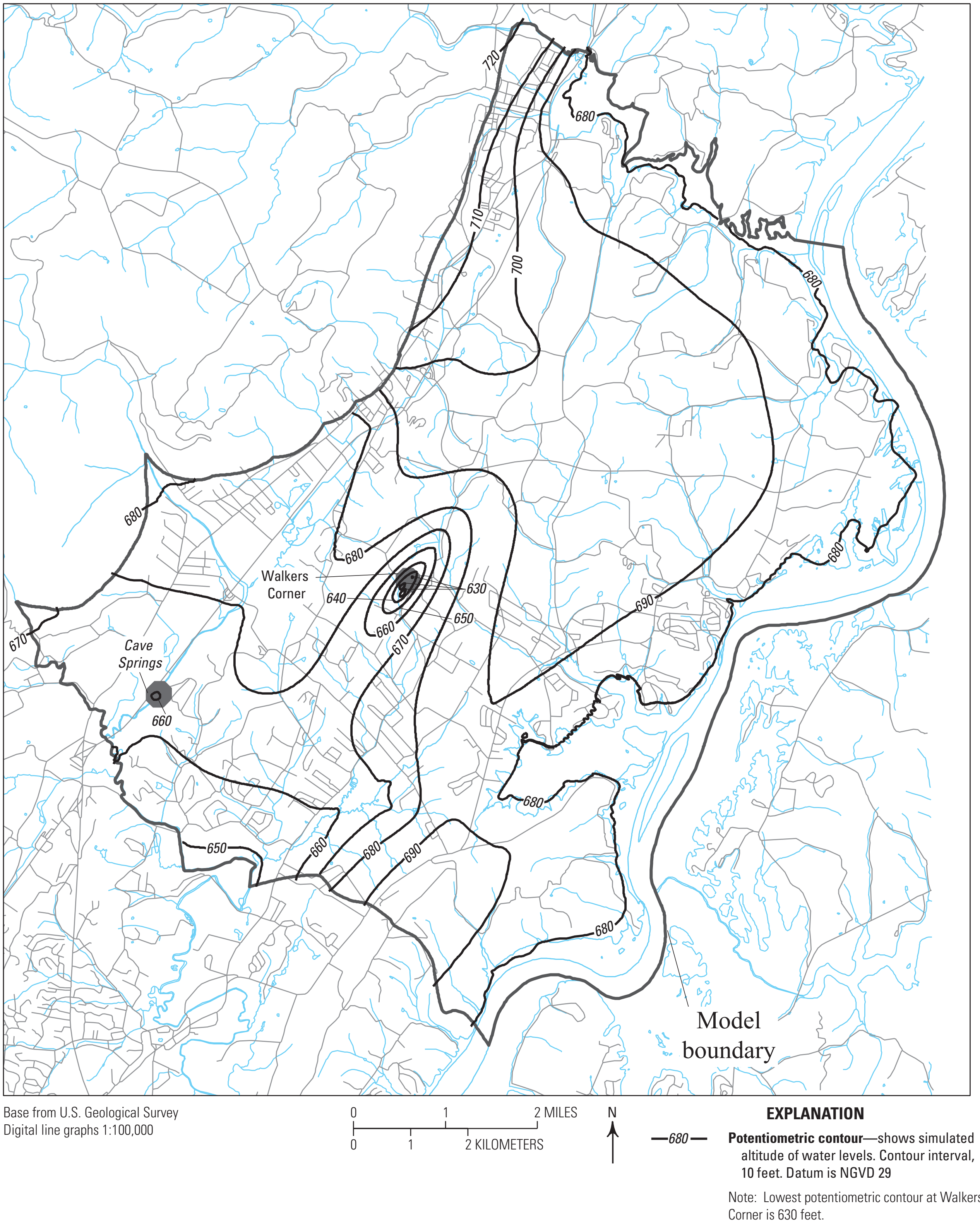


Figure 15. Simulated steady-state water levels under scenario C pumping conditions.

Table 4. Simulated groundwater discharges and withdrawals for scenarios C and D.

