Prepared in cooperation with the City of Augusta, Georgia

Groundwater Conditions and Studies in the Augusta–Richmond County Area, Georgia, 2008–2009

Scientific Investigations Report 2011–5188

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

Cover. Hydrologic technician checks manometer to ensure constant discharge rate during aquifer test. Photo by Michael D. Hamrick, USGS.

Groundwater Conditions and Studies in the Augusta–Richmond County Area, Georgia, 2008–2009

By Gerard J. Gonthier, Stephen J. Lawrence, Michael F. Peck, and O. Gary Holloway

Prepared in cooperation with the City of Augusta, Georgia

Scientific Investigations Report 2011–5188

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

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2011

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment, visit *http://www.usgs.gov* or call 1-888-ASK-USGS

For an overview of USGS information products, including maps, imagery, and publications, visit *http://www.usgs.gov/pubprod*

To order this and other USGS information products, visit *http://store.usgs.gov*

Suggested citation:
Gonthier, G.J., Lawrence, S.J., Peck, M.F., and Holloway, O.G., 2011, Groundwater conditions and studies in the Augusta–Richmond County area, Georgia, 2008–2009: U.S. Geological Survey Scientific Investigations Report 2011–5188, 45 p.

Contents

Figures

Appendix Figures

Tables

Conversion Factors and Datums

Multiply	By	To obtain
	Length	
inch	2.54	centimeter (cm)
inch	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
foot per day (ft/d)	0.3048	meter per day (m/d)
foot per year (ft/yr)	0.3048	meter per year (m/yr)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
	Specific capacity	
gallon per minute per foot [(gal/min)/ft)]	0.2070	liter per second per meter [(L/s)/m]
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Transmissivity*	
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)

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

$$°F = (1.8 \times °C) + 32$$

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

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

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

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

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 either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Stable isotopes are reported as delta (δ) values in units of per mil (‰). The ratio of two isotopes of the same element in a sample are compared to the ratio of those two isotopes in a standard.

$$\delta^{2}H = \left(\frac{\left(\frac{^{2}H}{^{1}H} \right)_{sample}}{\left(\frac{^{2}H}{^{1}H} \right)_{standard}} - 1 \right) \times 1{,}000\ ^{o}/_{oo} \quad , \quad \delta^{18}O = \left(\frac{\left(\frac{^{18}O}{^{16}O} \right)_{sample}}{\left(\frac{^{18}O}{^{16}O} \right)_{standard}} - 1 \right) \times 1{,}000\ ^{o}/_{oo}$$

The isotope in the numerator is rare compared to the isotope in the denominator. Values above zero in a sample mean that the relative abundance of the rare isotope is greater in the sample than in the standard. The water standard for hydrogen and oxygen isotopes is Vienna Standard Mean Ocean Water (VSMOW). Within VSMOW, there are approximately 6,420 ^{1}H atoms for every ^{2}H atom and approximately 499 ^{16}O atoms for every ^{18}O atom.

A femtogram is 1×10^{-15} grams.

Acronyms Used in this Report

*c*DCE	*cis*-1,2-dichloroethene
CWP	Cooperative Water Program
DO	dissolved oxygen
DOE	Department of Energy
GaEPD	Georgia Environmental Protection Division
MTBE	methyl-*tert*-butyl ether
PCE	tetrachloroethene
PVC	polyvinyl chloride
RMS	root mean square
SRS	Savannah River site
SU	standard units
TCE	trichloroethene
USGS	U.S. Geological Survey
VOC	volatile organic compound

Acknowledgments

George Bales, Drew Goins, Bobby Robinson, and Tom Wiedmeier of the Augusta Utilities Department provided valuable assistance with various project activities. Joe Beard of East Central Regional Hospital provided well access at the East Central Regional Hospital, Gracewood Campus. Bobby Robinson at the Augusta Utilities Department Water Plant provided access to production wells for both water-quality sampling and an aquifer test, and provided a pumping record for Well Field 2 for a few days prior to the test. Numerous private land owners allowed access to their wells for the collection of water-level data.

Michael Hamrick of the U.S. Geological Survey collected water-level data during the 24-hour aquifer test at Well Field 2.

Groundwater Conditions in the Augusta–Richmond County Area, Georgia, 2008–2009

By Gerard J. Gonthier, Stephen J. Lawrence, Michael F. Peck, and O. Gary Holloway

Abstract

Groundwater studies and monitoring efforts conducted during 2008–2009, as part of the U.S. Geological Survey (USGS) Cooperative Water Program with the City of Augusta in Richmond County, Georgia, provided data for the effective management of local water resources. During 2008–2009 the USGS completed: (1) installation of three monitoring wells and the collection of lithologic and geophysical logging data to determine the extent of hydrogeologic units, (2) collection of continuous groundwater-level data from wells near Well Fields 2 and 3, (3) collection of synoptic groundwater-level measurements and construction of potentiometric-surface maps in Richmond County to establish flow gradients and groundwater-flow directions in the Dublin and Midville aquifer systems, (4) completion of a 24-hour aquifer test to determine hydraulic characteristics of the lower Dublin aquifer, and upper and lower Midville aquifers in Well Field 2, and (5) collection of groundwater samples from selected wells in Well Field 2 for laboratory analysis of volatile organic compounds and groundwater tracers to assess groundwater quality and estimate the time of groundwater recharge.

Potentiometric-surface maps of the Dublin and Midville aquifer systems for 2008–2009 indicate that the general groundwater flow direction within Richmond County is eastward toward the Savannah River, with the exception of the area around Well Field 2, where pumping interrupts the eastward flow of water toward the Savannah River and causes flow lines to bend toward the center of pumping.

Results from a 24-hour aquifer test conducted in 2009 within the upper and lower Midville aquifers at Well Field 2 indicated a transmissivity and storativity for the upper and lower Midville aquifers, combined, of 4,000 feet-squared per day and 2×10^{-4}, respectively. The upper and lower Midville aquifers and the middle lower Midville confining unit, which is 85-feet thick in this area, yielded horizontal hydraulic conductivity and specific storage values of about 45 feet per day and 2×10^{-6} ft^{-1}, respectively. Results from the 24-hour aquifer test also indicate a low horizontal hydraulic conductivity for the lower Dublin aquifer of less than 1 foot per day.

Of the 35 volatile organic compounds (VOCs) analyzed in 23 groundwater samples during 2008–2009, only six were detected above laboratory reporting limits in samples from eight wells. No concentration in groundwater samples collected during 2008–2009 exceeded drinking water standards. Trichloroethene had the maximum VOC concentration (1.9 micrograms per liter) collected from a water sample during 2008–2009. Water-quality sampling of several wells near Well Field 2 indicate that, while in operation, the northernmost production well might have diverted groundwater, containing low levels of trichloroethene from at least two other production wells. Analysis of sulfur hexafluoride data indicate the average year of recharge ranges between 1981and 1984 for water samples from five wells open to the upper and lower Midville aquifers, and 1991 for a water sample from one shallow well open to the lower Dublin aquifer. All of these ages suggest a short flow path and nearby source of contamination. The actual source of low levels of VOCs at Well Field 2 remains unknown.

Three newly installed monitoring wells indicate that hydrogeologic units beneath Well Fields 2 and 3 are composed of sand and clay layers. Hydrogeologic units, encountered at Well Field 2, in order of increasing depth are the lower Dublin confining unit, lower Dublin aquifer, upper Midville confining unit, upper Midville aquifer, lower Midville confining unit, and lower Midville aquifer. West of Well Field 3, hydrogeologic units, in order of increasing depth are the Upper Three Runs aquifer, Gordon confining unit, Gordon aquifer, lower Dublin confining unit, lower Dublin aquifer, upper Midville confining unit, upper Midville aquifer, lower Midville confining unit, and lower Midville aquifer.

Introduction

Water supply in the Augusta–Richmond County, Georgia, area is provided, in part, by three well fields (fig. 1) that withdraw water from the upper and lower Midville aquifers, which is part of the larger Cretaceous aquifer system composed of sand of Late Cretaceous age. In 1999, low levels of volatile organic compounds (VOCs) were detected in water samples from several wells in Augusta's northernmost well field (Well Field 1), resulting in the closure of those wells. Also in 1999, the VOCs tetrachloroethene (PCE) and trichloroethene (TCE)

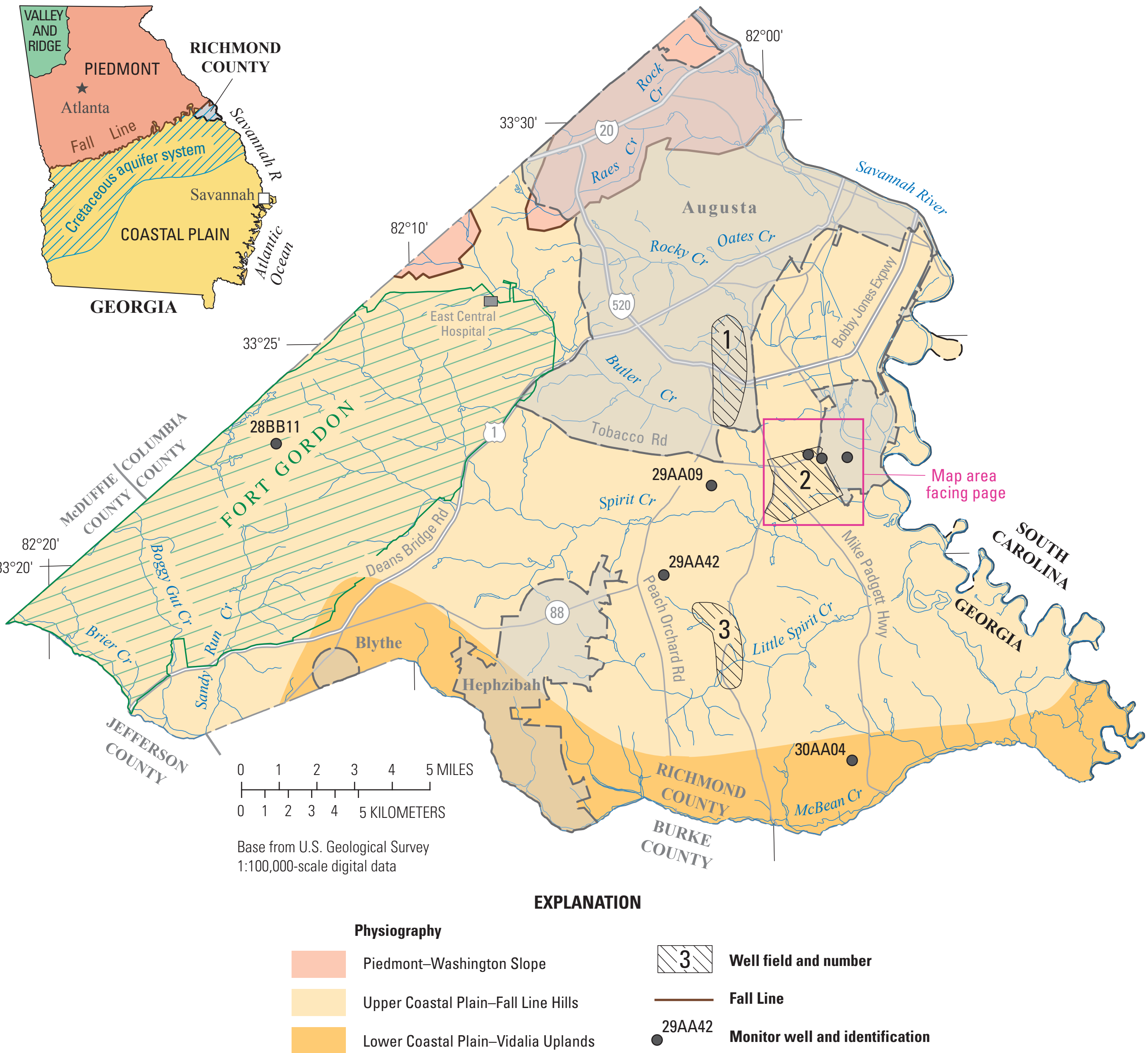


Figure 1. Location of selected wells and weather station in Richmond County, Georgia.

were detected in a production well at the northernmost extent of Well Field 2; however, the source of the contamination had not been identified. Declining water levels in nearby Hephzibah, Georgia, have been attributed to pumping at Well Field 3, although there are no data to confirm this hypothesis.

To better assess groundwater quantity and quality of Augusta's water resources, the U.S. Geological Survey (USGS), with the Augusta Utilities Department, began a cooperative water program (CWP) in 2007 to monitor groundwater levels and quality in the Augusta–Richmond County area.

The objectives of the Augusta CWP are to:

- Determine current groundwater levels, direction of groundwater flow, and water quality of the lower Dublin, upper Midville, and lower Midville aquifers in the Augusta–Richmond County area;
- Annually monitor groundwater levels and seasonal trends and track changes in groundwater availability and flow direction; and
- Annually monitor groundwater quality and identify possible source(s) of low-level concentrations of VOCs.

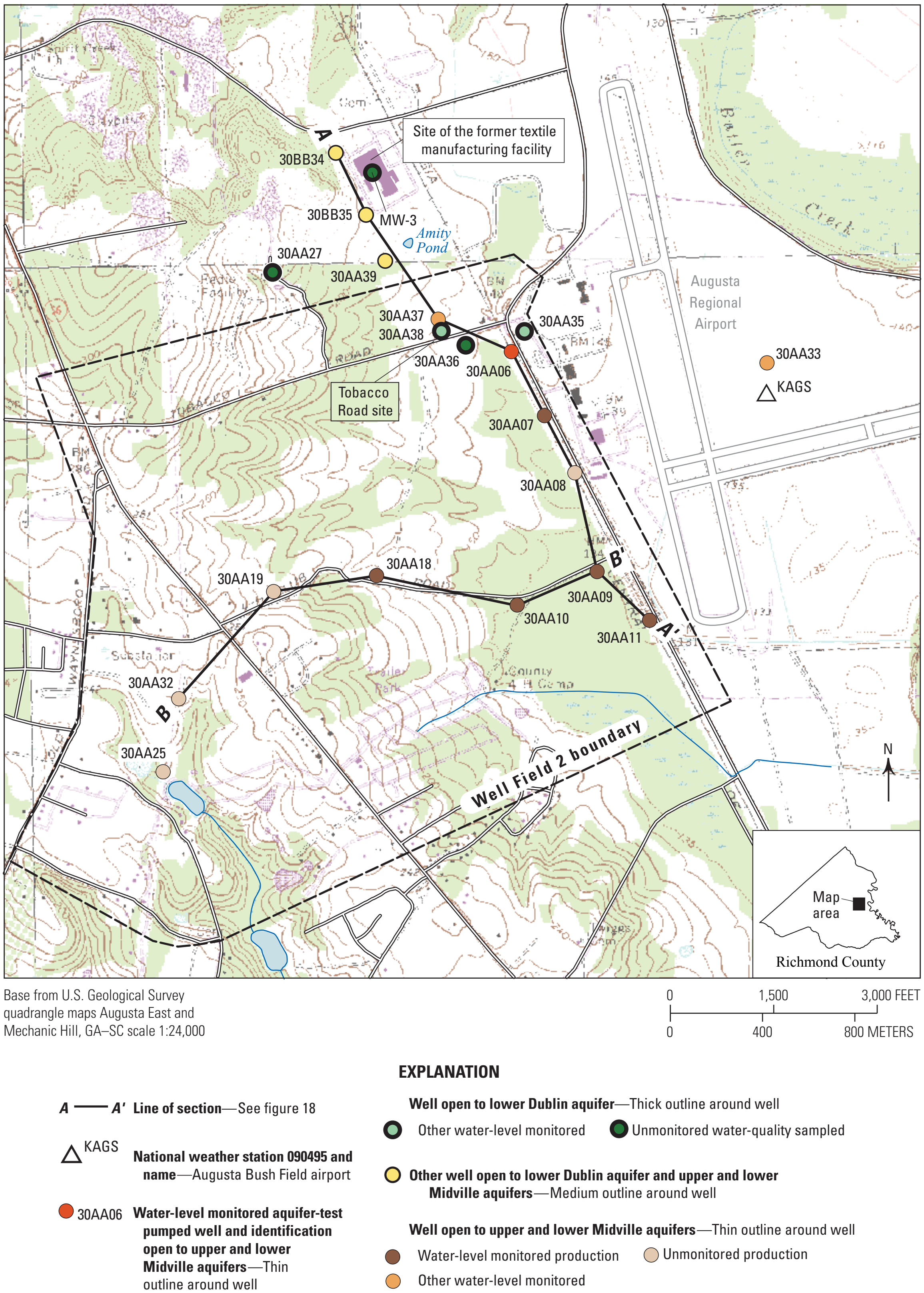


Figure 1. Location of selected wells and weather station in Richmond County, Georgia.—Continued

Data from this monitoring provide information to support water management decisions and serve as a basis for future groundwater modeling efforts while adding to improved regional characterization of groundwater conditions.

City of Augusta Cooperative Water Program

Studies under the CWP between the USGS and the City of Augusta are conducted by the USGS and supported by funding from Augusta Utilities Department and the USGS Federal Cooperative Water Program. The initial purpose of the CWP was to provide a better understanding of the water availability of the main producing aquifers in the City of Augusta's three well fields and monitor the contamination or potential contamination of VOCs that were recently found in low concentrations in some production wells.

The fundamental characteristic of a CWP is that local and State agencies provide at least one-half the funds, and the USGS funds the remaining portion and performs most of the work. The USGS uses established techniques to collect and archive data, and stores the information in a common database available on the Web (water-resource data are available at *http://waterdata.usgs.gov/nwis*). The knowledge gained in studies funded by the CWP is published and added to the growing body of information about the hydrology of the area. Recent examples of the CWP include work in the Brunswick–Glynn County area (Cherry and others, 2010 and 2011), Lawrenceville area of Gwinnett County (Clarke and Williams, 2010) and the Albany area of Dougherty County (Gordon, 2008).

Purpose and Scope

This report provides an overview of groundwater conditions and investigations completed as part of the CWP in the Augusta–Richmond County area during 2008–2009. The overview includes the presentation and analysis of precipitation data from one National Weather Service station (fig. 1); groundwater-use data, continuous groundwater-level data from eight wells; periodic water-level measurements from a network of 53 wells in June 2008 and 51 wells in August 2009 (plus 2 wells measured in June and October 2009, herein discussed as part of the August 2009 network); hydrogeologic description, a 24-hour aquifer test, groundwater samples collected from 11 wells in 2008 and 11 wells in 2009, and analyzed for VOCs and field properties; and groundwater samples collected from 7 wells in 2009 and analyzed for tracers.

Tasks performed during 2008–2009 to meet Augusta CWP objectives included: (1) installation of two additional wells north of Well Field 2 and one well near Well Field 3 and the collection of lithologic and geophysical logging data to determine the extent of hydrogeologic units, (2) collection of continuous groundwater-level data from eight wells near Well Fields 2 and 3, and (3) collection of synoptic groundwater-level measurements and construction of potentiometric-surface maps in Richmond County to establish flow gradients and groundwater-flow directions in the Dublin and Midville aquifer systems during June 2008 and August 2009, (4) completion of a 24-hour aquifer test to determine hydraulic characteristics of the lower Dublin, and the upper and lower Midville aquifers, combined, in Well Field 2, and (5) collection of groundwater samples from 11 wells in the vicinity of Well Field 2 for laboratory analysis of VOCs and from 7 wells for laboratory analysis of groundwater tracers of stable oxygen and hydrogen isotopes and sulfur hexafluoride to assess groundwater quality and estimate the time of groundwater recharge.

Description of Study Area

Because Augusta covers much of Richmond County, the study area includes the entire 328-square-mile (mi^2) area of the county (fig. 1). Richmond County includes four main municipalities and had a total population of 199,775 in 2000 (U.S. Census Bureau, 2011, accessed on January 25, 2011, at *http://factfinder.census.gov*). Most of the Richmond County population resides in Augusta, the largest city in the county. In 1996, the City of Augusta annexed all unincorporated areas in Richmond County (Augusta–Richmond County Planning Commission, 2003). Other municipalities or entities within Richmond County include Fort Gordon, Hephzibah, and Blythe. Fort Gordon is a U.S. Army military reservation that covers 69 mi^2 and has a population of about 16,000 military personnel and 7,000 civilians (U.S. Department of the Army, 2011, accessed on January 25, 2011, at *http://www.gordon.army.mil/contact.htm*). Two smaller corporate municipalities are Hephzibah and Blythe, which had populations of 3,880 and 713, respectively, during 2000 (U.S. Census Bureau, 2011, accessed on January 25, 2011, at *http://factfinder.census.gov*).

Physiography and Drainage

Richmond County is located at the eastern edge of Georgia and the northern edge of the Coastal Plain physiographic province, adjacent to the Fall Line (fig. 1). The Fall Line is the boundary between the Coastal Plain and the Piedmont physiographic provinces (Fennemann, 1938; Clark and Zisa, 1976). The Piedmont physiographic province is composed of crystalline metamorphic and igneous rock, whereas the Coastal Plain is composed of unconsolidated sediments. A small part of northeastern Richmond County extends into the Piedmont physiographic province. South of the Fall Line, rolling hills and some bottomlands cover much of the county. Rolling hills represent the Fall Line Hills and Vidalia Upland districts as defined by Clark and Zisa (1976). Topographic relief in the rolling hills generally is about 200 feet (ft), with maximum altitudes of about 530 ft in the northwestern part of the county, decreasing to about

315 ft in the southeastern part. Bottomlands exist along major streams and the Savannah River on the eastern edge of the county, south of the Fall Line. These bottomlands represent local alluvial plains and are composed of low-lying terraces and wetlands. Relief within the bottomlands is only about 5 ft in the low-lying terraces with almost no relief within the wetlands. The altitude of Savannah River bottomlands decreases from north to south, ranging from 130 ft where the Savannah River exits the Piedmont at the City of Augusta to 95 ft in the southeastern corner of the county. Bluffs surrounding the Savannah River bottomlands rise to heights greater than 100 ft, and form a boundary between the bottomlands and rolling hills to the west.

The Savannah River is the dominant surface-water feature in the region. The river drains an area of about 10,580 mi^2 and empties into the Atlantic Ocean near Savannah, Georgia. All of Richmond County is within the Savannah River drainage area. The county is moderately dissected by streams that form a dendritic drainage pattern, which drains mostly eastward across the county to the Savannah River. Major streams that flow directly into the Savannah River include Rock Creek, Raes Creek, Oates Creek, Rocky Creek, Butler Creek, Spirit Creek, Little Spirit Creek, and along the southern edge of the county, McBean Creek. Two other streams located in the western tip of the county—Boggy Gut Creek and Sandy Run Creek—flow south into Brier Creek, which flows to the south of the county, eventually flowing into the Savannah River about 50 miles (mi) from the southern edge of the county.

Land Use

Land use in Richmond County is mixed (fig. 2); the two dominant land use types are forest, at 32.1 percent, and urban (or developed), at 30.1 percent, (Multi-Resolution Land Characteristics Consortium, 2001). Other primary land-use types in the county include grassland, herbaceous, shrub and scrub (17.2 percent); wetland (10.0 percent); and agriculture (8.2 percent). Minor land uses include open water (1.5 percent) and barren land (0.9 percent). Most urban land use is associated with the City of Augusta and is located in the northeastern half of the county, with some developed areas in Fort Gordon, suburban sprawl between the Augusta and Hephzibah, Augusta Regional airport (formerly named Augusta Bush Field airport), and heavy industry south of Augusta Regional airport. Urban land use consists mostly of residential and commercially developed areas. Forested land is present in patches throughout the county, but is concentrated in the less-developed upland areas in the western and southern parts of the county. Other land uses concentrated in the less developed upland areas are grassland, herbaceous, shrub and scrub, agriculture, and barren land. About half of the agricultural land consists of cultivated crops such as vegetables, barley, and orchards; the other half consists of pastureland and hay (U.S. Department of Agriculture, 2009). Open water and wetlands are concentrated in the Savannah River and its associated bottomlands along the eastern edge of the county. Some development from Augusta extends into the Savannah River bottomlands.

Hydrogeology

South of the Fall Line, the northern Coastal Plain is underlain by a wedge of sand, clay, and minor limestone that range in age from Late Cretaceous through post-Eocene (fig. 3; Williams, 2007). The hydrogeologic units within this wedge thicken towards the southeast. The principal aquifer systems (in order of increasing depth) are the Floridan aquifer system, Dublin aquifer system, and the Midville aquifer system. Being close to the northern edge of the Coastal Plain, several of the hydrogeologic units are minor or absent in Richmond County.

In the study area, the Floridan aquifer system consists of the following hydrogeologic units in order of increasing depth below land surface: the Upper Three Runs aquifer, Gordon confining unit, and Gordon aquifer. Although the Floridan hydrogeologic units are not prevalent near Well Fields 1 and 2, they do exist as shallow deposits near the upper parts of hills, west and south of Well Fields 1 and 2. The Gordon aquifer exists as a shallow surficial aquifer at Well Field 3.

