Hydrogeology, Hydraulic Properties, and Water Quality of the Surficial and Brunswick Aquifer Systems, Eastern Liberty County, Georgia, January–February 2003

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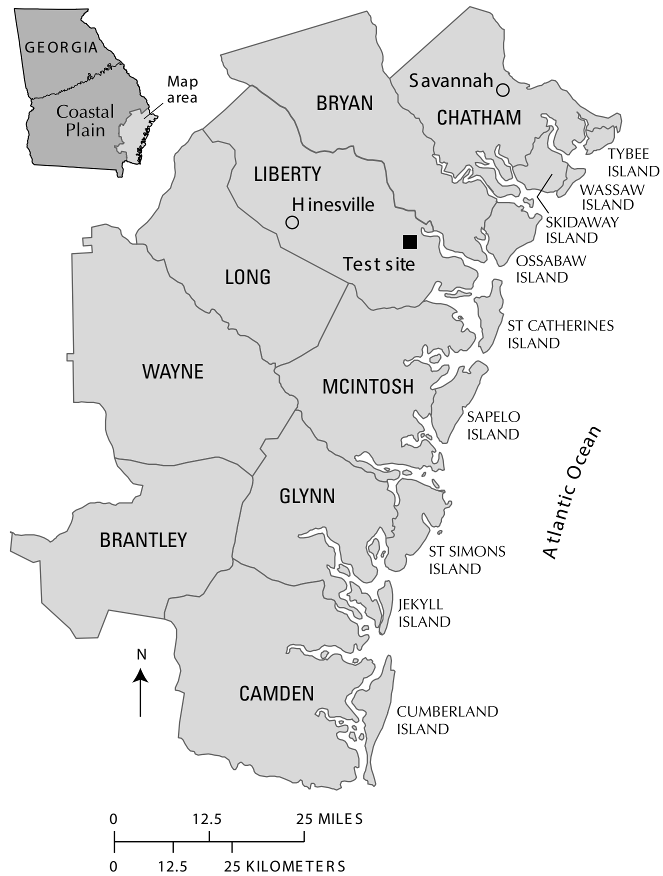
INTRODUCTION

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 regulators restricting withdrawals from the aquifer in parts 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, Brunswick aquifer system, and Lower Floridan aquifer.

The U.S. Geological Survey (USGS)—in cooperation with the Liberty County Development Authority 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 Old Sunbury Road, in the eastern part of Liberty County. The purpose of this study was to estimate the hydraulic properties and collect water-quality data for the upper confined zone of the surficial aquifer system and the lower 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 analysis, and water-quality sampling and analysis. These data are important for the successful development and management of ground-water resources in the county.



Base modified from U.S. Geological Survey 1:2,000,000-scale Digital Line Graph data

Old Sunbury Road test site, eastern Liberty County, Georgia.

Description of Study Area

The test site is located in eastern Liberty County, Georgia, in the Coastal Plain physiographic province. The site is about 23 miles south of the city of Savannah and 16 miles east of the city of Hinesville (maps at right and facing page). Land use in the area primarily is forest. Topographic relief across the area is low, and approximate land-surface altitude is 10 feet (ft) above the North American Vertical Datum of 1988 (NAVD 88). The climate in the area is humid and subtropical with a mean annual temperature of 66.2 degrees Fahrenheit at Savannah Municipal Airport (National Oceanic Atmospheric Administration, 2002). For the 30-year period 1971–2000, average monthly precipitation ranged from 2.49 inches during November to 7.20 inches during August, and annual precipitation averaged 49.58 inches (National Oceanic Atmospheric Administration, 2002).

Methods of Study

To better identify the water-bearing characteristics and lithology of the surficial and Brunswick aquifer systems, six wells were drilled. One well was completed in the upper confined zone of the surficial aquifer system (upper confined zone) (35N072) and in the lower Brunswick aquifer (35N071). An observation well was completed in the water-table zone of the surficial aquifer system (water-table zone) (35N076), upper confining unit overlying the confined zone of the surficial aquifer system (confining unit) (35N075), upper confined zone (35N074), and the lower Brunswick aquifer (35N073).

