Hydrogeology, Hydraulic Properties, and Water Quality of the Surficial and Brunswick Aquifer Systems Near the City of Ludowici, Long County, Georgia, July 2003

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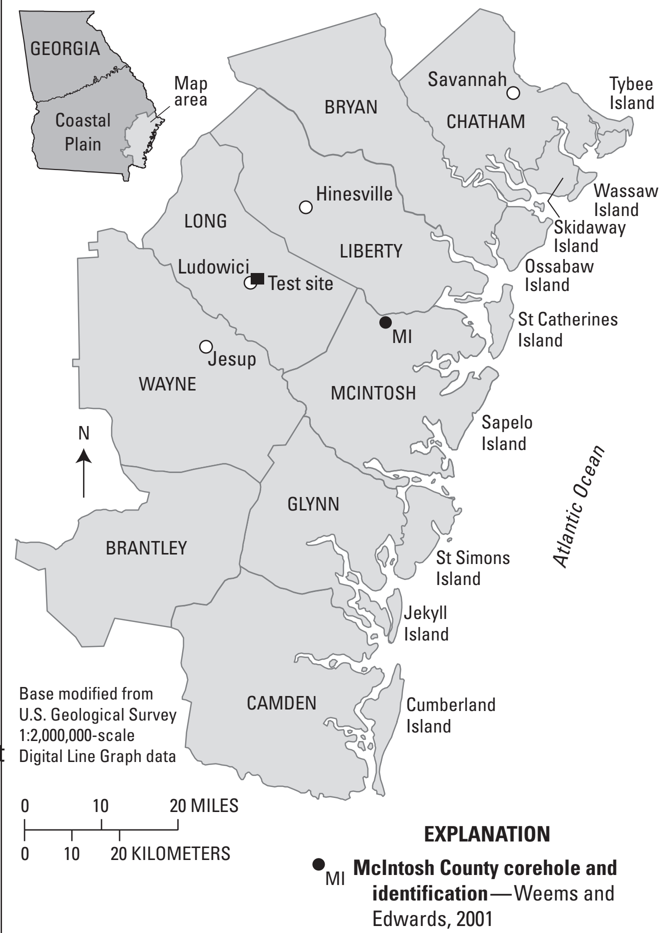
INTRODUCTION

The Upper Floridan aquifer is the principal source of water in the coastal area of Georgia. Declining water levels and localized saltwater contamination have resulted in regulations restricting withdrawals from the aquifer in parts of the coastal area and have prompted interest in developing supplemental sources of ground water. These supplemental sources of water include the surficial and Brunswick aquifer systems. In the coastal area, these aquifer systems have been used primarily for irrigation and industrial purposes.

The U.S. Geological Survey (USGS)—in cooperation with the City of Ludowici and the Georgia Department of Natural Resources, Environmental Protection Division (GaEPD) — conducted an evaluation of the potential for alternative sources of ground water at a site located at the Long County Detention Center near the City of Ludowici. The purpose of this study was to estimate the hydraulic properties and collect water-quality data for the lower confined zone of the surficial aquifer system (hereinafter referred to as lower confined zone) and the Brunswick aquifer system. The scope of this study included construction of test wells, collection of lithologic cuttings, borehole geophysical logging, aquifer testing and subsequent analysis, and water-quality sampling and analysis. These data are important for the successful development and management of ground-water resources in the county.



Ludowici test site, Long County, Georgia, 2003.

