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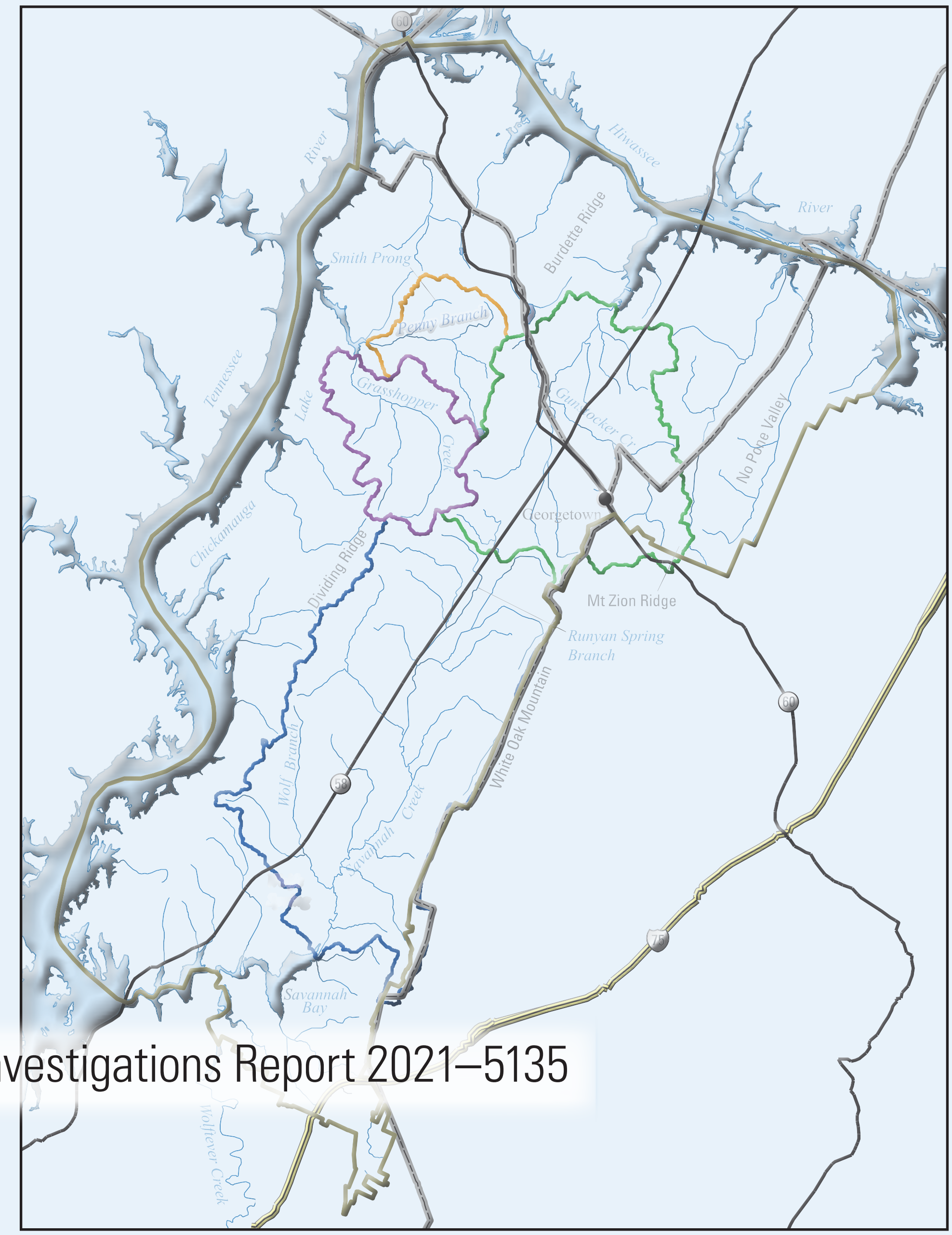
Groundwater Hydrology in the Area of Savannah and Gunstocker Creeks in Northeastern Hamilton, Southern Meigs, and Northwestern Bradley Counties, Tennessee, 2007–09



Scientific Investigations Report 2021–5135

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

Groundwater Hydrology in the Area of Savannah and Gunstocker Creeks in Northeastern Hamilton, Southern Meigs, and Northwestern Bradley Counties, Tennessee, 2007–09

By John K. Carmichael

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[Available for downloading from https://doi.org/10.3133/sir20215135]

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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)
gallon per minute (gal/min)	0.000063	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)

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

$°F = (1.8 \times °C) + 32$

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

$°C = (°F - 32) / 1.8$

Datum

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

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

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

Supplemental Information

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given in either milligrams per liter (mg/L) or micrograms per liter (µg/L).

Abbreviations

DO	dissolved oxygen
SC	specific conductance
SVUD	Savannah Valley Utility District
TVA	Tennessee Valley Authority
USGS	U.S. Geological Survey

Groundwater Hydrology in the Area of Savannah and Gunstocker Creeks in Northeastern Hamilton, Southern Meigs, and Northwestern Bradley Counties, Tennessee, 2007–09

By John K. Carmichael

Abstract

The U.S. Geological Survey, in cooperation with the Savannah Valley Utility District, evaluated the groundwater hydrology of the Valley and Ridge carbonate rock aquifer in northeastern Hamilton, southern Meigs, and northwestern Bradley Counties, Tennessee, from 2007 through 2009. The evaluation included, and built on, the results of test drilling conducted in the area in 1974 to determine the potential for groundwater as a source of public supply for the utility and the results of an investigation conducted to define recharge areas for wells used by groundwater-source public-supply water systems throughout Hamilton County in the early 1990s.

Groundwater-level data collected from wells open to the aquifer in the study area were used to prepare potentiometric-surface maps for fall 1992, spring and fall 1993, summer 2008, and spring 2009 conditions. Two primary groundwater basins were delineated from the maps—the larger of which coincides with the watershed of Savannah Creek in the southern part of the study area and the smaller of which coincides with the watershed of Gunstocker Creek in the northern part of the study area. Both basins are characterized by potentiometric surfaces that contain a central area of low-altitude groundwater levels and low gradients relative to the basin margins that reflect the orientation of enhanced permeability along dissolution-enlarged features that have developed parallel to strike in the aquifer. The recharge area of the Savannah Creek groundwater basin is estimated to be about 31 square miles, and the recharge area of the Gunstocker Creek groundwater basin is estimated to be about 17 square miles.

Recharge to the aquifer in the Savannah Creek and Gunstocker Creek groundwater basins primarily occurs in the uplands area along White Oak Mountain in the eastern part of the study area and along the western boundaries of the basins. Groundwater flows toward the potentiometric lows in each basin, discharging as base flow to the streams and to springs locally. Groundwater withdrawals for public supply by the utility influence the potentiometric low in the north-central part of the Savannah Creek groundwater basin and disrupt flow in the creek and nearby Anderson Spring, particularly during the summer and fall seasons. No large groundwater withdrawals currently occur in the Gunstocker Creek basin, but there is potential for groundwater supply development in the basin.

A conceptual model of the groundwater hydrology of the area developed from the evaluation indicates that Chickamauga Lake is the base-level control on groundwater discharge from the Savannah Creek and Gunstocker Creek basins and that lake stage affects the potentiometric surfaces and groundwater discharge in the most downgradient parts of the basins as a result of inferred hydraulic connection between the aquifer and the lake. The model also infers that captured surface water from sections of Savannah Creek and the Hiwassee River that are embayed by the lake could recharge the aquifer and serve as a source of water withdrawn by wells in each basin if the potentiometric surfaces were lowered to altitudes less than the stage of the lake, particularly under potential future groundwater-development scenarios in the Gunstocker Creek basin.

Geochemical analysis of samples collected from six wells for the study indicate that groundwater in the Valley and Ridge aquifer in the area generally is a calcium-magnesium-bicarbonate type, and although the water generally is hard, it is suitable for most uses. Trace-element concentrations were less than primary drinking-water criteria in all the samples.

Results of the investigation indicate that options are available for additional groundwater withdrawal in the study area. Water-level data collected since 1975 at the Savannah Valley Utility District Smith Road well site indicate that some additional amount of groundwater is available for withdrawal from the aquifer in the Savannah Creek groundwater basin. The potentiometric low within the Gunstocker Creek groundwater basin indicates that an area with enhanced permeability is present as a northeastern counterpart to the potentiometric low within the Savannah Creek basin. Because the Gunstocker Creek basin is about one-half the total area of the Savannah Creek basin, a commensurate decrease in available groundwater storage is likely. Furthermore, groundwater withdrawal locations in the Gunstocker Creek basin would be closer

to—and possibly connected hydraulically to—the Hiwassee River, thus increasing the potential for induced surface-water recharge in the basin if sustained drawdown from pumping lowered groundwater levels to altitudes less than the stage of the river.

Introduction

The Savannah Valley Utility District (SVUD) is a public water supplier with a service area located in northeastern Hamilton, southern Meigs, and northwestern Bradley Counties, Tennessee (fig. 1). The SVUD currently (2020) supplies from 2.2 to 2.75 million gallons of water per day (Mgal/d) to nearly 10,200 customers in the service area. Groundwater withdrawn from carbonate bedrock units of the karstic Valley and Ridge aquifer (Lloyd and Lyke, 1995) at three locations within and near the service area is the sole source of water supplied by the SVUD. Rapid development and population growth are occurring in parts of the SVUD service area. To meet the increasing demand for water, the SVUD contacted the U.S. Geological Survey (USGS) in 2007 about an interest in evaluating areas of additional groundwater development in its service area, particularly in the northern part of the area. As a result of this contact and its mission to collect information on and improve understanding of the water resources of the Nation, the USGS entered into a cooperative agreement with the SVUD to evaluate and characterize the groundwater hydrology of the Valley and Ridge aquifer within the SVUD service area.

Purpose and Scope

The purpose of this report is to present the results of an investigation of the groundwater hydrology in parts of the SVUD service area. The primary objectives of the investigation were to evaluate (1) the characteristics and extent of selected groundwater basins in the study area, (2) the temporal and spatial variations in water levels in the basins, and (3) the chemical characteristics of groundwater at selected locations within the basins. The study was conducted from 2007 through 2009. An additional component of the work included construction of potentiometric-surface maps using previously unpublished water-level data collected from wells in part of the area for a study that was conducted in 1992–93. The geospatial datasets that were used to create the potentiometric-surface maps developed from this study are available in Carmichael (2022).

Previous Investigations

The groundwater resources of East Tennessee were inventoried and described by DeBuchananne and Richardson (1956). The geology of East Tennessee was compiled and described by Rodgers (1953). The Tennessee Department of Conservation (1979) published an overview of the geology and the mineral and water resources of Hamilton County. Wilson mapped in detail the geology of the Snow Hill (Wilson, 1983), Ooltewah (Wilson, 1986), and Birchwood (Wilson, 2011) 7.5-minute quadrangles and summarized the mineral resources of these areas. Swingle and Finlayson (1963) mapped in detail the geology of the Grasshopper Creek (Soddy Island) 7.5-minute quadrangle and summarized the mineral resources of the area. Swingle (1959) described the stratigraphy, structural geology, mineral resources, and groundwater resources of a 240-square-mile (mi^2) area centered on Cleveland, Tennessee, that includes the South Cleveland 7.5-minute geologic quadrangle which contains a part of the study area described in this report. The discharge and chemical characteristics of 90 large springs in East Tennessee, including Anderson Spring and Carson Spring located in and near the study area (fig. 1), were described by Sun and others (1963). Hollyday and Smith (1990) developed discharge statistics for 171 large springs in the Valley and Ridge physiographic province in Tennessee, including Anderson Spring and Carson Spring. The groundwater hydrology of the lower Wolftever Creek basin, including Carson Spring, was described by Webster and Carmichael (1993). The Wolftever Creek basin lies immediately south of the SVUD study area and is relevant to the current study because of the similar hydrogeologic characteristics of the two areas. Lloyd and Lyke (1995) describe the geology and groundwater hydrology of the Valley and Ridge aquifers in East Tennessee as part of the Ground Water Atlas of the United States.

The USGS measured water levels in selected wells in Hamilton County during fall 1992 and spring and fall 1993, including wells in part of the SVUD service area, as part of a cooperative effort with the Chattanooga/Hamilton County Regional Planning Commission, the City of Chattanooga, Hamilton County, and the Hamilton County Association of Utility Districts to evaluate the recharge areas of wells used by groundwater-source public-supply water systems in the county. A generalized map of the potentiometric surface and inferred recharge area for its public-supply wells for spring 1993 conditions was prepared and submitted to the Tennessee Department of Environment and Conservation (TDEC) by the SVUD for the Wellhead Protection Program (TDEC, 2020). Because the data collected as part of the 1992–93 effort were never published, the spring 1993 potentiometric map was redrawn, and maps for fall 1992 and 1993 conditions were prepared as part of this study and are included in this report.

History of Public Groundwater Supply

The USGS has worked cooperatively on several efforts with the SVUD since the 1970s. In 1974, the USGS conducted a cooperative test-drilling program with the SVUD and Tennessee Valley Authority (TVA) to evaluate development of groundwater as an alternative to Chickamauga Lake, the source of water used by the SVUD at that time (D.R. Rima, USGS, written commun., 1974). As a result of this work,

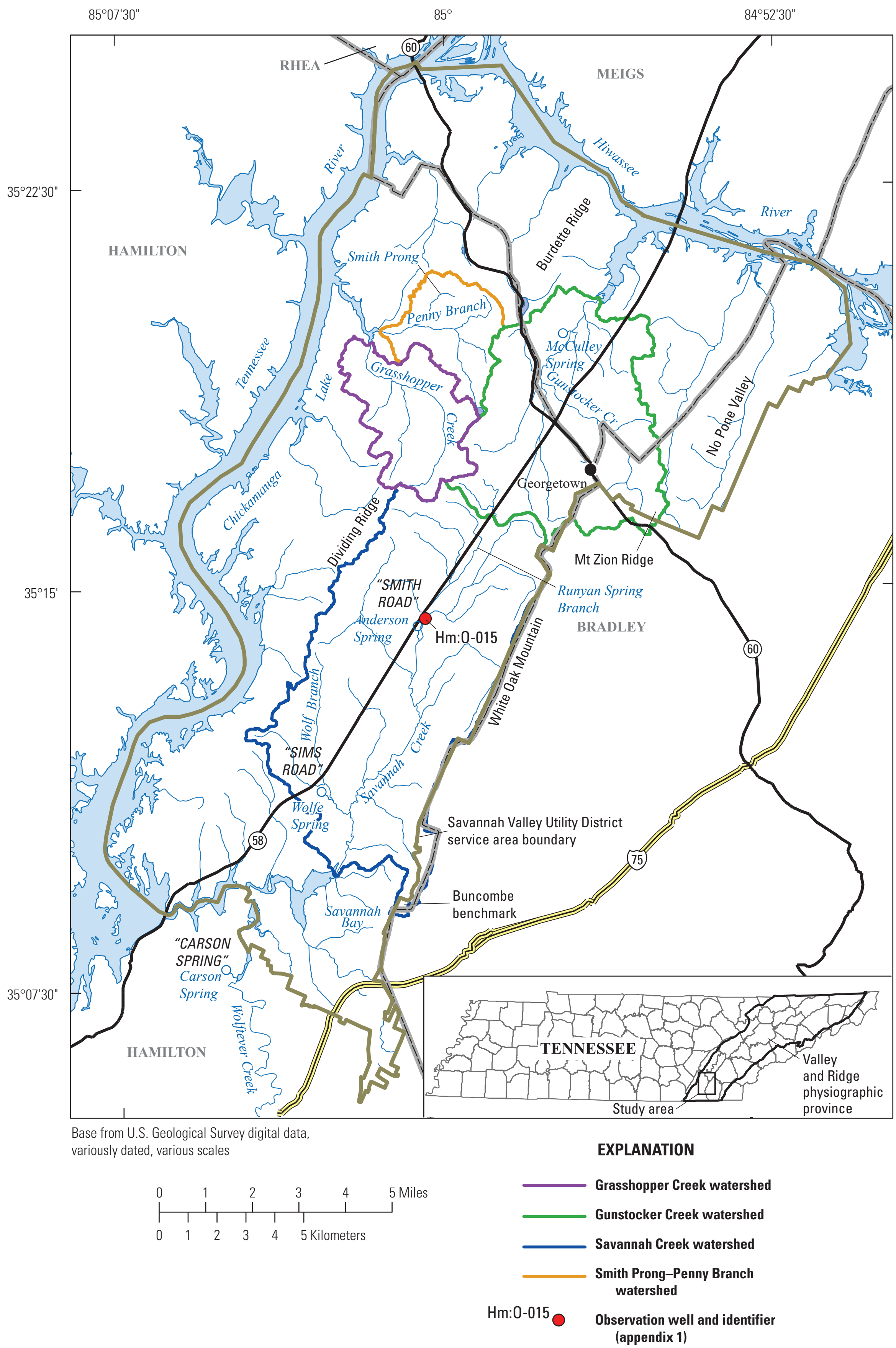


Figure 1. Location of the Savannah Valley Utility District study area in East Tennessee.

two wells were completed in the Valley and Ridge aquifer at one of the drilling sites tested for the study, located at the intersection of State Route 58 and Smith Road in northeastern Hamilton County (Smith Road well site, hereinafter referred to as the "Smith Road site"; fig. 1). One of the wells was completed as a production well. The other well (Hm:O-015) became an observation well, with continuous water-level data collected from it by the USGS since 1975 (USGS, 2020a). In 1977, a pump was installed in the production well, and a water treatment plant was constructed and brought online at the site. In 1978, a second production well was constructed at the Smith Road site. Currently, the two wells at the Smith Road site each have a reported capacity of about 700 gallons per minute (gal/min) and together can deliver up to about 2 Mgal/d into the onsite treatment plant that has a design capacity of 1.8 Mgal/d (Joe Barrows, SVUD, written commun., 2016).

