Groundwater Conditions in Georgia, 2012–14

Scientific Investigations Report 2016–5161

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

Preface

This report is published to summarize groundwater conditions in Georgia. The report, presented in stop format, is the culmination of a concerted effort by U.S. Geological Survey South Atlantic Water Science Center, Georgia office personnel who collected, compiled, organized, analyzed, verified, edited, and assembled the report. In addition to the authors, who were primarily responsible 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:

Gregory S. Cherry	Gerard J. Gonthier	O. Gary Holloway
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Cover. A hydrologic technician collecting a water sample from U.S. Geological Survey (USGS) test well 10 (34H363). The well was originally drilled on the east side of Andrews Island; however, due to erosion, the well is now located *in* the East River, Brunswick, Georgia. (Photograph by Alan M. Cressler, USGS.)

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U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Director

U.S. Geological Survey, Reston, Virginia: 2016

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Contents

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	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)

Datums

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88). Historical data collected and stored as National Geodetic Vertical Datum of 1929 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 in this publication.

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

Supplemental Information

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 (µg/L).

Groundwater Conditions in Georgia, 2012–14

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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 181 wells during calendar year 2012, 185 wells during calendar year 2013, and at 171 wells during calendar year 2014. Because of missing data or short periods of record (less than 3 years) for several of these wells, a total of 164 wells are discussed in this report. These wells include 17 in the surficial aquifer system, 18 in the Brunswick aquifer system and equivalent sediments, 68 in the Upper Floridan aquifer, 15 in the Lower Floridan aquifer and underlying units, 10 in the Claiborne aquifer, 1 in the Gordon aquifer, 11 in the Clayton aquifer, 16 in the Cretaceous aquifer system, 2 in Paleozoic-rock aquifers, and 6 in crystalline-rock aquifers. Data from the well network indicate that water levels generally rose during the 2012 through 2014 calendar-year period, with water levels rising in 151 wells, declining in 12, and remained about the same in 1. Water levels declined over the long-term period of record at 94 wells, increased at 60 wells, and remained relatively constant at 10 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 the following areas in Georgia: the Brunswick-Glynn County area during August 2012 and October 2014 and in the Albany-Dougherty County area during November 2012 and November 2014. Periodic water-level measurements were also collected and used to construct potentiometric surface maps for the Cretaceous aquifer system in the Augusta-Richmond County area during August 2012 and July 2014. In general, water levels in these areas were higher during 2014 than during 2012; however, the configuration of the potentiometric surface in each of the areas showed little change.

In the Brunswick area, maps showing chloride concentration of water in the Upper Floridan aquifer (constructed using data collected from 25 wells during August 2012 and from 32 wells during October 2014) indicate that chloride concentrations remained above the U.S. Environmental Protection Agency's secondary drinking-water standard in an approximately 2-square-mile area. During calendar years 2012 through 2014, chloride concentrations generally increased in over 90 percent of the wells sampled with a maximum increase of 410 milligrams per liter in a well located in the north-central part of the Brunswick area.

Introduction

Reliable and impartial scientific information about 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 groundwater-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).

Purpose and Scope

This report presents an overview of groundwater levels throughout the State and groundwater quality in the city of Brunswick, Glynn County (see map page 49), during calendar years 2012 through 2014 (hereafter referred to as "2012–14"). It is a continuation of a series of reports begun in 1978 (see table page 4). In this report, the data collection period is based on a calendar year, for example, the phrase "during 2014" refers to the calendar year of January 1, 2014, through December 31, 2014. In Georgia, water levels were monitored continuously at 181 wells during 2012, 185 wells during 2013, and 171 wells during 2014. Because of missing data or short periods of record (less than 3 years) for several of these wells, a total of 164 wells are discussed in this report. Water-level data are summarized in graphs, maps, and tables. Groundwater levels in major aquifers are presented on hydrographs for selected wells. Estimated annual water-level change is reported for the period of record and for 2012–14. Data from and additional information about the wells included in this report can be obtained from the USGS National Water Information System (NWIS) database 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 of the Upper Floridan aquifer and the Cretaceous aquifer system. The Upper Floridan aquifer potentiometric surface maps were completed in southwestern Georgia near Albany using measurements from 57 wells during November 2012 and from 47 wells during November 2014. In the Brunswick-Glynn County area, water-level data from 46 wells were collected during August 2012 and from 49 wells during October 2014 for use in constructing potentiometric surface maps of the Upper Floridan aquifer. Water-level data were collected from 64 wells during August 2012 and from 66 wells during July 2014 in the Augusta-Richmond County area (see map page 43) and used to construct potentiometric surface maps of the Cretaceous aquifer system.

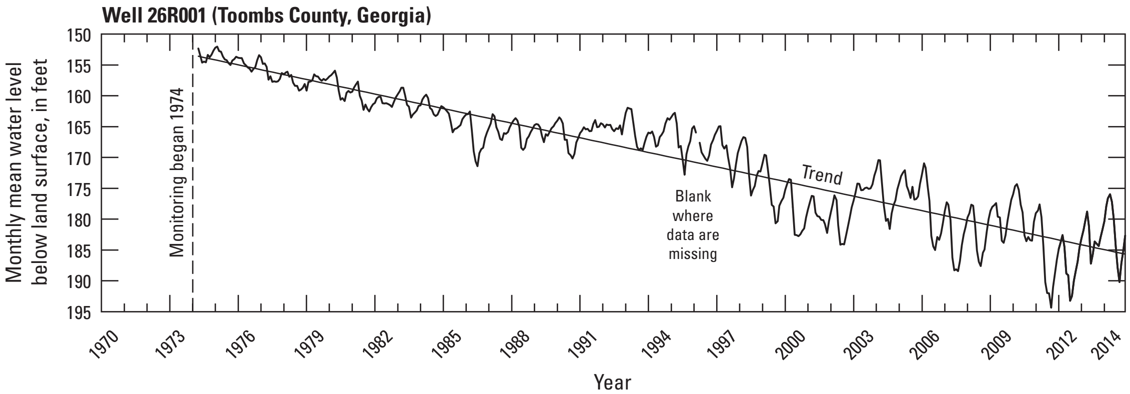
The quality of groundwater in the Upper and Lower Floridan aquifers is being monitored in the Brunswick-Glynn County area along the Georgia coast. Chloride concentration maps were constructed using data from 25 wells during 2012 and from 33 wells during 2014.

Methods of Analysis, Sources of Data, and Data Accuracy

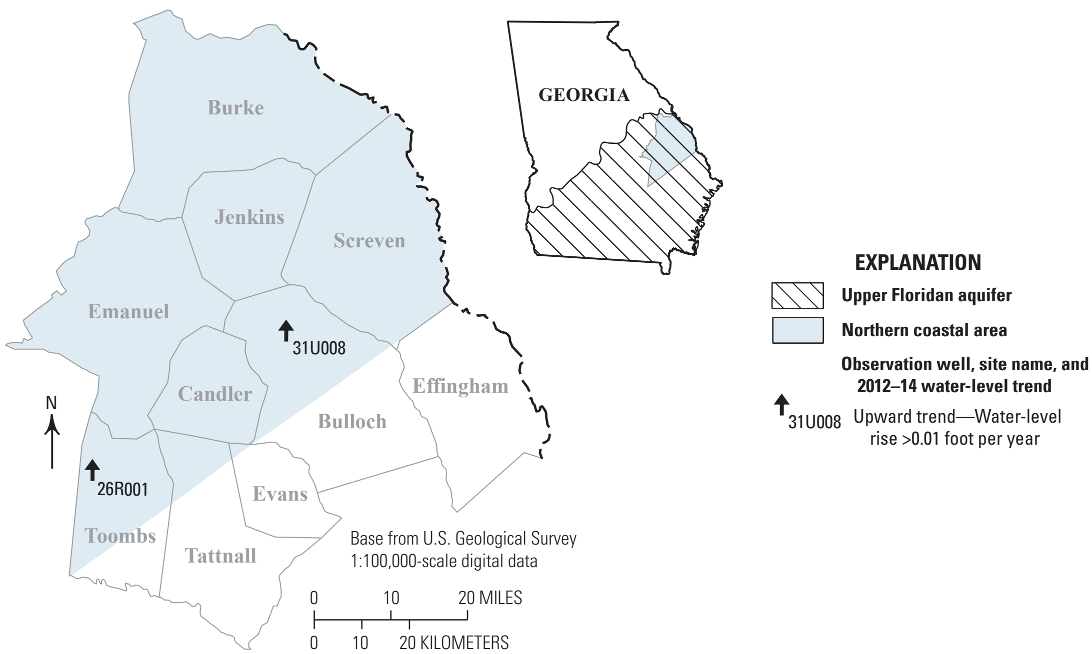
This report presents continuous water-level data from 164 wells throughout Georgia. During 2014, 125 wells had electronic data loggers that recorded water levels at 60-minute intervals, and the data generally were retrieved every 2 months Thirty-nine wells had real-time satellite telemetry that recorded water levels at 60-minute intervals. Real-time satellite telemetry data are transmitted every 1 to 4 hours (based on equipment) and are available at http://waterdata.usgs.gov/ga/nwis/current/?type=gw.

To illustrate long-term (period of record) and more recent (2012–14) water-level changes, hydrographs showing monthly mean water levels are presented together with maps showing water-level trends during 2012–14. 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 (example graph facing page). 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 2012–14. 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). Use of trend calculations in this report should be informed by the summary statistics provided in the appendix where missing periods of data, when present, may affect the interpretation of a given trend.

Water-level trends are presented in tables, hydrographs, and maps for each aquifer and sub-area in the groundwater-level section of this report. Trends for 2012–14 are denoted in 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 database at http://waterdata.usgs.gov/ga/nwis/gw/.



Example hydrograph showing monthly mean water levels in well 26R001 for the period 1974–2014, and period-of-record trend.



Water-level trends for 2012–2014 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.

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
2008–2009	SIR 2011–5048	Peck, M.F., Leeth, D.C., and Painter, J.A.	2011
2010–2011	SIR 2013–5084	Peck, M.F., Gordon, D.W., and Painter, J.A.	2013

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 in Georgia is conducted in cooperation with numerous local organizations, private companies, and State and Federal agencies. Cooperating organizations and agencies include the following:

- City of Albany Utility Operations
- Augusta Utilities Department, City of Augusta
- Georgia Department of Natural Resources, Environmental Protection Division
- Glynn County Joint Water and Sewer Commission
- Miller Coors LLC

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 groundwater monitoring and 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. A more complete description of the Cooperative Water Program is provided in Brooks (2001).

References

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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 in some places limestone. The surficial aquifer system is usually 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 beneath the Coastal Plain include the surficial aquifer system, Brunswick aquifer system, Floridan aquifer system, 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 metasedimentary 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." A more complete discussion of the State's groundwater resources is provided in Clarke and Pierce (1985).

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

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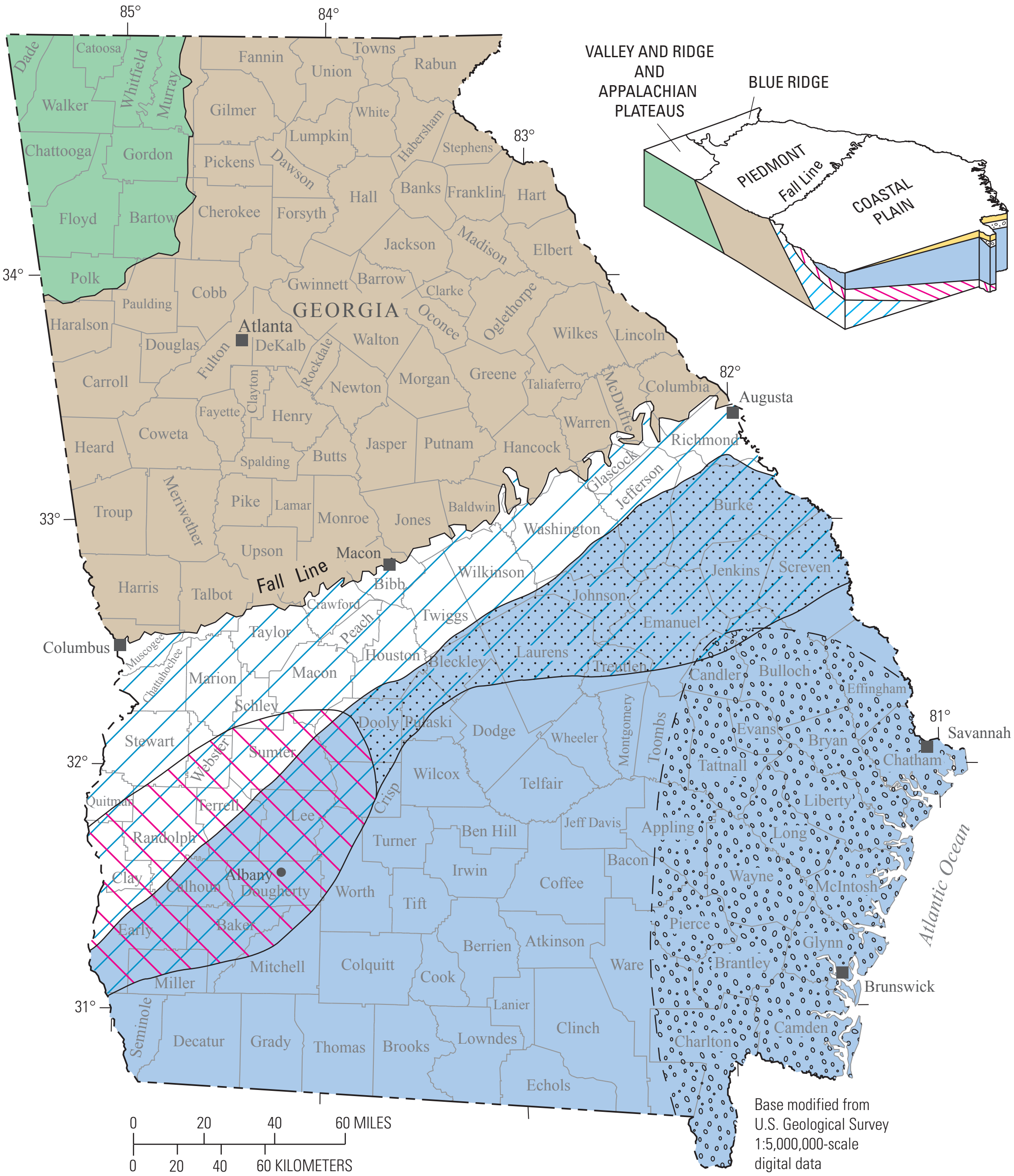


EXPLANATION

All provinces in State—Surficial aquifer system is present throughout. Shown here on block, not on map

Valley and Ridge and Appalachian Physiographic Provinces

Paleozoic-rock aquifers

Piedmont and Blue Ridge Provinces

Crystalline-rock aquifers

Coastal Plain Province

Brunswick aquifer system—Approximately located

Upper and Lower Floridan aquifers

Gordon aquifer system

Claiborne and Clayton aquifers

Cretaceous aquifer system

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).	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).	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.

Groundwater Conditions

Groundwater Levels

Maps and tables in this section provide an overview of groundwater levels in major aquifers in Georgia during 2012–14. Hydrographs of selected wells are presented to demonstrate period-of-record and 2012–14 water-level trends. Discussion of each aquifer is subdivided into areas where wells likely would have similar water-level fluctuations and trends. The map on the facing page shows the locations of 171 wells that were continuously monitored by the U.S. Geological Survey during the 2014 calendar year, including 40 wells that were monitored in real time. Of the 171 wells that were monitored, 164 are presented in this report.

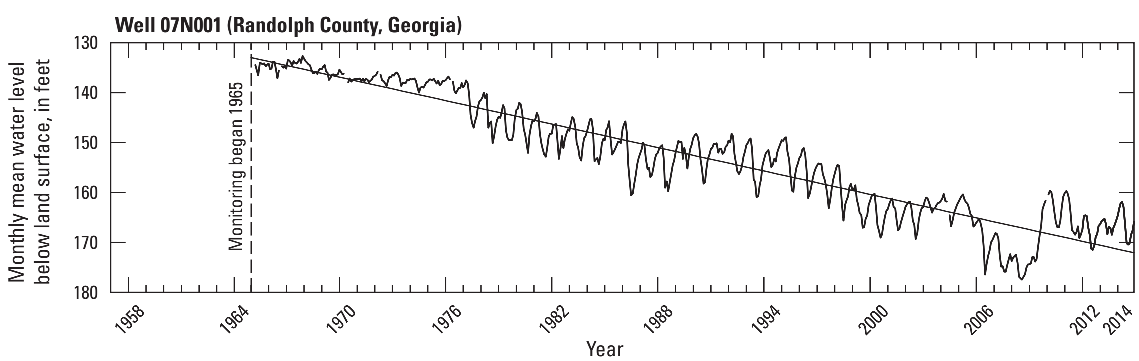
Changes in aquifer storage cause changes in groundwater levels in wells. Taylor and Alley (2001) describe many factors that affect groundwater storage; these factors are summarized here. When recharge to an aquifer exceeds discharge, groundwater levels rise; when discharge from an aquifer exceeds recharge, 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. Hydrologic responses and controls on groundwater levels in major aquifers in Georgia are summarized on pages 8–9.