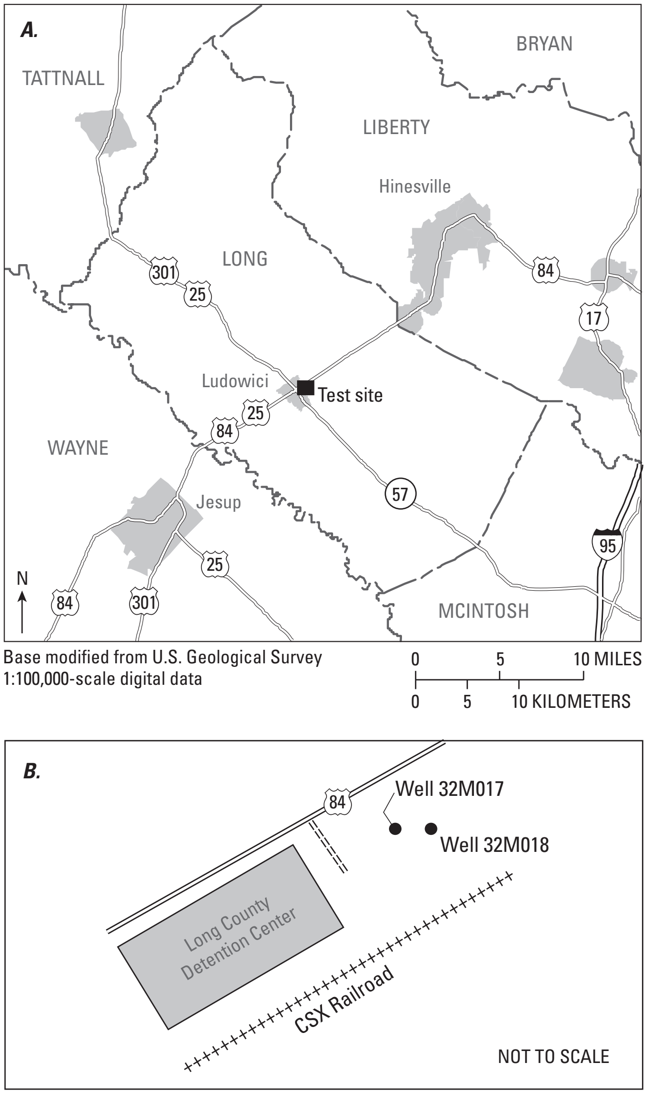
Description of Study Area

The Ludowici test site is located in central Long County near the city of Ludowici, Georgia, in the Coastal Plain physiographic province. The Ludowici site is about 12 miles southwest of the city of Hinesville and about 12 miles northeast of the city of Jesup (maps at right and facing page). Land use in the area is primarily forest. Topographic relief across the area is low, with an approximate land-surface altitude of 80 feet (ft) above the North American Vertical Datum of 1988 (NAVD 88). The climate in the area is mild, with a mean-annual temperature of 79.2 degrees Fahrenheit at the National Weather Station at Jesup, Georgia (National Oceanic Atmospheric Administration [NOAA], 2002). For the 30-year period 1971–2000, average monthly precipitation ranged from 2.42 inches during November to 6.40 inches during August, and annual precipitation averaged 48.70 inches (National Oceanic Atmospheric Administration, 2002).

Methods of Study

To better identify the water-bearing characteristics and lithology of the study area, two wells were drilled. One well (32M018) was completed in the lower confined zone on June 20, 2003. An additional well (32M017) was completed in the upper and lower Brunswick aquifers of the Brunswick aquifer system on June 27, 2003. Basic construction of these wells consists of 25-inch-diameter boreholes cased with 18-inch-diameter surface steel casing and a 17-inch-diameter hole with a 10-inch-diameter steel casing screened in the aquifer material (table, facing page). The screened interval was gravel packed, and the casing was grouted with bentonite.

On completion of the deepest hole (well 32M017), borehole geophysical logs were collected and included natural-gamma radiation, spontaneous potential, lateral resistivity, short- and long-normal resistivity, and caliper. Borehole geophysical logs and well cuttings were used to identify water-bearing zones, select casing depths and screened intervals for each well, and



(A) Location of test site; (B) detail showing relative locations of wells, Ludowici, Long County, Georgia.

to verify the correlation of stratigraphic units. Because many of the borehole cuttings were poorly recovered during drilling, it was necessary to use lithologic descriptions from another well drilled in northern McIntosh County (Weems and Edwards, 2001) to aid in the hydrogeologic and geologic descriptions and for correlation of units at the Ludowici test site. The A- and B-marker horizons were used to identify the tops of the upper and lower Brunswick aquifers, respectively, and are characterized by a sharp increase in the natural-gamma radiation (Clarke and others, 1990) (see page 105). The C-marker horizon, used to identify the top of the Upper Floridan aquifer, was not penetrated during the drilling of well 32M017.

Pretest ground-water levels were monitored in well 32M018 during a 3-day period and in well 32M017 during a 4-day period to document background water-level trends and possible atmospheric effects. Both wells were instrumented with an electronic pressure transducer and data logger, and water levels were recorded at 15-minute intervals.

