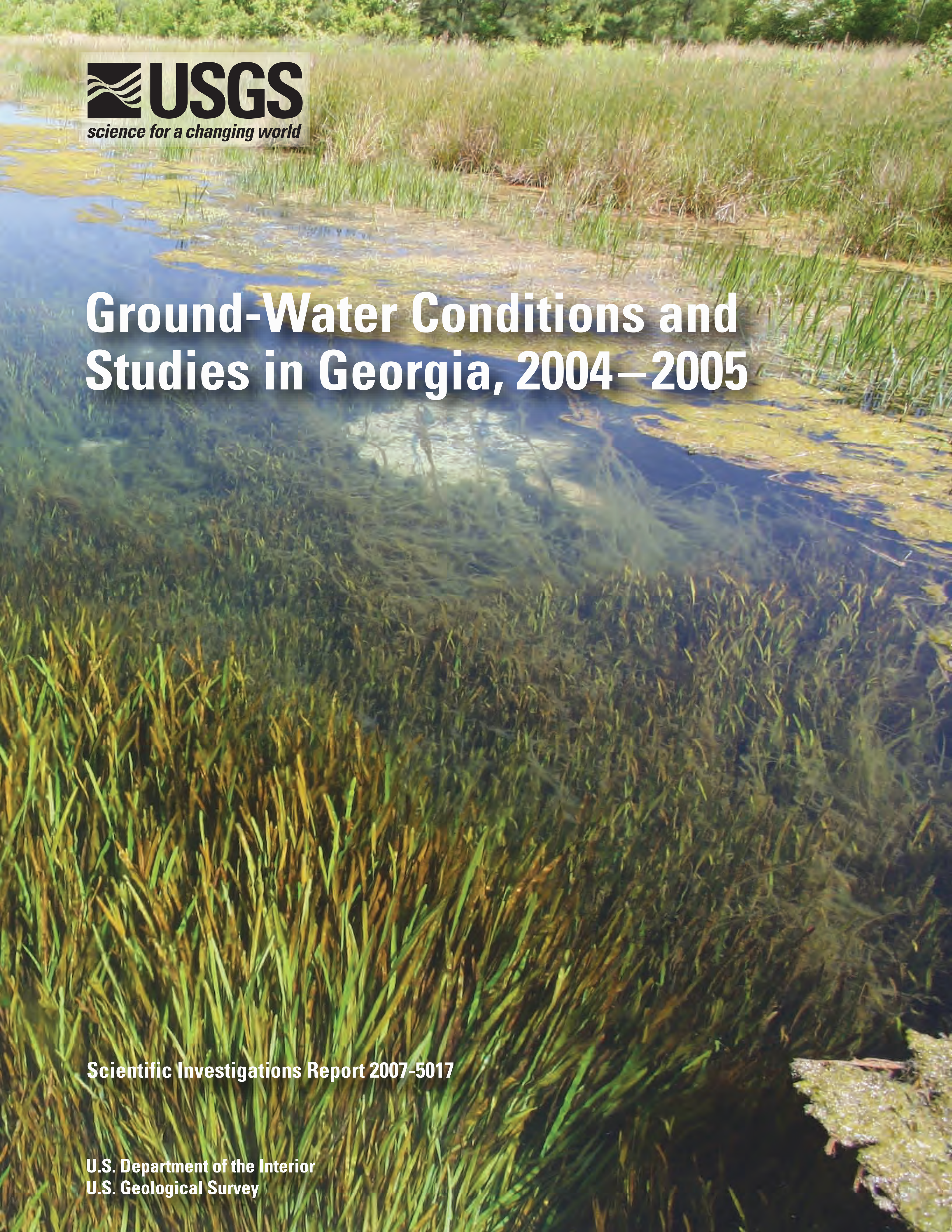

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Ground-Water Conditions and Studies in Georgia, 2004–2005

Scientific Investigations Report 2007-5017

U.S. Department of the Interior
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Cover photograph: Big Spring, Gordon County, Georgia

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VERTICAL AND HORIZONTAL DATUMS

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88). Historical data collected and stored as National Geodetic Vertical Datum of 1929 (NGVD 29) have been converted to NAVD 88 for use in this publication, unless otherwise noted.

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, 2004–2005

By David C. Leeth, Michael F. Peck, and Jaime A. Painter

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. During 2004–2005, ground-water levels were monitored continuously in a network of 183 wells completed in major aquifers throughout the State. Because of missing data or the short period of record for a number of these wells (less than 3 years), a total of 171 wells from the network are discussed in this report. These wells include 19 in the surficial aquifer system, 20 in the Brunswick aquifer system and equivalent sediments, 69 in the Upper Floridan aquifer, 17 in the Lower Floridan aquifer and underlying units, 10 in the Claiborne aquifer, 1 in the Gordon aquifer, 10 in the Clayton aquifer, 12 in the Cretaceous aquifer system, 2 in Paleozoic-rock aquifers, and 11 in crystalline-rock aquifers. Data from the network indicate that generally water levels rose after the end of a drought (fall 2002), with water levels in 152 of the wells in the normal or above-normal range by 2005. An exception to this pattern of water-level recovery is in the Cretaceous aquifer system where water levels in 7 of the 12 wells monitored were below normal during 2005.

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 the Camden County–Charlton County area during September 2004 and May 2005, in the Brunswick area during June 2004 and June 2005, and in the City of Albany–Dougherty County area during October 2004 and during October 2005. In general, the configuration of the potentiometric surfaces showed little change during 2004–2005 in each of the areas.

Ground-water quality in the Upper Floridan aquifer is monitored in the Albany, Savannah, and Brunswick areas, and in Camden County; and the Lower Floridan aquifer, monitored in the Savannah and Brunswick areas and in Camden County. In the Albany area, nitrate concentrations generally increased since the end of the drought during 2002. Concentrations increased in water collected from 13 of the 16 wells sampled during 2004–2005 and by November 2005, water from 2 wells had nitrate as N concentrations that were above the U.S. Environmental Protection Agency's (USEPA) 10-milligram-per-liter (mg/L) drinking-water standard.

In the Savannah area, measurement of fluid conductivity and chloride concentration in water samples from discrete depths in three wells completed in the Upper Floridan aquifer and one well in the Lower Floridan aquifer were used to assess changes in water quality in the Savannah area. At Tybee Island, chloride concentrations in samples from the Lower Floridan aquifer increased during 2004–2005 and were above the 250-mg/L USEPA drinking-water standard. At Skidaway Island, water in the Upper Floridan aquifer is fresh, and chloride concentrations did not appreciably change during 2004–2005. However, chloride concentrations in samples collected from the Lower Floridan aquifer during 2004–2005 showed disparate changes; whereby, chloride concentration increased in the deepest sampled interval (1,070 feet) and decreased in a shallower sampled interval (900 feet). At Fort Pulaski, water samples collected from the Upper Floridan aquifer are fresh and did not appreciably change during 2004–2005.

In the Brunswick area, maps showing the chloride concentration of water in the Upper Floridan aquifer were constructed using data collected from 41 wells during June 2004 and from 39 wells during June 2005. Analyses indicate that concentrations remained above the USEPA drinking-water standard in an approximate 2-square-mile area. During 2004–2005, chloride concentrations increased in samples from 18 wells and decreased in samples from 11 wells.

In the Camden County area, chloride concentrations during 2004–2005 were analyzed in water samples collected from eight wells, six completed in the Upper Floridan aquifer and two in the Lower Floridan aquifer. For most of the wells sampled during this period, chloride concentrations did not appreciably change; however, since the closure of the Durango Paper Mill during October 2002, chloride concentrations in the Upper Floridan aquifer near the mill decreased from a high of 184 mg/L during May 2002 to 52 mg/L during September 2005.

Ground-water studies during 2004–2005 include

- An assessment of ground-water flow near the Savannah River Site in Georgia and South Carolina;
- 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;
- 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 2004–2005 include an assessment of the hydrogeology and results from aquifer tests in the Brunswick and surficial aquifer systems at sites in Long and McIntosh Counties in coastal Georgia; revisions to potentiometric-surface maps of the Upper Floridan aquifer in the southwestern Albany area based on more accurate land-surface altitudes; and the influence that low-angle lithologic contacts and thrust faults have on ground-water flow in the crystalline-rock aquifer system of Rockdale County. Finally, selected publications, technical presentations, and outreach activities during 2004–2005 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 2004–2005 by the USGS in Georgia. Summaries are presented for selected ground-water studies, with objectives and progress, and selected technical highlights. These summaries and highlights include

- Permitted water-use data for the State during 2005, and ground-water-use trends for 2001–2005;
- Ground-water-level and ground-water-quality conditions in Georgia during 2004–2005, based on information collected from State and local monitoring networks;
- 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;
- The 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 and understand the sustainability of ground-water resources in the city of Lawrenceville area;
- Changes in the potentiometric surface of the Upper Floridan aquifer in the southwestern Albany area based on revised land-surface altitudes;
- Hydrogeology and results from aquifer tests in the surficial and Brunswick aquifers systems at sites in McIntosh and Long Counties in coastal Georgia;
- The influence that low-angle lithologic contacts and thrust faults have on ground-water flow in the crystalline-rock aquifer system of Rockdale County, and
- Previously published reports on ground-water conditions in Georgia (listed in the table, page 4).

Continuous water-level measurements were obtained from 183 wells during 2004 and 2005 (however, data from only 171 wells are summarized herein). Of the 183 wells equipped with continuous water-level recorders during 2005, 164 wells had electronic data recorders, which recorded the water level at 60-minute intervals with the data generally retrieved bimonthly. Nineteen wells had real-time satellite telemetry, which recorded the water level at 60-minute intervals and transmitted water levels from every 1 to 4 hours (based on equipment) for display on the USGS Georgia Water Science Center Web site at *http://water.usgs.gov/ga/nwis/current?type=gw/*.

Median-annual water levels for 2005 were compared with the normal range of ground-water levels for the period of record; 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 2001–2005 are shown with period-of-record water-level statistics for selected wells.

Periodic synoptic water-level measurements in the Upper Floridan aquifer were collected in 68 and 70 wells during October 2004 and October 2005, respectively, in south-central Dougherty County near Albany; 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 2004 and 2005 from 47 wells (Kinnaman, 2005, 2006).

The quality of ground water from the Upper and Lower Floridan aquifers is monitored in Albany and in several areas along the coast of Georgia. Nitrate concentrations in water from the Upper Floridan aquifer were analyzed for 15 wells in November 2004 and November 2005 in south-central Dougherty County near Albany.

Previous reports on ground-water conditions in Georgia.

[OFR, Open-File Report; WRIR, Water-Resources Investigations Report; SIR, Scientific Investigations Report]

Year of data collection	USGS report series and number	Author(s)	Year of publication
1977	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-W	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	WRIR 03-4032	Leeth, D.C., Clarke, J.S., and Craigg, S.D., and Wipperfurth, C.J.	2003
2002–2003	SIR 2005-5065	Leeth, D.C., Clarke, J.S., Wipperfurth, C.J., and Craigg, S.D.	2005

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 the city of Brunswick and in Camden County. In Savannah, four wells were assessed during December 2004 and 2005 using this technique.

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 eight 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 2004 using data from 41 wells and for June 2005 using data from 39 wells.

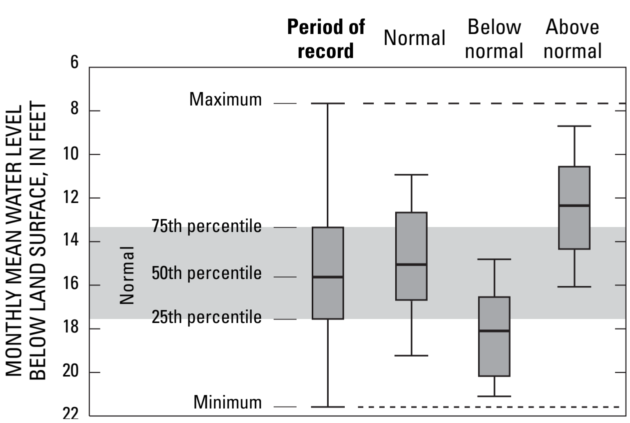
Water-use data compiled for 2001–2005, and reported herein, are based on State-mandated reporting requirements for water users withdrawing more than 100,000 gallons per day (gal/d). State-mandated reporting includes data for public supply, industrial and commercial, and thermoelectric-power water use; 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

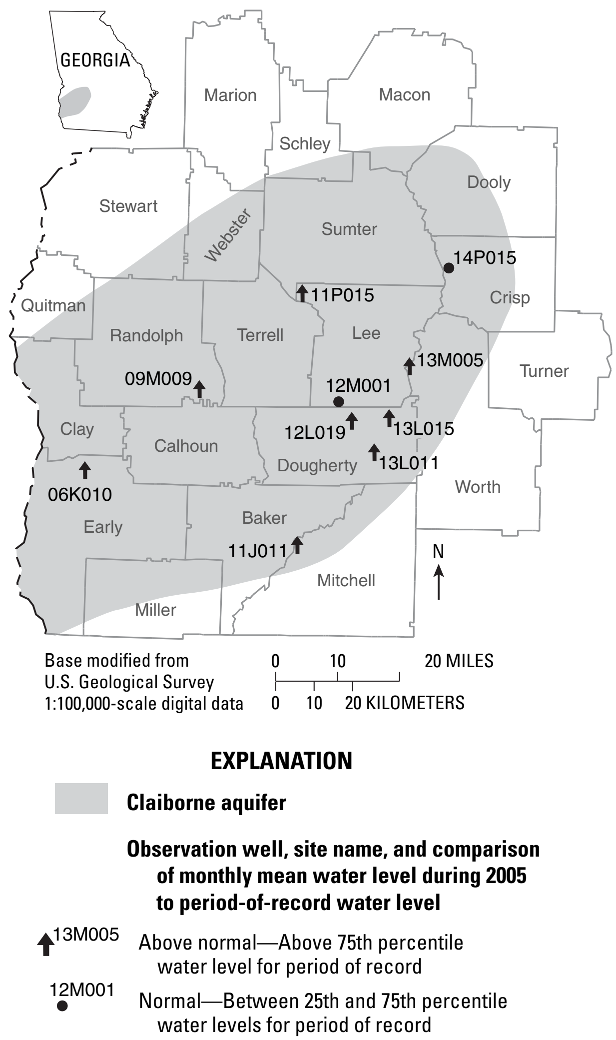
Hydrographs from selected wells are presented herein to compare 5-year trends and seasonal fluctuations to period-of-record statistics in major aquifers throughout the State. A more complete listing of water-level data and graphical summaries for each well from USGS continuously monitored wells is provided by site name in the Appendix. Those summaries 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 2005 were compared to period-of-record normal water levels to determine if water levels were above normal, below normal, or normal. For these comparisons the period of record was greater than 3 years, except for two wells where the period of record was nearly 3 years (these wells are identified in the text). 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). The normal range can be shown by examining a graphical representation of these values known as a box plot (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—2005 monthly mean water levels above period-of-record normal values; a down arrow—2005 monthly mean water levels below the normal range for the period of record; or a circle—2005 monthly mean water levels within the normal range for the period of record.



*Box plot depicting the method used to determine if 2005 water levels in a well were within, below, or above the normal range. If the median (50th percentile) water level for 2005 was between the 25th and 75th percentiles of period-of-record water levels, then the water level in the well was considered **normal**. If the median water level for 2005 was below the 25th percentile, then the water level in the well was considered **below normal**. If the median water level for 2005 was above the 75th percentile, then the water level was considered **above normal**.*



*Results of the comparison between period-of-record water levels and 2005 water levels in wells continuously monitored in the Claiborne aquifer 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**).*

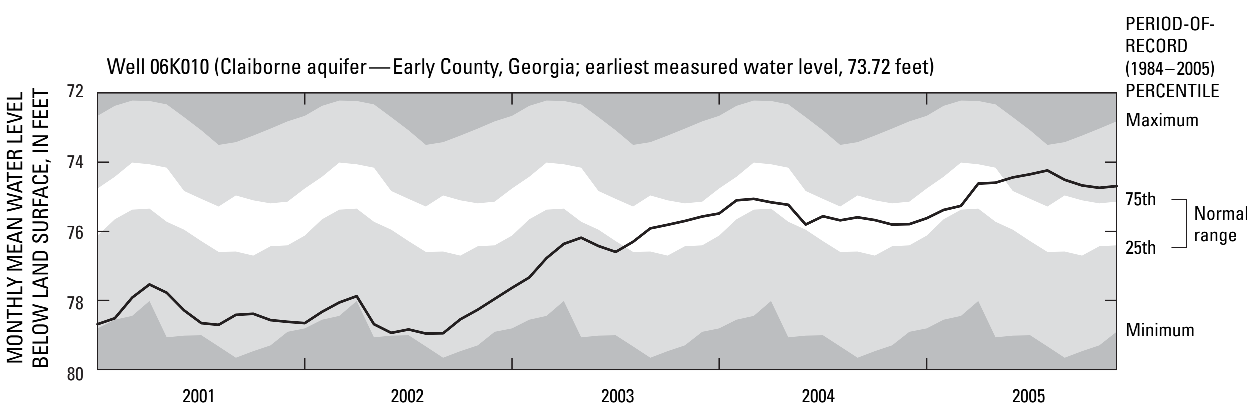
Data showing monthly mean ground-water levels during 2001–2005 were plotted together with data showing period-of-record water-level statistics (monthly mean normal, minimum, and maximum water levels) (hydrograph below). The period-of-record monthly statistics were calculated through December 2004 and are repeated on the graphs for 2001–2005. For example, statistics for the month of June are the same on the plots for each year during 2001–2005. 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 Denver, Colorado. Chloride analyses were conducted at the USGS laboratory, Atlanta, Georgia; the St. Johns River Water Management District in Palatka, Florida (for Camden County); and Severn Trent Laboratory, Savannah, Georgia. 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 for 1980–2005. 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 2001–2005 and a visual summary of water-level statistics for the period of record 1984–2005.

Cooperating Organizations and Agencies

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

- U.S. Air Force
- U.S. Army
- Georgia Department of Agriculture
- Georgia Department of Natural Resources Environmental Protection Division
- St. Johns River Water Management District (Florida)
- Jekyll Island Authority
- Flint River Water Planning and Policy Center
- Albany Water, Gas, and Light Commission
- Camden County
- Glynn County
- Lee County
- Liberty County Development Authority
- McIntosh County
- Rockdale County
- City of Brunswick
- City of Lawrenceville

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 (1985).

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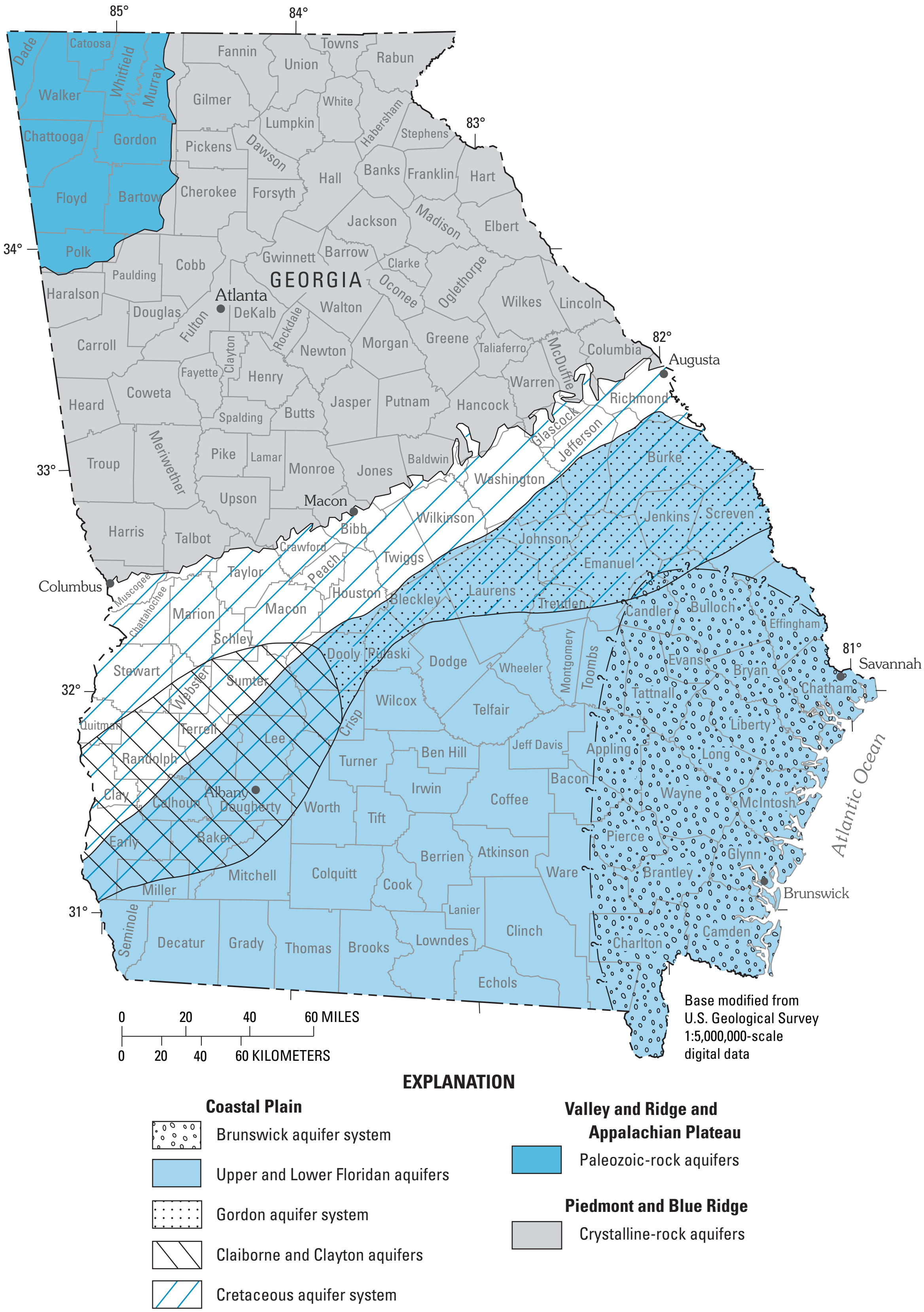


Areas of use of major aquifers in Georgia (modified from Clarke and Pierce, 1985). The surficial aquifer system is present throughout the State and is not shown.

Aquifer and well characteristics in Georgia [*modified from Clarke and Pierce (1985), and Peck and others (1992); ft, feet; gal/min, gallons per minute*]

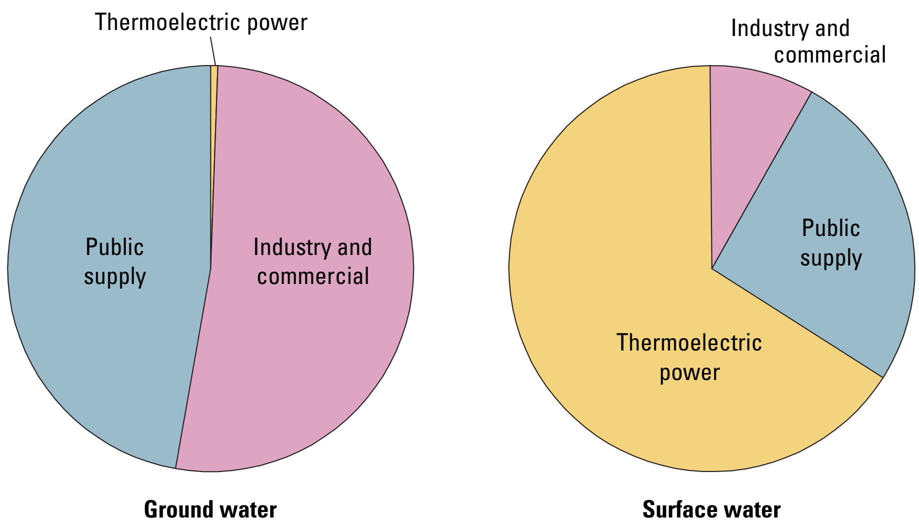
Aquifer name	Aquifer description	Well characteristics		
		Depth (ft)	Yield (gal/min)	
		Typical range	Typical range	May exceed
Surficial aquifer system	Unconsolidated sediments and residuum; generally unconfined. However, in the coastal area of the Coastal Plain, at least two semiconfined aquifers have 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 or discharge. 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 in depth 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.

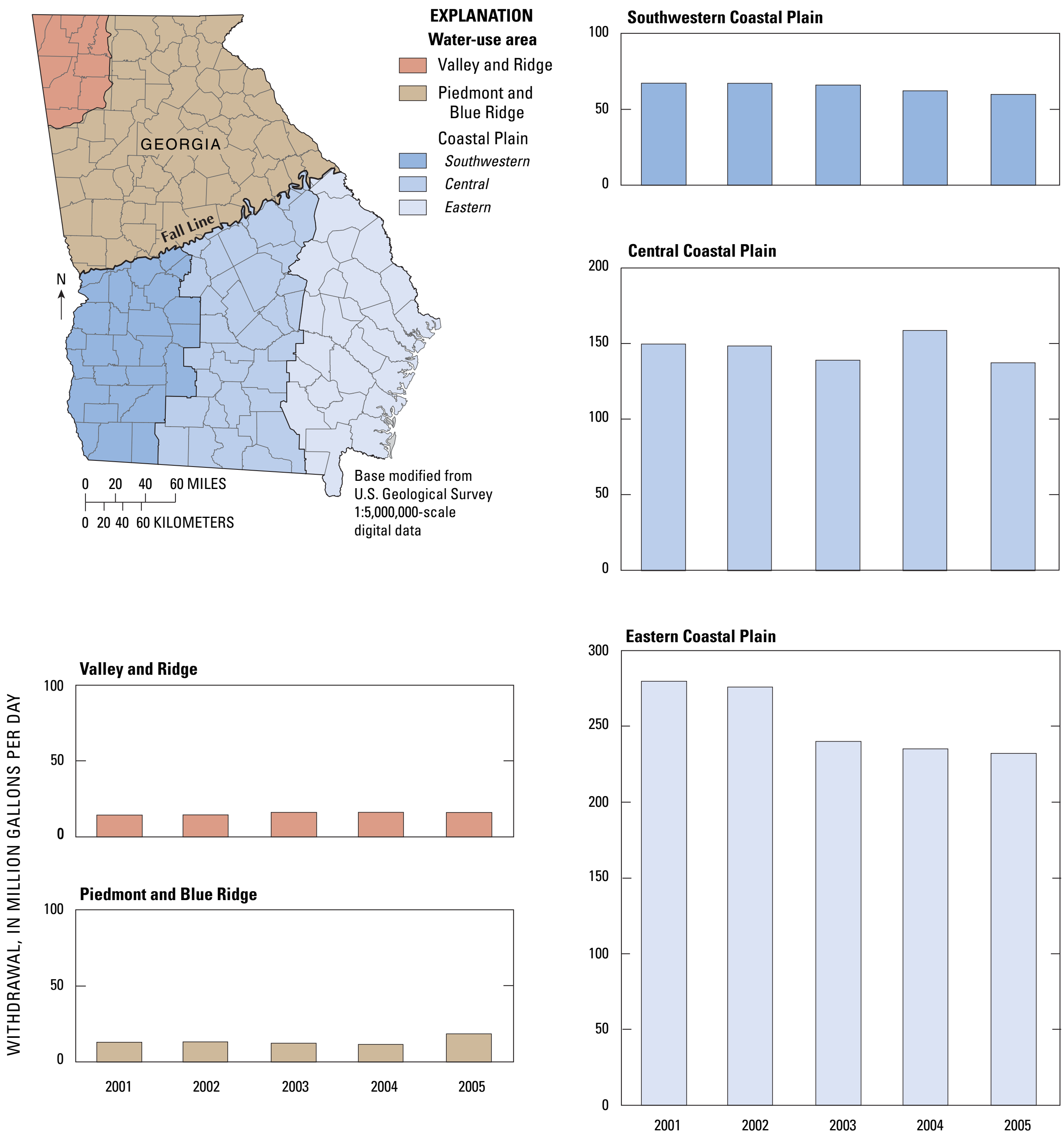
Permitted Water-Use Data for Georgia during 2005 and Ground-Water-Use Trends for 2001 – 2005

Permitted water-use data can be used to assess impacts of ground-water withdrawal on ground-water systems. Only water-use data from permitted water systems are included in this report. More specifically, estimates for irrigation, livestock, and domestic use are omitted herein. During 2005, permitted water withdrawal by public-supply systems totaled about 1,211 million gallons per day (Mgal/d), of which about 82 percent was from surface-water sources and 18 percent from ground-water sources (pie charts, below). Eighteen thermoelectric plants, the largest water users in Georgia, withdrew about 2,548 Mgal/d during 2005, mostly from surface-water sources. Permitted withdrawals by industrial and commercial users totaled about 562 Mgal/d, of which 57 percent was from surface-water sources and 43 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 in the State, data were grouped into five areas and are depicted from 2001 to 2005 (map and bar charts, facing page). In general, permitted ground-water withdrawal has decreased across the State since 2001 by about 12 percent; the only exception to this was in the Piedmont and Blue Ridge area. This decrease largely is a result of conservation efforts made by industrial and municipal users. In the Coastal Plain area, permitted ground-water use decreased during 2001–2005. In the eastern Coastal Plain, the decrease was about 47.7 Mgal/d, mostly because of thermoelectric-power plant closings and reduction in industrial withdrawals. In the central Coastal Plain, the decrease was about 12.3 Mgal/d; and in the southwestern Coastal Plain, the decrease was about 7 Mgal/d. In the Valley and Ridge area, withdrawal decreased about 0.6 Mgal/d during 2001–2005. The Piedmont and Blue Ridge area was the only area in the State where permitted ground-water withdrawal increased during 2001–2005 by about 5.5 Mgal/d.



Percentage of permitted water use in Georgia by category and source, 2005.



Ground-water withdrawal in Georgia by water-use area, 2001–2005.

GROUND-WATER CONDITIONS

Ground-Water Levels

Maps in this section provide an overview of ground-water levels in major aquifers in Georgia during 2005. In addition, hydrographs provide a visual summary of ground-water conditions for the past 5 years (2001–2005) compared to the period of record. Discussion of each aquifer is subdivided into areas where wells likely would 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 U.S. Geological Survey during the 2005 calendar year, including 19 wells that were monitored in real time.

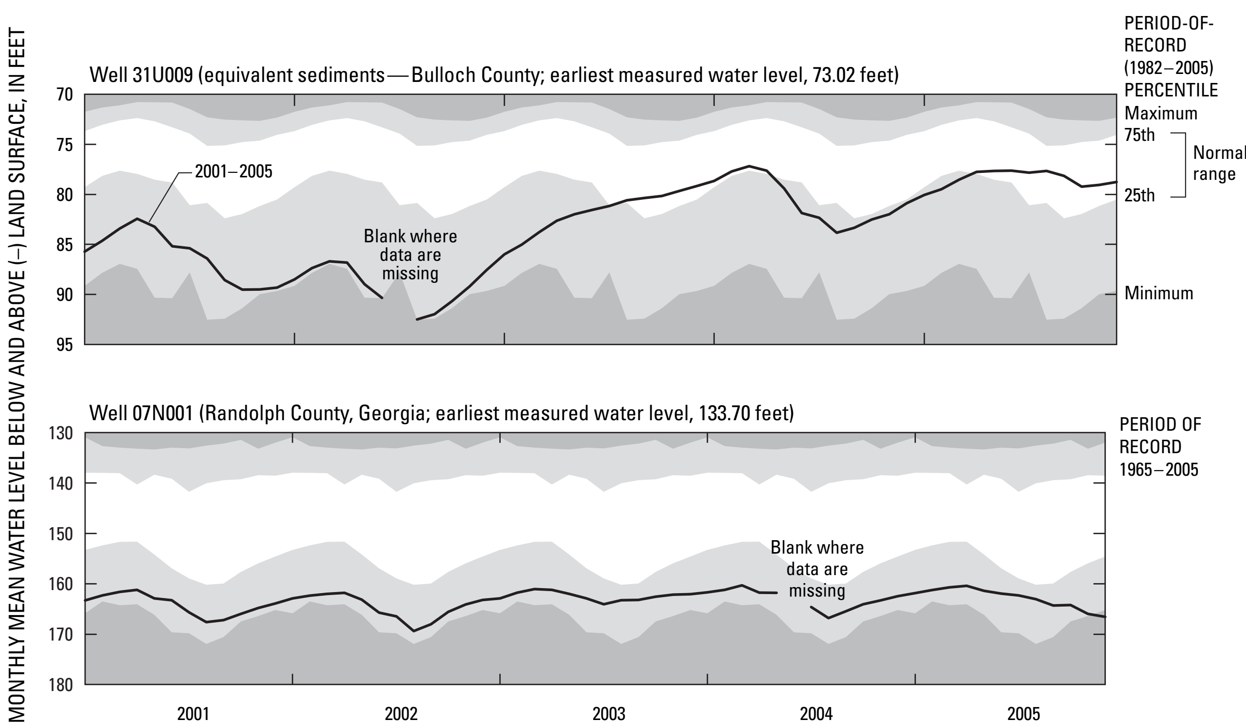
Changes in aquifer storage cause changes in ground-water levels measured in wells. Taylor and Alley (2001) described the many factors that affect ground-water storage; these are briefly discussed here. When recharge to an aquifer exceeds discharge, ground-water levels rise; when discharge to an aquifer 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).

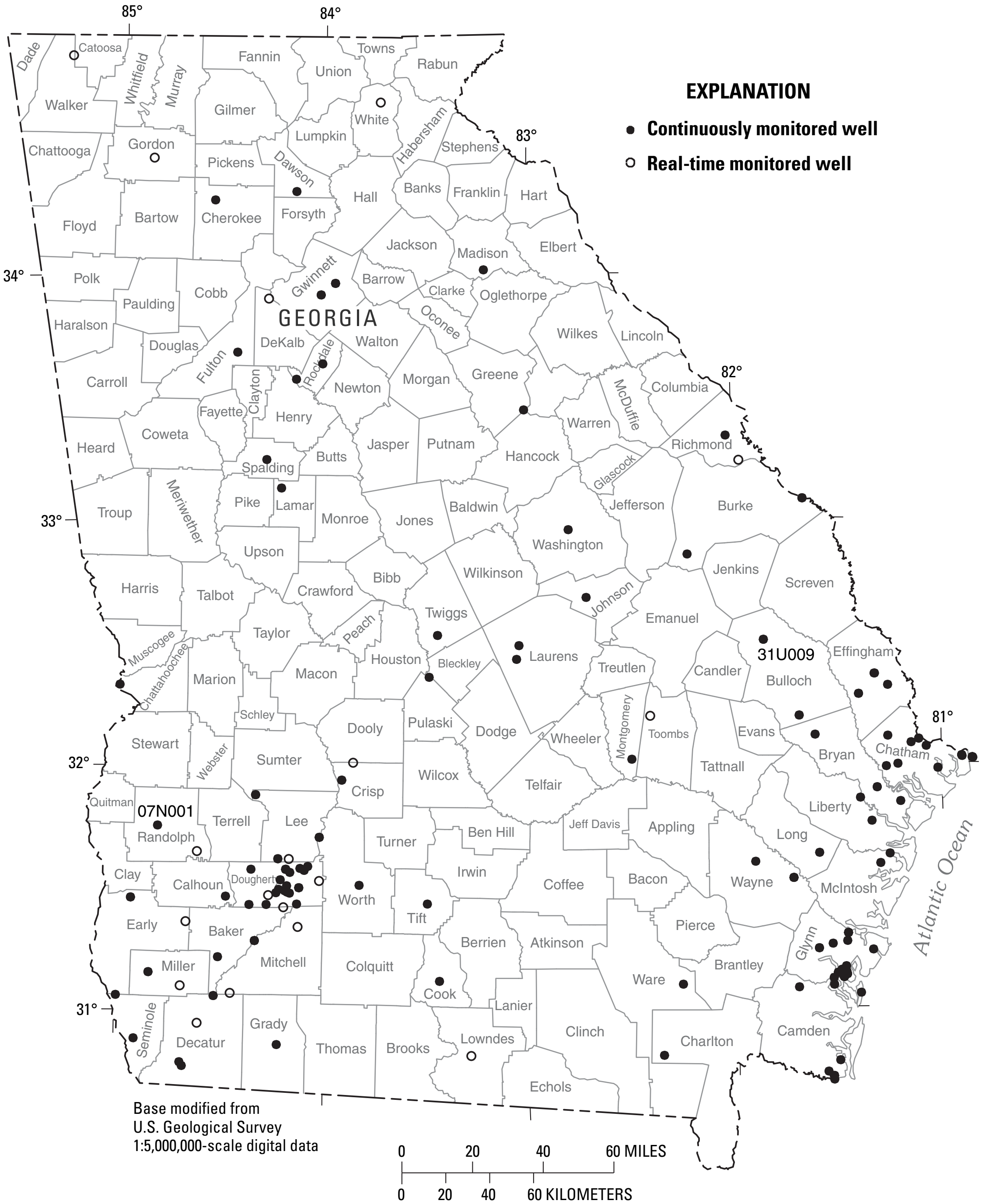
Ground-water pumping is the most important human activity that affects the amount of ground water in storage and the rate of discharge from an aquifer (Taylor and Alley, 2001). As ground-water storage is depleted within the radius of influence of pumping, water levels in the aquifer decline, forming 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 monthly mean water levels in wells 31U009 and 07N001 for the period 2001–2005 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 2005.

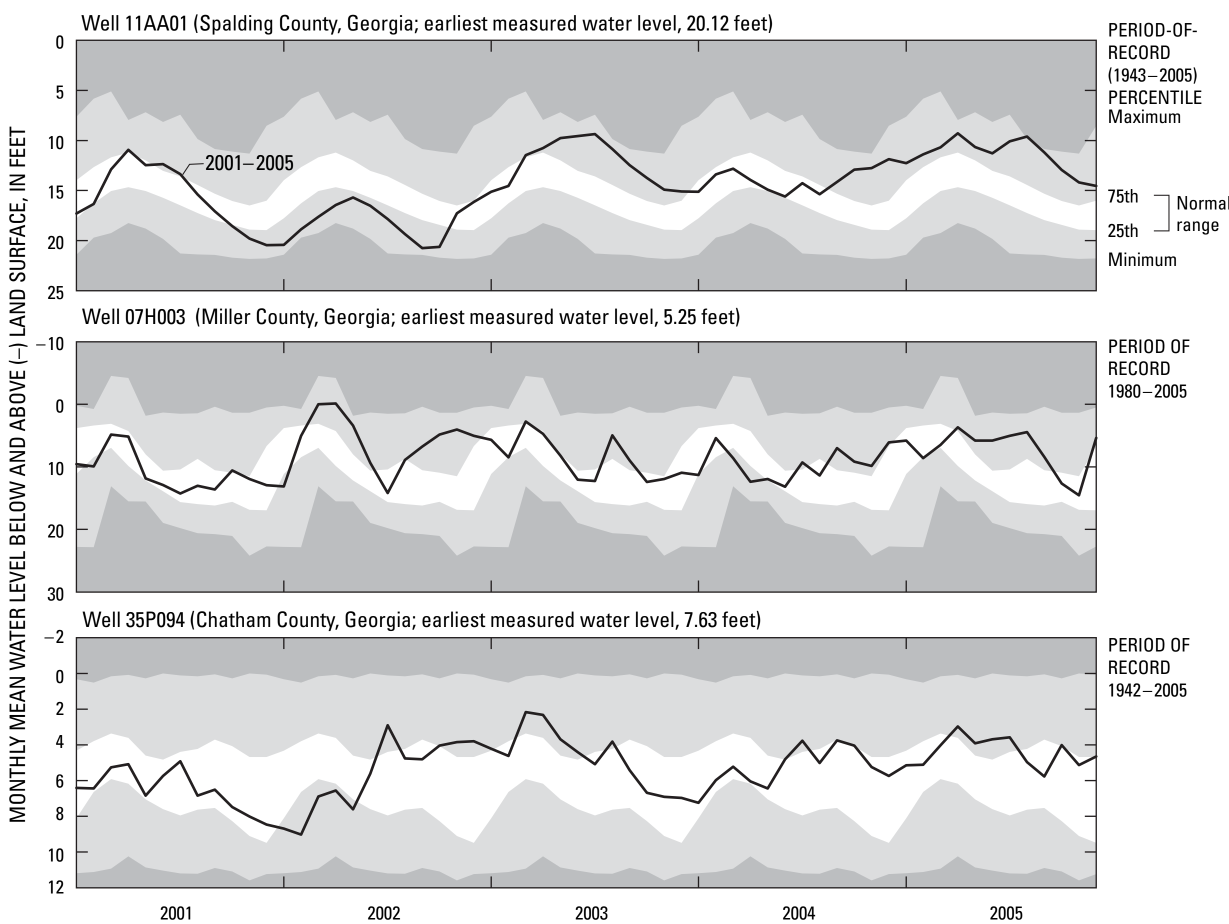
Ground-Water Levels

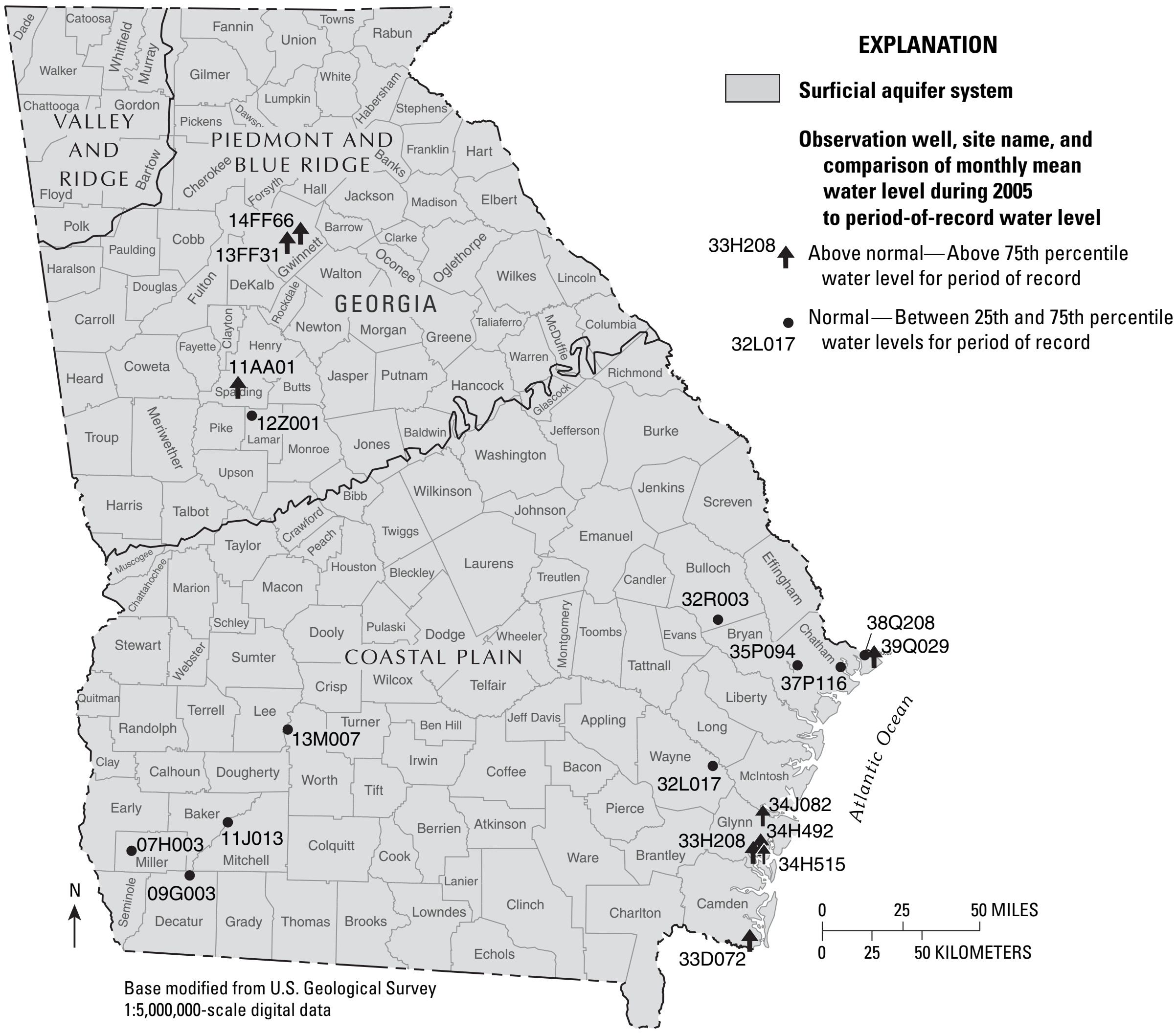
Surficial Aquifer System

Water levels in 19 wells were used to define conditions in the surficial aquifer system during 2005 (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 18 of the 19 wells measured were within or above the normal range during 2005 as a result of the relatively normal to above-normal rainfall that occurred in Georgia. Water-level hydrographs for three wells (below) completed in the surficial aquifer system were chosen to illustrate monthly mean water levels during 2001–2005 and period-of-record water-level statistics. The hydrographs show that water levels in the three wells generally rose during 2002–2003 but showed no discernible trend thereafter.

The hydrograph for well 11AA01, in Spalding County in the Piedmont physiographic province, shows that the water level during 2002 mostly was below normal but began to rise in the latter part of the year; this rise continued into 2005 when the water level was typically at or above normal. The hydrograph for well 07H003, in Miller County in the southwestern part of the Coastal Plain, shows a similar but slightly different pattern with the water level at or above normal during most of the period under discussion but dropping below normal for short periods during early 2001, early 2002, and early 2004. The hydrograph for well 35P094, in Chatham County in the southeastern part of the Coastal Plain, shows a similar pattern to that of well 11AA01 with the water level in or above the normal range after the first part of 2002 and continuing through 2005. 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 that had recovered from drought by 2003 were at or above normal during 2005.





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
39Q029	Chatham	Tybee, Savannah Harbor Expansion, monitoring well 1, COE
09G003	Decatur	U.S. Geological Survey, test well DP-6
33H208	Glynn	Koch Cellulose, south test well 3
34H492	Glynn	Coastal Georgia Community College P-17
[1]34H515	Glynn	Coffin Park test well 4
34J082	Glynn	Coastal Sound Science Initiative, Ebenezer Bend AR-4
13FF31	Gwinnett	Lawrenceville. Georgia, Johnson Road, shallow
14FF66	Gwinnett	Lawrenceville. Georgia, Highway 316, shallow
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

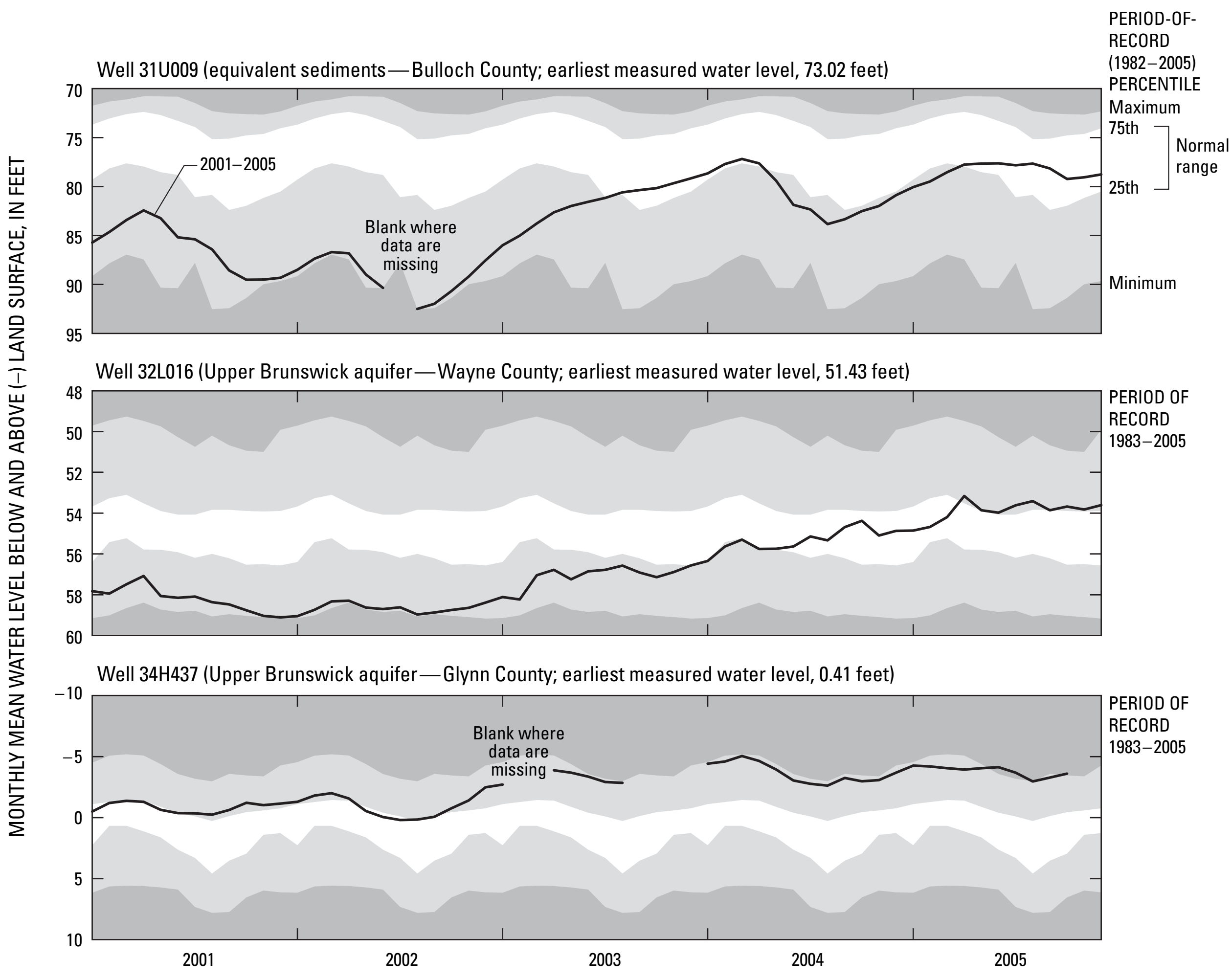
[1]Statistical comparison based on period of record less than 3 years.

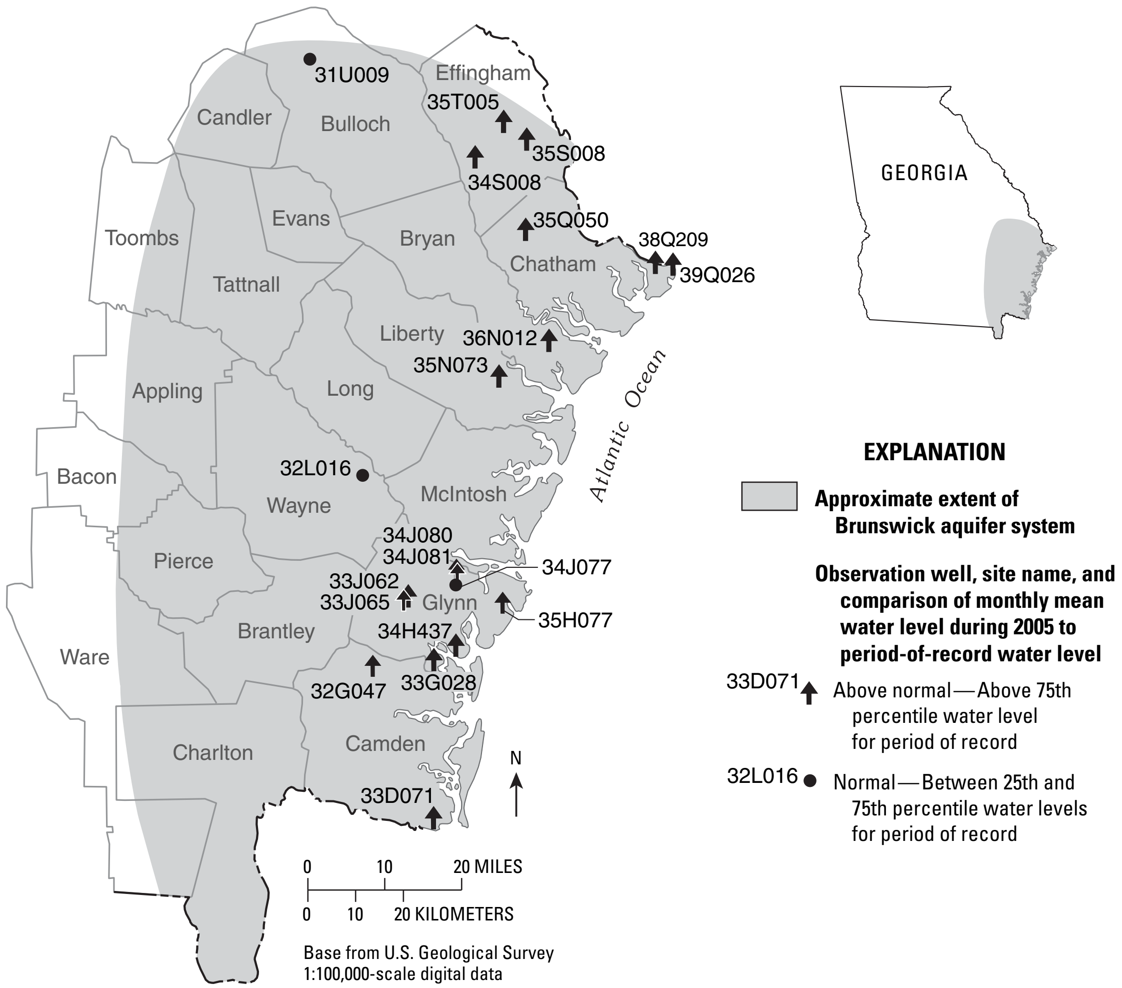
Ground-Water Levels

Brunswick Aquifer System

Water levels in 20 wells were used to define 2005 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 3 wells, water levels were in the normal range, and in 17 wells, water levels were above the normal range. These variations reflect differences in local pumping, interaquifer leakage effects, and recharge.