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 increased pumping. The magnitude of fluctuations can vary greatly from season to season and from year to year in response to changing climatic conditions.

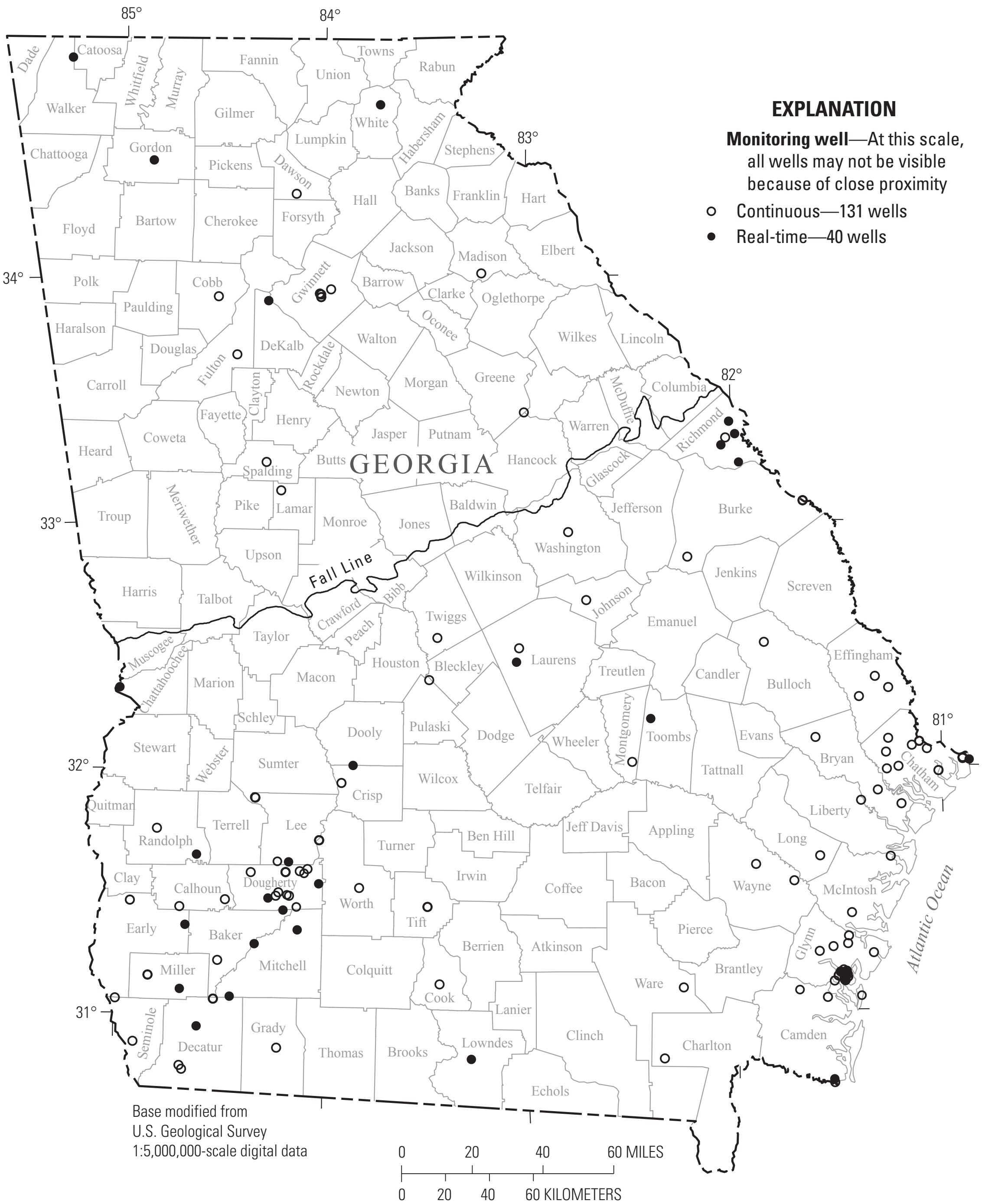
Groundwater pumping is the most important human activity that affects the amount of groundwater in storage and the rate of discharge from an aquifer (Taylor and Alley, 2001). As groundwater storage is depleted within the radius of influence of pumping, water levels in the aquifer decline and form a cone 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 1965–2014, Randolph County, Georgia.



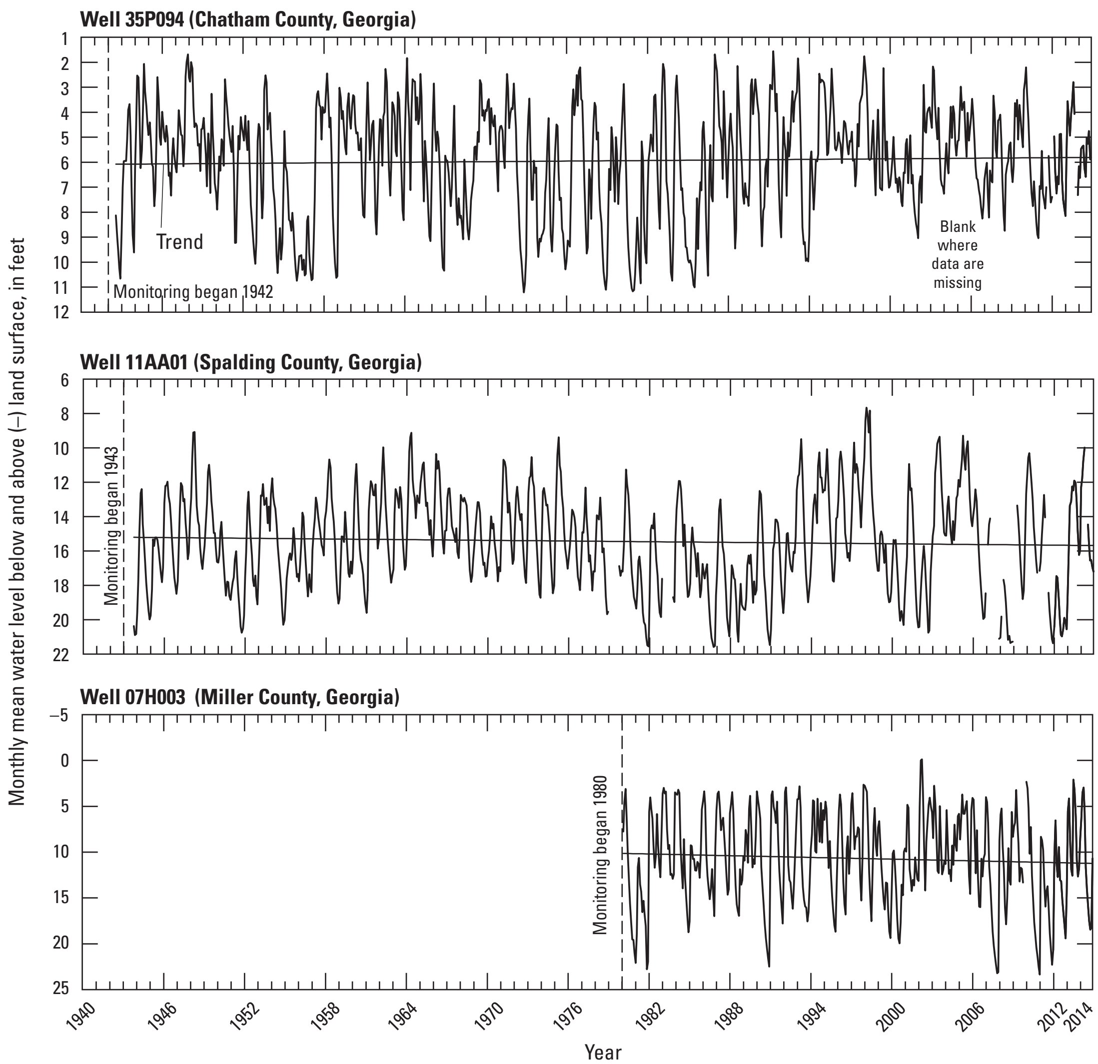
Locations of monitoring wells used to collect long-term groundwater-level data in Georgia during 2014.

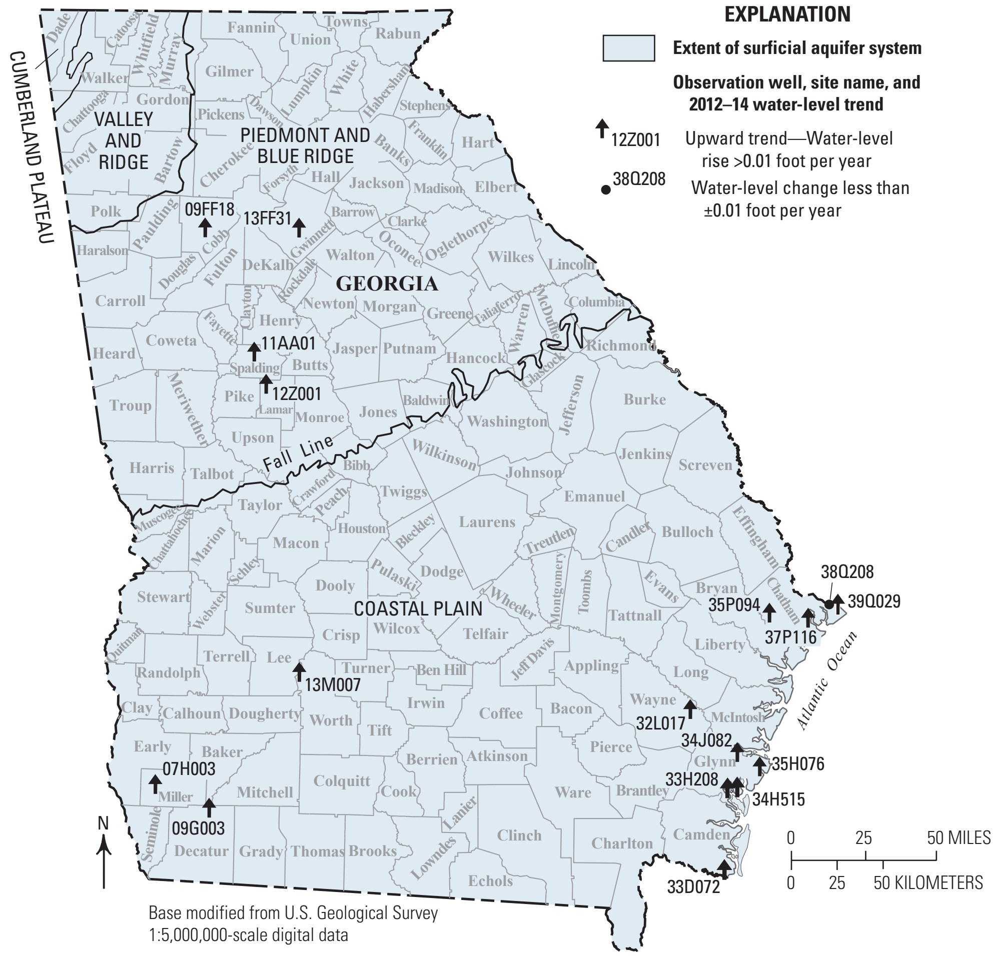
Groundwater Levels

Surficial Aquifer System

Water levels measured in 17 wells were used to define conditions in the surficial aquifer system during 2012–14 (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. In parts of coastal Georgia the surficial aquifer system is used as a source of irrigation supply and shows a response to local pumping. 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 surpluses 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 6 of the wells, declines of 0.01 to 0.15 ft/yr in 7 wells, and rises of 0.01 to 0.24 ft/yr in 4 wells. During 2012–14, water levels in 16 of the wells rose at rates of 0.11 to 2.40 ft/yr, corresponding to an increase in precipitation during the period; the water-level trend showed little change in 1 well.





Site name	County	Year monitoring began	Water-level change, in feet, per year[1]	
			Period of record	From 2012 to 2014
33D072	Camden	1998	0.24	0.66
35P094	Chatham	1942	<0.01	0.37
37P116	Chatham	1984	<0.01	0.18
38Q208	Chatham	1998	<0.01	<0.01
39Q029	Chatham	1998	<0.01	0.39
09FF18	Cobb	2001	–0.15	0.11
09G003	Decatur	1980	0.01	0.77
35H076	Glynn	2005	<0.01	0.48
33H208	Glynn	1983	0.14	0.59
34H515	Glynn	2005	0.01	0.30
34J082	Glynn	2002	–0.03	0.80
13FF31	Gwinnett	2003	–0.03	0.90
12Z001	Lamar	1967	–0.06	1.39
07H003	Miller	1980	–0.03	0.43
11AA01	Spalding	1943	<0.01	2.11
32L017	Wayne	1983	–0.15	1.63
13M007	Worth	1980	–0.01	2.40

[1]See appendix for summary statistics.

