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Groundwater Conditions and Studies in Georgia, 2008–2009

Scientific Investigations Report 2011–5048

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

Preface

This report is published biennially in stop format and presents a summary of groundwater conditions in Georgia, and a description of ongoing groundwater studies. This report is the culmination of a concerted effort by personnel of the U.S. Geological Survey, Georgia Water Science Center who collected, compiled, organized, analyzed, verified and edited and assembled the report. In addition to the authors, who had primary responsibility for ensuring that the information contained herein is accurate and complete, the following individuals contributed substantially to the collection, processing, tabulation, and review of the data:

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Cover. (Left) Well 13FF14 located in Lawrenceville, Georgia, being pumped during a 72-hour aquifer test. Water levels and discharge were continuously monitored during the test. The well is 280 feet deep with 23 feet of casing and is completed in the crystalline rock aquifer. Photo by Michael D. Hamrick, USGS.

(Center) A hydrologic technician from the Groundwater Information and Project Support Unit prepares to lower a geophysical logging tool in a well. The well is located at the Albany Water Gas and Light Commission well field, Dougherty County, Georgia. Photo by Debbie Warner Gordon, USGS.

(Right) Test well being drilled at Fort Stewart, Liberty County, Georgia, to assess the water-bearing properties of the surficial aquifer as a potential source of irrigation water for athletic fields. Photo shows the well being developed with a drill rig air-lifting water from the well prior to conducting a 24-hour pumping test. The well was completed to 100 feet with screen set from 50 to 90 feet. Results from the 24-hour pumping test indicated that the well yield ranged from 545 to 550 gallons per minute. Photo by Michael D. Hamrick, USGS.

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Conversion Factors and Datums

Multiply	By	To obtain
	Length	
inch	2.54	centimeter (cm)
inch	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
yard (yd)	0.9144	meter (m)
	Flow rate	
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)

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 have been converted to NAVD 88 for use in this publication.

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

Altitude, as used in this report, refers to distance above the vertical datum.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µ/L).

Groundwater Conditions and Studies in Georgia, 2008–2009

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Abstract

The U.S. Geological Survey collects groundwater data and conducts studies to monitor hydrologic conditions, better define groundwater resources, and address problems related to water supply, water use, and water quality. In Georgia, water levels were monitored continuously at 179 wells during 2008 and 181 wells during 2009. Because of missing data or short periods of record (less than 3 years) for several of these wells, a total of 161 wells are discussed in this report. These wells include 17 in the surficial aquifer system, 19 in the Brunswick aquifer and equivalent sediments, 66 in the Upper Floridan aquifer, 16 in the Lower Floridan aquifer and underlying units, 10 in the Claiborne aquifer, 1 in the Gordon aquifer, 11 in the Clayton aquifer, 12 in the Cretaceous aquifer system, 2 in Paleozoic-rock aquifers, and 7 in crystalline-rock aquifers. Data from the well network indicate that water levels generally rose during the 2008–2009 period, with water levels rising in 135 wells and declining in 26. In contrast, water levels declined over the period of record at 100 wells, increased at 56 wells, and remained relatively constant at 5 wells.

In addition to continuous water-level data, periodic water-level measurements were collected and used to construct potentiometric-surface maps for the Upper Floridan aquifer in Camden, Charlton, and Ware Counties, Georgia, and adjacent counties in Florida during September 2008 and May 2009; in the Brunswick, Georgia area during July 2008 and July–August 2009; and in the City of Albany–Dougherty County, Georgia area during November 2008 and November 2009. In general, water levels in these areas were higher during 2009 than during 2008; however, the configuration of the potentiometric surfaces in each of the areas showed little change.

Groundwater quality in the Floridan aquifer system is monitored in the Albany, Savannah, Brunswick, and Camden County areas of Georgia. In the Albany area, nitrate as nitrogen concentrations in the Upper Floridan aquifer during 2008–2009 generally increased, with concentrations in two wells above the U.S. Environmental Protection Agency (USEPA) 10-milligrams-per-liter (mg/L) drinking-water standard. In the Savannah area, measurement of specific conductance and chloride concentration in water samples from discrete depths in three wells completed in the Upper Floridan aquifer indicate that chloride concentrations in the Upper Floridan aquifer showed little change and remained below the 250 mg/L USEPA secondary drinking-water standard. Chloride concentrations in the Lower Floridan aquifer increased slightly at Tybee Island and Skidaway Island, remaining above the drinking-water standard. In the Brunswick area, maps showing the chloride concentration of water in the Upper Floridan aquifer were constructed using data collected from 28 wells during July 2008 and from 29 wells during July–August 2009, indicate that chloride concentrations remained above the USEPA secondary drinking-water standard in an approximately 2-square-mile area. During 2008–2009, chloride concentrations decreased, with a maximum decrease of 160 mg/L, in a well located in the northern part of the Brunswick area.

In the Camden County area, chloride concentration during 2008–2009 was analyzed in water samples collected from eight wells, six of which were completed in the Upper Floridan aquifer and two in the Lower Floridan aquifer. In most of the wells sampled during this period, chloride concentrations did not appreciably change; however, since the closure of the Durango Paper Company in October 2002, chloride concentrations in the Upper Floridan aquifer near the paper mill decreased from a high of 184 mg/L in May 2002 to 41 mg/L in September 2009.

Groundwater studies conducted in Georgia during 2008–2009 include the following:

- evaluation of groundwater flow, water-quality, and water-level monitoring in the Augusta–Richmond County area;
- evaluation of groundwater flow, water-quality, and water-level monitoring in the City of Albany–Dougherty County area;
- evaluation of saltwater intrusion, water-level, and water-quality monitoring in the City of Brunswick–Glynn County area;
- collection of groundwater data in and adjacent to the State of Georgia;
- assessment of the sustainability of groundwater resources in the City of Lawrenceville area;
- evaluation of alternative groundwater resources, flow, water quality, and water-level monitoring Hunter Army Airfield and Fort Stewart, Georgia; and
- evaluation and quality assurance of agricultural pumpage in Georgia.

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.

Groundwater-level and quality data are essential for water-resources 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 groundwater recharge, storage, and discharge. Long-term, systematic measurement of water levels provides essential data needed to evaluate changes in the resource over time, develop groundwater models and forecast trends, and design, implement, and monitor the effectiveness of groundwater management and protection programs (Taylor and Alley, 2001). Groundwater-quality data are necessary for the protection of groundwater resources because deterioration of groundwater quality may be virtually irreversible, and treatment of contaminated groundwater can be expensive (Alley, 1993). Reliable water-use data are important to many organizations and individuals in support of research and policy decisions and are essential in understanding the effects of humans on the hydrologic system (Hutson and others, 2004).

Purpose and Scope

This report presents an overview of groundwater conditions, permitted water use, and hydrologic studies conducted during 2008–2009 by the USGS in Georgia. Summaries are presented for selected groundwater studies along with objectives and progress. These summaries include the following;

- evaluation of groundwater flow, water-quality, and water-level monitoring in the Augusta–Richmond County area;
- evaluation of groundwater flow, water-quality, and water-level monitoring in the City of Albany–Dougherty County area;
- evaluation of saltwater intrusion, water-level, and water-quality monitoring in the City of Brunswick–Glynn County area;
- collection of groundwater data in and adjacent to the State of Georgia;
- assessment of the sustainability of groundwater resources in the City of Lawrenceville area;
- evaluation of alternative groundwater resources, at Hunter Army Airfield and Fort Stewart, Georgia;
- evaluation and quality assurance of agricultural pumpage in Georgia; and
- publication of reports on groundwater conditions in Georgia (listed on page 4).

Permitted water-use data compiled for 2005–2009 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.

Continuous water-level measurements were obtained from 179 wells during 2008 and 181 wells during 2009; however, data from 161 wells are summarized herein. Of the 181 wells equipped with continuous water-level recorders during 2009, 151 wells had electronic data recorders that recorded water levels at 60-minute intervals, and the data generally were retrieved bimonthly. Thirty wells had real-time satellite telemetry that recorded water levels at 60-minute intervals. Three of the real-time sites were equipped to monitor water levels and specific conductance, and at another site only specific conductance was monitored. Real-time satellite telemetry data are transmitted every 1 to 4 hours (based on equipment) for display on the USGS Georgia Water Science Center Web site at *http://waterdata.usgs.gov/ga/nwis/current?type=gw/*.

Groundwater levels in major aquifers are presented as hydrographs for selected wells throughout Georgia. Estimated annual water-level change is reported for the period of record and for 2008–2009. Additional well information can be obtained from the USGS National Water Information System (NWIS) at *http://waterdata.usgs.gov/ga/nwis/gw/*.

In addition to continuous water-level recording, periodic water-level measurements were collected to complete potentiometric surface maps for the Upper Floridan aquifer. In southwestern Georgia near Albany, measurements were collected in 81 wells during November 2008 and in 64 wells during November 2009. In the southern coastal area of Georgia, including Camden, Charlton, and Ware Counties and adjacent counties in Florida, water-level measurements were collected during September 2008 and May 2009 (Kinnaman and Dixon, 2009a, b).

The quality of groundwater in the Floridan aquifer system is being monitored in the Albany–Dougherty County area and in several areas along the Georgia coast. In the Albany area, nitrate as nitrogen concentrations in the Upper Floridan aquifer were determined in water from 25 wells during November 2008 and from 13 wells during November 2009. In the coastal area, groundwater quality of the Upper and Lower Floridan aquifers was determined in the Savannah, Brunswick, and St. Marys areas. In the Savannah area, groundwater quality was assessed in four wells by using a combination of borehole fluid-resistivity logs and grab samples collected at discrete depths.

Long-term chloride concentrations in the Brunswick area are presented by using composite-sample data from five wells for the periods 1960–2009 and 1965–2009 together with maps showing chloride concentrations in the Brunswick area during July 2008 (26 wells) and July–August 2009 (26 wells). Data are presented from a network of three continuous, specific-conductance monitoring sites (used as surrogate data for chloride concentration) surrounding the chloride plume at Brunswick. In the St. Marys area of Camden County, chloride-concentration data from 8 wells are presented for the period 1984–2009.

Methods of Analysis, Sources of Data, and Data Accuracy

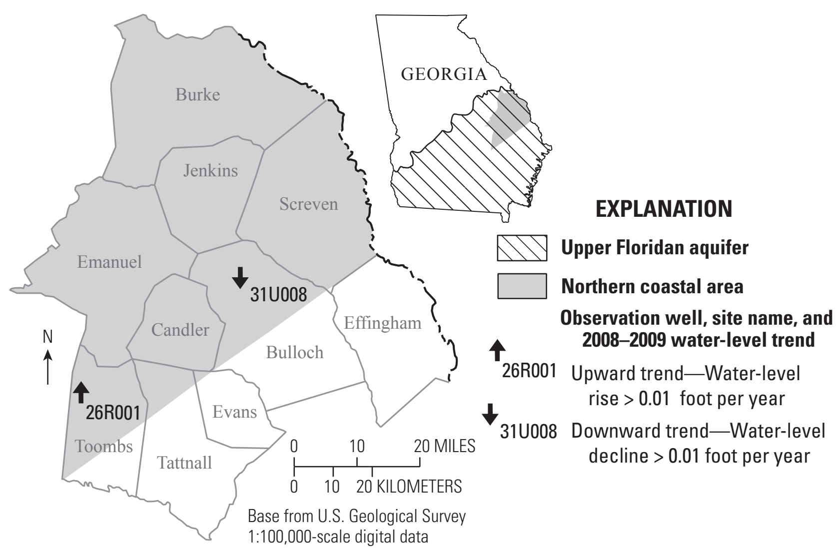
To illustrate long-term (period of record) and more recent (2008–2009) water-level changes, hydrographs showing monthly mean water levels are presented together with maps showing water-level trends during 2008–2009. To estimate water-level trends, the Levenberg–Marquardt (LMA) method for minimization of a weighted least-squares merit function (Janert, 2010) was used to determine a straight-line fit to both recent and period-of-record monthly-mean groundwater levels (see example graph below). Estimated water levels from these straight-line fits were used to compute an annual rate of change (yearly slope) for the period of record and for 2008–2009. A more thorough discussion of the LMA method is presented at the end of this report along with associated summary statistics for each well and for straight-line fits (appendix).

Water-level trends are presented on tables, hydrographs, and maps for each aquifer and sub-area in the groundwater level section of this report. Trends for 2008–2009 are presented on maps either by an upward arrow for a positive rate of change of 0.01 foot per year (ft/yr) or greater, or a downward arrow for a negative rate of change of 0.01 ft/yr or greater. A circle represents no water-level change on the map when the change was less than ± 0.01 ft/yr. Additional well information can be obtained from the USGS NWIS at *http://waterdata.usgs.gov/ga/nwis/gw/*.

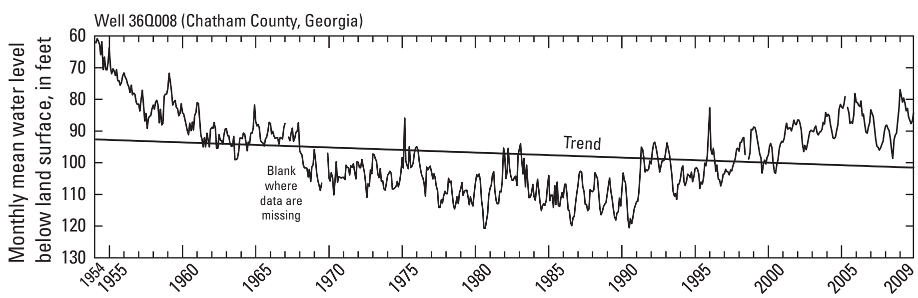
Water samples were analyzed for nitrate as nitrogen at the USGS laboratory in Denver, Colorado. Chloride analyses were conducted at the St. Johns River Water Management District in Palatka, Florida (for Camden County), and at TestAmerica Laboratory, Savannah, Georgia. Additional water-quality data for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

Permitted water-use data for 2008–2009 were compiled from the Georgia Water-Use Data System (GWUDS). The GWUDS contains permitted water-use information on public supplies, industrial and commercial supplies, and thermoelectric-power and hydroelectric-power uses for 1980–2009. These data are limited to permitted water withdrawals of 100,000 gal/d or greater, in compliance with Georgia water law that requires withdrawal permits for all public-supply, industrial, and other water users who withdraw more than 100,000 gal/d (*http://rules.sos.state.ga.us/docs/391/3/2/03.pdf*).

Water-level trends for 2008–2009 are presented on maps either by an upward arrow for a positive rate of change of 0.01 foot per year or greater, or a downward arrow for a negative rate of change of 0.01 foot per year or greater. A circle represents no water-level change.



Example hydrograph showing monthly mean water levels in well 36Q008 for the period 1954–2009, and period-of-record trend.



Previously published U.S. Geological Survey reports on groundwater 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	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
2004–2005	SIR 2007–5017	Leeth, D.C., Peck, M.F., and Painter, J.A.	2007
2006–2007	SIR 2009–5070	Peck, M.F., Painter, J.A. and Leeth, D.C.	2009

Georgia Well-Identification System

Wells described in this report are identified according to a system based on the index of USGS 7.5-minute topographic maps of Georgia. Each map in Georgia has been assigned a two- to three-digit number and letter designation (for example, 07H) 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 in the well-identification system. Wells inventoried in each quadrangle are numbered consecutively, beginning with 001. Thus, the fourth well inventoried in the 11A quadrangle is designated 11A004. In the USGS NWIS database, this information is stored in the "Station Name" field; in NWIS Web, it is labeled "Site Name."

Cooperating Organizations and Agencies

Groundwater monitoring and hydrologic studies in Georgia are conducted in cooperation with numerous local organizations and State and Federal agencies. Cooperating organizations and agencies include;

- Department of Defense, U.S. Army
- Georgia Department of Agriculture
- Georgia Department of Natural Resources, Environmental Protection Division
- St. Johns 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
- City of Brunswick/Glynn County
- City of Lawrenceville
- City of Augusta/Richmond County

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 State and local 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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Kinnaman, S.L., and Dixon, J.F., 2009b, Potentiometric surface of the Upper Floridan aquifer in the St. Johns River Water Management District and vicinity, Florida, May 2009: U.S. Geological Survey Scientific Investigations Map 3091, 1 sheet; available online at *http://pubs.usgs.gov/sim/3091/*.

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

Groundwater Resources

Contrasting geologic features and landforms of the physiographic provinces of Georgia (see map on p. 7 and table on p. 8–9) affect the quantity and quality of groundwater throughout the State. The surficial aquifer system is present in each of the physiographic provinces. In the Coastal Plain Physiographic Province, the surficial aquifer system consists of layered sand, clay, and limestone. The surficial aquifer system usually is under water-table (unconfined) conditions and provides water for domestic and livestock use. The surficial aquifer system is semiconfined to confined locally in the coastal area. In the Piedmont, Blue Ridge, and Valley and Ridge Physiographic 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 Physiographic 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 Physiographic Province, groundwater is transmitted through primary and secondary openings in folded and faulted sedimentary and meta-sedimentary rocks of Paleozoic age, herein referred to as "Paleozoic-rock aquifers."

In the Piedmont and Blue Ridge Physiographic Provinces, the geology is complex and consists of structurally deformed metamorphic and igneous rocks. Groundwater 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 groundwater resources, see Clarke and Pierce (1985).

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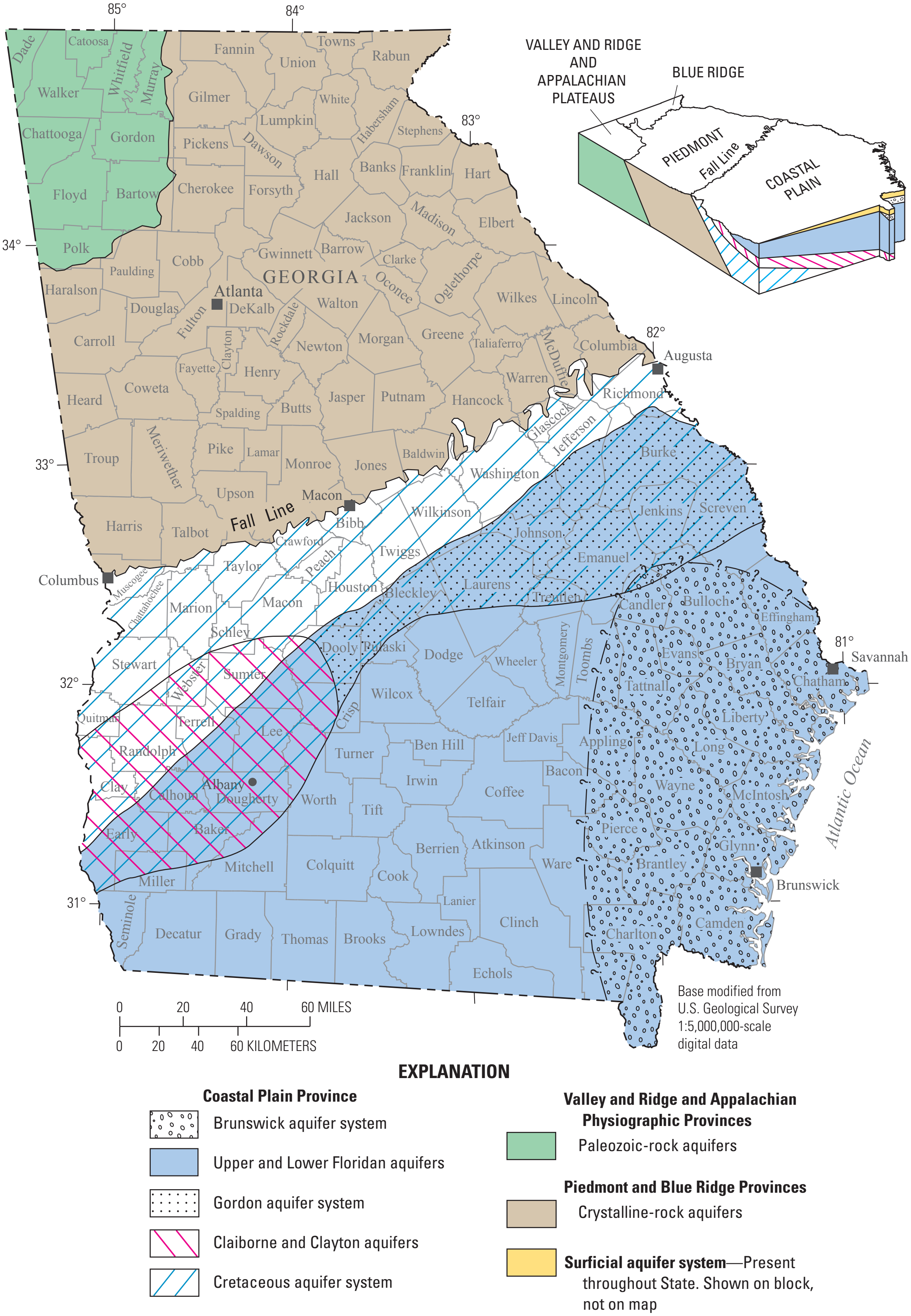


Areas of use of major aquifers in Georgia (modified from Clarke and Pierce, 1985).

Groundwater Resources

Aquifer and well characteristics in Georgia [modified from Clarke and Pierce, 1985; Peck and others, 1992; ft, foot; gal/min, gallon 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; confined and unconfined	40–600	1–25	500

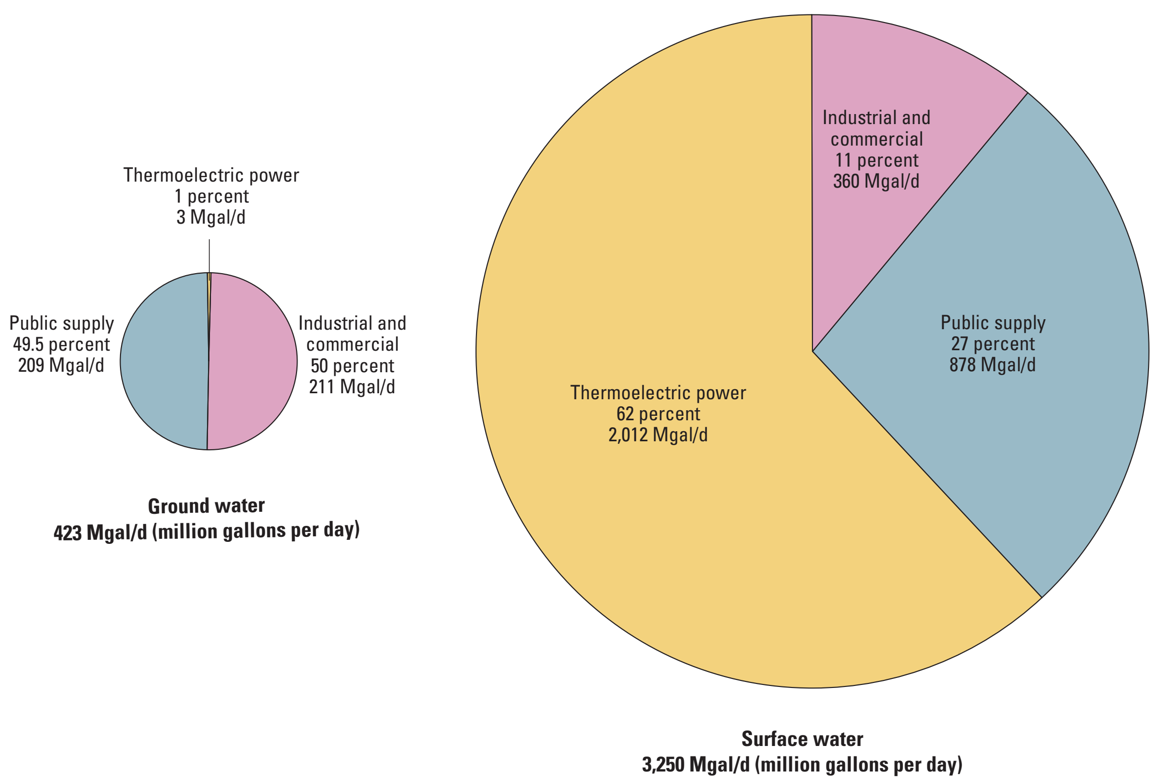
Hydrologic response	Remarks
Water-level fluctuations are caused mainly by variations in precipitation, evapotranspiration, and natural drainage or discharge. In addition, water levels in the City of Brunswick area are influenced by nearby pumping, precipitation, and tidal fluctuations (Clarke and others, 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 groundwater 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. 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 are mainly 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 are affected mainly by precipitation and local pumping (Cressler, 1964).	Not laterally extensive. Limestone and dolomite aquifers are the 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 are affected mainly 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 2009 and Groundwater-Use Trends for 2005–2009

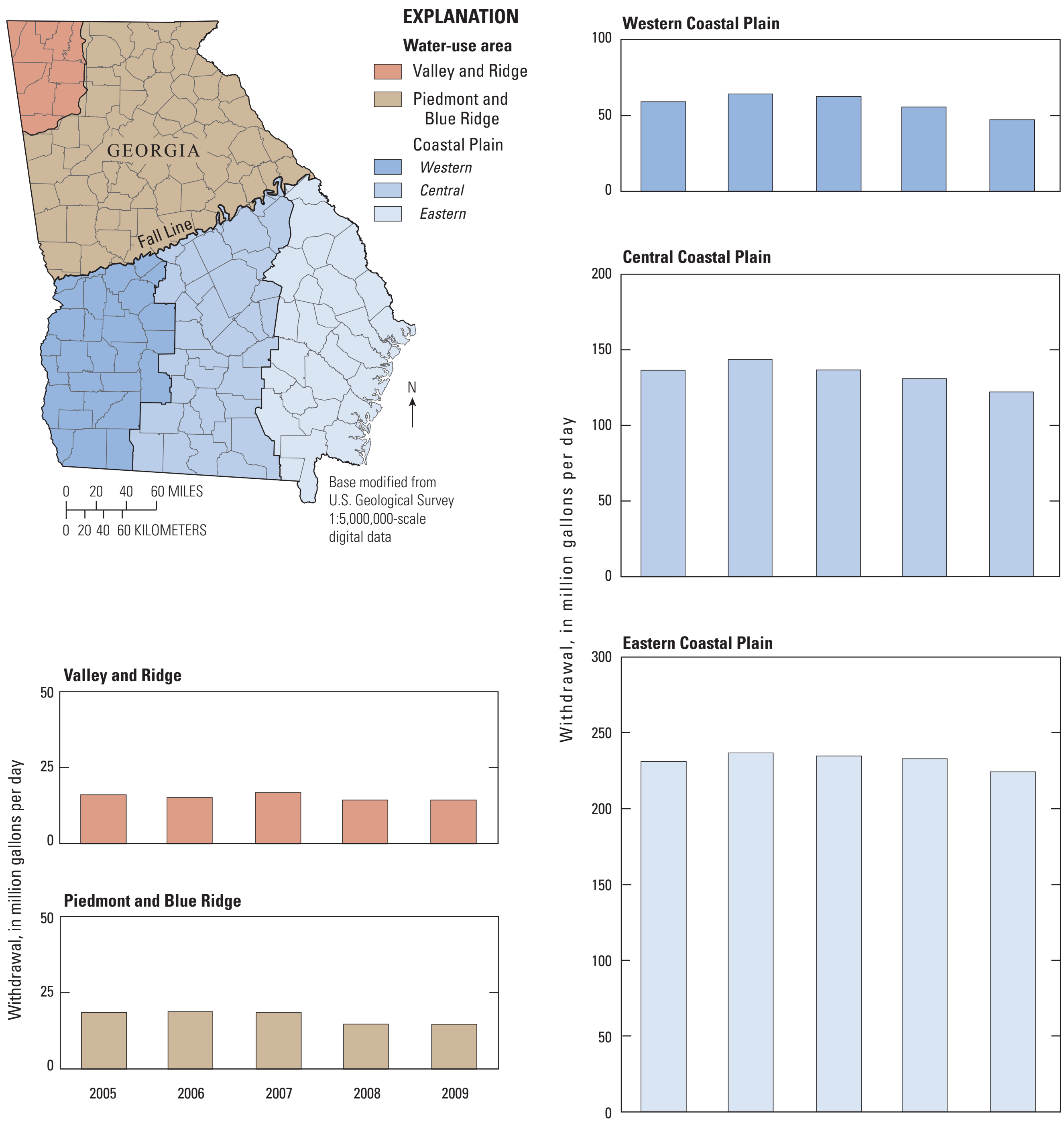
Permitted water-use data can be used to assess potential effects of groundwater withdrawal on groundwater systems. Only water-use data from permitted public supply, industrial and commercial, and thermoelectric systems are included in this report. Estimates for irrigation, livestock, and domestic use are omitted. During 2009, permitted water withdrawal in Georgia totaled 3,672 million gallons per day (Mgal/d) of which about 88 percent (3,250 Mgal/d) was from surface-water sources and 12 percent (423 Mgal/d) was from groundwater sources. Permitted withdrawal by public-supply systems totaled about 1,087 Mgal/d, about 81 percent of which was from surface-water sources and 19 percent was from groundwater sources (see pie charts below). Eighteen thermoelectric plants, the largest water users in Georgia, withdrew about 2,015 Mgal/d during 2009, mostly from surface-water sources. Permitted withdrawals by industrial and commercial users totaled about 571 Mgal/d, with 63 percent was from surface-water sources and 37 percent from groundwater sources. The major industrial users in Georgia include paper, textiles, chemicals, stone and clay, and mining.

Compared to 2007, total withdrawals for 2009 decreased by 975 Mgal/d. Thermoelectric power withdrawals saw the largest decrease during 2007–2009 (793 Mgal/d), mostly from surface-water sources. The largest decrease for groundwater-supplied users was for industrial and commercial systems, which decreased from 242 Mgal/d in 2007 to 211 Mgal/d in 2009. Public-supply withdrawals from groundwater sources also decreased during this period from 221 Mgal/d in 2007 to 209 Mgal/d in 2009.

To understand the areal distribution and trends of permitted groundwater withdrawal in the State, data from 2005 to 2009 were grouped into five areas as depicted in the map and graphs (facing page). Permitted groundwater withdrawal in each of the five areas decreased during 2005–2009. This decrease largely is a result of continued conservation efforts made by industrial and municipal users. In the Coastal Plain, groundwater use decreased from 14.4 to 6.97 Mgal/d, mostly because of a reduction in industrial withdrawals. In the northern one-half of the State, groundwater use also decreased 1.74 Mgal/d in the Valley and Ridge area and 3.85 Mgal/d in the Piedmont and Blue Ridge area. These decreases were largely due to conservation efforts by public-supply and industrial systems during the most recent drought.



Percentages of permitted water use in Georgia by category and source, 2009.



Groundwater withdrawals in Georgia by water-use area, 2005–2009.

Groundwater Conditions

Groundwater Levels

Maps and tables in this section provide an overview of groundwater levels in major aquifers in Georgia during 2008–2009. Hydrographs of selected wells are presented to demonstrate period-of-record and 2008–2009 water-level trends. 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 shows the locations of selected wells that were continuously monitored by the U.S. Geological Survey during the 2009 calendar year, including 30 wells that were monitored in real time.

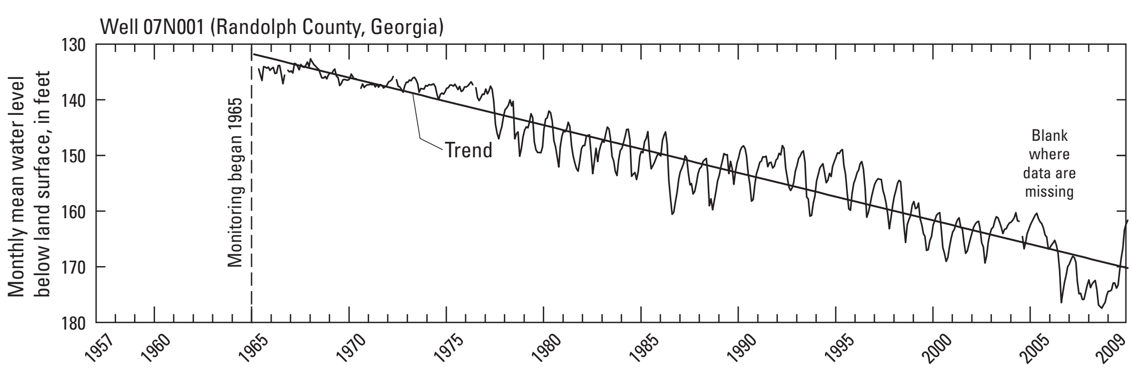
Changes in aquifer storage cause changes in groundwater levels in wells. Taylor and Alley (2001) described many factors that affect groundwater storage; these factors are discussed briefly here. When recharge to an aquifer exceeds discharge, groundwater levels rise; when discharge from an aquifer exceeds recharge, groundwater levels decline. Recharge varies in response to precipitation and surface-water infiltration to 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 groundwater levels in major aquifers in Georgia are summarized on pages 8 and 9.

Water levels in aquifers in Georgia typically follow a cyclical pattern of seasonal fluctuation. Water levels rise during winter and spring because of increased recharge from precipitation and decline during summer and fall because of decreased recharge, greater evapotranspiration, and pumping. The magnitude of fluctuations can vary greatly from season to season and from year to year in response to changing climatic conditions.

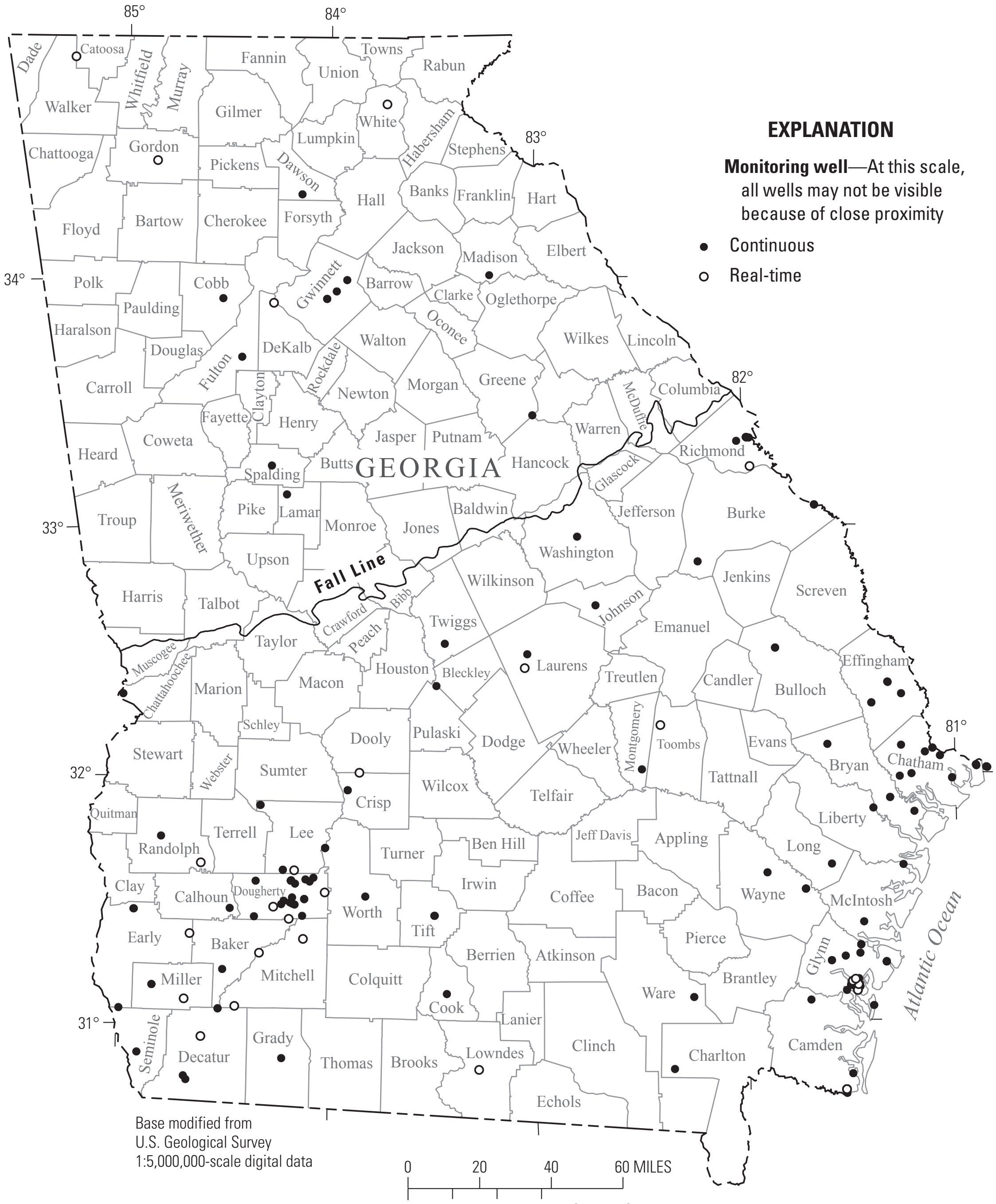
Groundwater pumping is the most important human activity that affects the amount of groundwater in storage and the rate of discharge from an aquifer (Taylor and Alley, 2001). As groundwater storage is depleted within the radius of influence of pumping, water levels in the aquifer decline forming a cone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

Reference

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 hydrograph showing monthly mean water levels and trend line for well 07N001 for the period 1965–2009, Randolph County, Georgia.



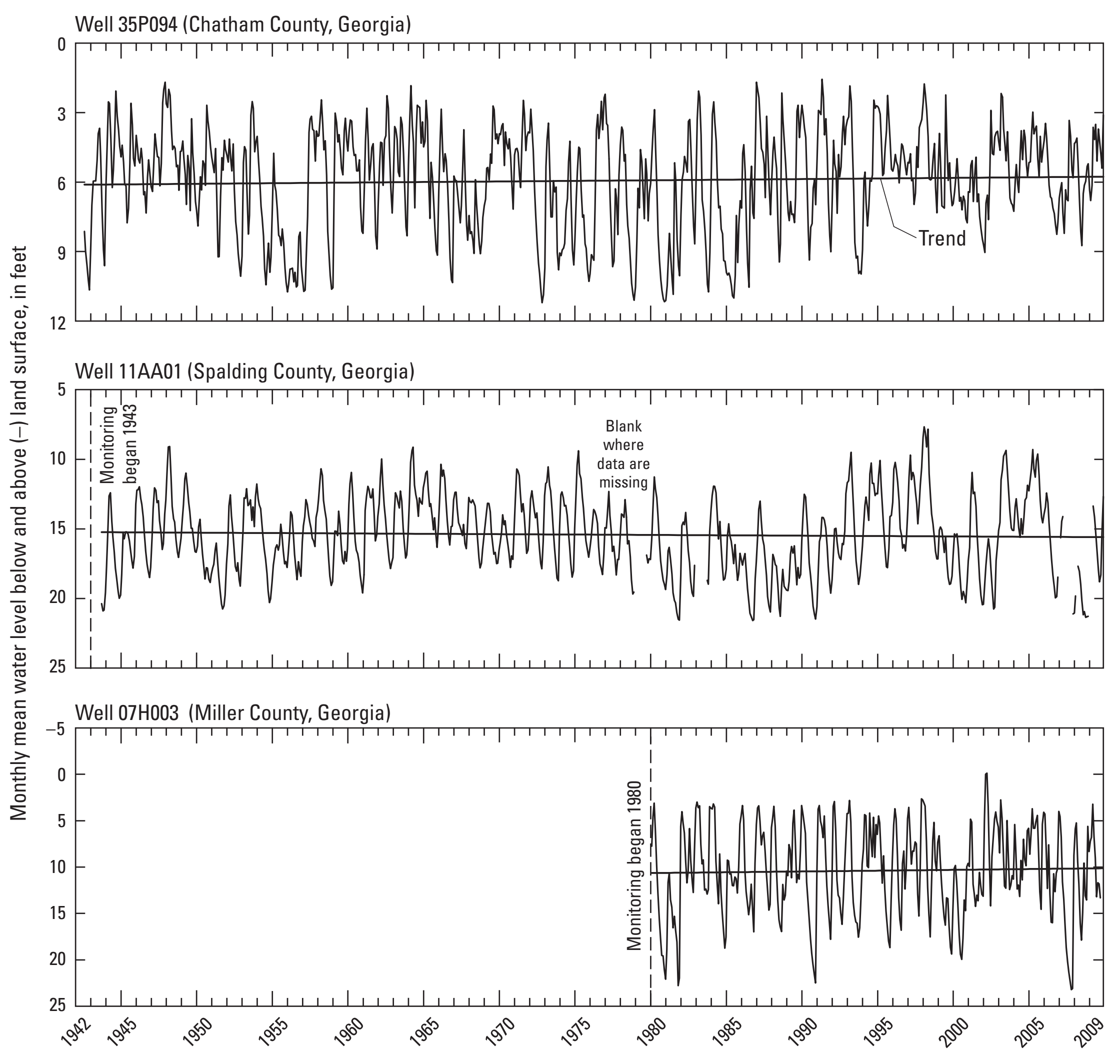
Locations of monitoring wells used to collect long-term water-level data in Georgia during 2008–2009.