Pretest pumping was conducted to verify that the pumped wells were fully developed and to determine the optimum pumping rate prior to the pumping phase of the aquifer tests. Water levels were monitored to ensure that the drawdown in the pumped well would not exceed the depth of the transducer and to provide information on the response of the aquifer to pumping. During the pretest pumping and subsequent aquifer test, ground-water levels were monitored using a commercially available data logger with a 100-pound-per-square-inch (psi) pressure transducer in the pumped well; manual measurements were made in the observation well. Verification measurements were made using dedicated electric tapes to confirm proper operation of the pressure transducers and data loggers. Atmospheric pressure was measured with an internal pressure sensor in the data logger. Starting at time equals 0, a sampling interval was programmed into the data logger to facilitate the rapid collection of early time data, using a logarithmic scale that was decreased to a 1-minute interval later in the test.

Location and construction data for wells used at city of Ludowici site, Long County, Georgia.

[NAVD 88, North American Vertical Datum of 1988; °, degree; ', minute; ", second; –, negative]

Well number	Well name	Aquifer	Latitude	Longitude	Hole depth (feet)	Well depth (feet)	Altitude (feet NAVD 88)			Casing diameter (inches)
							Land surface	Top of screen interval	Bottom of screen interval	
32M018	City of Ludowici PW-2	Lower water-bearing zone of surficial aquifer system	31°43'20"	–81°43'26"	295	290	60	–65	–145	10
32M017	City of Ludowici PW-1	Upper Brunswick	31°43'20"	–81°43' 26"	477	420	60	–170	–210	10
		Lower Brunswick						–280	–360	10

A submersible pump powered by a trailer-mounted diesel electric generator was used to pump each well. Approximately 80 ft of 6-inch polyvinyl-chloride pipe was used to discharge the water away from the well. Ground-water discharge was measured using a totalizing flowmeter. The gate valve setting was determined during pretest pumping and remained in that position throughout the duration of the test. The setting allowed the discharge rate from the pump to be maximized while applying sufficient back pressure to the pump; thus, water-level fluctuations caused by the operation of the pump were minimized.

An aquifer test was performed in the lower confined zone using pumped well 32M018 and well 32M017 for an observation well. A similar test was performed in the upper and lower Brunswick aquifers using pumped well 32M017 and observation well 32M018 screened in the lower confined zone. Data from these aquifer tests were analyzed to estimate transmissivity and hydraulic conductivity for the aforementioned water-bearing units.

During the aquifer tests, water-level fluctuations produced by changes in atmospheric pressure, local pumping, and tidal oscillations were minor in comparison to the amount of drawdown induced by the pumping. Therefore, data used in the aquifer-test analysis were not corrected for atmospheric pressure, local pumping, or tidal effects.

Drawdown and recovery data were analyzed using the modified nonequilibrium analytical model of Cooper and Jacob (1946) and the analytical model for nonsteady radial flow in an infinite leaky aquifer of Hantush and Jacob (1955). The Hantush and Jacob (1955) method accounts for leakage, but does not differentiate between leakage from above or below the aquifer. The raw drawdown and recovery data were analyzed using spreadsheets developed for the analysis of aquifer-test data (Halford and Kuniansky, 2002). The spreadsheets incorporate analytical solutions of the partial differential equation for ground-water flow to a well for a specific type of condition or aquifer (Halford and Kuniansky, 2002). Analysis of drawdown data using graphs aids in the determination of the accuracy of estimated hydraulic properties. Typically, the early part of a drawdown curve is steep, showing well-storage effects; the middle part follows a straight line as water enters the well from the aquifer; and the latter part continues along a straight line until the aquifer reaches steady-state conditions. A change in the slope in the latter part of the curve represents either recharge (leakage) to the aquifer or contact with an impermeable boundary. Leakage or recharge causes drawdown to decrease, whereas contact with an impermeable boundary causes drawdown to increase. Early termination of a test would result in an underestimation of hydraulic properties.