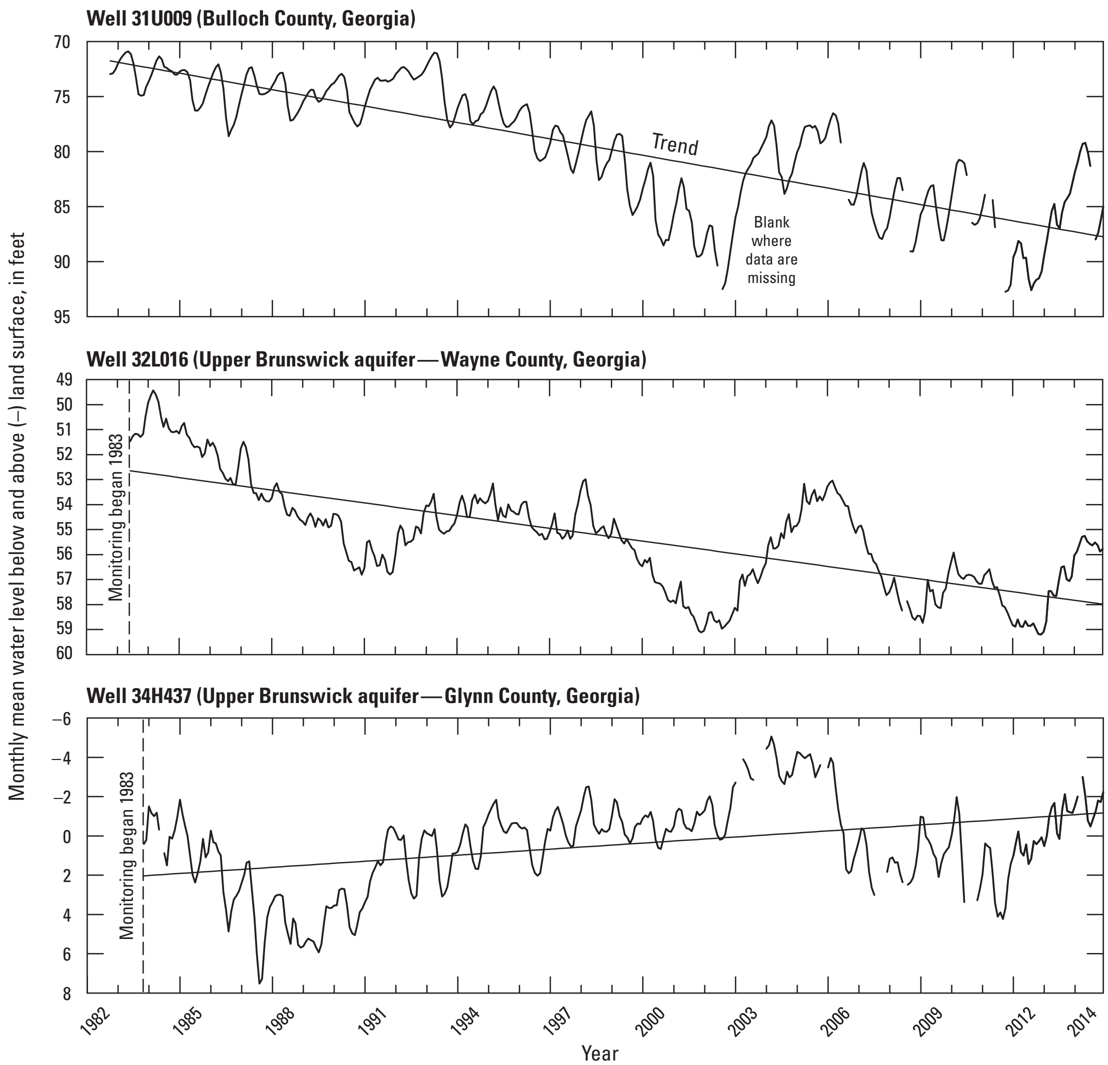
Groundwater Levels

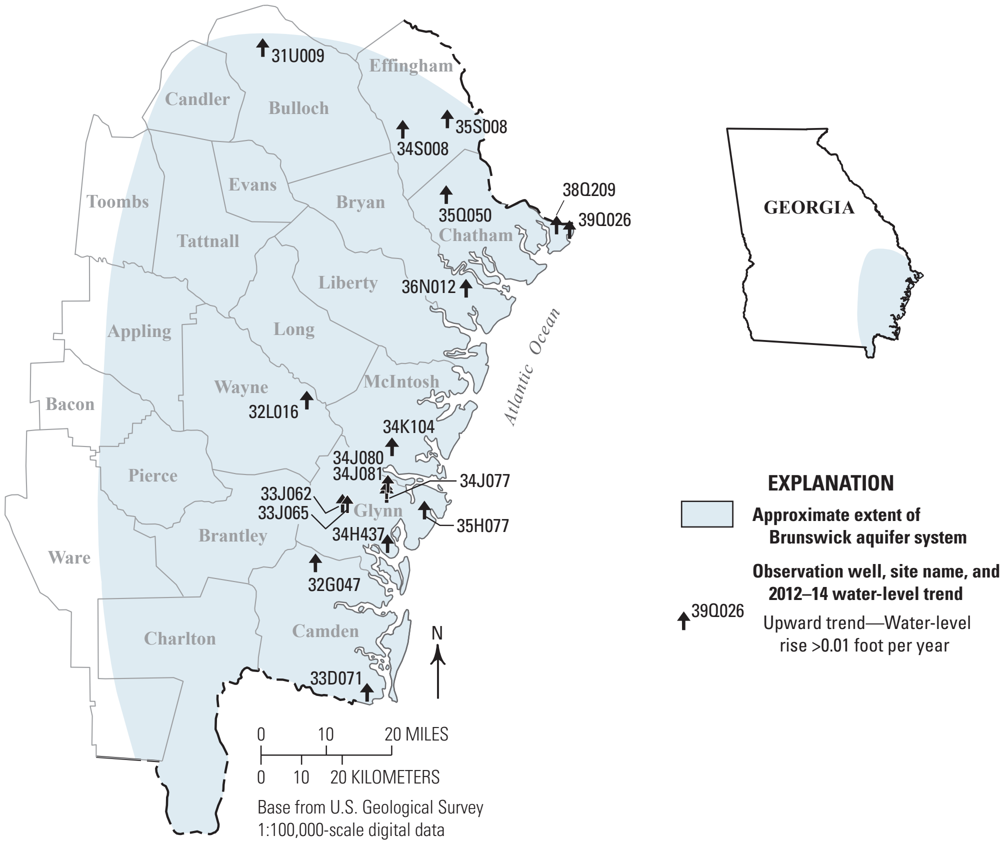
Brunswick Aquifer System

Water levels in 18 wells were used to define conditions during 2012–14 in the Brunswick aquifer system. The aquifer system consists of the confined upper and lower Brunswick aquifers and equivalent low-permeability sediments to the north and west in southeastern Georgia (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 surpluses or deficits in rainfall, respectively, and changes in pumping.

During the period of record, water levels in 12 of the 18 wells rose at rates of 0.01 to 1.32 feet per year (ft/yr) and water levels in the remaining 6 wells declined at rates of 0.03 to 0.50 ft/yr. During 2012–14, water levels in all 18 wells rose at rates of 0.24 to 3.19 ft/yr, which reflect the end of the drought conditions that began in mid-2010.





Site name	Water-bearing unit[1]	County	Year monitoring began	Water-level trend, in feet, per year[2]	
				Period of record	From 2012 to 2014
36N012	L	Bryan	1999	0.24	1.94
31U009	UX	Bulloch	1982	–0.50	3.19
32G047	U	Camden	2004	0.13	1.29
33D071	U	Camden	1998	1.32	1.34
35Q050	U	Chatham	2001	0.11	1.36
38Q209	B	Chatham	1998	0.03	0.24
39Q026	UX	Chatham	1996	0.01	0.27
34S008	LX	Effingham	2001	0.40	2.42
35S008	LX	Effingham	2000	0.31	1.65
33J062	L	Glynn	2001	–0.03	1.71
33J065	U	Glynn	2001	–0.04	1.00
34H437	U	Glynn	1983	0.10	1.02
34J077	U	Glynn	1998	–0.37	1.50
34J080	L	Glynn	2002	–0.08	1.55
34J081	U	Glynn	2002	0.08	1.42
35H077	L	Glynn	2005	0.07	2.67
34K104	L	McIntosh	2005	0.20	1.73
32L016	U	Wayne	1983	–0.17	1.51

[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). This aquifer is one of the most productive in the United States and a major source of water in the region.

The Upper Floridan aquifer predominately consists of Eocene to Oligocene age 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, including the Albany-Dougherty County area, 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).

South-central area. Seven 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 that has 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).

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.

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 (mi^2; Clarke, 2003). In the coastal area, the Upper Floridan aquifer may be thin or absent in the north (Burke County) and about 1,700 ft thick in the south (Ware County; Miller, 1986).

The coastal area of Georgia has been subdivided by GaEPD into three subareas—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 the northern subarea, 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 (Applied Coastal Research Laboratory, Georgia Southern University, 2002). In the southern subarea, the largest pumping center is located immediately south of the area at Fernandina Beach, Nassau County, Florida.

References

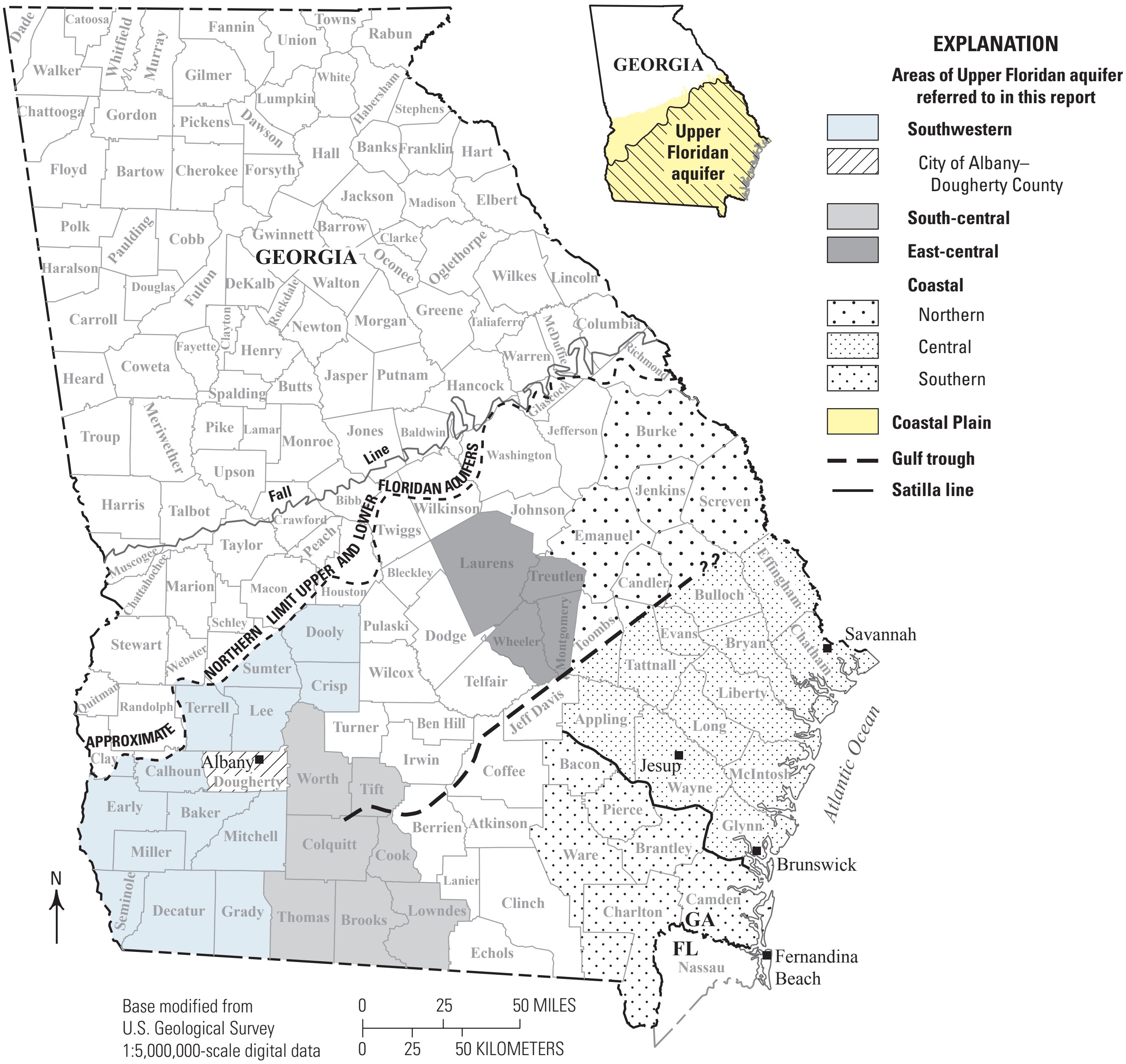
Applied Coastal Research Laboratory, Georgia Southern University, 2002, Gulf Trough and Satilla Line data analysis: Georgia Geologic Survey Project Report 48, accessed August 23, 2016, at https://epd.georgia.gov/sites/epd.georgia.gov/files/related_files/site_page/PR-48_0.pdf.

Clarke, J.S., 1987, Potentiometric surface of the Upper Floridan aquifer in Georgia, May 1985, and water-level trends, 1980–85: Georgia Geologic Survey Hydrologic Atlas 16, scale 1:1,000,000, 1 sheet.

Clarke, J.S., 2003 The surficial and Brunswick aquifer systems—Alternative ground-water resources for coastal Georgia, *in* Hatcher, K.A., ed., Proceedings of the 2003 Georgia Water Resources Conference, April 23–24, 2003, Institute of Ecology, The University of Georgia, Athens, Ga. accessed August 23, 2016, at http://ga.water.usgs.gov/publications/other/gwrc2003/pdf/Clarke-GWRC2003.pdf.

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., accessed August 23, 2016, at http://pubs.usgs.gov/wri/wri87-4145/pdf/wrir87-4145.pdf.



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

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, Camille, III, 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.

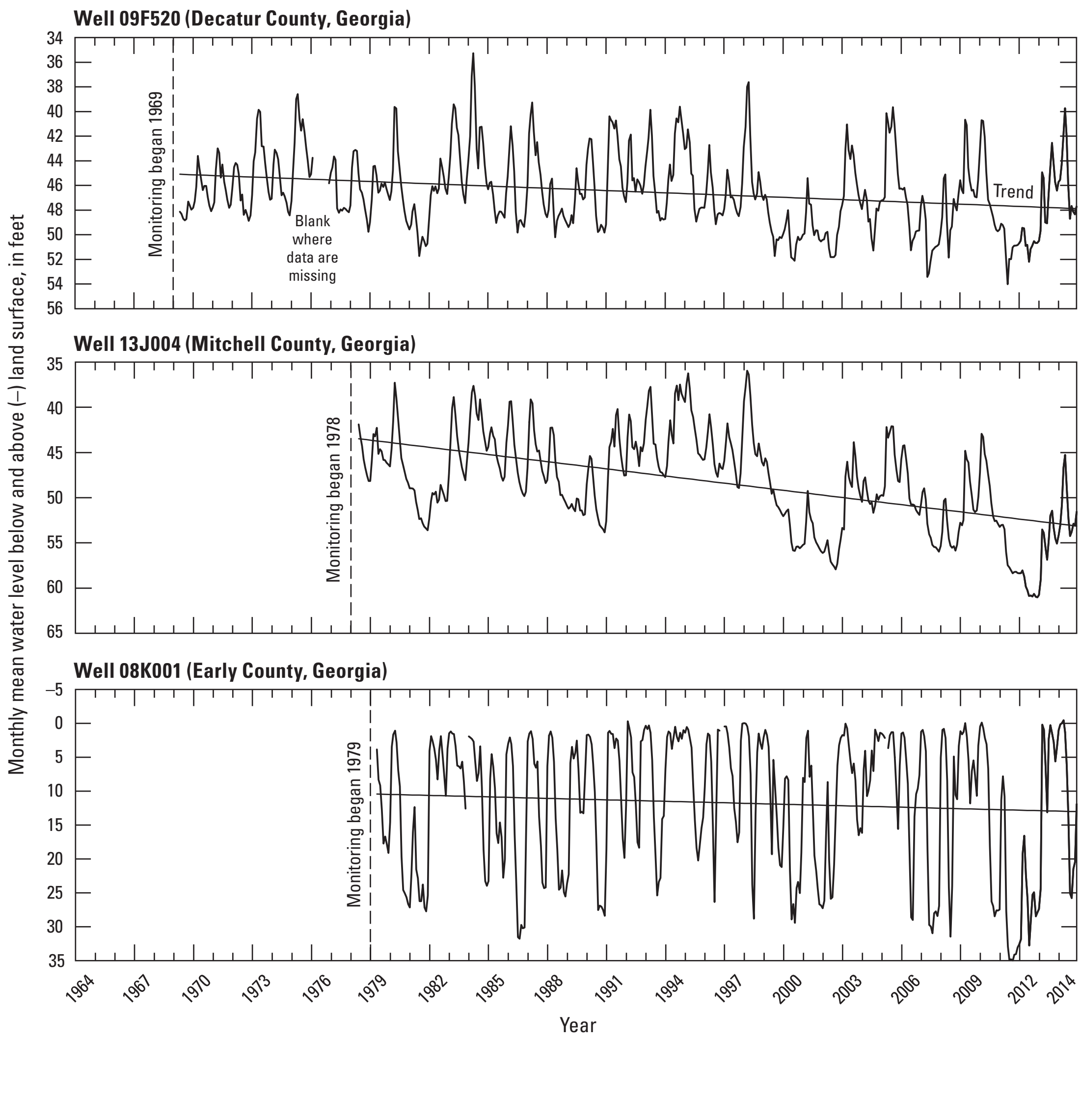
Groundwater Levels

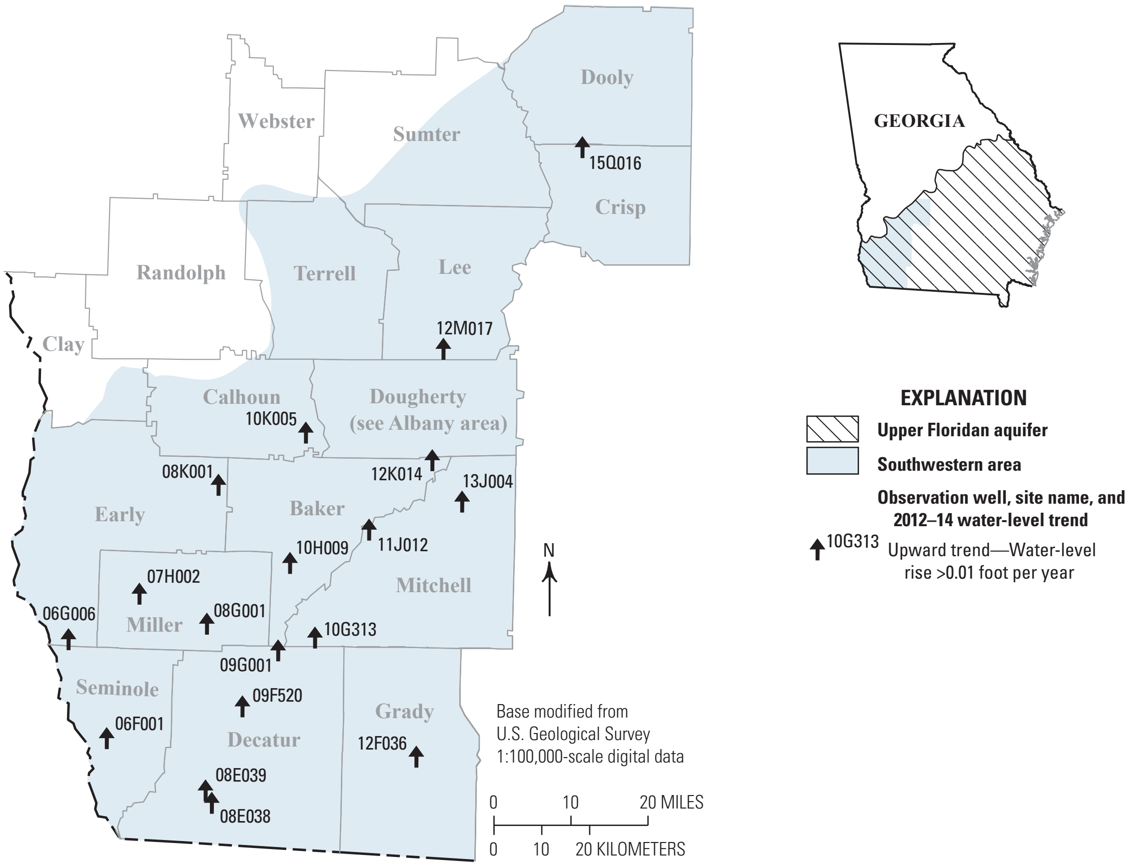
Upper Floridan Aquifer

Southwestern Area

Water levels in 18 wells were used to define groundwater conditions in the Upper Floridan aquifer in southwestern Georgia during 2012–14 (map and table, facing page). In this area, water in the Upper Floridan aquifer typically is confined; however, water is unconfined in areas where no sediments overlie the aquifer (typically to the north and west). 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 13 wells had declining trends of 0.02 to 0.65 feet per year (ft/yr), 4 wells had rising trends of 0.03 to 0.25 ft/yr, and 1 well changed little (less than 0.01 ft/yr). During 2012–14, water levels in all 18 of the wells rose at rates of 0.53 to 7.21 ft/yr.