Wells 35N072 and 35N071 were completed on January 21, 2003, and December 5, 2002, respectively; the four observa-

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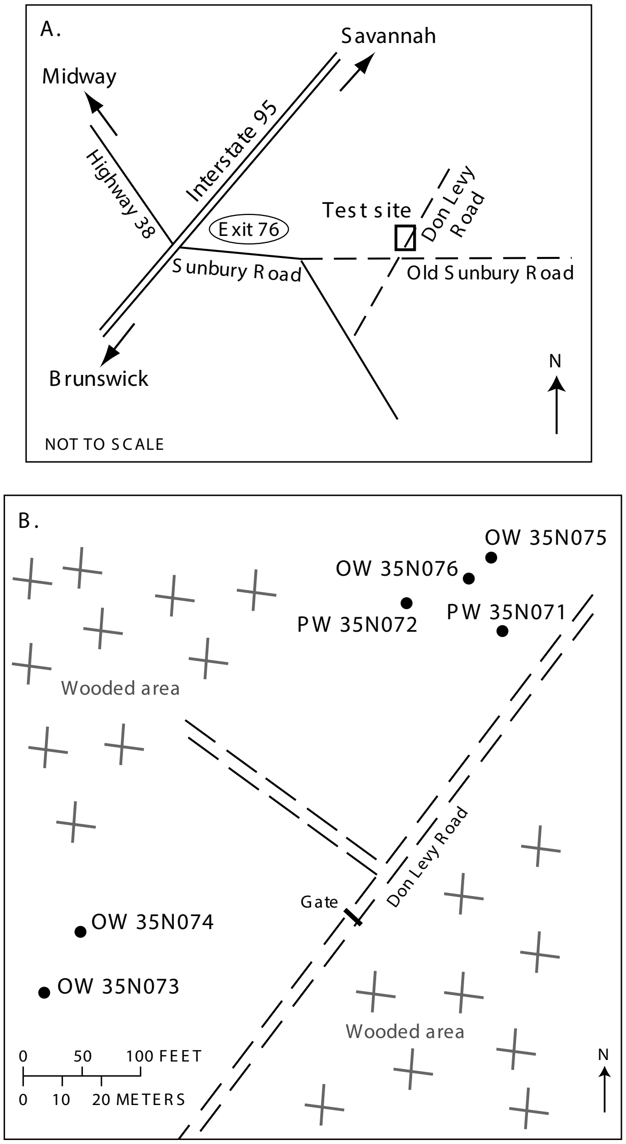


(A) Generalized location of test site; and(B) test site showing relative locations of pumping wells (PW) and observation wells (OW).

tion wells (35N076, 35N075, 35N074, and 35N073) were completed at approximately the same time using standard mud-rotary techniques, except for well 35N076, which was hand augured (well construction table, below).

On completion of the deepest hole (well 35N071), borehole geophysical logs were collected including natural-gamma radiation, spontaneous potential, lateral resistivity, short- and long-normal resistivity, and caliper. Borehole geophysical logs and lithologic cuttings were used to select casing depths and screened intervals for each well. Natural-gamma radiation and electric logs were used to verify the correlation of the stratigraphic units and identify water-bearing zones. Lithologic cuttings were collected during the drilling of well 35N071 and used to determine the location of the A-, B-, and C-marker horizons. These markers are used to identify the tops of the upper Brunswick, lower Brunswick, and Upper Floridan aquifers, respectively, and are characterized by a sharp increase in natural-gamma radiation (Clarke and others, 1990). Lithologic and hydrogeologic descriptions for well 35N071 derived from the lithologic cuttings and borehole geophysical logs were related to stratigraphic description of a well drilled in McIntosh County, Georgia (Weems and Edwards, 2001).

Pretest ground-water levels were monitored prior to the start of each aquifer test using pressure transducers and data loggers. Ground-water levels in wells 35N075, 35N074, and 35N073 were monitored prior to the aquifer test in the upper confined zone (well 35N072). Ground-water levels in wells 35N074, 35N072, 35N073, and 35N071 were monitored prior to the lower Brunswick aquifer test (well 35N071).

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. This pumping also ensured that the drawdown in the pumped wells would not exceed the depth of the pressure transducer or induce cavitation (bubbling) in the wells. During the pretest pumping and subsequent aquifer test, ground-water levels were measured using an In-Situ, Inc. Hermit 3000™ data logger with a 100-pound-per-square-inch (psi) pressure transducer in the pumping well and an In-Situ, Inc.

Well location and construction for aquifer test at Old Sunbury Road test site, Liberty County, Georgia

[OW, observation well; PW, pumping well; WT, water-table zone; CU, confining unit; UCZ, upper confined zone; —, not applicable; do., ditto]

Well name	Other identifier	Well depth (feet below land surface)	Casing depth (feet below land surface)	Casing diameter (inches)	Altitude (feet)			Type of opening	Aquifer	Aquifer zone
					Top of screen or open interval	Bottom of screen or open interval	Land surface			
35N076	Old Sunbury Road OW-4	8	8	2	5	2	10	Screened	Surficial	WT
35N075	Old Sunbury Road OW-3	52	52	4	−42	−43	do.	do.	do.	CU
35N072	Old Sunbury Road PW-2	150	150	6	−50	−140	do.	do.	do.	UCZ
35N074	Old Sunbury Road OW-2	65	65	4	−50	−55	do.	do.	do.	do.
35N071	Old Sunbury Road PW-1	365	365	6	−305	−355	do.	do.	Lower Brunswick	—
35N073	Old Sunbury Road OW-1	322	322	4	−307	−312	do.	do.	do.	—

[1]Negative value denotes below NAVD 88

Hermit 2000™ data logger with either a 20- or 30-psi transducer in the observation wells. 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 loggers. 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.

