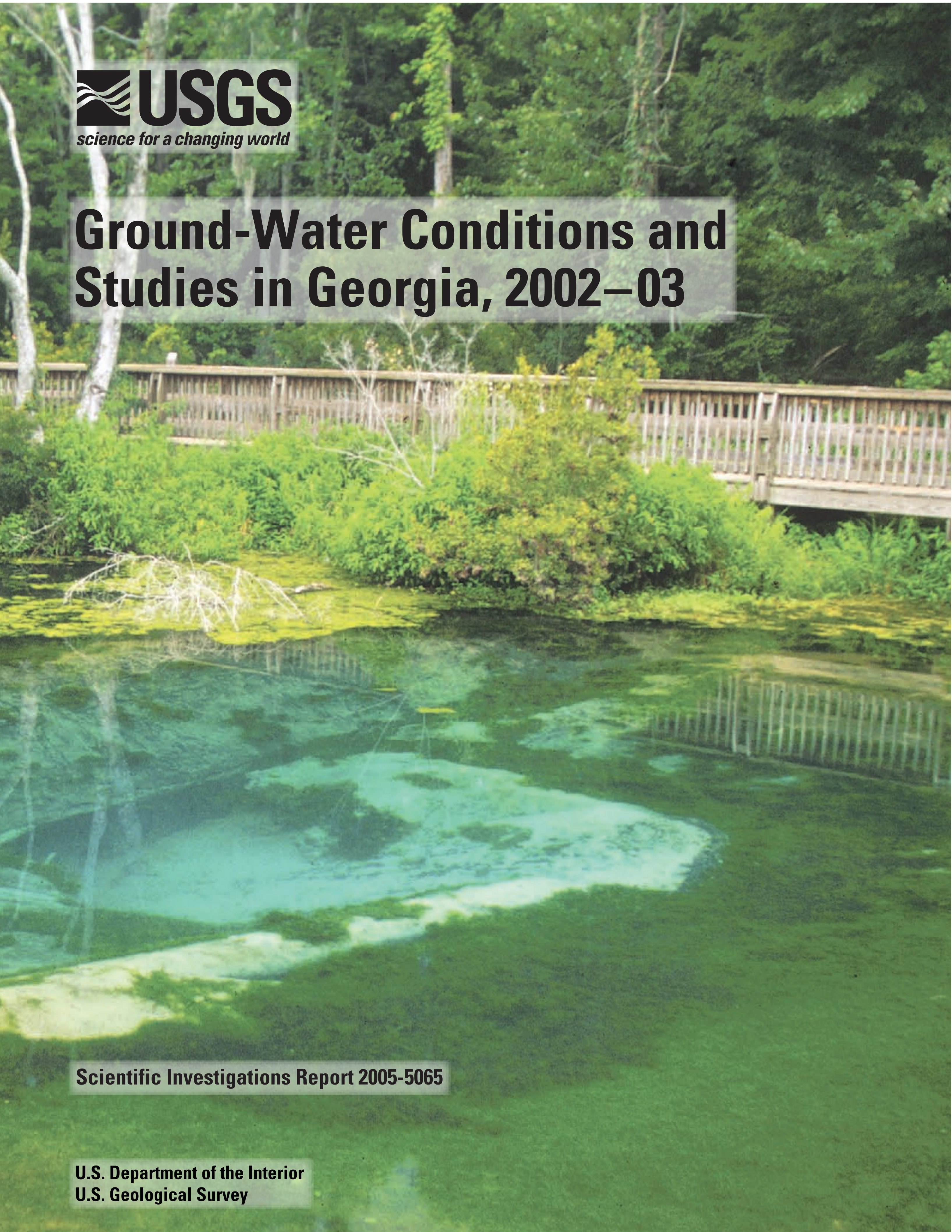

Ground-Water Conditions and Studies in Georgia, 2002–03

Scientific Investigations Report 2005-5065

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

Cover photograph: Magnolia Springs, Magnolia Springs State Park, Jenkins County, Georgia
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Ground-Water Conditions and Studies in Georgia, 2002–03

By David C. Leeth, John S. Clarke, Caryl J. Wipperfurth, and Steven D. Craigg

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U.S. Department of the Interior
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Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83). Historical data collected and stored and North American Datum of 1927 (NAD 27) have been converted to NAD 83 for use is in this publication.

Ground-Water Conditions and Studies in Georgia, 2002–03

by David C. Leeth, John S. Clarke, Caryl J. Wipperfurth, and Steven D. Craigg

ABSTRACT

The U.S. Geological Survey (USGS) collects ground-water data and conducts studies to monitor hydrologic conditions, better define ground-water resources, and address problems related to water supply, water use, and water quality. Data collected as part of ground-water studies include geologic information, geophysical logs, hydraulic properties, water levels, and water-quality information. During 1938, a ground-water-level network was established for Georgia. Later, ground-water-quality networks were established in the cities of Albany, Savannah, and Brunswick and in Camden County, Georgia.

Ground-water levels are monitored continuously in a network of wells completed in major aquifers throughout the State. The size of this network varies each year because of changes in Federal, State, or local interest. Continuous water-level recorders were operated in 185 wells during 2002 and 177 wells during 2003. Because of the short period of record for a number of these wells (less than 3 years), only 155 wells from the network are discussed in this report. These wells include 18 in the surficial aquifer system, 15 in the Brunswick aquifer system and equivalent sediments, 64 in the Upper Floridan aquifer, 13 in the Lower Floridan aquifer and underlying units, 12 in the Claiborne aquifer, 1 in the Gordon aquifer, 11 in the Clayton aquifer, 12 in the Cretaceous aquifer system, 2 in Paleozoic-rock aquifers, and 7 in crystalline-rock aquifers. In this report, data from these 155 wells were evaluated to determine whether mean-annual ground-water levels were within, below, or above the normal range during 2003, based on summary statistics for the period of record. Information from these summaries and from long-term hydrographs indicates that as a result of drought, water levels continued to decline through the middle of 2002 in almost all aquifers monitored, with water levels in some wells falling below historical lows. During 2003, however, water levels were at or above normal in almost all aquifers monitored, reflecting a recovery from drought. An exception to this general conclusion (water-level recovery from drought) is in the Cretaceous aquifer system where water levels in 10 of the 12 wells monitored were below normal during 2003.

In addition to continuous water-level data, periodic synoptic water-level measurements were collected and used to construct potentiometric-surface maps for the Upper Floridan aquifer in selected areas. In the Camden County–Charlton County area, measurements were taken in 52 wells during September 2003. In the Brunswick area, measurements in 8 wells were collected during May and June 2002 and in 22 wells during June 2003. In the city of Albany–Dougherty County area, during October 2002 and September 2003, water-level measurements were taken in 68 wells.

Ground-water quality in the Upper Floridan aquifer is monitored in the Albany, Savannah, and Brunswick areas, and in Camden County; and monitored in the Lower Floridan aquifer in the Savannah and Brunswick areas. In the Albany area, nitrate concentrations have been monitored since 1998. Nitrate concentrations increased in 11 of 14 wells from November of 2002 to November 2003 and were above the U.S. Environmental Protection Agency's (USEPA) 10 milligrams per liter (mg/L) drinking-water standard in November 2003. In the Savannah area, chloride concentrations in water from four wells in the Upper Floridan aquifer showed no appreciable change during 2003, remaining within the USEPA 250-mg/L drinking-water standard.

In the Brunswick area, water samples from 43 wells were collected during June 2002 and from 56 wells in 2003 and analyzed for concentrations of chloride. Maps showing chloride concentrations in the Upper Floridan aquifer during June 2002 and 2003 indicate that concentrations remained above USEPA drinking-water standards across a 2-square-mile area.

In the Camden County area, chloride concentrations in six wells completed in the Upper Floridan aquifer remained within drinking-water standards. With the exception of one well, concentrations showed little change during 2002–03 and were below 40 mg/L. In one well, concentrations remained above 110 mg/L.

Ongoing studies during 2002–03 include an assessment of ground-water flow near the Savannah River Site in Georgia and South Carolina; assessment of the surficial and Brunswick aquifer systems in coastal Georgia; evaluation of ground-water flow, and water-quality and water-level monitoring in the city of Albany–Dougherty County area; evaluation of saltwater intrusion and water-level and water-quality monitoring in the city of Brunswick–Glynn County area; evaluation of salt-water intrusion and alternative water sources as part of the Coastal Sound Science Initiative; effects of impoundment of Lake Seminole on water resources in southwestern Georgia; assessment and simulation of stream-aquifer relations in the Lower Apalachicola–Chattahoochee–Flint River Basin; the continuing effort to collect ground-water data in and adjacent to the State of Georgia; assessment of ground-water resources and hydrogeology of crystalline-rock aquifers in Rockdale County, and a study to understand the sustainability of ground-water resources in the city of Lawrenceville area.

Technical highlights from selected USGS studies during 2002–03 include that of the hydrogeology and results from aquifer tests in the Brunswick and surficial aquifer systems at selected sites in coastal Georgia; establishment of a ground- and surface-water monitoring network in Lawrenceville, Georgia; water-bearing characteristics of sheet fractures in Rockdale County, Georgia; and projected water use in the coastal area of Georgia, 2000–2050. Selected publications, technical presentations, and outreach activities during 2002 and 2003 also are summarized.

INTRODUCTION

Reliable and impartial scientific information on the occurrence, quantity, quality, distribution, and movement of water is essential to resource managers, planners, and others throughout the Nation. The U.S. Geological Survey (USGS)—in cooperation with numerous local, State, and Federal agencies—collects hydrologic data and conducts studies to monitor hydrologic conditions and better define the water resources of Georgia and other States and territories.

Ground-water-level and ground-water-quality data are essential for water-resource assessment and management. Water-level measurements from observation wells are the principal source of information about the hydrologic stresses on aquifers and how these stresses affect ground-water recharge, storage, and discharge. Long-term, systematic measurements of water levels provide essential data needed to evaluate changes in the resource over time, develop ground-water models and forecast trends, and design, implement, and monitor the effectiveness of ground-water management and protection programs (Taylor and Alley, 2001). Ground-water-quality data are necessary for the protection of ground-water resources because deterioration of ground-water quality may be virtually irreversible, and treatment of contaminated ground water can be expensive (Alley, 1993). Reliable water-use data are important to many organizations and individuals in support of research and policy decisions, and as an essential part of understanding the effects of humans on the hydrologic system (Hutson and others, 2004).

Purpose and Scope

This report presents an overview of ground-water conditions, water-use information, and hydrologic studies conducted during 2002 and 2003 by the USGS in Georgia. Summaries of selected ground-water studies, with objectives and progress, and selected technical highlights are presented. These summaries and highlights include:

- Permitted water-use data for the State during 2003, and ground-water use trends for 1999–2003;
- Ground-water-level and ground-water-quality conditions in Georgia during 2002 and 2003, based on information collected from State and local monitoring networks;
- Assessment of ground-water flow near the Savannah River Site in Georgia and South Carolina;
- Assessment of the surficial and Brunswick aquifer systems in coastal Georgia;
- Evaluation of ground-water flow, and water-quality and water-level monitoring in the city of Albany–Dougherty County area;
- Evaluation of saltwater intrusion and water-level and water-quality monitoring in the city of Brunswick–Glynn County area;
- Evaluation of saltwater intrusion and alternative water sources as part of the Coastal Sound Science Initiative;
- Effects of impoundment of Lake Seminole on water resources in southwestern Georgia;
- Assessment and simulation of stream-aquifer relations in the Lower Apalachicola–Chattahoochee–Flint River Basin;
- Continuing efforts to collect ground-water data in and adjacent to the State of Georgia;
- Assessment of ground-water resources and hydrogeology of crystalline-rock aquifers in Rockdale County;
- A study to assess the sustainability of ground-water resources in the city of Lawrenceville area;
- Hydrogeology and results from aquifer tests in the surficial and Brunswick aquifers systems at selected sites in coastal Georgia;
- Establishment of a ground- and surface-water monitoring network in the city of Lawrenceville area;
- Water-bearing characteristics of sheet fractures in Rockdale County;
- Projected water use in the coastal area of Georgia, 2000–2050; and
- Previously published reports on Georgia ground-water conditions (listed in the table, page 4).

Periodic water-level measurements were taken in 870 wells, and continuous water-level measurements were obtained from 185 wells during 2002 and 177 wells during 2003 (however, only data from 155 wells are summarized herein). Of the 177 wells equipped with continuous water-level recorders during 2003, 159 wells had electronic data recorders, which recorded the water level at 60-minute intervals with these data generally retrieved monthly. Eighteen wells had real-time satellite telemetry, which recorded the water level at 60-minute intervals and transmitted water levels every 4 hours for display on the USGS Georgia District Web site at *http://water.usgs.gov/ga/nwis/current?type=gw*

Median-annual water levels for 2003 were compared with the normal range of ground-water levels for the period of record; the results of this comparison are shown on maps for selected aquifers and areas of the State. In addition, hydrographs showing monthly mean ground-water levels for the period 1999–2003 are shown with period-of-record water-level statistics for selected wells.

Periodic water-level measurements in the Upper Floridan aquifer were collected during October 2002 and September 2003 in 68 wells in south-central Dougherty County near Albany, and maps showing the potentiometric surface of the aquifer were constructed from these data. A similar map of the Upper Floridan aquifer was constructed for Camden, Charlton, and Ware Counties and adjacent counties in Florida using water-level measurements collected during September 2003 from 52 wells (Kinnaman and Knowles, 2004).

Previous reports on ground-water conditions in Georgia

Year of data collection	USGS report series and number	Author(s)	Year of publication
1977	[1]OFR 79-213	U.S. Geological Survey	1978
1978	OFR 79-1290	Clarke, J.S., Hester, W.G., and O'Byrne, M.P.	1979
1979	OFR 80-501	Mathews, S.E., Hester, W.G., and O'Byrne, M.P.	1980
1980	OFR 81-1068	Mathews, S.E., Hester, W.G., and O'Byrne, M.P.	1981
1981	OFR 82-904	Mathews, S.E., Hester, W.G., and McFadden, K.W.	1982
1982	OFR 83-678	Stiles, H.R., and Mathews, S.E.	1983
1983	OFR 84-605	Clarke, J.S., Peck, M.F., Longsworth, S.A., and McFadden, K.W.	1984
1984	OFR 85-331	Clarke, J.S., Longsworth, S.A., McFadden, K.W., and Peck, M.F.	1985
1985	OFR 86-304	Clarke, J.S., Joiner, C.N., Longsworth, S.A., McFadden, K.W., and Peck, M.F.	1986
1986	OFR 87-376	Clarke, J.S., Longsworth, S.A., Joiner, C.N., Peck, M.F., McFadden, K.W., and Milby, B.J.	1987
1987	OFR 88-323	Joiner, C.N., Reynolds, M.S., Stayton, W.L., and Boucher, F.G.	1988
1988	OFR 89-408	Joiner, C.N., Peck, M.F., Reynolds, M.S., and Stayton, W.L.	1989
1989	OFR 90-706	Peck, M.F., Joiner, C.N., Clarke, J.S., and Cressler, A.M.	1990
1990	OFR 91-486	Milby, B.J., Joiner, C.N., Cressler, A.M., and West, C.T.	1991
1991	OFR 92-470	Peck, M.F., Joiner, C.N., and Cressler, A.M.	1992
1992	OFR 93-358	Peck, M.F., and Cressler, A.M.	1993
1993	OFR 94-118	Joiner, C.N., and Cressler, A.M.	1994
1994	OFR 95-302	Cressler, A.M., Jones, L.E., and Joiner, C.N.	1995
1995	OFR 96-200	Cressler, A.M.	1996
1996	OFR 97-192	Cressler, A.M.	1997
1997	OFR 98-172	Cressler, A.M.	1998
1998	OFR 99-204	Cressler, A.M.	1999
1999	OFR 00-151	Cressler, A.M.	2000
2000	OFR 01-220	Cressler, A.M., Blackburn, D.K., and McSwain, K.B.	2001
2001	[2]WRIR 03-4032	Leeth, D.C., Clarke, J.S., and Craigg, S.D., and Wipperfurth, C.J.	2003

[1]OFR, Open-File Report; [2]WRIR, Water-Resources Investigations Report

Chloride concentrations in water collected from the Upper and Lower Floridan aquifers are shown in graphs for five wells in the city of Brunswick area and six wells in the Camden County area. Maps were constructed showing the chloride concentrations in water from the upper water-bearing zone of the Upper Floridan aquifer at Brunswick for June 2002 using data from 43 wells and for June 2003 using data from 56 wells. Nitrate concentrations in water from the Upper Floridan aquifer were analyzed for 12 wells using November 2002 data, for 4 wells and one stream using May 2003 data, and for 14 wells and one stream using 2003 data in south-central Dougherty County near Albany.

In the city of Savannah area, a combination of fluid resistivity logs and collection of depth-dependent "grab" samples have supplanted the more traditional water-quality collection method of purging and sampling a well as is done in Brunswick and Camden County. In Savannah, four wells were assessed during December 2003 using this technique.

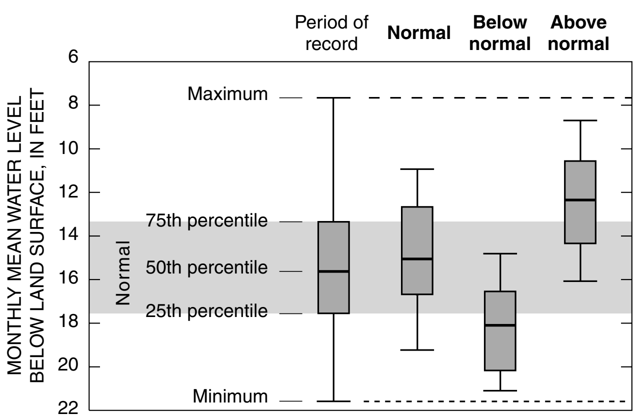
Water-use data compiled for 1999–2003, and reported herein, are based on State-mandated reporting requirements for water users withdrawing more than 100,000 gallons per day (gal/d). State-mandated reporting includes data for public supply, industrial and commercial, and thermoelectric-power water use; however, reporting of information on irrigation water use is not mandated and, therefore, not discussed in this report.

Methods of Analysis, Sources of Data, and Data Accuracy

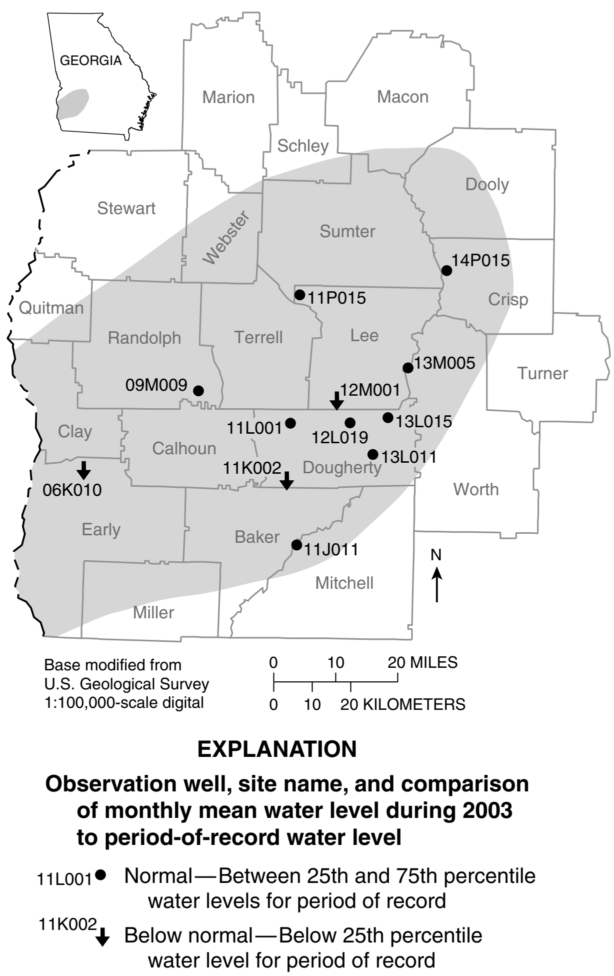
Hydrographs from selected wells are presented herein to compare 5-year trends and seasonal fluctuations to period-of-record statistics in major aquifers throughout the State. A more complete listing of water-level data from USGS continuously monitored wells is provided in the CD–ROM reports, "Continuous ground-water-level data, and periodic surface-water- and ground-water-quality data, calendar year 2002" (Coffin and others, 2003) and "Continuous ground-water-level data, and periodic surface-water- and ground-water-quality data, calendar year 2003" (Coffin and others, 2004). Those reports include annual and period-of-record ground-water-level hydrographs, summary statistics (maximum, minimum, and mean), and well information (construction and location). Additional well information can be obtained from the USGS National Water Information System (NWIS) at *http://waterdata.usgs.gov/ga/nwis/gw*

Median water levels for 2003 were compared to period-of-record normal water levels to determine if water levels were above normal, below normal, or normal. In this report, the normal range is defined as those water-level observations during the calendar year that lie between the 25th and 75th percentiles (first and third quartiles), also known as the inter-quartile range, for the period of record. The 75th percentile (third quartile) means that three-quarters of the observations lie below it; the 25th percentile (first quartile) means that one-quarter of the observations lie below it, and the median or 50th percentile (second quartile) means that two-quarters (one-half) of the observations lie below it and two-quarters (one-half) of the observations lie above it (Hamburg, 1985). This can be shown by examining a graphical representation of these values known as a boxplot (Tukey, 1977) (below left).

The results of this comparison are graphically represented on maps in the ground-water-level section of this report (map below, for example) either by an up arrow—2003 monthly mean water levels above period-of-record normal values; a down arrow—2003 monthly mean water levels below the normal range for the period of record; or a circle—2003 monthly mean water levels within the normal range for the period of record.



*Boxplot depicting the method used to determine if 2003 water levels in a well were within, below, or above the normal range. If the median (50th percentile) water level for 2003 was between the 25th and 75th percentiles of period-of-record water levels, then water levels in the well were considered **normal**. If the median water level for 2003 was below the 25th percentile, then water levels in the well were considered **below normal**. If the median water level for 2003 was above the 75th percentile, then water levels were considered **above normal**.*



*Results of the comparison between period-of-record water levels and 2003 water levels in wells continuously monitored by the USGS. A circle represents water level in a well that is within the normal range (**normal**). An arrow pointing upward represents water level in a well that is above the normal range (**above normal**). An arrow pointing downward represents water level in a well that is below the normal range (**below normal**).*

Cooperating Organizations

Ground-water monitoring and hydrologic studies in Georgia are conducted in cooperation with numerous local, State, and Federal organizations. Cooperating organizations include:

- United States Air Force
- United States Army
- Georgia Department of Agriculture
- Georgia Department of Natural Resources
- St. Johns Water Management District (Florida)
- Jekyll Island Authority
- Albany Water, Gas, and Light Commission
- Camden County
- Glynn County
- Liberty County Development Authority
- McIntosh County
- Rockdale County
- City of Brunswick
- City of Lawrenceville
- City of Ludowici

With the exception of the Federal agencies, all of these organizations participate in the USGS Cooperative Water Program, an ongoing partnership between the USGS and non-Federal agencies. The program enables joint planning and funding for systematic studies of water quantity, quality, and use. Data obtained from these studies are used to guide water-resources management and planning activities and provide indications of emerging water problems. For a more complete description of the Cooperative Water Program, see Brooks (2001).

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GROUND-WATER RESOURCES

Contrasting geologic features and landforms of the physiographic provinces of Georgia (map, facing page; table, pages 10 and 11) affect the quantity and quality of ground water throughout the State. The surficial aquifer system is present in each of the physiographic provinces. In the Coastal Plain Province, the surficial aquifer system consists of intermixed layers of sand, clay, and limestone. The surficial aquifer system usually is under water-table (unconfined) conditions and is used for domestic and livestock supplies. The surficial aquifer system is semiconfined to confined locally in the coastal area. In the Piedmont, Blue Ridge, and Valley and Ridge Provinces, the surficial aquifer system consists of soil, saprolite, stream alluvium, colluvium, and other surficial deposits.

The most productive aquifers in Georgia are in the Coastal Plain Province in the southern half of the State. The Coastal Plain is underlain by alternating layers of sand, clay, dolomite, and limestone that dip and thicken to the southeast. Coastal Plain aquifers generally are confined, except near their northern limits where they crop out or are near land surface. Aquifers in the Coastal Plain include the surficial aquifer system, Brunswick aquifer system, Upper and Lower Floridan aquifers, Gordon aquifer system, Claiborne aquifer, Clayton aquifer, and Cretaceous aquifer system.

In the Valley and Ridge Province, ground water is transmitted through primary and secondary openings in folded and faulted sedimentary and metasedimentary rocks of Paleozoic age, herein referred to as "Paleozoic-rock aquifers."

In the Piedmont and Blue Ridge Provinces, the geology is complex and consists of structurally deformed metamorphic and igneous rocks. Ground water is transmitted through secondary openings along fractures, foliation, joints, contacts, or other features in the crystalline bedrock. In these provinces, aquifers are referred to as "crystalline-rock aquifers." For a more complete discussion of the State's ground-water resources, see Clarke and Pierce (1984).

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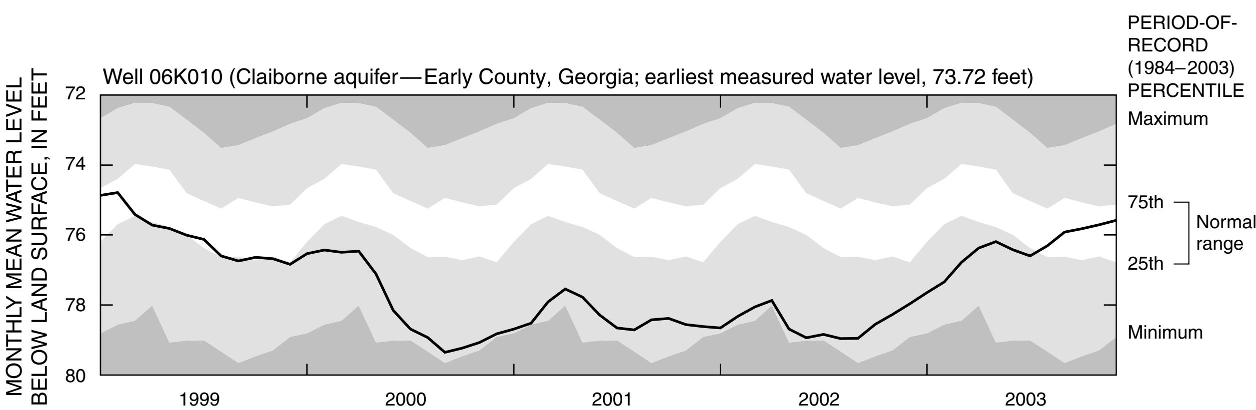
Data showing monthly mean ground-water levels during 1999–2003 were plotted together with data showing period-of-record water-level statistics (monthly mean normal, minimum, and maximum water levels) (hydrograph below). The period-of-record monthly statistics were calculated through December 2002 and are repeated on the graphs for 1999, 2000, 2001, 2002 and 2003. For example, statistics for the month of June are the same on the plots for each year during 1999–2003. Land-surface altitude for most wells was determined from topographic maps and is accurate to about one-half the contour interval (usually from 2.5 to 5 feet). Some land-surface altitudes were determined by surveying methods or Global Positioning System (GPS) and are more accurate.

Water samples were analyzed for nitrate at the USGS laboratory in Ocala, Florida. Chloride analyses were conducted at the USGS Ocala laboratory, at the USGS Atlanta, Georgia, laboratory, and at the St. Johns River Water Management District in Palatka, Florida (for Camden County). Additional water-quality data for Georgia can be obtained from the USGS National Water Information System (NWIS) at *http://waterdata.usgs.gov/ga/nwis/qw*

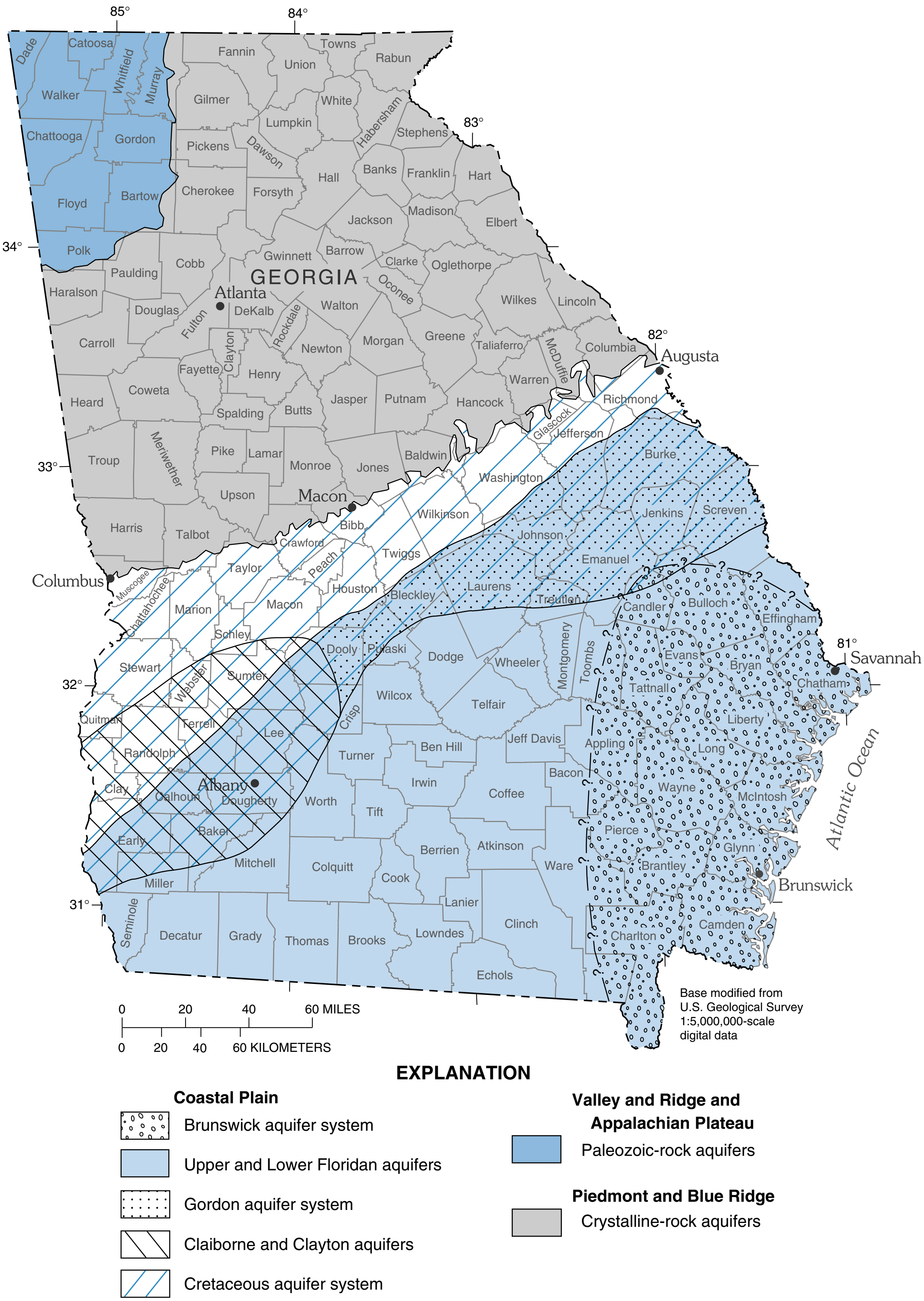
The Georgia Water-Use Program (GWUP), a cooperative project between the USGS and the Georgia Department of Natural Resources, Environmental Protection Division, has documented the use of water in the State since 1977. Water-use data—compiled by various Federal, State, and local agencies—are combined into a centralized database known as the Georgia Water-Use Data System (GWUDS). GWUDS contains permitted water-use information on public supplies, industrial and commercial supplies, and thermoelectric-power and hydroelectric-power uses from 1980–2003. Georgia water law requires a withdrawal permit for all public-supply, industrial, and other water users who withdraw more than 100,000 gal/d, an exception to this requirement is for irrigation water. During 1988, the Georgia Legislature enacted a permitting law for irrigation water users who withdraw more than 100,000 gal/d of water, but the reporting of water withdrawal is not required.

Georgia Well-Naming System

Wells described in this report are given a well name according to a system based on the USGS index of topographic maps of Georgia. Each 7½-minute topographic quadrangle in the State has been assigned a three- to four-digit number and letter designation (for example, 07H or 11AA) beginning at the southwestern corner of the State. Numbers increase sequentially eastward, and letters advance alphabetically northward. Quadrangles in the northern part of the State are designated by double letters: AA follows Z, and so forth. The letters “I,” “O,” “II,” and “OO” are not used. Wells inventoried in each quadrangle are numbered consecutively, beginning with 01. Thus, the fourth well inventoried in the 11AA quadrangle is designated 11AA04. In the USGS NWIS database, this information is stored under the field “Well Name.”



Hydrograph showing monthly mean water level in well 06K010 for the period 1999–2003 and summary water-level statistics for the period of record 1984–2003.



Areas of use of major aquifers in Georgia (modified from Clarke and Pierce, 1984). The surficial aquifer system is present throughout the State and is not shown.

Aquifer and well characteristics in Georgia [*modified from Clarke and Pierce (1984), and Peck and others (1992); ft, feet; gal/min, gallons per minute*]

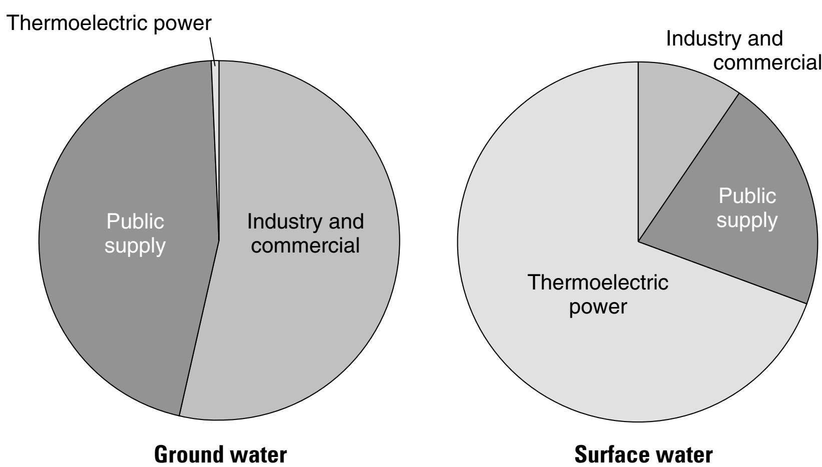
Aquifer name	Aquifer description	Well characteristics		
		Depth (ft)	Yield (gal/min)	
		Typical range	Typical range	May exceed
Surficial aquifer system	Unconsolidated sediments and residuum; generally unconfined. However, in the coastal area of the Coastal Plain, at least two semiconfined aquifers have been identified	11–300	2–25	75
Brunswick aquifer system, including upper and lower Brunswick aquifers	Phosphatic and dolomitic quartz sand; generally confined	85–390	10–30	180
Upper and Lower Floridan aquifers	Limestone, dolomite, and calcareous sand; generally confined	40–900	1,000–5,000	11,000
Gordon aquifer system	Sand and sandy limestone; generally confined	270–530	87–1,200	1,800
Claiborne aquifer	Sand and sandy limestone; generally confined	20–450	150–600	1,500
Clayton aquifer	Limestone and sand generally confined;	40–800	250–600	2,150
Cretaceous aquifer system	Sand and gravel; generally confined	30–750	50–1,200	3,300
Paleozoic-rock aquifers	Sandstone, limestone and dolomite; generally confined	15–2,100	1–50	3,500
Crystalline-rock aquifers	Granite, gneiss, schist, and quartzite; generally confined	40–600	1–25	500

Hydrologic response	Remarks
Water-level fluctuations mainly are caused by variations in precipitation, evapotranspiration, and natural drainage. In addition, water levels in the city of Brunswick area are influenced by nearby pumping, precipitation, and tidal fluctuations (Clarke and others, 1990). Water levels generally rise rapidly during wet periods and decline slowly during dry periods. Prolonged droughts may cause water levels to decline below pump intakes in shallow wells, particularly those located on hilltops and steep slopes, resulting in temporary well failures. Usually, well yields are restored by precipitation (Clarke, 2003).	Primary source of water for domestic and livestock supply in rural areas. Supplemental source of water for irrigation supply in coastal Georgia.
In the coastal area, the aquifers may respond to pumping from the Upper Floridan aquifer as a result of the hydraulic connection between the aquifers. Elsewhere the water level mainly responds to seasonal variations in recharge and discharge. In Bulloch County, unnamed aquifers equivalent to the upper and lower Brunswick aquifers are unconfined to semiconfined and are influenced by variations in recharge from precipitation and by pumping from the Upper Floridan aquifer; in the Wayne and Glynn County area, the aquifers are confined and respond to nearby pumping (Clarke and others, 1990; Clarke, 2003).	Not a major source of water in coastal Georgia, but considered a supplemental water supply to the Upper Floridan aquifer.
In and near outcrop areas, the aquifers are semiconfined and water levels in wells tapping the aquifers fluctuate seasonally in response to variations in recharge rate and pumping. Near the coast, where the aquifers are confined, water levels primarily respond to pumping, and fluctuations related to recharge are less pronounced (Clarke and others, 1990).	Supplies about 50 percent of ground water in Georgia. The aquifer system is divided into the Upper and Lower Floridan aquifers. In the Brunswick area, the Upper Floridan aquifer includes two freshwater-bearing zones, the upper water-bearing zone and the lower water-bearing zone The Lower Floridan aquifer is not considered a major aquifer. In the Brunswick area and in southeastern Georgia, the Lower Floridan aquifer includes the brackish-water zone, the deep freshwater zone, and the Fernandina permeable zone (Krause and Randolph, 1989). The Lower Floridan aquifer extends to more than 2,700 ft deep and yields high-chloride water below 2,300 ft (Jones and Maslia, 1994).
Water levels are influenced by seasonal fluctuations in recharge from precipitation, discharge to streams, and evapotranspiration (Clarke and others, 1985).	Major source of water for irrigation, industrial, and public-supply use in east-central Georgia.
Water levels mainly are affected by precipitation and by local and regional pumping (Hicks and others, 1981). The water level is generally highest following the winter and spring rainy seasons, and lowest in the fall following the summer irrigation season.	Major source of water for irrigation, industrial, and public-supply use in southwestern Georgia.
Water levels are affected by seasonal variations in local and regional pumping (Hicks and others, 1981).	Major source of water for irrigation, industrial, and public-supply use in southwestern Georgia.
Water levels are influenced by variations in precipitation and pumping (Clarke and others, 1983, 1985).	Major source of water in east-central Georgia. Supplies water for kaolin mining and processing. Includes the Providence aquifer in southwestern Georgia, and the Dublin, Midville, and Dublin–Midville aquifer systems in east-central Georgia.
Water levels mainly are affected by precipitation and local pumping (Cressler, 1964).	Not laterally extensive. Limestone and dolomite aquifers are most productive. Storage is in regolith, primary openings, and secondary fractures and solution openings in rock. Springs in limestone and dolomite aquifers discharge at rates of as much as 5,000 gal/min. Sinkholes may form in areas of intensive pumping.
Water levels mainly are affected by precipitation and evapotranspiration, and locally by pumping (Cressler and others, 1983). Precipitation can cause a rapid rise in water levels in wells tapping aquifers overlain by thin regolith.	Storage is in regolith and fractures in rock.

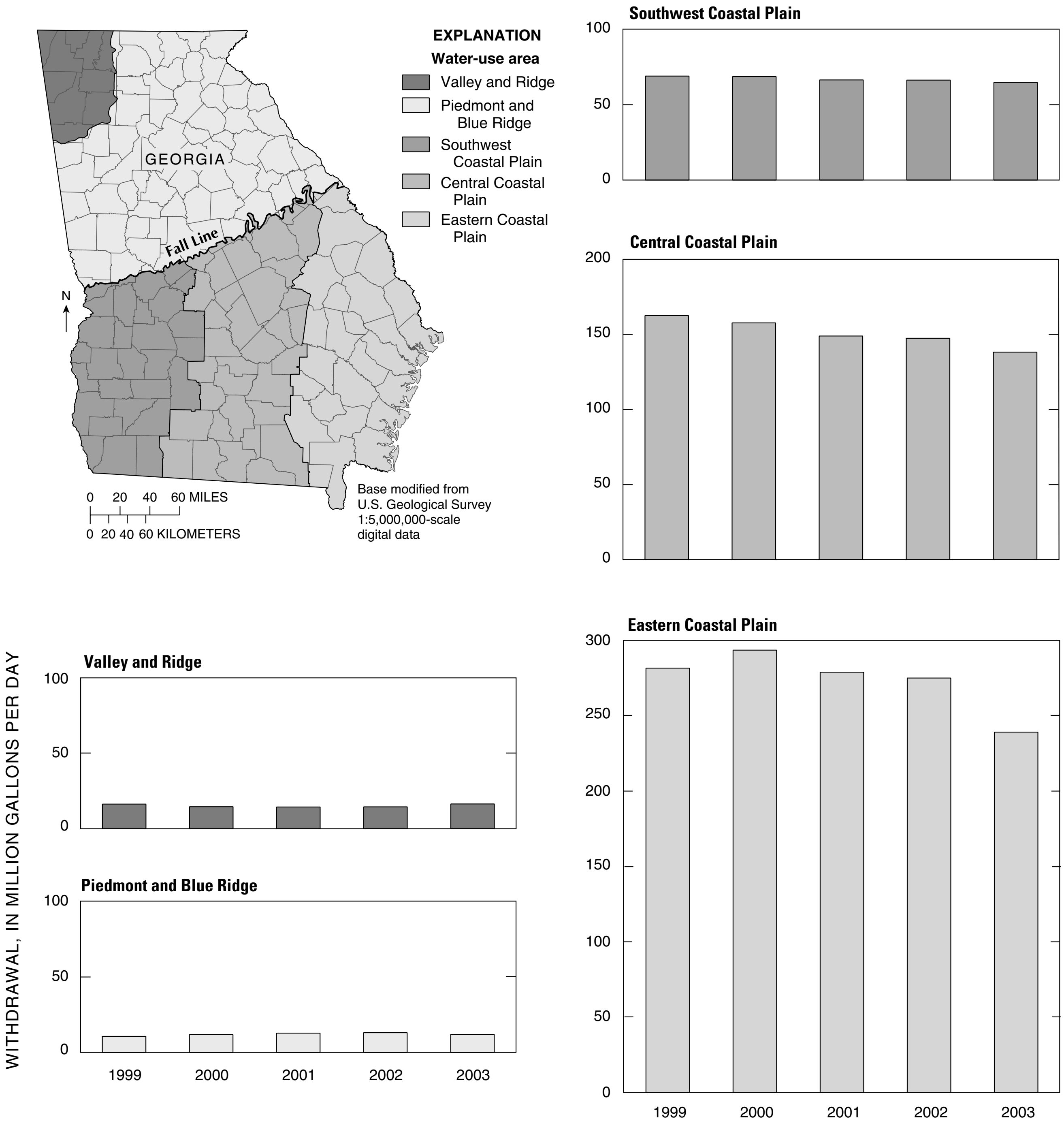
PERMITTED WATER-USE DATA FOR GEORGIA DURING 2003 AND GROUND-WATER-USE TRENDS FOR 1999–2003

When complete water-use data are not available, permitted water-use data can be used to assess impacts of ground-water withdrawal on ground-water systems. Because data from every water-use category are only compiled by the U.S. Geological Survey every 5 years, only water-use data from permitted water systems are included in this report. More specifically, estimates for irrigation and domestic supply are not included herein. During 2003, permitted withdrawal by public-supply systems totaled about 1,120 million gallons per day (Mgal/d), of which about 80 percent was from surface-water sources and 20 percent from ground-water sources (pie chart, below). Permitted withdrawals by industrial and commercial users totaled about 670 Mgal/d, of which 62 percent was from surface-water sources and 38 percent was from ground-water sources. The major industrial users in Georgia include paper, textiles, chemicals, stone and clay, and mining.

To understand the areal distribution and trends of permitted ground-water withdrawal, data were grouped into five physiographic provinces of the State and are depicted from 1999–2003 (map and barcharts, facing page). In general, permitted ground-water withdrawal has decreased across the State since 1999; the only exception to this was in the Piedmont and Blue Ridge. This decrease largely is a result of conservation efforts made by industrial and municipal users. In the Coastal Plain, permitted ground-water use generally decreased during 1999–2003. In the eastern Coastal Plain, the decrease was about 42.3 Mgal/d (about 54.3 Mgal/d from 2000 to 2003), mostly because of plant closings and reduction in industrial withdrawals. In the central Coastal Plain, the decrease was about 24.6 Mgal/d, and in the southwest Coastal Plain the decrease was about 4 Mgal/d. In the Valley and Ridge area, withdrawal decreased about 0.5 Mgal/d during 1999–2003. Unlike the rest of the State, permitted ground-water withdrawal in the Piedmont and Blue Ridge increased by about 1.4 Mgal/d from 1999 to 2003. Peak ground-water usage in this area occurred during 2002 when the increase from 1999 was about 2.3 Mgal/d.



Percentage of permitted water use in Georgia by category and source, 2003.



Ground-water withdrawal in Georgia by water-use area, 1999–2003.

GROUND-WATER LEVELS

Maps in this section provide an overview of ground-water levels in major aquifers in Georgia during 2003. In addition, hydrographs provide a visual summary of ground-water conditions for the past 5 years (1999–2003) compared to the period of record. Discussion of each aquifer is subdivided into areas where wells would likely have similar water-level fluctuations and trends if they were unaffected by pumping. The map on the facing page gives the location of selected wells that were continuously monitored by the USGS during the 2003 calendar year, including 18 wells that were monitored in real time.

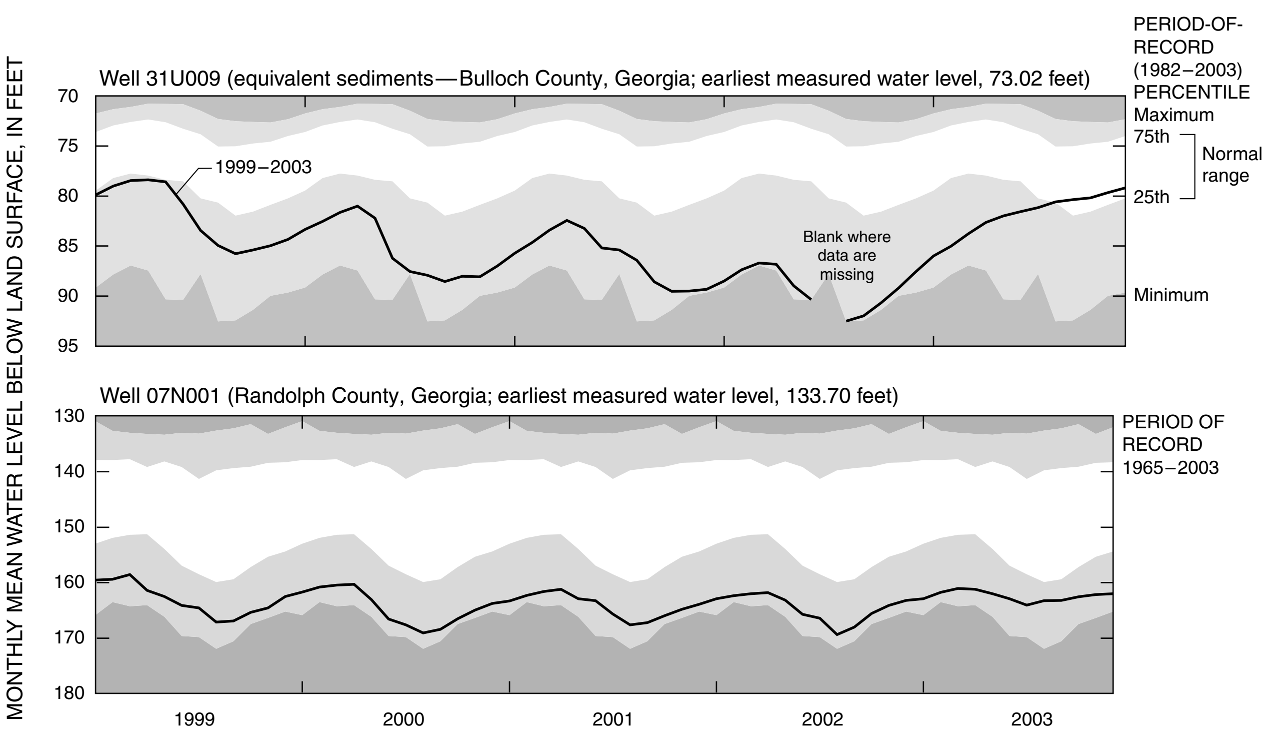
Changes in ground-water levels measured in wells are caused by changes in aquifer storage. Taylor and Alley (2001) described the many factors that affect ground-water storage; these are briefly discussed here. When recharge to an aquifer exceeds discharge, ground-water levels rise; when discharge to an aquifer exceeds recharge, ground-water levels decline. Recharge varies in response to precipitation and surface-water infiltration into an aquifer. Discharge occurs as natural flow from an aquifer to streams and springs, as evapotranspiration, and as withdrawal from wells. Hydraulic responses and controls on ground-water levels in major aquifers in Georgia are summarized in the table on pages 10 and 11.

Water levels in aquifers in Georgia typically follow a cyclic pattern of seasonal fluctuation, with rising water levels occurring during winter and spring because of greater recharge from precipitation and declining water levels occurring during summer and fall because of less recharge, greater evapotranspiration, and pumping. The magnitude of fluctuations can vary greatly from season to season and from year to year in response to varying climatic conditions. This cyclic pattern can be seen on the 5-year hydrograph of well 31U009 in Bulloch County (below).

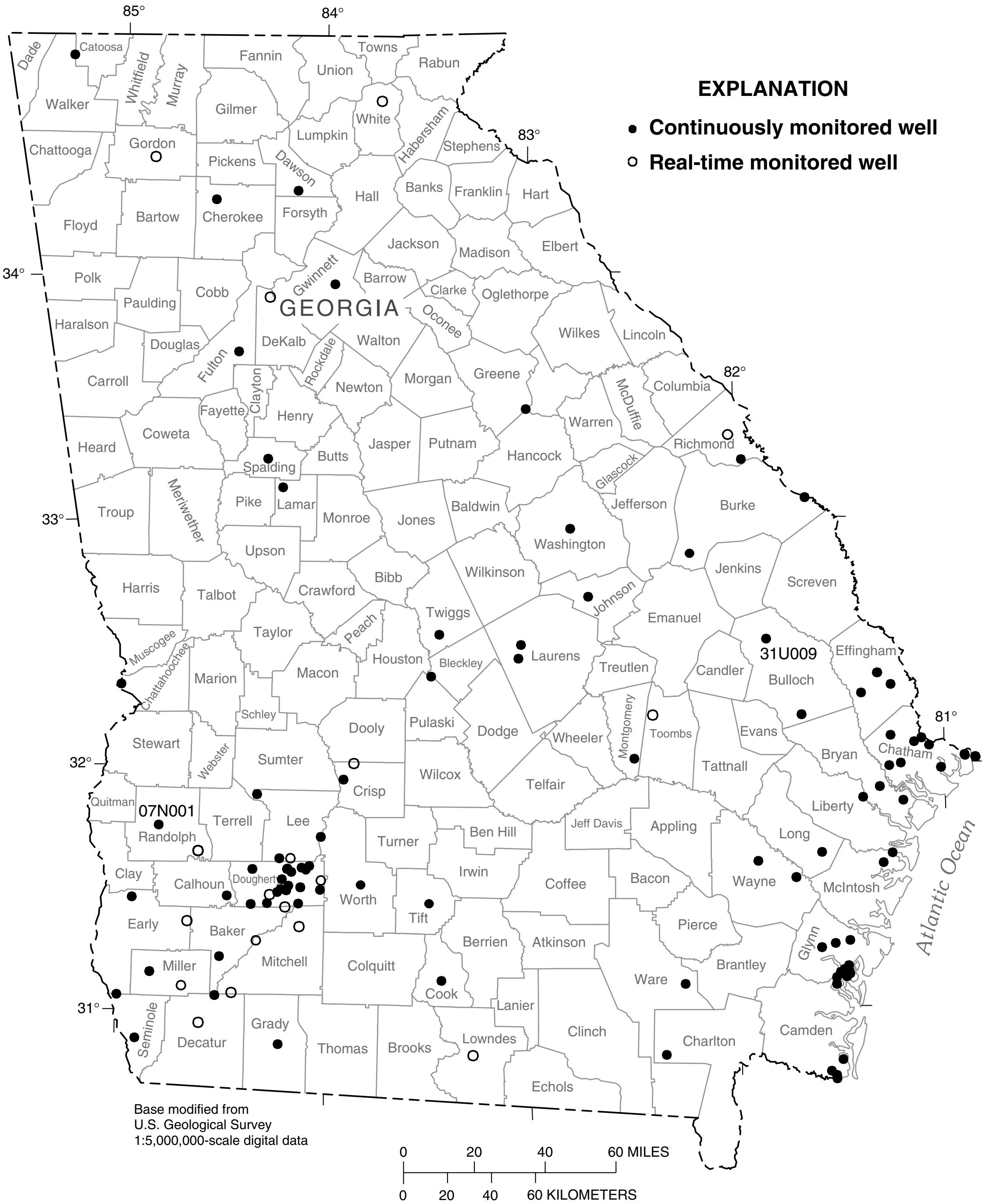
Ground-water pumping is the most significant human activity that affects the amount of ground water in storage and the rate of discharge from an aquifer (Taylor and Alley, 2001). As ground-water storage is depleted within the radius of influence of pumping, water levels in the aquifer decline, forming a cone of depression around the well. In areas having a high density of pumped wells, multiple cones of depression can form and produce water-level declines across a large area. These declines may alter ground-water-flow directions, reduce flow to streams, capture water from a stream or adjacent aquifer, or alter ground-water quality. The effects of sustained pumping can be seen on a hydrograph of well 07N001 in Randolph County (below).

Reference Cited

Taylor, C.J., and Alley, W.M., 2001, Ground-water-level monitoring and the importance of long-term water-level data: U.S. Geological Survey Circular 1217, 68 p.



Example hydrographs showing montly mean water levels in wells 31U009 and 07N001 for the period 1999–2003 and summary statistics for the period of record for these wells.



Selected ground-water-level monitoring wells used to collect long-term water-level data in Georgia during 2003.