The two production wells at the Smith Road site served as the sole water supply source for the utility until the early 1990s when SVUD completed construction of a second treatment plant and installed a single production well at another of the test-drilling sites evaluated by the USGS in 1974. Located about 3 miles (mi) south of the Smith Road site and just east of the intersection of Sims Road and State Route 58, this plant at the Sims Road well site (hereinafter referred to as the "Sims Road site"; fig. 1) has a reported design capacity of 0.86 Mgal/d (Joe Barrows, SVUD, written commun., 2016). The well at this site also is completed in the Valley and Ridge aquifer and is reported to pump about 500 gal/min (Joe Barrows, SVUD, written commun., 2016). The Sims Road plant has been used intermittently since its construction and currently serves as a standby water source for the utility.

The southern boundary of the SVUD service area coincides with the northern boundary of the service area for the Eastside Utility District (EUD). Until the early 1990s, the EUD used wells that withdraw groundwater from the Valley and Ridge aquifer at the site of Carson Spring, a large spring located adjacent to the Wolftever Creek embayment of Chickamauga Lake, an impoundment of the Tennessee River (fig. 1) that forms the western boundary of the EUD and SVUD service areas, as its sole source of water for public supply. Carson Spring has a mean annual discharge of about 6.0 cubic feet per second, or about 3.9 Mgal/d (Hollyday and Smith, 1990; Webster and Carmichael, 1993). Average annual production by the EUD from wells at the site was about 3.5 Mgal/d for 1987–89 (Webster and Carmichael, 1993). The EUD discontinued operation of the Carson Spring facility in the early 1990s when it took over operation of a surface-water treatment plant on Chickamauga Lake. In 2003, SVUD leased the Carson Spring facility from EUD and began using it as a supplemental water source to its Smith Road plant. Based on results of water-quality analyses of groundwater withdrawn by wells at the Carson Spring site, TDEC determined that groundwater at the site is under the influence of surface water from the constructed spring pool at the Carson Spring site and possibly from the Wolftever Creek embayment of Chickamauga Lake. Because of the surface-water influence and because treatment of groundwater at the original water plant at the Carson Spring site did not include filtration, TDEC set a maximum production limit of 1 Mgal/d for the onsite wells and plant for public-supply distribution (Joe Barrows, SVUD, oral commun., 2007). In 2013, the SVUD completed construction of a new membrane filtration water plant at the Carson Spring site. The new plant has an initial operating capacity of 2 Mgal/d and is designed to allow the SVUD to treat all sources of water withdrawn by the wells at the site.

Description of the Study Area

The study area approximately coincides with the SVUD service area (fig. 1) which has an area of about 144 mi^2. The study area is bounded on the north by the Hiwassee River, on the east by the approximate borders of Hamilton and Meigs Counties with Bradley County along White Oak Mountain, on the south by the Wolftever Creek and Savannah Creek (Savannah Bay) embayment of Chickamauga Lake, and on the west by Chickamauga Lake. The study area comprises parts of the Snow Hill, Birchwood, South Cleveland, and Grasshopper Creek (Soddy Island) 7.5-minute topographic and geologic quadrangle maps. Within the area, the primary focus of the study was on evaluating the groundwater hydrology and the extent of groundwater basins within the surface watersheds of Savannah Creek and Gunstocker Creek, and to a lesser extent, Grasshopper Creek and the Smith Prong–Penny Branch watersheds; these four watersheds cover a combined area of about 57 mi^2 within the east-central part of the SVUD service area (fig. 1).

Land use in the study area is primarily rural residential and agricultural. Small commercial centers are located in Georgetown and at various points along State Routes 58 and 60 (fig. 1), which provide primary access to the area.

Physiographic, Surface-Water, and Precipitation Characteristics

The study area lies within the Valley and Ridge physiographic province of East Tennessee (Fenneman, 1938), an area generally characterized by a parallel succession of northeast-trending ridges and valleys. Land-surface altitudes in the study area range from a low of about 680 feet (ft) above the National Geodetic Vertical Datum of 1929 (NGVD 29) at the mouth of Savannah Creek at Savannah Bay, to 1,495 ft above NGVD 29 at the Buncombe benchmark on White Oak Mountain, the highest of the parallel ridges in Hamilton County, which is located in the southeastern corner of the study area about 1.5 mi north of Interstate 75 (fig. 1).

Surface water in the study area drains either to the Hiwassee River, which flows westward along the northern boundary of the area and empties into the Tennessee River, or to the Tennessee River, which flows to the southwest along the western boundary of the study area and through the center of Hamilton County (fig. 1). Chickamauga Lake is formed by impoundment of the Tennessee River by Chickamauga Dam, which is located about 7.5 mi southwest of the southwestern corner of the study area. The elevation of the water surface (stage) of Chickamauga Lake is adjusted seasonally by the TVA for flood control and for hydroelectric power generation. The average stage of the lake ranges from about 677 ft above the North American Vertical Datum of 1988 (NAVD 88) at winter pool to about 683 ft above NAVD 88 at summer pool (Lakes Online, 2018).

Annual precipitation at the Chattanooga Metropolitan Airport, located about 10 mi southwest of the study area, averaged 52.48 inches (in.) for the period 1981–2010 (National Weather Service, 2018). The lowest average monthly precipitation in Chattanooga occurs during October, and the highest occurs during February–March. Precipitation during the period of study was below average in 2007 (38.62 in.) and 2008 (47.33 in.) and above average in 2009 (62.59 in.). Compared to the average precipitation for 1981–2010, precipitation for the 1992–93 period during which the USGS conducted an initial round of groundwater-level measurements in part of the study area, was slightly above average for 1992 (55.86 in.) and below average for 1993 (40.09 in.).

Geologic Setting

The bedrock geology in the study area consists of rock units of Cambrian to Mississippian age within the Valley and Ridge province (fig. 2) that make up part of the Valley and Ridge aquifer (Webster and Carmichael, 1993). These rock units have been folded and faulted by tectonic forces that are responsible for the creation of the Appalachian and Blue Ridge Mountains that lie to the east of the study area. Lateral compression of the Earth's crust from the southeast caused rock strata of the Valley and Ridge province to be folded into anticlines and synclines. These anticlines and synclines have been weathered from land surface to depths of a few hundred feet below land surface and are preserved as the succession of remnant valleys and ridges that trend northeast parallel to geologic strike and give rise to the province's name. The ridges typically are formed by sandstones and argillaceous/siliceous carbonate rocks that are more resistant to weathering than the valleys that are underlain by cherty carbonate rocks. In some places, forces causing deformation of the strata also produced thrust faults where older, more resistant units were pushed westward over the younger and weaker rocks (Fenneman, 1938). Where thrust faults occur, repeating sequences of older to younger rocks have been formed with decreasing depth across thrust planes.

Two significant thrust faults have been mapped in and near the study area: (1) the Kingston Fault (Wilson, 2011), which is mapped as a relatively simple, single plane thrust that runs east of and parallel to the Tennessee River in the western part of the study area; and (2) the Whiteoak Mountain Fault (Swingle, 1959), which is mapped as a more complex fault zone consisting of multiple thrust planes that runs parallel to and east of White Oak Mountain, about 1 mi east of the central and southern parts of the study area, and west of Mt. Zion Ridge in the northeastern part of the area (fig. 2*A*). Complex deformation consisting of crumpling and breakage of beds from folding is common near the leading edge of thrust-faulted strata, particularly the Whiteoak Mountain Fault, causing dips to steepen to as much as 70 degrees in the vicinity of Mount Zion Ridge (fig. 2*B*, geologic section *A–A′*). Away from the fault lines where formations are less deformed, strata dip more gently to the southeast at angles ranging from about 8 to 25 degrees across most of the study area.

Most of the study area is underlain by carbonate bedrock. Cherty dolomitic units of the Knox Group and limestones of the lower part of the Stones River Group represent the predominant lithology and tend to be the most important karst-forming units in the study area because of deeper weathering and increased secondary porosity of dissolution-enlarged features caused by circulating groundwater than has developed in other carbonate and shale units (Webster and Carmichael, 1993). Much of the Knox Group units are overlain by thick clay-rich residuum that contains large quantities of chert and other insoluble material derived from in situ chemical weathering of the carbonate parent rock. Residuum thicknesses of more than 100 ft overlie the deeply weathered dolomitic units in Hamilton County, particularly the Chepultepec Dolomite. Formations overlying the Knox Group are composed predominantly of limestone, argillaceous limestone, and fine-grained clastic matter. Because strata overlying the Knox Group contain less chert, residuum overlying these formations tends to be thin or nonexistent as a result of the higher resistance of these purer limestone units to weathering. Cavities occur in the dolomite and limestone units in the study area, and where present, they can lead to formation of sinkholes, which commonly develop as residuum is transported downward into cavities in the underlying bedrock.

Alluvium of Quaternary (Pleistocene and Holocene) age and fluvial deposits of Tertiary (Pliocene and Pleistocene) age occur in the study area, primarily along the Tennessee and Hiwassee Rivers, but some alluvium also occurs at locations along the other, smaller stream channels. Alluvium consists primarily of silt, sand, and gravel/cobbles that are composed primarily of chert, and ranges from 0 to 40 ft in thickness (Wilson, 1983). Fluvial deposits occur on the sides and tops of low hills near the Tennessee River. These deposits differ from the younger alluvium in that they consist primarily of rounded and poorly sorted quartzite, with sizes that range from pebbles through boulders, commonly in a fine sand and clay matrix

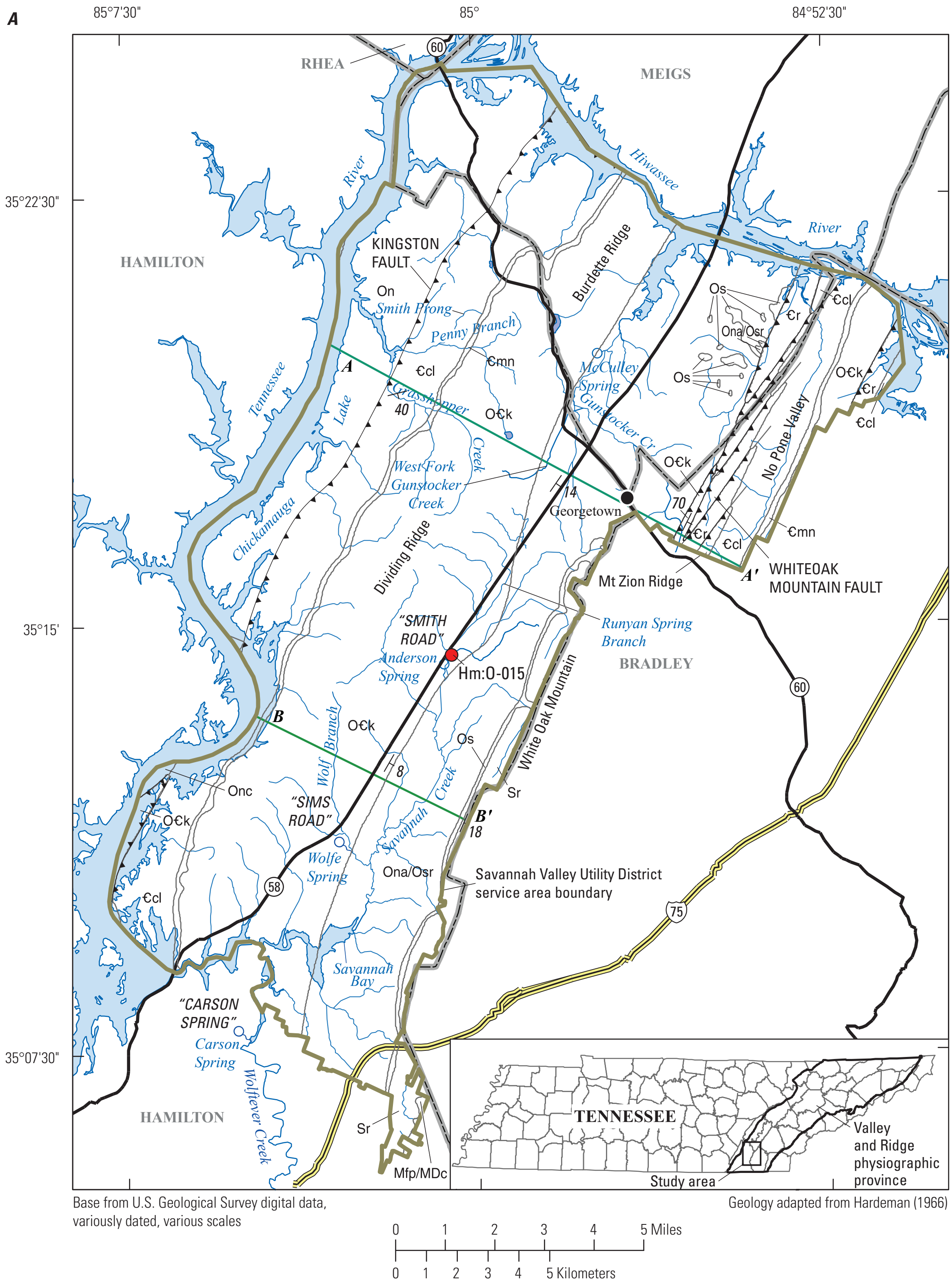
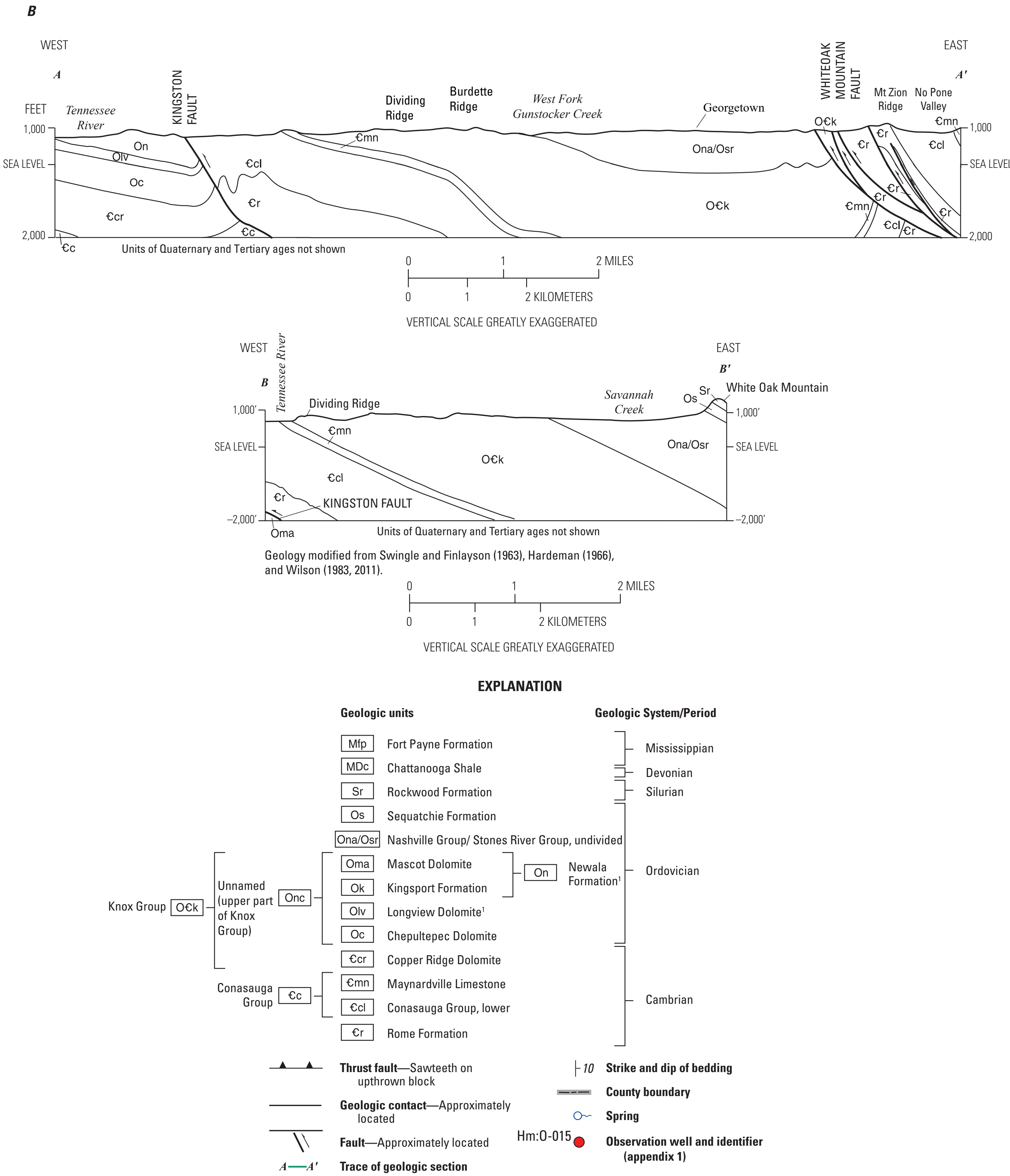


Figure 2. *A*, Geologic map of the Savannah Valley Utility District study area in East Tennessee and *B*, geologic sections *A*–*A*' and *B*–*B*'.