A 5-horsepower submersible pump was used for constant ground-water withdrawals from wells 35N072 and 35N071. A trailer-mounted diesel-powered electric generator provided power to the submersible pump. About 80 ft of 6-inch-diameter polyvinyl chloride pipe was used to transport water away from the wells. Ground-water discharge was measured using a totalizing flowmeter. An appropriate discharge was determined during pretest pumping and was held constant throughout the duration of the aquifer tests.

An aquifer test was performed in the upper confined zone using pumping well 35N072 and observation wells 35N076, 35N075, 35N074, 35N073, and 35N071. An aquifer test was performed in the lower Brunswick aquifer using pumping well 35N071 and observation wells 35N072, 35N074, and 35N073. Data from these aquifer tests were analyzed to estimate transmissivity, storage coefficient, and hydraulic conductivity for the aforementioned water-bearing units.

During the aquifer test, 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, 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 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 above or below the aquifer.

Water samples were collected from wells 35N072 and 35N071 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. Water samples were collected after several hours of pumping when field properties had stabilized. Field properties were measured in a flow-through chamber using a 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.

Previous Investigations

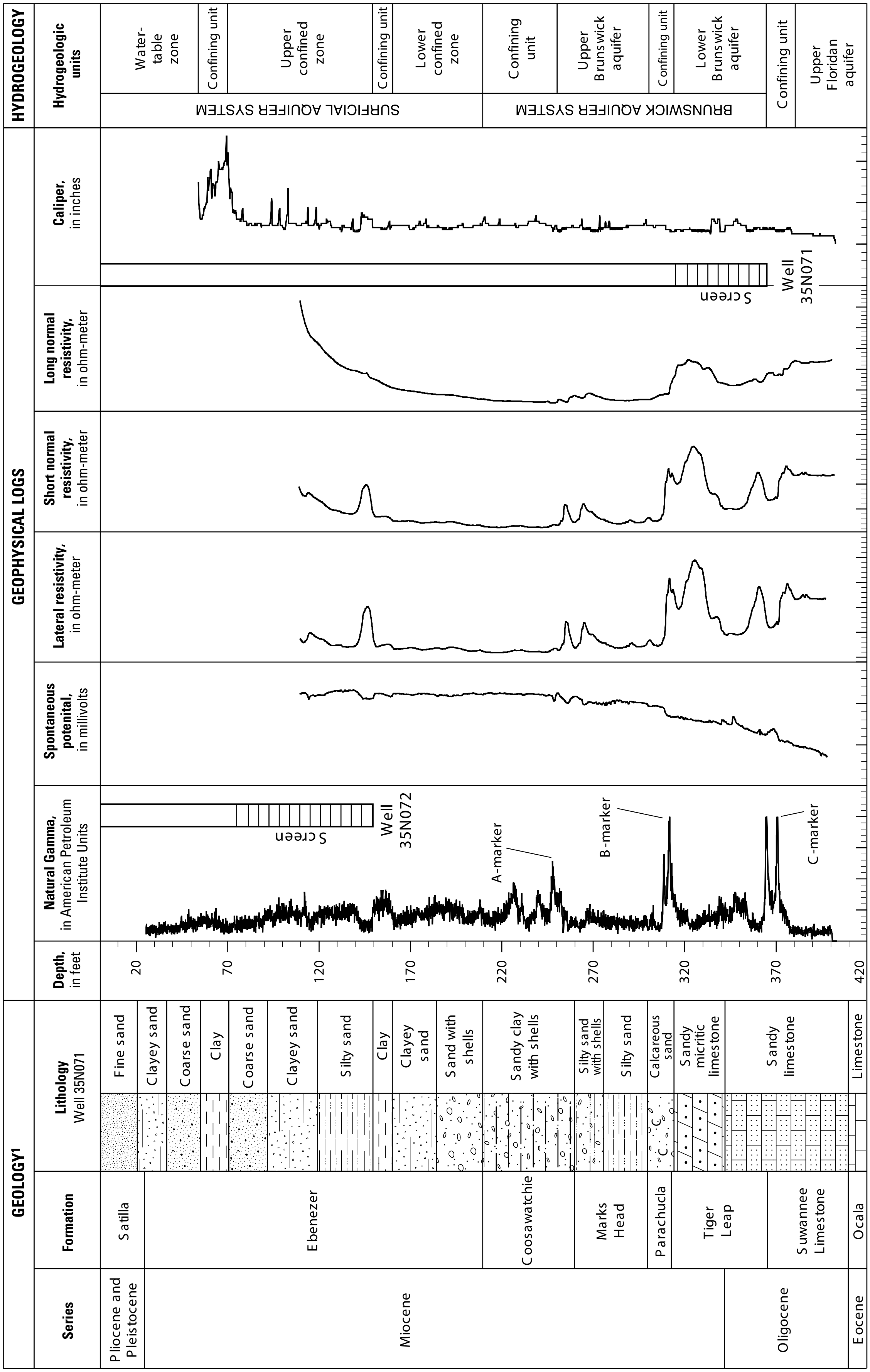
Clarke and others (1990) defined the surficial and upper and lower Brunswick aquifers and described their water-bearing characteristics. Steele and McDowell (1998) mapped the permeable thickness and areal distribution of the upper and lower Brunswick aquifers. Sharpe and others (1998) described results 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 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 Liberty County, Georgia, include in descending order, the surficial aquifer system, consisting of the water-table zone, upper confined zone, and lower confined zone (Clarke, 2003); the Brunswick aquifer system, consisting of the upper Brunswick and lower Brunswick aquifers (Clarke and others, 1990); and the Upper Floridan aquifer (Miller, 1986) (hydrogeologic chart, facing page). The upper confined zone of the surficial aquifer system and lower Brunswick aquifer are the focus of this study. The lithology of the upper confined zone consists of sand interbedded with clay and silt with shell fragments; these sediments overlay the micritic limestone and sandy limestone of the lower Brunswick aquifer.