Site name	County	Year monitoring began	Water-level trend, in feet, per year[1]	
			Period of record	From 2012 to 2014
10H009	Baker	1998	0.05	5.98
12K014	Baker	1982	–0.09	2.83
10K005	Calhoun	1983	–0.10	0.63
15Q016	Crisp	2002	–0.65	2.62
08E038	Decatur	2001	0.03	0.55
08E039	Decatur	2002	<0.01	0.53
09F520	Decatur	1972	–0.06	2.25
09G001	Decatur	1980	–0.07	2.83
06G006	Early	1982	–0.06	6.49
08K001	Early	1982	–0.07	6.64
12F036	Grady	1971	0.19	1.92
12M017	Lee	1982	–0.02	4.28
07H002	Miller	1980	0.25	1.39
08G001	Miller	1977	–0.14	7.21
10G313	Mitchell	1976	–0.10	5.83
11J012	Mitchell	1981	–0.07	1.89
13J004	Mitchell	1978	–0.26	3.75
06F001	Seminole	1979	–0.09	4.10

[1]See appendix for summary statistics.

Groundwater Levels

Upper Floridan Aquifer

City of Albany–Dougherty County Area

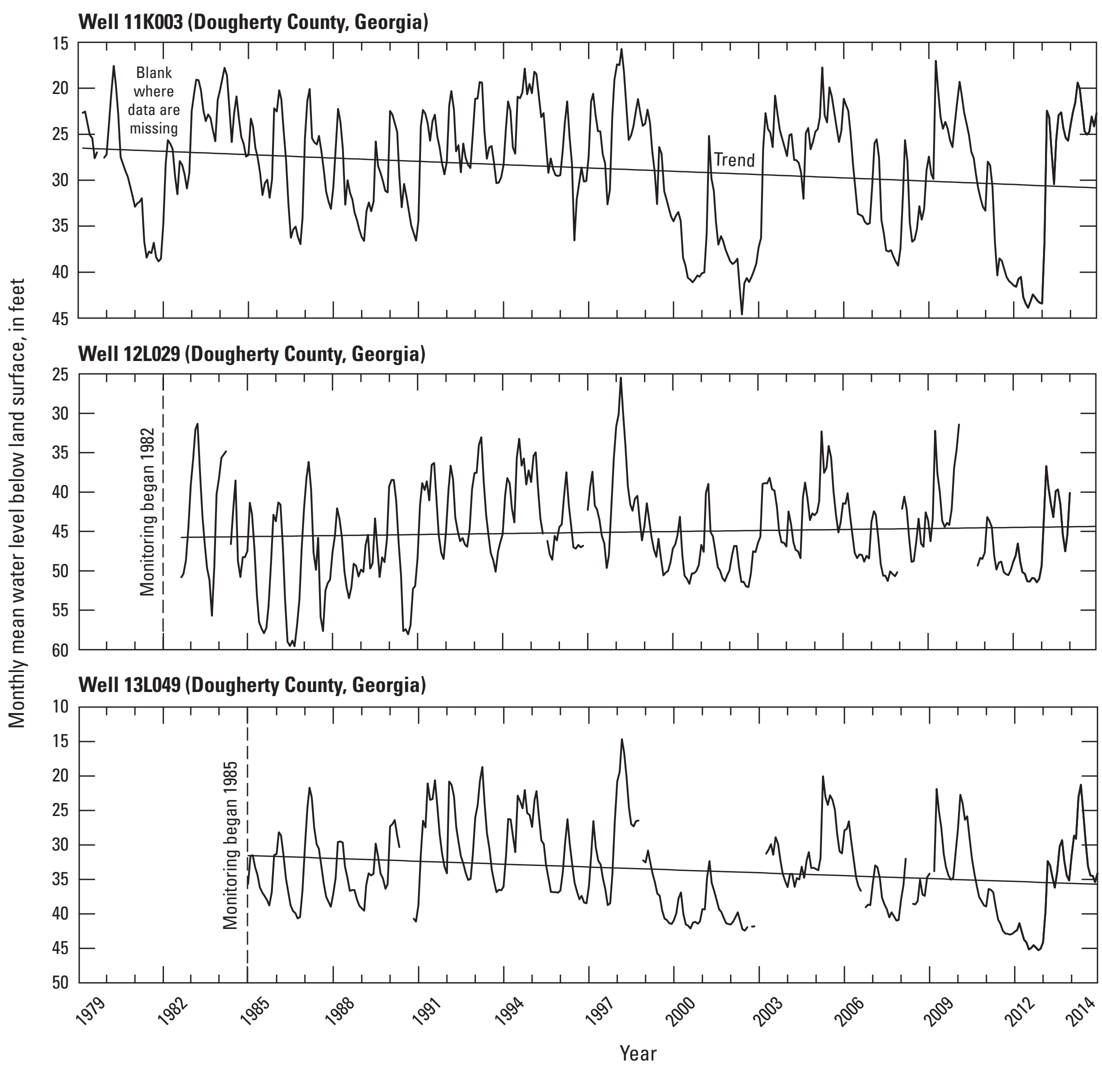
Water levels in 12 wells were used to define groundwater conditions in the Upper Floridan aquifer near Albany, Georgia, during 2012–14 (Dougherty County map and table, facing page). Water levels in this area are affected by changes in precipitation and pumping (Gordon and others, 2012). Hydrographs for 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.

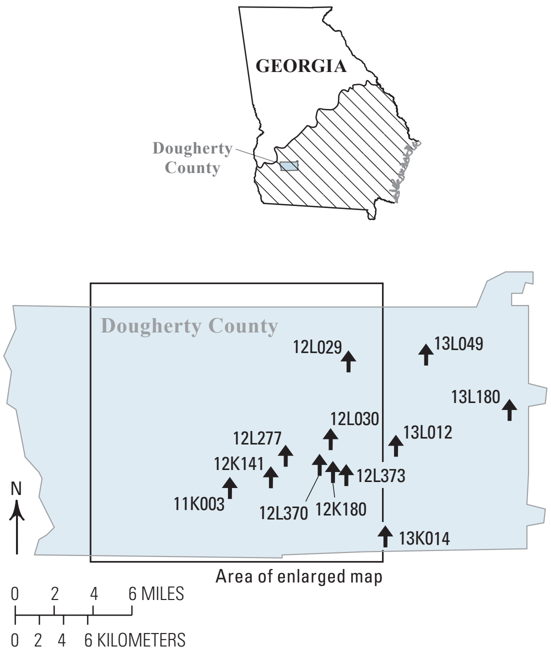
During the period of record, water levels in 10 of the 12 wells had declining trends ranging from 0.06 to 0.24 per year (ft/yr); the other 2 wells had rising trends of 0.04 and 0.09 ft/yr. During 2012–14, water levels in all 12 wells rose at rates of 2.66 to 12.10 ft/yr, which reflect the end of drought conditions that began in mid-2010.

In addition to continuous water-level monitoring, synoptic water-level measurements are made periodically in wells southwest of Albany. Water-level measurements from 57 wells during November 2012 and 47 wells during November 2014 were used to construct maps showing the potentiometric surface of the Upper Floridan aquifer. Although water levels in 2014 generally were higher than in 2012, the configuration of the potentiometric surface maps (facing page) was similar. The potentiometric-surface maps show that water generally flows from the northwest to southeast toward the Flint River.

Reference

Gordon, D.W., Painter, J.A., and McCranie, J.M., 2012, Hydrologic conditions, groundwater quality, and analysis of sinkhole formation in the Albany area of Dougherty County, Georgia, 2009: U.S. Geological Survey Scientific Investigations Report 2012–5018, 60 p., accessed August 24, 2016, at http://pubs.usgs.gov/sir/2012/5018/.





EXPLANATION

Upper Floridan aquifer

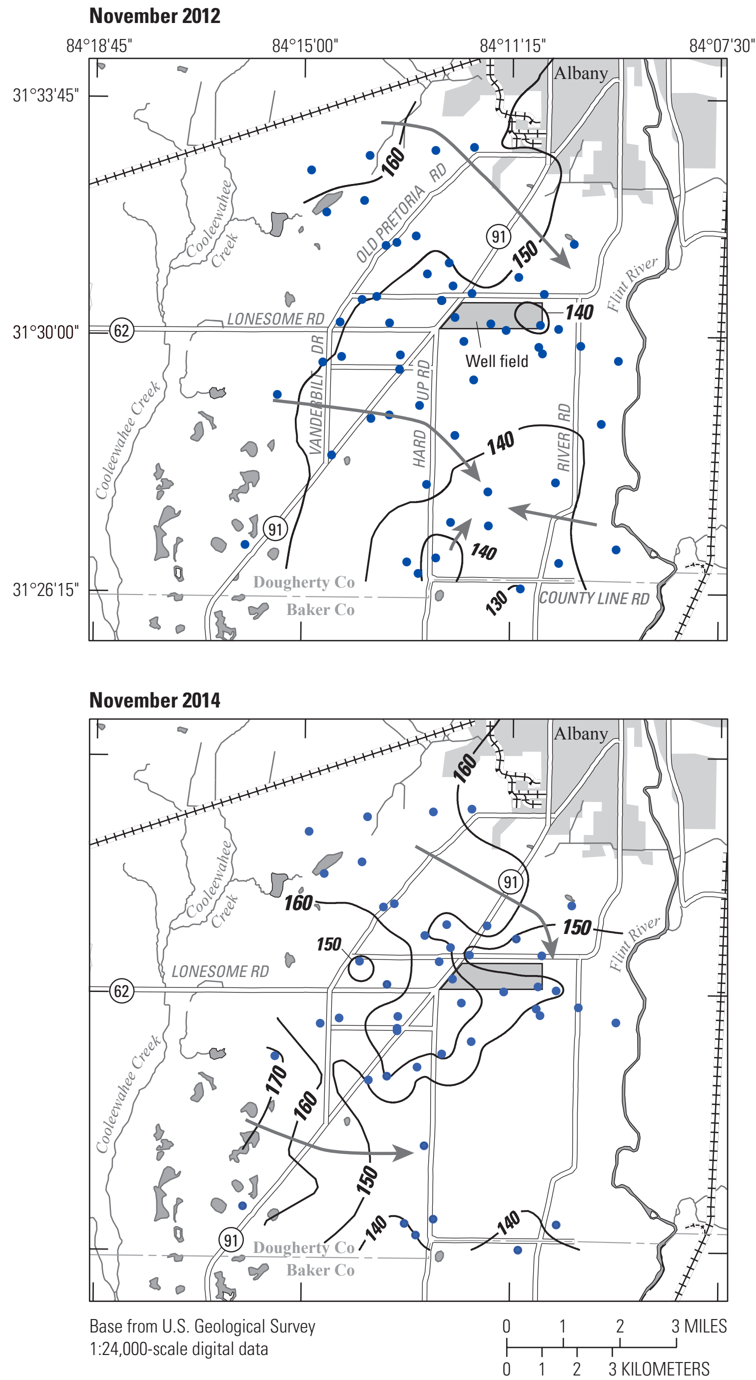
City of Albany and Dougherty County area

Observation well, site name, and 2012–14 water-level trend

13L049 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 2012 to 2014
11K003	Dougherty	1982	–0.12	8.97
12K141	Dougherty	1996	–0.24	12.10
12K180	Dougherty	2002	–0.11	2.66
12L029	Dougherty	1982	0.04	4.79
12L030	Dougherty	1985	–0.08	7.29
12L277	Dougherty	2000	0.09	9.25
12L370	Dougherty	2000	–0.26	9.29
12L373	Dougherty	2002	–0.09	3.68
13K014	Dougherty	1982	–0.11	2.76
13L012	Dougherty	1978	–0.06	4.15
13L049	Dougherty	1985	–0.14	5.95
13L180	Dougherty	1996	–0.24	7.44

[1]See appendix for summary statistics.



EXPLANATION

—150— **Potentiometric contour**—Shows altitude at which water level would have stood in tightly cased wells. Contour interval 10 feet. Datum is North American Vertical Datum of 1988

Direction of groundwater flow

Well data point

Groundwater Levels

Upper Floridan Aquifer

South-Central Area

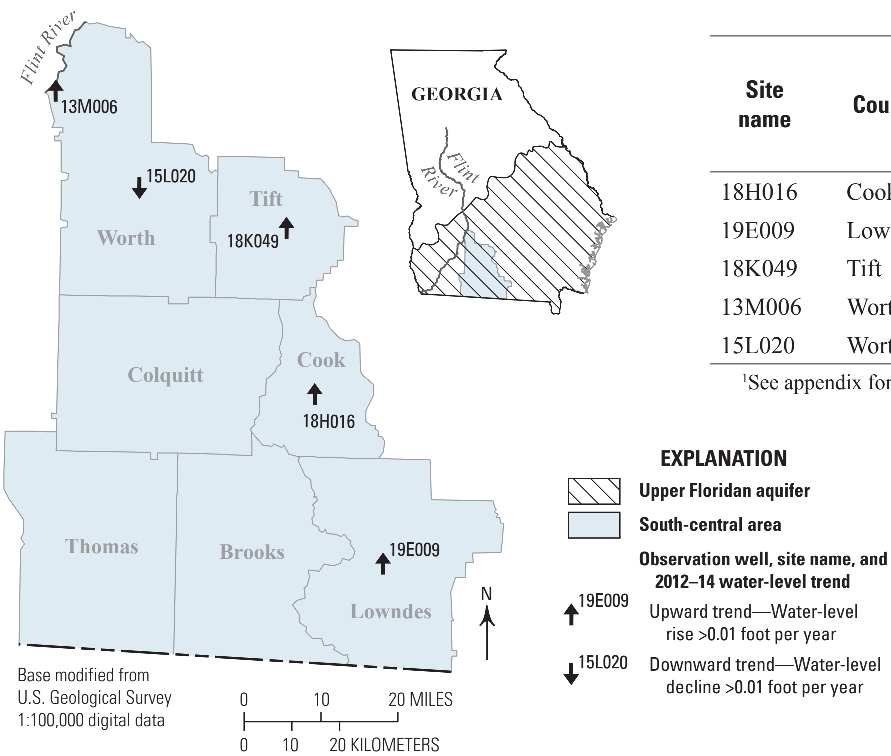
Water levels in five wells were used to define groundwater conditions in the Upper Floridan aquifer in south-central Georgia during 2012–14 (map and table below). In this area, water in the Upper Floridan aquifer generally is confined but locally is unconfined in karst areas in Lowndes County. Water 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 four 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 at rates of 0.10 to 0.91 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). During 2012–14, water levels in 4 of the wells rose at rates ranging from 0.67 to 4.18 ft/yr and declined at 1 well at a rate of 0.40 ft/yr.