¹Longview Dolomite and Newala Formation names follow usage of the Tennessee Geological Survey.

Figure 2. *A*, Geologic map of the Savannah Valley Utility District study area in East Tennessee and *B*, geologic sections *A–A*′ and *B–B*′.—Continued

and loosely cemented by iron/manganese oxides. Thickness of the fluvial deposits in the area ranges from 0 to 50 ft (Wilson, 1983). Because of limited hydrogeologic significance in the study area, the alluvium and fluvial deposit units are not included with other surficial geologic units shown on figure 2.

Groundwater Hydrology

The principal groundwater-bearing units of the Valley and Ridge aquifer in the study area are the dolomitic formations of the Knox Group and limestones in the lower part of the Stones River Group that strike north-northeast and occupy the central part of the area (fig. 2). Formations in the upper part of the Stones River Group and younger overlying units in the study area typically contain less water because of their lesser thickness, fine-grained texture, clay content, and absence of appreciable quantities of chert (Webster and Carmichael, 1993).

Groundwater occurs in the interstices of the regolith and along bedding plane and fracture openings in bedrock. Saturated regolith supplies water to the openings in the underlying bedrock, with the thickest regolith having the greatest water storage capacity and potential for recharging bedrock (Webster and Carmichael, 1993). Water-table conditions occur in regolith and bedrock in the study area, and perched-groundwater conditions are present locally. Perched-water conditions are more common in topographically high-altitude areas that are underlain by bedded chert and have a relatively deep water table (Webster and Carmichael, 1993).

Recharge, Discharge, and Direction of Flow

The Valley and Ridge aquifer underlying the study area is refilled naturally by recharge from precipitation, either as diffuse infiltration through the regolith, or as concentrated runoff that recharges the bedrock through open swallets and (or) as surface-water flow that is lost to the bedrock following storm events where the water table occurs at a lower altitude than streambeds (Webster and Carmichael, 1993). A minor source of recharge likely occurs through recirculation of water used to irrigate lawns and gardens during the growing season.

Discharge from the Valley and Ridge aquifer occurs naturally at springs and seeps, along stream channels where the water table intersects the streambeds, and through evapotranspiration where the water table is at or near land surface (Webster and Carmichael, 1993). Additional discharge occurs by the pumping of wells. During this study, USGS personnel observed that some stream reaches in the study area, particularly those at higher altitudes and along the middle and upper reaches of Savannah Creek upstream of the Smith Road site, are ephemeral and flow only during the wet seasons or immediately following storm events during the dry seasons.

Throughout most of the study area, groundwater withdrawals are relatively small and consist only of pumping by private wells for domestic and (or) farmstead purposes. This likely is in part because the SVUD supplies water throughout the study area. The largest groundwater withdrawals in the area occur at the SVUD Smith Road site (fig. 1). Withdrawals for public supply at this location cause declines in groundwater levels locally, with the greatest declines during the summer and fall when precipitation is at its seasonal lowest and withdrawals are at their highest (fig. 3). Discharge from Anderson Spring, located about 0.25 mi south of the Smith Road site, is affected by withdrawals by the nearby production wells. During 2007–08, flow at the spring stopped during the summer and fall as a result of the combined effects of abnormally dry weather conditions and seasonal increase in withdrawals at the Smith Road site. Results of an elevation survey of observation well Hm:O-015, the two production wells at the Smith Road site, and Anderson Spring conducted by the USGS in September 2008 indicate that flow will cease at Anderson Spring when the water-level altitude in the observation well falls below about 736 ft above NAVD 88. When water levels in well Hm:O-015 fall below this altitude, withdrawals by wells at the Smith Road site become the primary mode of discharge from the aquifer locally, and the rate of water-level decline increases as groundwater storage in shallow water-bearing zones is depleted, particularly as seen during the drier than normal summers and falls of 2007 and 2008 (fig. 3). These findings are consistent with data collected from test drilling at the site in 1974 that show water-bearing zones at the overburden-bedrock interface at depths between about 25 and 35 ft below land surface that appear to represent zones of significant groundwater storage (D.R. Rima, USGS, written commun., 1974). Conversely, when the water-level altitude in observation well Hm:O-015 is greater than about 736 ft above NAVD 88, Anderson Spring and Savannah Creek serve as overflow locations for discharge from the Valley and Ridge aquifer locally, and the rate of water-level rise in the aquifer slows as the amount of groundwater released from storage to the spring and creek increases.

To determine the location and extent of groundwater basins and the direction of groundwater flow in the study area, potentiometric-surface maps were prepared for fall 1992, spring and fall 1993, summer 2008, and spring 2009 conditions (pls. 1–5, available at https://doi.org/10.3133/sir20215135). The maps are based on water levels measured in about 60 wells in 1992 and in about 100 wells in 1993 and 2008–09 in the study area (appendix 1). Most of the wells either are active or inactive domestic wells that are drilled into and are completed as open holes in bedrock. Supplemental information about the methods used for construction of the potentiometric-surface maps and delineation of the groundwater basins is presented in appendix 2.

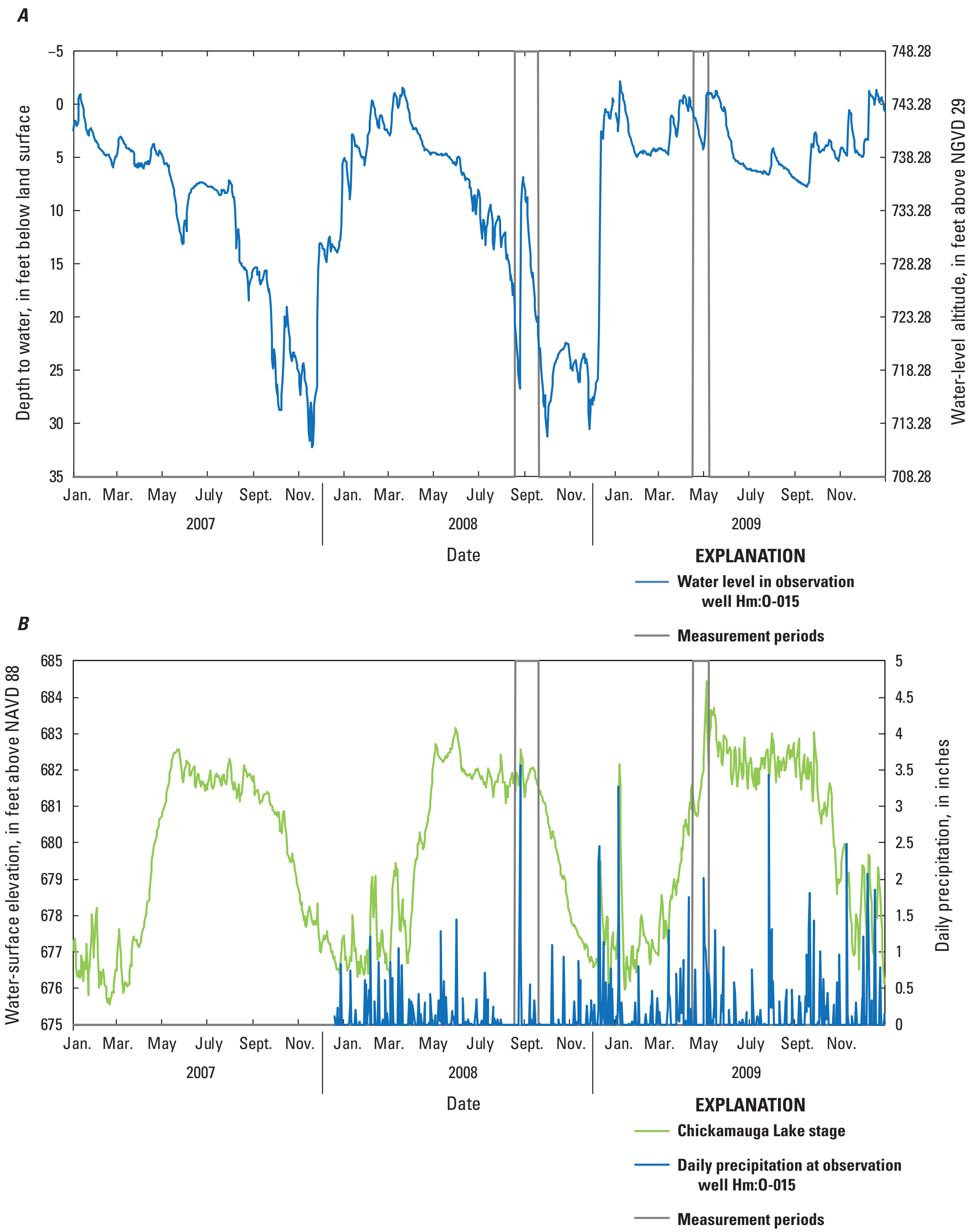


Figure 3. *A*, Depth to water and water-level altitude in observation well Hm:O-015 and *B*, water-surface elevation for Chickamauga Lake at Chickamauga Dam, daily precipitation at observation well Hm:O-015, and periods of groundwater-level measurements, 2007–09, Savannah Valley Utility District study area, East Tennessee. [NGVD 29, National Geodetic Vertical Datum of 1929; NAVD 88, North American Vertical Datum of 1988]

Hydraulic-head data shown on the potentiometric-surface maps indicate that net groundwater flow generally is from higher topographic areas in the eastern part of the study area toward the Hiwassee River to the north and toward the Tennessee River to the west and south (pls. 1–5). The lowest hydraulic heads occur in the northern and southern parts of the study area, while the highest hydraulic heads are inferred to occur beneath White Oak Mountain and Mount Zion Ridge along the eastern boundary of the area. Notable exceptions to these general flow directions occur in two primary areas where flow is intercepted and converges along lows in the potentiometric surfaces that parallel the strike of bedrock units of the Knox Group and lower part of the Stones River Group and that form groundwater basins that generally are coincident with the Savannah Creek and Gunstocker Creek watersheds. These groundwater basins are bounded to the west by a potentiometric divide that lies beneath Dividing and Burdette Ridges (fig. 1), and the basins are separated from each other by a potentiometric divide that is oriented perpendicular to State Route 58 about 1.75 mi southeast of the Hamilton-Meigs County line in the central part of the study area and that is about 0.75 mi north of the surface-water divide between the Savannah Creek and Gunstocker Creek watersheds (pls. 4 and 5).

The potentiometric-surface maps indicate that groundwater gradients range from relatively flat to steep across the study area (pls. 1–5). The steepest gradients in the area occur along the western slopes of White Oak Mountain and Mount Zion Ridge (fig. 1) and approximately correspond to the geologic contact between the Stones River Group and the overlying Sequatchie Formation, and to the imbricated zones of the lower Conasauga Group and the Rome Formation along the Whiteoak Mountain Fault complex, respectively (fig. 2). Steepening of the potentiometric surfaces in these areas implies reduced permeability and impeded flow within the bedrock units that underlie these elevated topographic features, and that increased gradients are required for groundwater movement. The lowest gradients occur within units of the upper Knox Group and lower part of the Stones River Group (fig. 2), particularly within the areas of Savannah Creek and Gunstocker Creek (pls. 4 and 5), and indicate the presence of hydraulically interconnected zones of relatively high permeability in bedrock in these areas that offer less resistance to flow.

The larger of the two mapped groundwater basins underlies the watershed of the southerly flowing Savannah Creek and its major tributaries in the central and southern parts of the study area (fig. 1). Although the basin is not fully delineated on the 1992–93 maps, all five maps indicate the primary direction of groundwater drainage in the basin is to the south (pls. 1–5). The Savannah Creek groundwater basin (pls. 4 and 5) is characterized by a potentiometric surface that contains a central area of low-altitude groundwater levels and low gradients (potentiometric low) relative to the basin margins that reflect the orientation of enhanced permeability along dissolution-enlarged features that have developed parallel to strike in the Mascot Dolomite, Kingsport Formation, and Chepultepec Dolomite of the Knox Group and in units of the lower part of the Stones River Group (fig. 2). The test-drilling program that was conducted with the SVUD in 1974 and led to development of the Smith Road and Sims Road sites was focused in this area, and large, water-filled cavities in bedrock were encountered during the drilling of several of the test holes (D.R. Rima, USGS, written commun., 1974). Although a limited number of wells exist for measuring water levels in the southern, most downgradient part of the Savannah Creek basin, each of the five potentiometric-surface maps infer that the primary location of groundwater discharge in this basin is to the lower reaches of Savannah Creek within the potentiometric low in the southern part of the study area (pls. 1–5). Anderson Spring and Wolfe Spring, which are focused discharge points for groundwater in the central and southern parts of the basin, issue near the mapped contact between the lower Stones River Group and the Mascot Dolomite, the uppermost unit of the Knox Group (fig. 2). Water-level data (USGS, 2020a) collected from observation well Hm:O-015 indicate that the effects of groundwater withdrawals from nearby production wells at the Smith Road site and the seasonal discharge from Anderson Spring are seen locally and thus exert control on the configuration of the water surface in the north-central part of the potentiometric low. Although the single production well at the Sims Road site currently is used only as a standby source by the SVUD, occasional pumping from this well during the study, particularly during the summer and fall, was observed to produce short-term declines in the potentiometric surface locally that reduced the discharge of nearby Wolfe Spring (fig. 1).

The other prominent groundwater basin identified is coincident with the watershed of the northerly flowing Gunstocker Creek in the northern part of the study area (fig. 1). Although none of the basin is shown on the 1992 map and the basin is only partially delineated on the 1993 maps, the primary direction of groundwater drainage in the basin is to the north (pls. 2–5). Similar to the potentiometric low of the Savannah Creek groundwater basin, a potentiometric low also has developed along strike in the central part of the Gunstocker Creek groundwater basin, primarily in the Mascot Dolomite and Kingsport Formation of the Knox Group and units of the lower Stones River Group; the gentle gradient it exhibits also indicates the existence of subsurface features with enhanced permeability in bedrock. While only a limited number of wells were available for use in delineating the potentiometric surface in the northern, most downgradient part of the Gunstocker Creek groundwater basin, the 1993 and 2008–09 maps infer that the primary location of groundwater discharge appears to be the lower reaches of Gunstocker Creek within the potentiometric low in the northern part of the study area (pls. 2–5). Other than withdrawals for domestic and (or) farmstead use, no large groundwater production currently occurs in this basin.

Seasonal water-level fluctuations were compared between the summer 2008 and spring 2009 measurement periods, even though the summer 2008 measurement period included a significant rainfall event, because measurements made during these two periods represent the most complete water-level datasets for comparison. Between summer 2008 and spring 2009, water levels increased in 84 of the 92 wells that were measured during both periods. The minimum increase was 0.3 ft, the maximum increase was 29.8 ft, the average increase was 8.5 ft, and the median increase was 6.0 ft. Five wells had water levels that declined between the two periods, with declines ranging from 2.1 to 9.5 ft. Water levels measured in three wells differed by only ±0.01 ft and are considered as unchanged between the two periods. The eight wells with declines or no change in water levels all are located in a fairly small, higher altitude area in the northeastern part of the Savannah Creek groundwater basin that is underlain by units of the upper Stones River Group, which are considered less permeable than the lower part of this Group and the underlying Knox Group, and where groundwater gradients steepen to the east along the western flank of White Oak Mountain. Wells with the greatest water-level increases (greater than 15 ft) are almost exclusively within the potentiometric low of the Savannah Creek groundwater basin, in the area that is underlain by the more permeable units of the Knox and lower Stones River Groups. Wells with the least amount of water-level change between the two measurement periods (less than 5 ft) are relatively evenly distributed throughout the study area.