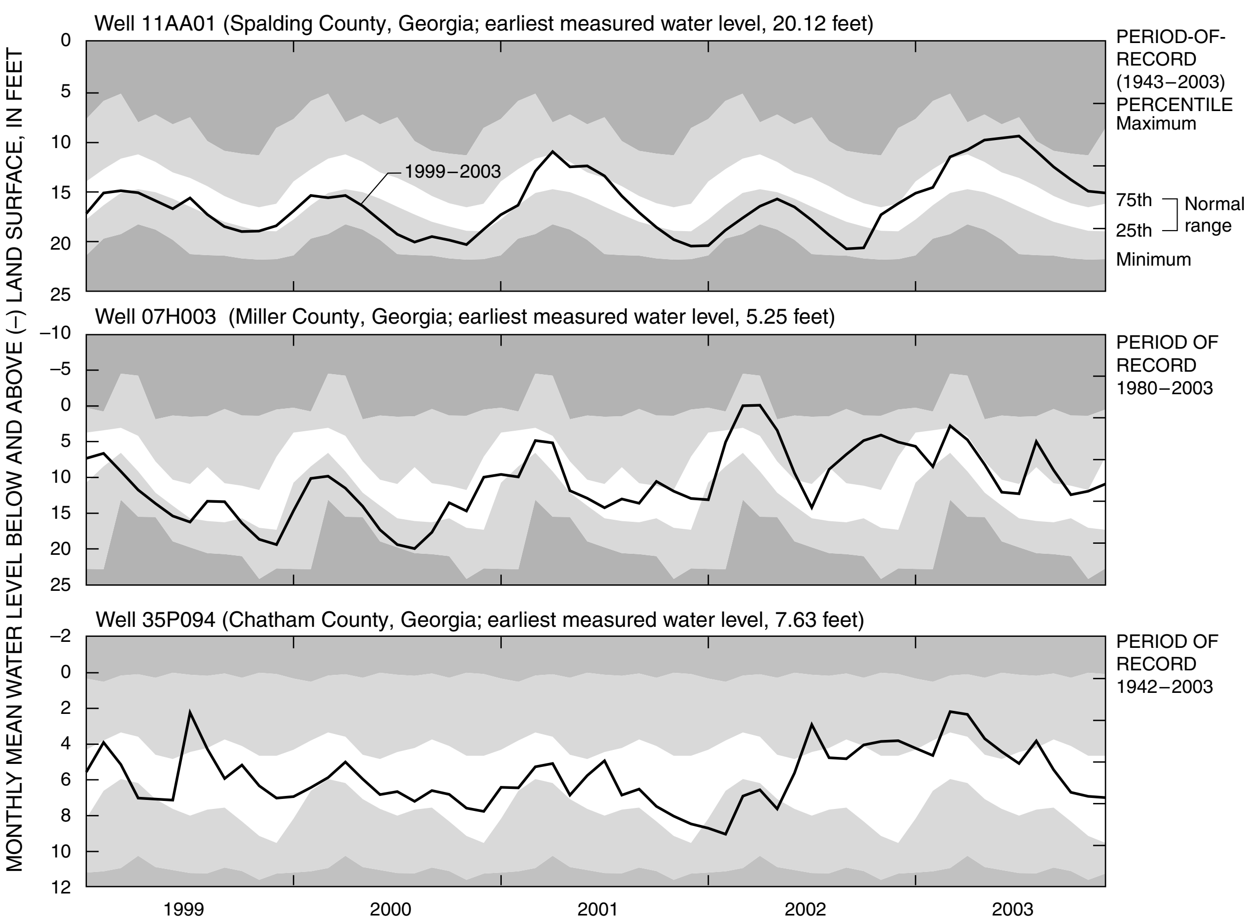
Surficial Aquifer System

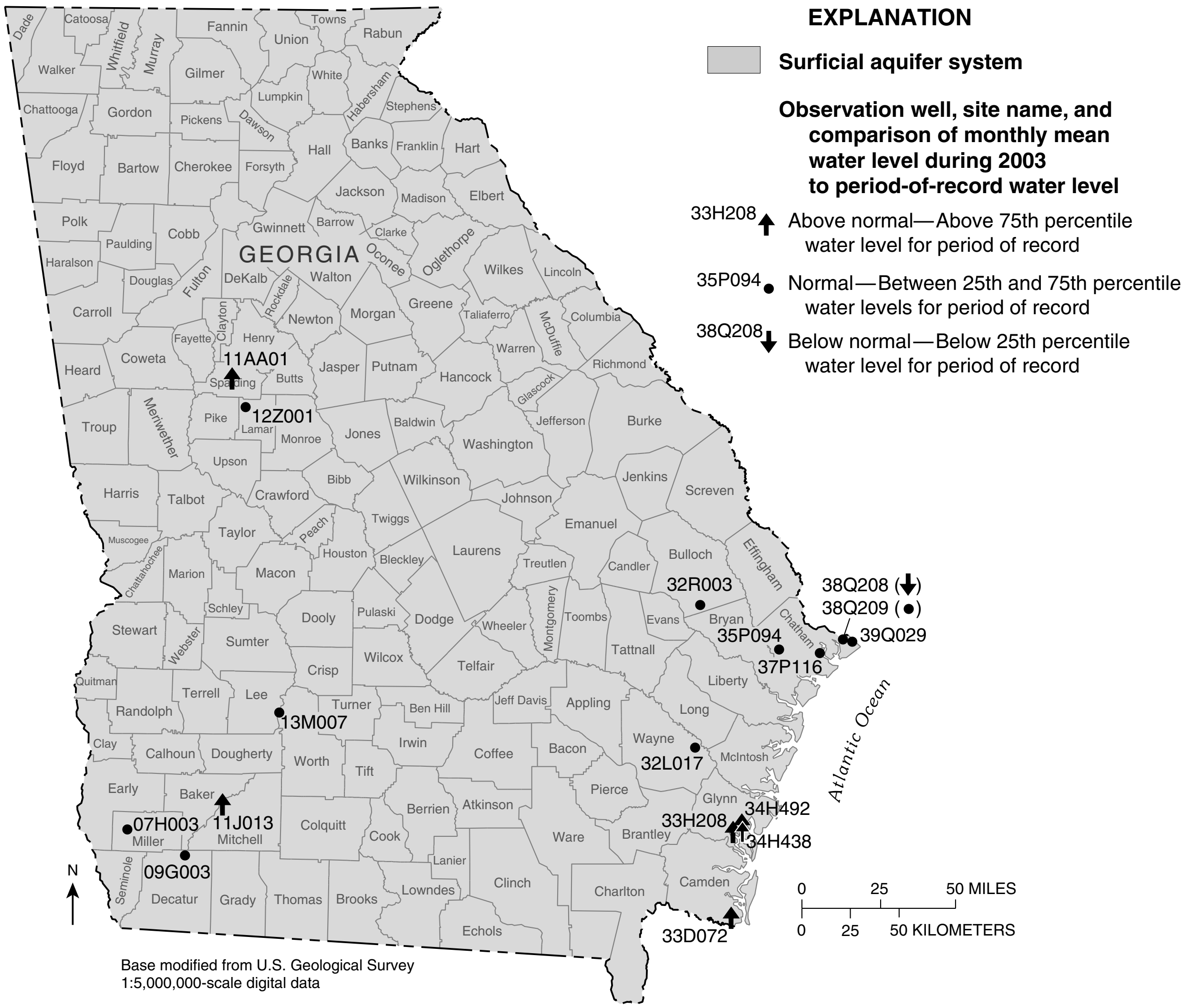
Water levels in 17 wells were used to define conditions in the surficial aquifer system during 2003 (map and table, facing page). Water in the surficial aquifer system typically is in contact with the atmosphere (referred to as an unconfined or water-table aquifer), but locally (especially in coastal Georgia) may be under pressure exerted by overlying sediments or rocks (referred to as a confined aquifer). Where unconfined, water levels change quickly in response to recharge and discharge. Consequently, hydrographs from these wells show a strong relation to climatic fluctuations.

Water levels in 10 of the 17 wells measured were within the normal range during 2003, with well 38Q208 below normal. Well 38Q208 was constructed during 1998, and water levels in the well have generally declined since that time. The hydrograph for this well does not show an obvious influence from pumping. Water levels in seven of the wells were above normal during 2003 as a result of the relatively normal to above normal rainfall that occurred in Georgia.

Water-level hydrographs for three wells (shown below) completed in the surficial aquifer system were chosen to illustrate monthly mean water levels during 1999–2003 and period-of-record water-level statistics. These long-term water-level records indicate that during 2002 and 2003, water levels in the surficial aquifer system were at or above normal throughout Georgia, with the effects of drought lessening by early 2002 and ending almost everywhere by the end of 2003.

The hydrograph for well 11AA01 in Spalding County shows that the water level during 2002 was mostly below normal but began to rise in the latter part of the year; this rise continued into 2003 when the water level was typically at or above normal. The hydrograph for well 07H003 in Miller County shows a different pattern with the water level at or above normal during 2002 and 2003. The hydrograph for well 35P094 in Chatham County shows a similar pattern to that of well 07H003 with the water level in or above the normal range after the first part of 2002 and continuing through 2003. It is apparent from both the hydrographs and the water-level summary maps that for most of the State, water levels in the surficial aquifer system had recovered from drought by 2003.





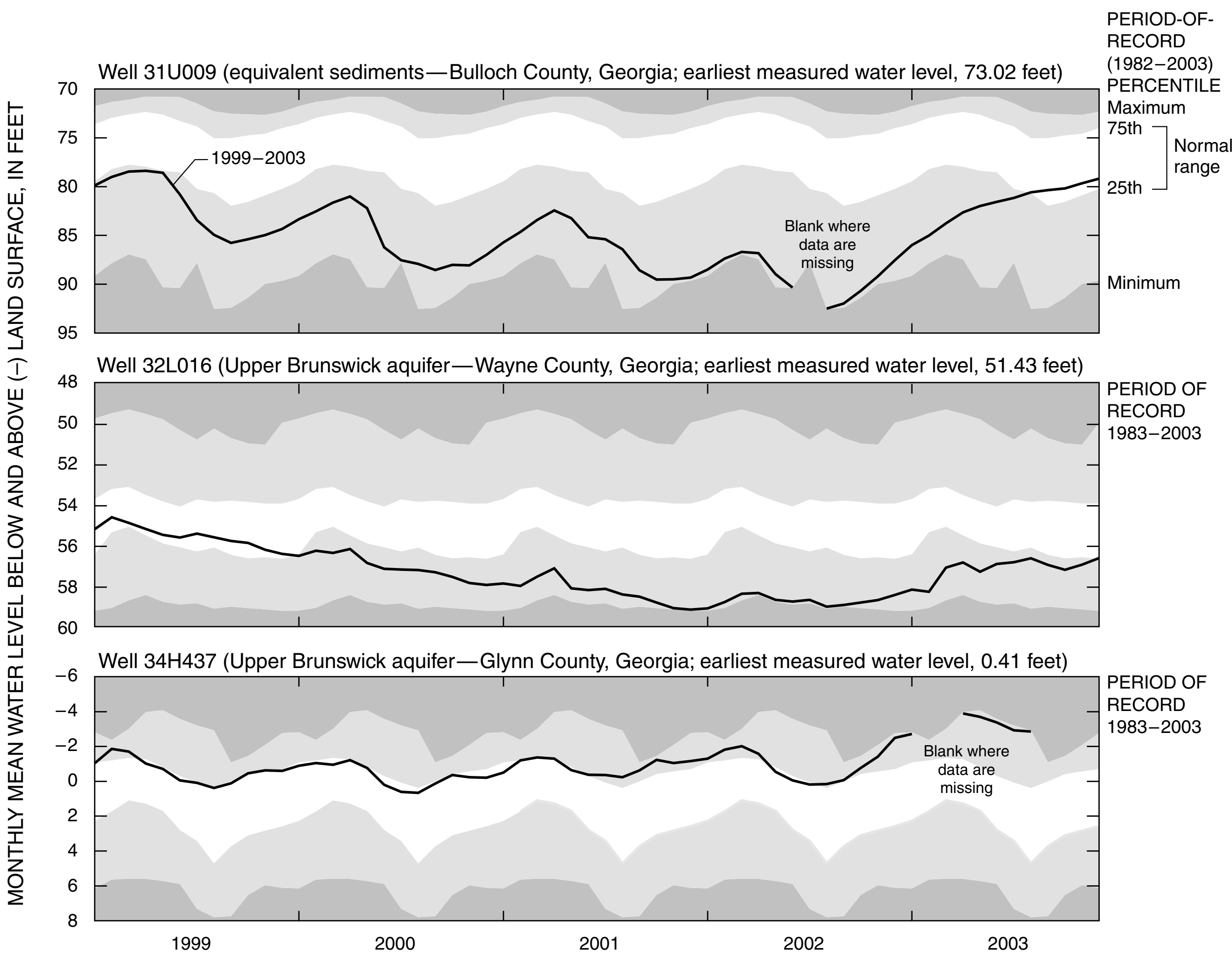
Site name	County	Other identifier
32R003	Bulloch	Bulloch South test well 2
33D072	Camden	Georgia Geologic Survey, St. Marys, test well 3
35P094	Chatham	University of Georgia, Bamboo Farm well
37P116	Chatham	Georgia Geologic Survey, Skidaway Institute, test well 4
38Q208	Chatham	Fort Pulaski, Savannah Harbor Expansion, monitoring well 4, COE
38Q209	Chatham	Fort Pulaski, Savannah Harbor Expansion, monitoring well 3, COE
39Q029	Chatham	Tybee, Savannah Harbor Expansion, monitoring well 1, COE
09G003	Decatur	U.S. Geological Survey, test well DP-6
33H208	Glynn	Georgia–Pacific, south test well 3
34H438	Glynn	Georgia Geologic Survey, Coffin Park, test well 3
34H492	Glynn	Coastal Georgia Community College P-17
12Z001	Lamar	Dixie Pipeline
07H003	Miller	U.S. Geological Survey, test well DP-3
11J013	Mitchell	U.S. Geological Survey, test well DP-12
11AA01	Spalding	University of Georgia, Experiment Station
32L017	Wayne	Georgia Geologic Survey, Gardi, test well 3
13M007	Worth	U.S. Geological Survey, test well DP-9

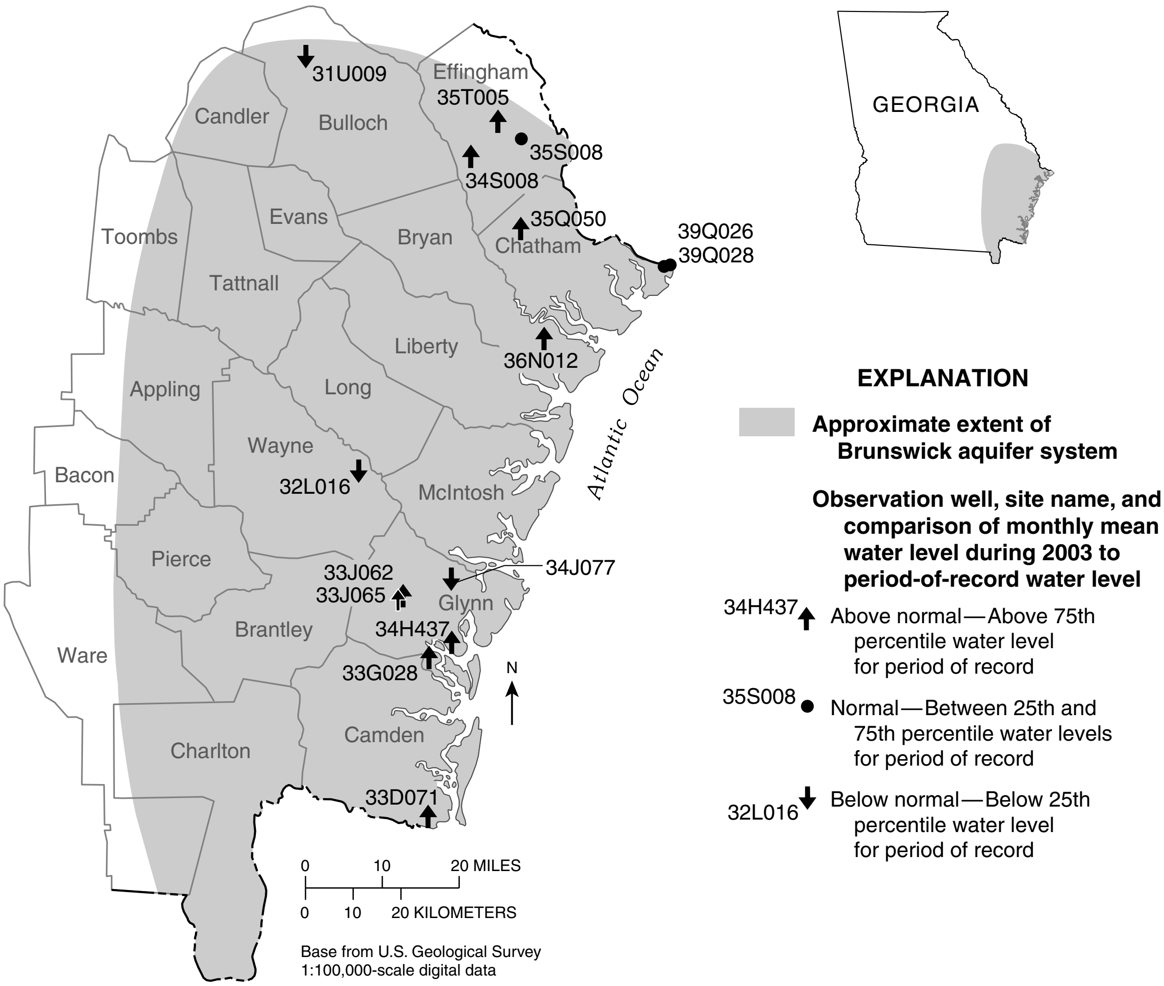
Brunswick Aquifer System

Water levels in 15 wells were used to define 2003 conditions in the Brunswick aquifer system—consisting of the upper and lower Brunswick aquifers—and equivalent low-permeability sediments to the north and west in southeastern Georgia. The Brunswick aquifer system is confined throughout the known area of extent (map and table, facing page). In three wells, water levels were in the normal range; in three wells, water levels were below the normal range; and in nine wells water levels were above the normal range. These variations reflect differences in local pumping, interaquifer leakage effects, and recharge.

Water-level hydrographs for the Brunswick aquifer system and equivalent-sediment wells (shown below) were chosen to illustrate monthly mean water levels during 1999–2003 and period-of-record water-level statistics. These water levels show that during 2002, effects from drought were still apparent, but by 2003 water levels had begun to rise into the normal range. Conversely, in well 34H437, the water level remained at or above normal during this same period, as it has been for the previous 5 years.

The water level in well 31U009 (completed in undifferentiated sediments equivalent to the upper Brunswick aquifer) was well below normal during 2002, reaching a record low in August 2002, but began to rise in the second half of the year and was normal by the end of 2003. The hydrograph for well 32L016, completed in the upper Brunswick aquifer, shows the water level for 2002–03 was below the normal range, nearing record lows in January of 2002. The water level in this well began to rise in the latter half of 2002 and continued to rise through 2003. Well 34H437, also completed in the upper Brunswick aquifer, is unusual because the water level generally remained above normal for the entire period. Like wells 31U009 and 32L016, the water level in well 34H437 began to rise in the latter part of 2002 and continued through 2003, so that the water level reached record highs by May of 2003.





Site name	Water-bearing unit[1]	County	Other identifier
36N012	L	Bryan	Genesis Pointe
31U009	UX	Bulloch	Georgia Geologic Survey, Hopeulikit, test well 2
33D071	U	Camden	Georgia Geologic Survey, St. Marys, test well 2
35Q050	B	Chatham	Georgia Forestry Commission, test well CB-1
39Q026	UX	Chatham	Tybee Island, test well 3
39Q028	UX	Chatham	Tybee, Savannah Harbor Expansion, monitoring well 2, COE
34S008	LX	Effingham	Pineora test well EB-1
35S008	LX	Effingham	Effingham County, Georgia Geologic Survey, corehole
35T005	UX	Effingham	Springfield, Georgia, Miocene well
33G028	B	Glynn	Georgia Ports Authority, well 3
33J062	L	Glynn	Georgia Forestry Commission, test well GB-1
33J065	U	Glynn	Georgia Forestry Commission, test well GB-4
34H437	U	Glynn	Georgia Geologic Survey, Coffin Park, test well 2
34J077	U	Glynn	Golden Isle, test well 1S
32L016	U	Wayne	Georgia Geologic Survey, Gardi, test well 2

[1]B, Brunswick aquifer system; L, lower Brunswick aquifer; U, upper Brunswick aquifer;
UX, undifferentiated, low-permeability equivalent to the upper Brunswick aquifer;
LX, undifferentiated, low-permeability equivalent to the lower Brunswick aquifer

Upper Floridan Aquifer

The Upper Floridan aquifer underlies most of the Coastal Plain of Georgia, southern South Carolina, extreme southeastern Alabama, and all of Florida (Miller, 1986). The aquifer is one of the most productive in the United States, and a major source of water in the region. During 2000, approximately 819 million gallons per day (Mgal/d) were withdrawn from the Upper and Lower Floridan aquifers in Georgia, primarily for industrial and irrigation uses (Fanning, 2003).

The Upper Floridan aquifer predominately consists of Eocene to Oligocene limestone, dolomite, and calcareous sand. The aquifer is thinnest along its northern limit (map, facing page) and thickens to the southeast, where the maximum thickness is about 1,700 feet (ft) in Ware County (Miller, 1986). The aquifer is confined throughout most of its extent, except where it crops out or is near land surface along the northern limit, and in areas of karst topography in parts of southwestern and south-central Georgia.

The Coastal Plain of Georgia has been informally divided into four hydrologic areas for discussion of water levels (map, facing page)—the southwestern, south-central, east-central, and coastal areas. This subdivision is a modification of that used by Peck and others (1999) and is similar to that used by Clarke (1987).

Southwestern area. All or parts of 16 counties constitute the southwestern area. In this area, the Upper Floridan aquifer ranges in thickness from about 50 ft in the northwest to about 475 ft in the southeast (Hicks and others, 1987). The aquifer is overlain by sandy clay residuum, which is hydraulically connected to streams. With the introduction of center pivot irrigation systems around 1975, the Upper Floridan aquifer has been used widely as the primary water source for irrigation in southwestern Georgia (Hicks and others, 1987). According to Fanning (2003), about 514 Mgal/d of water was withdrawn from the Upper Floridan aquifer in the southwestern area during 2000, with 87 percent used for irrigation.

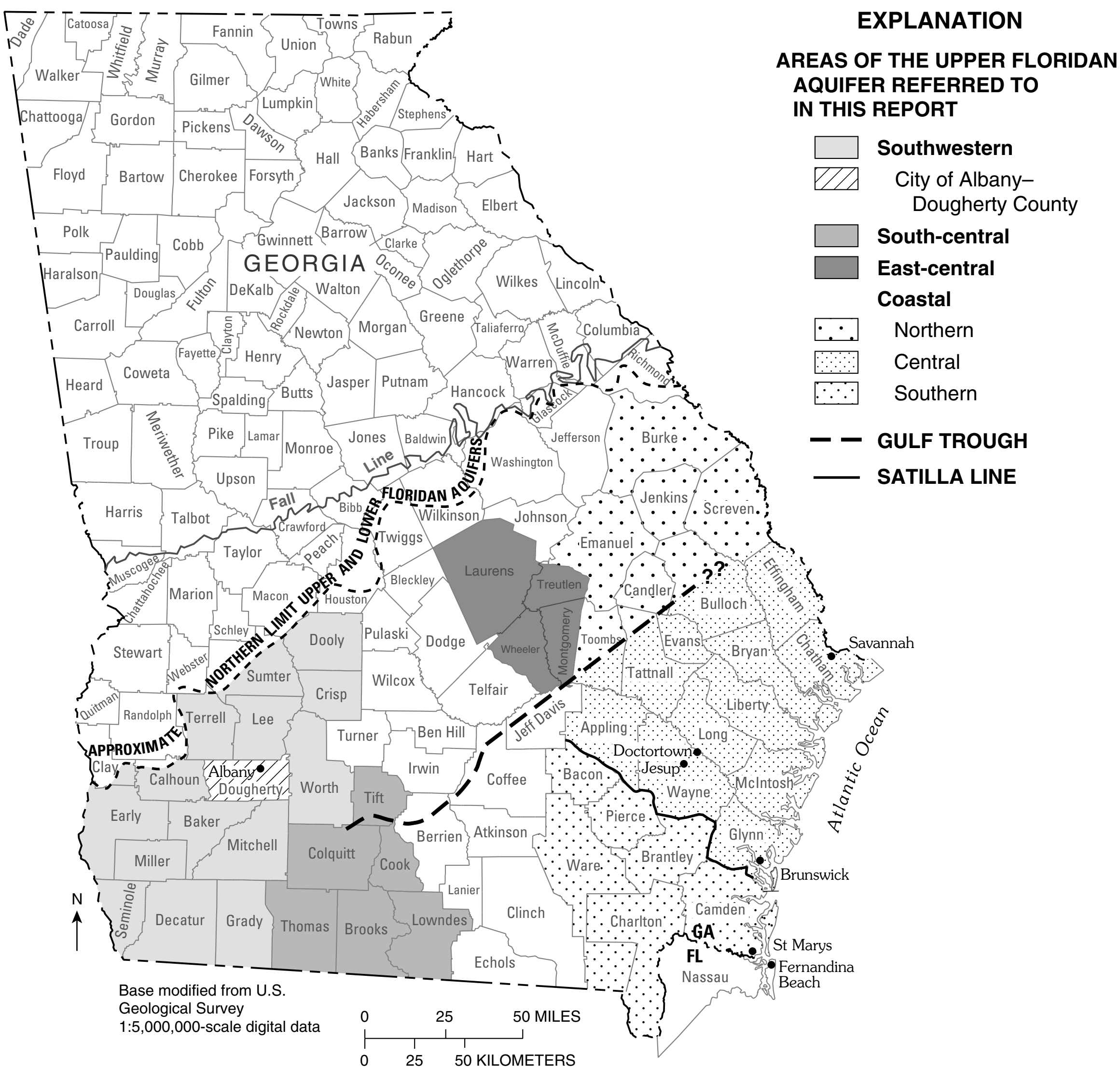
Within the southwestern area, lies the city of Albany–Dougherty County area. In this area, most of the water withdrawn from the Upper Floridan aquifer is for public supply; about 19 Mgal/d of water was withdrawn during 2000 with irrigation withdrawal about the same amount (20 Mgal/d) (Fanning, 2003).

South-central area. Six counties constitute the south-central area. In this area, the Upper Floridan aquifer ranges in thickness from about 300 to 700 ft (Miller, 1986). Lowndes County is a karst region, having abundant sinkholes and sinkhole lakes that have formed where the aquifer crops out and the overlying confining unit has been removed by erosion (Krause, 1979). Direct recharge from rivers to the Upper Floridan aquifer occurs through these sinkholes at a rate of about 70 Mgal/d (Krause, 1979). In the south-central area, ground-water use totaled about 94 Mgal/d in 2000, with the majority of the withdrawal used for irrigation (Fanning, 2003).

East-central area. Four counties constitute the east-central area. In this area, the Upper Floridan aquifer can be as thick as about 650 ft in the southeast to absent in the north. In this area, ground-water withdrawal totaled about 15 Mgal/d during 2000 and was used predominantly for irrigation (Fanning, 2003).

Coastal area. The Georgia Environmental Protection Division (GaEPD) defines the coastal area of Georgia to include the 6 coastal counties and adjacent 18 counties, an area of about 12,240 square miles. In this 24-county area, the Upper Floridan aquifer may be thin or absent in the north (Burke County) to about 1,700 ft thick in the south (Ware County) (Miller, 1986). Excluding withdrawals for thermoelectric-power generation, nearly 71 percent of all withdrawals in the area are from ground water (Fanning, 2003), primarily for industrial purposes. During 2000, about 382 Mgal/d of water was withdrawn from the Upper Floridan aquifer in the coastal area (Julia L. Fanning, U.S. Geological Survey, oral commun., 2003).

The coastal area has been subdivided by GaEPD into three subareas—the northern, central, and southern—to facilitate implementation of the State's water-management policies. The central subarea includes the largest concentration of pumpage in the coastal area—the Savannah, Brunswick, and Jesup pumping centers. The northern subarea is northwest of the Gulf Trough (Herrick and Vorhis, 1963), a prominent geologic feature that is characterized by a zone of low permeability in the Upper Floridan aquifer that inhibits flow between the central and northern subareas. In this area, pumping from the aquifer primarily is agricultural, with no large pumping centers. The southern subarea is separated from the central subarea by the Satilla line, a postulated hydrologic boundary (W.H. McLemore, Georgia Environmental Protection Division, Geologic Survey Branch, oral commun., 2000). In this area, the largest pumping center is at St. Marys, Georgia–Fernandina Beach, Florida.



Areas of the Upper Floridan aquifer referred to in this report.

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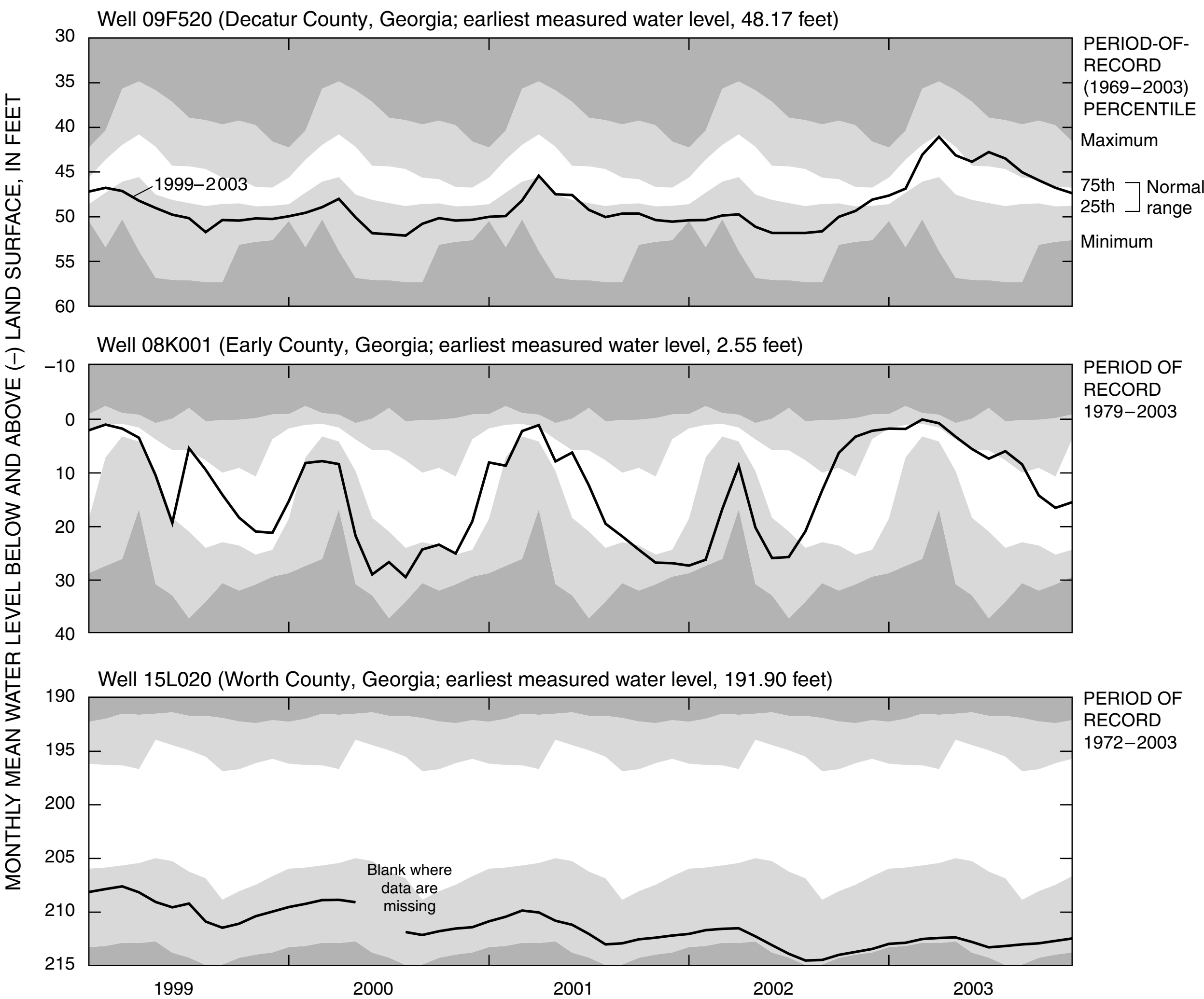
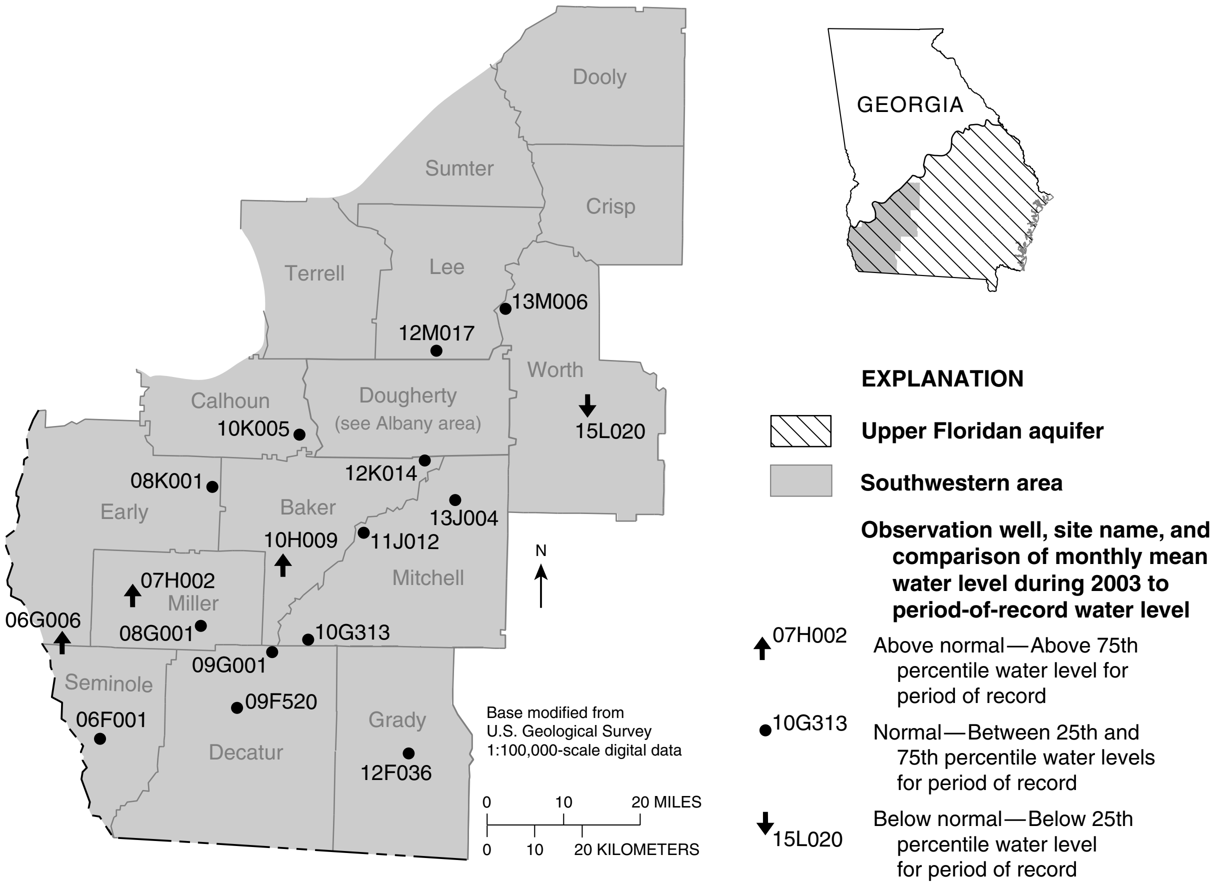
Upper Floridan Aquifer

Southwestern area

Water levels in 17 wells were used to define ground-water conditions in the Upper Floridan aquifer in southwestern Georgia during 2003 (map, facing page). In this area, water in the Upper Floridan aquifer typically is confined; however, in areas where no sediments overlie the aquifer (typically to the north and west) water is unconfined. Water levels in 13 of the 17 wells were within the normal range during 2003. Water levels in three wells were above normal, and the water level in one well was below normal.

Water-level hydrographs for three Upper Floridan aquifer wells in southwestern Georgia (below) were chosen to illustrate monthly mean water levels during 1999–2003 and period-of-record water-level statistics. Drought effects continued to be reflected by ground-water levels through 2002, but obvious recovery began to occur in the latter part of the year and continued throughout 2003. Water levels in wells 09F520 and 08K001 show pronounced seasonal responses to climatic effects and irrigation pumpage. The water level in well 09F520 in Decatur County was below normal during most of 2002 but rose in early 2003 to above normal ending the year in the normal range. The water level in well 08K001 in Early County was below normal at the beginning of 2002 but rose to above normal in 2003 and ended the year in the normal range. The water level in well 15L020 in Worth County has shown a downward trend for most of the period of record. The rate of this downward trend increased during early 1999 and continued through most of 2002 when the water level in this well reached a record low. The water level did rise in the well in 2003, similar to the other wells discussed but was still below normal because of the long-term decline.





Site name	County	Other identifier
10H009	Baker	Ichauway
12K014	Baker	Blue Springs, observation well
10K005	Calhoun	Bill Jordan, Ocala well
09F520	Decatur	Graham Bolton
09G001	Decatur	U.S. Geological Survey, test well DP-4
06G006	Early	Doug Harvey, test well 1
08K001	Early	Ike Newberry, test well 1
12F036	Grady	U.S. Geological Survey, Cairo
12M017	Lee	U.S. Geological Survey, test well 19
07H002	Miller	U.S. Geological Survey, test well DP-2
08G001	Miller	Viercocken
10G313	Mitchell	Harvey Meinders
11J012	Mitchell	U.S. Geological Survey, test well DP-11
13J004	Mitchell	Aurora Dairy
06F001	Seminole	Roddenbery Company Farms, test well 1
13M006	Worth	U.S. Geological Survey, test well DP-8
15L020	Worth	City of Sylvester

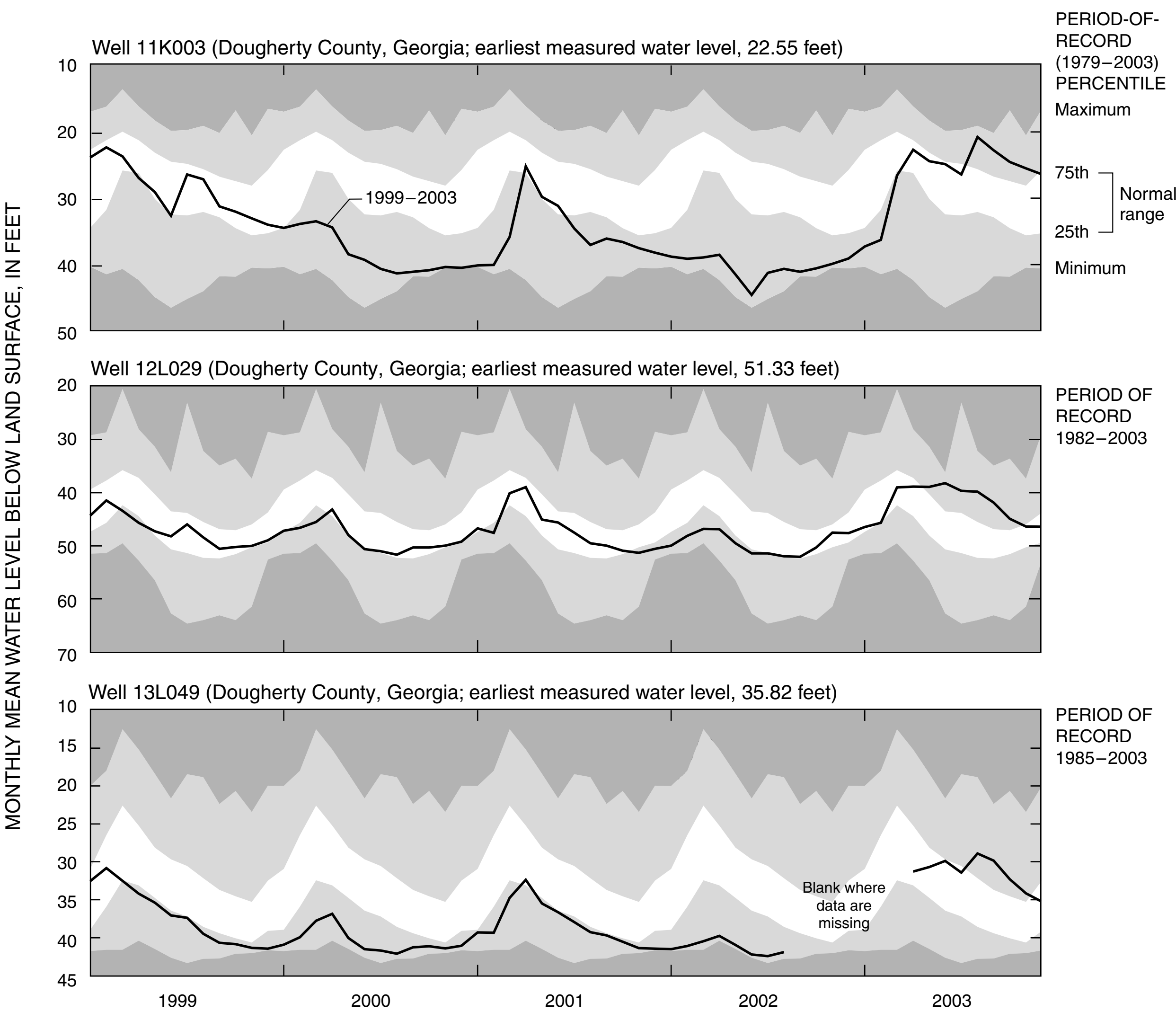
Upper Floridan Aquifer

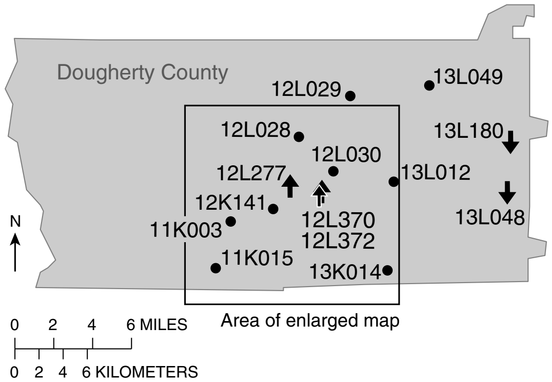
City of Albany–Dougherty County area

Water levels in 14 wells were used to define ground-water conditions in the Upper Floridan aquifer near Albany, Georgia, during 2003 (Dougherty County map, facing page). In this area, water in the Upper Floridan aquifer is semiconfined. Water levels in 9 of the 14 wells were within the normal range during 2003. Water levels in three of the wells were above normal and in two of the wells were below normal.

Water-level hydrographs for three Upper Floridan aquifer wells in the Albany area (below) were chosen to illustrate monthly mean water levels during 1999–2003 and period-of-record water-level statistics. Effects from drought are apparent from water-level declines in the three wells through 2000; although water levels were near normal in 2001, water levels continued to decline into early 2002, when the drought ended. The water level in well 11K003 in the southwest was below normal for all 2002 but rose to normal or above normal in 2003. The water level in well 12L029 in the northeastern area was below normal at the beginning of 2002 but rose through the normal range to above normal for a majority of 2003. The water level in well 13L049 remained well below normal during 2002 reaching record lows by summer. Because of data loss in the latter part of 2002 and early 2003, the time of the rise from below normal is uncertain but during most of 2003 the water level was at or above normal.

In addition to continuous water-level monitoring, synoptic water-level measurements are taken periodically in wells in and around the Albany area. During October 2002 and September 2003, water-level measurements were collected from 68 wells and subsequently used to construct maps showing the potentiometric surface of the Upper Floridan aquifer. The potentiometric-contour maps (facing page) show that water generally flows from northwest to southeast, toward the Flint River. Water levels were low in the fall of 2002, and a few small depressions existed in the water surface. In these areas, water was flowing toward these depressions. In the southeastern part of the mapped area, flow was away from the river toward the southwest. In the fall of 2003, water levels had increased, but depressions in the water surface remained, with flow toward the depressions.





EXPLANATION

Upper Floridan aquifer

City of Albany–Dougherty County area

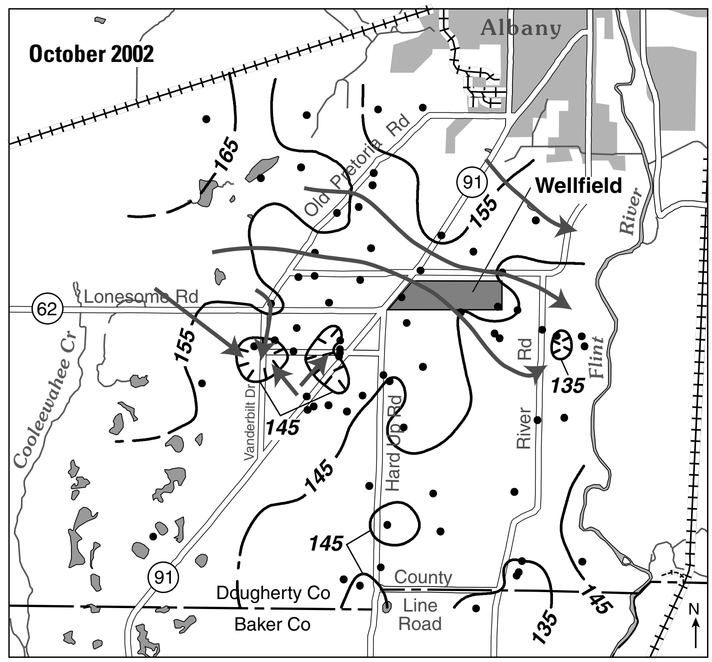
Observation well, site name, and comparison of monthly mean water level during 2003 to period-of-record water level

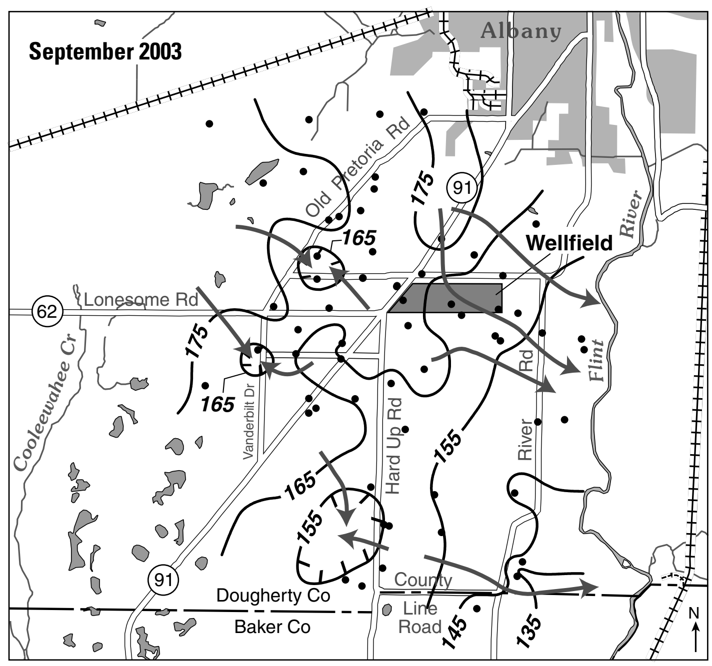
12L277 ↑ Above normal—Above 75th percentile water level for period of record

12K141 • Normal—Between 25th and 75th percentile water levels for period of record

13L180 ↓ Below normal—Below 25th percentile water level for period of record

Site name	Other identifier
11K003	Nilo test well, north
11K015	U.S. Geological Survey, test well 14
12K141	Albany Water, Gas, and Light Commission, A750
12L028	Vandy W. Musgrove
12L029	U.S. Geological Survey, test well 13
12L030	U.S. Geological Survey, test well 16
12L277	Albany Water, Gas, and Light Commission, test well 1
12L370	Albany Water, Gas, and Light Commission, MW-100D
12L372	Albany Water, Gas, and Light Commission, MW-100I
13K014	U.S. Geological Survey, test well 15
13L012	U.S. Geological Survey, test well 3
13L048	U.S. Geological Survey, test well 17
13L049	Miller Ammo Supply
13L180	Marine Corps Logistic Base, core hole 3





Base from U.S. Geological Survey 1:100,000-scale digital data

0 1 2 3 MILES
0 1 2 3 KILOMETERS

EXPLANATION

— 165 — **Potentiometric contour**—Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Hachures indicate depression. Contour interval 10 feet. Datum is NAVD 88

Direction of ground-water flow

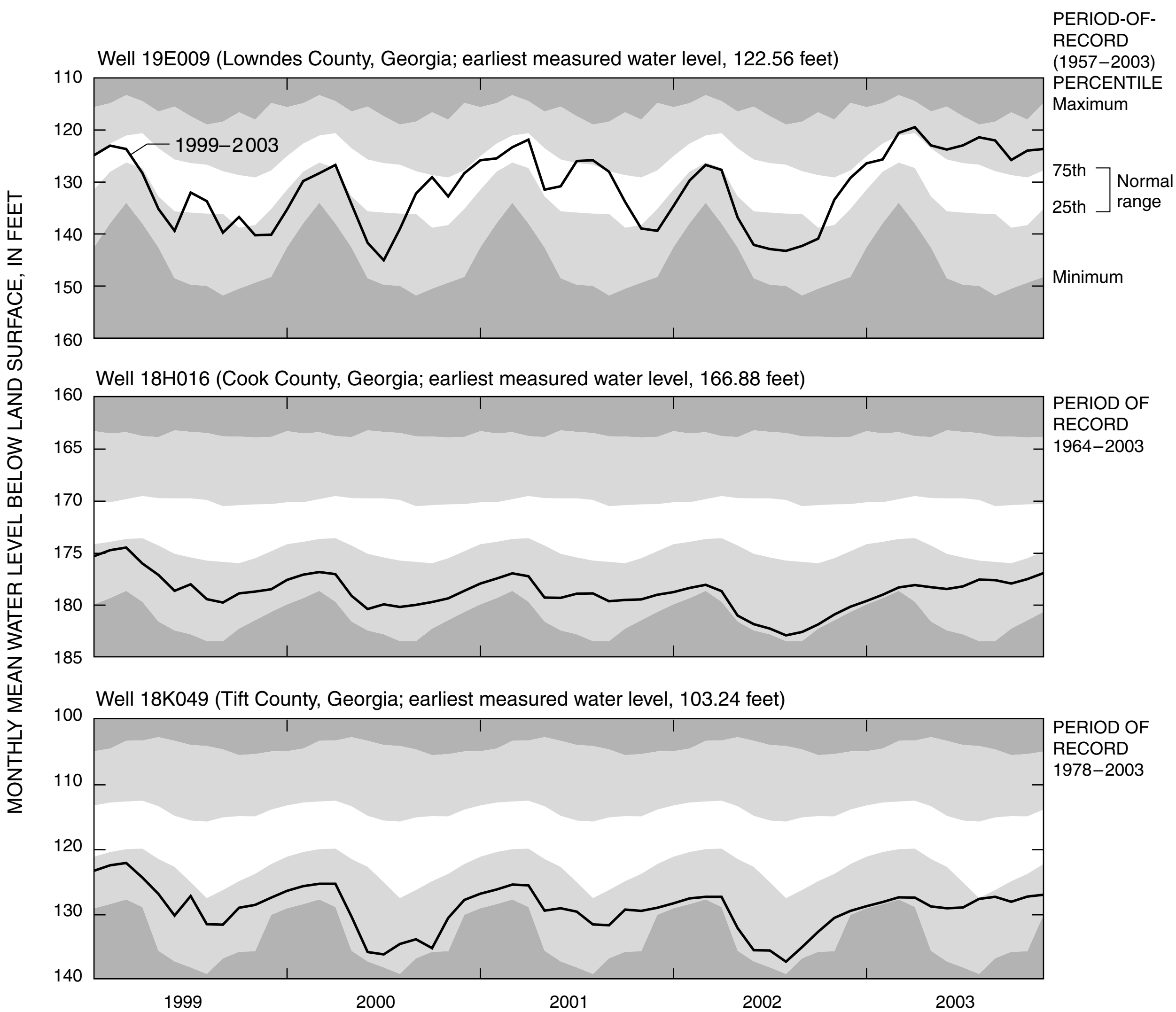
• **Well**

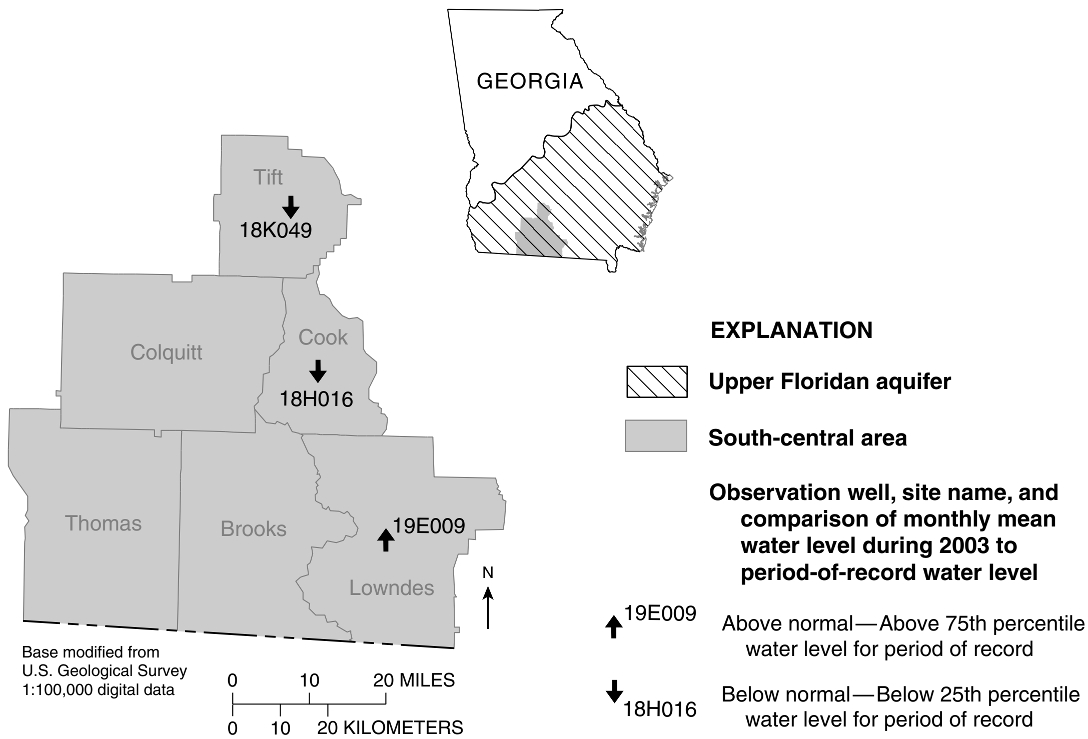
Upper Floridan Aquifer

South-Central area

Water levels in three wells were used to define ground-water conditions in the Upper Floridan aquifer in south-central Georgia during 2003 (map and table, facing page). In this area, water in the Upper Floridan aquifer generally is confined, but locally is unconfined in areas of karst features in Lowndes County. Water levels in all three wells were below normal for most of 2002 and in two of the three wells during 2003.

Water-level hydrographs for the three Upper Floridan aquifer wells in south-central Georgia (below) were chosen to illustrate monthly mean water levels during 1999–2003 and period-of-record water-level statistics. Drought effects are apparent in the three wells beginning mid-1999 and continuing into 2002. The water level in well 19E009 in Lowndes County was below normal during most of 2002 but began to rise in the latter part of the year and was above normal for most of 2003. In well 19E009, the water level shows a more pronounced response to climatic effects because of proximity to karst features. In the other two wells, climatic effects are less pronounced, and water levels are influenced primarily by pumping. The hydrograph for well 18H016 in Cook County shows the continued downward trend of previous years, with the water level reaching record lows during 2002 but rising for most of 2003, though still below normal. The hydrograph for well 18K049 in Tift County shows a similar pattern with the long-term decline continuing into late 2002 and early 2003 (when record low water levels were reached) but with some water level rise in the latter part of the year—again, not enough to reach the normal water-level range.