Water-level hydrographs for three wells in the Brunswick aquifer system and equivalent-sediment wells (below) were chosen to illustrate monthly mean water levels during 2001–2005 and period-of-record water-level statistics. Hydrographs indicate that water levels rose during late 2002 reflecting recovery from drought effects. The water level in well 31U009 in Bulloch County (completed in undifferentiated sediments equivalent to the upper Brunswick aquifer) was well below normal during 2002, reaching a record low during August 2002, but began to rise in the second half of the year and was normal by the end of 2003. During 2004, water levels again dropped below normal, but rose to normal levels during mid-2005. The water level for well 32L016 near Jesup in Wayne County (completed in the upper Brunswick aquifer) shows the water level during 2001–2002 was below the normal range, nearing record daily lows during December 2001 and January 2002. The water level in this well began to rise in the latter half of 2002 and continued to rise through the period to finish above normal during early 2005. The water level for well 34H437 near Brunswick in Glynn County (completed in the upper Brunswick aquifer), unlike the other two wells, 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 2005, with record highs during May–July 2005.





Site name	Water-bearing unit[1]	County	Other identifier
36N012	L	Bryan	Genesis Pointe
31U009	UX	Bulloch	Georgia Geologic Survey, Hopeulikit, test well 2
32G047	U	Camden	Waverly Firestation
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
38Q209	B	Chatham	Fort Pulaski, Savannah Harbor Expansion, monitoring well 3, COE
34S008	LX	Effingham	Pineora test well EB-1
35S008	LX	Effingham	Effingham County, Georgia Geologic Survey, corehole
35T005	UX	Effingham	Springfield, Georgia, observation 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
34J080	L	Glynn	Coastal Sound Science Initiative, Ebenezer Bend AR-2
34J081	U	Glynn	Coastal Sound Science Initiative, Ebenezer Bend AR-3
35H077	L	Glynn	Coastal Sound Science Initiative, St. Simons test well 2
35N073	L	Liberty	Old Sunbury Road OW-1
32L016	U	Wayne	Georgia Geologic Survey, Gardi, test well 2

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

Ground-Water Levels

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, about 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.

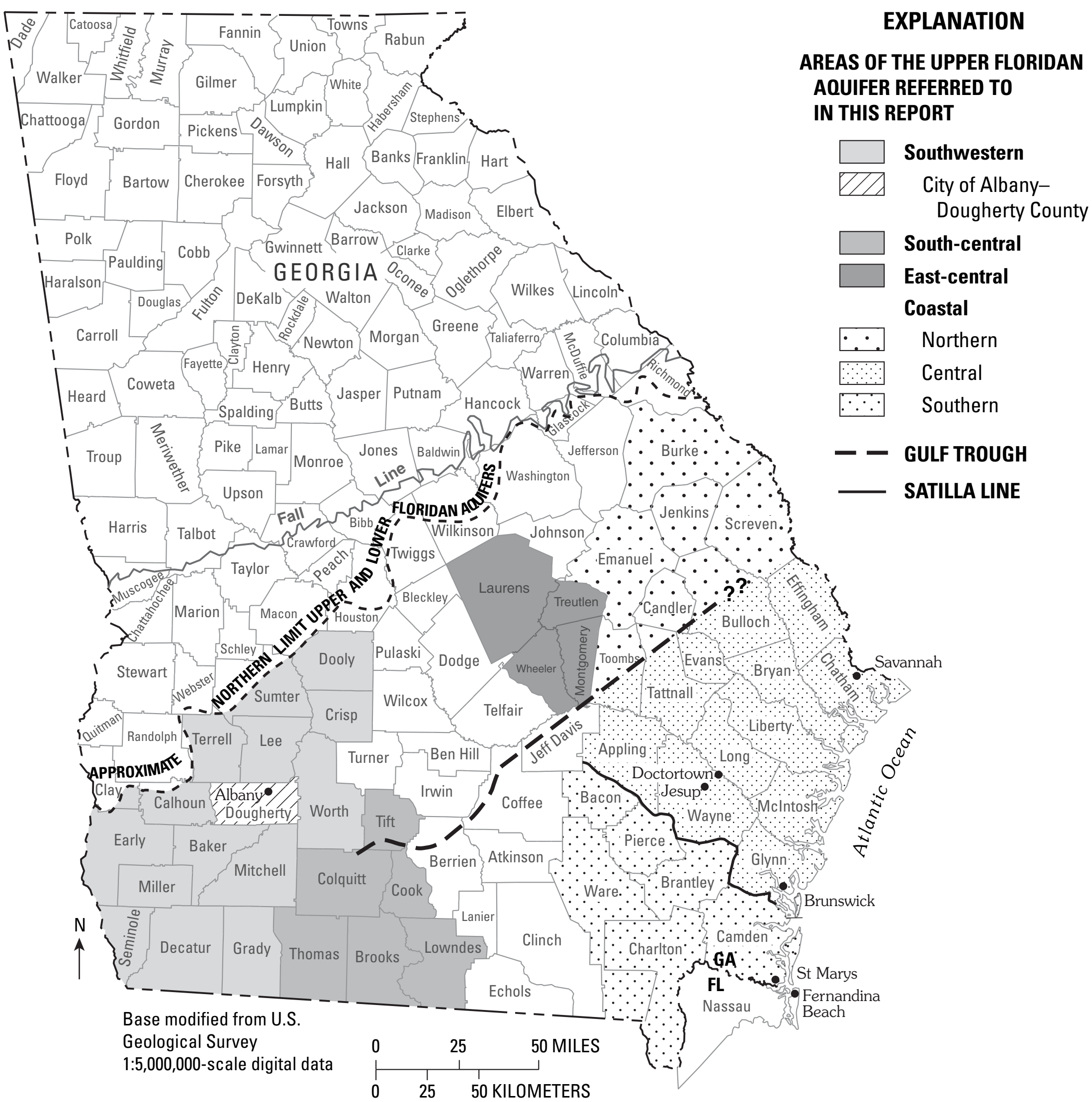
The city of Albany–Dougherty County area lies within the southwestern area. In this area, most of the water withdrawn from the Upper Floridan aquifer is for public-supply use; about 19 Mgal/d of water was withdrawn during 2000 with irrigation withdrawal about the same amount (20 Mgal/d) (Fanning, 2003).

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 most 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 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 Fernandina Beach, Florida.



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

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Herrick, S.M., and Vorhis, R.C., 1963, Subsurface geology of the Georgia Coastal Plain: Georgia Department of Natural Resources, Division of Mines, Mining, and Geology Information Circular 25, 80 p.

Hicks, D.W., Gill, H.E., and Longsworth, S.A., 1987, Hydrogeology, chemical quality, and availability of ground water in the Upper Floridan aquifer, Albany area, Georgia: U.S. Geological Survey Water-Resources Investigations Report 87-4145, 52 p.

Krause, R.E. 1979, Geohydrology of Brooks, Lowndes, and western Echols Counties, Georgia: U.S. Geological Survey Water-Resources Investigations Report 78-117, 48 p.

Miller, J.A., 1986, Hydrogeologic framework of the Floridan aquifer system in Florida and parts of Georgia, Alabama, and South Carolina: U.S. Geological Survey Professional Paper 1403-B, 91 p.

Peck, M.F., Clarke, J.S., Ransom, III, Camille, and Richards, C.J., 1999, Potentiometric surface of the Upper Floridan aquifer in Georgia and adjacent parts of Alabama, Florida and South Carolina, May 1998, and water-level trends in Georgia, 1990–98: Georgia Department of Natural Resources, Environmental Protection Division, Georgia Geologic Survey, Hydrologic Atlas 22, 1 plate.

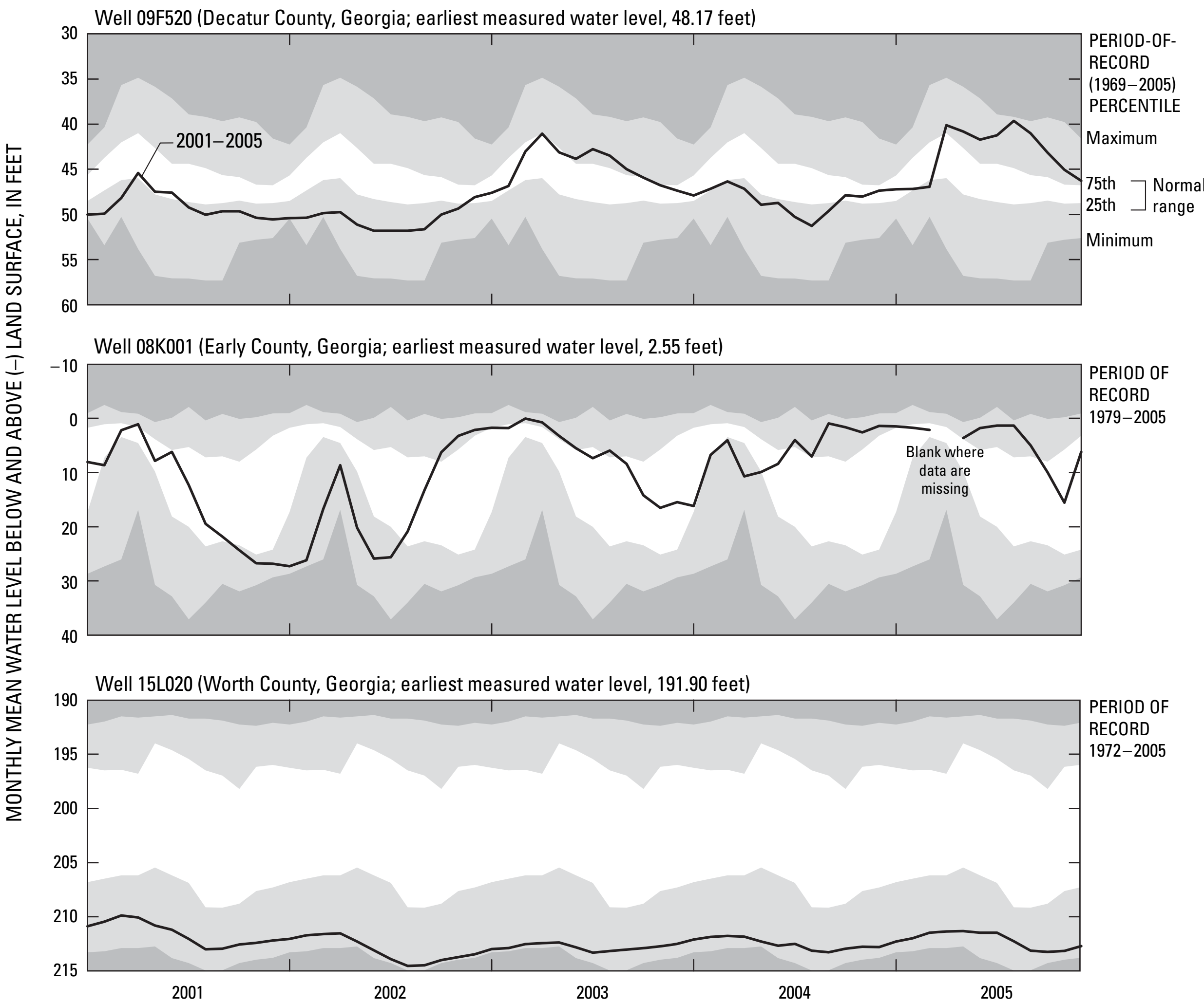
Ground-Water Levels

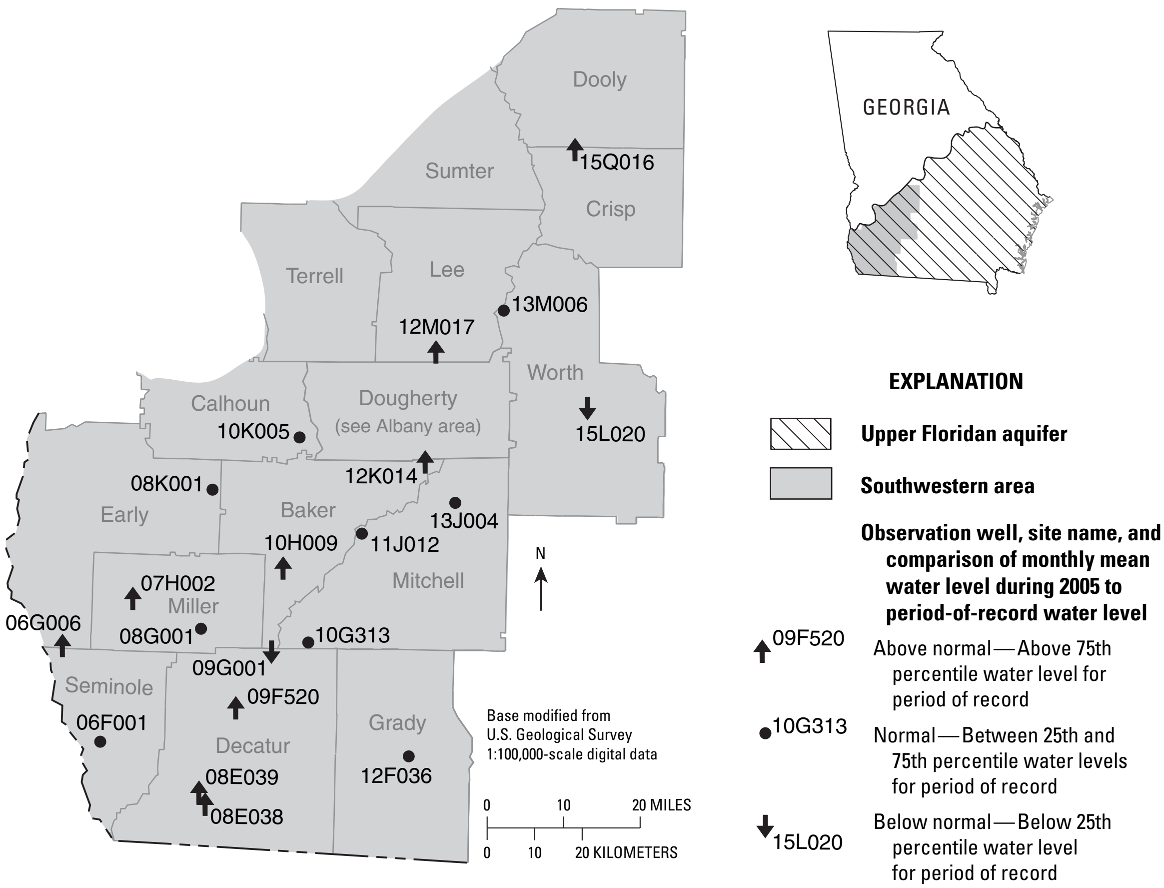
Upper Floridan Aquifer

Southwestern Area

Water levels in 20 wells were used to define ground-water conditions in the Upper Floridan aquifer in southwestern Georgia during 2005 (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 18 of the 20 wells were at or above the normal range during 2005. Water levels in two wells were below normal during 2005.

Water-level hydrographs for three Upper Floridan aquifer wells in southwestern Georgia (below) were chosen to illustrate monthly mean water levels during 2001–2005 and period-of-record water-level statistics. 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 2001 and 2002, but rose to the normal range during late 2002, then dropped below normal for most of 2004, and finally rose to above normal for most of 2005. The water level in well 08K001 in Early County was below normal at the beginning of 2002 but rose to the normal range during late 2002; the water level fell below normal during early 2004 but remained normal or above normal for the remainder of the period. 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 showed a slight rise during 2003–2005, but was still below normal because of long-term decline.





Site name	County	Other identifier
10H009	Baker	Ichauway
12K014	Baker	Blue Springs, observation well
10K005	Calhoun	Jordan, Ocala well
15Q016	Crisp	CDM site 12 prod
08E038	Decatur	U.S. Army Corps of Engineers
08E039	Decatur	Lake Seminole Project, International Paper well 1
09F520	Decatur	Bolton, observation well
09G001	Decatur	U.S. Geological Survey, test well DP-4
06G006	Early	Harvey, test well 1
08K001	Early	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	Meinders, observation well
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

Ground-Water Levels

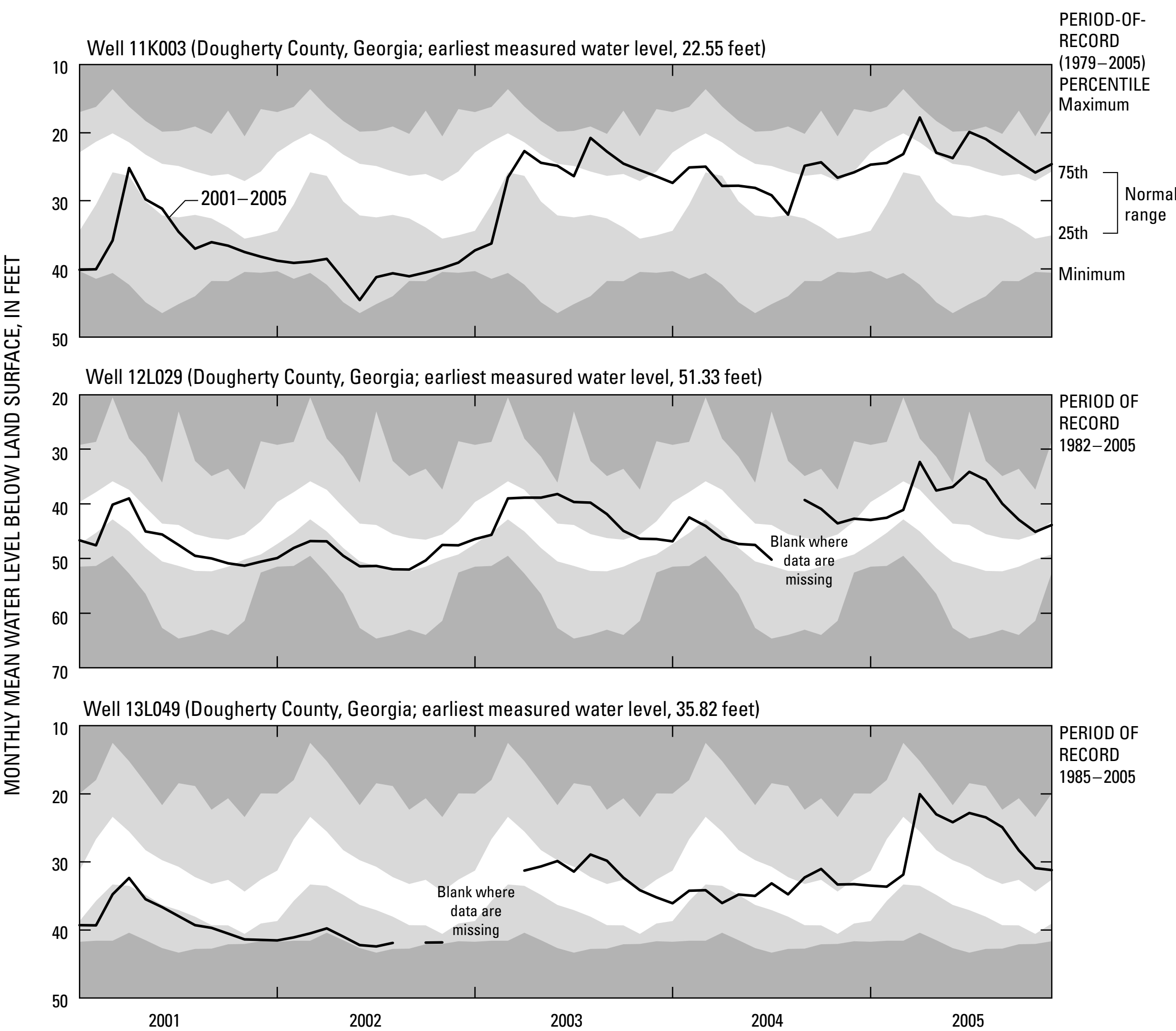
Upper Floridan Aquifer

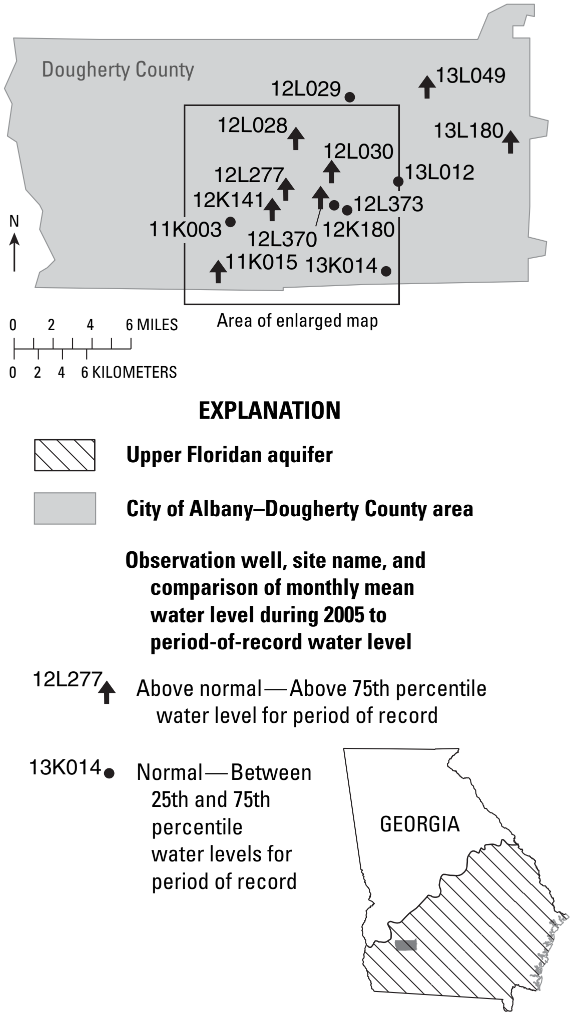
City of Albany–Dougherty County Area

Water levels in 14 wells were used to define ground-water conditions in the Upper Floridan aquifer near Albany, Georgia, during 2005 (Dougherty County map, facing page). In this area, water in the Upper Floridan aquifer is semiconfined. Water levels in 8 of the 14 wells were above the normal range during 2005. Water levels in six of the wells were normal.

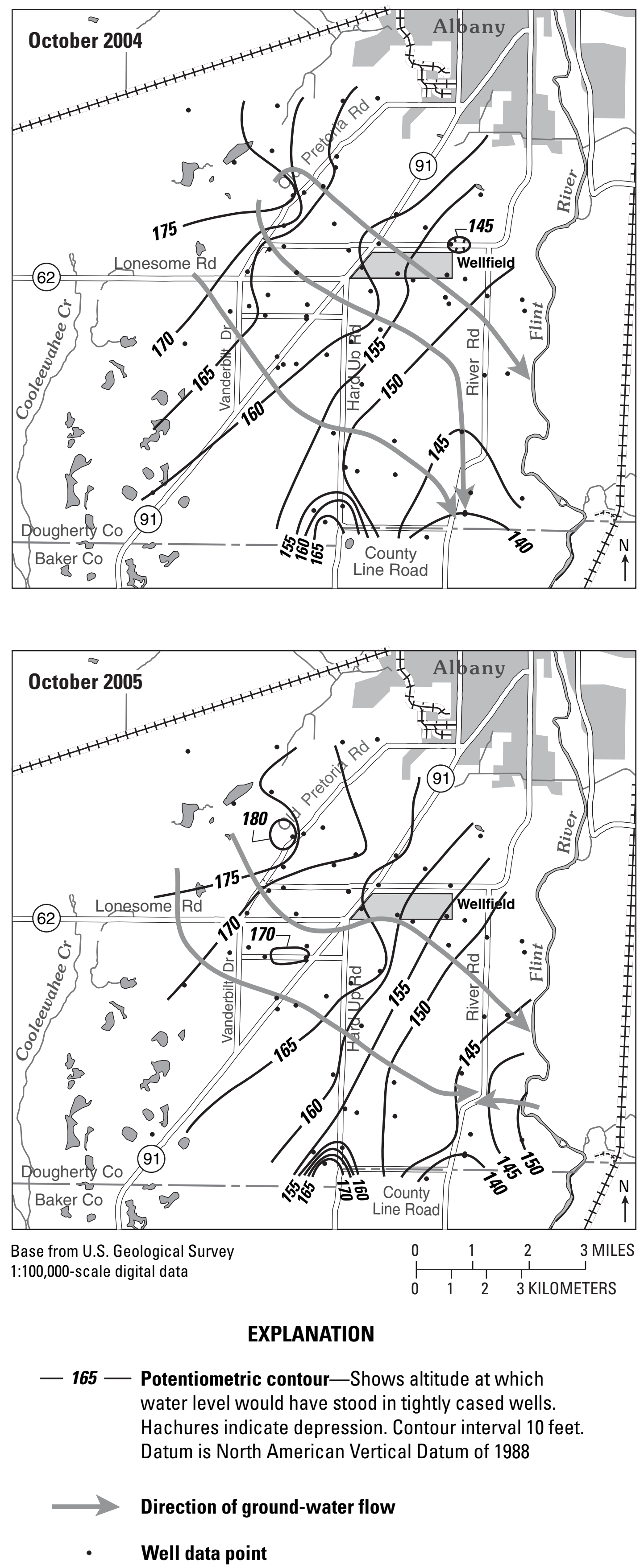
Water-level hydrographs for three Upper Floridan aquifer wells in the Albany area (below) were chosen to illustrate monthly mean water levels during 2001–2005 and period-of-record water-level statistics. Hydrographs indicate that water levels generally rose in the three wells during 2002–2005, reflecting recovery from drought effects. By 2005, water levels in all three wells were in the above-normal range.

In addition to continuous water-level monitoring, synoptic water-level measurements are taken periodically in wells southwest of Albany. Water-level measurements were collected from 68 wells during October 2004 and 70 wells during October 2005. The measurements were used to construct maps showing the potentiometric surface of the Upper Floridan aquifer for those two time periods. The potentiometric-contour maps (facing page) show that water generally flows from northwest to southeast, toward the Flint River. In the southeastern part of the mapped area, flow was away from the river toward the west. Water levels were higher during 2005 than during 2004.





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
12K180	Albany Water, Gas, and Light Commission, Georgia Environmental Protection Division, MW-2
12L028	Musgrove, observation well
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
12L373	Albany Water, Gas, and Light Commission, Georgia Environmental Protection Division, MW-1
13K014	U.S. Geological Survey, test well 15
13L012	U.S. Geological Survey, test well 3
13L049	Miller, observation well
13L180	Marine Corps Logistic Base, core hole 3



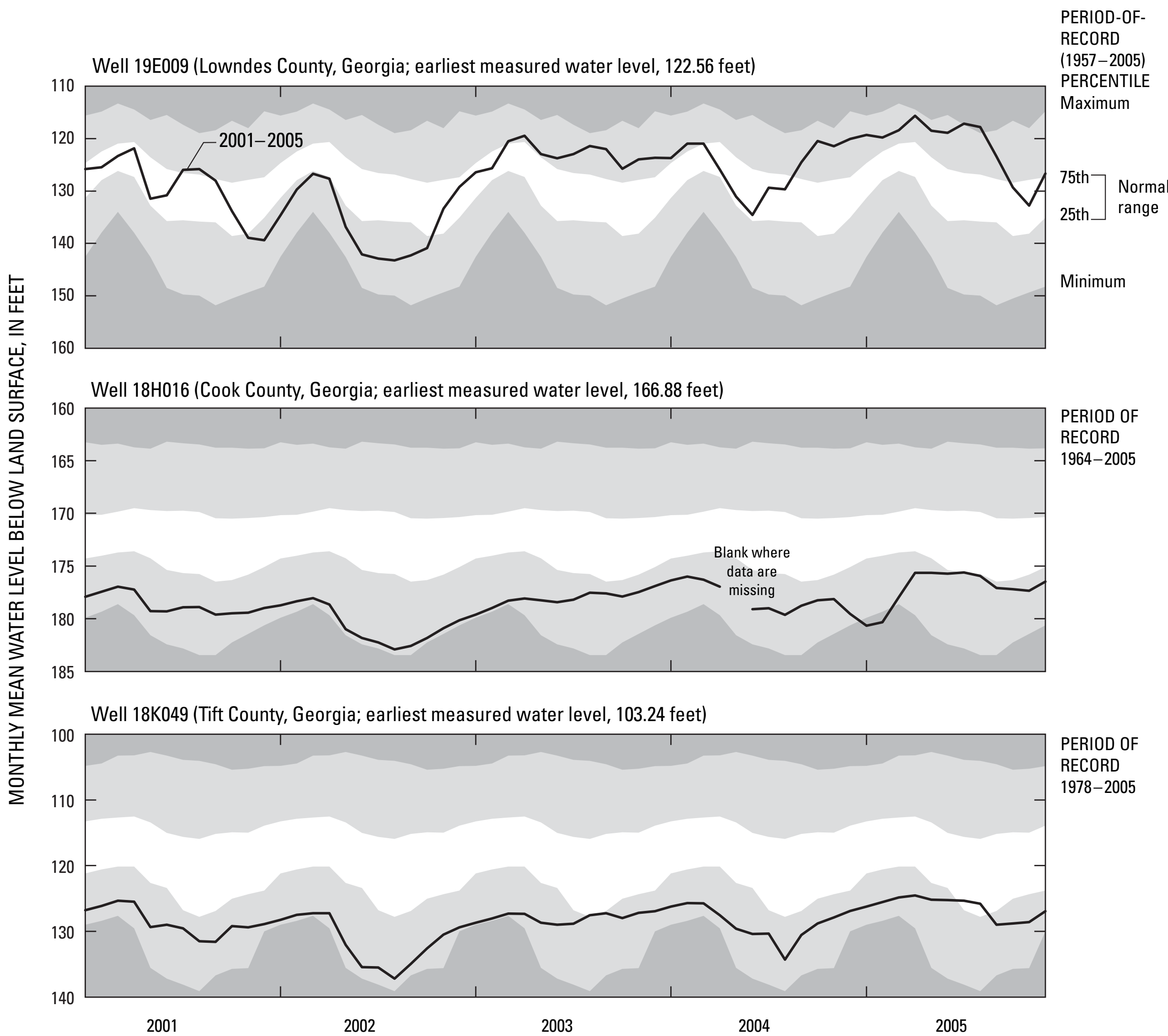
Ground-Water Levels

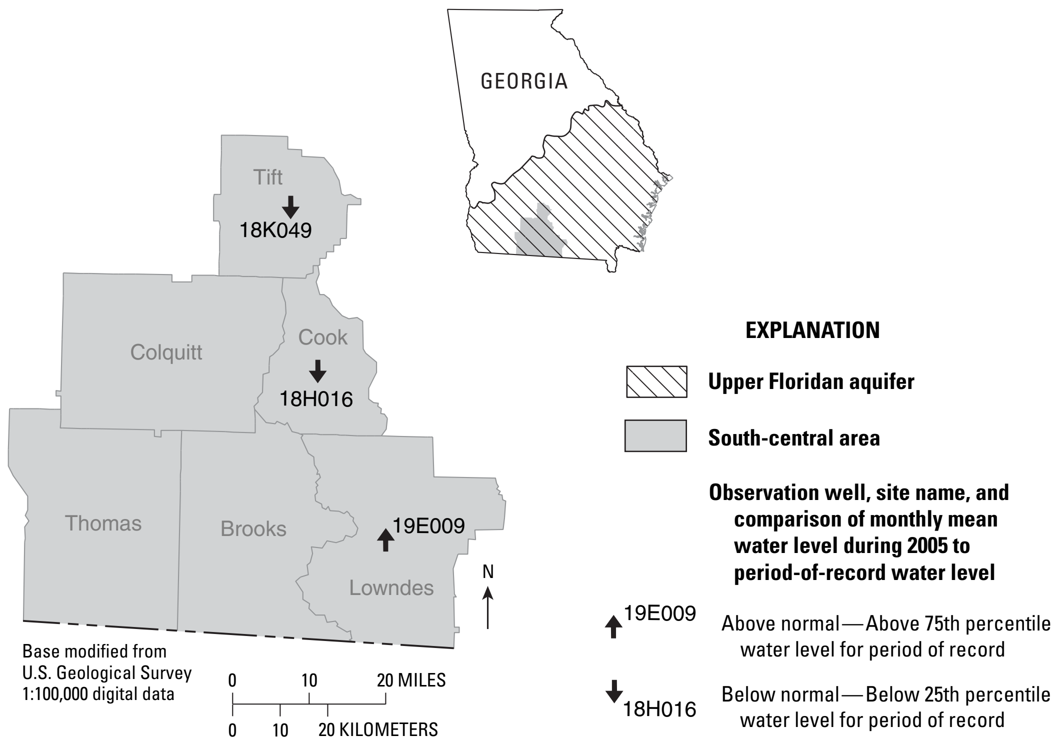
Upper Floridan Aquifer

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 2005 (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 two of three wells were below normal during 2005 and the water level in one well was above normal.

Water-level hydrographs for the three Upper Floridan aquifer wells in south-central Georgia (below) were chosen to illustrate monthly mean water levels during 2001–2005 and period-of-record water-level statistics. Drought effects are apparent in the three wells during 2002, but water levels do show some rise in subsequent years through 2005. The water level in well 19E009 in Lowndes County was below normal during most of 2002 but began to rise during the latter part of the year and was above normal or normal during most of 2003–2005. In well 19E009, the water level shows a quicker and more pronounced response to climatic effects because of proximity to karst. In the other two wells, climatic effects are less pronounced, and water levels primarily are influenced by pumping. Hydrographs for wells 18H016 in Cook County and 18K049 in Tift County both show a long-term downward trend, with water levels in the below-normal range. Both wells showed some recovery from drought effects during 2002–2005; however, levels remained below normal during 2005. A record low water level was recorded in well 18H016 during 2005.





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

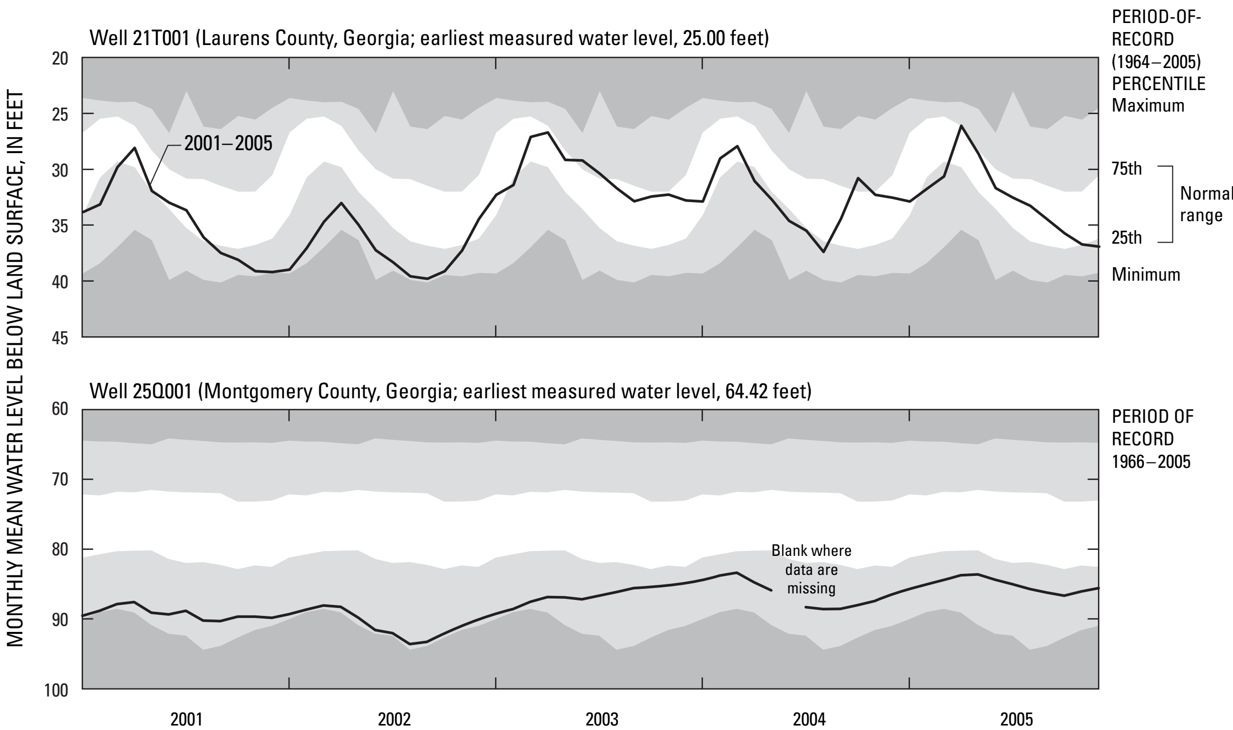
Ground-Water Levels

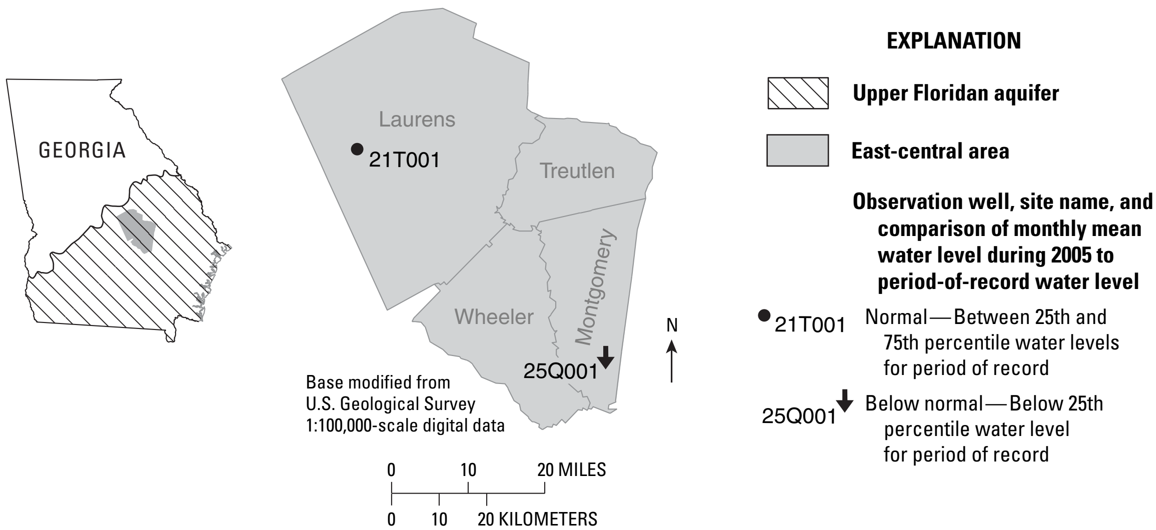
Upper Floridan Aquifer

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 2005 (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 well 21T001 was within the normal range and in well 25Q001 was below normal during 2005.

Water-level hydrographs for both Upper Floridan aquifer wells in east-central Georgia (below) were chosen to illustrate monthly mean water levels during 2001–2005 and period-of-record water-level statistics. Effects from drought are apparent in both wells during 2001 through mid-2002, when the water level in both wells were at or neared record lows. However, water levels in both wells began to rise after mid-2002. 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 much of 2001 and 2002, reaching a record low during 2002; water levels in this area are influenced by climatic effects and agricultural pumping. During 2003–2005, water levels in well 21T001 were generally normal, with some changes due to local variations in climate and 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 through 2005 the water level in this well rose, although water levels remained below normal, as a result of long-term declines from pumping.





Site name	County	Other identifier
21T001	Laurens	Hogan, observation well
25Q001	Montgomery	Montgomery County Board of Education

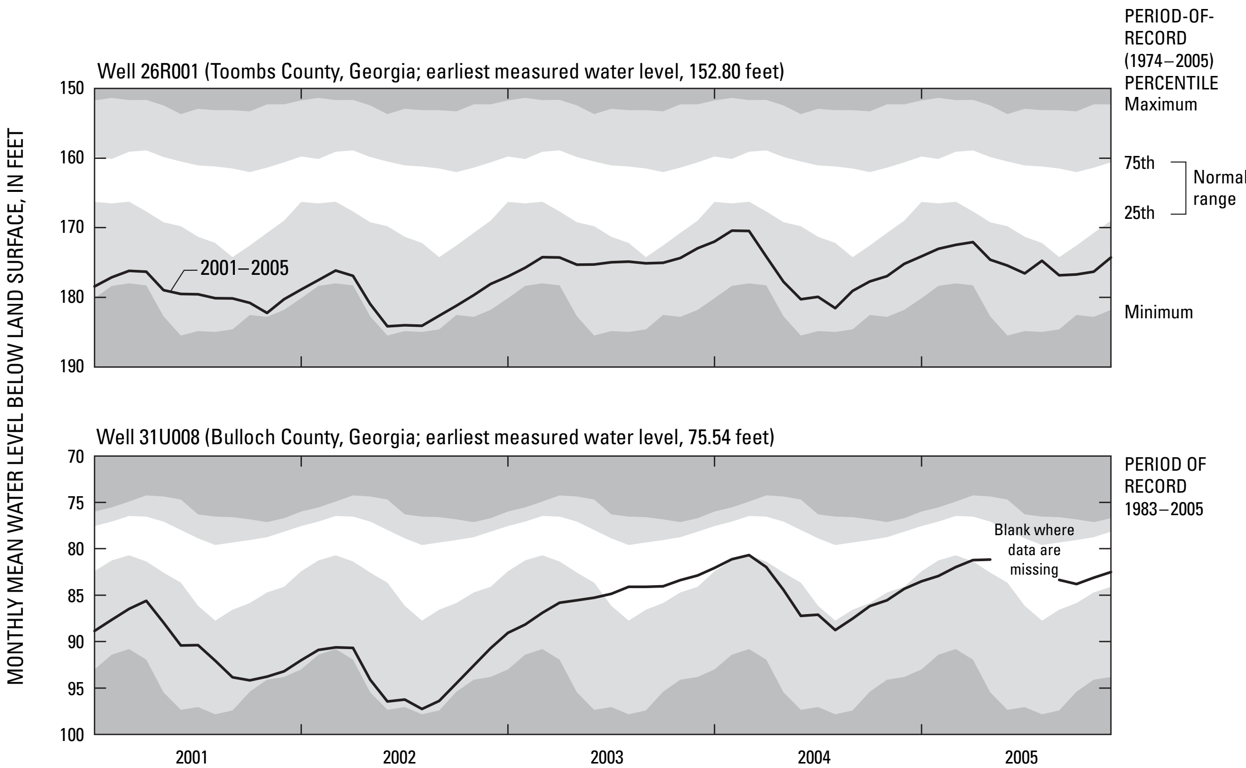
Ground-Water Levels

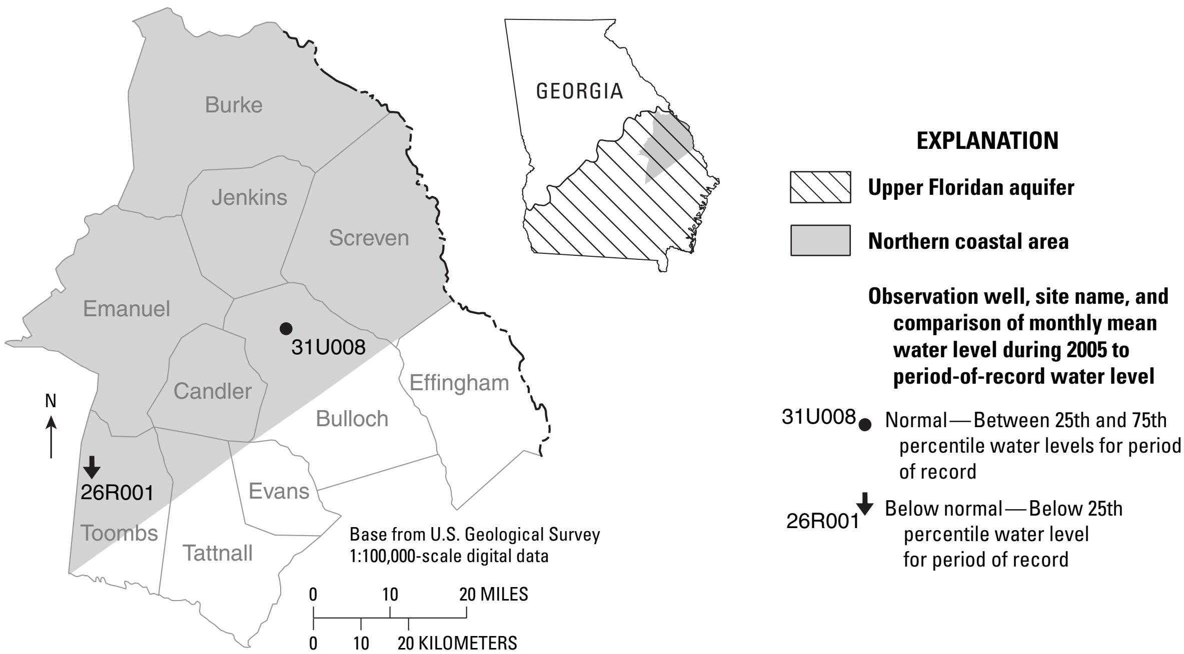
Upper Floridan Aquifer

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 2005 (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 level in the central well was within the normal range while water level to the southwest was below normal. 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 2001–2005 and period-of-record water-level statistics. Drought effects are apparent in both wells during 2001 through mid-2002, followed by a general recovery through 2005. The water-level trend in well 26R001 in Toombs County has been downward for most of the period of record continuing through 2002, when water levels reached near record daily lows up to that time. In the latter part of 2002 through 2005, water level generally rose but remained below normal throughout that time. The water level in well 31U008 in Bulloch County shows a similar trend. Near-record lows were recorded 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. During 2004, the water level fell below normal for most of the year and into early 2005, but rose into the normal range by the latter half of 2005.





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

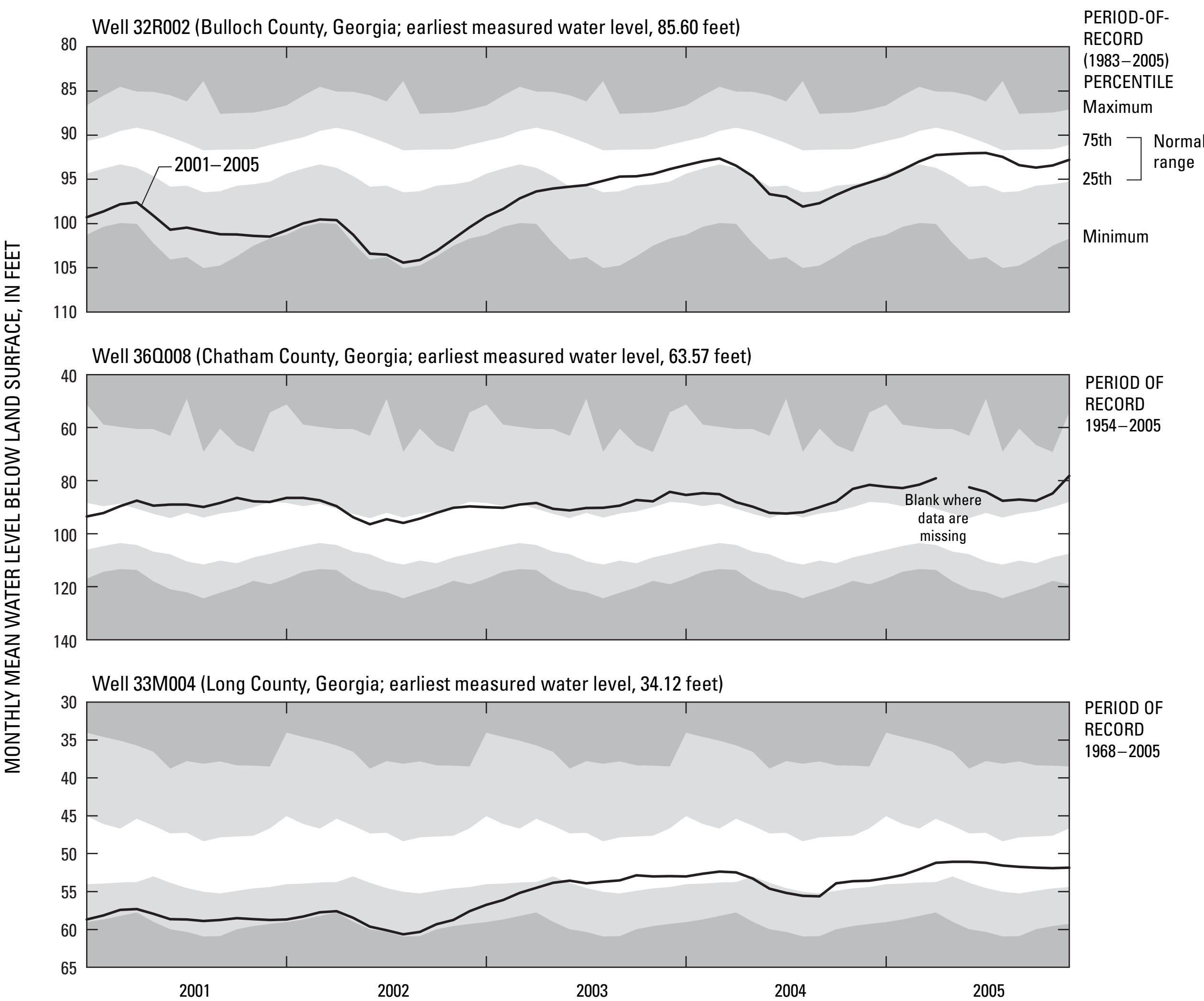
Ground-Water Levels

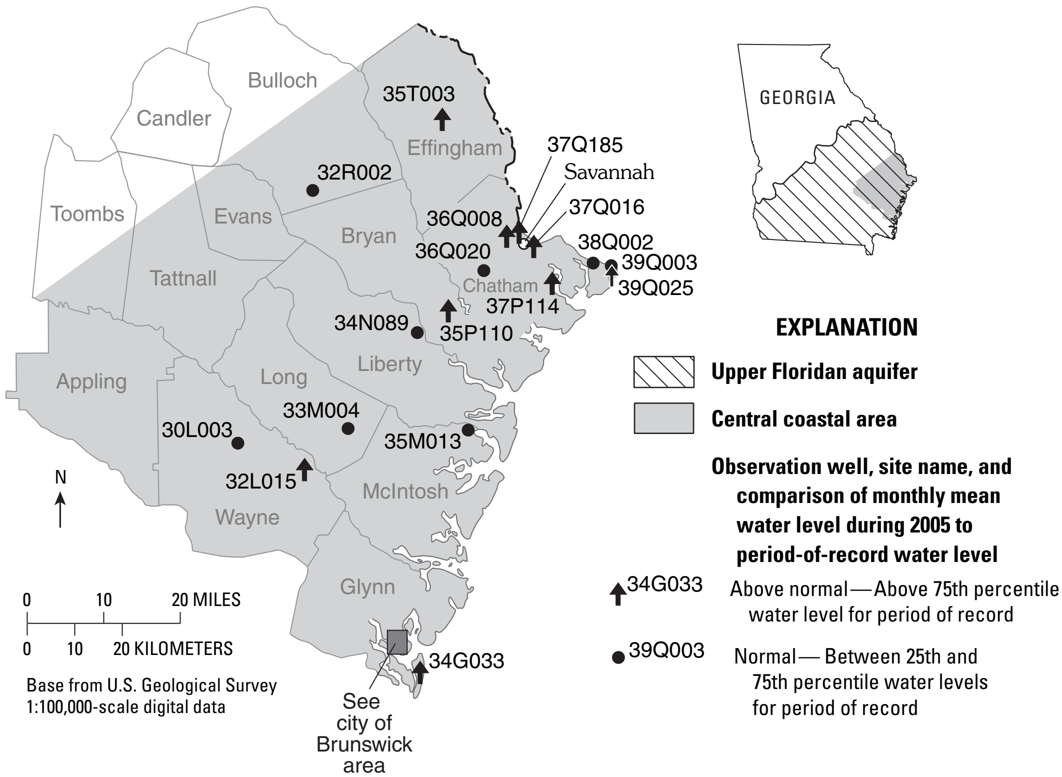
Upper Floridan Aquifer

Central Coastal Area

Water levels in 17 wells were used to define ground-water conditions in the Upper Floridan aquifer in the central coastal area of Georgia (excluding Glynn County) during 2005 (map and table, facing page). In this area, water in the Upper Floridan aquifer is confined and influenced primarily by pumping. Water levels in eight wells were within the normal range, and water levels in nine wells were above normal, reflecting recovery from drought and reduced pumping.

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 2001–2005 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; by mid-2003, it was within the normal range. The well dropped below normal for most of 2004 but rose back to the normal range for most of 2005. Well 36Q008 near Savannah in Chatham County was normal or above normal during 2001–2005 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. The water level then fell to below normal for a brief period during 2004, but was back to normal by the end of the year and continued to be so through 2005.