At the Old Sunbury Road test site, the surficial aquifer system is present from land surface to 210 ft below land surface (bls). For this study, it is informally divided into a water-table zone, an upper confined zone, and a lower confined zone. These water-bearing zones are separated by clay confining units. The upper confined zone is the zone that is being investigated. The upper confined zone is present from 70 to 150 ft bls and consists mostly of fine to coarse sand interbedded with clay and silt. The thickness of the upper confined zone is approximately 80 ft. The confining unit underlying the surficial aquifer system is identified on natural-gamma radiation logs by the A-marker horizon, which is present just above the upper Brunswick aquifer (Clarke and others, 1990). Well 35N072 is screened through the upper confined zone.

At the Old Sunbury Road test site, the lower Brunswick aquifer extends from 315 to 365 ft bls and consists of micritic limestone with partially cemented, mostly fine to medium grained, sandy limestone. The thickness of the lower Bruns-



[1]Modified from Weems and Edwards, 2001

Generalized lithologic, geologic, and hydrologic descriptions of study area, Old Sunbury Road, Liberty County, Georgia.

wick aquifer is 50 ft. The top of the aquifer was determined by locating the B-marker horizon identified by a sharp increase in natural gamma radiation on the natural-gamma log (Clarke and others, 1990). The bottom of the aquifer was determined by the location of the C-marker horizon, which coincides with the top of the Upper Floridan aquifer (Clarke and others, 1990). The C-marker horizon is present near the top of the Suwannee Limestone in the study area. Well 35N071 is screened in the lower Brunswick aquifer.

HYDRAULIC PROPERTIES

Each multiwell aquifer test was designed to provide hydraulic data to calculate the hydraulic properties for the upper confined zone and the lower Brunswick aquifer. Aquifer tests consisted of background water-level monitoring prior to the test, pretest pumping, 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, whereas contact with an impermeable boundary would cause drawdown to increase. Early termination of a test would result in an underestimation of hydraulic properties.

Upper Confined Zone of the Surficial Aquifer System

The upper confined zone multiwell aquifer test consisted of pumping the upper confined zone well 35N072 while monitoring water levels in observation well 35N074 open to the upper confined zone. Additionally, the water-table zone well 35N076, confining-unit well 35N075, and lower Brunswick aquifer wells 35N071 and 35N073 were monitored. Prior to the upper confined zone aquifer test, water levels were monitored for 6 days. The test was conducted February 6–7, 2003, and consisted of 24 hours of constant pumping and 24 hours of water-level recovery. During the pretest period (January 29–February 3, 2003), water levels ranged from 3.43 to 3.49 ft bls in well 35N076 open to the water-table zone; from 8.54 to 8.87 ft bls in well 35N075 open to the confining unit; from 12.52 to 12.76 ft bls in well 34N074, open to the upper confined zone; and from 46.97 to 47.22 bls in well 35N073, open to the lower Brunswick aquifer. Average discharge during the test was 39.8 gallons per minute (gal/min), with a total drawdown of 28.7 ft after 24 hours of pumping (graphs, facing page).

