Hydrogeology, Hydraulic Properties, and Water Quality of the Surficial and Brunswick Aquifer Systems, Northern Camden County, Georgia, October–December 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 occurrences of saltwater contamination have resulted in regulators restricting withdrawals from the aquifer in portions of the coastal area, and have prompted interest in developing supplemental sources of ground-water supply. These supplemental sources of water include the surficial aquifer system, the Brunswick aquifer system, and the Lower Floridan aquifer.

The U.S. Geological Survey (USGS)—in cooperation with Camden County 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 near Waverly in the northern part of Camden County. The purpose of this study was to calculate the hydraulic properties and collect water-quality data for the confined zone of the surficial aquifer system (confined surficial aquifer) and for the upper Brunswick aquifer of 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 analyses, and water-quality sampling and analysis. These data are important for the successful development and management of ground-water resources in the county.

Waverly test site, northern Camden County, Georgia.

Description of Study Area

The site is located in northern Camden County, Georgia, in the Coastal Plain physiographic province, and is about 13 miles southwest of the city of Brunswick and 1 mile east of the city of Waverly (maps at right and facing page). Land use in the area primarily is forest. Topographic relief across the area is low, with approximate land-surface altitude of 20 feet (ft) above North American Vertical Datum of 1988 (NAVD 88). The climate in the area is mild with a mean annual temperature of 69.5 degrees Fahrenheit at Brunswick National Weather Station (National Oceanic Atmospheric Administration, 2002). For the 30-year period 1971–2000, average monthly precipitation ranged from 2.49 inches per month during November to 6.50 inches per month during August, and annual precipitation averaged 49.42 inches (National Oceanic Atmospheric Administration, 2002).

Method of Study

To better identify the water-bearing capability and lithology of the surficial and Brunswick aquifer systems, three wells were drilled. One well was completed in the confined surficial aquifer (32G048), and a second well was completed in the upper Brunswick aquifer (32G047). A third well (32G046) was drilled in the lower Brunswick aquifer; however, this well was not completed nor tested because of an obstruction in the well. Lithologic cuttings and borehole geophysical logs were collected from well 32G046. In the other two wells, background water-level monitoring and aquifer testing were performed and water-quality samples were collected and analyzed. The wells completed in the confined surficial and upper Brunswick aquifers partially penetrate the aquifer. Wells 32G048, 32G047, and 32G046 were drilled

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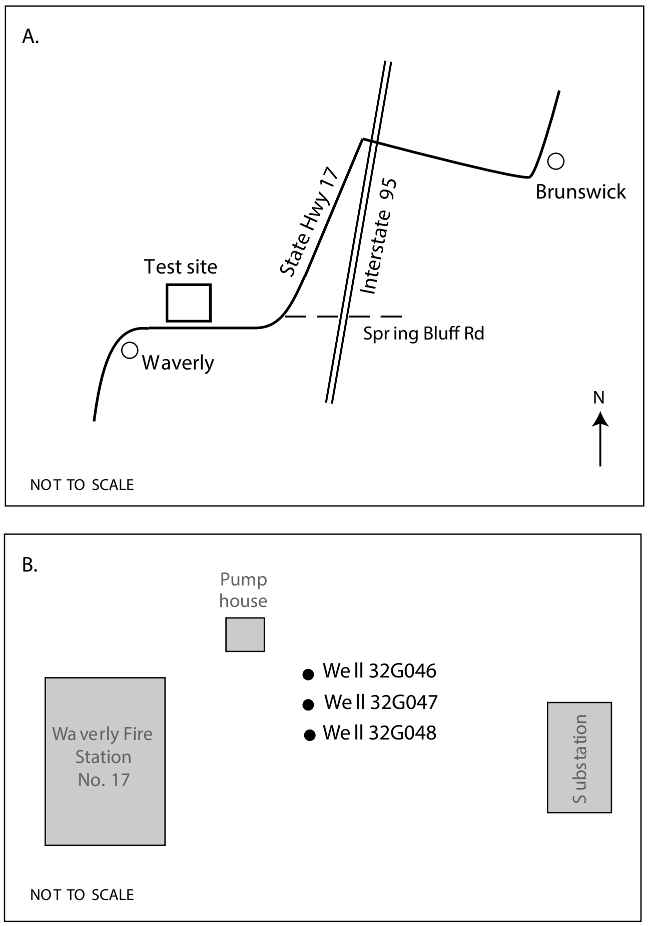
during November 2002 – February 2003 using standard mud-rotary techniques. The table below presents the well construction information.