The large water-level changes in some wells between the two measurement periods may be explained in part by the change in rainfall from below average in 2007 (38.62 in.) and 2008 (47.33 in.) to above average in 2009 (62.59 in.) (National Weather Service, 2018) and especially by the large amount of rainfall that fell in the area in the middle of the summer 2008 measurement period (fig. 3) from the remnants of Tropical Storm Fay (Stewart and Beven, 2009). Approximately 6.3 inches of rain from the storm were measured in the gage at observation well Hm:O-015 at the Smith Road site during August 26–28, 2008. Water levels in well Hm:O-015 increased 20 ft in response to the storm. Water levels had been measured in 20 wells in the northern part of the study area during the week prior to the storm, with the remaining 75 wells in the southern part of the study area measured over a 3-week period following the storm (see pre-post rain line indicating areas where wells were measured in the northern (pre-rain) and southern (post-rain) parts of the study area on plate 4). Based on the continuous water-level data collected from well Hm:O-015, it took approximately 1 month for groundwater levels to return to pre-storm levels in this well. If the hydrograph for well Hm:O-015 is illustrative of general groundwater conditions over the study area, then groundwater levels in the area where wells were measured before the storm in the northern part of the study area may be considered representative of low stream base-flow conditions, whereas levels in the remaining part of the study area where wells were measured after the storm can be considered to represent higher base-flow conditions (pl. 4). Although the rainfall also resulted in higher water levels in the southern part of the study area, the potentiometric-surface map for summer 2008 generally maintains the same potentiometric features as, and conforms to the overall shape of, the map for spring 2009 (pls. 4 and 5).

Savannah Creek and Gunstocker Creek Groundwater Basin Recharge Areas

The recharge area for the Smith Road and Sims Road sites originally was estimated from the spring 1993 potentiometric-surface map, and this area was used as the delineated Wellhead Protection Area for the Smith Road site (pls. 2–5). The estimated area was calculated to be about 13.8 mi^2 and is coincident in part with the Savannah Creek watershed. The potentiometric-surface maps for the summer 2008 and spring 2009 measurements cover a larger area than the maps for 1992–93. Based on the expanded coverage, the recharge area for the Smith and Sims Road sites (coincident with the Savannah Creek groundwater basin) was redrawn, and the recharge area of the Gunstocker Creek groundwater basin also was estimated (pls. 4 and 5). The revised recharge area estimated from the 2008–09 maps more than doubled the size of the Savannah Creek groundwater basin from about 14 to about 31 mi^2, and the size of the Gunstocker Creek groundwater basin was estimated to be about 17 mi^2. Furthermore, the total areas estimated for the Savannah Creek and Gunstocker Creek groundwater basins compare favorably between the summer 2008 and spring 2009 maps at about 31.2 and 31.0 mi^2, and 17.0 and 16.8 mi^2, respectively. The estimated total areas of the Savannah Creek and Gunstocker Creek groundwater basins also compare closely with the delineated watersheds of the streams at 30.9 and 16.0 mi^2, respectively.

The southern boundary of the Savannah Creek groundwater basin is at the confluence of Savannah Creek and Savannah Bay, and the northern boundary of the Gunstocker Creek groundwater basin is at the confluence of Gunstocker Creek and the Hiwassee River embayment (pls. 4 and 5). According to the maps, these two points are inferred to be the downgradient-most locations for groundwater discharge from the two basins, and, as such, the relation between groundwater levels and the amount of groundwater discharged at each location likely is influenced by changes in the stage of Chickamauga Lake between winter (677 ft above NAVD 88) and summer (683 ft above NAVD 88) pools (fig. 3). If withdrawal of groundwater in either basin was to reduce the potentiometric surfaces to lower altitudes than the stage of Chickamauga Lake at the downgradient ends of the basins, captured surface water from the embayments could recharge the aquifer in that basin. Because no large groundwater withdrawals presently occur in the Gunstocker Creek basin, surface water from the Hiwassee River embayment is an unlikely source of recharge to this basin. Because of abnormally dry conditions, water levels in observation well Hm:O-015 at the Smith Road site decreased to altitudes of less than 715 ft above NAVD 88 for short periods during fall 2007 and fall and winter 2008 (fig. 3). Future climatic conditions and potential for increased groundwater withdrawals for public supply at the Smith Road and Sims Road sites could lower hydraulic heads enough in the aquifer in the Savannah Creek groundwater basin to induce capture of surface water from Savannah Bay. Notably, only a few wells were measured during fall 1992 (well C-18), spring 1993 (well C-18), fall 1993 (wells C-12, C-14, C-18, C-57, and C-58), and summer 2008 (well C-15) (pls. 1–4) in the southern part of the Savannah Creek groundwater basin with water levels that were less than 680 ft above NAVD 88, which is the approximate annual average stage of Chickamauga Lake. Except for well C-15, which was not being used for production when measured in 2008, it is possible that water-level altitudes that are less than 680 ft above NAVD 88 for the other five wells measured in 1992–93 may represent pumping-affected levels, and (or) in the case of all the wells, that the DEM-derived land-surface altitudes that were used to calculate the water-level altitudes for the indicated periods (appendix 1) may be incorrect.

Conceptualization of the Groundwater System

Discussion presented in the previous sections provides the basis for development of a conceptual model of the groundwater system in the Savannah Creek and Gunstocker Creek groundwater basins. Because the Savannah Creek groundwater basin is the larger of the two basins and because withdrawal of groundwater for public supply currently only affects the flow field in this basin, emphasis is given to this basin in the following conceptualization of the overall groundwater-flow system in the study area.

The conceptual model implies a balance of groundwater-flow system components that account for recharge, storage, transmission, and discharge for the aquifer. Regionally, recharge from precipitation infiltrates the groundwater-flow system in the higher altitude areas along the western side of White Oak Mountain and then flows westward toward the potentiometric lows in the central parts of the Savannah Creek and Gunstocker Creek groundwater basins (pls. 4 and 5). Recharge also enters the higher altitude areas along the eastern side of Dividing Ridge (fig. 1) before it flows eastward toward the low in the Savannah Creek basin, as well as the higher altitude areas along the eastern side of Burdette Ridge (fig. 1) before it flows eastward toward the low in the Gunstocker Creek basin. Locally, recharge to the aquifer in the two groundwater basins also occurs from drainage of water held in storage in regolith overlying bedrock and in the form of lost streamflow following precipitation events where and when the potentiometric surfaces are at a lower altitude than land surface, particularly in the Savannah Creek basin near the Smith Road site where groundwater levels are affected by withdrawals by the SVUD. Bedrock cavities that are aligned with strike in units of the Knox Group and lower Stones River Group and that are interconnected laterally and vertically intersect the flow fields and provide for the storage and transmission of water in transit from recharge to discharge areas in each groundwater basin. The size and interconnectivity of the cavities determine their transmissivity and the amount of water they can convey.

Groundwater in excess of the storage and transmission capacity of the bedrock cavity system in the study area is inferred to discharge primarily to Savannah and Gunstocker Creeks and to springs and seeps within the corresponding groundwater basins. In the central and northern parts of the Savannah Creek basin, near and north of the Smith Road site, the potentiometric surface has been lowered by withdrawals by SVUD, causing seasonal changes in groundwater storage in the aquifer and ephemeral base-flow discharge to the creek. South of Anderson Spring in the central and southern parts of the Savannah Creek basin, outside the area affected by withdrawals at the Smith Road site, the potentiometric surface intersects the streambed, and groundwater discharge sustains base flow in the stream. The southern extent of the area affected by pumping at the Smith Road site, south of which groundwater discharges to Savannah Creek, varies seasonally and from year to year depending on rainfall and the extent of effects of groundwater withdrawals by the wells. Based on water levels measured in observation well Hm:O-015, the intermittent nature of flow from Anderson Spring, and observations of flow from Wolfe Spring throughout the study except during periods of pumping at the Sims Road site, the conceptual model implies that the point of sustained base-flow discharge to Savannah Creek likely moves north and south between these two springs seasonally. No large groundwater withdrawals currently (2021) are occurring in the Gunstocker Creek basin; therefore, groundwater discharge occurs primarily as base flow to the creek and to springs and seeps throughout the basin where the altitude of the potentiometric surface exceeds that of land surface.

Chickamauga Lake serves as the base level for discharge from the Savannah Creek and Gunstocker Creek groundwater basins, and the seasonally adjusted stage of the lake influences storage and discharge from the aquifer in the downgradient-most parts of each basin. The delineated downgradient boundaries of the two basins as indicated by the potentiometric maps terminate at the points where Savannah Creek and Gunstocker Creek meet the Savannah Bay embayment and the Hiwassee River embayment by Chickamauga Lake, respectively. Additional groundwater discharge may occur farther downgradient at locations that are inundated by the embayments, including submerged locations along the contact between formations in the lower part of the Stones River Group and upper part of the Knox Group which forms the issue points for Wolfe and Anderson Springs in the Savannah Creek groundwater basin and Carson Spring in the Wolftever Creek groundwater basin (fig. 2).

The cavity systems that have developed in bedrock in the groundwater basins also provide storage for water that is discharged at springs and withdrawn by wells. Storage changes in the Gunstocker Creek basin primarily occur in response to seasonal variability in recharge and discharge, the latter of which is influenced to some extent by adjustments in the stage of the Hiwassee River embayment by Chickamauga Lake, because of the small amount of groundwater withdrawals by wells and the absence of large unsubmerged springs in this basin. In the Savannah Creek basin, changes in storage occur primarily in response to groundwater withdrawals by the SVUD production wells at the Smith Road site, as evidenced by the prominent potentiometric low that is present in the central part of the basin (pls. 1–5). Regardless of current groundwater withdrawals, the conceptual model implies that large groundwater withdrawals by wells in either basin could reverse gradients such that embayed surface water could serve as a source of recharge to the aquifer. In this situation, the bedrock cavity systems would function as conduits that deliver water not only from the aquifer but possibly from these surface-water sources to production wells.

The conceptual model also includes evidence that formations of the Knox Group and lower Stones River Group are the most permeable units in the study area, whereas units in the upper Stones River Group and the lower Conasauga Group are the least permeable. Higher permeability is indicated by the uniformly low gradients seen in the potentiometric surfaces within units of the Knox Group and lower Stones River Group in the Savannah Creek and Gunstocker Creek groundwater basins. In the Savannah Creek groundwater basin, higher permeability also is indicated by secondary potentiometric lows that lie to the west of the primary low and that indicate the presence of tributary cavities that merge with the primary cavities present in bedrock in the vicinity of Savannah Creek. Conversely, areas within the Savannah Creek and Gunstocker Creek groundwater basins where bedrock permeability is lower are indicated by steeper gradients in the potentiometric surfaces that occur along the flanks of the potentiometric lows within these basins in areas underlain by units of the upper part of the Stones River and lower part of the Conasauga Groups.

Groundwater Quality

Groundwater samples were collected from six wells completed in bedrock units within the Valley and Ridge aquifer in the study area (fig. 4) in December 2008 using procedures described in USGS (2006), and the samples were analyzed for major dissolved constituents and trace metals (table 1) at the USGS National Water Quality Laboratory (Fishman and Friedman, 1989). The sampled wells are relatively evenly distributed throughout the SVUD service area, with four of the wells located in the northern part of the area and two wells located in the southern part. Two of the wells (C-21 and C-56) are located in the Savannah Creek groundwater basin (pls. 4 and 5), one well (C-80) is located in the Gunstocker Creek groundwater basin, one well (C-82b) is located along the divide between the Savannah and Gunstocker Creek groundwater basins, one well (C-91b) is located in a topographic saddle along the northwestern divide of the Gunstocker Creek groundwater basin, and one well (C-93) is located in the western, downgradient part of the Grasshopper Creek watershed.

Analyses of water samples collected from the six wells indicate that the water is a calcium-magnesium-bicarbonate type (fig. 5) and is suitable for most uses. Water from all six wells is oxic, with dissolved oxygen (DO) concentrations ranging from 2.3 to 8.9 milligrams per liter (mg/L) (table 1). Water from most of the wells is characterized as hard or very hard (Hem, 1985), with hardness values for samples from five of the six wells (C-21, C-56, C-80, C-82b, and C-93) greater than 142 mg/L as calcium bicarbonate ($CaCO_3$) (table 1). Samples from these five wells also had specific conductance (SC) values ranging from 263 to 762 microsiemens per centimeter at 25 degrees Celsius (µS/cm), near neutral pH values ranging from 6.6 to 7.7, and dissolved solids concentrations ranging from 140 to 457 mg/L. Concentrations of all analyzed trace elements were less than primary drinking-water criteria (U.S. Environmental Protection Agency, 2018).

All the sampled wells are reported to be completed as open holes in bedrock. Wells C-56, C-80, and C-82b are three of the deepest wells that were sampled, with depths ranging from 180 to 270 ft below land surface. These three wells are open to intervals in bedrock units of the Knox Group (fig. 4) in the Savannah Creek (C-56) and the Grasshopper Creek (C-80 and C-82b) groundwater basins (pls. 4 and 5), and SC values and dissolved solids concentrations in samples from these wells ranged from 263 to 762 µS/cm and from 140 to 457 mg/L, respectively (table 1). Well C-93 produced a sample with a relatively high SC value (308 µS/cm) and dissolved solids concentration (168 mg/L). This well, located along the Kingston Fault, is 225 ft deep and is open to bedrock units of the lower Conasauga Group and (or) the upper Knox Group in the Grasshopper Creek watershed (fig. 4). In general, the chemistry of samples from wells C-56, C-80, C-82b, and C-93 (fig. 5) is indicative of water in circulation in carbonate bedrock units that make up the Valley and Ridge aquifer.

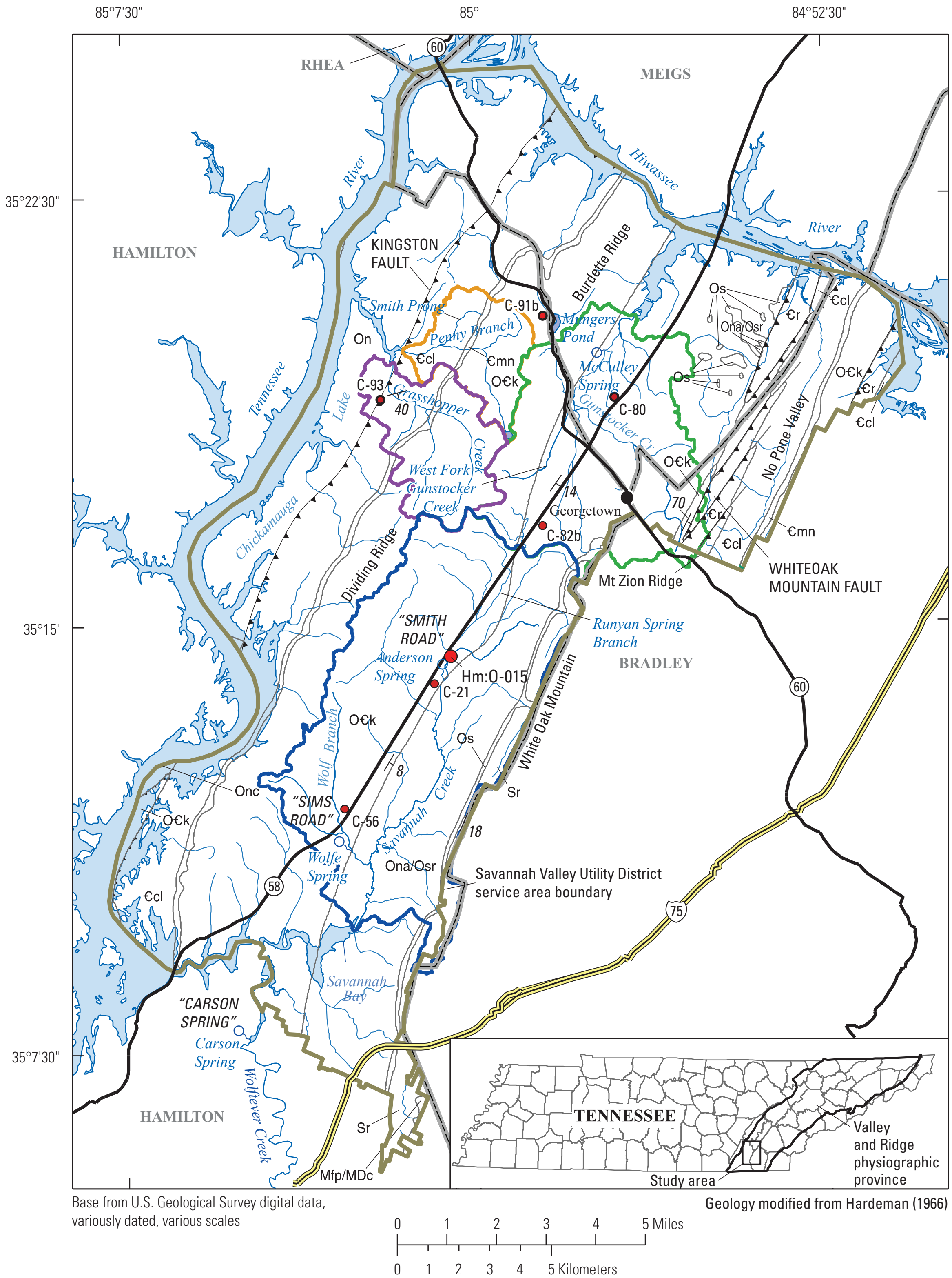


Figure 4. Location of wells sampled for water-quality analyses in the Savannah Valley Utility District study area in East Tennessee, December 2008.