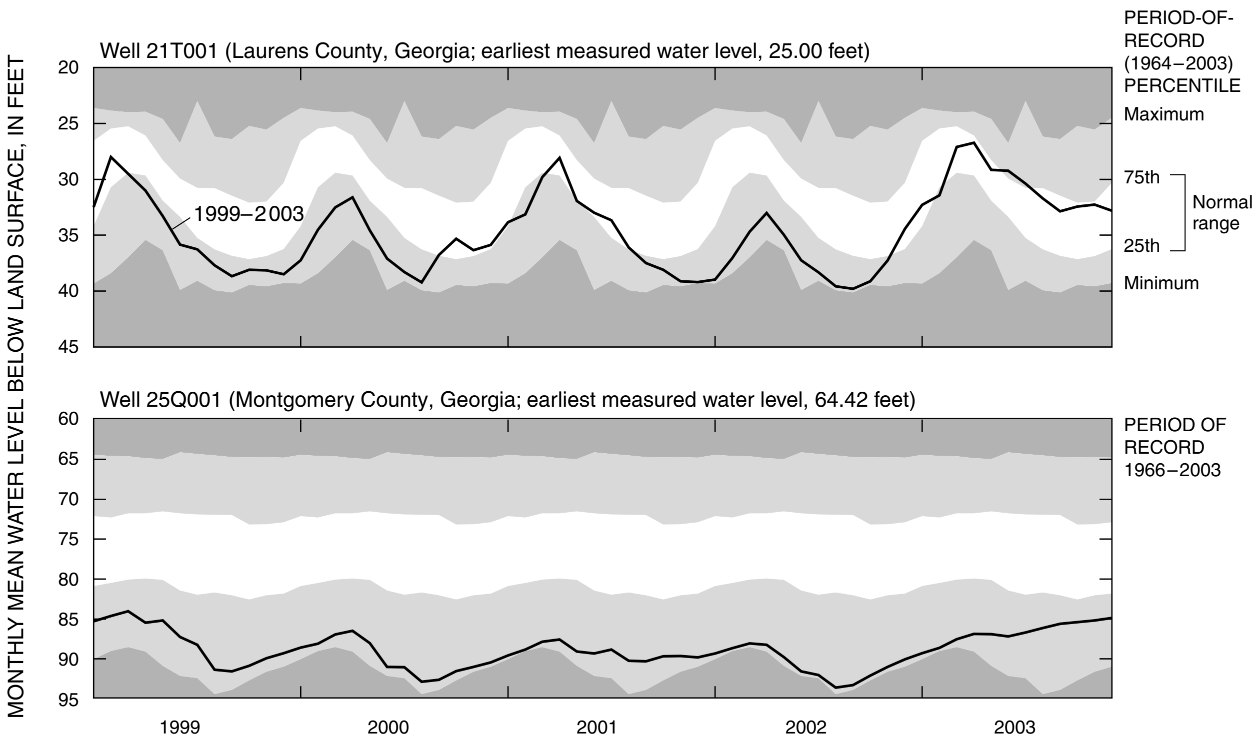
Site name	County	Other identifier
18H016	Cook	U.S. Geological Survey, Adel test well
19E009	Lowndes	City of Valdosta
18K049	Tift	U.S. Geological Survey, test well 1

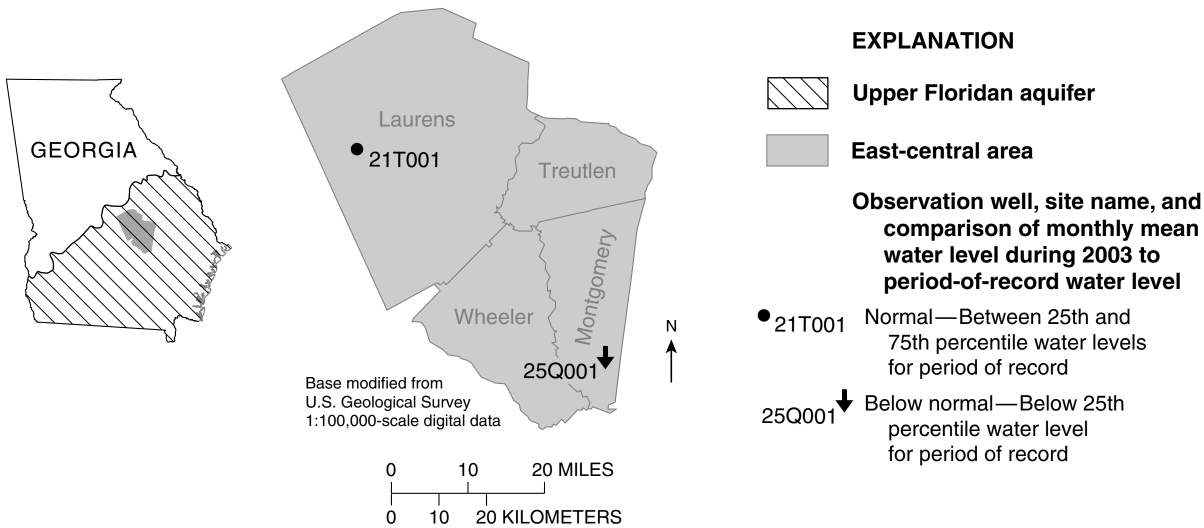
Upper Floridan Aquifer

East-Central area

Water levels in two wells were used to define ground-water conditions in the Upper Floridan aquifer in east-central Georgia during 2003 (map and table, facing page). In this area, water in the Upper Floridan aquifer is confined to the southeast and is semiconfined to the northwest. The water level in one of the wells was within the normal range and in the other well was below normal during 2003.

Water-level hydrographs for both Upper Floridan aquifer wells in east-central Georgia (below) were chosen to illustrate monthly mean water levels during 1999–2003 and period-of-record water-level statistics. Effects from drought are apparent in both wells during early 2002, with recovery apparent during the latter half of 2002 and during 2003. Well 21T001 in Laurens County is located in the northwestern part of the area, where the aquifer is semiconfined. The water level in the well was below normal during early 2002, reaching a record low that year but began to recover in the last quarter of the year and was normal or slightly above normal during most of 2003. Water levels in this area are influenced by climatic effects and agricultural pumping. Well 25Q001 in Montgomery County is located in an area where the aquifer is deeply buried and confined and is influenced by local and regional pumping. The water level in this well has shown a downward trend for most of the period of record. The downward trend in water level continued through 2002, but for most of 2003 the water level in this well rose, although water levels remained below normal.





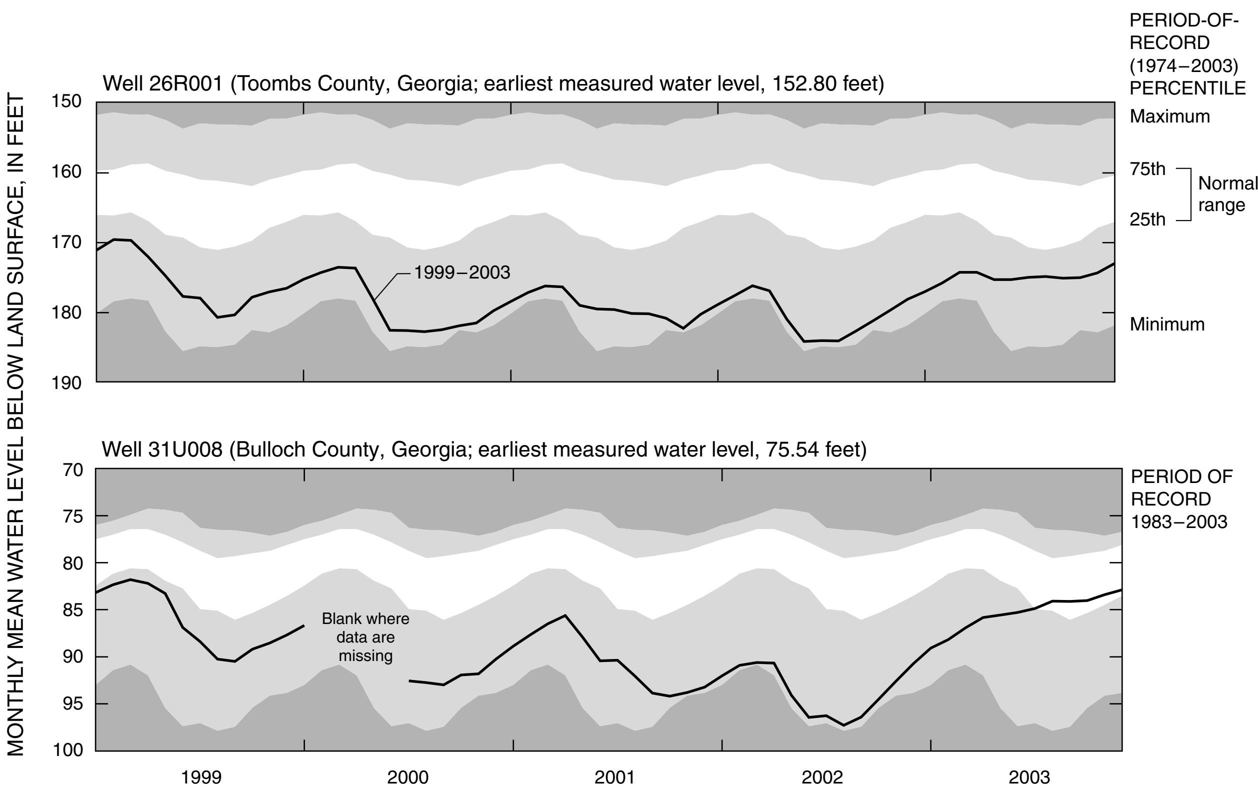
Site name	County	Other identifier
21T001	Laurens	Danny Hogan
25Q001	Montgomery	Montgomery County Board of Education

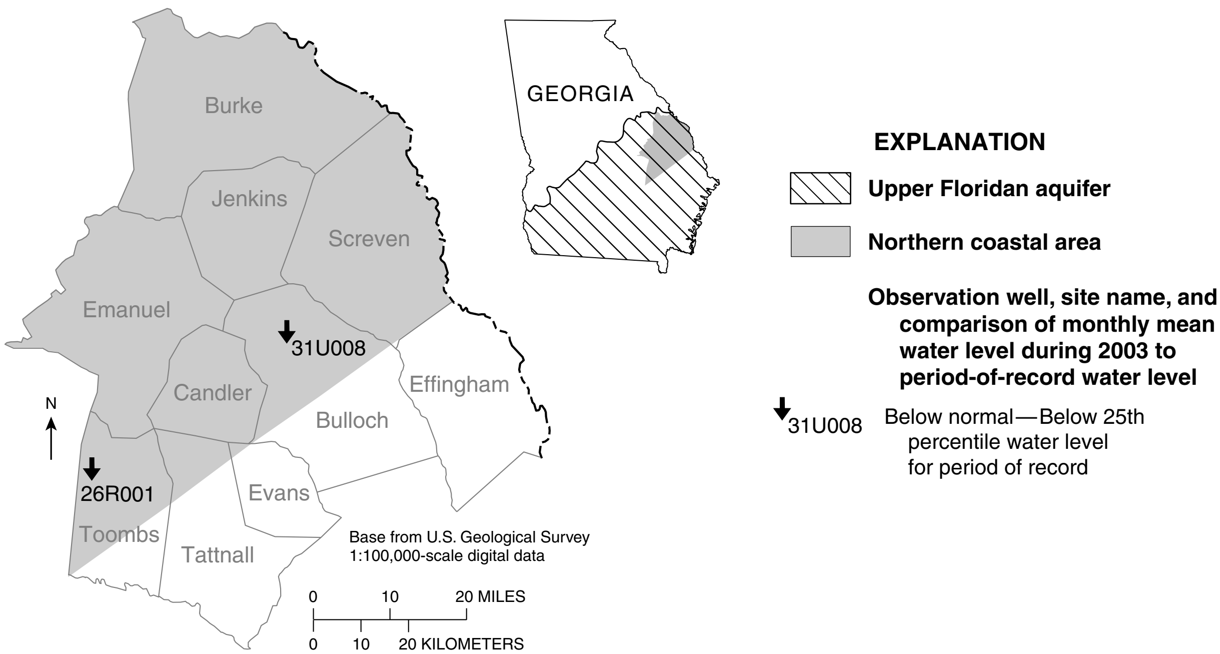
Upper Floridan Aquifer

Northern Coastal area

Water levels in two wells were used to define ground-water conditions in the Upper Floridan aquifer in the northern coastal area during 2003 (map and table, facing page). In this area, water in the Upper Floridan aquifer is unconfined, especially in updip areas to the north, and confined elsewhere. Water levels in both of the wells generally were at or below the normal range during 2003. Both wells are located in areas where agricultural water use is prevalent.

Water-level hydrographs for both Upper Floridan aquifer wells in northern coastal Georgia (below) were chosen to illustrate monthly mean water levels during 1999–2003 and period-of-record water-level statistics. Drought effects are apparent in both wells through 2002 but were beginning to abate by the latter part of the year. The water level in well 26R001 in Toombs County has a downward trend for most of the period of record continuing through 2002, when water levels reached record lows. This trend ended in the latter part of 2002, however, when the water level began to rise but remained below normal through 2003. A similar pattern occurs in the water level in well 31U008 in Bulloch County, which was near record lows during 2002, because of long-term declines; however, during late 2002, the water level began to rise and reached the normal range during the last half of 2003.





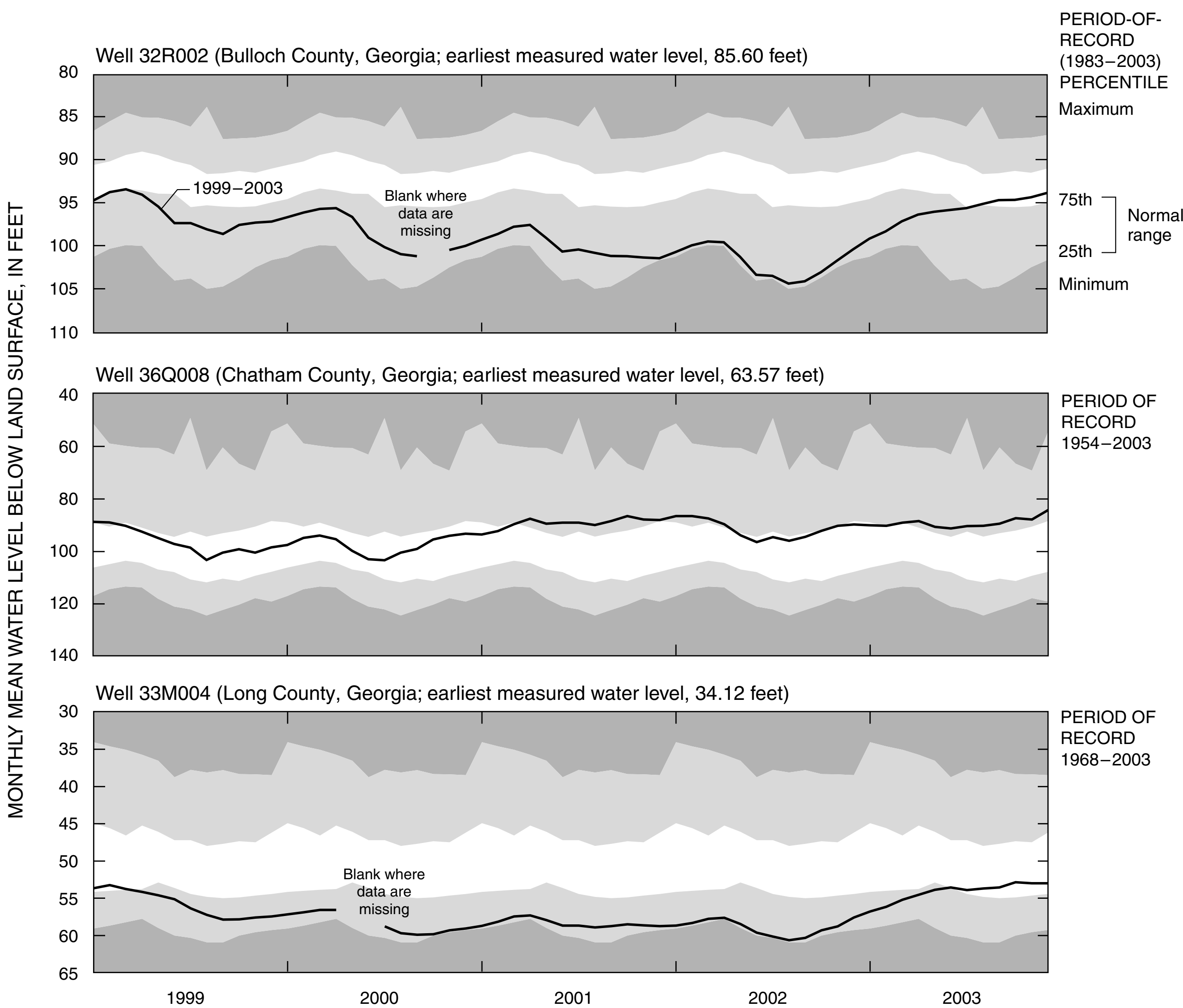
Site name	County	Other identifier
26R001	Toombs	City of Vidalia, well 2
31U008	Bulloch	Georgia Geologic Survey, Hopeulikit, test well 1

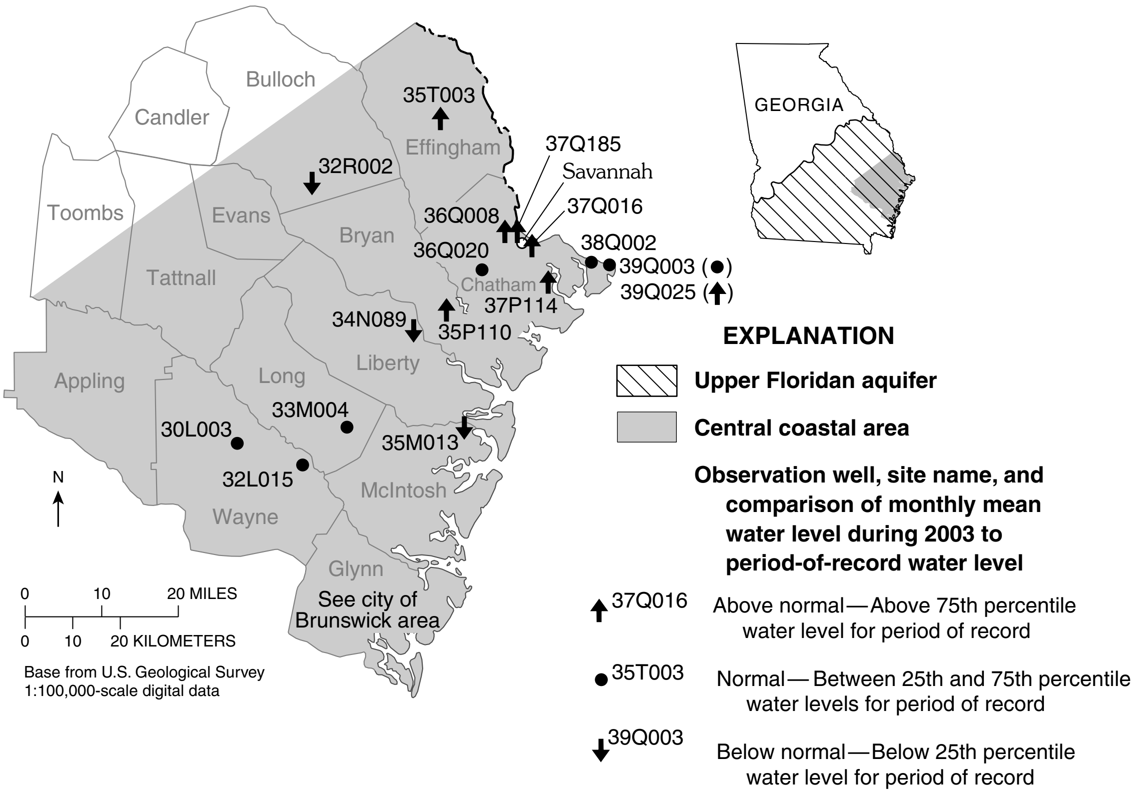
Upper Floridan Aquifer

Central Coastal area

Water levels in 16 wells were used to define ground-water conditions in the Upper Floridan aquifer in the central coastal area of Georgia (excluding Glynn County) during 2003 (map and inset, facing page). In this area, water in the Upper Floridan aquifer is confined and influenced primarily by pumping. Water levels in six wells were within the normal range, water levels in seven wells were above normal, and water levels in three wells were below normal during 2003.

Water-level hydrographs for three Upper Floridan aquifer wells in the central coastal area of Georgia (below) were chosen to illustrate monthly mean water levels during 1999–2003 and period-of-record water-level statistics. The water level in well 32R002 in Bulloch County equaled record lows during 2002 and continued to be below normal for most of the year. During late 2002, the water level in the well began to rise, and by mid-2003 was within the normal range. Well 36Q008, near Savannah in Chatham County, was normal or above normal during 2002–03, likely because of continued decreases in water use from conservation (Julia L. Fanning, U.S. Geological Survey, oral commun., 2003). The hydrograph for well 33M004 in Long County shows a continuation of the long-term decline from drought that carried into 2002 when record lows were reached. Beginning about mid-2002, however, the water level began to rise and was within the normal range by the end of 2003.





Site name	County	Other identifier
35P110	Bryan	Richmond Hill, test well
32R002	Bulloch	Georgia Geologic Survey, Bulloch South, test well 1
36Q008	Chatham	Lance-Atlantic Company
36Q020	Chatham	H.J. Morrison
37P114	Chatham	Georgia Geologic Survey, Skidaway Institute, test well 2
37Q016	Chatham	East Coast Terminal well
37Q185	Chatham	U.S. Geological Survey, Hutchinson Island, test well 1
38Q002	Chatham	U.S. National Park Service, test well 6
39Q003	Chatham	U.S. Geological Survey, test well 7
39Q025	Chatham	Georgia Geologic Survey, Tybee Island, test well 2
35T003	Effingham	City of Springfield
34N089	Liberty	U.S. Geological Survey, test well 1
33M004	Long	U.S. Geological Survey, test well 3
35M013	McIntosh	U.S. Fish and Wildlife Service, Harris Neck 1
30L003[1]	Wayne	City of Jesup Housing Authority
32L015	Wayne	Georgia Geologic Survey, Gardi, test well 1

[1] Well completed in upper and lower Brunswick aquifers and the Upper Floridan aquifer

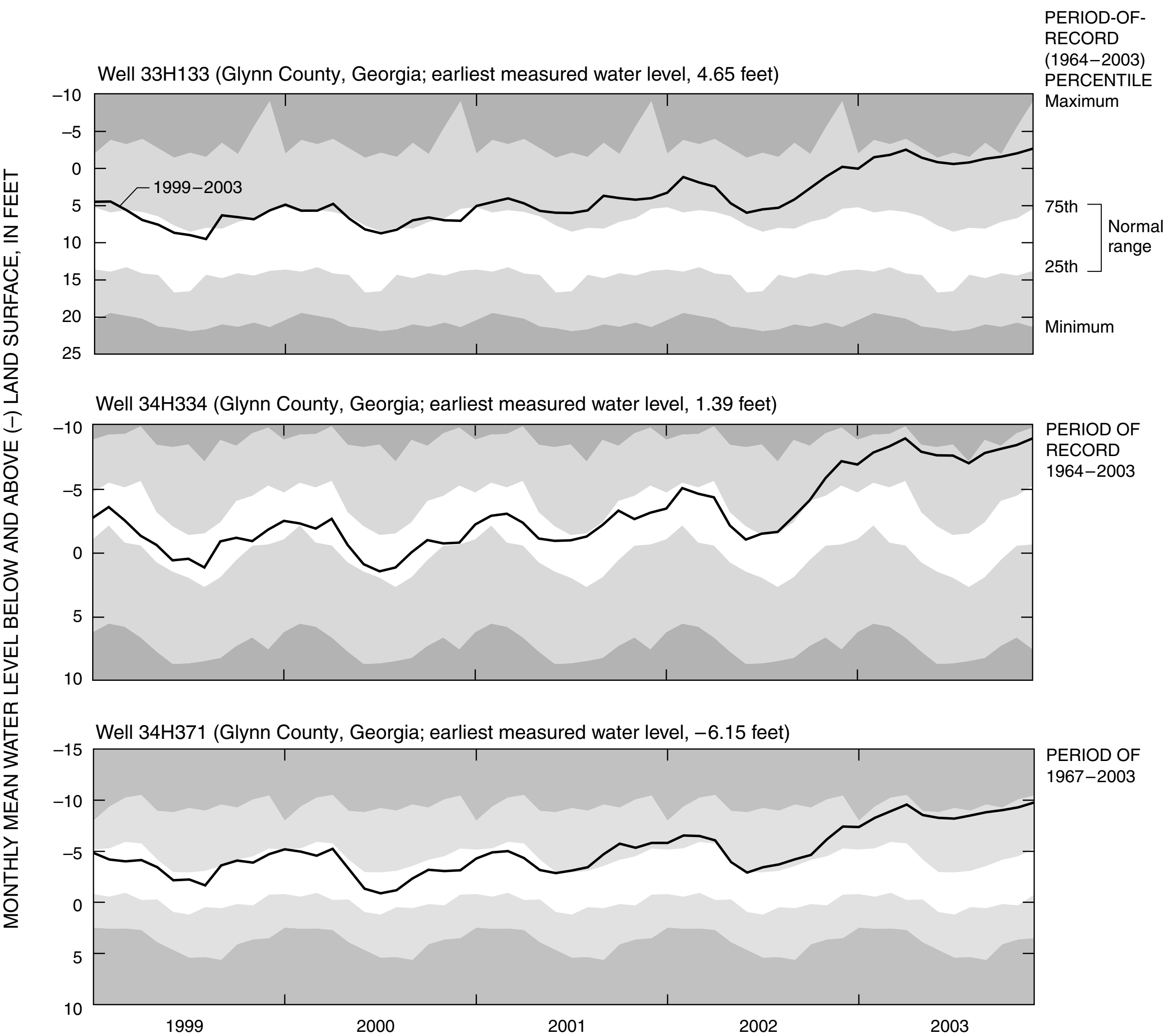
Upper Floridan Aquifer

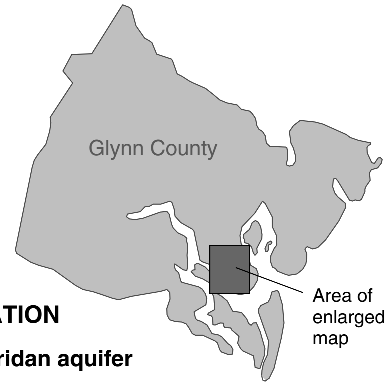
City of Brunswick area

Water levels in six wells were used to define ground-water conditions in the Upper Floridan aquifer in the city of Brunswick in the central coastal area of Georgia during 2003 (map and inset, facing page). In this area, water in the Upper Floridan aquifer is confined and primarily influenced by pumping for industrial and public supply. Water levels in all six wells were above the normal range during 2003.

Water-level hydrographs for three Upper Floridan aquifer wells at the city of Brunswick (below) were chosen to illustrate monthly mean water levels during 1999–2003 and period-of-record water-level statistics. Water levels in all three wells followed a similar pattern of long-term rise, primarily because of decreases in water use. The water level in well 33H133 was above the normal range during all of 2002 and continued to rise, nearing record highs, during 2003. The water level in well 34H334 was within the normal range during early 2002, but rose to above normal during the latter half of 2002 and continued to rise, reaching record highs during 2003. The water level in well 34H371 showed a similar pattern to that of well 33H133, whereby the water level was above normal for all of 2002 and continued to rise during 2003 to reach near record highs.

In addition to continuous water-level monitoring, synoptic water-level measurements are periodically taken in wells in the Brunswick area. Water-level measurements from 8 wells were collected during May and June 2002 and from 22 wells during June 2003, and subsequently used to construct maps showing the potentiometric surface of the Upper Floridan aquifer. The potentiometric-contour maps (facing page) show that water generally flows from the southeast to the north-northwest toward industrial pumping centers in north Brunswick, which have caused a depression in the potentiometric surface. The change in water-level altitudes between the 2002 and 2003 maps is indicative of the overall rise in water levels between 2002 and 2003.





EXPLANATION

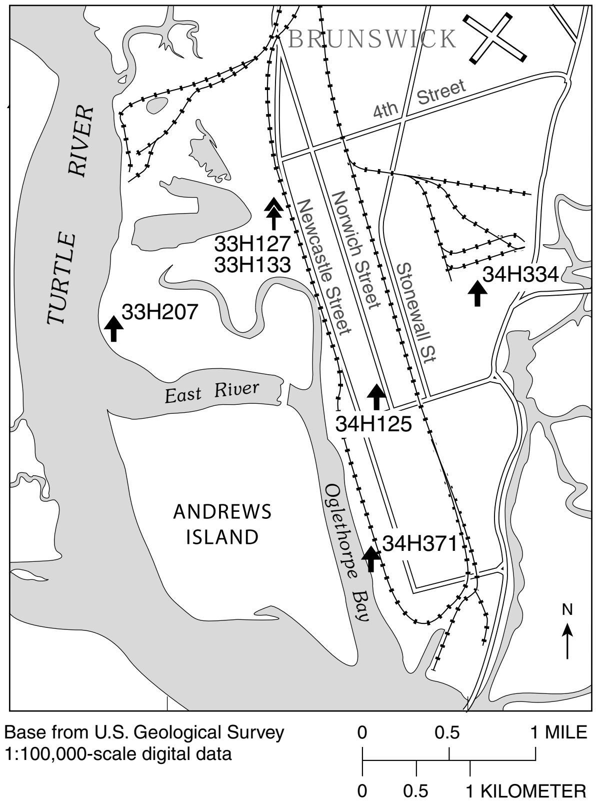
Upper Floridan aquifer

City of Brunswick area

Observation well, site name, and comparison of monthly mean water level during 2003 to period-of-record water level

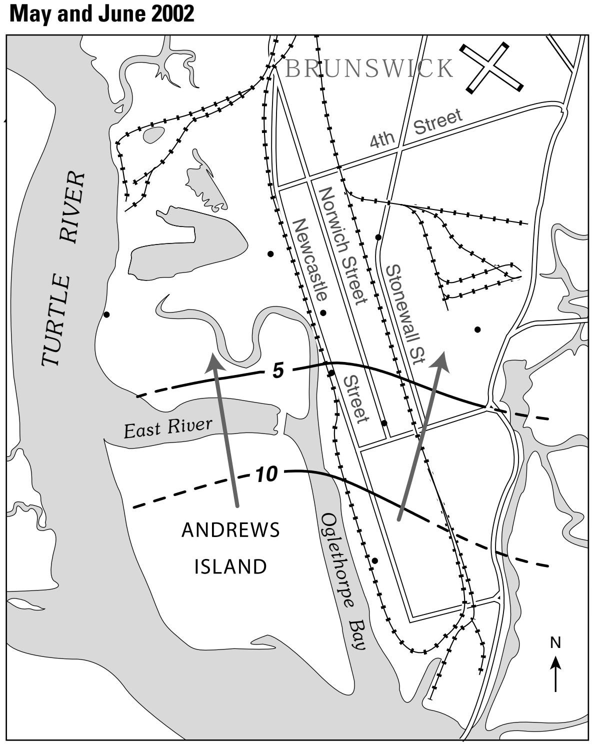
33H207 Above normal—Above 75th percentile water level for period of record

Site name	County	Other identifier
33H127	Glynn	U.S. Geological Survey, test well 3
33H133	Glynn	U.S. Geological Survey, test well 6
33H207	Glynn	Georgia-Pacific, south, test well 2
34H125	Glynn	U.S. Geological Survey, test well 1
34H334	Glynn	U.S. Geological Survey, test well 4
34H371	Glynn	U.S. Geological Survey, test well 11

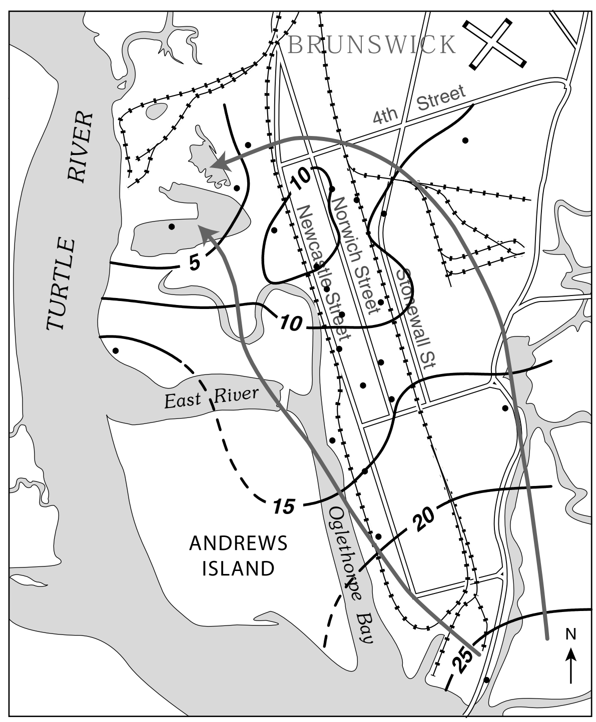


Base from U.S. Geological Survey 1:100,000-scale digital data

May and June 2002



June 2003



EXPLANATION

— *10* — **Potentiometric contour**—Shows altitude at which water level would have stood in tightly cased wells in the Upper Floridan aquifer. Contour interval 5 feet. Dashed where approximately located. Datum is NAVD 88

General direction of ground-water flow

• **Well**

Upper Floridan Aquifer

Southern Coastal area

Water levels in five wells were used to define ground-water conditions in the Upper Floridan aquifer in the southern coastal area of Georgia during 2003 (map and table, facing page). In this area, water in the Upper Floridan aquifer is confined and influenced mostly by pumping in the St. Marys, Georgia–Fernandina Beach, Florida, area to the east, and by climatic effects and pumping to the west. The water level in two wells, one in Ware and the other in Charlton County, was within the normal range. The three other wells were above normal during 2003.

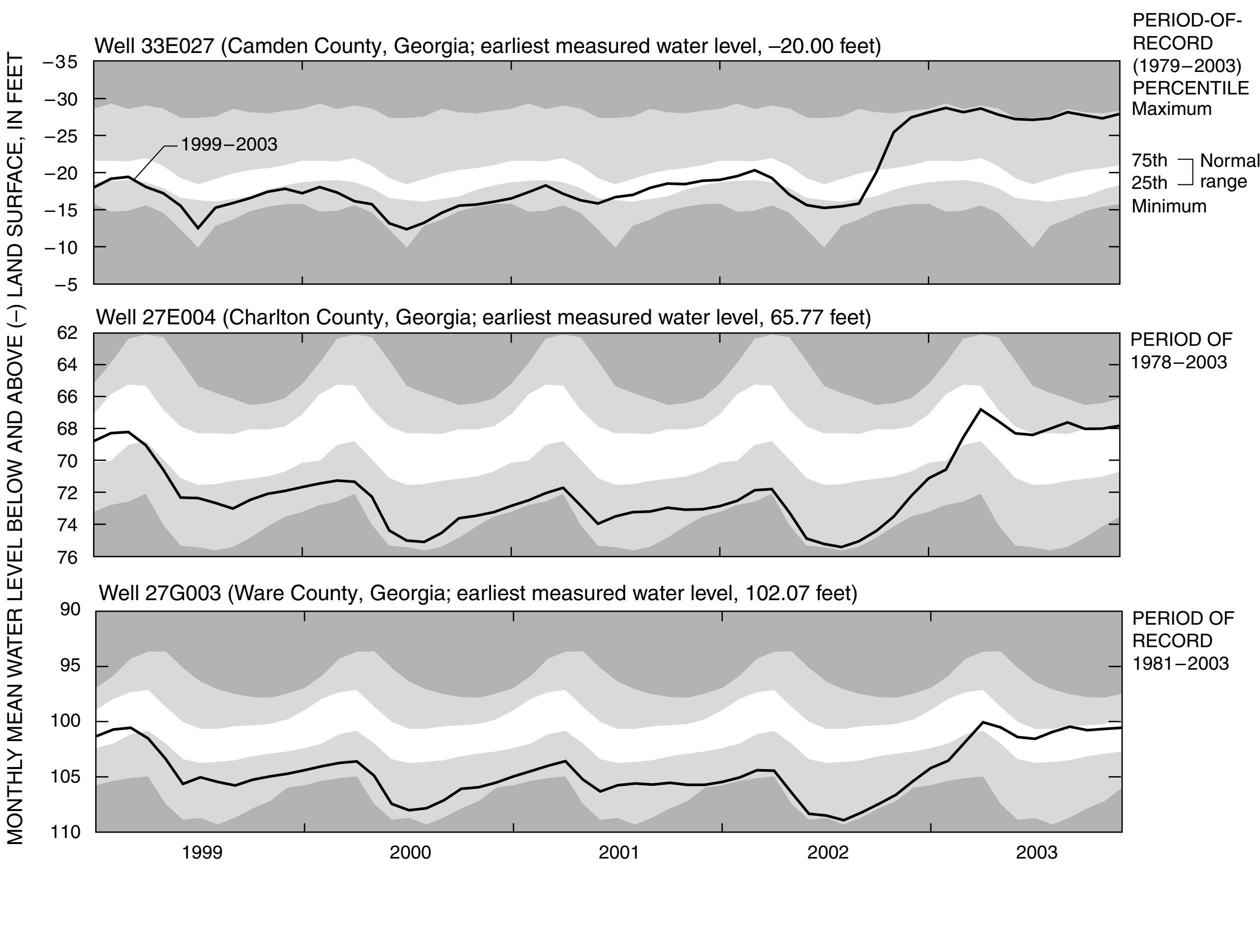
Water-level hydrographs for three Upper Floridan aquifer wells in the central coastal area (below) were chosen to illustrate monthly mean water levels during 1999–2003 and period-of-record water-level statistics. Water-level declines in all three wells continued from mid- to late 2002, but water levels began to rise markedly in the latter part of the year. The water level in well 33E027 in Camden County was at or below normal during early 2002 but rose markedly in the last quarter of the year to reach record highs during 2003. This marked rise resulted from the end of the drought and a large decrease in water use that occurred during late 2002. During October 2002, the Durango Corporation ceased operations at the paper mill in St. Marys, Georgia, decreasing water use by about 35 million gallons per day (Michael F. Peck, U.S. Geological Survey, written commun., 2004). The water level in well 27E004 in Charlton County was above normal until early 1999 when the water level began to decline. This decline continued until mid-2002 when water levels neared record lows. This decline ended during late 2002 when the water level began to rise and was above normal for most of 2003. A hydrograph for well 27G003 in Ware County shows an almost identical pattern to that of well 27E004, with water-level decline beginning during early1999, reaching record lows during 2002 and rising to normal during 2003.

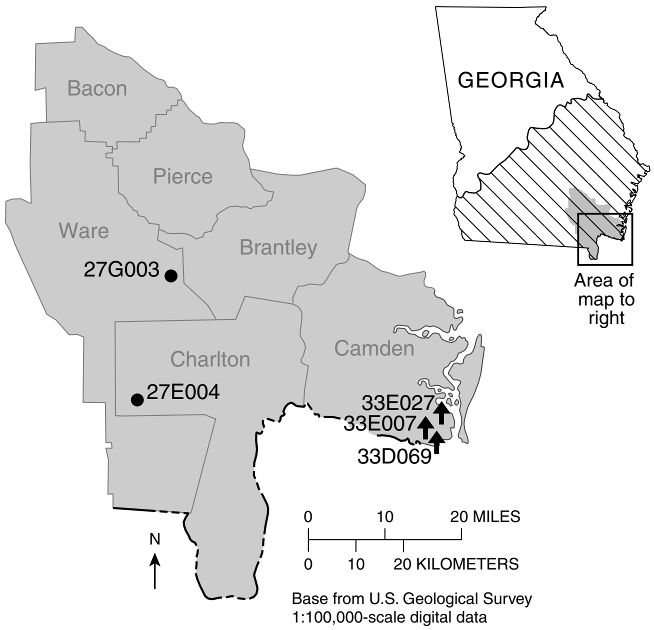
In addition to continuous water-level monitoring, synoptic water-level measurements are taken periodically, in cooperation with the St. Johns River Water Management District, in wells in and around the southern coastal area of Georgia and adjacent parts of Florida. During September 2003, water levels were measured in 52 wells and subsequently used to construct a potentiometric-surface map of the Upper Floridan aquifer. The map (inset, facing page) shows that water generally flowed from west to east, toward the Atlantic Ocean, and toward pumping centers at Fernandina Beach, and Jacksonville, Florida. Compared to the published map for 2001 potentiometric contours in this same area (Knowles and Kinnaman, 2002), water levels have risen throughout the area.

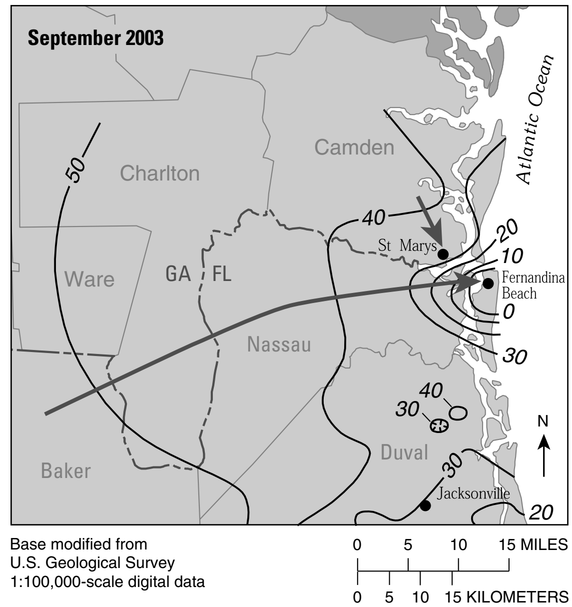
Reference Cited

Knowles, Leel, Jr., and Kinnaman, S.L., 2002, Potentiometric surface of the Upper Floridan aquifer in the St. Johns River Water Management District and vicinity, Florida, September 2001: U.S. Geological Survey Open-File Report 02-182, 1 sheet.

Kinnaman, S.L., and Knowles, Leel, Jr., 2004, Potentiometric surface of the Upper Floridan aquifer in the St. Johns River Water Management District and vicinity, Florida, September 2003: U.S. Geological Survey Open-File Report 04-1288, 1 sheet.







EXPLANATION

Upper Floridan aquifer

Southern coastal area

Observation well, site name, and comparison of monthly mean water level during 2003 to period-of-record water level

33E007 ↑ Above normal—Above 75th percentile water level for period of record

● 27E004 Normal—Between 25th and 75th percentile water levels for period of record

EXPLANATION

— *45* — **Potentiometric contour**—Shows altitude at which water level would have stood in tightly cased wells during September 2003. Hachures indicate depressions. Contour interval 10 feet. Datum is NAVD 88. (Modified from Kinnaman and Knowles, 2004)

→ **Direction of ground-water flow**

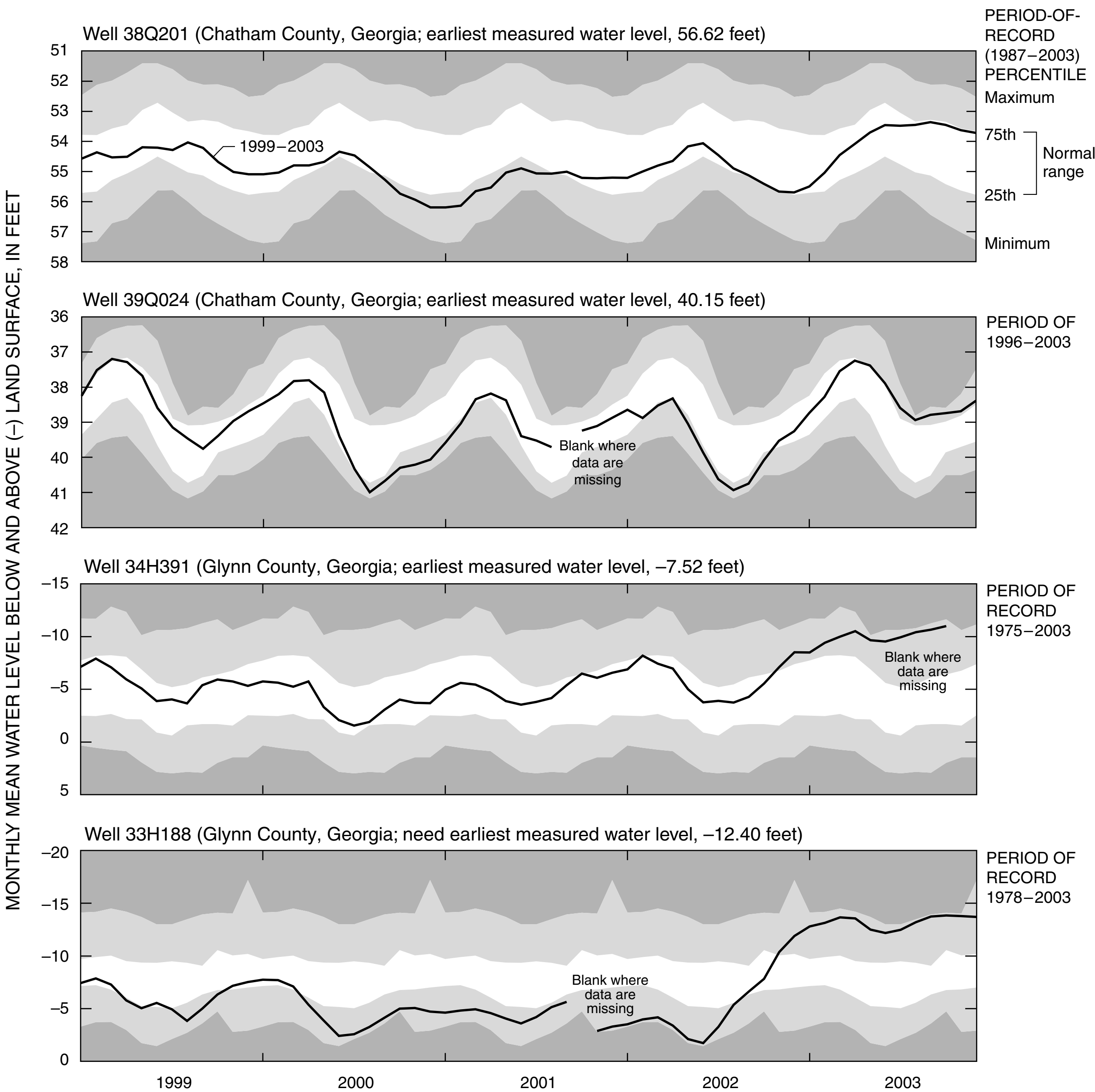
Site name	County	Other identifier
33D069	Camden	U.S. National Park Service, Cumberland Island National Seashore
33E007	Camden	Huntly-Jiffy
33E027	Camden	U.S. Navy, Kings Bay, test well 1
27E004	Charlton	U.S. Geological Survey, test well OK-9
27G003[1]	Ware	U.S. Geological Survey, test well 1

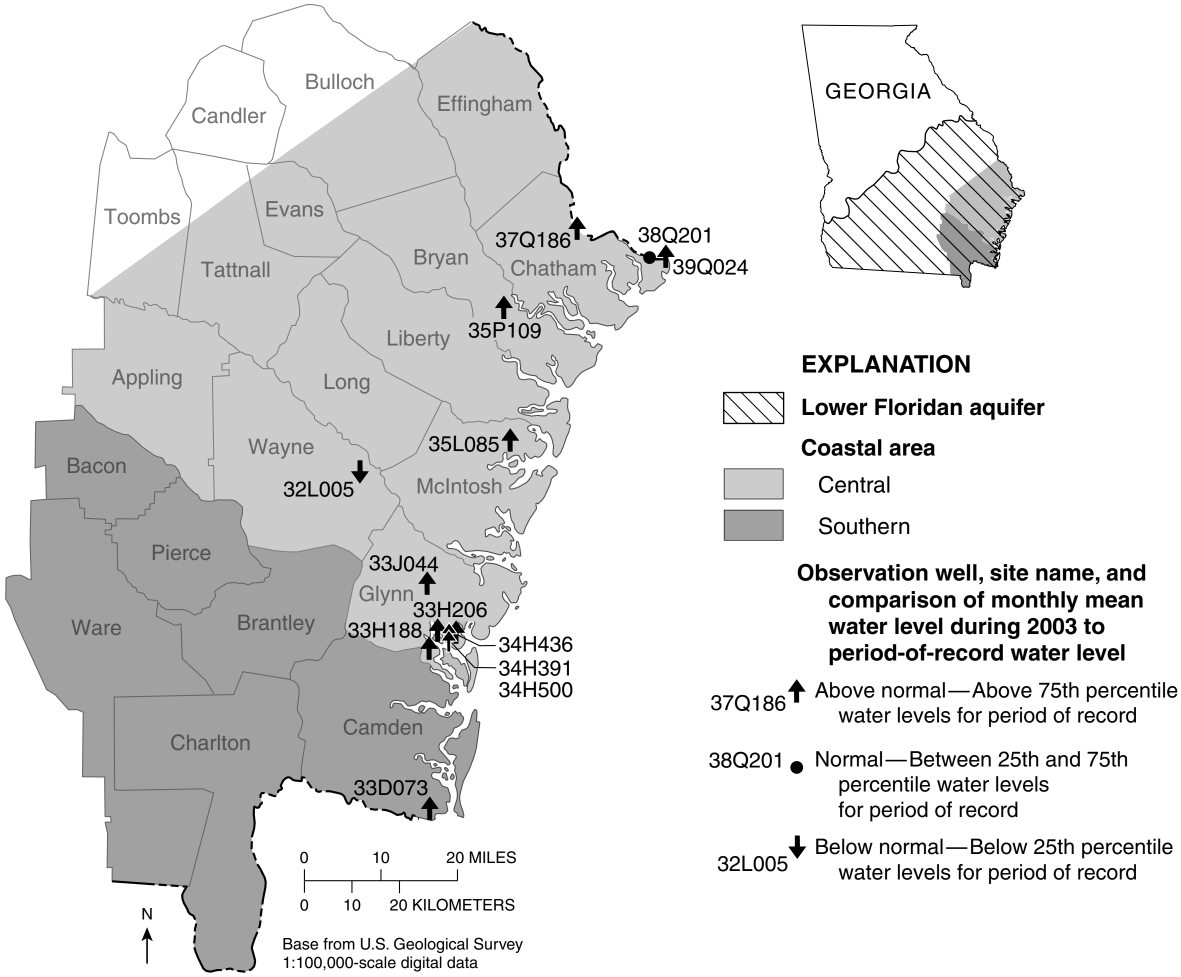
[1] Well completed in both Upper and Lower Floridan aquifers, with most contribution from the Upper Floridan aquifer

Lower Floridan Aquifer and Underlying Units in Coastal Georgia

Water levels in 13 wells were used to define ground-water conditions in the Lower Floridan aquifer and underlying units in central and southern coastal Georgia during 2003 (map and table, facing page). In this area, water in the Lower Floridan aquifer is confined and influenced mostly by pumping. Water levels in 11 of the 13 wells were above the normal range during 2003. The water level in one well was below normal in Wayne County, and one well was within the normal range in Chatham County.

Water-level hydrographs for four Lower Floridan aquifer wells in coastal Georgia (below) were chosen to illustrate monthly mean water levels during 1999–2003 and period-of-record water-level statistics. In wells 39Q024 (Chatham County) and 33H188 (Glynn County), water levels neared record lows during 2002 but were at or above normal by the end of 2002, with the water level in well 33H188 reaching record highs during 2003. In contrast wells 38Q201 (Chatham County) and 34H391 (Glynn County) were within the normal range during 2002 and rose to above normal by late 2003 with well 34H391 nearing record highs by midyear. Note that the water-level rise in this aquifer during 2003 was regional in extent, including wells as far south as Camden County and as far north as Chatham County.





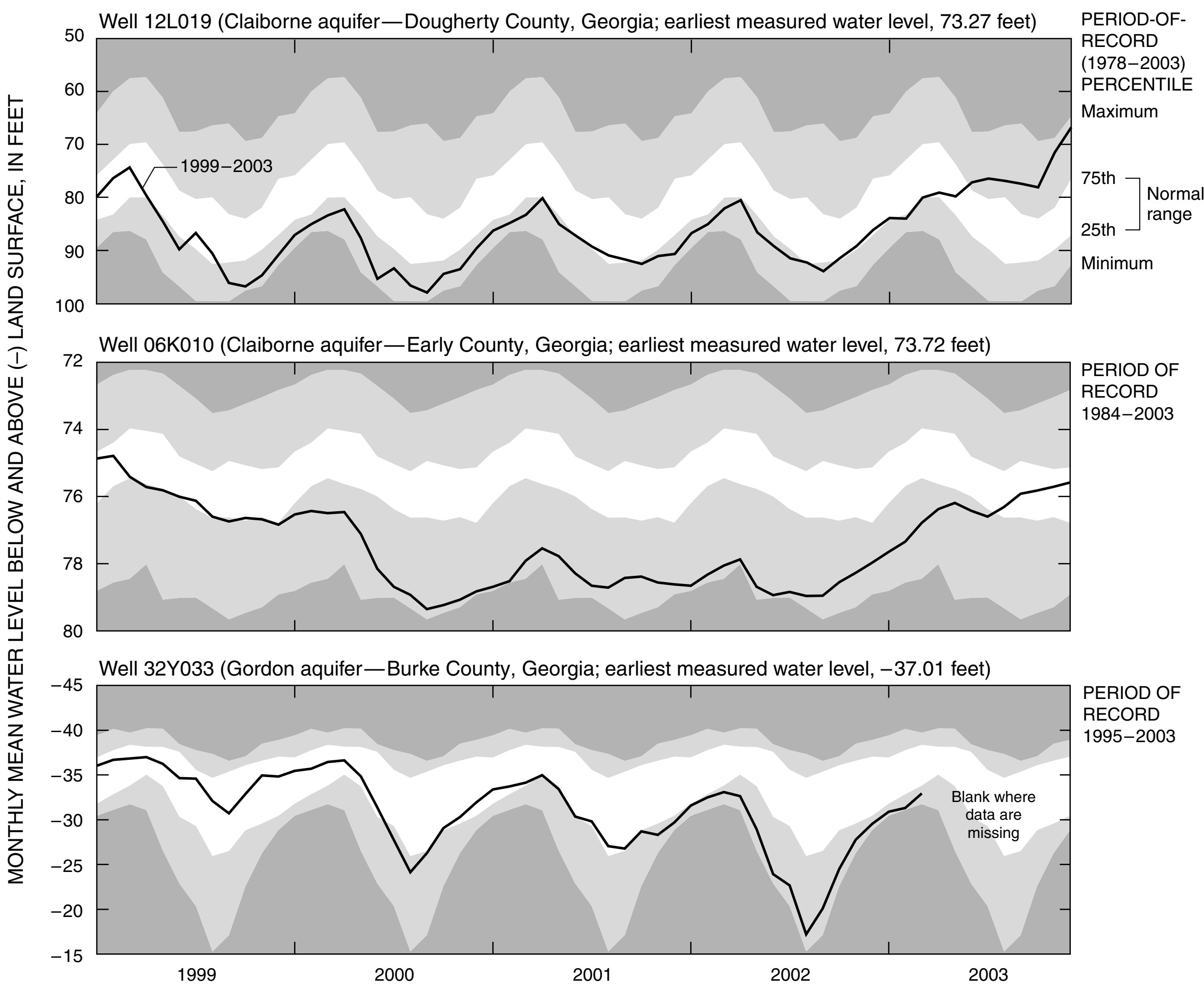
Site name	Water-bearng unit[1]	County	Other identifier
35P109	LF	Bryan	Richmond Hill, test well
33D073	LF	Camden	St. Marys, test well (deep)
37Q186	P	Chatham	Hutchinson Island, test well 2
38Q201	P	Chatham	Georgia Geologic Survey, Fort Pulaski, test well
39Q024	LF	Chatham	Georgia Geologic Survey, Tybee Island, test well 1
33H188	F	Glynn	U.S. Geological Survey, test well 26
33H206	LF	Glynn	Georgia-Pacific, south, test well 1
33J044	LF	Glynn	U.S. Geological Survey, test well 27
34H391	LF	Glynn	U.S. Geological Survey, test well 16
34H436	LF	Glynn	Georgia Geologic Survey, Coffin Park, test well 1
34H500	LF	Glynn	U.S. Geological Survey, test well 30
35L085	LF	McIntosh	Dan Hawthorne, test well 1
32L005	LF	Wayne	Hopkins No. 2

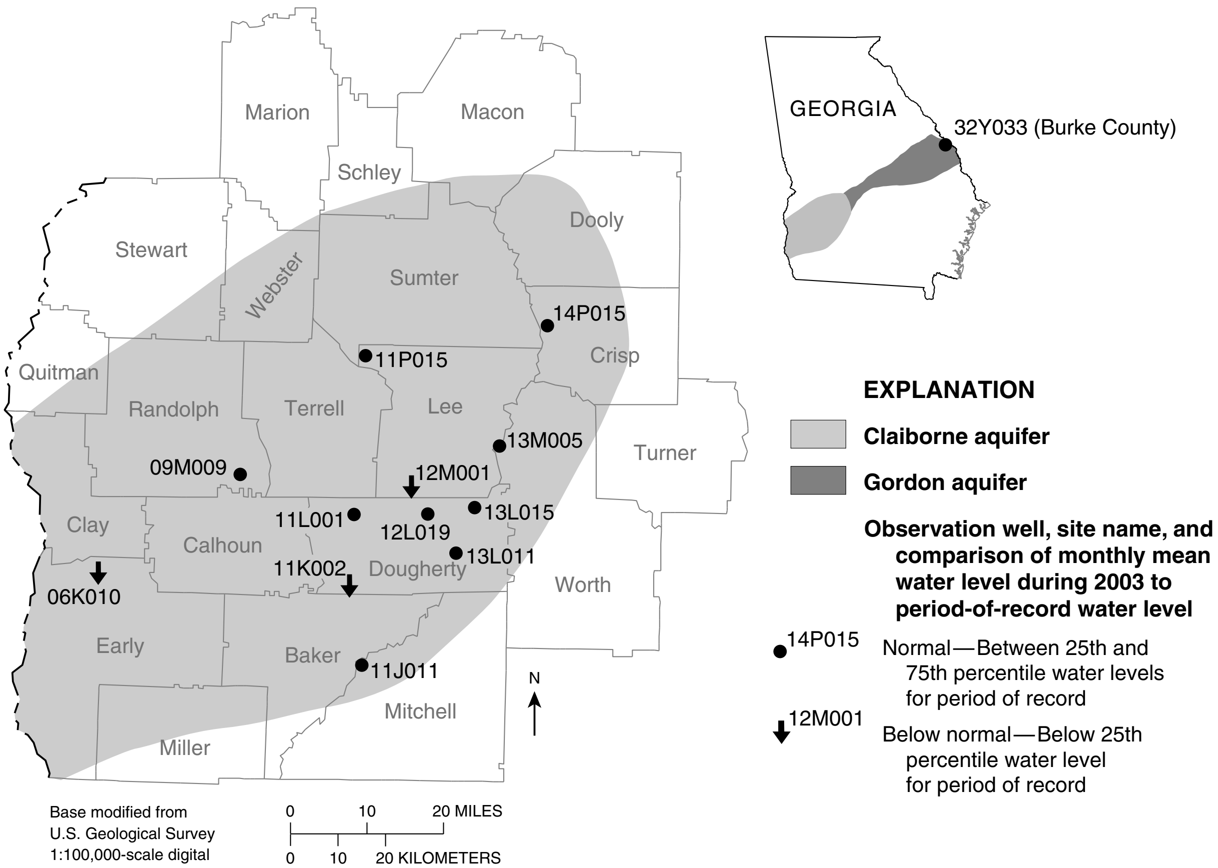
[1]LF, Lower Floridan aquifer; P, Paleocene unit of low permeability; F, Fernandina permeable zone

Claiborne and Gordon Aquifers

Water levels in 12 Claiborne aquifer wells and 1 Gordon aquifer well were used to define ground-water conditions in southwestern and east-central Georgia during 2003 (map and table, facing page). Water in the Claiborne and Gordon aquifers can be confined or unconfined. Water levels in 9 of the 12 Claiborne aquifer wells and 1 Gordon aquifer well were normal during most of 2003, likely reflecting effects of recharge and decreased pumping. Water levels in three wells penetrating the Claiborne aquifer were below normal during 2003; these wells are located in areas near agricultural pumping and likely reflect that pumping.