On completion of the deepest hole (well 32G046), borehole geophysical logs were collected that included natural-gamma radiation, spontaneous potential, lateral resistivity, short- and long-normal resistivity, and caliper. The borehole geophysical logs and lithologic cuttings were used to select casing depth and screened intervals for each well. Natural-gamma radiation and electric logs were used to support correlation of stratigraphic units and identify water-bearing zones. Lithologic cuttings were collected throughout the drilling of well 32G046 and used to help determine the location of the A-, B-, and C-marker horizons. These markers are distinct stratigraphic horizons that are used to identify the tops of the upper Brunswick, lower Brunswick, and Upper Floridan aquifers, respectively, and are identified by a sharp change in radiation in the natural-gamma logs (Clarke and others, 1990). Lithologic and hydrogeologic descriptions for well 32G046 derived from lithologic cuttings and borehole geophysical logs were related to the stratigraphic descripton of a well drilled at St. Marys, Camden County, Georgia (Weems and Edwards, 2001).



(A) Generalized location of test site, and (B) test site showing relative locations of wells, Waverly test site, Camden County, Georgia.

Pretest ground-water levels were monitored before the start of each aquifer test using pressure transducers and data loggers. Ground-water levels in well 32G048 were monitored prior to the aquifer test in the confined surficial aquifer. Additionally, ground-water levels in wells 32G048 and 32G047 were monitored prior to the upper Brunswick aquifer test.

Pretest pumping was performed to verify that wells 32G048 and 32G047 were fully developed and to determine the optimum pumping rate for the 24-hour pumping phase of the aquifer tests. This pumping also ensured that the drawdown in the wells would not exceed the depth of the pressure transducer or induce cavitation (bubbling). During the pretest pumping and subsequent aquifer test, ground-water levels were measured and recorded using an In-Situ, Inc. Hermit 3000™ data logger with 100-pound-per-square-inch (psi) pressure transducers in wells 32G047 and 32G048 and with a 20-psi pressure transducer confined surficial aquifer well 32G048 during the upper Brunswick aquifer test. Verification measurements were made using dedicated electric tapes to confirm proper operation of the pressure transducers and data logger. 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.

Well location and construction for aquifer test at Waverly test site, Camden County, Georgia

[bls, below land surface; PW, pumping well; —, not applicable]

Well name	Other identifier	Land surface elevation (feet)	Well depth (feet bls)	Casing depth (feet bls)	Casing diameter (inches)	Top of screen or open interval (feet bls)	Bottom of screen or open interval (feet bls)	Type of opening	Screen-diameter	Aquifer
32G048	Waverly Fire Station PW-2	20	195	110	6	110	190	Screened	4	Confined surficial
32G047	Waverly Fire Station PW-1	20	295	240	6	250	290	Screened	4	Upper Brunswick
32G046	Waverly Fire Station	20	455*	370	6	—	—	Open	6	Lower Brunswick

* Well collapsed at 430 feet

A 2½-horsepower submersible pump was used for constant ground-water withdrawals for wells 32G048 and 32G047. Approximately 60 ft of 4-inch-diameter hose was used to transport water away from the wells. Ground-water discharge was measured using a Model FL-30005 Closed Pipe System Water Measurement Flowmeter. An appropriate discharge was determined during pretest pumping and was constantly maintained throughout the duration of the aquifer tests.

An aquifer test was performed in the confined surficial aquifer using well 32G048 and in the upper Brunswick aquifer using well 32G047. Data from aquifer tests were analyzed to calculate transmissivity and hydraulic conductivity for the aforementioned water-bearing units.

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

Drawdown and recovery data were analyzed using the nonequilibrium method of Theis (1935), the modified nonequilibrium analytical model of Cooper and Jacob (1946), and the Hantush and Jacob (1955) analytical model for nonsteady radial flow in an infinite leaky aquifer. The Hantush and Jacob (1955) method accounts for leakage, but does not differentiate between leakage from above or below the aquifer.