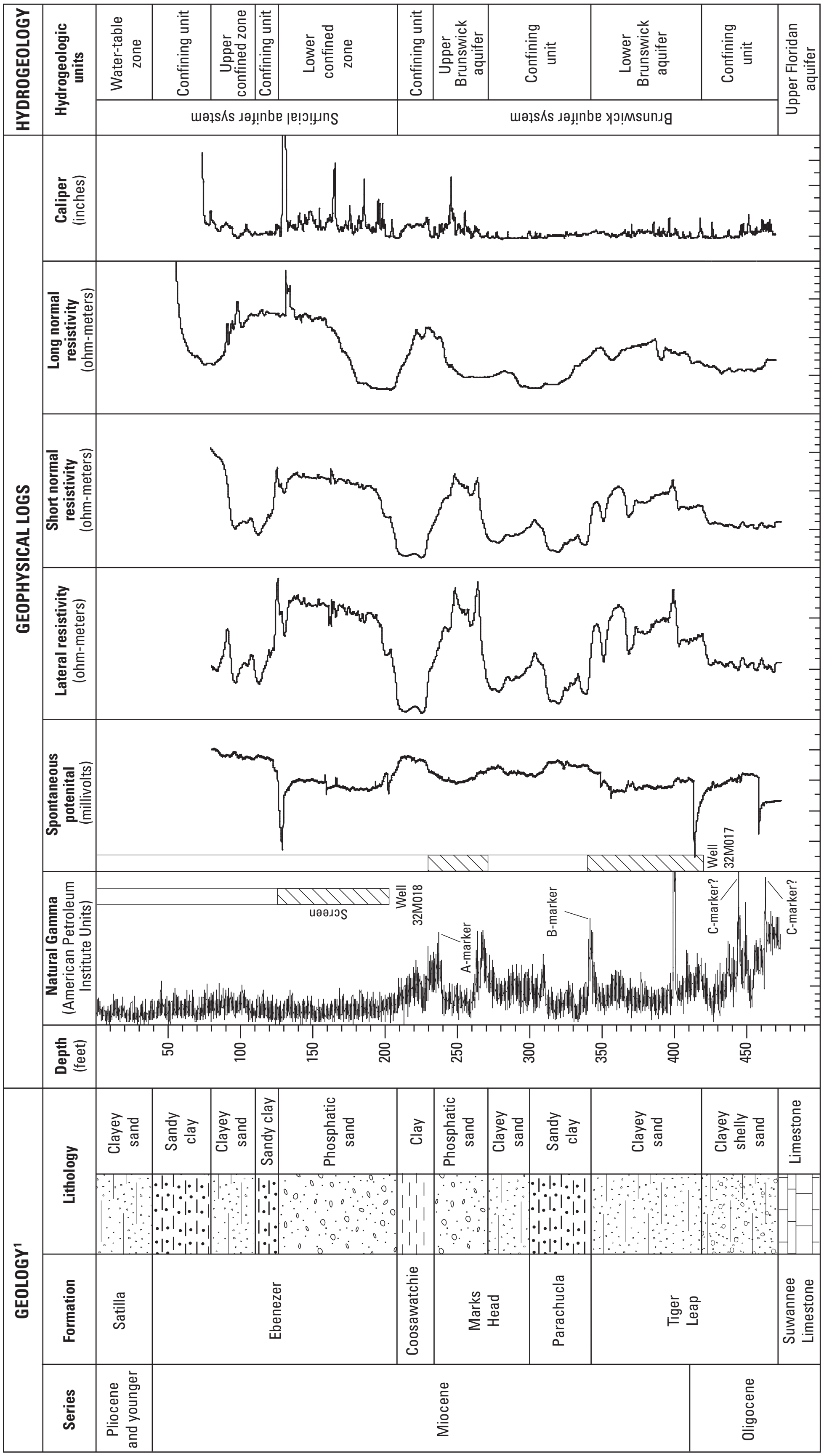
Water samples were collected from wells 32M018 and 32M017 and analyzed for major ions, nutrients, metals, and radionuclides. Water samples were collected after several hours of pumping when field conditions had stabilized. Field properties were measured in a flow-through chamber using a commercially available water-quality multiprobe following USGS protocols (Wilde and Radtke, 1999). Water samples were preserved and stored in polyethelene or acid-rinsed bottles and sent by overnight carrier to the USGS National Water Quality Laboratory, Denver, Colorado.