[Groundwater withdrawal amounts are shown here in ft³/s. To convert ft³/s to Mgal/d, multiple by 0.65. Mgal/d, million gallons per day; ft³/s, cubic foot per second]

	Base case	Scenario C: Increase pumping in the Walkers Corner well field by 2.6 Mgal/d			Scenario D: Increase pumping in the Walkers Corner well field by 4.5 Mgal/d		
	Discharge, in ft³/s	Discharge, in ft³/s	Change from base case, in ft³/s	Percent change from base case, in ft³/s	Discharge, in ft³/s	Change from base case, in ft³/s	Percent change from base case, in ft³/s
Groundwater discharge							
Chickamauga Lake	18.3	17.0	–1.3	–7	16.0	–2.3	–13
Poe Branch	3.6	3.0	–0.6	–17	2.6	–1.0	–28
Cave Springs	16.0	15.7	–0.3	–2	15.5	–0.5	–3
North Chickamauga Creek	33.6	32.5	–1.1	–3	31.5	–2.1	–6
Lick Branch and Rogers Spring	2.9	2.2	–0.7	–24	1.8	–1.1	–40
Groundwater withdrawal							
Wells at Cave Springs	7.8	7.8	0.0	0	7.8	0.0	0
Wells at Walkers Corner	4.2	8.2	4.0	95	11.2	7.0	167
Total from wells	12.0	16.0	4.0	33	19.0	7.0	58