The Dublin aquifer system consists of the following hydrogeologic units in order of increasing depth below land surface: Millers Pond confining unit, Millers Pond aquifer, upper Dublin confining unit, upper Dublin aquifer, lower Dublin confining unit and the lower Dublin aquifer (fig. 3). The Millers Pond confining unit and aquifer are absent at Well Fields 1, 2, and 3. In the vicinity of Well Fields 2 and 3, the Dublin aquifer system is composed largely of clayey sand layers of the lower Dublin confining unit and lower Dublin aquifer. Driller and geophysical logs and interpretation by Williams (2007) indicate that only the lower Dublin aquifer is present in Well Fields 1 and 2. Williams (2007) indicates that the lower Dublin aquifer is not a large water-producing unit in the Augusta–Richmond County area. Falls and others (1997) report horizontal hydraulic conductivities for the upper and lower Dublin aquifers just south of Richmond County (at Millers Pond) of less than 1 foot per day (ft/d).

The Midville aquifer system consists of the following hydrogeologic units in order of increasing depth below land surface: the upper Midville confining unit, upper Midville aquifer, lower Midville confining unit, and the lower Midville aquifer (fig. 3). Production wells within the three Augusta well fields primarily are open to both the upper and lower Midville aquifers (Clarke and others, 1985). Within Well Field 1 the upper and lower Midville aquifers are merged as a single aquifer (Williams, 2007). The Midville aquifer system is composed of an interlayered sequence of medium to coarse sand and gravel, clayey sand, sand with clay layers, and massive hard clay (Williams, 2007).

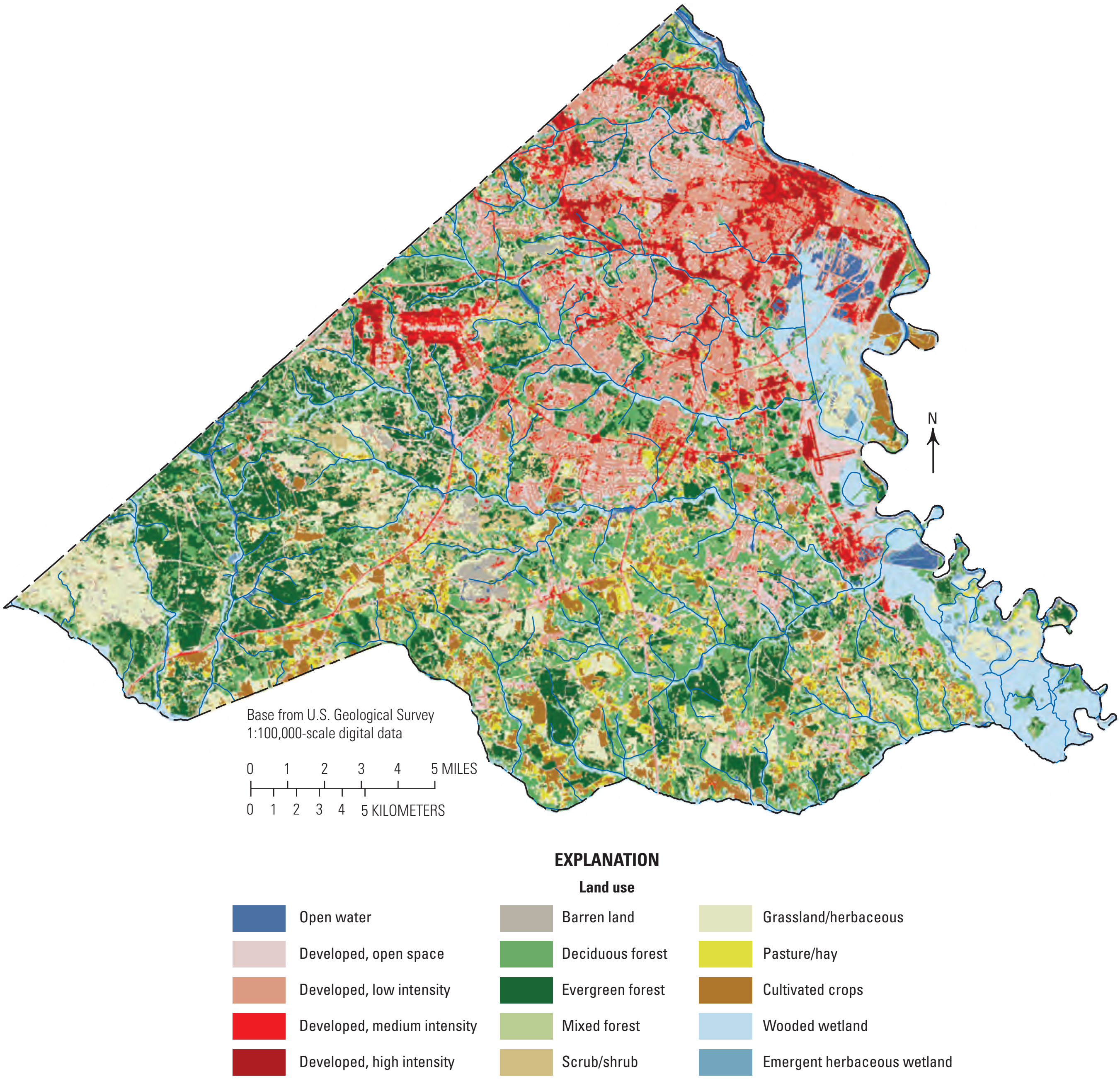


Figure 2. Land use in Richmond County, Georgia, 2001 (data are from the Multi-Resolution Land Characteristics Consortium, 2001).

Previous Studies

Clarke and others (1985) and Gorday (1985) describe the hydrogeology of the Dublin and Midville aquifers and Coastal Plain strata, respectively, in Richmond County. Hetrick (1992) provides a detailed geologic description of the Paleocene, Eocene, and Miocene formations in Richmond County. Williams (2007) describes lithology of the Cretaceous sediments and indicates to which units the production wells are open. Williams (2007) also mapped the potentiometric surface of the Dublin and Midville aquifer systems within Richmond County during January 2007 to better understand groundwater movement in the Cretaceous aquifer system. Priest and Bukowski-McSwain (2002) describe work completed at a landfill located on Fort Gordon; the effort involved assessing the hydrogeology of the shallowest unit, the Upper Three Runs aquifer, and collecting water-quality data.

Several studies were performed to assess the hydrogeology and water quality on the U.S. Department of Energy (DOE) Savannah River Site (SRS). Most of the 310-mi^2 SRS is located in Aiken and Barnwell Counties on the South Carolina side of the Savannah River. Richmond County is located just west of Aiken County on the Georgia side of the Savannah River. Falls and others (1997) describe the geology

GEOLOGY: System	GEOLOGY: Series	GEOLOGY: Unit, Falls and others (1997)	GEOLOGY: Unit, Hetrick (1992)	Hydrogeologic unit		Well Field 2	Well Field 3	Model layer
Tertiary	Miocene	Barnwell unit	Altamaha Formation	Floridan aquifer system	Upper Three Runs aquifer	Absent		Inactive
	Eocene		Tobacco Road Sand Formation					
			Dry Branch Formation / Irwinton Sand / Twiggs Clay					
		Tinker/Santee unit	Clinchfield Formation		Gordon confining unit		Gordon confining unit	
			Lisbon Formation					
		Four mile Branch/ Congaree/ Warley Hill unit	Huber Formation		Gordon aquifer		Gordon aquifer	
	Paleocene	Snapp Formation		Dublin aquifer system	Millers Pond confining unit Millers Pond aquifer		Upper Dublin confining unit	
		Ellenton Formation			Upper Dublin confining unit			
Cretaceous	Upper Cretaceous	Steel Creek Formation	Gaillard and Pio Non Formations undifferentiated		Upper Dublin aquifer			
					Lower Dublin confining unit	Lower Dublin confining unit	Lower Dublin confining unit	Layer 1 Layer 2
		Black Creek Group (undivided)			Lower Dublin aquifer	Lower Dublin aquifer	Lower Dublin aquifer	Layer 3
			?	Midville aquifer system	Upper Midville confining unit	Upper Midville confining unit	Upper Midville confining unit	Layer 4
					Upper Midville aquifer	Upper Midville aquifer	Upper Midville aquifer	Layer 5
		Middendorf Formation	Upper Cretaceous, formations unidentified		Lower Midville confining unit	Lower Midville confining unit	Lower Midville confining unit	
					Lower Midville aquifer	Lower Midville aquifer	Lower Midville aquifer	
		Cape Fear Formation		Basal confining unit	Basal confining unit	Basal confining unit	Basal confining unit	Inactive

Figure 3. Correlation chart of geologic and hydrogeologic units in the vicinity of Well Field 2 near Augusta, Georgia (modified from Hetrick, 1992; and Falls and others, 1997).

and hydrogeology of the Coastal Plain within an eight-county area that encompasses Richmond County. The hydrogeologic framework from Falls and others (1997) was used to develop a groundwater flow model of the multi-county area (described by Clarke and West, 1998). Particle tracking was used to determine how pumping in the area affects groundwater flow and possible contaminant migration (Clarke and West, 1998; Cherry, 2006; and Cherry and Clarke, 2007).

Unpublished reports by the Georgia Environmental Protection Division (GaEPD; James S. Guentert, Georgia Environmental Protection Division, written commun., 2003) indicated that the TCE concentration in Augusta well 30AA06 increased from 0.7 microgram per liter (µg/L) to 2.5 µg/L between December 1999 and October 2002. Groundwater samples from a shallow monitoring well (between 45 and 65 ft below land surface; MW-3 on fig. 1) located at the main building of a former textile manufacturing facility, located 0.5 mi, north of Well Field 2, (fig. 1) contained TCE and *cis*-1,2-dichloroethene (*c*DCE) at concentrations of 11 and 12 µg/L, respectively. Groundwater samples from other monitoring wells at the textile site, however, did not contain detectable concentrations of VOCs.

Well Numbering System

In this report, wells are identified using a numbering system based on USGS topographic maps. In Georgia, each 7-1/2-minute topographic map has been given a number and letter designation beginning at the southwestern corner of the State. Numbers increase eastward through 39, and letters increase alphabetically northward through “Z” and then become double-letter designations “AA” through “PP”; the letters “I” and “O” are not used. Wells inventoried in each quadrangle are numbered sequentially beginning with “1.” Thus, the forty-second well inventoried in the Hephzibah quadrangle (map 29AA) is designated 29AA42.

Methods of Analysis and Sources of Data

Groundwater conditions were evaluated by collecting continuous and periodic groundwater-level data and comparing to water-use and precipitation data. Groundwater quality was evaluated through the collection and analysis of water samples near Well Field 2. Groundwater resources in Richmond County were assessed through well construction and geophysical logging, and aquifer testing and analysis.

Groundwater-Use Data

Groundwater-use data for 1975–2009 were compiled from data files of the USGS Georgia Water Use Program (Stephen J. Lawrence, U.S. Geological Survey, written commun., November 23, 2010). These data were compiled from permit files maintained by GaEPD. Fanning and Trent (2009) provide a summary of water use in Georgia by county during 1980–2005. The report includes a description of methods used to estimate water use for non-permitted withdrawals, and provides a summary of water use by major river basin and principal aquifer.

Precipitation Data

Precipitation data were obtained from the Augusta Regional airport weather station (KAGS, National Weather Station 090495) located about 0.5 mi east of Well Field 2. Precipitation conditions were indexed as the cumulative departure from long-term normal (1971–2000) conditions. Cumulative departure for a given day is the daily departure from the long-term average for that day. Daily normal (average) precipitation values for Augusta Regional airport during 1971–2000 are from the National Climatic Data Center (2001). Wet conditions are herein defined as those times when the cumulative departure from normal has been increasing over about 3 months. Conversely, dry conditions are defined as those times when the cumulative departure from normal has been decreasing over about 3 months.

Groundwater Levels

Water-level measurements from selected wells were used to create potentiometric-surface maps for the Dublin-Midville aquifer system in Richmond County during June 2008 and August 2009, establish long-term water-level trends, and monitor effects of pumping during a 24-hour aquifer test conducted at Well Field 2. Continuous and intermittent water-level measurements are collected according to USGS standard procedures (Brunett and others, 1997). All water-level data are available at *http://waterdata.usgs.gov/ga/nwis*.

Intermittent water-level measurements in wells were made manually to enable construction of potentiometric-surface maps, for calibration of groundwater-level recorder readings, and for direct monitoring of the aquifer test. Manual measurements were made using a steel tape or electric tape to the nearest 0.01 ft following procedures described in Garber and Koopman (1968).

Continuous groundwater level recorders were equipped with submerged, vented pressure transducers. For long-term monitoring sites, pressure transducers collected water-level measurements hourly; for the aquifer test, pressure transducers collected water-level measurements every 15 minutes except immediately following the start or stop of pumping when pressure transducers collected water-level measurements every minute.

Potentiometric-surface maps were initially contoured using automated, computer techniques to aid in quick linear interpolation of contours and to assist in quality assurance. Computer-generated contours then were hand modified based on interpretation of hydrogeologic conditions. Because many land-surface altitudes at measured wells were estimated using topographic maps, potentiomentric-surface altitudes are accurate to plus or minus one-half the contour interval or (±) 5 ft. Least-squares linear regression was used to determine long-term trends in groundwater levels. More than 30 sample points were used for each well and an r-squared was used to report the goodness-of-fit of the data.

Well Construction and Geophysical Logging

Boreholes for wells were drilled using a mud rotary drill rig running a 6-inch tri-cone bit. Drill cuttings were collected every 20 ft or as lithologic changes were observed. Once total depth was reached, mud was circulated within the borehole to stabilize the formation and allow for safe deployment of the geophysical probes. Geophysical logs collected at each borehole included caliper; natural gamma; spontaneous potential; lateral, long (64-inch) and short (16-inch) normal resistivity; single-point resistance; borehole fluid temperature; and fluid resistivity.

Polyvinyl chloride (PVC) casing and screen were installed in wells 30AA37 and 30AA38. Steel casing and stainless steel screen were installed in well 29AA42. Bentonite was used to plug the annular spacing adjacent to the well casings; gravel filled the annular spacing around the screens.

Water-Quality Sampling and Analysis

Water samples were collected from selected wells after three casing volumes of water were removed from the well, and measurement of field water-quality properties in discharge water from the well had stabilized using the methods described in Gibs and others (2007). Field water-quality properties included specific conductance in microsiemens per centimeter at 25 degrees Celsius (°C), dissolved oxygen (DO) in milligrams per liter, pH, and water temperature in degrees Celsius. All water-quality data are available at *http://waterdata.usgs.gov/ga/nwis/gw*.

Water samples were collected for the analysis of VOCs using Teflon-lined polyethylene tubing that was cleaned with Alconox detergent, rinsed with tap and deionized water, and rinsed with methanol. Nitrile gloves were worn by field personnel during collection and processing. Water samples were preserved with 3 drops of ultrapure 1:1 hydrochloric acid and chilled below 4 °C; (Wilde and others, 2004). Samples were analyzed for 35 VOCs (34 VOC analytes), including PCE and TCE at the USGS National Water Quality Laboratory in Denver, Colorado, using analytical methods described in Connor and others (1998).

Water samples were collected for analysis of the stable isotope ratios of hydrogen-2/hydrogen-1 and oxygen-18/oxygen-16 using the methods described in Wilde and others (2004), and analyzed at the USGS Reston Stable Isotope Laboratory in Reston, Virginia, using methods described in Révész and Coplen (2008a,b).

Water samples were collected for the analysis of sulfur hexafluoride and dissolved gases using the procedures described by the USGS Reston Chlorofluorocarbon Laboratory accessed June 28, 2011, online at *http://water.usgs.gov/lab/sf6/sampling/* and at *http://water.usgs.gov/lab/dissolved-gas/sampling/*. The method used to analyze water samples for sulfur hexafluoride and dissolved gases are described in Busenberg and Plummer (2000).

Aquifer Testing and Analysis

A 24-hour aquifer test was performed in former production well 30AA06, open to the upper and lower Midville aquifers at Well Field 2, October 21–22, 2009, to determine hydraulic properties of the lower Dublin, upper Midville, and lower Midville aquifers, and to assess groundwater-flow directions resulting from well-field pumping. The well was pumped from October 21 at 7:14 a.m. to October 22 at 7:15 a.m. at a rate of 684 gallons per minute (gal/min). Water levels were monitored in nine wells and the pumped well during October 19–23, 2009. Of the 10 monitored wells, 6 were monitored continuously and 4 were monitored with intermittent manual water-level measurements.

Prior to the aquifer test, eight production wells at Well Field 2 were running on an intermittent pumping schedule whereby all wells were turned on and off at the same time. Wells generally would pump for about 2 to 2.5 hours, followed by an inactive period for about 3 to 8 hours. The well field was shut off for the aquifer test about 10:30 a.m. on October 19, 2009, and remained out of operation until 2:00 p.m. on October 23, 2009.

Monitoring-well drawdown in response to the 24-hour aquifer test at well 30AA06 was estimated by filtering out extraneous water-level influences. The primary extraneous influence on water levels was well-field recovery as a result of shutting off all production wells for the aquifer test. This recovery continued throughout the aquifer test and needed to be accounted for to enable more accurate interpretation of aquifer-test data. To filter out the extraneous recovery at each monitoring well, synthetic water levels were matched to measured water levels during a fitting period from the morning of October 20 at 7:14 a.m. to October 21 at 7:14 a.m., just prior to the aquifer test, similar to the approach presented by Halford (2006a). The root-mean-square (RMS) of the difference between synthetic and measured water levels was used to quantify "goodness-of-fit." This measure was used to indicate how well synthetic water levels represent the measured well-field recovery curve. For each monitored well the "matched" synthetic hydrograph from the fitting period was extended into the aquifer-test period to represent water levels that were free of aquifer-test influence. The drawdown response of each monitored well to aquifer-test pumping then was estimated as the synthetic water level minus the measured water level during the test. Graphs of synthetic and measured water levels and estimated drawdown are presented in appendix 1.

Aquifer test data were applied to a numerical model with a calibration tool to estimate hydraulic properties of the lower Dublin aquifer and upper Midville confining unit as separate hydrogeologic units; and the upper Midville aquifer, lower Midville confining unit and lower Midville aquifer, combined as a single hydrogeologic unit. Details of the modeling and its use to assess the hydraulic properties of hydrogeologic units are discussed in the section on Hydraulic Properties of the Local Aquifers.

Groundwater Conditions

Groundwater levels and water quality in the study area have been monitored since 2007 as part of the CWP. In addition, precipitation and groundwater-use information have been compiled to assess their influence on groundwater conditions. These data are used to guide water-management decisions by State and local authorities and are available at *http://waterdata.usgs.gov/ga/nwis*.

Monitoring Network

Between 2007 and 2010, six wells were instrumented with continuous water-level monitoring equipment to assess long-term water-level trends in the Augusta–Richmond County area as part of the CWP. Two of the wells are completed in the lower Dublin aquifer (30AA35 and 30AA38), and four are completed in the both the upper and lower Midville aquifers (30AA37, 30AA06, 30AA33 and 29AA42). Of the six wells, five are located near Well Field 2 and one (29AA42) is located about 2 mi northwest of Well Field 3 (fig. 1). The combination of wells 30AA37 and 30AA38 forms a lower Dublin aquifer-Midville aquifer well cluster. Well 30AA35 is 284 ft from 30AA06, the nearest well that is open to the upper and lower Midville aquifers. In addition, the USGS operates two continuous water-level monitoring wells as part of a statewide network in cooperation with the GaEPD. The first well, 30AA04, is completed in the Gordon and upper and lower Dublin aquifers and is located about 8 mi south of Well Field 2; the second well, 29AA09, is completed in the upper Midville aquifer and located about 2 mi west of Well Field 2. Wells 30AA04 and 29AA09 have periods of record that began in 1979 and 1990, respectively. Real-time water-level recorders were installed in four of the eight network wells. Wells with real-time capabilities include the Tobacco Road well cluster (30AA37 and 30AA38) and two wells that are part of the statewide network (29AA09 and 30AA04). Three of the CWP wells were installed in 2009; their construction is further described in the section on Groundwater-Study Activities.

Factors Affecting Groundwater Levels

Long-term groundwater-level trends in the Dublin and Midville aquifer systems are affected by precipitation, groundwater pumping, and the discharge of groundwater to streams and the Savannah River alluvial aquifer (Clarke and West, 1998). Barometric-pressure changes and earth tides also have minor short-term effects, which are evident in wells distant from the pumping wells.

Precipitation

Precipitation in the Richmond County area increases groundwater levels in the Dublin and Midville aquifer systems through direct recharge. In addition, precipitation decreases the pumping demand for irrigation, which also indirectly increases groundwater levels.

Average monthly precipitation in Augusta, Georgia, slightly fluctuates throughout the year in a semi-annual pattern (fig. 4). Based on monthly precipitation averages from 1971 to 2000 at Augusta Regional airport, a typical year consists of two wet periods and two relatively dry periods (National Oceanic and Atmospheric Administration, 2002). The wet periods are late winter/early spring and summer, whereas the relatively dry periods are late spring and late autumn (fig. 4).

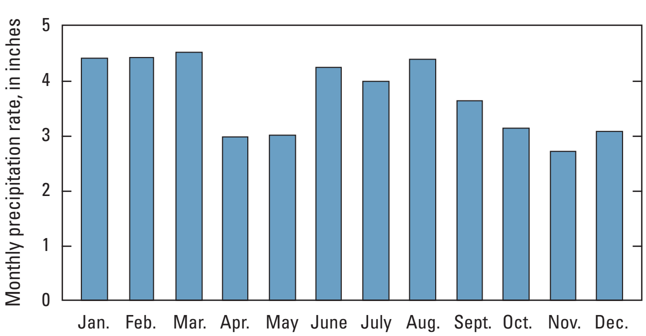


Figure 4. Monthly average precipitation (1971–2000) at Augusta Bush Field airport, KAGS, Richmond County, Georgia. Bar width and area is proportional to average length and precipitation of month, respectively. Monthly precipitation rate is the amount of precipitation, in inches per 30.44-day period.

The months with the highest monthly precipitation rate during these separate periods tend to be March and August, averaging 4.53 and 4.40 inches per month, respectively. The months with the lowest monthly precipitation rate typically are April and November, averaging 2.98 and 2.72 inches per month, respectively. Average annual precipitation at Augusta Regional airport is 44.58 inches over the period from 1971 to 2000.

Precipitation generally was below average during much of the period from 2000 to 2010 (fig. 5*A*). Based on cumulative daily departure from normal, dry conditions prevailed during the period from early 2000 through early 2003, during early 2004, during early 2005, and during the period from early 2006 to late 2008; wet conditions prevailed during much of 2003, during the middle of 2005, during late 2008, and during late 2009 (fig. 5).

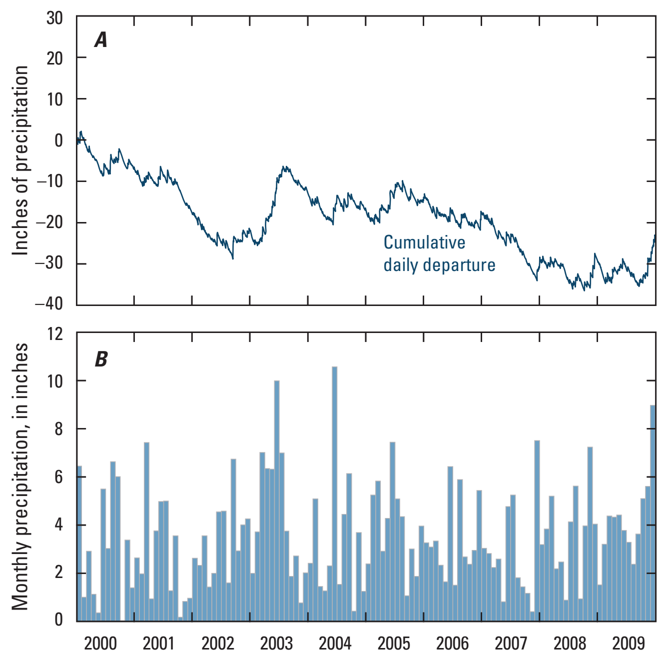


Figure 5. Precipitation trend at Augusta Bush Field airport, KAGS. Richmond County, Georgia, 2000–2009. *(A)* Cumulative departure from daily average. *(B)* Total monthly precipitation.

Groundwater Pumpage

The location of groundwater pumping centers and amounts of water withdrawn from these centers may substantially affect groundwater levels in the Augusta–Richmond County area. Changes in the pumping rate and the addition of new pumping centers may alter the configuration of potentiometric surfaces, reverse groundwater-flow directions, and increase seasonal and long-term water-level fluctuations in the aquifers.