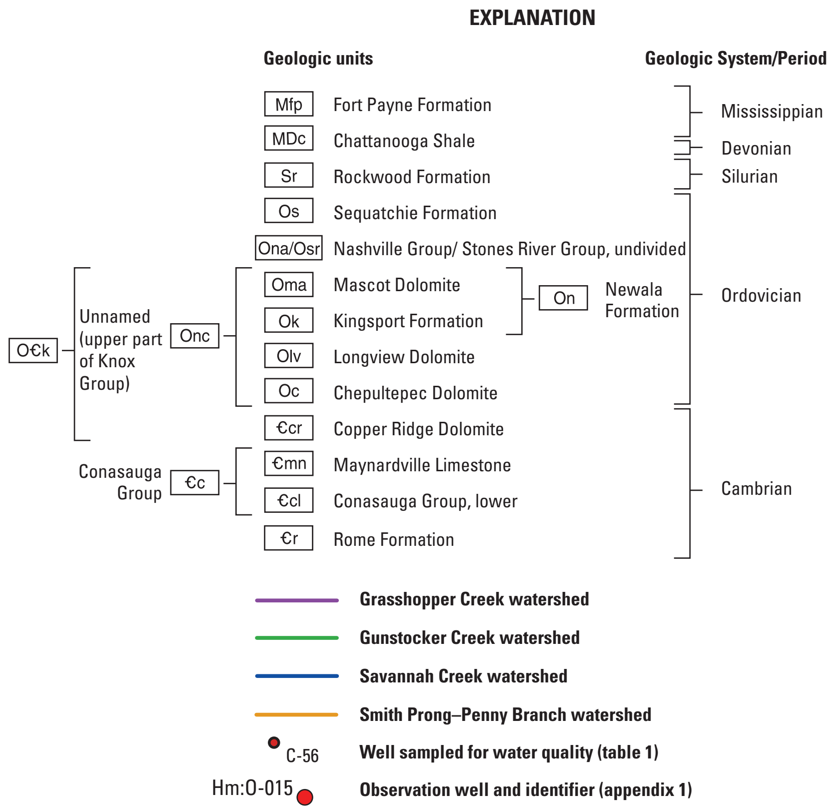


Figure 4. Location of wells sampled for water-quality analyses in the Savannah Valley Utility District study area in East Tennessee, December 2008.—Continued

Well C-21 (fig. 4) is a relatively shallow well (reported depth of 79 ft below land surface) that is open to units of the Knox Group in the Savannah Creek groundwater basin near the Smith Road well site and Anderson Spring (pls. 4 and 5). Although the chemistry of the sample from well C-21 (fig. 5) also indicates that it produces water that has been in contact with carbonate bedrock and its relatively shallow depth is consistent with intervals of enhanced secondary porosity that yield water to the public-supply wells at the Smith Road site and to Anderson Spring, results of the chemical analysis indicate that the well produces water that is considerably more mineralized than a groundwater sample collected from a test well (USGS Site Number 351428085003900) drilled at the Smith Road site in 1974 (D.R. Rima, USGS, written commun., 1974; USGS, 2020c).

The sample collected from well C-91b (fig. 4) generally indicates the water is a calcium-magnesium-bicarbonate type (fig. 5); however, the well is the shallowest well sampled (reported depth of 75 ft below land surface), and the general chemistry of the water it produced indicates that its ionic strength is substantially lower than that of samples collected from the other wells (table 1). Although this well is located in an area underlain by bedrock units of the Knox Group, it lies in a topographic saddle that contains a small surface-water reservoir (Mungers Pond, fig. 4). A saddle also is interpreted to be present locally in the potentiometric surface (pls. 4 and 5), based largely on topography and surface drainage, indicating a groundwater recharge area which is reflected in the water sample collected from the well having low SC (25 µS/cm), pH (4.8), alkalinity (less than 8.0), hardness (6.14 mg/L), and dissolved solids concentration (15 mg/L), as well as an elevated DO concentration of 8.9 mg/L. Given the relatively shallow depth of the well, the low ionic strength and high DO concentration of the water reflect a limited residence time within the carbonate bedrock and imply a localized flow system that could include recharge by surface water from the nearby reservoir. As such, the chemistry of water from this well contrasts with the chemistry of the groundwater samples collected from other wells open to the bedrock units of the Valley and Ridge aquifer in the study area.

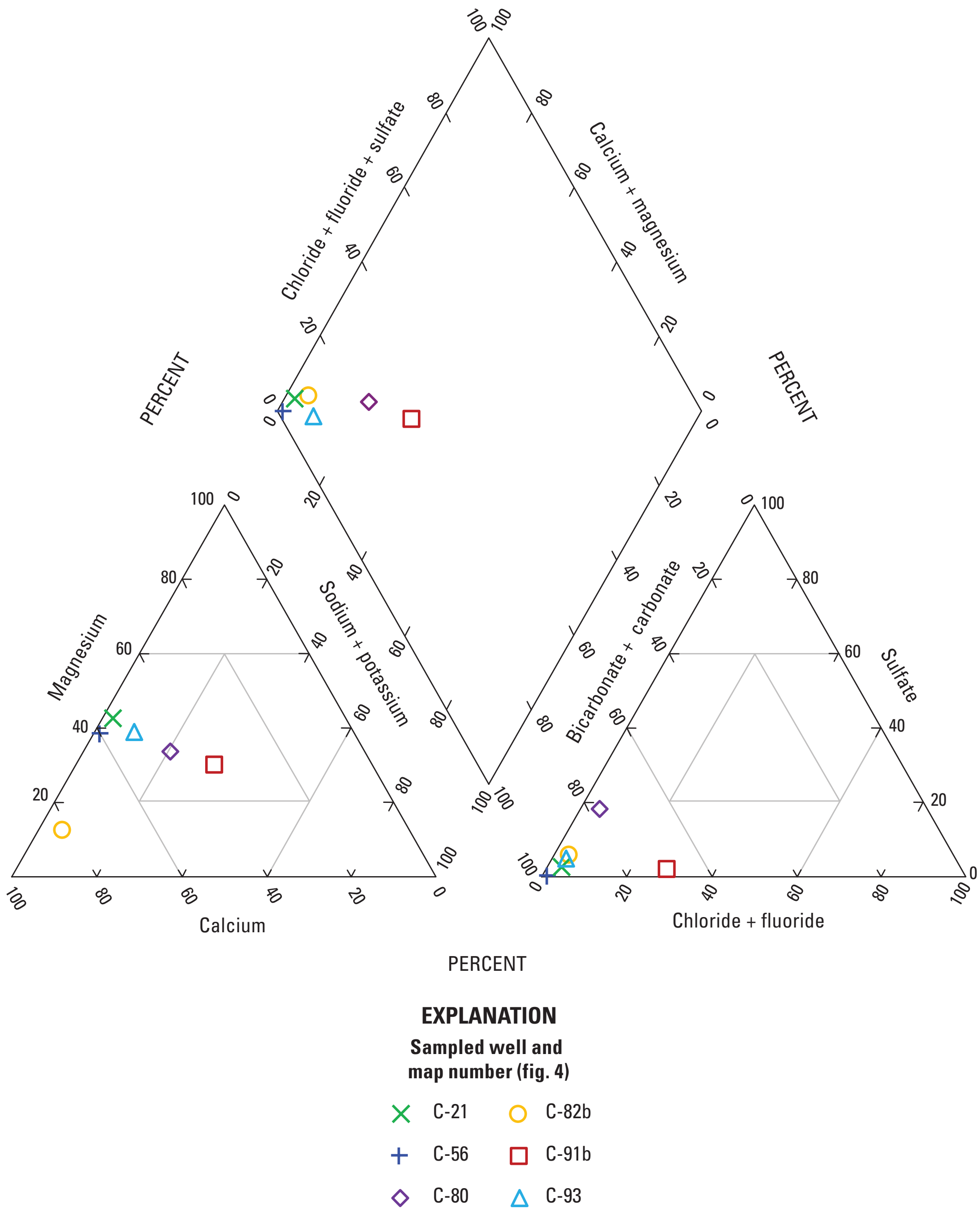


Figure 5. Chemical characteristics of groundwater samples collected from wells in the Savannah Valley Utility District study area in East Tennessee, December 2008.

Table 1. Water-quality data for wells sampled in the Savannah Valley Utility District study area in East Tennessee, December 2008.

[USGS, U.S. Geological Survey; ft, foot; BLS, below land surface; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 °C; mg/L, milligrams per liter; µg/L, micrograms per liter; $CaCO_3$, calcium bicarbonate; SiO_2, silica dioxide; <, less than; E, estimated]

Well identifier (fig. 4)	USGS site name	USGS site number	Date	Well depth (ft BLS)	Temperature (°C)	Specific conductance, field (µS/cm)	Dissolved oxygen, unfiltered (mg/L)	pH, unfiltered, field (standard units)	Carbon dioxide, unfiltered (mg/L)	Calcium, filtered (mg/L)
C-21	Hm:O-044	351355085005201	12/4/2008	79	13.8	411	5.6	6.7	78	49.5
C-56	Hm:O-065	351141085024901	12/4/2008	189	15.9	263	7.2	7.5	8.1	34.6
C-80	Me:B-003	351856084565601	12/9/2008	180	16.1	762	2.3	7	59	82.8
C-82b	Hm:T-015	351650084583301	12/4/2008	270	15.7	719	3.4	6.6	164	134
C-91b	Hm:T-020	352001084582101	12/5/2008	72	15.4	25	8.9	4.8	<278	1.36
C-93	Hm:S-035	351854085015901	12/8/2008	225	16.3	308	2.9	7.7	6.6	34.5

Well identifier (fig. 4)	USGS site name	USGS site number	Date	Magnesium, filtered (mg/L)	Potassium, filtered (mg/L)	Sodium, filtered (mg/L)	Alkalinity, filtered, laboratory (mg/L as $CaCO_3$)	Chloride, filtered (mg/L)	Fluoride, filtered (mg/L)	Silica, filtered (mg/L as SiO_2)	Sulfate, filtered (mg/L)
C-21	Hm:O-044	351355085005201	12/4/2008	23.5	0.68	1.94	210	4.07	0.28	7.5	6.1
C-56	Hm:O-065	351141085024901	12/4/2008	13.5	0.43	0.63	144	0.81	<0.08	8.4	0.51
C-80	Me:B-003	351856084565601	12/9/2008	36.9	5.12	38.9	333	13	0.23	12.4	75.7
C-82b	Hm:T-015	351650084583301	12/4/2008	12.4	1.76	9.68	349	10.5	E0.09	8.7	21
C-91b	Hm:T-020	352001084582101	12/5/2008	0.664	0.2	1.27	<8.0	1.11	<0.08	8.3	<0.18
C-93	Hm:S-035	351854085015901	12/8/2008	15.7	2.45	5.59	150	2.72	0.47	10.6	7.64

Table 1. Water-quality data for wells sampled in the Savannah Valley Utility District study area in East Tennessee, December 2008—Continued.

[USGS, U.S. Geological Survey; ft, foot; BLS, below land surface; °C, degrees Celsius; uS/cm, microsiemens per centimeter at 25 °C; mg/L, milligrams per liter; µg/L, micrograms per liter; $CaCO_3$, calcium bicarbonate; SiO_2, silica dioxide; <, less than; E, estimated]

Well identifier (fig. 4)	USGS site name	USGS site number	Date	Hardness (mg/L as $CaCO_3$)	Solids, residue at 180 °C, filtered (mg/L)	Aluminum, filtered (µg/L)	Antimony, filtered (µg/L)	Arsenic, filtered (µg/L)	Barium, filtered (µg/L)	Beryllium, filtered (µg/L)	Boron, filtered (µg/L)
C-21	Hm:O-044	351355085005201	12/4/2008	220	219	<4.0	<0.040	0.1	13	<0.020	6
C-56	Hm:O-065	351141085024901	12/4/2008	142	140	<4.0	<0.040	0.11	7	<0.020	E3
C-80	Me:B-003	351856084565601	12/9/2008	361	457	<4.0	<0.040	<0.06	61	<0.020	245
C-82b	Hm:T-015	351650084583301	12/4/2008	387	415	<4.0	E0.032	0.15	34	<0.020	36
C-91b	Hm:T-020	352001084582101	12/5/2008	6.14	15	5	<0.040	<0.06	4	<0.020	<4
C-93	Hm:S-035	351854085015901	12/8/2008	152	168	<4.0	0.308	2.3	272	<0.020	45

Well identifier (fig. 4)	USGS site name	USGS site number	Date	Cadmium, filtered (µg/L)	Chromium, filtered (µg/L)	Cobalt, filtered (µg/L)	Copper, filtered (µg/L)	Iron, filtered (µg/L)	Lead, filtered (µg/L)	Lithium, filtered (µg/L)	Manganese, filtered (µg/L)	Molybdenum, filtered (µg/L)
C-21	Hm:O-044	351355085005201	12/4/2008	<0.020	0.80	0.07	8.4	<4.0	0.132	<1.00	<0.20	0.057
C-56	Hm:O-065	351141085024901	12/4/2008	0.047	0.69	0.04	5.6	<4.0	0.395	<1.00	<0.20	0.074
C-80	Me:B-003	351856084565601	12/9/2008	<0.020	<0.12	0.09	<1.0	16	<0.060	32.9	2.86	0.023
C-82b	Hm:T-015	351650084583301	12/4/2008	<0.020	0.13	0.28	7.4	4.7	0.184	2.48	E0.20	0.084
C-91b	Hm:T-020	352001084582101	12/5/2008	<0.020	<0.12	0.15	5.0	E3.7	1.57	<1.00	7.37	<0.020
C-93	Hm:S-035	351854085015901	12/8/2008	0.023	0.20	0.18	<1.0	<4.0	3.46	6.76	0.86	2.75

Well identifier (fig. 4)	USGS site name	USGS site number	Date	Nickel, filtered (µg/L)	Selenium, filtered (µg/L)	Silver, filtered (µg/L)	Strontium, filtered (µg/L)	Thallium, filtered (µg/L)	Vanadium, filtered (µg/L)	Zinc, filtered (µg/L)	Uranium, filtered (µg/L)
C-21	Hm:O-044	351355085005201	12/4/2008	0.61	0.2	<0.008	47.8	<0.040	0.47	3.4	0.264
C-56	Hm:O-065	351141085024901	12/4/2008	0.41	0.08	<0.008	25.4	<0.040	0.5	30.7	0.202
C-80	Me:B-003	351856084565601	12/9/2008	0.72	<0.06	E0.005	1,380	<0.040	<0.16	<2.0	<0.006
C-82b	Hm:T-015	351650084583301	12/4/2008	1.6	0.32	<0.008	287	<0.040	0.21	9.5	0.337
C-91b	Hm:T-020	352001084582101	12/5/2008	0.13	<0.06	<0.008	6.14	<0.040	<0.16	3.3	0.007
C-93	Hm:S-035	351854085015901	12/8/2008	1	0.51	<0.008	1,010	<0.040	E0.08	33	1.09

Groundwater Development

Water-level data collected from observation well Hm:O-015 at the Smith Road site since 1975 (USGS, 2020a) indicate no long-term loss of groundwater storage in the aquifer locally from withdrawals for public supply (fig. 6). During the summers and falls of 1986, 1988, 2001, 2006–08, 2010, and 2016–17, water levels in this observation well declined substantially because of drier than normal conditions and seasonal increases in groundwater withdrawals for public supply at the Smith Road site. Water-level data for the period of record indicate that groundwater levels at the site returned to normal levels following the resumption of normal seasonal rainfall conditions during the winter and spring. These results and an apparent upward trend in water levels in the well during the period of record qualitatively indicate that additional water is available for withdrawal from the aquifer for public supply at the Smith Road site. However, changes in infrastructure (construction of additional deeper wells or the lowering of pump intake depth settings) would be necessary to support increased pumping at this location based on historic low water levels and existing well construction/pump settings, and increased pumping likely would cause expansion of the area of ephemeral flow in Savannah Creek and longer periods of disruption of flow from Anderson Spring.