Water levels in two Claiborne aquifer wells and one Gordon aquifer well (below) were chosen to illustrate monthly mean water levels during 1999–2003 and period-of-record water-level statistics. Water levels continued to fall to below normal during early 2002 but began to rise in the latter half of the year, and continued to rise throughout 2003 so that the water level was above normal in the Claiborne aquifer well 12L019 in Dougherty County. A similar pattern occurs in well 06K010 in Early County, with the water level nearing record lows in the early part of 2002 but beginning to rise into 2003 and continuing to rise into the normal range by the close of 2003. The water level in the Gordon aquifer well 32Y033 in Burke County was below normal during 2002 and the early part of 2003, but record loss in the well in the latter part of the year preclude discussion of most of 2003.





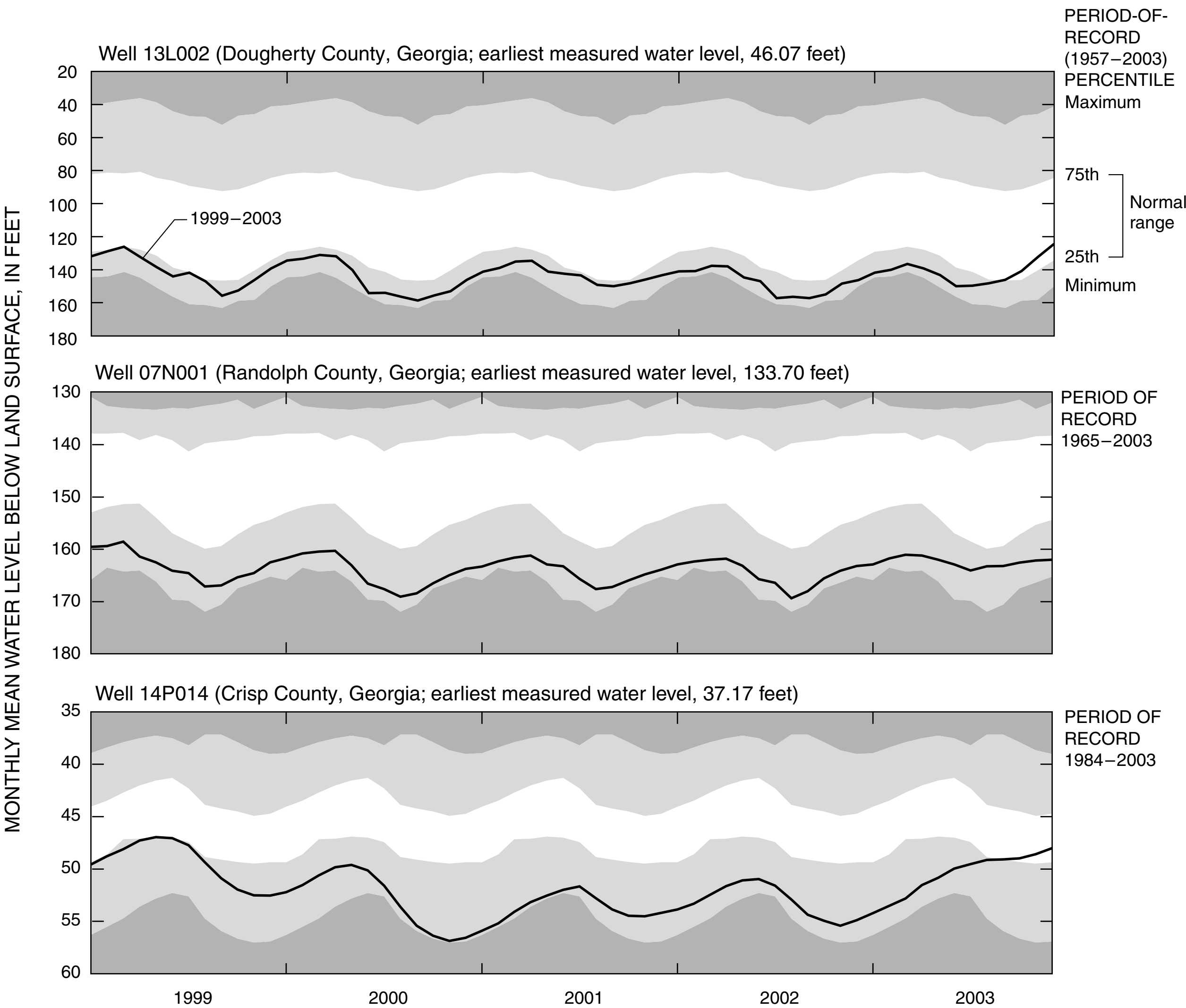
Site name	Water-bearing unit[1]	County	Other identifier
14P015	C	Crisp	Georgia Geologic Survey, Veteran's Memorial State Park, test well 2
11K002	C	Dougherty	U.S. Geological Survey, test well 11
11L001	C	Dougherty	U.S. Geological Survey, test well 4
12L019	C	Dougherty	U.S. Geological Survey, test well 5
13L011	C	Dougherty	U.S. Geological Survey, test well 2
13L015	C	Dougherty	Miller Brewing Company
06K010	C	Early	Georgia Geologic Survey, Kolomoki Mounds State Park, test well 3
11P015	C	Lee	Pete Long, test well 2
12M001	C	Lee	U.S. Geological Survey, test well 8
11J011	C	Mitchell	U.S. Geological Survey, test well DP-10
09M009	C	Randolph	C.T. Martin, test well 1
13M005	C	Worth	U.S. Geological Survey, test well DP-7
32Y033	G	Burke	Brighams Landing, test well 3

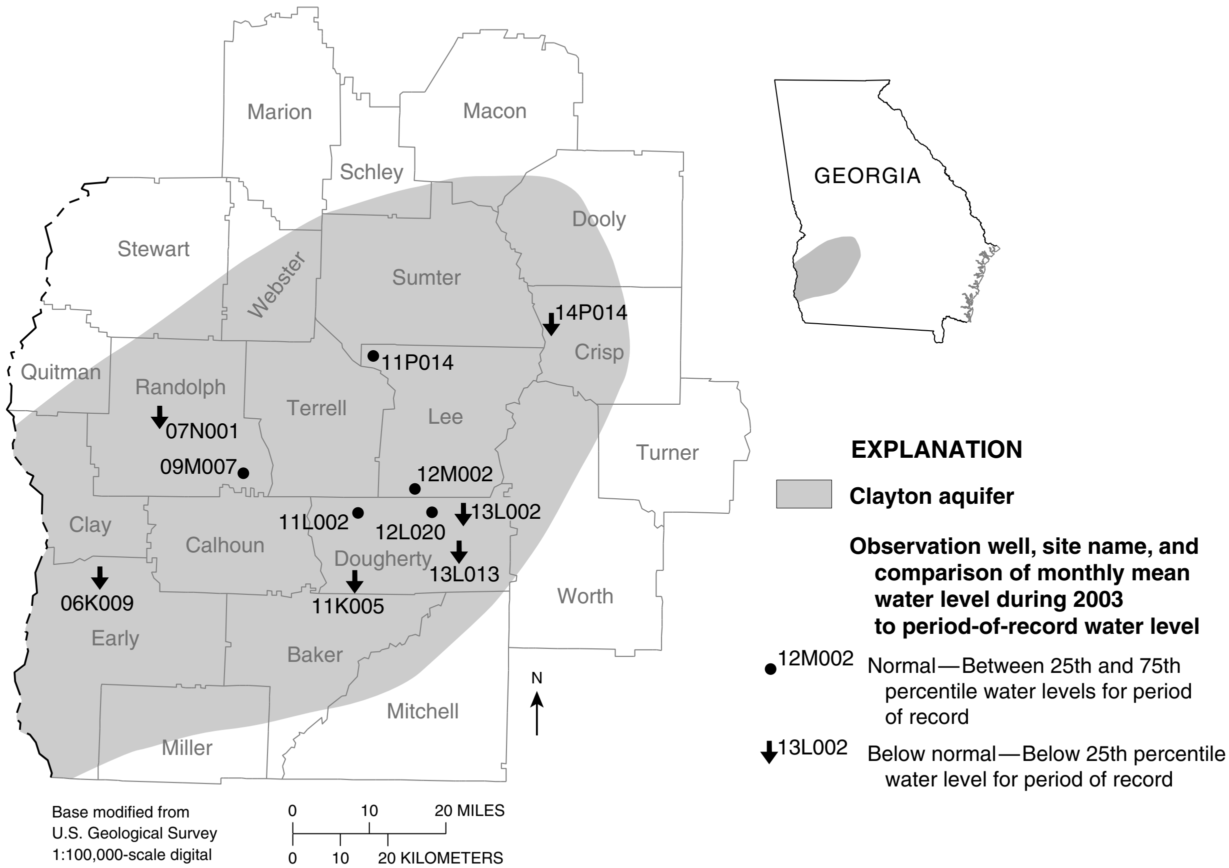
[1]C, Claiborne aquifer; G, Gordon aquifer

Clayton Aquifer

Water levels in 11 wells were used to define ground-water conditions in the Clayton aquifer in southwest Georgia during 2003 (map, facing page). In this area, water in the Clayton aquifer is confined and influenced mostly by pumping. Water levels in 6 of the 11 wells were below normal, with 5 wells within the normal range.

Water-level hydrographs for three Clayton aquifer wells in southwest Georgia (below) were chosen to illustrate monthly mean water levels during 1999–2003 and period-of-record water-level statistics. Long-term water-level decline in all three of the wells is apparent from the hydrographs. The water level in well 13L002 in Dougherty County continued to be below normal until late into 2003, when the water level rose to within the normal range for the first time since 1999. The water level in well 07N001 (Randolph County) also continued below normal for 2002 and 2003, with very little apparent recovery from drought effects. The water level in well 14P014 (Crisp County) began to rise during late 2001—when the water level was below normal—through 2003, when the water level rose into the normal range for the first time since 1999.



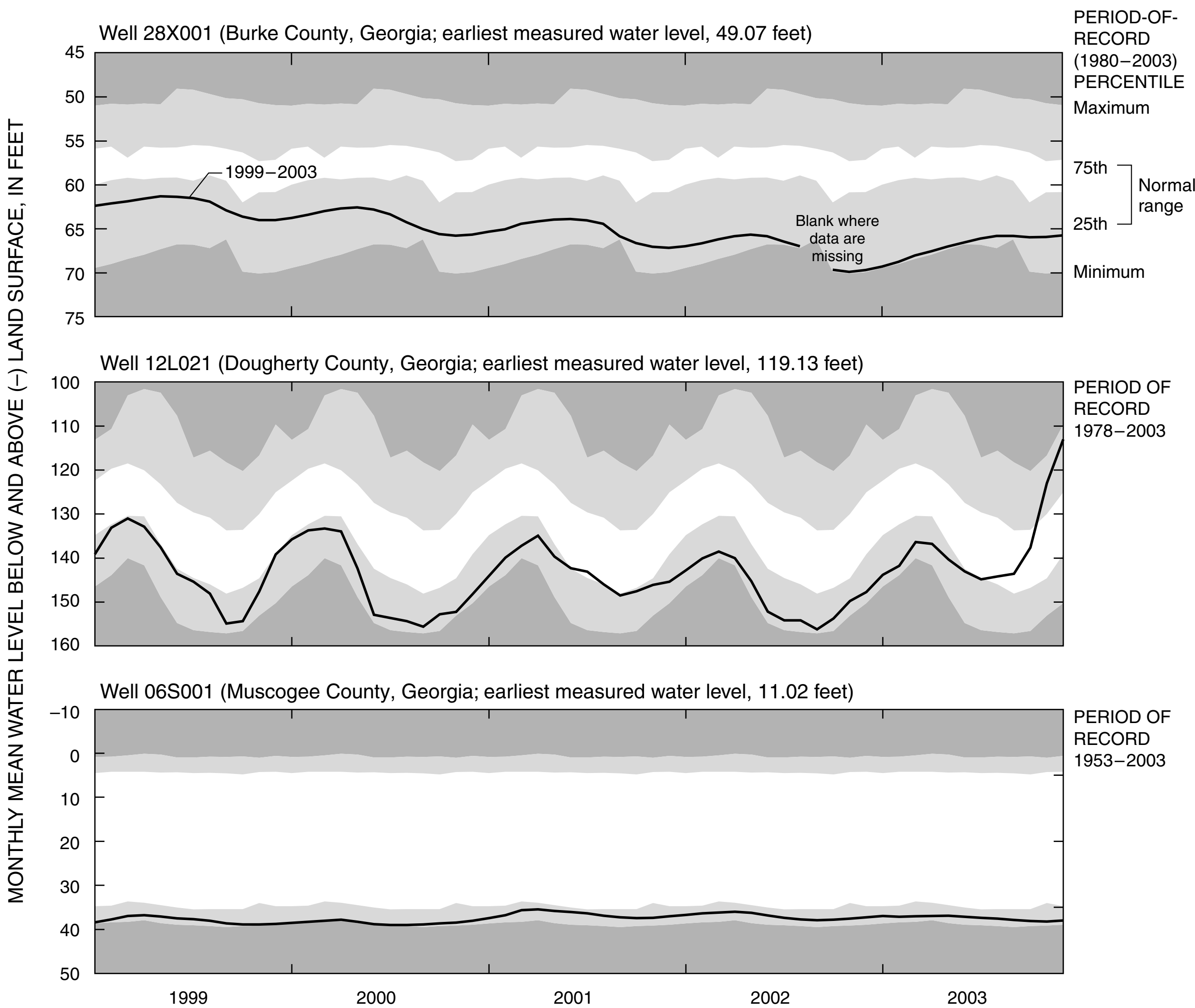


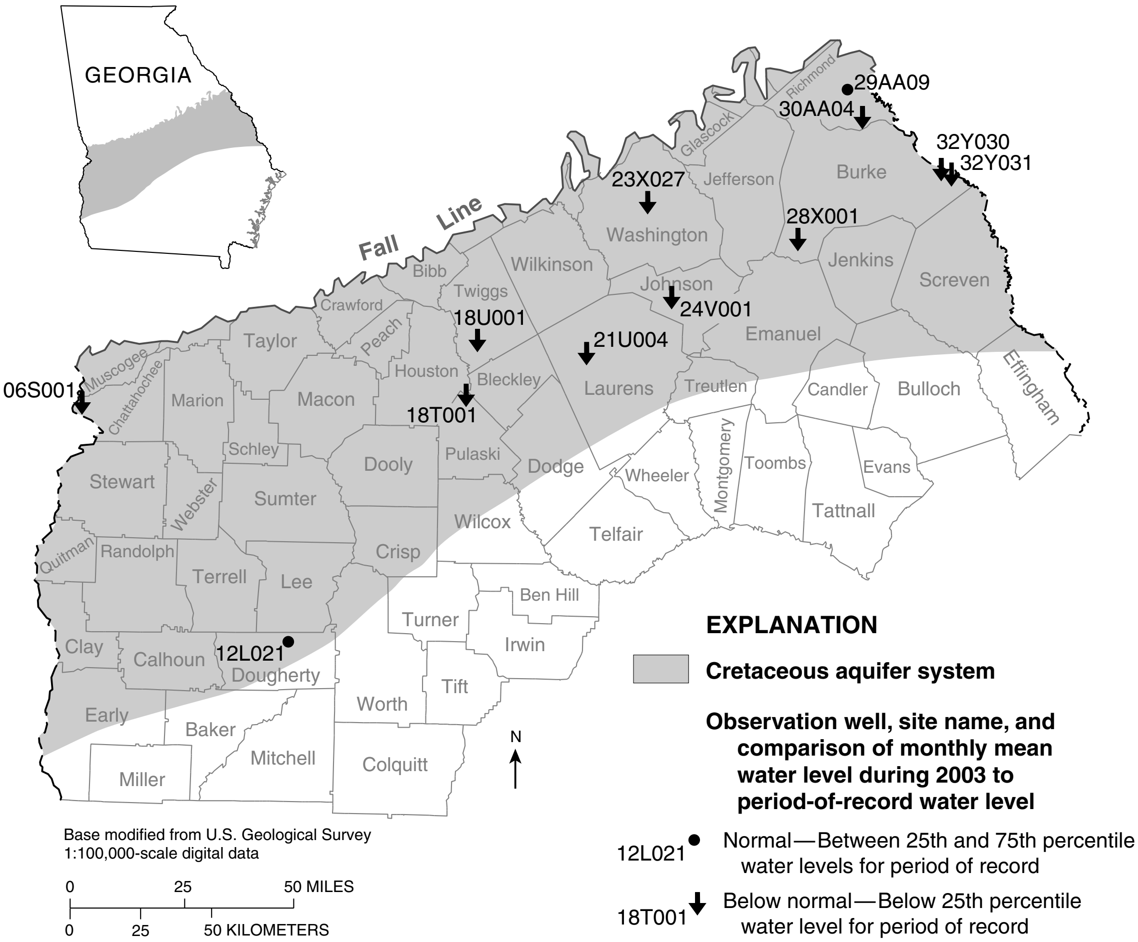
Site name	County	Other identifier
14P014	Crisp	Georgia Geologic Survey, Veteran's Memorial State Park, test well 1
11K005	Dougherty	U.S. Geological Survey, test well 12
11L002	Dougherty	Georgia Geologic Survey, Albany Nursery
12L020	Dougherty	U.S. Geological Survey, test well 6
13L002	Dougherty	Albany Water, Gas, and Light Commission, Turner City 2
13L013	Dougherty	U.S. Geological Survey, test well 7
06K009	Early	Georgia Geologic Survey, Kolomoki Mounds State Park, test well 1
11P014	Lee	Pete Long, test well 1
12M002	Lee	U.S. Geological Survey, test well 9
07N001	Randolph	City of Cuthbert
09M007	Randolph	C.T. Martin, test well 2

Cretaceous Aquifer System

Water levels from 12 wells that penetrate the Cretaceous aquifer system were used to define ground-water conditions throughout central and southwest Georgia during 2003 (map and table, facing page). In this area, water in the Cretaceous aquifer system mostly is confined but can be unconfined in stream valleys. Water levels in 10 of the wells were below the normal range during 2003, reflecting declines related to ground-water pumping. Two wells were within the normal range.

Water-level hydrographs for three Cretaceous aquifer wells in central and southwest Georgia (below) were chosen to illustrate monthly mean water levels during 1999–2003 and period-of-record water-level statistics. Water levels in the three wells generally declined and were below the normal range during most of 1999–2003. In well 28X001 in Burke County, the water level continued the trend of decline through the latter part of 2002 when water levels reached record lows, and although this trend was reversed during 2003, the water level was still below normal at the end of 2003. A similar pattern of long-term decline with a water-level rise during 2003 is apparent in well 12L021 in Dougherty County; however, the water-level rise during 2003 was such that the water level was above normal by the end of 2003. The effects of long-term water-level decline are apparent from the hydrograph of well 06S001 in Muscogee County, where the change in water level has been small during the past 5 years but where heavy agricultural pumping continues.





Site name	Water-bearing unit[1]	County	Other identifier
28X001	M	Burke	U.S. Geological Survey, Midville, test well 1
32Y030	LM	Burke	Brighams Landing, test well 1
32Y031	LD	Burke	Brighams Landing, test well 2
06S001	T	Muscogee	U.S. Army, Fort Benning
12L021	P	Dougherty	U.S. Geological Survey, test well 10
24V001	M	Johnson	U.S. Geological Survey, test well 1
21U004	M	Laurens	Georgia Department of Natural Resources, No. 3
18T001	M	Pulaski	U.S. Geological Survey, Arrowhead test well 1
29AA09	UM	Richmond	Georgia Geologic Survey, Gracewood State Hospital
30AA04	DM	Richmond	Richmond County Water System, U.S. Geological Survey, McBean 2 Survey, McBean 2
18U001	D	Twiggs	Georgia Kraft, U.S. Geological Survey, test well 3
23X027	DM	Washington	City of Sandersville, well 8

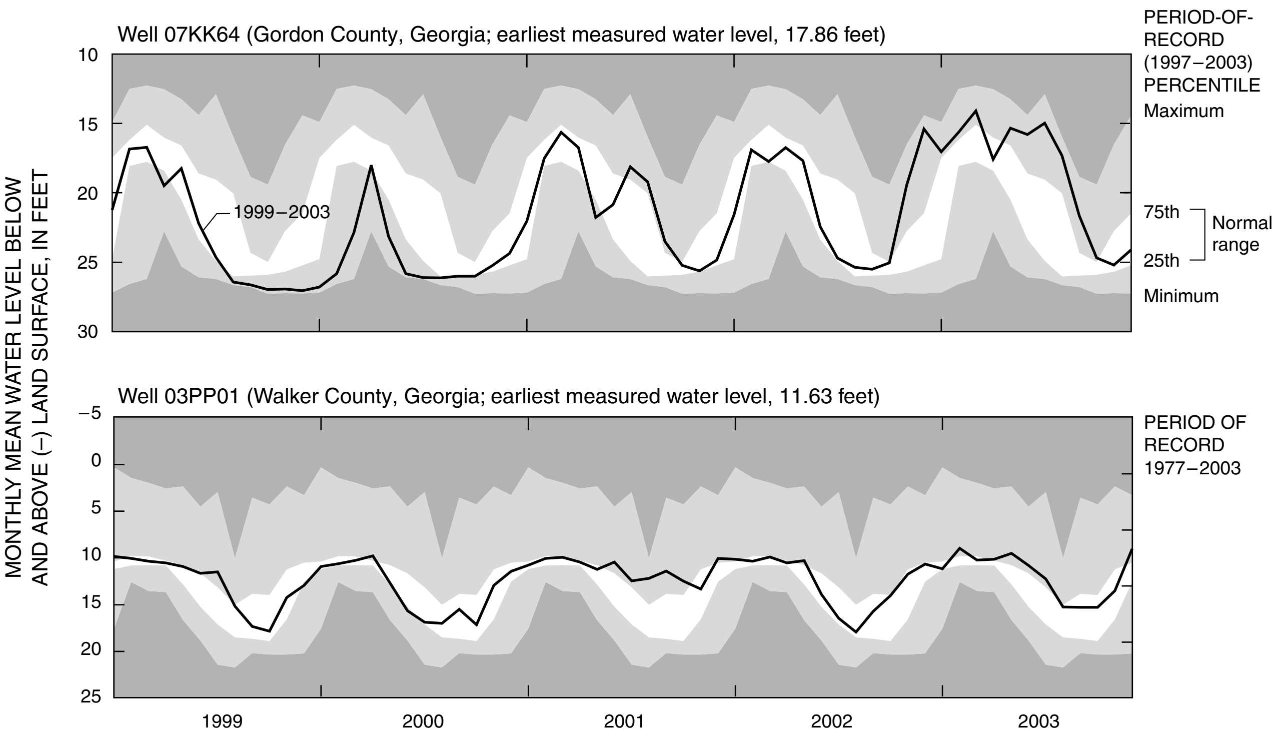
[1]D, Dublin aquifer system; DM, Dublin–Midville aquifer system; LD, Lower Dublin aquifer; LM, Lower Midville aquifer; M, Midville aquifer system; P, Providence aquifer; T, Tuscaloosa Formation; UM, Upper Midville aquifer

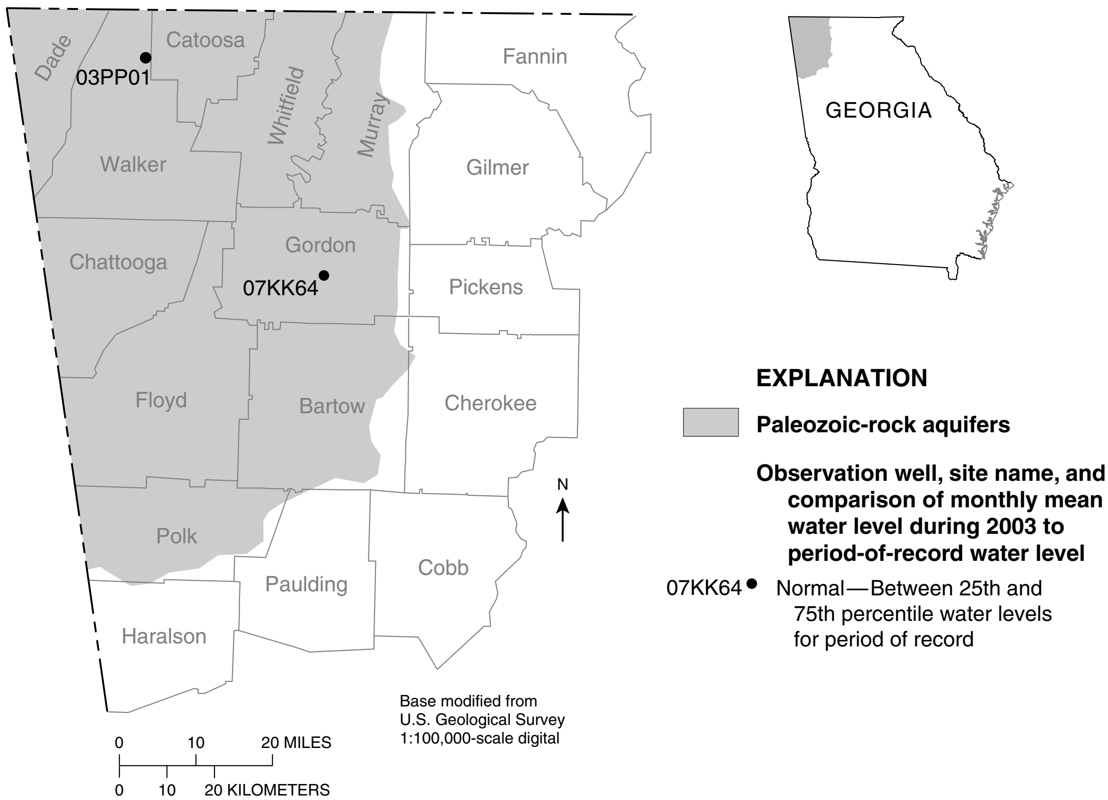
Paleozoic-Rock Aquifers

Water levels were measured in two wells in the Paleozoic-rock aquifers of northwest Georgia during 2003 (map and table, facing page). In this area, water in the Paleozoic-rock aquifers is under confined conditions in wells. Water levels in two wells monitored by the U.S. Geolgoical Survey (USGS) were within the normal range during 2003.

Water-level hydrographs for the two Paleozoic-rock aquifer wells in northwestern Georgia (below) were chosen to illustrate monthly mean water levels during 1999–2003 and period-of-record water-level statistics. It should be stressed that because the USGS monitors only two wells in this aquifer, these statistics represent only a limited area and not the aquifer as a whole.

The water level in well 07KK64 in Gordon County was normal or above normal throughout 2002 and 2003, showing complete recovery from the minimal effects of drought in this area. The water level in well 03PP01 in Walker County also was normal or above normal during 2002 and 2003.



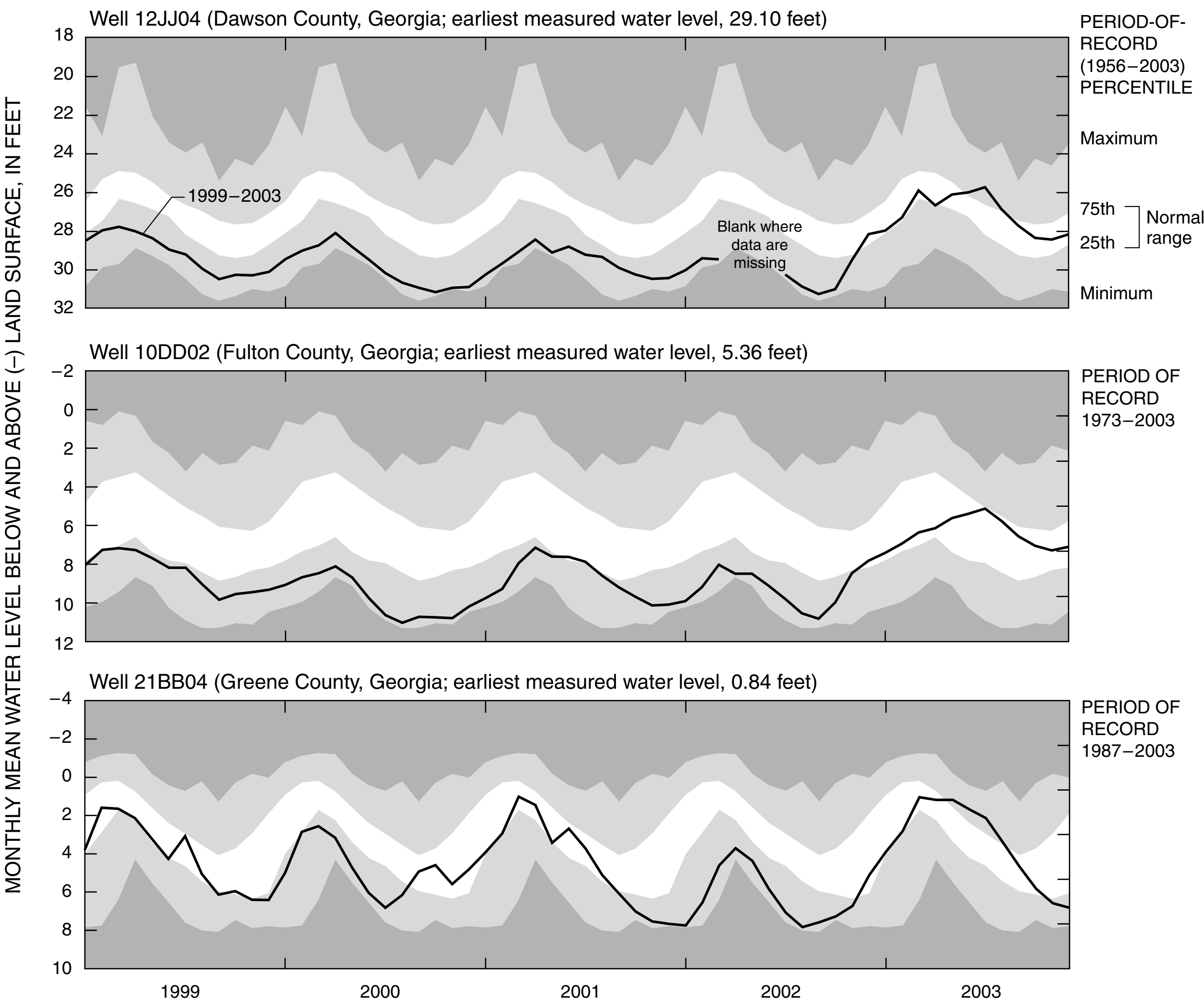


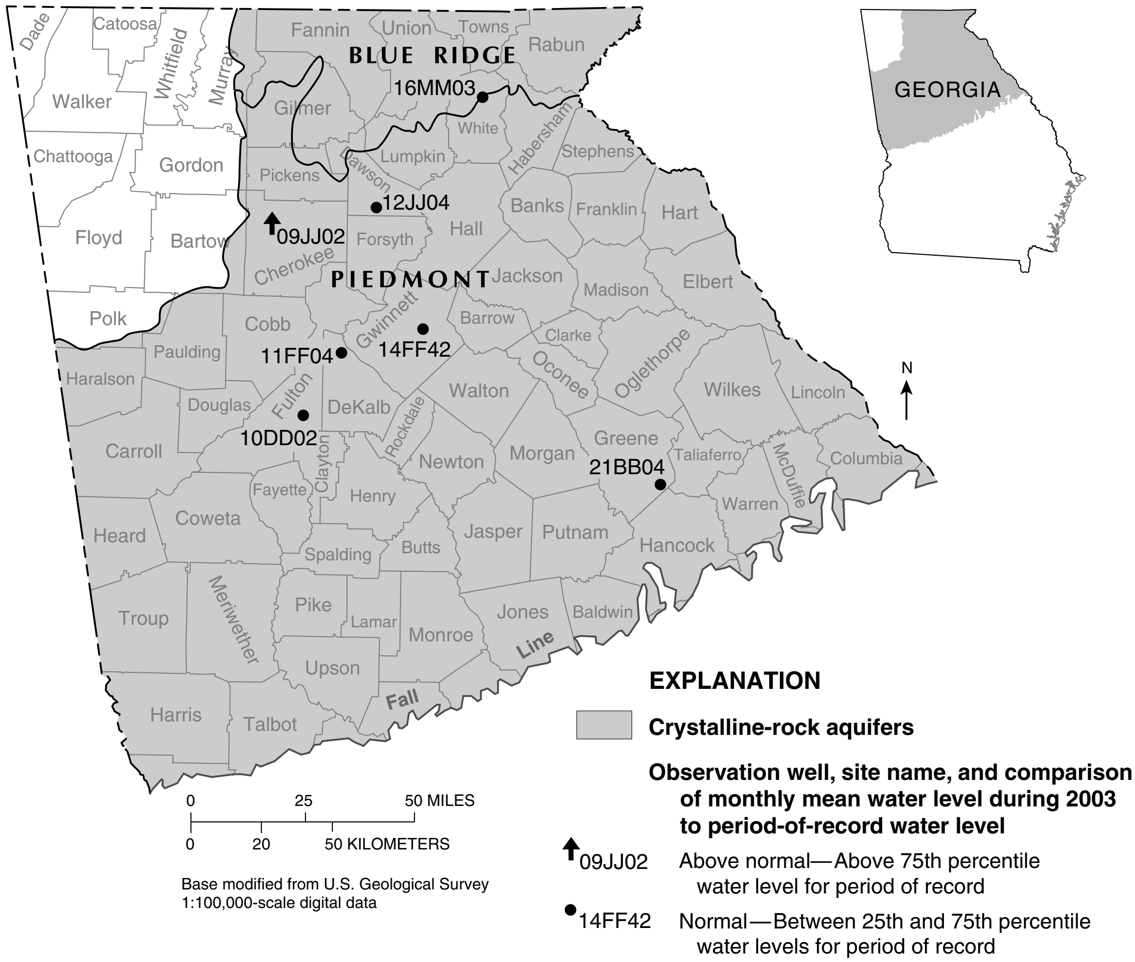
Site name	County	Other identifier
07KK64	Gordon	Calhoun, Georgia, test well 1
03PP01	Walker	U.S. National Park Service, Chickamauga Battlefield Park

Crystalline-Rock Aquifers

Water levels in seven wells were measured in crystalline-rock aquifers in the Piedmont and Blue Ridge physiographic provinces of Georgia during 2003 (map and table, facing page). In this area, water is present in discontinuous joints and fractures and may be confined or unconfined. Crystalline-rock aquifers typically have local extent and can be highly affected by localized water use and climate. Water levels in six of the wells were within the normal range, with the water level in a single well above the normal range during 2003.

Water-level hydrographs for three crystalline-rock aquifer wells (below) were chosen to illustrate monthly mean water levels during 1999–2003 and period-of-record water-level statistics. Effects of drought were still apparent in all three wells during the early part of 2002. Water levels in the three wells began to rise in the latter part of 2002 at the end of the drought. Water levels in well 12JJ04 in Dawson County and well 10DD02 in Fulton County were below normal in early 2002 but began to rise in the latter part of the year and were within the normal range by the middle of and into late 2003. The water level in well 21BB04 in Greene County also was below normal during early 2002 but rose in the latter part of the year. The water level in the well was above normal by the middle of 2003 but had again fallen below normal by the end of the year.

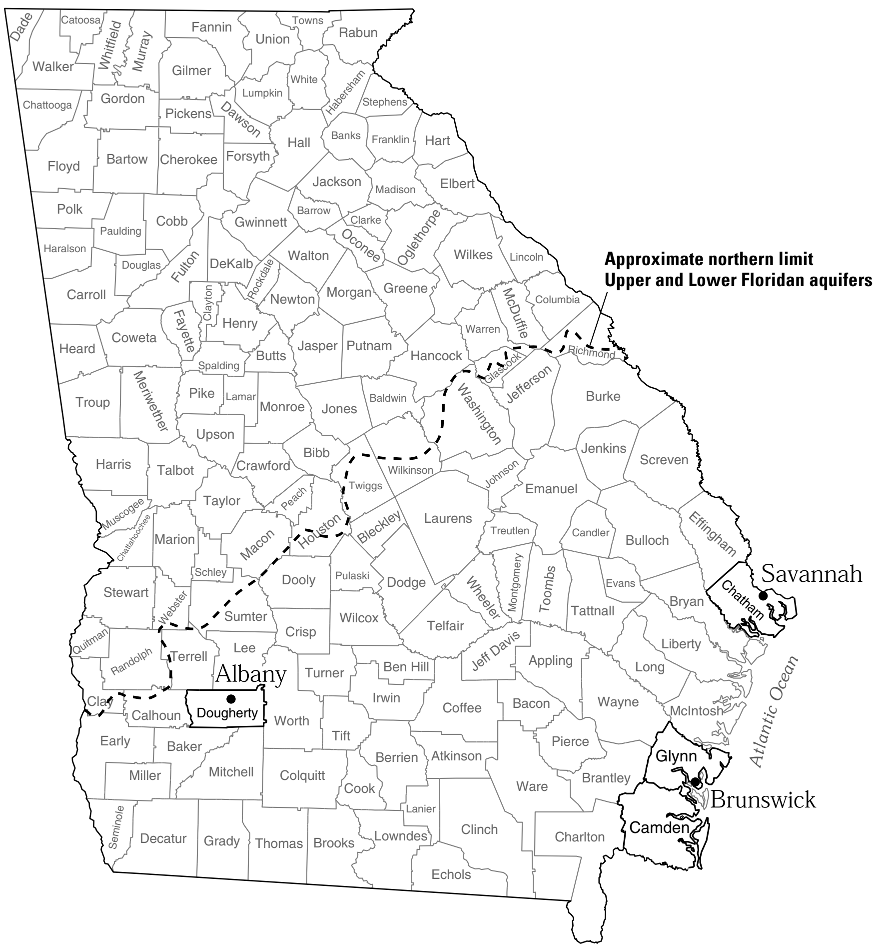




Site name	County	Other identifier
09JJ02	Cherokee	Reinhardt College, well A
12JJ04	Dawson	U.S. Geological Survey, test well 1
11FF04	DeKalb	U.S. Geological Survey, test well 5
10DD02	Fulton	U.S. Army, Fort McPherson
21BB04	Greene	Charles Veazey
14FF42	Gwinnett	Gwinnett County Airport
16MM03	White	Unicoi State Park, well 4

GROUND-WATER QUALITY OF THE UPPER AND LOWER FLORIDAN AQUIFERS

The quality of ground water from the Upper and Lower Floridan aquifers is monitored in the Albany and coastal areas. In the south-central part of Dougherty County near Albany, wells are monitored annually for nitrate concentration. In coastal Georgia, chloride concentration in water from the Upper and Lower Floridan aquifers has been monitored since the 1950s in the Savannah and Brunswick areas and since the early 1990s in the Camden County area.



City of Albany area

The Upper Floridan aquifer is shallow in southwest Georgia where agricultural land use is prevalent, making the ground water susceptible to contamination from nitrates and other chemicals. Monitoring may serve as an early-warning sign of potential contamination of water supplies. Nitrate levels greater than 10 milligrams per liter (mg/L) (the maximum contaminant level for nitrate set by the U.S. Environmental Protection Agency, 2000) have been detected in the area.

Samples were collected from 12 wells during November 2002, from 4 wells and one stream during May 2003, and from 14 wells and one stream during November 2003 southwest of Albany, and analyzed for nitrate concentrations. Nitrate concentrations increased in 8 of the 14 ground-water samples from November of 2002 to November 2003 (table, below). By November 2003, one sample had a concentration greater than 10 mg/L, seven samples had concentrations ranging between 3 and 10 mg/L, and seven samples had concentrations less than 3 mg/L (map, facing page).

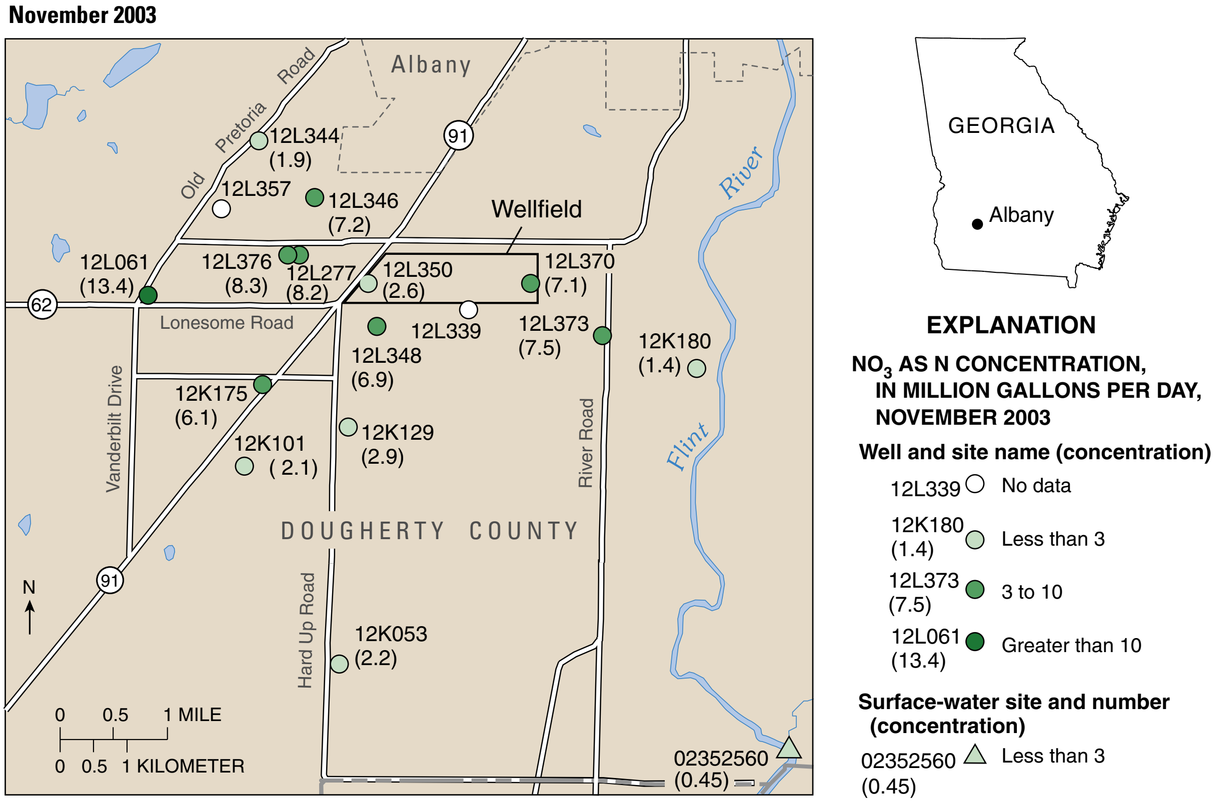
Samples collected during November 2002 and November 2003 were plotted on a trilinear diagram. Both of these diagrams (bottom of facing page) show that the surface-water sample has a different chemical composition than the ground-water samples. The surface-water sample has a higher sodium, potassium, and magnesium content and a lower carbonate and bicarbonate content than do the ground-water samples.

References Cited

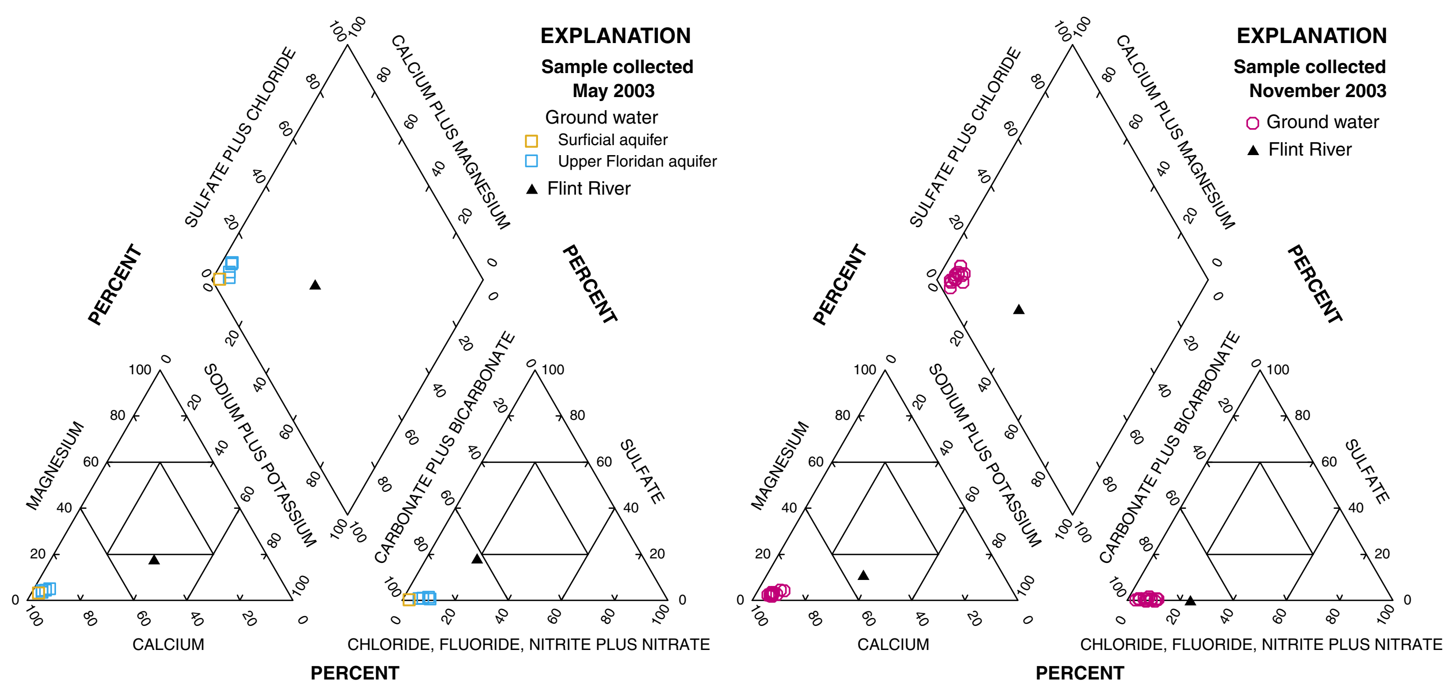
U.S. Environmental Protection Agency, 2000, Maximum contaminant levels (Part 143, National Secondary Drinking Water Regulations): U.S. Code of Federal Regulations, Title 40, Parts 100–149, revised as of July 1, 2000, p. 612–614.

Site name	September 1998 NO_3-N, in mg/L	April 1999 NO_3-N, in mg/L	April 2001 NO_2+NO_3 as N, in mg/L	November 2001 Dissolved NO_2+NO_3 as N, in mg/L	November 2002 NO_3-N, in mg/L	May 2003 NO_3-N, in mg/L	November 2003 NO_3-N, in mg/L
12K053	—	—	—	—	2.0	—	2.2
12K101	1.8	1.9	—	2.2	2.1	—	2.1
12K129	—	—	—	3.1	2.9	—	2.9
12K175	3.8	5.7	5.0	5.9	5.4	—	6.1
12K180	—	—	—	—	1.56	1.7	1.4
12L061	11	12	12	12	12.5	—	13.4
12L277	7.5	6.9	6.5	8.0	6.3	9.0	8.2
12L339	5.9	5.4	—	5.0	—	—	—
12L344	6.0	5.1	2.7	1.6	1.7	—	1.9
12L346	—	—	—	—	—	—	7.2
12L348	—	6.5	6.4	7.1	6.8	—	6.9
12L350	3.0	2.9	—	4.8	5.5	—	2.6
12L357	5.9	3.1	—	2.0	—	—	—
12L370	—	—	—	—	—	—	7.1
12L373	—	—	—	7.2	6.6	8.6	7.5
12L376	—	—	—	—	6.5	8.8	8.3
02352560	—	—	—	—	—	0.4	0.45

NO_3-N, nitrate as nitrogen; $NO_2 + NO_3$ as N, nitrite plus nitrate as nitrogen; mg/L, milligrams per liter; —, no data



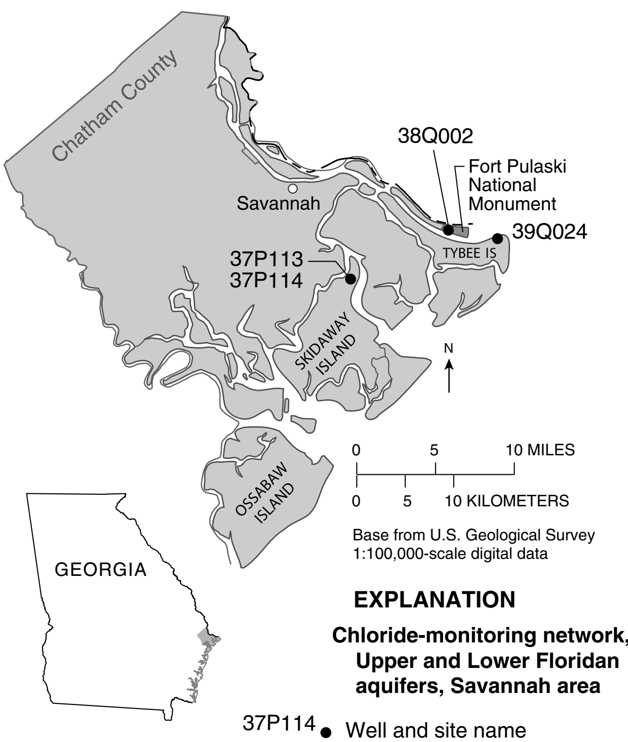
Base from U.S. Geological Survey 1:100,000-scale digital data



City of Savannah area

Procedures for monitoring chloride concentration in the city of Savannah area were modified during 2003 to account for considerable variation in measured concentrations, largely because of partial mixing of water within the interval of the well open to the Upper or Lower Floridan aquifer. Stratification of fresh-water and relatively denser saline water within the open interval result in variations in water chemistry with depth—water having higher chloride concentrations has a higher density than fresher water, resulting in stratification within the open interval.

To provide a more accurate representation of chloride concentrations, a new procedure for monitoring chloride concentration was implemented during December 2003, with focus on three areas—Tybee Island, Fort Pulaski, and Skidaway Island (map, below). These areas represent the most seaward locations in the Savannah area and likely the first locations to be affected by saltwater migrating laterally from the sea. Historical data from these areas indicate that chloride concentration generally increases with depth below land surface.



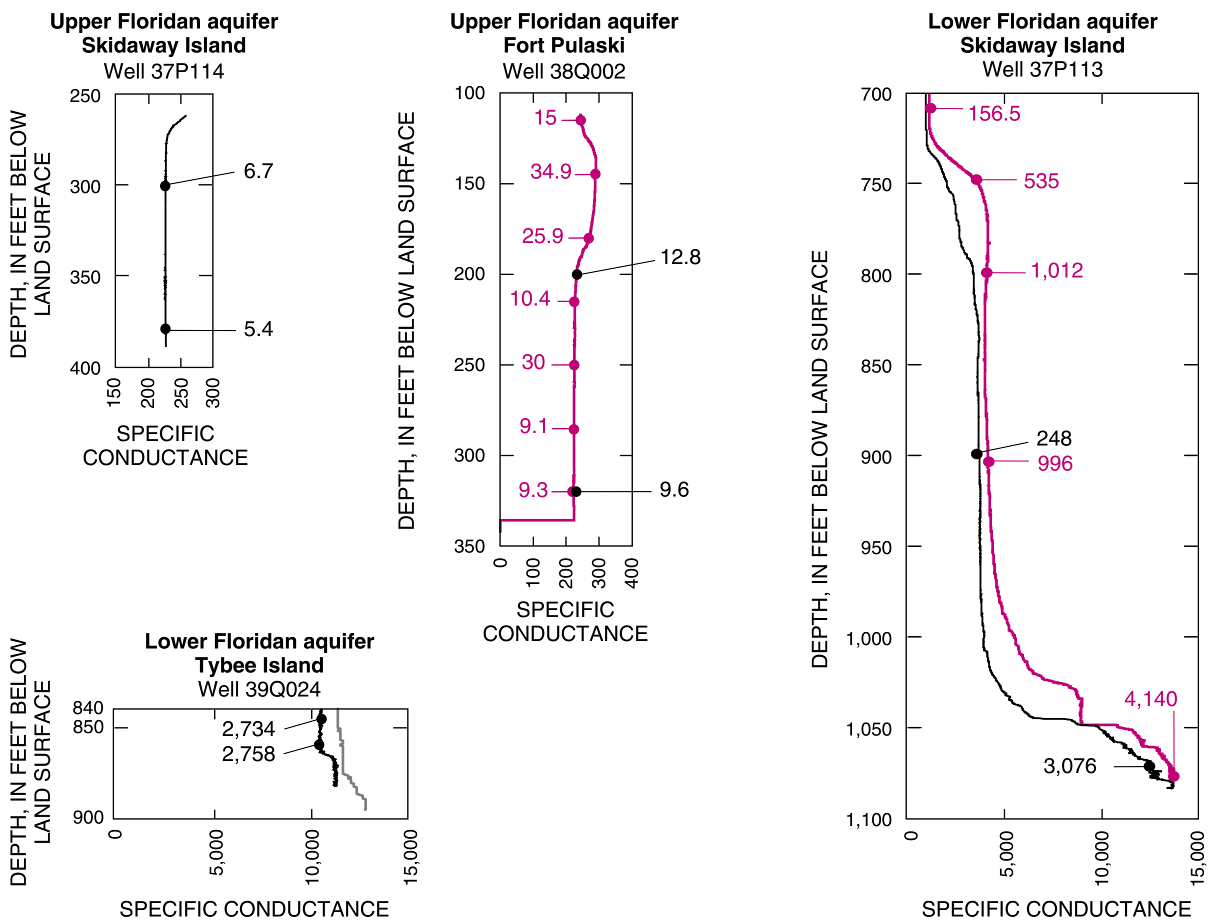
The new procedure involves collection of borehole geophysical logs and grab water samples from open intervals in wells completed in the Upper or Lower Floridan aquifer (table, facing page). Borehole geophysical logs include fluid resistivity, which is an indicator of dissolved-solids concentration; and fluid temperature and caliper, which are indicators of possible breaches in the well casing that might compromise the reliability of water-quality measurements. The inverse of fluid resistivity is fluid conductivity, which is reported herein in units of specific conductance, microsiemens per centi-meter (µS/cm)—higher values reflect higher concentrations of dissolved solids, which are mostly comprised of dissolved chloride in the Savannah area. Grab samples were collected at discrete intervals reflecting the range of specific conductance observed in the well during logging. Analysis of grab samples is summarized in a table and shown together with geophysical logs on the facing page.