Since 1975, the Augusta–Richmond County Water System has been the largest groundwater user in the county (table 1; Fanning, 2003; Fanning and Trent, 2009). The rate of withdrawal from the Augusta–Richmond County Water System during the period of record was about 5 million

Table 1. Groundwater use in Richmond County, Georgia, 1975–2009.

[Industrial pumpage data reported by industries in Richmond County; municipal pumpage data from Georgia Environmental Protection Division, Watershed Protection Branch; NR, groundwater use not reported; totals may not sum because of independent rounding]

Groundwater use catagory		1975	1980	1985	1990	1995	2000	2005	2009	Average
		Pumpage, in million gallons per day								
Municipal	Augusta	5.03	10.36	11.52	13.18	12.30	12.50	8.42	6.97	10.04
	Non-Augusta[1]	.41	.53	.56	.36	.29	.58	.56	.46	.47
	Hephzibah	.08	.14	.27	NR	NR	.35	.34	.37	.26
	Blythe	NR	NR	NR	NR	NR	NR	NR	.09	.09
	East Central Regional Hospital	.34	.39	.29	.36	.29	.22	.22	NR	.30
	Fort Gordon	NR	NR	NR	NR	NR	.009	.003	.003	.005
	Municipal subtotal	5.44	10.89	12.08	13.54	12.59	13.08	8.98	7.43	10.50
Industrial		2.96	2.75	2.08	2.37	3.19	2.77	2.34	2.25	2.59
Total		**8.40**	**13.64**	**14.16**	**15.91**	**15.78**	**15.85**	**11.32**	**9.68**	**13.09**

[1]Non-Augusta pumpage consists of the totals from Hephzibah, Blythe, East Central Regional Hospital, and Fort Gordon.

gallons per day (Mgal/d) in 1975, increasing to about 13 Mgal/d in 1990, and generally declining to about 7 Mgal/d by 2009 (fig. 6). All other municipal reported groundwater withdrawals (City of Hephzibah, the City of Blythe, East Central Regional Hospital, and Fort Gordon) were less than 0.6 Mgal/d from 1975 to 2009. Industrial withdrawals are concentrated along the Savannah River. Groundwater withdrawals for industrial use ranged from 2.1 to 3.2 Mgal/d during the period of record (Fanning and Trent, 2009).

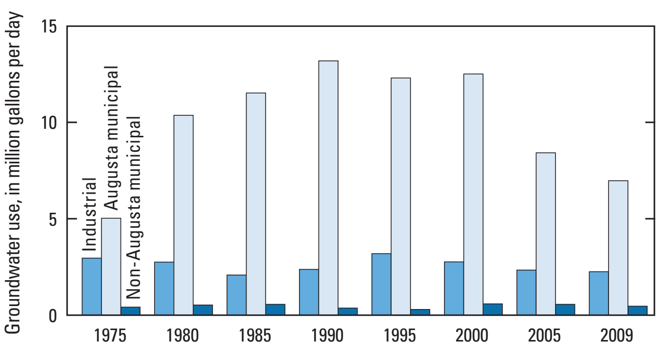


Figure 6. Groundwater usage in Richmond County, Georgia, 1975–2009.

Potentiometric Surface

The potentiometric surface of an aquifer is an imaginary surface representing the altitude to which water would rise in tightly cased wells that penetrate an aquifer and is represented on maps with contours showing lines of equal water-level altitude or head. Areas of high head represent recharge to the aquifer whereas areas of low head represent discharge. The general direction of groundwater flow can be inferred from potentiometric contours, from areas of high head to areas of low head in a direction perpendicular to the contour.

According to Williams (2007), many wells in Richmond County are constructed with multiple screened intervals and are open to both the Dublin and Midville aquifer systems. Water-level measurements collected from these wells represent a composite of the heads from both aquifer systems. Two wells (28BB11 and 30AA04) had screens open to the Gordon aquifer as well as the Dublin aquifer system (table 2). The water levels in these wells were nearly the same as surrounding wells open only to the Dublin and Midville aquifer systems. The majority of the wells used to construct the potentiometric-surface map in Richmond County are completed in the Midville aquifer system, and the map is more representative of the Midville rather than the Dublin aquifer system.

The June 2008 and August 2009 potentiometric-surface maps, constructed each using 53 wells (figs. 7 and 8; table 2), are similar to the previously published map of Williams (2007). However, the August 2009 map shows a cone of depression in Well Field 2 (fig. 8) because water-level measurements were obtained while the pumping wells were active, unlike the two previous potentiometric-surface maps. In Richmond County, the potentiometric surface maps indicate that groundwater generally flows west to east toward the Savannah River. The water-level altitude is about 300 to 420 ft in the western part of the county, about 200 ft in the central part, and about 100 ft in the eastern part near the Savannah River (figs. 7 and 8). In the vicinity of Well Field 2, however, the August 2009 map shows potentiometric surfaces lower than those in the June 2008 map, due the effects of well-field pumping, in the form of a cone of depression. The August 2009 map contours indicate that the flow direction changes when Well Field 2 is pumping (fig. 8). These withdrawals cause the groundwater flow direction to bend toward the center of pumping activity instead of toward the Savannah River.

Table 2. Wells used to create potentiometric-surface maps of the Dublin and Midville aquifer systems in Richmond County, Georgia, 2008–2009.

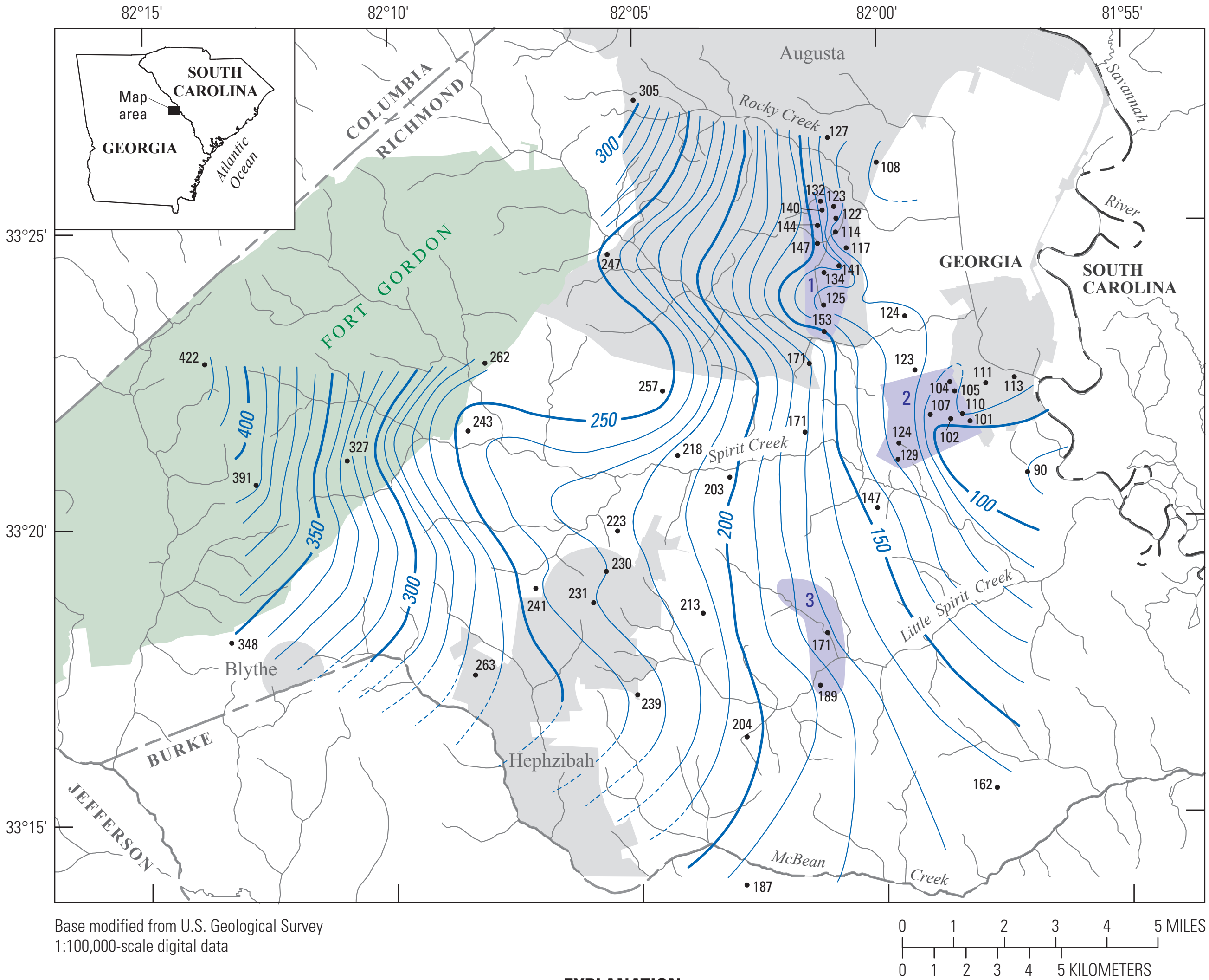
[—, not measured; vertical datum is NGVD 29]

Well information			2008 potentiometric-surface map			2009 potentiometric-surface map		
Station name	Aquifer	Altitude of land surface, in feet	Date measured m/dd/yyyy	Depth to water below land surface, in feet	Altitude of water surface, in feet	Date measured m/dd/yyyy	Depth to water below land surface, in feet	Altitude of water surface, in feet
28AA06	Lower Dublin	412.00	6/2/2008	148.64	263.36	8/6/2009	138.89	273.11
28AA21	Lower Dublin	453.90	6/11/2008	62.71	391.19	8/6/2009	62.52	391.38
28AA22	Lower Dublin	459	6/11/2008	132.33	326.67	8/6/2009	136.73	322.27
28AA46	Lower Dublin	469.03	6/4/2008	121.52	347.51	8/6/2009	121.45	347.58
28AA48	Lower Midville	265	6/3/2008	21.95	243.05	8/7/2009	29.59	235.41
28BB101	Lower Dublin	285.31	6/11/2008	23.7	261.61	—	—	—
28BB102	Lower Dublin	298.75	6/11/2008	58.83	239.92[p]	8/6/2009	42.54	256.21
28BB11	Gordon, Dublin	504	6/11/2008	81.66	422.34	—	—	—
29AA03	Midville	410	6/2/2008	180.03	229.97	8/6/2009	179.9	230.10
29AA04	Lower Dublin	191.79	6/11/2008	44.88	146.91	8/6/2009	44.54	147.25
29AA05	Midville	217.36	6/5/2008	-0.17	217.53	8/5/2009	-0.34	217.70
29AA06	Lower Dublin	185.52	6/4/2008	14.9	170.62	8/5/2009	17.3	168.22
29AA07	Midville	214.06	6/5/2008	11.42	202.64	8/5/2009	11.5	202.56
29AA08	Lower Midville	411	6/3/2008	170.2	240.80	—	—	—
29AA09	Upper Midville	242	6/11/2008	71.07	170.93	8/6/2009	70.61	171.39
29AA24	Lower Dublin	381.3	6/2/2008	168.23	213.07	—	—	—
29AA28	Lower Dublin	316.23	6/2/2008	93.25	222.98	8/28/2009	105.25	210.98
29AA29	Dublin	264.43	6/12/2008	60.52	203.91	8/6/2009	61.37	203.06
29AA30	Midville	204.75	6/4/2008	72.48	132.27[p]	8/5/2009	29.58	175.17
29AA32	Midville	178.88	6/4/2008	39.07	139.81[p]	8/5/2009	7.17	171.71
29AA33	Midville	214.06	6/4/2008	24.77	189.29	—	—	—
29AA34	Lower Dublin	404.94	6/11/2008	148.02	256.92	8/6/2009	148.12	256.82
29AA37	Lower Dublin	385	6/3/2008	146.16	238.84	8/6/2009	145.27	239.73
29AA39	Dublin, Midville	435	6/2/2008	204.05	230.95	8/6/2009	203.44	231.56
29BB01	Lower Midville	144.31	6/5/2008	22.38	121.93	8/6/2009	18.25	126.06
29BB02	Lower Midville	216.22	6/3/2008	45.22	171.00	8/7/2009	44.6	171.62
29BB04	Lower Midville	169	6/3/2008	16.07	152.93	8/7/2009	14.42	154.58
29BB05	Lower Midville	166.35	6/5/2008	31.92	134.43	8/6/2009	23.84	142.51
29BB08	Lower Midville	138.26	6/5/2008	24.27	113.99	8/6/2009	12.78	125.48
29BB09	Lower Midville	179.53	6/5/2008	32.75	146.78	8/6/2009	24.33	155.20
29BB10	Lower Midville	154.92	6/5/2008	37.83	117.09	8/6/2009	24.51	130.41
29BB13	Lower Midville	114.14	6/3/2008	5.67	108.47	8/4/2009	14.25	99.89
29BB20	Lower Midville	160.45	6/5/2008	19.67	140.78	8/6/2009	21.49	138.96
29BB32	Lower Midville	320	6/3/2008	15.4	304.60	8/4/2009	15.1	304.90
29BB59	Lower Midville	164.09	6/5/2008	24.33	139.76	8/5/2009	21.75	142.34
29BB84	Midville	177.58	6/5/2008	52.76	124.82	8/6/2009	34.53	143.05

Table 2. Wells used to create potentiometric-surface maps of the Dublin and Midville aquifer systems in Richmond County, Georgia, 2008–2009.—Continued

[—, not measured; vertical datum is NGVD 29]

Well information			2008 potentiometric-surface map			2009 potentiometric-surface map		
Station name	Aquifer	Altitude of land surface, in feet	Date measured m/dd/yyyy	Depth to water below land surface, in feet	Altitude of water surface, in feet	Date measured m/dd/yyyy	Depth to water below land surface, in feet	Altitude of water surface, in feet
29BB85	Midville	169.77	6/5/2008	25.92	143.85	8/6/2009	25.92	143.85
29BB86	Midville	158.25	6/5/2008	26.25	132.00	8/6/2009	23.73	134.52
29BB88	Midville	136.58	6/5/2008	13.83	122.75	8/6/2009	11.28	125.30
29BB89	Dublin	335.36	6/3/2008	88.05	247.31	8/4/2009	91.38	243.98
29BB94	Midville	152.79	6/4/2008	26.17	126.62	8/4/2009	29	123.79
29Z014	Dublin	269.06	6/3/2008	82.27	186.79	8/5/2009	81.7	187.36
30AA03	Lower Midville	129.23	6/3/2008	39.39	89.84	8/6/2009	38.89	90.34
30AA04	Gordon, Dublin	293	6/9/2008	131.3	161.70	6/17/2009	131.39	162
						10/16/2009	131.56	161
30AA06	Midville	138.26	6/4/2008	34.41	103.85	6/17/2009	38.47	99.79
						10/16/2009	36.71	101.55
30AA07	Midville	131.31	6/4/2008	26.41	104.90	8/5/2009	43.08	88.23
30AA09	Midville	131.37	6/4/2008	20.92	110.45	8/5/2009	52.5	78.87
30AA10	Midville	128.46	6/4/2008	26.41	102.05	8/5/2009	63.16	65.30
30AA11	Midville	124.96	6/4/2008	24.08	100.88	8/5/2009	60.25	64.71
30AA18	Midville	176.43	6/4/2008	69.51	106.92	8/5/2009	122.09	54.34
30AA20	Dublin, Midville	238.6	—	—	—	8/6/2009	119.22	119.38
30AA25	Midville	215.26	6/4/2008	91.08	124.18	8/5/2009	109.4	105.86
30AA26	Lower Midville	218.98	6/4/2008	89.83	129.15	8/5/2009	94.33	124.65
30AA27	Lower Dublin	226.32	6/2/2008	103.15	123.17	8/4/2009	103.76	122.56
30AA33	Lower Midville	135	6/10/2008	23.96	111.04	8/4/2009	25.97	109.03
30AA34	Lower Midville	140	6/10/2008	27.28	112.72	8/4/2009	28.25	111.75
30AA39	Dublin, Midville	184	—	—	—	8/7/2009	66.2	117.80
30BB32	Lower Midville	143.95	6/5/2008	19.45	124.50	8/6/2009	22	121.95



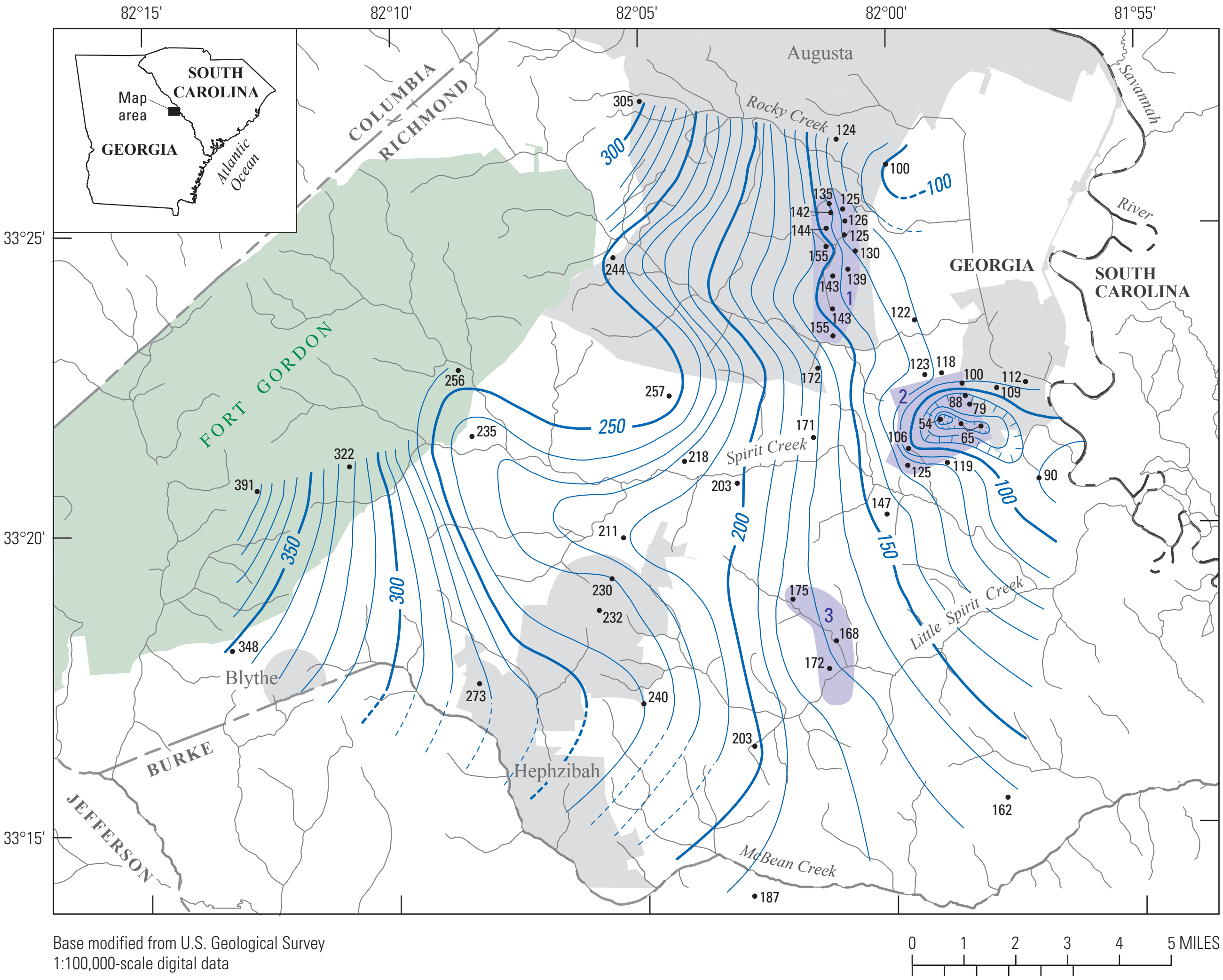
EXPLANATION

3 **County well field and number**

— 250 — **Potentiometric contours**—Shows altitude at which water level would have stood in tightly cased wells, June 2008. Dashed where approximately located. Contour interval 10 feet. National Geodetic Vertical Datum of 1929 (NGVD 29)

263 **Well and water level**—In feet above NGVD 29

Figure 7. Potentiometric surface in the Dublin and Midville aquifer systems in Richmond County, Georgia, June 2008.



EXPLANATION

3	**County well field and number**
— 250 —	**Potentiometric contours**—Shows altitude at which water level would have stood in tightly cased wells, August 2009. Dashed where approximately located. Hachures indicate depression. Contour interval 10 feet. National Geodetic Vertical Datum of 1929 (NGVD 29)
•240	**Well and water level**—In feet above NGVD 29

Figure 8. Potentiometric surface in the Dublin and Midville aquifer systems in Richmond County, Georgia, August 2009.

A natural upward head gradient from the Midville aquifer system to the Dublin aquifer system is present in the Savannah River valley in the vicinity of Well Field 2 (Clarke and West, 1997). Pumping from the Midville aquifer system, however, has reversed this head gradient (fig. 9) and groundwater has the potential to flow downward from the Dublin aquifer system into the Midville aquifer system. During October 19–21, 2010, pumping from Well Field 2 ceased prior to the start of an aquifer test, causing the water levels in the Midville aquifer system to rise above the water level in the Dublin aquifer system at the Tobacco Road well cluster (wells 30AA37 and 30AA38), located about 1,045 ft northwest of well 30AA06 (fig. 1). These conditions are evident in figure 9, which shows that the water level in well 30AA37 temporarily becomes higher than that of well 30AA38. This resumption to natural head gradient was not observed in wells 30AA06 (Midville aquifer system) and 30AA35 (Dublin aquifer system) located about 280 ft apart. Because 30AA06 is closer than well 30AA35 to the center of pumping at Well Field 2, water levels in the former well remained lower than those in the latter well. After the aquifer test was completed, regular pumping schedules resumed and the head gradient at Well Field 2 was downward from the Dublin aquifer system into the Midville aquifer system.

Long-term trends for two wells in the area slightly vary (figs. 10 and 11). The 30AA04 hydrograph indicates a sharp drop in water level during 1985, which is attributed to below-normal precipitation and increased groundwater withdrawals in the area (Joiner and others, 1989; fig. 10). From January 1, 1991, to November 18, 2010, water levels in 30AA04 declined an average rate of 0.32 foot per year (ft/yr; r^2=0.69). Data from well 29AA09 are sparse, and include a 5-year gap from May 4, 1994, to August 12, 1999. Thereafter, the record is fairly complete and has no significant long-term, water-level trend (fig. 11).

Groundwater Quality

Twenty-three groundwater samples were collected from 11 wells in the vicinity of Well Field 2 in the summer of 2008 and in the summer and fall of 2009 (tables 3–5). These samples were analyzed for 35 VOCs (34 VOC analytes, table 3), including PCE and TCE. In 2009, water samples from

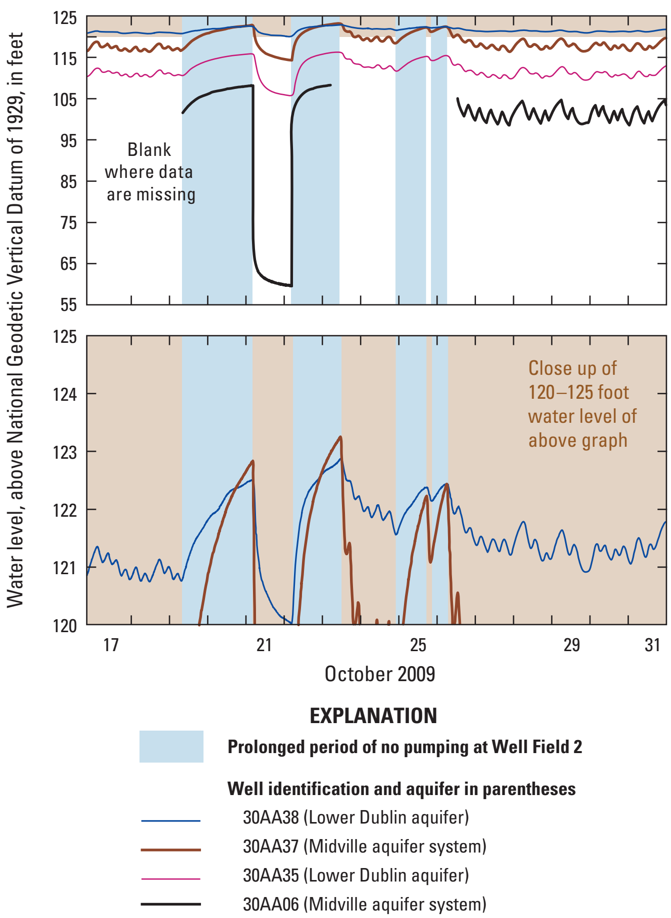


Figure 9. Hydrographs of four wells with continuous water-level monitoring equipment at Well Field 2 near Augusta, Georgia, October 17–31, 2009.