Results of this study indicate that the Gunstocker Creek groundwater basin is an area for potential groundwater supply development within the SVUD service area. The summer 2008 and spring 2009 potentiometric-surface maps indicate that an area with enhanced permeability is present within the Gunstocker Creek basin as a northeastern extension of the cavity system developed within the hydrogeologic units that underlie the Savannah Creek groundwater basin (pls. 4 and 5). The configuration of the potentiometric surface indicates that the Gunstocker Creek basin is about one-half the total area of the Savannah Creek basin; therefore, a commensurate decrease in available groundwater storage is likely. Note also that because of the smaller size of the basin and its proximity to the Hiwassee River embayment, potential withdrawal locations within the Gunstocker Creek groundwater basin would be closer and perhaps connected hydraulically to the embayed section of Gunstocker Creek, increasing the likelihood of induced recharge to the aquifer from surface water if sustained drawdown from pumping were to lower groundwater levels to altitudes less than the stage of the Hiwassee River.

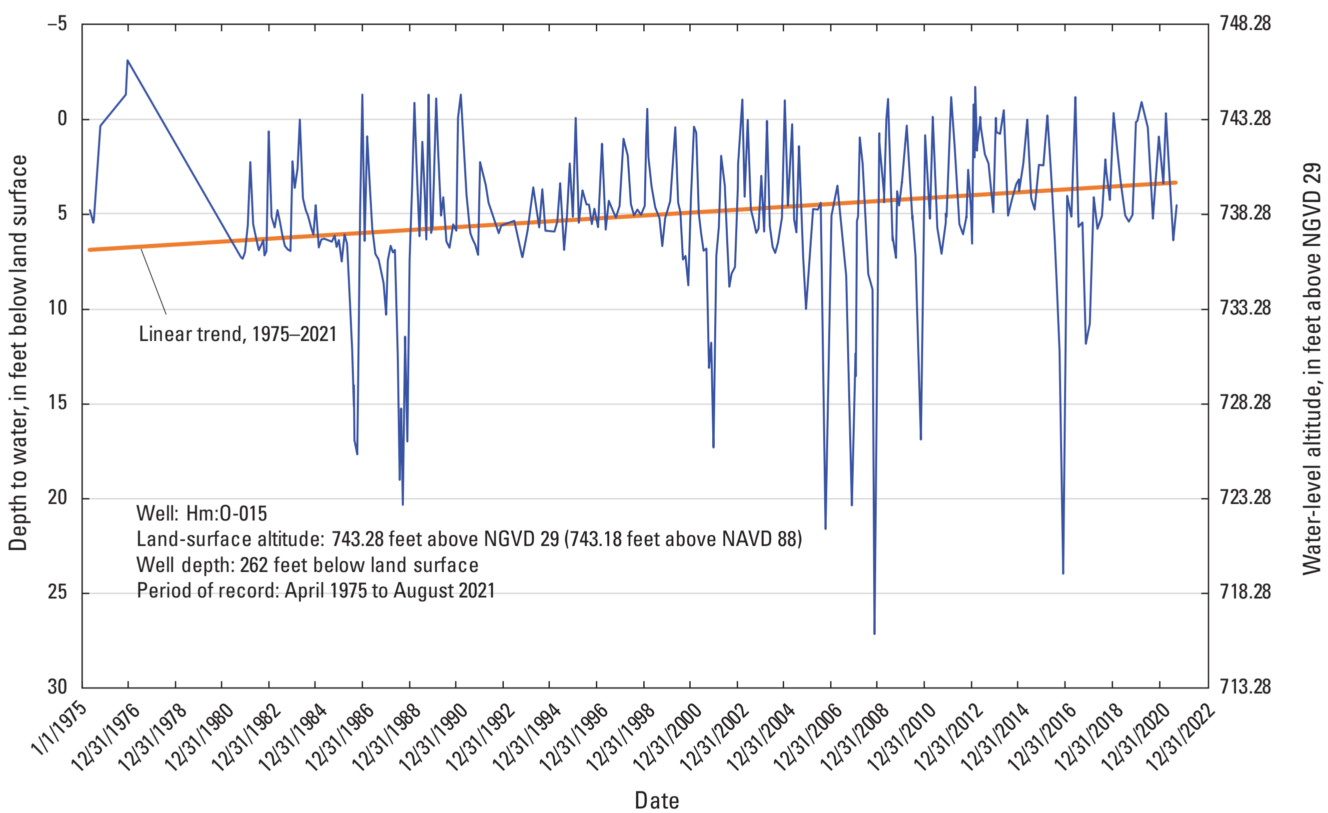


Figure 6. Periodic water-level measurement data for observation well Hm:O-015 at the Smith Road site, Savannah Valley Utility District study area, East Tennessee. [NGVD 29, National Geodetic Vertical Datum of 1929; NAVD 88, North American Vertical Datum of 1988. Linear trendline was generated from least squares methods where slope and intercept coefficients are determined such that $y = bx + a$, where b is the slope of a trendline, and a is the y-intercept, which is the expected mean value of y when all x variables are equal to 0.]

Summary and Conclusions

An investigation of the groundwater hydrology of the Valley and Ridge carbonate rock aquifer was conducted during 2007–09 in an area which approximately coincides with the water distribution service area for the Savannah Valley Utility District (SVUD) in northeastern Hamilton, southern Meigs, and northwestern Bradley Counties, Tennessee. The primary objectives of the investigation were to evaluate (1) the characteristics and extent of selected groundwater basins in the area, (2) the temporal and spatial variations in water levels in the basins, and (3) the chemical characteristics of groundwater at selected locations within the basins.

Groundwater-level data collected from wells open to the aquifer in the study area were used to prepare potentiometric-surface maps for fall 1992, spring and fall 1993, summer 2008, and spring 2009 conditions. The maps are based on water levels measured in about 60 wells in 1992 and 100 wells in 1993 and 2008–09 in the study area.

The 1993, 2008, and 2009 potentiometric-surface maps indicate the presence of two primary groundwater basins in the Valley and Ridge aquifer in the study area. The larger of the two groundwater basins underlies and is coincident with the watershed of southerly flowing Savannah Creek in the southern part of the area. The groundwater basin is characterized by a potentiometric low that underlies Savannah Creek and its major tributaries, and groundwater drainage in the basin primarily is to the south. A smaller groundwater basin coincides with the watershed of northerly flowing Gunstocker Creek in the northern part of the study area. This basin is characterized by a potentiometric low that underlies Gunstocker Creek and its major tributaries, and groundwater drainage in the basin primarily is to the north. The geometry and relatively flat gradients of the potentiometric lows within the two basins reflect the strike-parallel orientation of enhanced permeability along dissolution-enlarged features that have developed in bedrock units of the Knox Group and overlying Stones River Group of Cambrian to Ordovician age.

The recharge areas for the SVUD Smith Road and Sims Road well sites (equivalent to the Savannah Creek groundwater basin) and the Gunstocker Creek groundwater basin were estimated from the potentiometric-surface maps for summer 2008 and spring 2009. The recharge area of the Savannah Creek basin is estimated to be about 31 square miles (mi^2), and the recharge area of the Gunstocker Creek basin is estimated to be about 17 mi^2. The recharge areas of the Savannah Creek and Gunstocker Creek basins compare favorably between summer 2008 and spring 2009 at about 31.2 and 31.0 mi^2, and 17.0 and 16.8 mi^2, respectively. The estimated recharge areas of the Savannah Creek and Gunstocker Creek groundwater basins also compare closely with the delineated watersheds of the streams at 30.9 and 16.0 mi^2, respectively.

Chickamauga Lake serves as the base level for groundwater discharge from the Savannah Creek and Gunstocker Creek basins. The stage of the lake is adjusted seasonally by the Tennessee Valley Authority and ranges from about 677 feet above the North American Vertical Datum of 1988 (NAVD 88) at winter pool to 683 feet above NAVD 88 at summer pool. The adjusted stage of the lake likely affects the potentiometric surfaces and groundwater discharge in the most downgradient parts of the Savannah Creek and Gunstocker Creek basins, based on inferred hydraulic connection between the aquifer and Savannah Bay and the Hiwassee River, respectively. If groundwater withdrawals reduced the potentiometric surfaces in the basins to lower altitudes than the stage of Chickamauga Lake, the gradient could reverse and cause captured surface water to recharge the aquifer. The absence of large groundwater withdrawals in the Gunstocker Creek basin currently makes surface water from the embayed section of the Hiwassee River an unlikely source of recharge in this basin. Future climatic conditions and potential for increased groundwater withdrawal for public supply at the Smith Road and Sims Road well sites could lower hydraulic heads enough in the Savannah Creek basin to induce capture of surface water from Savannah Bay to the aquifer.

Results from the study provide components for development of a conceptual model of the groundwater-flow system in the area. Regionally, recharge from precipitation infiltrates the aquifer in the Savannah Creek and Gunstocker Creek groundwater basins in the higher altitude areas along the eastern and western sides of the basins to flow toward the potentiometric lows in the central parts of both basins. Locally, recharge to the aquifer also occurs as drainage of water held in storage in regolith overlying bedrock and from streamflow losses following precipitation events where and when the potentiometric surfaces lie at a lower altitude than streambeds, particularly in the Savannah Creek basin in the vicinity and north of the Smith Road well site where groundwater levels are affected by withdrawals for public supply.

Bedrock cavities that are aligned with strike in bedrock units of the Knox Group and lower Stones River Group and that are interconnected laterally and vertically intersect the groundwater-flow fields and provide for the storage and transmission of water in transit from recharge to discharge areas in the two primary groundwater basins. The size and interconnectivity of the cavities determine their transmissivity and the amount of water they can convey. Changes in groundwater storage in the Gunstocker Creek basin primarily occur in response to seasonal variability in recharge and discharge, the latter of which likely is influenced by the adjusted seasonal stage of Chickamauga Lake and the Hiwassee River embayment. In the Savannah Creek basin, changes in storage primarily occur in response to groundwater withdrawals for public supply at the Smith Road well site.

The conceptual model infers that discharge of groundwater in excess of the storage and transmission capacity of the bedrock cavity systems occurs primarily as withdrawals for public supply by the SVUD in the Savannah Creek groundwater basin, as base flow to Savannah Creek outside the area affected by public-supply withdrawals and to Gunstocker Creek, and as flow to springs and seeps within the corresponding groundwater basins. Although the delineated downgradient boundaries of the two basins terminate at the confluences of Savannah Creek with Savannah Bay and Gunstocker Creek with the Hiwassee River, additional groundwater discharge likely occurs farther downgradient at locations inundated by the embayments, including submerged locations along the contacts between formations in the lower Stones River Group and upper Knox Group. Hydraulic connection between the embayments and the aquifer in these locations would increase the potential for induced recharge by surface water if groundwater withdrawals lowered the potentiometric surface and reversed gradients in the basins.

The conceptual model also implies that formations of the upper Knox Group and lower Stones River Group are the most permeable bedrock units in the study area, whereas units in the upper Stones River Group and the lower Conasauga Group are the least permeable. Higher permeability is indicated by the uniformly low gradients seen in the potentiometric lows within units of the Knox and lower part of the Stones River Groups in the Savannah Creek and Gunstocker Creek groundwater basins. Conversely, areas where bedrock permeability is lower are indicated by steeper groundwater gradients that occur along the flanks of the potentiometric lows in the two basins in areas underlain by units of the upper Stones River Group and the lower Conasauga Group.

Groundwater samples were collected from six wells open to bedrock units within the Valley and Ridge aquifer in the study area in December 2008, and the samples were analyzed for major dissolved constituents and trace metals. Water from the sampled wells generally is a calcium-magnesium-bicarbonate type and is suitable for most uses. Water from all six wells is oxic with dissolved oxygen concentrations ranging from 2.3 to 8.9 milligrams per liter (mg/L). Water from most of the wells is characterized as hard or very hard, with hardness values for samples from five of the six wells greater than 142 mg/L as calcium bicarbonate. Samples from these five wells also had specific conductance values ranging from 263 to 762 microsiemens per centimeter at 25 degrees Celsius, near neutral pH values (6.6 to 7.7), and dissolved solids concentrations ranging from 140 to 457 mg/L. Concentrations of all analyzed trace elements were less than primary drinking-water criteria in samples collected from the six wells.

Water-level data collected since 1975 in an observation well at the Smith Road site indicate an apparent upward trend in water levels and no long-term loss of groundwater storage in the aquifer at the site from withdrawals by the SVUD for public supply. Between 1986 and 2017, substantial declines in water levels in the well were observed intermittently during summer and fall as a result of drier than normal conditions and seasonal increases in groundwater withdrawals at the site. The long-term record shows that these seasonal low water levels return to normal levels following periods of average rainfall conditions in the winter and spring. These data also indicate that some additional amount of water is available for withdrawal from the aquifer at the Smith Road site, with the understanding that changes in infrastructure likely would be necessary to support increased pumping at the site and that increased pumping could cause deleterious effects to flow in Savannah Creek and from Anderson Spring.

Results of the study indicate that the Gunstocker Creek groundwater basin is an area for potential groundwater supply development. The area of low-altitude water levels in the basin that is shown on the summer 2008 and spring 2009 potentiometric-surface maps indicates that enhanced permeability is present within the Gunstocker Creek basin as a northeastern counterpart to the bedrock cavity system in the Savannah Creek basin. Because the Gunstocker Creek basin is estimated to be about one-half the total area of the Savannah Creek basin, a commensurate decrease in available groundwater storage is likely. Furthermore, because of its smaller size and proximity to the Hiwassee River embayment, withdrawal locations would be closer to and possibly connected hydraulically to the embayment, increasing the potential for induced recharge to the aquifer from surface water if sustained drawdown from pumping lowered groundwater levels to altitudes less than the stage of the Hiwassee River.

References Cited

Carmichael, J.K., 2022, Geospatial data for groundwater potentiometric-surface maps in northeastern Hamilton, southern Meigs, and northwestern Bradley Counties, Tennessee, fall 1992, spring and fall 1993, summer 2008, and spring 2009: U.S. Geological Survey data release, https://doi.org/10.5066/P9QVHDI5.

DeBuchananne, G.D., and Richardson, R.M., 1956, Groundwater resources of East Tennessee: Tennessee Division of Geology Bulletin 58, pt. 1, 393 p., 15 pls.

Fenneman, N.M., 1938, Physiography of the eastern United States: New York, McGraw-Hill, 714 p.

Fishman, M.J., and Friedman, L.C., 1989, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1, 545 p.

Hardeman, W.D., 1966, Geologic map of Tennessee, East-Central Sheet: Tennessee Department of Conservation, Division of Geology, 1 sheet, scale 1:250,000.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water (3d ed.): U.S. Geological Survey Water-Supply Paper 2254, 264 p. [Also available at http://pubs.er.usgs.gov/publication/wsp2254.]

Hollyday, E.F., and Smith, M.A., 1990, Large springs in the Valley and Ridge province in Tennessee: U.S. Geological Survey Water-Resources Investigations Report 89–4205, 9 p.

Lakes Online, 2018, Chickamauga Lake water level, accessed December 2018 at http://www.chickamaugalake.info/Level.asp.

Lloyd, O.B., and Lyke, W.L., 1995, Groundwater atlas of the United States—Segment 10, Illinois, Indiana, Kentucky, Ohio, Tennessee: U.S. Geological Survey Hydrologic Atlas 730–K, 30 p.

National Weather Service, 2018, Chattanooga climate page, accessed December 2018 at https://www.weather.gov/mrx/chaclimate.

Rodgers, J., comp., 1953, Geologic map of East Tennessee with explanatory text: Tennessee Division of Geology Bulletin 58, pt. 2, 168 p., 15 pls.

Stewart, S.R., and Beven, J.L., II, 2009, Tropical cyclone report, Tropical Storm Fay, (AL062008), 15–26 August 2008: National Oceanic and Atmospheric Administration, National Hurricane Center, 29 p., accessed January 2009 at https://www.nhc.noaa.gov/data/tcr/AL062008_Fay.pdf.

Sun, P.-C.P., Criner, J.H., and Poole, J.L., 1963, Large springs of East Tennessee: U.S. Geological Survey Water-Supply Paper 1755, 52 p.

Swingle, G.D., 1959, Geology, mineral resources and ground water of the Cleveland area, Tennessee: Tennessee Department of Conservation, Division of Geology Bulletin 61, 125 p., 6 pls.

Swingle, G.D., and Finlayson, C.P., 1963, Geologic map and mineral resources summary of the Grasshopper Creek quadrangle (Soddy Island), Tennessee: Tennessee Department of Conservation, Division of Geology map GM 111-SE and MRS 111-SE, scale 1:24,000.

Tennessee Department of Conservation, 1979, Geology of Hamilton County, Tennessee: Tennessee Department of Conservation, Division of Geology Bulletin 79, 128 p., 2 pl.