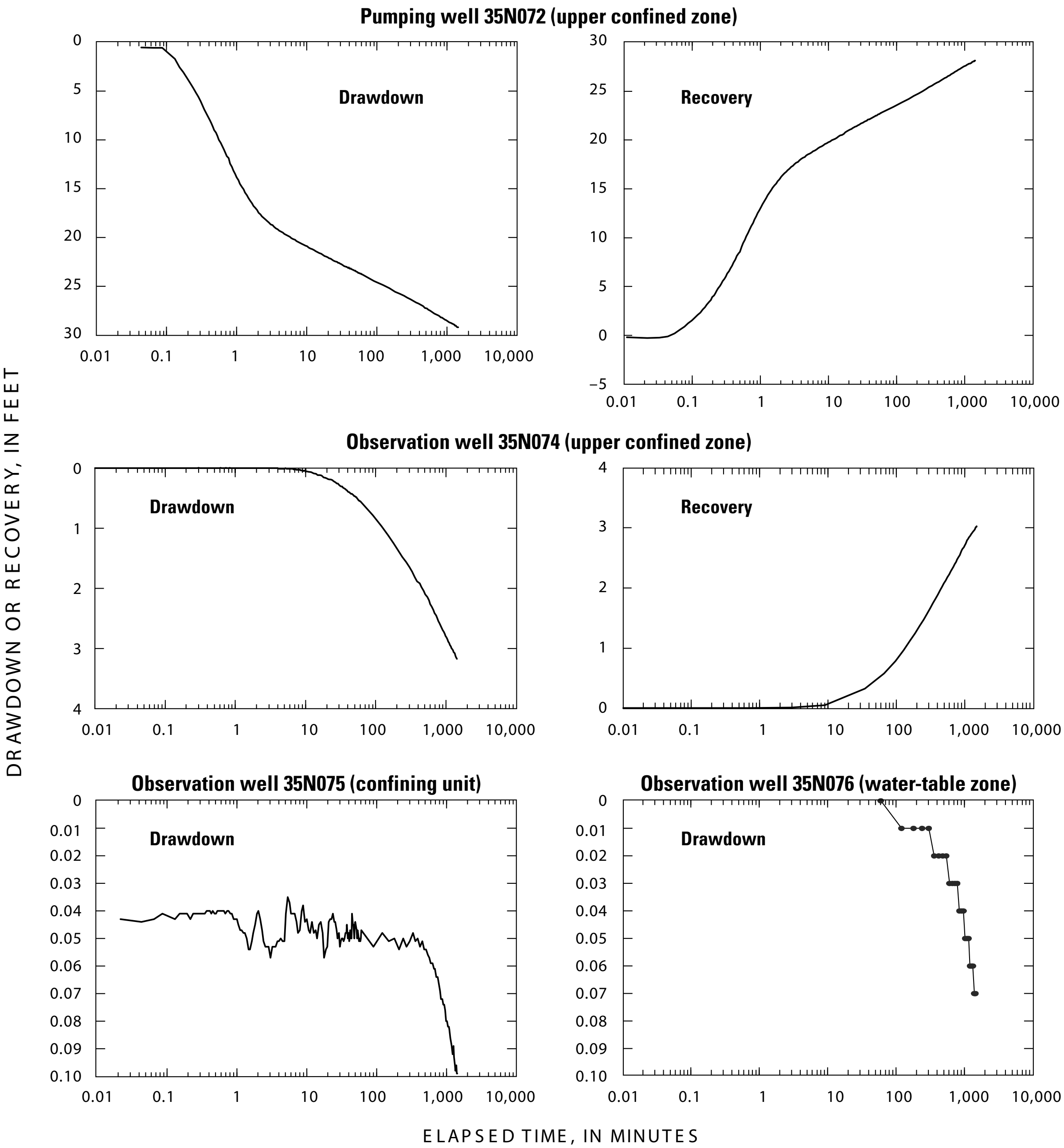
Results from the drawdown and recovery data analysis using the Cooper and Jacob (1946) and Hantush and Jacob (1955) analytical methods provided a reasonable estimation of the hydraulic properties for the upper confined zone. Using both drawdown and recovery data, results from the two solutions indicate the transmissivity of the upper confined zone ranges from 400 to 600 feet squared per day (ft^2/d) with a hydraulic conductivity ranging from 4 to 7 feet per day (ft/d) (hydraulic properties table, below).