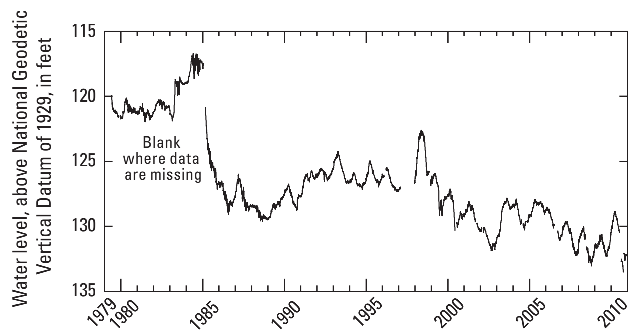


Figure 10. Water-level hydrograph for well 30AA04 in Richmond County, Georgia, 1979–2010.

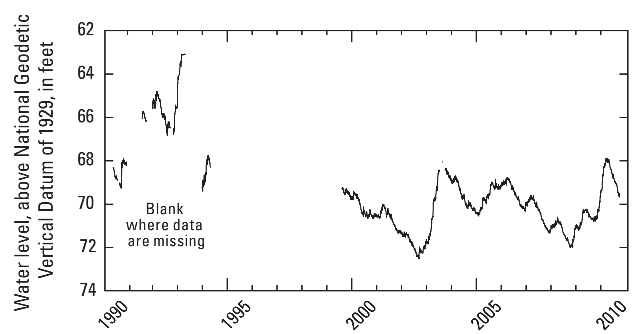


Figure 11. Water-level hydrograph for well 29AA09 in Richmond County, Georgia, 1990–2010.

Table 3. List of volatile organic compounds analyzed in groundwater samples collected from wells in the vicinity of Well Field 2 near Augusta, Georgia, 2008–2009.

[µg/L, microgram per liter; ND, not detected in any sample; *m*- and *p*-xylenes are two volatile organic compounds that constitute one volatile organic compound analyte]

Parameter name	CAS number[a]	Reporting level concentration	Concentration unit	Detection status
1,1,1-Trichloroethane	71-55-6	0.1	µg/L	ND
1,1,2-Trichlorotrifluoroethane	76-13-1	.1	µg/L	ND
1,1-Dichloroethane	75-34-3	.1	µg/L	ND
1,1-Dichloroethylene	75-35-4	.1	µg/L	ND
1,2-Dichlorobenzene	95-50-1	.1	µg/L	ND
1,2-Dichloroethane	107-06-2	.2	µg/L	ND
1,2-Dichloropropane	78-87-5	.1	µg/L	ND
1,3-Dichlorobenzene	541-73-1	.1	µg/L	ND
1,4-Dichlorobenzene	106-46-7	.1	µg/L	ND
Benzene	71-43-2	.1	µg/L	ND
Bromodichloromethane	75-27-4	.1	µg/L	Yes
Bromoform	75-25-2	.2	µg/L	ND
Chlorobenzene	108-90-7	.1	µg/L	ND
Chloroform	67-66-3	.1	µg/L	Yes
cis-1,2-Dichloroethene (*c*DCE)	156-59-2	.1	µg/L	Yes
Dibromochloromethane	124-48-1	.2	µg/L	ND
Dichlorodifluoromethane	75-71-8	.2	µg/L	ND
Dichloromethane	75-09-2	.2	µg/L	ND
Diethyl ether	60-29-7	.2	µg/L	ND
Diisopropyl ether	108-20-3	.2	µg/L	ND
Ethyl *tert*-butyl ether	637-92-3	.1	µg/L	ND
Ethylbenzene	100-41-4	.1	µg/L	ND
m- and *p*-Xylene	179601-23-1	.2	µg/L	ND
o-Xylene	95-47-6	.1	µg/L	ND
Styrene	100-42-5	.1	µg/L	ND
Methyl-*tert*-butyl ether (MTBE)	1634-04-4	.2	µg/L	Yes
tert-Pentyl methyl ether	994-05-8	.2	µg/L	ND
Tetrachloroethene (PCE)	127-18-4	.1	µg/L	Yes
Tetrachloromethane	56-23-5	.2	µg/L	ND
Toluene	108-88-3	.1	µg/L	ND
trans-1,2-Dichloroethene (*t*DCE)	156-60-5	.1	µg/L	ND
Trichloroethene (TCE)	79-01-6	.1	µg/L	Yes
Trichlorofluoromethane	75-69-4	.2	µg/L	ND
Vinyl chloride	75-01-4	.2	µg/L	ND

[a]CAS Registry Number® is a Registered Trademark of the American Chemical Society. CAS recommends the verification of CAS Registry Numbers through CAS Client Services at *http://www.cas.org*.

Table 4. Physical properties of wells and groundwater, and volatile organic compound concentrations in groundwater samples from selected wells in the vicinity of Well Field 2 near Augusta, Georgia, 2008–2009.

[USGS, U.S. Geological Survey; lsd, land surface datum; mg/L, milligrams per liter; SU, standard units; µS/cm, microsiemens per centimeter; °C, degrees Celsius; —, not measured; nd, no data; E, estimated]

Augusta well number	USGS grid number	Latitude	Longitude	Aquifer	Sampling		Depth to water, feet below lsd	Dissolved oxygen, field, mg/L	pH, field SU	Specific conductance, µS/cm at 25 °C	Groundwater temperature, °C	Depth of well, feet below lsd
		Degrees, minutes, seconds NAD 83			Date	Time						
110	30AA25	33°21'19"	81°59'36"	Midville	7/22/2008	0850	—	—	—	—	—	nd
					8/27/2009	0830	—	—	—	—	—	
104	30AA11	33°21'39"	81°58'12"	Midville	7/21/2008	1500	—	—	—	—	—	244
					8/27/2009	1235	—	7.2	5.0	19	19.4	
106	30AA10	33°21'42"	81°58'35"	Midville	7/21/2008	1450	—	—	—	—	—	254
					8/27/2009	1330	—	5.9	4.1	26	19.3	
105	30AA09	33°21"47"	81°58'22"	Midville	7/21/2008	1515	—	—	—	—	—	250
					8/27/2009	1240	—	7.7	5.0	18	19.8	
107	30AA18	33°21'46"	81°58'59"	Midville	7/21/2008	1545	—	—	—	—	—	291
					8/27/2009	1000	—	8.2	3.0	15	19.8	
103	30AA08	33°22'00"	81°58'24"	Midville	7/21/2008	1440	—	—	—	—	—	240
					8/27/2009	1420	—	7.9	4.3	20	20.8	
102	30AA07	33°22'09"	81°58'29"	Midville	6/11/2008	1030	—	8.3	4.6	23	20.1	232
					8/27/2009	1525	—	8.1	4.2	22	20.4	
101	30AA06	33°22'17"	81°58'35"	Midville	6/12/2008	1230	—	—	—	—	—	231
					10/21/2009	1600	—	4.1	7.7	25	19.4	
—	30AA35	33°22'20"	81°58'33"	Lower Dublin	7/22/2008	1345	—	—	6.6	38	—	113
—	30AA36	33°22'19"	81°58'42"	Midville	6/10/2008	1930	—	9.7	4.4	25	19.5	140
—	30AA37	33°22'21"	81°58'46"	Midville	11/23/2009	1300	37.30	—	—	—	—	200
—	30AA38	33°22'21"	81°58'46"	Lower Dublin	9/17/2009	0940	41.14	8.0	4.2	43	19.2	120
—	30AA27	33°22'27"	81°59'12"	Lower Dublin	6/11/2008	0915	—	8.5	4.8	20	22.4	180
—	30AA39	33°22'30"	81°58'56"	Dublin/ Midville	9/16/2009	1430	65.50	8.7	1.2	22	19.0	254
					9/17/2009	1100		—	—	—	—	

Table 4. Physical properties of wells and groundwater, and volatile organic compound concentrations in groundwater samples from selected wells in the vicinity of Well Field 2 near Augusta, Georgia, 2008–2009.—Continued

[USGS, U.S. Geological Survey; lsd, land surface datum; mg/L, milligrams per liter; SU, standard units; µS/cm, microsiemens per centimeter; °C, degrees Celsius; —, not measured; nd, no data; E, estimated]

Augusta well number	USGS grid number	Sampling		Sampling depth, feet below lsd	Concentration, in micrograms per liter					
		Date	Time		Tetra-chloro-ethene (PCE)	Tri-chloro-ethene (TCE)	*cis*-1,2-Dichloro-ethene (cDCE)	Methyl *tert*-butyl ether (MTBE)	Chloro-form	Bromo-dichloro-methane
110	30AA25	7/22/2008	0850	—	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1
		8/27/2009	0830	—	<.1	<.1	<.1	<.2	<.1	<.1
104	30AA11	7/21/2008	1500	—	<.1	<.1	<.1	<.2	<.1	<.1
		8/27/2009	1235	—	<.1	<.1	<.1	<.2	<.1	<.1
106	30AA10	7/21/2008	1450	—	<.1	<.1	<.1	<.2	.2	<.1
		8/27/2009	1330	—	<.1	<.1	<.1	<.2	.2	<.1
105	30AA09	7/21/2008	1515	—	<.1	<.1	<.1	<.2	<.1	<.1
		8/27/2009	1240	—	<.1	<.1	<.1	<.2	<.1	<.1
107	30AA18	7/21/2008	1545	—	<.1	<.1	<.1	<.2	<.1	<.1
		8/27/2009	1000	—	<.1	<.1	<.1	<.2	.1	<.1
103	30AA08	7/21/2008	1440	—	<.1	1.0	.1	.7	<.1	<.1
		8/27/2009	1420	—	<.1	.2	<.1	<.2	<.1	<.1
102	30AA07	6/11/2008	1030	—	E.1	1.4	.1	.3	<.1	<.1
		8/27/2009	1525	—	.1	1.9	.1	.3	<.1	<.1
101	30AA06	6/12/2008	1230	—	.3	.5	.6	<.2	<.1	<.1
		10/21/2009	1600	—	.5	.5	.4	<.2	<.1	<.1
—	30AA35	7/22/2008	1345	—	<.1	<.1	<.1	<.2	<.1	<.1
—	30AA36	6/10/2008	1930	—	<.1	<.1	<.1	<.2	<.1	<.1
—	30AA37	11/23/2009	1300	114	<.1	<.1	<.1	<.2	.5	<.1
—	30AA38	9/17/2009	0940	62.9	<.1	<.1	<.1	<.2	2.2	.3
—	30AA27	6/11/2008	0915	—	<.1	<.1	<.1	<.2	.1	<.1
—	30AA39	9/16/2009	1430	90.0	<.1	<.1	<.1	<.2	<.1	<.1
		9/17/2009	1100	155	<.1	<.1	<.1	<.2	<.1	<.1

Table 5. Groundwater tracer data measured in groundwater samples collected from selected wells in the vicinity of Well Field 2 near Augusta, Georgia, 2009.

[USGS, U.S. Geological Survey; mg/L, milligram per liter; fg/kg, femtogram per kilogram; —, not measured]

Augusta well number	USGS grid number	Sampling		Concentration (mg/L)			Sulfur hexa-fluoride, fg/kg	Deuterium/ Protium ratio, per mil	Oxygen-18/ oxygen-16 ratio, per mil	Apparent year of recharge[a]
		Date	Time	Carbon dioxide	Dissolved nitroge gas	Argon				
104	30AA11	8/27/2009	1235	42	17.9	0.638	49.6	–25.62	–4.82	1980
103	30AA08	8/27/2009	1420	33	24.3	.746	330	–25.80	–4.86	—
102	30AA07	8/27/2009	1525	29	17.2	.613	38.6	–25.38	–4.86	1980
101	30AA06	10/21/2009	1600	30	17.5	.625	74.7	–25.71	–4.90	1984
—	30AA37	11/23/2009	1300	—	—	—	68.4	–26.00	–4.89	1983
—	30AA38	9/17/2009	0940	25	17.3	.626	152	–25.92	–4.98	1991
—	30AA39	9/16/2009	1430	32	16.7	.606	69.4	–25.07	–4.72	1982
		9/17/2009	1100	—	—	—	—	–24.99	–4.72	—

[a]Adjusted for entrained air. Actual year of recharge is not possible because of the mixing of older and younger water.

seven wells were analyzed for hydrogen and oxygen stable isotopes and concentrations of atmospheric gases (table 5).

In 2009, specific conductance ranged from 15 to 43 microsiemens per centimeter (µS/cm) at 25 °C, DO concentrations ranged from 4.1 to 9.7 milligrams per liter (mg/L), and pH ranged from 1.2 to 7.7 standard units (SU) (table 4). Data from the National Atmospheric Deposition Program (2010) indicate that the pH of precipitation generally is about 4.7 in the Augusta area.

Of the 35 VOCs analyzed in groundwater samples during 2008–2009, only 6 were detected above laboratory reporting limits in samples from eight wells (fig. 12; table 4). Detected VOCs included three chlorinated ethenes (PCE, TCE, and cDCE), methyl-*tert*-butyl ether (MTBE), and two trihalomethanes (chloroform and bromodichloromethane). Concentrations in groundwater samples collected during 2008–2009 did not exceed drinking water standards (U.S. Environmental Protection Agency, 2011). The maximum VOC concentration during 2008–2009 was for TCE (1.9 µg/L) in a water sample from well 30AA07 during 2009.

TCE has been detected in all water samples collected from Augusta well 30AA06 since 1999 (fig. 13). During 2008–2009, TCE, PCE, and *c*DCE were detected in water samples from well 30AA06 at concentrations ranging from 0.3 to 0.6 µg/L (table 4). TCE concentrations were nearly identical at 0.5 µg/L in 2008–2009 samples; PCE concentrations increased slightly from 0.3 µg/L in 2008 to 0.5 µg/L in 2009; and *c*DCE concentrations decreased slightly from 0.6 µg/L in 2008 to 0.4 µg/L in 2009. These VOC concentrations were an order of magnitude lower than the Georgia Drinking Water Standard of 5 µg/L (Georgia Environmental Protection Division, 2011).

The site of a former textile mill, located about 0.5 mi north of Well Field 2 is a potential source of VOC contamination near the well field (see location, figs. 1 and 14). At this site, contaminants have been detected in monitoring wells completed in the lower Dublin aquifer (including well MW-3, James S. Guentert, Georgia Department of Natural Resources, written commun., 2003). Although groundwater samples from three wells in Well Field 2 contained detectable concentrations of TCE (30AA06, 30AA07, and 30AA08) during 2008–2009, the samples collected during 2008–2009 from five other wells (30AA39, 30AA37, 30AA38, 30AA36, and 30AA35), located 1,400 to 2,800 ft south of the former textile facility did not contain detectable PCE, TCE, or *c*DCE concentrations. Flow lines based on the potentiometric-surface map for August 2009 (fig. 8) and the vertical head gradient indicate the absence of contaminants at these wells may be related to pumping-induced flow paths in the vicinity of the well field (fig. 14). Flow line A in figure 14 starts west of the former textile facility, flows through the facility and turns south toward the three wells with detectable VOC concentrations (30AA06, 30AA07, and 30AA08). Flow lines B, C, and D start southwest of the former textile facility, do not intersect the textile facility, and turn southward through wells without detectable VOC concentrations (30AA39, 30AA36, 30AA37, and 30AA38). Although flow line A nearly intercepts well 30AA35, in map view, samples from the well did not contain detectable concentrations of PCE, TCE or *c*DCE. Well 30AA35 is completed in the lower Dublin aquifer and, as mentioned previously, has a hydraulic head higher than the underlying Midville aquifer system. The lack of contaminants in this lower-Dublin-aquifer well suggests that a TCE plume, if it exists, may have migrated to greater depth and missed

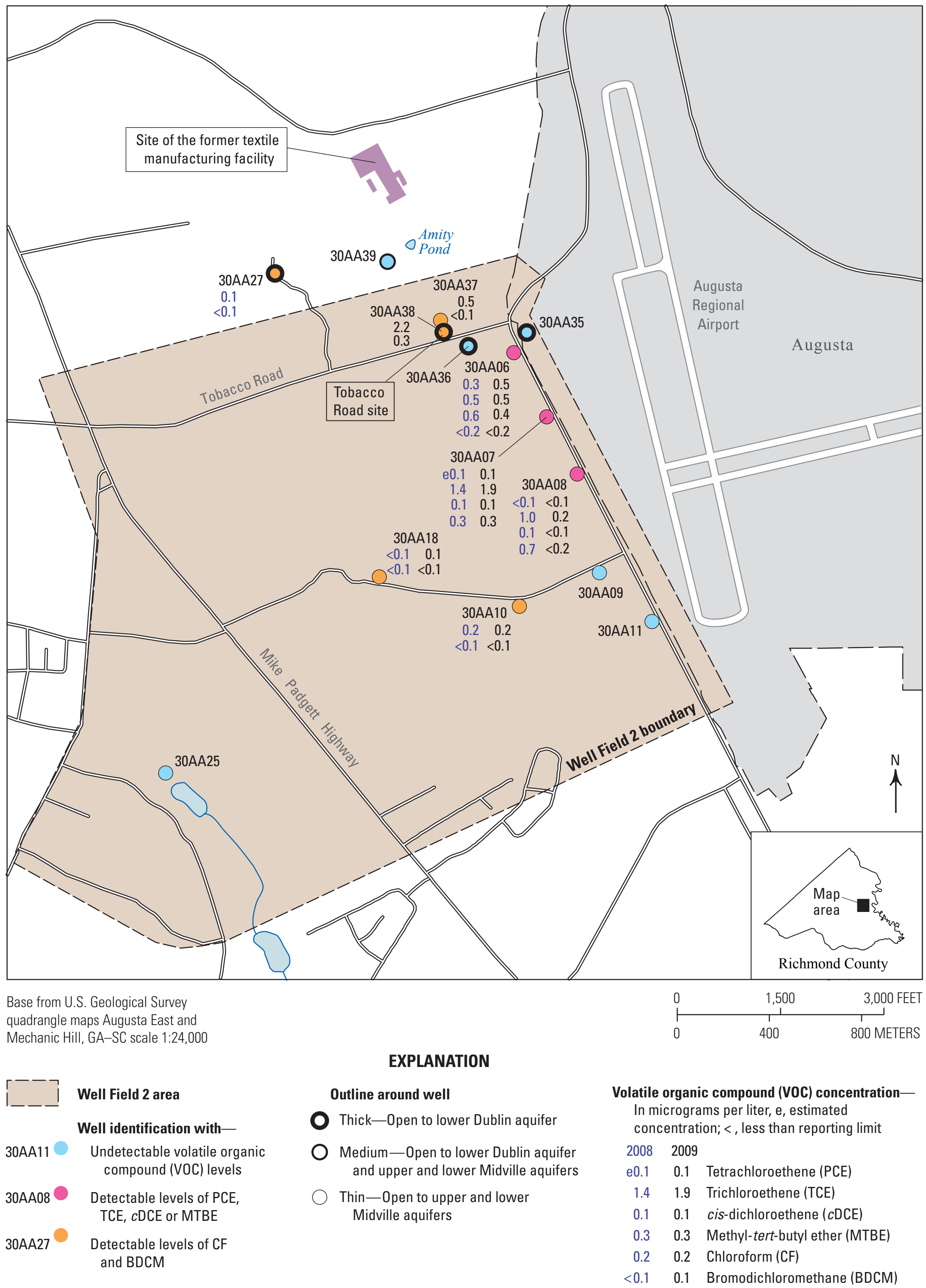


Figure 12. Concentrations of volatile organic compounds in groundwater samples from selected wells in the vicinity of Well Field 2 near Augusta, Georgia, 2008 and 2009.

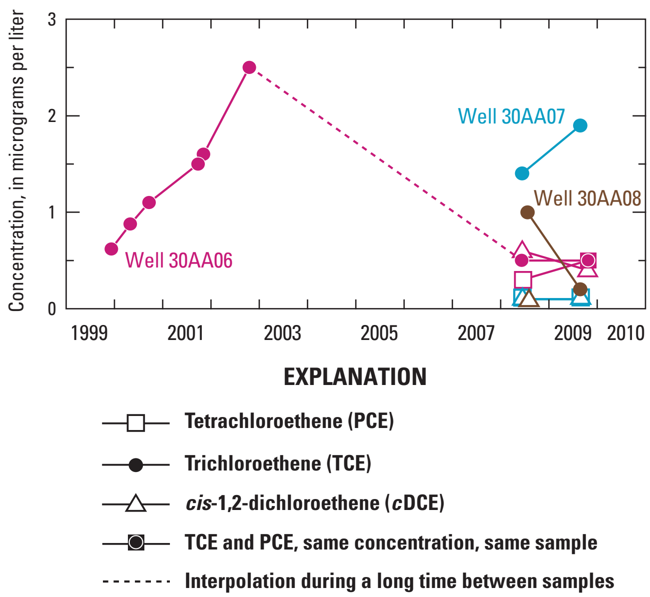


Figure 13. Concentration of trichloroethene in groundwater samples from well 30AA06, 1999–2002, and tetrachloroethene, trichloroethene, and *cis*-1,2-dichloroethene concentrations in groundwater samples from wells 30AA06, 30AA07, and 30AA08 in Well Field 2 near Augusta, Georgia, 2008 and 2009.

the opening at well 30AA35. These flow paths indicate that a plume from the former textile manufacturing facility could be a source of VOCs at the three well-field wells.

Pumping conditions and, therefore, the potentiometric surface will change through time causing flow lines to change through time. For example, potentiometric contours during June 2008 (fig. 7) show a less pronounced influence of pumping at Well Field 2 than the map for August 2009 (fig. 8). Although flow lines show some temporal variation, the general direction of plume migration might follow flow line A in figure 14. Additional monitor wells installed southeast of the former textile facility would provide information to delineate any plume that might follow theoretical flow paths from the textile facility.

Concentrations of VOCs in wells at and near Well Field 2 have changed during 1999–2009. Between 1999 and 2002, the GaEPD also collected water samples at Well Field 2 from wells 30AA07 and 30AA08 for VOC analysis (James S. Guentert, Georgia Environmental Protection Division, written commun., May 28, 2003). During this period, neither well contained any detectable VOCs and GaEPD discontinued sampling the two wells. By 2003, pumping from well 30AA06 was discontinued by the Augusta Utilities Department because of increasing TCE concentration (a maximum concentration of 2.5 µg/L was found in 2002, fig. 13).

During 2008–2009, water samples collected from well 30AA07, located about 1,000 ft down gradient of well 30AA06 (based on contours in fig. 14) by the USGS contained detectable concentrations of PCE, TCE, and *c*DCE. In contrast, water samples collected at the next well downgradient of 30AA07, well 30AA08, contained TCE and *c*DCE but no detection of PCE during 2008–2009. The PCE and *c*DCE concentrations in samples collected from well 30AA07 during 2008–2009 were nearly identical at 0.1 µg/L; however, TCE increased from 1.4 µg/L during 2008 to 1.9 µg/L during 2009 (fig. 13; table 4). These TCE concentrations are similar to those measured in well 30AA06 during 2001. In water samples from well 30AA06, *c*DCE decreased during 2008–2009 and TCE concentrations where 0.5 µg/L, only about one-fifth what they were in 2002. Therefore, it appears that ceasing pumping at well 30AA06 changed the potentiometric surface allowing TCE to migrate beyond well 30AA06 and be captured by pumping wells 30AA07 and 30AA08.

MTBE and trihalomethanes (mainly chloroform), were detected in water samples collected during 2008–2009 from Augusta wells 30AA07, 30AA08, 30AA10, 30AA18, and 30AA27; and from the nested shallow and deep monitoring wells 30AA37 and 30AA38, constructed during 2009 (fig. 12; table 4). In water samples collected during 2008–2009, the MTBE concentrations at well 30AA07 were identical (0.3 µg/L); whereas, the MTBE concentrations in water from well 30AA08 decreased from the maximum concentration in any groundwater sample of 0.7 µg/L in 2008 to a concentration below the laboratory reporting limit of 0.2 µg/L in 2009. The source of these low-level concentrations of MTBE is unknown.

Volatile organic compounds (trihalomethanes) associated with the chlorine disinfection of water (such as, treated municipal drinking water or chlorinated effluents) were detected in water samples from five wells in the vicinity of Well Field 2. No well had a water sample with detections of both a trihalomethane and either PCE, TCE, *c*DCE, or MTBE. Chloroform was detected at concentrations slightly higher than the laboratory reporting limit in 2008–2009 water samples from well 30AA10, and in 2009 water samples from well 30AA18. The 2009 water samples from the shallow nested well 30AA38 contained the maximum concentration of chloroform for any water sample (2.2 µg/L) and a detection of bromodichloromethane (0.3 µg/L; table 4). In addition, the 2009 water samples from the nested deep well 30AA37 contained chloroform at a concentration of 0.5 µg/L. Well 30AA27 also contained chloroform at a concentration of 0.1 µg/L. The source of these low-level concentrations of trihalomethanes is unknown.