Tennessee Department of Environment and Conservation [TDEC], 2020, Wellhead Protection Program, accessed August 5, 2020, at https://www.tn.gov/environment/program-areas/wr-water-resources/water-quality/wellhead-protection-program.html.

U.S. Environmental Protection Agency [EPA], 2018, National Primary Drinking Water Regulations, accessed December 13, 2018, at https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations.

U.S. Geological Survey [USGS], 2006, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations book 9, chap. A4, accessed January 3, 2020, at http://water.usgs.gov/owq/FieldManual/.

U.S. Geological Survey [USGS], 2020a, USGS 351428085003600 Hm:O-015, *in* USGS water data for the Nation: U.S. Geological Survey National Water Information System database, accessed January 3, 2020, at https://nwis.waterdata.usgs.gov/nwis/inventory/?site_no=351428085003600&agency_cd=USGS&.

U.S. Geological Survey [USGS], 2020b, USGS water data for the Nation: U.S. Geological Survey National Water Information System database, accessed January 3, 2020, at https://doi.org/10.5066/F7P55KJN.

U.S. Geological Survey [USGS], 2020c, Site inventory for Tennessee, Hamilton County, Hm:O-008 TW #1 and Hm:O-008 PW #1, *in* USGS water data for the Nation: U.S. Geological Survey National Water Information System database, accessed January 3, 2020, at https://nwis.waterdata.usgs.gov/tn/nwis/inventory?search_station_nm=O-008&search_station_nm_match_type=anywhere&county_cd=47065&format=station_list&group_key=NONE&list_of_search_criteria=county_cd%2Csearch_station_nm.

Webster, D.A., and Carmichael, J.K., 1993, Ground-water hydrology of the lower Wolftever Creek basin, with emphasis on the Carson Spring area, Hamilton County, Tennessee: U.S. Geological Survey Water-Resources Investigations Report 91–4190, 47 p. [Also available at https://doi.org/10.3133/wri914190.]

Wilson, R.L., 1983, Geologic map and mineral resources summary of the Snow Hill quadrangle, Tennessee: Tennessee Department of Conservation, Division of Geology map GM 112-NE and MRS 112-NE, scale 1:24,000.

Wilson, R.L., 1986, Geologic map and mineral resources summary of the Ooltewah quadrangle, Tennessee: Tennessee Department of Conservation, Division of Geology map GM 112-SE and MRS 112-SE, scale 1:24,000.

Wilson, R.L., 2011, Geologic map of the Birchwood quadrangle, Tennessee: Tennessee Division of Geology Open File Map GM 119-SW, 1 sheet, scale 1:24,000.

Appendixes

Appendix 1. Wells and water-level measurements used to construct potentiometric-surface maps of the Valley and Ridge aquifer in the Savannah Valley Utility District (SVUD) study area in East Tennessee.

[Original land-surface altitudes from topographic maps (values given in whole feet) or surveys of selected wells (values given in feet and tenths of feet) from 1992-93 measurements, originally reported as referenced to sea level; revised land-surface altitudes from digital elevation model using well locations obtained from a handheld Global Positioning System unit when wells were visited in 2008–09, and used for generation of the potentiometric-surface maps presented in this report, except where indicated otherwise; water-level measurement data from USGS (2020b) except where indicated otherwise; water-level altitudes rounded to nearest foot; pls., plates; USGS, U.S. Geological Survey; ft, foot; BLS, below land surface; NAVD 88, North American Vertical Datum of 1988; --, not measured; ??, unknown; SVUD, Savannah Valley Utility District; in., inch; ~, approximate; <, less than; >, greater than; flowing, water-level altitude estimated as approximately equal to land-surface altitude]

Well identifier (pls. 1–5)	USGS site name	USGS site number	Well depth, in ft BLS	Original land-surface altitude, in ft above sea level	Revised land-surface altitude, in ft above NAVD 88	Fall 1992		Spring 1993		Fall 1993		Summer 2008		Spring 2009		Remarks
						Depth to water, in ft BLS	Water-level altitude, in ft above NAVD 88	Depth to water, in ft BLS	Water-level altitude, in ft above NAVD 88	Depth to water, in ft BLS	Water-level altitude, in ft above NAVD 88	Depth to water, in ft BLS	Water-level altitude, in ft above NAVD 88	Depth to water, in ft BLS	Water-level altitude, in ft above NAVD 88	
C-1	Hm:T-002	351636084575801	196	865	870	15.42	855	17.50	853	22.48	848	--	--	--	--	Revised land-surface altitude from topo map.
C-2a	Hm:T-003	351552084582501	248	855	872	17.18	855	18.49	854	25.14	847	28.83	843	28.21	844	
C-2b	Hm:T-004	351552084582601	79.5	860	864	23.80	840	23.90	840	25.68	838	24.02	840	24.03	840	Summer 2008 and spring 2009 water-level altitudes are the same.
C-3	Hm:T-005	351502084585401	80	840	840	13.73	826	14.98	825	17.05	823	15.23	825	15.23	825	
C-4a	Hm:P-001	351427084591901	63	800	800	7.98	792	8.00	792	8.77	791	8.30	792	3.92	796	
C-4b	Hm:P-002	351426084592101	81	805	809	24.02	785	23.89	785	26.58	782	26.37	783	14.86	794	
C-5	Hm:P-003	351414084592801	58	800	801	27.19	774	27.20	774	28.99	772	28.96	772	17.25	784	Well depth from 1990s measurements; new owner reported well is 110 ft deep.
C-6	Hm:P-004	351405084593801	69	799.5	802	16.89	785	17.34	785	19.81	782	--	--	--	--	Well destroyed.
C-7	Hm:P-005	351349084591701	32	815	816	3.92	812	5.48	811	--	--	7.30	809	1.85	814	
C-8	Hm:O-032	351252085001001	106	742	745	8.91	736	9.87	735	--	--	12.66	732	7.33	738	
C-9	Hm:O-093	351149085005201	255	742	747	18.37	729	19.40	728	20.36	727	17.93	729	14.28	733	
C-10	Hm:O-010	351103085012401	52	740	740	15.24	725	16.72	723	--	--	--	--	--	--	Well covered; can't measure.
C-11	Hm:O-001	351050085031501	118	735	735	28.20	707	--	--	--	--	29.75	705	18.25	717	SVUD test well SV-1.
C-12	Hm:O-036	351054085031501	94	730	733	28.57	704	41.27	692	58.09	675	46.57	686	16.74	716	
C-13	Hm:O-003	351054085023801	85	698	697	4.02	693	4.48	693	6.81	690	5.03	692	0.10	697	SVUD test well SV-3.
C-14	Hm:O-038	351101085024801	66	710	710	15.16	695	20.72	689	39.76	670	19.02	691	9.30	701	
C-15	Hm:O-039	351103085034401	219	840	819	114.50	705	126.89	692	128.61	690	142.56	676	123.48	696	
C-16	Hm:O-040	351120085021101	225	710	714	0.49	714	1.20	713	--	--	19.50	695	5.66	708	
C-17	Hm:O-057	351056085022201	63	705	702	15.20	687	14.47	688	11.97	690	12.81	689	9.35	693	
C-18	Hm:O-042	351146085015201	430	720	721	45.81	675	58.90	661	61.50	660	4.14	717	−1.00	722	2008–09 water-level measurements too high; well plugged?

Appendix 1. Wells and water-level measurements used to construct potentiometric-surface maps of the Valley and Ridge aquifer in the Savannah Valley Utility District (SVUD) study area in East Tennessee.—Continued

[Original land-surface altitudes from topographic maps (values given in whole feet) or surveys of selected wells (values given in feet and tenths of feet) from 1992-93 measurements, originally reported as referenced to sea level; revised land-surface altitudes from digital elevation model using well locations obtained from a handheld Global Positioning System unit when wells were visited in 2008–09, and used for generation of the potentiometric-surface maps presented in this report, except where indicated otherwise; water-level measurement data from USGS (2020b) except where indicated otherwise; water-level altitudes rounded to nearest foot; pls., plates; USGS, U.S. Geological Survey; ft, foot; BLS, below land surface; NAVD 88, North American Vertical Datum of 1988; --, not measured; ??, unknown; SVUD, Savannah Valley Utility District; in., inch; ~, approximate; <, less than; >, greater than; flowing, water-level altitude estimated as approximately equal to land-surface altitude]

Well identi-fier (pls. 1–5)	USGS site name	USGS site number	Well depth, in ft BLS	Original land-surface altitude, in ft above sea level	Revised land-surface altitude, in ft above NAVD 88	Fall 1992		Spring 1993		Fall 1993		Summer 2008		Spring 2009		Remarks
						Depth to water, in ft BLS	Water-level altitude, in ft above NAVD 88	Depth to water, in ft BLS	Water-level altitude, in ft above NAVD 88	Depth to water, in ft BLS	Water-level altitude, in ft above NAVD 88	Depth to water, in ft BLS	Water-level altitude, in ft above NAVD 88	Depth to water, in ft BLS	Water-level altitude, in ft above NAVD 88	
C-20	Hm:O-043	351249085010701	69	750	750	16.68	733	16.62	733	23.71	726	21.57	728	11.23	739	
C-21	Hm:O-044	351355085005201	79	770.9	764	37.84	726	38.60	725	40.10	724	40.96	723	34.50	730	
C-22	Hm:O-045	351401085004901	200	781.8	767	46.93	720	58.62	708	51.08	716	59.50	708	42.00	725	
C-23	Hm:O-046	351404085005001	80	784.4	764	47.21	717	47.93	716	--	--	53.08	711	40.79	723	
C-24	Hm:O-047	351407085004701	167	745.5	737	8.59	728	9.28	728	9.70	727	20.72	716	4.32	733	
C-25	Hm:O-048	351419085001601	??	768.5	772	27.34	745	30.12	742	39.04	733	--	--	--	--	Well not located for 2008–09 measurements.
C-26	Hm:O-049	351416085000601	160	774.8	771	40.07	731	40.71	730	42.70	728	41.20	730	38.31	733	
C-27	Hm:T-021	351605084584301	100	840	841	23.10	818	22.96	818	27.52	813	19.80	821	21.95	819	
C-28	Hm:T-006	351604084584801	250	835	833	15.81	817	--	--	--	--	15.35	818	18.38	815	
C-29	Hm:T-007	351545084590401	167	810	811	18.86	792	19.67	791	21.89	789	17.05	794	19.28	792	
C-30a	Hm:T-008	351526084593601	274	780	778	26.66	751	--	--	--	--	--	--	28.15	750	Unreliable measurement in summer 2008.
C-30b	Hm:T-009	351527084593501	165	780	778	18.88	759	19.29	759	20.15	758	--	--	3.93	774	
C-31	Hm:T-010	351501084594801	98	805	807	39.47	768	42.56	764	45.01	762	42.52	764	39.99	767	
C-32	Hm:O-050	351456085000601	116	790	776	47.33	729	49.46	727	51.85	724	52.12	724	47.03	729	
C-33	Hm:O-051	351451085001201	150	772.6	766	--	--	32.90	733	35.48	731	35.95	730	31.29	735	
C-34	Hm:O-052	351444085001601	146	780.6	774	39.35	735	40.76	733	43.59	730	44.46	730	39.07	735	
C-35	Hm:O-053	351440085002201	125	773	761	32.29	729	33.50	728	35.96	725	40.85	720	31.52	729	Water level rose by ~10 ft above value reported for spring 2009 after 4.5 in. rain in early May 2009.
C-36	Hm:O-007	351437085002701	247	748	748	9.91	738	10.21	738	12.30	736	23.67	724	8.18	740	SVUD test well SV-7.
C-37	Hm:O-009	351436085003001	151	747.6	741	9.11	732	9.68	731	11.73	729	23.89	717	7.56	733	SVUD test well SV-9.
C-38	Hm:O-015	351428085003600	262	744.5	743	5.57	737	5.32	738	7.23	736	20.45	723	−1.06	744	SVUD test well SV-15.
C-39	Hm:O-058	351441085003701	120	804.9	804	64.58	739	64.56	739	67.30	737	76.58	727	56.20	748	
C-41	Hm:S-023	351502085005601	120	835	840	--	--	51.24	789	65.79	774	83.17	757	66.92	773	

Appendix 1. Wells and water-level measurements used to construct potentiometric-surface maps of the Valley and Ridge aquifer in the Savannah Valley Utility District (SVUD) study area in East Tennessee.—Continued

[Original land-surface altitudes from topographic maps (values given in whole feet) or surveys of selected wells (values given in feet and tenths of feet) from 1992-93 measurements, originally reported as referenced to sea level; revised land-surface altitudes from digital elevation model using well locations obtained from a handheld Global Positioning System unit when wells were visited in 2008–09, and used for generation of the potentiometric-surface maps presented in this report, except where indicated otherwise; water-level measurement data from USGS (2020b) except where indicated otherwise; water-level altitudes rounded to nearest foot; pls., plates; USGS, U.S. Geological Survey; ft, foot; BLS, below land surface; NAVD 88, North American Vertical Datum of 1988; --, not measured; ??, unknown; SVUD, Savannah Valley Utility District; in., inch; ~, approximate; <, less than; >, greater than; flowing, water-level altitude estimated as approximately equal to land-surface altitude]

Well identifier (pls. 1–5)	USGS site name	USGS site number	Well depth, in ft BLS	Original land-surface altitude, in ft above sea level	Revised land-surface altitude, in ft above NAVD 88	Fall 1992		Spring 1993		Fall 1993		Summer 2008		Spring 2009		Remarks
						Depth to water, in ft BLS	Water-level altitude, in ft above NAVD 88	Depth to water, in ft BLS	Water-level altitude, in ft above NAVD 88	Depth to water, in ft BLS	Water-level altitude, in ft above NAVD 88	Depth to water, in ft BLS	Water-level altitude, in ft above NAVD 88	Depth to water, in ft BLS	Water-level altitude, in ft above NAVD 88	
C-42	Hm:S-024	351513085005701	150	830	834	25.27	809	22.22	812	29.05	805	35.09	799	26.07	808	
C-44	Hm:S-025	351525085005801	230	903	886	--	--	99.12	787	113.25	773	144.60	741	--	--	
C-45	Hm:S-026	351540085005501	180	910	906	--	--	122.25	784	130.99	775	--	--	--	--	Well may be destroyed.
C-46	Hm:S-027	351545085005901	215	945	942	--	--	155.28	787	--	--	185.12	757	176.66	765	
C-47	Hm:S-028	351543085010701	260	955	954	188.18	766	169.96	784	180.63	773	--	--	--	--	Couldn't get water-level tape below ~145 ft in summer 2008.
C-48	Hm:S-029	351528085013101	165	860	861	100.92	760	83.47	778	93.54	767	138.06	723	136.58	724	
C-49	Hm:O-059	351459085015501	110	825	829	66.87	762	50.52	778	61.87	767	--	--	--	--	Well covered; can't measure.
C-50	Hm:O-060	351411085014901	79	780	777	26.84	750	16.15	761	31.62	745	55.04	722	29.07	748	
C-51	Hm:O-061	351401085010201	143	761.7	760	18.96	741	24.90	735	30.60	729	36.83	723	21.40	739	
C-53	Hm:O-062	351303085014801	106	800	803	89.39	714	73.25	730	84.30	719	82.13	721	71.57	731	
C-54	Hm:O-063	351221085021801	106	800	798	78.61	719	82.98	715	--	--	87.18	711	78.45	720	
C-55	Hm:O-064	351155085023501	81	760	760	40.71	719	44.53	715	72.29	688	44.38	716	39.27	721	Fall 1993 measurement too deep?
C-56	Hm:O-065	351141085024901	189	775	776	62.60	713	64.67	711	66.86	709	62.07	714	61.11	715	
C-57	Hm:O-066	351130085025401	59	715	718	7.62	710	10.47	708	41.36	677	7.58	710	7.57	710	Fall 1993 measurement too deep?
C-58	Hm:O-067	351115085033601	251	860	865	183.00	682	174.72	690	197.14	668	183.10	682	178.02	687	
C-59	Hm:O-068	351334085020001	230	870	868	141.41	727	128.72	739	148.21	720	168.16	700	150.27	718	
C-60	Hm:O-069	351240085025501	120	800	800	55.50	745	47.48	753	64.07	736	74.62	725(?)	57.24	743	Obstruction at approximate water level in summer 2008; measurement suspect?
C-61	Hm:O-041	351206085030701	112	750	750	43.75	706	39.57	710	--	--	57.05	693	33.01	717	State well records indicate well is 112 ft deep; depth sounded at 101 ft in 1992.
C-62	Hm:O-071	351230085034301	210	885	886	160.63	725	148.60	737	160.64	725	176.80	709	165.64	720	

Appendix 1. Wells and water-level measurements used to construct potentiometric-surface maps of the Valley and Ridge aquifer in the Savannah Valley Utility District (SVUD) study area in East Tennessee.—Continued