Previous Investigations

Clarke and others (1990) defined the surficial and upper and lower Brunswick aquifers and described their water-bearing characteristics. Steele and McDowell (1998) mapped the permeable thickness and areal distribution of the upper and lower Brunswick aquifers. Sharpe and others (1998) described results of a lower Brunswick aquifer test in Chatham County, Georgia. Leeth (1999) described the hydrogeology of the surficial aquifer at Naval Submarine Base Kings Bay in Camden County, Georgia. More recent investigations include Gill (2001), who described the development potential of the upper and lower Brunswick aquifer in Glynn and Bryan Counties, Georgia; Radtke and others (2001), who described the results of an engineering assessment of the "Miocene" aquifer system in coastal Georgia; Weems and Edwards (2001) who described the geology of the Oligocene and younger deposits in coastal Georgia; and Clarke (2003), who described the surficial and Brunswick aquifer systems as alternative sources of ground water.

HYDROGEOLOGY AND LITHOLOGY

Hydrologic units in Long County, Georgia, include, in descending order, the water-table zone and upper and lower confined zones of the surficial aquifer system (Miller, 1986; Krause and Randolph, 1989; Clarke and others, 1990; Clarke, 2003); the upper and lower Brunswick aquifers of the Brunswick aquifer system (Clarke and others, 1990); and the Floridan aquifer system (Miller, 1986). A profile showing geologic and hydrogeologic units at the Ludowici site is shown in the chart, facing page. The surficial aquifer system at the Ludowici site is present from land surface to a depth of 210 ft. The lower confined zone consists of 80 ft of medium to coarse sand and is present from 125 to 205 ft below land surface. The lower confined zone and the upper Brunswick aquifer are separated by a clay confining unit at a depth of 210–230 ft. The upper Brunswick aquifer consists of about 40 ft of medium sand with shells and is present from a depth of 230 to 270 ft. The top of the aquifer is indicated by the A-marker horizon on the natural-gamma log. The lower Brunswick aquifer consists of about 85 ft of clayey sand and is present from 340 to 425 ft. The top of the aquifer is indicated by the B-marker horizon on the natural-gamma log. The upper and lower Brunswick aquifers are separated by a 70-ft-thick confining unit consisting of clay and sand.



Generalized lithologic, geologic, and hydrologic descriptions of Ludowici test site, Long County, Georgia.

[1]Modified from Weems and Edwards, 2001

HYDRAULIC PROPERTIES

Single-well aquifer tests were designed to provide hydraulic data for computation of hydraulic properties. Aquifer tests consisted of background water-level monitoring prior to the test, pretest pumping, a constant-discharge pumping test (drawdown), and post-test water-level monitoring (recovery).

Lower Confined Zone, Surficial Aquifer System

The surficial aquifer system test was conducted July 29–August 1, 2003, and consisted of 24 hours of constant pumping and 55 hours of water-level recovery. For the test, well 32M018, completed in the lower confined zone, was pumped and monitored. During the test, water levels in well 32M017 were monitored to record any response within the Brunswick aquifer system. Prior to the surficial aquifer system test, water levels were measured during a 7-day period in both wells to document background water-level trends and possible tidal effects. Water-level measurements varied from about 32.98 to 33.28 ft below land surface in well 32M018, indicating minor changes in water level during pretest monitoring. During the test, water levels were measured manually using an electric tape. In well 32M018, discharge varied from 800 to 850 gallons per minute (gal/min), averaging 826 gal/min throughout the test with a total 1,189,440 gallons pumped. Total drawdown was 21 ft after 24 hours of pumping (lower confined zone graphs, below).