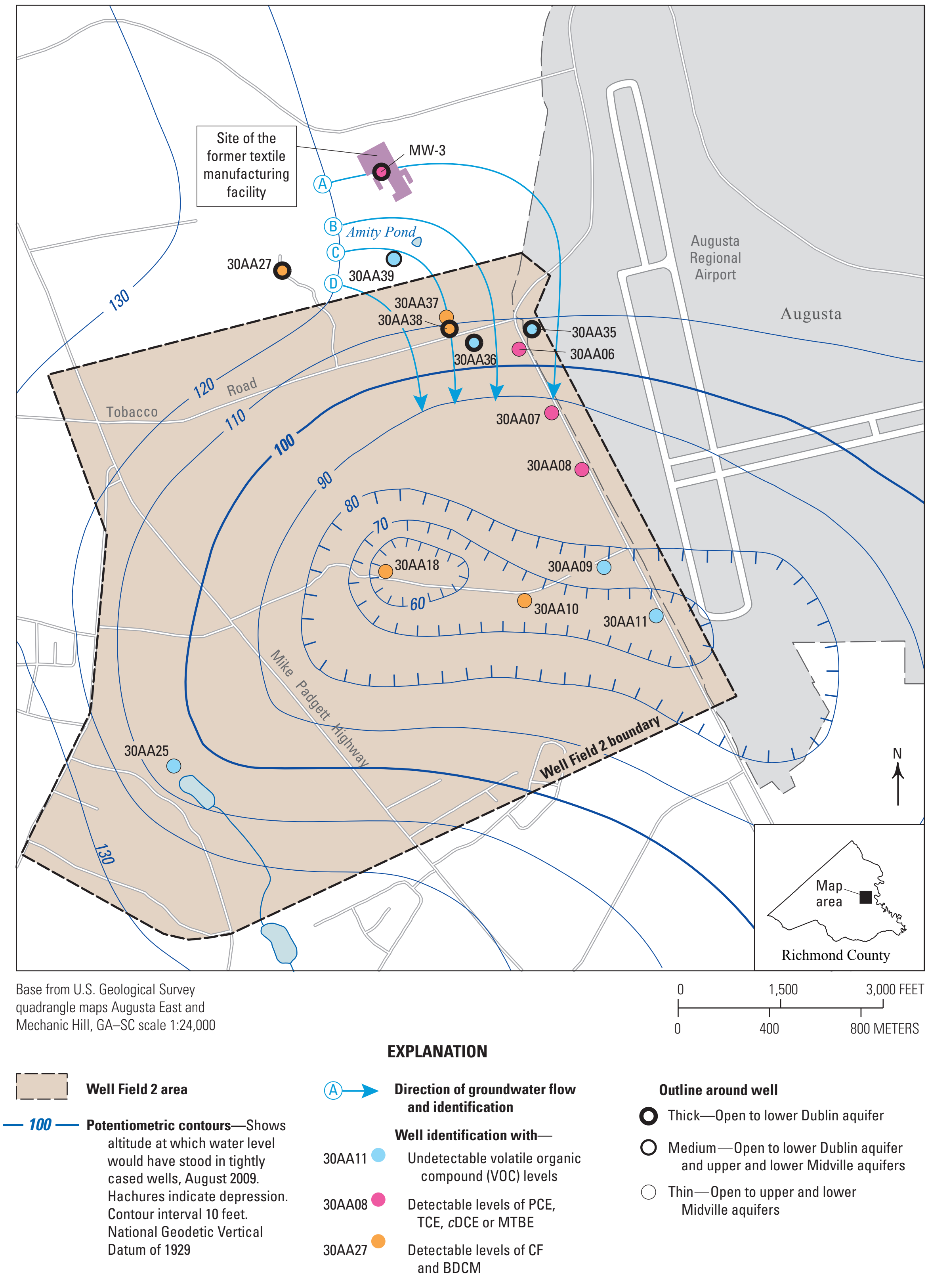


Figure 14. Potentiometric contours, flow lines, and detections of volatile organic compounds in ground water samples from selected wells in the vicinity of Well Field 2 near Augusta, Georgia, 2008 and 2009.

Groundwater-Study Activities

In addition to ongoing groundwater monitoring in the study area, the CWP provides for the ongoing collection of hydrologic data to support a better understanding of the hydrogeology of Coastal Plain sediments in Richmond County, the occurrence and controls of VOC contamination in production wells, and the effect of active production wells on water levels in less-developed areas. In past years, the CWP included borehole geophysical measurements to characterize the lithologic properties of hydrogeologic units and field inventories of existing wells to obtain groundwater-level and water-quality data, and to improve data coverage in the study area. In 2007, this included the publication of a report by Williams (2007) on the Dublin and Midville (Cretaceous) aquifer systems in Richmond County.

During 2008–2009, groundwater studies completed as part of the CWP included characterizing the hydrogeology near Well Fields 2 and 3 during the construction of three new test wells, completion of an aquifer-performance test at Well Field 2 to characterize hydraulic properties and groundwater-flow gradients, and an evaluation of groundwater tracers in an effort to identify potential source areas for VOC contamination at Well Field 2.

Hydrogeologic Framework Characterization Near Well Fields 2 and 3

In August 2009, three 2-inch-diameter monitoring wells were constructed upgradient of Well Fields 2 and 3 to improve current understanding of the hydrogeology of Coastal Plain sediments, and to augment the current groundwater-level and water-quality monitoring network. At each site, drillers' logs and geophysical logs were collected to enable identification of water-bearing zones, and for the placement of well screens.

Well Field 2

At the northern edge of Well Field 2 along Tobacco Road, wells 30AA37 and 30AA38 were constructed as a well cluster, spaced 15 ft apart (fig. 1). The wells are near the western extent of the Savannah River alluvial plain with a land surface altitude of 160 ft. Hydrogeologic units were delineated using driller and geophysical logs collected at the site, geologic descriptions from Hetrick (1992), and hydrogeologic interpretation from Falls and others (1997). Hydrogeologic units, encountered at the Tobacco Road site are, in order of increasing depth, the lower Dublin confining unit, lower Dublin aquifer, upper Midville confining unit, upper Midville aquifer, lower Midville confining unit, and lower Midville aquifer (table 6, fig. 15). Hydrogeologic units consist of sands and clays.

Table 6 Depth and altitude to the top of each aquifer and confining unit in constructed wells 30AA37 and 29AA42, Richmond County, Georgia.

[NGVD 29, National Geodetic Vertical Datum of 1929; NA, not applicable; UK, unknown]

Hydrogeologic unit (top)	Wells 30AA37			Well 29AA42		
	Depth below land surface, in feet	Altitude, in feet, relative to NGVD 29	Thickness, in feet	Depth below land surface, in feet	Altitude, in feet relative to NGVD 29	Thickness, in feet
Land surface	0	160	NA	0	415	NA
Upper Three Runs aquifer	Absent	Absent	0	0	415	91
Gordon confining unit	Absent	Absent	0	91	324	52
Gordon aquifer	Absent	Absent	0	143	272	82
Upper Dublin confining unit	Absent	Absent	0	Absent	Absent	0
Upper Dublin aquifer	Absent	Absent	0	Absent	Absent	0
Lower Dublin confining unit	0	160	40	225	190	11
Lower Dublin aquifer	40	120	80	236	179	103
Upper Midville confining unit	120	40	18	339	76	11
Upper Midville aquifer	138	22	55	350	65	49
Lower Midville confining unit	193	–33	3	399	16	33
Lower Midville aquifer	196	–36	>24	432	–17	38
Well bottom (30AA37)	220	–60	NA	NA	NA	NA
Basal confining unit	Absent	Absent	UK	470	–55	>30
Well bottom (29AA42)	NA	NA	NA	500	–85	NA

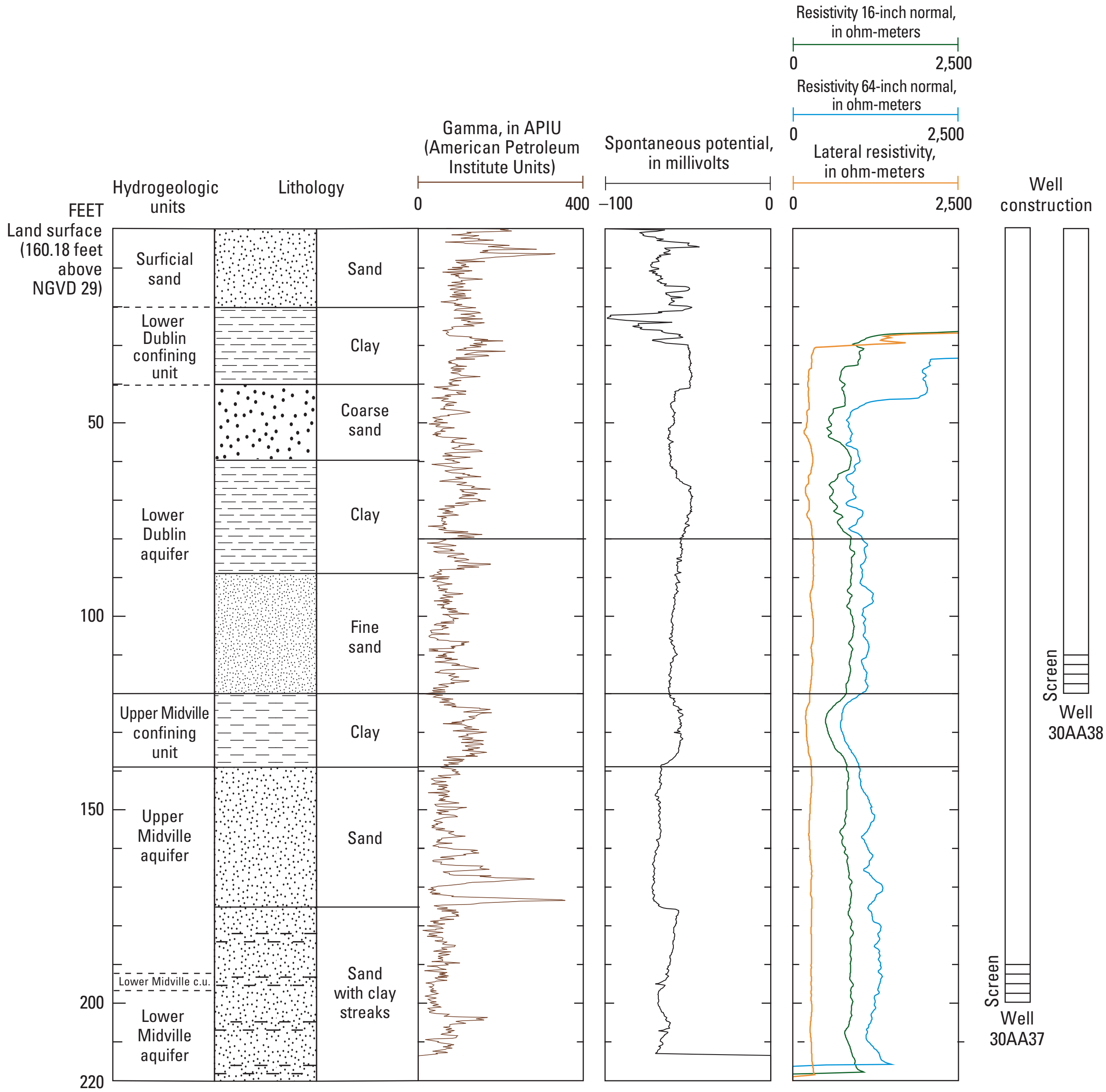


Figure 15. Hydrogeologic units, lithology, and geophysical properties at the Tobacco Road well-cluster site (wells 30AA37 and 30AA38) near Augusta, Georgia. [c.u., confining unit]

Well 30AA38 is screened from 110 to 120 ft depth (figs. 15 and 16) and is open to the base of the lower Dublin aquifer (fig. 15); well 30AA37 is screened from 190 to 200 ft deep (figs. 15 and 17) and is open to the transition between the upper and lower Midville aquifers (fig. 15). During well development and subsequent pumping for water sampling, the Midville aquifer well (30AA37) was more productive than the lower Dublin well (30AA38).

To determine the depth and thickness of aquifers and confining units near Well Field 2, data from the Tobacco Road well cluster and other existing wells were used to construct two hydrogeologic cross sections. Section *A–A′* was constructed along the geologic dip from north-northwest to south-southeast across the well field (fig. 18*A*); section *B–B′* was constructed along the geologic strike from west-southwest to east-northeast across the well field (fig. 18*B*). Hydrogeologic units were delineated using geologic descriptions from Hetrick (1992), and hydrogeologic interpretation from Falls and others (1997) and Williams (2007). The cross sections demonstrate the change in land-surface altitude from the hilly, upland areas west of the well field to the relatively flat, low-lying areas of the Savannah River bottomlands east of the well field where the Savannah River alluvial aquifer is present in the subsurface.

In the vicinity of Well Field 2, the Gordon aquifer is thin and may be present mostly on hill tops west of the well field (fig. 18*B*) based on geologic maps showing outcrops of the Huber Formation (which comprises the two hydrogeologic units) in these areas (Hetrick, 1992). The lower Dublin aquifer, upper Midville confining unit, upper Midville aquifer, lower Midville confining unit, and lower Midville aquifer are the main hydrogeologic units at Well Field 2. The lower Dublin aquifer is from 100 to 150 ft thick and the upper and lower Midville aquifers, combined, are from 80 to 100 ft thick. The lower Dublin aquifer includes one or two layers of clay as indicated on sections *A–A′* and *B–B′* (fig. 18). The lower Midville confining unit is discontinuous in the vicinity of Well Field 2 as indicated on section *A–A′* (fig. 18*A*).

Well Field 3

Northwest of Well Field 3 (fig. 1), well 29AA42 was constructed to a depth of 510 ft below land surface (fig. 19). The well is located in the Fall Line Hills District on a hill top with a land-surface altitude of 415 ft. Hydrogeologic units were delineated using driller and geophysical logs collected at the site, geologic descriptions from Hetrick (1992), and hydrogeologic interpretation from Falls and others (1997). Hydrogeologic units encountered at the site are, in order of increasing depth the Upper Three Runs aquifer, Gordon confining unit, Gordon aquifer, lower Dublin confining unit, lower Dublin aquifer, upper Midville confining unit, upper Midville aquifer, lower Midville confining unit, lower Midville aquifer, and a basal confining bed (table 6). Hydrogeologic units consist of sands and clays.

To replicate zones tapped by wells at Well Field 3, screens were placed in the upper and lower Midville aquifers. The upper screened interval is between 360 and 380 ft below land surface and open to the upper Midville aquifer; the lower screened interval is between 440 and 460 ft below land surface and open to the lower Midville aquifer (figs. 19 and 20). The depth to water in the Midville aquifer system is deep in this upland area, extending to 281.47 ft below land surface in well 29AA42 on December 2, 2010.

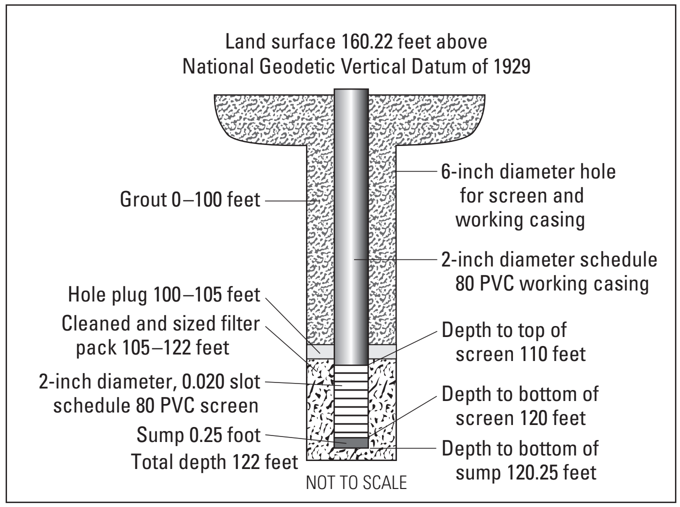


Figure 16. Well completion diagram of well 30AA38 near Augusta, Georgia.

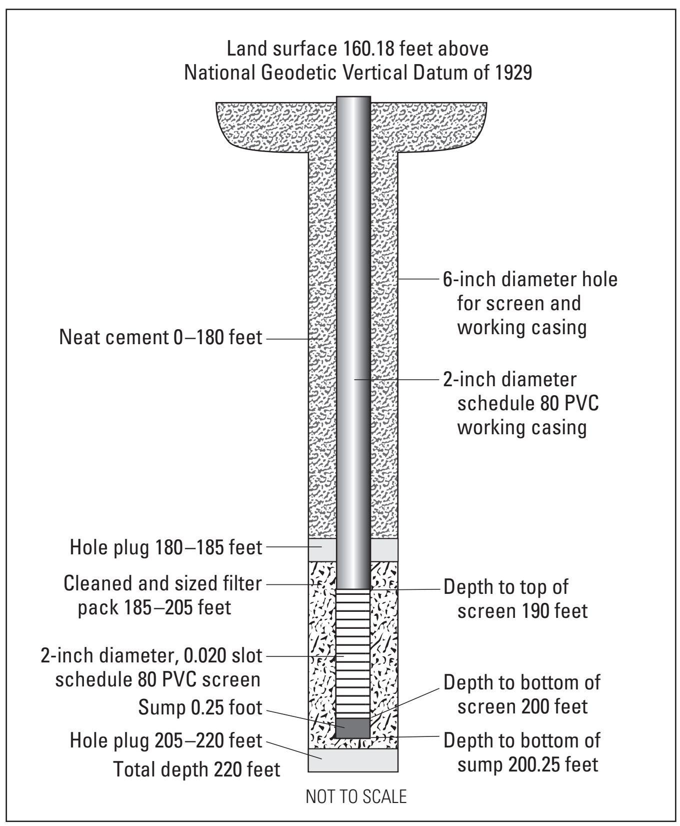


Figure 17. Well completion diagram of well 30AA37 near Augusta, Georgia.

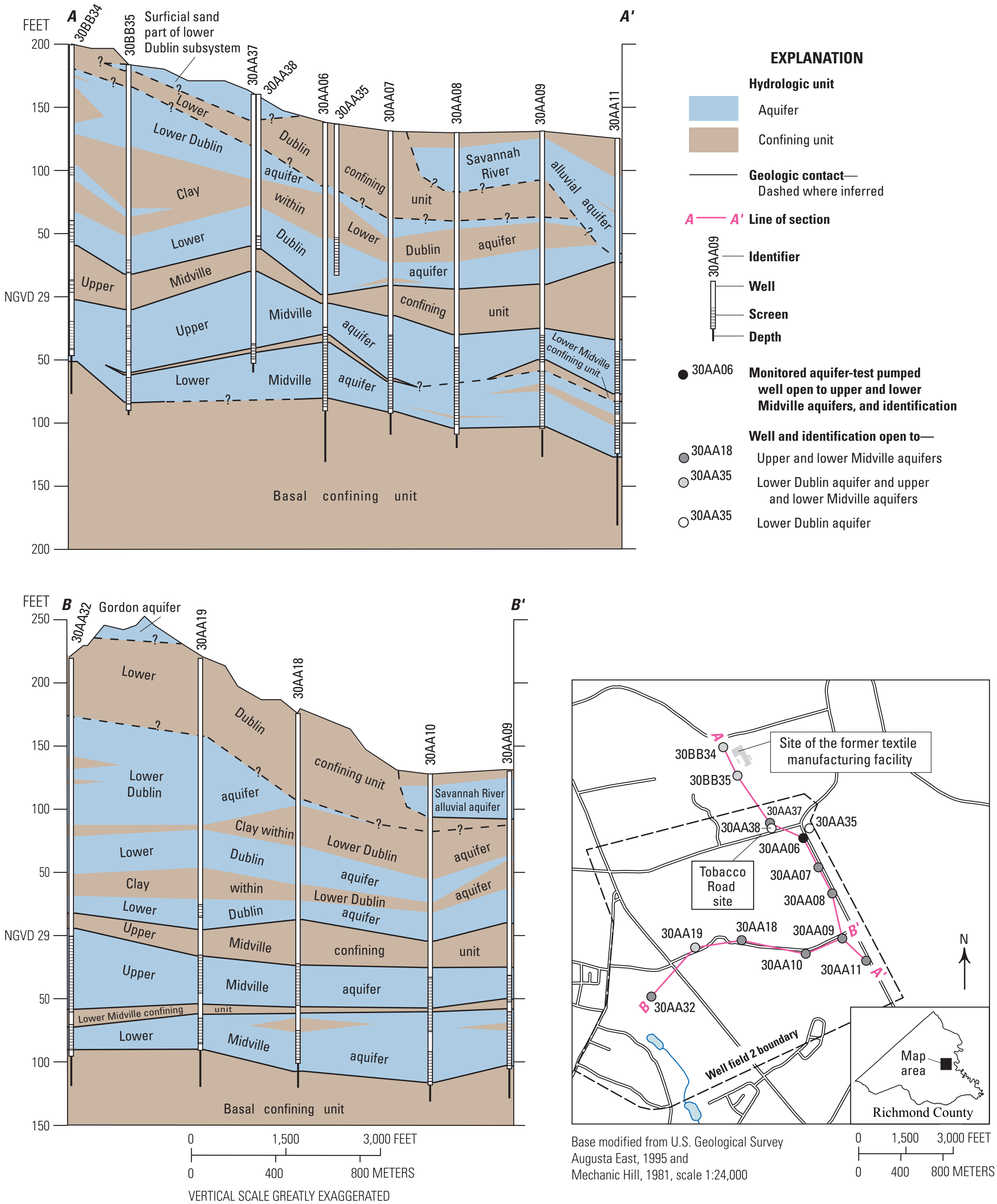


Figure 18. Hydrogeologic cross sections of Well Field 2 near Augusta, Georgia, based on driller's logs and interpretation from Falls and others (1997). Trace of cross section *A–A′* north-northwest to south-southeast and *B–B′* west to east.