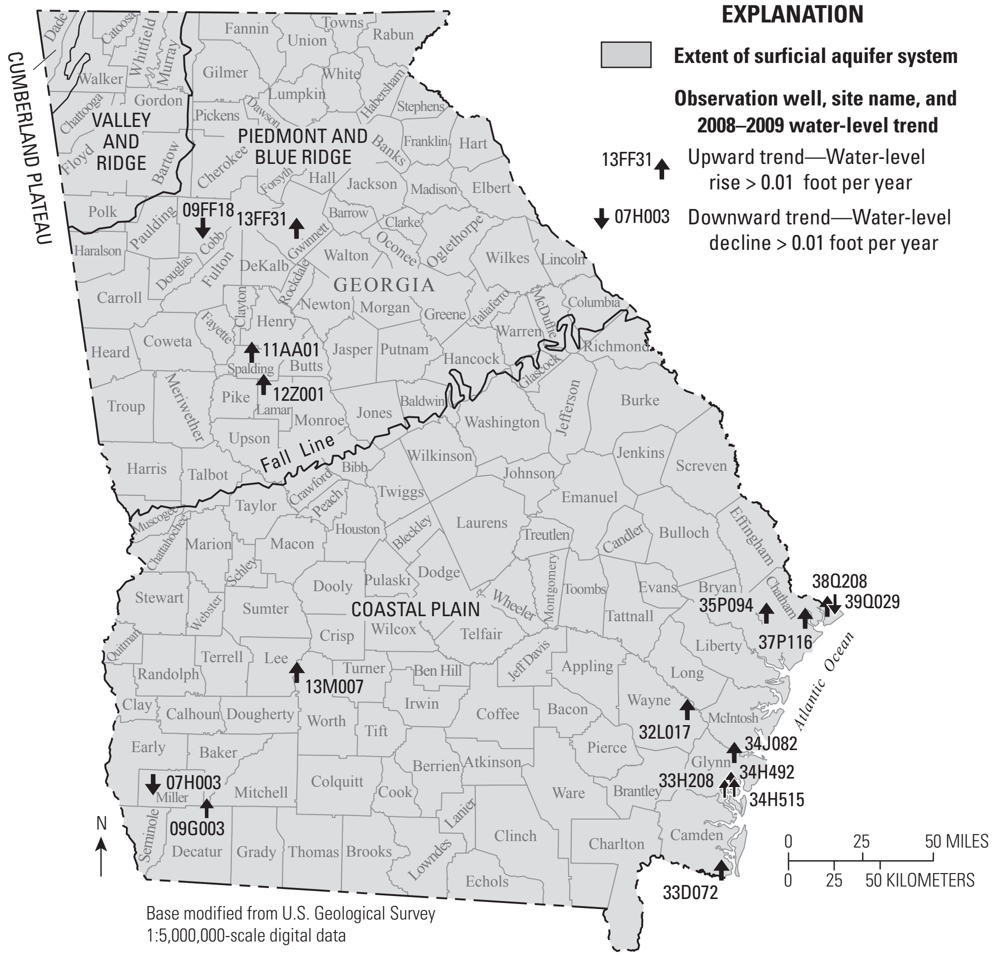
Groundwater Levels

Surficial Aquifer System

Water levels measured in 17 wells were used to define conditions in the surficial aquifer system during 2008–2009 (map and table, facing page). Groundwater 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-level hydrographs for selected wells (below) illustrate monthly mean water levels for the period of record. The hydrographs show mostly seasonal variations, with periodic upward or downward trends that respectively reflect surplus or deficits in rainfall. These periodic trends tend to be level over the long term.

Water levels in the surficial aquifer have shown little change in long-term trend during the period of record with rates of change less than ±0.01 foot per year (ft/yr) in three of the wells, declines of 0.01 to 0.33 ft/yr in nine wells, and rises of 0.02 to 0.41 ft/yr in five wells. During 2008–2009, water levels in all but two of the wells rose from 0.12 to 2.85 ft/yr corresponding to an increase in precipitation at the end of a 2-year drought in 2008. Well 09FF18 in Cobb County had a decline of 0.38 ft/yr during 2008–2009, continuing a downward trend since 2001. The reason for this downward trend is unknown but may be related to nearby pumping.





Site name	County	Year monitoring began	Water-level trend, in feet, per year[1]	
			Period of record	From 2008 to 2009
33D072	Camden	1998	0.41	0.88
35P094	Chatham	1942	<.01	0.94
37P116	Chatham	1984	<.01	0.12
38Q208	Chatham	1998	–0.01	0.65
39Q029	Chatham	1998	–0.01	0.79
09FF18	Cobb	2001	–0.10	–0.38
09G003	Decatur	1980	–0.04	1.27
33H208	Glynn	1985	0.15	1.05
34H492	Glynn	1999	0.08	0.88
34H515	Glynn	2005	0.03	0.24
34J082	Glynn	2002	–0.08	0.40
13FF31	Gwinnett	2003	–0.33	1.21
12Z001	Lamar	1967	–0.07	1.23
07H003	Miller	1980	0.02	–0.08
11AA01	Spalding	1943	–0.01	2.85
32L017	Wayne	1983	–0.15	0.39
13M007	Worth	1980	<.01	0.39

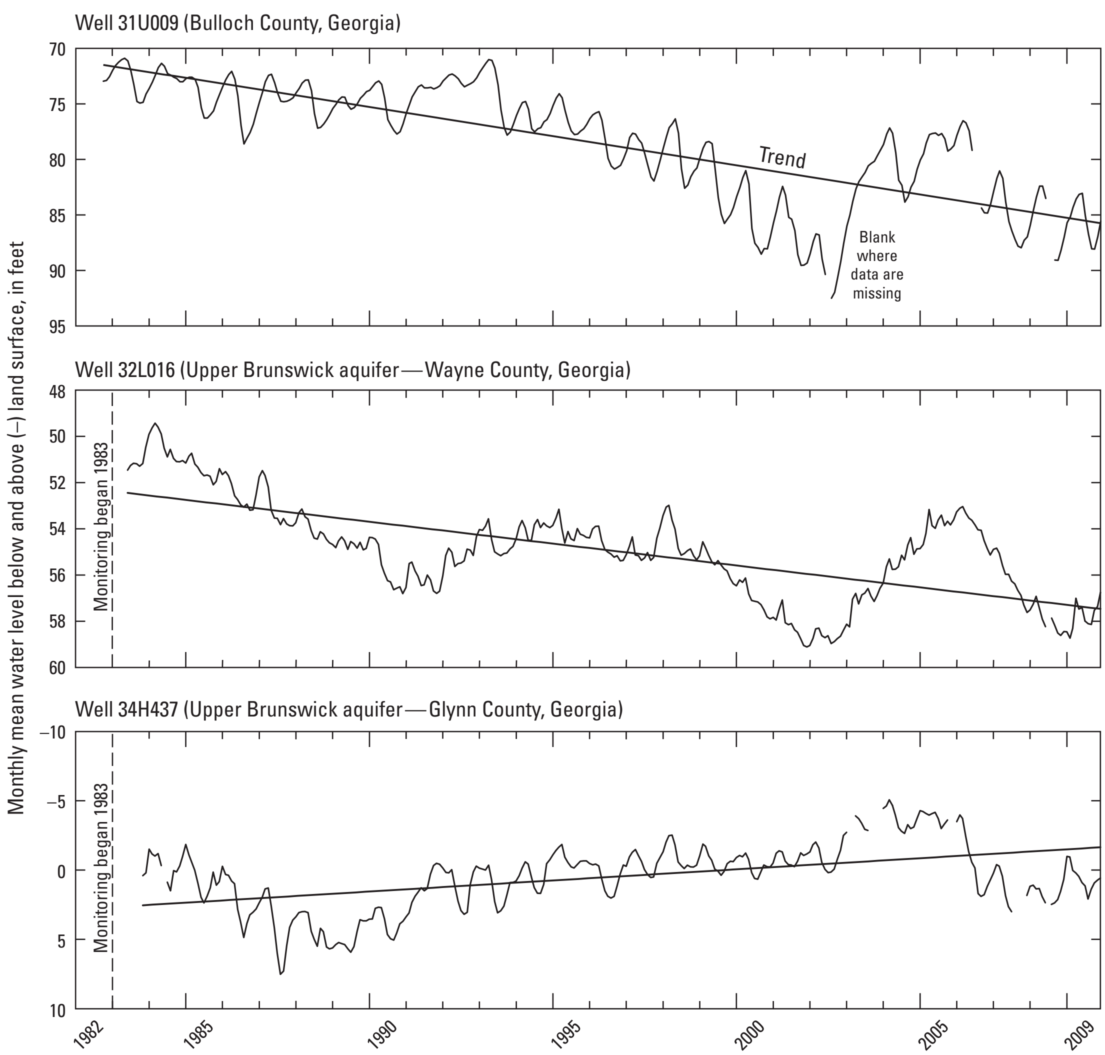
[1]See appendix for summary statistics.

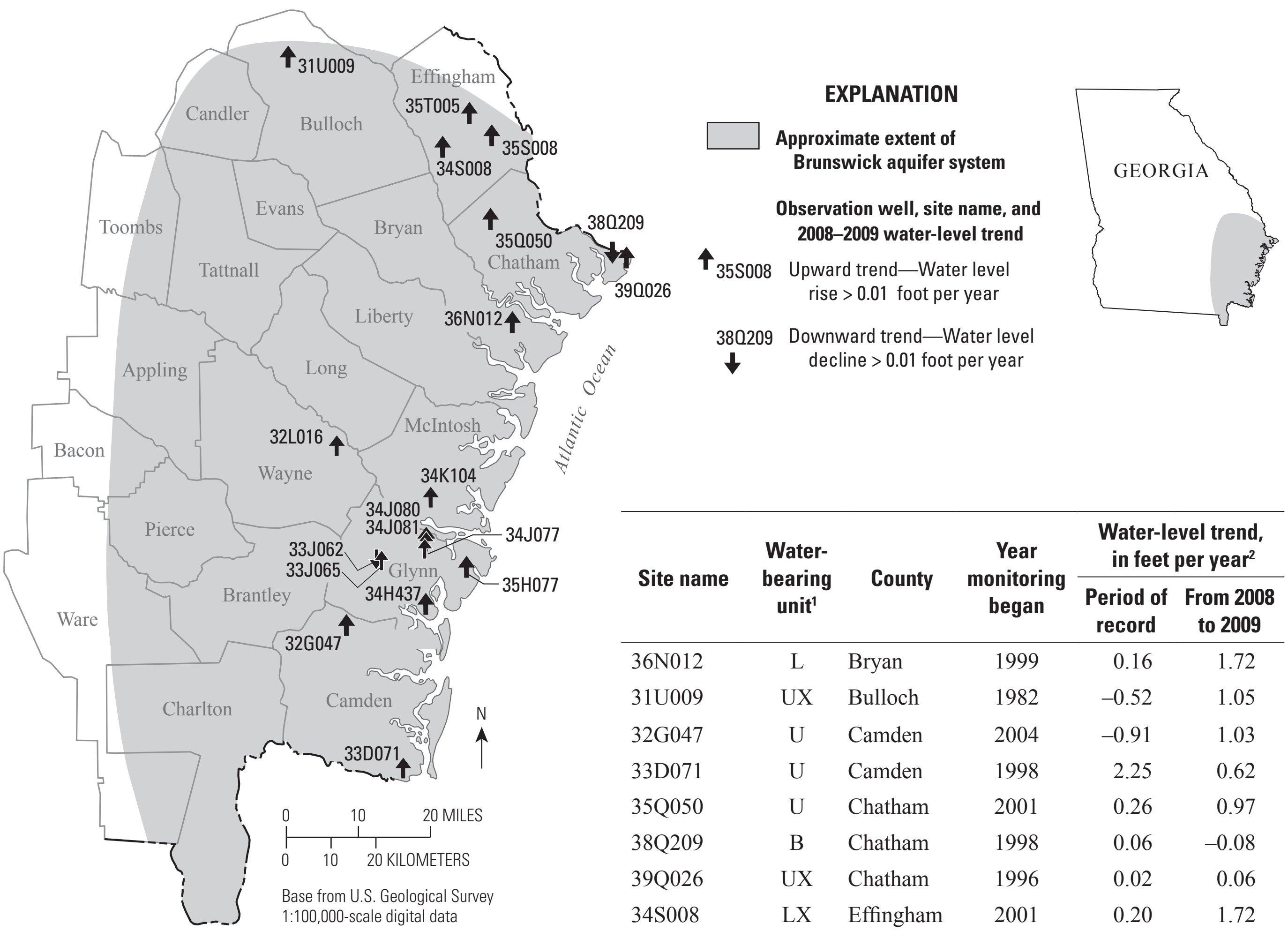
Groundwater Levels

Brunswick Aquifer System

Water levels in 19 wells were used to define conditions during 2008–2009 in the Brunswick aquifer system. The aquifer system consists of the upper and lower Brunswick aquifers and equivalent low-permeability sediments to the north and west in southeastern Georgia, which are confined throughout the known area of extent (map and table, facing page). Water-level fluctuations reflect changes in local pumping, interaquifer-leakage effects, and recharge. Water-level hydrographs for selected wells (below) illustrate monthly mean water levels for the period of record. The hydrographs show periodic upward or downward trends that reflect surplus or deficits in rainfall, respectively, and changes in pumping.

During the period of record, water levels in 11 of the 19 wells have remained the same or have been rising at rates of 0.02 to 2.25 feet per year (ft/yr). Water levels in eight wells declined at rates of 0.06 to 0.94 ft/yr during the period of record. During 2008–2009, water levels in 17 wells rose at rates of 0.05 to 2.30 ft/yr, which reflects recovery from the drought that ended in late 2008. Water levels in two wells declined from 0.08 to 0.37 ft/yr. The reason for the declining levels in these two wells is unknown but may be related to local variations in pumping





Site name	Water-bearing unit[1]	County	Year monitoring began	Water-level trend, in feet per year[2]	
				Period of record	From 2008 to 2009
36N012	L	Bryan	1999	0.16	1.72
31U009	UX	Bulloch	1982	–0.52	1.05
32G047	U	Camden	2004	–0.91	1.03
33D071	U	Camden	1998	2.25	0.62
35Q050	U	Chatham	2001	0.26	0.97
38Q209	B	Chatham	1998	0.06	–0.08
39Q026	UX	Chatham	1996	0.02	0.06
34S008	LX	Effingham	2001	0.20	1.72
35S008	LX	Effingham	2000	0.27	1.02
35T005	UX	Effingham	2000	0.23	1.11
33J062	L	Glynn	2001	<.01	–0.37
33J065	U	Glynn	2001	<.01	0.32
34H437	U	Glynn	1983	0.16	0.52
34J077	U	Glynn	1998	–0.94	2.30
34J080	L	Glynn	2002	–0.52	1.46
34J081	U	Glynn	2002	–0.16	1.30
35H077	L	Glynn	2005	–0.06	1.59
34K104	L	McIntosh	2005	–0.40	1.06
32L016	U	Wayne	1983	–0.19	0.05

[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.

[2]See appendix for summary statistics.

Groundwater 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 2005, about 658 million gallons per day (Mgal/d) were withdrawn from the Upper and Lower Floridan aquifers in Georgia, primarily for industrial and irrigation uses (Fanning and Trent, 2009).

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, Georgia (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 karst areas in parts of southwestern and south-central Georgia.

The Coastal Plain of Georgia has been divided informally 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. Since the introduction of center-pivot irrigation systems around 1975, the Upper Floridan aquifer has been widely used as the primary water source for irrigation in southwestern Georgia (Hicks and others, 1987). According to Fanning and Trent (2009), about 314 Mgal/d of water was withdrawn from the Upper Floridan aquifer in the southwestern area during 2005, and 80 percent of this amount was used for irrigation.

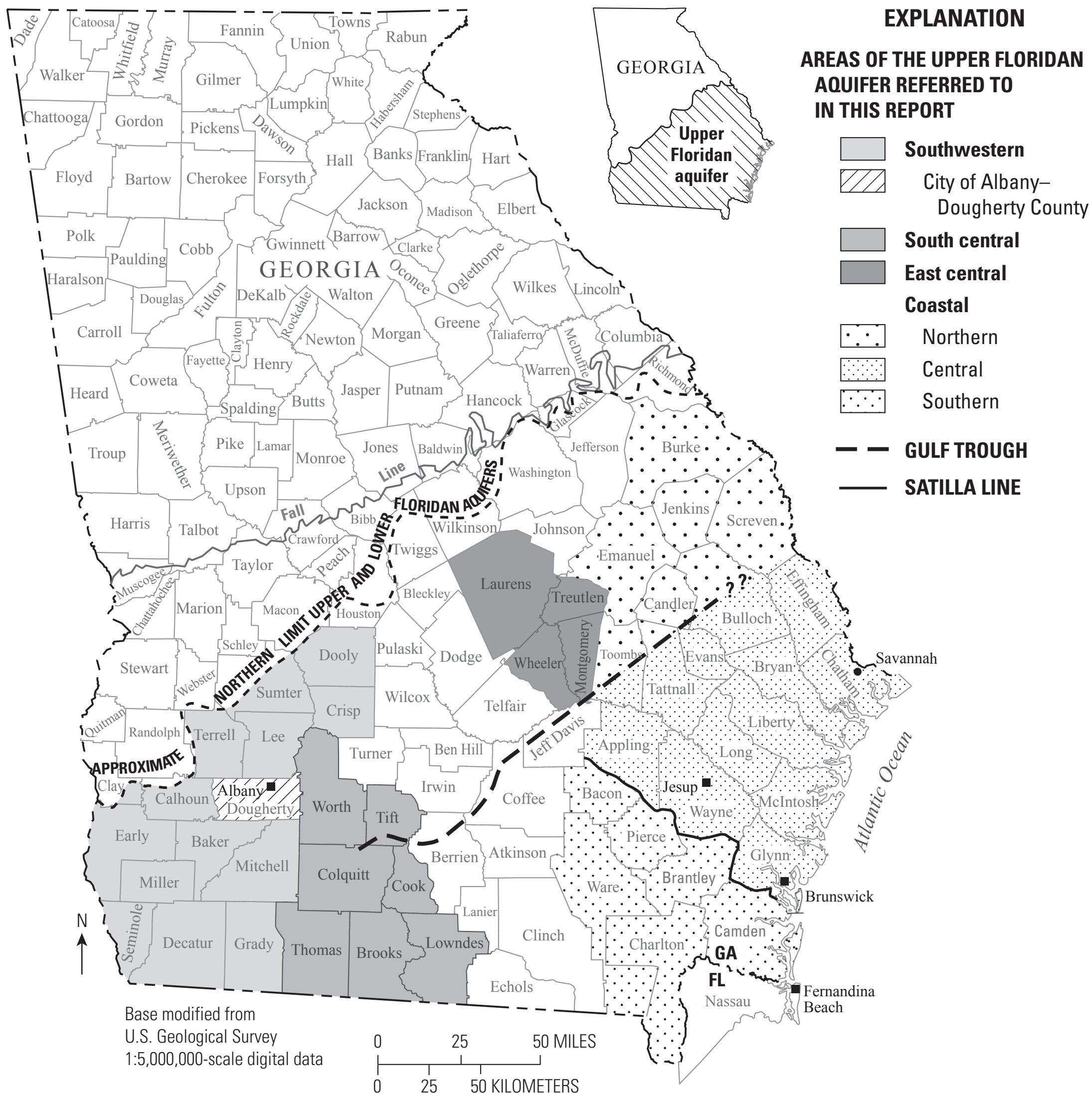
The City of Albany–Dougherty County lies in the southwestern area of Georgia. During 2005, most of the water withdrawn from the Upper Floridan aquifer in this area was used for public-supply (about 14 Mgal/d) and industry (14 Mgal/d; Fanning and Trent, 2009).

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 with 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, groundwater use totaled about 91 Mgal/d in 2005, and most of this withdrawal was used for irrigation (Fanning and Trent, 2009).

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 or absent in the north. In the east-central area, groundwater withdrawal totaled about 15 Mgal/d during 2005 and was used predominantly for irrigation (Fanning and Trent, 2009).

Coastal area. The Georgia Environmental Protection Division (GaEPD) defines the coastal area of Georgia as a 24-county area that includes 6 coastal counties and the adjacent 18 counties—an area of about 12,240 square miles. In the coastal 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 70 percent of all withdrawals in the area are from groundwater, primarily for industrial purposes. During 2005, about 308 Mgal/d of water was withdrawn from the Upper Floridan aquifer in the coastal area (Fanning and Trent, 2009).

The coastal area of Georgia 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 of 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 these two subareas, pumping from the aquifer primarily is for agricultural use, and no large pumping centers are located in the area. 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, Nassau County, 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; available online at *http://pubs.usgs.gov/wri/wri87-4145/*.

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 pl.

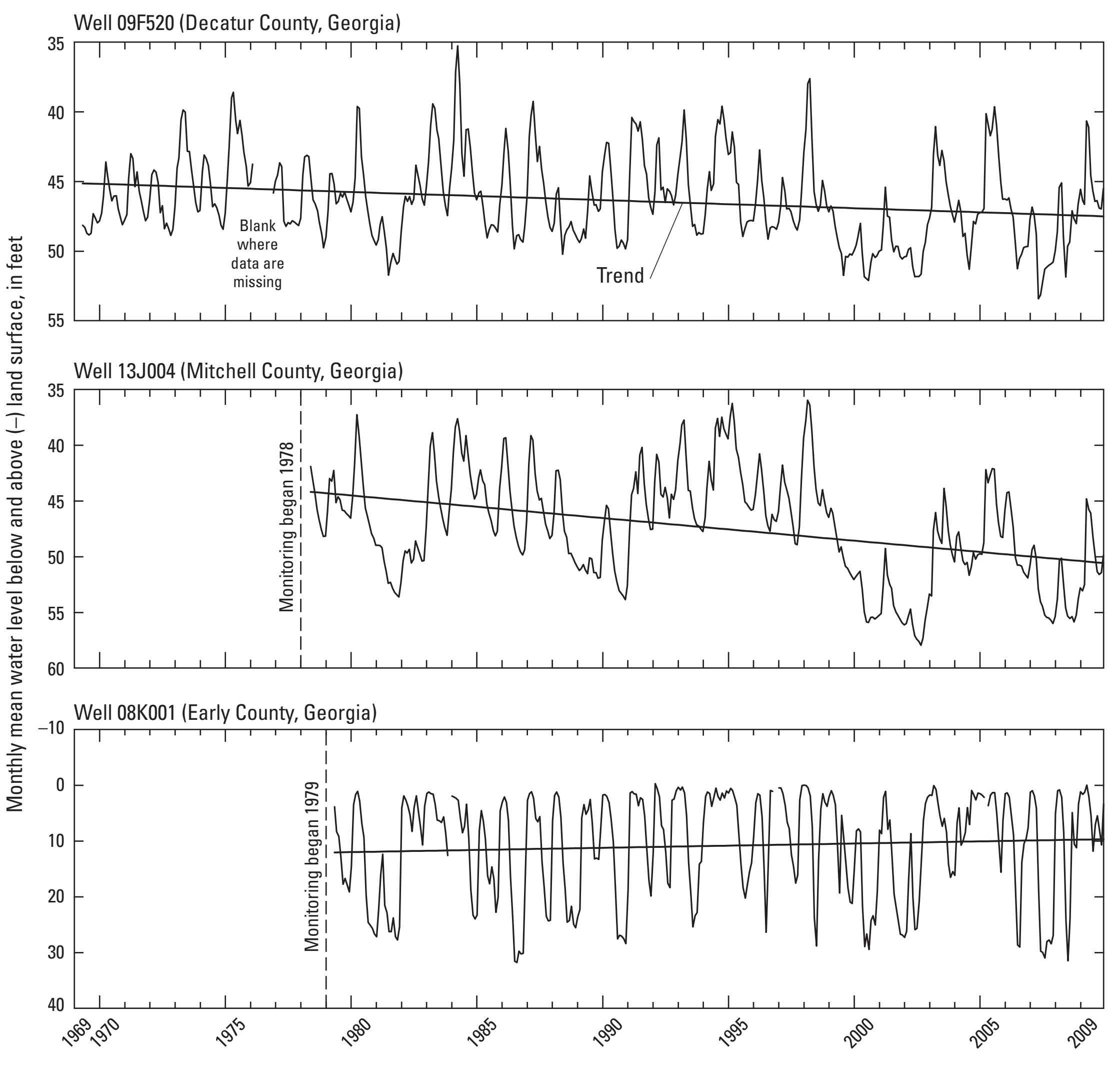
Groundwater Levels

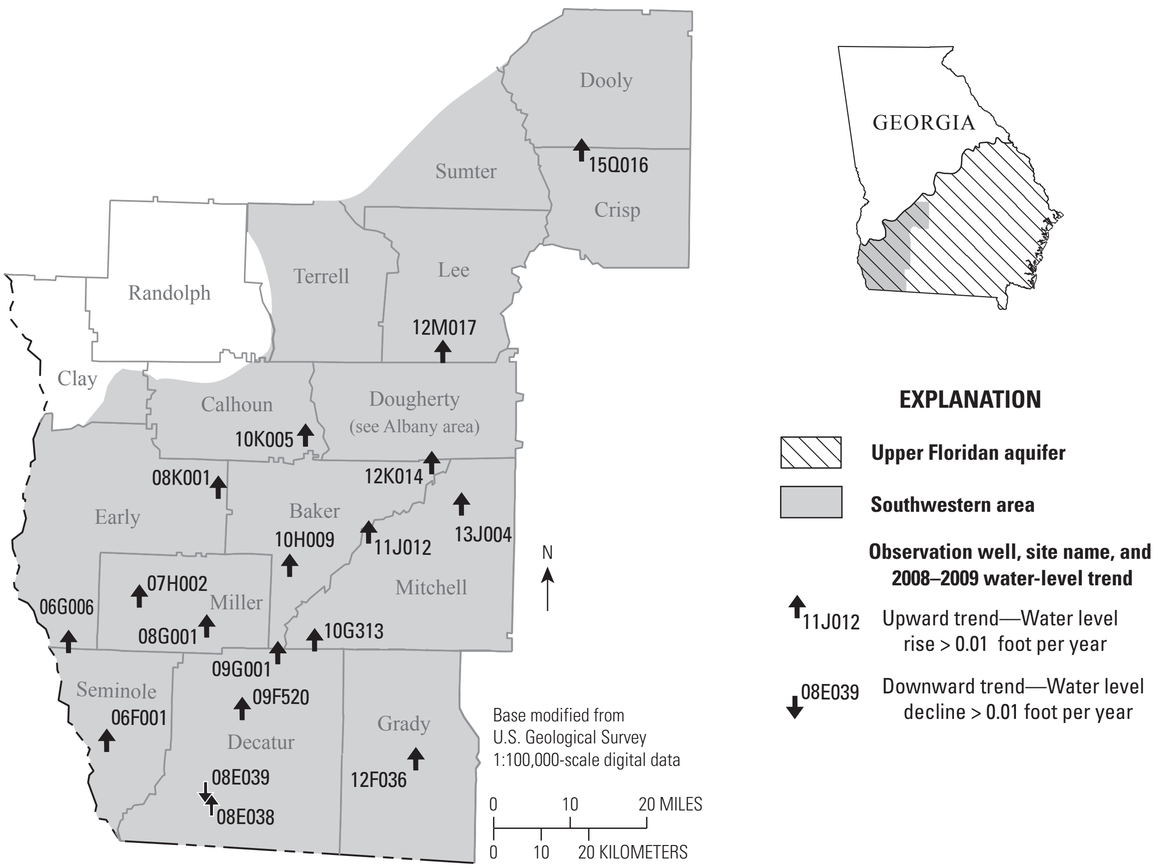
Upper Floridan Aquifer

Southwestern Area

Water levels in 18 wells were used to define groundwater conditions in the Upper Floridan aquifer in southwestern Georgia during 2008–2009 (map and table, 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 this area are affected by changes in precipitation and pumping. Hydrographs for selected wells (below) illustrate monthly mean water levels for the period of record. The hydrographs show periodic upward or downward trends that reflect surplus or deficits in rainfall, respectively, and changes in pumping.

During the period of record, water levels in 11 wells had declining trends of 0.05 to 0.73 foot per year (ft/yr), and 7 wells had rising trends of 0.01 to 0.38 ft/yr. During 2008–2009, water levels in 17 of the wells rose 0.37 to 6.02 ft/yr, which reflect recovery from the drought that ended in late 2008. One well (08E039), however, had a declining trend of 0.48 ft/yr.





Site name	County	Year monitoring began	Water-level trend, in feet, per year[1]	
			Period of record	From 2008 to 2009
10H009	Baker	1998	0.33	4.53
12K014	Baker	1982	–0.09	2.03
10K005	Calhoun	1983	–0.09	1.19
15Q016	Crisp	2002	–0.73	1.78
08E038	Decatur	2001	0.12	0.37
08E039	Decatur	2002	0.01	–0.48
09F520	Decatur	1972	–0.06	2.03
09G001	Decatur	1980	–0.07	2.04
06G006	Early	1982	–0.05	5.06
08K001	Early	1982	0.08	2.22
12F036	Grady	1971	0.26	2.30
12M017	Lee	1982	0.06	0.86
07H002	Miller	1980	0.38	3.29
08G001	Miller	1977	–0.11	6.02
10G313	Mitchell	1976	–0.08	2.91
11J012	Mitchell	1981	–0.06	1.95
13J004	Mitchell	1978	–0.20	2.82
06F001	Seminole	1979	–0.10	4.41

[1]See appendix for summary statistics.

Groundwater Levels

Upper Floridan Aquifer

City of Albany–Dougherty County Area

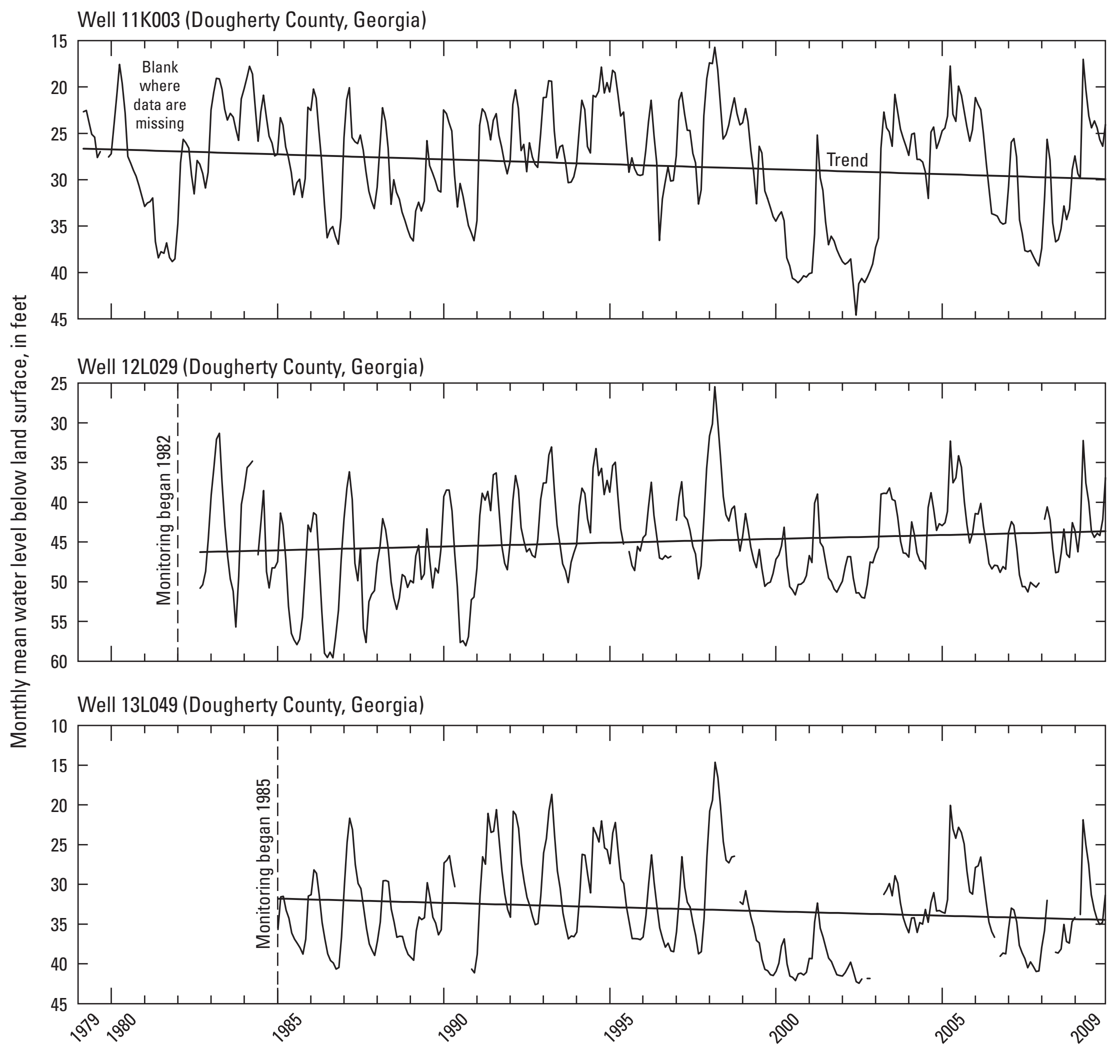
Water levels in 12 wells were used to define groundwater conditions in the Upper Floridan aquifer near Albany, Georgia, during 2008–2009 (Dougherty County map and table, facing page). Water levels in this area are affected by changes in precipitation and pumping. Hydrographs for selected wells (below) illustrate monthly mean water levels for the period of record. The hydrographs show periodic upward or downward trends that reflect surplus or deficits in rainfall, respectively, and changes in pumping.

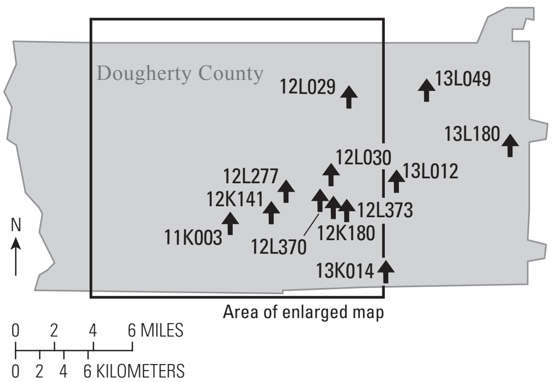
During the period of record, water levels in 9 of the 12 wells had declining trends of 0.03 to 0.36 foot per year (ft/yr); the remaining 3 wells had rising trends of 0.07 to 0.10 ft/yr. During 2008–2009, water levels in all of the wells rose from 1.86 to 7.33 ft/yr, which reflect recovery from the drought that ended in late 2008.

In addition to continuous water-level monitoring, synoptic water-level measurements are made periodically in wells southwest of Albany. Water-level measurements from 81 wells during November 2008 and 64 wells during November 2009 were used to construct maps showing the potentiometric surface of the Upper Floridan aquifer. Although water levels in 2009 generally were higher than in 2008, the configuration of the potentiometric surface maps (facing page) was similar. The potentiometric-surface maps 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 southwest.

Reference

Gordon, D.W., 2009, Groundwater conditions and studies in the Albany area of Dougherty County, Georgia, 2008: U.S. Geological Survey Open-File Report 2009–1244, 54 p.; available online at *http://pubs.usgs.gov/of/2009/1244/*.





EXPLANATION

Upper Floridan aquifer

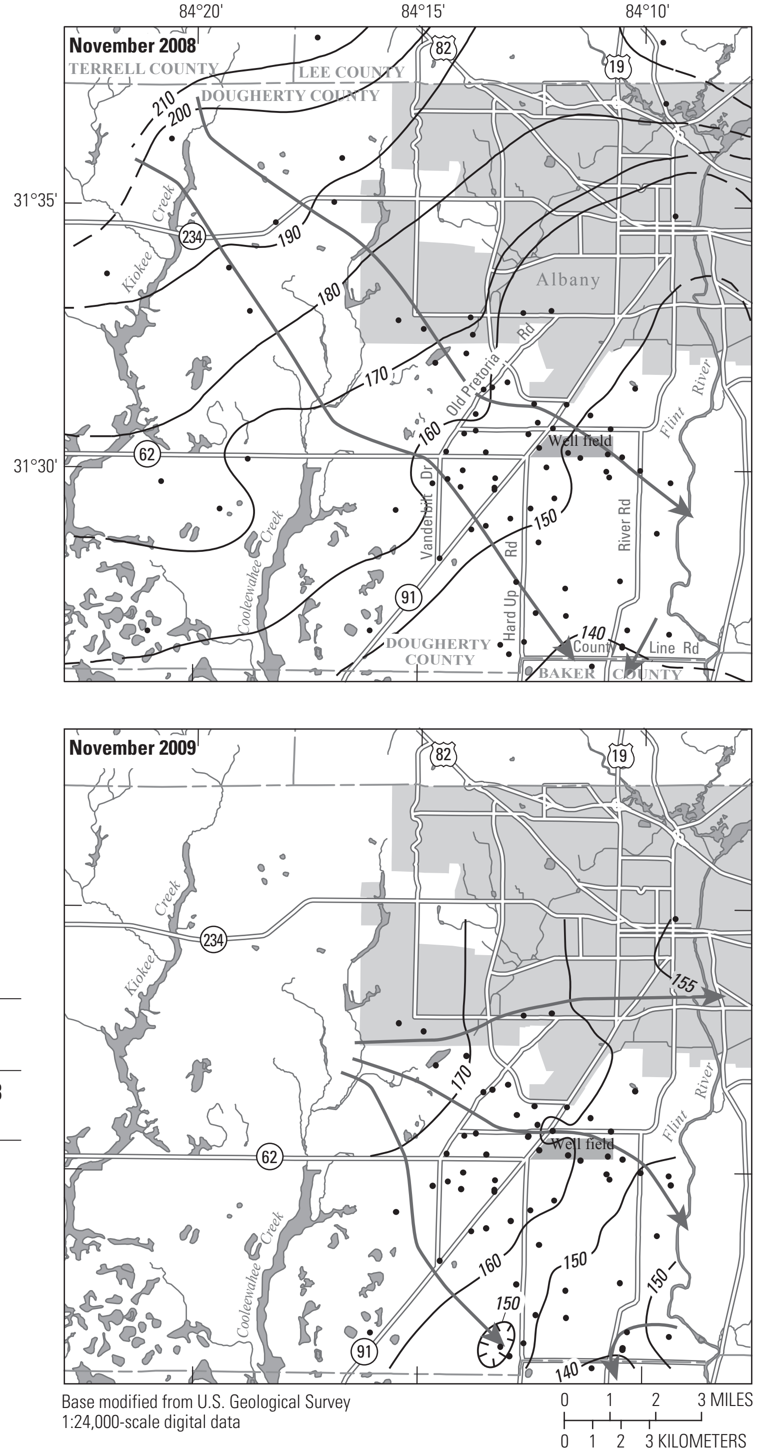
City of Albany–Dougherty County area

Observation well, site name, and 2008–2009 water-level trend

11K003 Upward trend—Water level rise > 0.01 foot per year

Site name	County	Year monitoring began	Water-level trend, in feet, per year[1]	
			Period of record	From 2008 to 2009
11K003	Dougherty	1982	–0.11	6.39
12K141	Dougherty	1996	–0.36	7.33
12K180	Dougherty	2002	–0.15	2.78
12L029	Dougherty	1982	0.10	2.39
12L030	Dougherty	1985	–0.06	3.81
12L277	Dougherty	2000	0.07	6.43
12L370	Dougherty	2000	0.07	3.32
12L373	Dougherty	2002	–0.16	3.27
13K014	Dougherty	1982	–0.11	1.86
13L012	Dougherty	1978	–0.04	2.14
13L049	Dougherty	1985	–0.11	3.35
13L180	Dougherty	1996	–0.03	2.83

[1]See appendix for summary statistics.