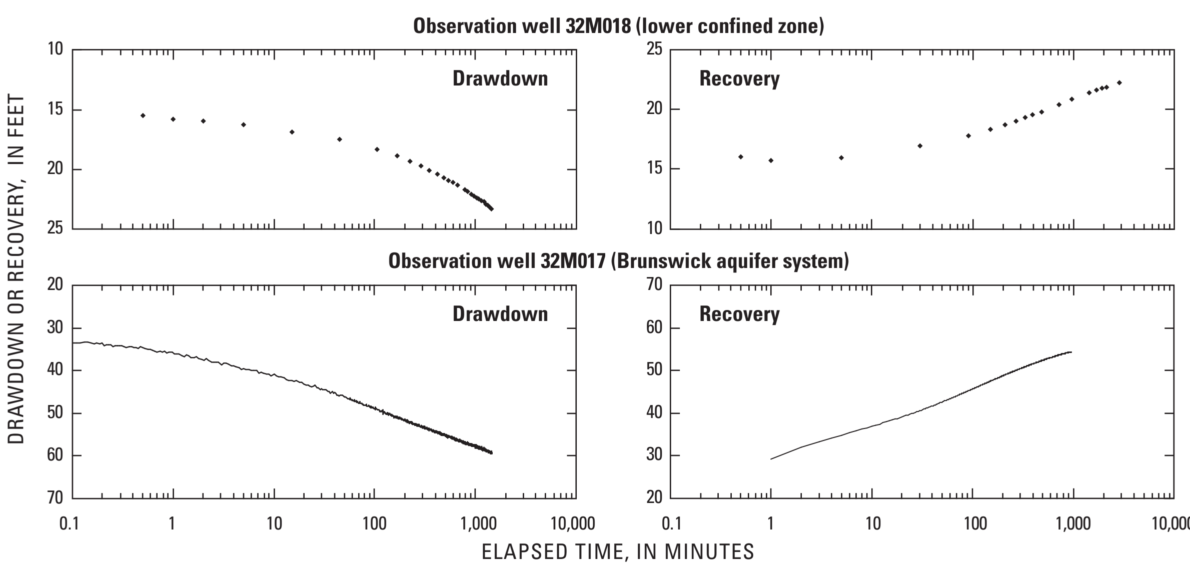
Results from the analyses of the drawdown data from well 32M018 using the Cooper and Jacob (1946) and the Hantush and Jacob (1955) analytical methods provided a reasonable estimate of the hydraulic properties of the lower confined zone of the surficial aquifer system. Results from the two solutions are consistent with one another and indicate the transmissivity for the lower confined zone is about 6,000 feet squared per day (ft^2/d) with a hydraulic conductivity of 70 feet per day (ft/d) (hydraulic properties table, facing page).

Upper and Lower Brunswick Aquifers

The Brunswick aquifer test was conducted July 8-10, 2003, and consisted of 24 hours of constant pumping and 16 hours of water-level recovery. For the test, well 32M017, completed in the upper and lower Brunswick aquifers was pumped and monitored. During the test, water levels in well 32M018 were monitored to record any response within the lower confined zone. For the analysis, the two Brunswick aquifers were treated as one, and the hydraulic conductivity was based on the thickness of the sum of the two aquifers, disregarding the 70-ft-thick confining unit between the aquifers. Because of this assumption, it is difficult to reliably estimate the hydraulic conductivity and transmissivity of the upper and lower Brunswick aquifers individually; thus, the transmissivity is a composite value for the entire aquifer.

Prior to the Brunswick aquifer system test, water levels were measured during a 4-day period in both wells to document background water-level trends and possible tidal effects. Water-level measurements varied from about 34.93 to 34.98 ft below land surface in well 32M017, indicating virtually no change in water level during pretest monitoring. In well 32M017, discharge varied from 580 to 650 gal/min, averaging 600 gal/min throughout the test; a total of about 861,120 gallons were discharged. Total drawdown was 64 ft after 24 hours of pumping (Brunswick aquifer system graphs, below).

Results from the analyses of the drawdown and recovery data from well 32M017 using the Cooper and Jacob (1946) analytical method provided a reasonable estimate of the hydraulic properties of the combined upper and lower Brunswick aquifers. Results from the pumping and recovery phase of the aquifer test are consistent with one another and indicate the combined transmissivity for the upper and lower Brunswick aquifers is about 2,000 ft^2/d with a hydraulic conductivity of 20 ft/day (hydraulic properties table, facing page).



Drawdown and recovery in observed wells during aquifer test of the lower confined zone and the Brunswick aquifer system, Ludowici test site, Long County, Georgia, July 8–10, 2003.

Hydraulic properties at wells 32M018 and 32M017, Ludowici test site, Long County, Georgia

[ft^2, square foot; ft, foot; do., ditto]

Well identification	Transmissivity (ft^2)	Hydraulic conductivity (ft)	Condition	Method
Lower confined zone				
32M018	6,000	70	Drawdown	Cooper and Jacob (1946)
do.	6,000	70	Drawdown	Hantush and Jacob (1955)
Brunswick aquifer system				
32M017	2,000	20	Drawdown	Cooper and Jacob (1946)
do.	2,000	20	Recovery	Cooper and Jacob (1946)