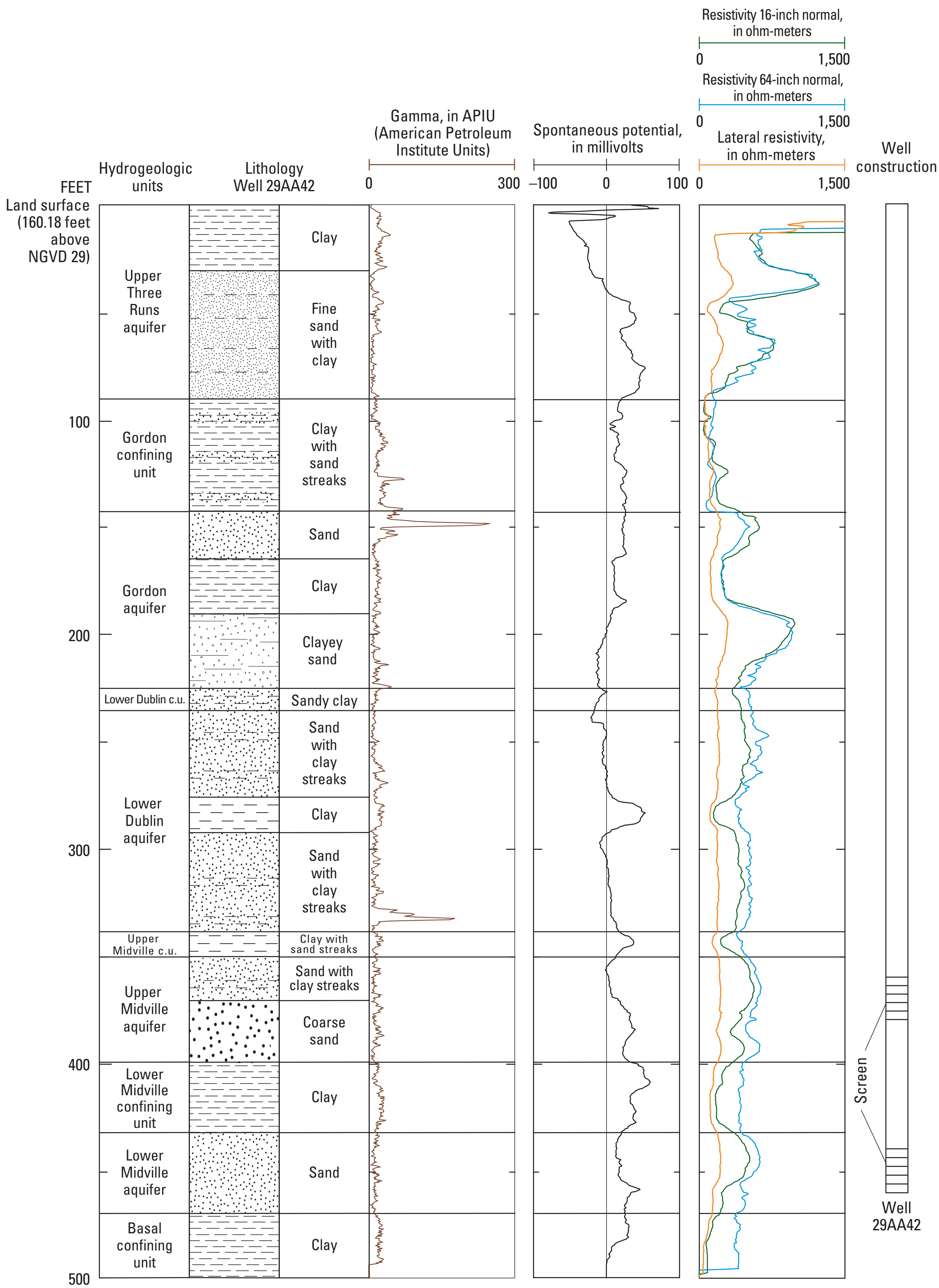


Figure 19. Lithology and geophysical properties of well 29AA42, near Hephzibah, Georgia. [c.u., confining unit]

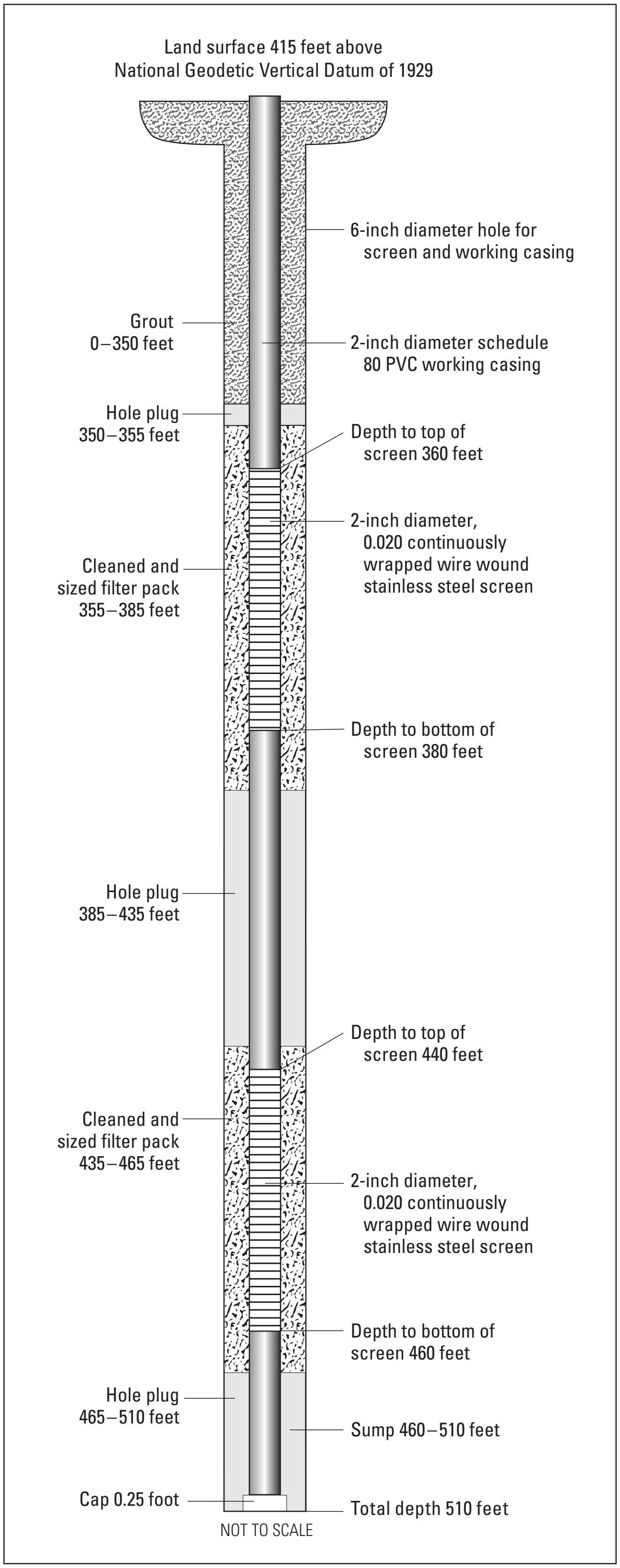


Figure 20. Well completion diagram of well 29AA42 near Hephzibah, Georgia.

Hydraulic Properties of the Local Aquifers

The transmissivity and specific storage of the lower Dublin aquifer and undifferentiated upper and lower Midville aquifers were estimated based on data collected during a 24-hour aquifer test at well 33AA06, open to both the upper and lower Midville aquifers. The well was pumped at a rate of 684 gal/min beginning on October 21, 2009, at 7:14 a.m. and continued for approximately 24 hours to October 22, 2009, at 7:15 a.m. Test data included water levels from two wells open to the lower Dublin aquifer and seven wells open to the upper and lower Midville aquifers. The water-level decline in response to the aquifer test (drawdown) ranged from a maximum of 49.0 ft at pumped well 30AA06 to a minimum of 1.5 ft at the most distant well (30AA11) located 4,355 ft from the pumped well (table 7).

Hydraulic properties of the lower Dublin aquifer and the upper and lower Midville aquifers were estimated using the numerical model MODFLOW-96 (McDonald and Harbaugh, 1988, and Harbaugh and McDonald, 1996) with the calibration tool MODOPTIM (Halford, 2006b). Aquifer-test analysis details are documented in an unpublished USGS aquifer-test report (G.J. Gonthier, U.S. Geological Survey, written commun., December 15, 2010).

The aquifer system was simulated using a two-dimensional, axisymmetric radial, transient groundwater-flow model that incorporated drawdown data from pumped well 30AA06 and nine other monitored wells (fig. 21). Horizontal hydraulic conductivity and specific storage were assumed to be homogeneous within each hydrogeologic unit. A vertical anisotropy ratio (vertical hydraulic conductivity divided by the horizontal hydraulic conductivity) of 0.1 was assumed for each hydrogeologic unit.

The model domain was discretized into 114 rows representing the different aquifer thicknesses and 59 columns representing the radial distance from pumped well 30AA06 to the external model boundary (fig. 21). The model radially extends 200,000 ft from well 30AA06, and represents the subsurface depth interval between a few feet below land surface (the estimated water-table depth in the alluvial plain) and 192 ft below land surface. Radial grid spacing (column width) increases from 0.67 ft at pumped well 30AA06 to

Table 7. Information for wells used in a 24-hour aquifer test at pumped well 30AA06 in Well Field 2 near Augusta, Georgia, October 21–23, 2009.

[NA, not applicable; —, data not available; vertical datum is NGVD 29; well 30AA39 was only used in the construction of the hydrogeologic cross sections]

Well name	Latitude	Longitude	Surface altitude, in feet	Open interval depth below land surface, in feet		Screen diameter, in inches	Well depth below land surface, in feet	Distance from pumped well, in feet	24-hour drawdown	Aquifer
	Degrees, minutes, seconds NAD 83			Top	Bottom					
30AA06	33°22'17"	81°58'35"	138.26	161.42	222.42	14	231	NA	49.0	Midville system
30AA35	33°22’20"	81°58'33"	145	93	113	6	113	280	10.9	Lower Dublin
30AA07	33°22'09"	81°58'29"	131.31	159.75	221.17	14	232	1,020	8.4	Midville system
30AA37	33°22'21"	81°58'46"	160.18	190	200	2	200.25	1,040	9.1	Lower Midville
30AA38	33°22'21"	81°58'46"	160.22	110	120	2	120	1,040	2.8	Lower Dublin
30AA39	33°22'30"	81°58'56"	185	139	149	10	254	2,200	3.5	Lower Dublin
				186	196	10				Upper Midville
				207	217	10				Lower Midville
				236	246	10				Lower Midville
30AA09	33°21'47"	81°58'22"	131.37	163	203	14	250	3,310	3.2	Upper Midville
				224	244	14				Lower Midville
30AA10	33°21'42"	81°58'35"	128.46	170	200	14	254	3,590	2.6	Upper Midville
				208	218	14				Lower Midville
				225	246	14				Lower Midville
30AA33	33°22'15"	81°57'52"	135	—	—	—	220	3,640	2.0	Midville system
30AA18	33°21'46"	81°58'59"	176.43	202	232	14	291	3,820	2.9	Upper Midville
				252	283	14				Lower Midville
30AA11	33°21'39'	81°58'12"	124.96	162.17	182.42	14	244	4,360	1.5	Upper Midville
				192.42	232.92	14				Lower Midville

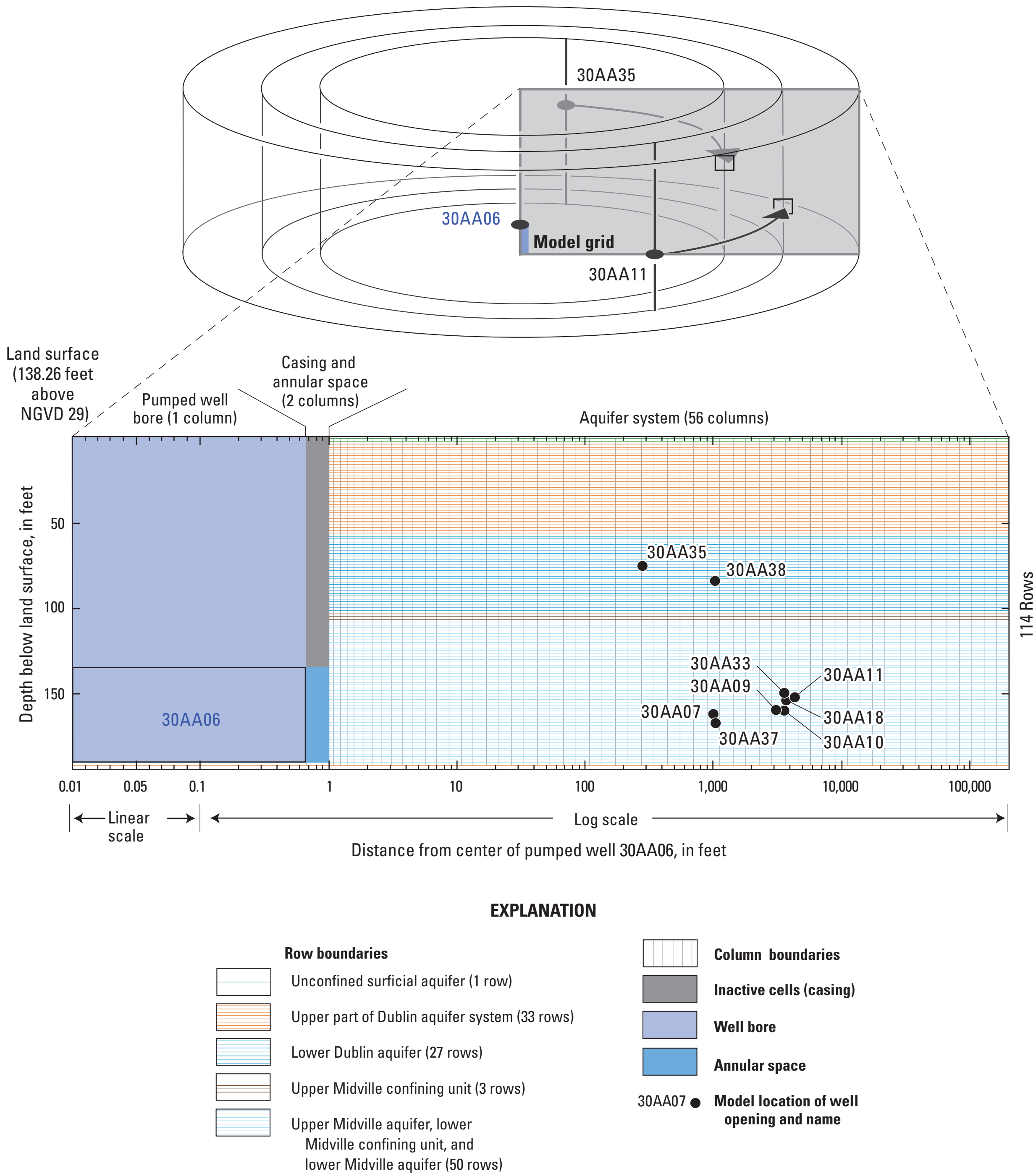


Figure 21. Axisymmetric model for 24-hour aquifer test at pumped well 30AA06, Well Field 2 near Augusta, Georgia, October 21–22, 2009. The wells nearest (30AA35) and farthest (30AA11) from pumped well 30AA06 are included on the top diagram. Curved arrows in the top diagram represent transforming three-dimensional location of well opening to the two-dimensional model grid.

38,252 ft at the edge of the model. Each row height represents a vertical thickness of 1.684 ft for the simulated aquifers and intervening confining layers.

Hydrogeologic units are represented in the model as five layers:

- Layers 1 and 2, represents the lower Dublin confining unit;
- Layer 3, represents the lower Dublin aquifer;
- Layer 4, represents the upper Midville confining unit; and
- Layer 5, represents the upper Midville aquifer, lower Midville confining unit, and lower Midville aquifer, combined (fig. 3).

Storage is estimated or assigned separately to the lower Dublin confining unit (Layers 1 and 2). A single model row represents water-table conditions with specific storage assigned a value for an unconfined aquifer or specific yield (Layer 1). Multiple model rows represent confined conditions in the rest of the lower Dublin confining unit with specific storage assigned a value typical for a confined aquifer (Layer 2). Horizontal hydraulic conductivity was estimated or assigned to both Layers 1 and 2 as a single layer.

The radial edge distal to the well and edge adjacent to the base and top (first and last row) of the model were simulated as no-flow boundaries; the upper boundary (Layer 1), represents the water table. The aquifer-test stress period of 1 day was approximately represented using 58 time steps. Time steps during the pumping stress period ranged from about 0.05 second to 4 hours 48 minutes, with each successive time step increasing by a factor of 1.25. The recovery stress period of 2 days was represented using 58 time steps. Time steps during this period ranged from about 0.10 second to 9 hours 36 minutes, with each successive time step increasing by a factor of 1.25. During model simulation, water was injected at the same rate that water was withdrawn at the pumped well (684 gal/min). The resultant increase in simulated head was taken as the drawdown in response to actual aquifer-test pumping.

Hydraulic properties were estimated by minimizing the weighted sum-of-squares of differences between simulated and estimated drawdown (hereafter, these differences are referred to as residuals). During model calibration, residuals were weighted slightly more for small drawdown values than residuals for large drawdown values to eliminate bias in the optimization. Drawdown values for pumped well 30AA06 also were reduced by subtracting an offset during the aquifer test. Weighting and offsets prevent small drawdown values at observation wells from being superfluous during the calibration process (Halford, 2006b). Weights for the drawdown and recovery periods were smallest for pumped well 30AA06 and greatest for well 30AA11.

MODOPTIM computes the relative sensitivity of parameters and measure of the redundancy between parameters (Halford, 2006b). Parameter sensitivity indicates how adjustments to a parameter value will affect the objective function, and provides the basis for comparing simulated and measured drawdown. Parameters with very low sensitivity are not estimated, but rather, are assigned a general value in the model. The measure of redundancy is made between a pair of parameters. A high measure of redundancy usually means that one parameter should be estimated for multiple units as a single merged unit. The relative sensitivities of parameters and measures of redundancy between parameters in a MODOPTIM run were then used to determine which, if any, parameters should be eliminated from the estimation process in subsequent MODOPTIM runs.

Based on the relative sensitivities and measures of redundancy of estimated parameters from three MODOPTIM runs, specific storage for the water-table (Layer 1), lower Dublin confining unit (Layer 2), lower Dublin aquifer (Layer 3), and upper Midville confining unit (Layer 4) was insensitive and, therefore, was not estimated. A specific storage of 2.80×10^{-6} ft^{-1} was assigned to the lower Dublin confining unit (Layer 2), lower Dublin aquifer (Layer 3), and upper Midville confining unit (Layer 4). The lower Dublin confining unit (Layers 1 and 2), and lower Dublin aquifer (Layer 3) were only mildly redundant for horizontal hydraulic conductivity. The third MODOPTIM run estimated horizontal hydraulic conductivity values of less than 1 ft/d for the lower Dublin confining unit (Layers 1 and 2), lower Dublin aquifer (Layer 3), and upper Midville confining unit (Layer 4), and a value of 45 ft/d for the upper and lower Midville aquifers, combined (Layer 5). In addition, the third MODOPTIM run estimated a specific storage value of 2.18×10^{-6} ft^{-1} for the upper and lower Midville aquifers, combined, which is near the lowest expected value for a sand aquifer. A horizontal-hydraulic-conductivity value of 45 ft/d and a thickness of 85 ft for the upper and lower Midville aquifers, combined, yielded a transmissivity of 3,800 feet squared per day (ft^2/d). The specific storage of 2.18×10–6 ft^{-1} and a thickness of 85 ft yielded a storativity (or storage coefficient) of 1.85×10^{-4}.

Simulated drawdown from the third MODOPTIM run showed a good fit to measured drawdown for most of the wells opened to the upper and lower Midville aquifers (appendix 2). The exceptions were Midville-aquifer-system wells 30AA09, 30AA10 and 30AA18, where simulated drawdown near the end of the aquifer test and during recovery was underestimated (figs. 1–3, 1–4, and 1–6). Simulated drawdown from the third MODOPTIM run underestimated drawdown and recovery in lower Dublin aquifer well 30AA35, and overestimated drawdown and recovery in lower Dublin aquifer well 30AA38 (figs. 1–8 and 1–9, respectively). The lack of fit of simulated water levels to measured water levels may be due to the axisymmetric model being too simple to incorporate heterogeneity within the hydrogeologic system.

Because of the poor match of the lower-Dublin-aquifer wells, MODOPTIM runs also were made that excluded the two wells (setting their weights for residuals to zero). Excluding the lower-Dublin-aquifer wells had little effect on the final results. The resulting MODOPTIM runs, guided by relative sensitivity and measure of redundancy of parameters, best estimated horizontal hydraulic conductivity for the upper layers (Midville confining unit and above) when treated as a single unit, and for the upper and lower Midville aquifers when treated as a single unit. Simulated hydraulic conductivity was less than 1 ft/d for the combined overlying layers and 47 ft/d for the upper and lower Midville aquifers, combined. When multiplied by aquifer thickness (85 ft) the simulated hydraulic conductivity for the upper and lower Midville aquifers, combined, yielded a transmissivity of 3,900 ft^2/d. The specific storage for all confined layers was estimated to be about $1.99 \times 10^{-6} ft^{-1}$. The storativity for the upper and lower Midville aquifers, combined, was estimated to be 1.69×10^{-4}.

The hydraulic properties of the upper and lower Midville aquifers, combined, also were determined using the Theis (1935) model and the principle of superposition (Gonthier, 2011). Values of transmissivity and storativity from the alternate approach were very close to the values resulting from the model. Values of transmissivity and storativity for the upper and lower Midville aquifers, combined, derived using the alternative approach were 4,000 ft^2/d and 2×10^{-4}, respectively.

Potential Source Areas for Volatile Organic Compounds at Well Field 2

To assess possible source area(s) for VOC contamination at Well Field 2, groundwater samples were collected from seven wells within and north of the well field and analyzed for the stable isotopes of hydrogen (hydrogen-1 and hydrogen-2) and oxygen (oxygen-16 and oxygen-18), and for sulfur hexafluoride (table 5). In groundwater samples from the seven study wells, the mean delta hydrogen value was –25.58 per mil with a standard deviation of 0.311 per mil and the mean delta oxygen value was –4.86 per mil with a standard deviation of 0.086 per mil (fig. 22). These standard deviations are within the analytical confidence limits for delta hydrogen (±2 per mil) and delta oxygen (±0.2 per mil), indicating the groundwater tapped by the seven study wells most likely originates from the same source. These delta hydrogen and delta oxygen values are similar to those computed for precipitation from the Augusta area (Bowen, 2008). The delta hydrogen and delta oxygen values in a water sample taken from a small detention pond on the former textile manufacturing site (Amity Pond) were substantially heavier (more positive) than the values in samples from the seven study wells, indicating that evaporation controls the stable isotope values in the pond.

The concentrations of sulfur hexafluoride in groundwater samples typically are used to identify recently recharged groundwater (post-1970; Busenberg and Plummer, 2000). The age determined from analyses is an apparent age that is a mix of older and newer water. In 2009, sulfur hexafluoride was analyzed in groundwater samples from five wells open to the upper and lower Midville aquifers and one well open to the lower Dublin aquifer, all wells located within and near Well Field 2 (table 5). In the five samples collected from the upper and lower Midville aquifers sulfur hexafluoride concentrations indicated recharge occurred between 1980 and 1984 (fig. 23). At the Tobacco Road well-cluster site the sulfur hexafluoride concentration in a shallow, 120-ft deep well open to the lower Dublin aquifer (30AA38), indicated recharge occurred around 1991. A 220-ft deep well (30AA37) completed in the transition between the upper and lower Midville aquifers at the same site indicated recharge occurred around 1983.

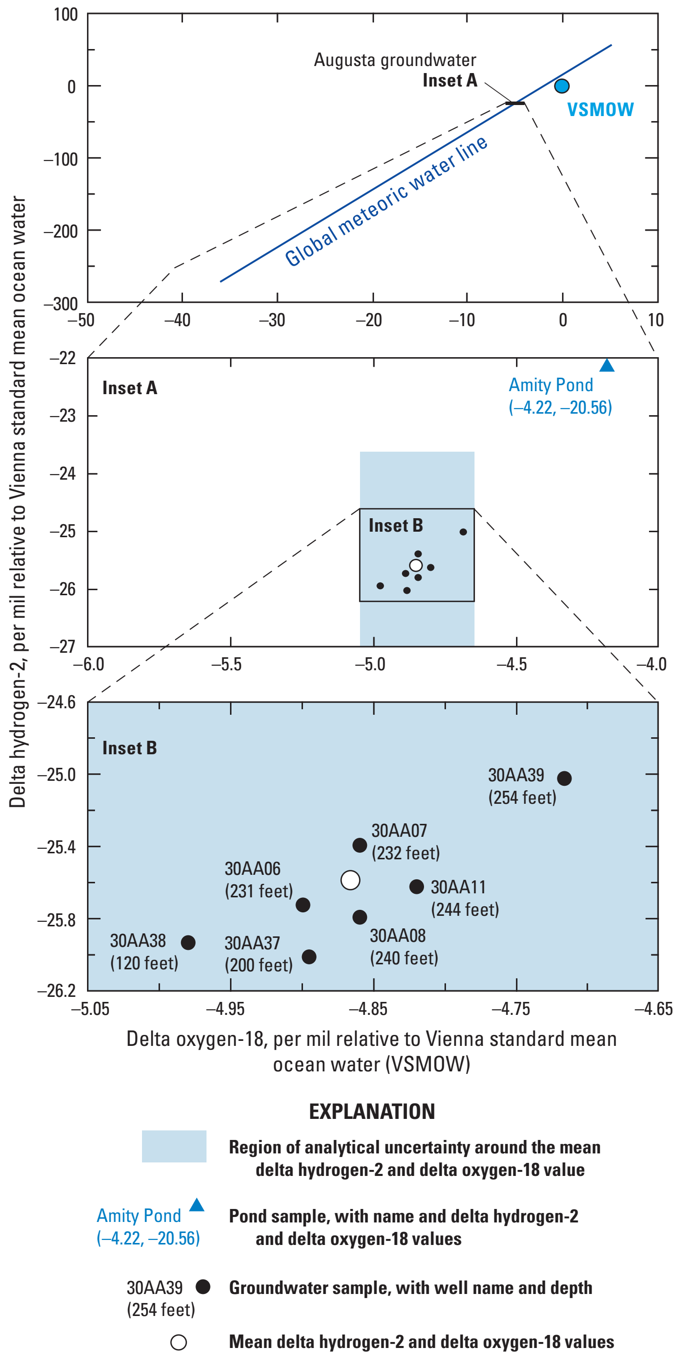


Figure 22. Stable oxygen and hydrogen isotopes in water from wells and a detention pond in the vicinity of Well Field 2 near Augusta, Georgia 2009.