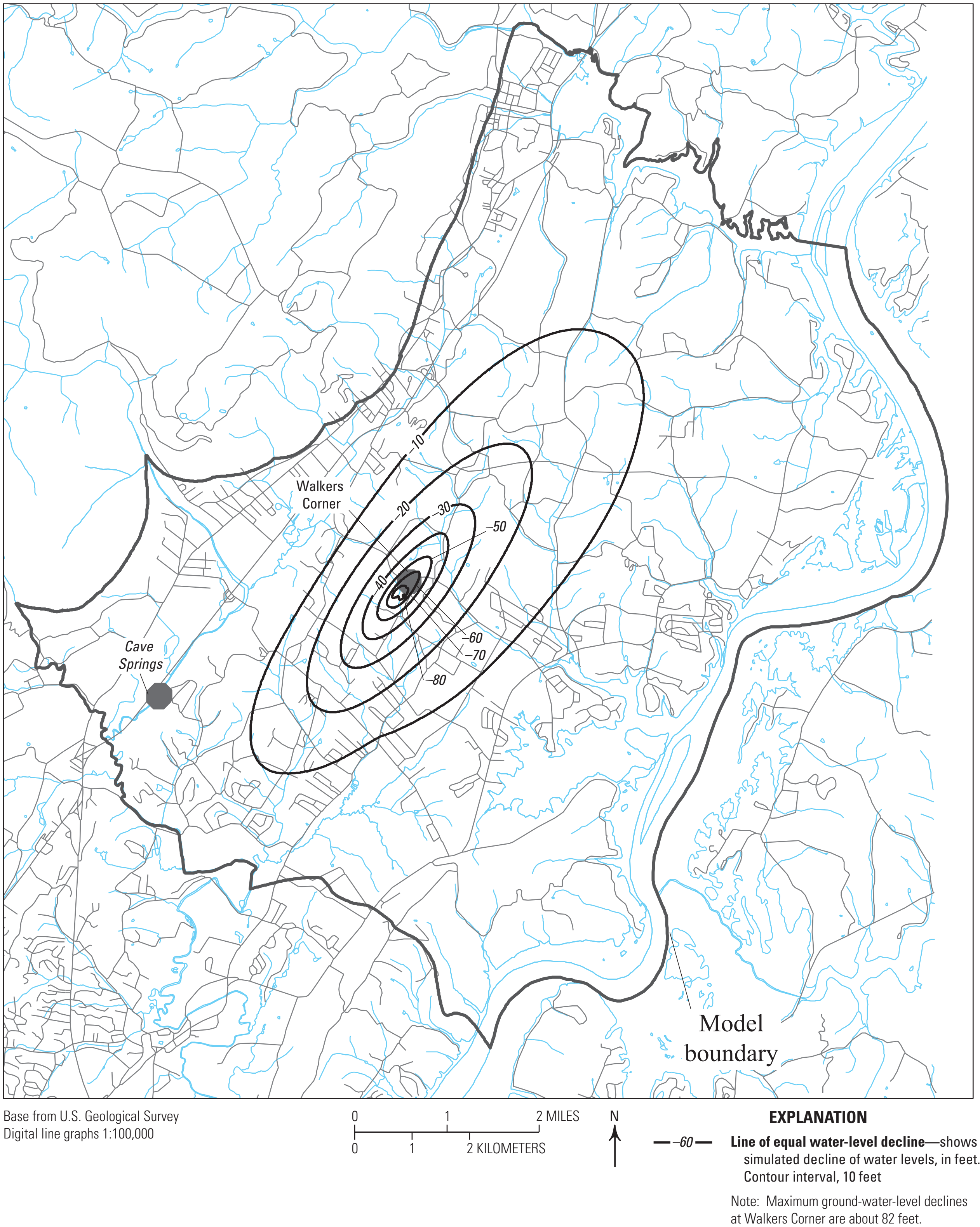
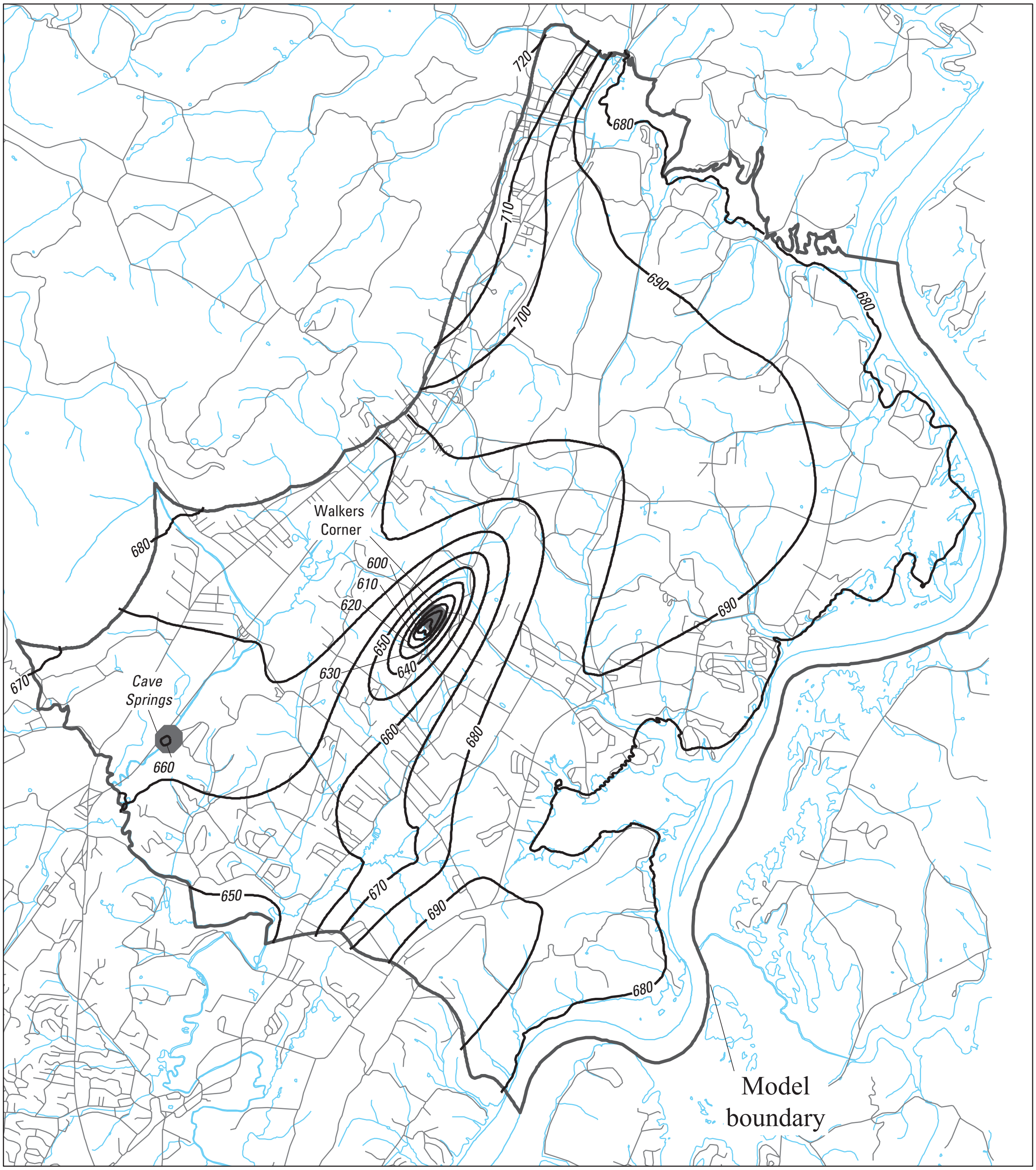


Figure 16. Simulated groundwater-level change from pumpage under scenario D.



Base from U.S. Geological Survey
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0 1 2 MILES
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EXPLANATION

—680— **Potentiometric contour**—shows simulated altitude of water levels. Contour interval, 10 feet. Datum is NGVD 29

Note: Lowest potentiometric contour at Walkers Corner is 600 feet.

Figure 17. Simulated steady-state water levels under scenario D pumping conditions.