Lower Brunswick aquifer

The lower Brunswick aquifer test consisted of pumping and monitoring well 35N071, while monitoring the ground-water levels in the observation well 35N073 open to the lower Brunswick aquifer. Additionally, upper confined zone wells 35N072 and 35N074 were monitored. Prior to the lower Brunswick aquifer test, water levels were monitored for 11 days. The test was conducted January 14–16, 2003, and consisted of 48 hours of constant pumping and 20 hours of

Hydraulic properties determined from the upper confined zone of the surficial aquifer system (35N072) and lower Brunswick aquifer (well 35N071) tests, January–February 2003. [ft^2/d, feet squared per day; ft/d, feet per day; storage coefficient is dimensionless; —, no data]

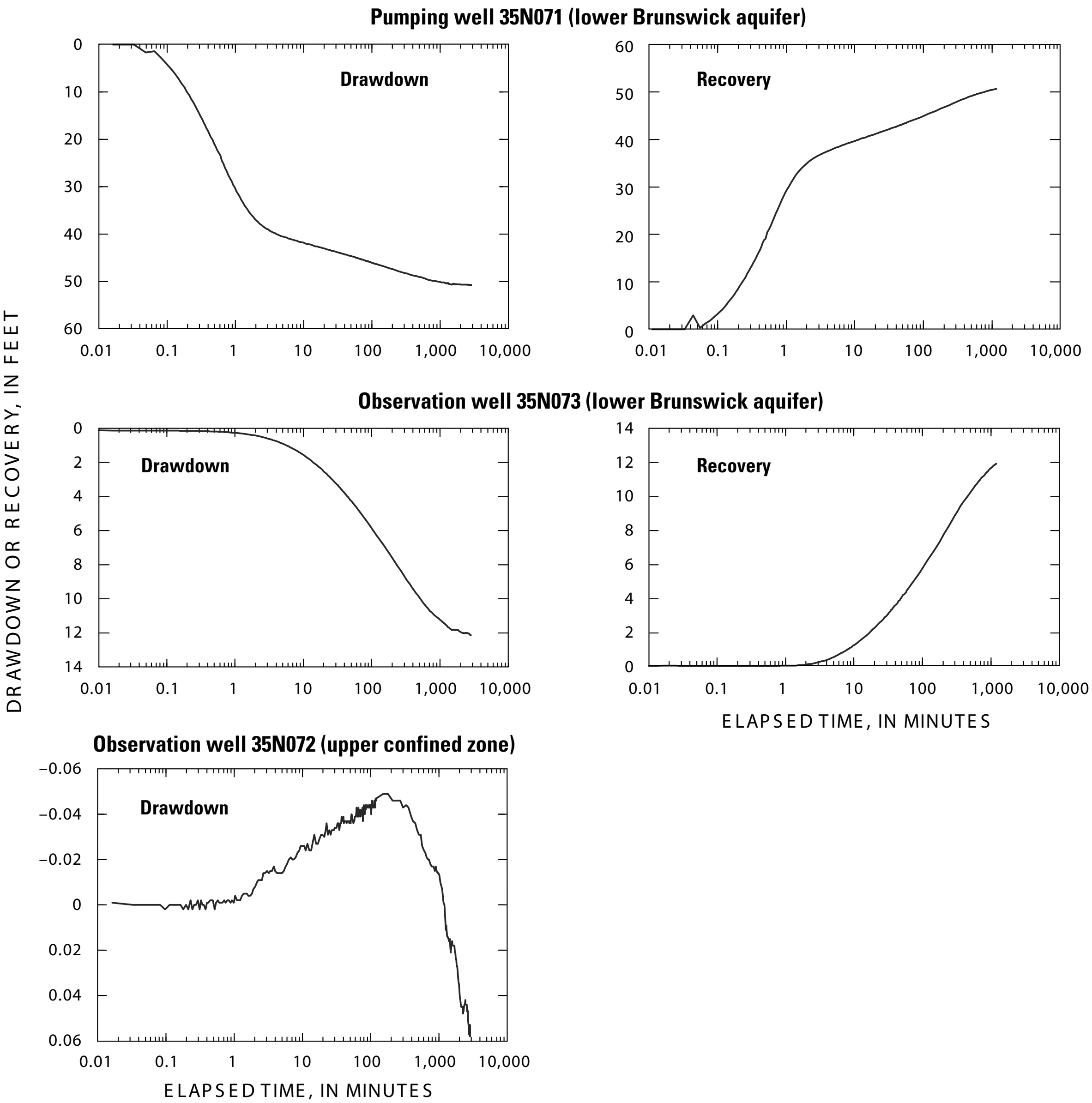
Well name	Transmissivity (ft^2/d)	Hydraulic conductivity (ft/d)	Storage coefficient	Condition	Method used	Date of aquifer test
Upper confined zone of the surficial aquifer system test						
35N072	400	4	—	Drawdown	Cooper and Jacob (1946)	Feb 5–7, 2003
35N072	400	4	—	Recovery	Cooper and Jacob (1946)	—
35N074	600	7	—	Drawdown	Hantush and Jacob (1955)	—
Lower Brunwick aquifer test						
35N071	600	10	—	Drawdown	Cooper and Jacob (1946)	Jan 14–17, 2003
35N073	400	9	0.00004	Drawdown	Hantush and Jacob (1955)	—