Base modified from U.S. Geological Survey 1:24,000-scale digital data

0 1 2 3 MILES
0 1 2 3 KILOMETERS

EXPLANATION

— *150* — **Potentiometric contour**—Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Hachures indicate depression. Contour interval 10 feet. Datum is National Geodetic Vertical Datum 1929 (November 2008 map modified from Gordon, 2009)

Direction of groundwater flow

• **Well data point**

Groundwater Levels

Upper Floridan Aquifer

South-Central Area

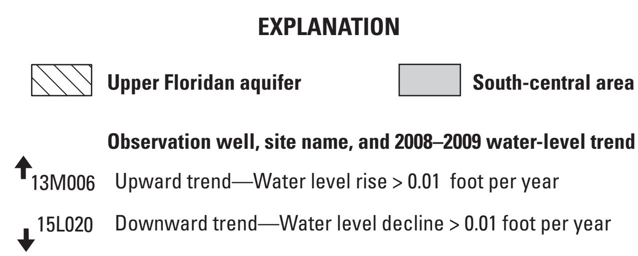
Water levels in five wells were used to define groundwater conditions in the Upper Floridan aquifer in south-central Georgia during 2008–2009 (map and table below). In this area, water in the Upper Floridan aquifer generally is confined but locally is unconfined in karst areas in Lowndes County. Water levels in this area are affected by changes in pumping and by precipitation, with climatic effects more pronounced in areas where the aquifer is close to land surface, such as the karst area in Lowndes County and near the Flint River in the northwestern part of Worth County.

Hydrographs for selected wells (facing page) illustrate monthly mean water levels for the period of record. In Lowndes County, water-level fluctuations in well 19E009 show a pronounced response to climatic effects because the well is in a karst area. Climatic effects are less pronounced in the other three wells, and water levels primarily are influenced by pumping. The hydrographs show periodic upward or downward trends that reflect surplus or deficits in rainfall, respectively, and changes in pumping.

During the period of record, water levels in all five of the wells monitored in the south-central area declined 0.10 to 0.87 foot per year (ft/yr). The greatest declines were in Tift, Cook, and Worth Counties in the northern and eastern part of the area, where recharge is limited by low permeability overburden and irrigation pumping is high (Torak and others, 2010). The rate of decline was lower in wells located near areas of recharge in Lowndes County (well 19E009) and near the Flint River in northwestern Worth County (well 13M006). During 2008–2009, water levels in three of the five wells rose at rates ranging from 1.37 to 2.83 ft/yr, which reflect recovery from the drought that ended in late 2008. Despite the end of the drought, however, water levels in wells 15L020 and 18K049 continued to decline at rates of 0.76 and 0.03 ft/yr, respectively, which reflect the restricted recharge and influence of continued pumping in the area.

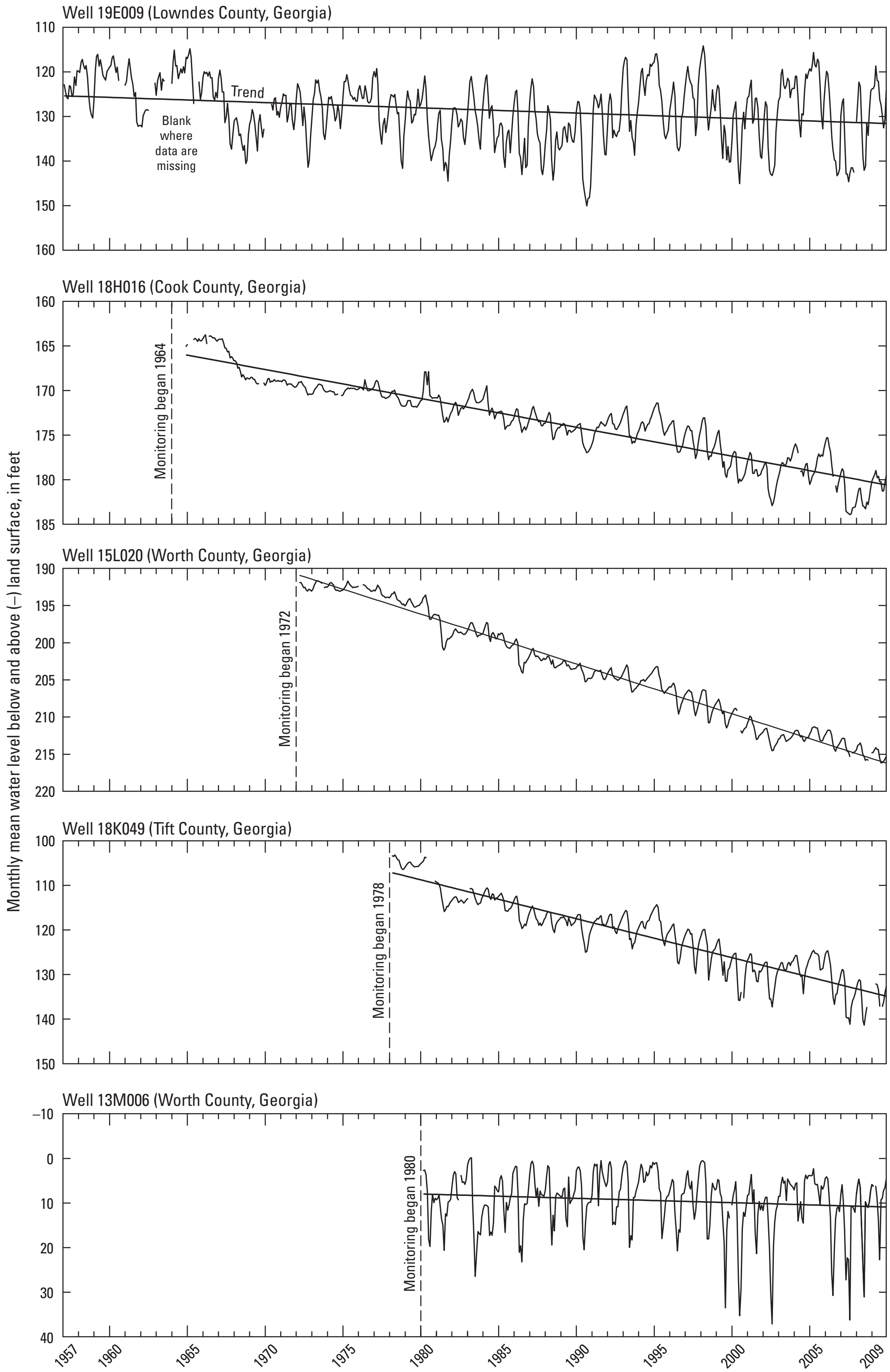
Reference

Torak, L.J., Painter, J.A., and Peck, M.F., 2010, Geohydrology of the Aucilla–Suwannee–Ochlockonee River basin, south-central Georgia and adjacent parts of Florida: U.S. Geological Survey Scientific Investigations Report 2010–5072, available online at *http://pubs.usgs.gov/sir/2010/5072/*.



Site name	County	Year monitoring began	Water-level trend, in feet, per year[1] Period of record	From 2008 to 2009
18H016	Cook	1971	–0.32	1.37
19E009	Lowndes	1957	–0.12	2.83
18K049	Tift	1978	–0.87	–0.03
13M006	Worth	1980	–0.10	1.62
15L020	Worth	1972	–0.67	–0.76

[1]See appendix for summary statistics.


Well 19E009 (Lowndes County, Georgia)
Trend
Blank where data are missing
Well 18H016 (Cook County, Georgia)
Monitoring began 1964
Well 15L020 (Worth County, Georgia)
Monitoring began 1972
Well 18K049 (Tift County, Georgia)
Monitoring began 1978
Well 13M006 (Worth County, Georgia)
Monitoring began 1980
Monthly mean water level below and above (–) land surface, in feet
1957
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2009

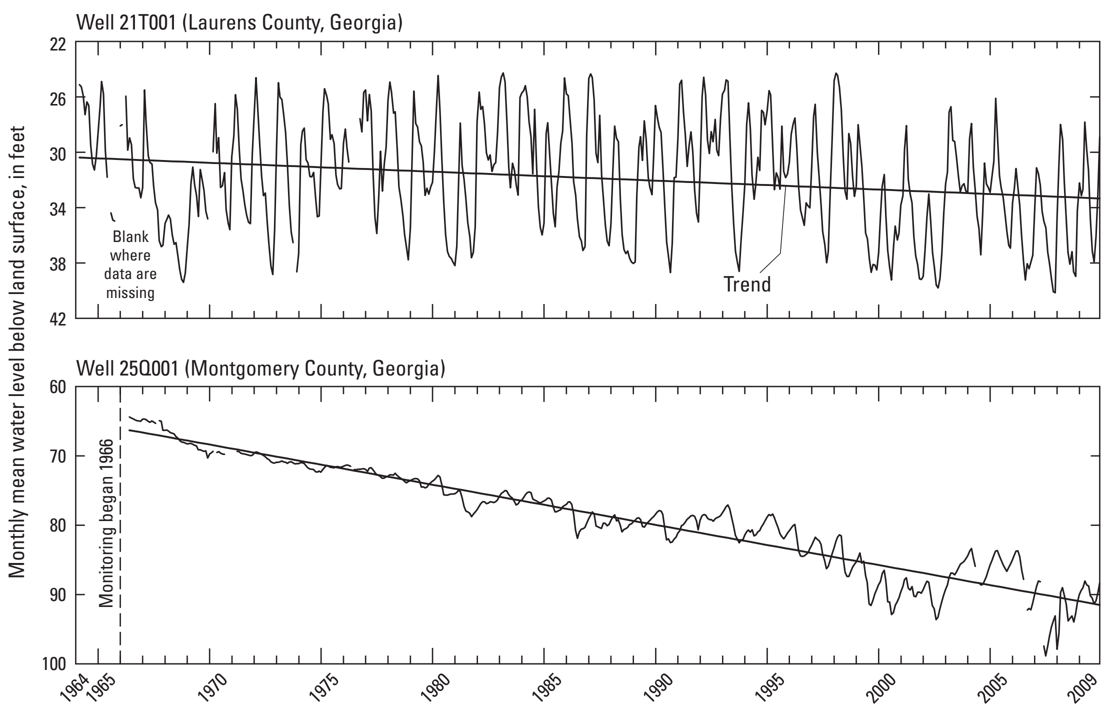
Groundwater Levels

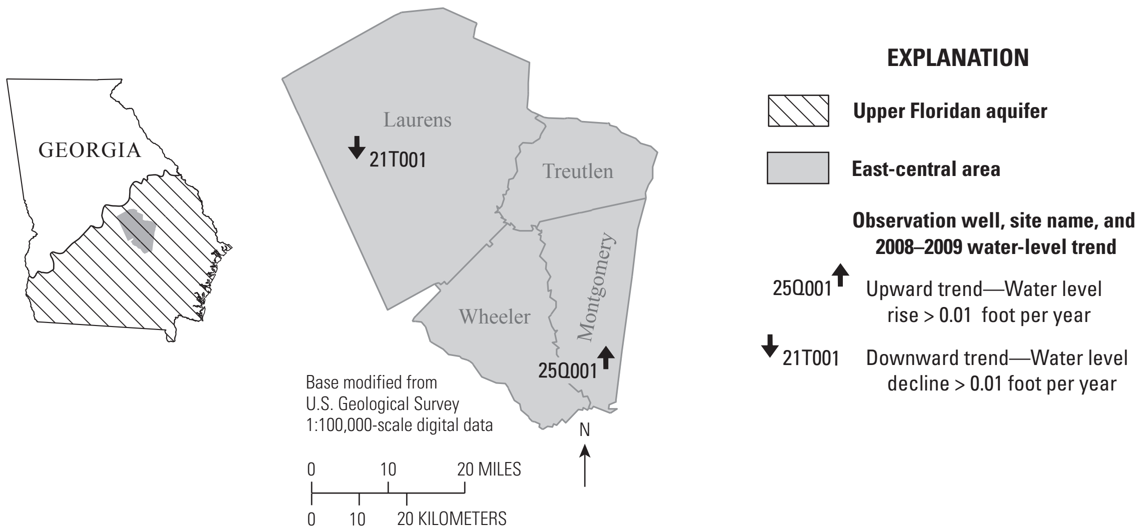
Upper Floridan Aquifer

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 2008–2009 (map and table, facing page). In this area, water in the Upper Floridan aquifer is confined in the southeast and is semiconfined in the northwest, and water levels are influenced by climatic effects and agricultural pumping in these areas. Hydrographs for the two wells (below) illustrate monthly mean water levels for the period of record. The hydrographs show periodic upward or downward trends that reflect surplus or deficits in rainfall, respectively, and changes in pumping.

During the period of record, water levels in both wells showed a long-term decline, ranging from 0.06 foot per year (ft/yr) in well 21T001 to 0.58 ft/yr in well 25Q001. During 2008–2009, water levels in well 21T001 continued to show a slight decline (0.18 ft/yr), whereas water levels in well 25Q001 rose 2.39 ft/yr. These variations in water-level response may be related to differences in proximity to available recharge and to local pumping changes. Well 21T001 in Laurens County is in the northwestern part of the area where the aquifer is semiconfined and close to the area of recharge. Well 25Q001 in Montgomery County is in an area where the aquifer is deeply buried and confined and is more isolated from recharge sources. Local and regional pumping have a more pronounced effect on water levels in well 21T001, which may account for the larger rate of change observed during the period of record and 2008–2009.





Site name	County	Year monitoring began	Water-level trend, in feet, per year[1]	
			Period of record	From 2008 to 2009
21T001	Laurens	1964	–0.06	–0.18
25Q001	Montgomery	1966	–0.58	2.39

[1]See appendix for summary statistics.

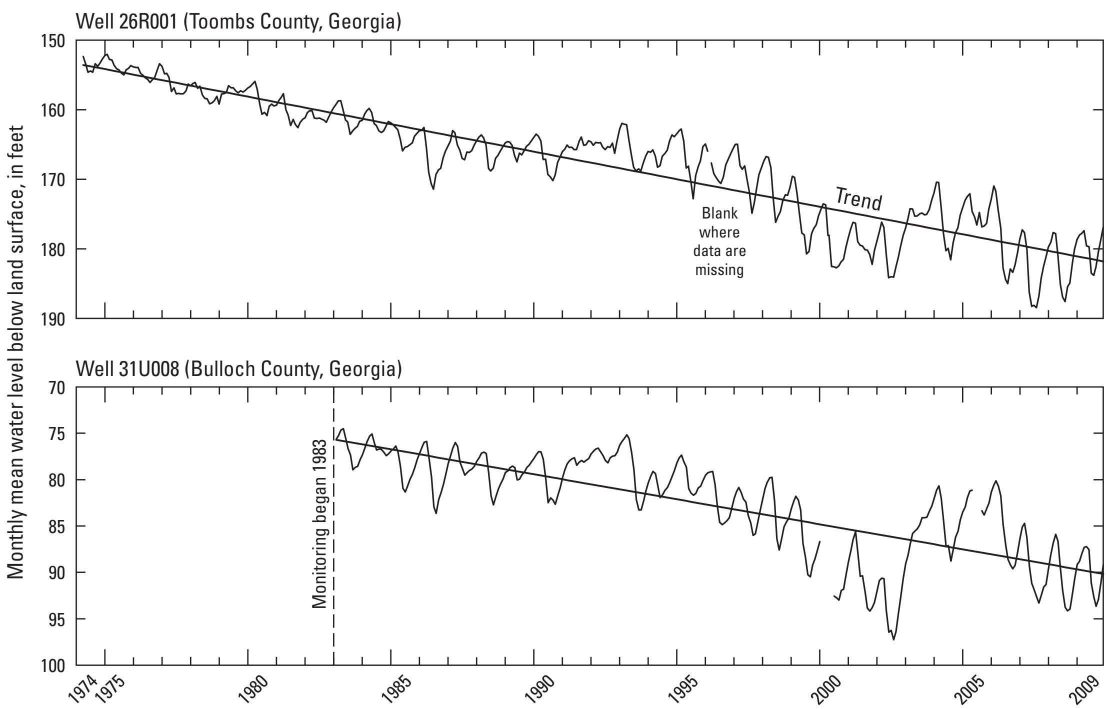
Groundwater Levels

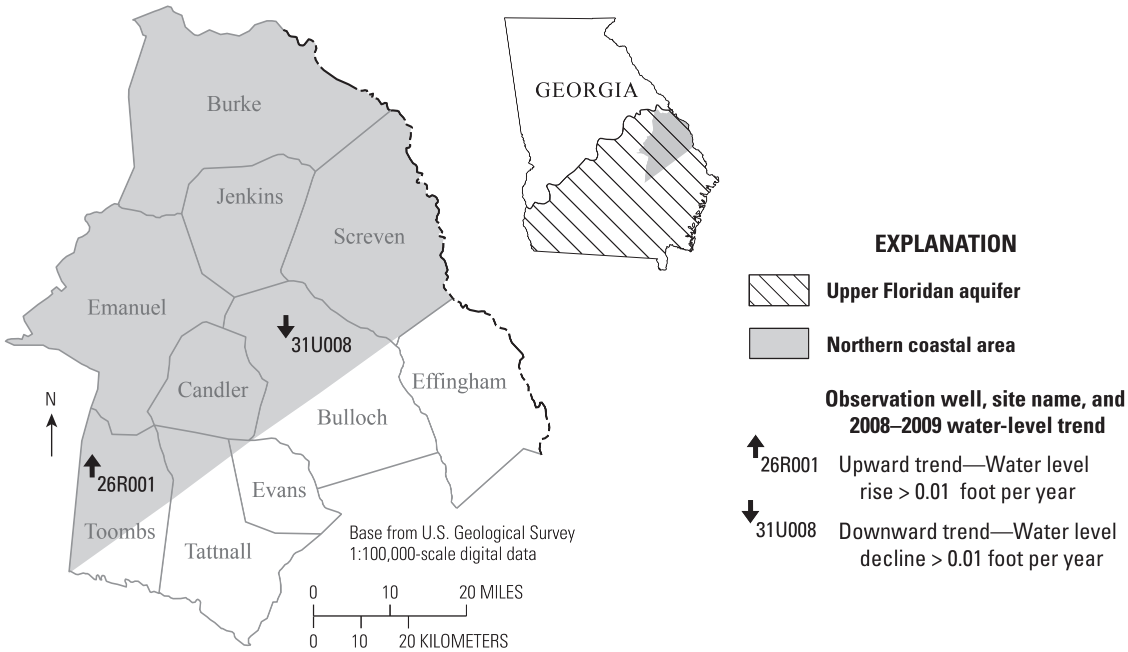
Upper Floridan Aquifer

Northern Coastal Area

Water levels in two wells were used to define groundwater conditions in the Upper Floridan aquifer in the northern coastal area during 2008–2009 (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, and water levels are influenced by climatic effects and agricultural pumping in these areas. Hydrographs for the two wells (below) illustrate monthly mean water levels for the period of record. The hydrographs show periodic upward or downward trends that reflect surplus or deficits in rainfall, respectively, and changes in pumping.

During the period of record, water levels declined at rates of 0.54 foot per year (ft/yr) in well 31U008 and 0.79 ft/yr in well 26R001. During 2008–2009, water levels declined at an accelerated rate of 1.13 ft/yr in well 31U008, whereas water levels in well 26R001 rose at a rate of 0.92 ft/yr. These variations likely resulted from changes in nearby pumping.





Site name	County	Year monitoring began	Water-level trend, in feet, per year[1]	
			Period of record	From 2008 to 2009
31U008	Bulloch	1983	–0.54	–1.13
26R001	Toombs	1974	–0.79	0.92

[1]See appendix for summary statistics.

Groundwater Levels

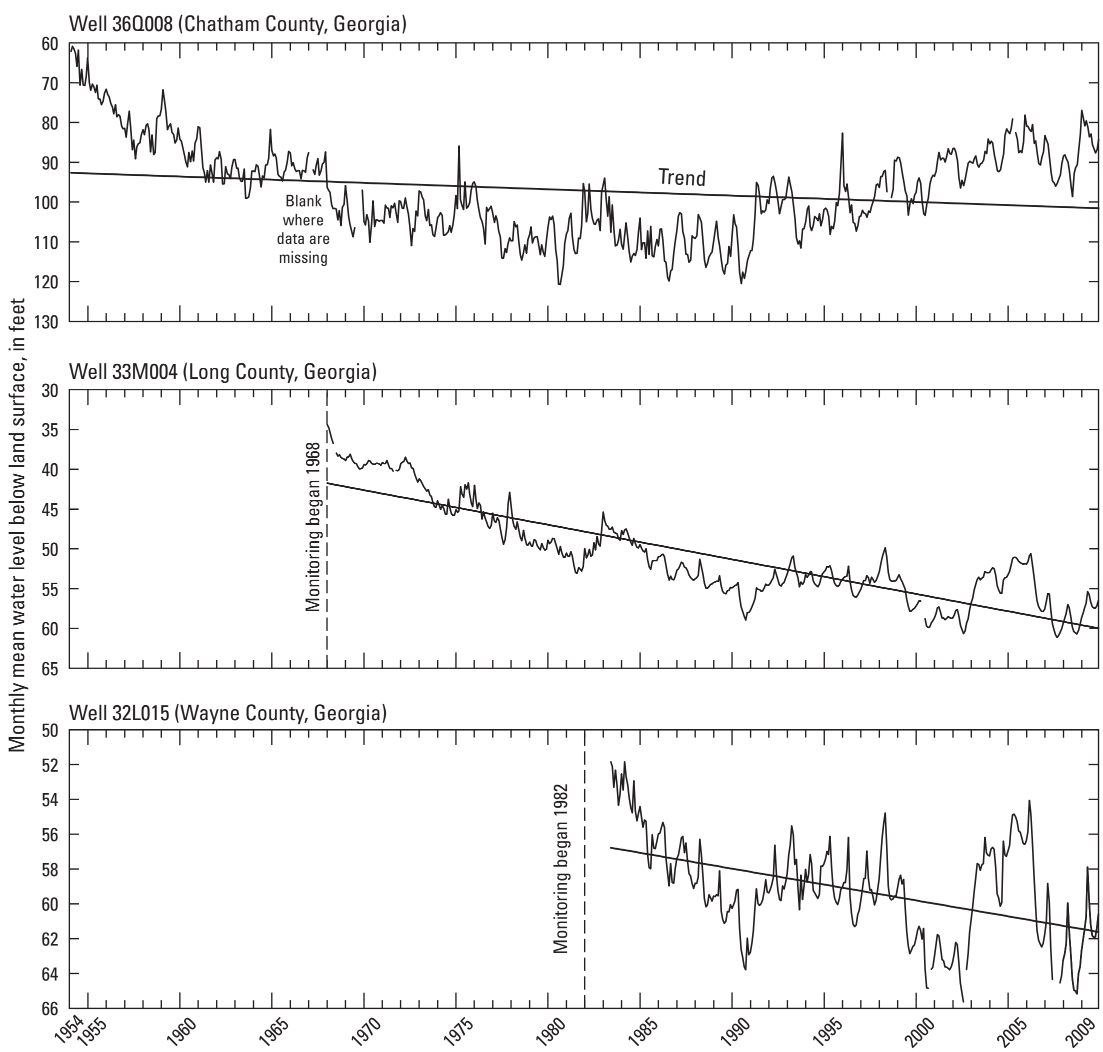
Upper Floridan Aquifer

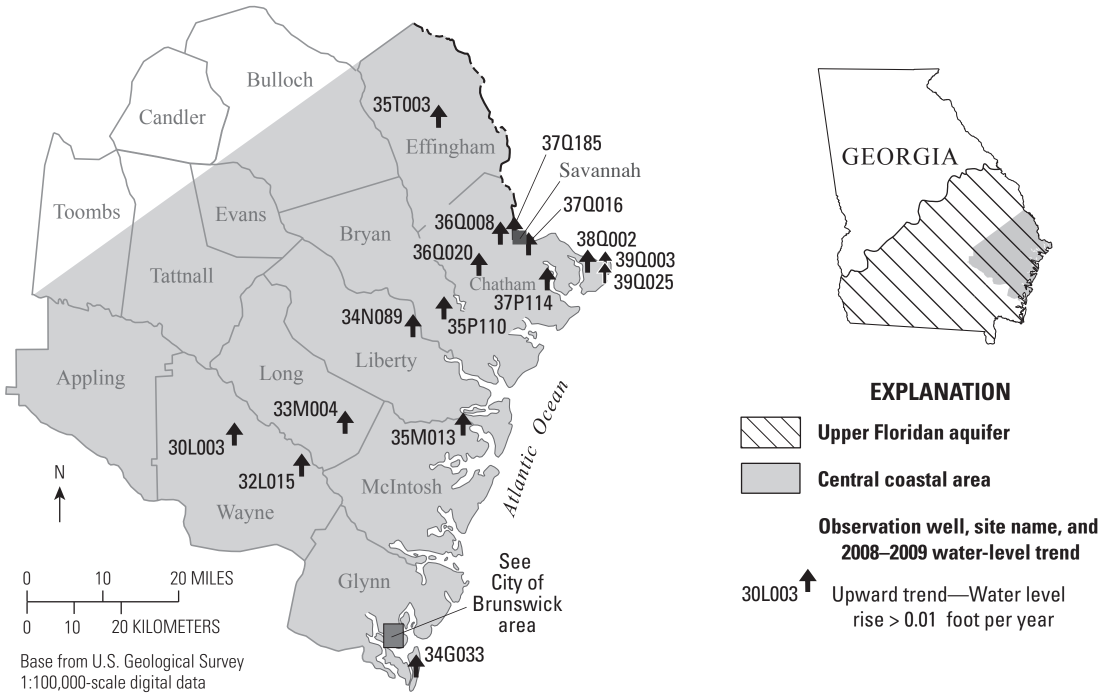
Central Coastal Area

Water levels in 16 wells were used to define groundwater conditions in the Upper Floridan aquifer in the central coastal area of Georgia (excluding the Brunswick area of Glynn County) during 2008–2009 (map and table below). In this area, water in the Upper Floridan aquifer is confined and primarily influenced by pumping. Hydrographs for selected wells (below) illustrate monthly mean water levels for the period of record. The hydrographs show periodic upward or downward trends that reflect changes primarily in pumping.

During the period of record, water levels in 11 of the 16 wells declined 0.04 to 1.49 feet per year (ft/yr). Water levels in the remaining five wells rose at rates of 0.05 to 1.5 ft/yr. During 2008–2009, water levels in all 16 wells rose at rates ranging from 0.72 to 5.88 ft/yr, which reflect reduced water use in the coastal area as the result of conservation practices and recovery from the drought that ended in late 2008.

The hydrograph for well 36Q008 near Savannah in Chatham County shows an overall downward trend of 0.16 ft/yr in water levels for the period of record. Since 1991, however, water levels have been rising in the well, largely as the result of decreased water use due to conservation practices in the area (J.L. Fanning, U.S. Geological Survey, oral commun., 2008). This rising trend continued during 2008–2009 when water levels in well 36Q008 rose 4.72 ft/yr.





Site name	County	Year monitoring began	Water-level trend, in feet, per year[1]	
			Period of record	From 2008 to 2009
35P110	Bryan	2000	0.05	2.20
36Q008	Chatham	1954	–0.16	4.72
36Q020	Chatham	1958	–0.54	2.75
37P114	Chatham	1984	0.22	3.04
37Q016	Chatham	1955	–0.04	4.40
37Q185	Chatham	1985	1.50	5.88
38Q002	Chatham	1956	–0.27	1.48
39Q003	Chatham	1962	–0.26	0.72
39Q025	Chatham	1996	0.18	1.10
34G033	Glynn	2004	–1.49	1.38
35T003	Effingham	2000	0.23	1.11
34N089	Liberty	1967	–0.49	1.96
33M004	Long	1968	–0.43	1.41
35M013	McIntosh	1966	–0.42	1.68
30L003[2]	Wayne	1964	–0.46	2.43
32L015	Wayne	1983	–0.18	1.31

[1]See appendix for summary statistics.

[2]Well is completed in the Upper and Lower Brunswick aquifers and the Upper Floridan aquifer.

Groundwater Levels

Upper Floridan Aquifer

City of Brunswick Area

Water levels in seven wells were used to define groundwater conditions in the Upper Floridan aquifer near the City of Brunswick in the central coastal area of Georgia during 2008–2009 (maps and table, facing page). In this area, water in the Upper Floridan aquifer is confined, and groundwater flow paths are influenced primarily by pumping for industrial and public supply.

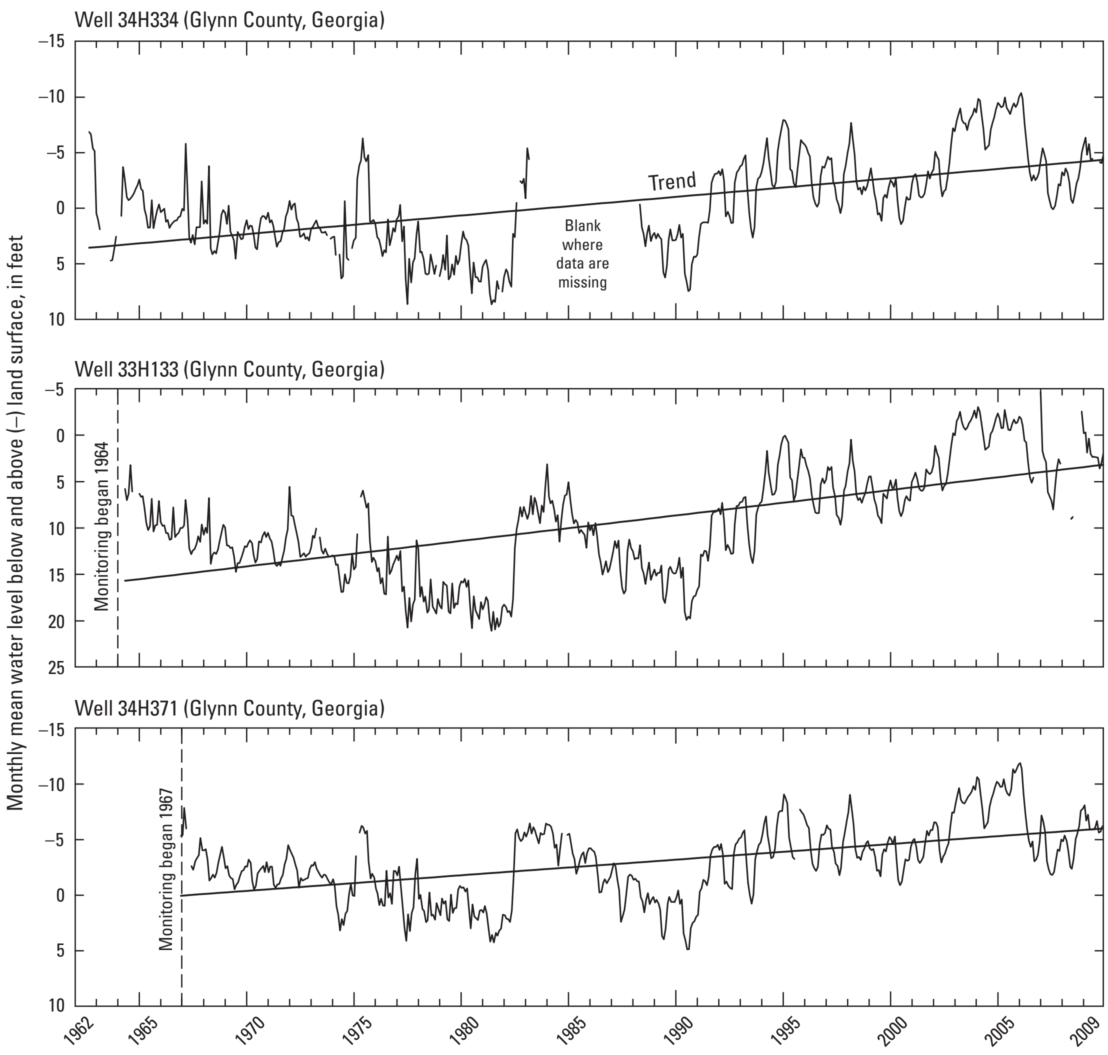
During the period of record, water levels in all of the wells had rising trends with rates of change that ranged from 0.05 to 4.26 feet per year (ft/yr). Hydrographs for three wells in the Upper Floridan aquifer in the Brunswick area (below) illustrate monthly mean water levels for the period of record. During 2008–2009, water levels in the seven wells rose at rates ranging from 0.89 to 7.58 ft/yr.

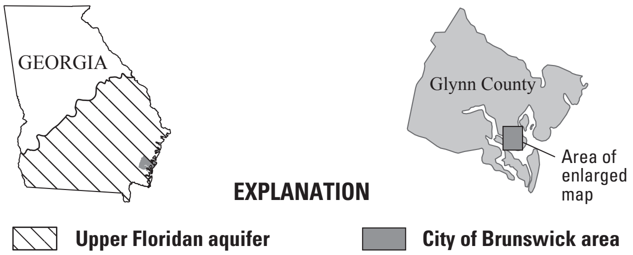
In addition to continuous water-level monitoring, synoptic water-level measurements are made periodically in wells in the Brunswick area. Water-level measurements from 20 wells were collected during July 2008 and from 22 wells during July–August 2009, which subsequently were used to construct potentiometric-surface maps of the Upper Floridan aquifer. The maps on the facing page show that groundwater generally flows from the south, where water-level altitudes are greater than 15 ft, toward industrial pumping centers in northern Brunswick, where water-level altitude is less than 0 ft.

References

Cherry, G.S., Peck, M.F., Painter, J.A., and Stayton, W.L., 2010, Groundwater conditions and studies in the Brunswick–Glynn County area, Georgia, 2008: U.S. Geological Survey Open-File Report 2009–1275, 54 p.; available online at *http://pubs.usgs.gov/of/2009/1275/*.

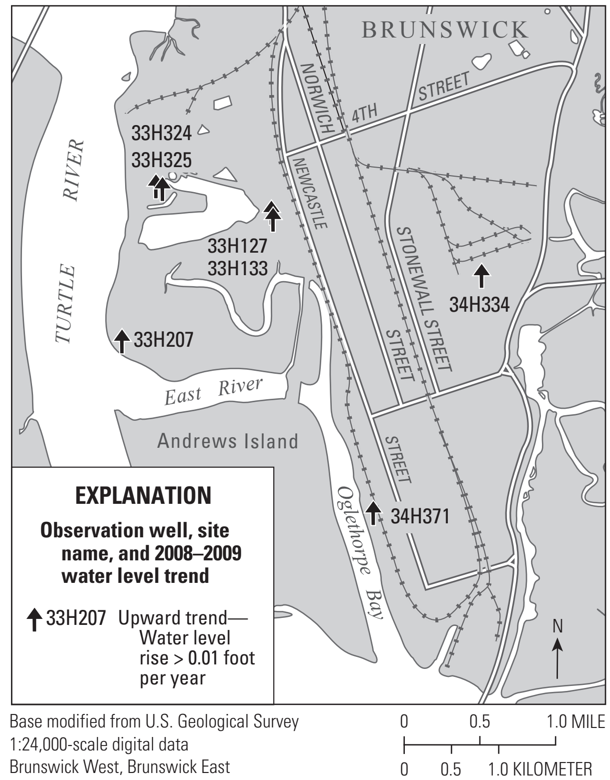
Peck, M.F., Painter, J.A., and Leeth, D.C., 2009, Groundwater conditions and studies in Georgia, 2006–2007: U.S. Geological Survey Scientific Investigations Report 2009–5070, 86 p.; available online at *http://pubs.usgs.gov/sir/2009/5070/*.



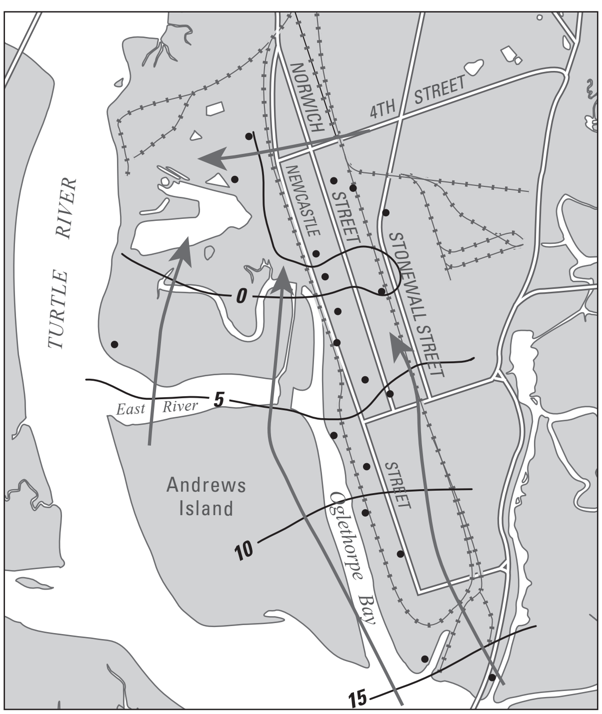


Site name	County	Year monitoring began	Water-level trend, in feet, per year[1]	
			Period of record	From 2008 to 2009
33H127	Glynn	1962	0.05	2.07
33H133	Glynn	1964	0.27	2.43
33H207	Glynn	1986	0.47	0.89
33H324	Glynn	2007	1.73	2.24
33H325	Glynn	2007	4.26	7.58
34H334	Glynn	1985	0.17	1.54
34H371	Glynn	1986	0.14	1.28

[1]See appendix for summary statistics.