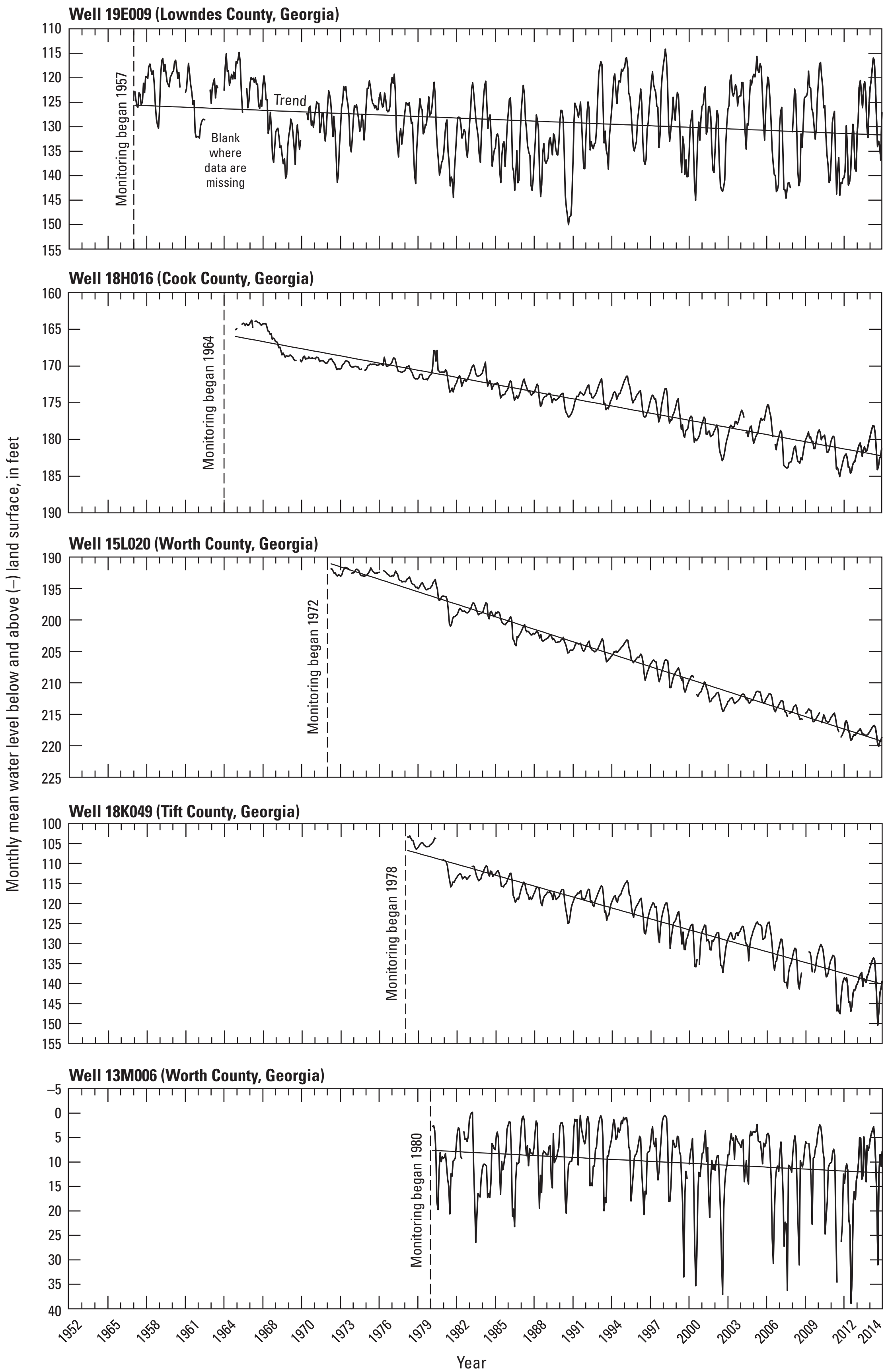
Reference

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 2012–5072; accessed August 24, 2016, 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 2012 to 2014
18H016	Cook	1971	–0.32	0.88
19E009	Lowndes	1957	–0.10	4.18
18K049	Tift	1978	–0.91	0.67
13M006	Worth	1980	–0.13	3.61
15L020	Worth	1972	–0.66	–0.40

[1]See appendix for summary statistics.


Well 19E009 (Lowndes County, Georgia)
Monitoring began 1957
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
1952
1965
1958
1961
1964
1968
1970
1973
1976
1979
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
2014
Year

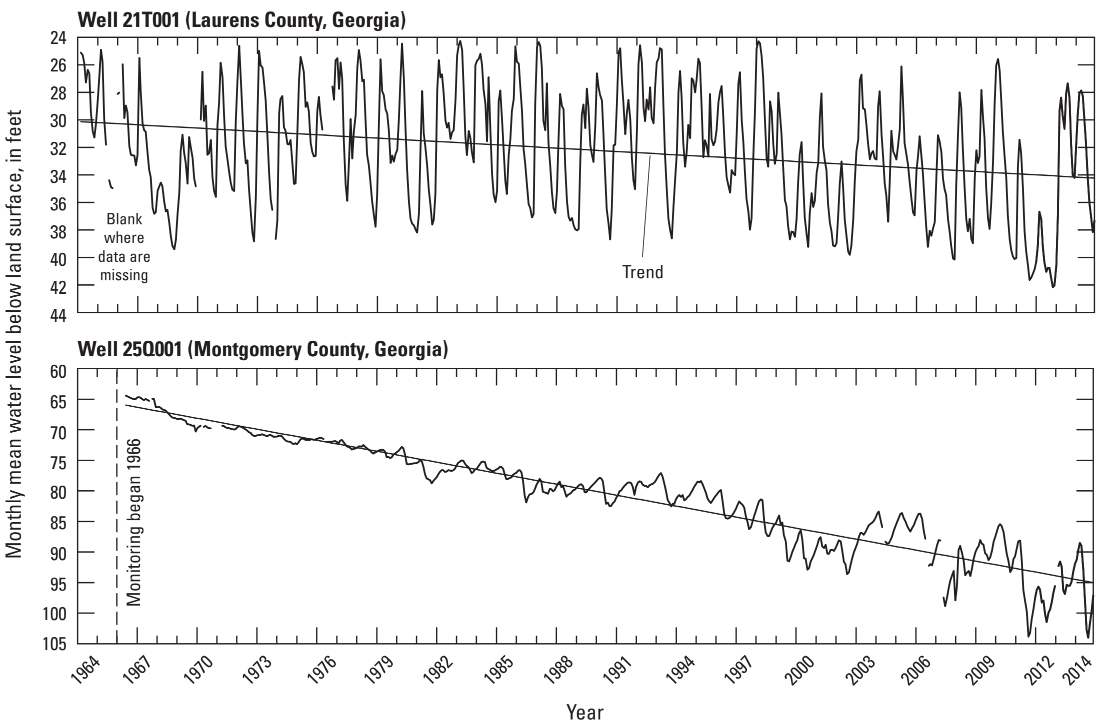
Groundwater Levels

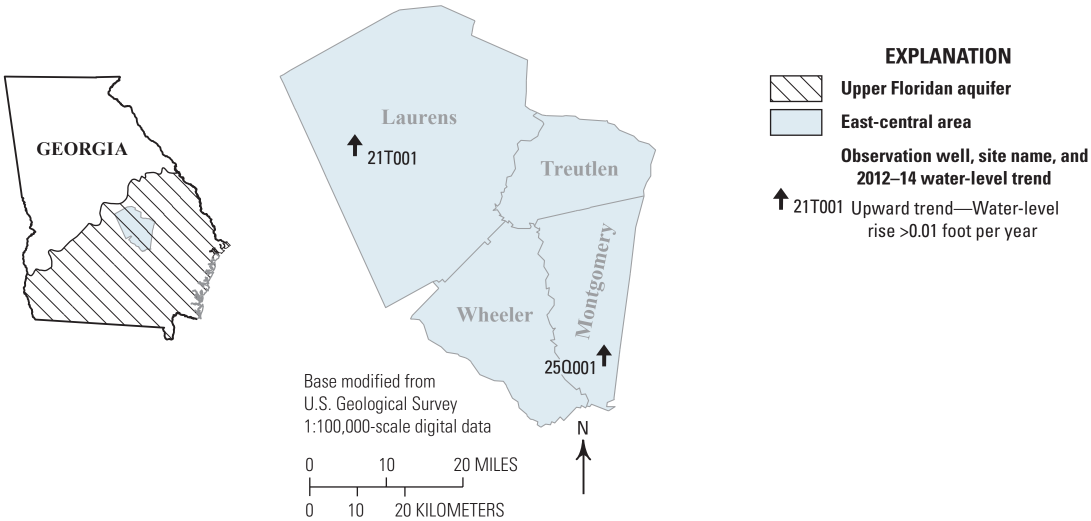
Upper Floridan Aquifer

East-Central Area

Water levels in two wells were used to define groundwater conditions in the Upper Floridan aquifer in east-central Georgia during 2012–14 (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 decline, ranging from 0.08 foot per year (ft/yr) in well 21T001 to 0.60 ft/yr in well 25Q001. During 2012–14, water levels in both wells rose, ranging from 0.51 to 2.95 ft/yr, respectively. 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.





Site name	County	Year monitoring began	Water-level trend, in feet, per year[1]	
			Period of record	From 2012 to 2014
21T001	Laurens	1964	–0.08	2.95
25Q001	Montgomery	1966	–0.60	0.51

[1]See appendix for summary statistics.

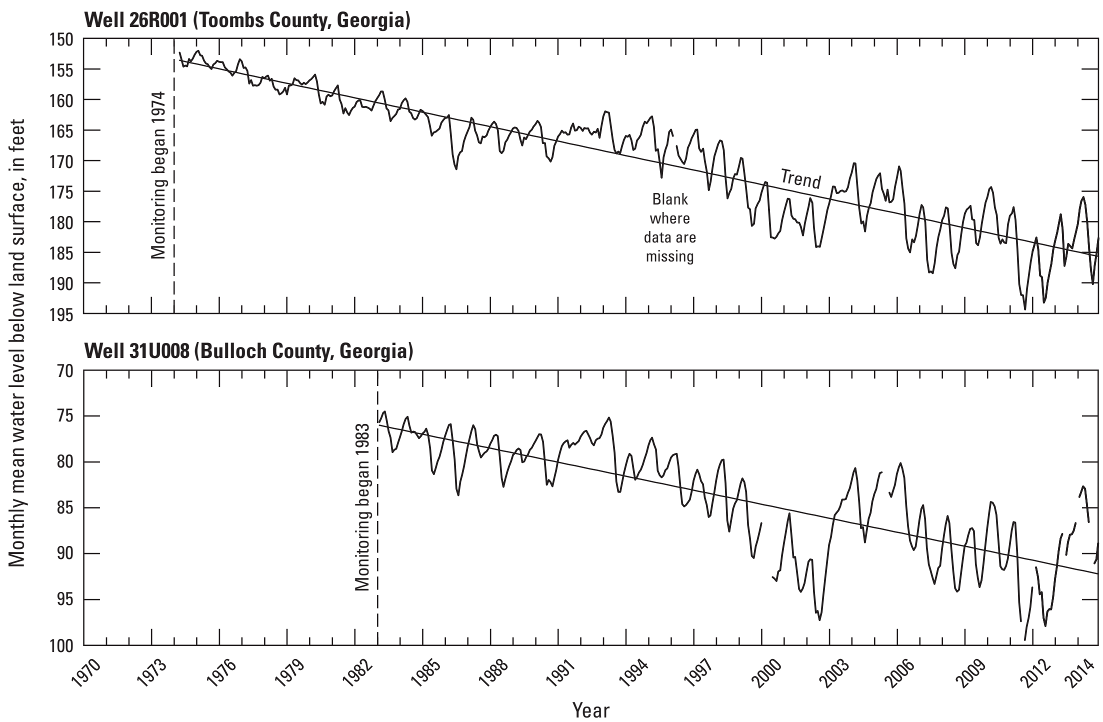
Groundwater Levels

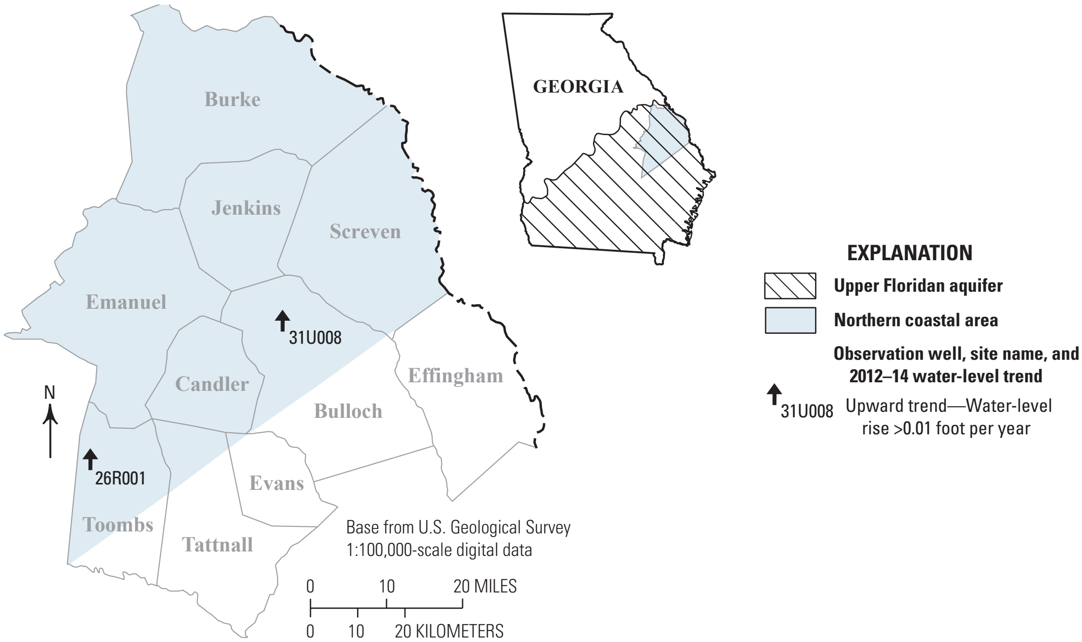
Upper Floridan Aquifer

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 2012–14 (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 0.51 foot per year (ft/yr) in well 31U008 and 0.79 ft/yr in well 26R001. During 2012–14, water levels rose at a rate of 3.73 ft/yr in well 31U008 and 1.68 ft/yr in well 26R001 and likely resulted from the end of drought conditions during this period.





Site name	County	Year monitoring began	Water-level trend, in feet, per year[1]	
			Period of record	From 2012 to 2014
31U008	Bulloch	1983	–0.51	3.73
26R001	Toombs	1974	–0.79	1.68

[1]See appendix for summary statistics.