Summary

The Hixson Utility District (HUD) uses groundwater resources in the Cave Springs area, Tennessee, as a water supply. HUD withdraws water from two well fields located at Cave Springs and Walkers Corner. Historically, HUD has withdrawn about 5 million gallons per day (Mgal/d) at the Cave Springs well field and between 2 and 3 Mgal/d at the Walkers Corner well field. Groundwater is present in both regolith and bedrock. Groundwater flow in the regolith occurs as diffuse flow as recharge from precipitation moves through the regolith to discharge to streams and springs or to the underlying bedrock. Most of the bedrock in the study area has low primary porosity and permeability; however, fracturing and dissolution have produced substantial secondary porosity and permeability. Groundwater flow through the bedrock occurs as both diffuse and conduit flow. Water levels in the aquifer at the well fields show normal seasonal variations and appear to be in equilibrium with current pumping rates.

Recharge to the aquifer is from two distinct sources: direct infiltration of precipitation and losing streams. A major source of recharge to the aquifer that supplies Cave Springs is surface water that is lost from North Chickamauga Creek as it flows off the Cumberland Plateau onto the Newman Limestone. The primary factors creating this losing reach are the altitude of the streambed relative to the water table and the presence of the Newman Limestone, which contains dissolution-enlarged fractures that can easily transmit water. Average annual streamflow loss (groundwater recharge) from this reach of North Chickamauga Creek for the period November 2000 through June 2006 is about 18 cubic feet per second (ft^3/s). Groundwater leaves the aquifer as either discharge to North Chickamauga Creek, Poe Branch, and Lick Branch; discharge to Chickamauga Lake; spring flow to Cave Springs or Rogers Spring; or withdrawals at Cave Springs or Walkers Corner well fields.

To assess the response of the groundwater system to meet possible future stresses, four different scenarios of increased groundwater withdrawals were analyzed using computer model simulations and compared to a base-case simulation. The base-case simulation used withdrawal amounts from 2012 with pumpage from the Cave Springs well field at 5.1 Mgal/d and Walkers Corner well field at 2.7 Mgal/d for total withdrawal of 7.8 Mgal/d. Effects of the increased withdrawals were analyzed by comparing water budget changes in groundwater discharges to Chickamauga Lake, North Chickamauga Creek, Cave Springs, and Poe Branch and Lick Branch/Rogers Spring for each of the scenarios. Under scenarios A and B, pumpage is increased at Cave Springs by 2 Mgal/d and 5 Mgal/d, respectively, while pumpage at Walkers Corner remains unchanged. The increases of 2 Mgal/d and 5 Mgal/d are based on estimates of future demand from the Cave Springs well field. The largest change in the water budget occurs for flow to Cave Springs, with decreases of 1.9 and 4.7 ft^3/s, respectively, for scenarios A and B. Similarly, groundwater discharge to North Chickamauga Creek decreases by 1.0 ft^3/s and 2.6 ft^3/s, respectively, for scenarios A and B. Under scenarios C and D, pumpage is increased at Walkers Corner by 2.6 Mgal/d and 4.5 Mgal/d, respectively, while pumpage at Cave Springs remains unchanged. The increase of 2.6 Mgal/d in scenario C assumes a third well is added at Walkers Corner and the two existing wells are pumped near capacity. The increase of 4.5 Mgal/d in scenario D assumes two additional wells at Walkers Corner and the two existing wells are pumped near capacity. The largest change in the water budget from scenarios C and D occurs for flow to Chickamauga Lake, with decreases of 1.3 ft^3/s and 2.3 ft^3/s, respectively. Similarly, groundwater discharge to North Chickamauga Creek decreases by 1.1 ft^3/s and 2.1 ft^3/s, respectively, for scenarios C and D. Because Walkers Corner is located near the center of the groundwater basin, effects of increased withdrawals at Walkers Corner are spread out among all the discharge points.

Changes in groundwater levels at the well fields were also analyzed. At the Cave Springs well field, maximum declines in groundwater levels due to additional pumpage are less than 1 foot (ft) for all scenarios. Groundwater-level changes at the Cave Springs well field are small due to the highly transmissive nature of the aquifer in this location. Maximum groundwater-level declines at Walkers Corner are less than 1 foot for scenarios A and B and about 52 ft and 82 ft for scenarios C and D, respectively. Under scenarios C and D, the regional potentiometric surface shows a large cone of depression centered on the Walkers Corner well field and elongated along geologic strike.

The results of the study indicate that the groundwater system in the Cave Springs area can supply the increased withdrawals simulated in the scenarios. The primary effects from the increased withdrawals at Cave Springs would be decreases in flow from Cave Springs and in the North Chickamauga Creek drainage. The primary effects from increased withdrawals at Walkers Corner would be lower groundwater levels around the Walkers Corner well field.

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