Drawdown and recovery in wells observed during aquifer test of the upper confined zone of the surficial aquifer, Old Sunbury Road test site, Liberty County, Georgia, February 2003.

water-level recovery. During the pretest period (January 2–13, 2003), the water levels ranged from 8.15 to 8.48 ft bls in wells 35N072 and 35N074 open to the upper confined zone, respectively; and from 47.24 to 47.60 ft bls in wells 35N071 and 35N073, open to the lower Brunswick aquifer, respectively. Average discharge during the test was 78.5 gal/min with a total drawdown of 50.2 ft bls after 48 hours of pumping (graphs, page 90).

Results from the analyses of the drawdown data from well 35N071 using the Cooper and Jacob (1946) and Hantush and Jacob (1955) analytical methods provided a reasonable estimation of the hydraulic properties for the lower Brunswick aquifer. Results from the two solutions indicate the transmissivity for the lower Brunswick aquifer ranges from 400 to 600 ft^2/d with a hydraulic conductivity ranging from 9 to 10 ft/d (hydraulic properties table, facing page).



Drawdown and recovery in wells observed during aquifer test of the lower Brunswick aquifer, Old Sunbury Road test site, Liberty County, Georgia, January 2003.

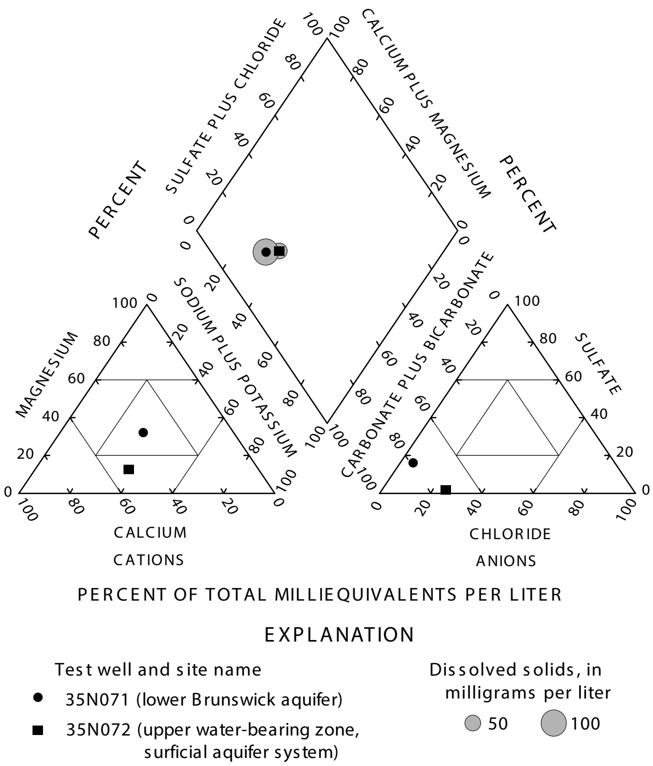
GROUND-WATER QUALITY

Results of the chemical analyses for the ground-water samples obtained from wells completed in the upper confined zone and the lower Brunswick aquifer were used to compare the geochemical variability of ground water in the two aquifers. Water samples from wells 35N072 and 35N071 were analyzed for major ions, metals, total organic carbon, nutrients, and radionuclides (water-quality table, page 92). 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) for drinking water. These data were compared to the Georgia Environmental Protection Division (GaEPD) (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 upper confined zone and lower Brunswick aquifer is shown at right. As the diagram shows, water from the upper confined zone is a calcium-chloride type and water from the lower Brunswick aquifer is a carbonate type, with the upper confined zone having a lower concentration of dissolved solids than the lower Brunswick aquifer. Hardness of water in the upper confined zone is 30 milligrams per liter (mg/L) as calcium carbonate ($CaCO_3$) and hardness of water in the lower Brunswick aquifer is 100 mg/L as $CaCO_3$ (based on the sum of milliequivalents of calcium, magnesium, barium, and strontium). According to the classification of Durfor and Becker (1964), the ground water in the upper confined zone is categorized as soft and the ground water in the lower Brunswick aquifer is categorized as moderately hard.