[Original land-surface altitudes from topographic maps (values given in whole feet) or surveys of selected wells (values given in feet and tenths of feet) from 1992-93 measurements, originally reported as referenced to sea level; revised land-surface altitudes from digital elevation model using well locations obtained from a handheld Global Positioning System unit when wells were visited in 2008–09, and used for generation of the potentiometric-surface maps presented in this report, except where indicated otherwise; water-level measurement data from USGS (2020b) except where indicated otherwise; water-level altitudes rounded to nearest foot; pls., plates; USGS, U.S. Geological Survey; ft, foot; BLS, below land surface; NAVD 88, North American Vertical Datum of 1988; --, not measured; ??, unknown; SVUD, Savannah Valley Utility District; in., inch; ~, approximate; <, less than; >, greater than; flowing, water-level altitude estimated as approximately equal to land-surface altitude]

Well identifier (pls. 1–5)	USGS site name	USGS site number	Well depth, in ft BLS	Original land-surface altitude, in ft above sea level	Revised land-surface altitude, in ft above NAVD 88	Fall 1992		Spring 1993		Fall 1993		Summer 2008		Spring 2009		Remarks
						Depth to water, in ft BLS	Water-level altitude, in ft above NAVD 88	Depth to water, in ft BLS	Water-level altitude, in ft above NAVD 88	Depth to water, in ft BLS	Water-level altitude, in ft above NAVD 88	Depth to water, in ft BLS	Water-level altitude, in ft above NAVD 88	Depth to water, in ft BLS	Water-level altitude, in ft above NAVD 88	
C-63	Hm:O-072	351213085041101	>210	910	908	193.73	714	180.74	727	--	--	208.98	699	199.72	708	Well depth based on summer 2008 water-level measurement.
C-64	Hm:O-073	351143085041501	190	840	840	121.52	718	106.49	734	121.78	718	132.45	708	126.76	713	Owner reported well originally 160 ft deep and had deepened to 190 ft
C-65	Hm:O-075	351140085040801	200	900	899	165.04	734	166.62	732	167.11	732	166.76	732	165.40	734	
C-66	Hm:O-076	351121085040501	97	815	812	88.55	723	84.52	727	89.30	723	90.63	721	87.82	724	
C-67	Hm:O-077	351052085040601	104	770	766	80.21	686	77.67	688	84.82	681	82.30	684	80.92	685	
C-68	Hm:P-006	351402084593901	57	800	801	--	--	17.38	784	--	--	--	--	--	--	Couldn't locate well in 2008; may be destroyed?
C-69	Hm:O-070	351216085004401	100	735	731	--	--	12.54	718	12.98	718	12.62	718	9.42	722	
C-70	Hm:P-007	351336084595701	64	760	765	--	--	11.96	753	29.40	736	13.20	752	9.52	755	Well depth from sounding, spring 2009; water level reported as recovering for fall 1993 measurement.
C-71	Hm:O-079	351221085012901	105	745	743	--	--	27.98	715	30.64	712	28.13	715	15.26	728	
C-72	Hm:O-080	351352085011101	145	805	803	--	--	68.12	735	--	--	91.77	711	64.88	738	Summer 2008 measurement may be suspect; too deep?
C-73	Hm:O-081	351105085021901	172	710	710	--	--	14.80	695	23.81	686	18.80	691	7.98	702	
C-74	Hm:O-082	351104085021901	206	710	710	--	--	18.60	691	--	--	22.78	687	11.81	698	
C-75	Hm:O-083	351126085025301	46	715	707	--	--	4.10	703	6.31	701	--	--	--	--	Well destroyed.
C-76	Hm:T-011	351608084581001	86	890	881	--	--	20.28	861	21.18	860	9.83	871	19.33	862	Spring 2009 measurement suspect; pump may have been running.
C-77	Hm:T-012	351708084564701	100	838	843	--	--	39.64	803	42.61	800	52.51	790	39.91	803	
C-78	Br:L-001	351709084551301	70	870	827	--	--	33.50	794	--	--	41.82	785	23.32	804	
C-79b	Me:B-002	351855084562001	90	820	819	--	--	54.76	764	--	--	58.09	761	55.09	764	

Appendix 1. Wells and water-level measurements used to construct potentiometric-surface maps of the Valley and Ridge aquifer in the Savannah Valley Utility District (SVUD) study area in East Tennessee.—Continued

[Original land-surface altitudes from topographic maps (values given in whole feet) or surveys of selected wells (values given in feet and tenths of feet) from 1992-93 measurements, originally reported as referenced to sea level; revised land-surface altitudes from digital elevation model using well locations obtained from a handheld Global Positioning System unit when wells were visited in 2008–09, and used for generation of the potentiometric-surface maps presented in this report, except where indicated otherwise; water-level measurement data from USGS (2020b) except where indicated otherwise; water-level altitudes rounded to nearest foot; pls., plates; USGS, U.S. Geological Survey; ft, foot; BLS, below land surface; NAVD 88, North American Vertical Datum of 1988; --, not measured; ??, unknown; SVUD, Savannah Valley Utility District; in., inch; ~, approximate; <, less than; >, greater than; flowing, water-level altitude estimated as approximately equal to land-surface altitude]

Well identi-fier (pls. 1–5)	USGS site name	USGS site number	Well depth, in ft BLS	Original land-surface altitude, in ft above sea level	Revised land-surface altitude, in ft above NAVD 88	Fall 1992		Spring 1993		Fall 1993		Summer 2008		Spring 2009		Remarks
						Depth to water, in ft BLS	Water-level altitude, in ft above NAVD 88	Depth to water, in ft BLS	Water-level altitude, in ft above NAVD 88	Depth to water, in ft BLS	Water-level altitude, in ft above NAVD 88	Depth to water, in ft BLS	Water-level altitude, in ft above NAVD 88	Depth to water, in ft BLS	Water-level altitude, in ft above NAVD 88	
C-79a	Me:B-001	351854084561701	260	805	812	--	--	21.12	791	31.52	780	32.79	779	28.27	784	Owner reported well is 220 ft deep.
C-80	Me:B-003	351856084565601	180	740	754	--	--	29.67	724	42.41	712	39.75	714	36.08	718	
C-81	Hm:T-013	351750084574701	67	775	781	--	--	24.48	757	28.68	752	26.17	755	23.70	757	Well depth from sounding, summer 2008.
C-82a	Hm:T-014	351649084583401	138	845	849	--	--	31.60	817	--	--	--	--	--	--	Couldn't locate well reported to be measured in the 1990s.
C-82b	Hm:T-015	351650084583301	270	846	851	--	--	31.80	819	41.34	810	38.85	812	29.90	821	
C-83	Hm:T-016	351613084590601	90	801.1	808	--	--	22.38	786	25.20	783	16.66	791	21.83	786	
C-84	Hm:S-030	351503085030401	250	820	838	--	--	91.24	747	106.81	731	131.79	706	116.42	722	
C-85	Hm:S-031	351625085032001	58	810	808	--	--	30.12	778	--	--	34.49	774	25.23	783	
C-86	Hm:S-032	351554085012001	244	950	950	--	--	160.28	790	167.42	783	216.62	733	216.32	733	
C-87	Hm:S-033	351650085003701	165	922	918	--	--	113.42	805	120.10	798	>145	<773	--	--	Well obstructed between ~133 and 145 ft BLS; water level deeper than 145 ft BLS in summer 2008.
C-88	Hm:T-017	351818084592801	130	925	875	--	--	73.28	802	80.80	794	102.08	773	93.59	781	
C-89	Hm:S-034	352004085002301	35	730	732	--	--	5.44	727	11.99	720	--	--	--	--	Well not located for 2008–09 measurements.
C-90	Hm:T-018	351945084584801	27	900	900	--	--	12.22	888	--	--	22.09	878	--	--	Well too shallow to be in bedrock.
C-91a	Hm:T-019	351954084582201	200	820	829	--	--	56.02	773	62.21	767	83.37	746	82.17	747	Owner reported well is 200 ft deep; sounded at 100 ft deep in 1993.
C-91b	Hm:T-020	352001084582101	72	810	814	--	--	24.72	789	30.52	783	48.90	765	47.50	767	Owner reported well is ~75 ft deep.
C-92	Hm:S-036	352006085002601	365	--	720	--	--	--	--	--	--	4.12	716	1.73	718	

Appendix 1. Wells and water-level measurements used to construct potentiometric-surface maps of the Valley and Ridge aquifer in the Savannah Valley Utility District (SVUD) study area in East Tennessee.—Continued

[Original land-surface altitudes from topographic maps (values given in whole feet) or surveys of selected wells (values given in feet and tenths of feet) from 1992-93 measurements, originally reported as referenced to sea level; revised land-surface altitudes from digital elevation model using well locations obtained from a handheld Global Positioning System unit when wells were visited in 2008–09, and used for generation of the potentiometric-surface maps presented in this report, except where indicated otherwise; water-level measurement data from USGS (2020b) except where indicated otherwise; water-level altitudes rounded to nearest foot; pls., plates; USGS, U.S. Geological Survey; ft, foot; BLS, below land surface; NAVD 88, North American Vertical Datum of 1988; --, not measured; ??, unknown; SVUD, Savannah Valley Utility District; in., inch; ~, approximate; <, less than; >, greater than; flowing, water-level altitude estimated as approximately equal to land-surface altitude]

Well identifier (pls. 1–5)	USGS site name	USGS site number	Well depth, in ft BLS	Original land-surface altitude, in ft above sea level	Revised land-surface altitude, in ft above NAVD 88	Fall 1992		Spring 1993		Fall 1993		Summer 2008		Spring 2009		Remarks
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C-93	Hm:S-035	351854085015901	225	--	734	--	--	--	--	--	--	23.33	710	flowing	~734	Well flowing at spring 2009 measurement; water-level altitude ~ at land surface
C-94	Hm:T-022	352138084593601	210	--	743	--	--	--	--	--	--	6.65	736	~5.00	~738	
C-95	Me:B-004	351956084571101	200	--	730	--	--	--	--	--	--	30.09	700	25.04	705	Water level recovering slowly during spring 2009 measurement.
C-96	Hm:T-023	351945084584701	>190	--	895	--	--	--	--	--	--	161.80	733	160.78	734	
C-97	Br:L-006	351710084551401	82	--	825	--	--	--	--	--	--	38.04	787	21.00	804	
C-98	Hm:S-039	351652085002501	180	--	928	--	--	--	--	--	--	167.27	761	149.13	779	Owner reported well ~175–180 ft deep; originally 160 ft deep but deepened at some later date.
C-99	Hm:O-090	351453085020301	>108	--	833	--	--	--	--	--	--	108.16	725	107.06	726	Depth from summer 2008 measurement.
C-100	Hm:S-038	351702085011901	170	--	905	--	--	--	--	--	--	102.8	802	88.28	817	
C-101	Hm:S-037	351834085002001	~120	--	766	--	--	--	--	--	--	15.70	750	5.60	760	Well depth reported by owner.
C-103	Hm:O-091	351144085015101	~100	--	721	--	--	--	--	--	--	11.32	710	6.98	714	Well depth reported by owner.
C-104	Hm:O-092	351053085013401	35	--	735	--	--	--	--	--	--	7.51	727	3.22	732	
C-105	Hm:O-031	351115085025001	150	--	703	--	--	--	--	--	--	10.97	692	8.89	694	Sims Road well site observation well.
C-106	Hm:T-024	351525084593701	305	--	777	--	--	--	--	--	--	56.33	721	27.54	749	
C-107	Me:E-015	352345084594901	208	--	719	--	--	--	--	--	--	--	--	26.10	693	
C-108	Me:B-005	352205084565701	350	--	909	--	--	--	--	--	--	--	--	206.95	702	
C-109	Me:B-006	351946084542201	125	--	742	--	--	--	--	--	--	--	--	11.25	731	
C-110	Hm:T-025	351652084583201	~400	--	846	--	--	--	--	--	--	--	--	61.98	784	Well depth reported by owner.

Appendix 1. Wells and water-level measurements used to construct potentiometric-surface maps of the Valley and Ridge aquifer in the Savannah Valley Utility District (SVUD) study area in East Tennessee.—Continued

[Original land-surface altitudes from topographic maps (values given in whole feet) or surveys of selected wells (values given in feet and tenths of feet) from 1992-93 measurements, originally reported as referenced to sea level; revised land-surface altitudes from digital elevation model using well locations obtained from a handheld Global Positioning System unit when wells were visited in 2008–09, and used for generation of the potentiometric-surface maps presented in this report, except where indicated otherwise; water-level measurement data from USGS (2020b) except where indicated otherwise; water-level altitudes rounded to nearest foot; pls., plates; USGS, U.S. Geological Survey; ft, foot; BLS, below land surface; NAVD 88, North American Vertical Datum of 1988; --, not measured; ??, unknown; SVUD, Savannah Valley Utility District; in., inch; ~, approximate; <, less than; >, greater than; flowing, water-level altitude estimated as approximately equal to land-surface altitude]

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						Depth to water, in ft BLS	Water-level altitude, in ft above NAVD 88	Depth to water, in ft BLS	Water-level altitude, in ft above NAVD 88	Depth to water, in ft BLS	Water-level altitude, in ft above NAVD 88	Depth to water, in ft BLS	Water-level altitude, in ft above NAVD 88	Depth to water, in ft BLS	Water-level altitude, in ft above NAVD 88	
C-111	Hm:T-026	351620084590701	~180	--	819	--	--	--	--	--	--	--	--	43.83	775	Well depth from sounding, spring 2009.
C-112	Hm:T-027	351636084575901	--	--	863	--	--	--	--	--	--	14.11	849	7.17	856	On same property as well C-1 but different well than C-1.

Appendix 2. Methods Used for Construction of Potentiometric-Surface Maps and Delineation of Groundwater Basins

The potentiometric-surface maps presented in this report (pls. 1–5) were generated based on the following hydrologic principles and assumptions:

- The bedrock units of the Valley and Ridge carbonate aquifer in the study area contain a network of openings that are hydraulically interconnected in three dimensions so as to form a regional groundwater surface that can be defined by water-level altitudes in the measured wells in the area.
- The spring 2009 potentiometric map was drawn first because of better well distribution; maps for the preceding measurement periods were drawn subsequently, using concepts developed from the 2009 map.
- The maps represent a conceptual model that implies a balance of hydrologic flow system components that account for recharge, storage, transmission, and discharge for the aquifer in the study area.
- The potentiometric surfaces shown on the maps represent a subdued replica of topography; that is, water levels are deeper but at higher altitudes beneath topographic highs and shallower but at lower altitudes beneath topographic lows.
- Contours are dashed where inferred in areas without well measurement control. In these areas, dashed contours were drawn to generally conform with topography.
- Surface-water elevations along streams were extracted from the North American Vertical Datum of 1988 (NAVD 88) digital elevation model and were used for supplemental control in areas without well control and where large groundwater withdrawals have not occurred. In areas where water-level measurements were made, potentiometric contours are weighted toward groundwater-altitude data rather than the surface-water elevations.
- Maps were constructed with only general abidance to gaining or losing stream reaches, except in the Smith Road well site area where groundwater levels are affected by withdrawals for public supply, particularly during dry seasons, and where Savannah Creek and its tributaries are losing streams and typically flow only during wet periods.
- Surface-water divides were used as additional control for potentiometric contours, particularly in areas lacking groundwater control, except where potentiometric data indicate deviation of groundwater basin boundaries from surface-water divides is warranted.
- The stage of Chickamauga Lake, the regional base level for groundwater discharge, is estimated at an elevation of 680 feet (ft) above NAVD of 1988, the intermediate elevation between average summer (683 ft) and winter (677 ft) pool elevations. The lowest potentiometric contour shown on the maps is 700 ft, except on the summer 2008 map (pl. 4) where the lowest contour is 680 ft because water-level altitudes measured in a few wells in the southern part of the study areas were less than 700 ft above NAVD of 1988.
- Groundwater basins/recharge areas were hand-drawn in ArcGIS using groundwater divides derived from the potentiometric-surface contour maps, with supplemental locational control provided by topography-derived surface-water divides in some areas. Assumptions were made that withdrawals at the Sims Road and (or) Smith Road well sites could induce recharge from Savannah Bay if the potentiometric surface in the Savannah Creek groundwater basin was lowered to altitudes below the stage of Savannah Bay by pumping at these sites, and that recharge from the Hiwassee River impoundment of Gunstocker Creek could be induced to the Gunstocker Creek groundwater basin if pumping were to lower the potentiometric surface in this basin to levels below the stage of the Hiwassee River embayment.
- Once delineated, the areas of polygons representing the groundwater basins were calculated using ArcGIS.

For more information about this publication, contact
Director, Lower Mississippi-Gulf Water Science Center
U.S. Geological Survey
640 Grassmere Park, Suite 100
Nashville, TN 37211

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