Water samples were collected after several hours of pumping when field properties were stable. Field properties were measured in a flow-through chamber using DataSonde® Hydrolab® 4 Water Quality multiprobe following USGS protocols (Wilde and Radtke, 1999). Whole-water samples were preserved and stored in polyethylene or acid-rinsed bottles and sent by overnight carrier to the USGS National Water Quality Laboratory, Denver, Colorado (NWQL). Water samples were collected from wells 32G048 and 32G047 and analyzed for major ions, nutrients, metals, and radionuclides. Based on major ionic composition, results from the chemical analyses were used to describe the ground-water quality and to differentiate the chemical quality between the water-bearing units.

Previous Investigations

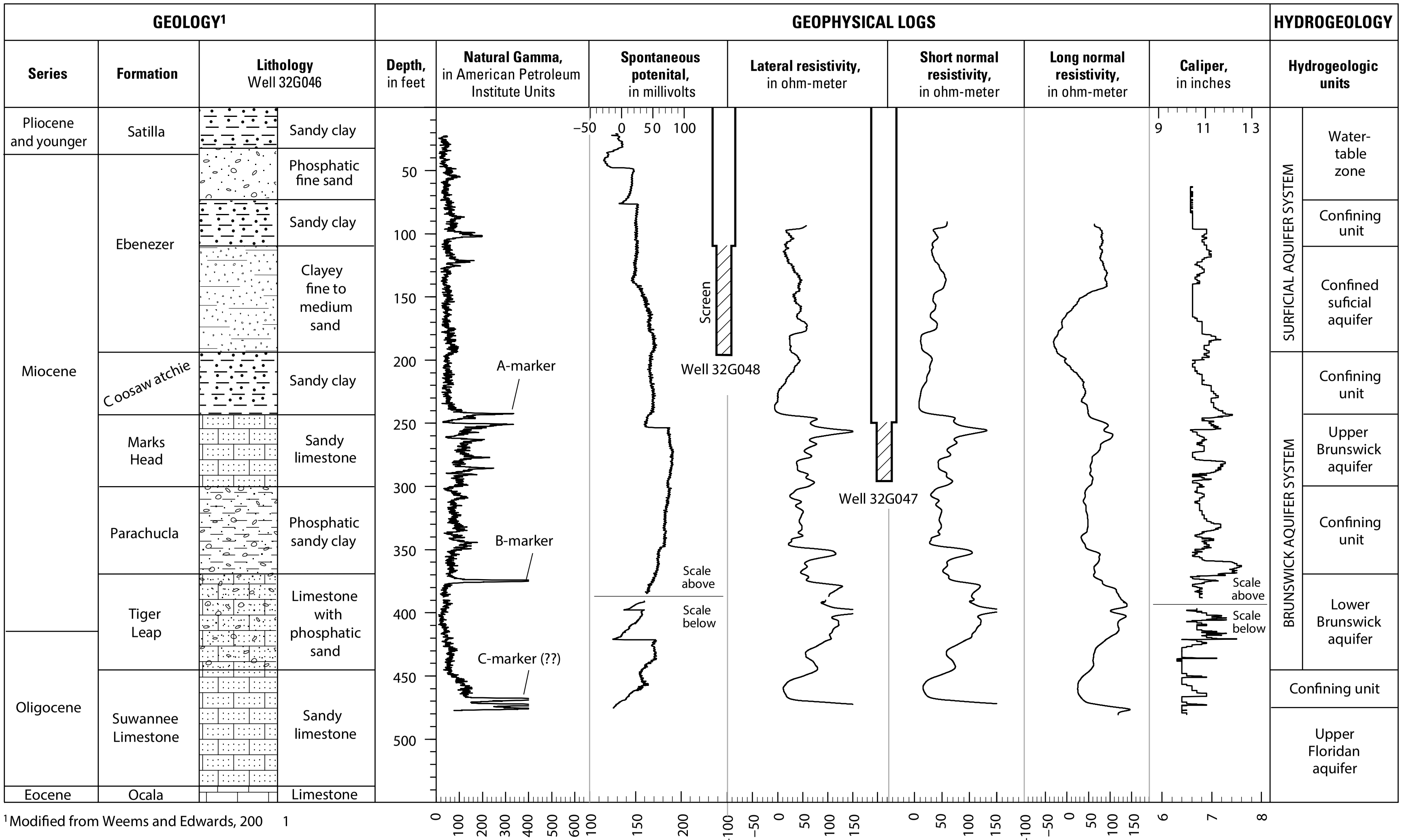
Clarke and others (1990) defined the surficial and upper and lower Brunswick aquifers and described their water-bearing characteristics. Sharpe and others (1998) described the results of an aquifer test in the Miocene-aged sediments in Camden County, Georgia. Steele and McDowell (1998) mapped the permeable thickness and areal distribution of the upper and lower Brunswick aquifers. 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 aquifers 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 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 Camden County, Georgia, include, but are not limited to, in descending order, the surficial aquifer system, consisting of water-table zone and confined surficial aquifer (Clarke, 2003); the Brunswick aquifer system, consisting of upper and lower Brunswick aquifers (Clarke and others, 1990); and the Upper Floridan aquifer (Miller, 1986) (hydrogeologic chart, facing page). The confined surficial aquifer and upper Brunswick aquifer are the focus of this study. The lithology of the confined surficial aquifer typically consists of sand and clay; these sediments overlay sandy limestone of the Brunswick aquifer system.