July 2008



(Modified from Cherry and others, 2010)

July–August 2009

EXPLANATION

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

→ **General direction of groundwater flow**

• **Observation well**

Groundwater Levels

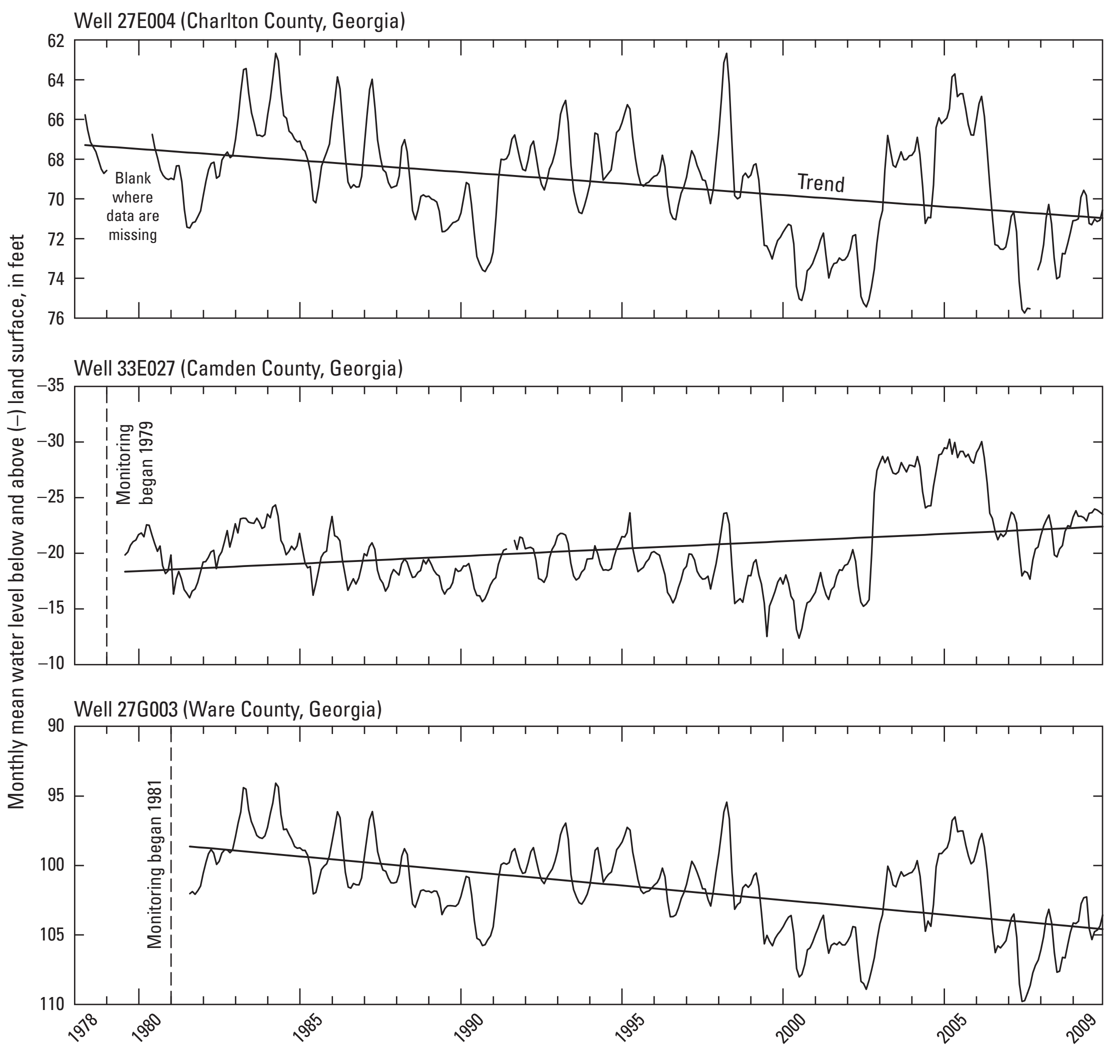
Upper Floridan Aquifer

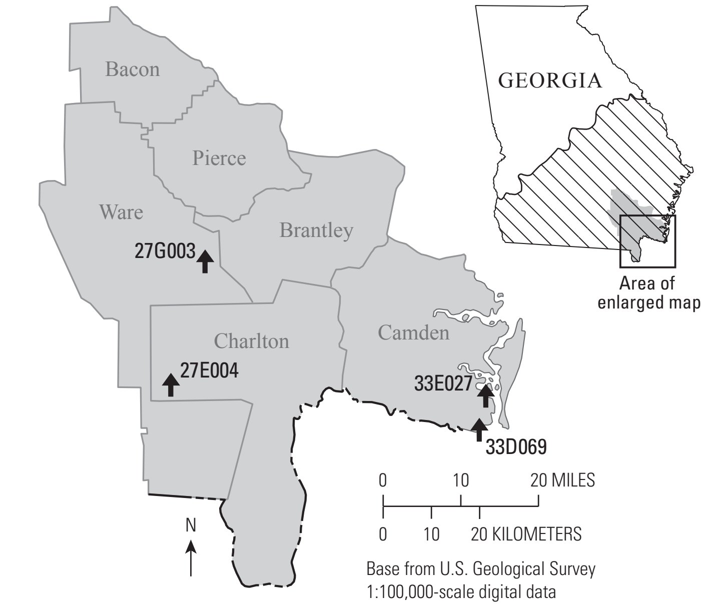
Southern Coastal Area

Water levels in four wells were used to define groundwater conditions in the Upper Floridan aquifer in the southern coastal area of Georgia during 2008–2009 (map and table, facing page). In this area, water in the Upper Floridan aquifer is confined and influenced mostly by pumping to the south in the Fernandina Beach area, Florida, and by climatic effects and pumping to the west. Hydrographs for selected wells (below) illustrate monthly mean water levels for the period of record. The hydrographs show periodic upward or downward trends that primarily reflect changes in pumping. The sharp rise in water levels in late 2002 on each of the hydrographs is the result of a 35 million gallons per day decrease in pumpage at a nearby industry in St. Marys (Peck and others, 2005).

Water-level changes during the period of record varied across the southern coastal area. In the western part of the area, water levels declined at rates of 0.12 to 0.21 foot per year (ft/yr). In the eastern part of the area, water levels rose at rates of 0.13 to 1.74 ft/yr. The larger water-level rises in the eastern part of the area result from the discontinuation of pumping at nearby St. Marys in 2002 (see hydrograph for well 33E027). During 2008–2009, water levels in all of the wells rose at rates ranging from 0.92 to 1.34 ft/yr, which corresponds to the end of a 2-year drought in 2008.

In addition to continuous water-level monitoring, synoptic water-level measurements are made 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 2008 and May 2009, water levels measured in this area were used to construct potentiometric-surface maps of the aquifer (Kinnaman and Dixon 2009a, b). The maps for 2008 and 2009 (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.





EXPLANATION

Upper Floridan aquifer

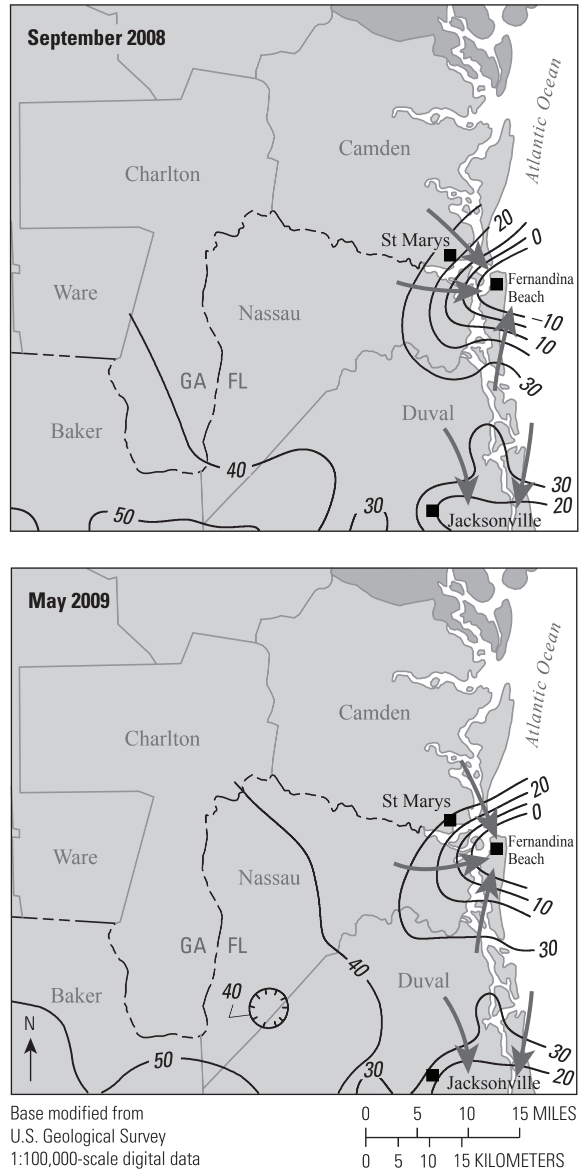
Southern coastal area

Observation well, site name, and 2008–2009 water-level trend

27E004 Upward trend—Water level rise > 0.01 foot per year

Site name	County	Year monitoring began	Water-level trend, in feet, per year[1]	
			Period of record	From 2008 to 2009
33D069	Camden	1994	1.74	0.92
33E027	Camden	1979	0.13	1.34
27E004	Charlton	1986	–0.12	1.09
27G003	Ware	1984	–0.21	0.98

[1]See appendix for summary statistics.



EXPLANATION

40 **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 and Dixon, 2009a, b)

Direction of ground-water flow

References

Kinnaman, S.L., and Dixon, J.F., 2009a, Potentiometric surface of the Upper Floridan aquifer in the St. Johns River Water Management District and vicinity, Florida, September 2008: U.S. Geological Survey Scientific Investigations Map 3070, 1 sheet; available online at *http://pubs.usgs.gov/sim/3070/*.

Kinnaman, S.L., and Dixon, J.F., 2009b, Potentiometric surface of the Upper Floridan aquifer in the St. Johns River Water Management District and vicinity, Florida, May 2009: U.S. Geological Survey Scientific Investigations Map 3091, 1 sheet; available online at *http://pubs.usgs.gov/sim/3091/*.

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.; available online at *http://pubs.usgs.gov/sir/2004/5295/*.

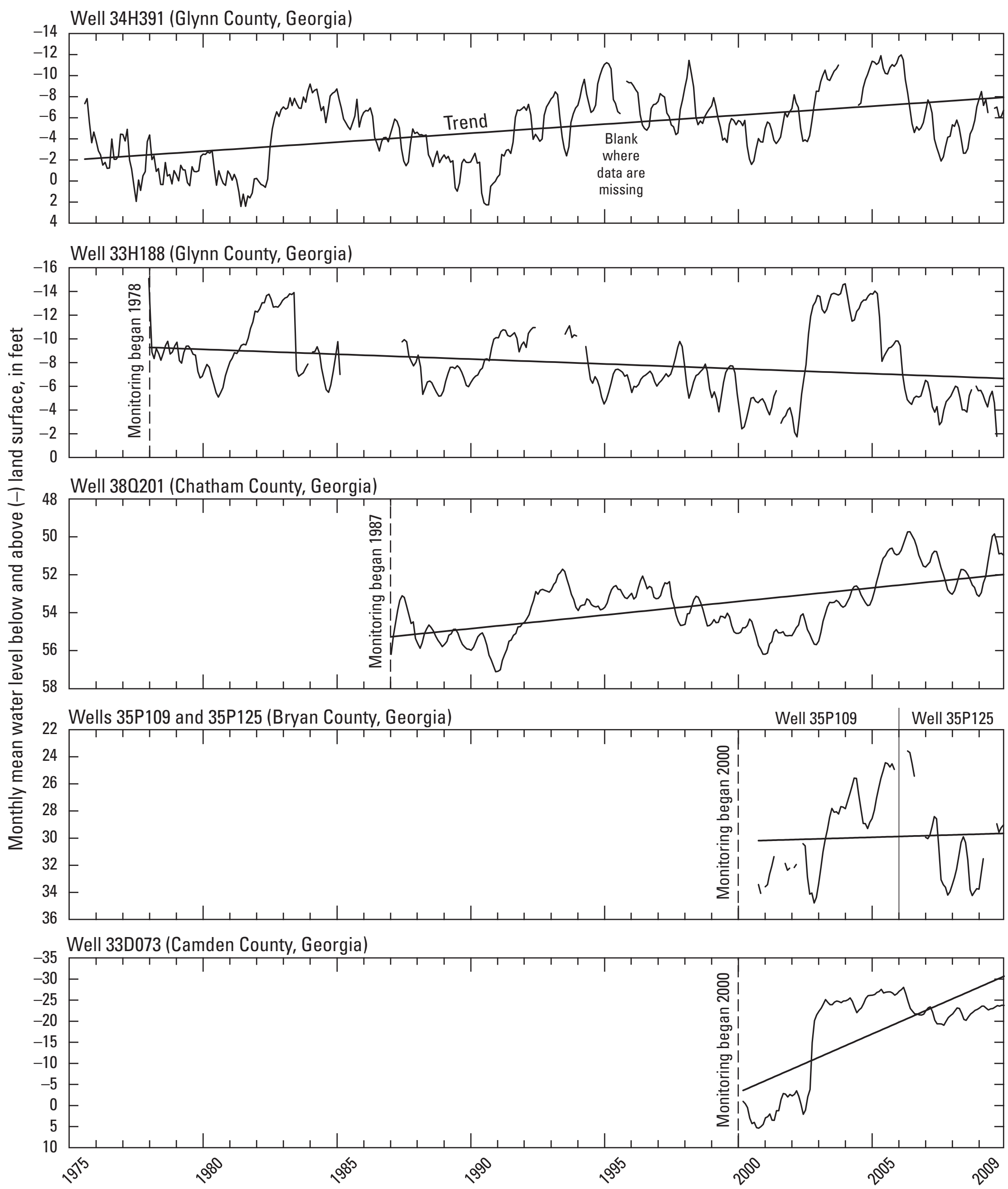
Groundwater Levels

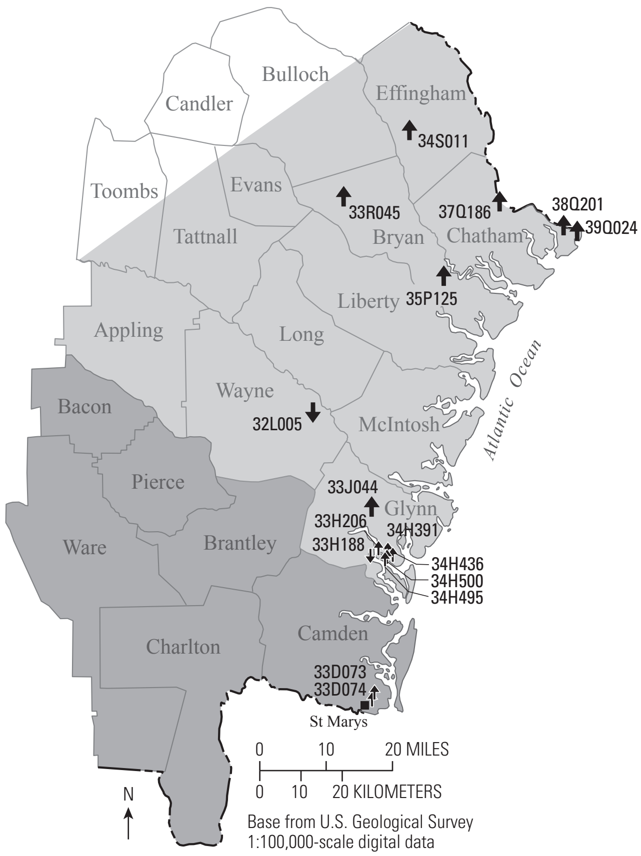
Lower Floridan Aquifer and Underlying Units in Coastal Georgia

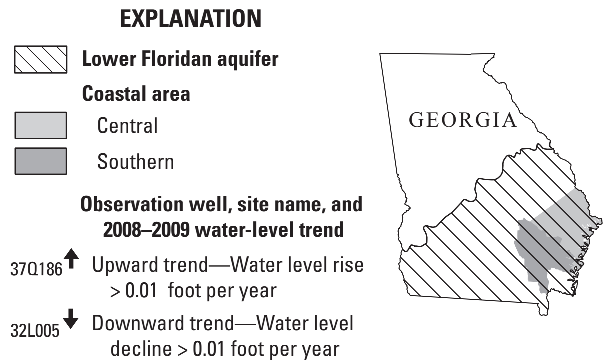
Water levels in 16 wells in central and southern coastal Georgia were used to define groundwater conditions in the Lower Floridan aquifer and underlying units during 2008–2009 (map and table, facing page). In this area, water in the Lower Floridan aquifer is confined and influenced mostly by pumping. Hydrographs for selected wells (below) illustrate monthly mean water levels for the period of record. The hydrographs show periodic upward or downward trends that primarily reflect changes in pumping.

During the period of record, water levels in 10 of the wells rose 0.05 to 2.77 feet per year (ft/yr), and declined in 6 wells from 0.06 to 0.46 ft/yr. The largest rise occurred in well 33D073 near St. Marys, Camden County, in response to the shutdown of an industry in 2002 (Peck and others, 2005).

During 2008–2009, water levels in 14 of the 16 wells rose at rates ranging from 1.10 to 2.33 ft/yr, which reflects reduced water use in the coastal area as the result of conservation practices and recovery from the drought that ended in late 2008. Despite this recovery, water levels in well 32L005 and 33H188 declined at rates of 0.42 and 0.83 ft/yr, respectively.







Reference

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.; available online at *http://pubs.usgs.gov/sir/2004/5295/*.

Site name	Water-bearing unit[1]	County	Year monitoring began	Water-level trend, in feet, per year[2]	
				Period of record	From 2008 to 2009
33R045	LF	Bryan	2002	–0.46	1.44
35P109/35P125[3]	LF	Bryan	2000	0.05	1.52
33D073	LF	Camden	2000	2.77	1.11
33D074	LF	Camden	2003	–0.46	1.10
37Q186	P	Chatham	1985	0.67	2.33
38Q201	P	Chatham	1987	0.14	1.14
39Q024	LF	Chatham	1996	0.17	1.18
34S011	LF	Effingham	2002	–0.34	1.14
33H188	F	Glynn	1985	–0.08	–0.83
33H206	LF	Glynn	1986	0.25	1.54
33J044	LF	Glynn	1979	0.09	1.98
34H391	LF	Glynn	1984	0.17	1.57
34H436	LF	Glynn	1983	0.18	1.46
34H495	LF	Glynn	2001	1.22	1.63
34H500	LF	Glynn	2001	–0.06	1.90
32L005	LF	Wayne	1980	–0.31	–0.42

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

[2]See appendix for summary statistics.

[3]Record from 2000–2006 is from well 35P109 that has now been replaced by 35P125.

Groundwater Levels

Claiborne and Gordon Aquifers

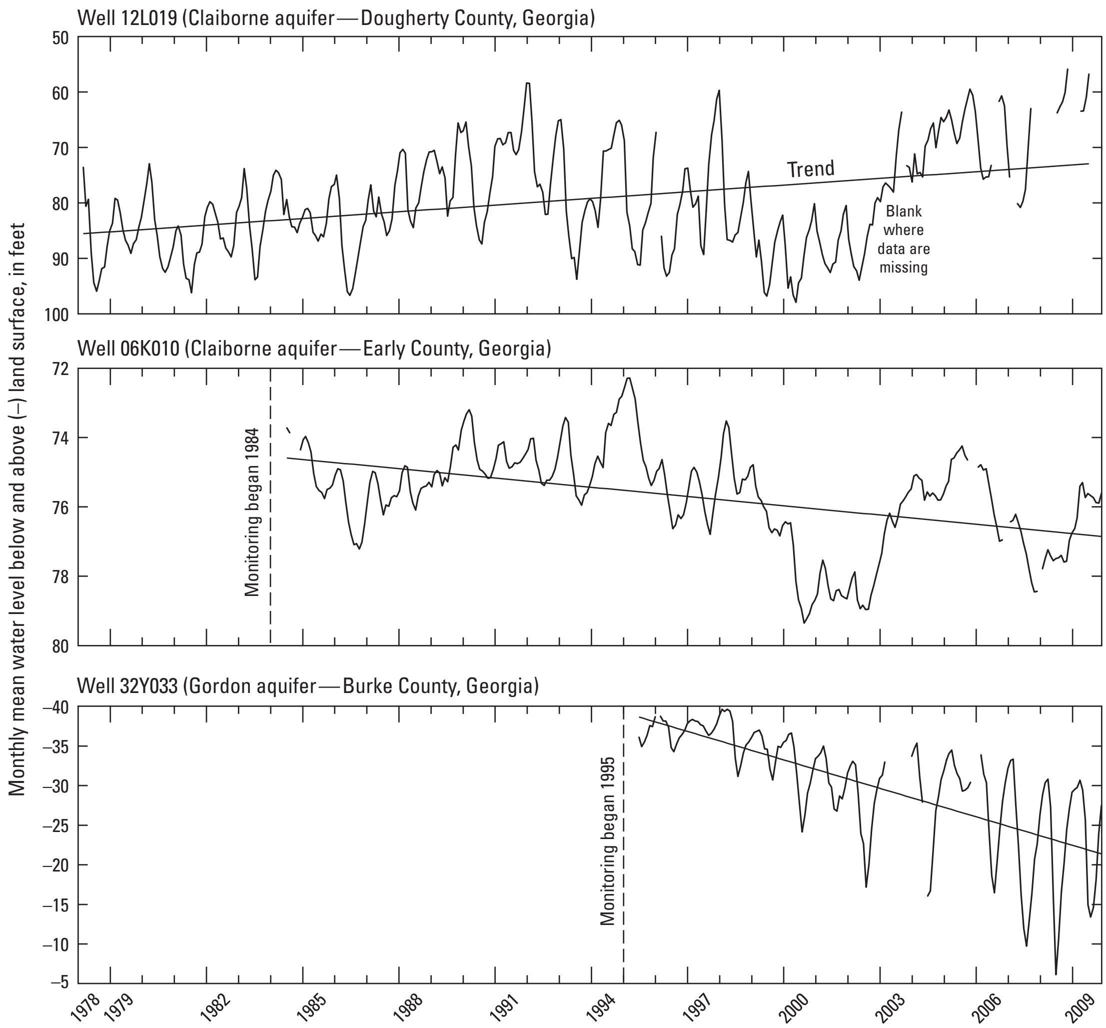
Water levels in 10 Claiborne aquifer wells and 1 Gordon aquifer well were used to define groundwater conditions in southwestern and east-central Georgia during 2008–2009 (map and table, facing page). Water in the Claiborne and Gordon aquifers can be confined or unconfined. Hydrographs showing water levels in two wells in the Claiborne aquifer and one well in the Gordon aquifer (below) illustrate monthly mean water levels for the period of record. The hydrographs show periodic upward or downward trends that reflect changes in precipitation and pumping.

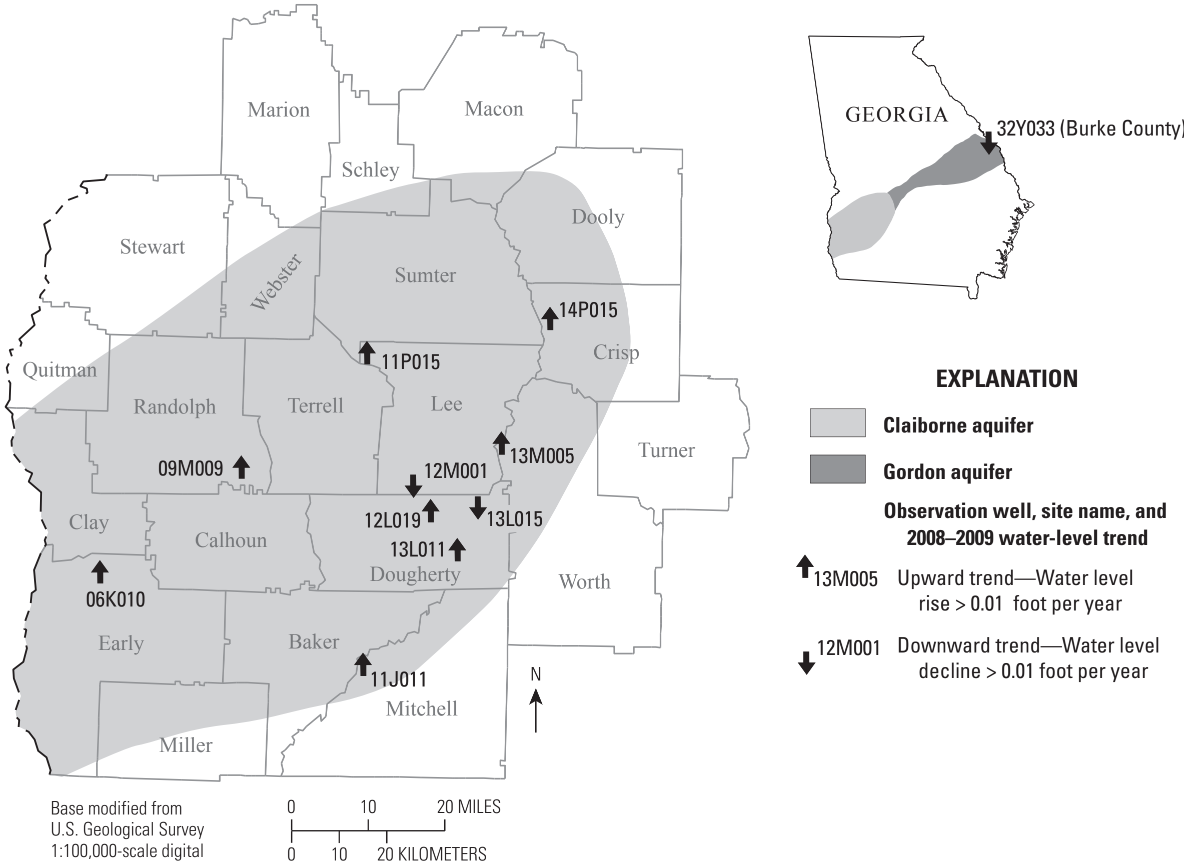
During the period of record, water levels in the Claiborne aquifer declined at rates of 0.04 to 1.10 feet per year (ft/yr) in 7 of the 10 wells monitored. The greatest decline (5.07 ft/yr) in well 12M001 in southern Lee County probably is related to increases in local pumping. During 2008–2009, water levels in 8 of the 10 Claiborne aquifer wells rose from 0.39 to 4.83 ft/yr, which corresponds to the end of a 2-year drought in 2008. Despite this overall recovery, however, water levels in wells 13L015 and 12M001 in the Claiborne aquifer continued to decline at rates of 0.92 and 5.07 ft/yr, respectively.

In the Gordon aquifer, water levels in well 32Y033 declined at a rate of 1.19 ft/yr for the period of record. During 2008–2009, water-levels continued to decline at a rate of 1.35 ft/yr. These declines correspond to increased agricultural use in east-central Georgia (Cherry, 2006).

Reference

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





Site name	Water-bearing unit[1]	County	Year monitoring began	Water-level trend, in feet, per year[2]	
				Period of record	From 2008 to 2009
14P015	C	Crisp	1984	–0.31	4.83
12L019	C	Dougherty	1978	0.04	3.79
13L011	C	Dougherty	1977	0.12	2.63
13L015	C	Dougherty	1979	–0.51	–0.92
06K010	C	Early	1986	–0.09	1.38
11P015	C	Lee	1984	–0.04	1.14
12M001	C	Lee	1978	–1.10	–5.07
11J011	C	Mitchell	1981	–0.15	3.58
09M009	C	Randolph	1984	0.01	1.56
13M005	C	Worth	1980	–0.23	0.39
32Y033	G	Burke	1995	–1.19	–1.35

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

[2]See appendix for summary statistics.

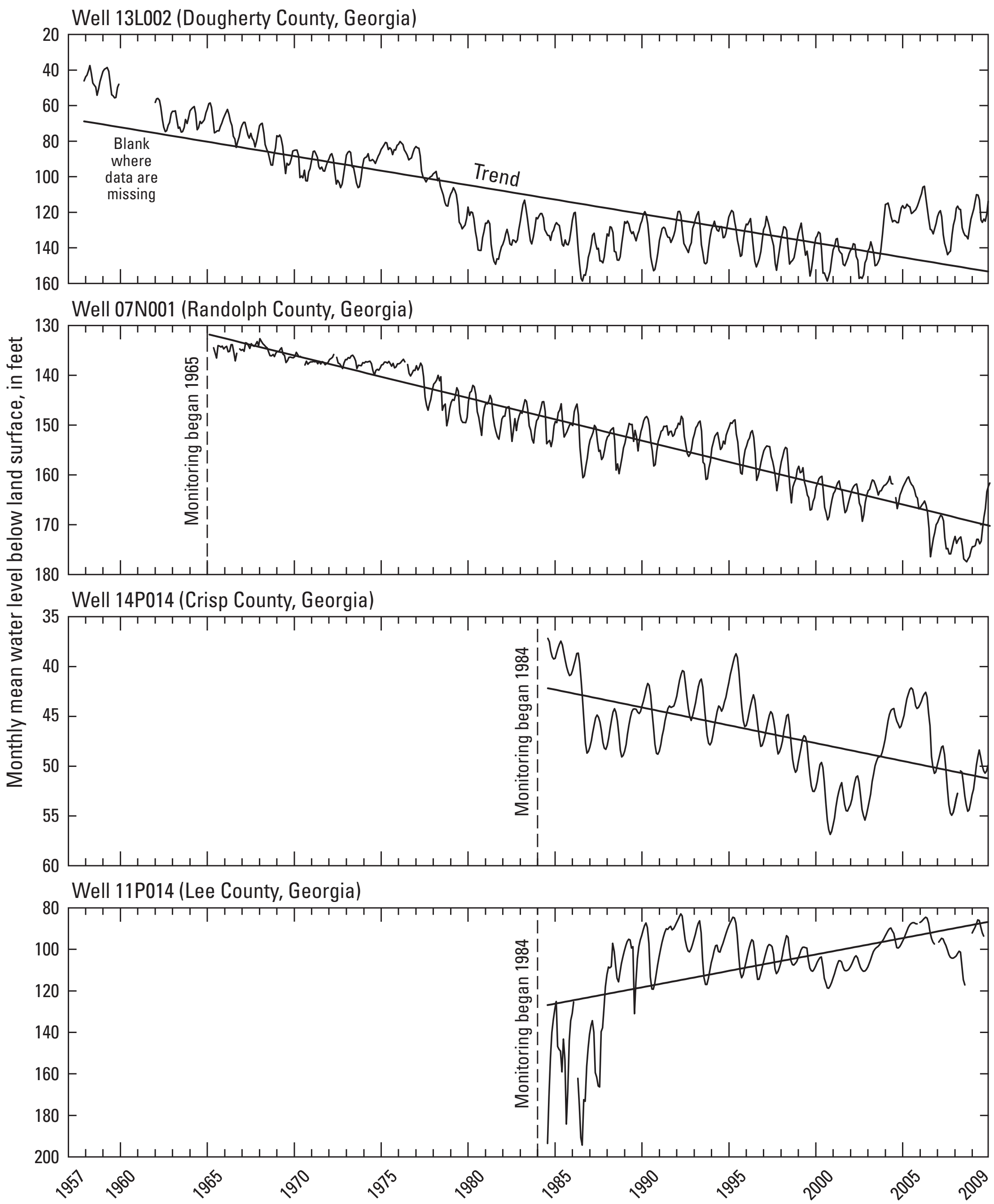
Groundwater Levels

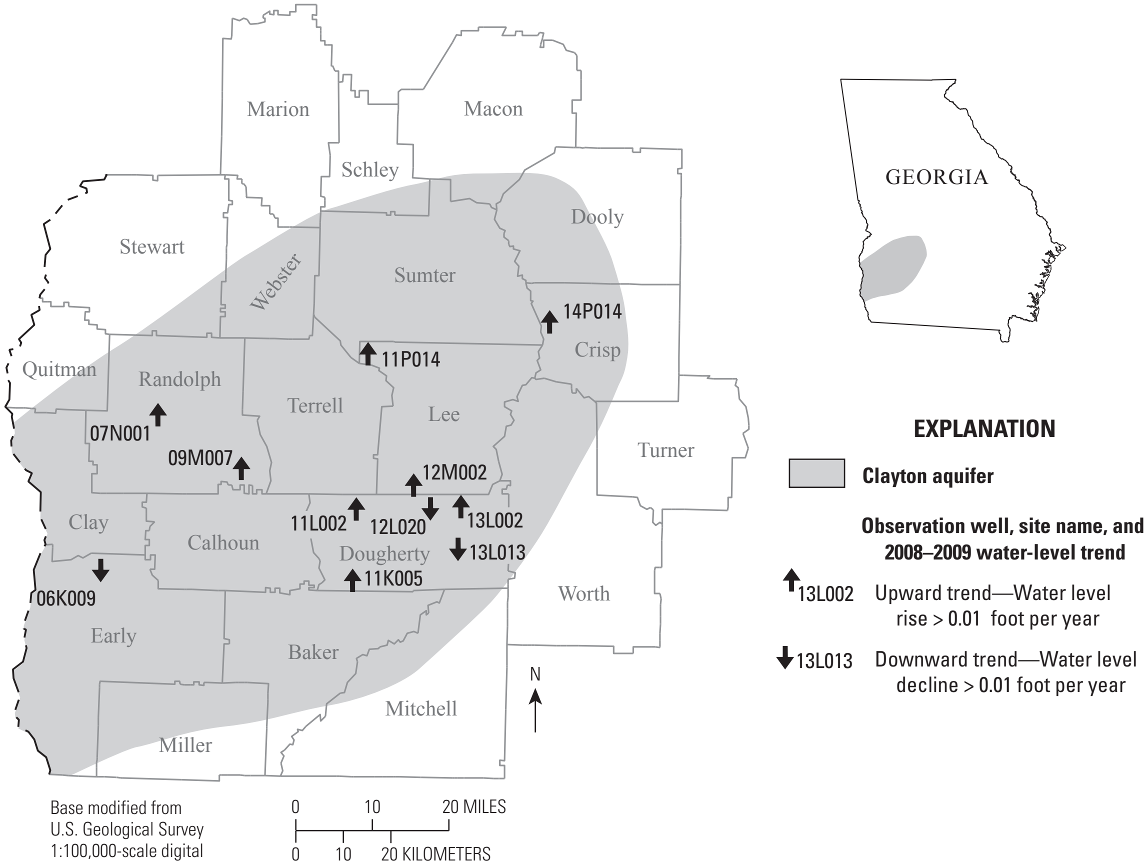
Clayton Aquifer

Water levels in 11 wells were used to define groundwater conditions in the Clayton aquifer in southwestern Georgia during 2008–2009 (map and table, facing page). In this area, water in the Clayton aquifer is confined and influenced mostly by pumping. Hydrographs for selected wells (below) illustrate monthly mean water levels for the period of record. The hydrographs show periodic upward or downward trends that reflect changes in pumping.

During the period of record, water levels in 8 of the 11 wells declined at rates of 0.36 to 1.85 feet per year (ft/yr). Water levels rose in three wells at rates from 0.07 to 1.58 ft/yr during the period of record. These changes reflect variations in local and regional pumping.

During 2008–2009, water levels in eight of the wells rose from 0.32 to 12.48 ft/yr, which corresponds to the end of a 2-year drought and the resulting decrease in irrigation in 2008. The largest rise occurred in well 11P014 in northern Lee County and likely results from a decrease in nearby pumping. Despite regional recovery from the drought, water levels in three of the wells declined from 0.10 to 4.01 ft/yr.





Site name	County	Year monitoring began	Water-level trend, in feet, per year[1]	
			Period of record	From 2008 to 2009
14P014	Crisp	1986	–0.36	2.01
11K005	Dougherty	1979	–1.64	0.32
11L002	Dougherty	1973	–1.79	5.25
12L020	Dougherty	1980	0.32	–1.98
13L002	Dougherty	1957	–1.62	2.92
13L013	Dougherty	1978	0.07	–4.01
06K009	Early	1986	–1.42	0.10
11P014	Lee	1984	1.58	12.48
12M002	Lee	1978	–0.73	3.71
07N001	Randolph	1965	–0.85	5.54
09M007	Randolph	1984	–1.85	4.16

[1]See appendix for summary statistics.

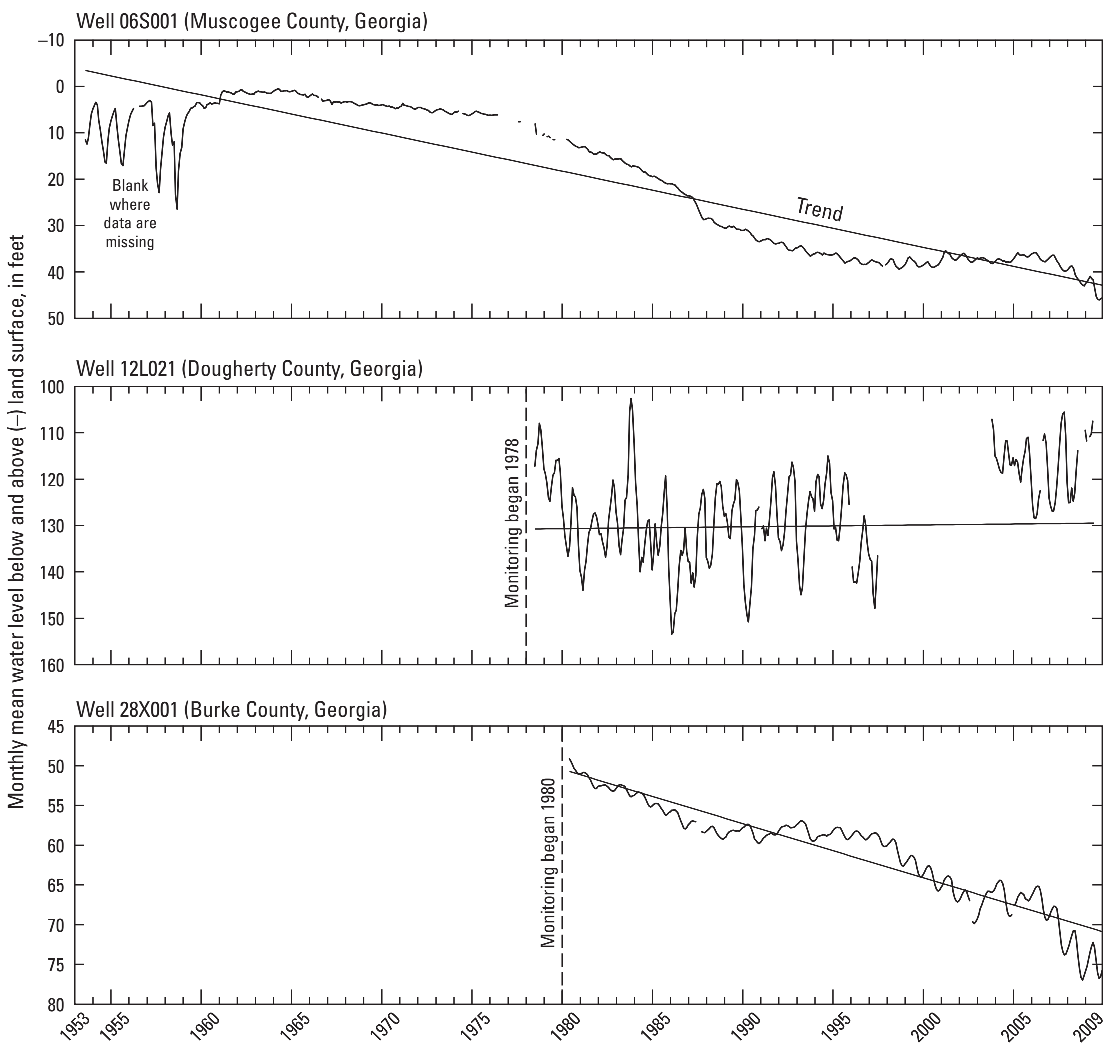
Groundwater Levels

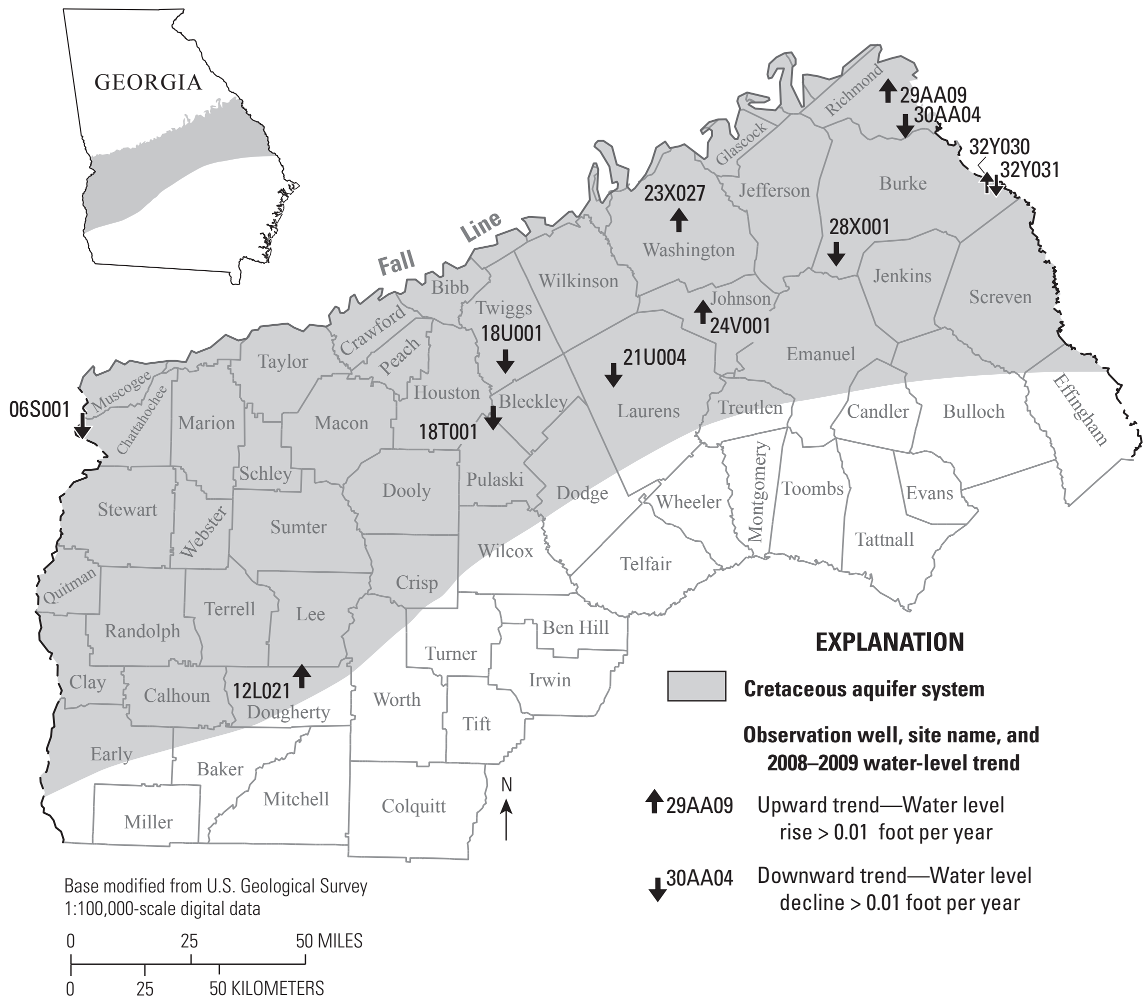
Cretaceous Aquifer System

Water levels in 12 wells in the Cretaceous aquifer system were used to define groundwater conditions throughout central and southwestern Georgia during 2008–2009 (map and table, facing page). In this area, water in the Cretaceous aquifer system mostly is confined but can be unconfined in stream valleys. Hydrographs for selected wells (below) illustrate monthly mean water levels for the period of record. The hydrographs show periodic upward or downward trends that largely reflect changes in pumping. Water levels in wells 06S001 and 28X001 both show a long term downward trend related to groundwater pumping. The hydrograph for well 12L021 shows a sharp water level rise in 2003 when pumping was discontinued from a nearby public-supply well.