Groundwater Levels

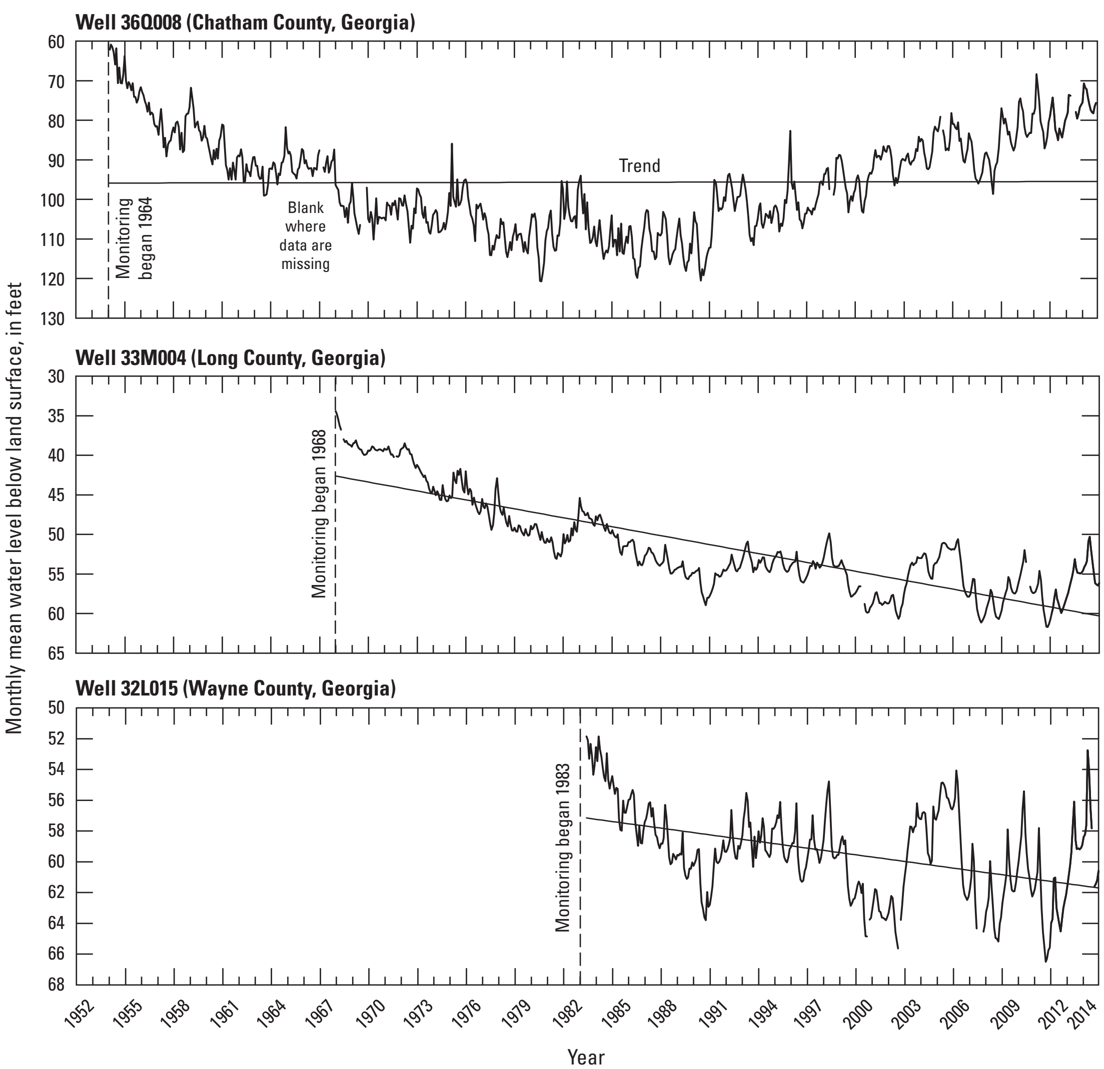
Upper Floridan Aquifer

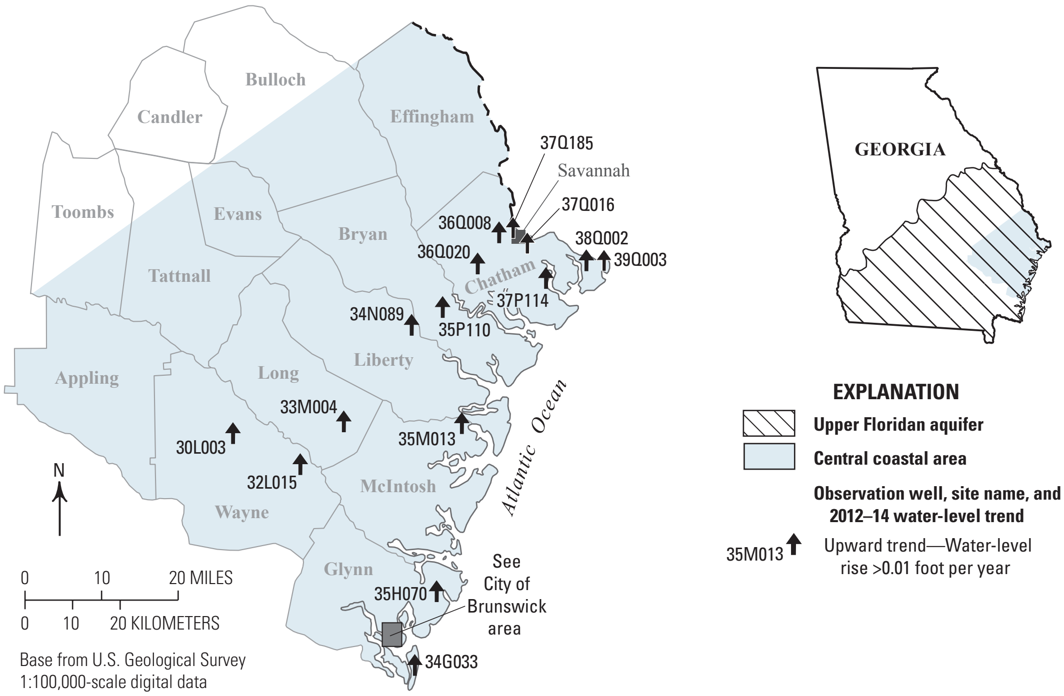
Central Coastal Area

Water levels in 15 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 2012–14 (map and table, facing page). 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 primarily reflect changes in pumping.

During the period of record, water levels in 8 of the 15 wells declined at rates of 0.14 to 0.43 foot per year (ft/yr). Water levels in 6 of the wells rose at rates of 0.11 to 1.55 ft/yr and the water level in 1 well remained about the same. During 2012–14, water levels in all 15 wells rose at rates ranging from 0.98 to 2.67 ft/yr, which reflect the end of drought conditions during the period.

The hydrograph for well 36Q008 near Savannah in Chatham County shows an overall upward trend of 2.17 ft/yr in water levels during 2012–14. Since 1991, water levels have been rising in the well, largely as the result of decreased water use because of conservation practices in the area (J.L. Fanning, U.S. Geological Survey, oral commun., 2008). Water levels in well 36Q008 have recovered to what they were during the mid- to late-1950s.





Site name	County	Year monitoring began	Water-level trend, in feet, per year[1]	
			Period of record	From 2012 to 2014
35P110	Bryan	2000	0.14	2.17
36Q008	Chatham	1954	<0.01	2.17
36Q020	Chatham	1958	–0.43	2.24
37P114	Chatham	1984	0.32	1.30
37Q016	Chatham	1955	0.11	1.81
37Q185	Chatham	1985	1.55	2.67
38Q002	Chatham	1956	–0.21	1.21
39Q003	Chatham	1962	–0.19	0.98
35H070	Glynn	2005	0.73	1.42
34G033	Glynn	2004	0.11	1.26
34N089	Liberty	1967	–0.42	2.16
33M004	Long	1968	–0.38	2.06
35M013	McIntosh	1966	–0.36	2.02
30L003	Wayne	1964	–0.40	1.72
32L015	Wayne	1983	–0.14	2.02

[1]See appendix for summary statistics.

Groundwater Levels

Upper Floridan Aquifer

City of Brunswick Area

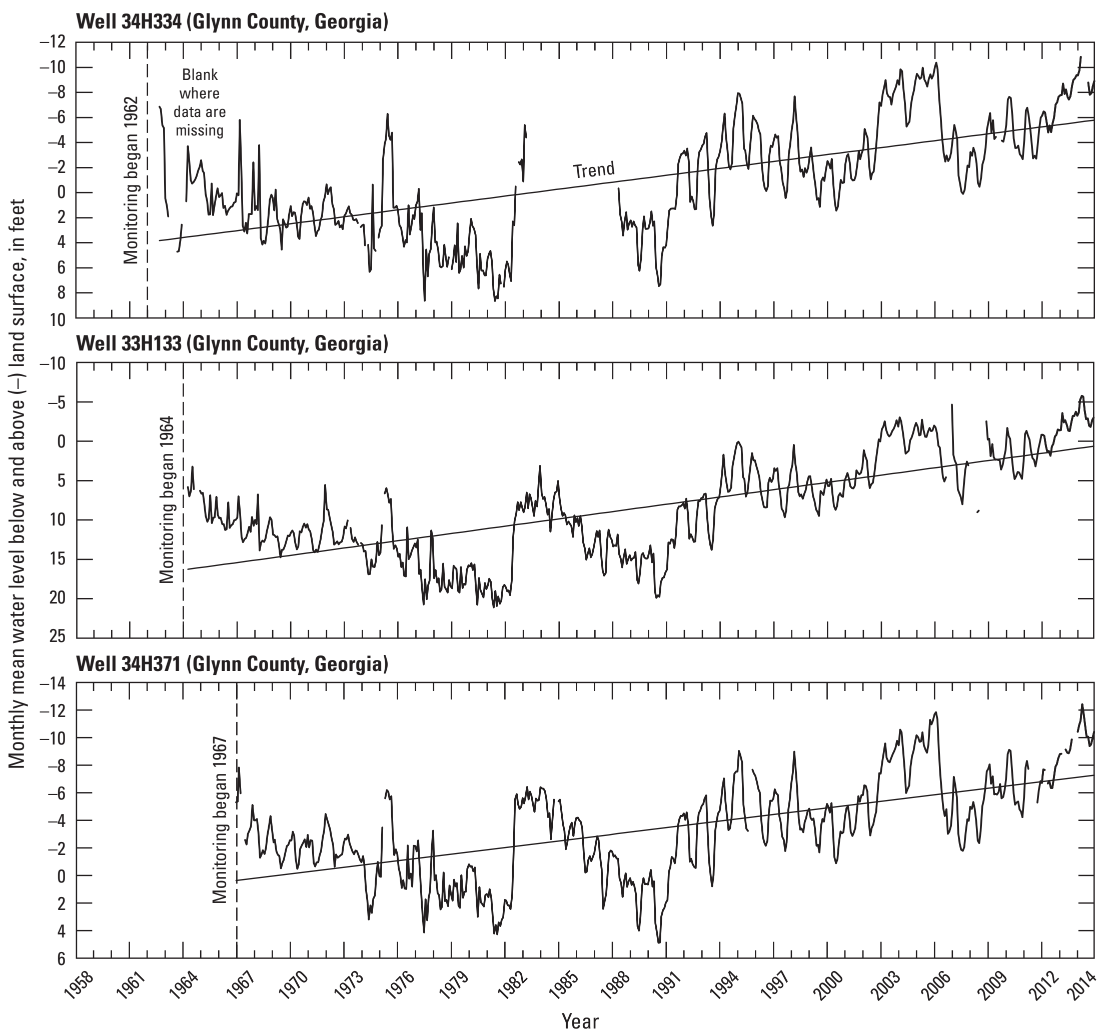
Water levels in 10 wells were used to define groundwater conditions in the Upper Floridan aquifer near the city of Brunswick in the central coastal area of Georgia during 2012–14 (maps and table, facing page). In this area, water in the Upper Floridan aquifer is confined, and groundwater flow paths are influenced primarily by pumping for industrial and public supply (Cherry and others, 2011).

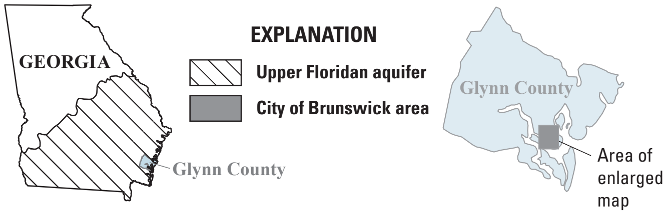
During the period of record, water levels in all of the wells had rising trends with rates of change that ranged from 0.10 to 6.48 feet per year (ft/yr). Hydrographs for three wells in the Upper Floridan aquifer in the Brunswick area (below) illustrate monthly mean water levels for the period of record. During 2012–14, water levels in nine wells rose at rates ranging from 1.17 to 1.69 ft/yr. The water level in one well, 33H325, declined at a rate of 2.46 ft/yr during 2012–14; this well is located in an area of industrial pumping. Although well 33H324 is located adjacent to well 33H325, its water levels rose 1.37 ft during the same period. The two wells are completed in different water-bearing zones of the Upper Floridan aquifer—the deeper zone in well 33H325 provides water to a nearby industrial user and therefore shows a greater response to changes in pumping at the industrial site (John S. Clarke, U.S. Geological Survey, written commun., August 17, 2012).

In addition to continuous water-level monitoring, synoptic water-level measurements are made periodically in wells in the Brunswick area. Water-level measurements from 46 wells during August 2012 and 49 wells during October 2014 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 and west, where water-level altitudes are greater than 15 ft, toward industrial pumping centers in northern Brunswick, where water-level altitudes are less than 0 ft..

Reference

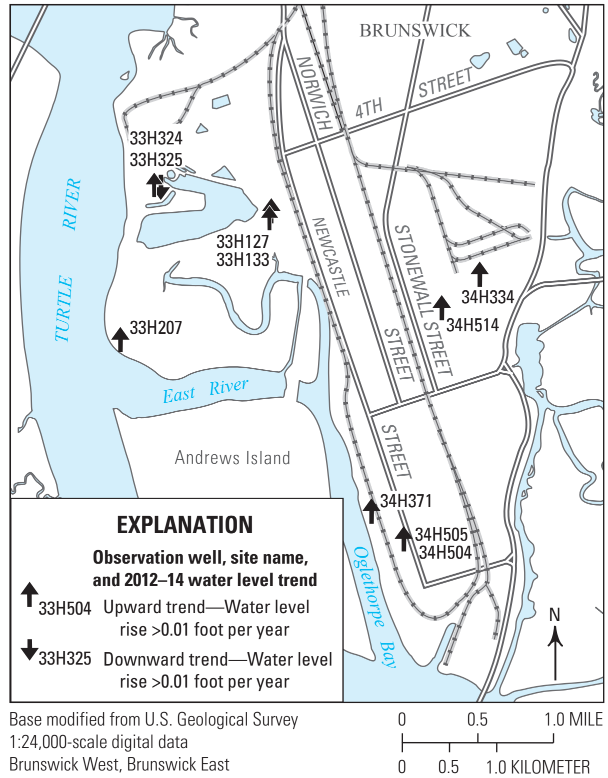
Cherry, G.S., Peck, M.F., Painter, J.A., and Stayton, W.L., 2011, Groundwater conditions in the Brunswick-Glynn County area, Georgia, 2009: U.S. Geological Survey Scientific Investigations Report 2014–5087, 58 p., accessed August 30, 2016, at http://pubs.usgs.gov/sir/2011/5087/.

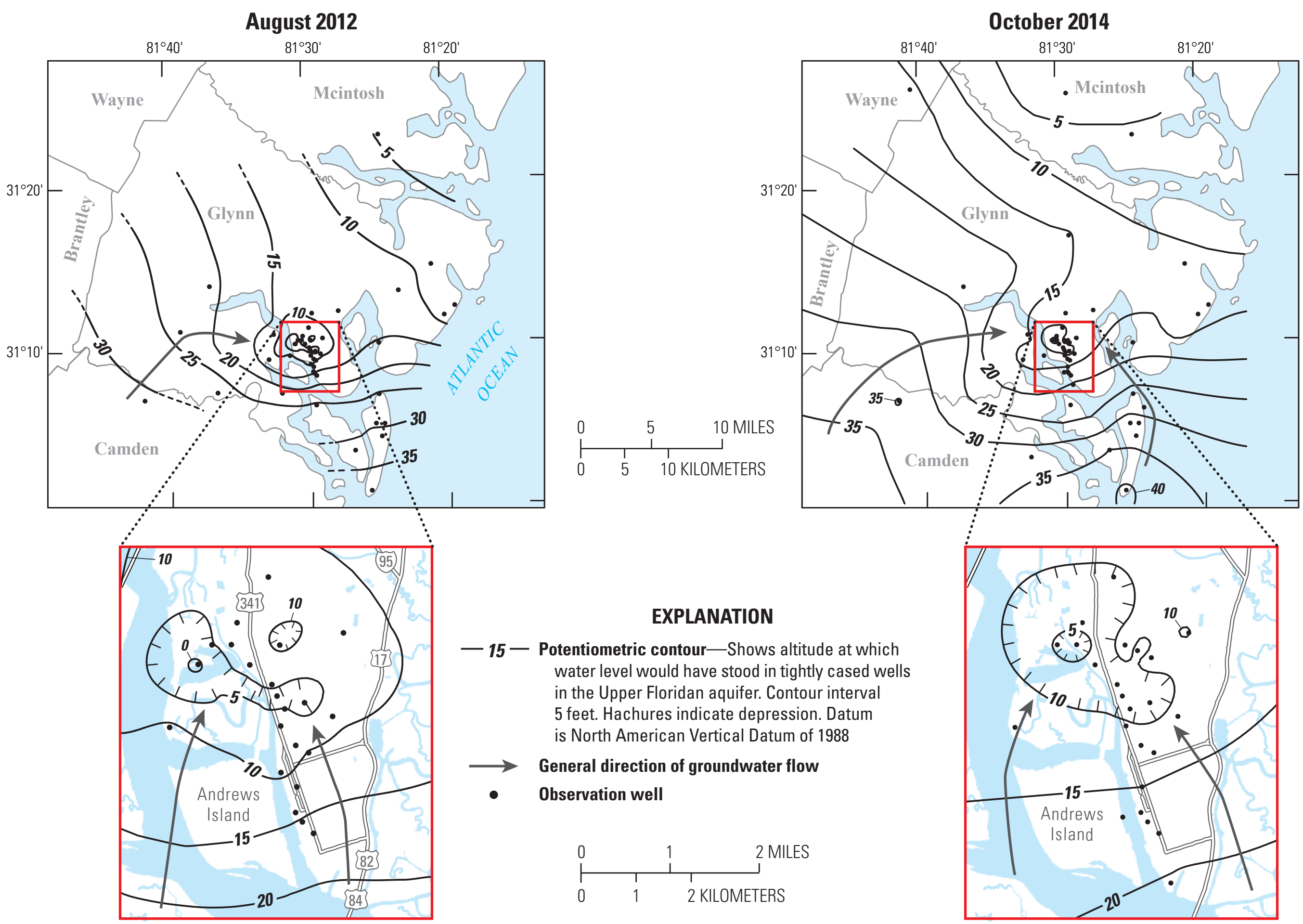




Site name	County	Year monitoring began	Water-level trend, in feet, per year[1]	
			Period of record	From 2012 to 2014
33H127	Glynn	1962	0.10	1.17
33H133	Glynn	1964	0.31	1.58
34H504	Glynn	2007	0.80	1.47
34H505	Glynn	2007	0.84	1.55
34H514	Glynn	2007	0.99	1.69
33H207	Glynn	1986	0.42	1.33
33H324	Glynn	2007	1.49	1.37
33H325	Glynn	2007	6.48	–2.46
34H334	Glynn	1985	0.18	1.32
34H371	Glynn	1986	0.16	1.50

[1]See appendix for summary statistics.