At Tybee Island, fluid conductivity (resistivity) logs (facing page) were collected from well 39Q024, completed in the Lower Floridan aquifer, on March 25, 1996, and on December 9, 2003. Grab samples also were collected on December 9, 2003—chloride concentration ranged from 2,734 milligrams per liter (mg/L) at a depth of 845 ft to 2,758 mg/L at a depth of 860 ft. Previous composite samples from the entire open interval (840–880 ft) during 1994–2001 ranged from about 2,700 to 3,400 mg/L. Between 1996 and 2003, fluid conductivity in the open interval of well 39Q024 generally decreased, reflecting a decrease in dissolved solids concentration from an average of 11,780 µS/cm during March 1996 to 10,690 µS/cm during December 2003.

At Skidaway Island, fluid conductivity (resistivity) logs and grab samples were collected on January 6, 2000, and December 10, 2003, from well 37P113, completed in the Lower Floridan aquifer (facing page). Chloride concentrations of grab samples collected from common intervals in well 37P113 decreased during 2000–03. During 2000, concentrations in samples collected at depths of 900 and 1,085 ft were 996 and 4,140 mg/L, respectively; whereas during 2003, concentrations in samples collected at depths of 900 and 1,070 ft were 248 and 3,076 mg/L, respectively. Chloride concentrations in previous composite samples from the entire open interval (700–1,100 ft) during 1985–2001 ranged from about 300 to 1,000 mg/L. Between 2000 and 2003, fluid conductivity in the open interval of well 37P113 generally decreased, reflecting a decrease in dissolved-solids concentration from an average of 4,910 µS/cm during January 2000 to 4,150 µS/cm during December 2003.

Fluid conductivity (resistivity) logs and grab samples were also collected on December 10, 2003, from well 37P114, completed in the Upper Floridan aquifer at Skidaway Island. Water in the Upper Floridan is fresh at this site, with dissolved chloride concentrations of 6.7 mg/L at 300 ft and 5.4 mg/L at 360 ft. Average fluid conductivity in the open interval of this well was 227 µS/cm.

At Fort Pulaski, fluid conductivity (resistivity) logs and grab samples were collected on January 4, 2000, and December 8, 2003, from well 38Q002, completed in the Upper Floridan aquifer (facing page). Unfortunately, the fluid resistivity probe malfunctioned during the December 2003 effort, so a log for this period is not available. Average fluid conductivity during January 2000 in the open interval of the well (110–348 ft) was 243 µS/cm. Chloride concentration of grab samples collected from similar intervals in well 38Q002 showed little change during 2000–03. During December 2003, concentrations in samples collected at depths of 200 and 320 ft were 12.8 and 9.6 mg/L, respectively.



Specific conductance (lines, microsiemens per centimeter) and chloride concentration (closed circles, milligrams per liter) of water, March 1996 (gray), January 2000 (magenta), and December 2003 (black).

Site name	Other identifier	Open interval (feet below land surface)	Water-bearing unit[1]	Grab sample depth (feet below land surface	Chloride concentration (mg/L)	Grab sample depth (feet below land surface	Chloride concentration (mg/L)
				January 2000		December 2003	
39Q024	Georgia Geologic Survey, Tybee Island, test well 1	840–880	L	—	—	860	2,758
				—	—	845	2,734
37P113	Skidaway Institute test well 1	700–1,100	L	710	156.5	900	248
				750	535	1,070	3,076
				800	1,012	—	—
				900	996	—	—
				1,085	4,140		
37P114	Skidaway Institute test well 2	262–400	U	—	—	300	6.7
				—	—	360	5.4
38Q002	U.S. National Park Service, Fort Pulaski Pilot House	110–348	U	115	14.96	200	12.8
				145	34.9	320	9.6
				180	25.85		
				215	10.35		
				250	30		
				285	9.06		
				320	9.28		

[1] L, Lower Floridan aquifer; U, Upper Floridan aquifer; mg/L, milligrams per liter

City of Brunswick area

Water supply in the Brunswick area primarily is obtained from wells completed in the Upper Floridan aquifer. Intense pumping has reduced pressure in the aquifer and resulted in saltwater intrusion locally at Brunswick. Saltwater was first detected in the southernmost part of Brunswick during the late 1950s (Wait, 1965). Saltwater was migrating upward from deep saline zones through breaches in confining units as a result of reduced pressure in the aquifer. By the 1960s, a plume had migrated northward toward two major industrial pumping centers. Currently (June 2003), chloride concentration in water from the Upper Floridan aquifer is above State and Federal secondary drinking-water standards (Georgia Environmental Protection Division, 1997; U.S. Environmental Protection Agency, 2000) in a 2-square-mile area, and exceeds 2,250 milligrams per liter (mg/L) in part of the area.

Chloride concentrations have been monitored in the Brunswick area since the late 1950s. Graphs of chloride concentration in water samples from wells in the upper and lower water-bearing zones of the Upper Floridan aquifer are shown for wells in the south Brunswick area (graphs for wells 34H393 and 34H403, below) and north Brunswick area (graphs for wells 33H127 and 33H133, below). Chloride concentration in water from the Lower Floridan aquifer is shown for well 34H391 in the south Brunswick area (graph, below). More information on the Brunswick area monitoring can be accessed at *http://ga2.er.usgs.gov/Brunswick*

Maps showing the concentration of dissolved chloride in the Upper Floridan aquifer at Brunswick were prepared for June 2002 and June 2003 (facing page). The June 2002 map (43 wells) is similar to the previously published map for 2001 (Leeth and others, 2003) and shows that areas of highest concentration are near the two industrial pumping centers in the northern part of the city, as well as the original area of contamination in the southern part of the city. The map for June 2003 (56 wells) shows the effect of reduced pumping from the Upper Floridan aquifer at an industrial wellfield located along the northeastern extent of the plume. This decrease in pumping changed flow patterns in the aquifer and the distribution of dissolved chloride. In the southern plume area, concentrations increased by as much as 237 mg/L. Directly north, in the central plume area, concentrations decreased by as much as 92 mg/L. In the north-central and western plume area, concentrations increased by as much as 421 mg/L. In parts of the area, concentrations in wells located adjacent to each other varied substantially—for example, in the northeastern plume area, concentrations in well 34H078 dropped by 107 mg/L, whereas concentrations in well 34H413, located about 700 ft northeast of the well increased by 202 mg/L. The reason for this variation is unknown; however, previous investigators have reported the presence of fractures and solution openings in the Brunswick area that could produce highly variable flow conditions in the area (Maslia and Prowell, 1990; Jones and others, 2002).

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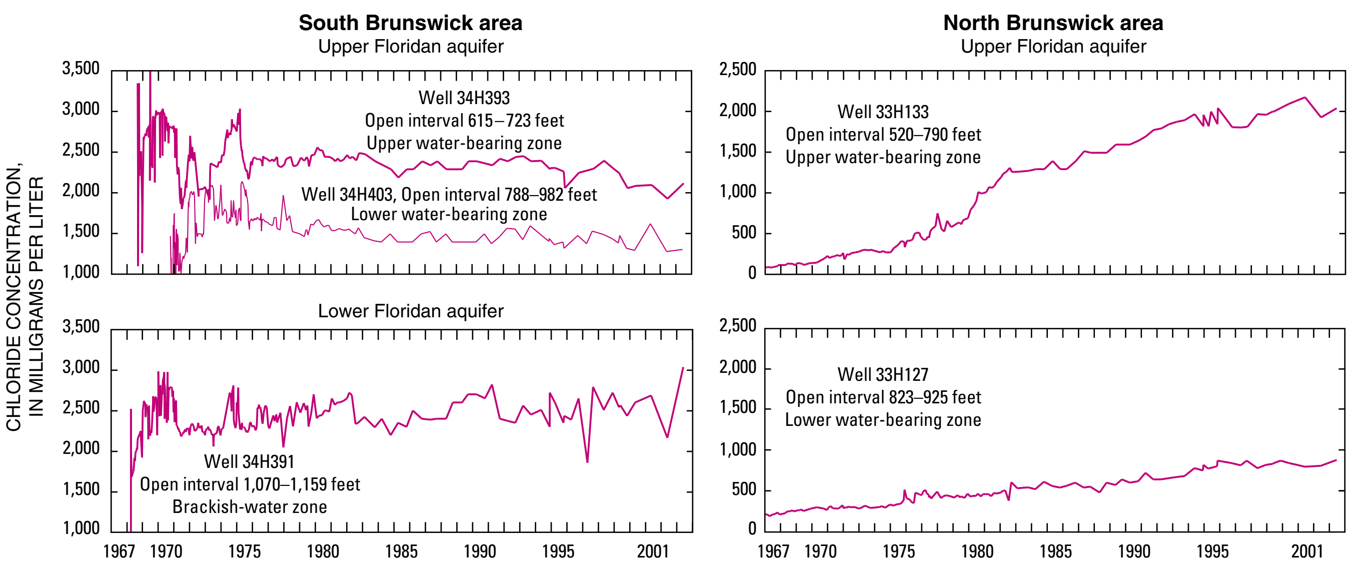
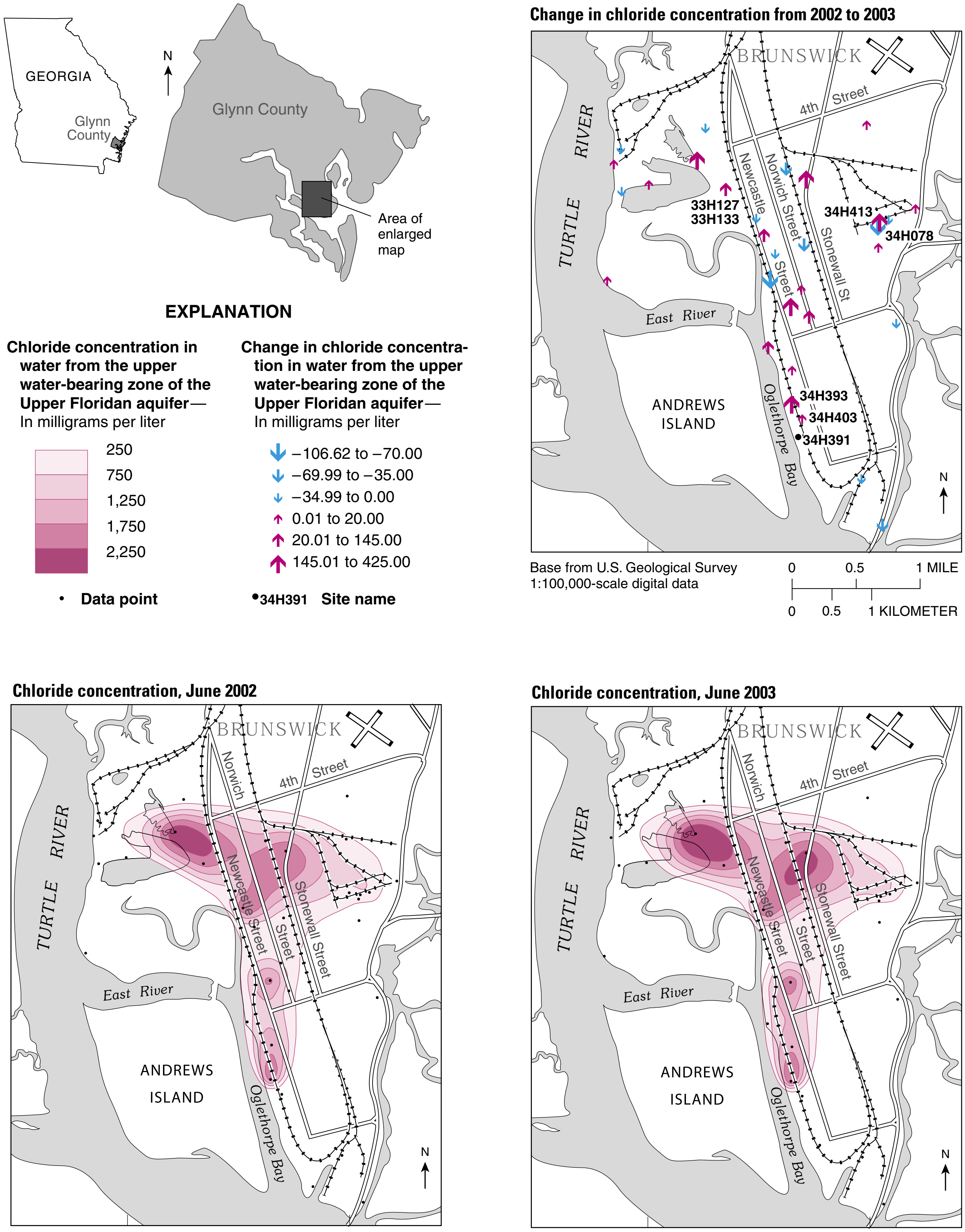



GEORGIA
Glynn County
N
Glynn County
Area of enlarged map
EXPLANATION
Chloride concentration in water from the upper water-bearing zone of the Upper Floridan aquifer—
In milligrams per liter
250
750
1,250
1,750
2,250
Data point
Change in chloride concentration in water from the upper water-bearing zone of the Upper Floridan aquifer—
In milligrams per liter
–106.62 to –70.00
–69.99 to –35.00
–34.99 to 0.00
0.01 to 20.00
20.01 to 145.00
145.01 to 425.00
34H391 Site name
Change in chloride concentration from 2002 to 2003
BRUNSWICK
4th Street
TURTLE RIVER
Newcastle Street
Norwich Street
Stonewall St
33H127
33H133
34H413
34H078
East River
ANDREWS ISLAND
Oglethorpe Bay
34H393
34H403
34H391
N
Base from U.S. Geological Survey
1:100,000-scale digital data
0 0.5 1 MILE
0 0.5 1 KILOMETER
Chloride concentration, June 2002
BRUNSWICK
Norwich
4th Street
TURTLE RIVER
Newcastle Street
Street
Stonewall Street
East River
ANDREWS ISLAND
Oglethorpe Bay
N
Chloride concentration, June 2003
BRUNSWICK
Norwich
4th Street
TURTLE RIVER
Newcastle Street
Street
Stonewall Street
East River
ANDREWS ISLAND
Oglethorpe Bay
N

Camden County area

Chloride concentrations in the Upper Floridan aquifer have been monitored periodically in the Camden County area from 1959 to 1997 and annually from 1994 to the present. During 2002–03, the U.S. Geological Survey collected 82 water samples from 35 wells. Six of the wells (table below) are part of a network maintained for the St. Johns Water Management District in Florida. The other 29 wells were sampled as part of a study evaluating the effects of decreased ground-water withdrawal in the Camden County, St. Marys area because of the closure of the Durango Paper Mill during October 2002. Data from these wells indicate chloride concentrations generally ranged from 30 to 50 milligrams per liter (mg/L), with the exception of well 33D061, which had concentrations ranging from 48 to 184 mg/L during 1982–2003. The source of the high chloride concentration in this well is not known; however, Rose (2001, 2002) evaluated the potential for saltwater intrusion in Camden County. In addition in adjacent Glynn County, several investigators (Wait, 1965; Gregg and Zimmerman, 1974; Krause and Randolph, 1989; Clarke and others, 1990; Jones and others, 2002) have documented chloride contamination of the Upper Floridan aquifer from deep saline zones.

References Cited

Clarke, J.S., Hacke, C.M., and Peck, M.F., 1990, Geology and ground-water resources of the coastal area of Georgia: Georgia Geologic Survey Information Circular 113, 106 p.

Gregg, D.O., and Zimmerman, E.A., 1974, Geologic and hydrologic control of chloride contamination in aquifers at Brunswick, Glynn County, Georgia: U.S. Geological Water-Supply Paper 2029-D, 44 p.

Jones, L.E., Prowell, D.C., and Maslia, M.L., 2002, Hydrogeology and water quality (1978) of the Floridan aquifer system at U.S. Geological Survey TW-26, on Colonels Island, near Brunswick, Georgia: U.S. Geological Survey Water-Resources Investigations Report 02-4020, 44 p.

Krause, R.E., and Randolph, R.B., 1989, Hydrology of the Floridan aquifer system in southeast Georgia and adjacent parts of Florida and South Carolina: U.S. Geological Survey Professional Paper 1403-D, 65 p.

Rose, Seth, 2001, Susceptibility of the Upper Floridan aquifer in Camden County to salt water intrusion: Georgia Geologic Survey Project Report 46, p. 42.

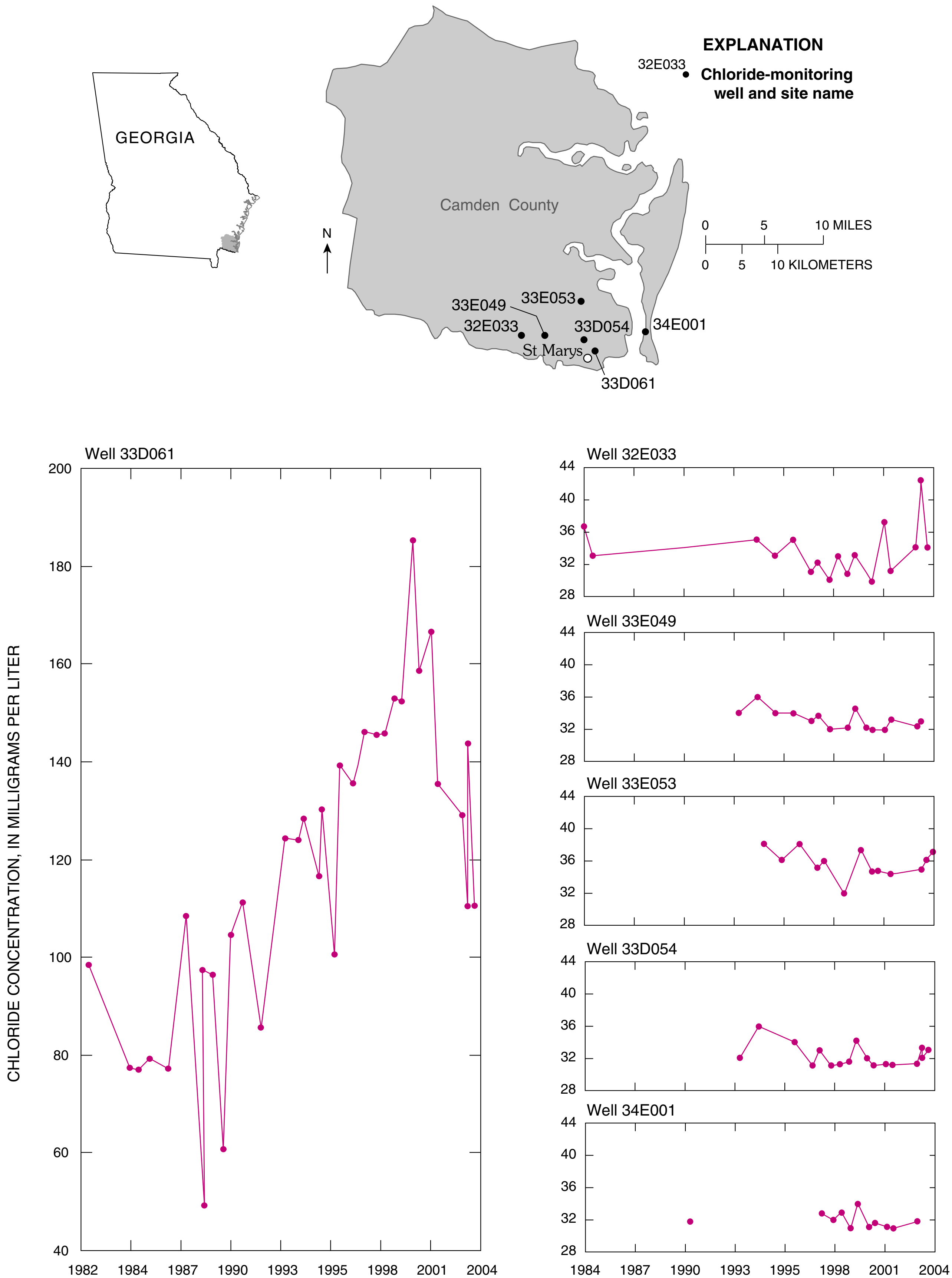
Rose, Seth, 2002, Salt-water intrusion potential for Camden County, Georgia: Georgia Geologic Survey Project Report 49, p. 78.

Wait, R.L., 1965, Geology and occurrence of fresh and brackish ground water in Glynn County, Georgia: U.S. Geological Survey Water-Supply Paper 1613-E, 94 p.

Chloride-monitoring network in the Upper Floridan aquifer, Camden County, Georgia
[mg/L, milligrams per liter, —, no data]

Site name	Other identifier	Open interval (feet below land surface)	Chloride concentration September 2002[1] (mg/L)	Chloride concentration January 2003[1] (mg/L)	Chloride concentration May 2003[1] (mg/L)
32E033	Georgia Welcome Center	420–600	30	34	41
33D054	St. Marys 2	563–1,000	31	31	32
33D061	Gilman Paper Company 11	550–1,090	175	129	110
33E049	Osprey Cove	522–840	31	32	33
33E053	Kings Bay 2	570–900	33	35	36
34E001	Cumberland Island Georgia Geologic Survey test well 1	540–640	—	32	33

[1]Bill Osborne, St. Johns River Water Management District, written commun., 2004

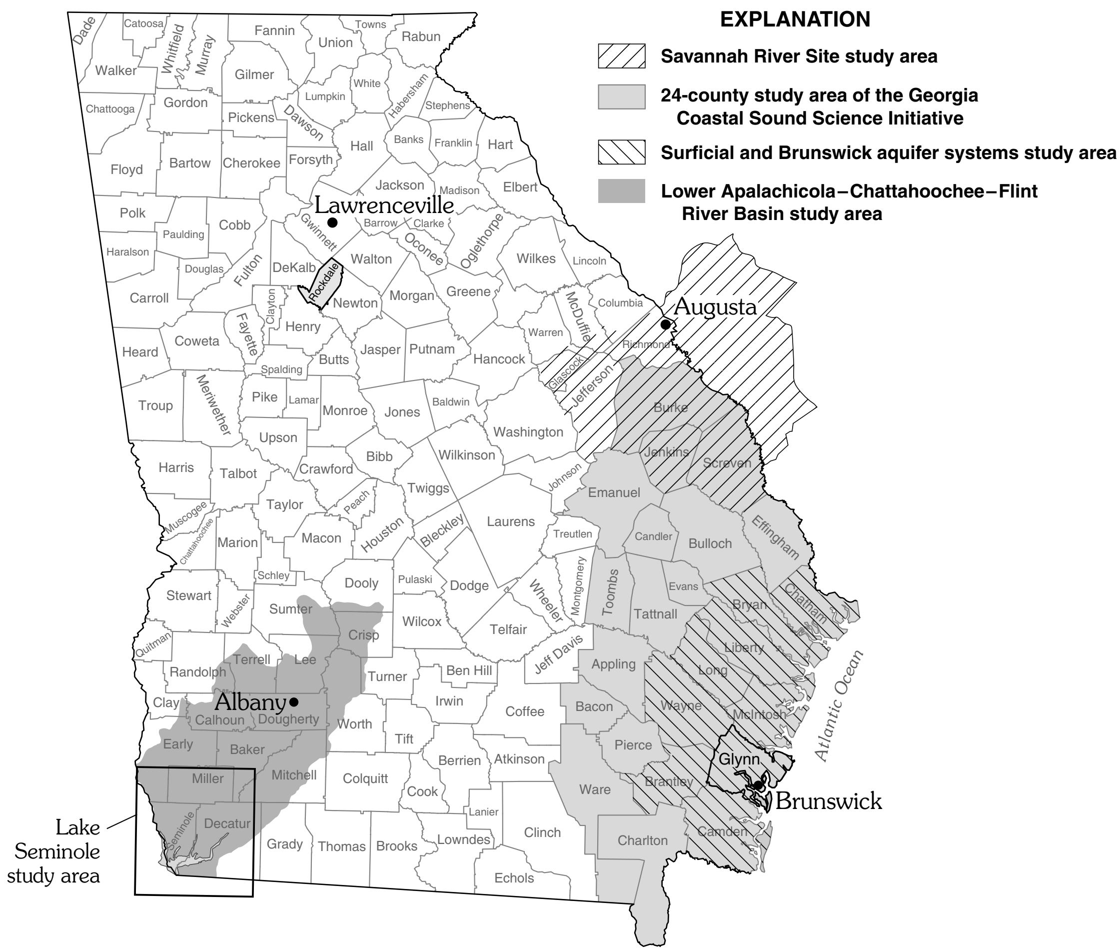


GEORGIA
Camden County
N
EXPLANATION
32E033
Chloride-monitoring well and site name
0 5 10 MILES
0 5 10 KILOMETERS
33E049
33E053
32E033
33D054
34E001
St Marys
33D061
Well 33D061
CHLORIDE CONCENTRATION, IN MILLIGRAMS PER LITER
200
180
160
140
120
100
80
60
40
1982 1984 1987 1990 1993 1995 1998 2001 2004
Well 32E033
Well 33E049
Well 33E053
Well 33D054
Well 34E001
44
40
36
32
28
1984 1987 1990 1993 1995 1998 2001 2004

SELECTED GROUND-WATER STUDIES IN GEORGIA, 2002–03

The U.S. Geological Survey (USGS)—in cooperation with local, State, and other Federal agencies—conducted several studies in Georgia and adjacent states during 2002–03 to better define the occurrence and quality of ground water and to monitor hydrologic conditions. Summaries of current USGS studies in Georgia are provided in the following sections and include information regarding:

- Study title
- Study area location
- Study chief
- Cooperating agency or agencies
- Year study began
- Problem
- Objectives
- Progress and significant results



Assessment of Ground-Water Flow near the Savannah River Site, Georgia and South Carolina

Study Chief Gregory S. Cherry

Cooperator U.S. Department of Energy

Year Started 2002

Problem

The U.S. Department of Energy (DOE) Savannah River Site (SRS) has manufactured nuclear materials for national defense since the early 1950s. A variety of hazardous materials—including radionuclides, volatile organic compounds, and trace metals—are either disposed of or stored at several locations at the SRS. As a result, contamination of ground water has been detected at several locations within the site and concern has been raised about the possible migration of water-borne contaminants offsite. Two issues have been raised: (1) is ground water flowing from the SRS and beneath the Savannah River into Georgia?; and (2) under what pumping scenarios could such ground-water movement occur? To address these concerns, the U.S. Geological Survey (USGS), in cooperation with the DOE, conducted a comprehensive study during 1991–97 that simulated ground-water flow and stream-aquifer relations in the vicinity of the SRS. These ground-water simulations are limited by simplification of the conceptual model, which was based on available data through 1992. Large increases in ground-water pumping in Burke and Screven Counties, Georgia, since 1992 and a pronounced drought during 1998–2002 may have changed hydraulic gradients near the river and affected the potential for transriver flow. To provide a more accurate and up-to-date evaluation of transriver flow near the SRS, the earlier model is being updated to incorporate new data and simulate 2002 conditions. The revised model will be used to simulate a variety of water-management scenarios that could impact transriver flow in the SRS area.

Objectives

- Update the previously developed ground-water flow model to better define present-day (2002) ground-water flowpaths near SRS.
- Utilize the 2002 calibrated model to identify ground-water flowpaths and quantitatively describe current ground-water flowpaths near SRS under a variety of hypothetical pumping scenarios.

Progress and Significant Results, 2002–03

- Collected water-level measurements from 282 wells in Georgia and South Carolina during September 9–13, 2002, and constructed potentiometric-surface maps for four major aquifers. The potentiometric-surface maps were integrated into a Geographic Information System to determine the horizontal and vertical hydraulic gradients for the aquifers along with any interaction with streams and rivers. The water-level measurements were used to adjust boundary conditions and determine if any additional calibration is required to the model under 2002 hydrologic conditions.
- Updated ground-water use estimates within the eight-county study area to reflect the changes that have occurred since the previous study (Clarke and West, 1998). The major increase in ground-water use between 1995 and 2000 is evident for Burke, Jefferson, and Screven Counties, Ga.; and Allendale and Barnwell Counties, S.C. In these counties, ground-water use for irrigation increased from 16.7 million gallons per day (Mgal/d) during 1995 to 53.1 Mgal/d during 2000 and irrigated acreage increased from 61,690 acres during 1995 to 97,690 acres during 2000 (Fanning, 2003).
- Converted existing regional ground-water model to Graphical User Interface (GUI) environment to generate current model input for MODFLOW-2000 simulations. The new MODFLOW GUI incorporates the hydrogeologic framework (Falls and others, 1997) into the various model layers and is essential when performing three-dimensional particle-tracking analysis.
- Adjusted specified heads in the source-sink layer (A1) of the model to conform with the 2002 potentiometric-surface map of the Upper Three Runs aquifer, and lowered the specified heads along the lateral boundaries of the model in layers A2–A7 based on observation points in each aquifer. The specified heads in the source-sink layer were lowered to reflect the decline in water levels that resulted from the drought that occurred from 1998 to 2002.
- Evaluated ground-water model under steady-state conditions for 2002 to determine if additional calibration is necessary. The model simulations conducted using updated pumping estimates, observed aquifer heads, and recharge rates from the source-sink layer (A1), indicated that no additional calibration was required.

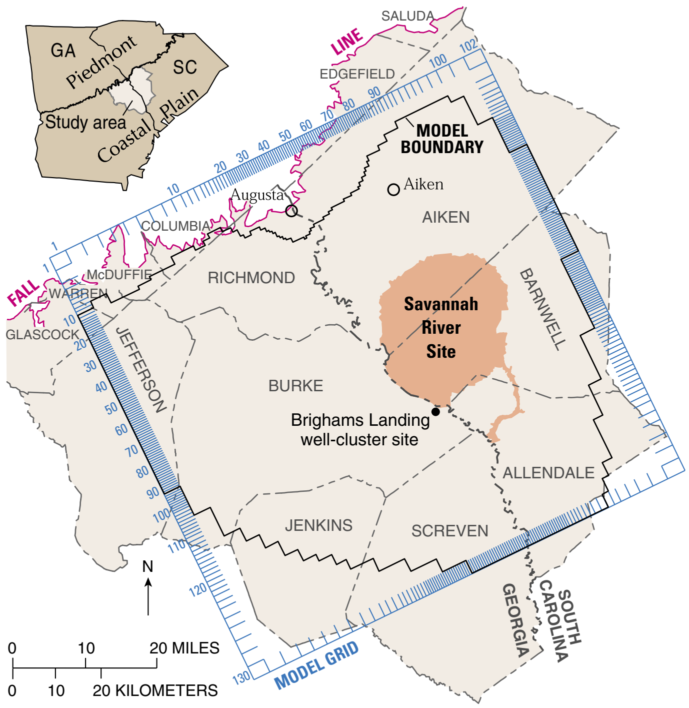
References Cited

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: U.S. Geological Survey Water-Resources Investigations Report 98-4062, 134 p.

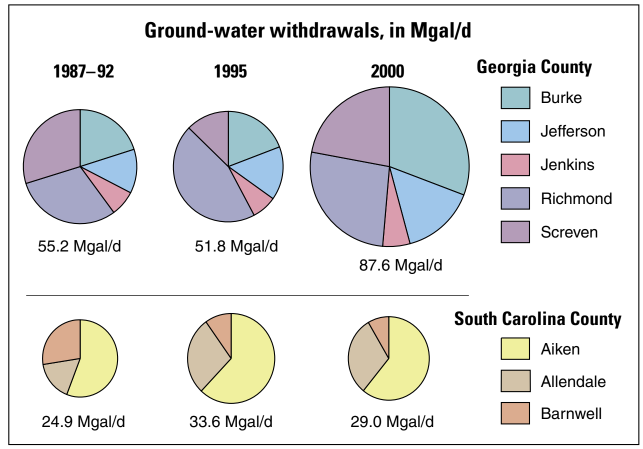
Falls, W.F., Baum, J.S., Harrelson, L.G., Brown, L.H., and Jerden, J.L., 1997, Geology and hydrogeology of Cretaceous and Tertiary strata, and confinement in the vicinity of the U.S. Department of Energy Savannah River Site, South Carolina and Georgia: U.S. Geological Survey Water-Resources Investigations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

Fanning, J.L., 1997, Water use in Georgia by county for 1995: Georgia Geologic Survey Information Circular 101, 95 p.

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.

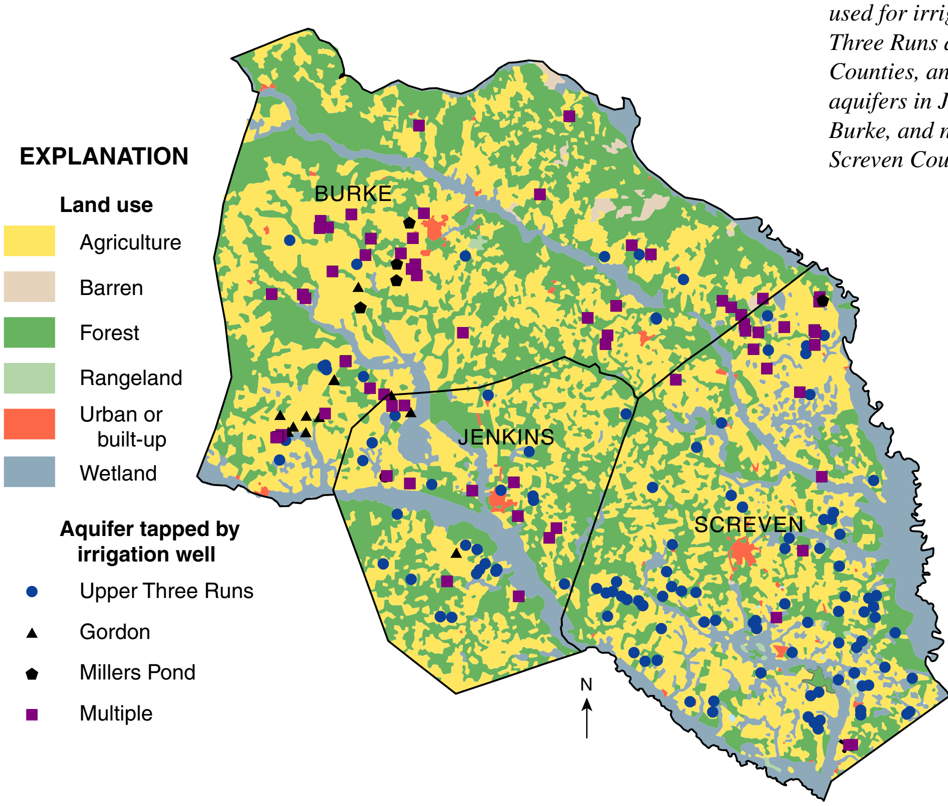


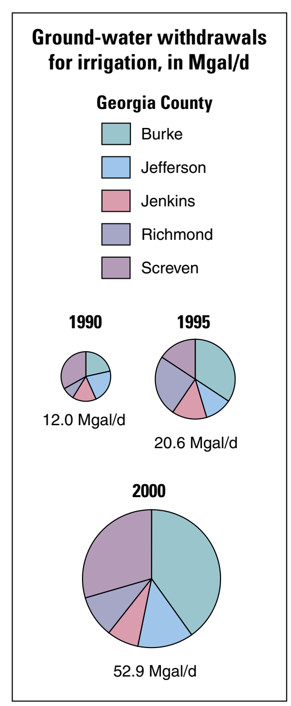
The 5,147-square-mile study area is in the Coastal Plain physiographic province, and is the same area investigated during the earlier 1991–97 study, including the SRS and adjacent parts of Georgia and South Carolina. Coastal Plain sediments consist of layers of silt, clay, sand, and minor amounts of limestone ranging in age from Cretaceous to Tertiary. Sediments dip to the southeast away from the Fall Line and reach a maximum thickness of about 2,700 feet near the southern boundary of the study area.



Data on ground-water use in the eight-county study area show a substantial increase since the earlier USGS study. Clarke and West (1998) reported that during 1987–92 total ground-water use was about 80 Mgal/d. By 1995, the total ground-water use was about 85.4 Mgal/d (Fanning, 1997). Available data for 2000 (Fanning, 2003; W.J. Stringfield, U.S. Geological Survey, written commun., 2002) show that total ground-water use was about 117 Mgal/d.

The major increase in ground-water use between 1995 and 2000 is evident for Burke, Jefferson, and Screven Counties, Ga. In these counties, ground-water use for irrigation increased from 12.6 Mgal/d during 1995 to 43.8 Mgal/d during 2000, and irrigated acreage increased from 53,520 acres during 1995 to 76,380 acres during 2000 (Fanning, 2003). In the Georgia part of the study area, the majority of ground water used for irrigation is withdrawn from the Upper Three Runs aquifer in Jenkins and southern Screven Counties, and from the Upper Three Runs and Gordon aquifers in Jefferson, Burke, and northern Screven Counties.





Assessment of Surficial and Brunswick Aquifer Systems, Coastal Georgia

Study Chief Sherlyn Priest

Cooperators Georgia Department of Natural Resources
Environmental Protection Division
Camden County
Glynn County
Liberty County Development Authority
McIntosh County
City of Ludowici

Year Started 2002

Problem

The Upper Floridan aquifer is the primary source of water in the coastal area of Georgia. Declining water levels and localized occurrences of saltwater contamination in the Upper Floridan aquifer have resulted in the Georgia Environmental Protection Division capping permitted withdrawals at 1997 rates from the Upper Floridan aquifer in parts of the coastal area. These restrictions have prompted interest in developing supplemental sources of ground water, including the surficial and Brunswick aquifer systems. The surficial aquifer system includes the water table and semiconfined zones; the Brunswick aquifer system includes the upper and lower Brunswick aquifers (Clarke, 2003).

Objectives

- Characterize the geologic and water-bearing properties of the surficial and Brunswick aquifer systems.
- Characterize the water quality of the surficial and Brunswick aquifer systems.
- Develop monitoring network for management of the surficial and Brunswick aquifer systems.

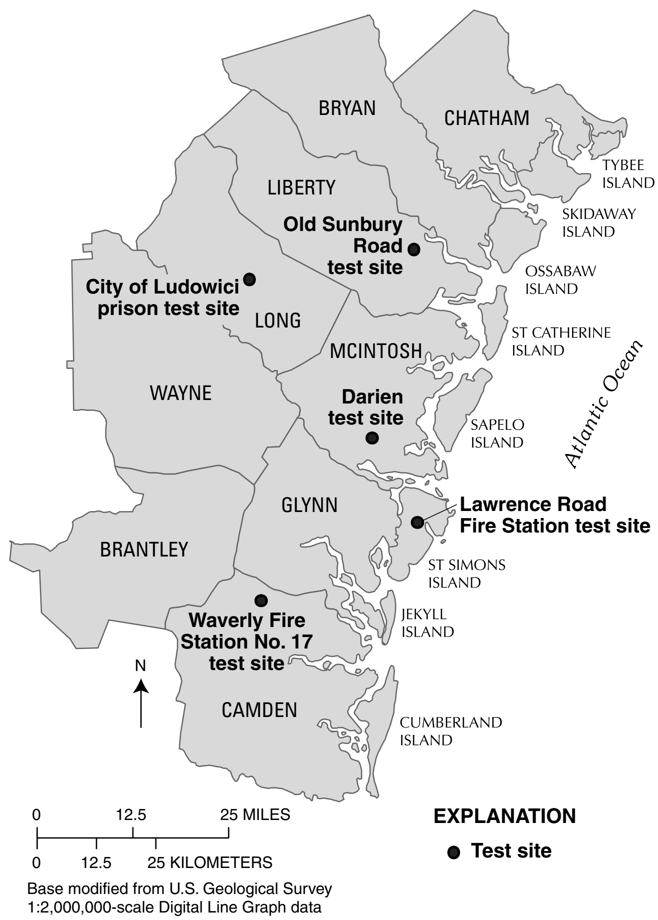
Progress and Significant Results, 2002–03

- *Old Sunbury Road site, Liberty County.* Completed six test wells, conducted a 24-hour aquifer test in the semiconfined zone of the surficial aquifer and a 48-hour aquifer test in the lower Brunswick aquifer.

- *City of Ludowici Prison site, Long County.* Completed two test wells and completed 24-hour aquifer tests in wells completed in the semiconfined zone of the surficial aquifer and in the upper and lower Brunswick aquifers, combined.

- *Waverly Fire Station No. 17 site, Camden County.* Completed three test wells and completed 24-hour aquifer tests in wells completed in the semiconfined zone of the surficial aquifer and the upper Brunswick aquifer.

- *Lawrence Road Fire Station site, St. Simons, Glynn County.* Completed wells in the semiconfined zone of the surficial aquifer and in the lower Brunswick aquifer.



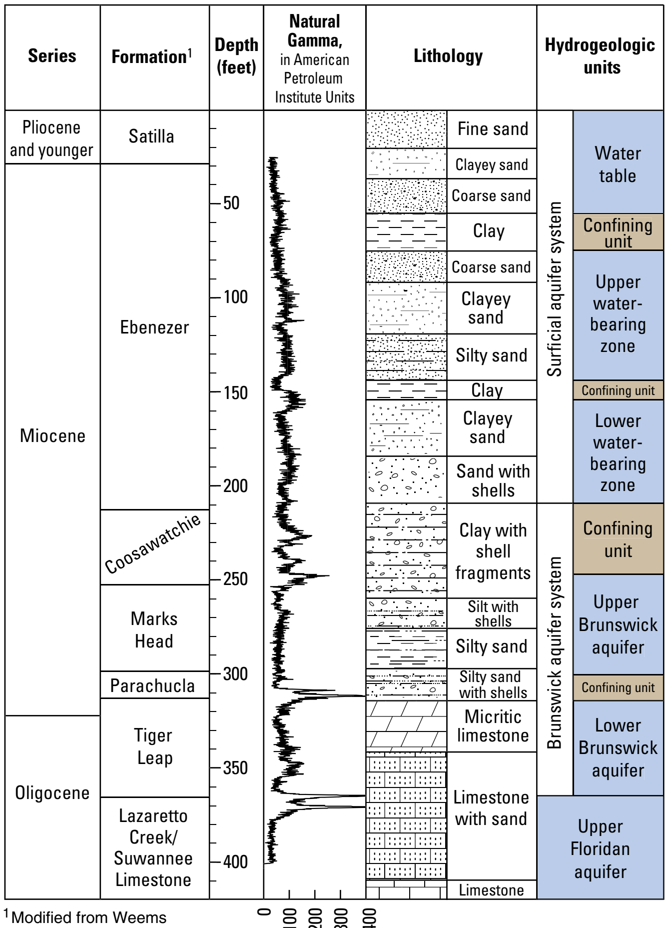
Location of test sites in coastal Georgia.

- *Darien site, McIntosh County.* Completed test wells in the surficial aquifer, semiconfined zone of the surficial aquifer, and lower Brunswick aquifer.

References Cited

Clarke, J.S., 2003, The surficial and Brunswick aquifer systems-alternative ground-water resources for Coastal Georgia, *in* Proceedings of the 2003 Georgia Water Resources Conference held April 23–23, 2003, at The University of Georgia, Kathryn J. Hatcher, ed, Institute of Ecology, The University of Georgia, Athens, Georgia, CD–ROM.

Weems, R.E., and Edwards, L.E., 2000, Geology of Oligocene, Miocene, and younger deposits in the coastal area of Georgia: Georgia Geologic Survey Bulletin 131, 124 p.



[1]Modified from Weems and Edwards, 2000

Generalized lithologic, geologic, and hydrologic descriptions of the surficial and Brunswick aquifer systems at the Old Sunbury Road test site, Liberty County, Georgia (at left).

A USGS hydrologist and drilling contractor taking water-level measurements during aquifer test of the lower Brunswick aquifer at Old Sunbury Road, Liberty County, Georgia, January 2002. The test is being conducted to better define the hydraulic properties of the surficial and Brunswick aquifer systems and to determine the usefulness of these aquifers as secondary sources of ground water. Photo by Sherlyn Priest, USGS.

Location and construction data for wells used in the study (gal/min/ft, gallons per minute per feet; —, no data; do., ditto).

Site name	Other identifier[1]	Water-bearing unit[2]	Altitude[3] (feet): Land surface	Altitude[3] (feet): Top of screen or open interval	Altitude[3] (feet): Bottom of screen or open interval	Casing diameter (inches)	Test dates during 2003	Draw-down (feet)	Yield (gal/min)	Specific capacity (gal/min/ft)
				Liberty County						
35N076	Old Sunbury Rd OW-4	WT	10	−5	−8	2	—	—	—	—
35N075	Old Sunbury Rd OW-3	CU	10	−42	−43	4	—	—	—	—
35N072	Old Sunbury Rd PW-2	SS	10	−50	−140	6	February 5–7	29	40	1.38
35N074	Old Sunbury Rd OW-2	SS	10	−50	−55	4				
35N071	Old Sunbury Rd PW-1	LB	10	−305	−355	6	January 14–17	50	78.5	1.57
35N073	Old Sunbury Rd OW-1	LB	10	−307	−312	4				
				Camden County						
32G046	Waverly Fire Station	LB	20	−340	−425	6	—	—	—	—
32G047	Waverly Fire Station PW-1	UB	20	−230	−270	6	October 9–11	98	12	0.12
32G048	Waverly Fire Station PW-2	SS	20	−80	−170	6	December 9–11	31	47.5	1.53
				Long County						
32M017	City of Ludowici Prison #1	UB	65	−165	−205	10	July 8–10	59	600	10.2
do.	do.	LB	do.	−275	−355	10	do.	do.	do.	do.
32M018	City of Ludowici Prison #2	SS	65	−60	−140	10	July 29–30	7.5	825	110
				McIntosh County						
34K102	Darien #1	S	30	10	−10	6	—	—	—	—
34K103	Darien #2	SS	30	−130	−230	6	—	—	—	—
34K104	Darien #3	LB	30	−458	−548	6	—	—	—	—
				Glynn County						
35H075	Lawrence Rd Fire Station #1	LB	20	−425	−505	6	—	—	—	—
35H076	Lawrence Rd Fire Station #2	SS	20	−90	−150	6	—	—	—	—

[1]OW, observation well; PW, pumping well

[2]CU, confining unit; LB, lower Brunswick aquifer; S, surficial aquifer; SS, semiconfined surficial aquifer; UB, upper Brunswick aquifer; WT, water table

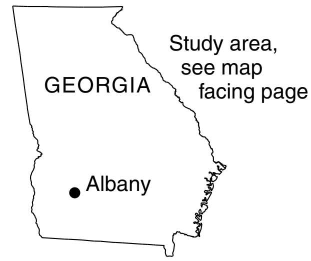
[3]Negative value denotes below NAVD 88

City of Albany Cooperative Water-Resources Program

Study Chief Debbie Warner

Cooperator Albany Water, Gas, and Light Commission

Year Started 1977



Problem

Long-term heavy pumping from the Claiborne, Clayton, and Cretaceous aquifers, which underlie the Upper Floridan aquifer, has resulted in substantial water-level declines in the deep aquifers in the Albany area. These declines have raised concern about the capacity of the deep aquifers to meet the increasing demand for potable water supply. To provide additional water supply and reduce the demand on the deep aquifers, the Albany Water, Gas, and Light Commission has developed a large wellfield southwest of Albany. The supply wells at this location primarily tap the Upper Floridan aquifer, a karstic unit that is the uppermost reliable source of water in the area. Because of local recharge to the aquifer, water quality may be affected by land-use practices. Nitrate levels exceeding the 10-milligrams per liter Maximum Contaminant Level (U.S. Environmental Protection Agency, 2000) have been detected in some wells upgradient of the proposed wellfield. The ground-water flow system and water quality of the Upper Floridan aquifer in the vicinity of the wellfield are complex and poorly understood.

Objectives

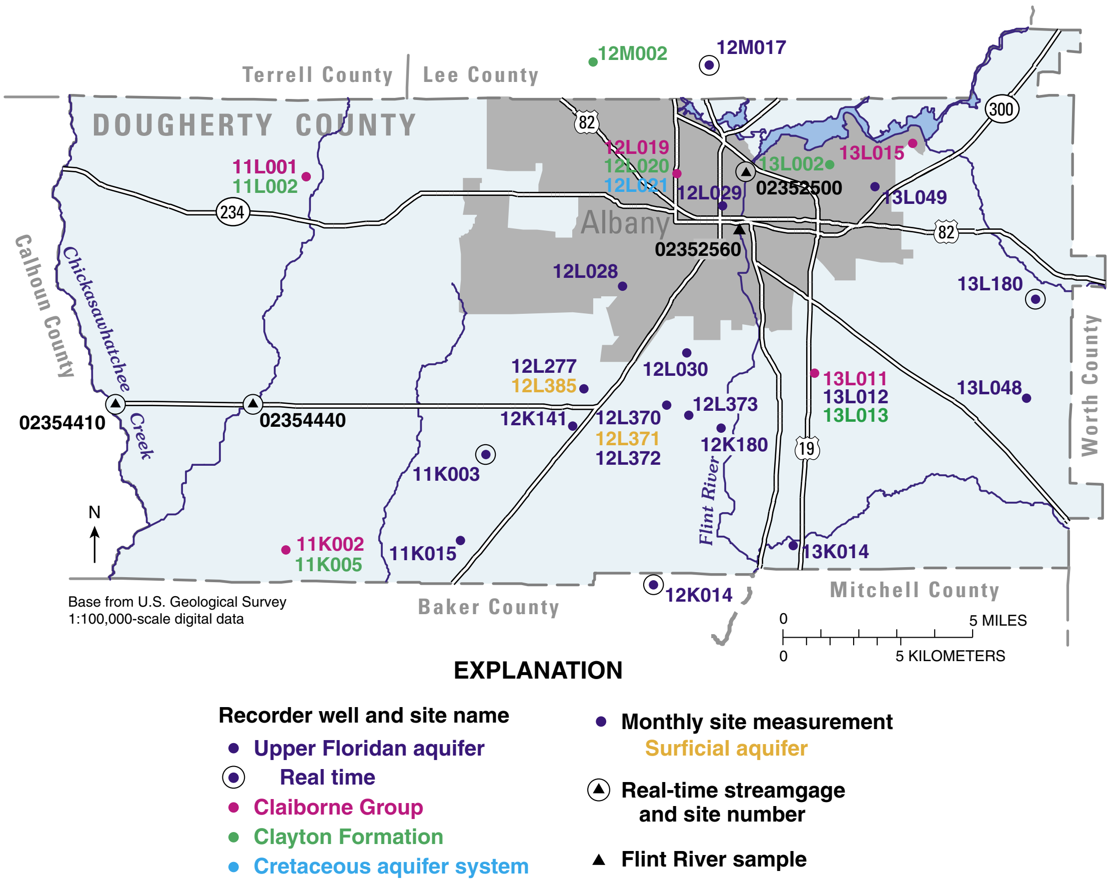
- Monitor water-level fluctuations in the four aquifers used in the Albany area and relate water-level trends to changes in climatic conditions and pumping patterns.
- Describe the ground-water flow and water quality of the Upper Floridan aquifer in the southwestern Albany area: identify ground-water flow directions and gradients for the Upper Floridan aquifer; determine if there is a rapid hydrologic response of ground-water levels to rainfall; describe the distribution of ground-water ages for the Upper Floridan aquifer in the study area; and describe ground-water quality, with a particular emphasis on nitrate concentrations.

Progress and Significant Results, 2002–03

- Continued hydrologic and water-quality monitoring, operation of continuous ground-water-level monitoring network, and added two wells to continuous recorder network in the vicinity of the wellfield. The network consists of 28 wells tapping four aquifers.
- Collected water-level measurements from 68 wells in the southwestern Albany area, October 1–3, 2002, and constructed a potentiometric-surface map.
- Collected water-level measurements from 74 wells in the southwestern Albany area, September 8–9, 2003, and constructed a potentiometric-surface map.
- Collected water samples from 12 wells in the southwestern Albany area, November 18–20, 2002, and analyzed samples for cations, anions, and nutrients. Collected water samples on May 13, 2003, from four wells—two upgradient and two downgradient from the wellfield. Collected a sample from the Flint River on May 13, 2003, to compare the water-quality characteristics of ground and surface water. These data were used to construct a trilinear diagram showing the percentage composition of major cations and anions.
- Collected water samples from 14 wells in the southwestern Albany area, November 3–5, 2003, and analyzed samples for cations, anions, and nutrients. Collected a sample from the Flint River on November 4, 2003, to compare the water-quality characteristics of ground and surface water. These data were used to construct a trilinear diagram showing the percentage composition of selected major cations and anions.
- Updated the Web site for the Albany program to provide the public with hydrologic information in the Albany area. Included on the Web site is information on ground-water activities; references and publications; ground-water, surface-water, and drought monitoring; ground-water-quality data; and links to other Web pages related to Albany's water issues. The Web site may be accessed at *http://ga.water.usgs.gov/ projects/albany/*

References Cited

U.S. Environmental Protection Agency, 2000, Maximum contaminant levels (Part 143, National Secondary Drinking Water Regulations): U.S. Code of Federal Regulations, Title 40, Parts 100–149, revised as of July 1, 2000, p. 612–614.



The USGS continuously records water levels at 30 wells and 3 streamgages in the Albany area, shown on the map above. Data from four of these wells and the three streamgages are available in real time at http://ga.waterdata.usgs.gov/nwis

Visit the Albany program Web site at http://ga.waterdata.usgs.gov/projects/albany

City of Brunswick and Glynn County Cooperative Water-Resources Program

Study Chief David C. Leeth and Gregory S. Cherry

Cooperator City of Brunswick
Glynn County
Jekyll Island Authority

Year Started 1959

Problem

In the Brunswick area, saltwater has contaminated the Upper Floridan aquifer for nearly 50 years. Currently (2003) within an area of several square miles of downtown Brunswick, the aquifer yields water that has a chloride concentration greater than the 250 milligrams per liter (mg/L) State and Federal drinking-water standard (Georgia Environmental Protection Division, 1997; U.S. Environmental Protection Agency, 2000) and in some areas exceeds 2,250 mg/L. Saltwater contamination has constrained further development of the Upper Floridan aquifer in the Brunswick area and prompted interest in the development of alternative sources of water supply, primarily from the shallower surficial and Brunswick aquifer systems, and from the deeper Lower Floridan aquifer.

Objectives

- Better define mechanisms of ground-water flow and movement of saltwater in the Floridan aquifer system.
- Define the vertical geometry of the high-chloride plume.
- Assess alternative sources of water supply from the surficial and Brunswick aquifer systems, and the Lower Floridan aquifer.
- Monitor long-term ground-water levels and quality, and develop and maintain a comprehensive ground-water database.