During the period of record, water levels in 11 of the 12 wells declined from 0.12 to 0.89 foot per year (ft/yr). The only well showing a water level rise (0.04 ft/yr) during the period of record was well 12L021 at Albany because of decreased pumping for public supply.

During 2008–2009, water levels in seven of the wells declined at rates of 0.16 to 3.40 ft/yr and rose in five wells at rates of 0.28 to 8.74 ft/yr. The variation in water-level response during 2008–2009 probably is related to changes in pumping across the area.





Site name	Water-bearing unit[1]	County	Year monitoring began	Water-level trend, in feet, per year[2]	
				Period of record	From 2008 to 2009
28X001	M	Burke	1980	–0.68	–1.87
32Y030	LM	Burke	1995	–0.44	0.28
32Y031	LD	Burke	1995	–0.51	–0.16
12L021	P	Dougherty	1978	0.04	1.57
24V001	M	Johnson	1980	–0.60	0.31
21U004	M	Laurens	1982	–0.32	–0.23
06S001	T	Muscogee	1953	–0.82	–3.40
18T001	M	Pulaski	1981	–0.23	–0.70
29AA09	UM	Richmond	1990	–0.23	0.51
30AA04	DM	Richmond	1979	–0.33	–0.19
18U001	D	Twiggs	1975	–0.12	–0.36
23X027	DM	Washington	1985	–0.89	8.74

[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.

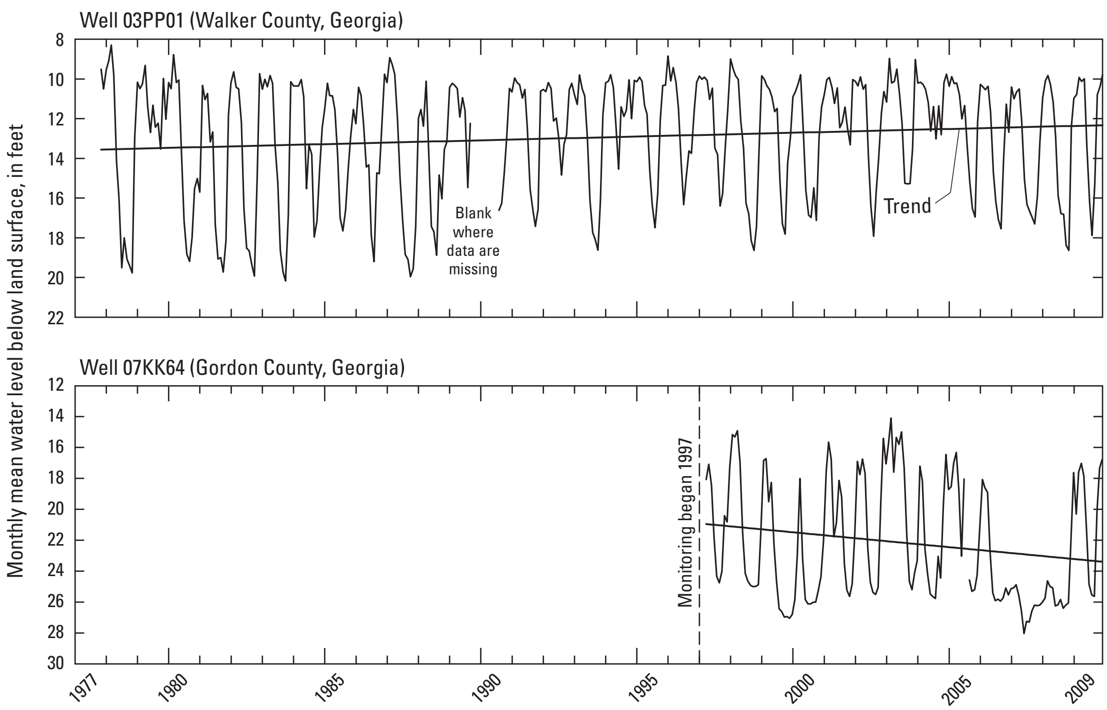
[2]See appendix for summary statistics.

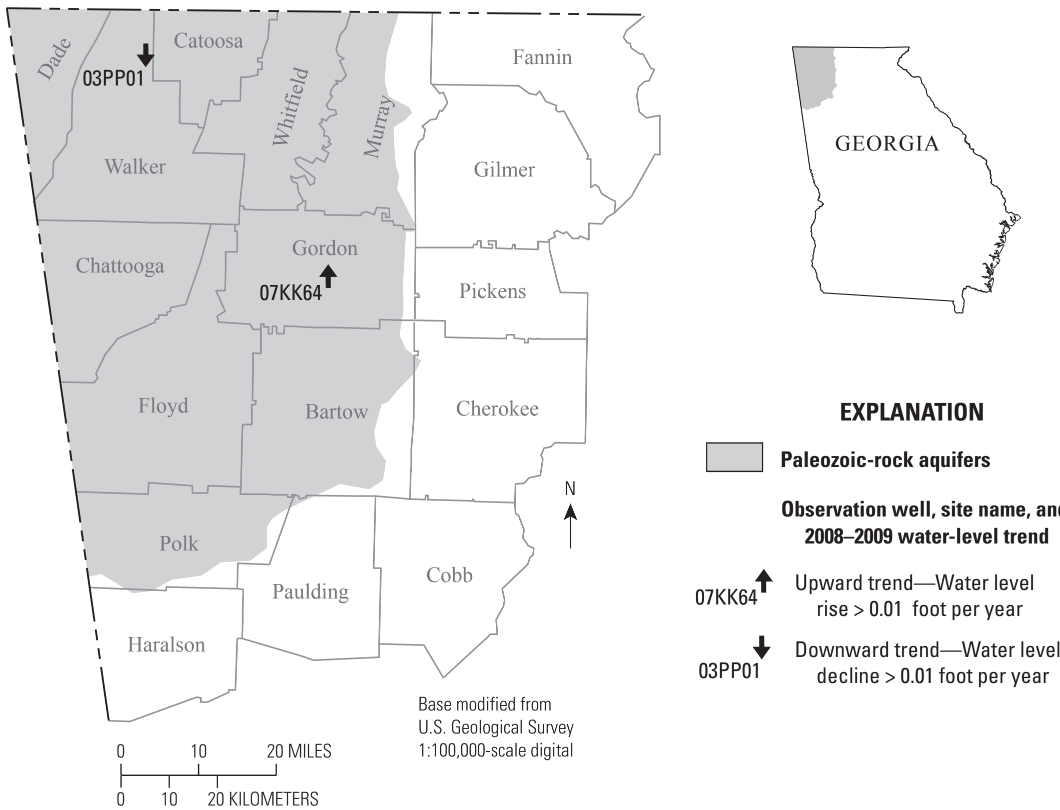
Groundwater Levels

Paleozoic-Rock Aquifers

Water levels were measured in two wells in the Paleozoic-rock aquifers of northwestern Georgia during 2008–2009 (map and table, facing page). In this area, the Paleozoic-rock aquifers are unconfined and show a pronounced response to precipitation. Hydrographs for selected wells (below) illustrate monthly mean water levels for the period of record. The hydrographs show periodic upward or downward trends that reflect changes in precipitation and pumping. Overall trends during the period of record and during 2008–2009 are described below.

During the period of record, the water level in well 07KK64 declined 0.19 foot per year (ft/yr) due to pumping from a nearby public-supply well. Conversely, the water level in well 03PP01 rose 0.04 ft/yr during the period of record. During 2008–2009, the water level in well 07KK64 rose 3.80 ft/yr and declined 0.12 ft/yr in well 03PP01. These differences relate to variations in local pumping and climatic conditions.





Site name	County	Year monitoring began	Water-level trend, in feet, per year[1]	
			Period of record	From 2008 to 2009
07KK64	Gordon	1997	–0.19	3.80
03PP01	Walker	1977	0.04	–0.12

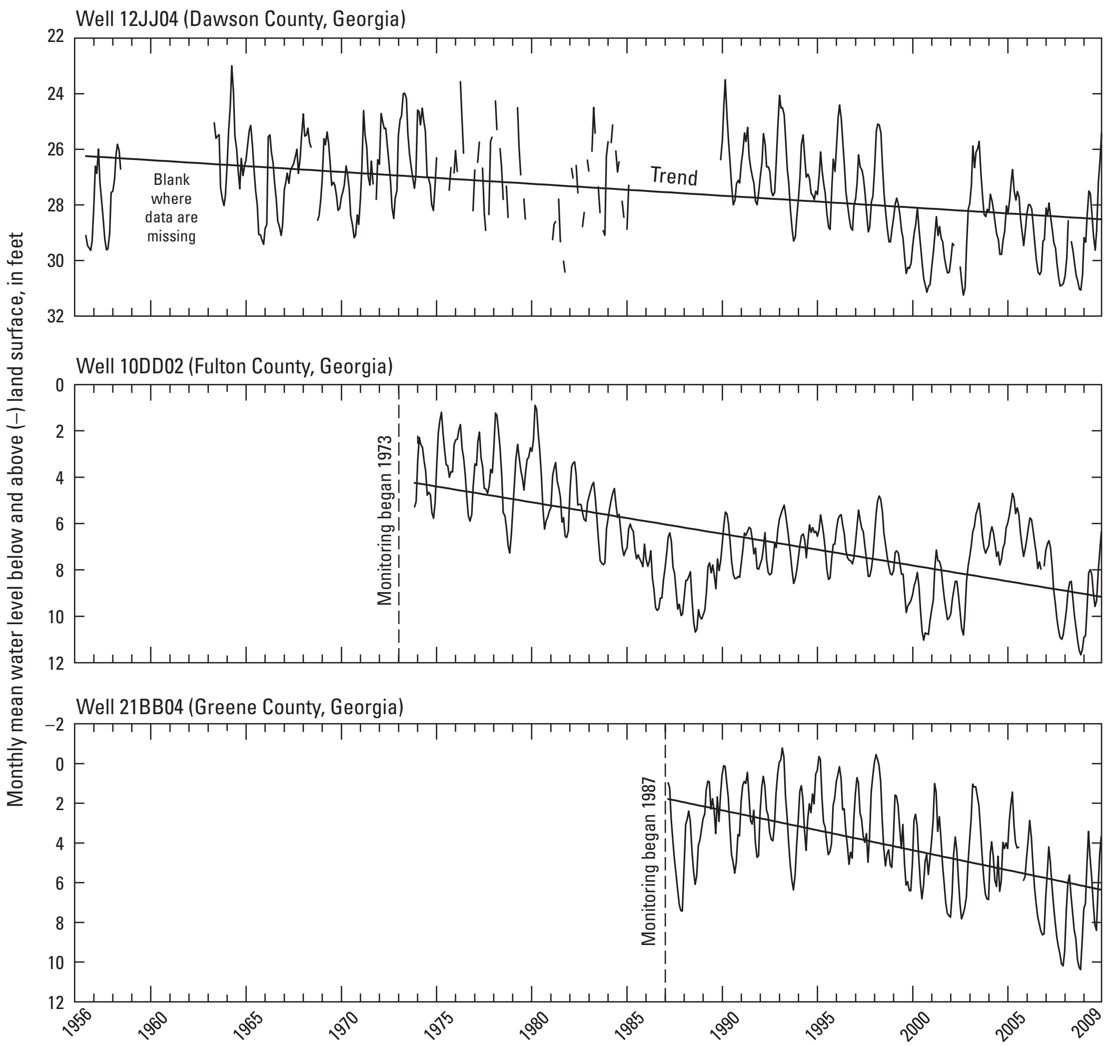
[1]See appendix for summary statistics.

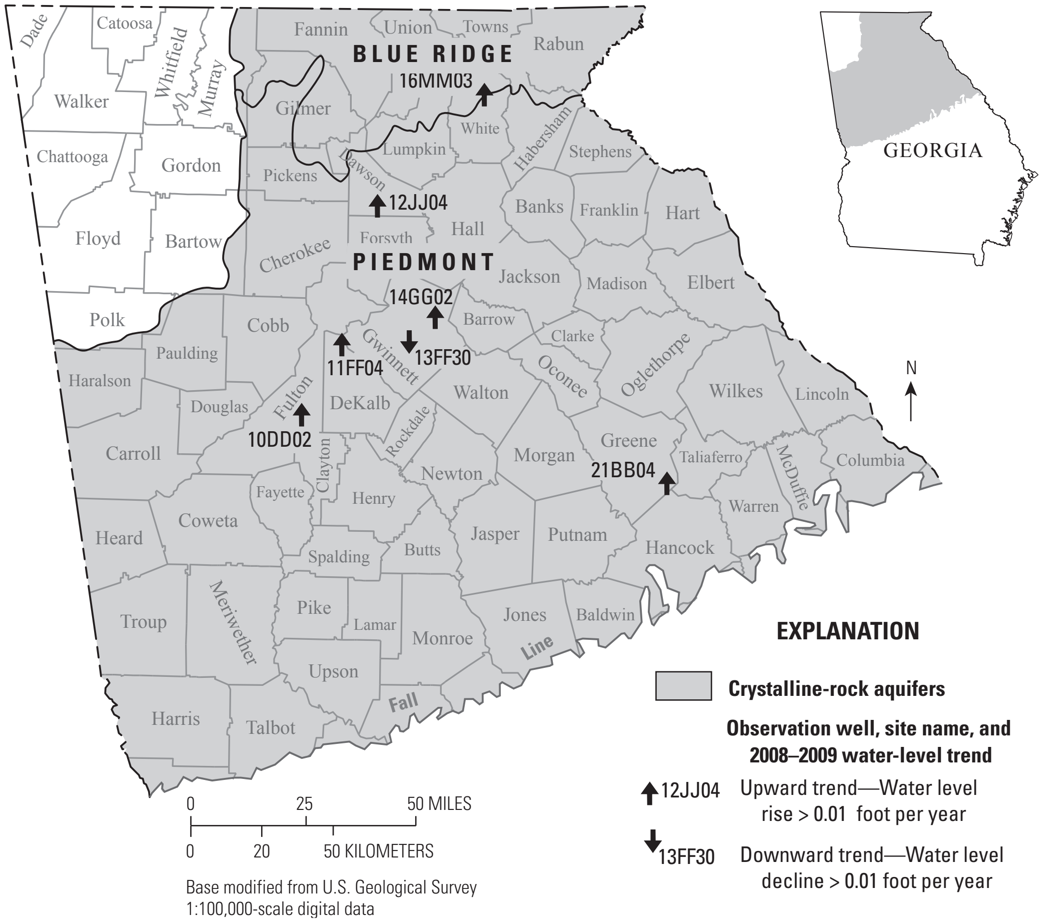
Groundwater Levels

Crystalline-Rock Aquifers

Water levels in seven wells were measured in crystalline-rock aquifers in the Piedmont and Blue Ridge Physiographic Provinces of Georgia during 2008–2009 (map and table, facing page). In this area, water is present in discontinuous joints and fractures and may be confined or unconfined. In general, crystalline-rock aquifers have local extent and can be greatly affected by localized water use and climate. Hydrographs for selected wells (below) illustrate monthly mean water levels for the period of record. The hydrographs show periodic upward or downward trends that reflect changes in precipitation and pumping.

During the period of record, water levels in all seven of the wells declined from 0.04 to 0.53 foot per year (ft/yr). During 2008–2009, water levels in six of the wells rose at rates of change ranging from 0.44 to 1.74 ft/yr, which corresponds to the end of a 2-year drought in 2008. Water levels in one well (13FF30) declined at a rate of 0.22 ft/yr.





Site name	County	Year monitoring began	Water-level trend, in feet, per year[1]	
			Period of record	From 2008 to 2009
12JJ04	Dawson	1956	–0.04	1.74
11FF04	DeKalb	1980	–0.05	0.44
10DD02	Fulton	1973	–0.14	1.07
21BB04	Greene	1987	–0.20	1.39
13FF30	Gwinnett	2003	–0.50	–0.22
14GG02	Gwinnett	2003	–0.53	0.73
16MM03	White	1988	–0.04	0.48

[1]See appendix for summary statistics.

Groundwater Quality in the Upper and Lower Floridan Aquifers

The quality of 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 as nitrogen concentrations. In coastal Georgia, chloride concentration in water from the Upper and Lower Floridan aquifers has been monitored in the Savannah and Brunswick areas since the 1950s and in the Camden County area since the early 1990s.

Groundwater Quality in 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, which increases the susceptibility of groundwater to contamination from nitrates and other chemicals. Nitrate as nitrogen (N) levels greater than 10 milligrams per liter (mg/L), the maximum contaminant level (MCL) for nitrate as N set by the U.S. Environmental Protection Agency (2000), have been measured in wells southwest of Albany.

Nitrate plus nitrite as N concentrations have been measured in the southwestern Albany area at least annually since September 1998. Because nitrite typically represents a small fraction of the total concentration, the reported values are presented and discussed as nitrate. During November 2008 and November 2009, samples were collected from selected wells and at one site on the Flint River and analyzed for major cations and anions and selected nutrients. The graph below shows the nitrate trend in selected wells and the Flint River.

Of the 25 wells sampled in November 2008, 14 are located in the well-field area where samples have been collected annually for the past 10 years. A sample from well 12L061, completed in the Upper Floridan aquifer, had a nitrate concentration of 12.5 mg/L, greater than the 10-mg/L MCL. Water from well 12L376, completed in the surficial aquifer, had a nitrate concentration of 10.1 mg/L.

Samples were collected from 13 wells and the Flint River during November 2009. Nitrate levels increased at most of the wells from November 2008 to November 2009, which is a typical response during wet years. Nitrate levels dropped slightly at well 12L348 during this period, with a larger decrease at well 12L350.

To assess nitrate concentrations in an area believed to provide recharge to the Upper Floridan aquifer, samples were collected from eight additional wells in 2008 northwest of the well field (*A*, facing page). The recharge area was delineated by preliminary simulations from a groundwater-flow model of the Upper Floridan aquifer (Gordon, 2009). Nitrate concentrations in all eight wells were below 2 mg/L (Gordon, 2009), similar to concentrations measured in five of the wells in July 1993 (Stewart and others, 1999).

Samples collected during November 2008 and November 2009 were plotted on trilinear diagrams (*B*, facing page), which show that the groundwater samples are chemically distinct from the surface-water sample. The groundwater samples had lower sodium, potassium, and magnesium content and higher carbonate and bicarbonate content than the surface-water sample.

A hazardous-waste site, the T.H. Agriculture & Nutrition (THAN) Company Superfund Site (*http://www.clu-in.org/products/costperf/THRMDESP/Thagr.htm*, accessed January 31, 2011), is located in the northern part of Albany (*A*, facing page). The USGS collected and analyzed water samples for pesticides from two wells closest to the Superfund Site in November 2008 (wells 12L010 and 12L018). The sample from well 12L010 contained no detectable pesticides, and the sample from well 12L018 had a very low concentration of p,p'-methoxychlor (0.0014 microgram per liter (µg/L)), which is below the reporting limit and nearly 2 orders of magnitude below the MCL of 0.04 mg/L (U.S. Environmental Protection Agency, 2000). Although such a low concentration is not a cause for concern, continued monitoring could enable tracking of any increasing trend. Well 12L018 was sampled again in November 2009, and pesticides were not detected in that water sample.

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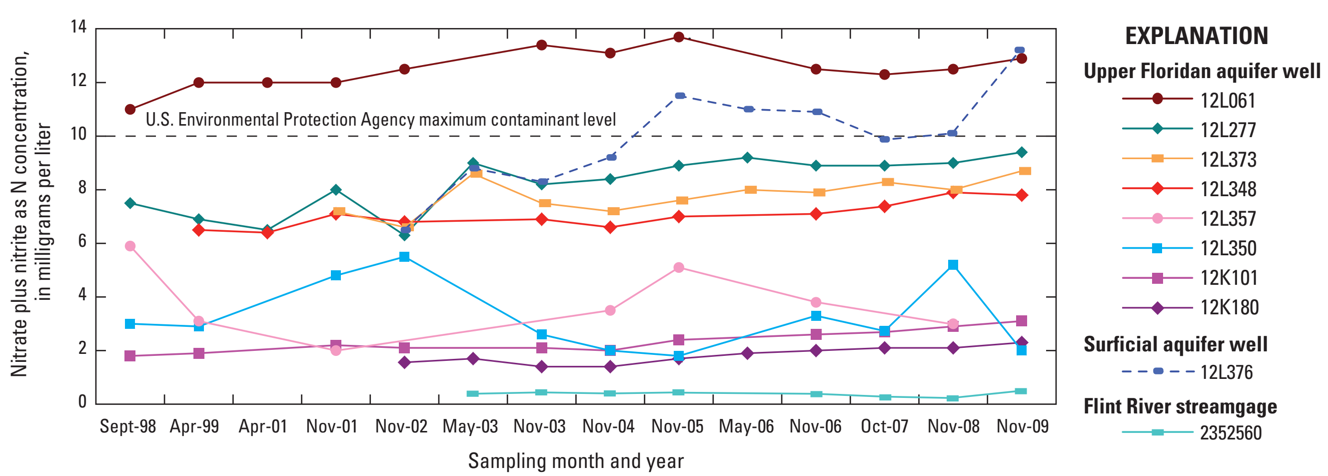
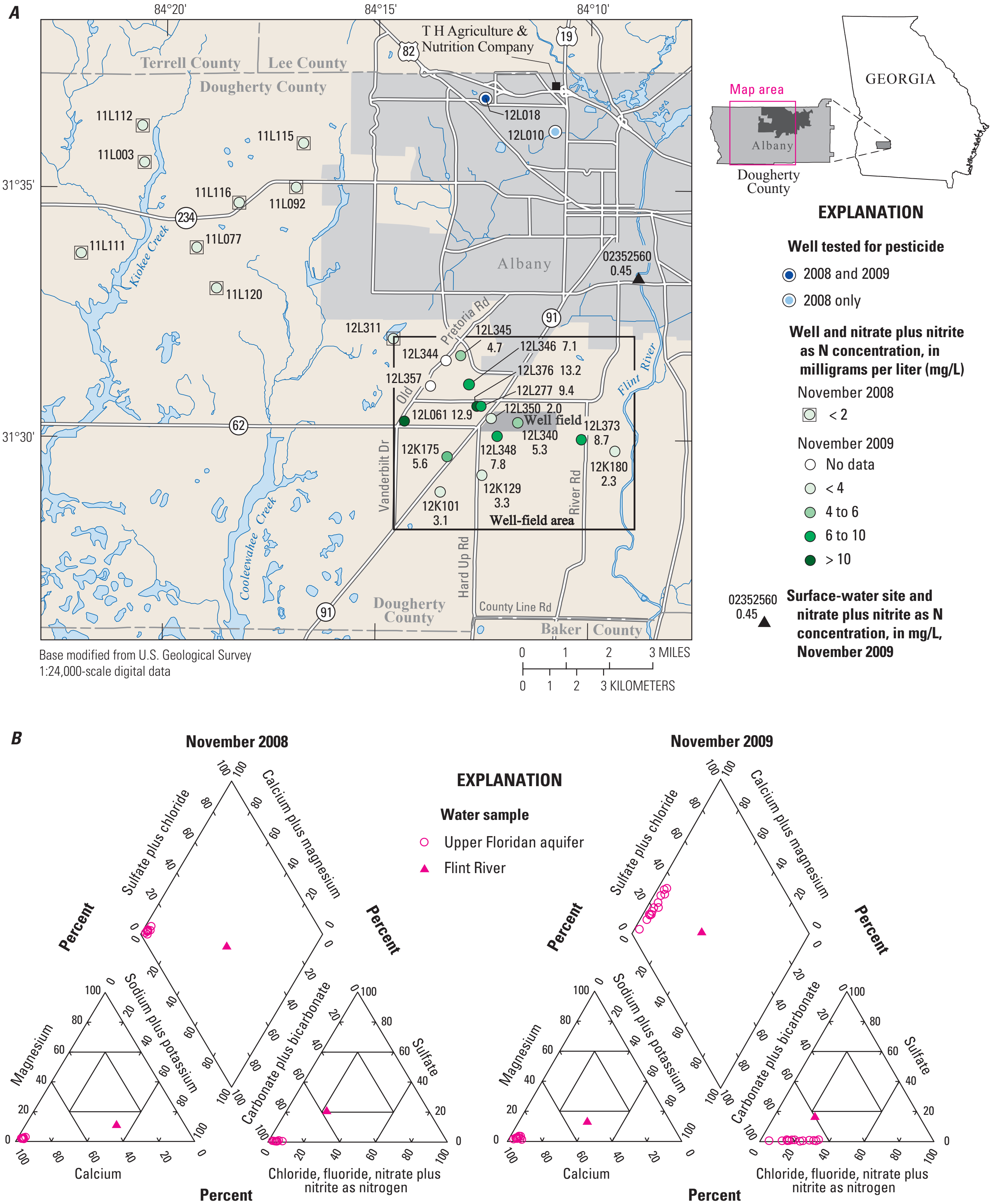
Gordon, D.W., 2009, Groundwater conditions and studies in the Albany area of Dougherty County, Georgia, 2008: U.S. Geological Survey Open-File Report 2009–1244, 54 p.; available online at *http://pubs.usgs.gov/of/2009/1244/*.

Stewart, L.M., Warner, Debbie, and Dawson, B.J., 1999, Hydrogeology, water quality, and potential contamination of the Upper Floridan aquifer, western Albany area, Georgia: U.S. Geological Survey Water-Resources Investigations Report 99–4140, 42 p.; available online at *http://pubs.usgs.gov/wri/wri99-4140/*.

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, rev. as of July 1, 2000, p. 612–614.





(A) Map of southwestern Albany area showing nitrate plus nitrite as nitrogen (N) concentrations in the well-field area, November 2009; and northeast of the well-field area, November 2008; and *(B)* piper plots of major cation and anion compositions of water samples from the Upper Floridan aquifer and the Flint River, November 2008 and November 2009.

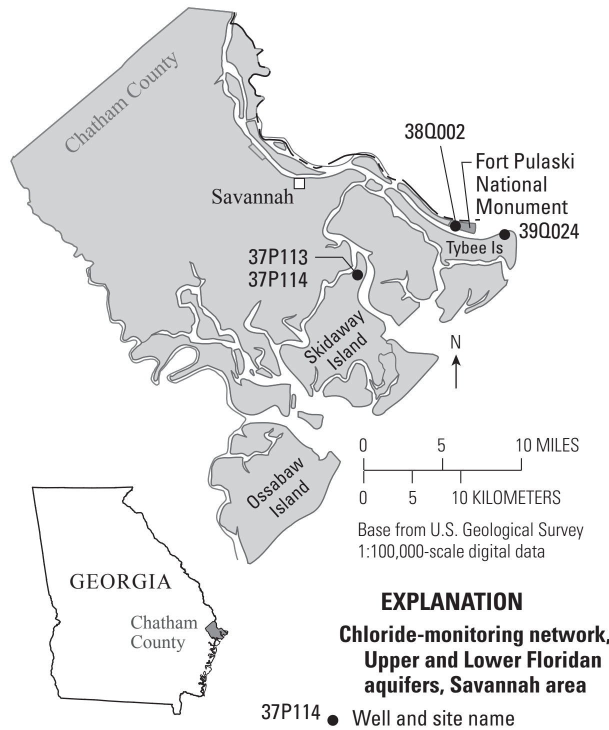
Groundwater Quality in the Upper and Lower Floridan Aquifers

City of Savannah Area

During December 2008 and December 2009, borehole geophysical logs and discrete 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, continuation of a program that began in 2003. 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. Water samples were collected at specific depth intervals in each well to reflect the range of fluid resistivity observed in the well during logging. The chloride concentrations in water samples are summarized in a table and shown graphically on the facing page.

At Fort Pulaski, fluid resistivity logs and water samples were collected from well 38Q002 completed in the Upper Floridan aquifer (facing page). The fluid resistivity logs collected during 2008–2009 indicated no changes or breaches in the well casing. During 2008 and 2009, chloride concentrations in all samples collected at depths of 200 and 320 feet (ft) were at or below 12 milligrams per liter (mg/L).

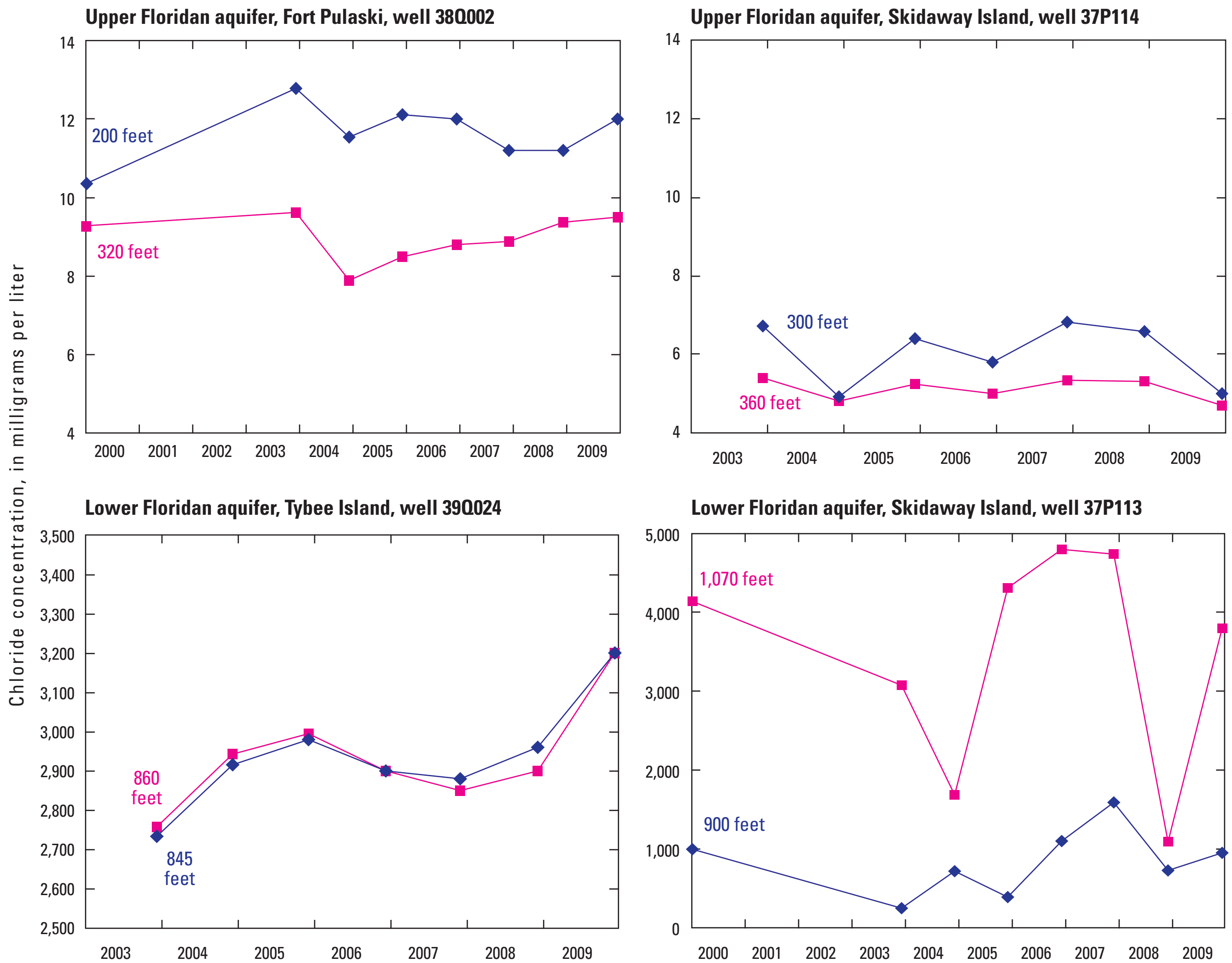
At Skidaway Island, fluid-resistivity logs and water samples were collected from well 37P114 completed in the Upper Floridan aquifer and from well 37P113 completed in the Lower Floridan aquifer. Water in the Upper Floridan aquifer is fresh (chloride concentrations less than 7 mg/L) at the Skidaway Island site and chloride concentrations of samples from well 37P114 did not appreciably change during 2008–2009. The fluid-resistivity logs collected indicated no changes or breaches in the well casing. During 2008 and 2009, chloride concentrations in samples collected at depths of 300 and 360 ft were less than 10 mg/L. In well 37P113, the fluid-resistivity logs collected during 2008–2009 indicated no changes or breaches in the well casing. The chloride concentrations were higher in samples collected at a depth of 1,070 ft and had greater variability than in the samples collected from the 900-ft interval. Chloride concentrations varied from 4,740 mg/L in 2007 to 1,090 in 2008 and 3,800 mg/L in 2009. Concentrations in samples collected from a depth of 900 ft during the same period ranged from 950 to 1,590 mg/L.



At Tybee Island, fluid-resistivity logs and water samples were collected from well 39Q024 completed in the Lower Floridan aquifer. The fluid-resistivity logs collected during 2008–2009 indicated no changes or breaches in the well casing. Chloride concentrations in samples collected at two depths in well 39Q024 increased during 2008–2009, a continuation of an upward trend that began in 2007 (Peck and others, 2009; facing page). Concentrations in samples from the 845-ft interval rose from 2,960 to 3,200 mg/L. Similarly, concentrations in samples from the 860-ft interval rose from 2,700 to 3,200 mg/L.

Reference

Peck, M.F., Painter, J.A., and Leeth, D.C., 2009, Ground-water conditions and studies in Georgia, 2006–07: U.S. Geological Survey Scientific Investigations Report 2009–5070, 86 p. available online at *http://pubs.usgs.gov/sir/2009/5070/.*



Chloride concentration in groundwater from wells in the Upper and Lower Floridan aquifers in the Savannah area, Georgia, 2000–2009.

Site name	Other identifier	Open interval (feet below land surface)	Water-bearing unit[1]	Water sample depth (feet below land surface) — December 2008	Chloride concentration (milligrams per liter) — December 2008	Water sample depth (feet below land surface) — December 2009	Chloride concentration (milligrams per liter) — December 2009
38Q002	U.S. National Park Service, Fort Pulaski Pilot House	110–348	U	200	11.2	200	12.0
				320	9.3	320	9.5
37P113	Skidaway Institute test well 1	700–1,100	L	900	727	900	950
				1,070	1,090	1,070	3,800
37P114	Skidaway Institute test well 2	262–400	U	300	6.5	300	5.0
				360	5.3	360	4.7
39Q024	Georgia Geologic Survey, Tybee Island, test well 1	840–880	L	845	2,960	845	3,200
				860	2,900	860	3,200

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

Groundwater Quality in the Upper and Lower Floridan Aquifers

City of Brunswick Area

Chloride concentrations have been monitored in the Brunswick area since the late 1950s when saltwater was first detected in wells completed in the Upper Floridan aquifer at the southern part of the area (Wait, 1965). By the 1960s, a plume of saltwater had migrated northward toward two major industrial pumping centers.

Since 1965, chloride concentrations have increased markedly in wells completed in the Upper Floridan aquifer in the northern Brunswick area. During 2008 and 2009, the chloride concentration 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 concentrations in water samples from wells in the upper and lower water-bearing zones of the Upper Floridan aquifer are shown below for wells in the southern Brunswick area (wells 34H393 and 34H403) and northern Brunswick area (wells 33H127 and 33H133). Chloride concentration in water from the Lower Floridan aquifer is shown for well 34H391 (graph below) in the southern Brunswick area. More information on monitoring groundwater quality in the Brunswick area is available at *http://ga.water.usgs.gov/projects/brunswick/*.

Dissolved chloride concentrations in the upper water-bearing zone of the Upper Floridan aquifer at Brunswick were mapped for July 2008 using data from 29 wells and for July–August 2009 using data from 28 wells (facing page). The 2008 and 2009 maps are similar to previously published maps for 2006 and 2007 (Peck and others, 2009) and show that areas of highest chloride concentrations are near the two industrial pumping centers in the northern part of the city, and the original area of contamination in the southern part of the city.

During 2008–2009, chloride concentrations within the plume area decreased in 18 of 28 wells sampled. The greatest decrease in concentration was 160 mg/L at well 33H130 in the northern part of the plume. Chloride concentrations in 10 wells increased from 0.1 to 80 mg/L during 2008–2009; the largest increase occurred in well 33H133 in the northern part of the plume. These changes probably reflect shifts in local pumping patterns.