At the Waverly test site, the surficial aquifer system is present from land surface to about 195 ft below land surface (bls). For this study, it is informally divided into a water-table zone and the confined surficial aquifer. These water-bearing zones are separated by sandy clay confining units. The confined surficial aquifer is the zone under investigation. The confined surficial aquifer is present from 110 to 195 ft bls and consists of fine to medium sand interbedded with clay. The total thickness of the confined surficial aquifer is about 85 ft. The confining unit underlying the surficial aquifer system is identified on natural-gamma radiation logs by the A-marker horizon, a zone of high natural-gamma radiation, which is present just above the upper Brunswick aquifer (Clarke and others, 1990). Well 32G048 partially penetrates the confined surficial aquifer.

At the Waverly test site, the upper Brunswick aquifer extends from 240 to 300 ft bls and consists of limestone with partially cemented fine to medium sand. The total thickness of the upper Brunswick aquifer is about 60 ft.



[1]Modified from Weems and Edwards, 200 1

Generalized lithologic, geologic, and hydrologic descriptions of study area, Waverly test site, Camden County, Georgia.

HYDRAULIC PROPERTIES

Each single-well aquifer test was designed to provide data to calculate the hydraulic properties of the confined surficial and upper Brunswick aquifers. The aquifer tests consisted of a pretest step-drawdown test, background ground-water level monitoring prior to the test, constant discharge pumping test, and post-test water-level monitoring.

Analysis of drawdown data using graphs aid 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, 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 would cause drawdown to decrease, while contact with an impermeable boundary would cause drawdown to increase. Early termination of a test would result in an underestimation of hydraulic properties.

Confined Surficial Aquifer

The confined surficial aquifer single-well aquifer test consisted of pumping and monitoring well 32G048. Prior to the confined surficial aquifer test, ground-water levels were monitored for 62 days. The test was conducted December 9–11, 2003, and consisted of 24 hours of constant pumping and about 26 hours of ground-water-level recovery. During the pretest period (October 7–December 7, 2003), the water-level ranged from 9.48 to 10.5 ft bls. Average discharge during the test was 47.5 gallons per minute (gal/min), with a total drawdown of 30.8 ft bls after 24 hours of pumping (confined surficial aquifer graphs, facing page).

Results from the drawdown and recovery data analysis using Cooper and Jacob (1946) and Hantush and Jacob (1955) methods provided a reasonable estimation of the hydraulic properties for the confined surficial aquifer. Using both drawdown and recovery data, results from the two solutions indicate the average transmissivity for the confined surficial aquifer was 500 feet squared per day (ft^2/d) with a hydraulic conductivity of about 6 feet per day (ft/d) (hydraulic properties table, below).