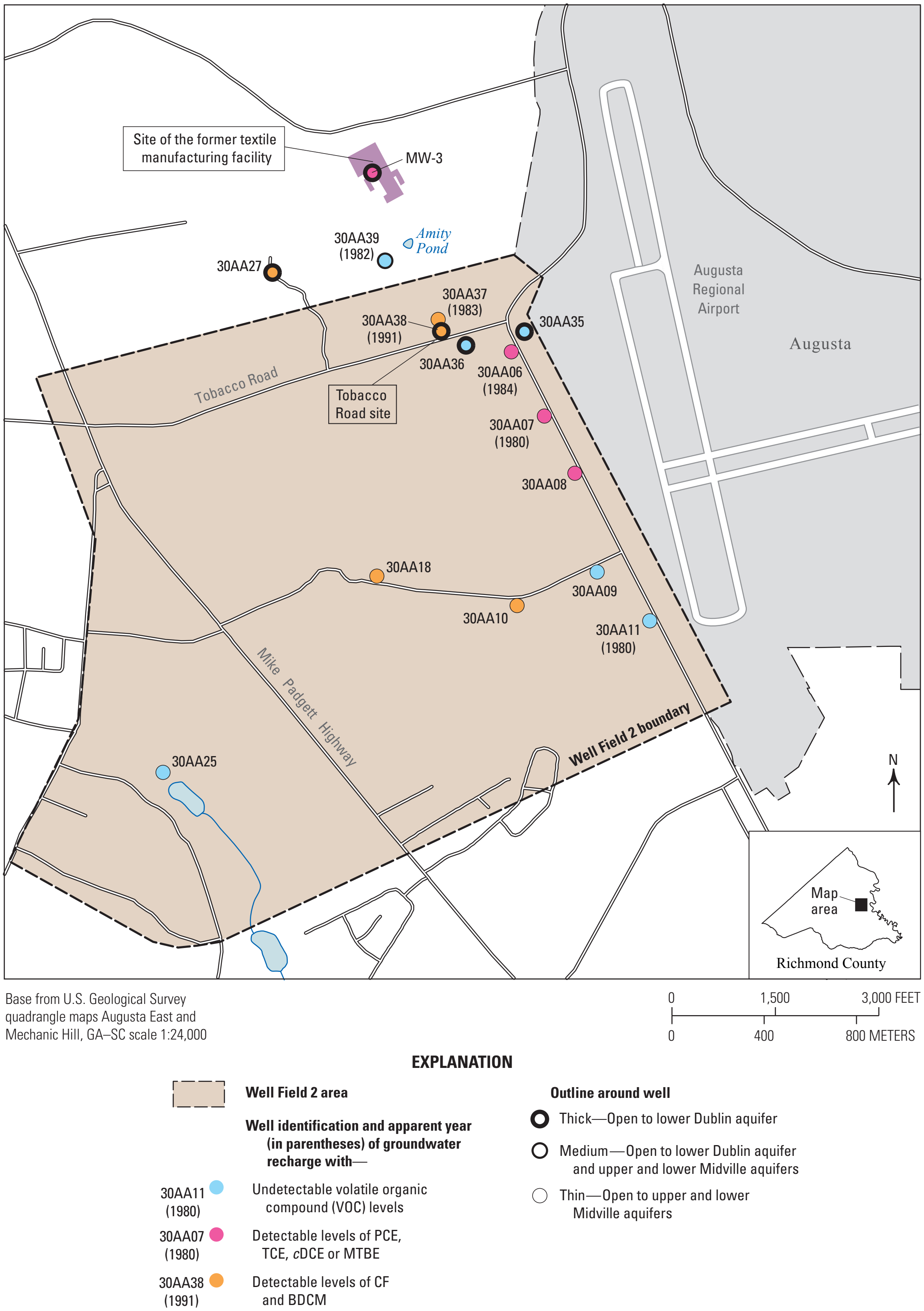


Figure 23. Apparent year of recharge for groundwater tapped by selected wells in the vicinity of Well Field 2 near Augusta, Georgia, 2009.

The apparent years of recharge for the upper and lower Midville aquifers suggest a nearby source of contamination. All apparent recharge years were within the 1976 to 1996 period of operations at the former textile manufacturing facility located upgradient of Well Field 2 that is a potential source of VOC contamination at the well field. The actual source of VOC contamination in Well Field 2 remains unknown and would require additional studies to confirm.

Summary

Water supply in the Augusta–Richmond County area is provided, in part, by three well fields that withdraw water from the Midville aquifer system, which is part of the larger Cretaceous aquifer system, composed of sand of Late Cretaceous age. In 1999 the volatile organic compounds (VOCs) tetrachloroethene (PCE) and trichloroethene (TCE) were detected in a production well at the northernmost extent of Well Field 2; however, the source of the contamination had not been identified. The U.S. Geological Survey (USGS), and the Augusta Utilities Department, began a Cooperative Water Program (CWP) in 2007 to monitor groundwater levels and quality in the Augusta–Richmond County area.

The objectives of the Augusta CWP are to:

- Determine current groundwater levels, direction of groundwater flow, and water quality of the Dublin and Midville aquifer systems in the Augusta–Richmond County area;
- Annually monitor groundwater levels and seasonal trends and track changes in groundwater availability and flow direction; and
- Annually monitor groundwater quality and identify possible source(s) of low-level concentrations of VOCs.

Data from this monitoring provide information to support water management decisions and serve as a basis for future groundwater modeling efforts while adding to improved regional characterization of groundwater conditions.

Tasks performed during 2008–2009 to meet Augusta CWP objectives included: (1) installation of two additional wells north of Well Field 2 and one well near Well Field 3 and the collection of lithologic and geophysical logging data to determine the extent of hydrogeologic units, (2) collection of continuous groundwater-level data from eight wells near Well Fields 2 and 3, (3) collection of synoptic groundwater-level measurements and construction of potentiometric-surface maps in Richmond County to establish flow gradients and groundwater-flow directions in the Dublin and Midville aquifer systems during June 2008 and August 2009, (4) completion of a 24-hour aquifer test to determine hydraulic characteristics of the lower Dublin aquifer and upper Midville confining unit as separate hydrogeologic units and the upper and lower Midville aquifers as a single hydrogeologic unit in Well Field 2, and (5) collection of groundwater samples from 11 wells in the vicinity of Well Field 2 for laboratory analysis of VOCs and from 7 wells for laboratory analysis of groundwater tracers to assess groundwater quality and estimate the time of groundwater recharge. Between 2007 and 2010, six wells were instrumented with continuous water-level monitoring equipment to assess long-term water-level trends in the Augusta–Richmond County area as part of the CWP. Two of the wells are completed in the lower Dublin aquifer, and four are completed in the upper and lower Midville aquifers. Of the six wells, five are located near Well Field 2 and one is located 4.7 miles (mi) southwest of Well Field 2. In addition, the USGS operates two continuous water-level monitoring wells as part of a statewide network in cooperation with the Georgia Environmental Protection Division. One well is located about 8 mi south of Well Field 2 and the second well is located about 2 mi west of Well Field 2. Real-time water-level recorders were installed in four of the eight network wells. All continuous water-level data are available at *http://waterdata.usgs.gov/nwis/current/?type=gw*.

Long-term groundwater-level trends in the Dublin and Midville aquifer systems are affected by precipitation, groundwater pumping, and discharge of groundwater to streams and the Savannah River alluvial aquifer. Precipitation generally was below average during much of the period from 2000 to 2010. Since 1975, the Augusta–Richmond County Water System has been the largest groundwater user in the county, averaging about 5 million gallons per day (Mgal/d). Groundwater withdrawals for industrial use ranged between 2.1 and 3.2 Mgal/d during the period of record.

Maps showing the potentiometric surface of the Dublin and Midville aquifer systems for June 2008 and August 2009 indicate groundwater generally flows from upland areas in the western part of Richmond County eastward toward the Savannah River. In the vicinity of Well Field 2 the August 2009 map shows a cone of depression resulting from well-field pumping that was not depicted on the June 2008 map. The August 2009 map contours indicate that pumping at Well Field 2 interrupts the eastward flow of water toward the Savannah River and causes flow lines to bend toward the center of pumping. This pumping has also reversed a natural upward head gradient from the Midville aquifer system to the Dublin aquifer system as indicated by paired water levels at a well-cluster site located along Tobacco Road north of the well field.

In 1999, low levels of the VOCs PCE and TCE were detected in a production well at the northernmost extent of Well Field 2. By 2003, production well 30AA06 was removed from service because of the increasing TCE concentration (a maximum concentration of 2.5 micrograms per liter [μg/L] in 2002). The site of a former textile mill, located about 0.5 mi north of Well Field 2 is a potential source of VOC contamination near the well field. To monitor the contamination and help establish its source, groundwater samples were collected from 11 wells in the vicinity of Well Field 2 in the summer of 2008 and in the summer and fall of 2009. Of the 35 VOCs analyzed in groundwater samples during 2008–2009, only 6 were detected above laboratory reporting limits in samples from eight wells. Detected VOCs included three chlorinated ethenes (TCE, PCE, and cis-1,2-dichloroethene [cDCE]), methyl-*tert*-butyl ether (MTBE), and two trihalomethanes (chloroform and bromodichloroform). No concentration in groundwater samples collected during 2008–2009 exceeded drinking water standards. The highest VOC concentration of 1.9 µg/L was TCE in well 30AA07 during 2009. Three wells at Well Field 2 had detectable concentrations of TCE; however five other wells located close to the former textile facility did not contain detectable PCE, TCE, or cDCE concentrations. The reasons for the absence of contaminants at these wells may be related to groundwater flow paths in the vicinity of the well field. Additional monitor wells installed southeast of the former textile facility would provide information to delineate any plume that might follow the theoretical flow path from the textile facility.

To assess possible source area(s) for VOC contamination at Well Field 2, groundwater samples were collected from seven wells within and north of the well field and analyzed for the stable isotopes of hydrogen and oxygen and for sulfur hexafluoride. Stable isotope values of delta hydrogen and delta oxygen indicate that groundwater tapped by the seven study wells most likely originates from the same source. Concentrations of sulfur hexafluoride in groundwater samples indicate that water from five wells opened to the upper and lower Midville aquifers had recharge occur between 1980 and 1984, whereas water from a shallower well open to the lower Dublin aquifer had recharge occur around 1991.

The apparent years of recharge for the upper and lower Midville aquifers suggest a nearby source of contamination. All apparent recharge years were within the 1976 to 1996 period of operations at the former textile manufacturing facility located upgradient of Well Field 2 that is a potential source of VOC contamination at the well field. The actual source of VOC contamination in Well Field 2 remains unknown and would require additional studies to confirm.

To determine the depth and thickness of aquifers and confining units near Well Field 2, wells completed in the lower Dublin aquifer (30AA38) and upper and lower Midville aquifers (30AA37) were constructed in 2009 and together with other existing wells were used to construct two hydrogeologic cross sections. Cross sections indicate that the lower Dublin aquifer, upper Midville confining unit, upper Midville aquifer, lower Midville confining unit, and lower Midville aquifer are the main hydrogeologic units at Well Field 2. Cross sections also indicate that thick layers of clay exist within the lower Dublin aquifer and the lower Midville confining is discontinuous in the vicinity of Well Field 2. Near Well Field 2, the lower Dublin aquifer is roughly 100 to 150 ft thick and consists of sands and clays. The upper and lower Midville aquifers combined are roughly 80 to 100 ft thick and consist of sand with clay layers.

The transmissivity and specific storage of the lower Dublin aquifer and undifferentiated upper and lower Midville aquifers were estimated based on data collected during a 24-hour aquifer test at well 33AA06, open to the upper and lower Midville aquifers at Well Field 2. Hydraulic properties of the lower Dublin aquifer and the upper and lower Midville aquifers, combined, were estimated using the numerical model MODFLOW-96 with the calibration tool MODOPTIM. The aquifer system was simulated using a two-dimensional, axisymmetric radial, transient, groundwater-flow model that incorporated drawdown data from pumped well 30AA06 and nine other monitored wells. Based on model calibration, the horizontal hydraulic conductivity of the Midville aquifer system was estimated to be 45 feet per day (ft/d). The lower Dublin aquifer had an estimate of horizontal hydraulic conductivity of less than 1 ft/d. Concluded values of transmissivity and storativity for the upper and lower Midville aquifers, combined, were 4,000 feet squared per day and 2×10^{-4}, respectively.

References Cited

Augusta–Richmond County Planning Commission, 2003, Augusta–Richmond County Comprehensive Plan, as adopted by the Augusta Commission: Augusta Ga., 222 p.

Bowen, G.J., 2008, The online isotopes in precipitation calculator, version 2.2: West Lafayette, Indiana, Purdue University, accessed December 6, 2009, at *http://www.waterisotopes.org*.

Brunett, J.O., Barber, N.L., Burns, A.W., Fogelman, R.P., Gillies, D.C., Lidwin, R.A., and Mack T.J., 1997, A quality-assurance plan for district groundwater activities of the U.S. Geological Survey: U.S. Geological Survey Open-File Report, 97–11, 19 p.

Busenberg, Eurybiades and Plummer, L.N., 2000, Dating young ground water with sulfur hexafluoride—Natural and anthropogenic sources of sulfur hexafluoride: Water Resources Research, v. 36, no. 10, p. 3011–3030.

Cherry, G.S., 2006, Simulation and particle-tracking analysis of groundwater flow near the Savannah River Site, Georgia and South Carolina, 2002, and for selected water-management scenarios, 2002 and 2020: U.S. Geological Survey Scientific Investigations Report 2006–5195, 156 p., also available online at *http://pubs.usgs.gov/sir/2006/5195/*.

Cherry, G.S., and Clarke, J.S., 2007, Simulation and particle-tracking analysis of selected groundwater pumping scenarios at Vogtle Electric Generation Plant, Burke County, Georgia: U.S. Geological Survey Open-File Report 2007–1363, 45 p., also available online at *http://pubs.usgs.gov/of/2007/1363/*.

Cherry, G.S., Peck, M.F., Painter, J.A., and Stayton, W.L., 2010, Groundwater conditions and studies in the Brunswick–Glynn County area, Georgia, 2008: U.S. Geological Survey Open-File Report 2009–1275, 54 p., also available online at *http://pubs.usgs.gov/of/2009/1275/*.

Cherry, G.S., Peck, M.F., Painter, J.A., and Stayton, W.L., 2011, Groundwater conditions and studies in the Brunswick–Glynn County area, Georgia, 2009: U.S. Geological Survey Scientific Investigations Report 2011–5087, 58 p., also available online at *http://pubs.usgs.gov/sir/2011/5087/*.

Clark, W.Z., and Zisa, A.C., 1976, Physiographic map of Georgia: Georgia Geological Survey, 1 sheet, scale 1:2,000,000.

Clarke, J.S., Brooks, Rebekah, and Faye, R.E., 1985, Hydrogeology of the Dublin and Midville aquifer systems of east central Georgia: Georgia Geologic Survey Information Circular 74, 62 p.

Clarke, J.S., and West, C.T., 1997, Ground-water levels, predevelopment ground-water flow, and stream-aquifer relations in the vicinity of the Savannah River Site, Georgia and South Carolina: U.S. Geological Survey Water-Resources Investigations Report 97–4197, 120 p.

Clarke, J.S., and West, C.T., 1998, Simulation of ground-water flow and stream-aquifer relations in the vicinity of the Savannah River Site, Georgia and South Carolina Predevelopment through 1992: U.S. Geological Survey Water-Resources Investigations Report 98–4062, 134 p., also available online at *http://pubs.usgs.gov/wri/wri98-4062/*.

Clarke, J.S., and Williams, L.J., 2010, Hydrologic conditions, stream-water quality, and selected groundwater studies conducted in the Lawrenceville area, Georgia, 2003–2008: U.S. Geological Survey, Scientific Investigations Report 2010–5032, 55 p., also available online at *http://pubs.usgs.gov/sir/2010/5032/*.

Connor, B.F., Rose, D.L., Noriega, M.C., Murtagh, L.K., and Abney, S.R., 1998, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of 86 volatile organic compounds in water by gas chromatography/mass spectrometry, including detections less than reporting limits: U.S. Geological Survey Open-File Report 97–829, 78 p. Method ID: O-4127-96.

Falls, W.F., Baum, J.S., Harrelson, L.G., Brown, L.H., and Jerden, J.L., Jr., 1997, Geology and hydrogeology of Cretaceous and Tertiary strata, and confinement in the vicinity of the U.S. Department of Energy Savannah River Site, South Carolina and Georgia: U.S. Geological Survey Water-Resources Investigations Report 97–4245, 125 p, 3 pls.

Fanning, J.L., 2003, Water use in Georgia by county for 2000 and water-use trends for 1980–2000: Georgia Geologic Survey Information Circular 106, 176 p., also available online at *http://ga.water.usgs.gov/publications/other/ggs-ic106/*.

Fanning, J.L., and Trent, V.P., 2009, Water use in Georgia by county for 2005; and water-use trends, 1980–2005: U.S. Geological Survey Scientific Investigations Report 2009–5002, 186 p., also available online at *http://pubs.usgs.gov/sir/2009/5002/*.

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

Garber, M.S., and Koopman, F.C., 1968, Methods of measuring water levels in deep wells: U.S. Geological Survey Techniques of Water-Resources Investigations, book 8, chapter A1, 23 p.

Georgia Environmental Protection Division, 2011, Primary maximum contaminant levels for drinking water: State of Georgia statute 391–3–5.18, accessed March 22, 2011, at *http://rules.sos.state.ga.us/docs/391/3/5/18.pdf*.

Gibs, Jacob, Wilde, F.D., and Heckathorn, H.A., 2007, Use of multiparameter instruments for routine field measurements (version 1.1): U.S. Geological Survey Techniques of Water Resources Investigations, book 9, chapter A6, section 6.8, accessed June 27, 2011, at *http://pubs.water.usgs.gov/twri9A/*.

Gonthier, G.J., 2011, Analysis of complex pumping interactions during an aquifer test conducted at a well field in the Coastal Plain near Augusta, Georgia, October 2009: Georgia Water Resources conference in Athens Georgia, 6 p, accessed May 2, 2011, at *http://gawrc.org/2011paper_pdfs/3.3.1Gonthier.pdf*.

Gorday, L.L., 1985, The hydrogeology of the Coastal Plain strata of Richmond and northern Burke Counties, Georgia: Georgia Geologic Survey Information Circular 61, 43 p.

Gordon, Debbie, 2008, Ground-water conditions and studies in the Albany Area of Dougherty County, Georgia, 2007: U.S. Geological Survey Open-File Report 2008–1328, 49 p., also available online at *http://pubs.usgs.gov/of/2008/1328/*.

Halford, K.J., 2006a, Documentation of a spreadsheet for time-series analysis and drawdown estimation: U.S. Geological Survey Scientific Investigations Report 2006–5024, 38 p.

Halford, K.J., 2006b, MODOPTIM: A general optimization program for ground-water flow model calibration and ground-water management with MODFLOW: U.S. Geological Survey Scientific Investigations Report 2006–5009, 62 p.

Harbaugh, A.W., and McDonald, M.G., 1996, Progammer's documentation for MODFLOW-96, an update to the U.S. Geological Survey modular finite difference ground-water flow model: U.S. Geological Survey Open-File Report 960–486, 220 p.

Hetrick, J.H., 1992, A geologic atlas of the Wrens–Augusta area: Georgia Department of Natural Resources, Geologic Atlas 8, 3 plates.

Joiner, C.N., Peck, M.F., Reynolds, M.S., and Stayton, W.L., 1989, Ground-water data for Georgia, 1988: U.S. Geological Survey Open-File Report 89–408, 176 p.

McDonald, M.G., and Harbaugh, A.W., 1988, A modular three-dimensional finite-difference ground-water flow model: U.S. Geological Survey Techniques of Water-Resources Investigations, book 6, chap. A1, 576 p.

Multi-Resolution Land Characteristics Consortium, 2001, 2001 National Land Cover Data: U.S. Environmental Protection Agency, accessed June 27, 2011, at *http://www.epa.gov/mrlc/nlcd-2001.html*.

National Atmospheric Deposition Program, 2010, NAPD Maps Access: Accessed November 24, 2010, *http://nadp.sws.uiuc.edu/maps/Default.aspx*.

National Climatic Data Center, 2001, Daily normals for Augusta Bush Field Airport, 1971–2000: U.S. Climate Normals, accessed October, 12, 2010, at *http://cdo.ncdc.noaa.gov/climatenormals/clim84/GA/GA090495.txt*.

National Oceanic and Atmospheric Administration, 2002, Monthly station normals of temperature, precipitation and heating and cooling degree days, 1971–2000, 09 Georgia: U.S. Department of Commerce, Climatography of the United States, no. 81, 28 p.

Priest, Sherlyn, and Bukowski-McSwain, Kristen, 2002, Hydrogeology and water quality of the Upper Three Runs aquifer in the vicinity of the Gibson Road Landfill, Fort Gordon, Georgia, June–November 1999: U.S. Geological Survey Water-Resources Investigations Report 02–4153, 22 p., also available online at *http://pubs.usgs.gov/wri/wri02-4153/*.

Révész, Kinga, and Coplen, T.B., 2008a, Determination of the δ(2H/1H) of water: RSIL lab code 1574, chapter C1 of Révész, Kinga, and Coplen, T.B., eds., Methods of the Reston Stable Isotope Laboratory: U.S. Geolgical Survey Techniques and Methods, 10–C1, 27 p.

Révész, Kinga, and Coplen, T.B., 2008b, Determination of the δ(18O/16O) of water: RSIL lab code 489, chapter C2 of Révész, Kinga, and Coplen, T.B., eds., Methods of the Reston Stable Isotope Laboratory: U.S. Geological Survey Techniques and Methods, 10–C2, 28 p.

Theis, C.V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage: Transactions of the American Geophysical Union, v. 16, p. 519–524.

U.S. Census Bureau, 2011, American fact finder: accessed January 25, 2011, at *http://factfinder.census.gov*.

U.S. Department of Agriculture, 2009, Census of agriculture 2007, Georgia State and county data, volume 1, Geographic area series, part 10: U.S. Department of Agriculture, 952 p.

U.S. Department of the Army, 2011, Fort Gordon Garrison, Installation Management Command, Southeast Region: U.S. Department of the Army, accessed January 25, 2011, at *http://www.gordon.army.mil/contact.htm*.

U.S. Environmental Protection Agency, 2011, National recommended water quality criteria: U.S. Environmental Protection Agency, accessed July 1, 2011, at *http://water.epa.gov/scitech/swguidance/standards/current/index.cfm*.

Wilde, F.D., Radtke, D.B., Gibs, Jacob, and Iwatsubo, R.T., eds., 2004 with updates through 2009, Processing of water samples (version 2.2): U.S. Geological Survey Water-Resources Investigations, book 9 chapter A5, accessed June 27, 2011, at *http://pubs.water.usgs.gov/twri9A5/*.

Williams, L.J., 2007, Hydrogeology and potentiometric surface of the Dublin and Midville aquifer systems in Richmond County, Georgia, January 2007: U.S. Geological Survey Scientific Investigations Map 2982, also available online at *http://pubs.usgs.gov/sim/2007/2982/*.

Appendix 1. Estimating Drawdown for Wells in Response to Aquifer-Test Pumping in Well 30AA06 in Well Field 2 near Augusta, Georgia, October 21–23, 2009

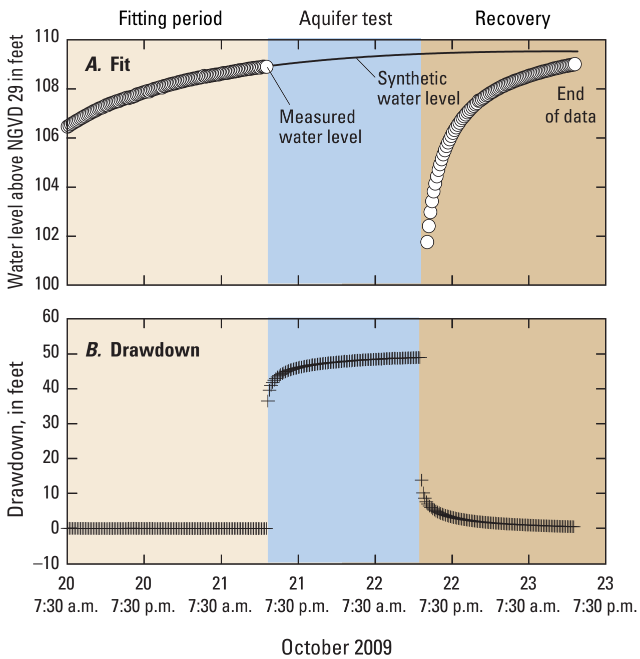


Figure 1–1. Estimating drawdown for well 30AA06 in response to aquifer-test pumping at 30AA06 in Well Field 2 near Augusta, Georgia, October 21–23, 2009. *(A)* Fitting synthetic water levels to measured water levels during production-well recovery prior to aquifer test. *(B)* Estimated drawdown in response to aquifer-test pumping computed by subtracting measured water levels from synthetic water levels.

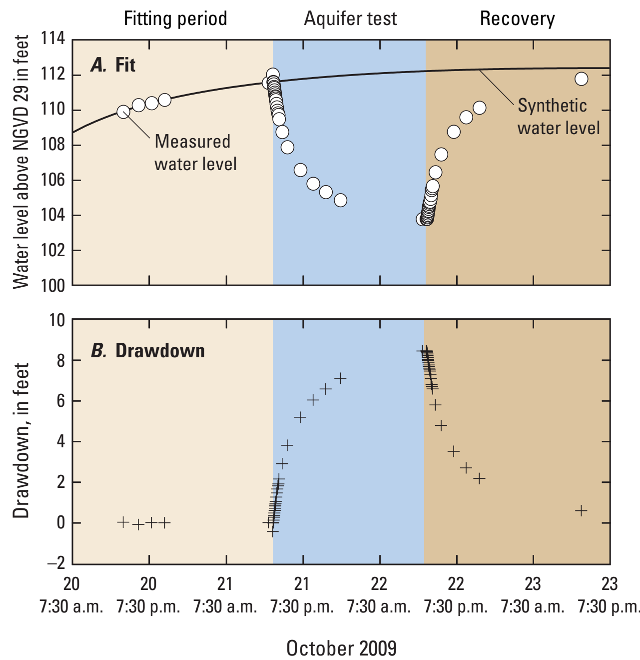


Figure 1–2. Estimating drawdown for well 30AA07 in response to aquifer-test pumping at 30AA06 in Well Field 2 near Augusta, Georgia, October 21–23, 2009. *(A)* Fitting synthetic water levels to measured water levels during production-well recovery prior to aquifer test. *(B)* Estimated drawdown in response to aquifer-test pumping computed by subtracting measured water levels from synthetic water levels.