References

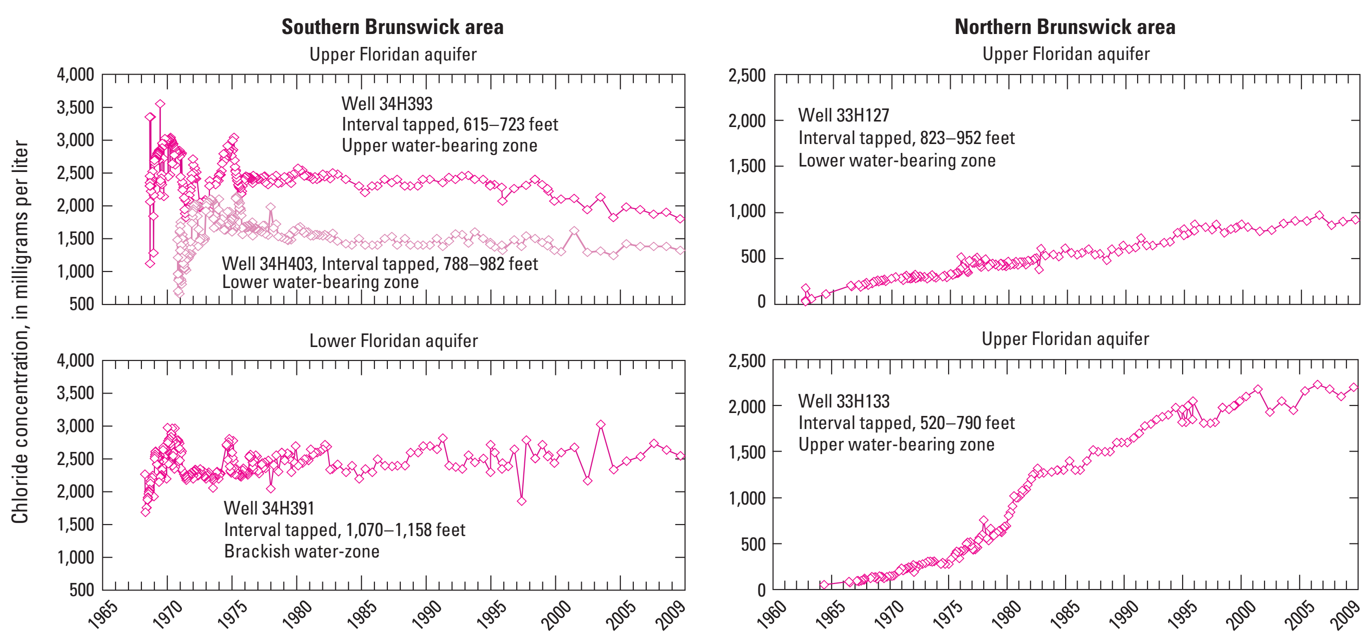
Cherry, G.S., Peck, M.F., Painter, J.A., and Stayton, W.L., 2010, Groundwater conditions and studies in the Brunswick–Glynn County area, Georgia, 2008: U.S. Geological Survey Open-File Report 2009–1275, 54 p.; available online at *http://pubs.usgs.gov/of/2009/1275/*.

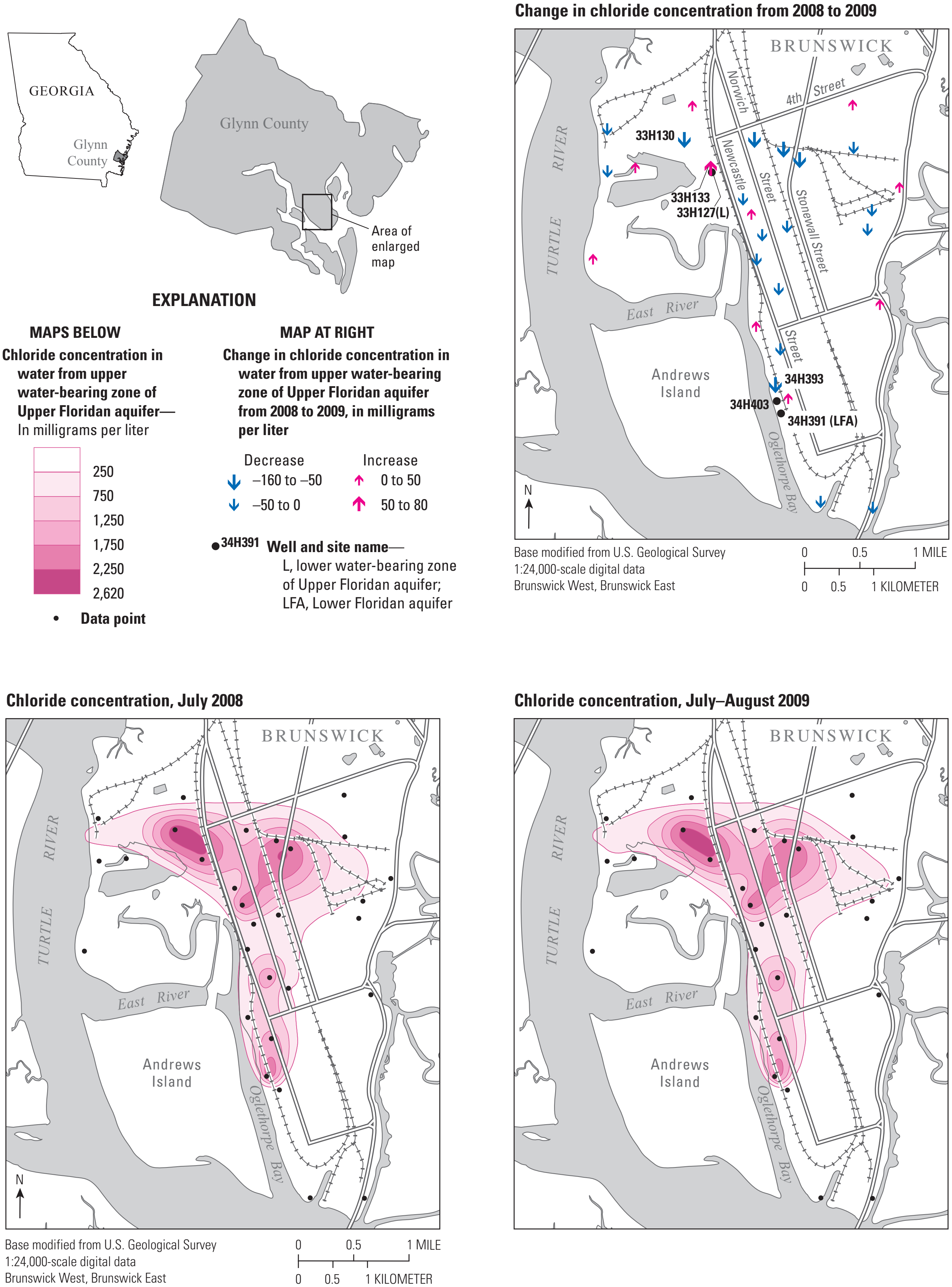
Georgia Environmental Protection Division, 1997, Secondary maximum contaminant levels for drinking water: Environmental Rule 391-3-5-19, revised October 1997: Official Code of Georgia Annotated Statutes, Statute 12-5-170 (Georgia Safe Drinking Water Act), variously paginated.

Peck, M.F., Painter, J.A., and Leeth, D.C., 2009, Ground-water conditions and studies in Georgia, 2006–2007: U.S. Geological Survey Scientific Investigations Report 2009–5070, 86 p.; available online at *http://pubs.usgs.gov/sir/2009/5070/*.

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, rev. July 1, 2000, p. 612–614.

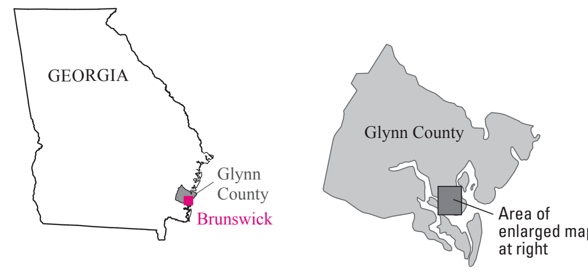
Wait, R.L., 1965, Geology and occurrence of fresh and brackish ground water in Glynn County, Georgia: U.S. Geological Survey Water-Supply Paper 1613-E , 94 p.




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
2,620
Data point
MAP AT RIGHT
Change in chloride concentration in water from upper water-bearing zone of Upper Floridan aquifer from 2008 to 2009, in milligrams per liter
Decrease
–160 to –50
–50 to 0
Increase
0 to 50
50 to 80
34H391 Well and site name—L, lower water-bearing zone of Upper Floridan aquifer; LFA, Lower Floridan aquifer
Change in chloride concentration from 2008 to 2009
BRUNSWICK
Norwich
4th Street
33H130
Newcastle Street
Stonewall Street
TURTLE RIVER
33H133
33H127(L)
East River
Andrews Island
34H393
34H403
34H391 (LFA)
Oglethorpe Bay
N
Base modified from U.S. Geological Survey 1:24,000-scale digital data Brunswick West, Brunswick East
0 0.5 1 MILE
0 0.5 1 KILOMETER
Chloride concentration, July 2008
BRUNSWICK
TURTLE RIVER
East River
Andrews Island
Oglethorpe Bay
N
Base modified from U.S. Geological Survey 1:24,000-scale digital data Brunswick West, Brunswick East
0 0.5 1 MILE
0 0.5 1 KILOMETER
Chloride concentration, July–August 2009
BRUNSWICK
TURTLE RIVER
East River
Andrews Island
Oglethorpe Bay

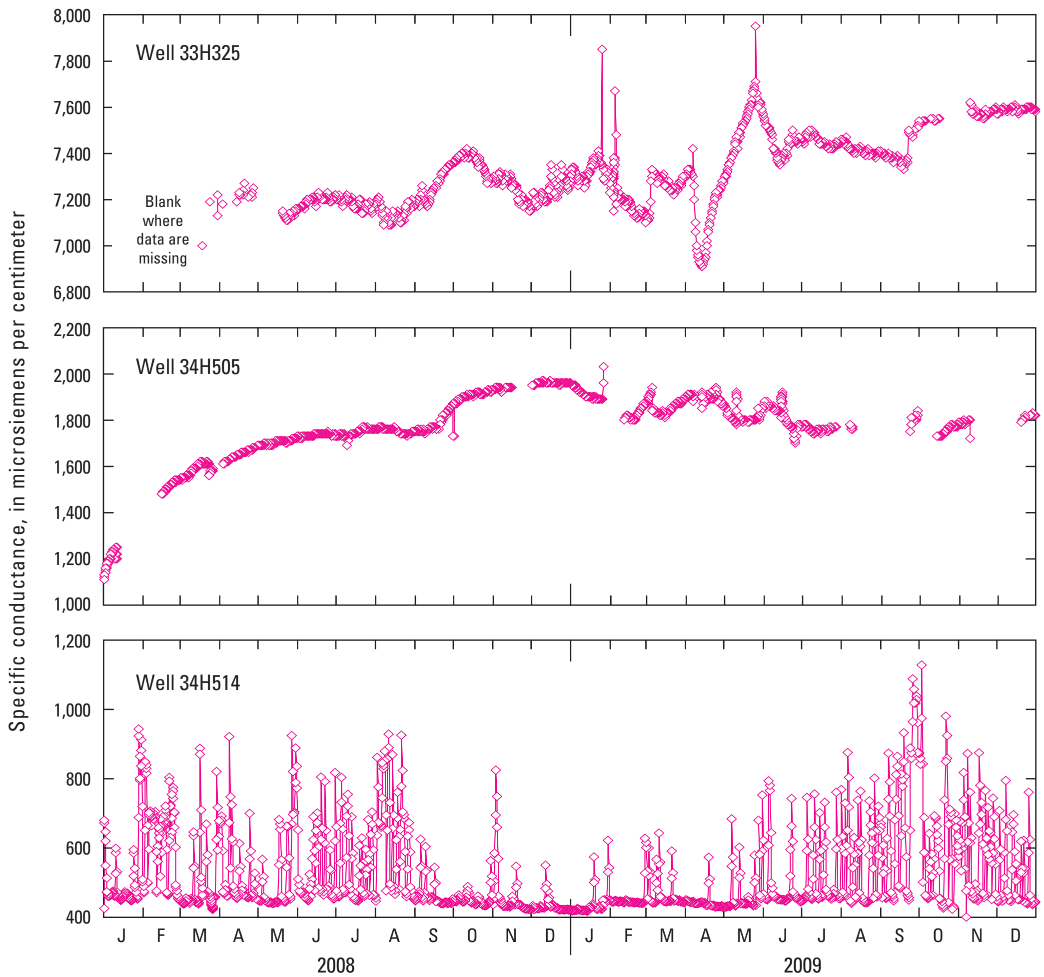
Groundwater Quality in the Upper and Lower Floridan Aquifer

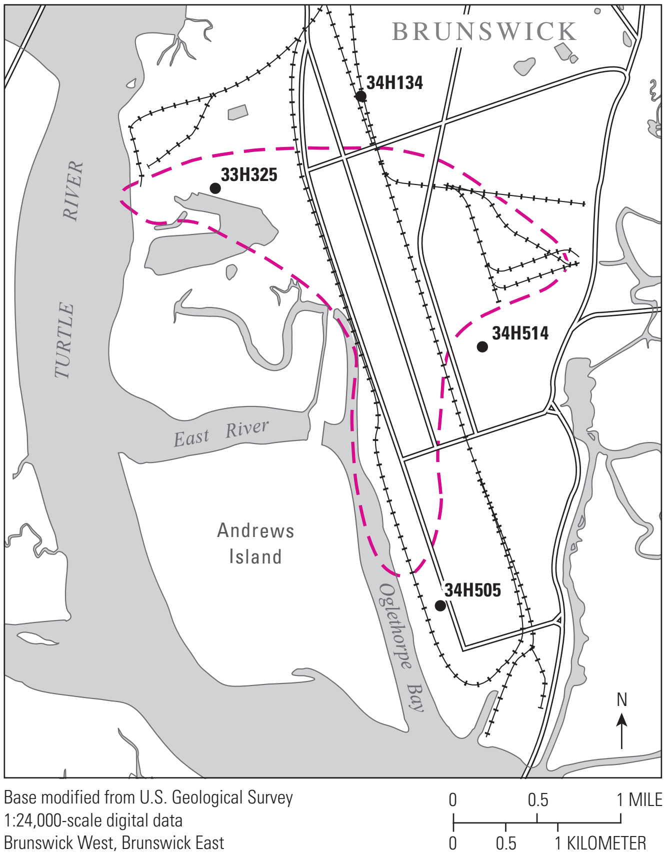
Real-Time Specific Conductance Monitoring in Brunswick Area



Beginning in 2007, a network of wells with real-time, satellite-telemetry was established at Brunswick to monitor changes in specific conductance in the upper and lower water-bearing zones of the Upper Floridan aquifer (specific conductance is a surrogate for changes in chloride concentration). Three of the wells are located immediately outside of the chloride plume, and one is located inside the plume area (see map, facing page). Of these four wells currently monitored in real time, three are monitored for daily specific conductance and hourly water levels and one is monitored for specific conductance only. Specific conductance is monitored in wells 33H325, 34H505, and 34H514 by pumping once a day from rigid, small-diameter tubing installed at predetermined depths (see table, facing page) to the water-bearing zone of interest (Walls and others, 2009). In supply well 34H134, specific conductance is recorded directly in the well-discharge pipe every 15 minutes. Data are transmitted every 1 to 4 hours, based on equipment, and can be viewed on the Web at *http://water.usgs.gov/ga/nwis/current?type=gw/*.

A correlation between specific conductance and chloride concentration presented by Cherry and others (2010) for the Brunswick area was used to determine the possible range of chloride concentration in these wells during 2008–2009 (see table, facing page). Estimated chloride concentration in wells 34H514 and 34H134 were at or below the 250-mg/L secondary drinking-water standard (Georgia Environmental Protection Division, 1997; U.S. Environmental Protection Agency, 2000). The estimated chloride concentration in wells 34H505 and 33H325 likely exceeded the secondary drinking-water standard.





Specific conductance, Upper Floridan aquifer, 2008–2009

[µS/cm, microsiemens per centimeter at 25º Celsius; mg/L, milligram per liter; LWBZ, lower water-bearing zone; UWBZ, upper water-bearing zone; ULWBZ, upper and lower water-bearing zones; modified from Cherry and others, 2010]

Site name	Water-bearing zone	Sampling interval (feet)	Specific conductance (µS/cm)	Estimated chloride concentration (mg/L)
34H514	UWBZ	605	401–1,130	15–250
34H134	ULWBZ	518–942	452–583	15–45
33H325	LWBZ	900	6,910–7,950	1,800–2,200
34H505	LWBZ	960	1,110–2,030	250–550

EXPLANATION

Approximate boundary of 2009 chloride plume— Chloride concentrations at least 250 milligrams per liter in the upper water-bearing zone of the Upper Floridan aquifer

34H505 **Real time specific conductance and water-level monitoring well**

Location of real-time specific conductance monitoring network and estimated chloride concentration in the upper water-bearing zone of the Upper Floridan aquifer in the Brunswick–Glynn County area, Georgia, July and August 2009.

References

Cherry, G.S., Peck, M.F., Painter, J.A, and Stayton, W.L., 2010, Groundwater conditions and studies in the Brunswick–Glynn County area, Georgia, 2009: U.S. Geological Survey Open-File Report 2009–1275, 54 p.; available online at *http://pubs.usgs.gov/of/2009/1275/*.

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, rev. July 1, 2000, p. 612–614.

Walls, C.B., Cressler, A.M., and Stayton, W.L., 2009, Real-time water-level and specific conductance monitoring of saltwater contamination in the Upper Floridan aquifer, Brunswick, Georgia, *in* Rasmussen, Todd, Carroll, D.G., and Georgakakos, Aris, eds., Proceedings of the 2009 Georgia Water Resources Conference, held April 27–29, 2009, at the University of Georgia, Athens, Institute of Ecology, The University of Georgia, accessed July 2, 2009, at *http://www.gwri.gatech.edu/conferences/previous-gwrc-conferences/gwrc-2009/*.

Groundwater Quality in 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 to semiannually from 1994 to the present. In the Lower Floridan aquifer, chloride concentrations have been monitored from 2001 to the present. During 2008–2009, the U.S. Geological Survey collected a total of 32 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 monitoring network maintained for the St. Johns Water Management District in Florida.

During 2008–2009, chloride concentrations in the Upper and Lower Floridan aquifers were relatively constant. Chloride concentrations in the Upper Floridan aquifer ranged from 30.2 to 44.8 milligrams per liter (mg/L), which are similar to the 20 to 40 mg/L background level for the area (Peck and others, 2005) and below the 250-mg/L drinking-water standard (Georgia Environmental Protection Division, 1997; U.S. Environmental Protection Agency, 2000). Chloride concentrations in the Lower Floridan aquifer remained below the 250-mg/L drinking-water standard, ranging from 27.5 to 30.3 mg/L in well 33D073, completed in the upper section of the Lower Floridan aquifer, and from 93.5 to 102 mg/L in well 33D074, completed in the lower section of the Lower Floridan aquifer (table, below).

References

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.; available online at *http://pubs.usgs.gov/sir/2004/5295/*.

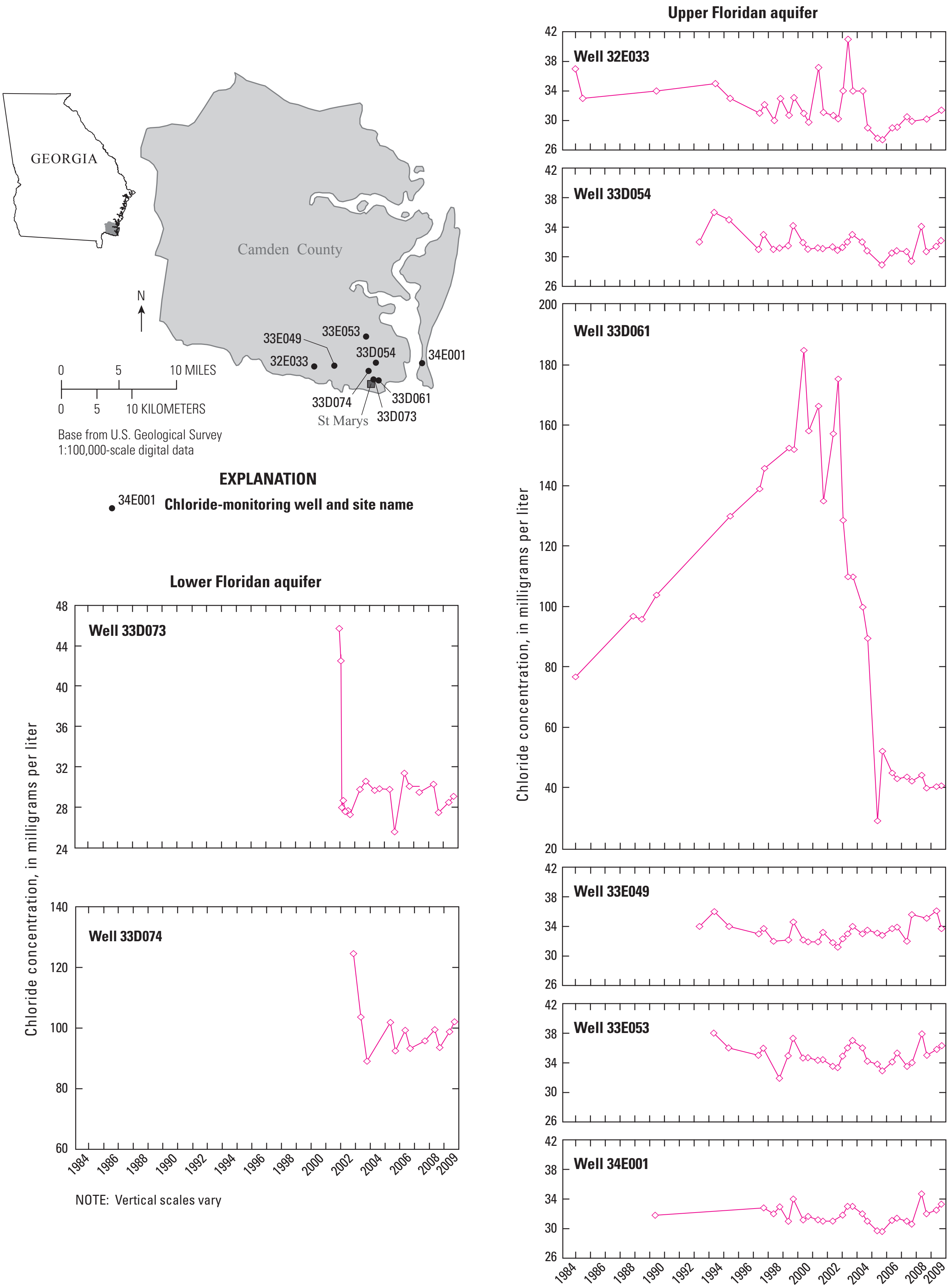
U.S. Environmental Protection Agency, 2000, Maximum contaminant levels (Part 143, National Secondary Drinking Water Regulations): U.S. Code of Federal Regulations, Title 40, Parts 100–149, rev. July 1, 2000, p. 612–614.

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

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

Site name	Aquifer	Open interval (feet below land surface)	Chloride concentration (milligrams per liter)			
			May 2008	September 2008	May 2009	September 2009
32E033	UF	420–600	—	130.2	—	131.4
33D054	UF	563–1,000	[1]34.1	130.7	131.4	132.2
33D061	UF	550–1,090	[1]44.6	140.3	144.8	141.1
33E049	UF	522–840	—	135.1	136.1	133.7
33E053	UF	570–900	[1]37.9	135.0	135.8	136.3
34E001	UF	540–640	[1]34.7	132.0	132.5	133.3
33D073	LF	1,360–1,500	30.3	27.5	28.5	29.1
33D074	LF	1,840–2,004	99.4	93.5	98.7	102.0

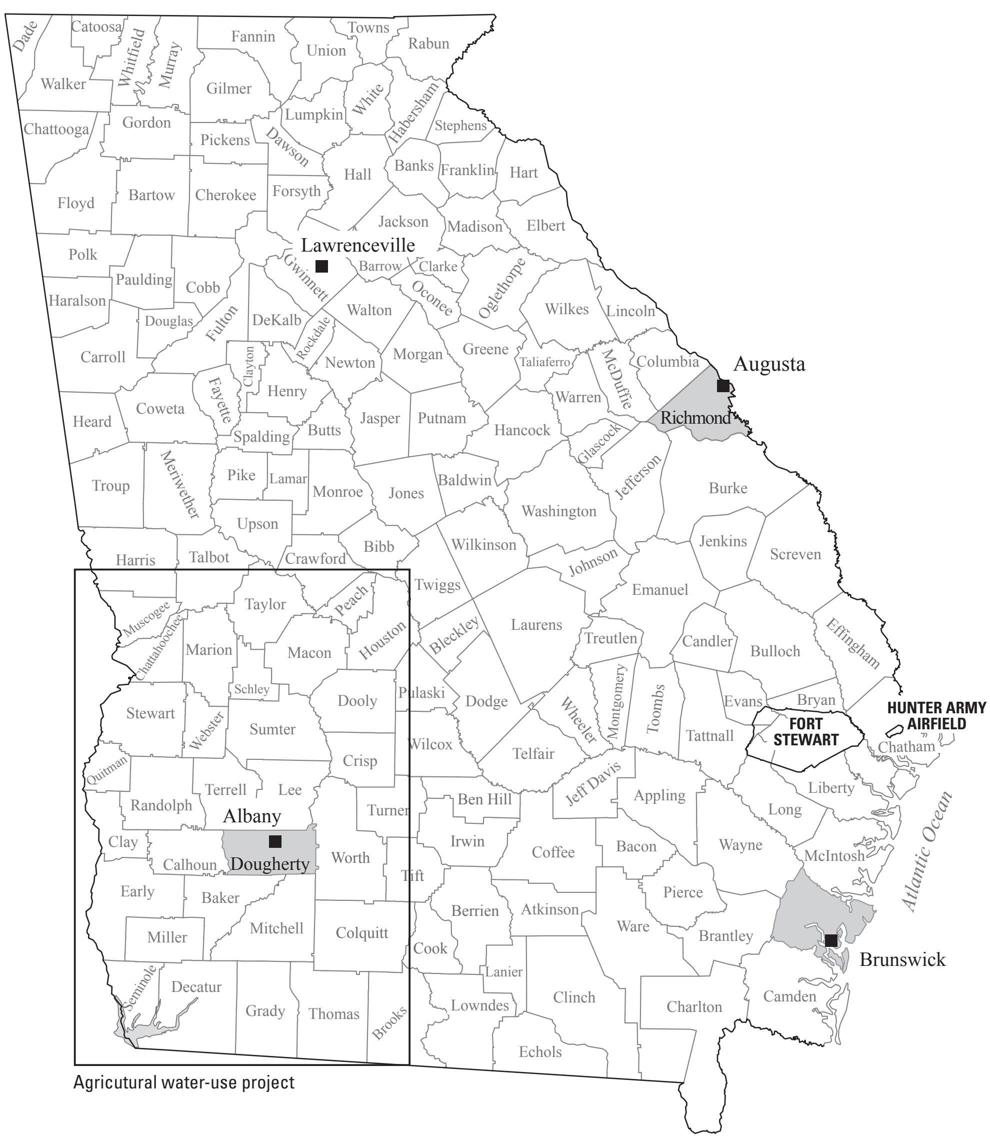
[1]Brian McGurk, St. Johns River Water Management District, written commun., February 2010.


GEORGIA
Camden County
N
0 5 10 MILES
0 5 10 KILOMETERS
Base from U.S. Geological Survey
1:100,000-scale digital data
33E049
33E053
32E033
33D054
34E001
33D074
33D061
St Marys
33D073
EXPLANATION
34E001 Chloride-monitoring well and site name
Lower Floridan aquifer
Well 33D073
Well 33D074
Chloride concentration, in milligrams per liter
NOTE: Vertical scales vary
Upper Floridan aquifer
Well 32E033
Well 33D054
Well 33D061
Well 33E049
Well 33E053
Well 34E001
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2009

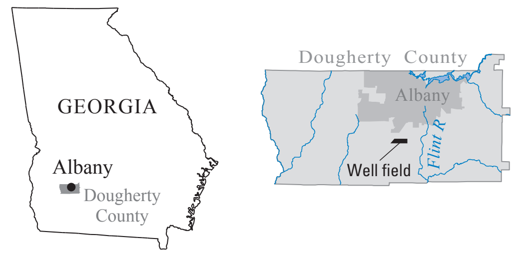
Selected Groundwater Studies in Georgia, 2008–2009

The U.S. Geological Survey (USGS), in cooperation with local, State, and other Federal agencies, conducted several studies in Georgia and adjacent States during 2008–2009 to better define the quantity and quality of groundwater 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



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) developed a large well field southwest of Albany with wells completed in 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. Concentrations of nitrate plus nitrite as nitrogen exceeding the 10-milligrams per liter (mg/L) maximum contaminant level (U.S. Environmental Protection Agency, 2000) have been detected in some wells upgradient from the well field.

Objectives

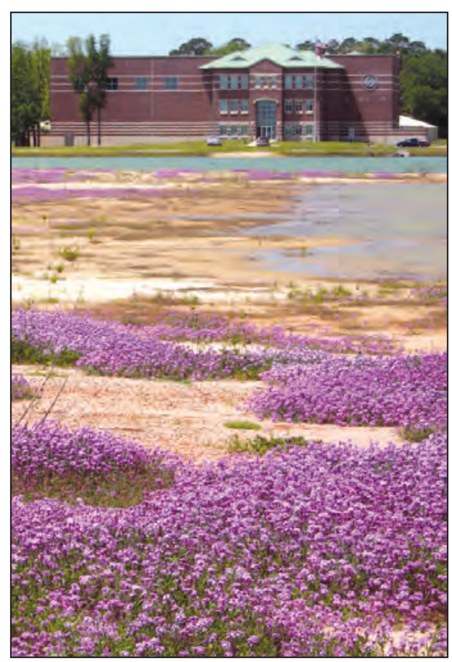
- Monitor water-level fluctuations in the five aquifers in the Albany area and relate water-level trends to changes in climatic conditions and pumping patterns.
- Describe the groundwater flow and water quality of the Upper Floridan aquifer near the new well field in the southwestern Albany area.

Progress and Significant Results, 2008–2009

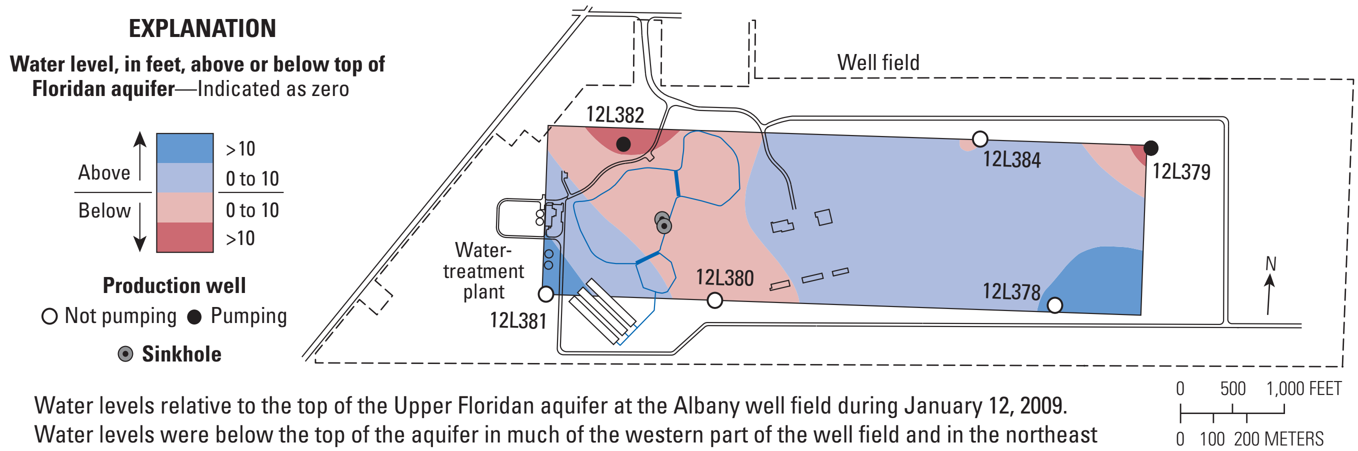
- Continued operation of the 14-well continuous groundwater-level monitoring network in the surficial, Upper Floridan, Claiborne, Clayton, and Providence aquifers.
- Continued groundwater-quality monitoring program. Water samples were collected and analyzed for major cations and anions, and selected nutrients during November 2008 (25 wells), and November, 2009 (17 wells). The USGS sampled wells 12L010 and 12L018 (map facing page), two of WGL's municipal supply wells, for pesticides in November 2008 and well 12L018 for pesticides in 2009.
- Constructed potentiometric-surface maps for the Upper Floridan aquifer near the well field based on measurements from 81 wells during November 2008, and 64 wells during November 2009. Both maps indicate that water generally flows from northwest to southeast near the well field. Water levels were higher during 2009 than during 2008. The well-field pumping did not result in the formation of a cone of depression surrounding the well field.
- Continued to map sinkholes at the well field. No new sinkholes formed during 2008; however, during 2009, six new sinkholes developed, two on January 12, 2009, two on April 26, 2009, and two on July 6, 2009.
- Began to study the reasons for sinkhole formation at the well field with regard to precipitation and water-level changes within the Upper Floridan aquifer.
- Continued development of a groundwater model to simulate flow in the vicinity of the Albany well-field area.

Reference

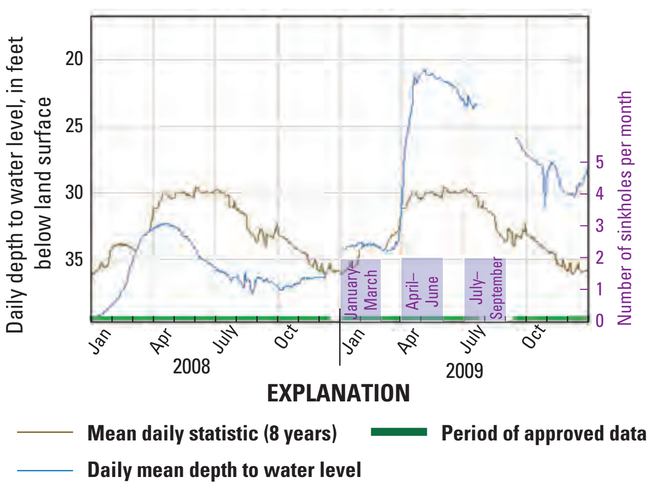
U.S. Environmental Protection Agency, 2000, Maximum contaminant levels (Part 143, National Secondary Drinking Water Regulations): U.S. Code of Federal Regulations, Title 40, Parts 100–149, rev. as of July 1, 2000, p. 612–614.



Albany Water, Gas, and Light Commission well field, Albany, Georgia, April 21, 2009. Photo by Debbie Warner Gordon, USGS.

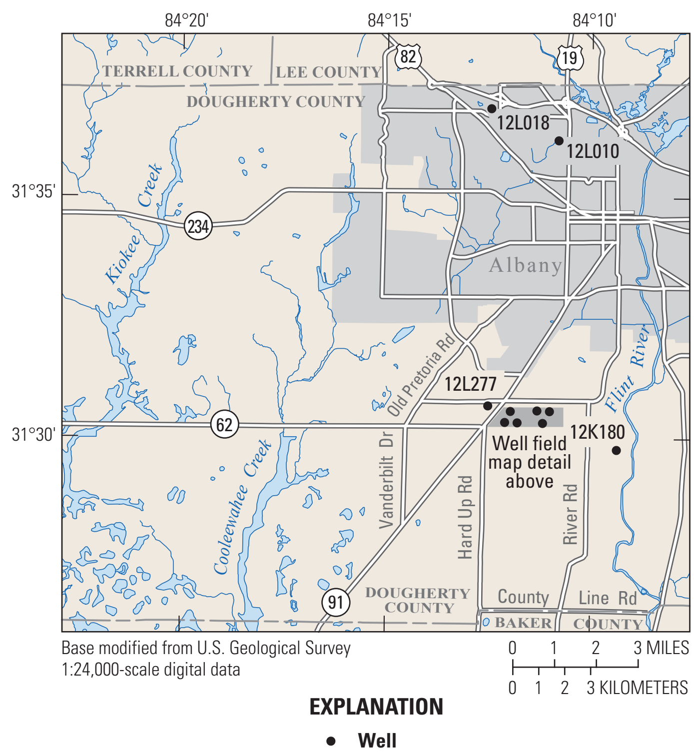


Water levels relative to the top of the Upper Floridan aquifer at the Albany well field during January 12, 2009. Water levels were below the top of the aquifer in much of the western part of the well field and in the northeast corner. Two production wells in the field were pumping during the period when two sinkholes formed.



Water level in well 12L277 (see map on right for location). No sinkholes formed in the well field during 2008, but six sinkholes formed in the well field during 2009.

Well 12K180 located on Victory Street, Albany, Georgia, April 21, 2009, following more than 15 inches of rain during March and April 2009. Photo by Debbie Warner Gordon, USGS.



Site map and well locations, Albany area.

Groundwater Monitoring Program for the Augusta–Richmond County Area

Study Chief John S. Clarke

Cooperator Augusta Utilities Department

Year Started 2006

Problem

Water supply in the Augusta–Richmond County area is provided in part by three well fields that withdraw water from the Dublin–Midville aquifer system—a Late Cretaceous sand aquifer. Low levels of the volatile organic compounds (VOCs) tetrachloroethene and trichloroethene have been detected in a supply well at the northernmost extent of well field number 2. To ensure that groundwater pumping does not adversely affect water levels in adjacent areas and to monitor groundwater quality, the U.S. Geological Survey operates a groundwater monitoring program for the Augusta–Richmond County area. Data from this network provide information to support water-management decisions and serve as a basis for future ground-water-modeling efforts while adding to improved regional characterization of groundwater conditions.

Objectives

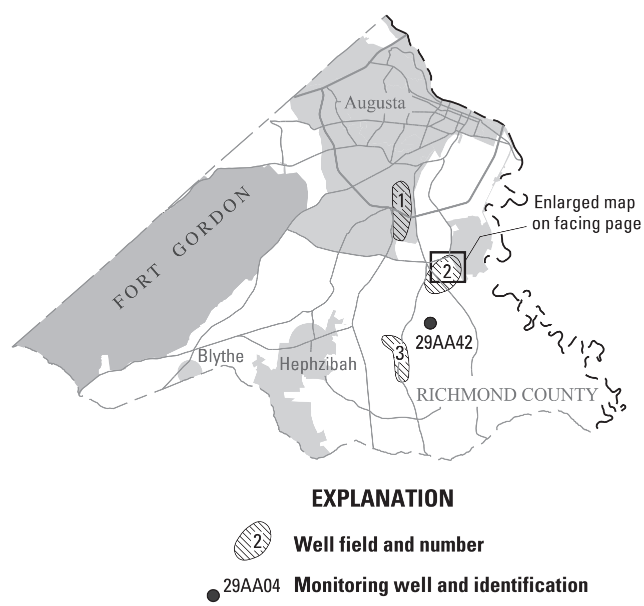
- Determine current groundwater levels, flow directions, and water quality of the Dublin–Midville aquifer system in the Augusta–Richmond County area.
- Monitor groundwater fluctuations and trends by operating a continuous water-level recorder network.
- Monitor groundwater quality in the vicinity of well field number 2 and assess the source of low-level volatile organic compounds.