Upper Brunswick Aquifer

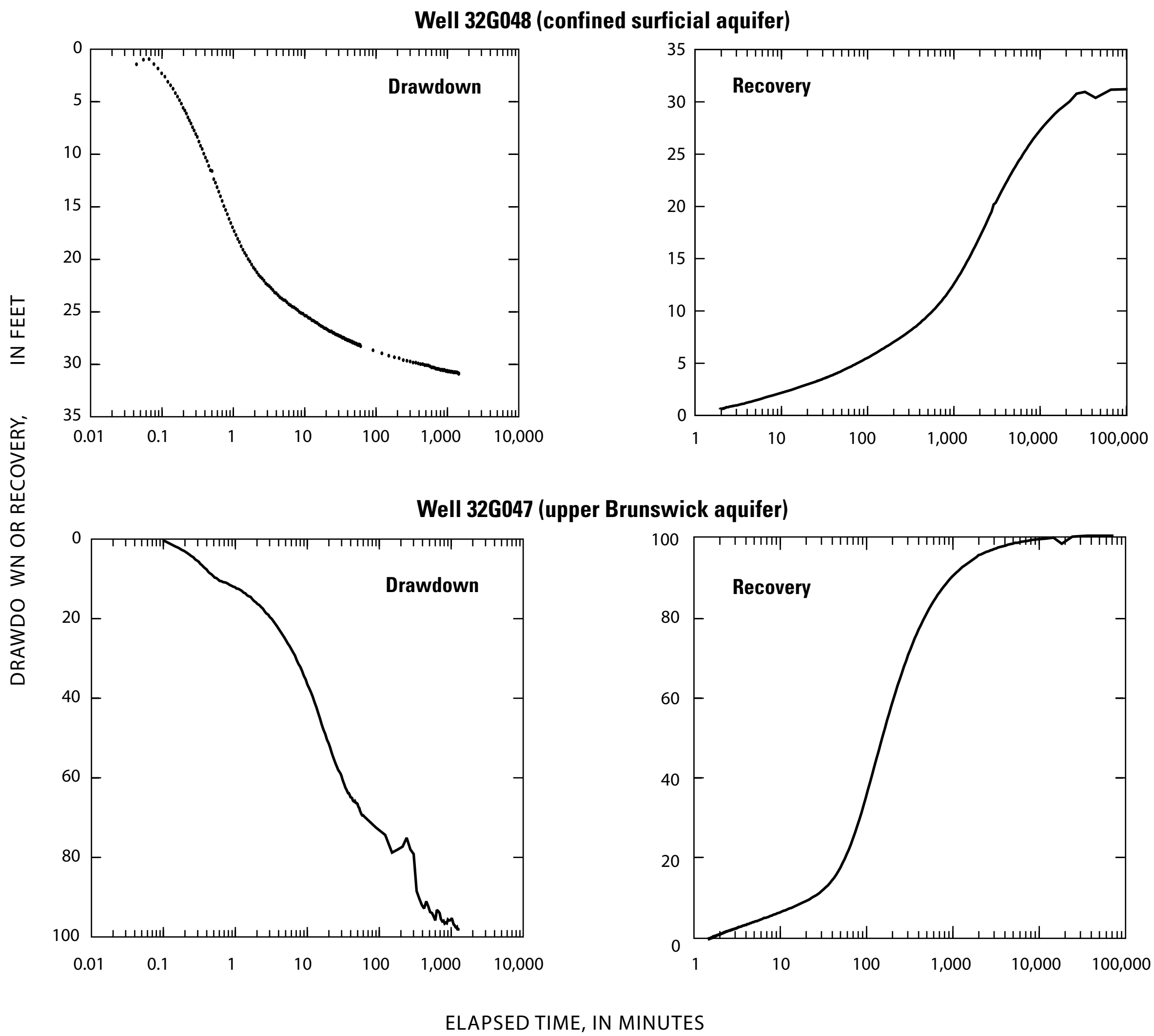
The upper Brunswick aquifer test consisted of pumping and monitoring well 32G047, open to the upper Brunswick aquifer, and monitoring well 32G048, open to the confined surficial aquifer. There was no change in the water level in the confined surficial aquifer, thus no data to analyze. Prior to the upper Brunswick aquifer test, water levels were monitored for 40 days. The test was conducted October 9–10, 2003, and consisted of 21 hours of constant pumping and 6 days of water level recovery. During the pretest period (August 27–October 5, 2003), the water-level ranged from 5.50 to 6.94 ft above land surface (als). Average discharge during the test was 12 gal/min with a total drawdown of 98.4 ft after 21 hours of pumping (upper Brunswick aquifer graphs, facing page).

Results from recovery data analyses from well 32G047, using the Cooper and Jacob (1946) and Hantush and Jacob (1955) methods, provided a reasonable estimation of the hydraulic properties for the upper Brunswick aquifer. Using the recovery data, results from the two solutions indicate the average transmissivity of the upper Brunswick aquifer was 70 ft^2/day with a hydraulic conductivity of about 2 ft/d (hydraulic properties table, below). Because of the low hydraulic conductivity, the aquifer in this area would not provide enough water to meet most industrial needs, but may meet small domestic needs.

Hydraulic properties determined from the confined surficial aquifer (well 32G048) and upper Brunswick aquifer (well 32G047) tests, Waverly test site, Camden County, Georgia, October 9–10 and December 9–10, 2003.