Site name	County	Other identifier
34G033	Brunswick	Jekyll Island Authority Number 9
35P110	Bryan	Richmond Hill, test well
32R002	Bulloch	Georgia Geologic Survey, Bulloch South, test well 1
36Q008	Chatham	Lance-Atlantic Company
36Q020	Chatham	Morrison, observation well
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
[1]30L003	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

Ground-Water Levels

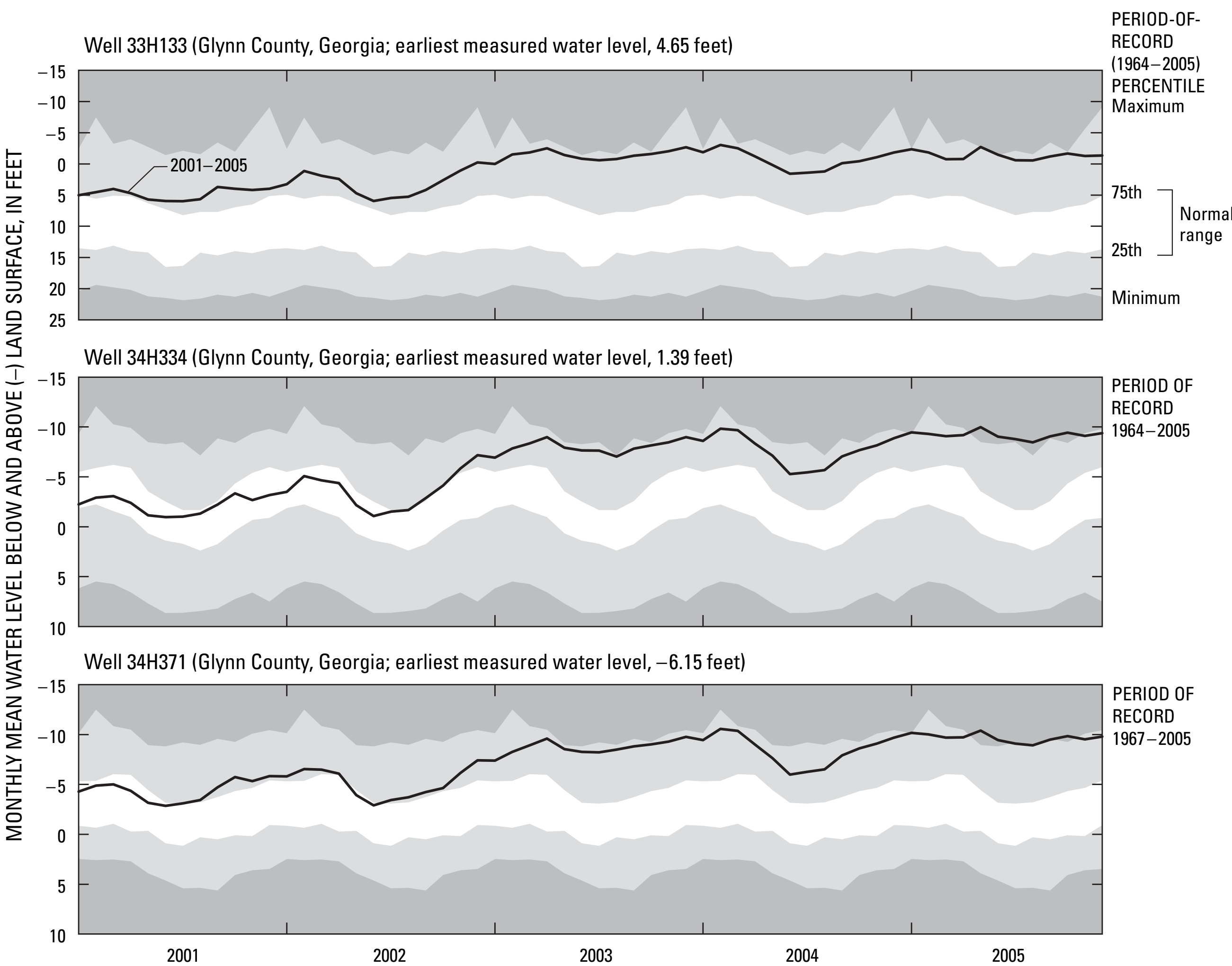
Upper Floridan Aquifer

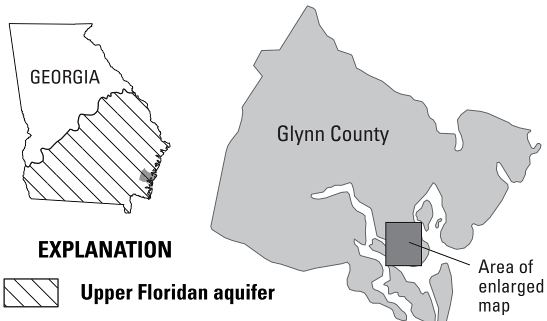
City of Brunswick Area

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 2005 (map and inset, facing page). In this area, water in the Upper Floridan is confined and primarily influenced by pumping for industrial and public supply. Water levels in all six wells were in the normal to above-normal range during 2005.

Water-level hydrographs for three Upper Floridan aquifer wells at the city of Brunswick (below) were chosen to illustrate monthly mean water levels during 2001–2005 and period-of-record water-level statistics. Water levels in all three wells followed a similar pattern of long-term rise, due to the combined effects of decreases in water use and above-normal precipitation contributing to increased recharge starting during mid-2002. By the end of 2002, water levels in all three wells were above normal and remained there through 2005.

In addition to continuous water-level monitoring, synoptic water-level measurements are taken periodically in wells in the Brunswick area. Water-level measurements from 21 wells were collected during June 2004 and from 15 wells during June 2005, and used to construct maps showing the potentiometric surface of the Upper Floridan aquifer. The potentiometric-contour maps (facing page) show that ground water generally flows northward toward industrial pumping centers in northern Brunswick, which have caused depressions in the potentiometric surface. Water-level altitudes generally increased during 2004–2005; however, the general direction of ground-water flow remained the same.





EXPLANATION

Upper Floridan aquifer

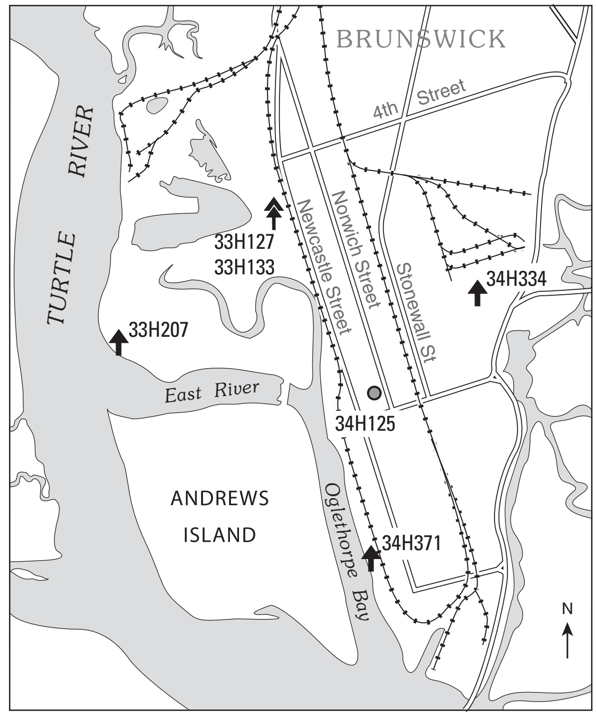
City of Brunswick area

Observation well, site name, and comparison of mean annual water level during 2005 to period-of-record water level

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

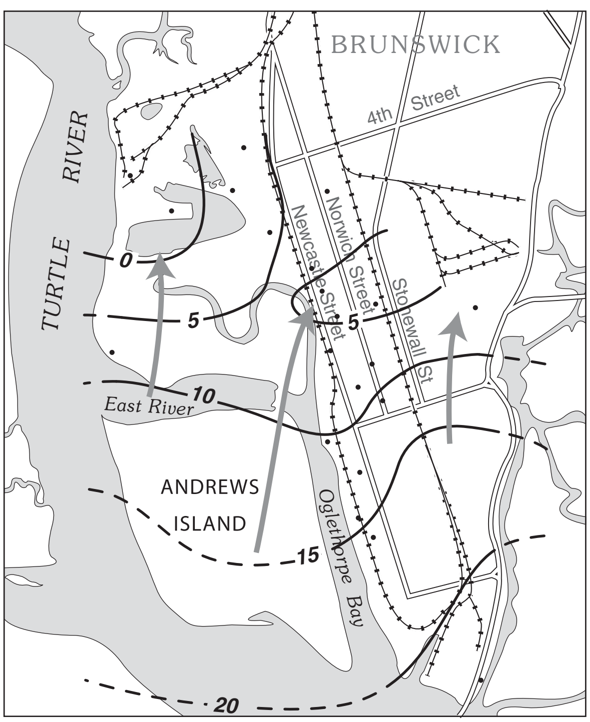
No data

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

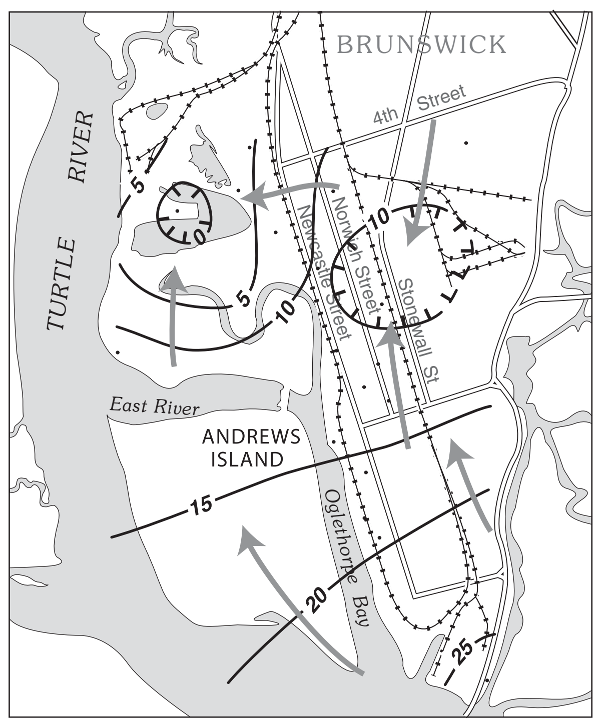


Base from U.S. Geological Survey 1:100,000-scale digital data

June 2004



June 2005



EXPLANATION

— *15* — — **Potentiometric contour**—Shows altitude at which water level would have stood in tightly cased wells in the upper Floridan aquifer. Dashed where approximately located. Hachures indicate depression. Contour interval 5 feet. Datum is North American Vertical Datum of 1988

General direction of ground-water flow

Ground-Water Levels

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 2005 (map and table, facing page). In this area, water in the Upper Floridan aquifer is confined and influenced mostly by pumping in the Fernandina Beach, Florida, area to the east, and by climatic effects and pumping to the west. The water level in all of the wells monitored mostly was above the normal range during 2005.

Water-level hydrographs for three Upper Floridan aquifer wells in the central coastal area (below) were chosen to illustrate monthly mean water levels during 2001–2005 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 and were normal to above normal during most of 2003. The marked rise during late 2002 resulted from the end of the drought and a large decrease in water use when the Durango Corporation Paper Mill in St. Marys, Georgia, ceased operations, decreasing water use by about 35 million gallons per day (Peck and others, 2005).

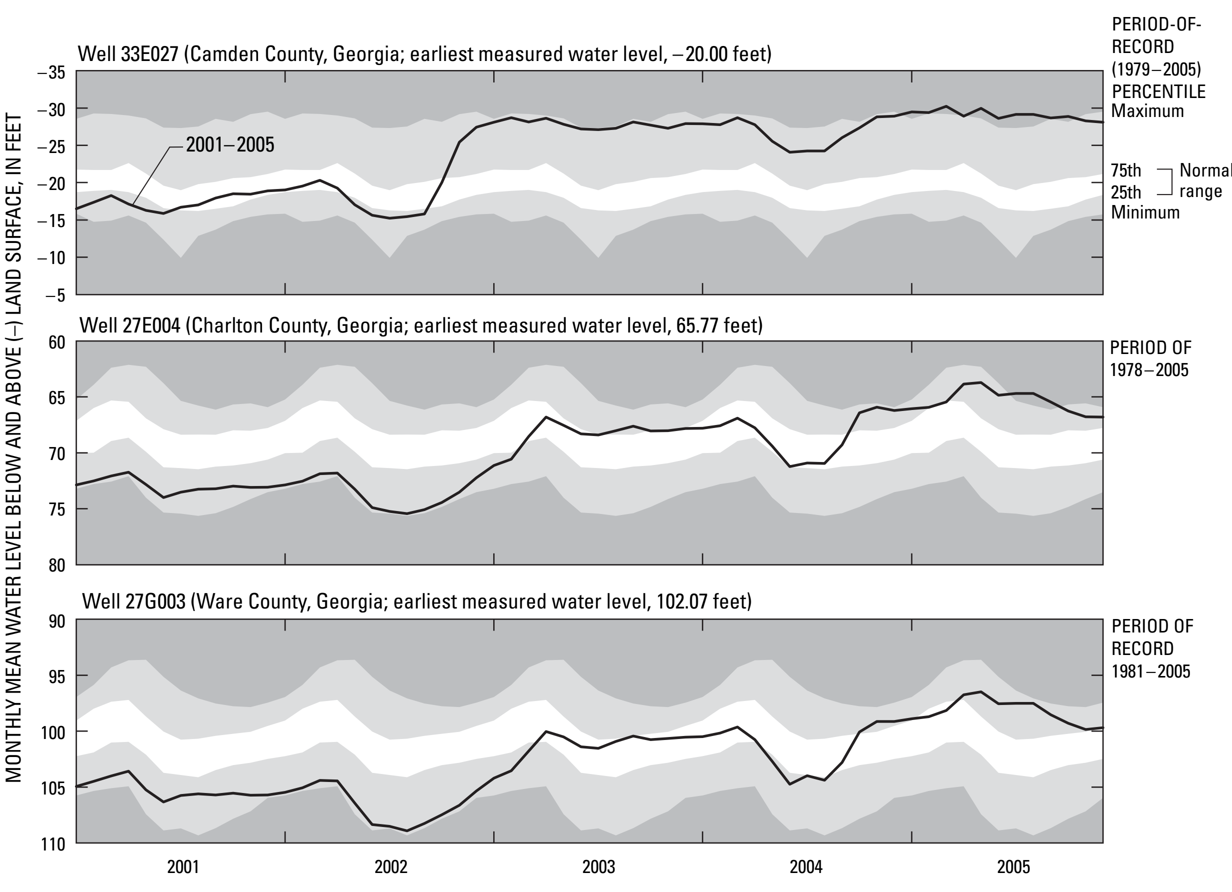
In addition to continuous water-level monitoring, synoptic water-level measurements are taken periodically, in cooperation with the St. Johns River Water Management District, in wells in and around the southern coastal area of Georgia and adjacent parts of Florida. During September 2004, water levels were measured in 95 wells; during September 2005 water levels were measured in 97 wells and subsequently used to construct a potentiometric-surface map of the Upper Floridan aquifer. The maps for 2004 and 2005 (Kinnaman 2005, 2006) (insets, facing page) show that water generally flowed from west to east, toward the Atlantic Ocean, and toward pumping centers at Fernandina Beach and Jacksonville, Florida.

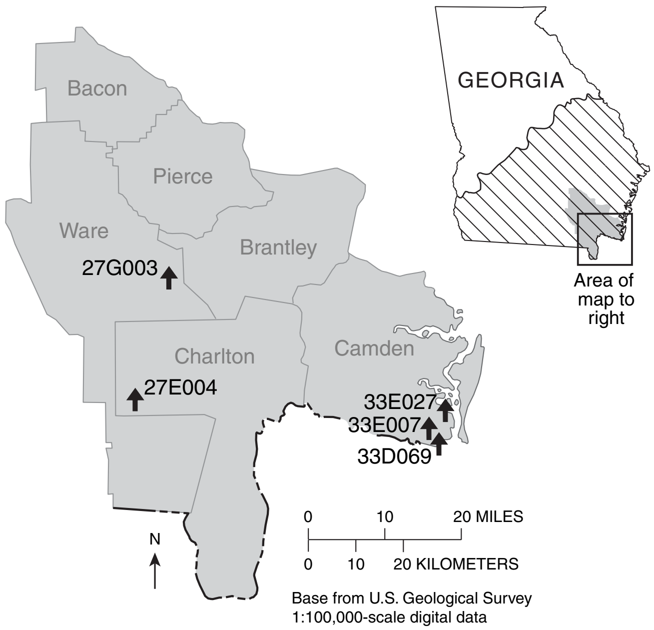
References Cited

Kinnaman, S.L., 2005, Potentiometric surface of the Upper Floridan aquifer in the St. Johns River Water Management District and vicinity, Florida, September 2004: U.S. Geological Survey Open-File Report 2005-1202, 1 sheet.

Kinnaman, S.L., 2006, Potentiometric surface of the Upper Floridan aquifer in the St. Johns River Water Management District and vicinity, Florida, September 2005: U.S. Geological Survey Open-File Report 2006-1108, 1 sheet.

Peck, M.F., McFadden, K.W., and Leeth, D.C., 2005, Effects of decreased ground-water withdrawal on ground-water levels and chloride concentrations in Camden County, Georgia, and ground-water levels in Nassau County, Florida, from September 2001 to May 2003: U.S. Geological Survey Scientific Investigations Report 2004-5295, 36 p., Web-only publication available at *http://pubs.usgs.gov/sir/2004/5295/*.





EXPLANATION

Upper Floridan aquifer

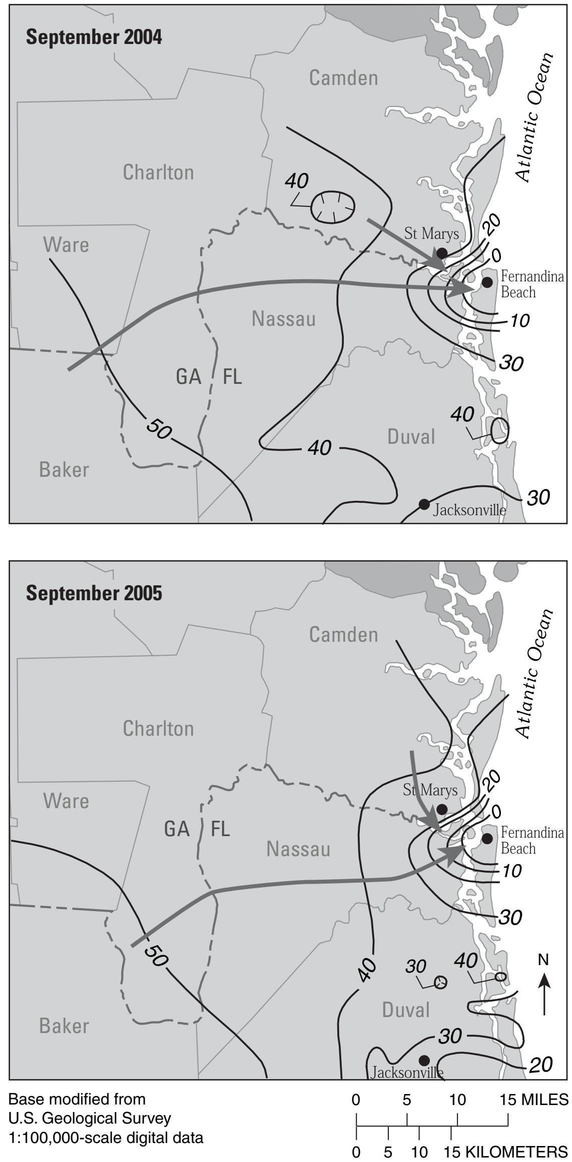
Southern coastal area

Observation well, site name, and comparison of monthly mean water level during 2005 to period-of-record water level

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

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
[1]27G003	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



EXPLANATION

— 45 — **Potentiometric contour**—Shows altitude at which water level would have stood in tightly cased wells. Hachures indicate depressions. Contour interval 10 feet. Datum is North American Vertical Datum of 1988. (Modified from Kinnaman, 2005, 2006)

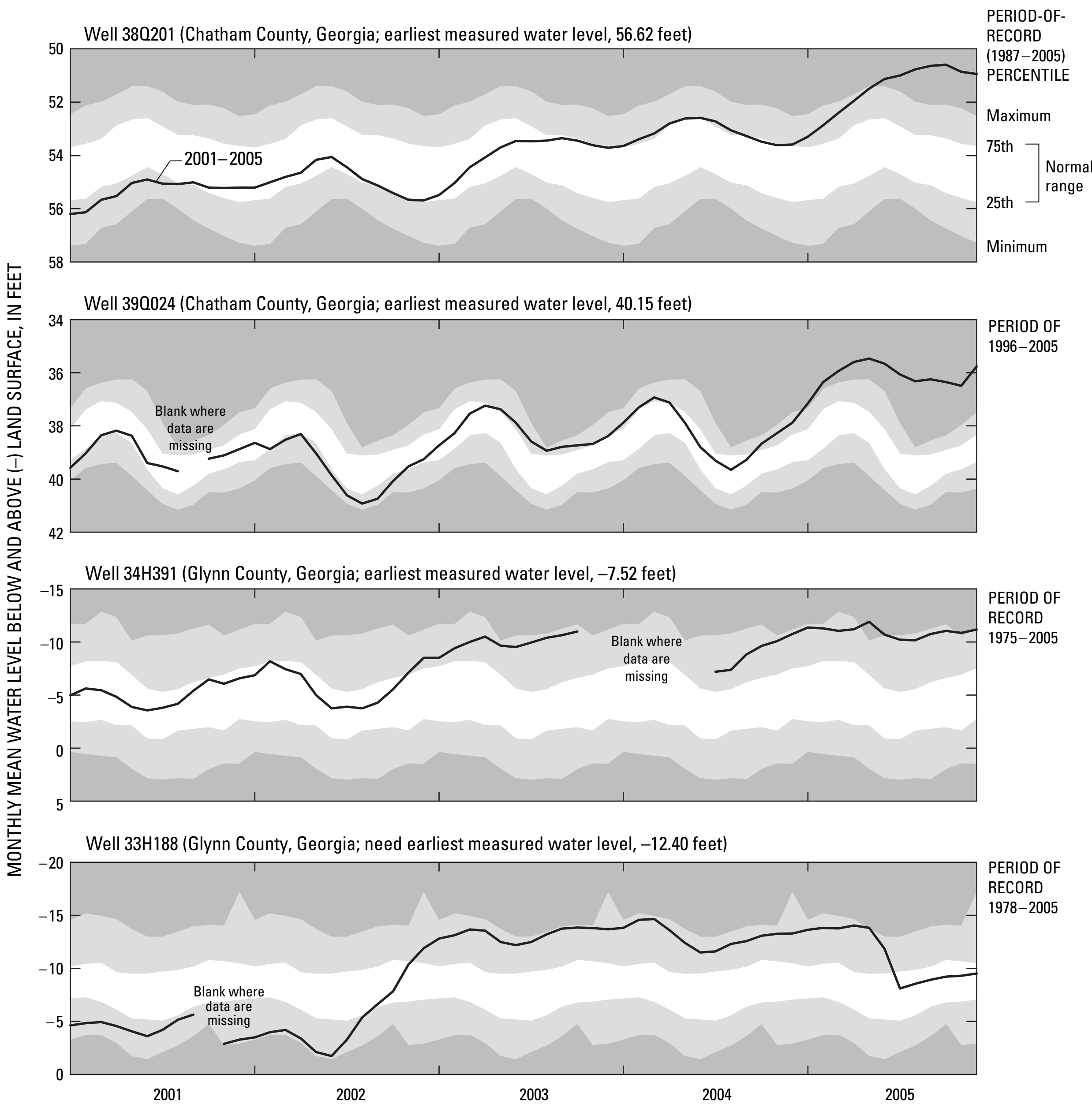
→ **Direction of ground-water flow**

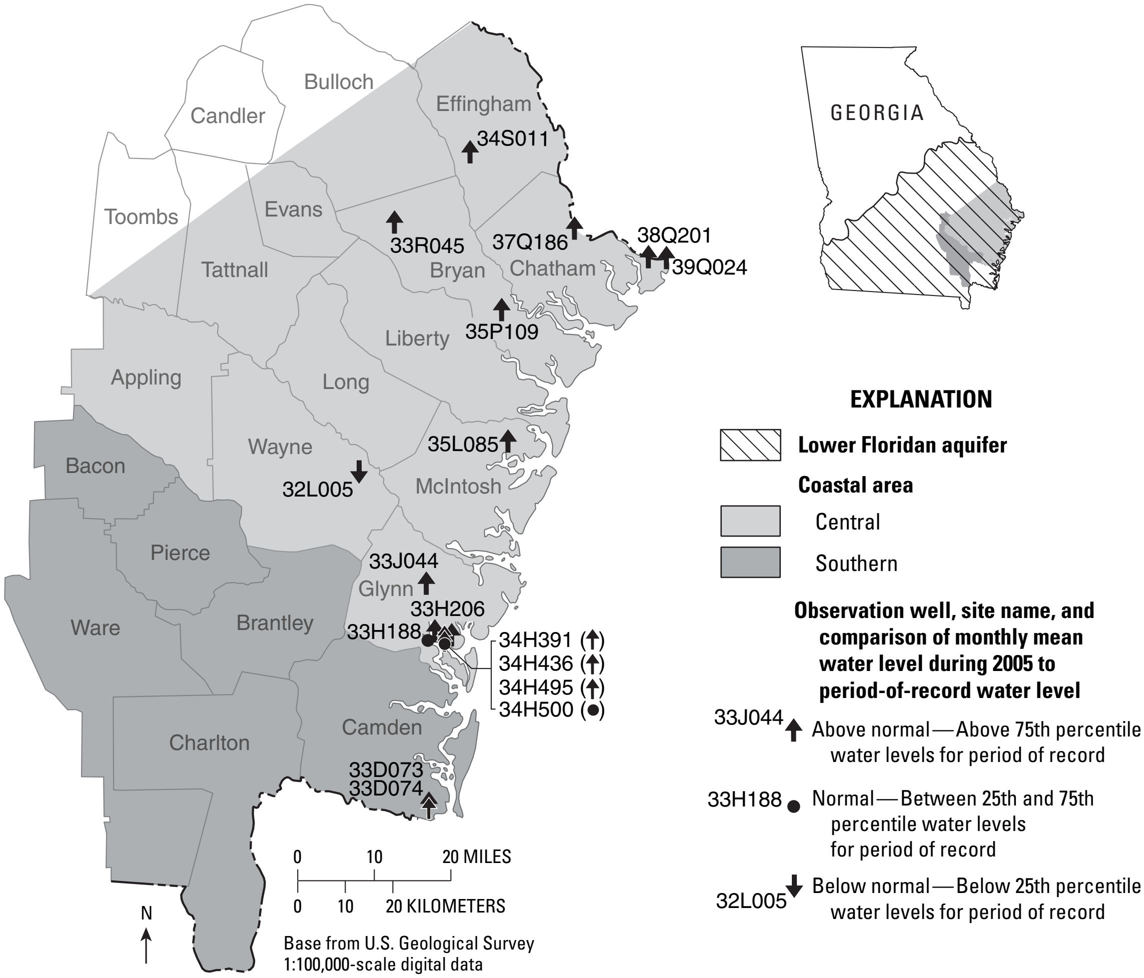
Ground-Water Levels

Lower Floridan Aquifer and Underlying Units in Coastal Georgia

Water levels in 17 wells were used to define ground-water conditions in the Lower Floridan aquifer and underlying units in central and southern coastal Georgia during 2005 (map and table, facing page). In this area, water in the Lower Floridan aquifer is confined and influenced mostly by pumping. Water levels in 16 of the 17 wells were above or within the normal range during 2005. The water level in one well was below normal in Wayne County, near the major pumping center of Jesup; however, data for the well are sparse and comparison is based on less than 3 years of record.

Water-level hydrographs for four Lower Floridan aquifer wells in coastal Georgia (below) were chosen to illustrate monthly mean water levels during 2001–2005 and period-of-record water-level statistics. Water levels in the four wells show a similar pattern and were generally in the above-normal range during 2003–2005. From 2002 to 2005, water levels rose in the four wells reaching record or near record highs during 2005. Pronounced rises were recorded during mid- to late 2002, reflecting recovery from drought. In well 33H188 in Glynn County there was a sharp drop in water level during mid-2005. This decline occurred when the well was allowed to flow for a 24-hour period prior to water sampling during June 2005. The water level in the well fell during this period and remained at that level once flow was ceased.





Site name	Water-bearing unit[1]	County	Other identifier
33R045	LF	Bryan	Coastal Sound Science Initiative test well
35P109	LF	Bryan	Richmond Hill, test well
33D073	LF	Camden	St. Marys, test well (deep)
33D074	LF	Camden	Coastal Sound Science Initiative, St. Marys test well 2
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
34S011	LF	Effingham	Coastal Sound Science Initiative, Pineora Ball Park test well
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
34H495	F	Glynn	Coastal Sound Science Initiative, Georgia Port Authority and U.S. Geological Survey test well 29
34H500	LF	Glynn	U.S. Geological Survey, test well 30
35L085	LF	McIntosh	Dan Hawthorne, test well 1
[2]32L005	LF	Wayne	Hopkins No. 2

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

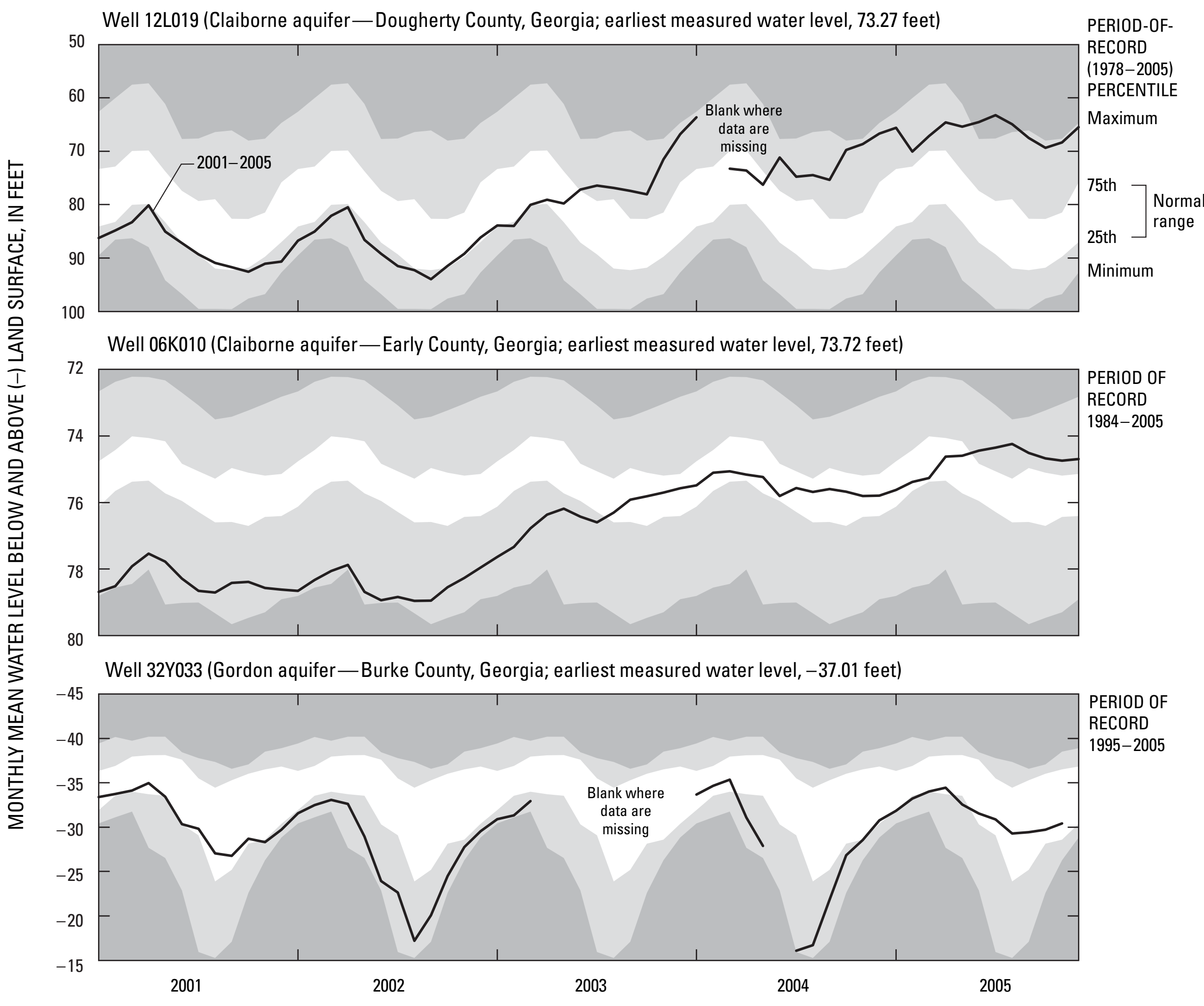
[2]Statistical comparison based on period of record less than 3 years

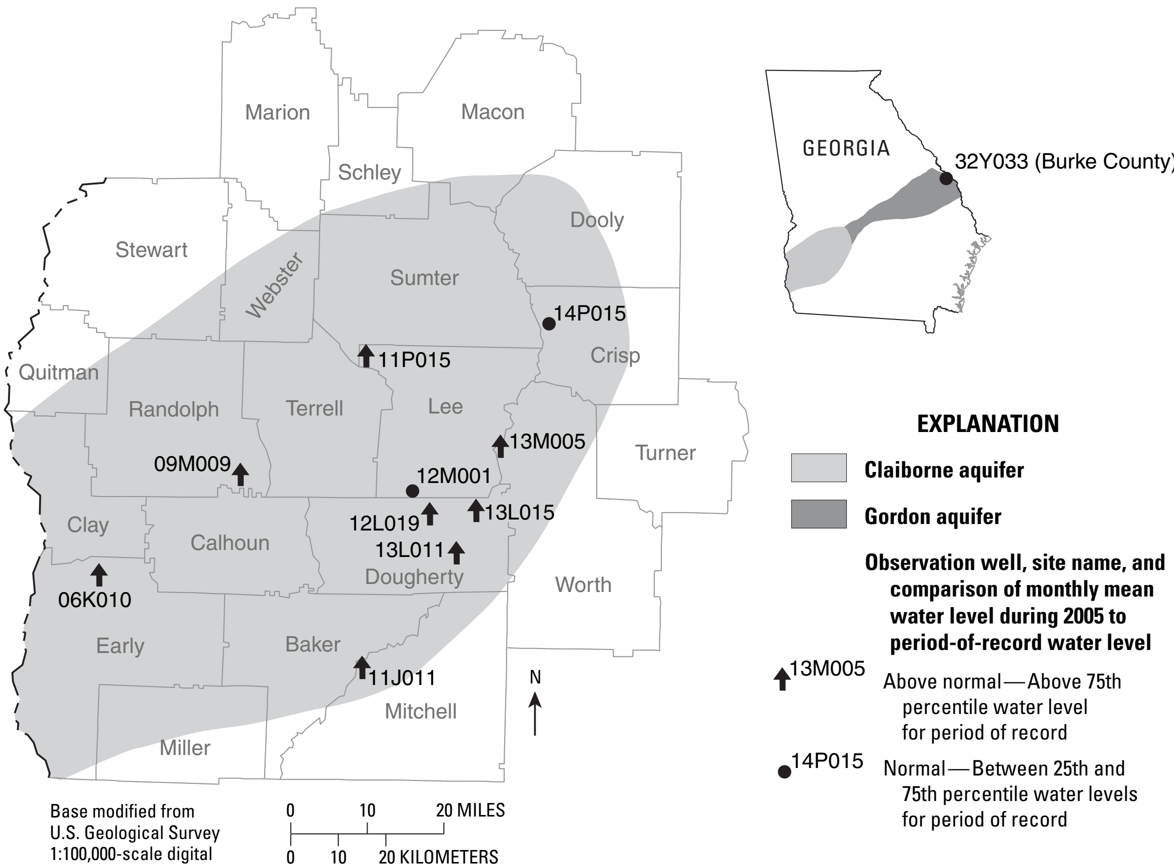
Ground-Water Levels

Claiborne and Gordon Aquifers

Water levels in 10 Claiborne aquifer wells and 1 Gordon aquifer well were used to define ground-water conditions in southwestern and east-central Georgia during 2005 (map and table, facing page). Water in the Claiborne and Gordon aquifers can be confined or unconfined. Water levels in wells completed in the Claiborne and Gordon aquifers were normal or above normal during 2005, likely reflecting effects of recharge and decreased pumping. This was true even in areas near agricultural pumping.

Water levels in two Claiborne aquifer wells and one Gordon aquifer well (below) were chosen to illustrate monthly mean water levels during 2001–2005 and period-of-record water-level statistics. In all three wells, water levels generally declined during 2001 through mid-2002. In the Claiborne aquifer, water levels in wells 12L019 and 06K010 were in the below-normal range from 2001 to early mid-2003, and rose into the normal and above-normal range during the remainder of 2003 through 2005. A record high water level was recorded in well 12L019 in mid-2005. The water level in the Gordon aquifer well 32Y033 in Burke County was below normal during most of 2001–2005 with the water level rising into the normal range during late 2003 and early 2004 and finally rising and staying in the normal range during early 2005.





Site name	Water-bearing unit[1]	County	Other identifier
14P015	C	Crisp	Georgia Geologic Survey, Veteran's Memorial State Park, test well 2
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	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	Martin, test well 1
13M005	C	Worth	U.S. Geological Survey, test well DP-7
32Y033	G	Burke	Brighams Landing, test well 3

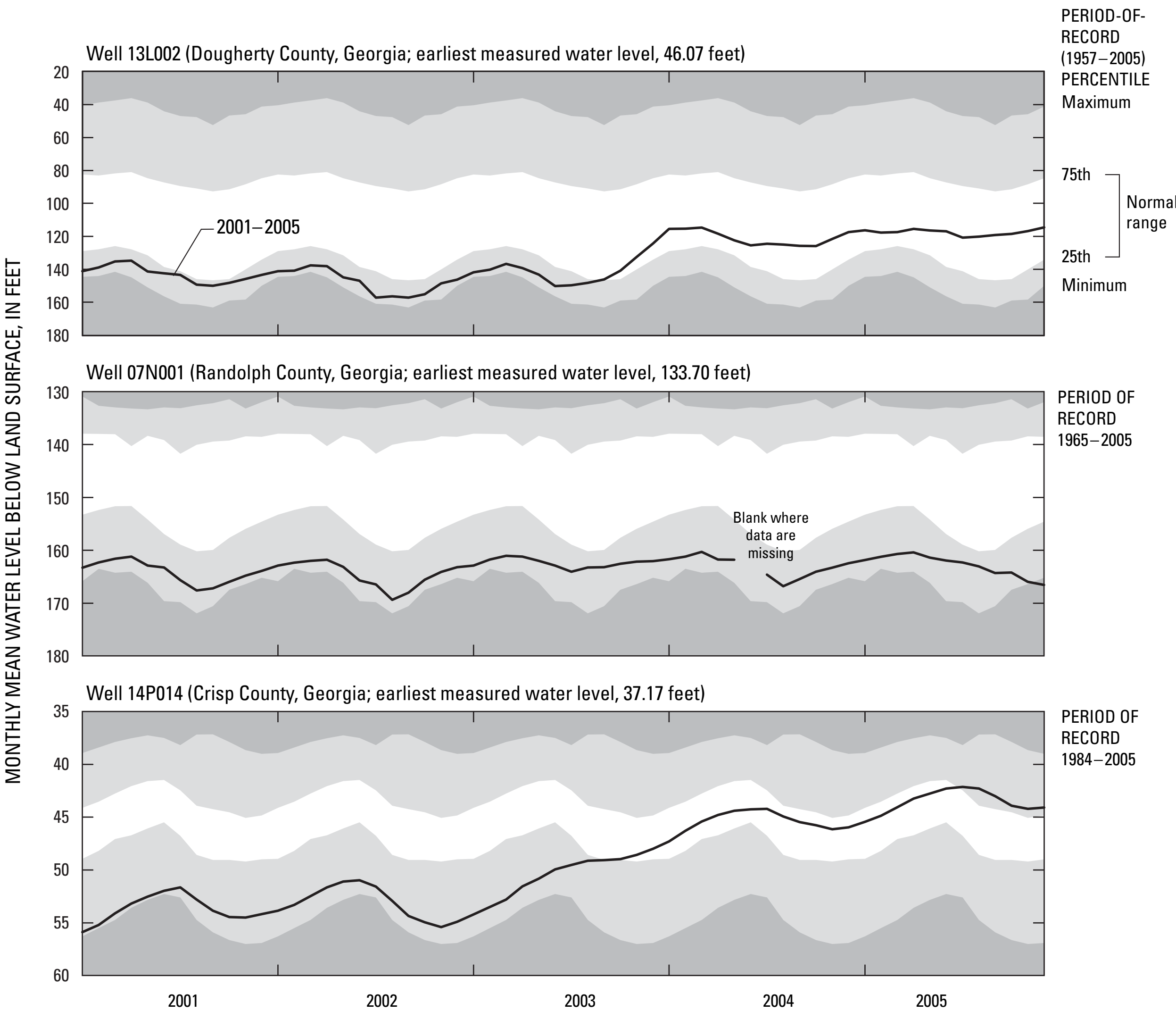
[1]C, Claiborne aquifer; G, Gordon aquifer

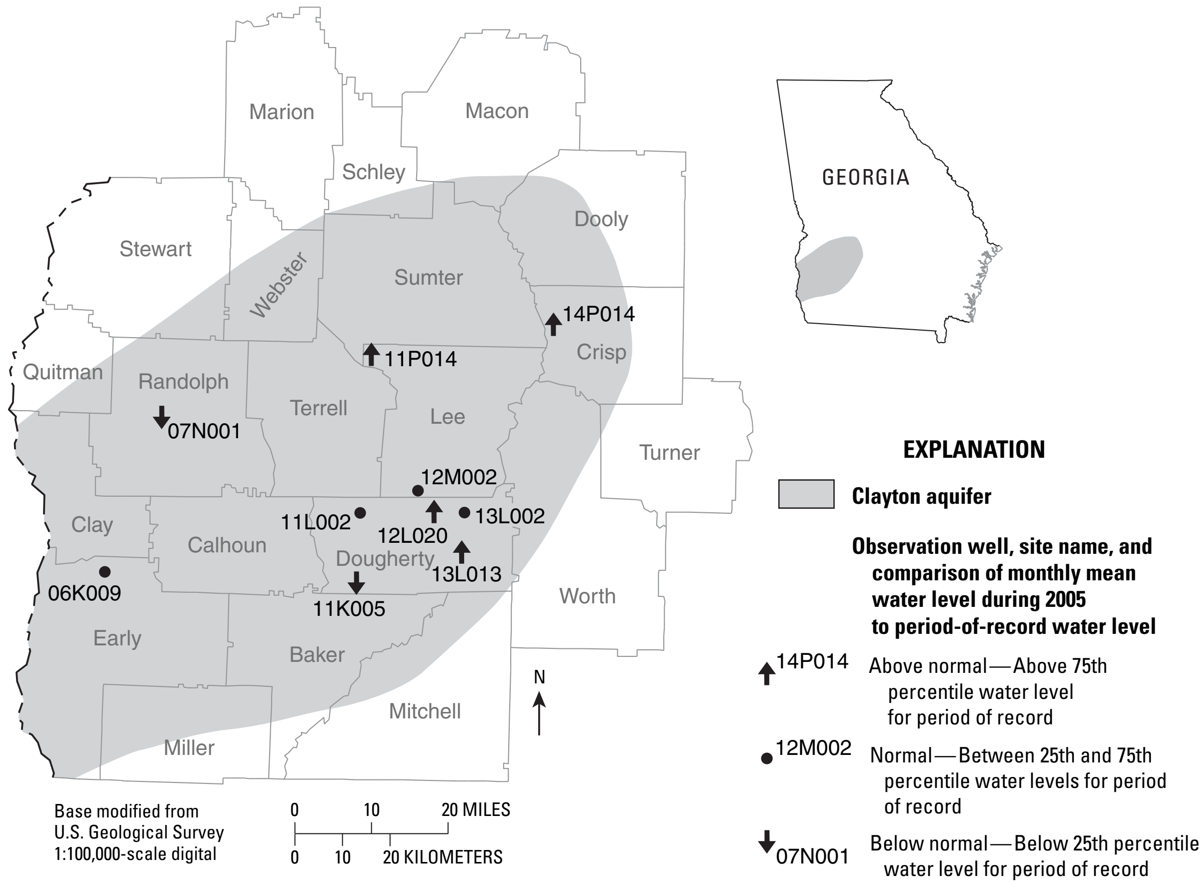
Ground-Water Levels

Clayton Aquifer

Water levels in 10 wells were used to define ground-water conditions in the Clayton aquifer in southwest Georgia during 2005 (map, facing page). In this area, water in the Clayton aquifer is confined and influenced mostly by pumping. During 2005, water levels in 8 of the 10 wells were normal or above normal. Two of the wells were below the normal range; both of these wells are affected by irrigation pumping.

Water-level hydrographs for three Clayton aquifer wells in southwestern Georgia (below) were chosen to illustrate monthly mean water levels during 2001–2005 and period-of-record water-level statistics. A similar pattern of continuous water-level rise occurs in wells 13L002 in Dougherty County and 14P014 in Crisp County. During 2003, water levels rose to within the normal range for the first time since 1999. This rise continued in both wells through 2005 and is especially pronounced in well 14P014, where the water level rose to the above-normal range during the latter part of 2005. Because of the period-of-record statistics, a long-term water-level decline is apparent in well 07N001 in Randolph County where the water level remained below normal during 2001–2005 and reached record lows during late 2005. The decline in this well is likely the result of irrigation pumping.





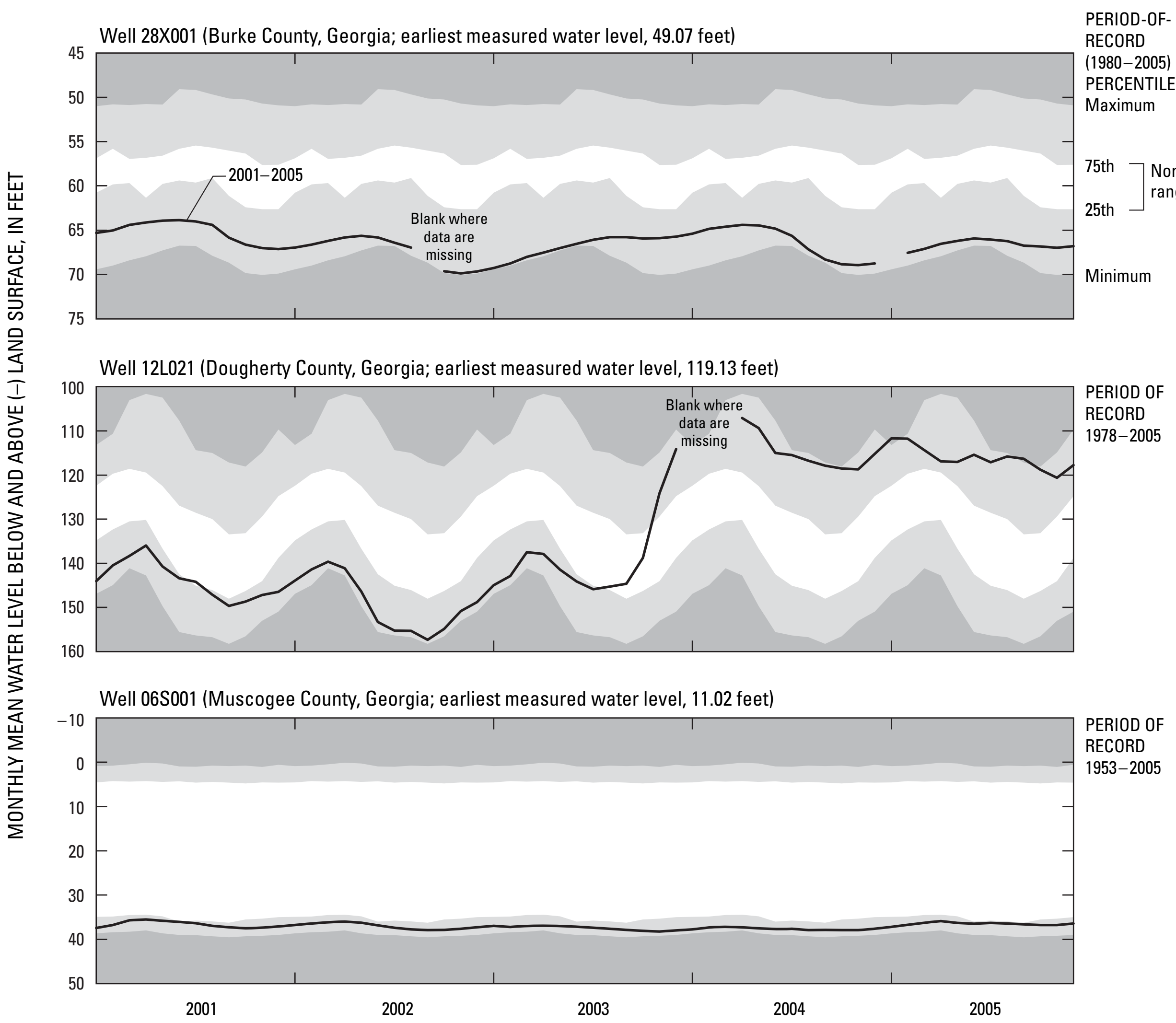
Site name	County	Other identifier
14P014	Crisp	Georgia Geologic Survey, Veteran’s Memorial State Park, test well 1
11K005	Dougherty	U.S. Geological Survey, test well 12
11L002	Dougherty	Georgia Geologic Survey, Albany Nursery
12L020	Dougherty	U.S. Geological Survey, test well 6
13L002	Dougherty	Albany 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	Long, test well 1
12M002	Lee	U.S. Geological Survey, test well 9
07N001	Randolph	City of Cuthbert

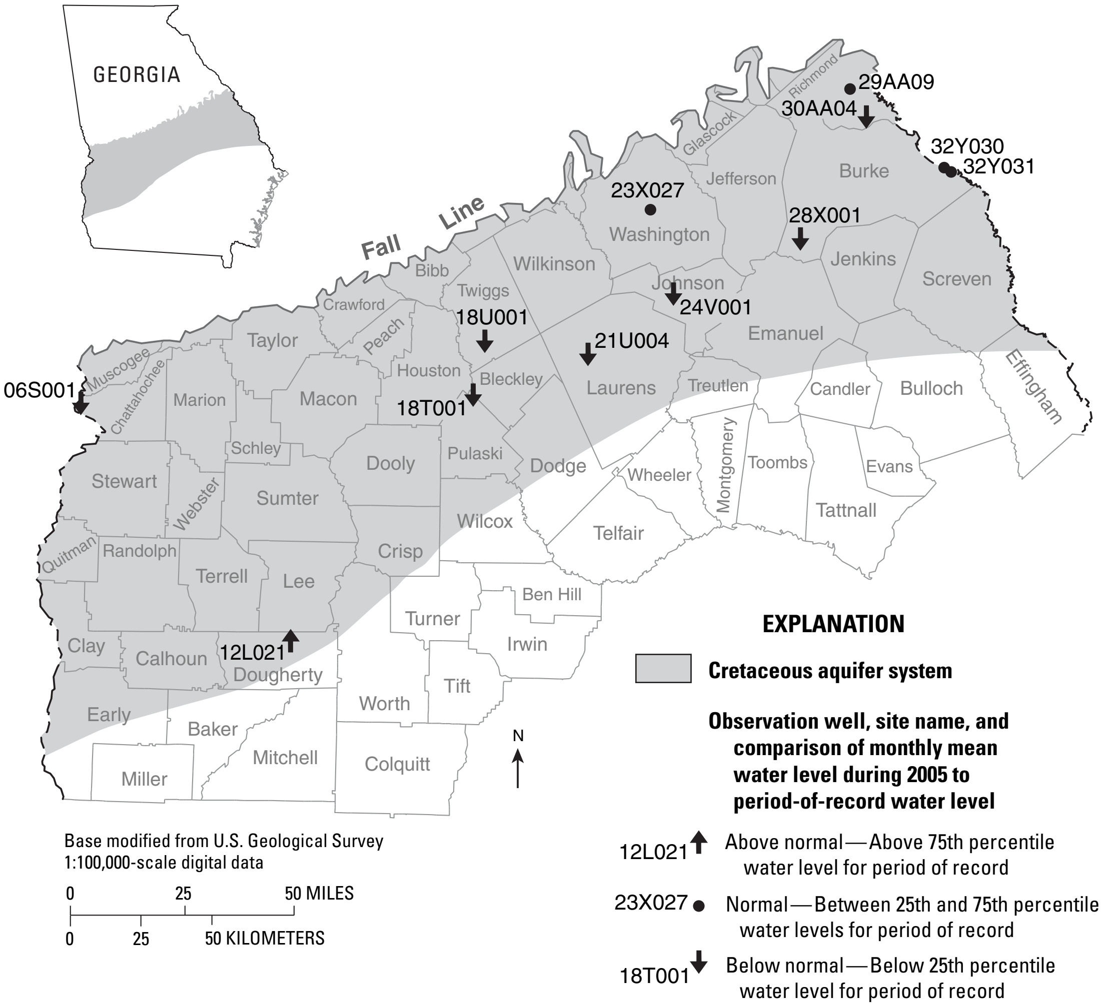
Ground-Water Levels

Cretaceous Aquifer System

Water levels in 12 wells in the Cretaceous aquifer system were used to define ground-water conditions throughout central and southwest Georgia during 2005 (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 seven of the wells were in the below-normal range during 2005, reflecting continued declines related to ground-water pumping. Water levels in five wells were within or above the normal range. It is notable that water levels in most wells monitored in the aquifer system are below normal. This is opposite of most areas and aquifers in the State where most wells are at or above normal. This disparity likely is caused by continued high pumping and low recharge to the aquifer.