Progress and Significant Results, 2008–2009

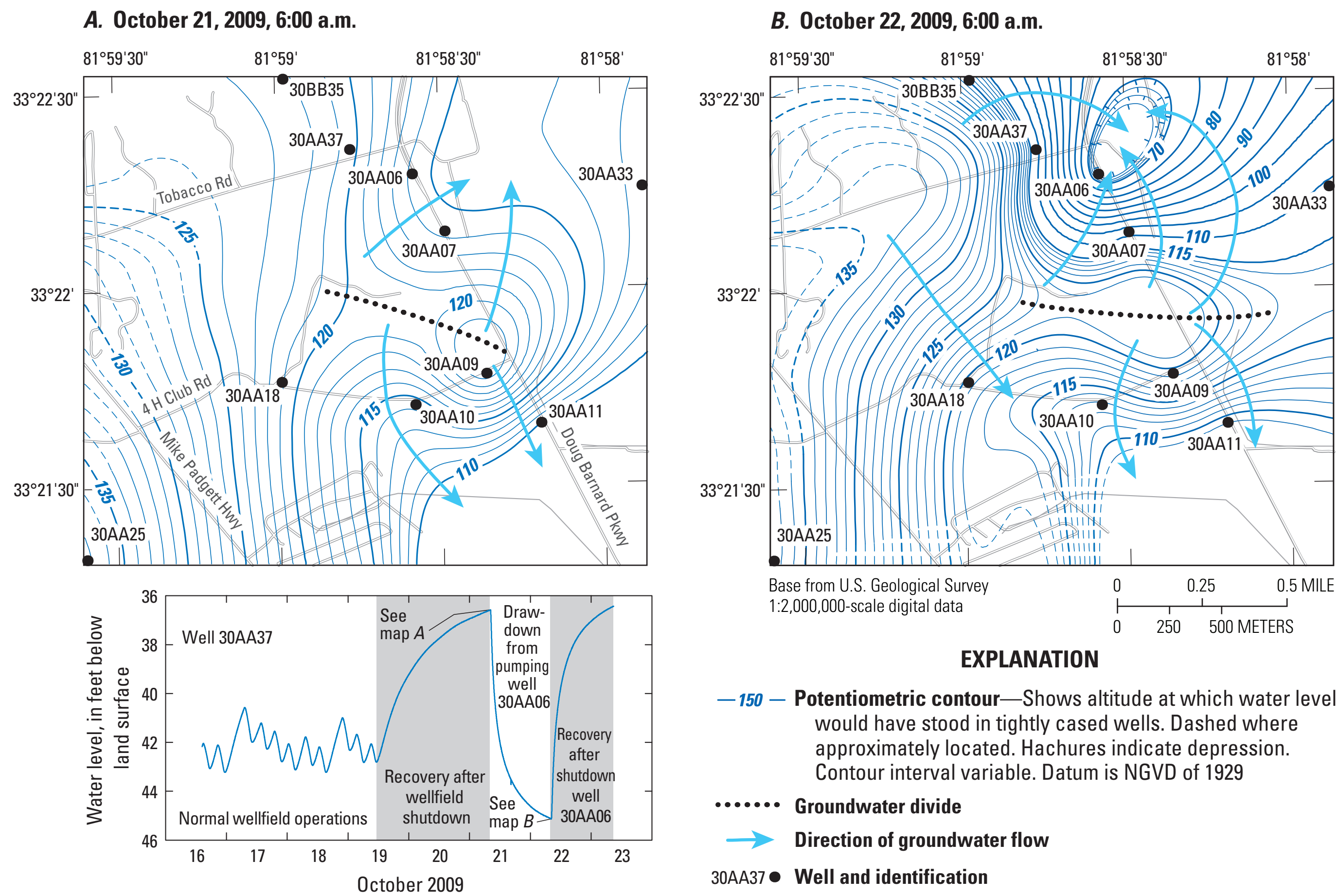
- Operated continuous water-level recorder network in wells 30AA06, 30AA33, and 30AA35 near well field number 2.
- Constructed three new test wells at two sites—one two-well site upgradient of well field number 2 (wells 30AA37 and 30AA38), and one single-well site located northwest of well field number 3 (well 29AA42).
- Obtained water-level measurements during June 2008 and September 2009 and constructed potentiometric-surface maps for the Dublin–Midville aquifer system.
- Conducted aquifer test at well field number 2 during October 19–24, 2009, to assess hydraulic properties of water-bearing units and to evaluate changes in groundwater levels and flow directions when various combinations of wells are pumped.
- Collected water samples during June–July 2008 and September 2009 and analyzed for VOCs near well field number 2.
- Collected water samples from selected wells in September 2009 for analysis of stable isotopes to provide an indication of the source(s) of low-level contaminants and age of water.
- Conducted borehole geophysical logging and flowmeter testing, and collected a grab water sample from well 30BB35 upgradient of well field number 2. Results indicate that borehole flow is downward from shallow to deep zones. VOCs were not detected in two water-quality samples collected from the well in September 2009.

Reference

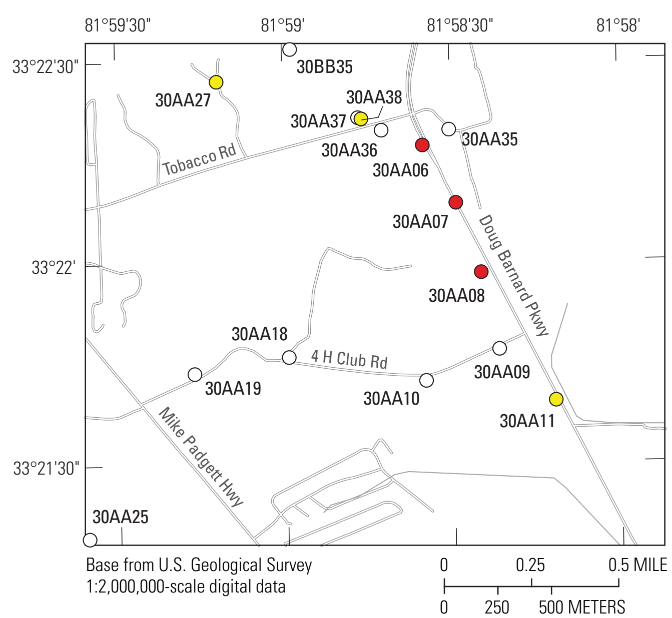
Williams, L.J., 2007, Hydrogeology and potentiometric surface of the Dublin and Midville aquifer systems in Richmond County, Georgia, January 2007: U.S. Geological Survey Scientific Investigations Map 2982, 1 sheet; available online at *http://pubs.usgs.gov/sim/2007/2982/*.



General area of the groundwater monitoring study showing the three municipal well fields and recorder well in the Augusta–Richmond County area of Georgia.



Graph and maps showing water levels in the Midville aquifer system near well field number 2 during aquifer test conducted in October 2009. Water levels shown on the graph are from well 30AA37, located upgradient of the well field. Map *A* shows water levels about 45 hours following shutdown of well field. Map *B* shows water levels 24 hours following initiation of pumping in well 30AA06. Note a groundwater divide has formed between wells in the southern part of the well field (not pumping) and the pumping well 30AA06. Groundwater north of this line flows toward well 30AA06, whereas south of the line water flows southeastward.



EXPLANATION

Well and identification with—

- 30AA25 Undetectable volatile organic compound levels
- 30AA08 Detectable volatile organic compound levels
- 30AA11 Detectable levels of chlorine disinfection byproducts

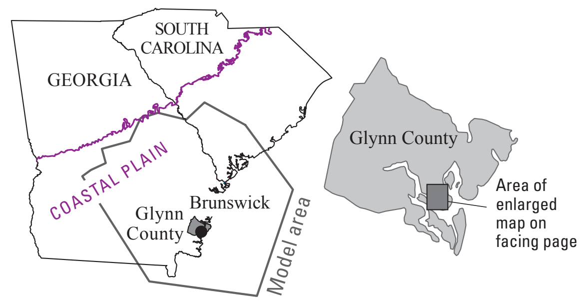
Results of water-quality monitoring near well field number two during 2008 and 2009 indicate presence of low-level concentrations of volatile organic compounds in some wells. Long-term water-quality monitoring provides information on water-quality trends to help assess contaminant migration. Analysis of groundwater age provides an indication of potential source areas of groundwater withdrawn at the well field. The apparent year of groundwater recharge in shallow well 30AA38, completed at a depth of 120 feet was 1991; whereas deeper wells at the well field (depths typically greater than 250 feet) were recharged between 1980 and 1984.

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 more than 50 years. Currently within an area of 2 square miles in downtown Brunswick, the aquifer yields water with a chloride concentration greater than 2,000 milligrams per liter (mg/L), markedly higher than the State and Federal secondary drinking-water standard of 250 mg/L (Georgia Environmental Protection Division, 1997; U.S. Environmental Protection Agency, 2000). This chloride contamination has constrained further development of the Upper Floridan aquifer in the Brunswick area and stimulated interest in the development of alternative sources of water, primarily from the shallower surficial and Brunswick aquifer systems.

Objectives

- Define and simulate mechanisms of groundwater flow and the occurrence and movement of saltwater in the Floridan aquifer system.
- Assess alternative sources of water supply from the surficial and Brunswick aquifer systems and the Lower Floridan aquifer.
- Monitor long-term groundwater levels and quality including real-time monitoring of the spatial extent of chloride contamination in the Upper Floridan aquifer.
- Develop and maintain a comprehensive groundwater database.

Progress and Significant Results, 2008–2009

A network of 32 continuous groundwater-level monitoring wells was operated—12 wells in the Upper Floridan aquifer, 8 wells in the Lower Floridan aquifer, 7 wells in the Brunswick aquifer system, and 5 wells in the surficial aquifer system (*C,* facing page). Of these 32 wells, 20 are funded by the Georgia Environmental Protection Division through the Coastal Georgia Sound Science Initiative.

Potentiometric surfaces of the Upper Floridan aquifer were mapped as follows:

- July 2008—mapping was based on water-level measurements made in 35 wells (Brunswick area only).
- August 2009—mapping was based on water-level measurements made in 52 wells (all of Glynn County).
- Chloride concentration of the Upper Floridan aquifer was mapped as follows:
- July 2008—mapping was based on analyses of samples collected from 67 wells.
- July–August 2009—mapping was based on analyses of samples collected from 60 wells.

A regional MODFLOW model of coastal Georgia and adjacent parts of Florida and South Carolina (Payne and others, 2005) was refined with higher resolution near the area of chloride contamination at Brunswick. The revised model is being used to assess the effects of pumping on hydraulic gradients along the outer margin of the contaminated area.

Real-time monitoring systems were installed in wells completed in the upper and lower water-bearing zones of the Upper Floridan aquifer that surround the area of chloride contamination. The following continuous data were collected:

- Water levels at Southside Baptist Church (wells 34H504 and 34H505), Perry Park (well 34H514), and Georgia–Pacific Cellulose (wells 33H324 and 33H325).
- Specific conductance at Southside Baptist Church (well 34H505), Perry Park (well 34H514; hydrograph, facing page), Georgia–Pacific Cellulose (well 33H325), and Brunswick Villa (well 34H134).

Information from the real-time groundwater-monitoring sites can be accessed at *http://waterdata.usgs.gov/ga/nwis/current/?type=quality&group%20Key=basin%20cd* and *http://waterdata.usgs.gov/ga/nwis/current/?type=gw&group_key=county_cd*.

References

Cherry, G.S., Peck, M.F., Painter, J.A, and Stayton, W.L., 2010, Groundwater conditions and studies in the Brunswick–Glynn County area, Georgia, 2008: U.S. Geological Survey Open-File Report 2009–1275, 54 p.; available online at *http://pubs.usgs.gov/of/2009/1275/*.

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.

Payne, D.F., Rumman M.A., and Clarke J.S., 2005, Simulation of groundwater flow in coastal Georgia and adjacent parts of South Carolina and Floridan Predevelopment, 1980, and 2000: U.S. Geological Survey Scientific Investigations Report 2005–5089, 91 p.; available online at *http://pubs.usgs.gov/sir/2005/5089/*.

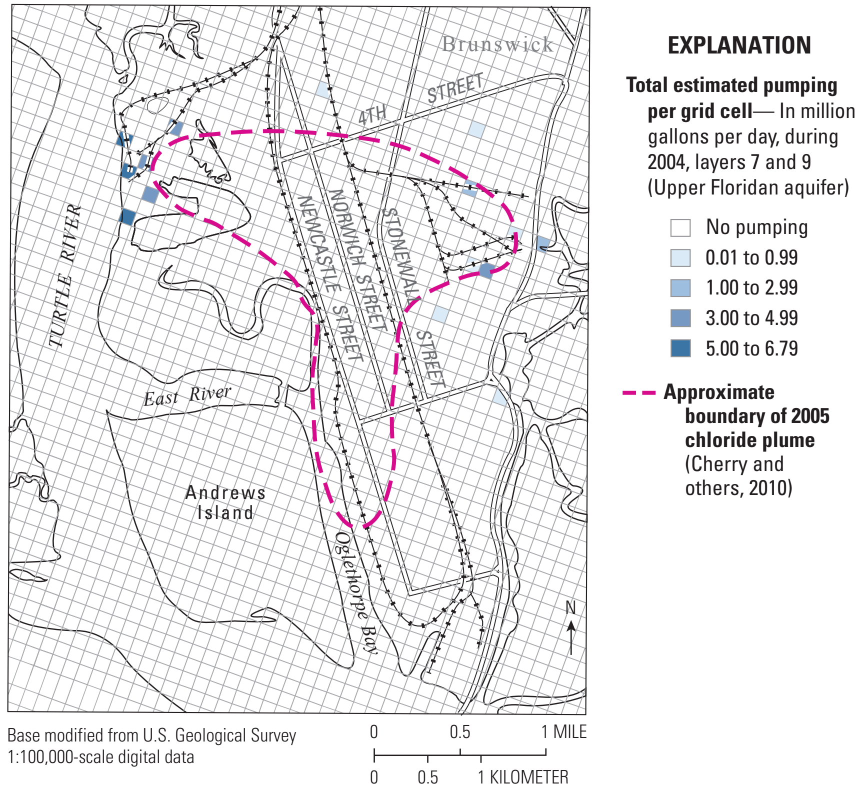
U.S. Environmental Protection Agency, 2000, Maximum contaminant levels (Part 143, National Secondary Drinking Water Regulations): U.S. Code of Federal Regulations, Title 40, Parts 100–149, rev. July 1, 2000, p. 612–614.

A. Hydrogeologic units and model layers

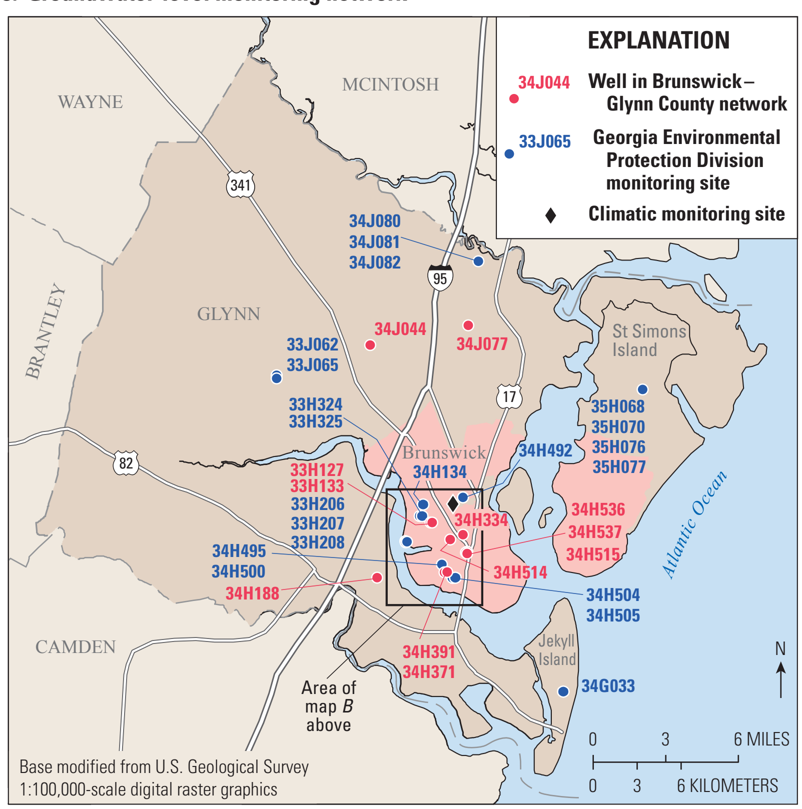
Hydrogeologic unit: Savannah	Hydrogeologic unit: Brunswick	Aquifer system	Model layer: Payne and others, 2005	Model layer: Revised model
Water-table zone		SURFICIAL AQUIFER SYSTEM	GHB (not modeled)	GHB (not modeled)
Confining unit	Upper water-bearing zone		1	1
	Lower water-bearing zone			
Confining unit		BRUNSWICK AQUIFER SYSTEM	2	2
	Upper Brunswick aquifer		3	3
				4
	Lower Brunswick aquifer			5
Upper Floridan confining unit			4	6
Upper Floridan aquifer	Upper water-bearing zone	FLORIDAN AQUIFER SYSTEM	5	7
	Upper Floridan semi-confining unit			8
	Lower water-bearing zone			9
Lower Floridan confining unit			6	10
Lower Floridan aquifer	Confining unit		7	11
	Fernandina permeable zone			
Confining unit			Not modeled	Not modeled

[GHB, general-head boundary]

B. Hydrogeologic units and model layers

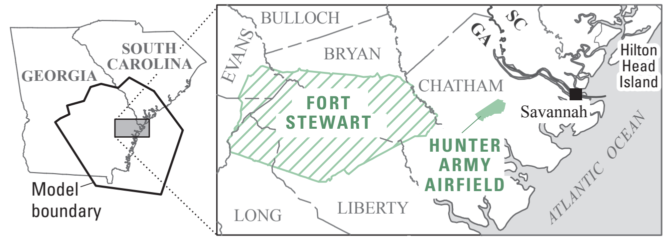


C. Groundwater-level monitoring network



A digital model is being developed to simulate groundwater flow in the vicinity of the chloride plume at Brunswick. The model is based on a regional model developed by Payne and others (2005) as part of the Coastal Sound Science Initiative. A greater number of model layers *(A)* and finer grid resolution *(B)* are being applied to enable more detailed simulations in the vicinity of the chloride plume, including assessment of the effects of pumping on the hydraulic gradients near the plume. A groundwater-level monitoring network *(C)* helps assess current hydrologic conditions and the effectiveness of water-management practices.

Fort Stewart–Hunter Army Airfield Alternative Water Resources



Study Chief John S. Clarke

Cooperator U.S. Department of the Army

Year Started 2009

Problem

The U.S. Department of the Army Fort Stewart and Hunter Army Airfield (HAAF), Georgia, are home of the 3rd Infantry Division. These two sites are located in coastal Georgia near Savannah, where concern over saltwater intrusion at Hilton Head Island, South Carolina, has resulted in increased restrictions on groundwater withdrawals from the Upper Floridan aquifer by the Georgia Environmental Protection Division (GaEPD). To meet the growing water demand in Georgia's coastal area, the GaEPD has encouraged use of alternative water sources to the Upper Floridan, including streams, ponds, and wells completed in the Lower Floridan aquifer and shallower surficial and Brunswick aquifer systems.

To assess the water-resource potential of these various sources for potable supply and irrigation, the U.S. Geological Survey, in cooperation with the Department of the Army, is conducting detailed field investigations at HAAF and Fort Stewart.

Objectives

- Analysis of shallow alternative aquifers (surficial and Brunswick aquifer systems)—Conduct detailed site investigations in new and existing wells, including borehole geophysical logging and flowmeter testing, depth-integrated water sampling and analysis, and aquifer-performance testing to determine the drawdown and water-bearing capacity of the aquifer.
- Analysis of Lower Floridan aquifer—Conduct detailed site investigations, including borehole geophysical logging and flowmeter testing, depth-integrated water sampling and analysis, and aquifer-performance testing to determine the drawdown and water-bearing capacity of the Lower Floridan aquifer and interconnection (leakage) with the overlying Upper Floridan aquifer. Perform groundwater model analyses to further assess the effects of pumping on leakage between the Upper and Lower Floridan aquifers.
- Analysis of ponds—Conduct detailed site investigations of selected ponds to assess water-supply potential, including describing the local site setting and pond bathymetry, estimating the volume of water stored in the ponds over a range of stages, estimating net groundwater seepage derived from water-budget analyses and pond-discharge tests, and determining the suitability of pond water quality for irrigation purposes.

Progress and Significant Results, 2008–2009

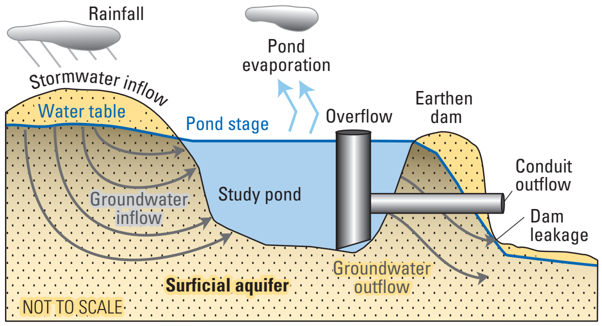
- Completed construction and field testing of new production well at HAAF completed in the Lower Floridan aquifer. Field testing included collection of drill cuttings, core, borehole geophysical logs and flowmeter data, conducting aquifer-performance tests in the Upper and Lower Floridan aquifers, collection and analysis of water samples from a variety of depths, conducting packer slug tests in the Lower Floridan confining unit, and laboratory analysis of core samples for determination of vertical hydraulic conductivity. Data were synthesized into an existing groundwater-flow model modified to assess interaquifer leakage between the Upper and Lower Floridan aquifers.
- Conducted evaluation of the hydrology, water-quality, and water-supply potential of four ponds at HAAF. This included determination of the volume of water stored in the ponds under a range of stage conditions; measurement of streamflow discharging from one of the ponds and development of a stage-discharge relation to determine flow rates over a range of climatic conditions; estimating net groundwater seepage by developing hydrologic budgets; and sampling and analysis to determine pond water quality. Results of the investigation are documented in a final report (Clarke and Painter, 2010).

References

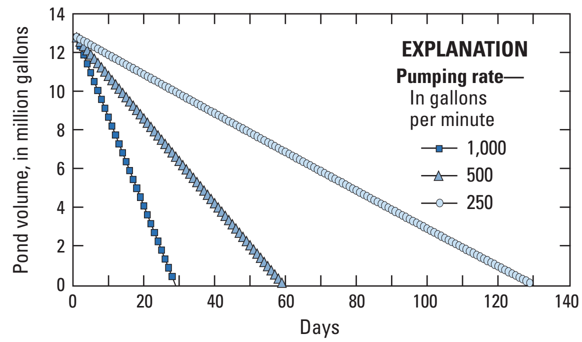
Clarke, J.S., and Painter, J.A., 2010, Hydrology, water quality, and water-supply potential of ponds at Hunter Army Airfield, Chatham County, Georgia, November 2008–July 2009: U.S. Geological Survey Scientific Investigations Report 2009–5265, 34 p.; available online at *http://pubs.usgs.gov/sir/2009/5265/*.

U.S. Environmental Protection Agency, 2009, Drinking water contaminants, accessed February 3, 2011, available online at *http://water.epa.gov/drink/contaminants/index.cfm*.

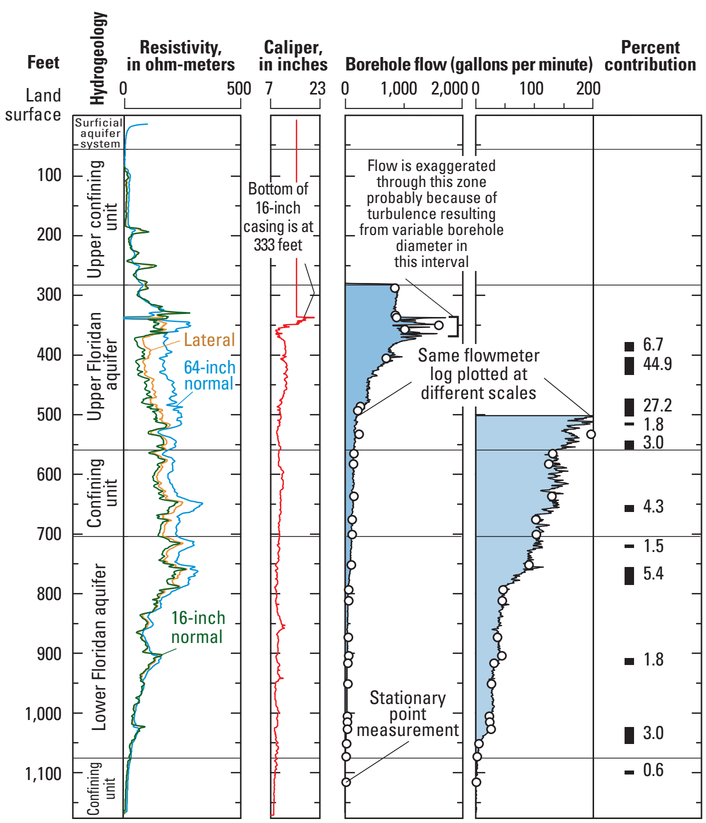
Williams, L.J., 2010, Summary of hydrologic testing of the Floridan aquifer system at Hunter Army Airfield, Chatham County, Georgia: U.S. Geological Survey Open-File Report 2010–1066, 30 p.; available online at *http://pubs.usgs.gov/of/2010/1066/*.



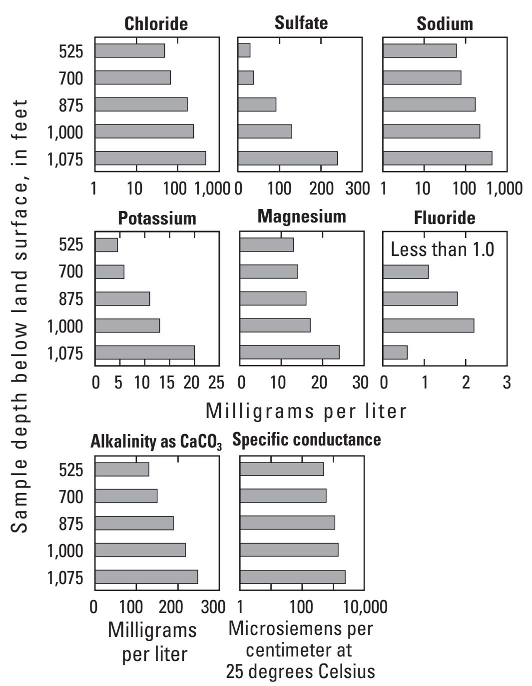
Conceptual model of pond-aquifer flow for a typical coastal area pond. Water supply from ponds is derived from the amount of available storage in the pond replenished by groundwater inflow and surface runoff. Evaporation, groundwater outflow, and leakage through earthen dams accounts for losses to pond storage. Field data including precipitation, evaporation, pond stage, and pond bathymetry were used to develop a hydrologic budget for three ponds at Hunter Army Airfield (HAAF) and assess their potential as sources of irrigation water supply (modified from Clarke and Painter, 2010).



At one of the ponds at HAAF, the total available volume was 12.8 million gallons and the average rate of net groundwater flow was 19 gallons per minute (gal/min). Assuming long-term average climatic conditions for July and an 8-hour-per-day pumping period, total depletion of pond volume would occur after 29 days at a pumping rate of 1,000 gal/min, after 60 days at a pumping rate of 500 gal/min, and after 130 days at a pumping rate of 250 gal/min. (modified from Clarke and Painter, 2010).



Geophysical logs and flowmeter data collected from a test boring open to both the Upper and Lower Floridan aquifers at HAAF were used to determine the relative flow contribution from water-bearing zones and to delineate the top and bottom of the Upper and Lower Floridan aquifers. While pumping at a rate of 847 gallons per minute (gal/min), flowmeter data indicated that the Upper Floridan aquifer, as a whole, produced 83.5 percent of the total flow with the remaining 16.5 percent derived from the underlying confining unit and the Lower Floridan aquifer. Two intervals in the Upper Floridan aquifer, 405–435 feet (ft) and 475–505 ft, produced the highest percentage of accumulated flow with an estimated 610 gal/min or 72 percent of the total pumping rate (modified from Williams, 2010).



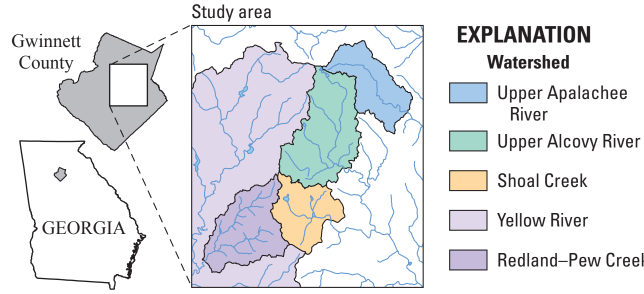
Discrete water samples collected from the Upper and Lower Floridan aquifers indicate that constituent concentrations generally increase with depth and are within drinking-water standards, with the exception of the deepest sample at 1,075 feet (ft). Water from the 1,075-ft interval had a chloride concentration of 480 milligrams per liter (mg/L), which exceeds the U.S. Environmental Protection Agency (USEPA) Secondary Maximum Contaminant Level (SMCL) of 250 mg/L (U.S. Environmental Protection Agency, 2009). The sulfate concentration of water from the same interval (240 mg/L) is slightly below the USEPA SMCL of 250 mg/L (U.S. Environmental Protection Agency, 2009). Flowmeter testing in the completed Lower Floridan aquifer well indicates that water from the 1,075-ft zone contributes less than 2 percent of the total flow to the well, and therefore the relatively higher concentrations of chloride and sulfate do not adversely affect the overall water quality from the well.

Monitoring of Groundwater and Surface-Water Resources in the City of Lawrenceville Area

Study Chief John S. Clarke

Cooperator City of Lawrenceville, Georgia

Year Started 2002



Problem

To meet Lawrenceville's growing need for water, the city is expanding development of its groundwater supply. During 1995–2007, Lawrenceville obtained 4–7 percent of its drinking water from groundwater (from a single well); the remainder of the drinking water was obtained from surface-water sources. In addition to a well near the center of town, the city plans additional groundwater withdrawal in the Redland–Pew Creek and upper Alcovy River watersheds. To enable informed decisions, city managers want to be able to quantify the effects (if any) of groundwater pumping on the surface-water resources as development increases. In addition to understanding groundwater resources, successful watershed management requires an understanding of how stream water quality is affected by watershed characteristics.

To support long-term management goals, the City of Lawrenceville, in cooperation with the U.S. Geological Survey (USGS), established a hydrologic monitoring network. The network consists of groundwater (regolith and bedrock wells) and surface-water (streamgages) sites in the two newly developed watersheds and in a background watershed (upper Apalachee River watershed) that is not influenced by the main pumping centers. In addition, sites in the Yellow River watershed are monitored to provide an indication of changes along the northern boundary of the Redland–Pew Creek watershed. An additional streamgage was installed in the adjacent Shoal Creek watershed. The data and information collected during the study can be used by local resource managers to develop a sustainable groundwater supply while minimizing the effects on surface-water resources. The data also will help in understanding changes in surface-water quality over time.

Objectives

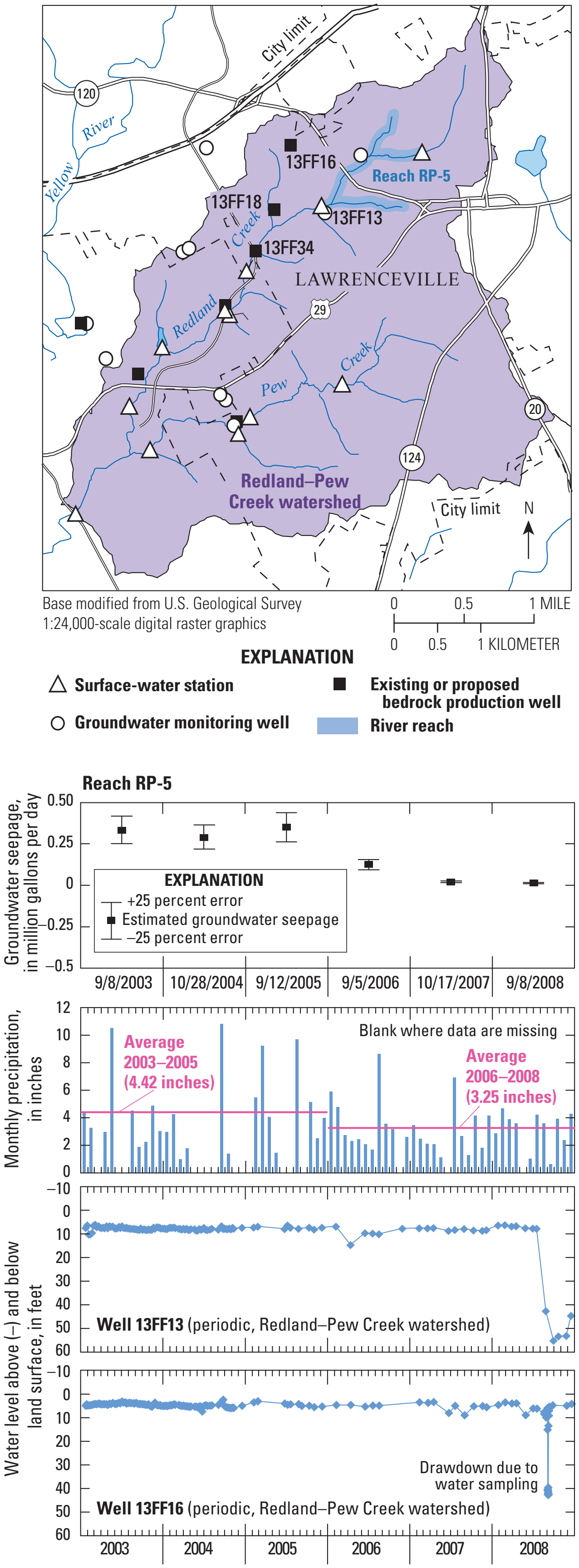
A cooperative water program (CWP) between the USGS and the City of Lawrenceville has been in place since 1994. The initial purpose of the CWP was to provide a better understanding of the geologic controls on groundwater availability in fractured crystalline rock. In 2002, the program was modified to incorporate groundwater and stream monitoring to assess the effects of groundwater development. Stream water-quality monitoring was added to the program in 2005.

Progress and Significant Results, 2008–2009

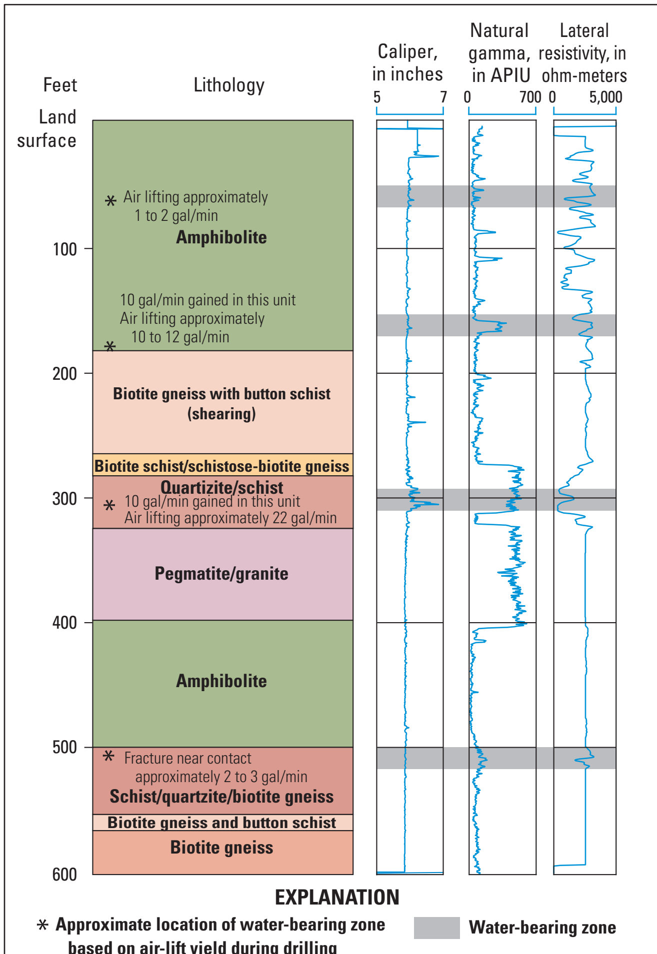
- Monitored groundwater levels in 26 wells, 3 of which recorded continuously, 21 wells were measured periodically, and 2 wells were continuously monitored during part of the year and measured periodically during the remainder of the year.
- Monitored streamflow and precipitation continuously at three sites, two of which included continuous water-quality monitoring of water temperature, specific conductance, and turbidity. In addition to these three continuously monitored surface-water sites, the network included periodic streamflow measurements at 22 other sites (the number of locations measured in a given year varied over the reporting period).
- Collected synoptic stream base-flow measurements in September 2008 to locate and quantify gains or losses to streamflow resulting from groundwater interaction (groundwater seepage). Measurements were not collected during the fall of 2009 because of above-normal precipitation and high streamflows.
- Collected borehole geophysical logs in well 13FF34, a 605-foot-deep test well drilled by the City of Lawrenceville in June 2008 to explore additional water resources in the Redland–Pew Creek watershed.
- Published study results in USGS Scientific Investigations Report 2010–5032, "Hydrologic conditions, stream-water quality, and selected groundwater studies conducted in the Lawrenceville area, Georgia, 2003–2008."
- Updated the project Web site, which can be accessed at *http://ga.water.usgs.gov/projects/lawrenceville/*.

Reference

Clarke, J.S., and Williams, L.J., 2010, Hydrologic conditions, stream-water quality, and selected groundwater studies conducted in the Lawrenceville area, Georgia, 2003–2008: U.S. Geological Survey Scientific Investigations Report 2010–5032, 55 p.; available online at *http://pubs.usgs.gov/sir/2010/5032/*.



Groundwater level and streamflow monitoring data are used to evaluate effects of groundwater pumping in the Lawrenceville area. In the Redland–Pew Creek watershed during 2003–2007, groundwater levels in wells 13FF13 and 13FF16 showed a similar, slightly downward trend in response to decreased precipitation. In 2008, water levels in well 13FF16 showed little change, whereas well 13FF13 showed a sharp decline of nearly 37 ft. This sharp decline was in response to the initiation of pumping in well 13FF18, located about 0.3 mile west of well 13FF13. In reach RP-5 along Redland Creek, streamflow gain was indicated throughout 2003–2008, with a decrease related to low precipitation during the drought period of 2006–2008. There was no appreciable difference in streamflow gain since the initiation of pumping in well 13FF18 (modified from Clarke and Williams, 2010).



Well 13FF34 is a 605-ft-deep test well drilled by the City of Lawrenceville in June 2008 to explore additional water resources in the Redland–Pew Creek watershed. Borehole geophysical logs and examination of drill cuttings indicate the rocks penetrated by this well include an upper and lower amphibolite unit, biotite gneiss and button schist unit, a quartzite/schist unit and a pegmatite/granite unit. Four water-bearing zones provide water to this well: (1) within the upper amphibolite unit, (2) near the contact of the upper amphibolite unit and the biotite gneiss and button schist unit, (3) within the quartzite/schist unit, (4) near the basal contact of the lower amphibolite unit. The final air-lift yield was measured at about 22 gal/min (gallon per minute; APIU, American Petroleum Institute Units; modified from Clarke and Williams, 2010).