[ft^2/day, feet squared per day; ft/day, feet per day]

Well name	Transmissivity (ft^2/day)	Hydraulic conductivity (ft/day)	Condition	Method used	Date of aquifer test
			Confined surficial aquifer test		
32G048	500	6	Drawdown	Hantush and Jacob (1955)	Dec 9–10, 2003
32G048	500	6	Recovery	Cooper and Jacob (1946)	
			Upper Brunswick aquifer test		
32G047	70	2	Recovery	Average of Cooper and Jacob (1946) and Hantush and Jacob (1955)	Oct 9–10, 2003



Drawdown and recovery during confined surficial aquifer and upper Brunswick aquifer tests, Waverly test site, Camden County, Georgia, October and December 2003.

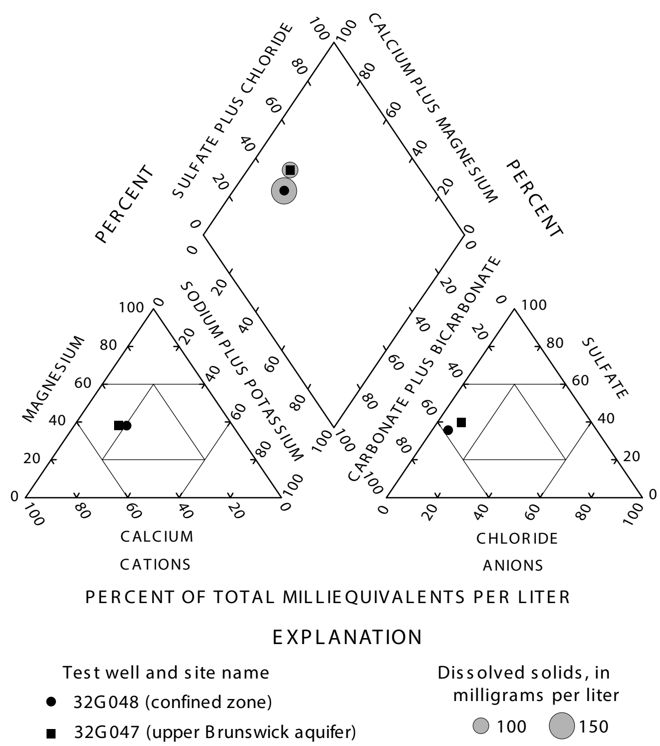
GROUND-WATER QUALITY

Results of the chemical analysis of ground-water samples obtained from wells completed in the confined surficial and upper Brunswick aquifers were used to compare the geochemical variability of ground water in the two aquifers. Water samples from wells 32G048 (confined surficial aquifer) and 32G047 (upper Brunswick aquifer) were analyzed for major ions, metals, total organic carbon, nutrients, and radionuclide material (water-quality table, facing page). Field properties including pH, specific conductance, and water temperature were measured onsite 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) for drinking water. Additionally, these data were compared to the GaEPD (1997a, 1997b) regulations for drinking water.

Graphical methods for the presentation of water-quality data provide a means of distinguishing the chemical properties of ground water from different water-bearing zones. A trilinear diagram showing the percent composition of selected major cations and anions, as well as dissolved solid concentrations of those constituents for the confined surficial and upper Brunswick aquifers is shown at right. As the diagram shows, water from both aquifers is a magnesium-carbonate-bicarbonate type with water from the confined surficial aquifer having a higher dissolved solids concentration. Hardness of water in both aquifers is more than 200 milligrams per liter (mg/L) of calcium carbonate ($CaCO_3$) (based on the sum of milliequivalent of calcium, magnesium, barium, and strontium), and is categorized as very hard (Durfor and Becker 1964).

Water from theconfined surficial aquifer has no major ionic concentrations that exceed drinking-water standards and the pH value of 7.6 is within the range of 6.5–8.5 for secondary drinking-water standards. Tritiumwas analyzed in water samples from the confined surficial aquifer to determine if water was entering the aquifer from surface recharge. Tritium in the water is less than the reporting limit of 5.7 picoCuries per liter, indicating no leakage. Water from the confined surficial aquifer has a dissolved chloride concentration of 12.0 mg/L, specific conductance of 484 microsiemens per centimeter (µS/cm), and total organic carbon concentration of 4.34 mg/L.