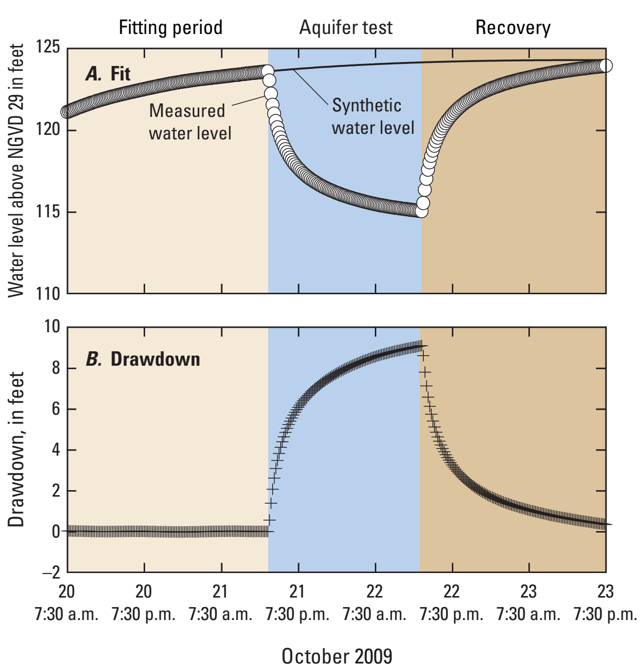


Figure 1–3. Estimating drawdown for well 30AA37 in response to aquifer-test pumping at 30AA06 in Well Field 2 near Augusta, Georgia, October 21–23, 2009. *(A)* Fitting synthetic water levels to measured water levels during production-well recovery prior to aquifer test. *(B)* Estimated drawdown in response to aquifer-test pumping computed by subtracting measured water levels from synthetic water levels.

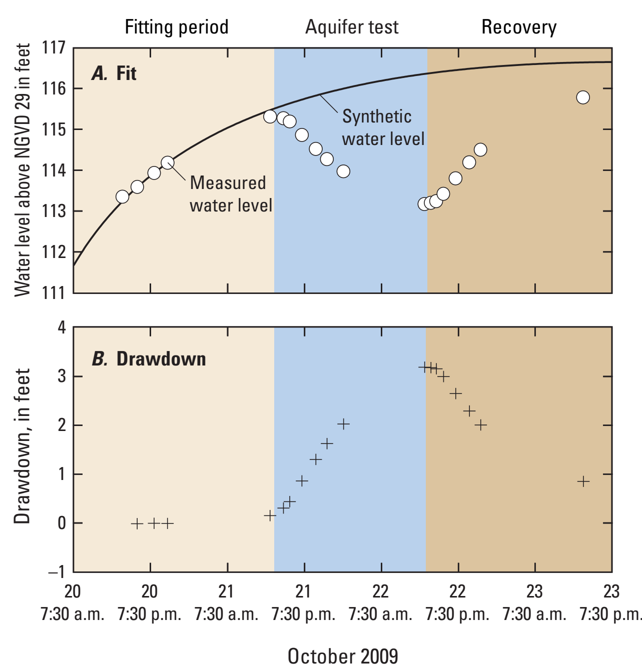


Figure 1–4. Estimating drawdown for well 30AA09 in response to aquifer-test pumping at 30AA06 in Well Field 2 near Augusta, Georgia, October 21–23, 2009. *(A)* Fitting synthetic water levels to measured water levels during production-well recovery prior to aquifer test. *(B)* Estimated drawdown in response to aquifer-test pumping computed by subtracting measured water levels from synthetic water levels.

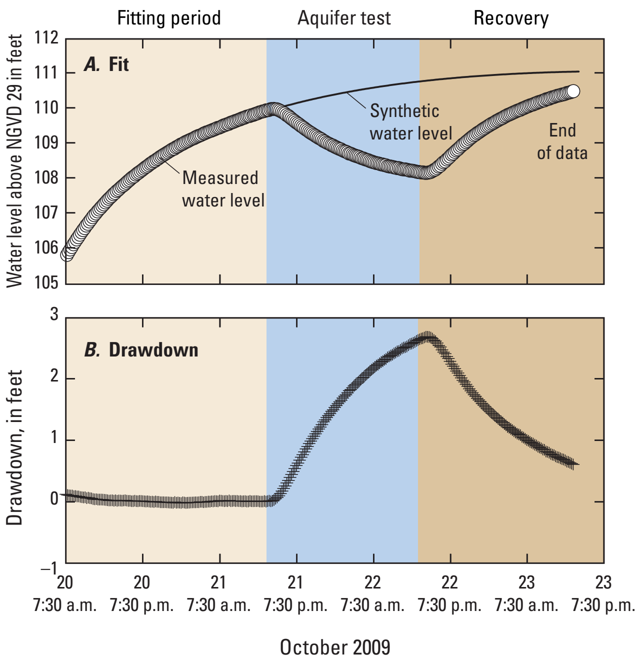


Figure 1–5. Estimating drawdown for well 30AA10 in response to aquifer-test pumping at 30AA06 in Well Field 2 near Augusta, Georgia, October 21–23, 2009. *(A)* Fitting synthetic water levels to measured water levels during production-well recovery prior to aquifer test. *(B)* Estimated drawdown in response to aquifer-test pumping computed by subtracting measured water levels from synthetic water levels.

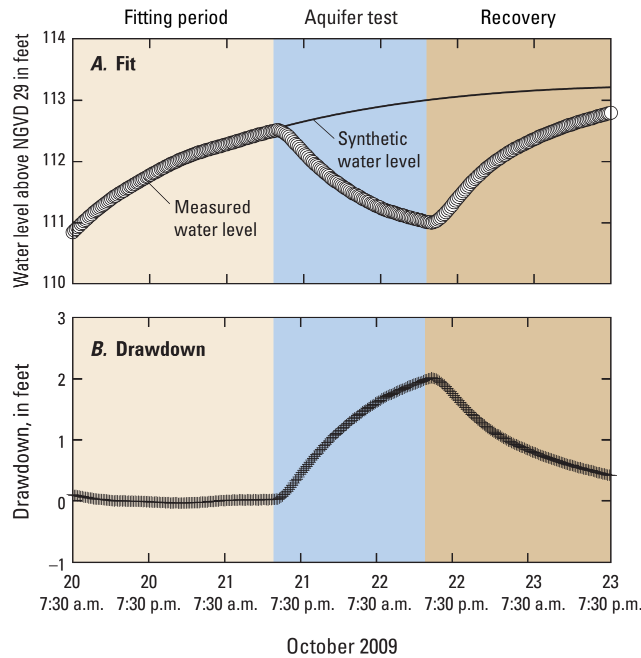


Figure 1–6. Estimating drawdown for well 30AA33 in response to aquifer-test pumping at 30AA06 in Well Field 2 near Augusta, Georgia, October 21–23, 2009. *(A)* Fitting synthetic water levels to measured water levels during production-well recovery prior to aquifer test. *(B)* Estimated drawdown in response to aquifer-test pumping computed by subtracting measured water levels from synthetic water levels.

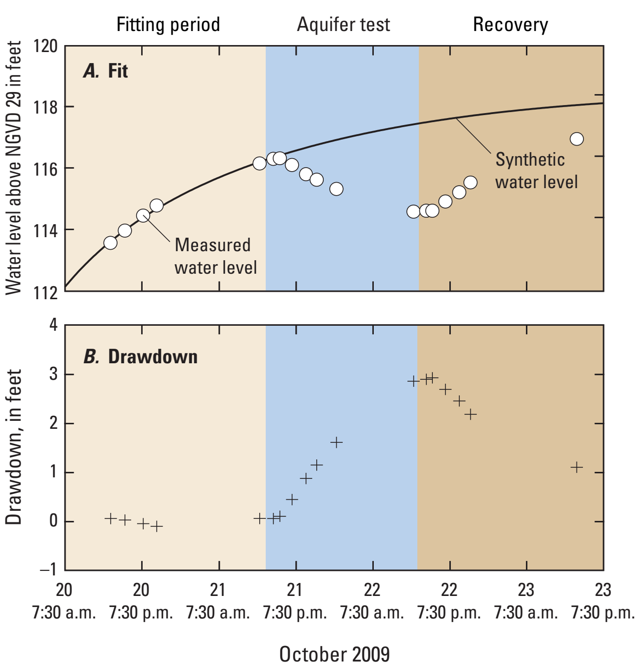


Figure 1–7. Estimating drawdown for well 30AA18 in response to aquifer-test pumping at 30AA06 in Well Field 2 near Augusta, Georgia, October 21–23, 2009. *(A)* Fitting synthetic water levels to measured water levels during production-well recovery prior to aquifer test. *(B)* Estimated drawdown in response to aquifer-test pumping computed by subtracting measured water levels from synthetic water levels.

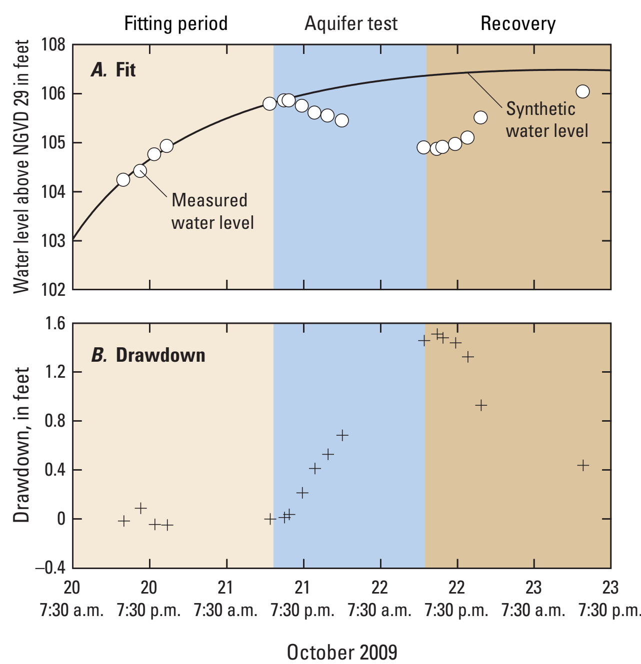


Figure 1–8. Estimating drawdown for well 30AA11 in response to aquifer-test pumping at 30AA06 in Well Field 2 near Augusta, Georgia, October 21–23, 2009. *(A)* Fitting synthetic water levels to measured water levels during production-well recovery prior to aquifer test. *(B)* Estimated drawdown in response to aquifer-test pumping computed by subtracting measured water levels from synthetic water levels.

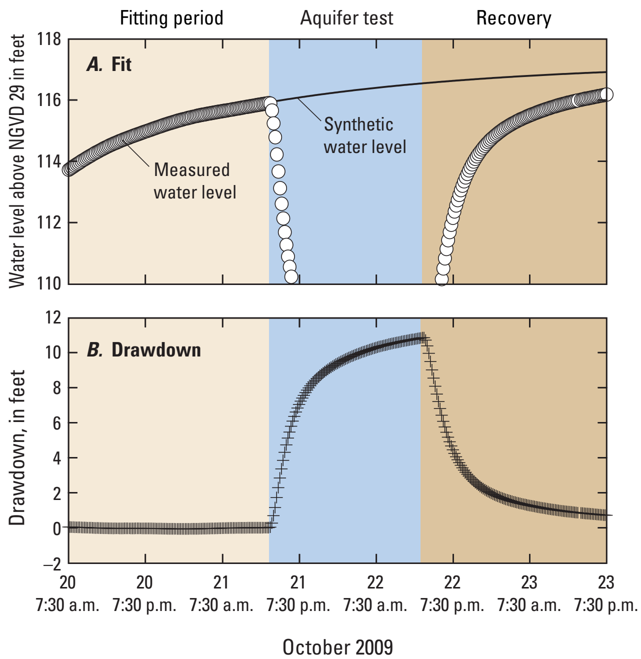


Figure 1–9. Estimating drawdown for well 30AA35 in response to aquifer-test pumping at 30AA06 in Well Field 2 near Augusta, Georgia, October 21–23, 2009. *(A)* Fitting synthetic water levels to measured water levels during production-well recovery prior to aquifer test. *(B)* Estimated drawdown in response to aquifer-test pumping computed by subtracting measured water levels from synthetic water levels.

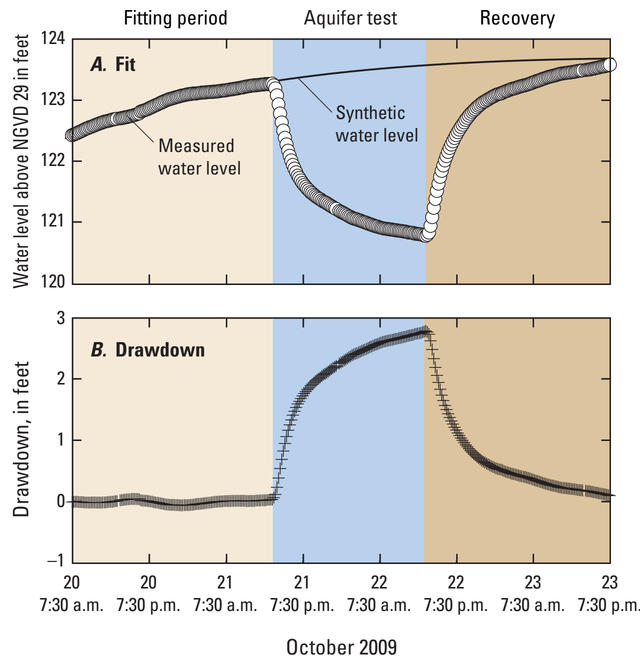


Figure 1–10. Estimating drawdown for well 30AA38 in response to aquifer-test pumping at 30AA06 in Well Field 2 near Augusta, Georgia, October 21–23, 2009. *(A)* Fitting synthetic water levels to measured water levels during production-well recovery prior to aquifer test. *(B)* Estimated drawdown in response to aquifer-test pumping computed by subtracting measured water levels from synthetic water levels.

Appendix 2. Simulated and Measured Drawdown During the 24-Hour Aquifer Test at Pumped Well 30AA06 in Well Field 2 Near Augusta, Georgia, October 21–23, 2009

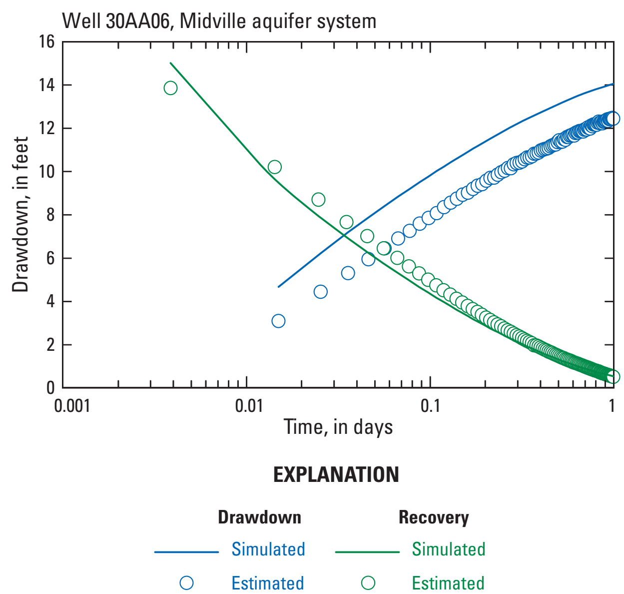


Figure 2–1. Simulated and measured drawdown during the 24-hour aquifer test at pumped well 30AA06, Well Field 2 near Augusta, Georgia, October 21–23, 2009. Drawdown during the aquifer test and recovery after the aquifer test are superimposed on the graph. Actual values of drawdown in response to the aquifer test, shown in figure 1–1, were reduced by 36.54 feet for the model calibration.

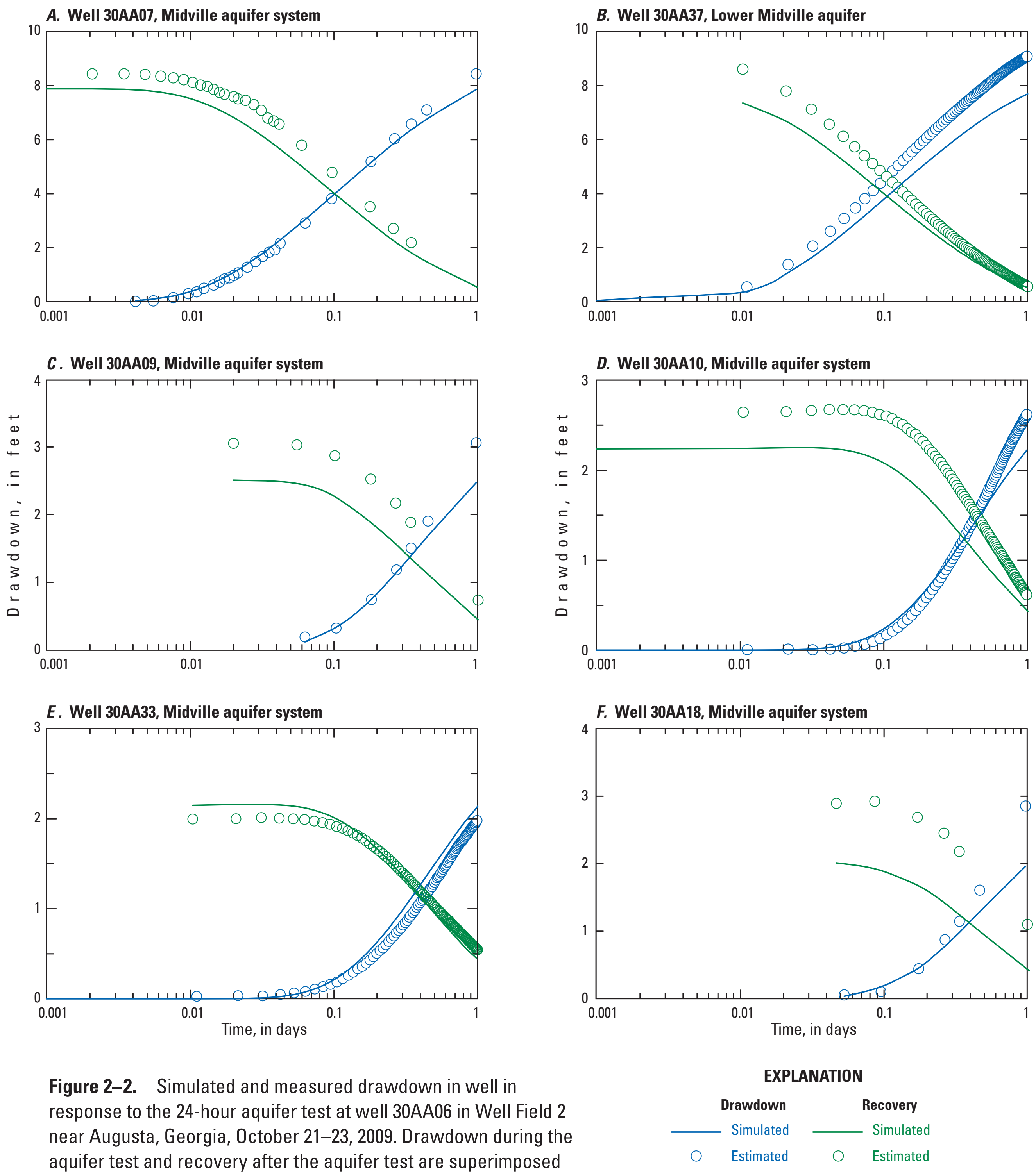


Figure 2–2. Simulated and measured drawdown in well in response to the 24-hour aquifer test at well 30AA06 in Well Field 2 near Augusta, Georgia, October 21–23, 2009. Drawdown during the aquifer test and recovery after the aquifer test are superimposed on the graph.

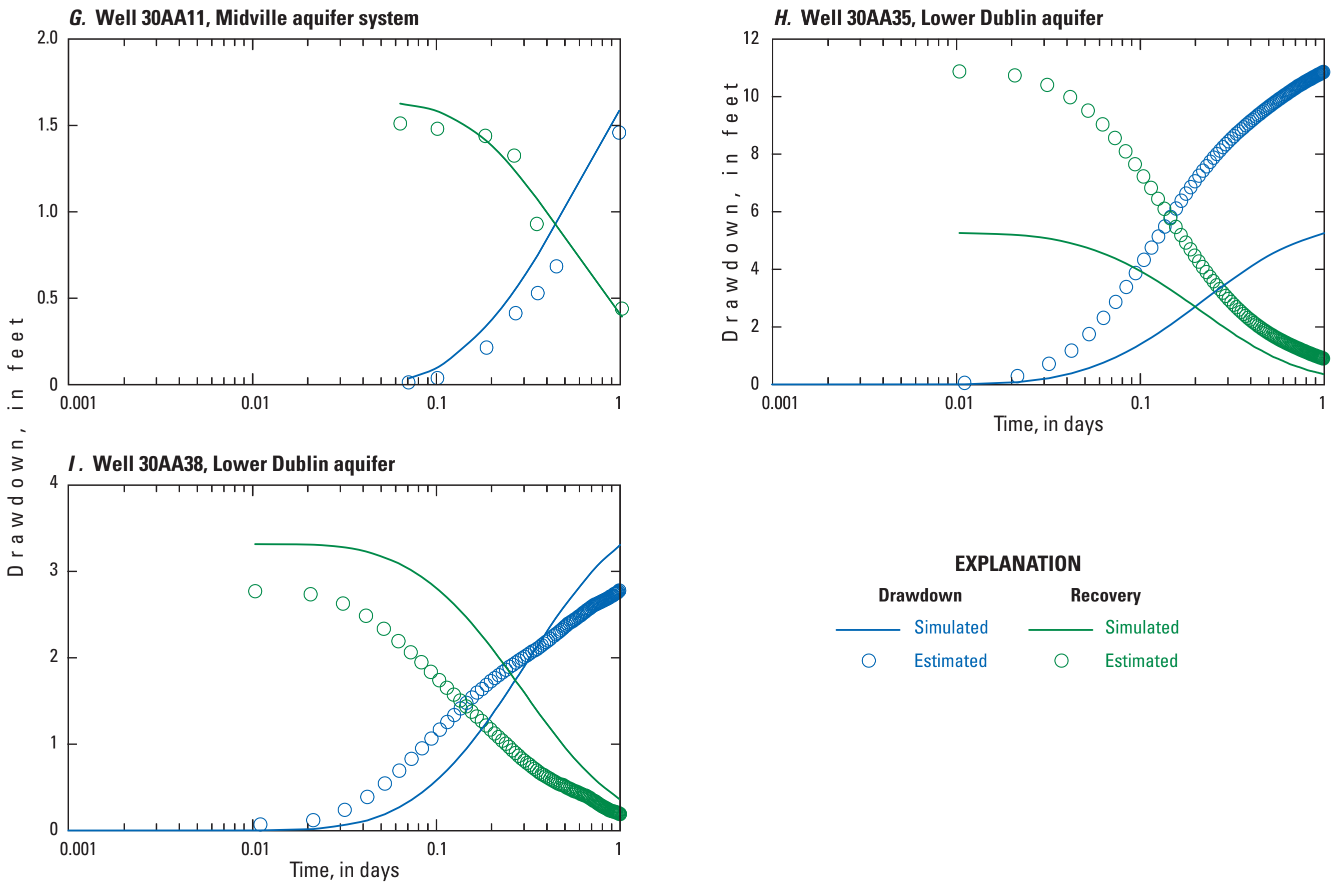


Figure 2–2. Simulated and measured drawdown in well in response to the 24-hour aquifer test at well 30AA06 in Well Field 2 near Augusta, Georgia, October 21–23, 2009. Drawdown during the aquifer test and recovery after the aquifer test are superimposed on the graph.—Continued

Manuscript approved for publication, October 7, 2011

Edited by Michael Deacon

Illustrations by Bonnie J. Turcott

Layout by Caryl J. Wipperfurth

For more information concerning the research in this report, contact
USGS Georgia Water Science Center
3039 Amwiler Road
Atlanta, Georgia 30360
telephone: 770-903-9100

http://ga.water.usgs.gov

Gonthier and others—**Groundwater Conditions and Studies in the Augusta–Richmond County Area, Georgia, 2008–2009**—Scientific Investigations Report 2011–5188