Georgia Agricultural Water-Use Project

Study Chief Lynn J. Torak

Cooperator Georgia Soil and Water Conservation Commission

Year started 2008

Area maps *A* and *B* facing page

Introduction

By the end of 2009, agricultural water withdrawals in south Georgia were being monitored from a network of 6,985 annually read flow meters and 148 daily reporting, satellite-transmitted, telemetry sites (see map *A*, facing page). The monitoring is a result of the enactment of House Bill 579 by the Georgia General Assembly on June 4, 2003, which granted jurisdiction to the Georgia Soil and Water Conservation Commission (Commission) to "[implement] a program of measuring farm uses of water in order to obtain clear and accurate information on the patterns and amounts of such use, which information is essential to proper management of water resources by the state and useful to farms for improving the efficiency and effectiveness of their use of water, …, and [for] improving water conservation" (Georgia General Assembly, 2003).

Since November 2008, the U.S. Geological Survey, in cooperation with the Commission, has been researching methods for estimating agricultural water use and growing-season pumping rates through the analysis of water-meter data. A geographic information system (GIS) has been used for geospatial analyses of the data and has yielded promising results for identifying seasonal pumping patterns.

Objectives

Objectives of the analysis were to (1) develop a quality-assurance program to ensure completeness and internal consistency of water-meter data, (2) calculate descriptive statistics of aggregated water-use data, (3) evaluate the potential to relate daily water-use telemetry to annually reported water use through a descriptive statistical model, and (4) identify spatial and temporal distributions of agricultural-irrigation pumpage

Progress and Significant Results

A GIS-compatible relational database was developed consisting of all annually reported and satellite-transmitted telemetry of agricultural water use for aggregated statistical evaluation and comparison by source (groundwater, surface-water, and well-to-pond irrigation systems). Quality-assurance checks indicated water-meter "rollback" or "roll forward" during periods of non-irrigation, and zero water use at some meter sites since the inception of the metering program in 2003; zero water use significantly affected calculations of mean annual water use. On average, irrigation volume supplied by groundwater exceeded the volume supplied by surface water by about one-third. Comparison of mean irrigation volumes by source indicated that groundwater and surface-water use represent two distinct data populations that require independent statistical analyses.

Analyses of 81 telemetered and 4,357 annually reported water-use sites, which constitute the metering program in the Chattahoochee–Flint River basin, were conducted to evaluate the randomness of the two datasets (groundwater and surface water)—a prerequisite for subsequent geospatial analyses—and to assess the spatial distribution of meter locations. The analyses indicated

- Possible outliers or "hot spots" (clusters of high or low water-use values) that may relate to variations in aquifer yield, streamflow availability, soil type, crop patterns, rainfall and topography, requiring further identification and study. Separate hot-spot analyses for surface water (map *B*) and groundwater (map *C*) indicated geographic bands trending northwest to southeast of low-to-high agricultural water-use volume.
- Concentrated distributions (clustering) of telemetry sites in areas containing low-irrigation volumes, which resulted in underestimating annually reported mean water use with the telemetry network.
- A wide range of applied irrigation volumes among meter sites, which required data conversion to per-acre application rates by dividing irrigation volume by field acres

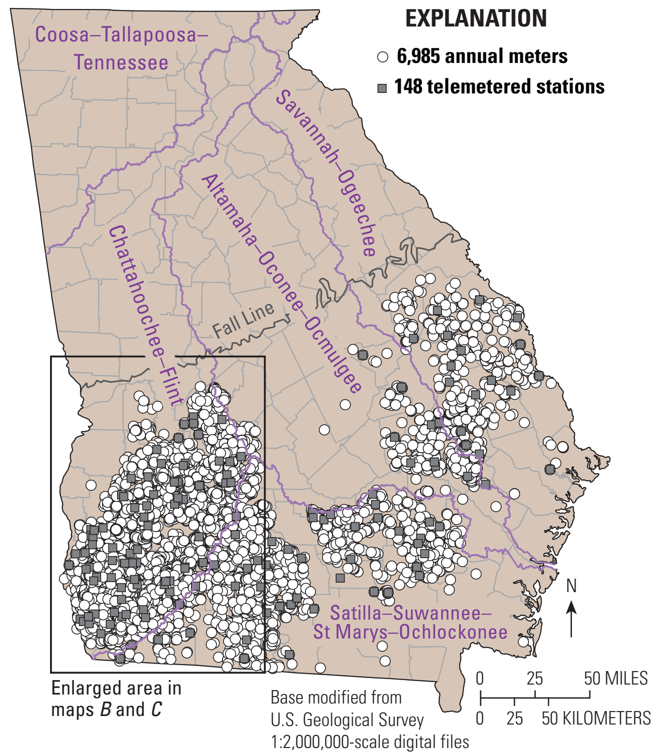
Reference

Environmental Systems Research Institute, Inc., 2009, How hot spot analysis: Getis-Ord Gi* (Spatial Statistics) works: Environmental Systems Research Institute, Inc., release 9.2, accessed March 24, 2010, at *http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=How%20Hot%20Spot%20Analysis:%20Getis-Ord%20Gi*%20(Spatial%20Statistics)%20works*.

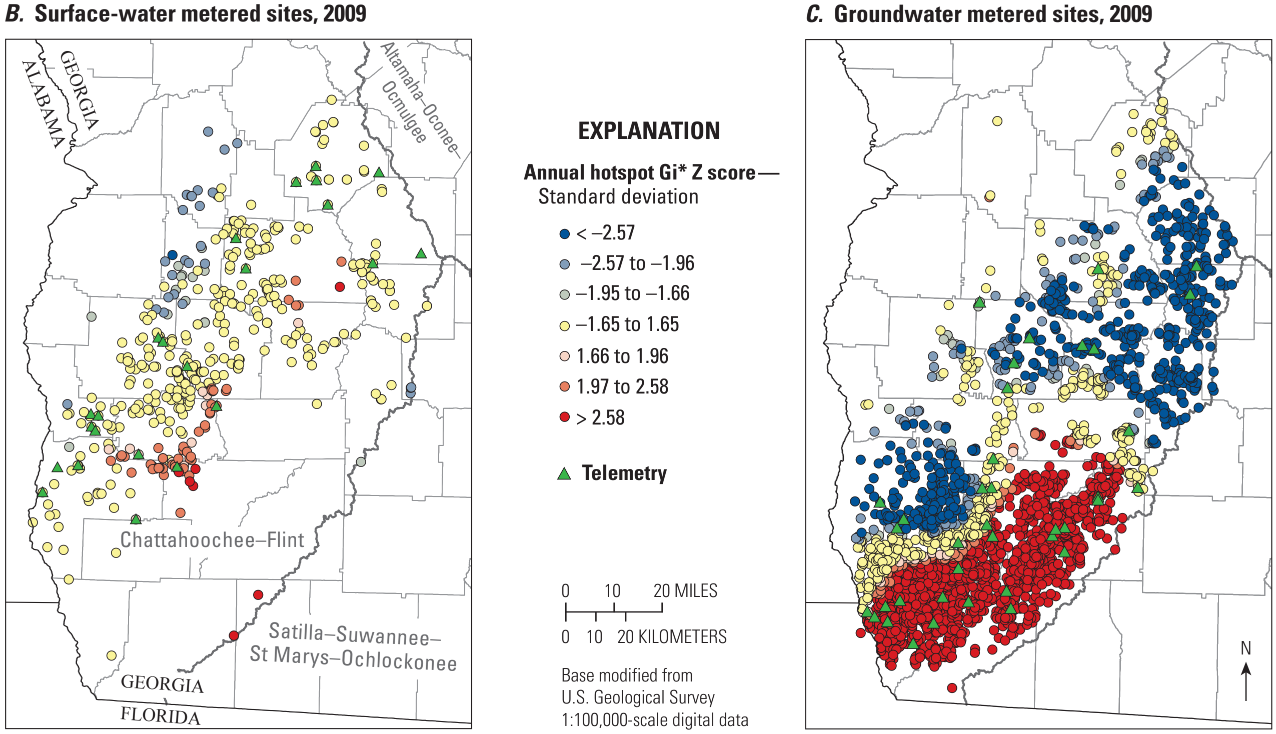
Georgia General Assembly, 2003, HB 579—Water resources; farm uses; water-measuring device: Georgia General Assembly, accessed March 23, 2010, at *http://www.legis.state.ga.us/legis/2003_04/search/hb579.htm*.

Locations of agricultural water metering program sites in south Georgia, 2009, including *(A)* 6,985 annually read and 148 daily satellite-transmitted data sites, with pattern of statistic (Gi* Z scores, Environmental Systems Research Institute, Inc., 2009) indicating geographic clustering of low-to-high annual irrigation volumes (“hot spots”) applied to *(B)* surface-water and *(C)* groundwater metered sites in the Chattahoochee–Flint River basin. The Gi* statistic defines a normal Z score (or standard score), which assesses the distribution of the annually reported water-use values about the mean. Statistically significant Z scores (less than −1.64 or greater than 1.65 standard deviations) of the Gi* statistic occur in areas containing clusters of either high (positive Z scores) or low (negative Z scores) irrigation water-use volume.

***A.* Georgia agricultural water metering program, 2009**



***B.* Surface-water metered sites, 2009** ***C.* Groundwater metered sites, 2009**

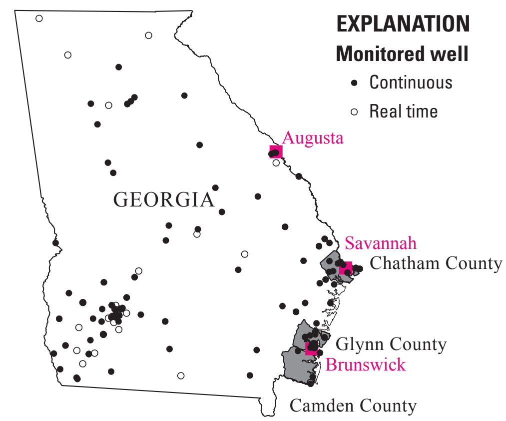


Groundwater Information and Project Support

Study Chief Michael F. Peck

Cooperator Georgia Department of Natural Resources Environmental Protection Division
St. Johns River Water Management District, Florida

Year Started 1938



Problem

Groundwater supplies about 22 percent of freshwater withdrawals in Georgia—more than 1.2 billion gallons per day during 2005. More than 1.9 million people are served by groundwater supplies, and 752 million gallons per day are withdrawn for irrigation (Fanning and Trent, 2009). The distribution and quality of groundwater are highly variable and directly related to geology and natural and human stresses. Monitoring groundwater levels and groundwater quality is essential for the management and development of this resource.

Objectives

- Collect groundwater-level and groundwater-quality data to assess the quantity, quality, and distribution of groundwater.
- Provide data to address water-management needs and evaluate the effects of national and local management and conservation programs.
- 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, 2008–2009

- Continuous water-level recorders were operated in 179 wells during 2008 and in 181 wells during 2009. Of the 181 wells, 30 are instrumented with real-time transmission (satellite relay) of continuous water-level records. During 2009 an additional well was instrumented with real-time equipment in the coastal area to monitor specific conductance, which brought the total to four wells being monitored for water quality. The data from these wells can be accessed through the National Water Information System (NWIS) database on the Web at *http://waterdata.usgs.gov/ga/nwis/current/?type=gw*.
- Periodic water-level measurements were made in more than 3,700 wells to define potentiometric surfaces and to assess long-term trends.
- Water samples for chloride analyses were collected from 66 wells during 2008 and 60 wells during 2009 in the Brunswick area, and from 4 wells in the Savannah area and 7 wells in Camden County during 2008–2009.
- During 2008–2009, borehole geophysical logs were collected in 11 wells in northern Georgia and in 22 wells in southern Georgia (map and table, facing page).
- 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 1,030 sites were added to the NWIS Groundwater Site Inventory to improve groundwater data coverage in the State. The NWIS database can be accessed on the Web at *http://waterdata.usgs.gov/ga/nwis/inventory/*.

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Fanning, J.L., and Trent, V.P., 2009, Water Use in Georgia by county for 2005; and water-use trends, 1980–2005: U.S. Geological Survey Scientific Investigations Report 2009–5002, 186 p.; available online at *http://pubs.usgs.gov/sir/2009/5002/.*

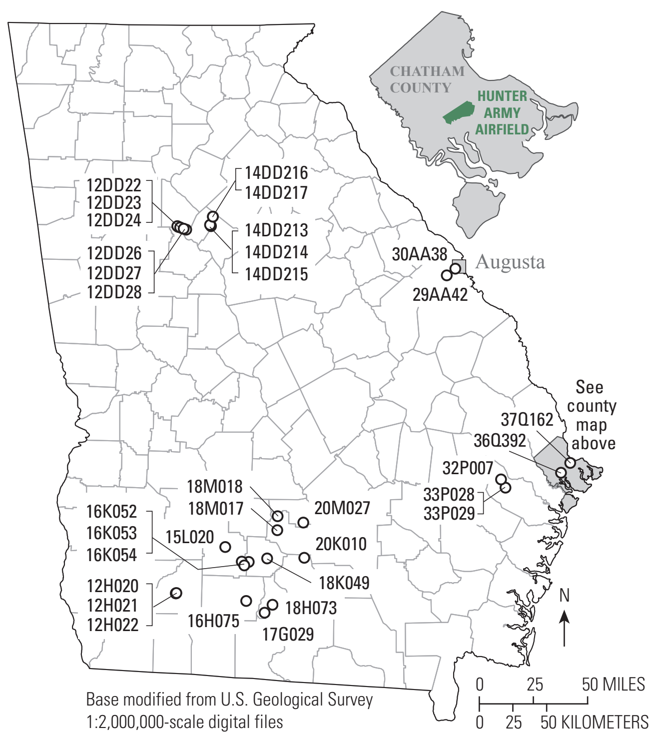
Peck, M.F., Painter, J.A., and Leeth, D.C., 2009, Ground-water conditions and studies in Georgia, 2006–2007: U.S. Geological Survey Scientific Investigations Report 2009–5070, 86 p.; available at *http://pubs.usgs.gov/sir/2009/5070/*.

Wells where geophysical logs were collected, 2008–2009

County name	Station name	Well depth, in feet, below land surface
Ben Hill	18M018	265.0
Ben Hill	20M027	304.0
Berrien	20K010	485.0
Chatham	36Q392	1,168.0
Chatham	37Q162	903.0
Colquitt	16H075	342.0
Cook	17G029	306.0
Cook	18H073	210.0
DeKalb	12DD22	228.0
DeKalb	12DD23	183.0
DeKalb	12DD24	165.0
DeKalb	12DD26	183.5
DeKalb	12DD27	206.6
DeKalb	12DD28	172.6
Liberty	32P007	505.0
Liberty	33P028	1,300.0
Liberty	33P029	560.0
Mitchell	12H020	133.0
Mitchell	12H021	76.0
Mitchell	12H022	200.0
Richmond	29AA42	509.0
Richmond	30AA38	122.0
Rockdale	14DD213	622.0
Rockdale	14DD214	622.0
Rockdale	14DD215	725.0
Rockdale	14DD216	305.0
Rockdale	14DD217	305.0
Tift	16K053	244.0
Tift	18K049	622.0
Tift	18M017	230.0
Worth	15L020	738.0
Worth	16K052	725.0
Worth	16K054	520.0

A hydrologic technician from the Groundwater Information and Project Support unit is recording the discharge from a well at Augusta, Georgia, during a 24-hour aquifer test. The well is completed in the Dublin–Midville aquifer system. Photo by Michael D. Hamrick, USGS.

Hydrologic technicians set up a data logger and pressure transducer to monitor the stage at Hunter Army Airfield in Chatham County, Georgia. A tipping bucket rain gage has also been installed to record precipitation during the test period. Data were used to develop a hydrologic budget for the pond to help assess water-bearing potential as a source of irrigation supply. Photo by John S. Clarke, USGS.



EXPLANATION

37Q162 **Well and station name**

Well locations where geophysical logs were collected during 2008–2009.

Selected Groundwater Publications, Conferences, and Outreach, 2008–2009

Many reports, conference proceedings papers, and abstracts were published during 2008 and 2009 presenting results of U.S. Geological Survey (USGS) groundwater investigations in Georgia. Oral and poster presentations were given at various technical conferences and outreach events throughout the State. These publications and presentations provide results of investigations conducted in cooperation with State, Federal, and local agencies including the Georgia Department of Natural Resources (primarily 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 the publications are available on the Web only and can be viewed and downloaded at *http://ga.water.usgs.gov/publications/*.

Georgia Water Resources Conference for 2009

The biennial Georgia Water Resources Conference is co-sponsored by the USGS, and the results of several USGS investigations are highlighted. The 11th biennial conference was held at The University of Georgia in Athens during April 2009. Twenty-eight USGS papers and posters, 14 of which addressed groundwater investigations, were published in the conference proceedings (see bibliographic listing below).

Other Conferences and Outreach Events

During 2008–2009, USGS groundwater scientists participated in a variety of conferences and outreach events, including the following:

- Georgia Association of Water Professionals Spring Conference and Expo, April 2009
- Carl E. Kindsvader Symposium, April 2008
- Geological Society of America, October 2008 and October 2009
- Sunbelt Agricultural Exposition, October 2008 and October 2009
- Georgia CoastFest, October 2008 and October 2009
- Georgia Groundwater Association, various
- Future Farmers of America, 2009
- Environmental Flows: Water for People and Nature in the Southeast, 2008
- Lake Seminole Workshop, 2008
- U.S. Geological Survey–U.S. Army Corps of Engineers (USGS–USACE) Annual Program Meeting, 2009
- American Society of Civil Engineers, Environmental and Water Resources Meetings and Georgia Section Meetings, 2009
- Managing Georgia's groundwater—A monitoring and modeling approach: Georgia Association of Environmental Professionals meeting, February 2009

Selected U.S. Geological Survey Reports and Conference Proceedings Articles

U.S. Geological Survey Reports

Calhoun, D.L., Gregory, M.B., and Wyers, H.S., 2008, Algal and invertebrate community composition along agricultural gradients—A comparative study from two regions of the Eastern United States: U.S. Geological Survey Scientific Investigations Report 2008–5046, 33 p.; also available online at *http://pubs.usgs.gov/sir/2008/5046/*.

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Gordon, D.W., 2008, Ground-water conditions and studies in the Albany area of Dougherty County, Georgia, 2007: U.S. Geological Survey Open-File Report 2008–1328, 49 p.; available online at *http://pubs.usgs.gov/of/2008/1328/*.

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Holloway, O.G., and Waddell, J.P.; 2008, Design and operation of a borehole straddle packer for ground-water sampling and hydraulic testing of discrete intervals at U.S. Air Force Plant 6, Marietta, Georgia: U.S. Geological Survey Open-File Report 2008–1349, 24 p.; available online at *http://pubs.usgs.gov/of/2008/1349/*.

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Knaak, A. E., Joiner, J. K., and Peck, M. F., 2009, Summary of hydrologic conditions in Georgia, 2008: U.S. Geological Survey Fact Sheet 2009–3109, 6 p.; also available online at *http://pubs.usgs.gov/fs/2009/3109/*.

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U.S. Geological Survey, 2008, Borehole geophysical logging of water-supply wells in the Piedmont, Blue Ridge, and Valley and Ridge, Georgia: U.S. Geological Survey Fact Sheet 2007–3048, 4 p.; available online at *http://pubs.usgs.gov/fs/2007/3048/*.

2009 Georgia Water Resources Conference Proceedings Papers

The following USGS papers were published *in* Rasmussen, Todd, Carroll, D.G., and Georgakakos, Aris, eds., 2009, Proceedings of the 2009 Georgia Water Resources Conference, April 27–29, 2009: Athens, Georgia, The University of Georgia, CD–ROM. All USGS papers also are available online at *http://www.gwri.gatech.edu/conferences/previous-gwrc-conferences/gwrc-2009/*.

Buell, G.R., Calhoun, D.L., and Wehmeyer, L.L., 2009, Hydrologic and land-use/land-cover metrics used in ecological assessments of six U.S. Fish and Wildlife Service National Wildlife Refuges in the southeastern USA, 8 p.

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Gonthier, G.J., 2009, Conceptual model of ground-water flow in fractured-crystalline rock—A case study based on constant-discharge tests at U.S. Air Force Plant 6, Marietta, Georgia, 2003, 6 p.

Gotvald, A.J., Weaver, J.C., and Feaster. T.D., 2009, Magnitude and frequency of floods in rural basins of Georgia, South Carolina, and North Carolina, 1 p.

Hall, M.E., and Holloway, O.G, 2009, Impact of declining water levels on domestic wells in south-central Georgia, 1 p.

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Appendix. Regression Statistics

Water-level trends in this report were estimated by applying the Levenberg–Marquardt Algorithm (LMA; Moré, 1978) to monthly mean water-level data for the period of record and during 2008–2009. Although the LMA typically is used for nonlinear fitting, it also can be used for deriving linear fits very near values derived using ordinary least squares fitting. In concept, LMA works by optimizing a mathematical function (called a merit function by statisticians) that measures how well the function represents the data. In this report, the merit function is the weighted sum of the squares of the differences (informally known as chi-squared and represented in equations and tables as χ^2).

In this report, the steps involved in minimizing this merit function are as follows:

1. Estimate a value for the slope and intercept, and calculate a line based on this estimate.

2. Calculate how far this line lies from the data (using the χ^2). Adjust the line so that it lies closer to the center of the data.

3. Repeat this until adjustments no longer affect the χ^2 value.

Each step is completed through manipulations of algebraic matrices, that are beyond the scope of this report, but are fully explained in Moré, (1978).

Summary statistics for the straight line (linear) fits of water-level trends described in the main body of the report are provided here as an indicator of goodness of fit (Janert, 2010), and so that readers can make decisions based on their tolerance for risk. These include:

- The degrees of freedom representing the number of data points minus the variables used. For this evaluation, two variables are used—slope (m) and intercept (b). A general rule of thumb is that the residuals and the χ^2 should be in the same order of magnitude, for the fit to be reasonable (with some exceptions).

- The root mean square error (RMSE) of the residuals is the square root of the average squared distance of a data point from the fitted line. RMSE units are in the same units as the quantity being estimated (in this report, feet).

- The chi-squared is the sum of squared residuals (differences) between the monthly mean water level and the values computed by the algorithm after the final iteration. Thus, the term “least-squares” fitting. The χ^2 from the fit along with χ^2 distribution tables may be used to estimate confidence intervals.

- The standard error (SE) of a variable (m or b in this report), expressed as a percentage, is a measure of how well m or b has been estimated and affects the location of the regression line. The greater the standard error, the greater the scatter around the regression line. In other words, standard error is a measure of dispersion.

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Table A–1. Regression statistics.

[%, percent]

Well name	Period of record summary statistics					2008–2009 summary statistics				
	Degrees of freedom	Root mean square error of residuals (RMSE)	Variance of residuals (χ^2)	Standard error of slope (SE_m %)	Standard error of intercept (SE_b %)	Degrees of freedom	Root mean square error of residuals (RMSE)	Variance of residuals (χ^2)	Standard error of slope (SE_m %)	Standard error of intercept (SE_b %)
03PP01	375	3.01	9.08	43.36	1.45	22	3.22	10.37	969.70	86.35
06F001	351	7.47	55.79	45.81	1.74	17	6.43	41.33	73.18	44.35
06G006	193	8.80	77.38	110.80	1.29	19	7.35	54.01	52.93	24.87
06K009	293	7.61	57.85	4.24	0.27	22	5.06	25.65	1,851.00	8.68
06K010	294	1.30	1.69	11.71	0.11	21	0.41	0.17	11.29	1.58
06S001	641	6.09	37.05	1.76	1.00	22	1.11	1.24	11.55	30.39
07H002	346	7.62	58.13	12.78	3.69	18	4.42	19.57	58.63	42.58
07H003	355	4.91	24.14	175.10	2.93	20	3.97	15.73	1,918.00	151.30
07KK64	150	3.81	14.54	43.60	2.00	22	3.00	8.99	27.88	16.74
07N001	530	3.44	11.82	1.35	0.13	22	3.26	10.60	20.75	4.66
08E038	89	0.79	0.62	29.50	0.91	19	0.40	0.16	39.67	5.13
08E039	91	1.27	1.62	771.10	2.76	22	1.07	1.15	79.38	37.54
08G001	393	8.47	71.73	42.42	1.64	22	6.84	46.80	40.09	25.11
08K001	362	9.32	86.84	71.45	5.48	22	8.29	68.64	131.90	95.31
09F520	477	3.00	8.99	20.08	0.39	22	2.25	5.08	39.18	11.02
09FF18	89	0.56	0.31	23.01	0.66	11	0.45	0.21	48.70	9.42
09G001	351	3.43	11.75	29.71	0.41	21	2.59	6.71	47.88	12.47
09G003	336	2.30	5.29	45.13	0.39	20	0.97	0.94	30.73	6.99
09M007	295	23.05	531.26	9.89	0.83	21	24.20	585.75	219.10	36.08
09M009	300	1.48	2.20	103.50	0.33	22	0.84	0.70	19.00	6.53
10DD02	431	1.69	2.86	5.72	1.32	22	1.29	1.66	42.54	21.49
10G313	463	5.35	28.67	23.65	0.61	21	3.47	12.02	44.39	14.96
10H009	136	5.68	32.31	44.52	1.97	22	6.03	36.42	47.04	24.63
10K005	306	1.80	3.24	15.93	0.51	19	2.93	8.61	89.23	28.05
11AA01	763	2.80	7.85	98.73	1.04	18	2.27	5.16	29.49	17.28
11FF04	355	0.38	0.15	4.89	0.32	22	0.42	0.18	33.37	11.48
11J011	345	3.69	13.61	15.24	0.55	22	2.22	4.92	21.86	9.48
11J012	342	3.61	13.05	42.04	0.48	22	3.54	12.53	64.15	17.77
11K003	139	1.05	1.11	223.20	1.39	22	4.14	17.16	22.88	15.27
11K005	362	4.29	18.39	1.54	0.39	22	0.91	0.84	101.70	3.53
11L002	452	15.58	242.67	4.05	0.79	17	13.52	182.83	122.60	32.11
11P014	291	17.52	306.80	9.07	1.09	15	6.82	46.52	23.67	12.61
11P015	296	1.69	2.84	30.88	0.28	18	0.97	0.95	30.51	6.37
12F036	520	5.87	34.44	7.60	0.26	17	1.39	1.93	24.71	3.11
12JJ04	464	1.52	2.31	10.50	0.34	21	1.13	1.29	23.82	8.36
12K014	330	3.95	15.58	31.37	0.56	21	3.67	13.45	64.68	19.48
12K141	161	6.81	46.31	36.82	2.04	22	3.67	13.47	17.67	11.50
12K180	84	3.96	15.65	126.80	5.51	20	4.12	16.95	56.17	28.84
12L019	362	8.70	75.67	12.96	0.74	10	3.39	11.46	42.63	15.22
12L020	357	14.43	208.33	26.28	0.69	14	10.04	100.74	213.30	39.42

Table A–1. Regression statistics.—Continued

[%, percent]

Well name	Period of record summary statistics					2008–2009 summary statistics				
	Degrees of freedom	Root mean square error of residuals (RMSE)	Variance of residuals (χ^2)	Standard error of slope (SE_m%)	Standard error of intercept (SE_b%)	Degrees of freedom	Root mean square error of residuals (RMSE)	Variance of residuals (χ^2)	Standard error of slope (SE_m%)	Standard error of intercept (SE_b%)
12L021	359	11.73	137.61	173.70	0.57	16	7.18	51.50	185.80	20.09
12L029	322	5.84	34.09	42.92	0.80	21	3.71	13.79	58.36	19.51
12L030	287	4.49	20.20	64.36	1.22	22	2.89	8.34	26.77	15.89
12L277	130	6.02	36.24	209.20	2.72	21	3.92	15.39	21.91	14.16
12L370	107	4.23	17.88	207.10	2.18	21	3.82	14.59	40.72	17.84
12L373	88	4.24	17.94	127.00	3.74	22	4.09	16.73	44.15	19.56
12M001	341	11.64	135.49	6.14	0.65	17	8.81	77.54	70.88	55.64
12M002	345	13.88	192.67	11.26	0.58	15	8.57	73.41	104.30	20.16
12M017	326	4.77	22.73	58.41	0.94	22	2.43	5.91	99.80	20.60
12Z001	483	2.07	4.30	11.84	1.09	17	1.41	1.99	40.80	19.53
13FF30	67	1.07	1.15	14.92	2.22	17	1.20	1.44	193.00	14.94
13FF31	66	1.04	1.08	20.77	2.33	22	0.81	0.65	23.46	7.34
13J004	377	4.49	20.18	12.48	0.56	22	2.85	8.14	35.76	11.75
13K014	323	4.64	21.53	30.17	0.88	19	4.39	19.24	84.12	28.54
13L002	599	17.20	295.76	2.96	0.74	22	7.25	52.63	87.87	15.55
13L011	382	6.54	42.72	28.73	0.54	18	1.67	2.78	27.59	6.89
13L012	388	3.69	13.60	50.84	0.53	22	3.57	12.77	58.98	18.40
13L013	367	8.91	79.31	71.72	0.52	18	0.48	0.23	5.27	2.75
13L015	358	9.18	84.36	10.89	0.60	21	3.52	12.39	136.30	13.43
13L049	284	5.85	34.20	44.80	1.11	19	4.04	16.34	45.41	21.55
13L180	137	5.11	26.11	344.90	1.15	22	2.42	5.86	30.15	9.77
13M005	352	5.10	26.03	13.58	2.18	20	4.17	17.39	385.10	71.30
13M006	353	6.51	42.35	41.32	4.02	21	6.76	45.75	147.40	85.60
13M007	351	2.10	4.40	234.10	1.55	21	1.52	2.30	137.60	41.78
14GG02	70	1.02	1.05	12.22	0.54	16	0.91	0.84	47.03	3.39
14P014	302	3.59	12.89	7.85	0.46	21	1.49	2.23	27.11	7.06
14P015	299	9.29	86.26	23.42	2.47	19	10.08	101.56	80.86	52.98
15L020	442	1.19	1.42	0.78	0.04	20	0.72	0.52	33.46	1.10
15Q016	76	8.02	64.37	66.34	5.95	22	7.43	55.25	147.30	31.04
16MM03	258	0.64	0.41	17.84	0.93	22	0.51	0.26	37.28	18.18
18H016	527	1.56	2.44	1.63	0.05	22	1.04	1.07	26.63	1.70
18K049	367	3.22	10.38	2.14	0.16	15	3.33	11.10	4,515.00	8.10
18T001	335	1.35	1.82	3.82	0.14	21	1.00	1.00	50.22	5.48
18U001	406	1.10	1.21	4.80	0.04	17	0.90	0.81	101.60	1.95
19E009	613	6.83	46.66	15.54	0.31	22	6.15	37.84	76.71	12.71
21BB04	270	2.07	4.30	9.51	2.95	22	1.86	3.44	47.11	30.05
21T001	536	3.88	15.08	19.76	0.71	22	3.58	12.83	713.80	35.42
21U004	333	0.70	0.49	1.47	0.10	22	0.49	0.24	75.02	3.61
23X027	291	4.26	18.11	3.92	0.10	21	2.62	6.85	10.63	2.53
24V001	338	1.00	1.01	1.10	0.05	15	0.84	0.71	124.10	2.38

Table A–1. Regression statistics.—Continued

[%, percent]

Well name	Period of record summary statistics					2008–2009 summary statistics				
	Degrees of freedom	Root mean square error of residuals (RMSE)	Variance of residuals (χ^2)	Standard error of slope (SE_m %)	Standard error of intercept (SE_b %)	Degrees of freedom	Root mean square error of residuals (RMSE)	Variance of residuals (χ^2)	Standard error of slope (SE_m %)	Standard error of intercept (SE_b %)
25Q001	510	2.16	4.68	1.33	0.15	22	2.08	4.32	30.71	5.87
26R001	426	3.20	10.21	1.89	0.11	22	3.26	10.65	125.10	5.48
27E004	361	2.52	6.33	12.90	0.22	22	1.07	1.14	34.57	4.16
27G003	339	2.63	6.93	8.27	0.16	22	1.42	2.02	51.45	3.98
28X001	348	2.07	4.28	1.90	0.20	22	1.76	3.09	33.17	9.73
29AA09	152	1.36	1.84	8.46	0.17	22	0.44	0.19	30.74	1.85
30AA04	353	2.26	5.09	4.08	0.11	22	0.71	0.51	130.90	1.75
30L003	425	3.43	11.74	3.14	0.24	18	1.66	2.77	49.36	5.33
31U008	313	3.39	11.48	4.54	0.25	22	2.59	6.73	81.28	10.38
31U009	320	3.18	10.12	4.32	0.25	20	2.11	4.45	72.52	9.08
32G047	65	1.43	2.05	11.42	7.03	22	0.43	0.18	14.70	21.25
32L005	133	1.02	1.05	2.85	0.16	22	0.30	0.09	25.52	1.72
32L015	312	2.53	6.41	10.25	0.26	22	1.64	2.69	44.07	7.04
32L016	316	1.55	2.37	5.97	0.17	21	0.59	0.34	452.40	3.25
32L017	309	1.54	2.37	7.35	0.23	22	0.81	0.65	73.58	5.45
32Y030	148	0.99	0.98	4.61	0.10	13	0.56	0.32	115.20	3.39
32Y031	164	1.42	2.01	5.06	0.17	22	0.95	0.90	213.20	4.21
32Y033	158	5.04	25.45	7.74	1.41	22	7.46	55.70	195.40	67.56
33D069	183	6.46	41.79	5.91	9.28	20	1.18	1.40	45.62	35.58
33D071	134	4.77	22.79	5.30	7.69	22	0.28	0.08	16.20	38.04
33D072	138	1.44	2.06	8.64	3.24	19	0.46	0.21	22.38	16.51
33D073	116	7.64	58.41	8.92	46.01	22	0.80	0.64	25.40	20.13
33D074	77	1.62	2.64	20.82	1.78	22	0.72	0.52	23.09	9.78
33E027	361	3.40	11.55	15.17	0.98	22	1.04	1.09	27.54	31.22
33H127	537	4.34	18.81	29.57	27.96	16	1.80	3.25	35.67	36.86
33H133	528	4.54	20.60	5.58	4.77	13	2.94	8.67	71.39	64.43
33H188	325	2.87	8.23	20.45	2.42	19	0.98	0.97	46.30	28.02
33H206	306	3.30	10.86	9.80	3.70	22	1.38	1.91	31.58	55.24
33H207	303	3.81	14.51	5.99	48.12	21	1.46	2.14	58.34	60.90
33H208	303	1.38	1.91	6.66	2.32	22	0.61	0.37	20.40	15.91
33H324	33	1.95	3.79	22.56	12.41	22	1.80	3.23	28.35	18.15
33H325	33	7.15	51.12	33.63	13.84	22	6.88	47.37	32.03	18.42
33J044	363	2.64	6.96	17.52	26.36	21	1.05	1.11	18.82	18.10
33J062	107	2.74	7.49	24.07	4.13	22	0.65	0.42	61.75	15.33
33J065	97	1.18	1.38	9,726.00	285.30	17	0.11	0.01	12.49	9.79
33M004	498	2.93	8.56	2.49	0.32	22	1.31	1.72	32.86	5.88
33R045	90	3.43	11.75	34.71	1.70	22	1.66	2.75	40.56	6.58
34G033	59	2.21	4.87	12.28	4.68	21	1.08	1.16	28.73	87.47
34H334	492	3.43	11.78	6.48	7.86	19	1.37	1.88	34.48	46.85
34H371	507	2.87	8.23	7.30	3.79	22	1.31	1.70	36.01	70.07

Table A–1. Regression statistics.—Continued

[%, percent]

Well name	Period of record summary statistics					2008–2009 summary statistics				
	Degrees of freedom	Root mean square error of residuals (RMSE)	Variance of residuals (χ^2)	Standard error of slope (SE_m%)	Standard error of intercept (SE_b%)	Degrees of freedom	Root mean square error of residuals (RMSE)	Variance of residuals (χ^2)	Standard error of slope (SE_m%)	Standard error of intercept (SE_b%)
34H391	399	2.82	7.94	8.34	2.84	20	1.39	1.92	32.36	55.03
34H436	310	2.92	8.55	11.86	2.01	22	1.21	1.45	29.14	96.02
34H437	298	2.09	4.39	10.12	286.80	21	0.92	0.84	63.33	51.45
34H492	119	1.06	1.13	38.80	4.59	22	0.75	0.57	30.10	20.78
34H495	88	2.85	8.13	9.29	7.15	21	0.94	0.88	21.66	85.01
34H500	102	3.52	12.38	218.40	6.61	20	1.14	1.31	21.30	58.57
34H515	48	0.52	0.27	200.70	14.44	17	0.42	0.18	64.39	28.20
34J077	136	3.77	14.18	10.15	2.99	22	2.58	6.65	39.52	18.35
34J080	90	2.33	5.42	21.19	92.57	22	1.19	1.42	28.74	20.11
34J081	88	1.60	2.57	47.25	3.70	22	1.27	1.62	34.50	14.93
34J082	90	0.89	0.80	49.25	4.10	22	0.50	0.25	43.80	14.19
34K104	52	2.44	5.94	54.27	6.13	22	0.71	0.51	23.84	5.59
34N089	508	3.00	9.03	2.18	0.70	22	1.33	1.78	24.04	9.17
34S008	98	1.22	1.49	25.17	1.02	22	0.46	0.21	9.48	3.29
34S011	90	3.14	9.89	43.63	1.35	22	1.46	2.14	45.38	5.40
35H077	52	4.45	19.81	747.70	19.21	22	4.17	17.41	92.90	40.12
35M013	506	2.52	6.34	2.13	0.65	22	0.91	0.83	19.16	7.02
35P094	807	2.23	4.96	78.57	2.12	22	1.36	1.86	51.04	31.44
35P110	111	3.10	9.60	223.30	2.10	22	1.62	2.26	26.05	10.16
35P109/125	108	3.08	9.46	62.41	2.00	19	1.64	2.70	27.90	10.58
35Q050	47	2.16	4.65	24.19	3.81	21	0.68	0.46	24.77	8.31
35S008	115	1.39	1.94	16.49	0.50	22	0.53	0.29	18.59	2.82
35T003	112	3.38	11.40	48.79	1.64	22	2.02	4.09	64.41	12.71
35T005	107	2.24	5.02	5,375.00	1.72	22	1.27	1.61	56.87	10.91
36N012	121	2.40	5.75	43.04	0.91	22	1.33	1.77	27.26	7.32
36Q008	660	11.29	127.38	17.03	0.66	22	4.71	22.19	35.26	11.59
36Q020	603	4.47	19.99	2.28	0.52	20	2.49	6.22	36.50	12.11
37P114	307	2.93	8.58	10.25	0.35	22	2.52	6.36	29.30	10.56
37P116	304	0.30	0.09	26.04	0.22	21	0.36	0.13	104.10	12.15
37Q016	647	8.29	68.69	56.25	0.58	22	4.45	19.79	35.65	12.73
37Q185	247	5.51	30.38	3.40	0.36	17	7.53	56.75	52.32	19.33
37Q186	67	1.89	3.56	15.43	2.68	21	0.87	0.76	14.08	3.47
38Q002	641	3.01	9.07	2.77	0.51	22	1.66	2.75	39.63	11.59
38Q201	274	1.31	1.72	8.31	0.15	22	0.76	0.58	23.52	3.89
38Q208	137	0.40	0.16	85.67	0.85	22	0.42	0.18	23.13	11.29
38Q209	141	0.32	0.11	14.14	0.46	22	0.36	0.13	152.90	14.53
39Q003	543	2.51	6.32	3.08	0.50	20	1.47	2.16	77.36	13.89
39Q024	159	1.30	1.68	15.13	0.34	22	1.02	1.05	30.71	6.74
39Q025	158	1.60	2.58	18.42	0.46	22	1.44	2.08	46.19	10.25
39Q026	152	0.50	0.25	62.52	0.46	21	0.48	0.23	284.50	12.91
39Q029	139	1.05	1.11	223.20	1.39	21	0.87	0.76	40.06	17.33

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