Progress and Significant Results, 2002–03

- During 2002 and 2003, a network of 22 continuous ground-water-level monitoring wells was operated (13 in the Upper Floridan aquifer, 4 in the Lower Floridan aquifer, 4 in the Brunswick aquifer system, and 1 in the surficial aquifer system). Nine wells were removed from service during January 2004 because of the rising cost of monitoring.
- Potentiometric surfaces of the upper Floridan aquifer were mapped:
  - During June 2002, based on water-level measurements collected in 95 wells.
  - During June 2003, based on water-level measurements collected in 56 wells.
- Choropleths of the Upper Floridan aquifer were mapped:
  - During June 2002, based on analysis of chloride samples collected in 66 wells.
  - During June 2003, based on chloride samples collected in 88 wells.
- New well information was incorporated into the U.S. Geological Survey (USGS) National Water Information System database, including seven additional Miocene wells and three Floridan aquifer wells.
- During 2003, the Georgia Geologic Survey installed three wells at a site on St. Simons Island (Lawrence Road site). Drilling and geophysical logging revealed the confined portion of the surficial aquifer system was present from 110 feet (ft) to 170 ft below land surface (bls); the upper Brunswick aquifer at this site was present from 360 to 370 ft bls, and the lower Brunswick aquifer was from 445 to 525 ft bls. An Upper Floridan aquifer monitor well also was installed and was completed from 640 to 780 ft as open hole.
- Geophysical logs were collected from 10 wells during 2002 and 2003.
- The Web site was updated for the Brunswick program that may be accessed at *http://ga2.er.usgs.gov/brunswick/*

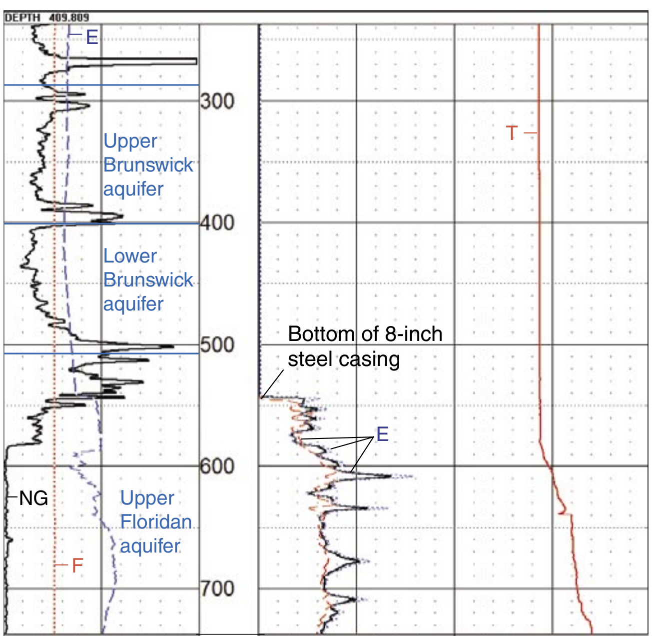
References Cited

Georgia Environmental Protection Division, 1997, Secondary maximum contaminant levels for drinking water: Environmental Rule 391-3-5-19, revised October 1997: Official Code of Georgia Annotated Statutes, Statute 12-5-170 (Georgia Safe Drinking Water Act), variously paginated.

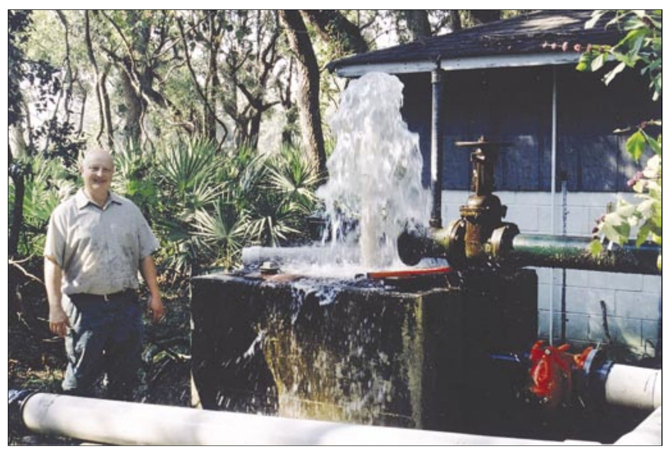
U.S. Environmental Protection Agency, 2000, Maximum contaminant levels (Part 143, National Secondary Drinking Water Regulations): U.S. Code of Federal Regulations, Title 40, Parts 100–149, revised as of July 1, 2000, p. 612–614.

Fluid resistivity log being collected from an observation well completed in the surficial aquifer at Brunswick, Georgia. The log is being collected to determine the integrity of the well casing and to locate zones where saltwater may be entering the well. Photo by Michael F. Peck, USGS.

A geologist for the Georgia Department of Natural Resources, Environmental Protection Division, processes geophysical logs collected from a surficial aquifer well at Brunswick, Georgia. These logs are being used to determine the source of saltwater entering the well. Photo by Michael F. Peck, USGS.

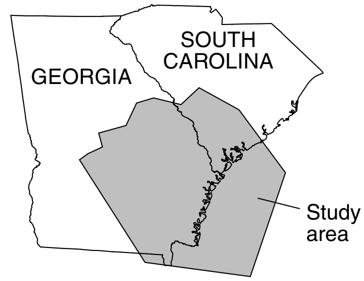


Examples of geophysical logs collected from an unused production well on Jekyll Island using a multiparameter logging tool. The natural-gamma (NG) and electric (E) logs are used to determine different water-bearing zones and well construction, the fluid resistivity (F) log indicates zones of higher conductivity, and the temperature (T) log measures borehole fluid temperature.



An unused production well on Jekyll Island is being converted into an observation well for continuous monitoring of ground-water levels. The 751-foot-deep well is completed in the Upper Floridan aquifer. Geophysical logs were collected to assess the integrity of the well casing and suitability for incorporation into the Georgia statewide ground-water-level monitoring network. A continuous ground-water-level recorder was installed at the well on October 25, 2004, at which time the water level was 21.83 feet above land surface. Photo by Michael F. Peck, USGS.

Georgia Coastal Sound Science Initiative



Study Chief Dorothy F. Payne

Cooperator Georgia Department of Natural Resources Environmental Protection Division

Year Started 2000

Problem

Pumping from the Upper Floridan aquifer has resulted in substantial water-level decline and saltwater intrusion at the northern end of Hilton Head Island, South Carolina, and at Brunswick, Georgia. This saltwater contamination has constrained further development of the Upper Floridan aquifer in the coastal area and created competing demands for the limited supply of water. The Georgia Environmental Protection Division has capped permitted withdrawal from the Upper Floridan aquifer at 1997 rates in parts of the coastal area, prompting interest in the development of alternative sources of water supply, primarily from the shallower surficial and Brunswick aquifer systems.

Objectives

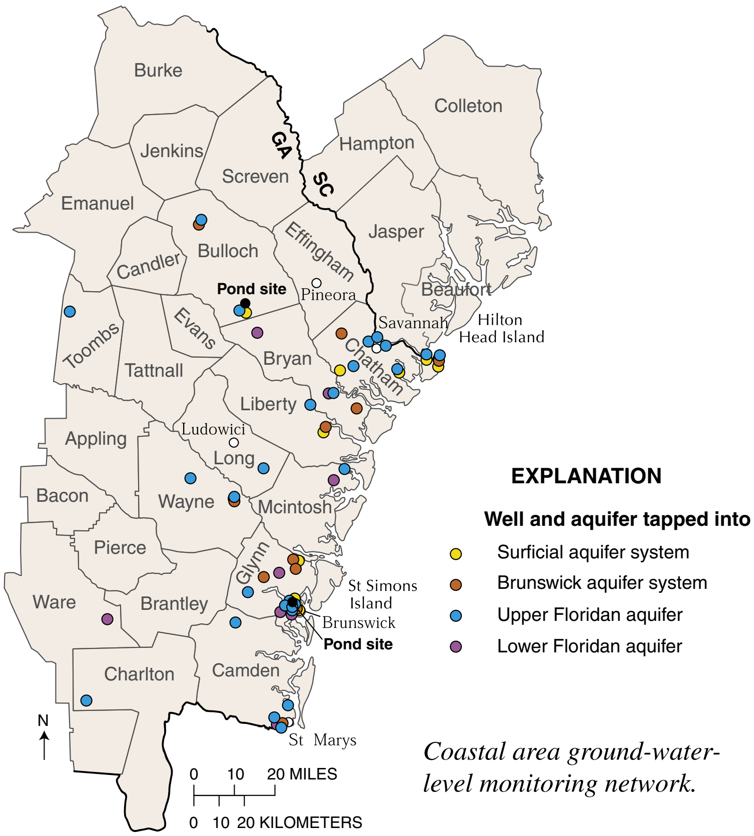
- Better define mechanisms of ground-water flow and movement of saltwater.
- Delineate paths and rates of ground-water flow and intrusion of saltwater into the Upper Floridan aquifer and develop models to simulate a variety of water-management scenarios.
- Delineate areas where saltwater is entering the Floridan aquifer system offshore of the Savannah–Hilton Head Island area.
- Assess long-term ground-water levels and quality, and develop and maintain a comprehensive ground-water database.
- Assess alternative sources of water supply from:
  a. seepage ponds connected to the surficial aquifer,
  b. the Lower Floridan aquifer, and
  c. the Brunswick aquifer system.

Progress and Significant Results, 2002–03

- Collected and acquired geophysical logs at multiple sites throughout study area in wells completed in the Brunswick aquifer system, and the Upper and Lower Floridan aquifers;
- Collected Lower Floridan aquifer water-quality samples at St. Marys and St. Simons Island.
- Installed continuous water-level recorders in Upper Floridan aquifer wells in Glynn and Camden Counties and in Lower Floridan aquifer wells at Pineora, Effingham County, and Pembroke, Bryan County.
- Completed assessments of pond-aquifer flow and water availability at seepage pond sites in Glynn and Bulloch Counties.
- Developed model database: acquired well-specific pumping rate data for Beaufort, Colleton, Jasper, and Hampton Counties in South Carolina, for the city of Savannah and industrial wells in Chatham County, and for the city of Brunswick and industrial wells in Glynn County; incorporated data into pumping distributions for models; incorporated hydrostratigraphy and water-quality data into a geographic information system database for Savannah–Hilton Head Island, and Brunswick solute-transport models.
- Calibrated single-density (MODFLOW) regional ground-water model to 1980 and 2000 conditions; began sensitivity testing of final model, including transient response and boundary condition testing.
- Continued development of solute-transport models; tested mechanism of saltwater transport in offshore area, and estimated predevelopment saltwater-freshwater interface.

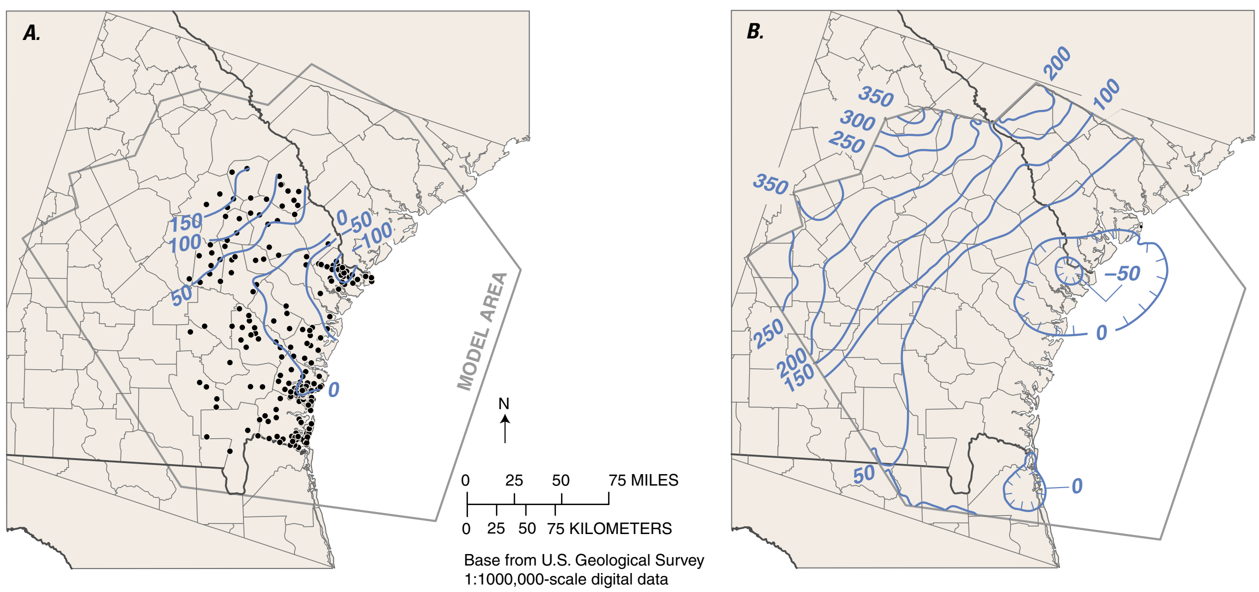
Reference Cited

Peck, M.F., and McFadden, K.W., 2004, Potentiometric surface of the Upper Floridan aquifer in the coastal area of Georgia, September 2000: U.S. Geological Survey Open-File Report 2004-1030. Available only online at *http://water.usgs.gov/pubs/of/2004/1030/*



Coastal area ground-water-level monitoring network.

Geophysical logging and water-quality sampling of the Lower Floridan aquifer well 39Q024 on Tybee Island in Chatham County, December 2003. Photo by Edward H. Martin, USGS.



EXPLANATION

—50— **Potentiometric contour**—Shows altitude at which level water would have stood in tightly cased wells completed in the Upper Floridan aquifer during September 2000. Contour interval 50 feet. Datum is NAVD 88. (Modified from Peck and McFaddden, 2004)

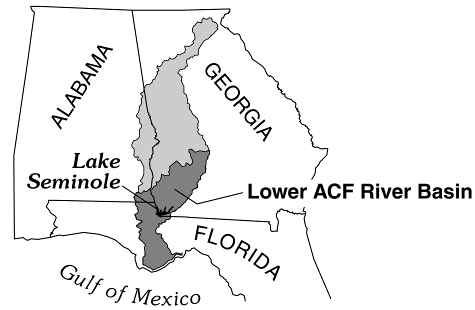
• **Water-level measurement**

EXPLANATION

—50— **Simulated potentiometric contour**—Shows altitude at which level water would have stood in tightly cased wells completed in the Upper Floridan aquifer during September 2000. Contour interval 50 feet. Hachures indicate depression. Datum is NAVD 88

(A) Potentiometric surface estimated from field measurements and (B) simulated potentiometric surface during 2000.

Effects of Impoundment of Lake Seminole on Water Resources in the Lower Apalachicola–Chattahoochee–Flint River Basin and in parts of Alabama, Florida, and Georgia



Study Chief Lynn J. Torak

Cooperator Georgia Department of Natural Resources Environmental Protection Division

Year Started 1999

Problem

Multiple uses of freshwater supplies in the lower Apalachicola–Chattahoochee–Flint (ACF) River Basin have concerned water managers in the States of Alabama, Florida, and Georgia for many years. Numerous studies have been conducted to understand the complex relations between hydrologic-system components and natural stresses, and to answer questions regarding the effects on those relations caused by human intervention. Although previous studies addressed important water-resource issues in the lower ACF River Basin, by design, none collected hydrologic data needed to develop and maintain a monthly water budget for Lake Seminole and the corresponding stream-lake-aquifer flow system. None of these studies investigated the hydrologic and hydrogeologic implications of Lake Seminole impoundment by construction of Jim Woodruff Lock and Dam and the effects of the lake on other flow-system components. Therefore, the U.S. Geological Survey—in cooperation with the Georgia Department of Natural Resources, Environmental Protection Division—developed a monthly water budget for Lake Seminole, estimated the volume of water flowing into Florida before and after construction of the dam, and assessed karst solution features to evaluate the potential for sinkhole collapse beneath the lake, followed by catastrophic lake drainage.

Objectives

- Develop a water budget for Lake Seminole that will result in reasonable understanding of the effect of the lake on the overall flow system in the lower ACF River Basin.
- Compare current (2001) and pre-Lake Seminole ground-water and surface-water flow to determine whether the volume of water flowing out of Georgia has changed significantly after construction of Jim Woodruff Lock and Dam and filling of the lake.
- Evaluate the possibility of a substantial amount of water entering the ground-water system from Lake Seminole, flowing beneath Jim Woodruff Lock and Dam, and entering Florida downstream of the dam.
- Assess the likelihood of failure of dissolution features in the karst limestone of the lake bottom, such as sinkhole collapse, and the likelihood of sudden partial or complete draining of the lake. If these events are likely, then propose a data-collection system to monitor conditions that might lead to sudden draining of Lake Seminole.

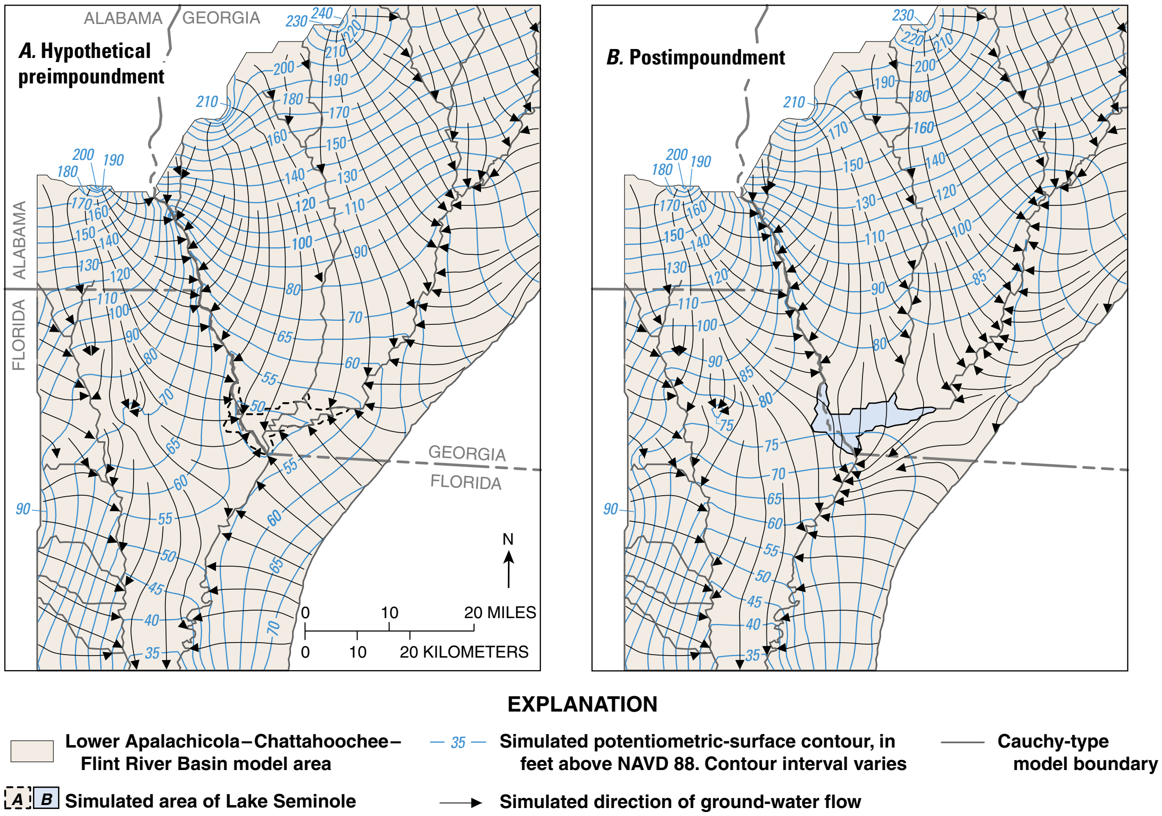
Progress and Significant Results, 2002–03

- Streamflow comprises nearly 81 percent of total lake inflow and about 89 percent of outflow.
- Ground water constitutes 10 percent of total inflow and about 5 percent of outflow, as lake leakage.
- Precipitation and evaporation comprise about 1 and 2 percent of the total water budget, respectively.
- Techniques used to estimate lake leakage resulted in a 4-percent error in lake outflow, which is within the acceptable error for streamflow measurements, defining the largest water-budget component.
- Apalachicola River flow is nearly the same for pre- and postimpoundment conditions. Prior to impoundment, ground water flowed from Florida to Georgia, discharging to the Flint River then into the Apalachicola River, back into Florida. After impoundment, ground water flows from Lake Seminole as leakage to the Upper Floridan aquifer that discharges to the Apalachicola River directly downstream of the dam.
- Solution features located near the lakeshore and along the lake bottom facilitate lake-water leakage into the Upper Floridan aquifer and ground-water inflow to the lake.
- Lake-water chemistry is conducive to limestone dissolution along ground-water flowpaths beneath the lake.
- Preimpoundment photographs show numerous karst features in the lake bottom that promote lake-aquifer interaction.
- Minimal potential for sinkhole collapse and sudden lake drainage exists because of small hydraulic gradients between the lake and aquifer.

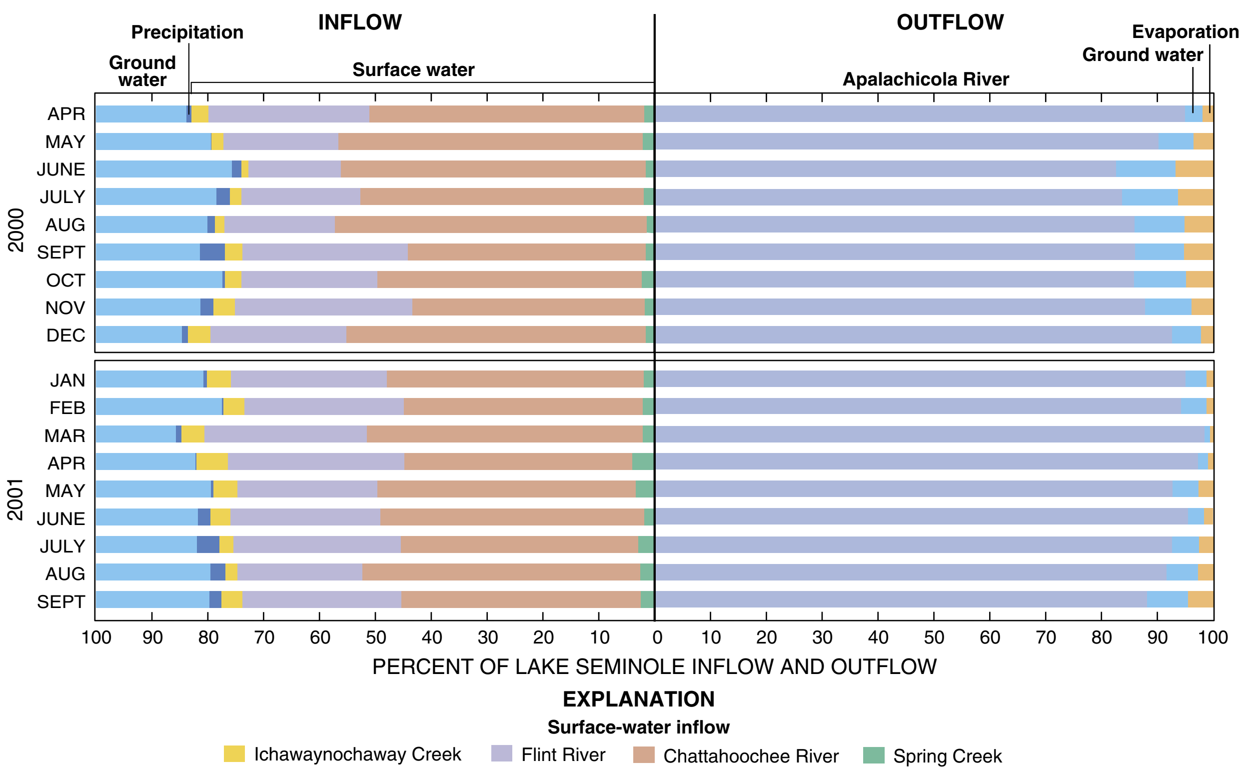
References Cited

Jones, L.E., and Torak, L.J., 2004, Simulated effects of impoundment of Lake Seminole on ground-water flow in the Upper Floridan aquifer in southwestern Georgia and adjacent parts of Alabama and Florida: U.S. Geological Survey Scientific Investigations Report 2004-5077, 22 p. Available only online at *http://water.usgs.gov/pubs/sir/2004/5077/*

Mosner, M.S., Aulenbach, B.T., and Torak, L.J., 2004, Ground-water and surface-water flow and estimated water budget for Lake Seminole, southwestern Georgia and northwestern Florida: U.S. Geological Survey Scientific Investigations Report 2004-5073, 54 p. Available only online at *http://water.usgs.gov/pubs/sir/2004/5073/*

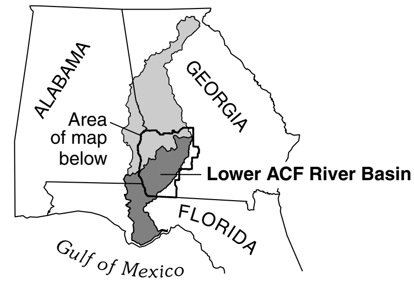


Simulated potentiometric surface and directions of ground-water flow in the Upper Floridan aquifer from simulation of (A) hypothetical preimpoundment conditions; and (B) postimpoundment conditions (modified from Jones and Torak, 2004).



Monthly water budget for Lake Seminole and relative contributions of inflow and outflow components (modified from Mosner and others, 2004).

Hydrogeologic Assessment and Simulation of Stream-Aquifer Relations in the Lower Apalachicola–Chattahoochee–Flint River Basin



Study Chief Lynn J. Torak

Cooperator Georgia Department of Natural Resources
Environmental Protection Division

Year Started 2000

Problem

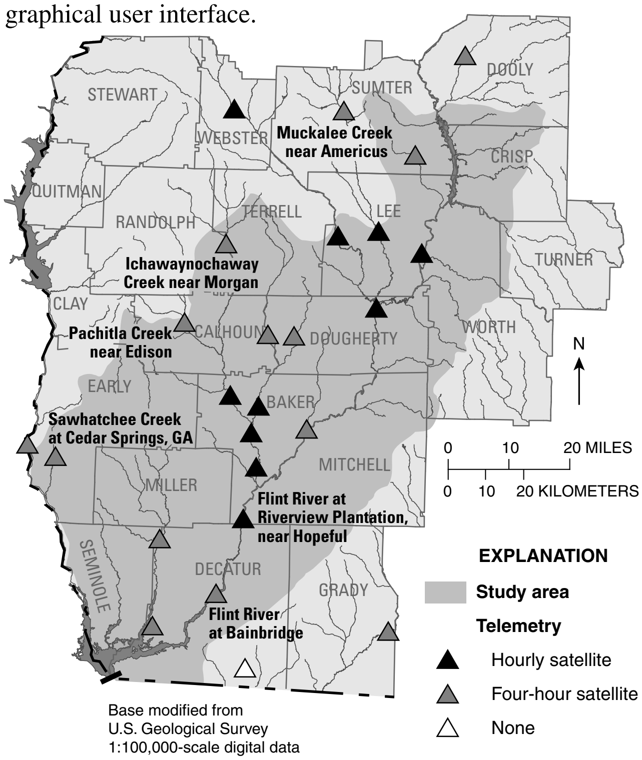
Current hydrologic information and ground-water flow modeling in the lower Apalachicola–Chattahoochee–Flint (ACF) River Basin (map below) are insufficient to describe effects of time-variant irrigation pumping on streamflow. Therefore, existing models cannot accurately predict ground-water or streamflow conditions during a growing season. The Georgia Department of Natural Resources, Environmental Protection Division (GaEPD) has implemented a hydrologic assessment of the Upper Floridan aquifer in southwestern Georgia to obtain new information and to further understanding of stream-aquifer relations and the effects of ground-water pumping on streamflow in a karst hydrologic setting. The U.S. Geological Survey (USGS) has engaged in a cooperative effort with GaEPD to develop a ground-water flow model that can account for stream-aquifer interaction and streamflow reduction because of agricultural pumping. Information obtained from the model is vital for the State's management of ground-water resources and for providing early indications of low-streamflow conditions that would affect delivery of water to downstream, out-of-state users.

Objectives

- Develop new data for the stream-aquifer system by evaluating well-drilling and aquifer-test information.
- Obtain accurate locations of pumped wells for municipal, industrial, and irrigation purposes.
- Collect and compile ground-water-level, stream-seepage, and off-stream spring-discharge data.
- Synthesize newly collected and existing hydrologic data into a transient finite-element model of ground-water flow that can simulate seasonal ground-water levels, stream-aquifer interaction, and pumpage-induced streamflow reduction, and assess the sensitivity of streamflow to ground-water pumping.

Progress and Significant Results, 2002–03

- Collected new hydrogeologic data defining aquifer and semiconfining-unit thickness and extent, and evaluated results of aquifer-performance tests; incorporated new information into Ground-Water-Site-Inventory database.
- Compiled recent (post-1986) hydrogeologic information on aquifer and semiconfining-unit thickness and extent, hydraulic properties, and pumpage, from GaEPD records.
- Incorporated well coordinates from agricultural wells, obtained by GaEPD using global-positioning-system technology, into local database used for developing model inputs.
- Analyzed agricultural withdrawal data for spatial and temporal relations.
- Evaluated ground-water-level measurements, stream-discharge data, hydrograph-separation methods, and off-stream springflow for October 1999, April 2000, and August 2000 conditions to define ground-water flow to streams.
- Installed five real-time streamgaging stations and upgraded one station for water-quality and acoustic velocity metering.
- Added 12 sites to monitor-well network of hourly ground-water-level recorders and one real-time satellite station.
- Initiated application of USGS transient finite-element model, MODFE, and development of automated input/output graphical user interface.



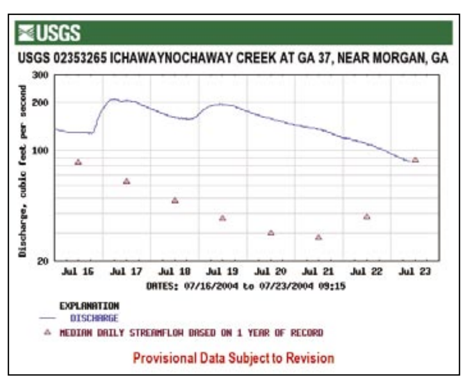
Streamflow gaging network in the lower Apalachicola–Chattahoochee–Flint River Basin and new/upgraded stations (labeled on map).

Chemigation/irrigation apparatus installed in well tapping the Upper Floridan aquifer southeast of Lake Seminole, Decatur County, Georgia. Well is 700 feet deep and was used in an aquifer-performance test. Photo by Lynn J. Torak, USGS.

Typical center-pivot spray-irrigation system used in the lower Apalachicola–Chattahoochee–Flint River Basin, southwestern Georgia. Photo by L. Elliott Jones, USGS.

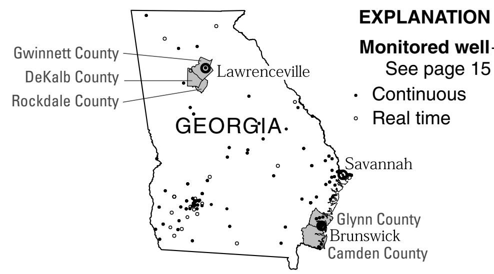
Control panel and time totalizer for monitoring usage of center-pivot irrigation system. Photo by L. Elliott Jones, USGS.

Flowmeter installed in discharge line of irrigation system. Photo by L. Elliott Jones, USGS.



Real-time streamflow data-collection platform installed at station 02353265, Ichawaynochaway Creek at Georgia Highway 37, near Morgan, Georgia, and graph of data that can be accessed at http://ga.waterdata.usgs.gov/nwis/current/?type=flow&group_key=basin_cd

Ground-Water Information and Project Support



Study Chief	David C. Leeth
Cooperator	Georgia Department of Natural Resources Environmental Protection Division Albany Water, Gas, and Light Commission City of Brunswick Glynn County Jekyll Island Authority St. Johns Water Management District, Florida
Year Started	1938

Problem

Ground water accounts for about 22 percent of freshwater withdrawals in Georgia—more than 2.7 billion gallons per day. More than 1.8 million people are served by ground-water supplies, and 734 million gallons per day are withdrawn for irrigation (Julia L. Fanning, U.S. Geological Survey, oral commun., 2004). The distribution and quality of ground water are highly variable and directly related to geology, and natural and human stresses. Monitoring ground-water levels and ground-water quality is essential for the management and development of this resource.

Objectives

- Collect ground-water-level and ground-water-quality data to assess the quantity, quality, and distribution of ground water.
- Provide date to address water-management needs and evaluate the effects of national and local management and conservation programs.
- Advance the knowledge of the regional hydrologic system.
- Advance field or analytical methodology.
- Advance the understanding of hydrologic processes.
- Provide data or results useful to multiple parties in potentially contentious interjurisdictional conflicts about water resources.
- Provide hydrologic data required for interstate and international compacts, Federal law, court decrees, and congressionally mandated studies.
- Provide water-resource information that can be used by multiple parties for planning and operational purposes.
- Contribute data to national databases that will be used to advance the understanding of regional and temporal variations in hydrologic conditions.

Progress and Significant Results, 2002–03

- Continuous water-level recorders were operated in 185 wells during 2002 and 177 wells during 2003; data from 159 wells during 2002 and 156 wells during 2003 (map, above) were included in annual data reports (Coffin and others, 2003; 2004). Periodic water-level measurements were made in more than 729 wells throughout the State during this period. Water-level data were collected to define potentiometric surfaces and to assess long-term trends. Water samples for chloride analysis were collected from 72 wells during 2002 and 87 wells during 2003 in the Brunswick area, 4 wells during 2003 in the Savannah area, and 6 wells during 2002 and 2003 in Camden County. Borehole-geophysical logs were collected from 9 wells in the Lawrenceville area, 9 in Rockdale County, and 18 in the coastal area. The types of logs collected include caliper, natural gamma, electric (lateral, long and short-normal resistivity) fluid-temperature, fluid-resistivity, electromagnetic induction, full-waveform sonic, acoustic televiewer, optical televiewer, and spinner-flowmeter.
- Well-inventory, water-level, and geologic data were verified for entry into the National Water Information System (NWIS) database. Field inventories were conducted to assist projects, and 186 sites were added to the NWIS Ground-Water Site Inventory to improve ground-water data coverage in the State. Five wells were instrumented with real-time transmission (satellite relay) of continuous water-level records to aid in drought planning. Currently, 18 wells are equipped for real-time transmission of continuous water-level data. The NWIS database may be accessed on the Web at *http://waterdata.usgs.gov/ga/nwis/current/?type=gw*

References Cited

Coffin, Robert, Grams, S.C., Leeth, D.C., and , and Peck, M.F., 2003, Continuous ground-water-level data, and periodic surface-water- and ground-water-quality data, calendar year 2002, v. 2 *in* Alhadeff, S.J., and McCallum, B.E. (compilers), Water resources data–Georgia, 2002: U.S. Geological Survey Water-Data Report GA-02-2, CD–ROM.

Coffin, Robert, Grams, S.C., Peck, M.F., and Cressler, A.M., 2004, Continuous ground-water-level data, and periodic surface-water- and ground-water-quality data, calendar year 2003, v. 2 *in* Alhadeff, S.J., McCallum, B.E., Landers, M.N., (compilers), Water resources data–Georgia, 2003: U.S. Geological Survey Water-Data Report GA-03-2, CD–ROM.

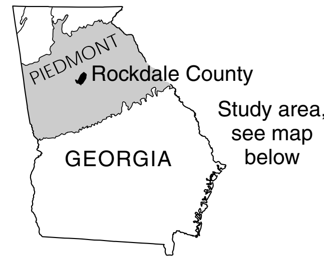
A downhole continuous recorder in Gwinnett County, Georgia, which is part of the ground-water-level monitoring network for an ongoing study. The equipment consists of a data logger, battery, and 15-pounds-per-square-inch transducer—all installed inside of a 6-inch-diameter casing. The recorder is set to collect data on an hourly basis, and processed and stored in National Water Information System. Photo by Alan M. Cressler, USGS.

A typical real-time continuous recorder well in DeKalb County, which is part of the ground-water-level monitoring network. The equipment consists of a data logger, 30-pounds-per-square-inch transducer, a radio and antenna for transmitting data, and a solar panel and battery. Real-time data are typically recorded at 60-minute intervals, stored on site, and then transmitted to USGS offices from every 1 to 4 hours via satellite, telephone, or radio relay. The NWIS database may be accessed on the Web at http://waterdata.usgs.gov/ga/nwis/current/?type=gw *Photo by Alan M. Cressler, USGS.*

A hydrologic technician from the Ground-Water Information and Project Support Unit collects a water sample for chloride analysis from a well in Glynn County, Georgia. The sampling trailer contains a 5-horsepower centrifugal pump, reel with 100 feet of suction hose, and pipe fittings and adapters. The samples are collected annually in support of the Brunswick and Glynn County Cooperative Water-Resources Program. Photo by Alan M. Cressler, USGS.

A public supply well in Glynn County is shown flowing at about 30 gallons per minute while spinner flowmeter logs were collected to estimate the percentages of water from different water-bearing zones. This well is completed in the confined surficial, upper Brunswick, and lower Brunswick aquifers, and the flowmeter logs help to quantify the ground-water contribution from each zone. Photo by Michael F. Peck, USGS.

Ground-Water Resources and Hydrogeology of Crystalline-Rock Aquifers in Rockdale County, North-Central Georgia



Study Chief	Lester J. Williams
Cooperator	Rockdale County
Year Started	2001

Problem

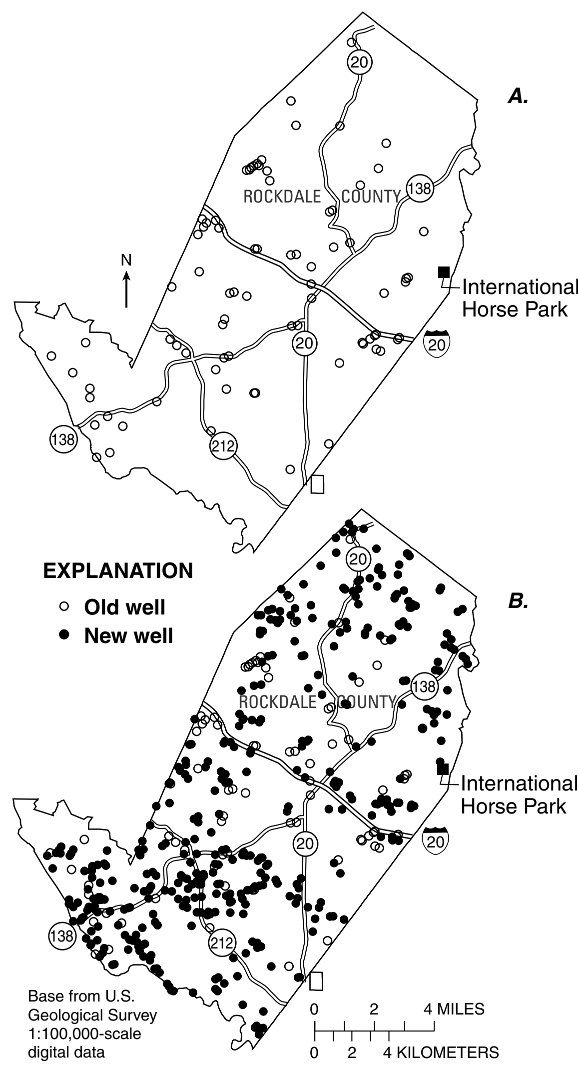
Ground water in crystalline rocks of the State has not been extensively tapped as a source of public drinking water. This source, however, may prove to be a valuable resource to communities wishing to supplement their existing surface-water supplies and augment the amount of available drinking water in rapidly-growing areas of north Georgia, such as in Rockdale County (map, right). Little information is available to evaluate fully the quantity and quality of ground-water resources in the area. Because geology is the principal control on the availability of ground water, the U.S. Geological Survey (USGS) is conducting this study, in cooperation with Rockdale County, to determine the rock types and geologic structures that influence ground-water availability. Ultimately, this information will increase the understanding of how ground water flows through complex crystalline-rock aquifer systems and provide critical information for the future development and management of this resource.

Objectives

- Evaluate the hydrogeology and ground-water resources of the study area.
- Provide baseline geologic and hydrologic information for a typical crystalline-rock aquifer setting in northern Georgia.
- Determine the hydraulic characteristics and storage potential of water-bearing zones/hydrogeologic units at various well sites.
- Define the best methods and approaches to characterize the availability of ground water in crystalline-rock areas.
- Develop a better understanding of crystalline-rock aquifer systems so that State and local water-management agencies can use this information when developing ground-water use policies.

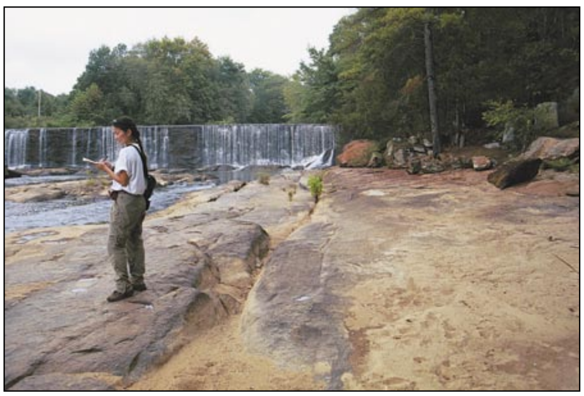
Progress and Significant Results, 2002–03

- Compiled data on approximately 450 wells (primarily rural domestic) including field confirmation of well location, casing diameter, well yield, casing depth, total depth, and static/pumping water level.
- Obtained geophysical logs from 19 wells to characterize the lithology, fracture, and yield characteristics of various rock units throughout Rockdale County.
- Collected ground-water samples from three wells to characterize water quality.
- Completed detailed geologic mapping throughout much of Rockdale County and began subsurface correlation with geophysical log data; hydrogeologic units and storage capabilities are being compiled from these data.
- Identified likely high-yielding water-bearing zones/hydrogeologic units in several parts of Rockdale County.
- Currently compiling a geographic information system database to combine well data with existing geologic, topographic, hydrographic, and other geographic data.



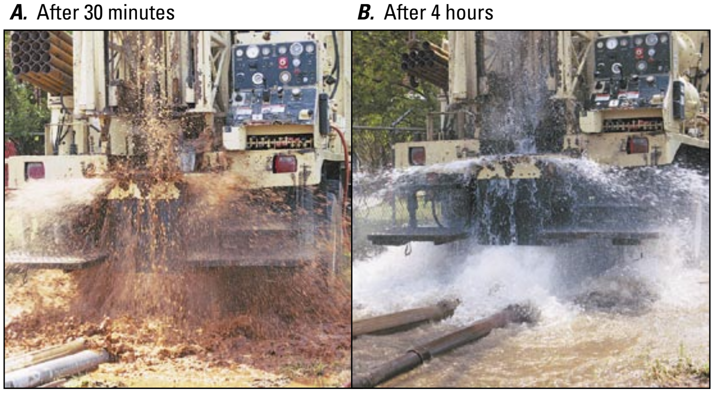
Although well inventories are time consuming and require a site visit, it is the only available means to obtain accurate location and water-level data for area wells. Depth, yield, and water level are obtained from wells. Map (A) shows wells inventoried during previous studies. Map (B) shows approximately 450 wells inventoried during this study.

Water-quality sampling—*Samples were collected from three wells to determine water quality. A pump is set into the well to collect the samples. Water-quality properties are monitored during the process of purging the well prior to sampling. Photo by Lester J. Williams, USGS.*



Geologic mapping—*Rock types, joints, fractures, and other water-bearing features are mapped by walking along roads, riverbeds, power lines and other access points. The above photo shows a prominent set of joints aligned parallel to the streambed of the Yellow River near Milstead, Georgia. Photo by Lester J. Williams, USGS.*

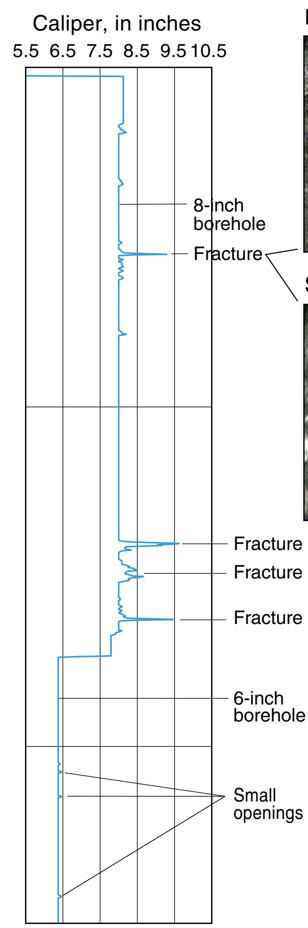
A. After 30 minutes ***B.*** After 4 hours



Well refurbishment—*Photos of an air-rotary drilling rig used to refurbish and clean out an old (unused) water-supply well in Conyers, Georgia. Photo A was taken after about 30 minutes (reddish color is iron scaling), and Photo B was taken after approximately 4 hours of development. The refurbishment was necessary to prepare the open portion of the borehole for logging and down-hole camera surveys. The drilling rig was air-lifting approximately 250 gallons of water per minute at the end of refurbishment. Photo by Lester J. Williams, USGS.*

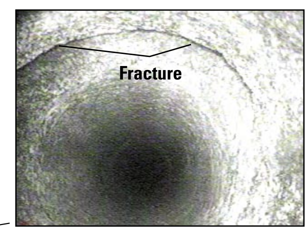
Borehole geophysical logging—*Borehole geophysical tools and down-hole cameras provide the most effective means to study the nature of water-bearing openings.*

Above, USGS employees calibrate a three-arm caliper tool. The caliper tool (right) measures diameter by pressing mechanical arms out against the borehole wall. Geophysical tools measure the physical properties of the rock surrounding the well. Photo by Lester J. Williams, USGS.



A caliper log is the simplest log to interpret. Peaks show where the borehole is enlarged and indicate sections of the borehole where a fracture opening may be present.

Downview



Sideview

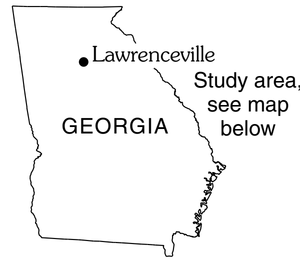
Down-hole camera images of a fracture formed parallel to rock layering at a depth of 73 feet.

Sustainability of Ground-Water Resources in the City of Lawrenceville area

Study Chief Phillip N Albertson

Cooperator City of Lawrenceville, Georgia

Year Started 2002



Problem

The city of Lawrenceville overlies an igneous and metamorphic-rock aquifer that supplies about 6 percent of the city's current water use. Lawrenceville plans to increase ground-water withdrawal from wells located in the upper Alcovy River Basin and from wells in the Redland–Pew Creek River Basin. Long-term effects of the withdrawal of ground water in this area are largely unknown. For this reason the U.S Geological Survey (USGS), in cooperation with the city of Lawrenceville, began a study to investigate the sustainability of ground-water resources as additional municipal wells become operational.

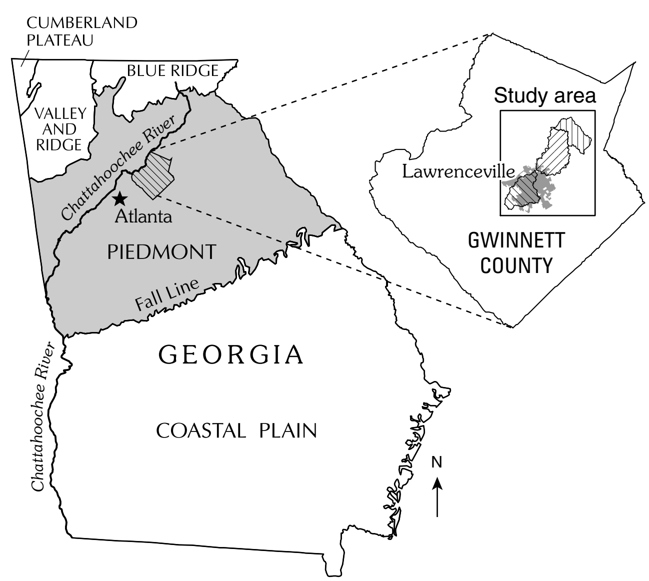
Concern about the possible effects of ground-water withdrawal has led the city of Lawrenceville to install a monitoring network to assess changes in the hydrologic system that pumping may initiate. These changes possibly include a decrease in ground-water levels, cross-basin transfer of ground water, dewatering of the overlying saprolite, and a decline in streamflows. As ground-water development continues to increase in the Piedmont region of Georgia, it is important to monitor the effects of ground-water withdrawal to better manage the resource.

Objectives

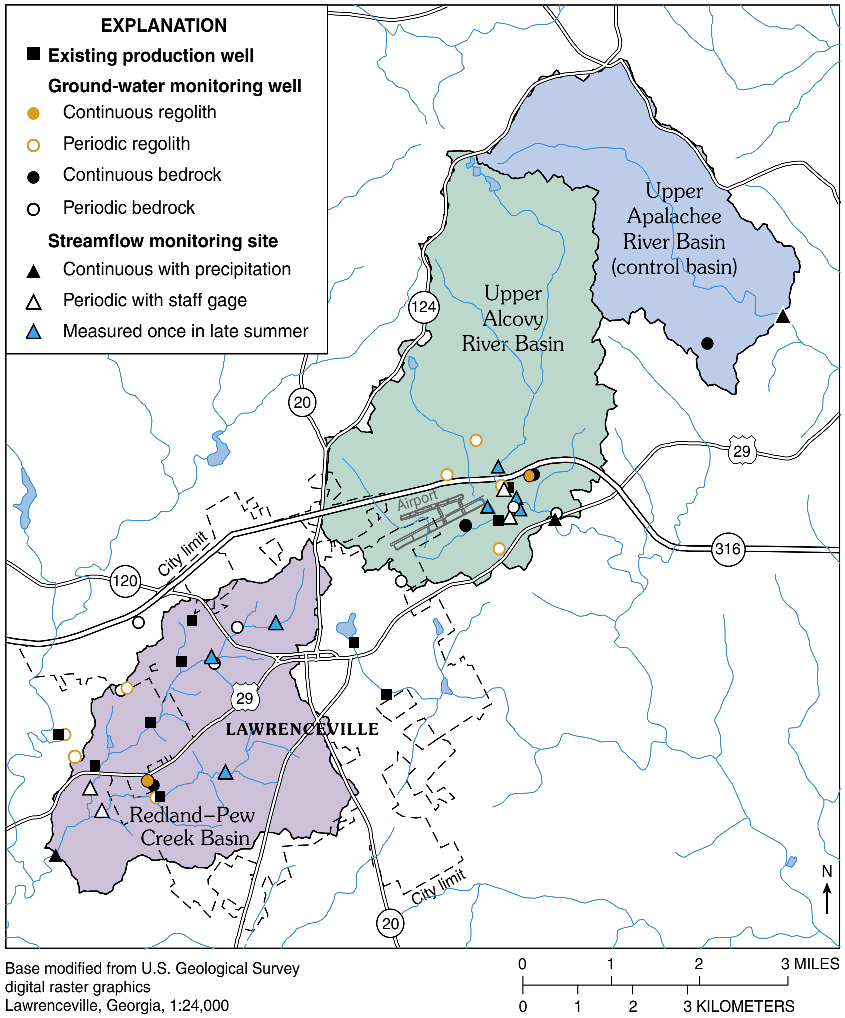
- Monitor the effect of increased ground-water withdrawals by additional municipal wells on surrounding ground-water levels and streamflow.
- Determine pre- and postpumping hydrologic budgets of the Alcovy and Pew–Redland Creek Basins.
- Provide drawdown data from surrounding monitoring wells to the city of Lawrenceville and estimate the zone of influence of active municipal wells.

Progress and Significant Results, 2002–03

- Installed 11 new monitoring wells during July 2003 to form a network of 27 wells to monitor long-term water levels in areas of increased ground-water withdrawal.
- Installed continuous water-level recorders on a well pair in the upper Alcovy River Basin, on a well pair in the Redland–Pew Creek River Basin, and on a single well in the upper Apalachee River Basin.
- Obtained weekly water-level measurements at 21 monitoring wells.
- Installed continuous-recording streamgages at the outflow of both the upper Alcovy River and the Redland–Pew Creek River Basins.
- Installed staff gages at four additional streamflow monitoring sites.
- Obtained weekly staff-gage readings and streamflow measurements at the four periodic streamflow measurement sites.
- Obtained seepage measurements during the low-flow period in the fall of 2003 to quantify the ground-water contribution to streamflow in areas to be pumped.
- Developed a project internet site, that may be accessed at *http://ga.water.usgs.gov/projects/lawrencevillegw*



Location of the Lawrenceville study area in the Piedmont physiographic province of Georgia.



Ground-water wells and streamflow monitoring sites for three river basins located near Lawrenceville, Georgia.

The USGS is monitoring streamflow weekly at four sites in the study area, one of these being Redland Creek, shown above. Photo by Phillip N. Albertson, USGS.

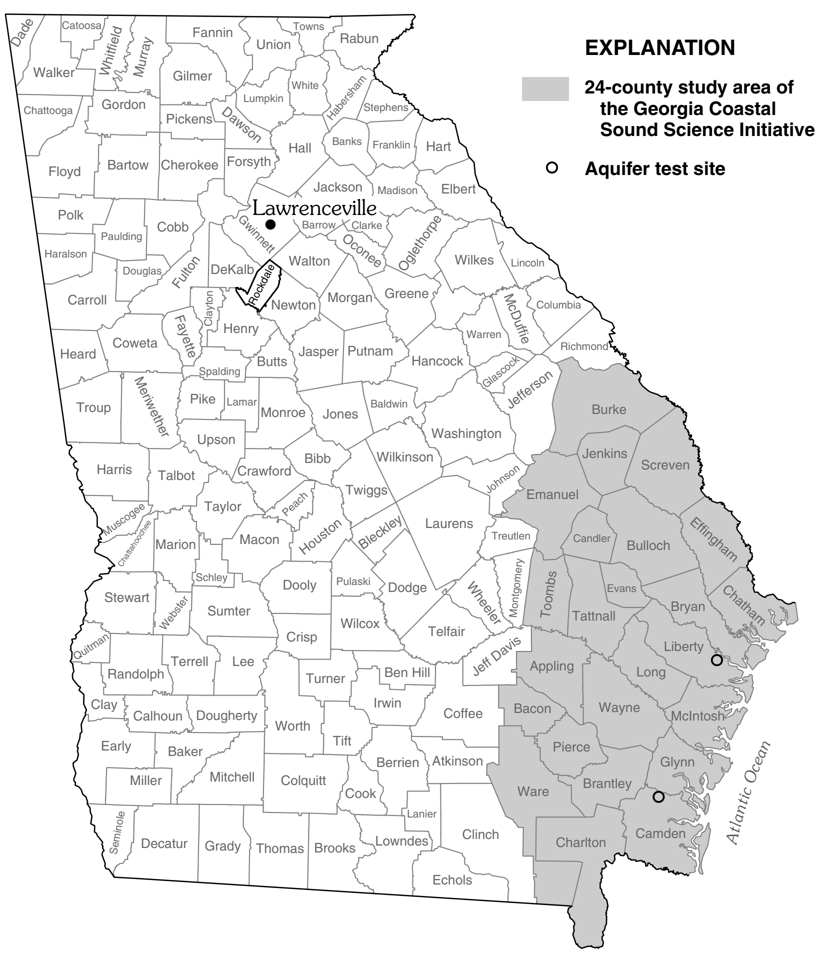
Staff gage on Cedar Creek. Photo by Phillip N. Albertson, USGS.

Drillers install a new regolith monitoring well. Photo by Phillip N. Albertson, USGS.