Water-level hydrographs for three Cretaceous aquifer wells in central and southwest Georgia (below) were chosen to illustrate monthly mean water levels during 2001–2005 and period-of-record water-level statistics. Water levels in well 28X001 in Burke County and well 06S001 in Muscogee County were below the normal range during most of 2001–2005. In well 28X001, the water level reached record lows and remained below normal through 2005. In well 12L021 in Dougherty County, the water level was below normal at the end of the drought during 2002; however, the water level rose quickly during 2003 to the above-normal range by the end of 2003. Water levels remained above normal through 2005 and record highs levels were recorded. 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

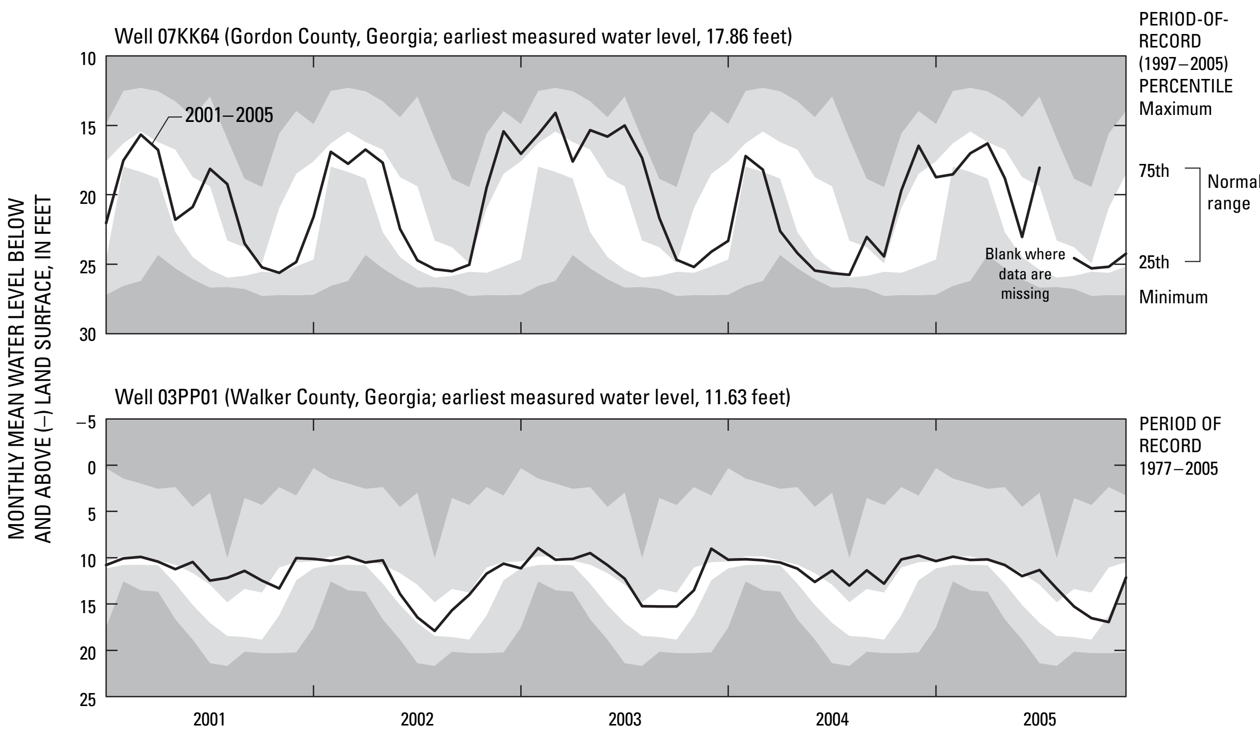
[1]M, Midville aquifer system; LM, Lower Midville aquifer; LD, Lower Dublin aquifer; T, Tuscaloosa Formation; P, Providence aquifer; UM, Upper Midville aquifer; DM, Dublin–Midville aquifer system; D, Dublin aquifer system

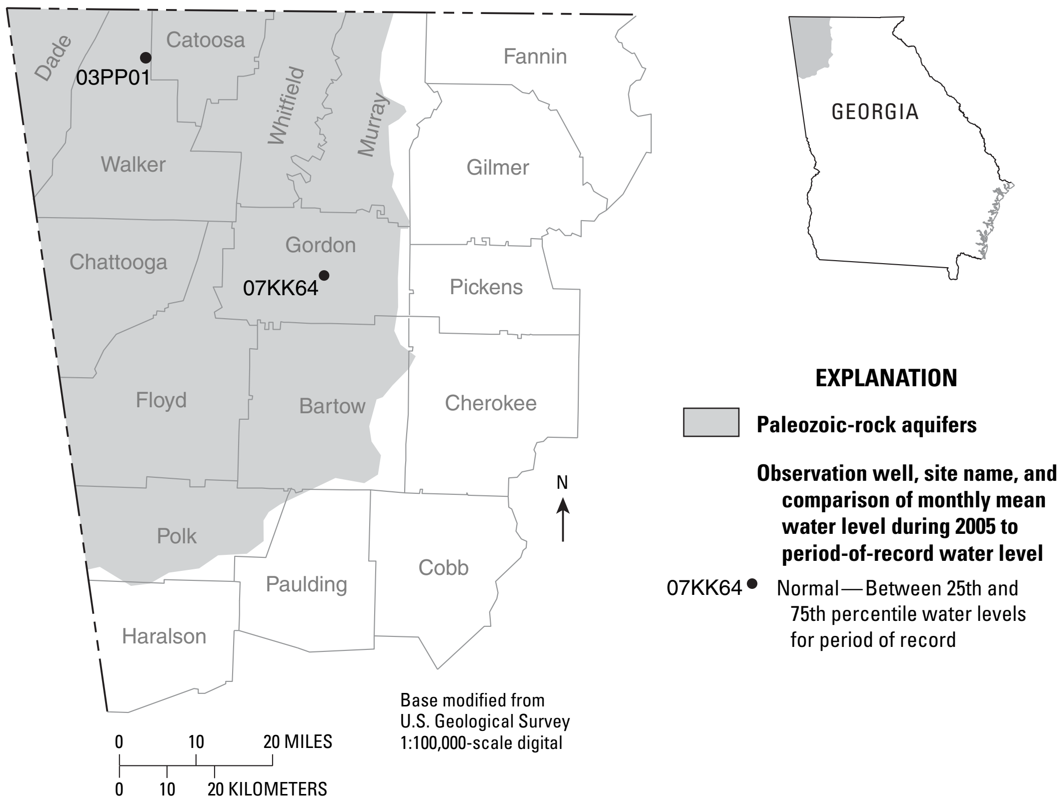
Ground-Water Levels

Paleozoic-Rock Aquifers

Water levels were measured in two wells in the Paleozoic-rock aquifers of northwest Georgia during 2005 (map and table, facing page). In this area, water in the Paleozoic-rock aquifers is under confined conditions. Water levels in two wells monitored were within the normal range during 2005.

Water-level hydrographs for the two Paleozoic-rock aquifer wells in northwestern Georgia (below) illustrate monthly mean water levels during 2001–2005 and period-of-record water-level statistics. It should be stressed that because the U.S. Geological Survey 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 2001–2005, briefly falling below normal during early 2004. The water level in well 03PP01 in Walker County also was normal or above normal during 2001 through most of 2005 but fell below normal during late 2005. There are no long-term trends apparent in either hydrograph.





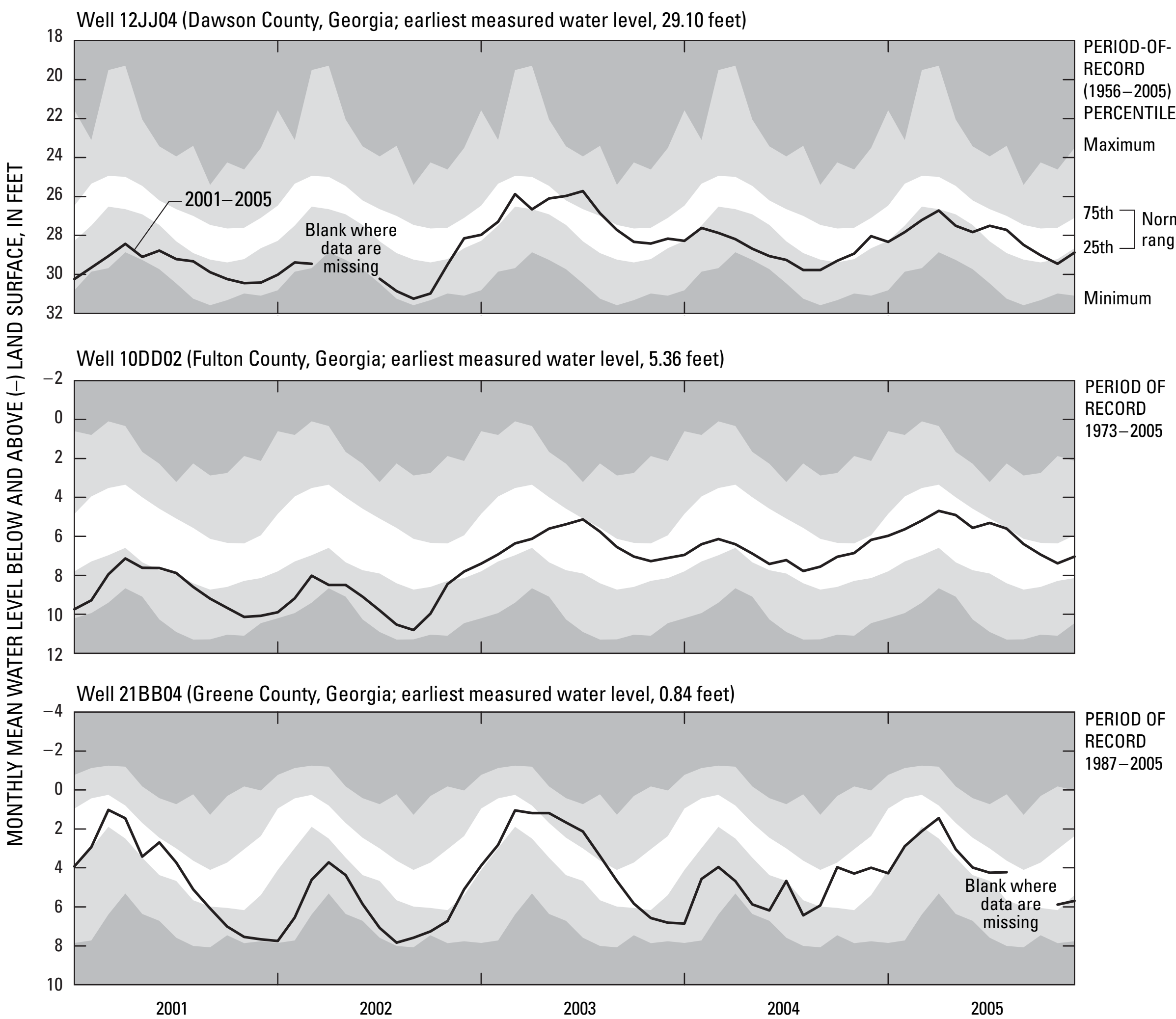
Site name	County	Other identifier
07KK64	Gordon	Calhoun, Georgia, test well 1
03PP01	Walker	U.S. National Park Service, Chickamauga Battlefield Park

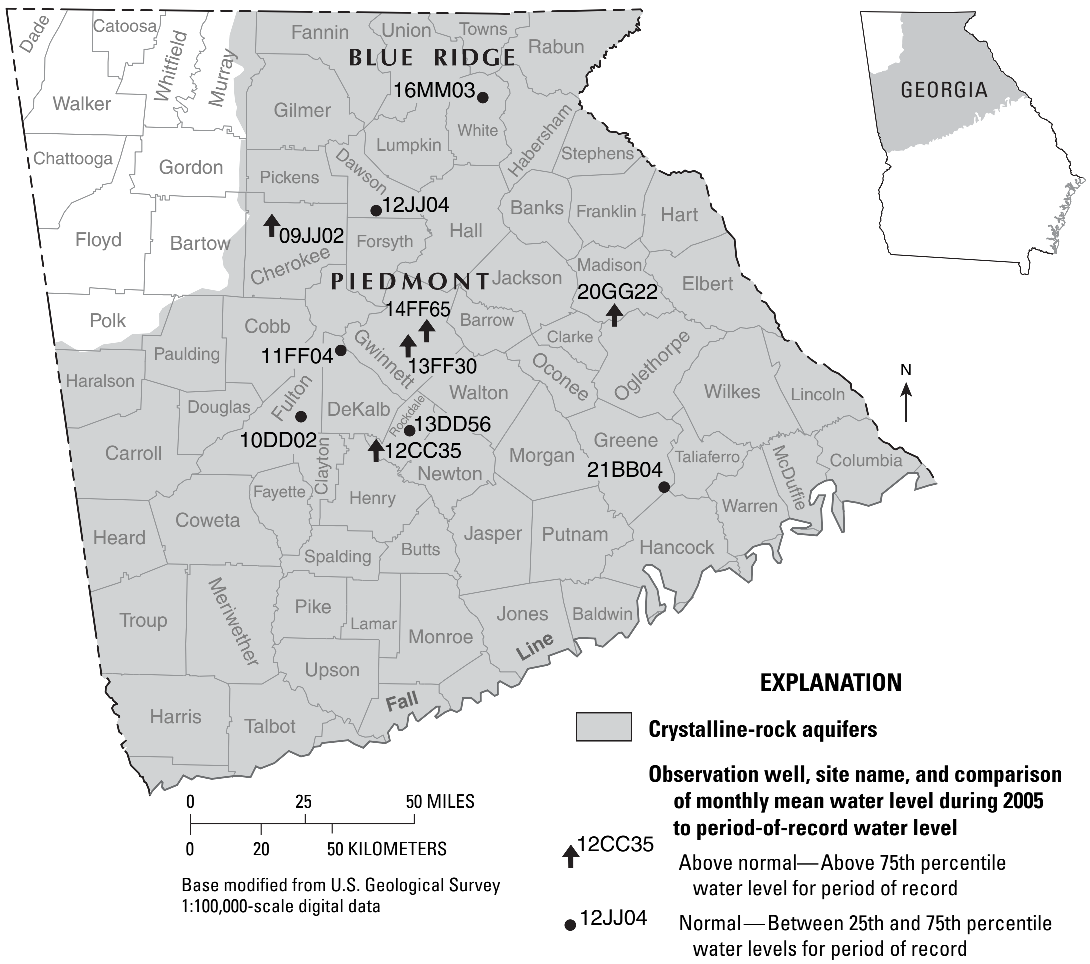
Ground-Water Levels

Crystalline-Rock Aquifers

Water levels in 11 wells were measured in crystalline-rock aquifers in the Piedmont and Blue Ridge physiographic provinces of Georgia during 2005 (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 greatly affected by localized water use and climate. Water levels in six of the wells were within the normal range, with water levels in five wells above the normal range during 2005.

Water-level hydrographs for three crystalline-rock aquifer wells (below) were chosen to illustrate monthly mean water levels during 2001–2005 and period-of-record water-level statistics. Effects of drought still were apparent in all three wells during 2001 through the early part of 2002. Water levels in all three wells were below normal during early 2002 but began to rise in the latter part of the year and in two wells were within or above the normal range by late 2003. Water levels generally declined from then through most of 2004, then rose through early 2005. Water levels in well 10DD02 (Fulton County) and well 21BB04 (Greene County) were within the normal range during 2005; water level in 12JJ04 in Dawson County was within the normal range during part of 2005, below normal at the beginning and end of the year.

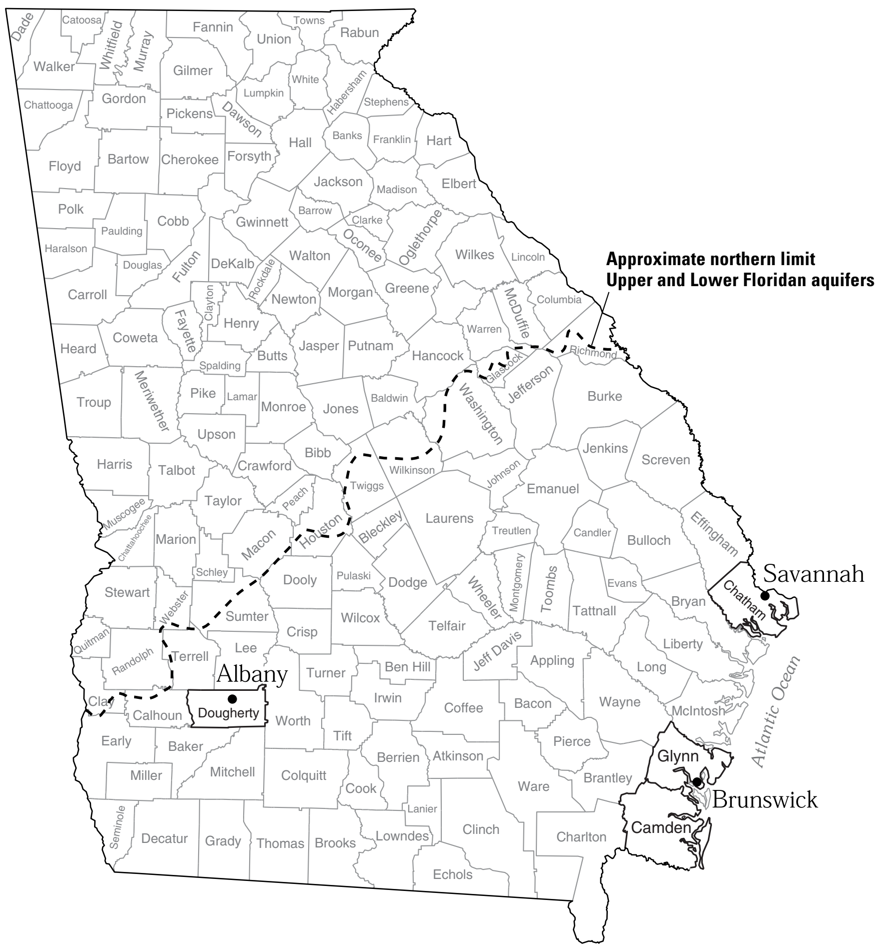




Site name	County	Other identifier
09JJ02	Cherokee	Reinhardt College, well A
12JJ04	Dawson	U.S. Geological Survey, test well 1
11FF04	DeKalb	U.S. Geological Survey, test well 5
10DD02	Fulton	U.S. Army, Fort McPherson
21BB04	Greene	Veazey, observation well
13FF30	Gwinnett	Lawrenceville, Georgia, Johnson Road, deep
14FF65	Gwinnett	Lawrenceville, Georgia, Highway 316, deep
20GG22	Madison	Colbert Georgia 4
12CC35	Rockdale	Rockdale County Fire Department
13DD56	Rockdale	Conyers, Georgia
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.



Ground-Water Quality of the Upper and Lower Floridan Aquifers

City of Albany Area

The Upper Floridan aquifer is shallow in southwestern Georgia where agricultural land use is prevalent, making the ground water susceptible to contamination from nitrates and other chemicals. Monitoring may provide 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 measured southwest of Albany.

Nitrate as N concentrations have been measured in the southwestern Albany area since September 1998. During November 2004 and 2005, samples were collected from selected wells and one gaging station on the Flint River. Since the end of a prolonged drought period during 2002, nitrate concentrations generally have increased in the area (table, below). During 2004–2005, nitrate concentrations increased in 13 of the 16 ground-water samples. Of the samples collected during November 2004, water from one well had a nitrate as N concentration greater than 10 mg/L. By November 2005, water from two wells had nitrate as N concentrations greater than 10 mg/L (map, facing page).

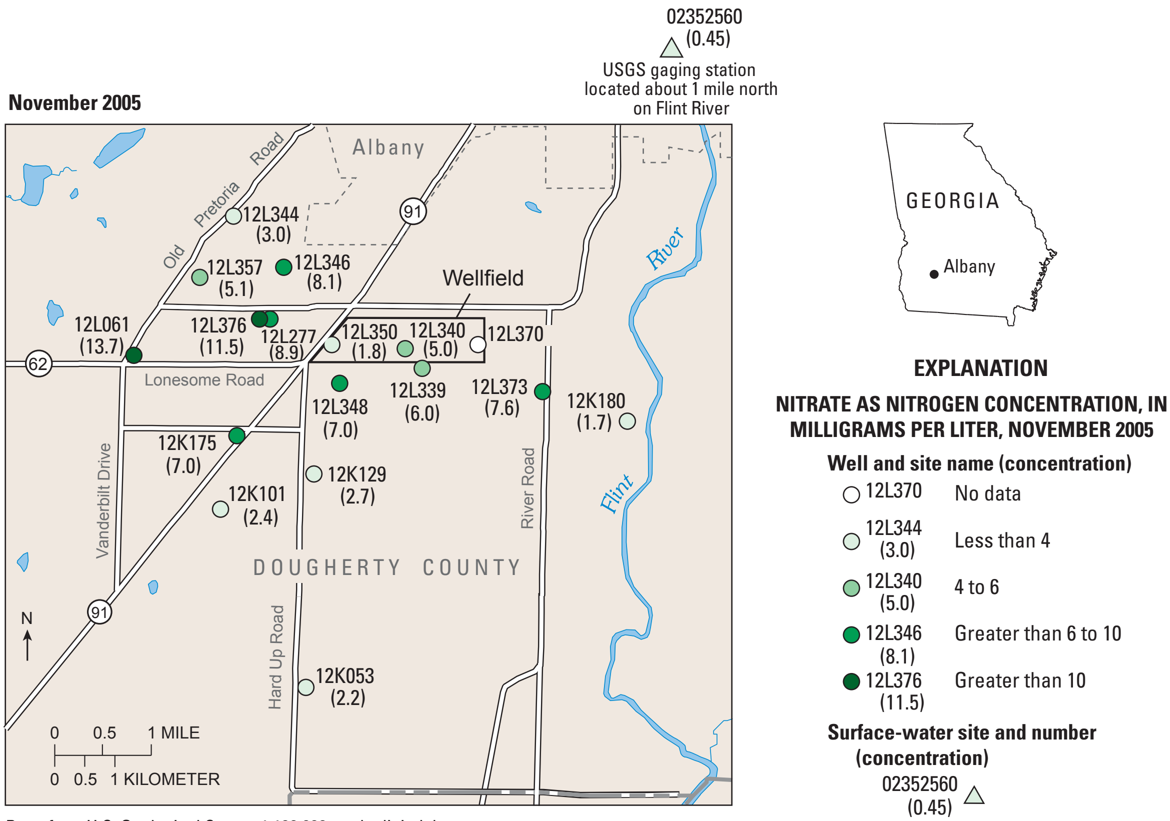
Samples collected during November 2004 and 2005 were plotted on trilinear diagrams. These diagrams (bottom, facing page) show that surface-water samples had a different chemical composition than ground-water samples. Surface-water samples had a higher sodium, potassium, and magnesium content and a lower carbonate and bicarbonate content than ground-water samples.

References Cited

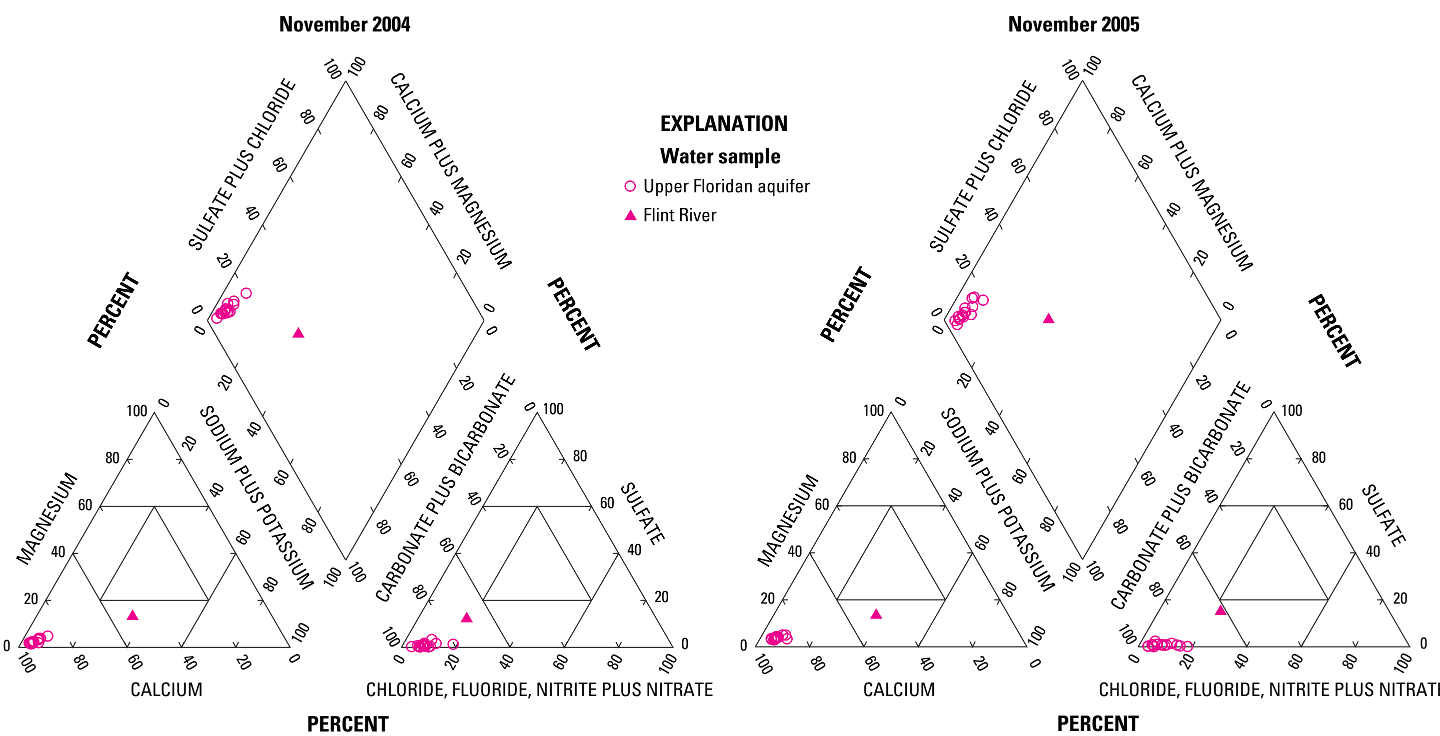
U.S. Environmental Protection Agency, 2000, Maximum contaminant levels (Part 143, National Secondary Drinking Water Regulations): U.S. Code of Federal Regulations, Title 40, Parts 100–149, revised as of July 1, 2000, p. 612–614.

Site name	**September 1998** NO_3–N (mg/L)	**April 1999** NO_3–N (mg/L)	**April 2001** NO_2+NO_3 as N (mg/L)	**November 2001** Dissolved NO_2+NO_3 as N (mg/L)	**November 2002** NO_3–N (mg/L)	**May 2003** NO_3–N (mg/L)	**November 2003** NO_3–N (mg/L)	**November 2004** NO_3–N (mg/L)	**November 2005** NO_3–N (mg/L)
Wells									
12K053	—	—	—	—	2.0	—	2.2	1.9	2.2
12K101	1.8	1.9	—	2.2	2.1	—	2.1	2.0	2.4
12K129	—	—	—	3.1	2.9	—	2.9	2.8	2.7
12K175	3.8	5.7	5.0	5.9	5.4	—	6.1	5.5	7.0
12K180	—	—	—	—	1.56	1.7	1.4	1.4	1.7
12L061	11	12	12	12	12.5	—	13.4	13.1	13.7
12L277	7.5	6.9	6.5	8.0	6.3	9.0	8.2	8.4	8.9
12L339	5.9	5.4	—	5.0	—	—	—	—	6.0
12L340	—	—	—	—	—	—	—	4.7	5.0
12L344	6.0	5.1	2.7	1.6	1.7	—	1.9	2.1	3.0
12L346	—	—	—	—	—	—	7.2	6.6	8.1
12L348	—	6.5	6.4	7.1	6.8	—	6.9	6.6	7.0
12L350	3.0	2.9	—	4.8	5.5	—	2.6	2.0	1.8
12L357	5.9	3.1	—	2.0	—	—	—	3.5	5.0
12L370	—	—	—	—	—	—	7.1	—	—
12L373	—	—	—	7.2	6.6	8.6	7.5	7.2	7.6
12L376	—	—	—	—	6.5	8.8	8.3	9.3	11.5
Gaging station									
02352560	—	—	—	—	—	0.4	0.45	0.41	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; for site locations, see map on facing page



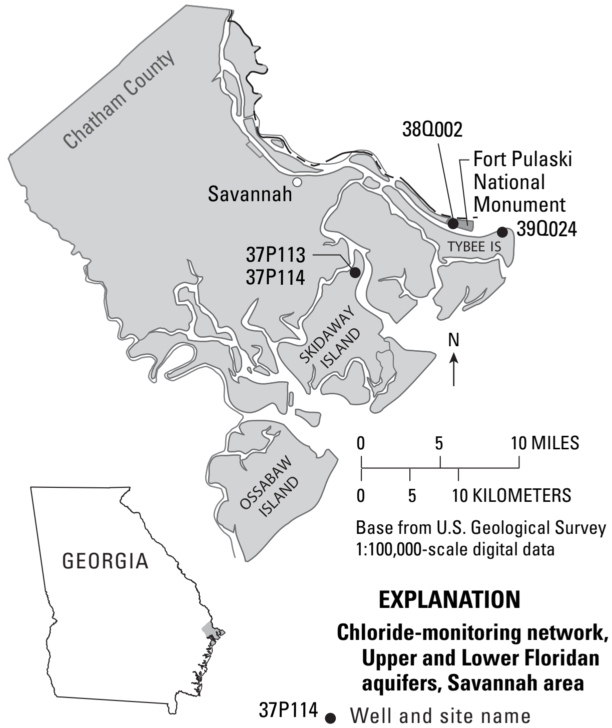
Base from U.S. Geological Survey 1:100,000-scale digital data



Ground-Water Quality of the Upper and Lower Floridan Aquifers

City of Savannah Area

During 2004–2005, borehole geophysical logs and water samples were collected from open intervals in wells completed in the Upper and Lower Floridan aquifers to assess changes in chloride concentration in the Savannah area, continuing a program that started during 2003 (Leeth and others, 2005). Borehole geophysical logs include fluid resistivity, an indicator of dissolved-solids concentration, and fluid temperature, an indicator 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 centimeter at 25 degrees Celsius (µS/cm); higher values reflect higher concentrations of dissolved solids, which are mostly composed of dissolved chloride in the Savannah area. Water samples were collected at specific intervals reflecting the range of specific conductance observed in the well during logging. The analysis of water samples is summarized in a table and shown with geophysical logs on the facing page.



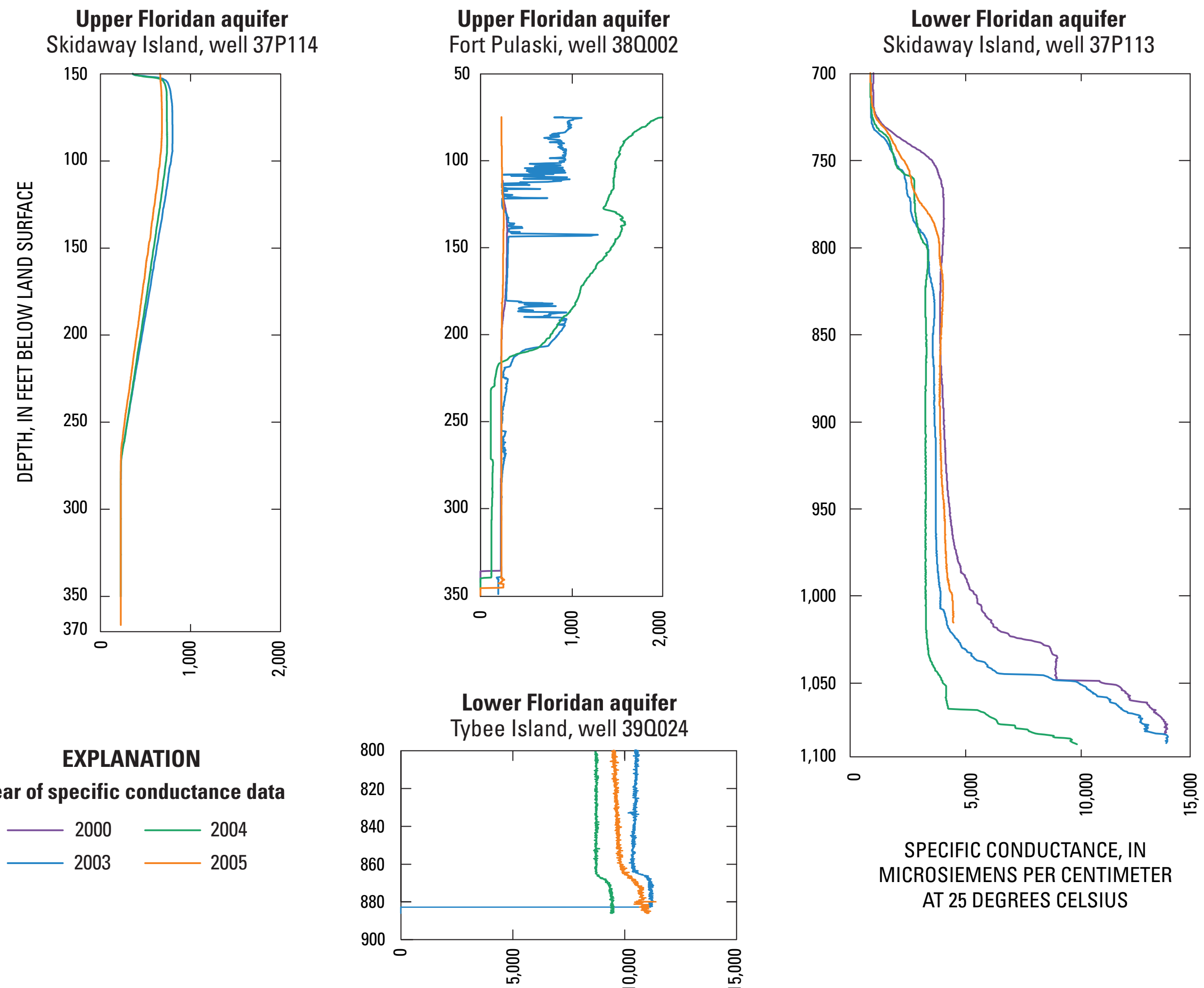
At Tybee Island, fluid conductivity (resistivity) logs and water samples were collected December 7, 2004, and December 6, 2005, from well 39Q024 completed in the Lower Floridan aquifer (facing page). Chloride concentrations of samples collected at common depths in well 39Q024 increased during 2004–2005. From March 1996 to December 2004, specific conductance of the open interval of the well (as determined from fluid conductivity logs) had decreased from an average of 11,779 to 9,016 µS/cm. During 2004, concentrations in samples collected at depths of 845 and 860 feet (ft) were 2,916 and 2,943 milligrams per liter (mg/L), respectively; whereas during 2005, concentrations in samples collected at the same depths were 2,979 and 2,995 mg/L, respectively. Previous composite samples from the entire open interval (840–880 ft) during 1994–2001 ranged from about 2,700 to 3,400 mg/L. From December 2004 to December 2005, the average specific conductance in the open interval of well 39Q024 increased from an average of 9,016 µS/cm during December 2004 to 10,276 µS/cm during December 2005.

At Skidaway Island, fluid conductivity (resistivity) logs and water samples were collected December 8, 2004, and December 7, 2005, from well 37P113 completed in the Lower Floridan aquifer and well 37P114 completed in the Upper Floridan aquifer (facing page). In well 37P113, chloride concentrations in samples collected at depths of 900 and 1,070 ft during 2004 were 717 and 1,685 mg/L, respectively; whereas during 2005, concentrations were 389 and 4,312 mg/L, respectively. Chloride concentrations in previous composite samples from the entire open interval (700–1,100 ft) in well 37P113 during 1985–2001 ranged from about 300 to 1,000 mg/L. Between 2000 and 2005, fluid conductivity in the open interval of well 37P113 decreased, from an average of 4,090 µS/cm during January 2000 to 3,459 µS/cm during December 2005. Water in the Upper Floridan is fresh at the Skidaway Island site and chloride concentrations of samples from well 37P114 did not appreciably change during 2004–2005. During 2004, concentrations in samples collected at depths of 300 and 360 ft were 4.9 and 4.8 mg/L, respectively; and during 2005 concentrations in samples collected at the same depths were 6.4 and 5.2 mg/L, respectively. Previous composite samples from the entire open interval (262–400 ft) during 1984–2002 ranged from 2 to 29 mg/L. From December 2003 to December 2005, the average fluid conductivity in the open interval of this well changed little and was about 227 µS/cm.

At Fort Pulaski, fluid conductivity (resistivity) logs and water samples were collected December 6, 2004, and December 5, 2005, from well 38Q002 completed in the Upper Floridan aquifer (facing page). During 2004, concentrations in samples collected at depths of 200 and 320 ft were 11.5 and 7.9 mg/L, respectively; and during 2005 concentrations in samples collected at the same depths were 12.1 and 8.5 mg/L, respectively. Average fluid conductivity during January 2000 in the open interval of the well (110–348 ft) was 243 µS/cm. From January 2000 to December 2005, the average fluid conductivity in the open interval of this well changed little and ranged from 242.9 during 2000 to 234.9 during 2005.

References Cited

Leeth, D.C., Clarke, J.S., Wipperfurth, C.J., and Craigg, S.D., 2005, Ground-water conditions and studies in Georgia, 2002–03: U.S. Geological Survey Scientific Investigations Report 2005-5065, 128 p., Web-only publication available at *http://pubs.usgs.gov/sir/2005/5065/*.



Specific conductance of water from the Upper and Lower Floridan aquifers in the Savannah area, Georgia, 2000 and 2003–2005.

Site name	Other identifier	Open interval (feet below land surface)	Water-bearing unit[1]	Water sample depth (feet below land surface)	Chloride concentration (mg/L)	Water sample depth (feet below land surface)	Chloride concentration (mg/L)
				December 2004		December 2005	
39Q024	Georgia Geologic Survey, Tybee Island, test well 1	840–880	L	845 860	2,916 2,943	845 860	2,979 2,995
37P113	Skidaway Institute test well 1	700–1,100	L	900 1,070	717 1,685	900 1,070	389 4,312
37P114	Skidaway Institute test well 2	262–400	U	300 360	4.9 4.8	300 360	6.4 5.2
38Q002	U.S. National Park Service, Fort Pulaski Pilot House	110–348	U	200 320	11.5 7.9	200 320	12.1 8.5

mg/L, milligrams per liter

[1] L, Lower Floridan aquifer; U, Upper Floridan aquifer

Ground-Water Quality of the Upper and Lower Floridan Aquifers

City of Brunswick Area

Water supply in the Brunswick area primarily is obtained from wells completed in the Upper Floridan aquifer. 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), and chloride concentrations have been monitored since that time. 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 of saltwater had migrated northward toward two major industrial pumping centers. During June 2005, the chloride concentration in water from the Upper Floridan aquifer was above the 250-milligrams-per-liter (mg/L) 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 exceeded 2,250 mg/L in part of the area.

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 southern Brunswick area (graphs for wells 34H393 and 34H403, below) and northern 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 southern Brunswick area (graph, below). More information on the Brunswick area monitoring may be accessed at *http://ga.water.usgs.gov/projects/brunswick/*.

Maps showing the concentration of dissolved chloride in the Upper Floridan aquifer at Brunswick were prepared for June 2004 (using 35 wells) and June 2005 (using 34 wells) (chloride concentration maps, facing page). Both maps are similar to the previously published map for 2003 (Leeth and others, 2005) and show 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.

During 2004–2005, chloride concentration within the plume area generally increased in the western and southern part of the contaminated area and decreased in the eastern part. In the south Brunswick area, the greatest increase was 180 mg/L at well 34H403. In the northwestern Brunswick area, chloride concentrations also generally increased, with a maximum increase of 230 mg/L in well 33H130. In the central Brunswick area, chloride concentrations generally rose, with increases ranging from 10 to 490 mg/L. Well 34H401, which showed a decrease in chloride concentration of 410 mg/L during the previous year (2003–2004), had the largest increase of 490 mg/L. In parts of the area, concentrations in adjacent wells varied significantly—for example, in the northwestern plume area, concentrations in well 33H221 decreased by 296 mg/L, whereas concentrations in well 33H227, located about 700 ft southwest of the well, increased by 122 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).

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.

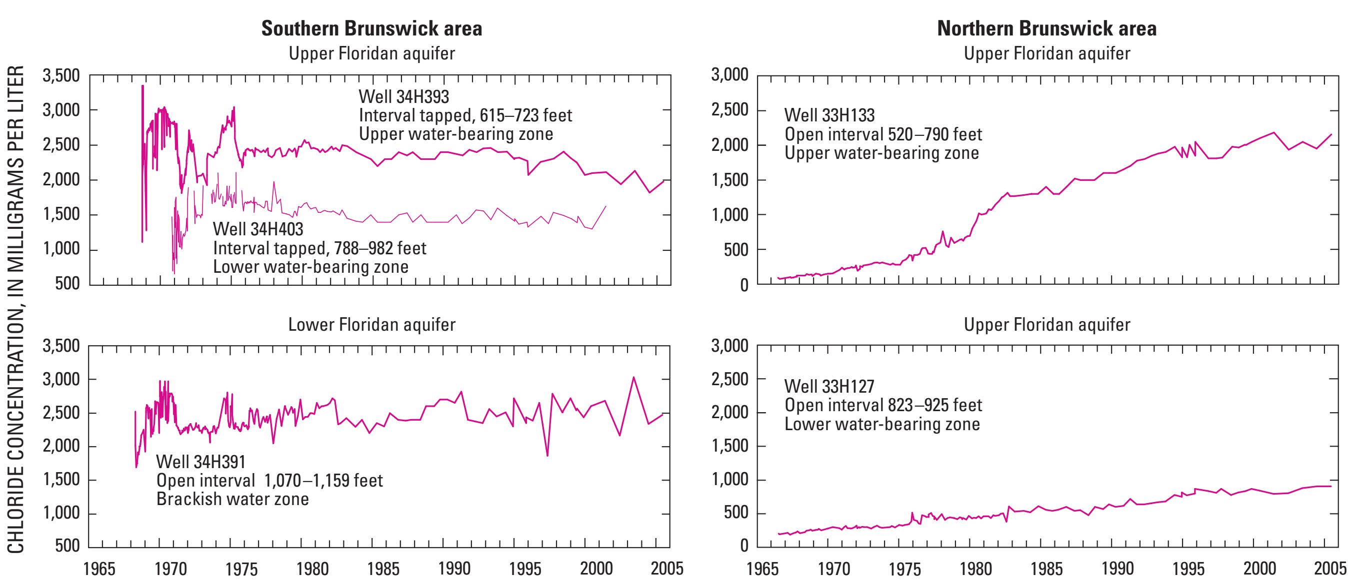
Jones, L.E., Prowell, D.C., and Maslia, M.L., 2002, Hydrogeology and water quality (1978) of the Floridan aquifer system at U.S. Geological Survey TW-26, on Colonels Island, near Brunswick, Georgia: U.S. Geological Survey Water-Resources Investigations Report 02-4020, 44 p.

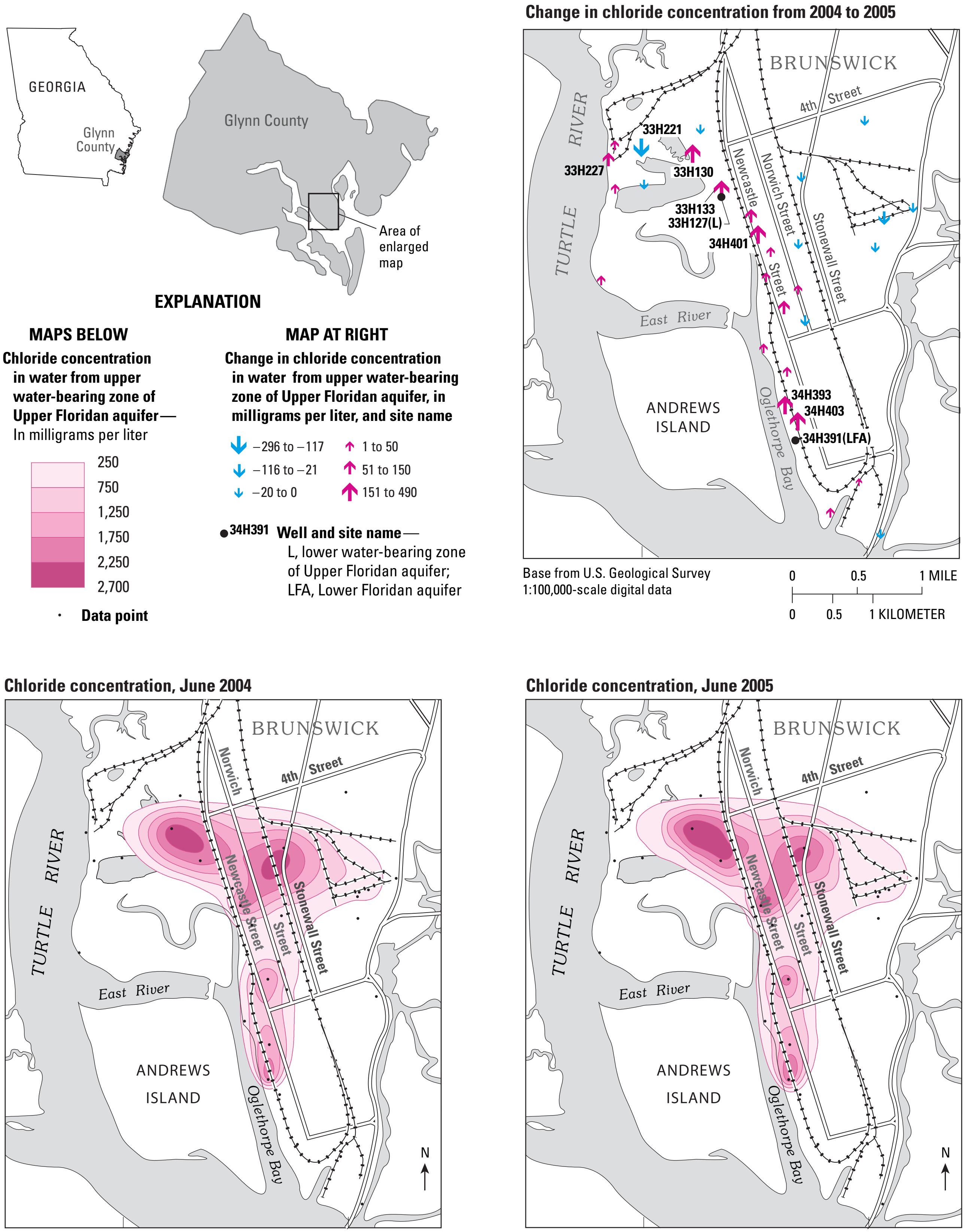
Leeth, D.C., Clarke, J.S., Wipperfurth, C.J., and Craigg, S.D., 2005, Ground-water conditions and studies in Georgia, 2002–03: U.S. Geological Survey Water-Resources Investigations Report 05-5065, 128 p., Web-only publication available at *http://pubs.usgs.gov/sir/2005/5065/*.

Maslia, M.L., and Prowell, D.C., 1990, Effect of faults on fluid flow and chloride contamination in a carbonate aquifer system: Journal of Hydrology, v. 115, p. 1–49.

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.

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.




GEORGIA
Glynn County
Glynn County
Area of enlarged map
EXPLANATION
MAPS BELOW
Chloride concentration in water from upper water-bearing zone of Upper Floridan aquifer—In milligrams per liter
250
750
1,250
1,750
2,250
2,700
Data point
MAP AT RIGHT
Change in chloride concentration in water from upper water-bearing zone of Upper Floridan aquifer, in milligrams per liter, and site name
−296 to −117
−116 to −21
−20 to 0
1 to 50
51 to 150
151 to 490
34H391 Well and site name—L, lower water-bearing zone of Upper Floridan aquifer; LFA, Lower Floridan aquifer
Change in chloride concentration from 2004 to 2005
BRUNSWICK
4th Street
TURTLE RIVER
33H221
33H227
33H130
33H133
33H127(L)
34H401
Newcastle Street
Norwich Street
Stonewall Street
East River
ANDREWS ISLAND
Oglethorpe Bay
34H393
34H403
34H391(LFA)
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 2004
BRUNSWICK
Norwich
4th Street
TURTLE RIVER
Newcastle Street
Street
Stonewall Street
East River
ANDREWS ISLAND
Oglethorpe Bay
N
Chloride concentration, June 2005
BRUNSWICK
Norwich
4th Street
TURTLE RIVER
Newcastle Street
Street
Stonewall Street
East River
ANDREWS ISLAND
Oglethorpe Bay
N

Ground-Water Quality of the Upper and Lower Floridan Aquifers

Camden County Area

In the Camden County area, chloride concentrations have been monitored periodically in the Upper Floridan aquifer from 1959 to 1993 and annually from 1994 to the present. In the Lower Floridan aquifer, chloride concentrations have been monitored from 2001 to present. During 2004–2005, the U.S. Geological Survey collected 16 water samples from eight wells; six wells were completed in the Upper Floridan aquifer and two wells were completed in the Lower Floridan aquifer. These wells (table, below) are part of a network maintained for the St. Johns River Water Management District in Florida. During 2004–2005, chloride concentration in the Upper Floridan aquifer ranged from 27.4 to 36 milligrams per liter (mg/L), except in well 33D061. In well 33D061, chloride concentrations ranged from about 30 to 100 mg/L (graphs, facing page), which are above the 20 to 40 mg/L background level (Peck and others, 2005) but below the 250-mg/L drinking-water standard (Georgia Environmental Protection Division, 1997; U.S. Environmental Protection Agency, 2000).

Since the closure of the Durango Paper Mill during October 2002, the chloride concentration in well 33D061 decreased from a high of 184 mg/L during May 2000 to 52 mg/L during September 2005. The decrease in concentration corresponds to a 22- to 26-foot water-level rise that occurred after the closure of the Durango Paper Mill (Peck and others, 2005). This rise reversed the downward hydraulic gradient near the well and caused upward movement of relatively fresh ground water, resulting in decreased chloride concentration in the well. Chloride concentrations in the Lower Floridan aquifer were below the 250-mg/L drinking-water standard and generally ranged from 25 to 45 mg/L in well 33D073, completed in the upper section of the Lower Floridan aquifer, and ranged from 89 to 124 mg/L in well 33D074, completed in the lower section of the Lower Floridan aquifer (table, below).

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.

Peck, M.F., McFadden, K.W., and Leeth, D.C., 2005, Effects of decreased ground-water withdrawal on ground-water levels and chloride concentrations in Camden County, Georgia, and ground-water levels in Nassau County, Florida, from September 2001 to May 2003: U.S. Geological Survey Scientific Investigations Report 2004-5295, 31 p., Web-only publication available at *http://pubs.usgs.gov/sir/2004/5295/*.