Water from the upper confined zone of the surficial aquifer system has an iron concentration of 1,263 micrograms per liter, which exceeds the drinking-water standard of 300 mg/L, and the pH value of 5.6 falls below the USEPA and GaEPD secondary drinking-water standard of 6.5. Tritium was analyzed in samples from the upper confined zone of the surficial aquifer system 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, which is not indicative of leakage or recharge. Water from the upper confined zone has a chloride concentration of 8.59 mg/L, specific conductance of 104 microsiemens per centimeter (µS/cm), and total organic carbon concentration of 1.74 mg/L.

Water from the lower Brunswick aquifer has no major ionic concentrations that exceed drinking-water standards and the pH value of 8.08 is within the range of 6.5 – 8.5 for secondary drinking-water standards. Water from the lower Brunswick aquifer has a dissolved chloride concentration of 4.58 mg/L and specific conductance of 285 µS/cm.



Percent composition of major ionic constituents and dissolved solids in water from upper confined zone of the surficial aquifer and lower Brunswick aquifer, Old Sunbury Road test site, Liberty County, Georgia, January 15 and February 5, 2003.

Field properties, major ions, and selected trace elements in water samples collected from the upper confined zone of the surficial aquifer system (well 35N072) and lower Brunswick aquifer (well 35N071), Old Sunbury Road test site, Liberty County, Georgia, January–February, 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; bold where sample exceeded standard; 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]		
	35N072, upper confined zone	35N071, lower Brunswick aquifer	MCL	SMCL	TT
Dissolved oxygen, mg/L	0.9	0.1	—	—	—
Field pH, standard units	5.6	8	—	6.5–8.5	—
Lab pH, standard units	6.5	8.1	—	6.5–8.5	—
Field specific conductance, in µS/cm	104	276	—	—	—
Lab specific conductance, in µS/cm	106	285	—	—	—
Water temperature, in degrees Celsius	20.6	22.8	—	—	—
Hardness as mg/L $CaCO_3$	30	100	—	—	—
Calcium, dissolved, mg/L	9.48	20.8	—	—	—
Magnesium, dissolved, mg/L	1.41	11.6	—	—	—
Potassium, dissolved, mg/L	1.18	3.81	—	—	—
Sodium, dissolved, mg/L	7.19	19.7	—	—	—
Alkalinity as $CaCo_3$, mg/L	35	106	—	—	—
Chloride, filtered, mg/L	8.59	4.58	—	250	—
Silica, dissolved, mg/L	29.2	35.9	—	—	—
Sulfate, dissolved, mg/L	0.2	20.8	—	250	—
Dissolved solids (sum of constituents), mg/L	57	117	—	500	—
Ammonia, dissolved, mg/L	0.17	0.08	—	—	—
Nitrite, nitrate, as N, dissolved, mg/L	<.022	<0.022	10	—	—
Phosphorus, filtered, dissolved, mg/L	1.35	E0.003	—	—	—
Phosphorus, unfiltered, dissolved, mg/L	1.33	0.005	—	—	—
Organic carbon, total, in mg/L	1.74	—	—	—	—
Aluminum, dissolved, in µg/L	<20	E8.6	—	50–200	—
Antimony, dissolved, in µg/L	<.30	<.30	6	—	—
Barium, dissolved, in µg/L	13	2	2,000	—	—
Beryllium, filtered, in µg/L	E.03	<.06	4	—	—
Cadmium, filtered, in µg/L	<.04	<.04	5	—	—
Chromium, dissolved, in µg/L	<.8	<.8	100	—	—
Cobalt, filtered, in µg/L	0.02	0.04	—	—	—
Copper, filtered, in µg/L	<.2	E.2	—	1,000	1,300
Iron, dissolved, in µg/L	1,263	<10	—	300	—
Lead, filtered, in µg/L	0.12	<.08	—	—	15
Manganese, dissolved, in µg/L	37.2	<2.0	—	50	—
Molybdenum, dissolved, in µg/L	<.3	0.5	—	—	—
Nickel, filtered, in µg/L	0.4	0.7	100	—	—
Siver, dissolved, in µg/L	<.20	<.20	—	100	—
Strontium, dissolved, in µg/L	66.8	390	—	—	—
Zinc, dissolved, in µg/L	E19	<24	—	5,000	—
Alpha radioactivity, 2-sigma, Th-230, in pCi/L	—	2	15	—	—
Alpha radioactivity,Th-230, in pCi/L	—	1.8	—	—	—
Beta radioactivity, 2-sigma, CS-137, in pCi/L	—	1.3	—	—	—
Gross beta radioactivity, CS-137, in pCi/L	—	5.4	—	—	—
Tritium 2-sigma, in pCi/L	3.2	—	—	—	—
Tritium, total, in pCi/L	<5.7	—	—	—	—
Uranium, filtered, in µg/L	E.01	E.01	30	—	—

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

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