TECHNICAL HIGHLIGHTS

During 2002–03, the U.S. Geological Survey (USGS)—in cooperation with State, local, and Federal agencies—conducted various hydrologic studies that provided information to better define and manage the State's water resources. Selected technical highlights from the USGS programs conducted in Georgia include:

- Hydrogeology, hydraulic properties, and water quality of the surficial and Brunswick aquifer systems, eastern Liberty County, Georgia, January–February 2003
  by Sherlyn Priest
- Hydrogeology, hydraulic properties, and water quality of the surficial and Brunswick aquifer systems, northern Camden County, Georgia, October–December 2003
  by Sherlyn Priest
- Establishment of a ground- and surface-water network to monitor the potential effects of ground-water development in an igneous and metamorphic rock aquifer, and preliminary data, Lawrenceville, Georgia, 2003
  by Phillip N. Albertson
- Water-bearing characteristics of sheet fractures in Rockdale County, Georgia,
  by Lester J. Williams
- Projected water use in the Coastal area of Georgia, 2000–2050
  by Julia L. Fanning



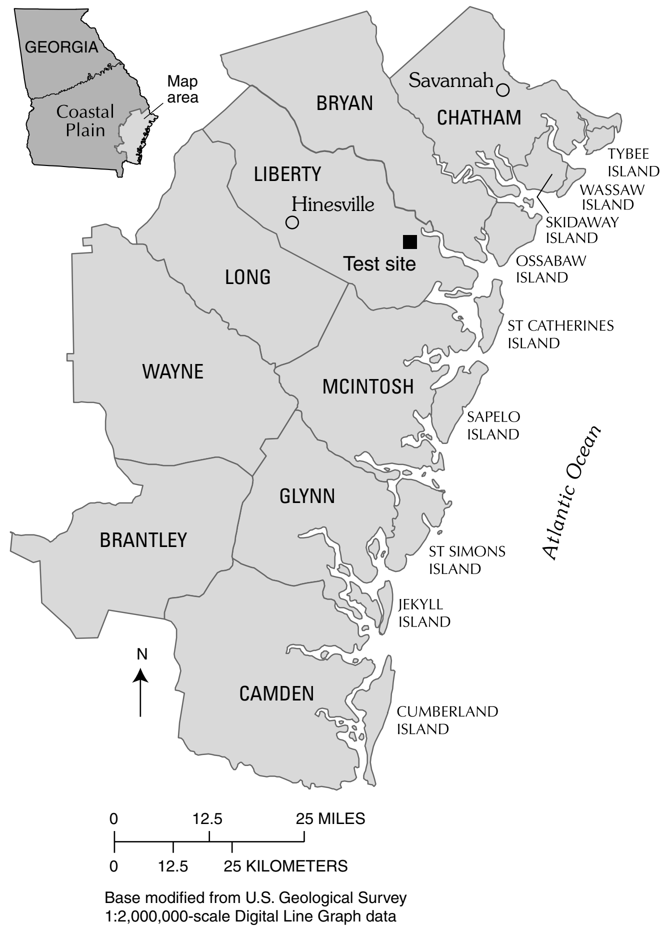
Hydrogeology, Hydraulic Properties, and Water Quality of the Surficial and Brunswick Aquifer Systems, Eastern Liberty County, Georgia, January–February 2003

By Sherlyn Priest

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.



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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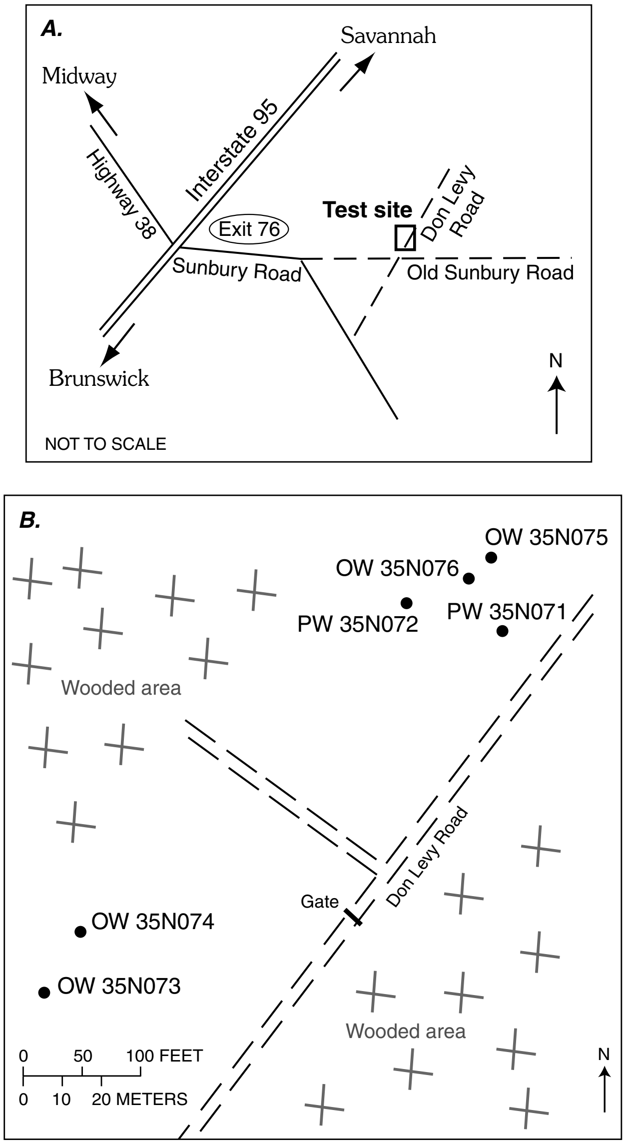


*(**A**) Generalized location of test site; and (**B**) test site showing relative locations of pumping wells (PW) and observation wells (OW).*

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

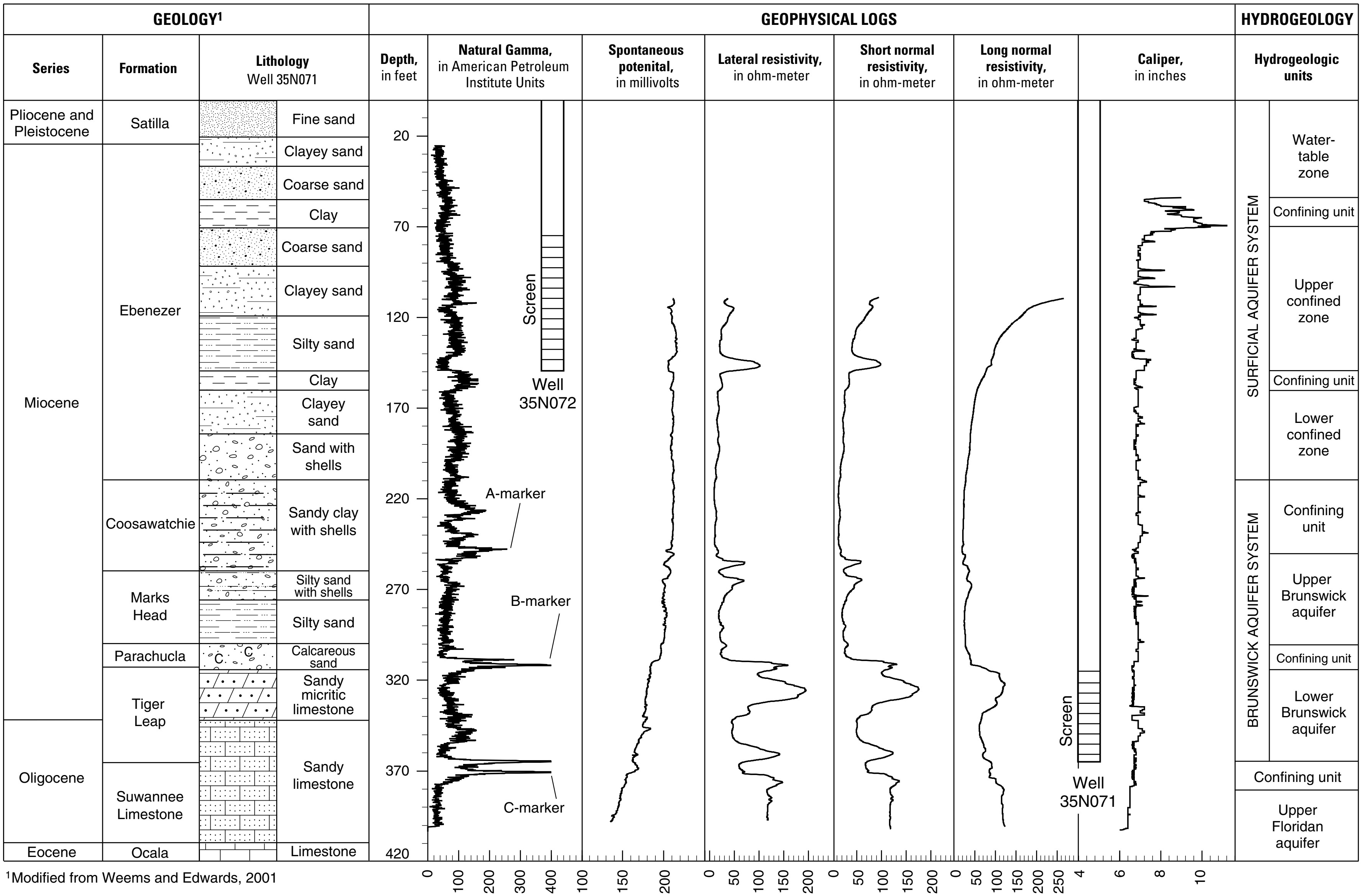
Clarke and others (1990) defined the surficial and upper and lower Brunswick aquifers and described their water-bearing characteristics. Steele and McDowell (1998) mapped the permeable thickness and areal distribution of the upper and lower Brunswick aquifers. Sharpe and others (1998) described results 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-



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).

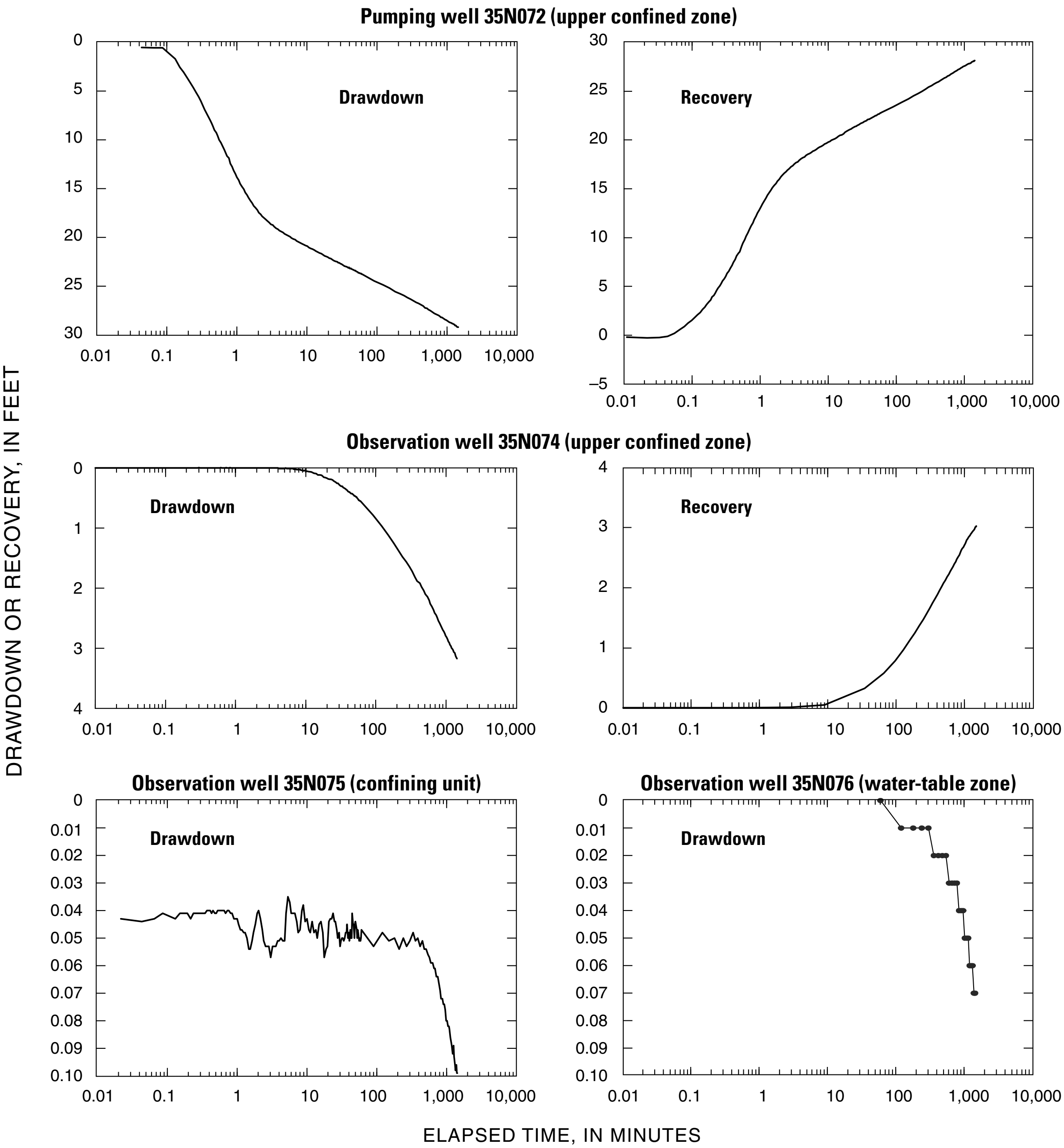
Results from the drawdown and recovery data analysis using the Cooper and Jacob (1946) and Hantush and Jacob (1955) analytical methods provided a reasonable estimation of the hydraulic properties for the upper confined zone. Using both drawdown and recovery data, results from the two solutions indicate 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]

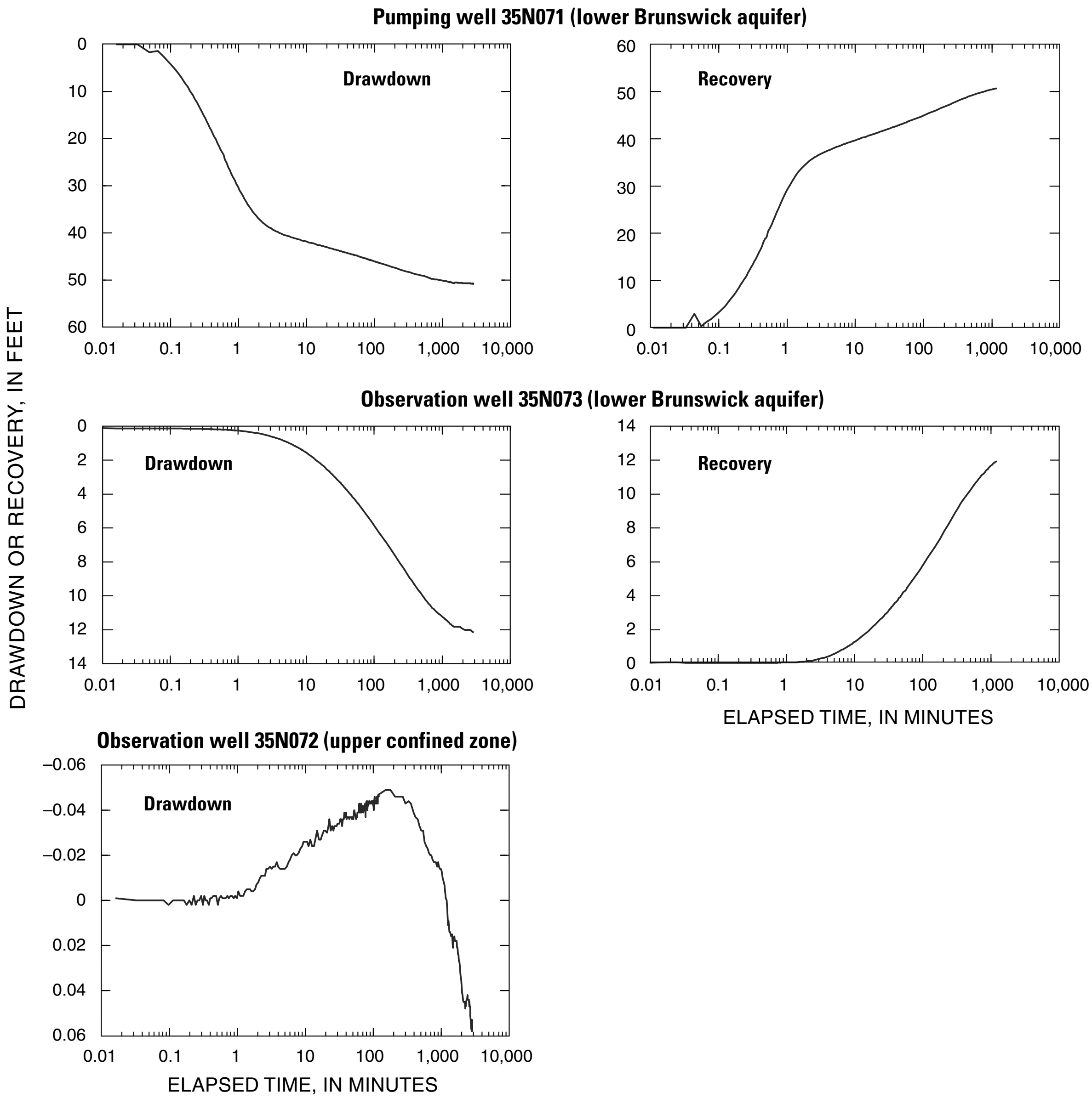
Well name	Transmissivity (ft^2/d)	Hydraulic conductivity (ft/d)	Storage coefficient	Condition	Method used	Date of aquifer test
Upper confined zone of the surficial aquifer system test						
35N072	400	4	—	Drawdown	Cooper and Jacob (1946)	Feb 5–7, 2003
35N072	400	4	—	Recovery	Cooper and Jacob (1946)	—
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.

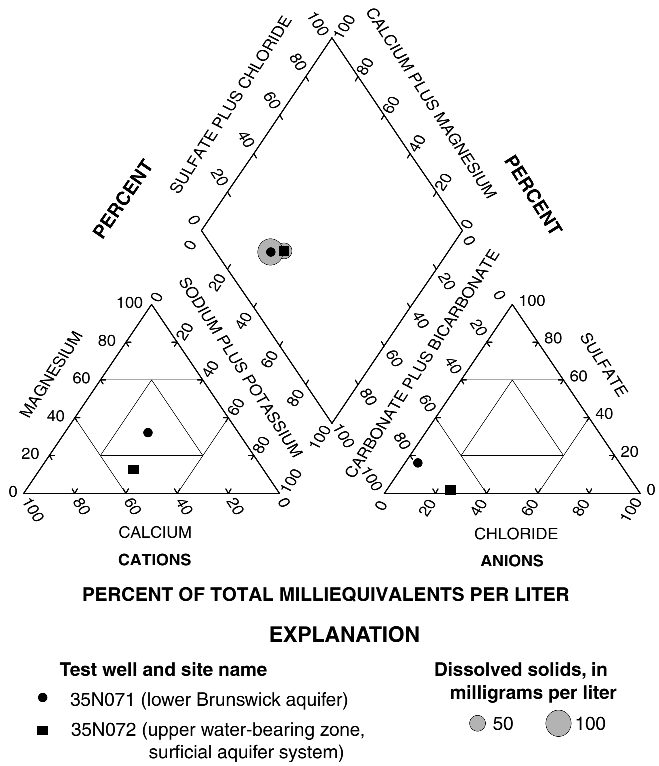
GROUND-WATER QUALITY

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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Hydrogeology, Hydraulic Properties, and Water Quality of the Surficial and Brunswick Aquifer Systems, Northern Camden County, Georgia, October–December 2003

By Sherlyn Priest

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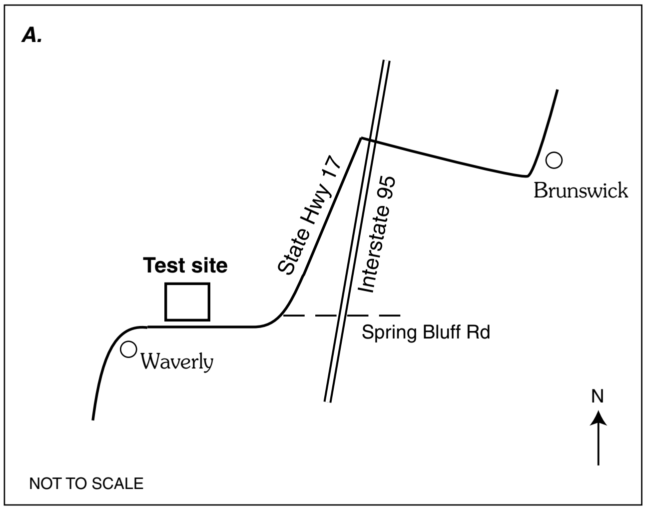
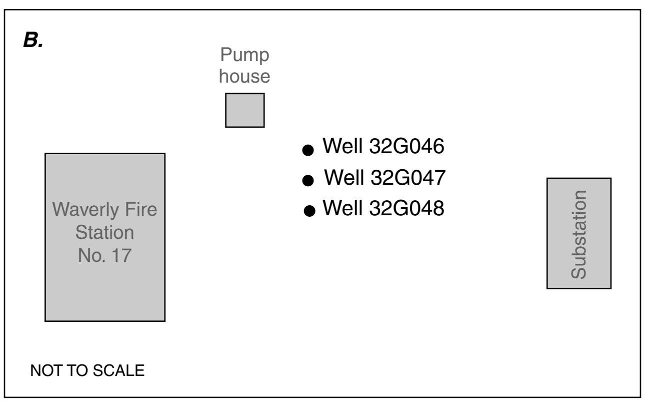
during November 2002–February 2003 using standard mud-rotary techniques. The table below presents the well construction information.

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

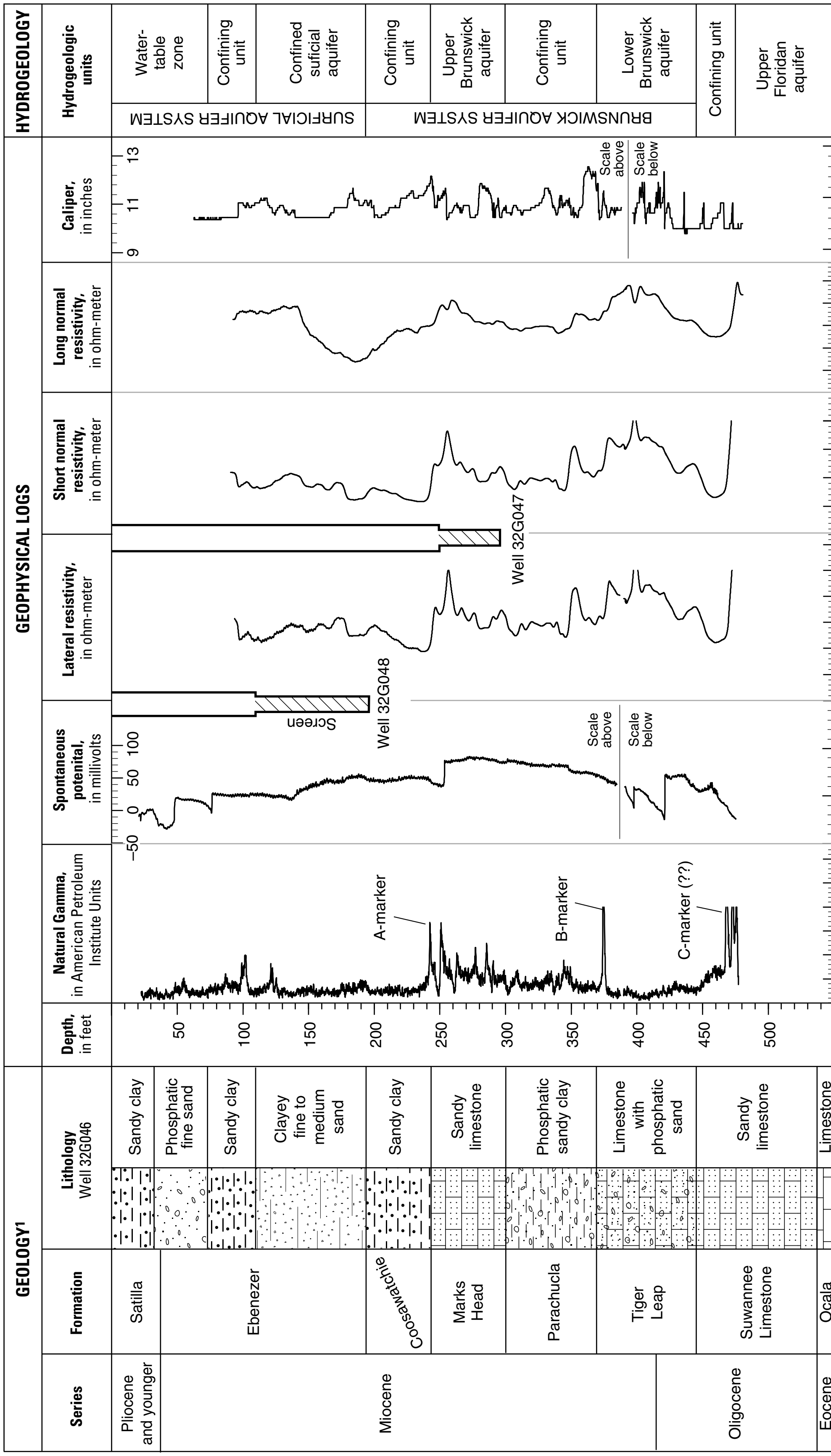
Clarke and others (1990) defined the surficial and upper and lower Brunswick aquifers and described their water-bearing characteristics. Sharpe and others (1998) described the results of an aquifer test in the Miocene-aged sediments in Camden County, Georgia. Steele and McDowell (1998) mapped the permeable 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, 2001

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

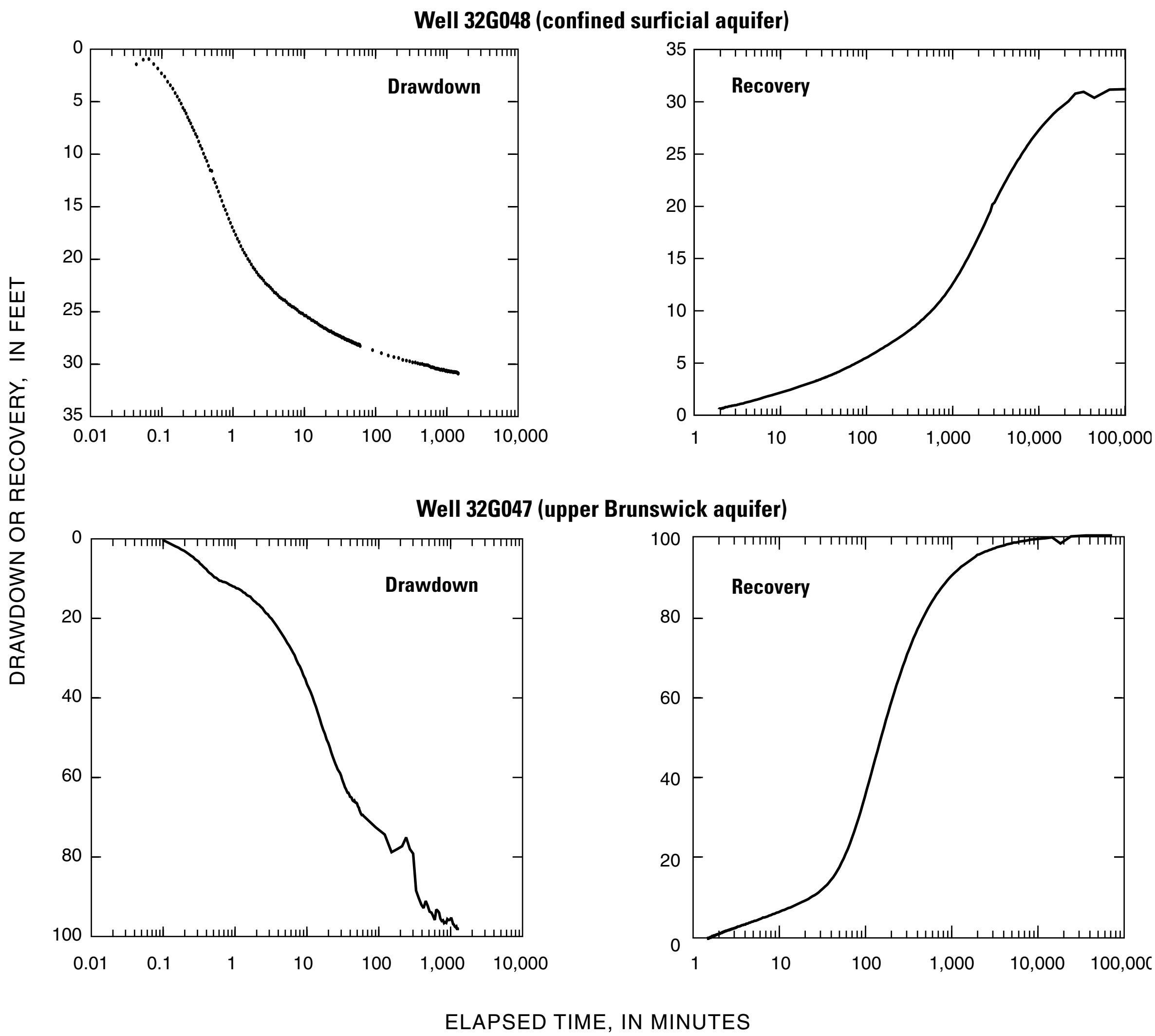
The upper Brunswick aquifer test consisted of pumping and monitoring well 32G047, open to the upper Brunswick aquifer, and monitoring well 32G048, open to the confined surficial aquifer. There was no change in the water level in the confined surficial aquifer, thus no data to analyze. Prior to the upper 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.

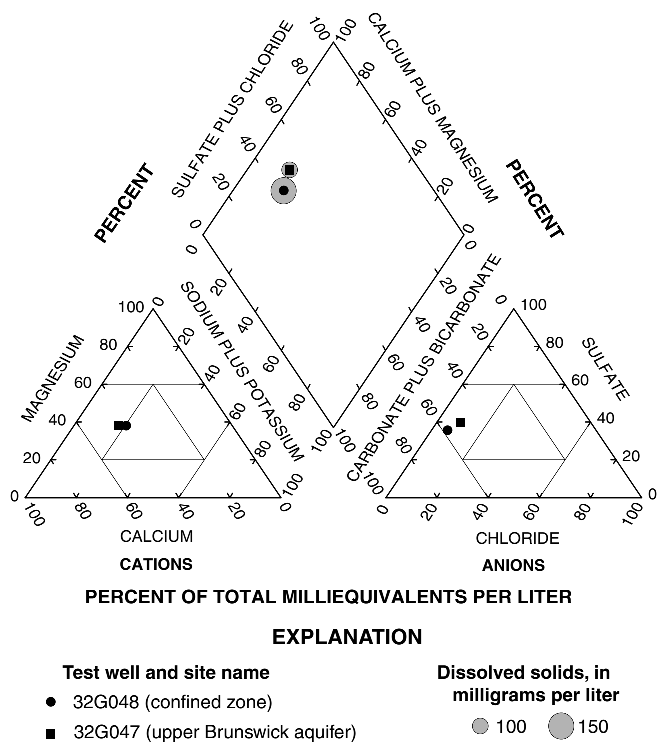
GROUND-WATER QUALITY

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 (CaCO3) (based on the sum of milliequivalent of calcium, magnesium, barium, and strontium), and is categorized as very hard (Durfor and Becker 1964).

Water from the confined 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. Tritium was 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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Establishment of a Ground- and Surface-Water Network to Monitor the Potential Effects of Ground-Water Development in an Igneous and Metamorphic Rock Aquifer, and Preliminary Data, Lawrenceville, Georgia, 2003

By Phillip N. Albertson

INTRODUCTION

The city of Lawrenceville plans to begin pumping ground water from two well fields in igneous and metamorphic rock aquifers. These well fields, located in the Redland–Pew Creek and upper Alcovy River watersheds, will supply a part of the city's future water supply. The potential effects of sustained ground-water pumping on igneous and metamorphic rock aquifers and streams in this area are poorly understood. Information on ground-water levels and streamflow is necessary to assess these potential effects on the hydrologic system, and to properly manage this important resource. During 2002, the U.S. Geological Survey (USGS), in cooperation with the city of Lawrenceville, established a ground-water-level and streamflow monitoring network to provide the data needed to properly manage and optimize withdrawal of ground water and compute water budgets.

Purpose and Scope

This paper describes the hydrologic monitoring system installed in the Lawrenceville area during 2003 and presents preliminary data collected during 2003 from monitoring wells and streamflow gaging stations. This network will provide baseline data to describe hydrologic conditions before additional ground-water pumping begins.

This cooperative study between the city of Lawrenceville and the USGS began during the fall of 2002 to determine the quantity of water that reasonably could be withdrawn from the igneous and metamorphic rock aquifer. To accomplish this objective, ground-water levels at 27 observation wells and streamflow at 14 surface-water monitoring stations are being recorded to provide baseline hydrologic information. Some of the production wells shown on the maps on the following pages, currently serve as observation wells in the ground-water monitoring network (14FF62 [page 106]; 13FF16; 13FF18; and 13FF22 [page 108]). In addition, climatic data are being used along with streamflow and ground-water-level data to compute water budgets for the two study watersheds.

Description of the Study Area

Lawrenceville is located approximately 26 miles northeast of Atlanta, Georgia, in the Piedmont physiographic province (map, page 105). During 2003, Lawrenceville obtained approximately 6 percent of its drinking water from ground water (Mike Bowie, City of Lawrenceville, oral commun., 2002). During 2005, Lawrenceville will increase this percentage by bringing on line additional municipal wells installed in two different watersheds near the city.

The upper Alcovy River watershed, 9.95 square miles (mi^2) in area, is located northeast of the city, whereas the Redland–Pew Creek watershed (7.50 mi^2) is located southwest of Lawrenceville. Streamflow and ground-water levels also will be measured in the upper Apalachee River watershed (5.68 mi^2), and these data will serve as background to data collected in the two watersheds where pumping is planned.

Hydrogeologic Setting

The Lawrenceville area is underlain by igneous and metamorphic rocks (bedrock) that have very little primary porosity and permeability. Fractures and other openings within the bedrock form secondary porosity and permeability that provide conduits for ground-water flow. Permeability of the bedrock is heterogeneous and anisotropic. Generally, the bedrock is overlain by regolith that varies in thickness, permeability, and porosity; however, locally, the regolith layer can be absent.

Ground water in igneous and metamorphic rock aquifers occurs in joints, fractures, and other secondary openings in the bedrock. Water from the overlying mantle of soil, saprolite, alluvium, and weathered rock, collectively referred to as regolith, provides much of the water to the igneous and metamorphic-rock aquifers in areas where the aquifers and regolith are hydraulically connected. In Lawrenceville, "fractures" refer to openings along compositional layering, foliation planes, joints, and brittle fractures related to faulting. Fractures also include openings at contacts between compositional layering (Williams and others, 2004). Yield of wells in the area range from 1 gallon per minute (gal/min) to more than 600 gal/min (Chapman and others, 1999).

The amount of water that recharges the aquifer is only a small fraction of the total annual precipitation. Much is lost to runoff, evapotranspiration, or to replenish soil-moisture deficits in the regolith. The amount of recharge available to the bedrock aquifer for water supply is controlled by (1) the interconnection between the regolith and the underlying bedrock system, (2) the transmissivity of the regolith and fracture network that enables movement of water from the recharge area into the bedrock, and (3) storage properties of the fractured bedrock and overlying regolith. Changes in storage in an aquifer are indicated by water-level fluctuations over time—increased storage is indicated by water-level rise, whereas decreased storage is indicated by water-level decline.

Water Budgets

Water budgets will be computed for the two study watersheds for both pre- and postpumping conditions. As pumping in the watersheds increases, the monitoring network presumably will indicate where additional recharge is occurring in response to the additional ground-water withdrawal.

Under low-flow conditions, ground-water recharge is equal to ground-water discharge. The amount of water discharged to streams and withdrawn by wells is an approximation of the amount of water recharging the aquifer.

Recharge to the aquifer is primarily from precipitation, but probably includes interbasin transfer of ground water through transmissive and extensive fracture networks. Recharge also includes future municipal improvements to increase recharge through infiltration fields and catchments. Septic tank effluent also is considered as a component of recharge. Discharge includes natural ground-water flow to streams (baseflow) and ground-water pumping.

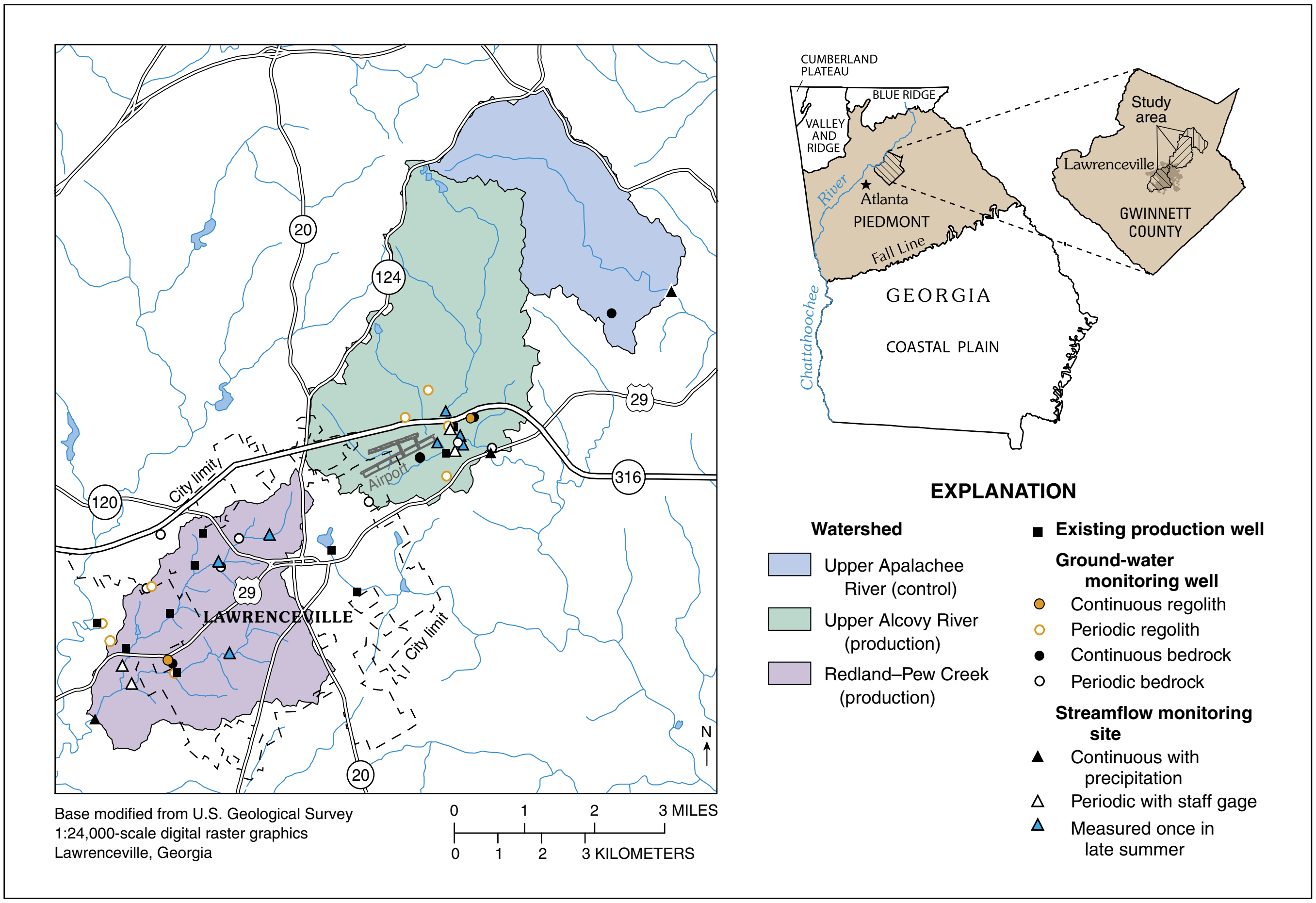
HYDROLOGIC MONITORING NETWORK

To collect baseline data on the sustainability of ground-water and surface-water resources, a monitoring network was established (map, facing page) to monitor ground-water levels and streamflow in both watersheds in which additional ground-water withdrawal will occur. Eight production wells — two in the upper Alcovy River watershed and six in, or near, the Redland–Pew Creek watershed — are scheduled to start pumping in the future (Mike Bowie, City of Lawrencevillle, oral commun., 2003). Some of these production wells currently serve as observation wells (14FF63; 13FF16; 13FF18; and 13FF22) in the ground-water monitoring network.

A total of 27 observation wells in a monitoring network will record ground-water levels in the area. Eleven observation wells were installed during the summer of 2003, and combined in a monitoring network along with 16 other existing wells. Of the 27 total wells, 10 are completed in the regolith, and 17 are completed in bedrock. Six well clusters, each cluster consisting of a regolith well and a bedrock well, are in the network; data from these clusters will identify vertical gradients between the regolith and the bedrock. These gradients will be monitored before and after pumping begins. Weekly ground-water-level measurements were collected from 21 of these wells throughout 2003. Continuous water-level measurements were collected from a well cluster in the upper Alcovy River and Redland–Pew Creek watersheds (14FF65–14FF66, 13FF30–13FF31, respectively), from well 14FF42 in the upper Alcovy River watershed, and from an observation well (14GG02) in the upper Apalachee River control watershed.

Continuous stream stage recorders were installed at the outlet of each of the two study watersheds (stations 02208050 and 02205522). A continuous stream stage recorder was present already at the outlet of the Apalachee River control watershed (station 02218565). Weekly streamflow measurements and staff gage readings were collected from the Alcovy River at Georgia Highway 316 (station 02208047), Cedar Creek at Cedars Road (station 02208048), Redland Creek at U.S. Highway 29 (station 02205520), and from Pew Creek at Sugarloaf Parkway (station 02205508). Streamflow measurements at these four sites were taken using a Price-Pygmy current meter, which was selected because of its ability to measure low velocities. The standard error of the Price-Pygmy current meter is 4 percent (Sauer and Meyer, 1992).

USGS personnel lower a video camera into well 14GG02 in the upper Apalachee River watershed. Photo by Phillip N. Albertson, USGS.



Study area location, production wells, and selected ground-water wells and streamflow monitoring sites near Lawrenceville, Georgia.

In addition, seepage measurements were made to determine the ground-water seepage (discharge or recharge) along selected reaches of the Alcovy River, Cedar Creek, Redland Creek, and Pew Creek when streams were at baseflow conditions in late summer. The gain or loss in streamflow is calculated by subtracting an upstream streamflow measurement from a downstream measurement. Seepage measurements calculated before and after the initiation of pumping will be compared to determine if pumping has an effect on the ground-water contribution to streamflow.

Climate data collected at various locations in the study area will be used in the water-budget estimations. Precipitation data are being collected continuously in the two study watersheds and in the control watershed. Air temperature data are being collected at a monitoring station at the Gwinnett County Airport and will be used in the estimate of evapotranspiration for the water budget of each study watershed.

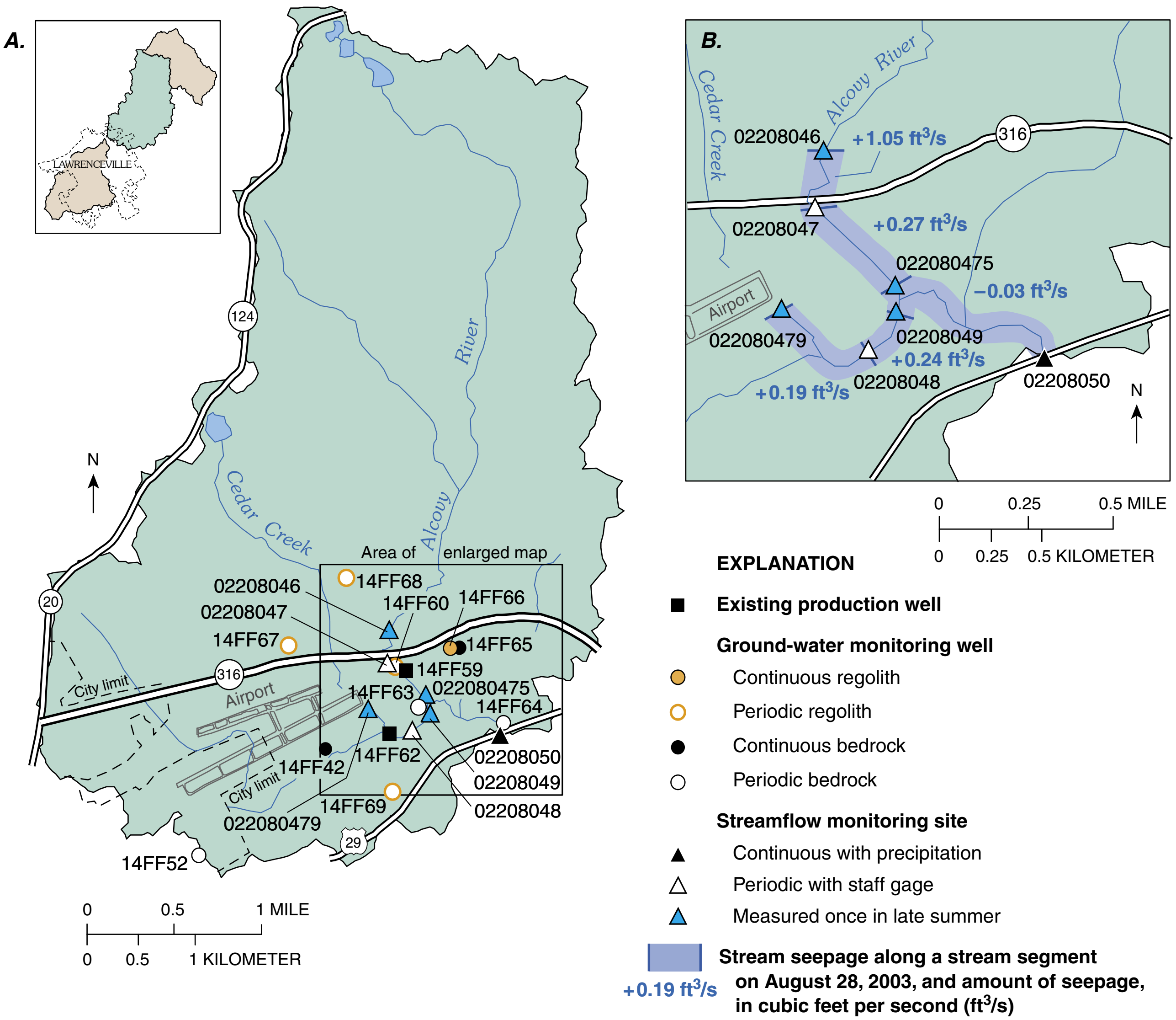
DATA FOR 2003

The hydrologic data collected for 2003 represent the first partial year of prepumping conditions in the study area. These baseline data, along with subsequent data being collected prior to pumping, will be compared with data collected after pumping begins in the “production” watersheds, as well as with data being collected in the control watershed, to evaluate the sustainability of withdrawing ground water for municipal use.

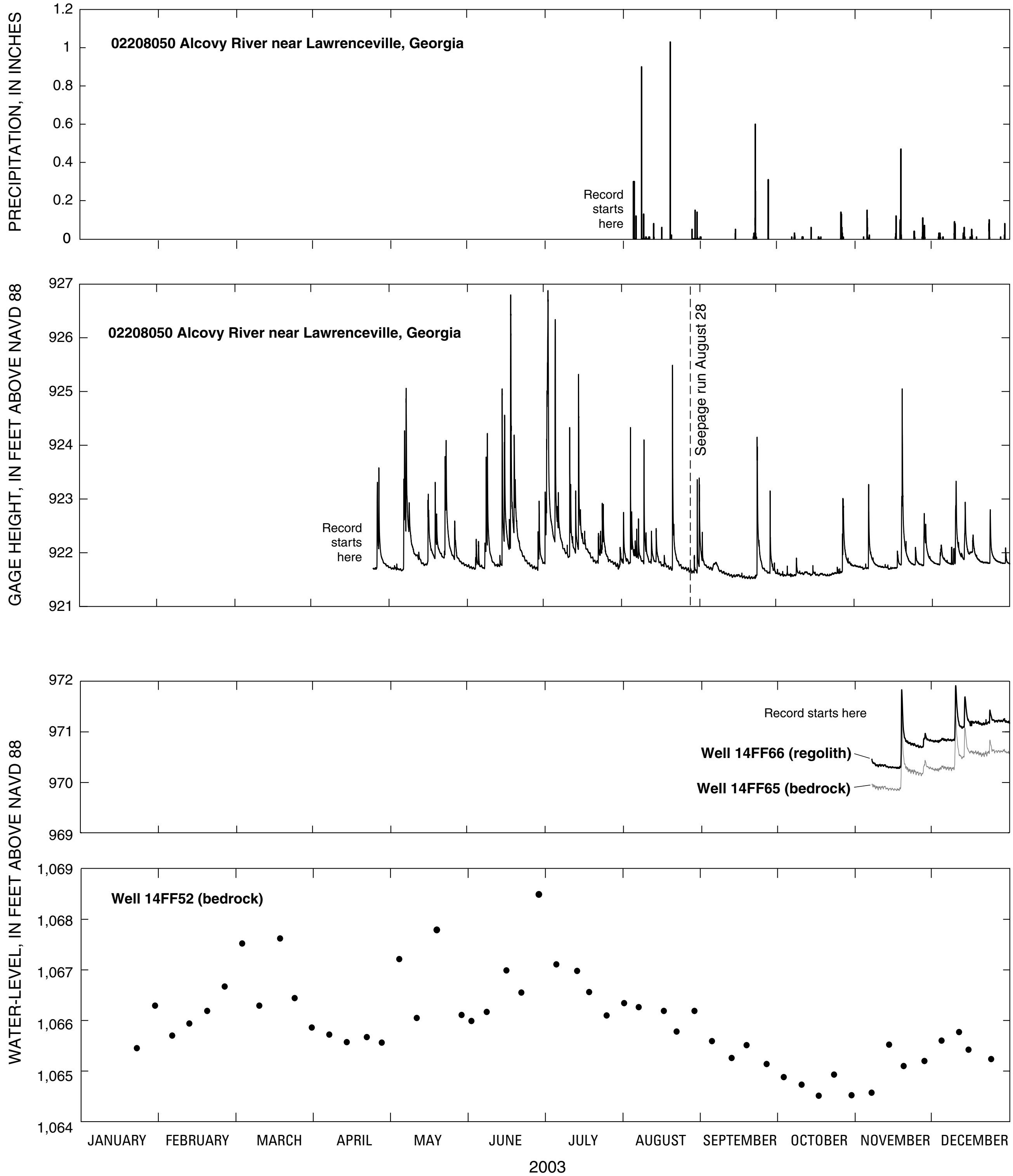
Upper Alcovy River Watershed

Production wells, monitoring network wells, and surface-water sites are shown in map *A* below. Examination of current (2003) and historical stream hydrograph data indicate streams are at baseflow conditions during late August. Therefore, streamflow measurements were made on August 28, 2003, along the Alcovy River and Cedar Creek to determine seepage (the gain or loss of water) in the vicinity of proposed future municipal wells (map *B*, below). Results from streamflow measurements indicate that streams generally gain water downstream; however, some stream reaches show a loss of streamflow and are considered as losing segments where discharge is less downstream than upstream. The reach showing the largest amount of gain because of ground-water discharge is between stations 02218046 and 02208047, which is one of the shortest reaches measured. From the confluence of the two rivers to the base of the watershed (station 02208050), the stream reach loses about 0.03 cubic feet per second (ft^3/s). Ground-water levels in bedrock wells located next to streams (14FF59, 14FF62, and 14FF63) are consistently above stream stage, indicating a potential vertical gradient from the aquifer to the stream.

Rainfall produces peaks in both ground-water and stream-stage hydrographs. Conversely, periods of no rainfall produce recessions in both ground-water and stream-stage hydrographs. Minimum stream stage occurs in the Alcovy River during September, a period of little or no rainfall (graphs, facing page). The minimum ground-water level (for example, well 14FF52, a well located away from the Alcovy River), occurs during October. A downward gradient at the well cluster (14FF65–14FF66) indicates potential recharge at this location. In addition, the rise in water levels indicates that storage increases during November and December.



(A) Upper Alcovy River watershed, production wells, selected ground-water-level wells, streamflow monitoring sites, and discharge measurements; and (B) stream seepage on August 28, 2003, along selected stream segments near Lawrenceville, Georgia.



Precipitation and gage height at Alcovy River near Lawrenceville, Georgia (station 02208050), and ground-water levels at well cluster 14FF65–14FF66 and well 14FF52 near Lawrenceville, Georgia, 2003 (locations shown on map, facing page; NAVD 88, North American Vertical Datum of 1988).

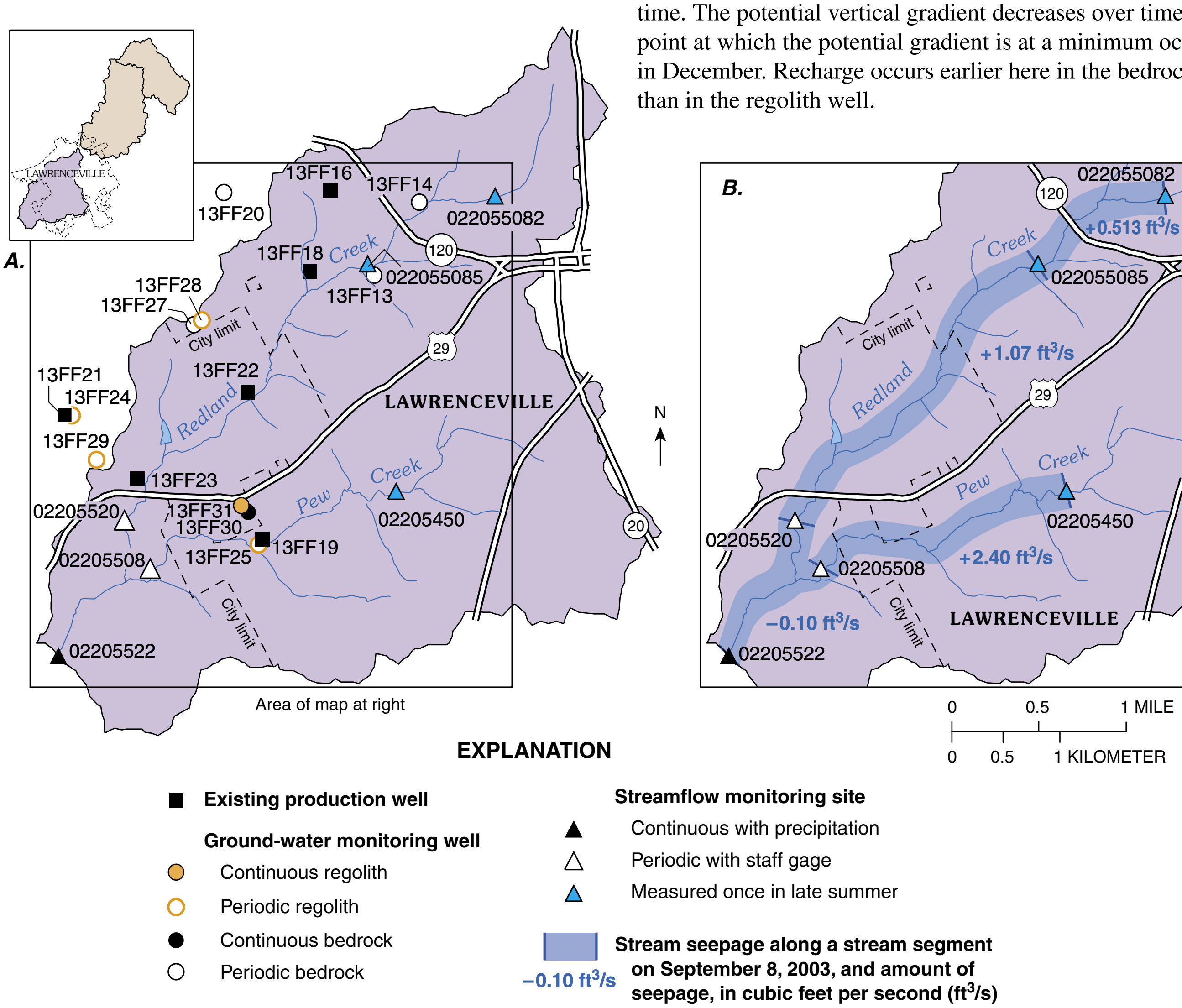
Redland–Pew Creek Watershed

Production wells, monitoring network wells, and surface-water sites are shown in map *A* below. Seepage was calculated from discharge measurements taken on September 8, 2003, at six stations in the Redland–Pew Creek watershed (map *B*, below). These discharge measurements indicate that most stream reaches are gaining. The largest gaining reach was on Pew Creek (+2.40 ft^3/s) from station 02205450 to 02205508. From the confluence of the two rivers to the base of the watershed the stream reach loses about 0.10 ft^3/s. Ground-water levels in bedrock wells near streams (13FF14, 13FF18, and 13FF22) are consistently above the nearby stream stage, indicating a potential vertical gradient from the aquifer to streams at these locations.