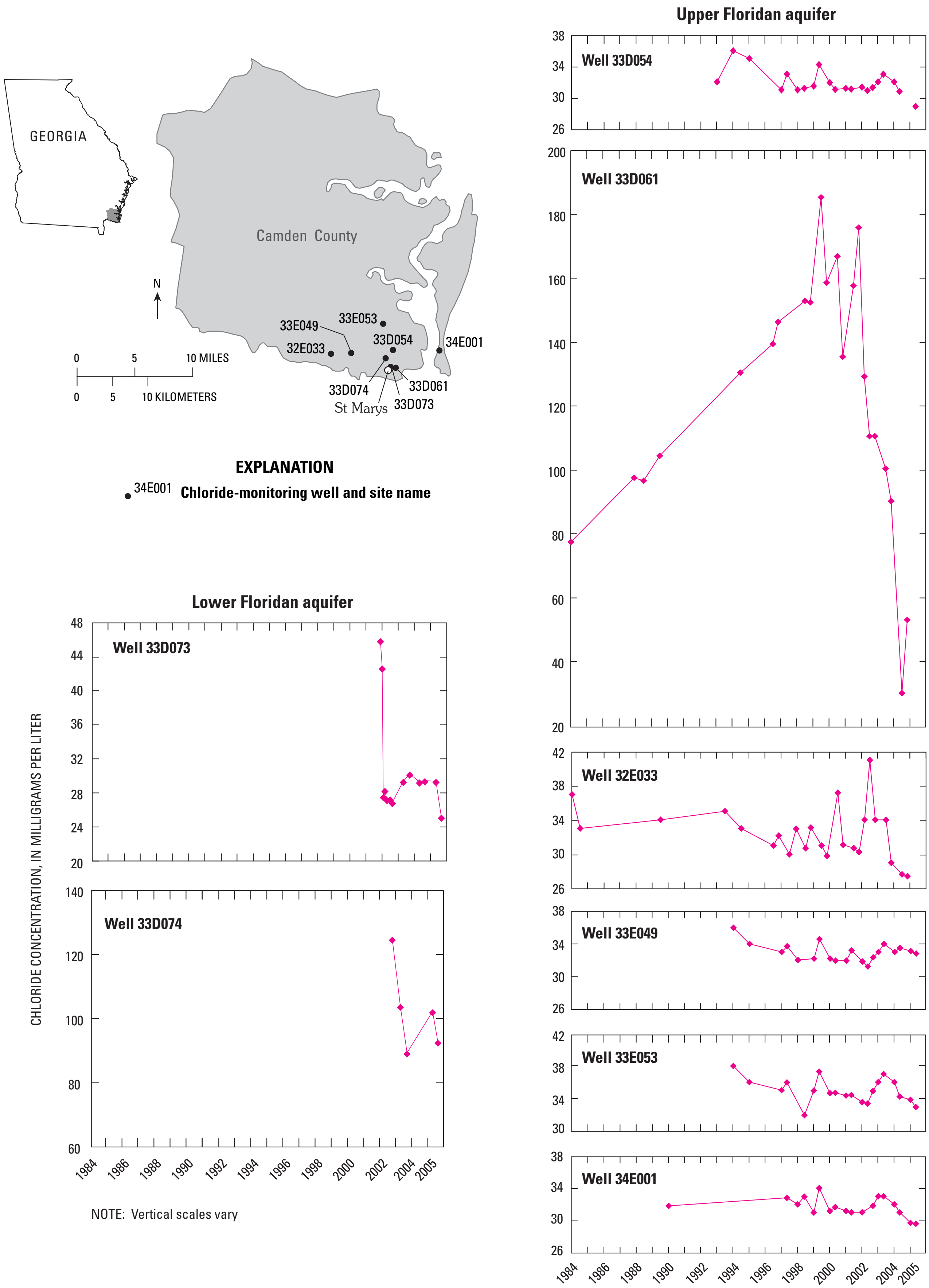
U.S. Environmental Protection Agency, 2000, Maximum contaminant levels (Part 143, National Secondary Drinking Water Regulations): U.S. Code of Federal Regulations, Title 40, Parts 100–149, revised as of July 1, 2000, p. 612–614.

Chloride-monitoring network in the Floridan aquifer system, Camden County, Georgia

[UF, Upper Floridan aquifer; LF, Lower Floridan aquifer; —, no data]

Site name	Other identifier	Aquifer	Open interval (feet below land surface)	Chloride concentration (milligram per liter)			
				May 2004	September 2004	May 2005	September 2005
32E033	Georgia Welcome Center	UF	420–600	[1]34.0	[1]29.0	[1]27.6	[1]27.4
33D054	St. Marys 2	UF	563–1,000	[1]32	[1]30.8	—	[1]28.9
33D061	Gilman Paper Company 11	UF	550–1,090	[1]100	[1]89.7	[1]29.5	[1]52.5
33E049	Osprey Cove	UF	522–840	[1]33	[1]33.5	[1]33.1	[1]32.8
33E053	Kings Bay 2	UF	570–900	[1]36	[1]34.2	[1]33.8	[1]32.9
34E001	Cumberland Island Georgia Geologic Survey test well 1	UF	540–640	[1]32	[1]31	[1]29.7	[1]29.6
33D073	CSSI St. Marys test well 1	LF	1,360–1,500	29.1	29.2	29.2	25
33D074	CSSI St. Marys test well 2	LF	1,840–2,004	—	—	101.8	92.4

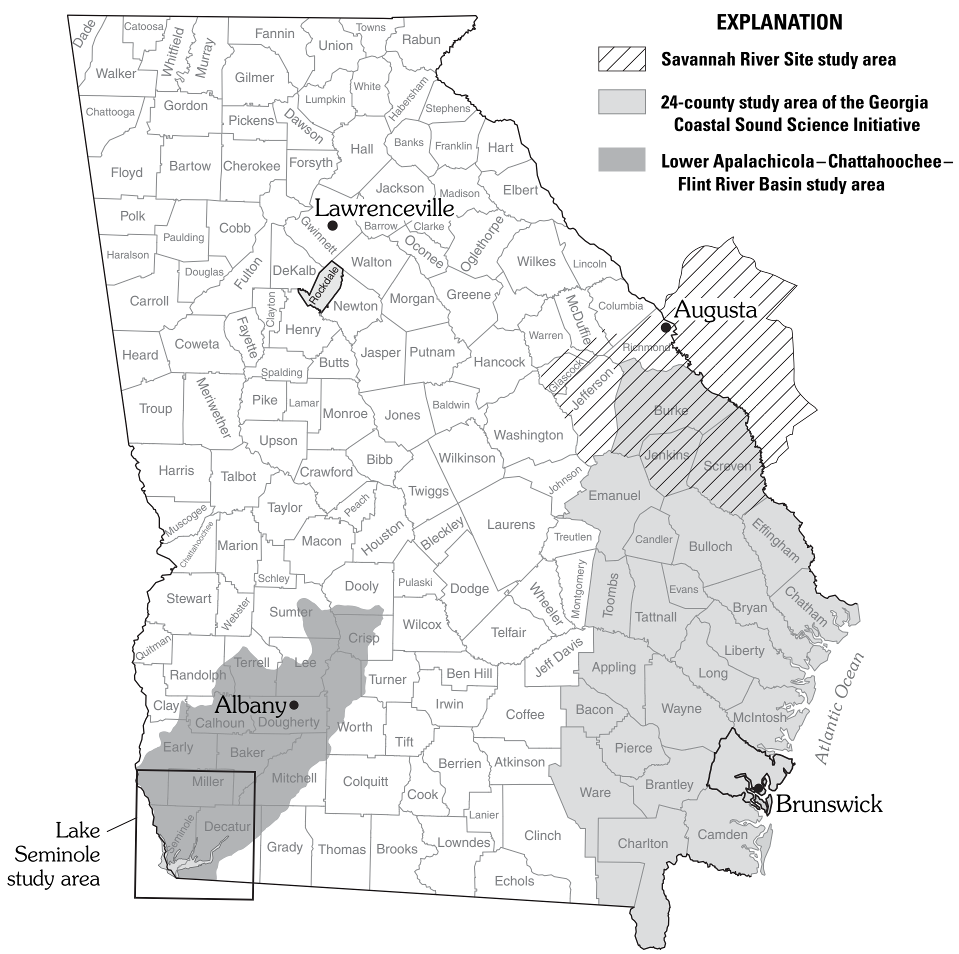
[1]Bill Osborne, St. Johns River Water Management District, written commun., January 2006


GEORGIA
Camden County
N
0 5 10 MILES
0 5 10 KILOMETERS
33E053
33E049
32E033
33D054
34E001
33D074
33D061
St Marys
33D073
EXPLANATION
34E001 Chloride-monitoring well and site name
Upper Floridan aquifer
Well 33D054
Well 33D061
Well 32E033
Well 33E049
Well 33E053
Well 34E001
Lower Floridan aquifer
Well 33D073
Well 33D074
CHLORIDE CONCENTRATION, IN MILLIGRAMS PER LITER
1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2005
NOTE: Vertical scales vary

SELECTED GROUND-WATER STUDIES IN GEORGIA, 2004–2005

The U.S. Geological Survey (USGS)—in cooperation with local, State, and other Federal agencies—conducted several studies in Georgia and adjacent states during 2004–2005 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 waterborne contaminants off-site. 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 near the SRS. 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 trans-river flow. To provide a more accurate and up-to-date evaluation of trans-river flow near the SRS, the earlier model was updated to incorporate new data and simulate 2002 conditions.

Objectives

- Update the previously developed ground-water-flow model to better define present-day (2002) ground-water flowpaths near SRS.
- Use 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, 2004–2005

- The previous model (Clarke and West, 1998) was updated to simulate ground-water flow under 2002 hydrologic conditions and for four hypothetical pumping scenarios based on ground-water-use trends from 1980 to 2000 (Fanning, 2003).
- Four steady-state pumping scenarios were developed to simulate a range of pumping and climatic conditions affecting potential contaminant migration from the SRS:
  - 2002 observed pumping and boundary conditions for an average year.
  - 2002 observed pumping and boundary conditions for an average year with SRS pumping discontinued.
  - Projected 2020 pumping and boundary conditions for an average year.
  - Projected 2020 pumping and boundary conditions for a dry year.
- The USGS particle-tracking code MODPATH (Pollock, 1994) was used to generate advective water-particle path lines and time-of-travel based on MODFLOW simulations of the four scenarios. Results of model simulations and particle tracking were summarized in USGS Scientific Investigations Report 2006-5195 (Cherry, 2006). Major findings include:
  - Simulated ground-water flowpaths for each of the four pumping scenarios indicate that time-of-travel from recharge areas originating near central SRS (D and K Areas) westward into Georgia range from 110 years to 800 years (facing page).
  - Particle-tracking analysis indicates travel times and flowpaths are similar for the various pumping scenarios; however, the shutdown of the SRS production wells allows fewer particles to penetrate into deeper units (layers A3–A5), and median travel times are decreased by about 90 years.

References Cited

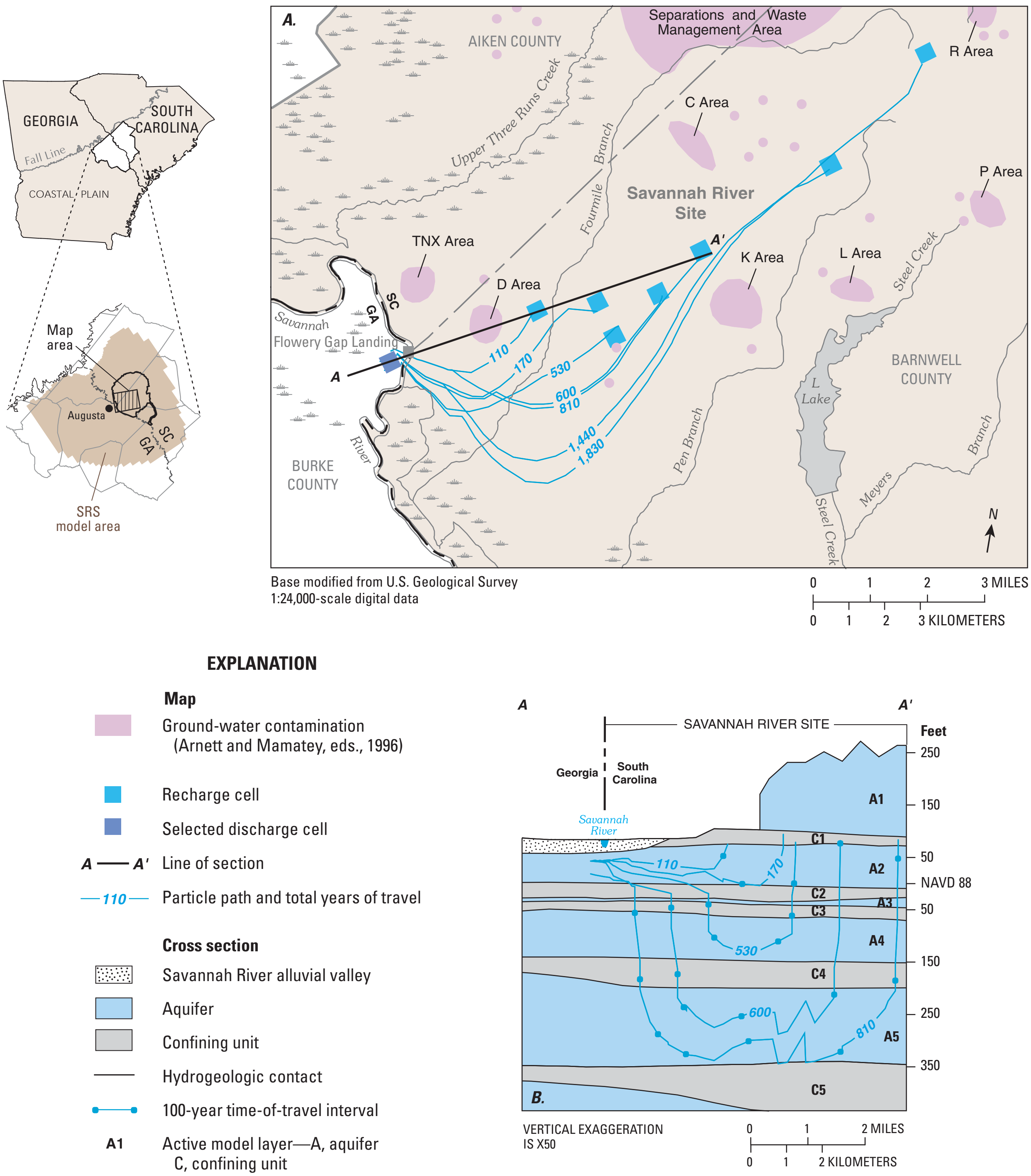
Arnett, M.W., and Mamatey, A.R., eds.,1996, Savannah River Site environmental report for 1995: Prepared for U.S. Department of Energy by Westinghouse Savannah River Company, Aiken, S.C., WSRC-TR-96-0075, 271 p.

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

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.

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.

Pollock, D.W., 1994, User's guide for MODPATH/MODPATH-PLOT, version 3: A particle tracking post-processing package for MODFLOW, the U.S. Geological Survey finite-difference ground-water-flow model: U.S. Geological Survey Open-File Report 94-464, 188 p.



(A) *Map and* (B) *cross section showing simulated ground-water flowpaths near the Savannah River Site (SRS) for scenario* B, *representing average climatic conditions and the elimination of pumping at the SRS. Longer flowpaths originate in upland areas where head in the uppermost unit provides a driving force to allow flow to greater depths of penetration through aquifers and intervening confining units (see 810-year flowpath). Shorter flowpaths originate in lowland areas where head in the uppermost unit is low and there is less driving force for penetration into deeper units (see 110-year flowpath). Modified from Cherry (2006). (NAVD 88, North American Veritcal Datum of 1988)*

City of Albany Cooperative Water Program

Study Chief Debbie Warner Gordon

Cooperator Albany Water, Gas, and Light Commission

Year Started 1977

Problem

Long-term heavy pumping from the Claiborne and Clayton aquifers and the Cretaceous aquifer system (includes the Providence aquifer), which underlie the Upper Floridan aquifer, has resulted in substantial water-level declines in these deep aquifers in the Albany area. To provide additional water supply and reduce the demand on the deep aquifers, the Albany Water, Gas, and Light Commission (WGL) has developed a large wellfield southwest of Albany. The supply wells at this location primarily penetrate 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 from the wellfield. The complexity of the ground-water-flow system and water quality of the Upper Floridan aquifer near the wellfield prompted development of a cooperative water program between the U.S. Geological Survey (USGS) and WGL.

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 near the new wellfield in the southwestern Albany area.

Progress and Significant Results, 2004–2005

- Continued to operate continuous ground-water-level monitoring network in the surficial, Upper Floridan, Claiborne, Clayton, and Providence aquifers. During 2004, the network consisted of 20 wells, fully funded by WGL. During 2005, the network consisted of 18 wells, 14 of which were funded by WGL, and 4 funded by new cooperative partners—The Flint River Water Planning and Policy Center, Miller Brewing Company, Merck and Company, and Lee County Utilities Authority.
- Continued ground-water-quality monitoring program. Water samples were collected and analyzed for cations, anions, and nutrients during:
    - May 13, 2004, from four wells, two upgradient and two downgradient from the wellfield; and one from the Flint River;
    - November 15–17, 2004, from 15 wells in the southwestern Albany area and one from the Flint River; and
    - November 8–11, 2005, from 16 wells in the southwestern Albany area and one from the Flint River.
- Constructed potentiometric-surface maps for the Upper Floridan aquifer based on measurements from 68 wells during October 19–20, 2004, and 70 wells during October 4–5, 2005 (see page 25). Both maps indicate that water generally flows from northwest to southeast near the wellfield. During fall 2003, WGL began to operate the wellfield on an intermittent basis. Although water levels during 2005 generally were lower than in the previous year, the wellfield pumping did not result in the formation of a cone of depression surrounding the wellfield.
- Four general observations are apparent from the analysis of ground-water samples collected during 1998 and 1999 of the Upper Floridan aquifer in the southwestern Albany area: (1) major ion and nitrate concentrations are elevated where recharge is evident, (2) elevated major ion and nitrate concentrations rapidly decrease as ground water flows from recharge areas toward the Flint River, (3) multiple sources of water containing elevated major ion and nitrate concentrations are present in the study area, and (4) animal and human waste and fertilizers are contributing to elevated nitrate concentrations in the study area (Warner and Lawrence, 2005) (top map, facing page).
- Conducted borehole video surveys in several monitoring wells located at the wellfield. Two wells in the southwestern corner of the wellfield were investigated to determine if there was any damage resulting from a lightning strike. The survey indicated that the wells were not damaged.
- Began development of a digital ground-water-flow model for the Upper Floridan aquifer near the new wellfield. The model will be used to assess ground-water flow under a variety of pumping scenarios and may provide insight into pathways of nitrate contamination. The illustration on the facing page shows the model area and grid spacing (lower map, facing page).

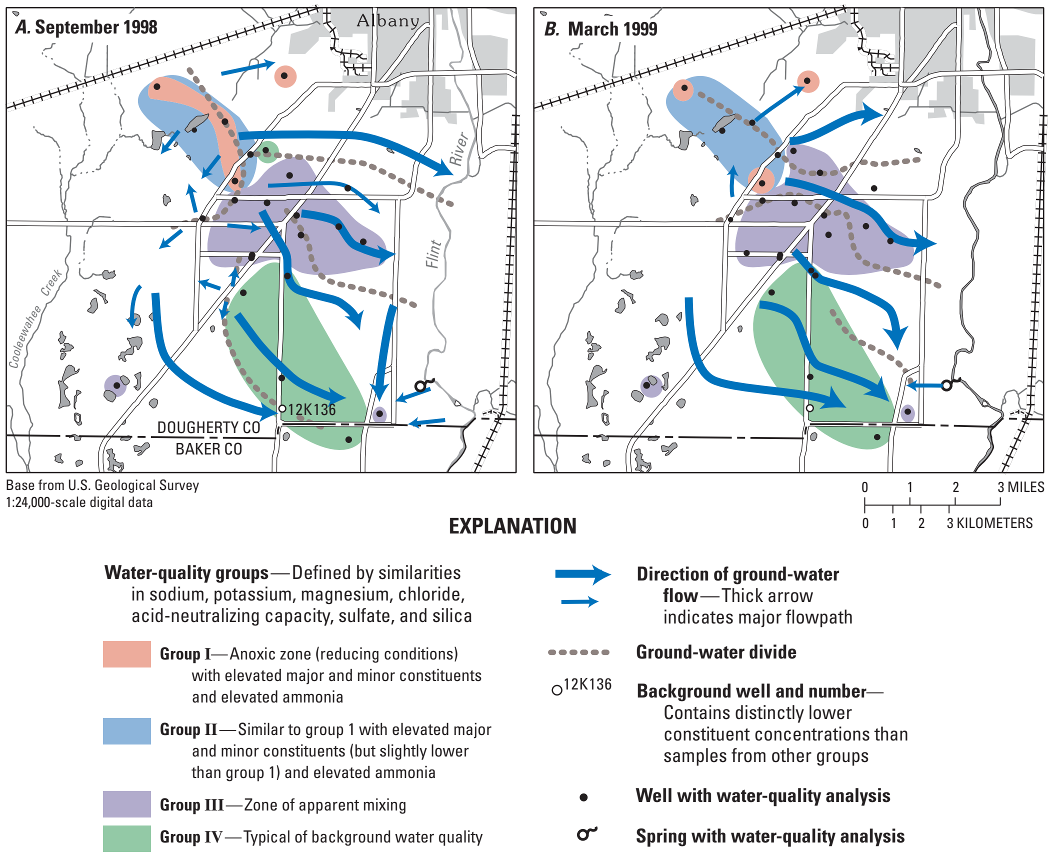
References Cited

Harbaugh, A.W., Banta, E.R., Hill, M.C., and McDonald, M.G., 2000, MODFLOW-2000, The U.S. Geological Survey modular ground-water model—User guide to modularization concepts and the ground-water flow process: U.S. Geological Survey Open-File Report 00-92, 121 p.

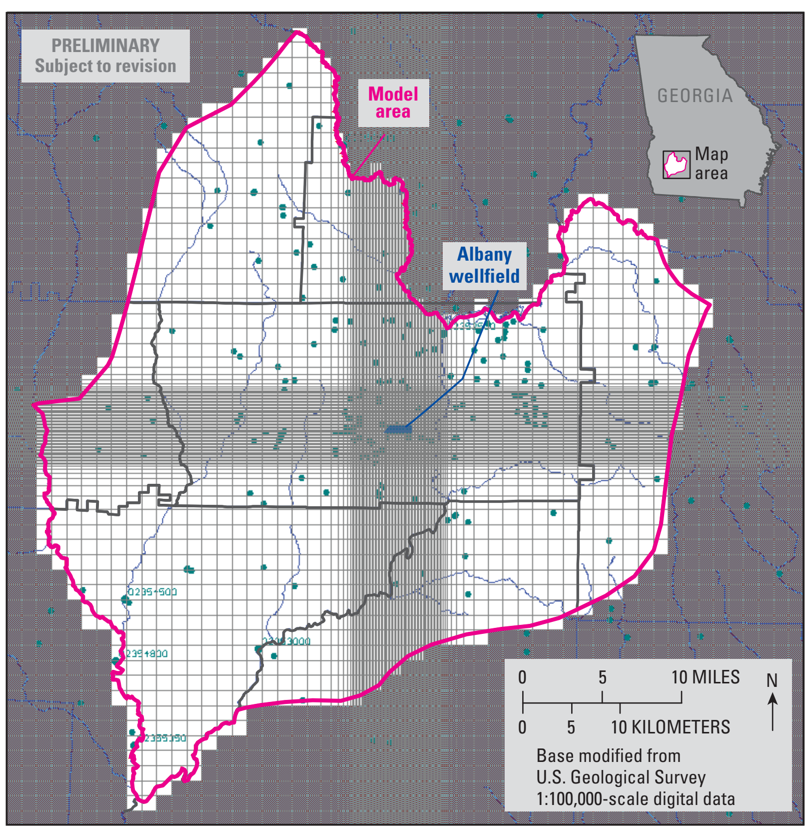
U.S. Environmental Protection Agency, 2000, Maximum contaminant levels (Part 143, National Secondary Drinking Water Regulations): U.S. Code of Federal Regulations, Title 40, Parts 100–149, revised as of July 1, 2000, p. 612–614.

Warner, Debbie, and Lawrence, S.J., 2005, Ground-water flow and water quality in the Upper Floridan aquifer, southwestern Albany area, Georgia, 1998–2001: U.S. Geological Survey Scientific Investigations Report 2005-5047, 86 p., Web-only publication available at *http://pubs.usgs.gov/sir/2005/5047/*.

Ground-water quality in the study area is divided into four groups, plus samples that do not fit into any of the groups. Water-quality group I is anoxic ground water containing elevated major chemical constituents and low nitrate concentrations. Group II is similar to group I except that group II samples have substantially less potassium, sulfate, and chloride concentrations. The anoxic ground water in groups I and II produces reducing conditions that may be causing denitrification (and lowering nitrate concentrations). Water-quality group III is a mixture of ground water that could indicate recharge or mixing of high nitrate water with background conditions. Finally, water-quality group IV is ground water that is typical of background (uncontaminated) water (Warner and Lawrence, 2005).



The USGS finite-difference-ground-water-flow simulator MODFLOW-2000 (Harbaugh and others, 2000) is being used to model the Upper Floridan aquifer near the southwestern Albany well-field. Grid spacing is 500 by 500 feet in the center around the wellfield, and increases to 5,000 by 5,000 feet in the rest of the model area. Model results will help improve the understanding of the ground-water-flow system and nitrate movement in the Albany area.



City of Brunswick and Glynn County Cooperative Water Program

Study Chief 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, so that currently within an area of several square miles in downtown Brunswick, the aquifer yields water that has a chloride concentration greater than 2,000 milligrams per liter (mg/L) and is above the State and Federal secondary drinking-water standard of 250 mg/L (Georgia Environmental Protection Division, 1997; U.S. Environmental Protection Agency, 2000). Saltwater contamination has constrained further development of the Upper Floridan aquifer in the Brunswick 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 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.
- Provide information to the Glynn County Water Resources Management Committee to mitigate saltwater intrusion in the Brunswick area.

Progress and Significant Results, 2004–2005

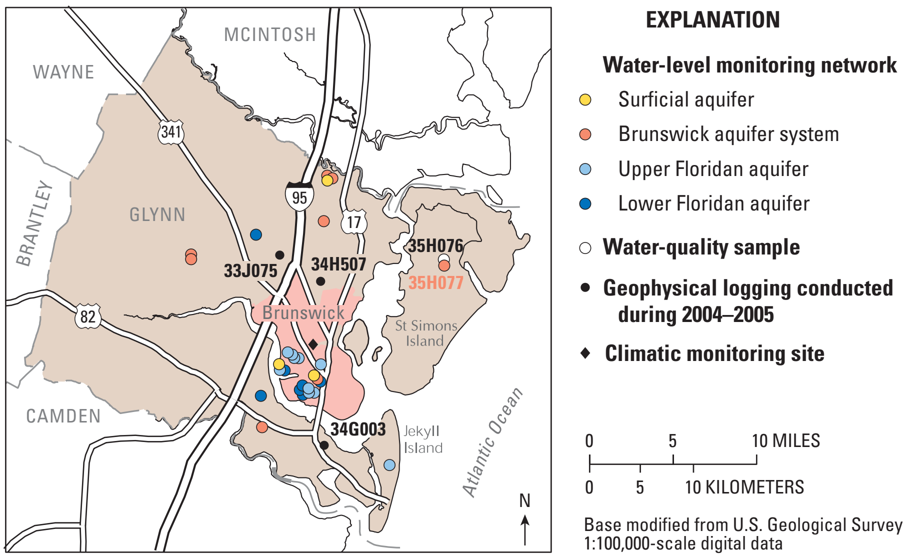
- During 2004 and 2005, a network of 28 continuous ground-water-level monitoring wells was operated—10 in the Upper Floridan aquifer, 7 in the Lower Floridan aquifer, 8 in the Brunswick aquifer system, and 3 in the surficial aquifer system (map, facing page). Fifteen of these wells are funded by the Georgia Environmental Protection Division.
- Potentiometric surfaces of the Upper Floridan aquifer were mapped (see page 35):
    - During June 2004, based on water-level measurements collected in 41 wells.
    - During June 2005, based on water-level measurements collected in 38 wells.
- Chloride concentration of the Upper Floridan was mapped (see page 57):
    - During June 2004, based on analysis of chloride concentrations in samples collected in 88 wells.
    - During June 2005, based on analysis of chloride concentrations in samples collected in 70 wells.
- Test wells at Lawrence Road test site on St. Simons Island were pumped for determination of yield, water chemistry (table, facing page), and hydraulic properties of the surficial and Brunswick aquifer systems during 2005:
    - Well 35H077 (lower Brunswick aquifer) was pumped at a rate of 170 gallons per minute with a maximum drawdown of 52 feet.
    - Well 35H076 (confined surficial aquifer) was pumped at a rate of 305 gallons per minute with a maximum drawdown of 37 feet.
- Borehole geophysical logs were collected from three wells during 2004–2005 (logs, facing page):
    - Well 34H507 (260 feet) at the Federal Law Enforcement Training Center in the north-central part of Glynn County.
    - Well 33J075 (560 feet) near Georgia Highway 99 in the western part of the county.
    - Well 34G003 (690 feet) at the western end of the Jekyll Island causeway.
- The Web site was updated for the Brunswick program and may be accessed at *http://ga.water.usgs.gov/projects/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.

The U.S. Geological Survey (USGS) continuously records water levels at 28 wells in the Brunswick–Glynn County area, shown on the map at right. Data from these wells are available at http://ga.waterdata.usgs.gov/nwis/.

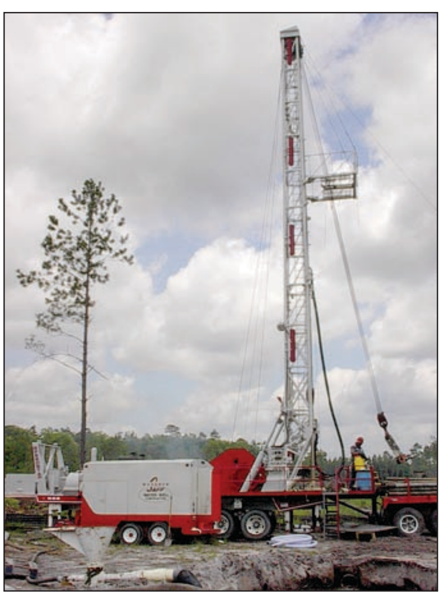


Water samples were collected from test wells on St. Simons Island during 2005 for evaluation of water chemistry of the surficial and Brunswick aquifer systems. Water from the test wells generally was within secondary drinking-water standards for major constituents; concentrations of iron were lower than the maximum secondary standard of 300 micrograms per liter.

[Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; Fe, iron; Mn, manganese; Cl, chloride; SO_4, sulfate; $CaCO_3$, alkalinity; mg/L, milligram per liter; µg/L, microgram per liter]

Well number	Aquifer	Sample date during 2005	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Fe (µg/L)	Mn (µg/L)	Cl (mg/L)	SO_4 (mg/L)	$CaCO_3$ (mg/L)
35H076	Confined surficial	May 3	62.1	2.4	16.7	1.7	29.5	6.8	30.1	5.3	184
35H077	Lower Brunswick	March 22	37.4	23.8	28.2	2.7	31.4	0.31	23.1	94.9	114

A.



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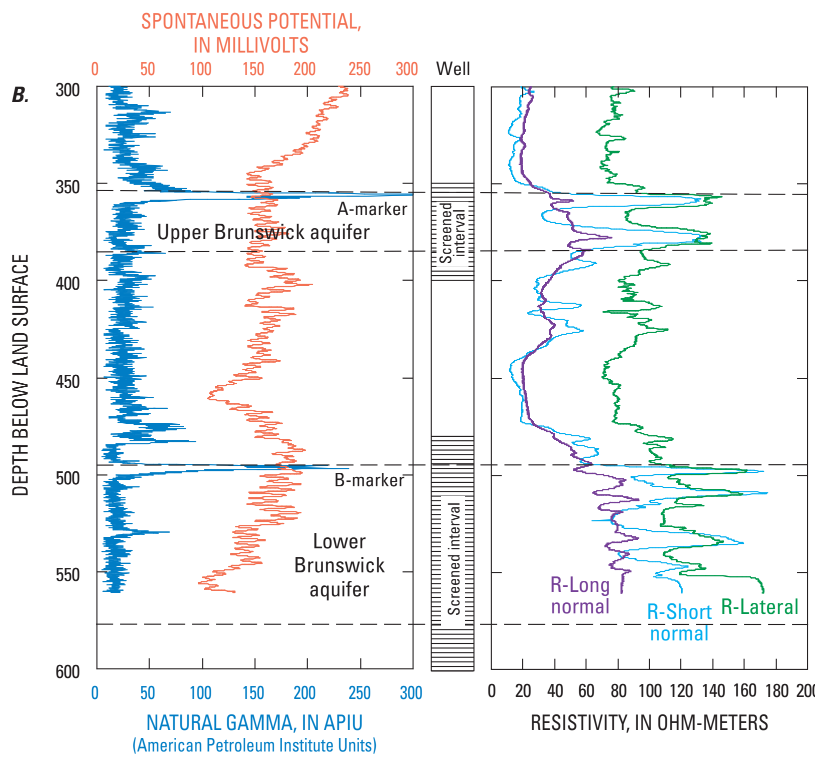


(A) *Drillers install a new public-supply well with production from the upper and lower Brunswick aquifers in Glynn County. The completed well will serve surrounding communities currently (2005) under development near the Interstate-95 corridor. Photo by Gregory S. Cherry, USGS.* (B) *The USGS assisted the county with geophysical logging of the test hole using a multi-parameter logging tool. The natural-gamma, spontaneous potential, and resistivity logs are used to determine water-bearing units for well construction.*

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 (Georgia Environmental Protection Division, 1997), 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:
  - seepage ponds connected to the surficial aquifer,
  - the Lower Floridan aquifer, and
  - the Brunswick aquifer system.

Progress and Significant Results, 2004–2005

- Completed study of stream-aquifer relations in the model area, reported in Priest (2004).
- Completed study of assessments of pond-aquifer flow and water availability at seepage pond sites in Glynn and Bulloch Counties, reported in Clarke and Abu Rumman (2004).
- Developed a set of ground-water management scenarios designed to help understand the flow system and the effects of anticipated future ground-water demands, to be simulated using the regional-flow model and the Savannah–Hilton Head Island solute-transport model.
- Completed single-density regional ground-water-flow model, calibrated to 1980 and 2000 conditions, reported in Payne and others (2005);
- Completed study of hydrogeology of the Lower Floridan aquifer in coastal Georgia, reported in Falls and others (2005a).
- Completed study of hydrogeology and saltwater intrusion in the Upper Floridan aquifer offshore of Hilton Head Island, South Carolina, reported in Falls and others (2005b).

Reference Cited

Clarke, J.S., and Abu Rumman, Malek, 2004, Pond-aquifer flow and water availability in the vicinity of two coastal area seepage ponds, Glynn and Bulloch Counties, Georgia: U.S. Geological Survey Scientific Investigations Report 2004-5260, 31 p., Web-only publication available at *http://pubs.usgs.gov/sir/2004/5260/*.

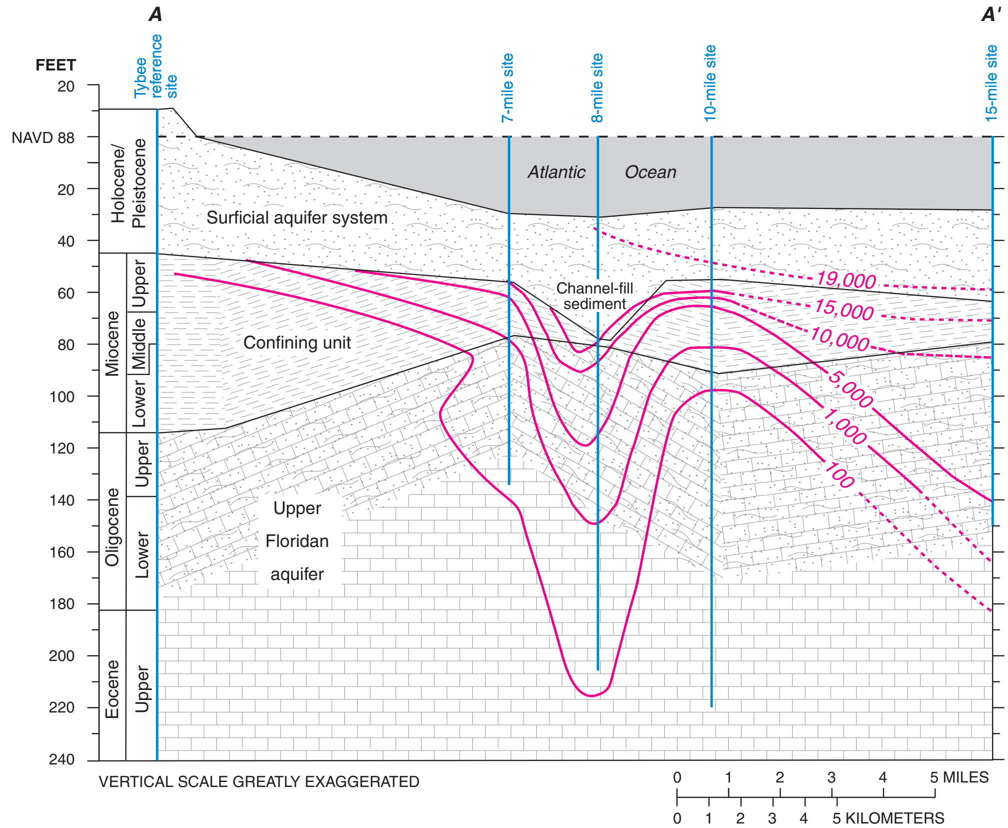
Falls, W.F., Harrelson, L.G., Conlon, K.J., and Petkewich, M.D., 2005a, Hydrogeology, water quality, and water-supply potential of the Lower Floridan aquifer, coastal Georgia, 1999–2002: U.S. Geological Survey Scientific Investigations Report 2005-5124, 98 p., Web-only publication available at *http://pubs.usgs.gov/sir/2005/5124/*.

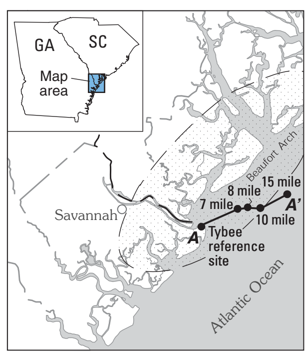
Falls, W.F., Ransom, Camille, Landmeyer, J.E., Reuber, E.J., and Edwards, L.E., 2005b, Hydrogeology, water quality, and saltwater intrusion in the Upper Floridan aquifer in the offshore area near Hilton Head Island, South Carolina, and Tybee Island, Georgia, 1999–2002: U.S. Geological Survey Scientific Investigations Report 2005-5134, 48 p., Web-only publication available at *http://pubs.usgs.gov/sir/2005/5134/*.

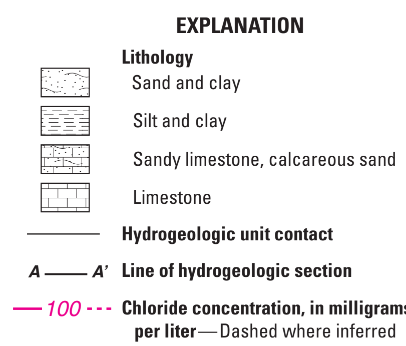
Georgia Environmental Protection Division, 1997, Interim strategy for managing saltwater intrusion in the Upper Floridan aquifer of southeast Georgia, April 23, 1997: Atlanta, Ga., Georgia Environmental Protection Division, 19 p.

Payne, D.F., Abu Rumman, Malek, and Clarke, J.S., 2005, Simulation of ground-water flow in coastal Georgia and adjacent parts of South Carolina and Florida—Predevelopment, 1980, and 2000: U.S. Geological Survey Scientific Investigations Report 2005-5089, 91 p., Web-only publication available at *http://pubs.usgs.gov/sir/2005/5089/*.

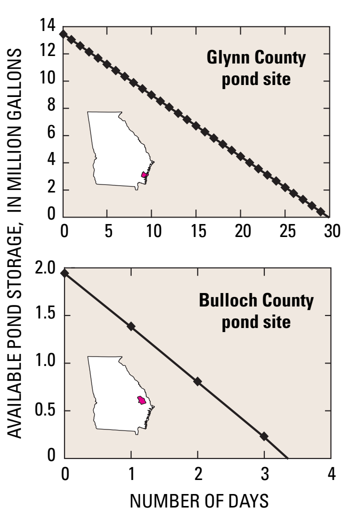
Priest, Sherlyn, 2004, Evaluation of ground-water contribution to streamflow in coastal Georgia and adjacent parts of Florida and South: U.S. Geological Survey Scientific Investigations Report 2004-5265, 46 p., Web-only publication available at *http://pubs.usgs.gov/sir/2004/5265/*.



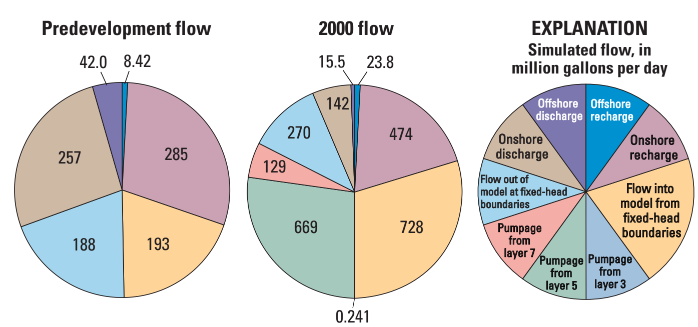




Sediment sample analyses from the offshore drilling sites indicate that the paleochannel fill at the 8-mile site is relatively permeable, reducing the thickness of Upper Floridan aquifer confinement. Compared to the other offshore sites, the hydrogeology at the 8-mile site may have created a preferential pathway for saltwater to leak downward into the Upper Floridan aquifer, as indicated by the ground-water-quality analyses (modified from Falls and others, 2005b).

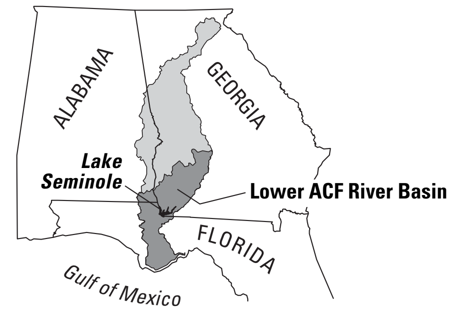


Results of the study to assess pond-aquifer flow and water availability at seepage pond sites indicate that such sources of water supply have limited utility during dry conditions because of low pond-storage volume and low net ground-water seepage rates. Simulations of the ponds showed that pumping 1,000 gallons per minute for 10 hours per day would drain the ponds on the order of days to tens of days, depending on the local hydrolgeology (Clarke and Abu Rumman, 2004).



In general, water-level declines have occurred with increases in the ground-water pumpage since predevelopment. To balance these increases, results of the regional MODFLOW model simulations indicate that the amount of simulated recharge has increased in both natural onshore and offshore areas, and discharge has decreased at these boundaries (Payne and others, 2005).

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, none of these studies 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

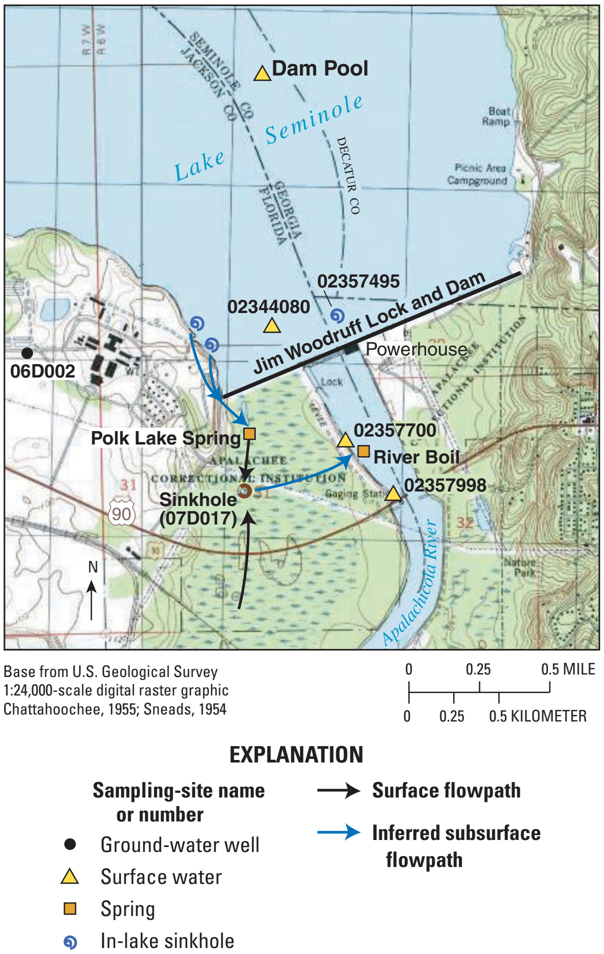
- Develop a water budget for Lake Seminole that will result in reasonable understanding of the effect of the lake on the overall flow system in the lower ACF River Basin.
- Compare current (2001) and pre-Lake Seminole ground-water and surface-water flow to determine whether the volume of water flowing out of Georgia has changed substantially 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 from 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, 2004–2005

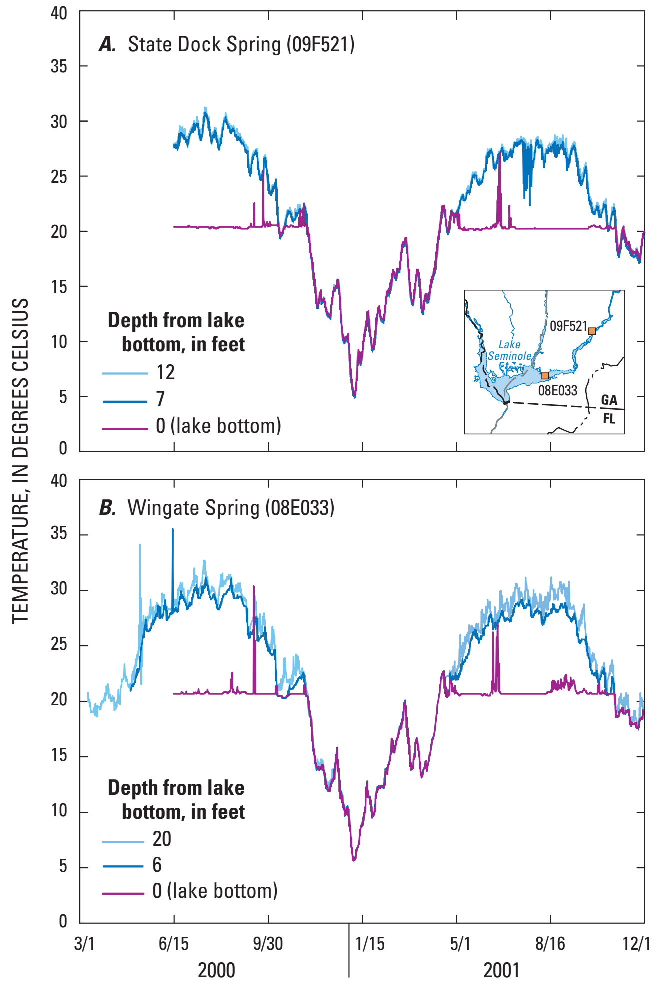
- Chemical weathering and dissolution of limestone hydraulically connect Lake Seminole with the Upper Floridan aquifer and promote lake leakage and ground-water inflow.
- Seasonal water-level fluctuations and cyclic, ground-water irrigation withdrawal from the Upper Floridan aquifer create complex patterns of water exchange, causing rapid, daily flow reversals in lake leakage and ground-water inflow.
- More than 250 karst features having the potential to hydraulically connect the lake and aquifer were identified from preimpoundment aerial photographs; some features coincide with locations of mapped springs, spring runs (channels), and other depressions characteristic of karst terrane.
- Seasonal variations in water temperature and chemistry indicate year-round ground-water inflow through the lake bottom at some in-lake springs and either no-flow or density-driven lake leakage into the aquifer at other springs during the winter.
- Vortex flow extending downward from the lake surface to the bottom, dye tracing, and results of multibeam and sidescan sonar confirm lake leakage into the Upper Floridan aquifer through sinkholes and other karst and fluvial features such as spring runs, former stream channels, and deep trenches that cut into limestone.
- Dye-tracing indicates that lake water mixes with ground water and flows through the Upper Floridan aquifer around the dam at velocities of about 500 feet per hour, discharging on the western floodplain of the Apalachicola River at Polk Lake Spring. This springflow eventually discharges into the channel bottom of the Apalachicola River at the River Boil, about 900 feet downstream from the dam. Flow entering the sinkhole is small (about 40 cubic feet per second) compared with discharge from the River Boil (140–220 cubic feet per second).
- Binary mixing-model analysis using naturally-occurring isotopes of oxygen and hydrogen indicates a 13-to-1 ratio of lake water to ground water discharging from the River Boil.

Reference Cited

Torak, L.J., Crilley, D.M., and Painter, J.A., 2006, Physical and hydrochemical evidence of lake leakage near Jim Woodruff Lock and Dam and of ground-water inflow to Lake Seminole, and an assessment of karst features in and near the lake, southwestern Georgia and northwestern Florida: U.S. Geological Survey Scientific Investigations Report 2005-5084, 90 p., Web-only publication available at *http://pubs.usgs.gov/sir/2005/5084/*.

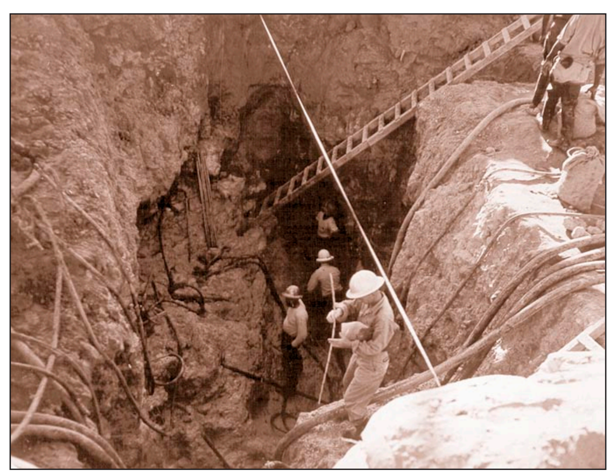


Hydrologic features in and around Lake Seminole evaluated during dye-tracing studies performed by the U.S. Army Corps of Engineers during 2001 and possible directions of lake leakage and subsurface flow to the River Boil on the Apalachicola River (Torak and others, 2006).



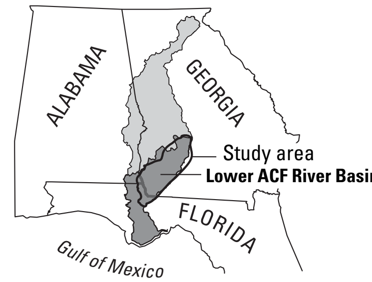
Lake-temperature variation with depth from March 2000 to December 2001 along Flint River impoundment arm to Lake Seminole at (A) *State Dock Spring (09F521) and* (B) *Wingate Spring (08E033) (Torak and others, 2006).*

Boat-mounted acoustic Doppler current profiling apparatus in use near the River Boil; looking north from Apalachicola River toward Jim Woodruff Lock and Dam in background. Photograph by Lynn J. Torak, U.S. Geological Survey.



Upstream guide wall to the lock, looking westward, showing a limestone cavity found by the U.S. Army Corps of Engineers during dam construction, circa 1950 (photo courtesy of U.S. Army Corps of Engineers, Mobile District archives) (Torak and others, 2006).

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 (inset map) 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 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 caused by agricultural pumping. Information obtained from the model is vital to the State's management of ground-water resources and for providing early indication of low-streamflow conditions that would affect delivery of water to downstream, out-of-state users.

Objectives

- Develop new data for the stream-lake-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, 2004–2005

Development of hydrogeologic framework revealed that:

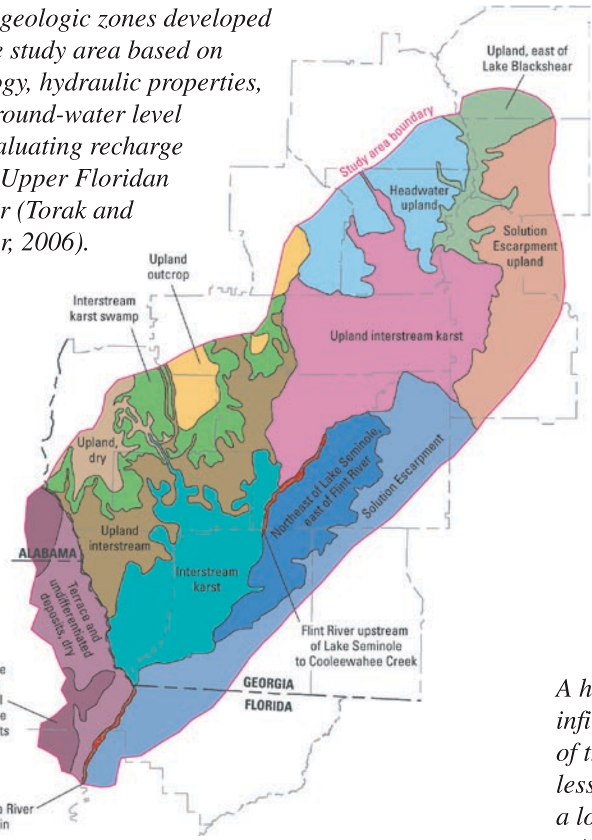
- Recharge to the Upper Floridan aquifer occurs by vertical leakage through a thin veneer of residuum or surficial deposits located in the outcrop areas of the Upper Floridan aquifer along the northwestern basin boundary and in the northern and central parts of the Dougherty Plain (recharge map, facing page).
- Sparse data defining the lithology, hydraulic properties, and ground-water level of the upper semiconfining unit limits the description of recharge to the Upper Floridan aquifer to the delineation of hydrogeologic zones and a general temporal distribution of saturated proportions of total thickness (hydrogeologic zone map, facing page).
- Large variations in hydraulic conductivity of the Upper Floridan aquifer exist at regional scales in the lower ACF River Basin; equally large variations at the local scale are inferred from descriptions of lithologic heterogeneity of limestone penetrated by closely spaced wells.
- Overpumping the Upper Floridan aquifer in specific areas of the lower ACF River Basin can have negative hydrologic effects on the Upper Floridan aquifer basinwide, such as ground-water-level decline, aquifer dewatering, reduced regional (intrabasin) flow and reduced interbasin flow to the east and south (hydrograph, facing page).
- Negative effects of increased pumping can occur where ground-water resources are limited or inadequate to sustain pumpage increases, such as in outcrop areas of the aquifer and downdip, along the Solution Escarpment, where diminished recharge from the outcrop area reduces intrabasin flow.