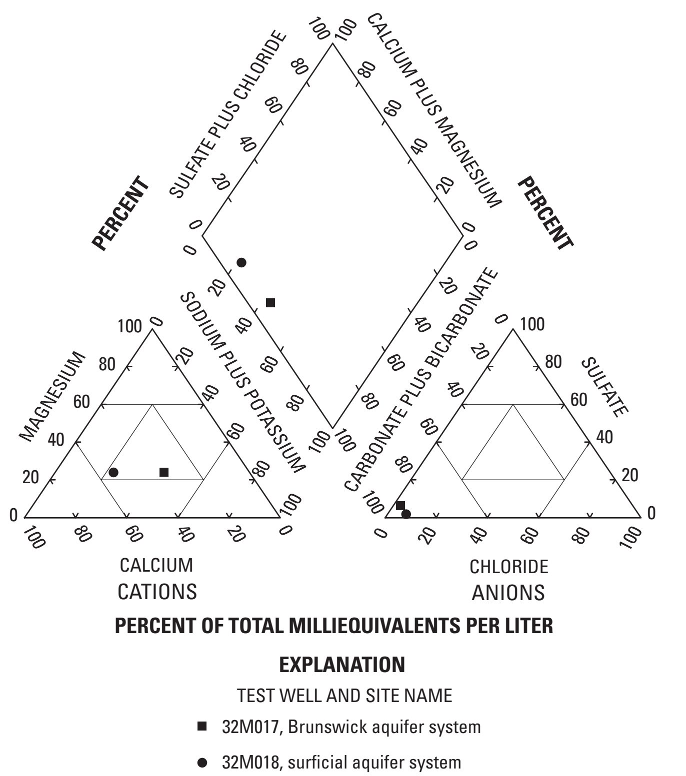
GROUND-WATER QUALITY

Results of the chemical analysis of ground-water samples obtained from the wells completed in the surficial and Brunswick aquifer systems were used to compare geochemical variability of ground water in the area. Water samples from wells 32M018 and 32M017 were analyzed for major ions, metals, total organic carbon, nutrients, and radionuclides (see water-quality table, following page). Field properties—including pH, specific conductance, and water temperature—were measured prior to sample collection. Concentrations of constituents were compared to the U.S. Environmental Protection Agency (USEPA) (2000a, 2000b) maximum contaminant levels (formerly known as primary maximum contaminant level) and secondary standards (formerly known as secondary maximum contaminant level) and Georgia Environmental Protection Division (1997a, 1997b) regulations for drinking water.

Graphical methods for the presentation of water-quality data provide a means to distinguish the chemical properties of ground water from various water-bearing zones. A trilinear diagram—illustrating the percent composition of selected major cations and anions, as well as dissolved-solid concentrations for these constituents for the surficial and Brunswick aquifer systems—is shown at right. As the diagram shows, water from the Brunswick aquifer system is a sodium-carbonate type, and water from the lower confined zone is a calcium-carbonate type. Water from the Brunswick aquifer system has a higher concentration of dissolved solids than the surficial aquifer system. Hardness of water in the Brunswick aquifer system is 107 milligrams per liter (mg/L) as calcium carbonate ($CaCO_3$), and hardness of water in the surficial aquifer system is 130 mg/L as $CaCO_3$ (based on the sum of milliequilalents of calcium, magnesium, barium, and strontium). According to the classification of Durfor and Becker (1964), water in the Brunswick aquifer system is categorized as moderately hard and in the surficial aquifer system is categorized as hard.

Water from surficial aquifer system has an iron concentration of 9.2 micrograms per liter (µg/L), well below the drinking-water standard of 300 µg/L, and the pH value of 7.5 falls above the secondary drinking-water standard of 6.5 (U.S. Environmental Protection Agency, 2000a, 2000b). Tritium was analyzed in samples from the surficial aquifer system to determine if water was entering the aquifer from surface recharge. Tritium activity in the water is less than the reporting limit of 5.7 picocurries per liter, which is not indicative of leakage or recharge. Water from the lower confined zone of the surficial aquifer system has a chloride concentration of 5.78 mg/L, specific conductance of 278 microsiemens per centimeter (µS/cm), and total organic carbon concentration of 0.83 mg/L.

Water from the Brunswick aquifer system has no major ionic concentrations that exceed drinking-water standards and the pH value of 7.9 is within the acceptable range of 6.5–8.5 for secondary drinking-water standards. Water from the Brunswick aquifer system has a dissolved chloride concentration of 6.64 mg/L and specific conductance of 331 µS/cm.