Water from the upper Brunswick aquifer has no major ionic concentrations exceeding drinking-water standards, and the pH value of 7.8 is within the range of 6.5–8.5 for secondary drinking-water standards. Water from the upper Brunswick aquifer has a dissolved chloride concentration of 15.8 mg/L, specific conductance of 433 µS/cm, and total organic carbon concentration of 1.33 mg/L.



Percent composition of major ionic constituents and dissolved solids in water from the confined surficial and the upper Brunswick aquifers, Waverly test site, Camden County, Georgia, October 2003.

Field properties, major ions, and selected trace elements in water samples collected from the confined surficial aquifer (well 32G048) and the upper Brunswick aquifer (well 32G047), Waverly test site, Camden County, Georgia, October–December 2003, and drinking-water standards for selected constituents.

[MCL, primary maximum contaminant level; SMCL, secondary maximum contaminant level; TT, treatment technique; mg/L, 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]

Constituents	Test well number and water-bearing zone		Drinking-water standards[1]		
	32G047, upper Brunswick aquifer	32G048, confined surficial aquifer	MCL	SMCL	TT
Dissolved oxygen, mg/L	2.49	—	—	—	—
Field pH, standard units	7.31	7.57	—	6.5–8.5	—
Lab pH, standard units	7.8	7.6	—	6.5–8.5	—
Field specific conductance, in µS/cm	462	501	—	—	—
Lab specific conductance, in µS/cm	433	484	—	—	—
Water temperature, in degrees Celsius	22.4	20.7	—	—	—
Hardness as mg/L $CaCO_3$	204	229	—	—	—
Calcium, dissolved, mg/L	43.8	47.9	—	—	—
Magnesium, dissolved, mg/L	23	26.4	—	—	—
Potassium, dissolved, mg/L	2.08	3.11	—	—	—
Sodium, dissolved, mg/L	18.6	24.3	—	—	—
Alkalinity as $CaCo_3$, mg/L	116	166	—	—	—
Chloride, filtered, mg/L	15.8	12	—	250	—
Silica, dissolved, mg/L	23.1	51.1	—	—	—
Sulfate, dissolved, mg/L	88.1	98	—	250	—
Dissolved solids (sum of constituents), mg/L	214	264	—	500	—
Ammonia, dissolved, mg/L	0.12	1.09	—	—	—
Nitrite, nitrate, as N, dissolved, mg/L	<.016	<0.002	10	—	—
Phosphorus, filtered, dissolved, mg/L	<.004	0.003	—	—	—
Phosphorus, unfiltered, dissolved, mg/L	E.003	0.0008	—	—	—
Organic carbon, total, in mg/L	1.33	4.34	—	—	—
Aluminum, dissolved, in µg/L	E1	—	—	50–200	—
Antimony, dissolved, in µg/L	<.20	<.20	6	—	—
Barium, dissolved, in µg/L	7	3	2,000	—	—
Beryllium, filtered, in µg/L	<.06	<.06	4	—	—
Cadmium, filtered, in µg/L	<.04	<.04	5	—	—
Chromium, dissolved, in µg/L	E.8	<.8	100	—	—
Cobalt, filtered, in µg/L	0.08	0.1	—	—	—
Copper, filtered, in µg/L	0.4	E.4	—	1,000	1,300
Iron, dissolved, in µg/L	110	10	—	300	—
Lead, filtered, in µg/L	<.08	E.04	—	—	15
Manganese, dissolved, in µg/L	2.6	2.1	—	50	—
Molybdenum, dissolved, in µg/L	<.4	<.4	—	—	—
Nickel, filtered, in µg/L	0.73	0.54	100	—	—
Siver, dissolved, in µg/L	<.20	—	—	100	—
Strontium, dissolved, in µg/L	565	849	—	—	—
Zinc, dissolved, in µg/L	E2	<3	—	5,000	—
Alpha radioactivity, 2-sigma, Th-230, in pCi/L	2.64	—	15	—	—
Alpha radioactivity,Th-230, in pCi/L	3.97	—	—	—	—
Beta radioactivity, 2-sigma, CS-137, in pCi/L	2.01	—	—	—	—
Gross beta radioactivity, CS-137, in pCi/L	4.68	—	—	—	—
Tritium 2-sigma, in pCi/L	—	—	—	—	—
Tritium, total, in pCi/L	—	—	—	—	—
Uranium, filtered, in µg/L	<.04	<.04	30	—	—

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

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