Model of ground-water flow with stream-aquifer interaction in the Upper Floridan aquifer included:

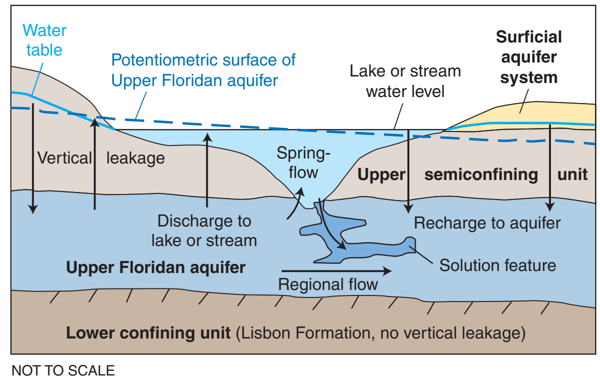
- Simulated pumpage at 3,280 irrigation, municipal, and industrial wells tapping the Upper Floridan aquifer; ground-water and surface-water exchange along 36 streams; recharge by direct infiltration and vertical leakage, and discharge to the upper semiconfining unit; and regional flow across model and basin boundaries.
- Calibration to October 1999, steady-state drought conditions using 275 measured ground-water levels and streamflow gains and losses along 53 reaches.
- Simulated transient conditions of March 2001–February 2002 containing time-varying irrigation pumpage, stream and lake stage, upper-confining unit water level, and recharge by direct infiltration to the Upper Floridan aquifer.

Reference Cited

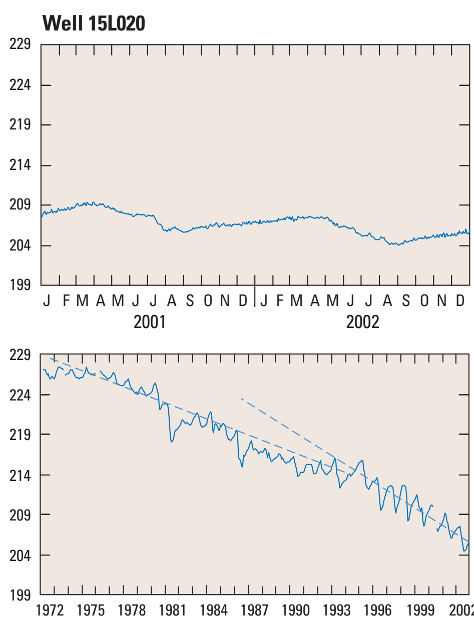
Torak, L.J., and Painter, J.A., 2006, Geohydrology of the Lower Apalachicola–Chattahoochee–Flint River Basin, southwestern Georgia, northwestern Florida, and southeastern Alabama: U.S. Geological Survey Scientific Investigations Report 2006-5070, 67 p. and interactive map, Web-only publication available at *http://pubs.usgs.gov/sir/2006/5070/*.



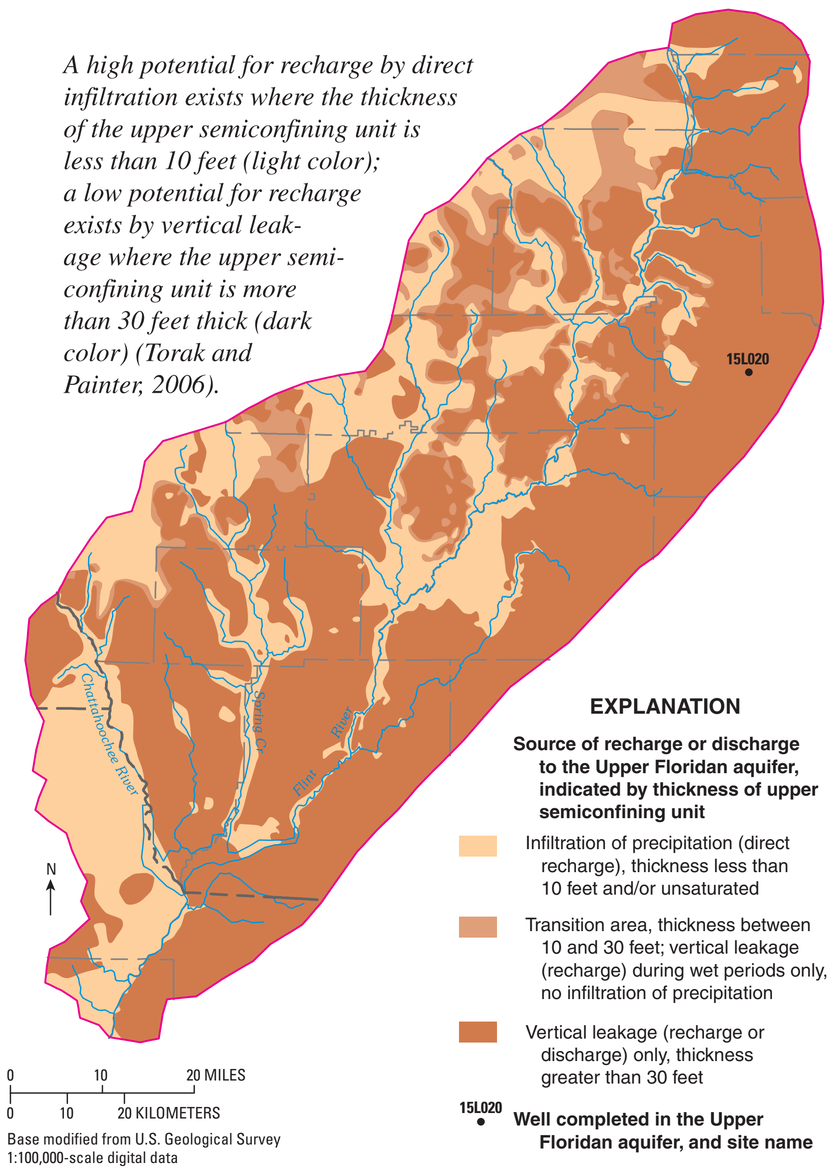
Hydrogeologic zones developed for the study area based on lithology, hydraulic properties, and ground-water level for evaluating recharge to the Upper Floridan aquifer (Torak and Painter, 2006).



Conceptual diagram of ground-water and surface-water flow showing the interconnected stream-lake-aquifer flow system of the lower Apalachicola–Chattahoochee–Flint River Basin (Torak and Painter, 2006).



Hydrograph for well 15L020 showing long-term, regional ground-water-level decline of more than 25 feet since the advent of center-pivot agricultural irrigation in the mid-1970s (Torak and Painter, 2006).



A high potential for recharge by direct infiltration exists where the thickness of the upper semiconfining unit is less than 10 feet (light color); a low potential for recharge exists by vertical leakage where the upper semiconfining unit is more than 30 feet thick (dark color) (Torak and Painter, 2006).

Ground-Water Information and Project Support

Study Chief Michael F. Peck

Cooperator Georgia Department of Natural Resources Environmental Protection Division

Albany Water, Gas, and Light Commission

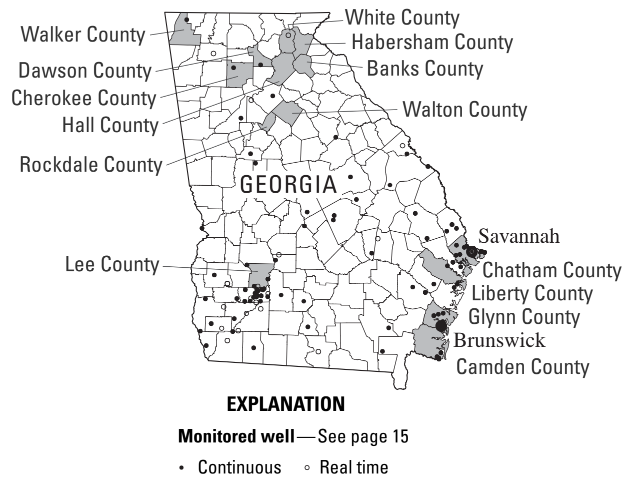
City of Brunswick

Glynn County

Jekyll Island Authority

St. Johns River 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 data 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 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.

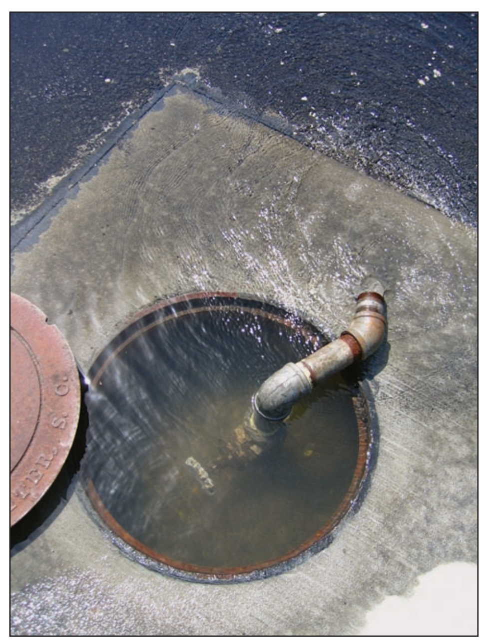
Progress and Significant Results, 2004–2005

- Continuous water-level recorders were operated in 184 wells during 2004 and 189 wells during 2005. One well in Walker County was instrumented with real-time transmission (satellite relay) of continuous water-level records to aid in drought planning. Currently, 19 wells are equipped for real-time transmission of continuous water-level data. The National Water Information System (NWIS) database may be accessed on the Web at *http://waterdata.usgs.gov/ga/nwis/current/?type=gw/*.
- Periodic water-level measurements were made in more than 3,542 wells throughout the State during 2004–2005 to define potentiometric surfaces and to assess long-term trends.
- Water samples for chloride analysis were collected from 66 wells during 2004 and 70 wells during 2005 in the Brunswick area, and 4 wells in the Savannah area and 8 wells in Camden County during 2004 and 2005.
- Borehole geophysical logs were collected in 26 wells in northern Georgia and 7 wells in coastal Georgia. 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, spinner-flowmeter, and borehole video camera.
- Well-inventory, water-level, and geologic data were verified for entry into the NWIS database. Field inventories of well sites were conducted to assist projects and 4,135 sites (mainly sites from the State of Georgia Drinking Water Program) were added to the NWIS Ground-Water Site Inventory database.

A typical real-time continuous recorder well in Walker 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 (A)*, and a solar panel and battery* (B)*. Real-time data typically are recorded at 60-minute intervals, stored on site, and then transmitted to U.S. Geological Survey (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 typical set up for a continuous recorder well that is part of the ground-water-level monitoring network. The equipment consists of (A) *an electronic data logger,* (B) *batteries, and* (C) *a dry-air cannister for a 30-pounds-per-square-inch pressure transducer (not shown). The recorder is set to collect data on an hourly basis, which is processed and stored in the NWIS and may be accessed at* http://nwis.waterdata.usgs.gov/ga/nwis/. *Photo by Alan M. Cressler, USGS.*

A USGS hydrologist samples an Upper Floridan aquifer well in Miller County for pesticides, metals, nutrients, and major ions. Samples are collected in support of the National Water-Quality Assessment agricultural land-use study. Photo by Alan M. Cressler, USGS.



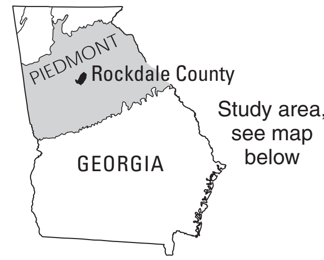
A USGS test well in Glynn County is shown flowing prior to sampling for chloride concentration. Samples are collected annually in support of the Brunswick and Glynn County Cooperative Water Program. Photo by Alan M. Cressler, USGS.

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

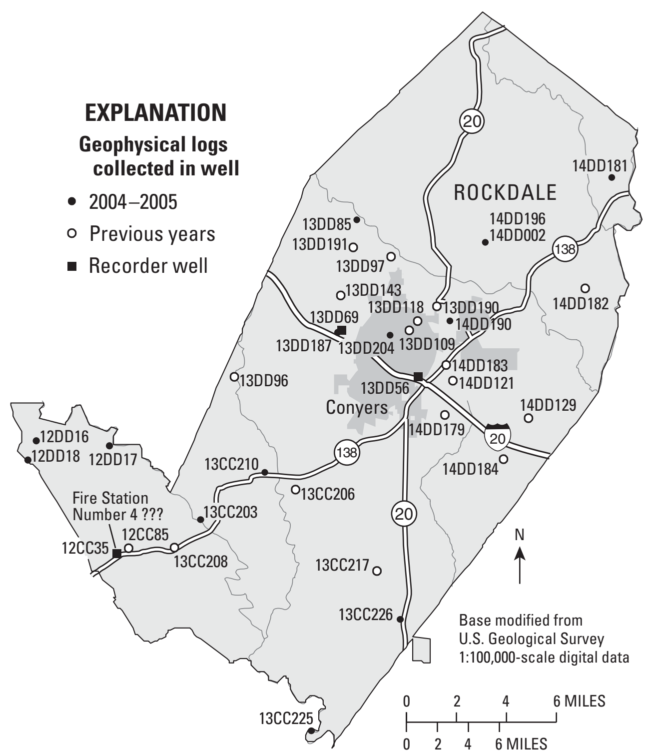
Ground water in crystalline rocks of the State has not been used extensively as a source of public drinking water. This source, however, may prove to be an important resource to communities that want to supplement their existing surface-water supplies and augment the amount of available drinking water in rapidly-growing areas of northern Georgia, such as Rockdale County (map, right). Few data are available to evaluate 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, 2004–2005

- Obtained geophysical logs from 13 wells to characterize the lithology, fracture, and yield characteristics of various rock units throughout Rockdale County (map, right).
- Completed additional detailed geologic mapping in specific areas of Rockdale County and completed subsurface correlation with geophysical-log data; hydrogeologic units and storage capabilities are being compiled from these data.
- Drilled two test wells in the Conyers area.
- Continued to operate three ground-water-level recorders.
- Completed a 72-hour aquifer test in the Conyers area.
- Completing a final lithologic map showing fault contacts, water-bearing units, and wells and springs for the Rockdale County area.



Thirteen additional wells were logged during 2004–2005 to obtain subsurface lithology, fracture, and yield characteristics. Additional geologic mapping also was completed in these areas to relate lithology to the water-bearing units tapped by the wells. Data from many wells in the area are being correlated to characterize and map hydrogeologic units in Rockdale County.

Pump removal—*Existing (mostly unused) domestic, commercial, and public-supply wells were used for geophysical logging during the study. The photo above shows a contractor removing a water-well pump prior to borehole geophysical logging. Photo by Lester J. Williams, USGS.*

Geologic mapping—*A new lithologic map is being produced from field geologic mapping conducted during this and previous years. The above photo shows moderately dipping sequence of biotite gneiss that is injected by pegmatite parallel to layering. Notice the openings formed along contacts. Photo by Lester J. Williams, USGS.*

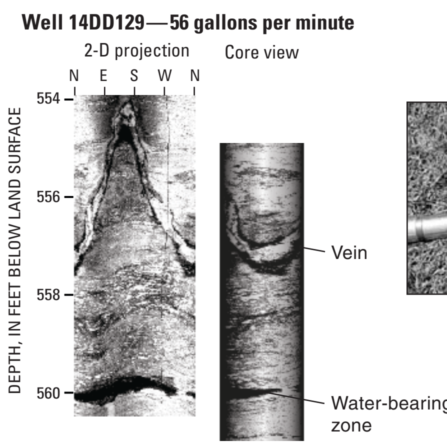
Test-well drilling—*A new test well was drilled near Conyers, Georgia, to investigate the water-bearing properties of the granite gneiss unit exposed in this area. Photo* A *shows the air-rotary drilling rig air-lifting only about 1 gallon per minute and photo* B *shows air-lifting more than 250 gallon per minute from a single water-bearing zone near the bottom of the well (360 feet). Photo by Lester J. Williams, USGS.*

Borehole geophysical logging—*A flowmeter and optical televiewer were used extensively to study the lithology and water-bearing characteristics in water wells in the area. Photos by Lester J. Williams, USGS.*

USGS geophysical logging unit *collecting a flowmeter log.*

Discharge *from pump during flowmeter test.*

A spinner flowmeter tool *is being used to measure the vertical flow in the well during pumping, which helps to determine the depth and yield of each water-bearing zone.*



Optical televiewer

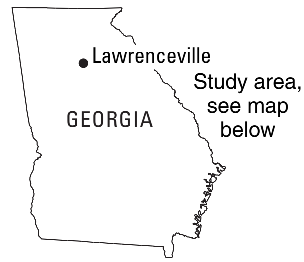
Optical televiewers *provide detailed images of the borehole wall. These images (above left) can be used to determine the depth and nature of water-bearing zones in relation to the rock type(s) in a well. The optical televiewer image shown for well 14DD129 indicates two potential water-bearing zones—a small dissolution opening associated with a moderately dipping vein at 556 feet below land surface and a foliation-parallel parting at 560 feet. An electromagnetic flowmeter log collected in this well indicated the zone at 556 feet yields 3 percent (1.7 gallons per minute) and the opening at 560 yields 92 percent (51.5 gallons per minute) of the total flow from this well. Overall, most of the high-yield water-bearing features observed in wells logged in Rockdale County were foliation-parallel parting features.*

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

Study Chief Lester J. Williams

Cooperator City of Lawrenceville, Georgia

Year Started 2002



Problem

The city of Lawrenceville currently is planning the installation of at least one additional ground-water treatment plant west of the city that will receive water from new municipal wells in the Redland–Pew Creek Basin and will upgrade its existing treatment plant to receive additional flows from wells located in the Upper Alcovy River Basin. Because the long-term effects of ground-water withdrawal in this area are largely unknown, the U.S. Geological Survey, in cooperation with the city of Lawrenceville, began a study to investigate the sustainability of ground-water resources as additional municipal wells become operational.

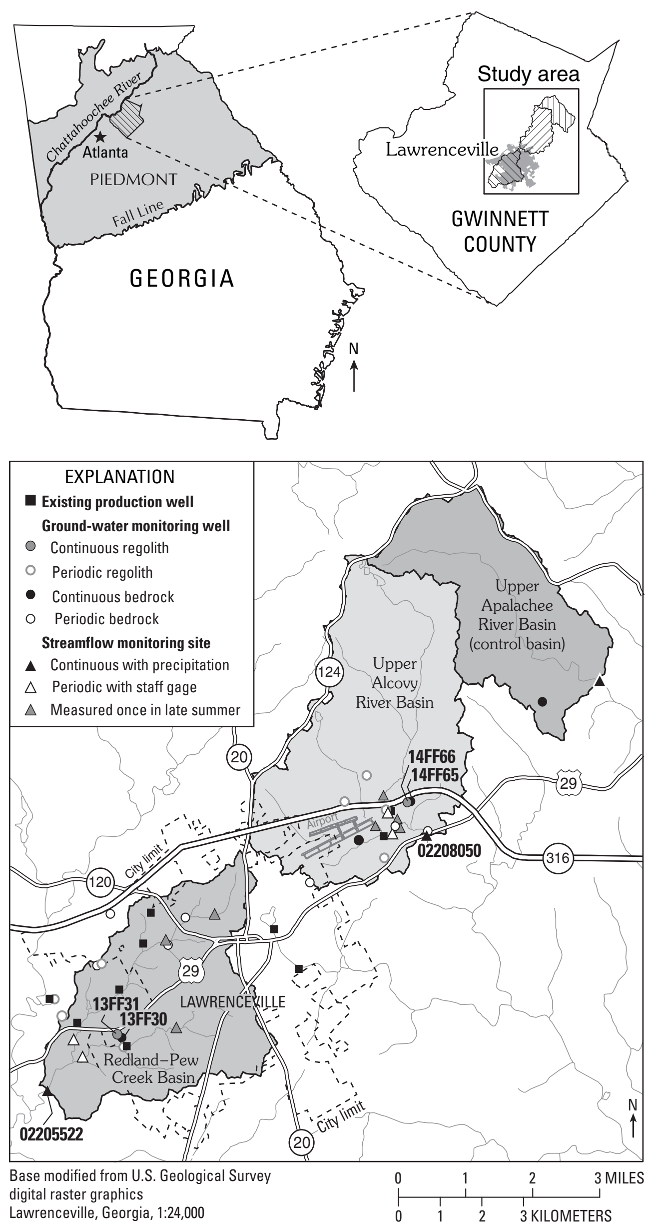
The hydrologic monitoring network consists of both ground-water (regolith and bedrock wells) and surface-water (stream gages) sites in each of the newly developed basins and in a control basin that is not influenced by the main pumping centers. Ground-water levels and surface-water monitoring provide the necessary data to determine the effects of pumping and manage the city municipal wells. 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

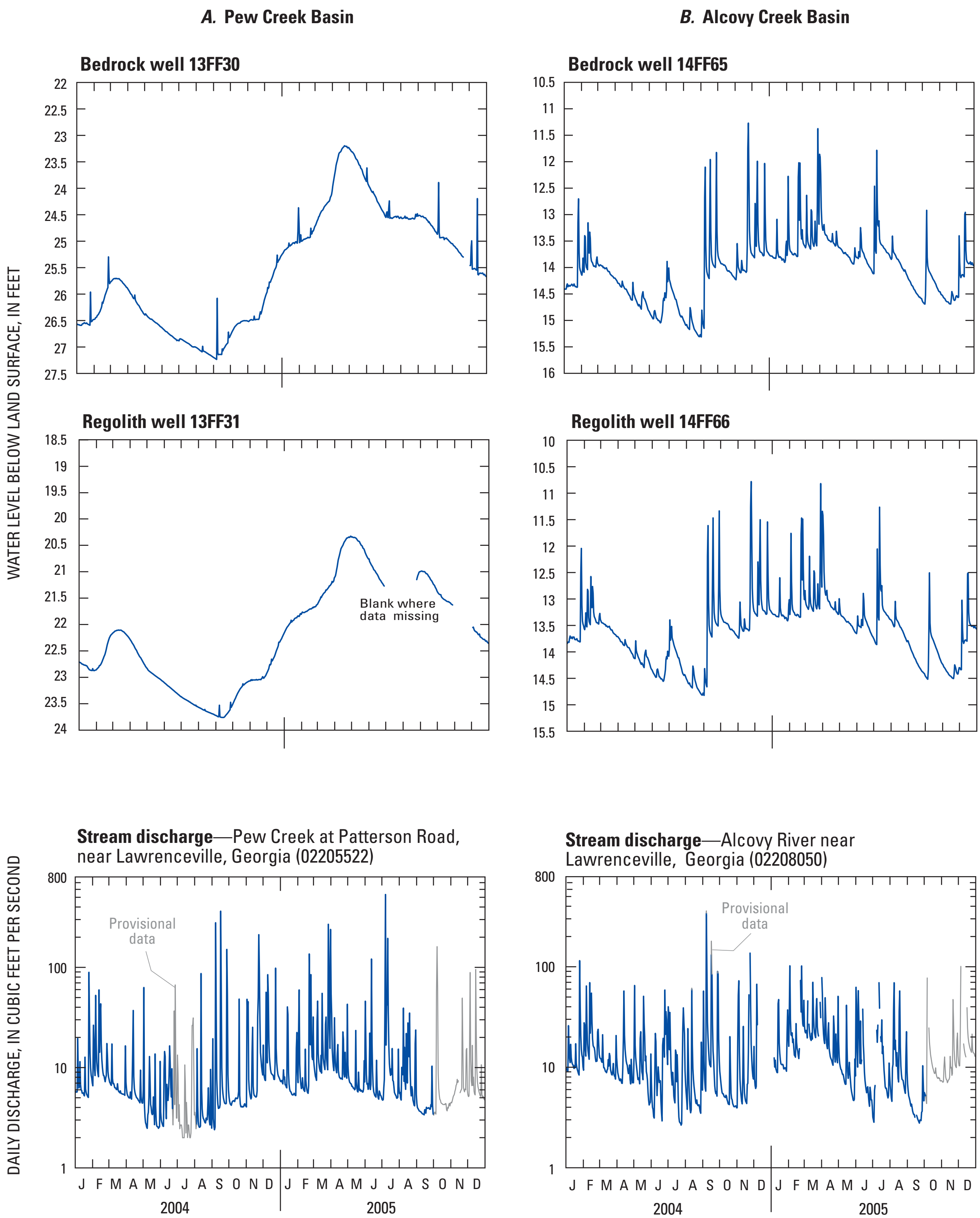
- Monitor the effect of increased ground-water withdrawal by additional municipal wells on surrounding ground-water levels and streamflow.
- Determine pre- and post-pumping hydrologic budgets of the Alcovy and Pew–Redland Creek Basins.
- Provide drawdown data from surrounding monitoring wells to the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

Progress and Significant Results, 2004–2005

- Maintained two continuous ground-water-level recorders in the upper Alcovy River Basin, two in the Redland–Pew Creek River Basin, and one in the upper Apalachee River Basin.
- Obtained biweekly water-level measurements at 21 monitoring wells.
- Maintained continuous-recording streamgages at the outflow of both the upper Alcovy River and the Redland–Pew Creek River Basins to establish baseline information on baseflow, runoff, and other hydrologic properties.
- Maintained and obtained streamflow readings at four additional staff-gage monitoring sites.
- Obtained seepage measurements during the fall 2004 low-flow period to quantify the ground-water contribution to streamflow in areas being monitored.
- Maintained a project Web 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.

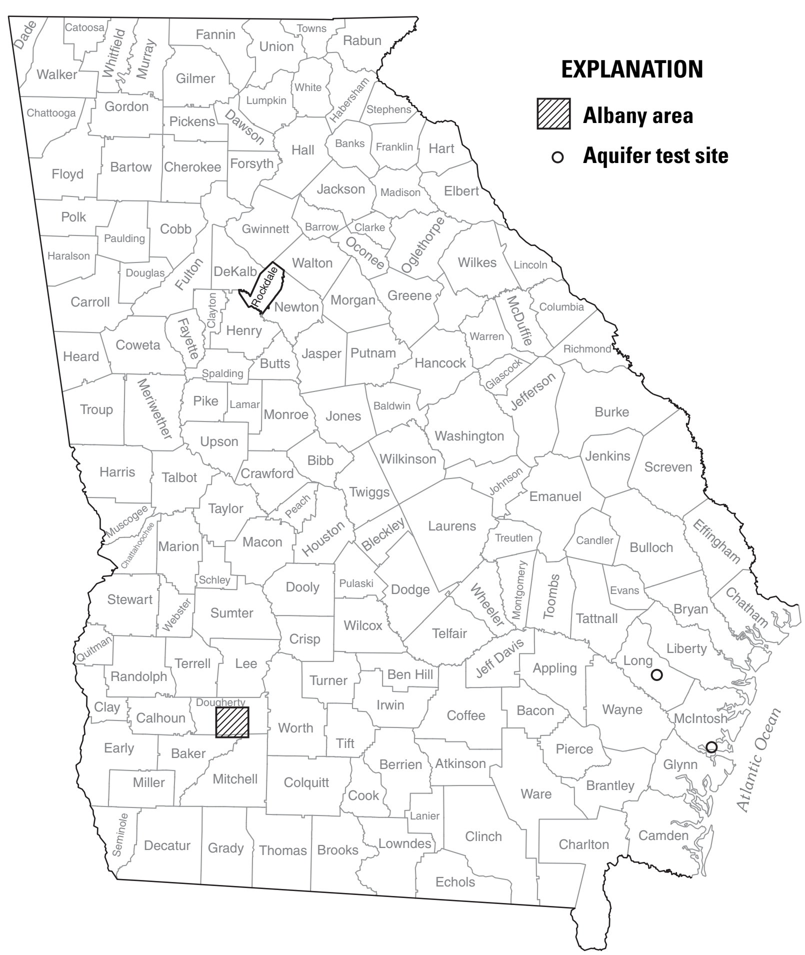


Bedrock and regolith water-level hydrographs in the (A) *Pew Creek Basin, and* (B) *Alcovy River Basin showing different responses to peak stream discharge. Water-level hydrographs in Pew Creek Basin show little relation to surface-water discharge, whereas the hydrographs in the Alcovy River Basin show a strong relation. Ground water and stream interaction is one of the components being investigated in this study.*

Technical Highlights

During 2004–2005, 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:

- Potentiometric surface of the Upper Floridan aquifer in the southwestern Albany area, Georgia, 1998–2005, based on revised land-surface altitudes
  by Debbie Warner Gordon
- Hydrogeology, hydraulic properties, and water quality of the surficial and Brunswick aquifer systems, McIntosh County, Georgia, May and November 2004
  by Sherlyn Priest
- Hydrogeology, hydraulic properties, and water quality of the surficial and Brunswick aquifer systems near the city of Ludowici, Long County, Georgia, July 2003
  by Sherlyn Priest and Gregory S. Cherry
- Influence of low-angle lithologic contacts and thrust faults on ground-water flow in a crystalline-rock aquifer system, Rockdale County, Georgia
  by Lester J. Williams



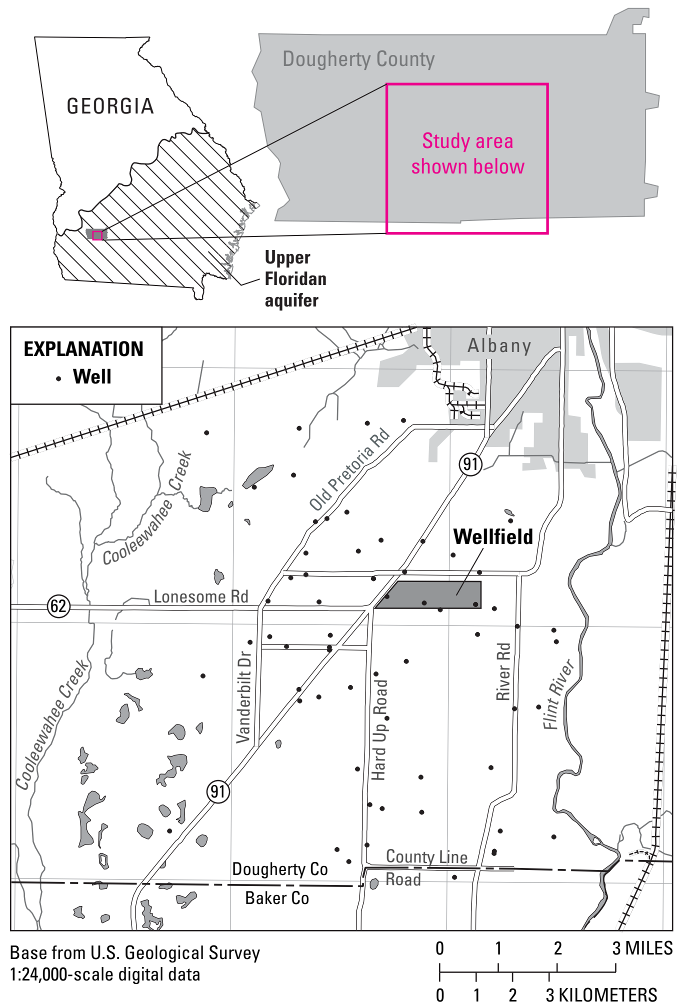
Potentiometric Surface of the Upper Floridan Aquifer in the Southwestern Albany Area, Georgia, 1998–2005, Based on Revised Land-Surface Altitudes

By Debbie Warner Gordon

INTRODUCTION

As part of a cooperative agreement with the Albany Water, Gas, and Light Commission (WGL), the U.S. Geological Survey (USGS) has been collecting annual water-level data from the Upper Floridan aquifer in the southwestern Albany area, Georgia, since 1998. The water-level data are used to construct potentiometric-surface maps of the Upper Floridan aquifer. These maps have been used to monitor the effects of ground-water withdrawals and climate on the Upper Floridan aquifer as well as ground-water-flow directions in the area. In addition to monitoring, the maps may be used to calibrate ground-water-flow-models in the area.

The study area encompasses about 64 square miles in Dougherty County, southwest of Albany, Georgia (map, right). Topography is karstic and relatively flat; altitudes at land surface range from about 160 to 200 feet (ft) above the National Geodetic Vertical Datum of 1929 (NGVD 29). Surface runoff is minimal because most of the drainage is internal. Sinkholes are prevalent in the area. The karstic nature of the Upper Floridan aquifer makes its top surface and its potentiometric surface irregular.



Study area location and network of wells in Dougherty County, southwestern Albany area, Georgia.

Scope of Work

Water-level measurements are collected from a network of 85 wells located in and around a municipal wellfield southwest of Albany. Precise land-surface altitudes at each well are critical for accurate potentiometric-surface maps. The land-surface altitudes for most of the wells originally were obtained from 7.5-minute topographic maps. These data have an accuracy of +/–2.5 ft. To improve the accuracy of the potentiometric-surface maps, WGL commissioned the Dougherty County Engineering Department to survey the land-surface altitude at each well. The new land-surface altitudes were used to construct more accurate potentiometric-surface maps for 1998 through 2005.

Methods of Study

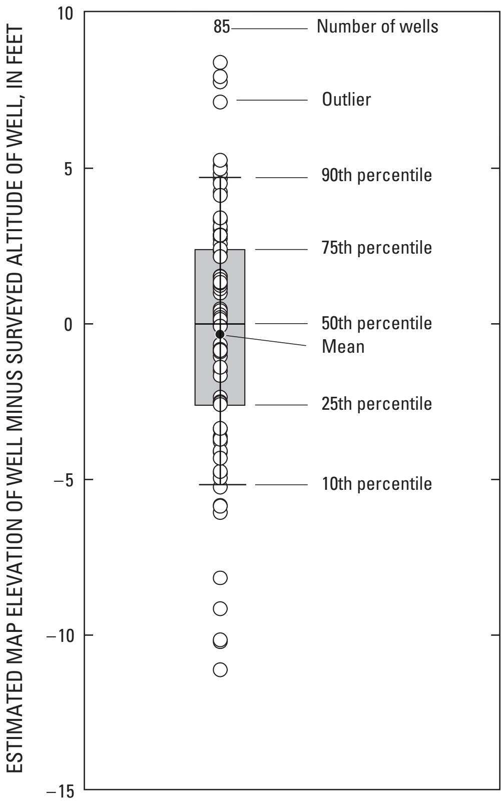
The Dougherty County Engineering Department used standard land-surveying techniques to tie the land-surface altitude at each well to altitude benchmarks. The location of each well was checked with a global positioning system. The well locations were plotted on a map using geographic information system (GIS) software. A value for water level below land surface for each well was subtracted from the land-surface altitude to derive the water-level altitude at each well. These water-level altitudes were plotted on the map, and the GIS software was used to contour the new potentiometric-surface data. Then contours were adjusted by hand where necessary. The new water-level altitude data are accurate to 0.01 ft.

Previous Studies

Potentiometric-surface maps have been previously published for the Upper Floridan aquifer in the southwestern Albany area using the old land-surface altitudes. A potentiometric-surface map for November 2001 was published in Leeth and others (2003), and maps for October 2002 and September 2003 were published in Leeth and others (2005). The May 1998, October 1999, and March 1999 maps were published in Warner and Lawrence (2005).

REVISED LAND-SURFACE ALTITUDES

The revised land-surface altitudes for the 85 wells range from 0 to about 11 ft from the original altitudes. A box plot below shows the difference between the original altitude data and the surveyed data. Fifty percent of the surveyed altitudes ranged from 2.5 ft less than to 2.5 ft greater than the original altitude data. Eighty percent of the surveyed altitudes ranged from about 5 ft less than to about 5 ft greater than the original data.



Difference between original well altitude taken from U.S. Geological Survey 1:24,000-scale map and surveyed well altitude.

REVISED POTENTIOMETRIC SURFACES, 1998–2005

The revised land-surface altitudes were used to reconstruct the potentiometric-surface maps. The nine revised maps are shown on the following pages: May 1998, October 1998, March 1999, August 2000, November 2001, October 2002, September 2003, October 2004, and October 2005, respectively. The November 2001 map is an example of how the revised land-surface altitudes affected the potentiometric surfaces; the old potentiometric-surface is shown in pink along with the revised potentiometric surface (shown in blue). As was the case with most of the revised maps, the contour lines of the revised November 2001 map are “smoother” than the old lines. The direction of ground-water flow is generally to the southeast, instead of southeast, west, and north. A mound of high water levels to the west of the wellfield shown on the old November 2001 map is an area of low water levels. Ground-water-flow directions were toward the east or southeast, toward the Flint River, from May 1998 through November 2001, except in the southeast corner of the study area. From October 2002 through October 2005, flow directions generally were toward the southeast. The ground-water levels dropped from October 1998 to October 2002 during drought conditions. Water levels in the wellfield area were about 165 ft during October 1998, and dropped to about 145 ft by August 2000. A cone of depression was evident on the east side of the wellfield during March 1999 and October 2000 before pumping at the wellfield began. Water levels rose at the wellfield to about 145–150 ft by November 2001 and October 2002 and to 160–165 by September 2003. Water levels were back down to 155–160 ft at the wellfield during October 2004 and rose to about 160 ft during October 2005. Pumping at the wellfield began during fall 2003 after the September 2003 water-level measurements were collected. Pumping rates were about 3.4 million gallons per day (Mgal/d) during October 2004 and about 4 Mgal/d during October 2005. No cone of depression is evident as a result of the wellfield pumping.

During August 2000, depressions in the potentiometric surface were present in, to the west of, and to the northwest of the wellfield. A depression was present to the west of the wellfield during November 2001 and September 2003. These depressions disrupt the southeasterly flow of water across the study area.

In the southeastern corner of the study area ground water flows west or southwest away from the Flint River. More data in the southeastern part of the study area are needed to determine the cause of the westward movement.

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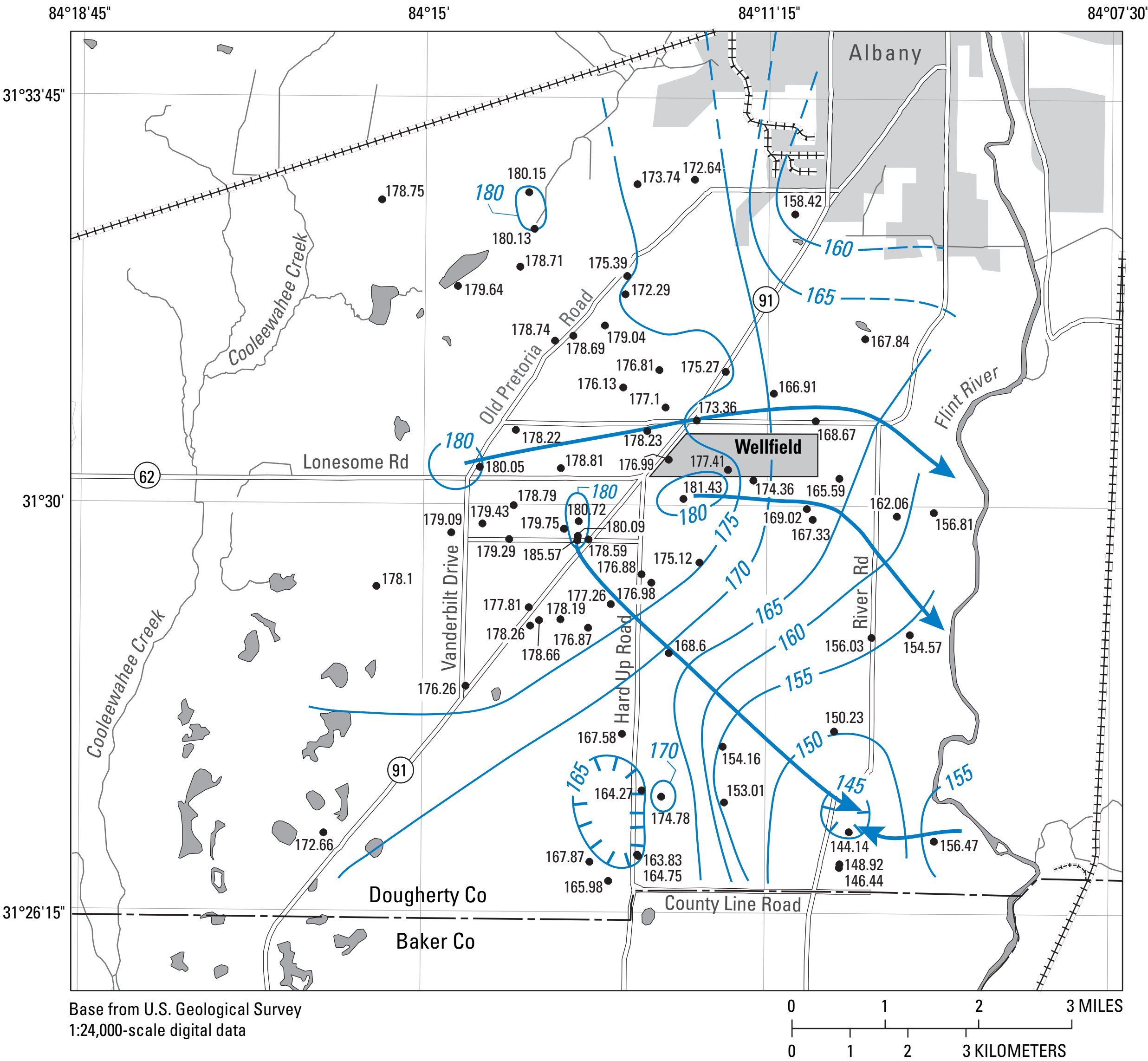
Leeth, D.C., Clarke, J.S., Craigg, S.D., and Wipperfurth, C.J., 2005, Ground-water conditions and studies in Georgia, 2002–03: U.S. Geological Survey Investigations Report 2005-5065, 128 p., Web-only publication available at *http://pubs.usgs.gov/sir/2005/5065/*.

Warner, Debbie, and Lawrence, S.J., 2005, Ground-water flow and water quality in the Upper Floridan aquifer, southwestern Albany area, Georgia, 1998–2001: U.S. Geological Survey Scientific Investigations Report 2005-5047, 77 p., Web-only publication available at *http://pubs.usgs.gov/sir/2005/5047/*.

May 1998



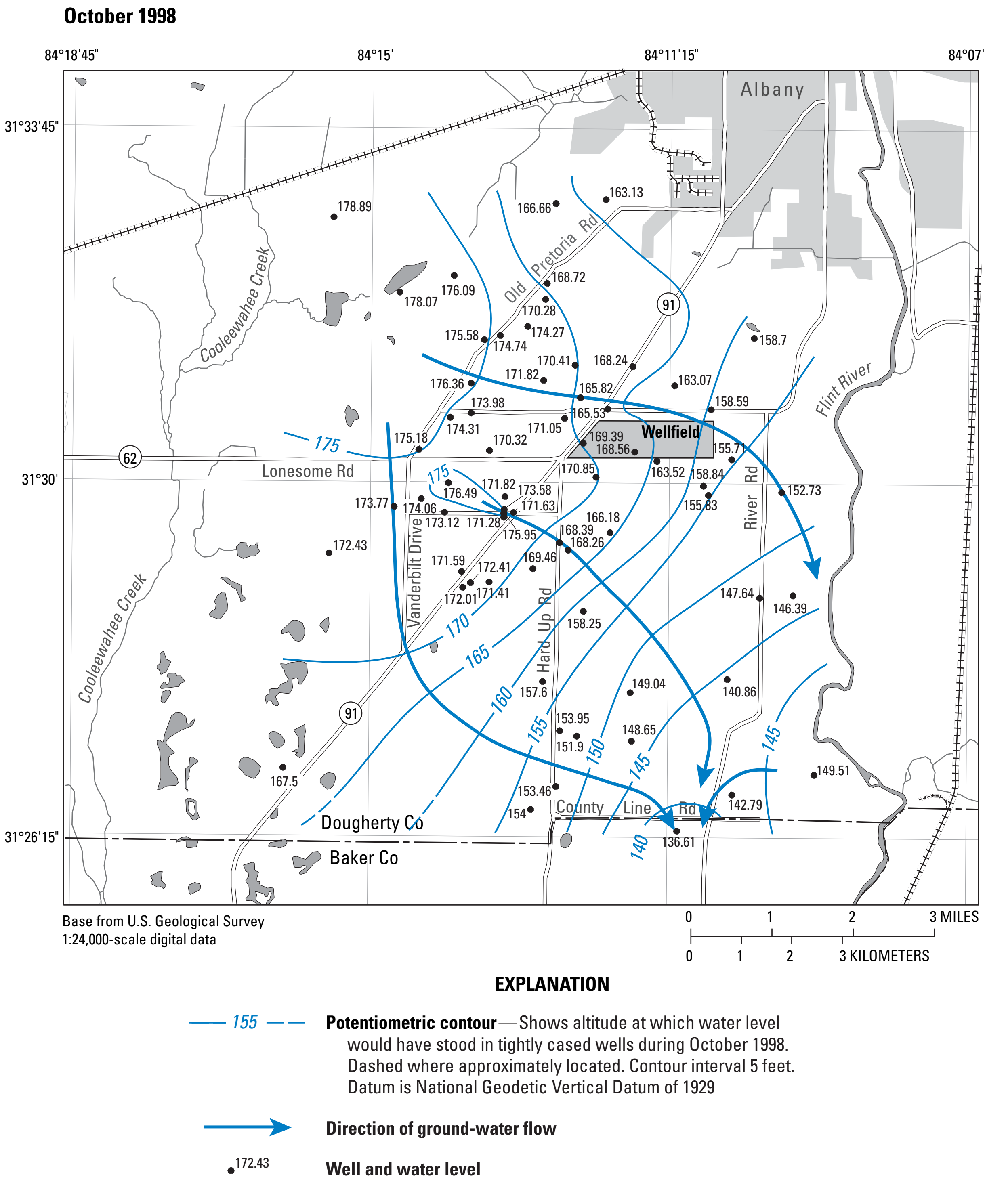
EXPLANATION

155 — **Potentiometric contour**—Shows altitude at which water level would have stood in tightly cased wells during May 1998. Dashed where approximately located. Hachures indicate depression. Contour interval 5 feet. Datum is National Geodetic Vertical Datum of 1929

Direction of ground-water flow

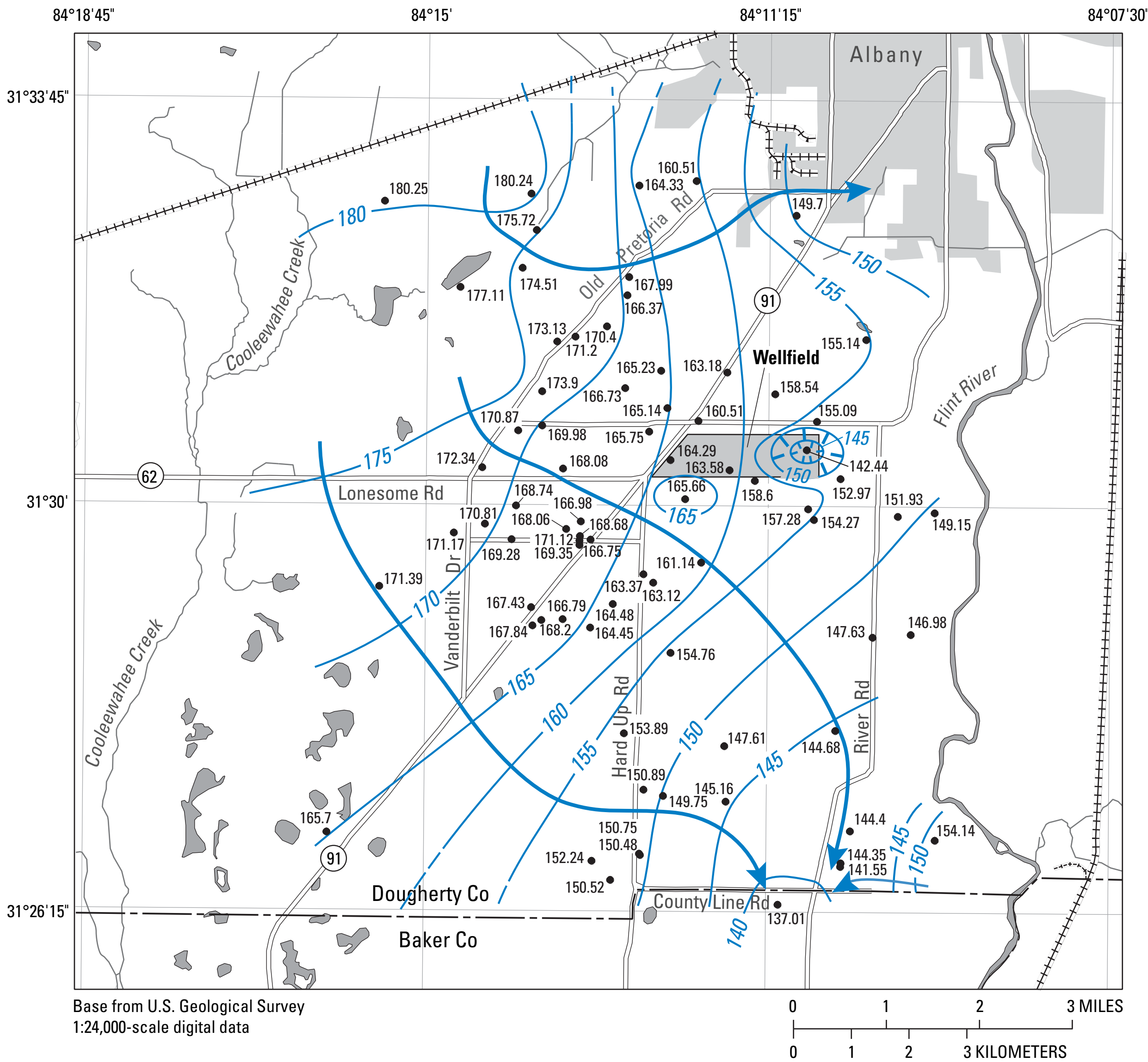
178.1 **Well and water level**

Potentiometric surface of the Upper Floridan aquifer, southwestern Albany area, Georgia, May 1998.



Potentiometric surface of the Upper Floridan aquifer, southwestern Albany area, Georgia, October 1998.

March 1999



EXPLANATION

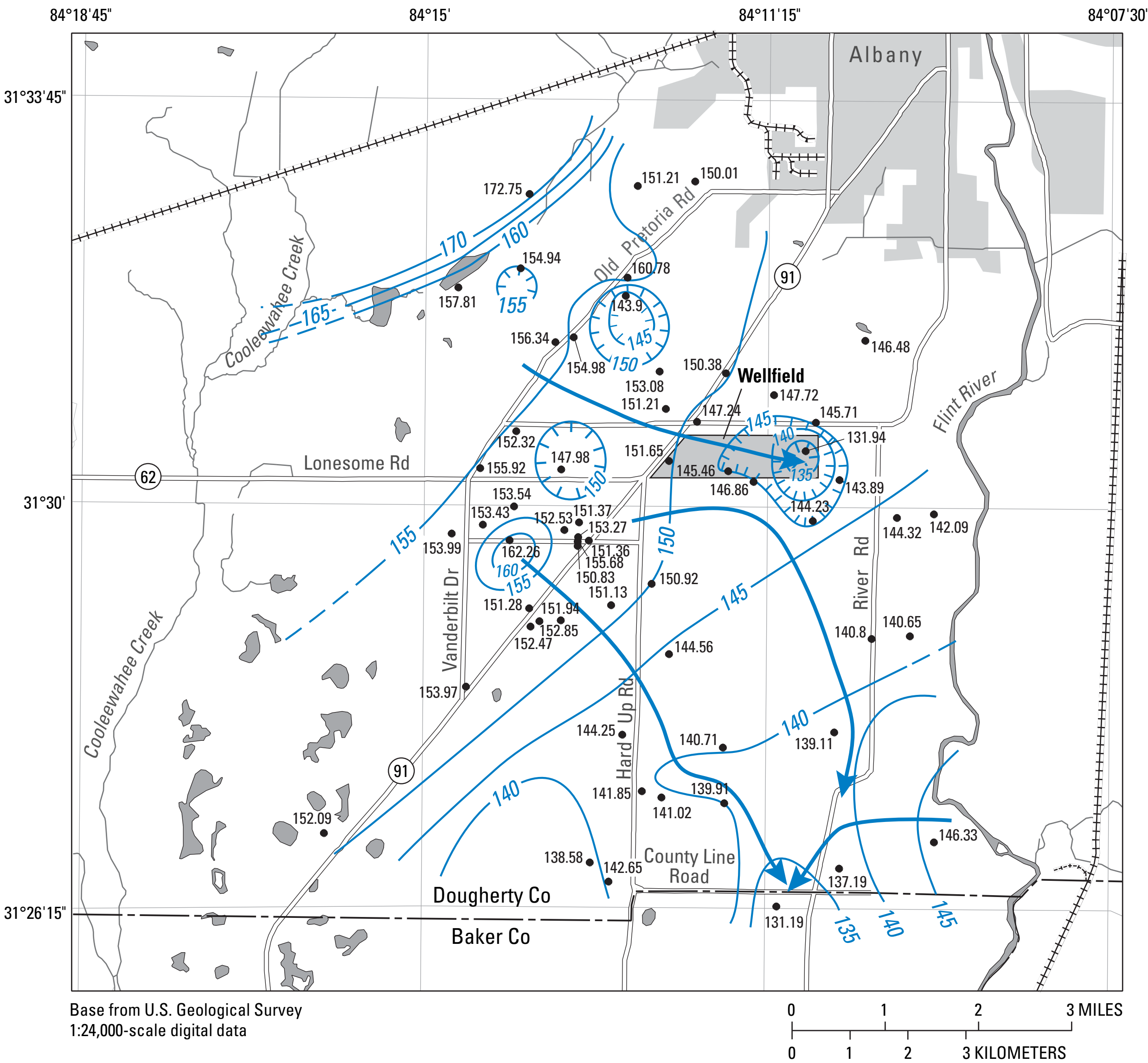
155 — **Potentiometric contour**—Shows altitude at which water level would have stood in tightly cased wells during March 1999. Dashed where approximately located. Hachures indicate depression. Contour interval 5 feet. Datum is National Geodetic Vertical Datum of 1929

Direction of ground-water flow

•171.39 **Well and water level**

Potentiometric surface of the Upper Floridan aquifer, southwestern Albany area, Georgia, March 1999.