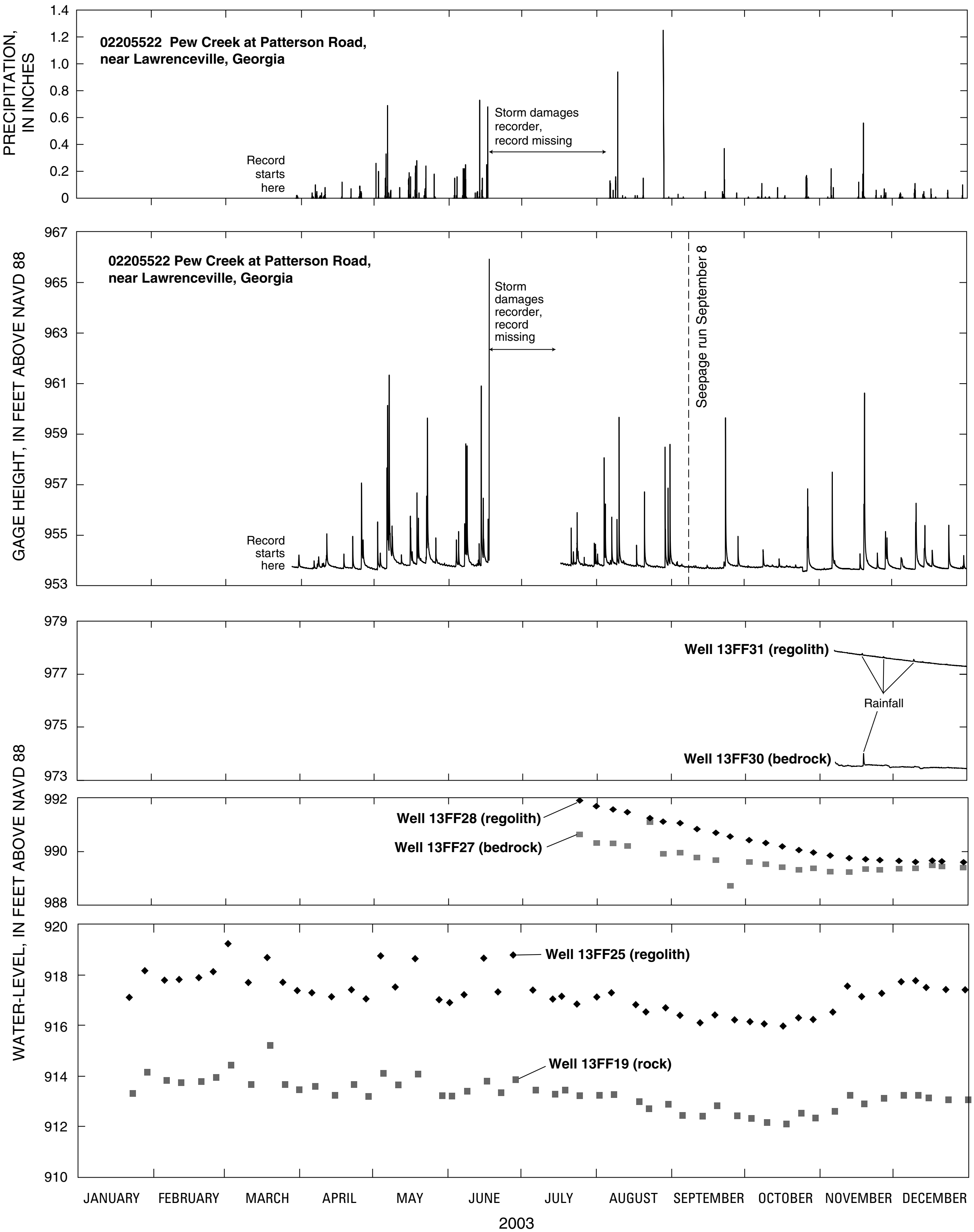
As in the upper Alcovy River Watershed, precipitation in the Redland–Pew Creek watershed causes peaks in ground-water and stream-stage hydrographs. Stream-stage response to precipitation is flashy, meaning stream stage rises and falls in a relatively short period of time. Periods of low or no rainfall produce recessions in both ground-water and stream-stage hydrographs. Examination of the hydrographs (facing page) shows minimum stream stage occurs during late October and water levels in well cluster 13FF19–13FF25 (cluster located on bank of Pew Creek) reach minimum levels in both wells during the same period.

Directly northwest of well cluster 13FF19–13FF25 is well cluster 13FF31–13FF30. Water levels in this cluster receded throughout the end of 2003. The vertical gradient at this location is downward and indicates potential recharge in the area. In addition, the vertical gradient decreases through the end of the year. The ground-water-level trend is downward through November and December, indicating loss of storage at this location during that period, which is opposite of the gain in storage occurring in the upper Alcovy River watershed during this same period.

A downward vertical gradient also exists at well cluster 13FF27–13FF28; however, the vertical gradient changes over time. The potential vertical gradient decreases over time. The point at which the potential gradient is at a minimum occurs in December. Recharge occurs earlier here in the bedrock well than in the regolith well.



(A) Redland–Pew Creek watershed, production wells, selected ground-water-level and streamflow monitoring sites, and discharge measurements; and (B) stream seepage on September 8, 2003, along selected stream segments near Lawrenceville, Georgia.



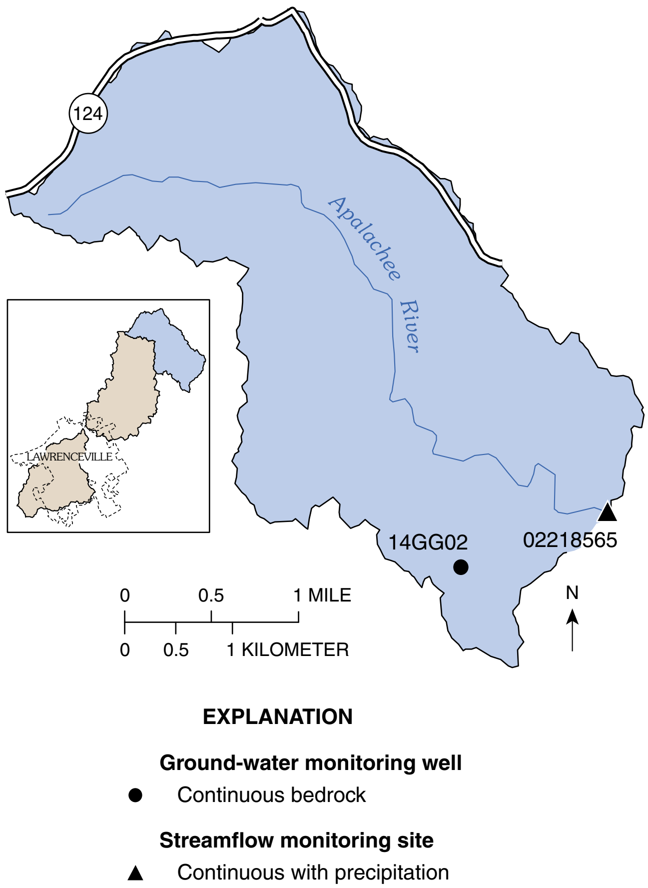
Precipitation and gage height at Pew Creek at Patterson Road near Lawrenceville, Georgia (station 02205522); and ground-water levels at well clusters 13FF30–13FF31, 13FF27–13FF28, and 13FF19–13FF25 near Lawrenceville, Georgia, 2003 (well 13FF19 is a future production well; locations shown on map, facing page; NAVD 88, North American Vertical Datum of 1988).

Apalachee River Watershed

Seasonal trends in precipitation, streamflow, and ground-water levels in well 14GG02 (map below) follow a similar pattern as those of the "production" watersheds. Precipitation causes a flashy stream response and periods of low or no precipitation cause periods of recession in streamflow. In well 14GG02, precipitation does not necessarily cause peaks in ground-water levels; drawdowns were caused by nearby irrigation (graphs, facing page).

DISCUSSION

The collection of streamflow, ground-water-level, seepage measurement, and climate data are necessary to provide the city of Lawrenceville a means to estimate the sustainability of the hydrologic system. The data collected during 2003, along with subsequent data collected during 2004 and 2005, will represent baseline conditions of the hydrologic system prior to the additional municipal well pumping scheduled to begin during 2005.



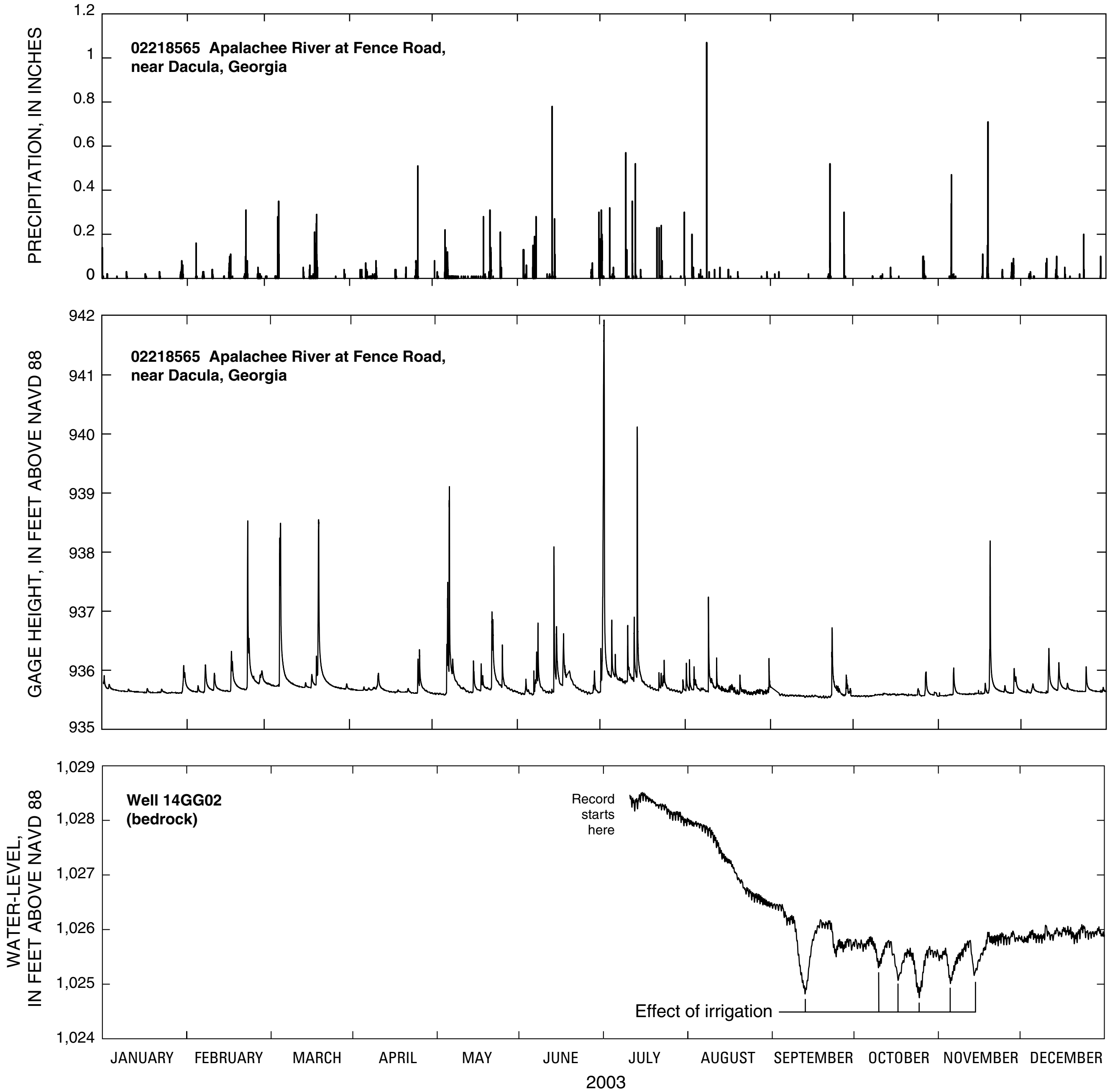
Upper Apalachee River watershed (control), and selected ground-water well and streamflow monitoring site near Lawrenceville, Georgia.

Precipitation causes almost instantaneous peaks in the hydrographs of stream stage for all three watersheds in the study area; periods of little or no precipitation produce periods of recession. Precipitation also causes a water-level rise in most wells being monitored except at well cluster 13FF30, 13FF31 and the control well 14GG02. This means that recharge, at some locations, infiltrates rapidly into the regolith.

Ground-water and streamflow data collected during 2003 indicate that seasonal trends in stream-stage and ground-water levels are similar in the three watersheds being monitored; however, minor differences exist when baseflow occurs in streams and when minimum water levels occur in wells. In the upper Alcovy River watershed, the lowest water levels in wells usually occur during October and the lowest stream-stage levels occur during late September. In the Redland–Pew Creek watershed, the lowest water levels in wells occur either during September, October, November, or December. Streamflow is lowest in Pew Creek during October. The water-level trend in well 14GG02 (control well) is downward from July through December and is affected by pumping.

Most well cluster water-level data indicate potential recharge to the igneous and metamorphic rock aquifer. This is evident in well clusters 13FF19–13FF25 and 13FF30–13FF31. Water-level data from well cluster 13FF19–13FF25, located on the bank of Pew Creek, indicate a potential downward gradient; however, seepage data indicate this reach to be gaining. This apparent contradiction may indicate that (1) the stream is losing water in this short section next to the well cluster but gaining overall, (2) there is little connection between the stream and the aquifer at this location, and/or (3) only the regolith is contributing water to the stream in this area.

Seepage measurements generally indicate that streams are gaining during the baseflow period, meaning there is a net positive contribution of ground water to streamflow. This is important because annual seepage measurements will be monitored both before and after pumping begins, to observe the long-term effects of pumping on the ground-water contribution to streamflow. Water levels in most bedrock wells located near streams are consistently higher than streams, indicating a potential vertical gradient from the aquifer to streams. These vertical gradients show the potential for water to flow from the aquifer to streams; this water sustains streamflow in times of little precipitation. The data collected thus far in this study represent prepumping conditions in the hydrologic system and will be compared with data after pumping begins.



Precipitation and gage height at Apalachee River at Fence Road near Dacula, Georgia (station 02218565); and ground-water levels in well 14GG02 near Lawrenceville, Georgia, 2003 (locations shown on map, facing page; NAVD 88, North American Vertical Datum of 1988).

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Water-Bearing Characteristics of Sheet Fractures in Rockdale County, Georgia

By Lester J. Williams

INTRODUCTION

Ground water in crystalline rocks underlying Rockdale County (map, below) and in other parts of the Georgia Piedmont has not been tapped extensively as a source of public drinking water. Such a source, however, may prove to be valuable to communities wishing to supplement their existing surface-water supplies and increase the amount of available drinking water in rapidly-growing areas of north Georgia. Understanding how ground water flows through crystalline rocks, where high-yielding water-bearing zones are present, and how much water is available, has been a focus of recent water-resource investigations being conducted by the U.S. Geological Survey (USGS) in cooperation with Rockdale County.

This technical highlight describes water-bearing characteristics of sheet fractures in Rockdale County. Sheet fractures have considerable influence on the availability of ground water in massive crystalline-rock geologic settings—particularly in the Lithonia Gneiss, which crops out in the northern part of Rockdale County. Water-bearing characteristics of sheet fractures penetrated at two well sites are discussed, and a photograph of one of these fractures in a local quarry is included.

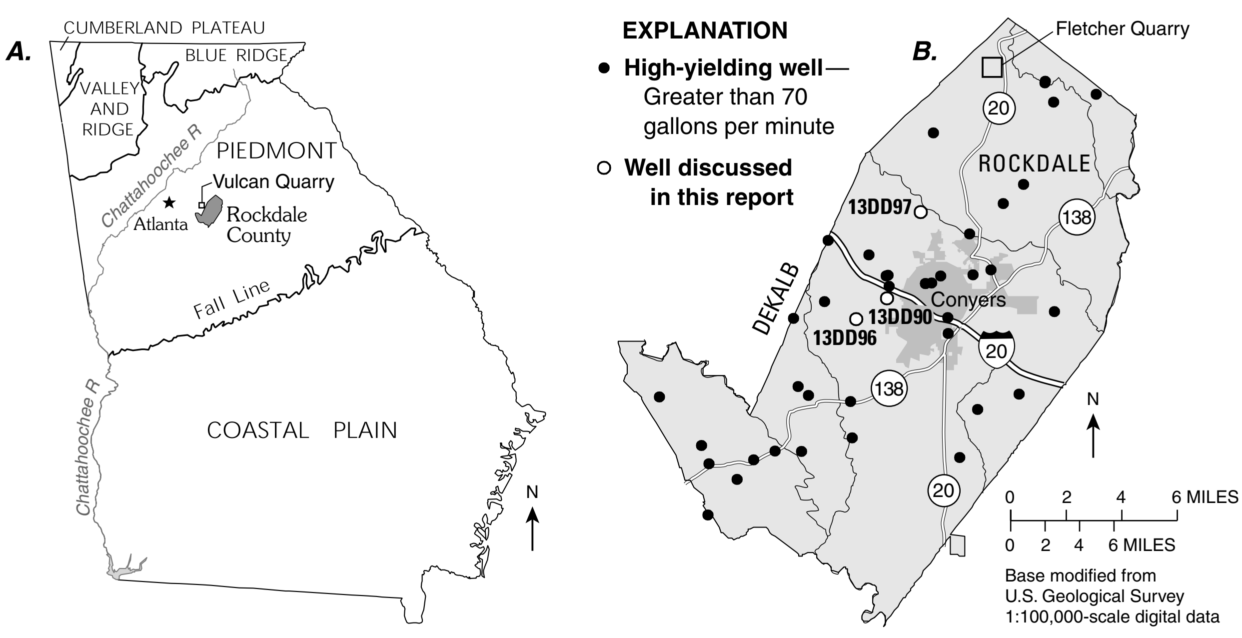
To investigate the depth and nature of subsurface fractures, the open boreholes of wells were inspected with a downhole camera and an optical televiewer. The optical televiewer records oriented digital images of the borehole wall, thus allowing the strike and dip of intersecting fractures and structures to be measured. Flowmeter logs were collected to identify water-producing fracture zones in open boreholes. Water-producing zones yield measurable amounts of water to the borehole when pumped, or where water is flowing into the borehole during ambient conditions.

WATER-BEARING CHARACTERISTICS OF SHEET FRACTURES

Sheet fractures, also called stress-relief fractures (Cressler and others, 1983; Williams, 2003), are planar fractures that are thought to form from the upward expansion of the rock column in response to erosional unloading or from weathering. These fractures typically are characterized by sets of subhorizontal joints, are reported to be most numerous, and have higher water-bearing capacity near the surface because they become tighter and more widely spaced with increasing depth (Cressler and others, 1983). Because sheet fractures form roughly parallel to the land surface, the greatest water-bearing potential is in topographic positions that are favorable for intercepting recharge (diagram, facing page).

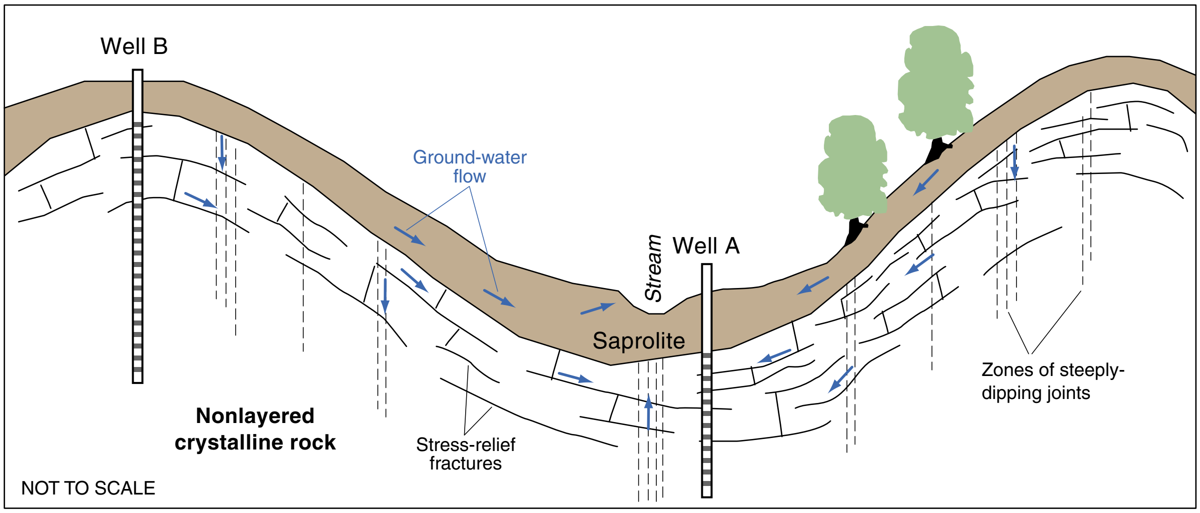
Water-Bearing Characteristics of Sheet Fractures

The water-bearing characteristics of sheet fractures were measured in two wells in Rockdale County. One well (13DD96) is located on a relatively steep slope on the west side of Honey Creek along Klondike Road (map, facing page). This

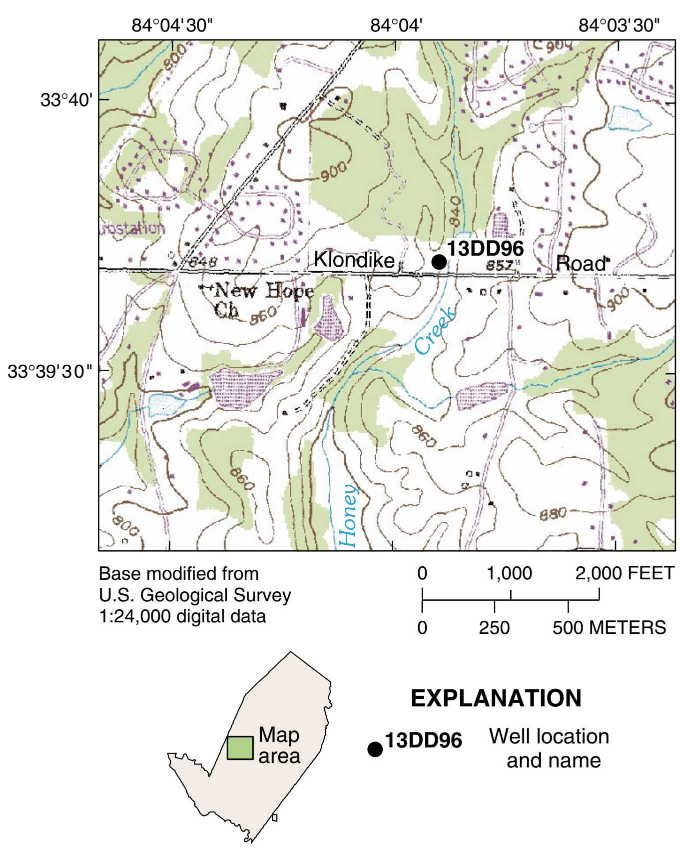


(A) Location of Rockdale County, Georgia, and (B) selected high-yielding wells in Rockdale County.

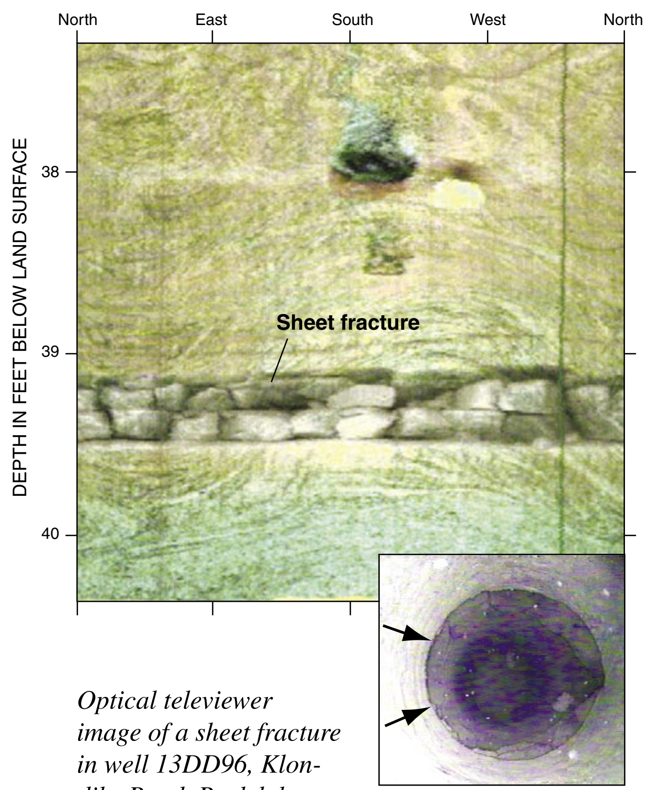
40-foot (ft) deep well penetrates a migmatitic granite gneiss that is characterized by swirled, weakly developed foliation. From the flowmeter log, the only water-bearing zone is a prominent sheet fracture at a depth of about 39 ft near the bottom of the well (images, below right). During pumping, the well yielded 6 gallons per minute (gal/min) from this fracture with approximately 1 ft of drawdown.



Relative positions of wells tapping sheet fractures in nonlayered rock. Well A is in a topographically favorable position to intercept recharge; well B is in a topographically less favorable position (modified from McCollum, 1966).



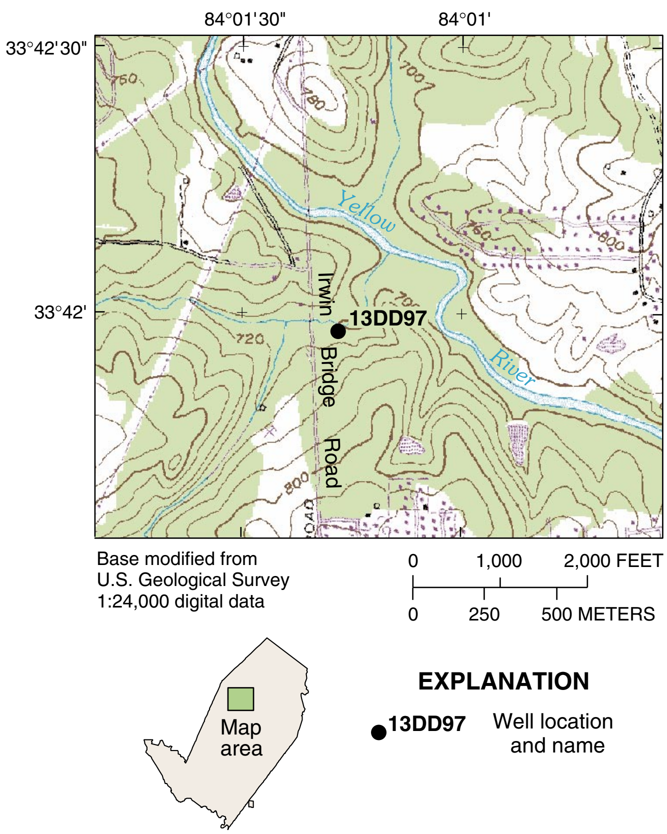
Topography and location of well 13DD96 along Klondike Road, Rockdale County, Georgia.



Optical televiewer image of a sheet fracture in well 13DD96, Klondike Road, Rockdale County, Georgia. Image is oriented true north; cardinal directions are indicated at top of image. Inset shows a downhole view of the fracture (arrows) using a borehole camera.

Another well (13DD97) that derives most of its yield from sheet fractures is located on the floodplain of a small tributary that flows into the Yellow River (map, below). The Lithonia Gneiss — a massive granite gneiss — crops out throughout this area and is penetrated in this 297-ft-deep well. From the flowmeter log, several water-bearing zones were identified between 10 and 50 ft (facing page). Most of the water is derived from two subhorizontal fractures at depths of 29 ft and 23 ft, respectively. Using a pumping rate of 6 gal/min, the fracture at 29 ft produced about 0.3 gal/min and the fracture at 23 ft produced 5.1 gal/min. The remainder of the water (0.7 gal/min) is derived from fractures between 13.5 and 20 ft. No water is produced from the lower portion of the borehole below these sheet fractures.

Wells penetrating sheet fractures have a wide range in yield. Cressler and others (1983) reported a yield of 50 gal/min for a well tapping a horizontal stress-relief fracture at well 13DD90 (map, page 112). Yields of the two wells discussed in this highlight (13DD96 and 13DD97) are 55 and 45 gal/min, respectively.



Topography and location of well 13DD97 along Irwin Bridge Road, Rockdale County, Georgia.

Sheet Fractures in Local Quarries

Sheet fractures are one of the most common type of fracture observed in rock outcrops and quarries in this area. These types of fractures appear to form as a result of spalling or exfoliation of bedrock sheets from the main bedrock exposure through the process of stress relief or weathering. One such fracture was observed in the Fletcher Quarry in northern Rockdale County (photographs, facing page). Photographs of sheet fractures in the Vulcan Quarry in eastern DeKalb County near the border with Rockdale County also were presented by Khallouf and Prowell (2003).

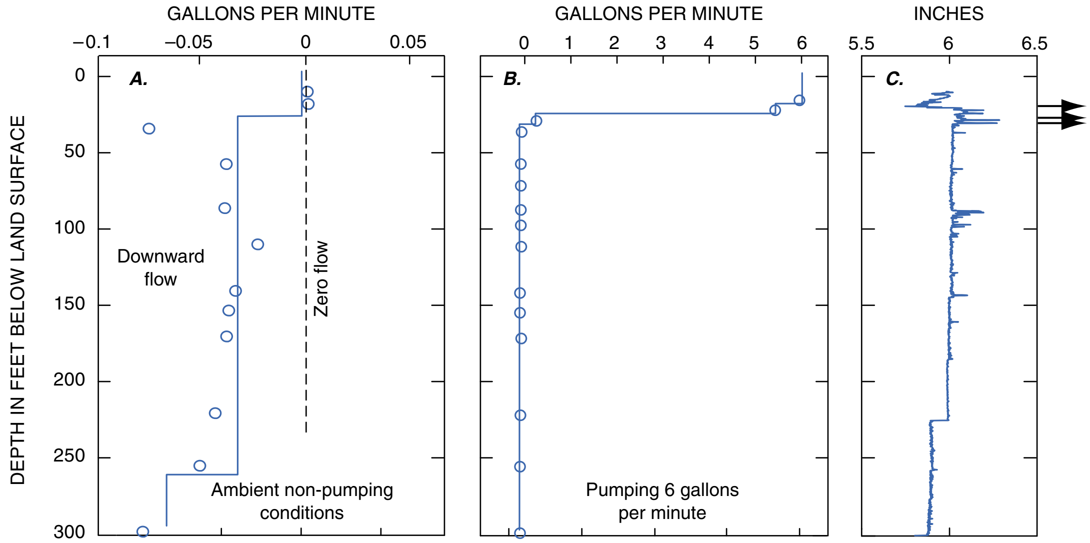
SUMMARY

Sheet fractures are an important source of water to several wells studied in Rockdale County. These near-surface water-bearing fractures form from spalling or exfoliation of rock sheets from the main bedrock exposure. Recharge probably occurs as a result of seepage from the overlying regolith, indicating that the best location to intercept these zones is in areas favoring recharge. Wells penetrating sheet fractures yield small to moderate amounts of water in quantities that are sufficient for single-household domestic use.

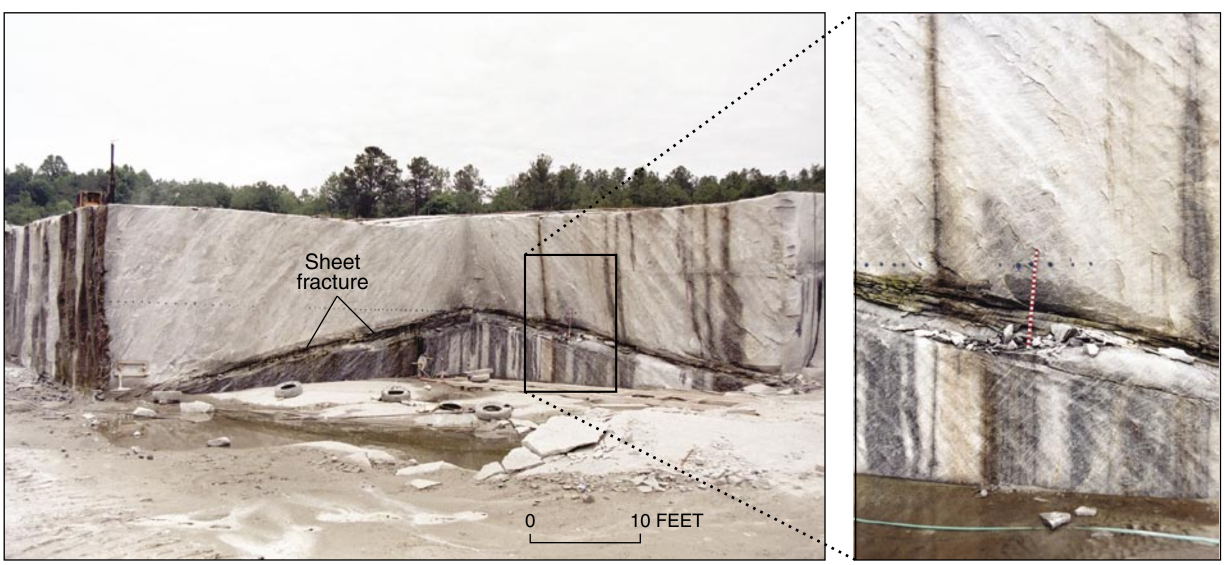
Further research is being conducted to investigate the occurrence and interconnectivity of water-bearing zones in Rockdale County. This study will help further water-resource managers' understanding of crystalline-rock aquifer systems and provide information needed for the development and management of ground-water resources in the Georgia Piedmont.

ACKNOWLEDGMENTS

This study was conducted by the USGS in cooperation with Rockdale County. Many people were involved with helping make this study possible, including Lauri Ashmore, Director of Rockdale County Water Resources, Scott Emmons, Chief Engineer for Rockdale County Water Resources and the Rockdale County Board of Commissioners. Property owners willingly supplied information about their wells and allowed wells to be measured and sampled. Mr. Richard Morrison and Pastor Wayne Wilson allowed the USGS to obtain geophysical logs on the wells featured in this report. Johnny Robinson, Robinson Well Co., Monroe, Georgia, and Jerry Caldwell, Middle Georgia Water Systems, Zebulon, Georgia, furnished construction and yield data for numerous wells in Rockdale County.



Flowmeter and caliper logs for well 13DD97 along Irwin Bridge Road, Rockdale County, Georgia. ***(A)*** *Ambient flowmeter log showing weak downward vertical flow,* ***(B)*** *pumping flowmeter log showing vertical flow in borehole while pumping 6 gallons per minute, and* ***(C)*** *caliper log showing peaks where the borehole diameter is enlarged at discrete fracture openings in the bedrock. Right-facing arrows indicate flow into borehole during pumping.*



Sheet fracture in the Fletcher Quarry, Georgia Highway 20 North, Rockdale County, Georgia. Ruler is 3 feet. Photographs by Lester J. Williams, USGS.

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Projected Water Use in the Coastal Area of Georgia, 2000–2050

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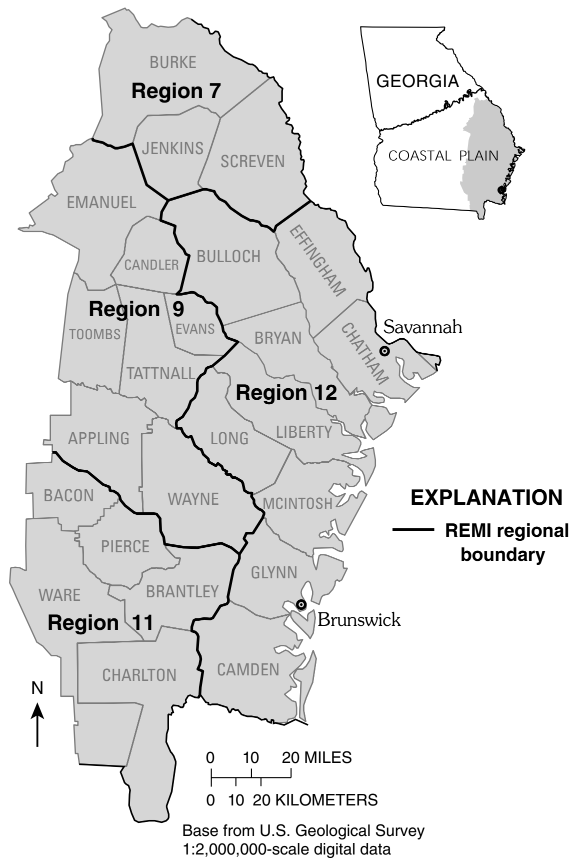
INTRODUCTION

The 24-county area of coastal Georgia is experiencing increasing demands on limited freshwater resources. To limit saltwater intrusion, the Georgia Department of Natural Resources, Georgia Environmental Protection Division (GaEPD) has restricted further development of the Upper Floridan aquifer—the principal source of water—in parts of the coastal area (Georgia Environmental Protection Division, 1997). The Georgia Coastal Sound Science Initiative is a series of scientific and feasibility studies to support development of the GaEPD final strategy to protect the Upper Floridan aquifer from saltwater contamination. As part of the Georgia Coastal Sound Science Initiative, the U.S. Geological Survey (USGS), in cooperation with the GaEPD, is developing numerical models to simulate ground-water flow and solute transport (saltwater contamination). These models will be used to evaluate water-management scenarios under various pumping conditions. To support this effort, ground- and surface-water-use data for 2000 were used to project future water demand for 2010, 2020, and 2035; these values were then compared to demand projections for 2010, 2020, and 2050 from county comprehensive water-supply plans.

Description of Study Area

The GaEPD defines the 24-county coastal area of Georgia to include the 6 coastal Georgia counties and 18 adjacent inland counties, an area encompassing about 12,240 square miles (map at right). The study area is located in the Coastal Plain physiographic province. Land use is largely urban in industrial areas and cities, such as Savannah and Brunswick; outside of these areas land use is a mix of forest, grazed woodland, cropland with pasture, marsh, and swampland. Topography ranges from flat in the coastal counties to relatively steep in northwestern parts of the area. Altitudes range from sea level along the coast to as high as 300 feet in the northwest.



Twenty-four county coastal area with Regional Economic Models, Inc. (REMI) regions.

SOURCES OF DATA AND METHOD OF ANALYSIS

In the 24-county coastal area, projected future water use was estimated based on 2000 water-use data by county from the Aggregated Water-Use Data System (AWUDS) as developed by the Georgia Water-Use Program, a cooperative effort between the USGS and the GaEPD. The 2000 water-use data—the latest published data—were used as the basis for public supply, industrial, thermoelectric power, and agricultural water-use projections (Fanning, 2003).

The Regional Economic Models, Inc. (REMI) database was provided by Dr. Phyllis Isley and Jeremy Hill of the Bureau of Business Research and Economic Development at Georgia Southern University, Statesboro, Ga. REMI is a dynamic economic model built around regional market behaviors; the model is dynamic in that it includes various key econometric estimates with historical data that interact with each other. The REMI database includes annual county population projections for 2000 to 2035 for each of four REMI regions (regions 7, 9, 11, and 12) located within the 24-county coastal area (map, facing page). The REMI database also includes annual employment population (number of working people) projections by industry type for the same 35-year period. Although no water-demand projections are made by the REMI model, the employment population projections are useful for making estimates of future water demands. REMI regions 7, 9, and 11 extend beyond the coastal area; region 12 lies entirely within the coastal area.

Because there is a direct correlation between population change and the amount of water withdrawn for public supply, a population percent change was calculated for each year from 2001 to 2035 using the projected REMI regional population data for each of the four regions. This percent change was then applied to each of the 24 counties. The 2000 AWUDS estimate for public-supply water use — consisting of the sum of the public supply, domestic, and commercial water-use estimates — was increased by the calculated percent change in population to determine projected public-supply water use for selected years during 2001–2035. Similarly, for industry, percentage change in the employment population for the 10 major industries in Georgia was used along with the AWUDS 2000 industry estimate to project industrial water-use demand for selected years during 2001–2035. This method similarly was applied to determine future thermoelectric-power use. These projections are herein referred to as USGS projections.

According to Kerry Harrison (Cooperative Extension Service, Tifton, Ga., oral commun., 2003), agricultural water use (irrigation water use) is expected to increase in the 24-county area at a rate of 5 percent every year through 2050. For the USGS projections, agricultural use was increased by this percentage per year.

A compilation of county Comprehensive Water-Supply Plans (CWSP) completed by Camp, Dresser & McKee, Inc. (2001) was developed as part of the Georgia Coastal Sound Science Initiative. The report summarizes historical, current, and projected population and water-demand information for the years 2010, 2020, and 2050 as derived from CWSP. Water demand was divided into categories of public supply (which includes domestic and commercial use), industry, and agriculture (irrigation).

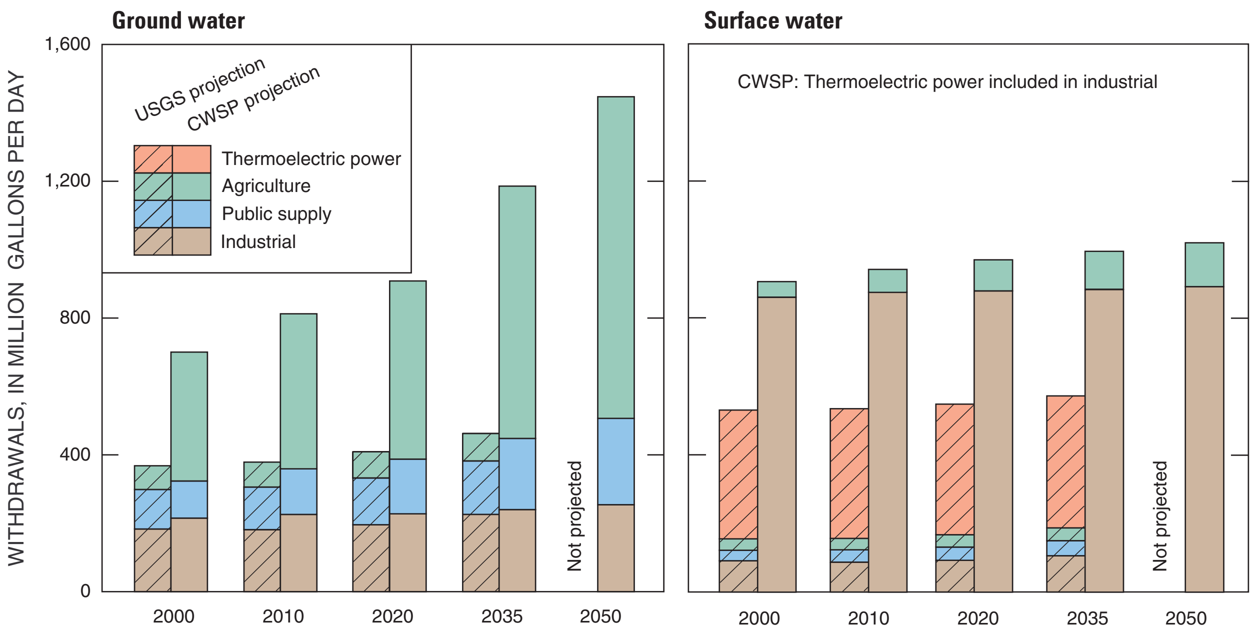
As part of the Georgia Coastal Sound Science Initiative, the GaEPD provided an outline of requirements and suggested forecast techniques (DRI McGraw Hill model) to each county for developing their water-supply plans; however, a specific methodology was not prescribed (Napoleon Caldwell, Georgia Environmental Protection Division, oral commun., 2004). In the 24-county area, nine consulting firms and regional development centers were used to develop the plans. Thus, forecasting techniques included a variety of methods and models (Camp, Dresser, & McKee, Inc., 2001).

PROJECTED WATER USE

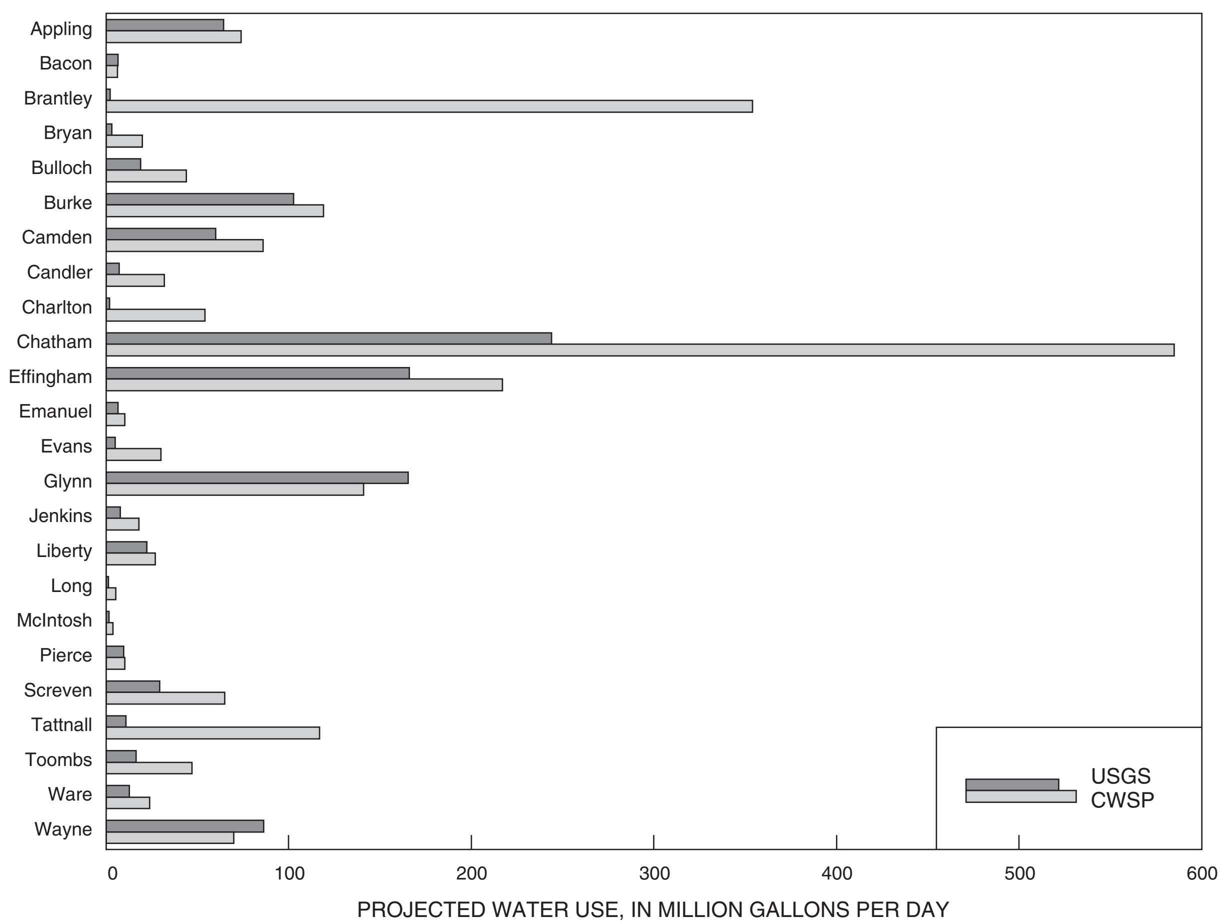
For 1980 – 97, the 24-county area showed a 6-percent increase in water use (Fanning, 1999). During the same period, the county populations increased about 28 percent. Population and public-supply water use are linked, that is, an increase in the number of people using public-supplied water will result in an increase in water use. In 2000, withdrawals were estimated at 922 million gallons per day (Mgal/d), with 536 Mgal/d from ground-water sources and 386 Mgal/d from surface-water sources.

Both the USGS and CWSP estimates showed an increase in water use in the 24-county area during 2001 – 2035; however, projected increases vary between the methods. USGS estimates using REMI indicate water use will increase by about 130 Mgal/d (14 percent) by 2035 for a total use of 1,052 Mgal/d. By comparison, CWSP projections are about four times the USGS projections. According to CWSP data, water use during 2000 was 1,610 Mgal/d and is expected to be 2,160 Mgal/d by 2035, an increase of 550 Mgal/d (34 percent).

USGS projections for ground-water use (graph, page 118) show a steady increase of about 96 Mgal/d (25 percent) during the 35-year period from 2000 to 2035. In contrast, CWSP projections show an increase in ground-water use of nearly 485 Mgal/d (69 percent) during the same period, mostly for irrigation. Surface-water-use projections (graph, page 118) for USGS are more conservative than ground-water projections, with minor increases in each category of use. CWSP projections show large increases in industrial use (which includes thermoelectric-power use). Over the 35-year period, the total surface-water-use increases predicted by CWSP are 87 Mgal/d (10 percent) as compared to 34 Mgal/d (6 percent) by USGS.



Projected water use in the coastal area of Georgia, 2000–2050 by category (USGS, U.S. Geological Survey; CWSP, Comprehensive Water-Supply Plans).



Projected water use by county in coastal Georgia for 2035 using the USGS and CWSP datasets.

Water demand from USGS projections and CWSP for the year 2035 for each county in the 24-county area was compared (bottom graph, facing page). Five counties—Brantley, Charlton, Chatham, Screven, and Tattnall—have significant differences in projected use between the USGS and CWSP, most of which are because of a predicted increase in groundwater irrigation during the 35-year period. Chatham County increases include surface-water use for two thermoelectric power plants. Also, a cooling tower installed at Plant McManus in Glynn County purportedly will reduce thermoelectric-power water use to one-seventh of its previously reported use (Burns Wetherton, Georgia Power Company, oral commun., 2004). In most counties, the CWSP projections exceed those of USGS.

During 2035, the counties showing the largest percentage of change from the USGS projections are Bryan, McIntosh, Long, Wayne, Brantley, and Charlton (graph below). The CWSP projections show Bryan, Tattnall, Screven, McIntosh, Jenkins, and Ware as the counties with the largest percentage change during 2035.

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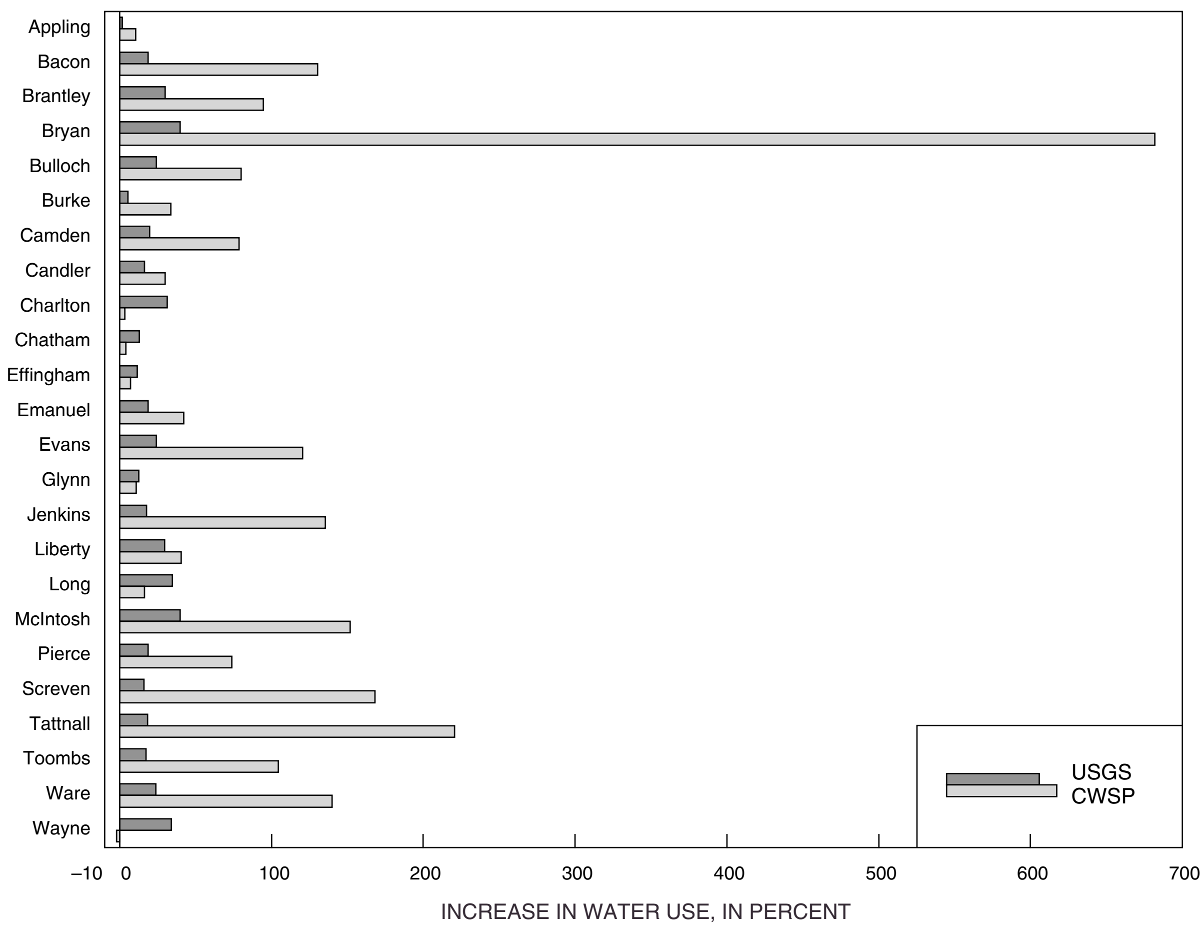

Projected percent increase in water use by county in coastal Georgia for 2035 using the USGS and CWSP datasets.

SELECTED GROUND-WATER PUBLICATIONS, CONFERENCES, AND OUTREACH, 2002–03

Introduction

During 2002–03, numerous reports, conference proceedings papers, and abstracts were published that discussed results of U.S. Geological Survey (USGS) ground-water investigations in Georgia. Oral and poster presentations were given at various technical conferences and outreach events throughout the State. These publications and presentations discussed results of investigations conducted in cooperation with State, Federal, and local agencies including the Georgia Department of Natural Resources; U.S. Department of Defense, City of Brunswick, Glynn County; Albany Water, Gas, and Light Commission; City of Lawrenceville; and Rockdale County. Most of these publications are online, as well as in hard copy; online versions can be viewed and downloaded at *http://ga.water.usgs.gov/ga004.html*

Georgia Water-Resources Conference for 2003

An important conference that is cosponsored by the USGS and at which results of several USGS investigations are highlighted is the biennial Georgia Water-Resources Conference. The 8th biennial conference was held at The University of Georgia in Athens, during April 2003. Forty USGS papers, 19 of which addressed ground-water investigations, were published in the conference proceedings.

Other Conferences and Outreach Events

Other conferences and outreach events in which USGS ground-water scientists participated during 2002–03 include:

- American Geophysical Union (AGU) Spring and Fall Meetings;
- Geological Society of America, Southeast Section Meeting;
- American Institute of Hydrology (AIH) Annual Conference;
- Georgia Water and Pollution Control Spring Conference and Annual Conference;
- Clemson University Annual Hydrogeology Symposium;
- Georgia Annual CoastFest;
- SunBelt Annual Exposition; and
- Earth Day activities.

Selected USGS Reports and Conference Proceedings Articles Published during 2002–03

USGS Reports

Albertson, P.A., and Torak, L.J., 2002, Simulated effects of ground-water pumpage on stream-aquifer flow in the vicinity of federally protected species of freshwater Mussels in the lower Apalachicola–Chattahoochee–Flint River Basin (Subarea 4), southeastern Alabama, northwestern Florida, and southwestern Georgia: U.S. Geological Survey Water-Resources Investigations Report 02-4016, 48 p. Online at *http://ga.water.usgs.gov/pubs/wrir/wrir024016/*

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Williams, L.J., Overview of geology, ground-water availability, and ground-water exploration and development in the greater Atlanta region, p. 4–15.

Khallouf, D.D., and Prowell, D.C., Description of water-bearing fractures in the Vulcan Minerals Quarry, eastern DeKalb County, Georgia, p. 16–24.

Williams, L.J., General geology and ground-water resources of Rockdale County, Georgia, p. 25–33.

Crawford, T.J., and Kath, R.L., Ground-water exploration and development in igneous and metamorphic rocks of the southern Piedmont/Blue Ridge, p. 34–39.

Johnson, C.D., and Williams, J.H., Hydraulic logging methods—A summary and field demonstration in Conyers, Rockdale County, Georgia, p. 40–47.

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