Percentage composition of major ionic constituents and dissolved solids in water from the lower confined zone and Brunswick aquifer system, Ludowici test site, Long County, Georgia, July 2003.

Field properties, major ions, and selected trace elements in water samples collected from the lower confined zone (32M018) and upper and lower Brunswick aquifers (32M017), Ludowici test site, Long County, Georgia, July 2003, and drinking-water standards for selected constituents.

[MCL, primary maximum contaminant level; SMCL, secondary maximum contaminant level; milligram per liter; —, no data available; µS/cm, microsiemens per centimeter; $CaCO_3$, calcium carbonate; <, less than; E, estimated value; µg/L, microgram per liter; pCi/L, picocurie per liter; –, minus]

Constituents	Test well number and water-bearing zone		Drinking-water standards[1]	
	32M018, Lower confined zone	32M017, Brunswick aquifer system	MCL	SMCL
Dissolved oxygen, in mg/L	0.5	0.5	—	—
Field pH, standard units	7.5	7.3	—	6.5–8.5
Lab pH, standard units	7.5	7.9	—	6.5–8.5
Field specific conductance, in µS/cm	274	336	—	—
Lab specific conductance, in µS/cm	278	331	—	—
Water temperature, in degrees Celsius	21.7	21.3	—	—
Hardness as $CaCO_3$, in mg/L	130	107	—	—
Calcium, dissolved, in mg/L	36.6	25.3	—	—
Magnesium, dissolved, in mg/L	9.39	10.6	—	—
Potassium, dissolved, in mg/L	1.71	3.10	—	—
Sodium, dissolved, in mg/L	16.6	36.8	—	—
Alkalinity as $CaCO_3$, in mg/L	130	296	—	—
Chloride, dissolved, in mg/L	5.78	6.64	—	250
Silica, dissolved, in mg/L	30.7	37.0	—	—
Sulfate, dissolved, in mg/L	3.26	16.1	—	250
Dissolved solids (sum of constituents), in mg/L	104	136	—	500
Ammonia, dissolved, in mg/L	0.06	0.10	—	—
Nitrite, nitrate, as N, dissolved, in mg/L	<0.022	<0.022	10	—
Phosphorus, dissolved, in mg/L	0.026	E 0.003	—	—
Phosphorus, total, in mg/L	0.009	0.004	—	—
Organic carbon, total, in mg/L	0.83	5.51	—	—
Aluminum, dissolved, in µg/L	E 1.0	—	—	50–200
Antimony, dissolved, in µg/L	<0.30	<0.30	6	—
Barium, dissolved, in µg/L	14.9	4.58	2,000	—
Beryllium, dissolved, in µg/L	<0.06	<0.06	4	—
Cadmium, dissolved, in µg/L	<0.037	<0.037	5	—
Chromium, dissolved, in µg/L	<0.8	<0.8	100	—
Cobalt, dissolved, in µg/L	0.069	0.067	—	—
Copper, dissolved, in µg/L	<0.23	E 0.13	—	1,000
Iron, dissolved, in µg/L	9.2	20.6	—	300
Lead, dissolved, in µg/L	0.19	<0.08	—	—
Manganese, dissolved, in µg/L	59.1	5.10	—	50
Molybdenum, dissolved, in µg/L	0.44	<0.33	—	—
Nickel, dissolved, in µg/L	0.49	0.66	100	—
Silver, dissolved, in µg/L	<0.20	<0.20	—	100
Strontium, dissolved, in µg/L	270	429	—	—
Zinc, dissolved, in µg/L	E 1.6	10.4	—	5,000
Alpha radioactivity, 2-sigma, Th-230, in pCi/L	0.99	1.93	15	—
Alpha radioactivity, Th-230, in pCi/L	–0.2	2.0	—	—
Beta radioactivity, 2-sigma, CS-137, in pCi/L	1.18	1.86	—	—
Gross beta radioactivity, CS-137, in pCi/L	1.9	4.1	—	—
Tritium 2-sigma, in pCi/L	3.6	—	—	—
Tritium, total, in pCi/L	<5.7	—	—	—
Uranium, dissolved, in µg/L	E 0.011	0.02	30	—

[1]U.S. Environmental Protection Agency, 2000a, b

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