August 2000



EXPLANATION

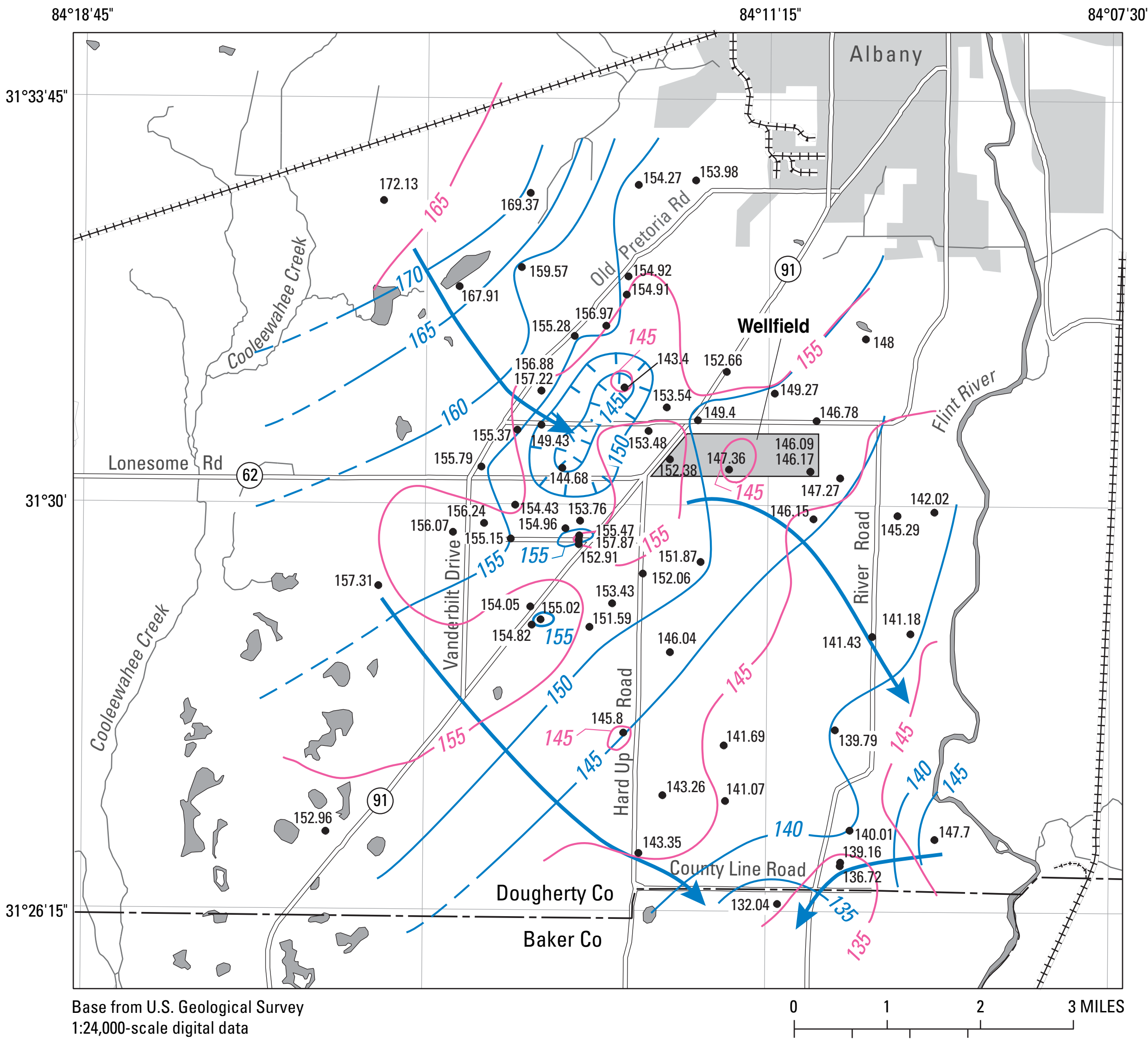
155 — Potentiometric contour—Shows altitude at which water level would have stood in tightly cased wells during August 2000. Dashed where approximately located. Hachures indicate depression. Contour interval 5 feet. Datum is National Geodetic Vertical Datum of 1929

Direction of ground-water flow

144.56 Well and water level

Potentiometric surface of the Upper Floridan aquifer, southwestern Albany area, Georgia, August 2000.

November 2001



EXPLANATION

145 — — **Potentiometric contour**—Shows altitude at which water level would have stood in tightly cased wells during November 2001. Dashed where approximately located. Contour interval 5 feet. Datum is National Geodetic Vertical Datum of 1929. Altitude data estimated from 1:24,000-scale map, plus or minus 5 feet

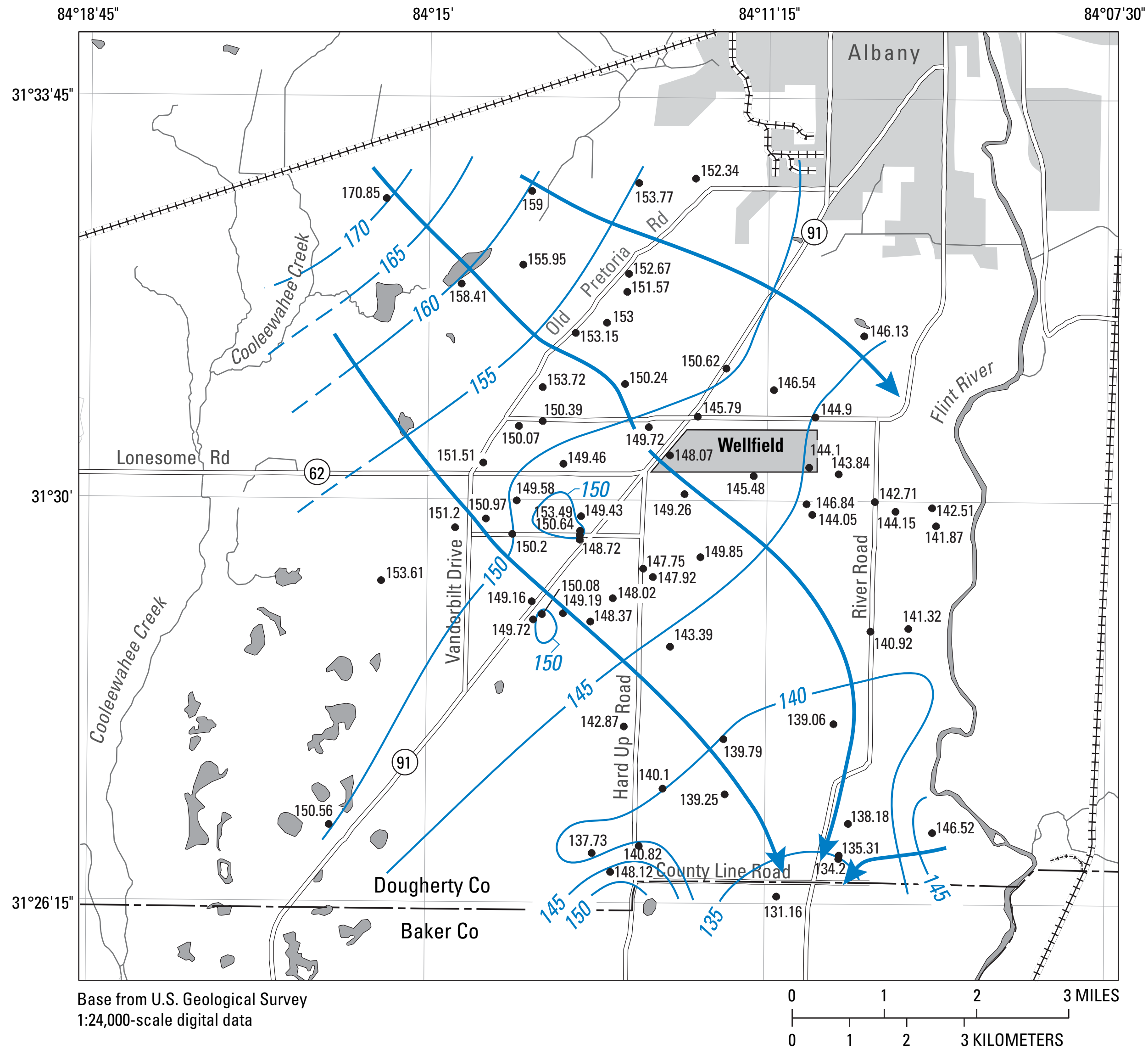
155 — — **Potentiometric contour**—Shows altitude at which water level would have stood in tightly cased wells during November 2001. Dashed where approximately located. Hachures indicate depression. Contour interval 5 feet. Datum is National Geodetic Vertical Datum of 1929. Altitude data from leveled land surface data (2005), to the nearest one hundredth of a foot

Direction of ground-water flow

143.26 **Well and water level**

Potentiometric surface of the Upper Floridan aquifer, southwestern Albany area, Georgia, November 2001.

October 2002



EXPLANATION

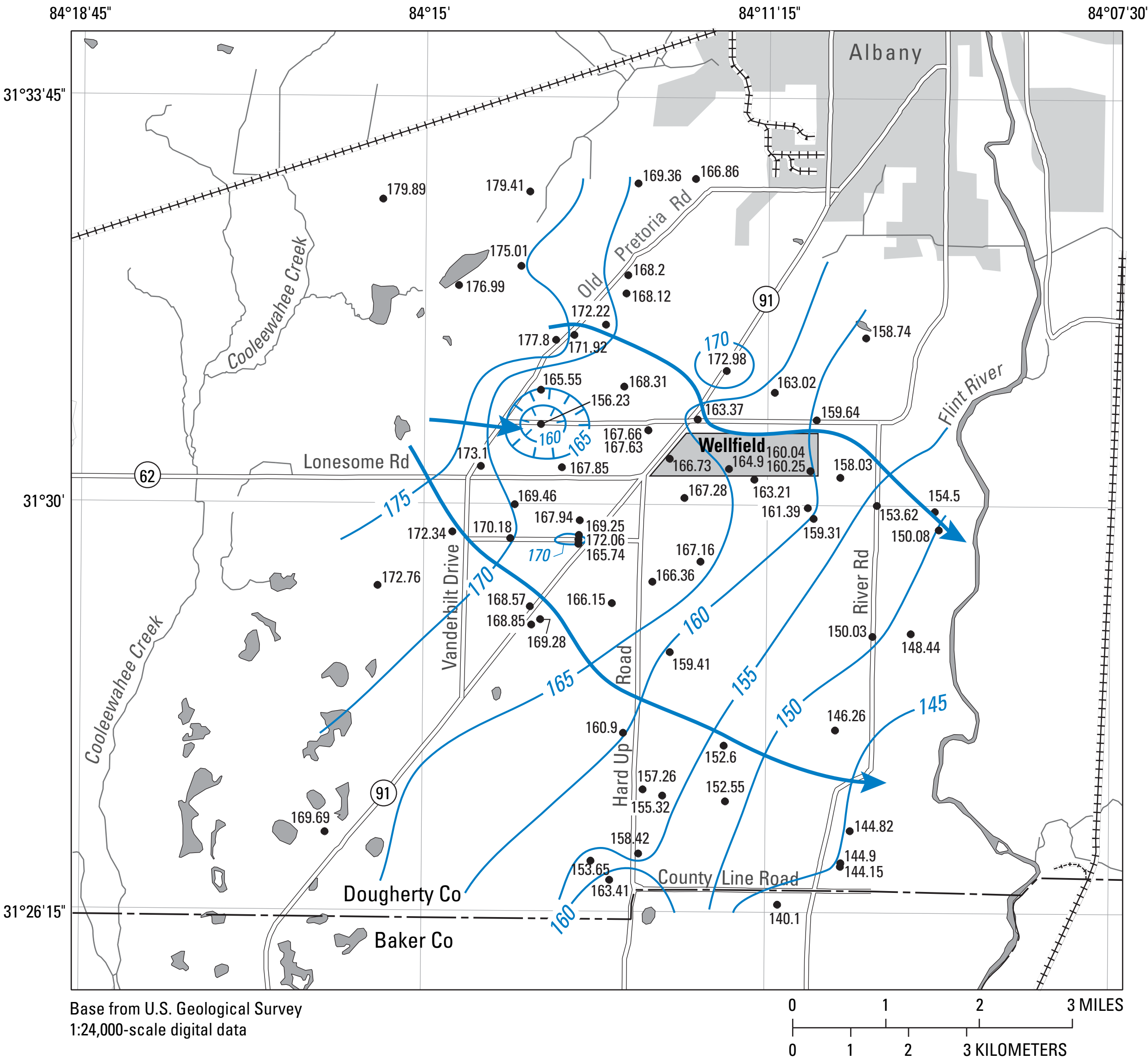
155 — Potentiometric contour—Shows altitude at which water level would have stood in tightly cased wells during October 2002. Dashed where approximately located. Contour interval 5 feet. Datum is National Geodetic Vertical Datum of 1929

Direction of ground-water flow

153.61 **Well and water level**

Potentiometric surface of the Upper Floridan aquifer, southwestern Albany area, Georgia, October 2002.

September 2003



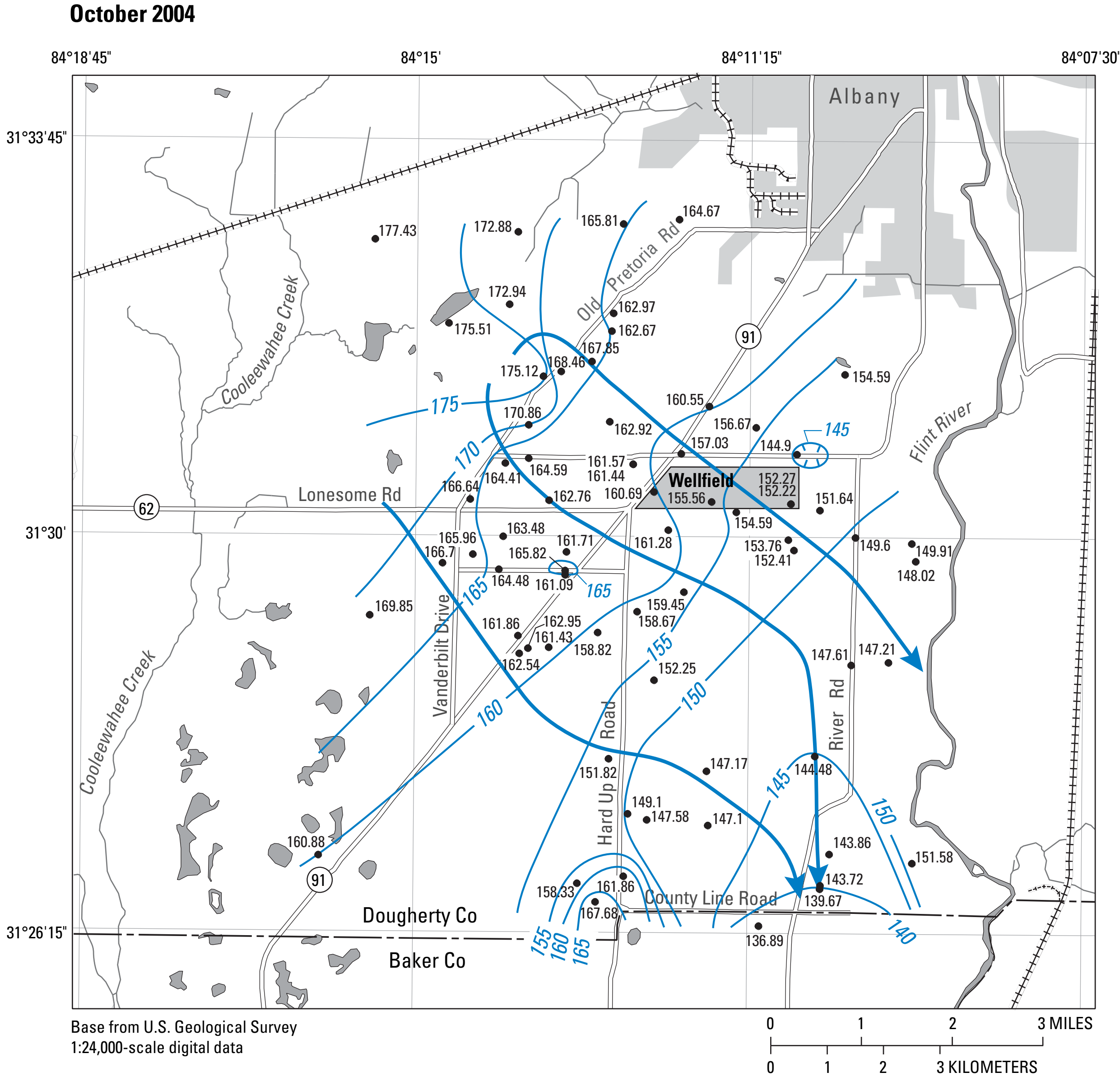
EXPLANATION

155 **Potentiometric contour**—Shows altitude at which water level would have stood in tightly cased wells during September 2003. Hachures indicate depression. Contour interval 5 feet. Datum is National Geodetic Vertical Datum of 1929

Direction of ground-water flow

172.76 **Well and water level**

Potentiometric surface of the Upper Floridan aquifer, southwestern Albany area, Georgia, September 2003.



EXPLANATION

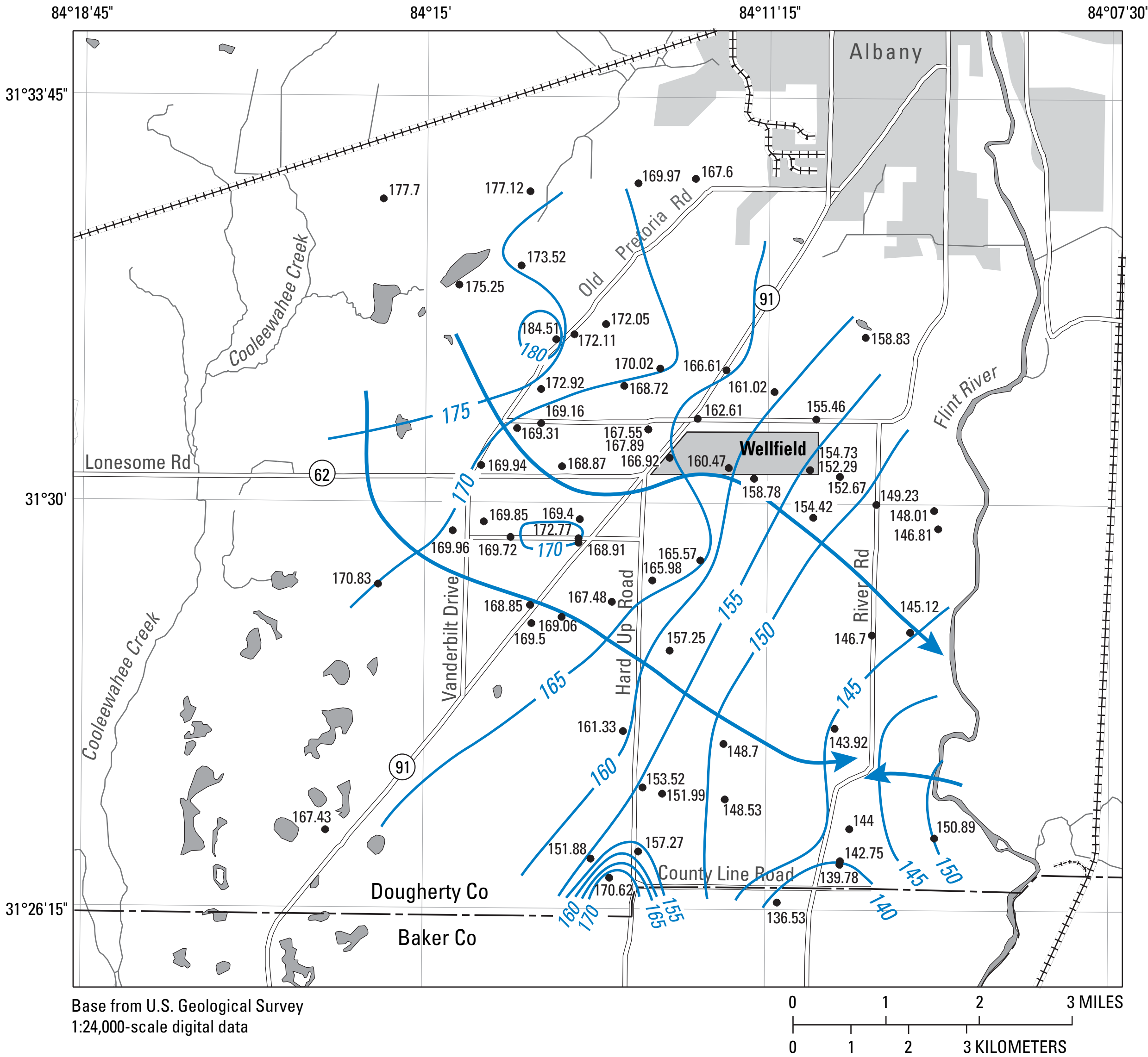
155 **Potentiometric contour**—Shows altitude at which water level would have stood in tightly cased wells during October 2004. Hachures indicate depression. Contour interval 5 feet. Datum is National Geodetic Vertical Datum of 1929

Direction of ground-water flow

169.85 **Well and water level**

Potentiometric surface of the Upper Floridan aquifer, southwestern Albany area, Georgia, October 2004.

October 2005



EXPLANATION

155 — **Potentiometric contour**—Shows altitude at which water level would have stood in tightly cased wells during October 2005. Contour interval 5 feet. Datum is National Geodetic Vertical Datum of 1929

→ **Direction of ground-water flow**

•170.83 **Well and water level**

Potentiometric surface of the Upper Floridan aquifer, southwestern Albany area, Georgia, October 2005.

Hydrogeology, Hydraulic Properties, and Water Quality of the Surficial and Brunswick Aquifer Systems, McIntosh County, Georgia, May and November 2004

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, the Brunswick aquifer system, and the Lower Floridan aquifer. The U.S. Geological Survey (USGS)—in cooperation with State and local agencies—is studying these supplemental supplies.

The USGS—in cooperation with the McIntosh County Development Authority, Georgia—is evaluating the potential for alternative sources of ground water for the county and the city of Darien. The purpose of this study is to calculate the hydraulic properties and collect water-quality data for the lower confined zone of the surficial aquifer system (hereinafter referred to as lower confined zone) and the lower Brunswick aquifer of the Brunswick aquifer system. The scope of this study includes well drilling, geophysical logging, aquifer testing and subsequent analyses, and water-quality sampling and analyses. These data are essential for the successful development and management of the ground-water resources in the coastal area and within the county. Water managers may use this information to make informed decisions on further development of ground-water resources.

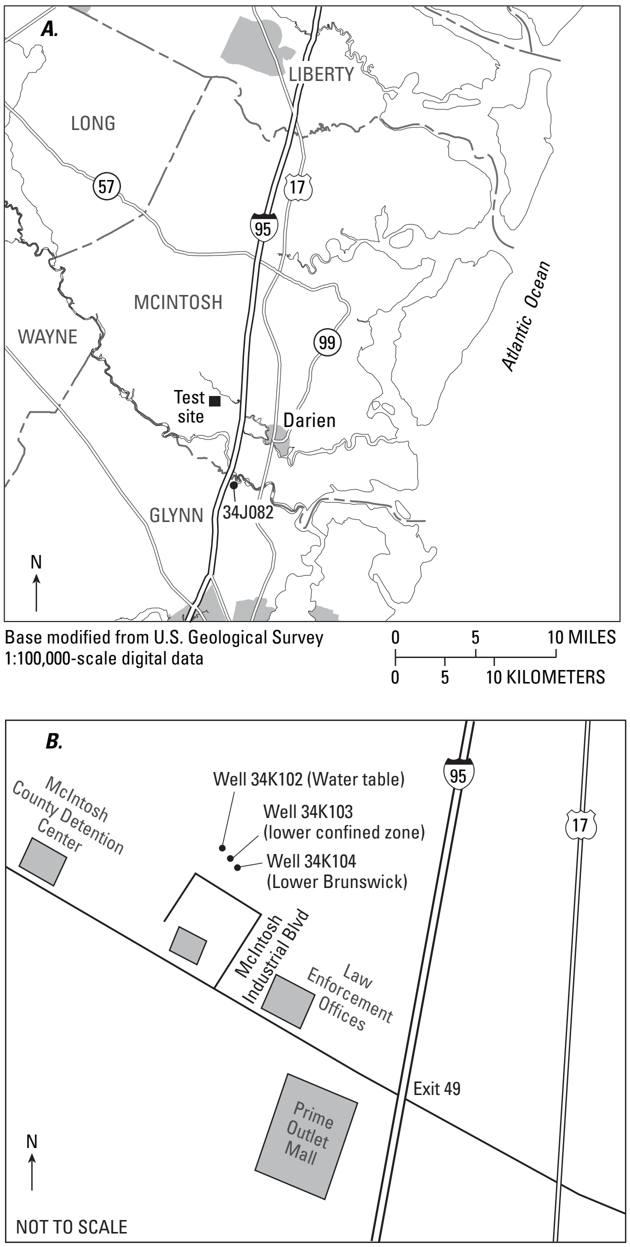
Darien test site, McIntosh County, Georgia, 2004.

Description of Study Area

The Darien test site is located about 2 miles northwest of the city of Darien, McIntosh County, Georgia, in the Coastal Plain physiographic province (Clark and Zisa, 1976). The site is about 16 miles northeast of the city of Brunswick and about 31 miles southeast of the city of Jesup (maps at right and following page). Land use in the area primarily is forest. Topographic relief across the area is low, with approximate land-surface altitude of 30 feet (ft) above National American Vertical Datum 1988 (NAVD 88). The climate in the area is mild, with a mean-annual temperature of 76 degrees Fahrenheit at the Brunswick National Weather Station (National Oceanic Atmospheric Administration [NOAA], 2002). Average monthly precipitation ranges from about 2.1 inches per month during November to 7.6 inches per month during September. Annual precipitation averaged 49.4 inches per year for the 30-year period 1971–2000 (National Oceanic Atmospheric Administration, 2002).

Methods of Study

To better identify the water-bearing capability and lithology of the study area, the investigation included drilling three wells, collecting drill cuttings and geophysical logging of the deepest well, pre-aquifer test background water-level monitoring and pre-aquifer test pumping, aquifer testing, and collecting water-quality samples from the tested intervals. Three wells were completed—one in the water-table zone (34K102), one in the lower confined zone (34K103), and one in the lower Brunswick aquifer (34K104)—during June and July 2003. Wells completed in the lower confined zone and the lower Brunswick aquifer are open to the entire thickness of the aquifer. Separate aquifer tests were performed in the lower confined zone using well 34K103 and in the lower Brunswick aquifer using well 34K104. Data from these aquifer tests were analyzed to



(A) *Location of test site and* (B) *detail showing relative position of wells, Darien, McIntosh County, Georgia.*

calculate transmissivity, storage coefficient, and hydraulic conductivity for the aforementioned water-bearing units.

All wells were constructed using standard mud-rotary techniques. Each well consists of 12-inch-diameter polyvinylchloride surface casing, 6-inch-diameter steel casing, and 4-inch-diameter stainless steel screen in the aquifer material. The screened interval was gravel packed, and the casing was grouted with cement. The table below presents the well construction information.

Upon completion of the deepest boring for well 34K104, borehole geophysical logs were collected that included natural-gamma radiation, spontaneous potential, lateral resistivity, short-normal resistivity, long-normal resistivity, and caliper. The borehole geophysical logs and well cuttings were used as a basis for stratigraphic correlation and to select casing depth and screened intervals for each well constructed. Natural-gamma logs were used to identify the location of the A-marker, B-marker, and C-marker horizons, which are identified by a sharp increase in radiation (Clarke and others, 1990). These markers were used to help identify the upper Brunswick, lower Brunswick, and Upper Floridan aquifers. Lithologic and hydrogeologic descriptions for well 34K104 are derived from the borehole cuttings recovered during well drilling and subsequent geophysical logging of well 34K104.

Background ground-water levels were monitored prior to the start of each aquifer test using pressure transducers and data loggers to document water-level trends and possible tidal effects within selected intervals being studied. Water levels in well 34J082, located in Ebenezer Bend about 10 miles south of the test site, were monitored prior to the aquifer test in the lower confined zone and in wells 34K103 and 34K104 prior to the aquifer test in the lower Brunswick aquifer.

Pretest pumping was undertaken to verify that wells 34K103 and 34K104 were fully developed and to determine the optimum pumping rate prior to 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) in the wells. For the lower Brunswick aquifer test, water levels

Well location and construction for aquifer test at the Darien test site, McIntosh County, Georgia.

[NAVD 88, North American Vertical Datum of 1988; –, negative; NI, not installed; do., ditto]

Well name	Other identifier	Aquifer	Well depth (feet)	Casing depth (feet)	Casing diameter (inches)	Altitude (feet NAVD 88)			Type of opening	Sump at bottom of screen (feet)
						Land surface	Top of screen interval	Bottom of screen interval		
34K102	MCDA TW-1	Water-table zone of surficial	40	20	6	30	10	–10	Screened	NI
34K103	MCDA TW-2	Lower confined zone of surficial	265	160	6	do.	–130	–230	do.	5
34K104	MCDA TW-3	Lower Brunswick	583	488	6	do.	–458	–548	do.	5

were measured using an electric tape in pumping well 34K104 and using an electronic recorder in observation wells 34K103 and 34K102. For the lower confined zone test, water levels were monitored using an In-Situ, Inc. Hermit 3000™ data logger with a 100-pound per square inch (psi) pressure transducer in pumping well 34K103 and using an electric tape in observation wells 34K102 and 34K104. During the lower confined zone test, atmospheric pressure was measured with an internal pressure sensor in the data logger. Starting at time equals 0, a sampling interval was programmed into the data logger to facilitate the rapid collection of early time data, using a logarithmic scale that was decreased to a 1-minute interval later in the test.

To provide constant pumping rates, a 25-horsepower submersible pump was used for well 34K103 and a 5-horsepower submersible pump was used for well 34K104. To transport water away from the wells, about 80 ft of 6-inch-diameter hose was used for well 34K103 and 60 ft of 4-inch-diameter hose was used for well 34K104. Well discharge was measured using a Model 2300078 Butler Brass Meter for well 34K103 and a Model FL-30005 Closed Pipe System Water Measurement Flowmeter for well 34K104. An appropriate discharge was determined during pretest pumping and was constantly maintained throughout the duration of the aquifer tests.

During each 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, the data used in the analysis of the aquifer test were not corrected for atmospheric pressure, local pumping, or tidal effects.

Using the drawdown and recovery data, the aquifer-test data were analyzed using the Cooper and Jacob (1946) modified nonequilibrium analytical method, the Theis method (1935) for confined aquifers and fully penetrating wells, and the Hantush and Jacob method (1955) analytical model for nonsteady radial flow in an infinite leaky aquifer. The Hantush and Jacob method (1955) accounts for leakage, but does not differentiate between leakage above or below the aquifer. Leakage may be indicated by the change in slope of the graphs near the end of the aquifer test. According to the boundaries for the models, the slope of the graphs would continue to follow a straight path unless a source of additional ground water or an impermeable boundary is encountered.

Water samples were collected from wells 34K103 and 34K104 and analyzed for major ions, nutrients, metals, and radionuclides. Based on major ionic composition, results from the chemical analyses were used to describe and differentiate the water quality between the water-bearing units. Water samples were collected after several hours of pumping when field properties (specific conductance and pH) were stable.

Any use of trade, product, or firm names in this publication is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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). Equipment blanks and duplicate water-quality samples were not collected.

Previous Investigations

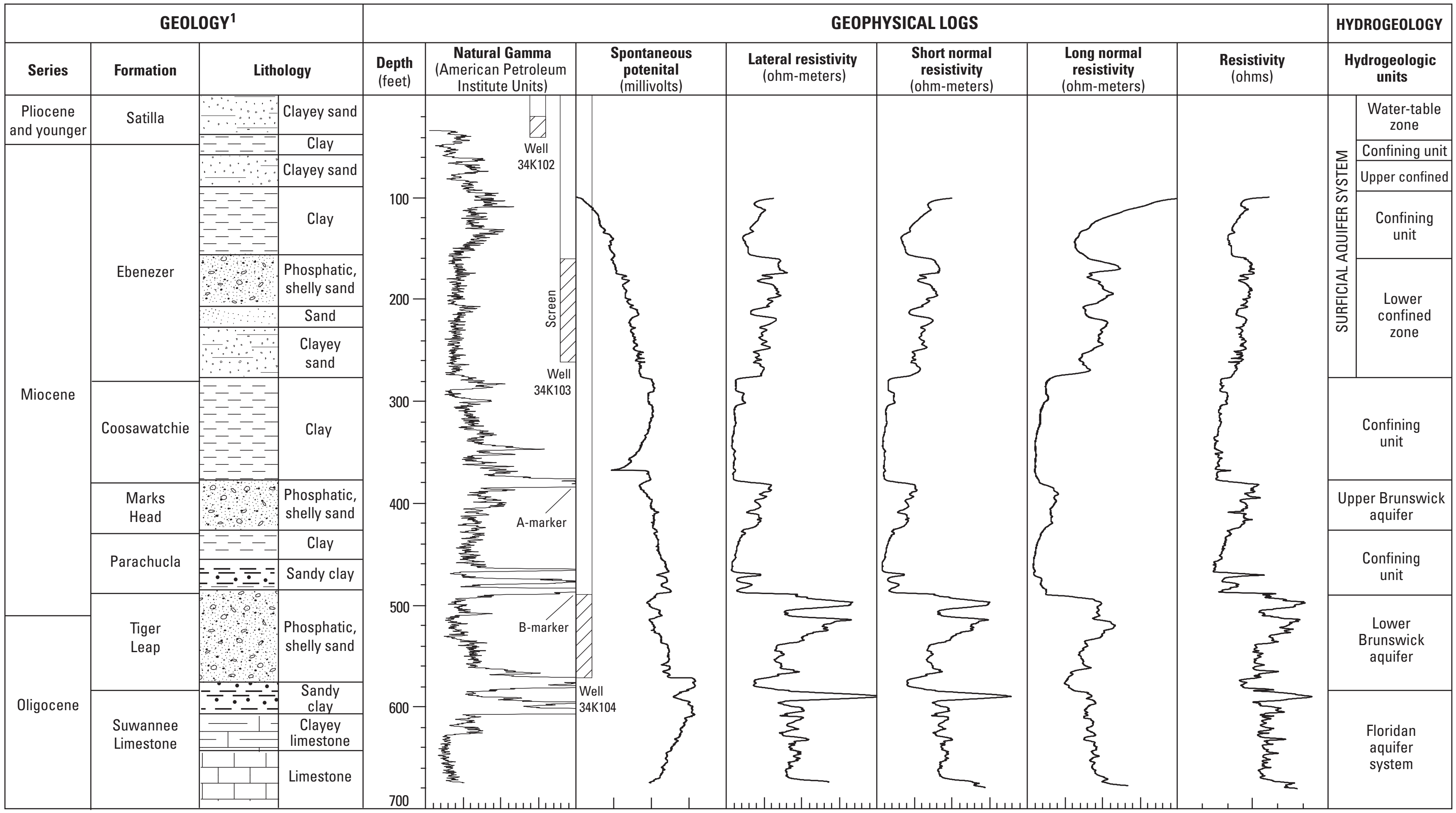
Clarke and others (1990) defined the surficial and upper and lower Brunswick aquifers and described their water-bearing characteristics. Steele and McDowell (1998) mapped the permeable thickness and areal distribution of the upper and lower Brunswick aquifers. Sharpe and others (1998) described results of the 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. Hodges (1998, 1999) described results of aquifer tests in Toombs and Evans Counties in 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.

Acknowledgments

The author extends special thanks to McIntosh County Development Authority, the cooperating agency in this study. Appreciation also is extended to Golden Isles Well Drilling, Inc., for supplying the personnel and equipment needed to perform the aquifer tests.

HYDROGEOLOGY AND LITHOLOGY

Hydrologic units in the Coastal Plain of Georgia include, but are not limited to, in descending order, the water table and lower confined zones of the surficial aquifer system (Miller, 1986; Krause and Randolph, 1989; Clarke and others, 1990; Clarke, 2003); the upper and lower Brunswick aquifers of the Brunswick aquifer system (Clarke and others, 1990); and the Upper and Lower Floridan aquifers of the Floridan aquifer system (Miller, 1986). The lower confined zone and lower Brunswick aquifer are the focus of this study. The lithology and description of well 34K104 is derived from borehole cuttings recovered during drilling (hydrogeologic chart, following page). The lithology of the surficial aquifer system typically consists of sand and clay; these sediments overlie sandy limestone of the Brunswick aquifer system.



[1]Modified from Weems and Edwards, 2001

Generalized lithologic, geologic, and hydrologic description of Darien test site, McIntosh County, Georgia.

At the Darien test site, the surficial aquifer system is present from land surface to a depth of about 280 ft. For this study, it is informally divided into three water-bearing zones: water-table zone, upper confined zone, and lower confined zone. These water-bearing zones are separated by clay and sandy clay confining units. The lower confined zone is the focus of this investigation and is present from 160 to 280 ft. The lower confined zone consists of fine to medium sand with few shell fragments and clay layers, with a total thickness of about 120 ft. The base of the confining unit underlying the surficial aquifer system (top of the upper Brunswick aquifer) is identified on natural gamma radiation logs by the A-marker horizon (Clarke and others, 1990). Well 34K103 is screened in the lower confined zone.

At the Darien test site, the lower Brunswick aquifer extends from a depth of 490 to 580 ft and consists mostly of phosphatic sand. The total thickness of the lower Brunswick aquifer is about 90 ft. The top of the aquifer is identified by the B-marker horizon, a zone of high natural gamma radiation (Clarke and others, 1990). Well 34K104 is screened in the lower Brunswick aquifer.

HYDRAULIC PROPERTIES

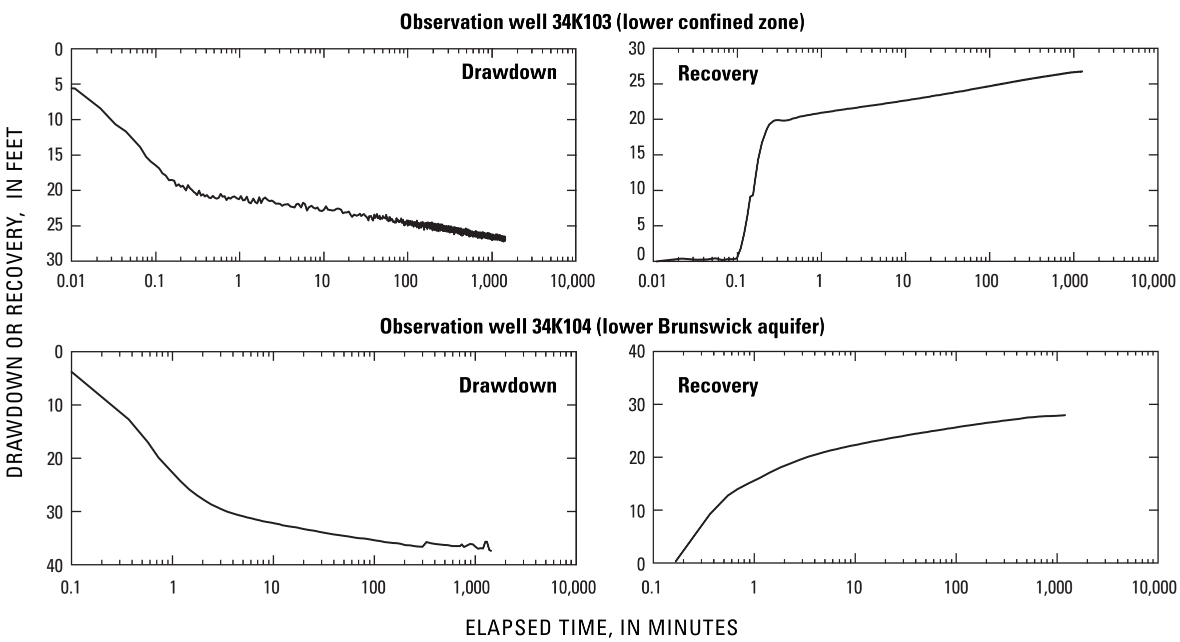
Each single-well aquifer test was designed to provide ground-water-level and well-discharge data to calculate hydraulic properties. The two aquifer tests included a pretest step drawdown test and background ground-water-level monitoring, constant discharge aquifer test followed by post-test recovery monitoring.

Lower Confined Zone, Surficial Aquifer System

The lower confined zone single-well test consisted of pumping and monitoring well 34K103. During November 1–4, 2004, the lower confined zone aquifer test consisted of about 1.5 hours of pretest pumping, 24 hours of constant-discharge pumping, and 24-hours monitoring ground-water-level recovery. Ten days of background water-level data were collected from another well completed in the lower confined zone (well 34J082, about 10 miles south of the Darien test site) to note any trends in the water level prior to pumping. During October 22–31, 2004, water levels in well 34J082 varied from 6.23 to 6.53 ft. Background data indicate there was a downward trend prior to the start of the test, which continued after completion of the test; however, the trend was not substantial enough to affect the aquifer test.

The pretest pumping of well 34K103 was performed on November 2, 2004. The static water level was 25.31 ft. Discharge during the pretest pumping averaged 311 gallons per minute (gal/min) for 1.5 hours. The maximum drawdown was 26.7 ft.

During November 2–3, 2004, a 24-hour aquifer test was conducted in well 34K103 with an average discharge of 310 gal/min. The total amount of ground water withdrawn from the lower confined zone during the test was about 446,400 gallons. The total drawdown from 24 hours of pumping was about 27 ft (lower confined zone drawdown graph, below). During November 3–4, water-level recovery was monitored for 24 hours.



Drawdown and recovery in observed wells during aquifer test of the lower confined zone and the lower Brunswick aquifer, Darien test site, McIntosh County, Georgia, May and November, 2004.

Hydraulic properties of wells 34K103 and 34K104, Darien test site, McIntosh County, Georgia.

[ft^2/d, feet squared per day; ft/d, feet per day; do., ditto]

Well identification	Transmissivity (ft^2/d)	Hydraulic conductivity (ft/d)	Condition	Method used
		Lower confined zone		
34K103	6,000	60	Drawdown	Hantush and Jacob (1955)
do.	6,000	60	Recovery	Cooper and Jacob (1946)
		Lower Brunswick aquifer		
34K104	700	7	Drawdown	Cooper and Jacob (1946)
do.	700	7	Recovery	Cooper and Jacob (1946)
do.	700	7	Drawdown	Hantush and Jacob (1955)

Results from the drawdown analysis using the Hantush and Jacob (1955) method and recovery analysis using the Cooper and Jacob (1946) method provided a reasonable estimate of the hydraulic properties for the lower confined zone. The two methods using drawdown and recovery data estimated the transmissivity of the lower confined zone to be about 6,000 feet squared per day (ft^2/d) with a hydraulic conductivity of about 60 feet per day (ft/d) (hydraulic properties table, above).

Lower Brunswick Aquifer

The lower Brunswick aquifer test consisted of pumping and monitoring well 34K104, open to the lower Brunswick aquifer, and monitoring well 34K103, open to the lower confined zone. There was no change in ground-water level in the lower confined zone resulting from pumping the lower Brunswick aquifer. During April 29–May 6, 2004, the lower Brunswick aquifer test consisted of 5 days of background ground-water level monitoring, 4 hours pretest pumping, 24 hours constant-discharge pumping, and 24 hours monitoring ground-water-level recovery.

From April 29 to May 3, 2004, background ground-water-level data were collected in well 34K104. The water level varied from 23.04 ft to 27.14 ft, increasing during the period. The pretest pumping of well 34K104, open to the lower Brunswick aquifer, was performed on May 3, 2004. The static water level was 27.23 ft. Discharge during the pretest pumping averaged 61 gal/min for 4 hours. Total drawdown was 37.38 ft.

During May 4–5, 2004, a 24-hour aquifer test was conducted in well 34K104 with an average discharge of 58 gal/min. The total amount of ground water withdrawn from the lower Brunswick aquifer was about 83,520 gallons. Total drawdown after about 24 hours of pumping was about 37 ft (lower Brunswick drawdown graph, previous page). During May 5–6, 2004, water-level recovery was monitored for 24 hours.

Results from the analyses of drawdown and recovery data from well 34K104 using Cooper and Jacob (1946) and Hantush and Jacob (1955) methods provided a reasonable estimate of the hydraulic properties for the lower Brunswick aquifer. The two methods estimated the transmissivity of the lower Brunswick aquifer to be about 700 ft^2/d with a hydraulic conductivity of about 7 ft/d (hydraulic properties table, above).

GROUND-WATER QUALITY

Results of the chemical analysis of ground-water samples obtained from wells completed in the lower confined zone and lower Brunswick aquifer were used to describe and compare the geochemical variability of ground water in the two aquifers. Water samples were analyzed for major ions, metals, total organic carbon, nutrients, and radionuclides (water-quality table, facing page). Field properties—including pH, specific conductance, and water temperature—were measured onsite prior to sample collection. Concentration of constituents from the two aquifers were compared and to the U.S. Environmental Protection Agency (USEPA) (2000a, b) maximum contaminant levels (formerly known as primary contaminant level) and secondary standards (formerly know as secondary contaminant level) for drinking water. Additionally, these data were compared to the Georgia Environmental Protection Division (GaEPD) regulations for drinking water (Georgia Environmental Protection Division, 1997a, b). The major ion data are presented graphically using a trilinear diagram (page 100) showing the percentage composition of selected major cations and anions, as well as total dissolved-solids concentrations.

Lower Confined Zone, Surficial Aquifer System

Constituent concentrations in water from the lower confined zone are generally within the USEPA and GaEPD regulations for drinking water. Water collected from the lower confined zone has a dissolved chloride concentration of 10.9 milligrams per liter (mg/L), specific conductance of 245 microsiemens per centimeter (µS/cm), total organic carbon of 3.7 mg/L, and pH of 7.3. The 1,290 µg/L concentration of iron and the 171 µg/L concentration of manganese exceed the GaEPD regulations for these constituents. An analysis of tritium in water from the lower confined zone was conducted to determine if water may be entering the aquifer from the surface recharge. Total tritium was 0.3 picocuries per liter (pCi/L), which is less then the reporting limit of 5.7 pCi/L (water-quality table, facing page).

Concentration of major ions and field properties in water samples collected from the lower confined zone (well 34K103) and the lower Brunswick aquifer (well 34K104), Darien test site, McIntosh County Georgia, May 3 and November 2, 2004

[MCL, primary maximum contaminant level; SMCL, secondary maximum contaminant level; mg/L, milligram per liter; —, no data; pH are in standard units; µS/cm, microsiemens per centimeter; $CaCO_3$, calcium carbonate; NTU, nephelometric turbidity unit; <, less than; µg/L, microgram per liter; pCi/L, picocurie per liter; E, estimated value]

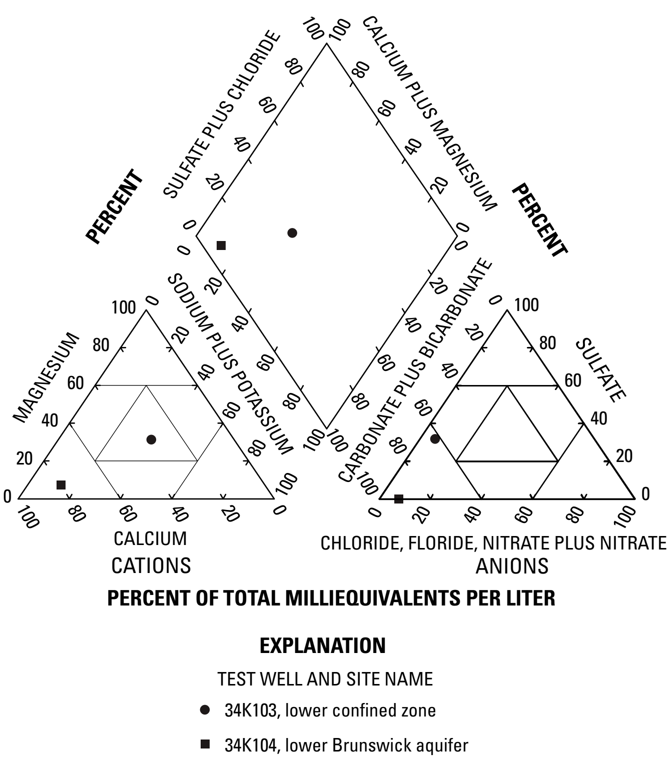
Constituents	Test well identification number and date		Drinking-water standards[1]	
	34K103 November 2, 2004	34K104 May 3, 2004	MCL	SMCL
Dissolved oxygen, in mg/L	6.4	0.3	—	—
Field pH, standard units	7.1	7.8	—	6.5–8.5
Lab pH, standard units	7.3	7.7	—	6.5–8.5
Field specific conductance, in µS/cm	355	412	—	—
Lab specific conductance, in µS/cm	245	443	—	—
Water temperature, in degrees Celsius	20.3	24.1	—	—
Hardness, as $CaCO_3$, in mg/L	188	152	—	—
Calcium, dissolved, in mg/L	68.8	31.1	—	—
Magnesium, dissolved, in mg/L	4.1	18.1	—	—
Potassium, dissolved, in mg/L	1.4	4.28	—	—
Sodium, dissolved, in mg/L	11.5	37.3	—	—
Alkalinity as $CaCO_3$, in mg/L	189	113	—	—
Turbidity, in NTU	10	—	—	—
Chloride, dissolved, in mg/L	10.9	10.2	—	250
Silica, dissolved, in mg/L	57.8	18.3	—	—
Sulfate, dissolved, in mg/L	<.2	75.2	—	250
Dissolved solids (sum of constituents), in mg/L	98	176	—	500
Ammonia, dissolved, in mg/L	0.2	0.1	—	—
Nitrite, nitrate, as N, dissolved, in mg/L	<.016	<.016	10	—
Phosphorus, dissolved, in mg/L	—	0.005	—	—
Phosphorus, total, in mg/L	—	<.004	—	—
Organic carbon, total, in mg/L	3.7	3.3	—	—
Aluminum, dissolved, in µg/L	<2	M	—	50–200
Antimony, dissolved, in µg/L	<.20	<.20	6	—
Barium, dissolved, in µg/L	8	5	2,000	—
Beryllium, dissolved, in µg/L	<.06	<.06	4	—
Cadmium, dissolved, in µg/L	<.04	<.04	5	—
Chromium, dissolved, in µg/L	<.8	<.8	100	—
Cobalt, dissolved, in µg/L	0.114	0.085	—	—
Copper, dissolved, in µg/L	E.2	0.6	—	1,000
Iron, dissolved, in µg/L	1,290	26	—	300
Lead, dissolved, in µg/L	0.27	E.05	—	—
Manganese, dissolved, in µg/L	171	<.8	—	50
Molybdenum, dissolved, in µg/L	<.4	E.2	—	—
Nickel, dissolved, in µg/L	<.06	0.52	100	—
Silver, dissolved, in µg/L	<.2		—	100
Strontium, dissolved, in µg/L	422	781	—	—
Zinc, dissolved, in µg/L	35	<3	—	5,000
Alpha radioactivity, Th-230, in pCi/L	—	0.2	—	—
Gross beta radioactivity, CS-137, in pCi/L	—	4.1	—	—
Tritium 2-sigma, in pCi/L	3.2	—	—	—
Tritium, total, in pCi/L	0.3	—	—	—
Uranium, dissolved, in µg/L	<.04	<.04	30	—

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

Lower Brunswick Aquifer

Constituent concentrations in water from the lower Brunswick aquifer are generally within the USEPA and GaEPD regulations for drinking water. Water collected from the lower Brunswick aquifer has a dissolved chloride concentration of 10.2 mg/L, specific conductance of 443 μS/cm, total organic carbon of 3.3 mg/L, and pH of 7.7.