Groundwater Levels

Upper Floridan Aquifer

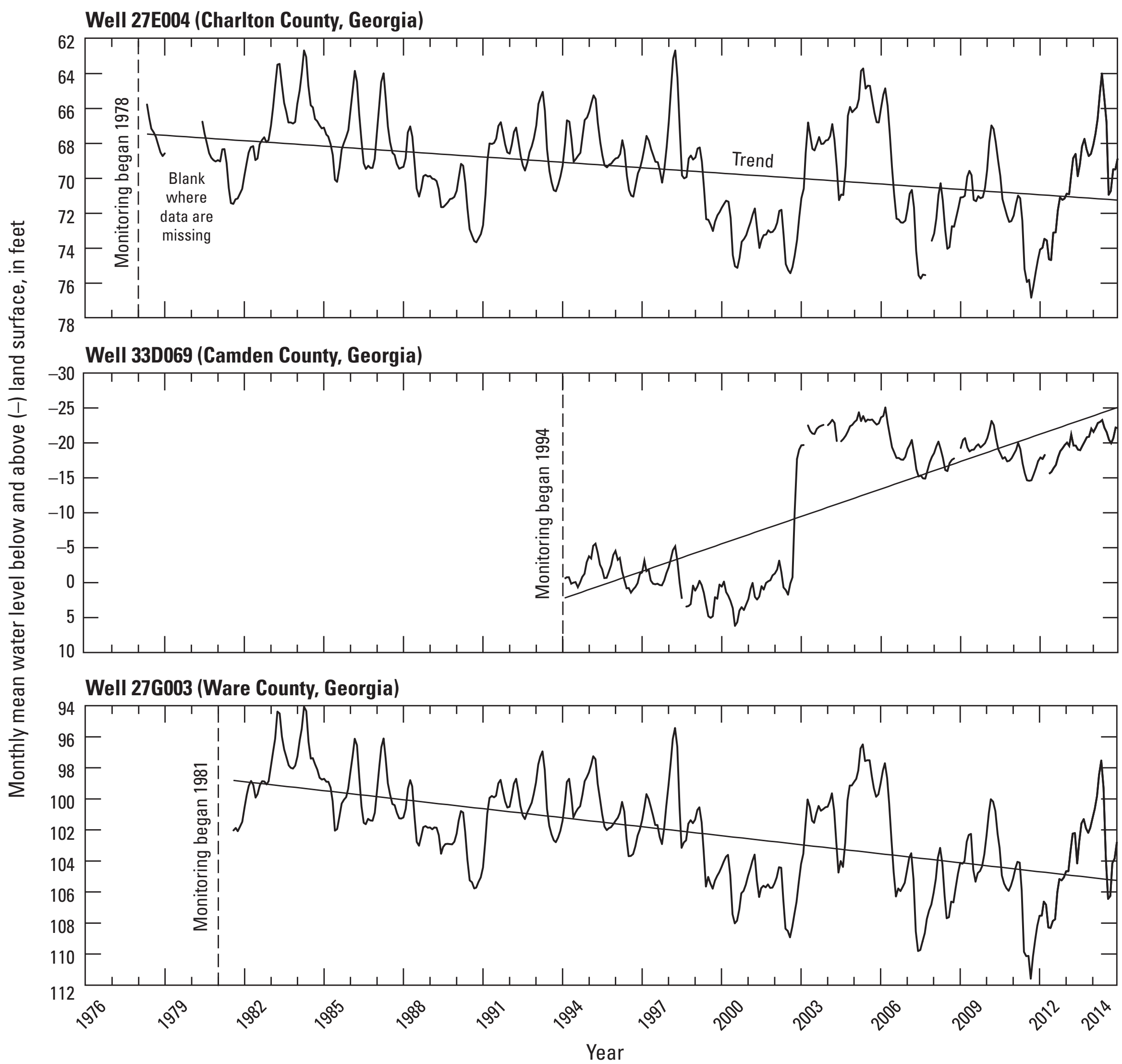
Southern Coastal Area

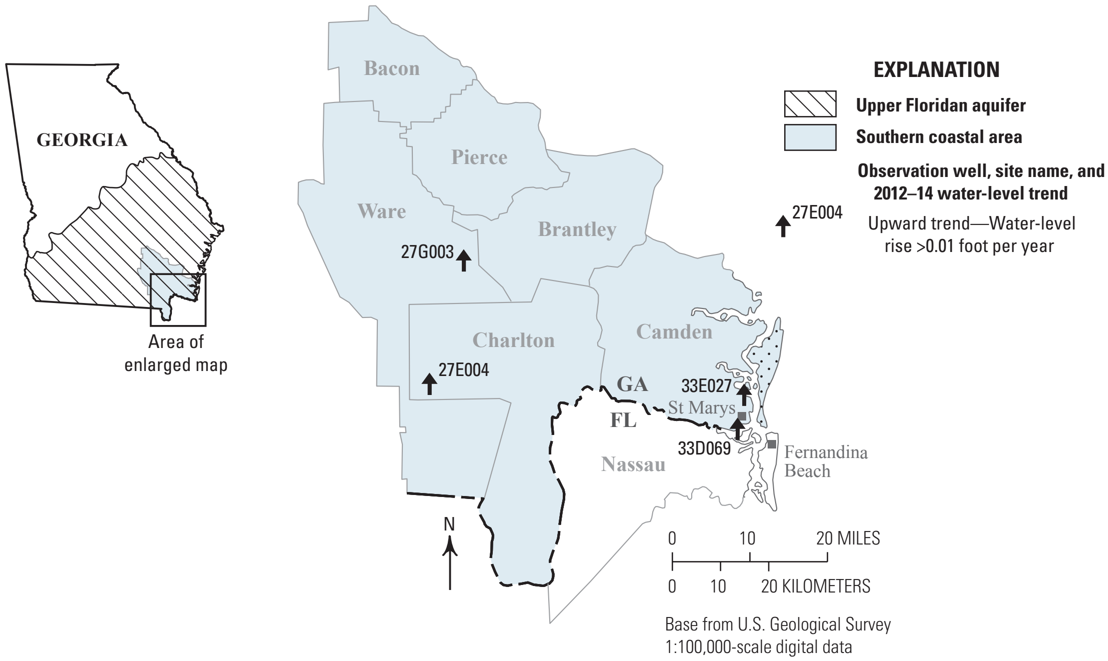
Water levels in four wells were used to define groundwater conditions in the Upper Floridan aquifer in the southern coastal area of Georgia during 2012–14 (map and table, facing page). In this area, water in the Upper Floridan aquifer is confined and influenced mostly by pumping to the south in the Fernandina 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.

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 0.10 to 0.19 foot per year (ft/yr). In the eastern part of the area, water levels rose at rates of 0.16 to 1.31 ft/yr. The sharp rise in water level in well 33D069 during late 2002 is the result of a decrease in pumpage of 35 million gallons per day (Mgal/d) at an industrial site in nearby St Marys, Camden County (Peck and others, 2005). During 2012–14, water levels in all of the wells rose at rates ranging from 1.92 to 2.54 ft/yr.

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., accessed August 30, 2016, at http://pubs.usgs.gov/sir/2004/5295/.





Site name	County	Year monitoring began	Water-level trend, in feet, per year[1]	
			Period of record	From 2012 to 2014
33D069	Camden	1994	1.31	1.92
33E027	Camden	1979	0.16	2.54
27E004	Charlton	1986	–0.10	2.41
27G003	Ware	1984	–0.19	2.13

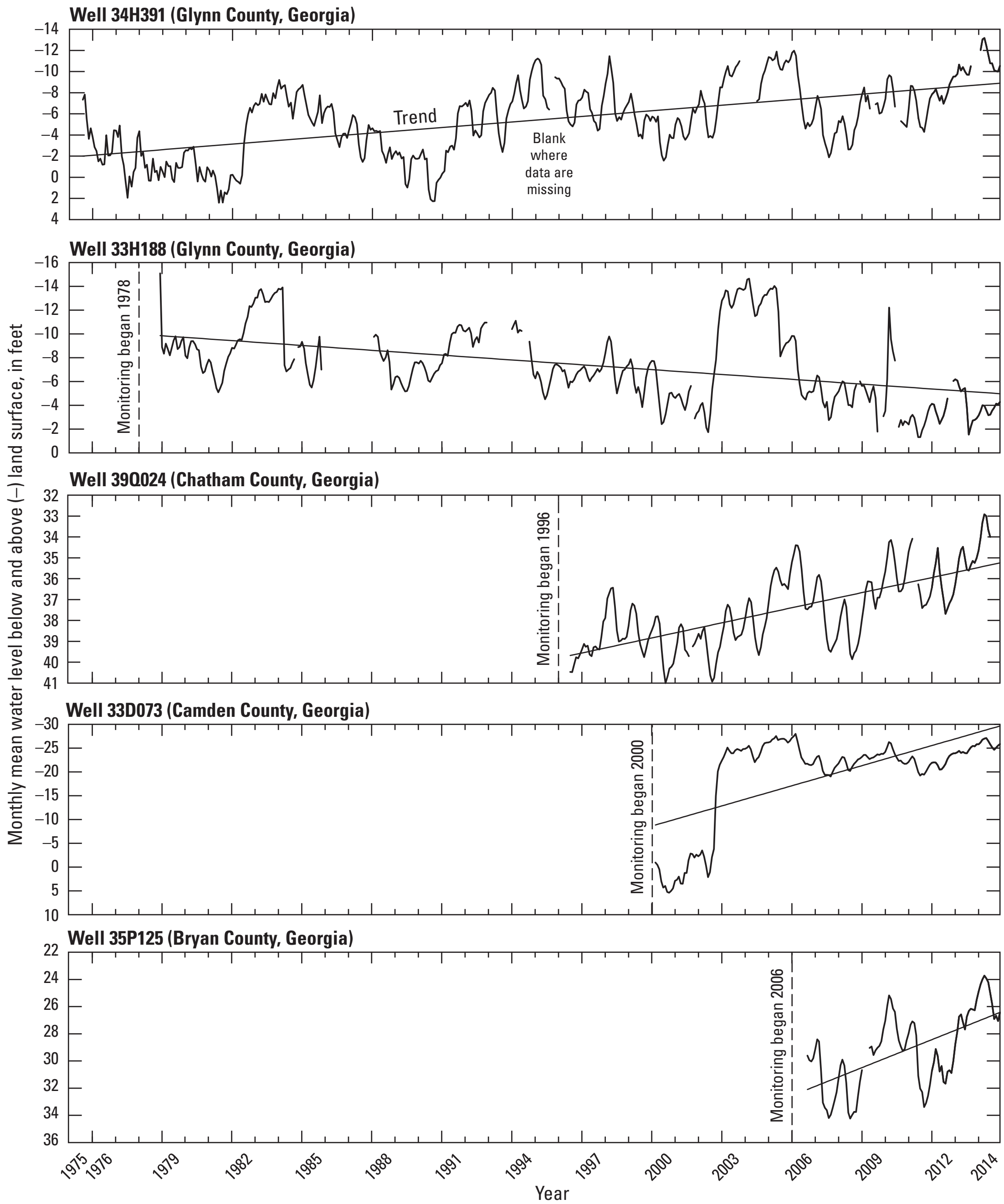
[1]See appendix for summary statistics.

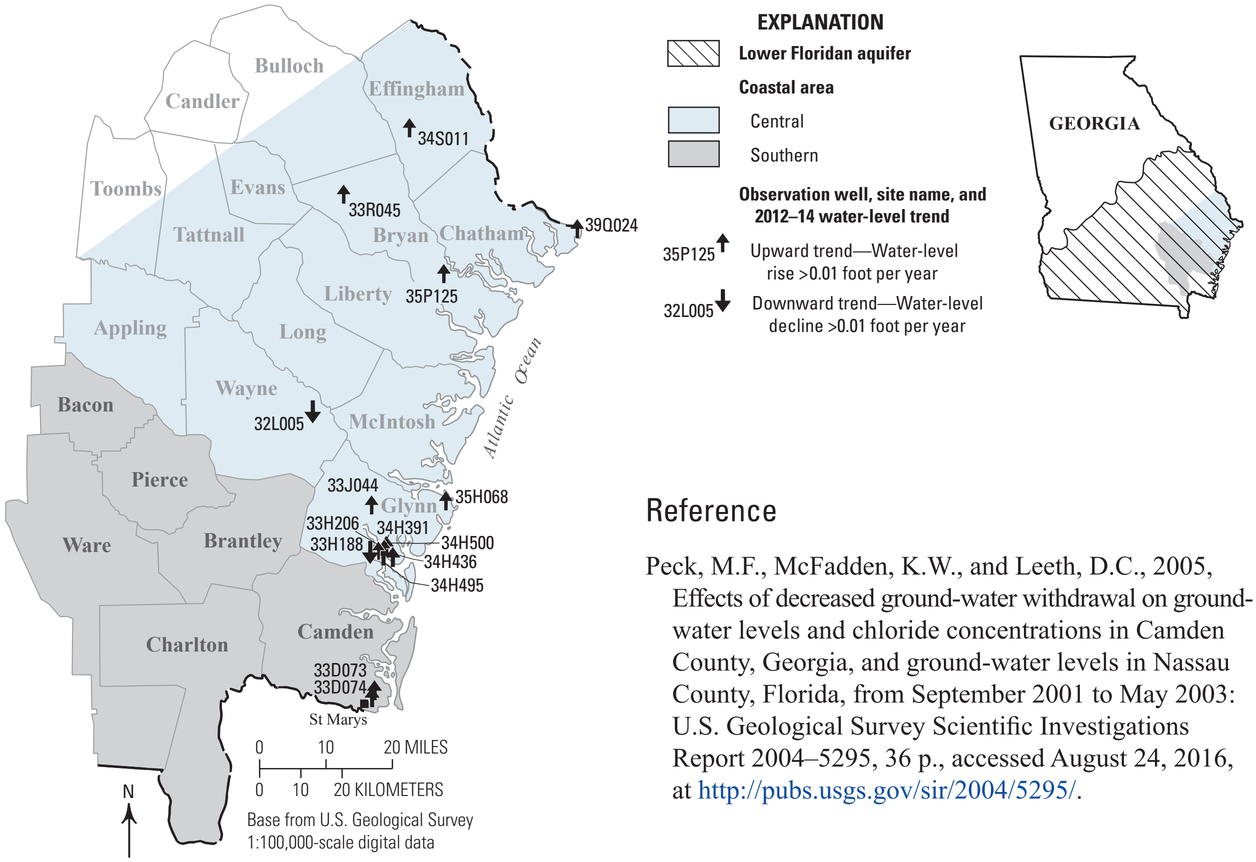
Groundwater Levels

Lower Floridan Aquifer and Underlying Units in Coastal Georgia

Water levels in 15 wells in central and southern coastal Georgia were used to define groundwater conditions in the Lower Floridan aquifer and underlying units during 2012–14 (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 at rates of 0.11 to 1.41 feet per year (ft/yr) and declined in 5 wells at rates of 0.02 to 0.32 ft/yr. The largest rise occurred in well 33D073 near St. Marys, Camden County, in response to the shutdown of a local industrial site in 2002 (Peck and others, 2005). During 2012–14, water levels in 13 of the 15 wells rose at rates ranging from 1.21 to 3.17 ft/yr. During the same period, water levels in two wells declined at rates of 0.13 to 0.31 ft/yr.





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., accessed August 24, 2016, 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 2012 to 2014
33R045	LF	Bryan	2002	–0.14	2.74
35P125	LF	Bryan	2000	0.69	2.27
33D073	LF	Camden	2000	1.41	1.84
33D074	LF	Camden	2003	–0.04	1.35
39Q024	LF	Chatham	1996	0.24	1.21
34S011	LF	Effingham	2002	–0.02	3.17
33H188	F	Glynn	1985	–0.14	–0.13
33H206	LF	Glynn	1986	0.25	1.36
33J044	LF	Glynn	1979	0.11	1.67
34H391	LF	Glynn	1984	0.17	1.39
34H436	LF	Glynn	1983	0.20	1.34
34H495	LF	Glynn	2001	0.68	1.31
34H500	LF	Glynn	2001	0.38	1.48
35H068	LF	Glynn	2007	0.65	1.39
32L005	LF	Wayne	1980	–0.32	–0.31

[1]LF, Lower Floridan aquifer; F, Fernandina permeable zone.

[2]See appendix for summary statistics.