A trilinear diagram showing the percentage composition of selected major cations and anions, as well as dissolved solids concentrations of those constituents is shown below. The trilinear diagram shows that water from the lower Brunswick aquifer is a calcium-carbonate type, and water from the lower confined zone is a bicarbonate type. Water in the lower confined zone has a hardness of 188 mg/L as $CaCO_3$, and water in the lower Brunswick aquifer has a hardness of 152 mg/L as $CaCO_3$ (based on the sum of milliequivalent of calcium, magnesium, barium, and strontium). According to Durfor and Becker (1964), water from the lower confined zone is classified as very hard and from the lower Brunswick aquifer is classified as hard.



Percentage composition of major ionic constituents and total dissolved solids in water from the lower confined zone of the surficial aquifer system and the lower Brunswick aquifer, Darien test site, McIntosh County, Georgia, May and November 2004.

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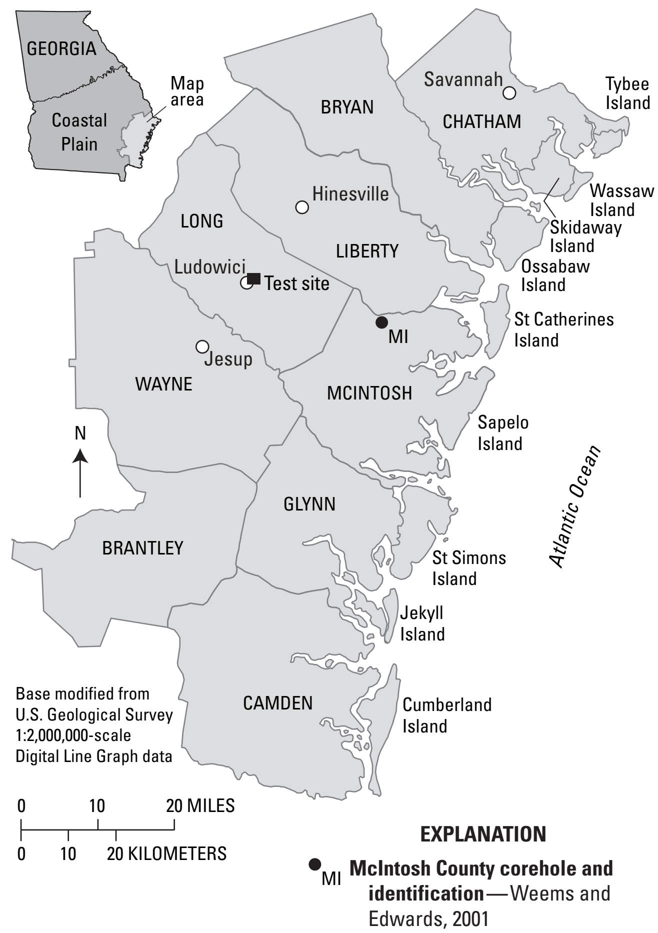
Hydrogeology, Hydraulic Properties, and Water Quality of the Surficial and Brunswick Aquifer Systems Near the City of Ludowici, Long County, Georgia, July 2003

By Sherlyn Priest and Gregory S. Cherry

INTRODUCTION

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

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



Ludowici test site, Long County, Georgia, 2003.

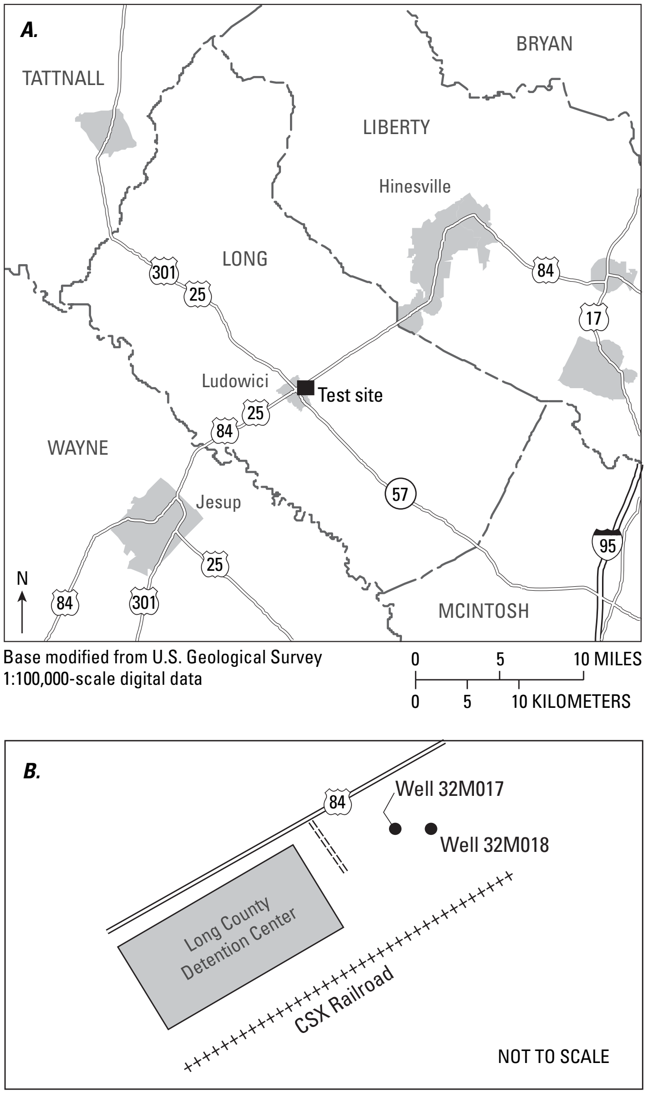
Description of Study Area

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

Methods of Study

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

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



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

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

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

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

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

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

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

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

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

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

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

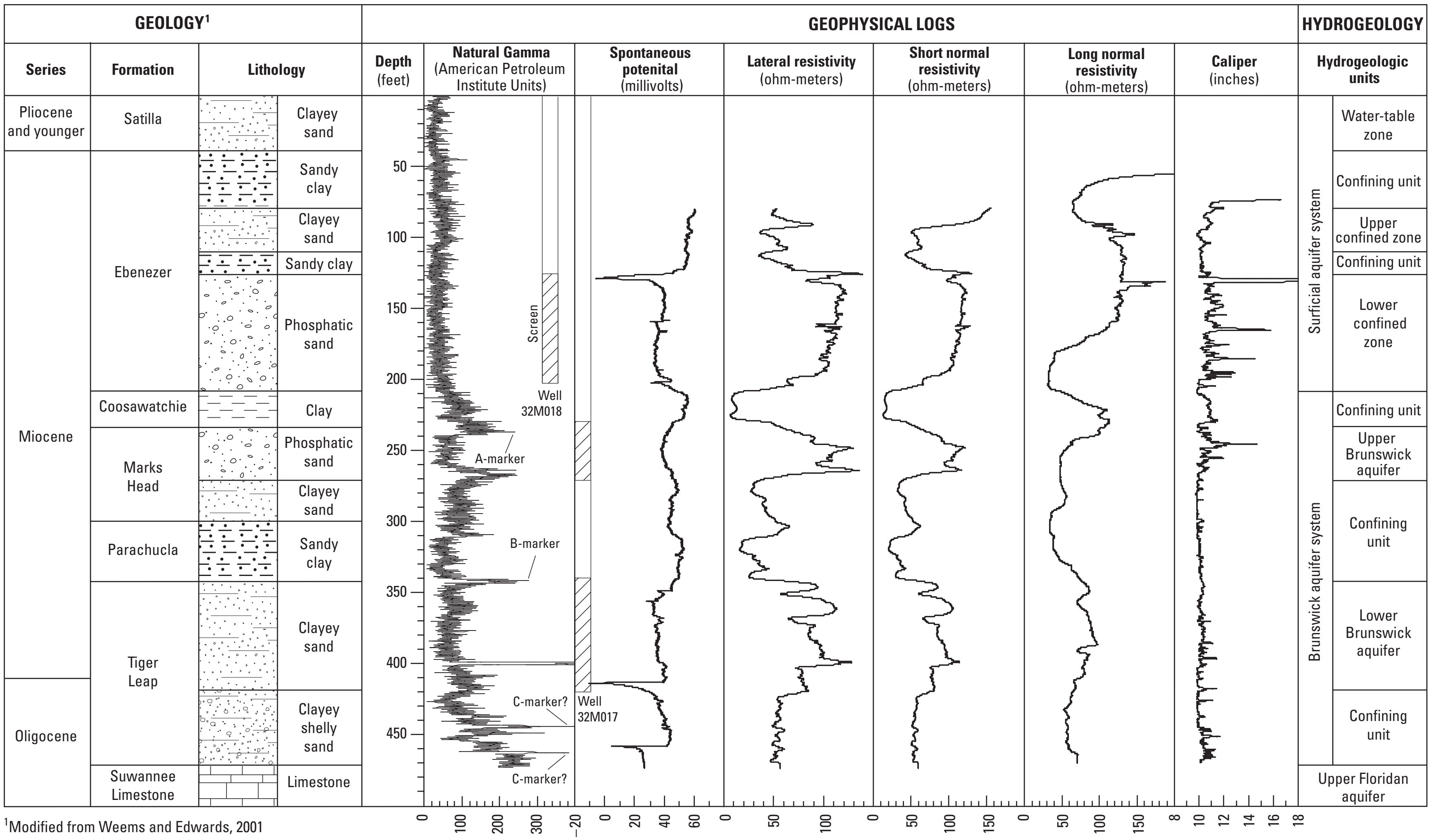
Water samples were collected from wells 32M018 and 32M017 and analyzed for major ions, nutrients, metals, and radionuclides. Water samples were collected after several hours of pumping when field conditions had stabilized. Field properties were measured in a flow-through chamber using a commercially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

Previous Investigations

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

HYDROGEOLOGY AND LITHOLOGY

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



[1]Modified from Weems and Edwards, 2001

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

HYDRAULIC PROPERTIES

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

Lower Confined Zone, Surficial Aquifer System

The surficial aquifer system test was conducted July 29–August 1, 2003, and consisted of 24 hours of constant pumping and 55 hours of water-level recovery. For the test, well 32M018, completed in the lower confined zone, was pumped and monitored. During the test, water levels in well 32M017 were monitored to record any response within the Brunswick aquifer system. Prior to the surficial aquifer system test, water levels were measured during a 7-day period in both wells to document background water-level trends and possible tidal effects. Water-level measurements varied from about 32.98 to 33.28 ft below land surface in well 32M018, indicating minor changes in water level during pretest monitoring. During the test, water levels were measured manually using an electric tape. In well 32M018, discharge varied from 800 to 850 gallons per minute (gal/min), averaging 826 gal/min throughout the test with a total 1,189,440 gallons pumped. Total drawdown was 23 ft after 24 hours of pumping (lower confined zone graphs, below).

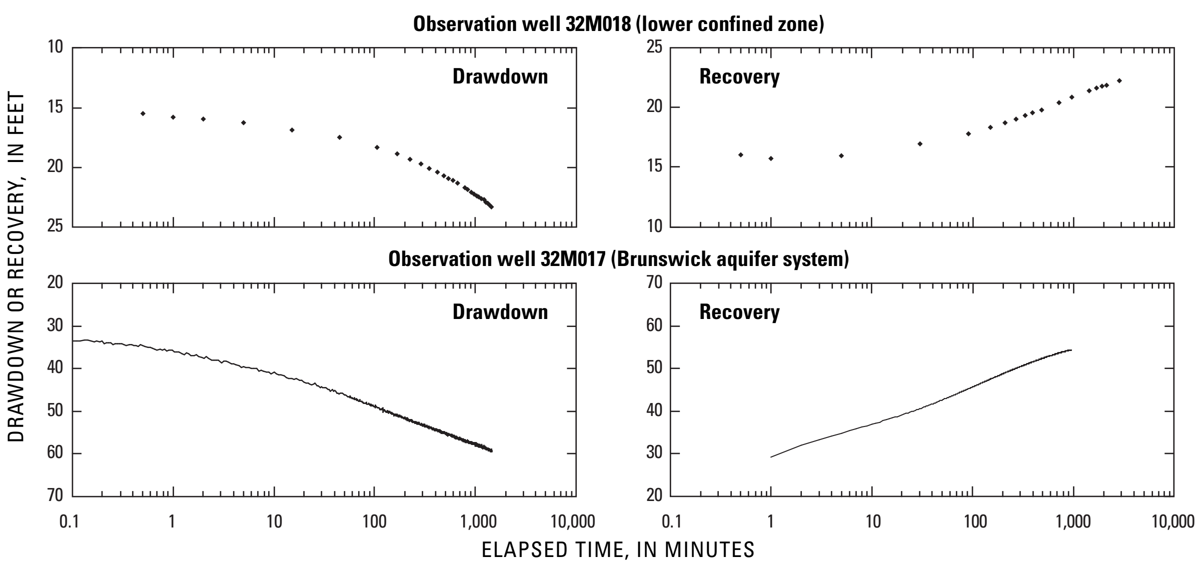
Results from the analyses of the drawdown data from well 32M018 using the Cooper and Jacob (1946) and the Hantush and Jacob (1955) analytical methods provided a reasonable estimate of the hydraulic properties of the lower confined zone of the surficial aquifer system. Results from the two solutions are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

Upper and Lower Brunswick Aquifers

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

Prior to the Brunswick aquifer system test, water levels were measured during a 4-day period in both wells to document background water-level trends and possible tidal effects. Water-level measurements varied from about 34.93 to 34.96 ft below land surface in well 32M017, indicating virtually no change in water level during pretest monitoring. In well 32M017, discharge varied from 580 to 650 gal/min, averaging 600 gal/min throughout the test; a total of about 861,120 gallons were discharged. Total drawdown was 64 ft after 24 hours of pumping (Brunswick aquifer system graphs, below).

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



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

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

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

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

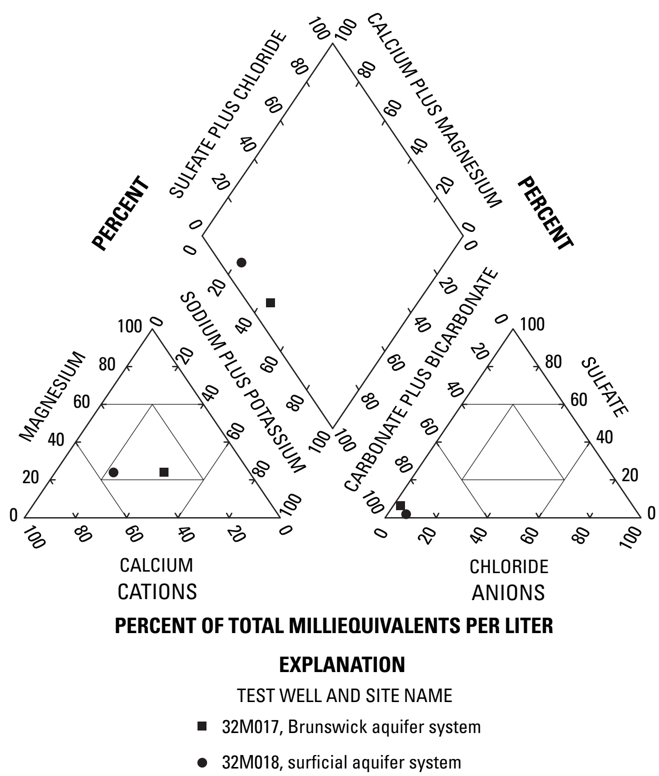
GROUND-WATER QUALITY

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

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

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

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



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

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

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

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

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

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Influence of Low-Angle Lithologic Contacts and Thrust Faults on Ground-Water Flow in a Crystalline-Rock Aquifer System, Rockdale County, Georgia

By Lester J. Williams and Alan M. Cressler

INTRODUCTION

The U.S. Geological Survey (USGS)—in cooperation with Rockdale County—began intensive field studies during 2003 to investigate the occurrence and availability of ground water in fractured-crystalline rock. These studies were undertaken with the hope that this information could be used to develop additional ground-water resources in the area. The results of these studies have:

- increased understanding of various geologic factors influencing ground-water flow in fractured-crystalline-rock geologic settings,
- helped improve ground-water exploration and development techniques, and
- provided insight into management of ground-water resources in complex aquifer settings of the Piedmont physiographic province.

This technical highlight presents results of focused studies in the Conyers area of Rockdale County (map, facing page). The Conyers area is highlighted because of the long-term ground-water use in that area and because of access to several municipal wells, which permitted direct observations of water-bearing zones in the subsurface.

Ground-water flow in the Piedmont physiographic province of Georgia is controlled by many different geologic factors. Lithologic contacts exert one of the stronger influences on the movement and availability of ground water in crystalline-rock aquifer systems. Many high-yield wells (defined herein as more than 25 gallons per minute) derive water from permeable lithologic contacts (Cressler and others, 1983; Chapman and others, 1999; Williams, 2003a). Thrust faulting also can be a major influencing factor when rocks of contrasting character are juxtaposed across the fault. Other factors include rock type, geologic structures, depth of weathering, topography, and the nature of the recharge area (Herrick and LeGrand, 1949; Crawford and Kath, 2003; Williams and others, 2005).

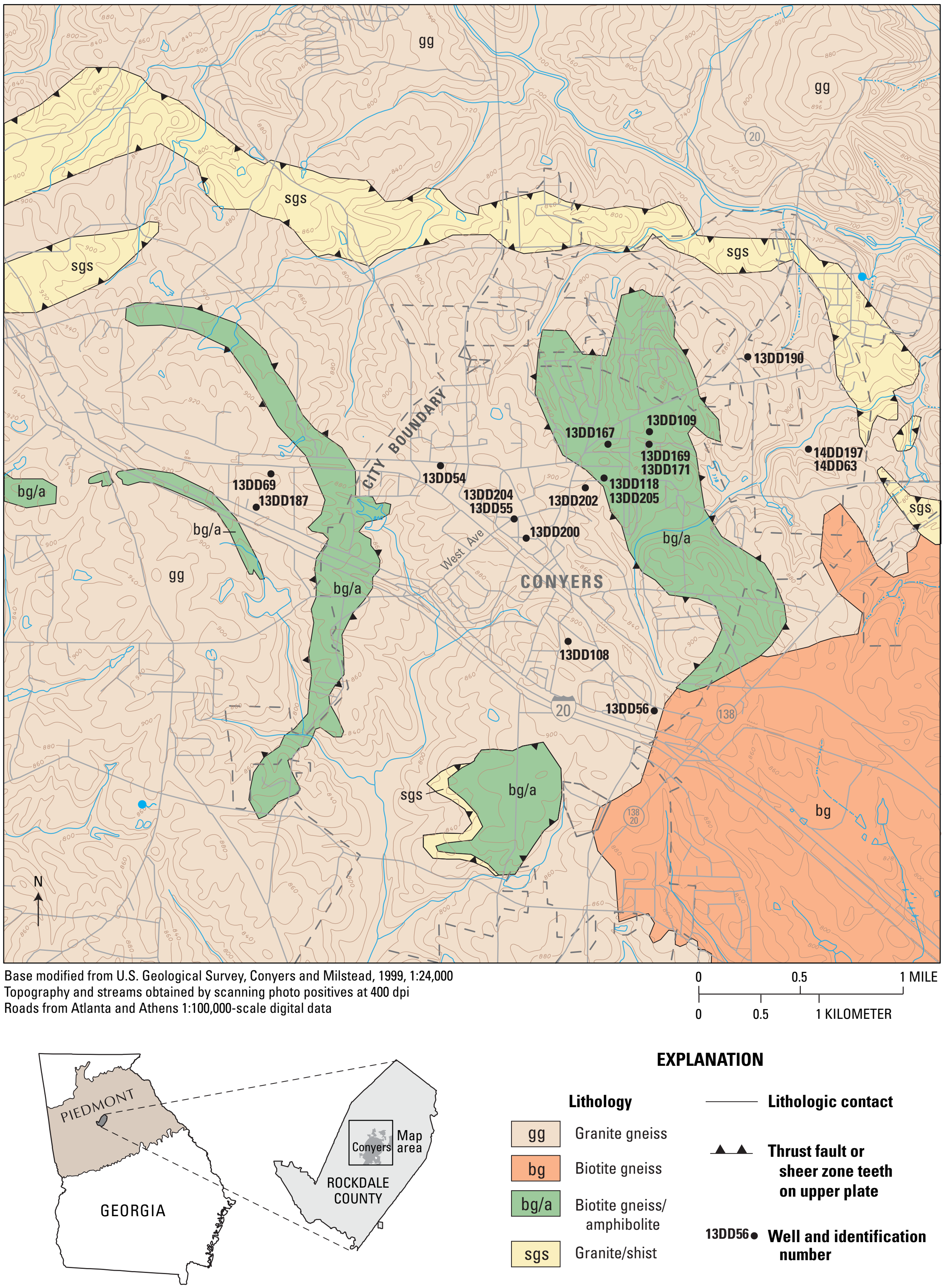
In many areas of the Piedmont, the inclination (dip) of lithologic contacts is moderate to steep; for this reason, it is common practice to site water wells near lithologic contacts with the hope of intercepting a water-bearing contact with depth. There are, however, areas where the lithologic contacts are at low angles and the structural attitude of the contact may not be coincident with the structural attitude of compositional layering and/or foliation (Crawford and Brackett, 1995). Knowing the depth and nature of permeable contacts can provide great insight into estimating the volume of water available to wells and their contributing recharge areas; thus, increasing the ability to protect the source of water to water-supply wells in these types of geologic settings.

Previous Studies

The most detailed account of the geology and ground-water resources in Rockdale County is by McCollum (1966). In that report, McCollum compiled a list of wells and springs in the county, described the weathering characteristics of major and minor rock units, and described the occurrence and availability of ground water in relation to the geology. McCollum's lithologic map shows the distribution of six major rock units including amphibolite gneiss, Panola Granite, muscovite quartzite, garnet-mica schist, Lithonia Gneiss, and porphyroblastic gneiss.

Atkins and Higgins (1980), McConnell and Abrams (1984), and Higgins and others (1984, 1988, 1998) also described the geology of the area and modified the original McCollum (1966) map. Higgins and others (1988) proposed one of the more widely accepted structural interpretations for the area. The authors suggested that the movement of massive stacks of thrust sheets during the Middle Ordovician through Carboniferous periods formed much of the deformation and metamorphism in the Atlanta region. The thrust sheets were injected by igneous intrusions at various times during thrusting. Thrust stacks and igneous intrusions were further metamorphosed, folded, and faulted, resulting in a complex distribution of lithologies.

Cressler and others (1983) reported on the ground-water resources for the 27-county "greater" Atlanta region. That report provides an acoustic-televiewer image and a rock core showing a horizontal stress-relief fracture for well 13DD90 located south of the Conyers area (just south of the area shown on geologic map, facing page). The authors also identified several municipal wells in the Conyers area (13DD55, 13DD56, 13DD69) that apparently tap horizontal stress-relief fractures. The areal extent of horizontal stress-relief fractures was believed to range from as little as 100 to more than 1,000 feet (ft) across. Cressler and others (1983) identified a municipal well in Conyers (13DD55) as one of the better producing wells. This well had been pumped continuously for more than 30 years; thus, indicating sustainable long-term pumping.



Locations of wells, lithology, and fault contacts in the Conyers area, Rockdale County, Georgia.

Acknowledgments

The USGS conducted this study in cooperation with Rockdale County. The authors gratefully acknowledge the many people who gave assistance during this study. Hundreds of property owners throughout Rockdale County supplied information about their wells and many permitted access to their wells for borehole geophysical logging. The authors are particularly grateful to Lauri Ashmore, Scott Emmons, Ray Hodges, and the Rockdale County Board of Commissioners who generously supported, provided feedback, and guided this water-resources study since 2003. The authors also thank companies that furnished well-construction information used in this study; these include Brown and Cox Drilling in Covington, Middle Georgia Well Drilling in Zebulon, and Robinson Well Drilling in Monroe.

INFLUENCE OF LOW-ANGLE LITHOLOGIC CONTACTS AND THRUST FAULTS AND ON GROUND-WATER FLOW

Low-angle lithologic contacts and/or thrust faults are often overlooked (or not recognized) as an important factor in controlling ground-water flow in crystalline-rock aquifers. Large areas may be underlain by low-angle lithologic units, and the flow systems developed in these rocks can be highly productive.

To investigate these features in the Conyers area, a detailed geologic map was compiled and used in conjunction with borehole geophysical logging. The geologic mapping and borehole logging were critical in defining the subsurface rock units and in providing data needed to understand the local stratigraphic section. Geologic mapping also was used to determine the overall structural relations and presence of major structural features, such as folds and faults. Aquifer testing (November 14–17, 2005) was used to determine the interconnectivity of the fracture system among municipal wells in Conyers, Georgia. Water levels in 10 drilled (bedrock) wells and 3 bored (regolith) wells were monitored before, during, and after the aquifer test to determine the response of pumping at various distances and directions from the pumped well. Well-construction details are provided in the table on the facing page.

Geologic Mapping and Borehole Geophysical Logging

Geologic mapping conducted during this study generally confirmed previous mapping by McCollum (1966) and Higgins and others (1988, 1998). The main lithologic contact in this area is between a white to yellowish-white weathered, quartz-rich granite gneiss (Lithonia Gneiss) and a dark-gray to grayish-brown biotite gneiss containing layers and lenses of hornblende plagioclase amphibolite in some places. The distribution of the rock units is shown on geologic map.

Several existing wells—including 13DD55, 13DD56, 13DD69, 13DD197, 13DD118, 13DD109, and 13DD190—were used for borehole geophysical logging (geologic map). Two new test wells, including 13DD204 and 14DD197, were drilled during the study. Lithologic cuttings and borehole geophysical logs also were collected from the two new test wells. Lithologic logs and borehole geophysical characteristics of selected wells in the study area are shown on page 114.

Before collecting the borehole geophysical logs and drilling the two new test wells, it was assumed that the granite gneiss in the Conyers area was thick and massive and that the wells were producing water from granite gneiss. The results of borehole geophysical logging and test wells, however, revealed that the granite gneiss is not as massive as originally believed, and there were other distinct water-bearing rock types within or below the granite gneiss. In some wells, such as 13DD69 14DD167, and 13DD204, as shown in logs on page 114, the sequence is granite gneiss over biotite gneiss and biotite gneiss/amphibolite; in other wells, the sequence is biotite gneiss over granite gneiss and biotite gneiss. The presence of biotite gneiss and amphibolite-bearing rock within or beneath the granite gneiss is explained through tight recumbent folding or thrust faulting, the latter explanation being more likely because of contact relations observed between the units.

At well 13DD69, located on the west side of the Conyers area, biotite gneiss, biotite gneiss with amphibolite lenses, granite gneiss, and minor pegmatite are overlain by 190 ft of granite gneiss. At this location the biotite gneiss/amphibolite unit is distinct and easily differentiated from the overlying massive, poorly foliated granite gneiss. Based on flowmeter logging, depths of water-bearing zones in this well range from 190 to 405 ft, with the largest zone near the bottom of the well in the biotite gneiss/amphibolite unit (Khallouf and Williams, 2003).

At well 13DD204 (drilled adjacent to the old municipal well 13DD55, now abandoned), a well-foliated biotite gneiss with minor amounts of hornblende and epidote-bearing gneiss are overlain by about 358 ft of granite gneiss. A weathered zone in the biotite gneiss is present just beneath the granite gneiss contact; this zone consists of weak friable rock that has been partially altered to saprolite or "saprock" as noted on page 114. Based on flowmeter logging, the main production zones in this well are located about 80 ft below the saprock zone at a depth of between 450 and 460 ft. From optical televiewer images (page 115), this water-bearing zone was determined to be two separate foliation-parallel parting planes, each only a few inches in aperture. Farther to the east, wells 13DD118, 13DD109, and 14DD197 penetrate similar low-angle biotite gneiss and granite gneiss units that appear to be stratigraphically equivalent to the units penetrated in 13DD204.

Overall, depths of the lithologic contacts (or fault contacts) determined from geophysical logs indicate low angles with dips of about 5 degrees or less. Although water-bearing zones are present at various depths, most are between 350 and 460 ft below land surface and are coincident with a major lithologic contact. Borehole camera and optical-televiewer images show that almost all of the "high yielding" (tens or hundreds of

Location and construction information for selected wells in the Conyers area, Rockdale County, Georgia.

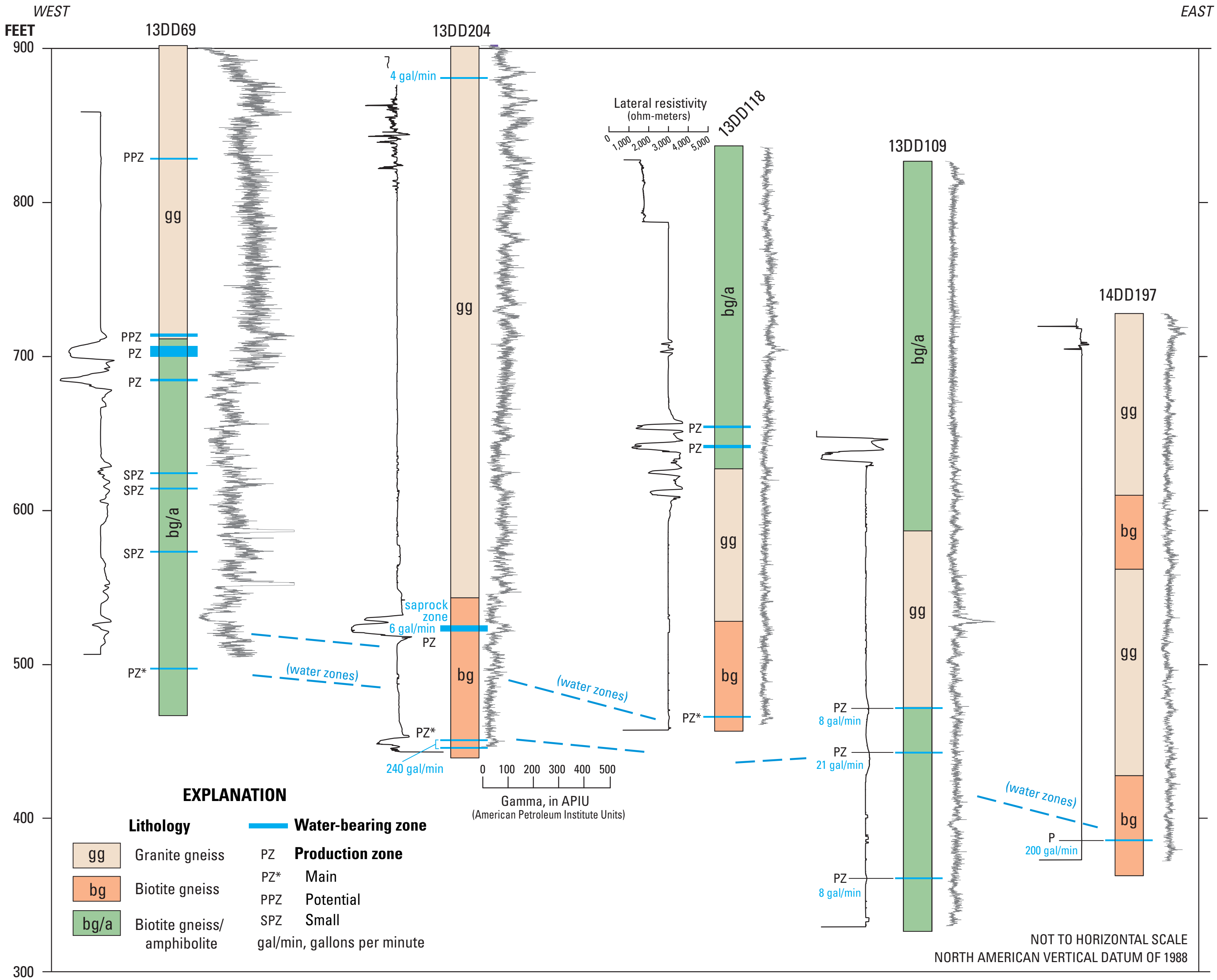
[ft, foot; gal/min, gallons per minute; PVC, polyvinyl chloride; —, no data available; latitude and longitude in decimal degrees North American Datum of 1983; altitude referenced to North American Vertical Datum of 1988; lithologic units are: bg, biotite gneiss, bg/a biotite gneiss with thin amphibolite layers; gg/bg, granite gneiss and biotite gneiss]

Well	Latitude/ longitude	Land-surface altitude (ft)	Yield (gal/min)	Well depth (ft)	Casing depth (ft)	Casing diameter (inch)	Casing material	Date drilled	Water-bearing unit
Bedrock wells									
13DD108	33.6617 –84.0164	900.0	60	480	10	6	PVC	11/88	bg
13DD109	33.6766 –84.0095	833	42	505	177	6	Steel	5/88	bg/a
13DD118	33.6732 –84.0131	863.5	100	380	30	6	PVC	4/86	bg/a
13DD167	33.6756 –84.0130	859	100	300	15	6	PVC	1995	bg/a
13DD171	33.6758 –84.0099	826	30	365	90	6	PVC	2/93	bg/a
13DD190	33.6819 –84.0013	848	30	705	15	6	PVC	6/88	gg/bg
13DD202	33.6726 84.0151	873.5	50	325	93	6	PVC	2000	bg/a
13DD204	33.6706 –84.0210	916	250	462	19.5	6	PVC	2/05	bg
13DD54	33.6740 –84.0278	893	90	350	—	8	Steel	—	bg
13DD55	33.6707 –84.0213	910.1	120	550	34	10	Steel	1930	bg
13DD56	33.6568 –84.0091	889.1	243	410	103	8	Steel	1966	bg
13DD69	33.6734 –84.0421	920.1	172	435	25	6	Steel	07/74	bg/a
14DD197	33.6755 –83.9959	740	200	365	6	6	PVC	10/05	bg
14DD63	33.6746 –83.9963	770.1	125	500	25	6	Steel	06/68	bg
Shallow wells									
13DD169	33.6761 –84.0100	823.5	—	32	32	24	Concrete	—	Surficial
13DD200	33.6693 –84.0200	910	—	25.4	—	32	—	—	Surficial
13DD205	33.6736 –84.0132	862	—	48	48	24	Concrete	—	Surficial

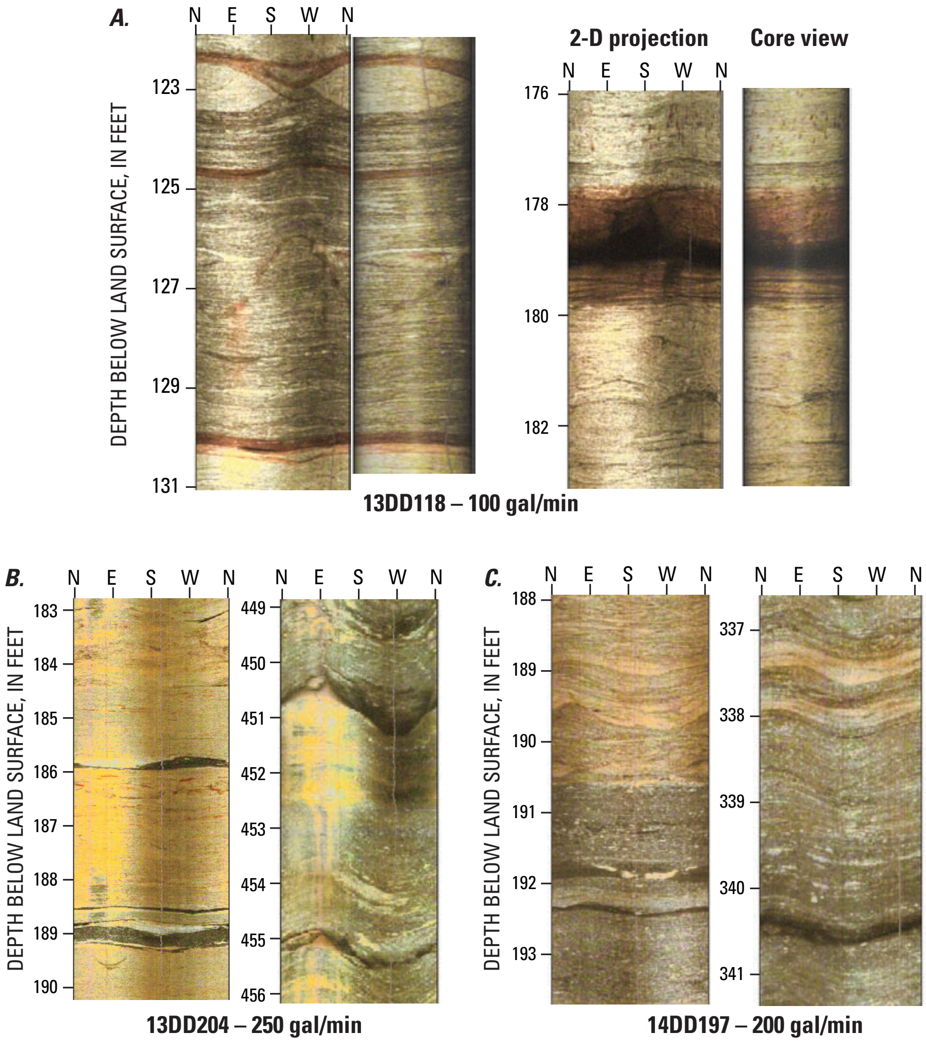
gallons per minute) water-bearing zones are foliation-parallel partings located at or near contacts between rocks of contrasting lithologic character. The foliation-parallel partings in these wells range from fractions of an inch to several inches in aperture (Williams and Burton, 2005).

The strike and dip measurements obtained from optical-televiewer logs are characteristic of low-angle lithologic contacts and/or thrust faulting. Abrupt strike and dip changes across some of the major lithologic contacts confirm that the structural attitude of the contacts is not always coincident with the structural attitude of foliation and indicates that some, if not all of the contacts, are produced by thrust faulting.

It should be noted that thrust faults described for this area were produced at great depths, under high confining pressures, and at elevated temperatures. The faults, therefore, do not create an increase in porosity or permeability, but rather provide a discontinuity whereby other processes, such as differential weathering (Williams, 2003a) or stress relief (Cressler and other, 1983), can increase permeability or water-storage capacity along these structures.



Lithology and borehole geophysical log characteristics for selected wells in the Conyers area, Rockdale County, Georgia.



A. Water-bearing zones in well 13DD118 range from small hairline foliation-parallel partings (shown at 122.5 and 130 feet) to much larger (from 1 to 8 inch) openings formed along nearly horizontal foliation and compositional layering in the bedrock (shown between 178 and 180 feet). Similar water-bearing zones were observed in other wells in the Conyers area in the biotite gneiss/amphibolite unit.

B. In well 13DD204, low-angle foliation in the granite gneiss (shown between 183 and 190 feet) as compared to moderately dipping foliation in the underlying biotite gneiss (shown between 449 and 456 feet). The two fractures shown at 450 and 455 feet are from 1- to 2-inch-wide foliation-parallel partings and are the main water zones in this well.

C. In well 14DD197, a horizontal contact between granite gneiss and biotite gneiss is shown at 190.5 feet. Near the bottom of the well a fracture at about 340 feet produces an estimated 200 gal/min from 1- to 2-inch-wide foliation parallel parting dipping about 20 degrees to the south. Dips are highly variable in this well.

Optical-televiewer images are oriented to magnetic north and shown in both two-dimensional projections and three-dimensional "virtual core" views. Cardinal directions are indicated at top of the two-dimensional projection (gal/min, gallons per minute; yield listed is for entire well and is estimated).

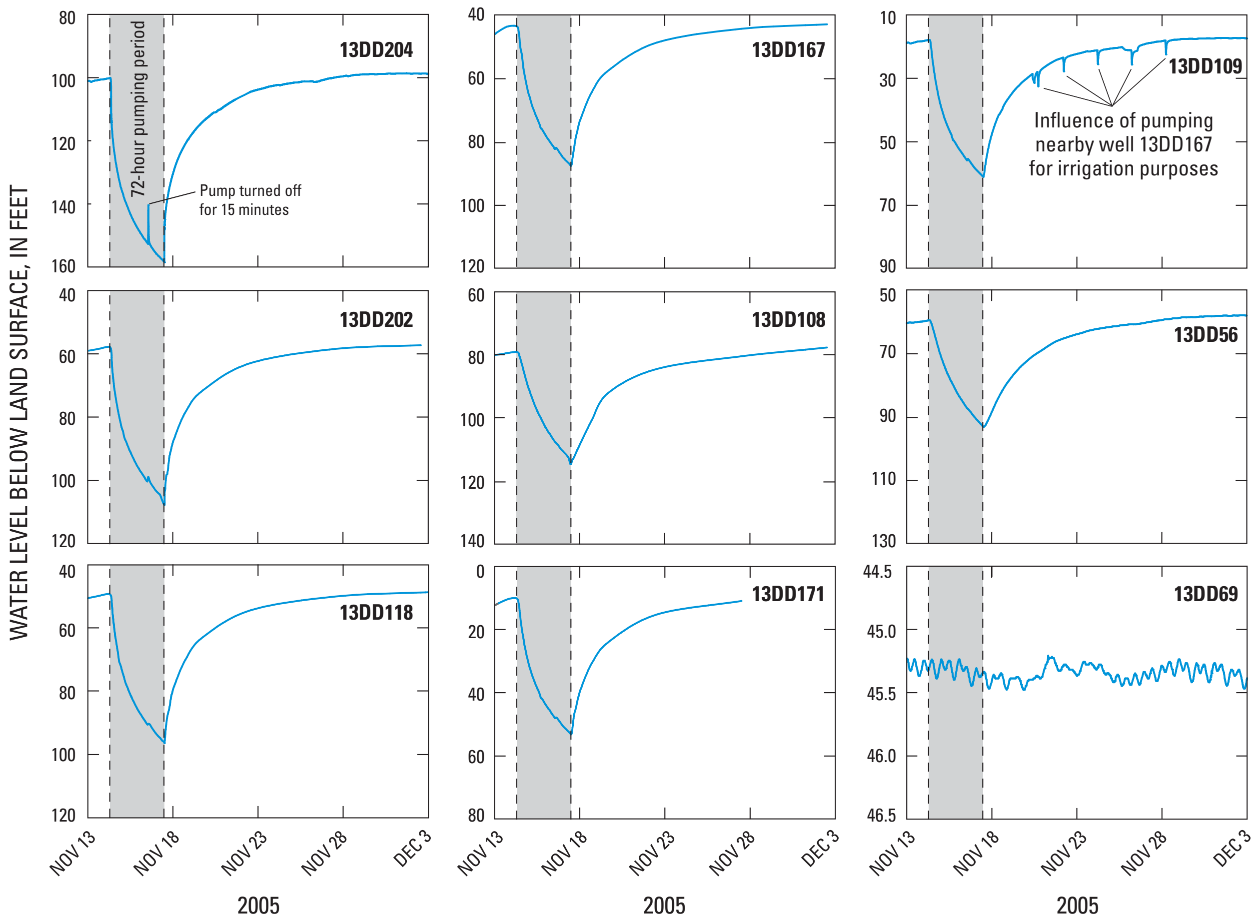
Optical-televiewer images of water-bearing zones in wells (A) *13DD118,* (B) *13DD204, and* (C) *14DD197, in the Conyers area, Rockdale County, Georgia.*

Aquifer Test and Response to Pumping

To investigate the interconnectivity of the fracture system among wells and to determine whether or not drawdown would extend out along the lithologic contacts, a 72-hour aquifer test was conducted from November 14, 2005, to November 17, 2005. A new test well (13DD204) was drilled specifically to conduct the aquifer test. This new well was placed adjacent to the old municipal well 13DD55. Prior to 1985, well 13DD55 and several other wells in the area were used to furnish the city of Conyers water supply. Well 13DD55 was the most productive well and reportedly sustained a pumping rate of 120 gal/min for 11 years under continuous pumping (Cressler and others, 1983).

Test well 13DD204 was drilled to a total depth of 462 ft and remained essentially dry until penetrating high-yielding fractures near the bottom of the well. An attempt was made to drill the well to 550 ft (total depth of 13DD55); however, the large volume of water produced from the deep fractures "drowned out" the pneumatic hammer, effectively preventing deeper drilling beyond 462 ft.

During the aquifer test, well 13DD204 was pumped for 72 hours at a nearly constant rate. The starting pumping rate was 202 gal/min, and the ending rate was 197 gal/min. During pumping, the water level in the pumped well was lowered from about 100 ft below land surface at the beginning of the test to about 160 ft at the end of the test. The pumping water



Drawdown and recovery in wells observed during aquifer test of well 13DD204, in the Conyers area, Rockdale County, Georgia.

level did not stabilize during the test period (graphs, above). Water levels in 7 of 10 observation wells responded quickly to the pumping, and began drawing down within a few minutes and continued to drawdown throughout the remainder of the test. Drawdown in the observation wells ranged from about 50 ft at well 13DD202 (located 1,900 ft away from the pumped well) to about 33 ft at well 13DD56 (located 6,200 ft away) (table, facing page). None of the water levels in observation wells stabilized during the test, indicating that the aquifer system did not reach equilibrium with sources of recharge supplying the deep water-bearing fracture zones.

After pump shutdown, the water level in the pumped well recovered about 80 percent in 3 days and took more than 9 days to fully recover. A similar recovery response was observed in wells 13DD109, 13DD118, 13DD167, 13DD171, 13DD202, and 13DD56 (table, facing page). The slow recovery in the pumped well and in the observation wells indicates a slow recharge rate to the water-bearing zones supplying the well. Recovery was even slower in well 13DD108, which took 4 days to recover 80 percent and took more than 12 days to fully recover. The delayed response probably indicates that the deep bedrock fracture system is being recharged across a relatively wide area possibly through vertical leakage along steep joints and fractures identified in the area (Khallouf and Prowell, 2003; Tucker and Williams, 2005) or along compositional layering from outcrop areas (Williams, 2003b).

Water levels were monitored in three shallow wells to determine the interconnectivity of the deep bedrock system to the shallow water-table zone. Despite the substantial drawdown in the deep bedrock system, no detectable drawdown was observed in the shallow wells during the aquifer test (hydrographs, facing page). This indicates that the deep permeable fractures are either (1) not receiving a substantial amount of recharge directly from the overlying shallow zone near the pumped well or (2) recharge from the shallow zone to the deep system occurs slowly across a widespread area.

The extensive drawdown observed during the 72-hour aquifer test indicates that several of the municipal wells in the Conyers area tap the same interconnected horizontal fracture system. In this type of system, high-capacity wells pumped simultaneously from the same zone could easily lead to overpumping

Distance, drawdown, and recovery response observed during aquifer test of well 13DD204, November 2005, Conyers area, Rockdale County, Georgia.

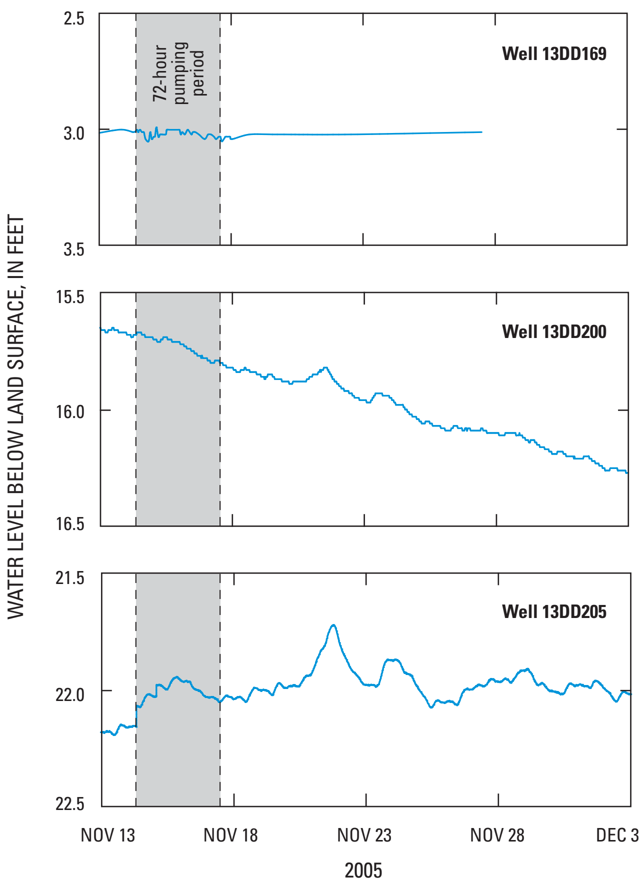
[ft, foot; bls, below land surface; %, percent; —, no data available]

		Drawdown details[1]			Recovery response in hours[2]			
Well	**Distance from pumped well (ft)**	**Starting water level (ft bls)**	**Ending water level (ft bls)**	**Drawdown (ft)**	**50%**	**80%**	**90%**	**100%**
13DD204	Pumped well	100.3	158.6	58.3	25	66	107	233
13DD202	1,909	58.1	107.9	49.8	22	74	121	265
13DD118	2,568	49.5	96.6	47.1	23	81	121	299
13DD167	3,044	43.6	87.4	43.8	25	83	132	284
13DD108	3,523	79.2	114.9	35.7	49	96	165	300
13DD171	3,841	10.2	53.3	43.2	26	92	127	—
13DD109	4,100	17.9	61.3	43.4	25	85	131	287
13DD56	6,193	59.7	93.2	33.6	44	106	155	267

Note: No drawdown was observed in bedrock wells 13DD69 and 14DD199; no drawdown observed in shallow wells 13DD169, 13DD200, and 13DD205.

[1]Well 13DD204 was pumped at an average rate of about 200 gallons per minute for 72 hours starting on November 14, 2005; water levels are shown at the start and end of pumping.

[2]Recovery response is expressed in hours to recover within 50%, 80%, 90%, and 100% of the starting water level.



Water-level hydrographs for shallow wells observed during aquifer test of well 13DD204, in the Conyers area, Rockdale County, Georgia.

and decreased well yield during long periods of time. Sources of recharge may be many thousands of feet from the pumped well and could be located in both upland and lowland areas. Long-term pumping rates and pumping interferences among wells could be determined through water-level monitoring.

From the aquifer test, it is evident that pumping high-capacity wells, such as those operated by the city of Conyers prior to 1985, can quickly reverse the natural hydraulic gradient across permeable horizontal fracture systems without regard to topographic position or location. This could be a concern with respect to wellhead protection and watershed management strategies commonly employed today. The efficiency of these horizontal systems could permit movement of water from distant sources located across topographic divides and from distances as much as 1 mile or more away from the pumped well.

SUMMARY AND CONCLUSIONS

Geologic mapping and borehole geophysical logging were used to investigate the high-capacity municipal wells and hydrogeologic characteristics of the fractured-crystalline rock in the city of Conyers, Georgia. Based on geophysical logging interpretation, the fracture zones in the Conyers area were found to be developed primarily along nearly horizontal lithologic and/or thrust fault contacts below massive, poorly foliated granite gneiss. Differential weathering along the contacts has produced semicontinuous water-bearing zones across the area consisting of small- to medium-sized foliation-parallel partings that range from fractions of an inch to several inches in aperture and zones of saprolite and saprock. Because of the low-angle dip of the lithologic contacts across the area, the horizontal permeability is many times greater than the vertical permeability. As a result, when water is pumped from these horizontal systems, drawdown quickly expands out from the well until sources of recharge are intercepted to sustain the pumping rate.

The lithologic contacts and/or thrust faults produce favorable geologic conditions for the development of stratigraphically controlled water-bearing zones in the Conyers area. Where the contacts are low-angle and laterally extensive, the flow in these systems may not necessarily follow contours of topographic basins. Water-supply wells tapping these fracture systems can easily reverse the hydraulic gradient and can produce a large area of influence around the pumped well. Knowing the depth and nature of permeable contacts and/or faults can provide additional insight into better understanding the volume of water available to wells and their contributing recharge areas; thus, increasing the ability to protect the source of water to water-supply wells in these types of geologic settings.

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SELECTED GROUND-WATER PUBLICATIONS, CONFERENCES, AND OUTREACH, 2004–2005

Introduction

Numerous reports, conference proceedings papers, and abstracts were published during 2004 and 2005 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 (mainly the Environmental Protection Division); U.S. Department of Defense, City of Brunswick and Glynn County; Albany Water, Gas, and Light Commission; City of Lawrenceville; and Rockdale County. Most of these publications are Web-only and can be viewed and downloaded at *http://ga.water.usgs.gov/ga004.html*

Georgia Water Resources Conference for 2005

An important conference that is co-sponsored by the USGS and at which results of several USGS investigations are highlighted is the biennial Georgia Water Resources Conference. The 9th biennial conference was held at The University of Georgia in Athens during April 2005. Twenty-five USGS papers, 12 of which addressed ground-water investigations, were published in the conference proceedings (see bibliographic listing, below).

Other Conferences and Outreach Events

Other conferences and outreach events in which USGS ground-water scientists participated during 2004 and 2005 include:

- American Geophysical Union (AGU) spring and fall meetings;
- Geological Society of America, Southeast Section meeting;
- Georgia Water and Pollution Control, spring and annual conferences;
- Georgia Rural Water Association, fall conference;
- Clemson University David S. Snipes Annual Hydrogeology Symposium;
- Georgia Ground Water Association;
- Association of Engineering Geologists;
- Georgia Annual CoastFest; and
- SunBelt Annual Exposition.

Selected USGS Reports and Conference Proceedings Articles

USGS Reports

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Williams, L.J., and Burton, W.C., Common types of water-bearing features in bedrock, Rockdale County, Georgia, 7 p.

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Ground-Water Conditions and Studies in Georgia, 2004–2005

Scientific Investigations Report 2007-5017

David C. Leeth and others