Groundwater Levels

Claiborne and Gordon Aquifers

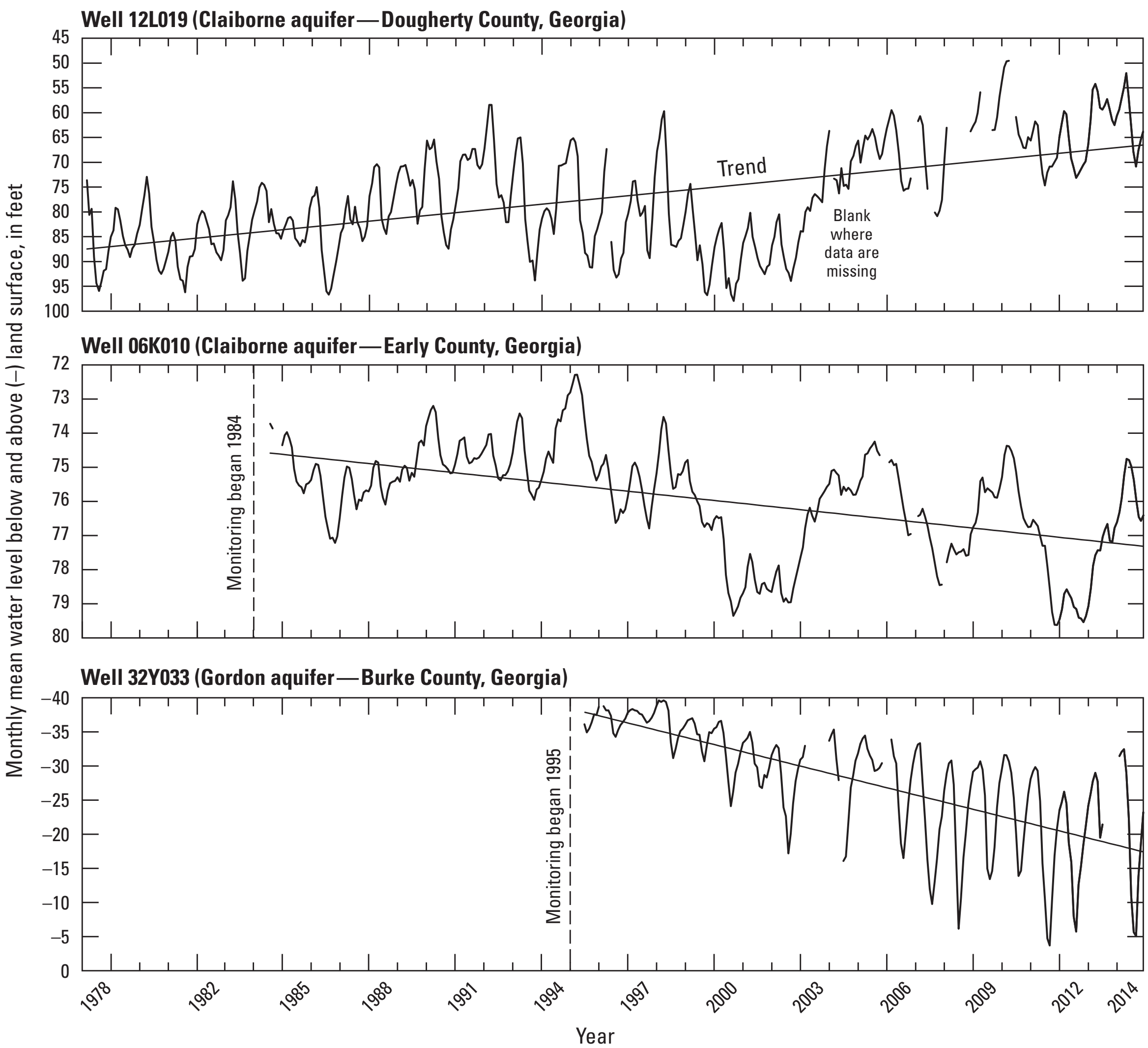
Water levels in 10 Claiborne aquifer wells and 1 Gordon aquifer well were used to define groundwater conditions in southwestern and east-central Georgia during 2012–14 (map and table, facing page). Water in the Claiborne and Gordon aquifers can be confined or unconfined. Hydrographs showing water levels in 2 wells in the Claiborne aquifer and 1 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.

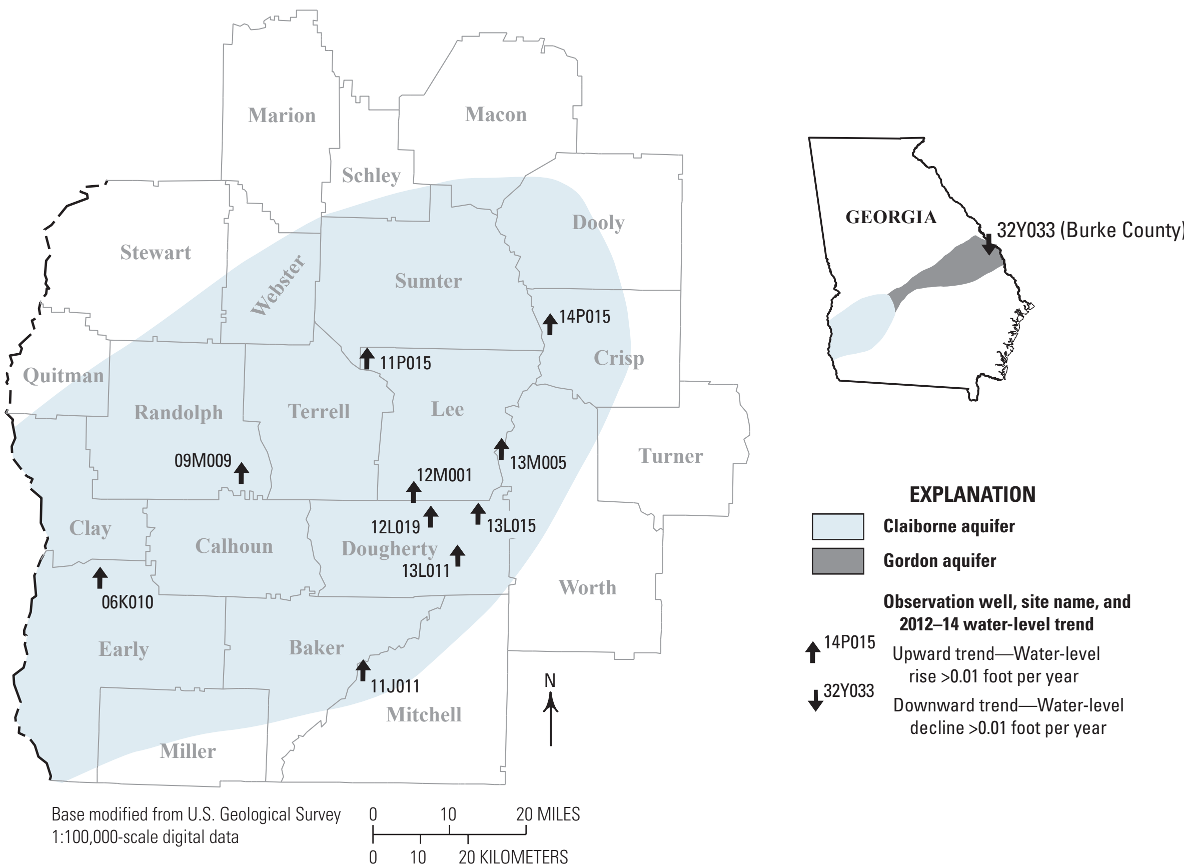
During the period of record, water levels in the Claiborne aquifer declined at rates of 0.09 to 0.75 foot per year (ft/yr) in 7 of the 10 wells monitored. The water levels rose in 2 wells at rates of 0.16 to 0.57 ft/yr and remained about the same in 1 well. During 2012–14, water levels in all 10 of the Claiborne aquifer wells rose at rates of 0.21 to 6.51 ft/yr.

In the Gordon aquifer, water levels in well 32Y033 declined at a rate of 1.05 ft/yr for the period of record. During 2012–14, water-levels continued to decline at a rate of 0.27 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., accessed August 30, 2016, 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 2012 to 2014
14P015	C	Crisp	1984	–0.33	0.21
12L019	C	Dougherty	1978	0.57	1.68
13L011	C	Dougherty	1977	0.16	5.86
13L015	C	Dougherty	1979	–0.42	6.51
06K010	C	Early	1986	–0.09	1.52
11P015	C	Lee	1984	–0.09	1.49
12M001	C	Lee	1978	–0.75	0.77
11J011	C	Mitchell	1981	–0.17	3.86
09M009	C	Randolph	1984	<0.01	1.54
13M005	C	Worth	1980	–0.23	3.38
32Y033	G	Burke	1995	–1.05	–0.27

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

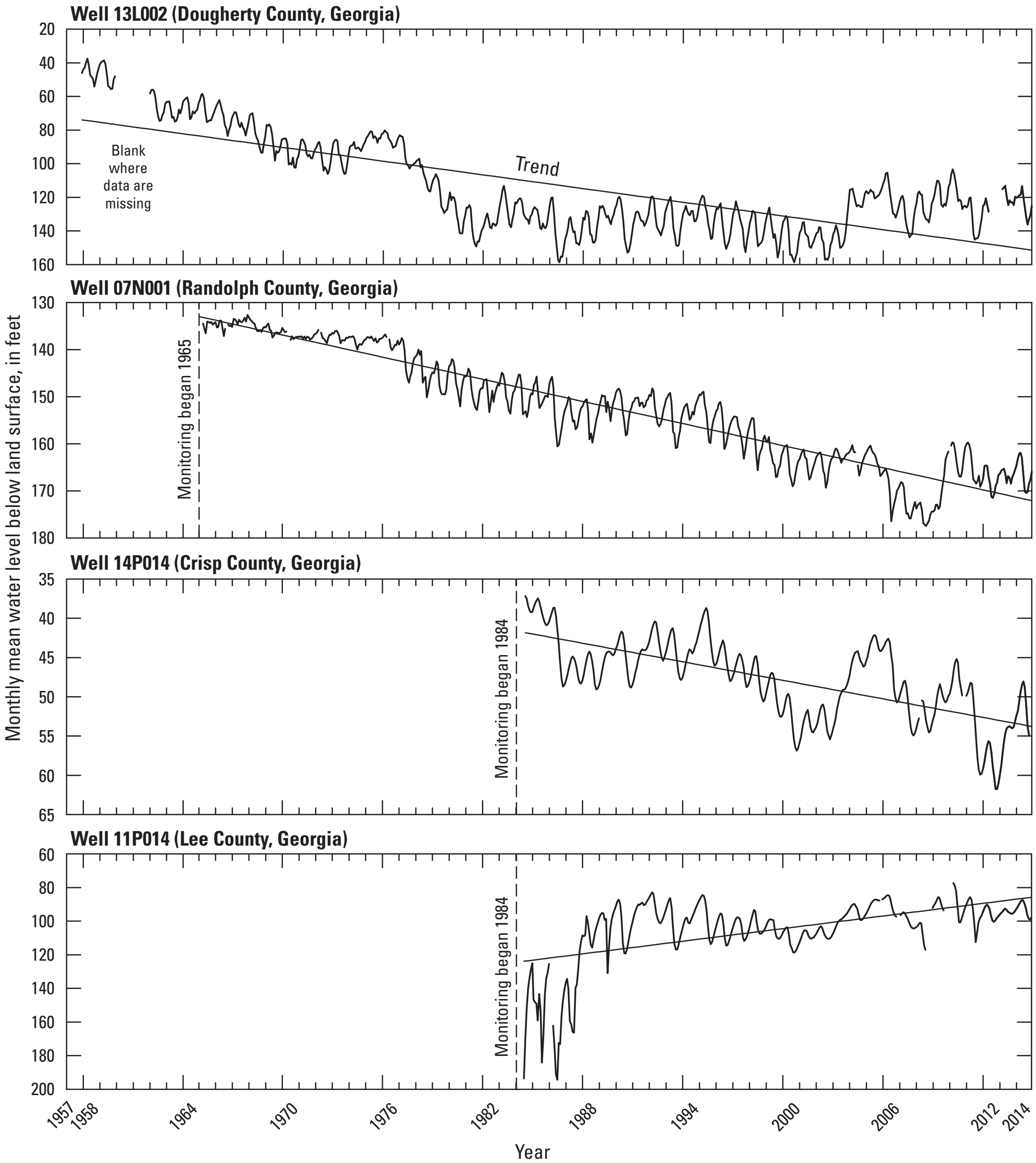
[2]See appendix for summary statistics.

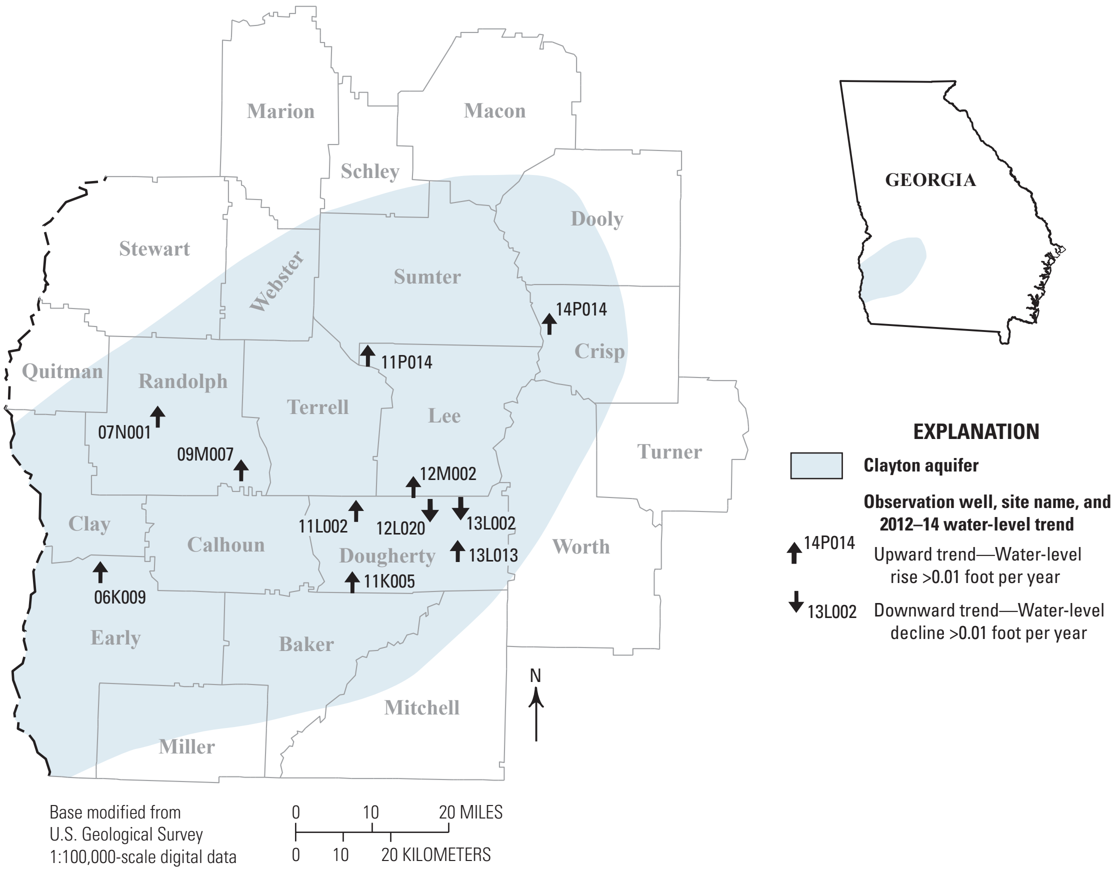
Groundwater Levels

Clayton Aquifer

Water levels in 11 wells were used to define groundwater conditions in the Clayton aquifer in southwestern Georgia during 2012–14 (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 0.39 to 1.98 feet per year (ft/yr). Water levels rose in three wells at rates of 0.12 to 1.25 ft/yr during the period of record. These increases and declines reflect variations in local and regional pumping. During 2012–14, water levels in 9 of the wells rose at rates of 0.15 to 13.32 ft/yr and declined in 2 wells at rates of 0.82 to 2.17 ft/yr.





Site name	County	Year monitoring began	Water-level trend, in feet, per year[1]	
			Period of record	From 2012 to 2014
14P014	Crisp	1986	–0.39	3.69
11K005	Dougherty	1979	–1.54	0.15
11L002	Dougherty	1973	–1.63	5.90
12L020	Dougherty	1980	0.50	–2.17
13L002	Dougherty	1957	–1.35	–0.82
13L013	Dougherty	1978	0.12	2.60
06K009	Early	1986	–1.47	3.16
11P014	Lee	1984	1.25	0.50
12M002	Lee	1978	–0.58	13.32
07N001	Randolph	1965	–0.78	0.29
09M007	Randolph	1984	–1.98	6.35

[1]See appendix for summary statistics.

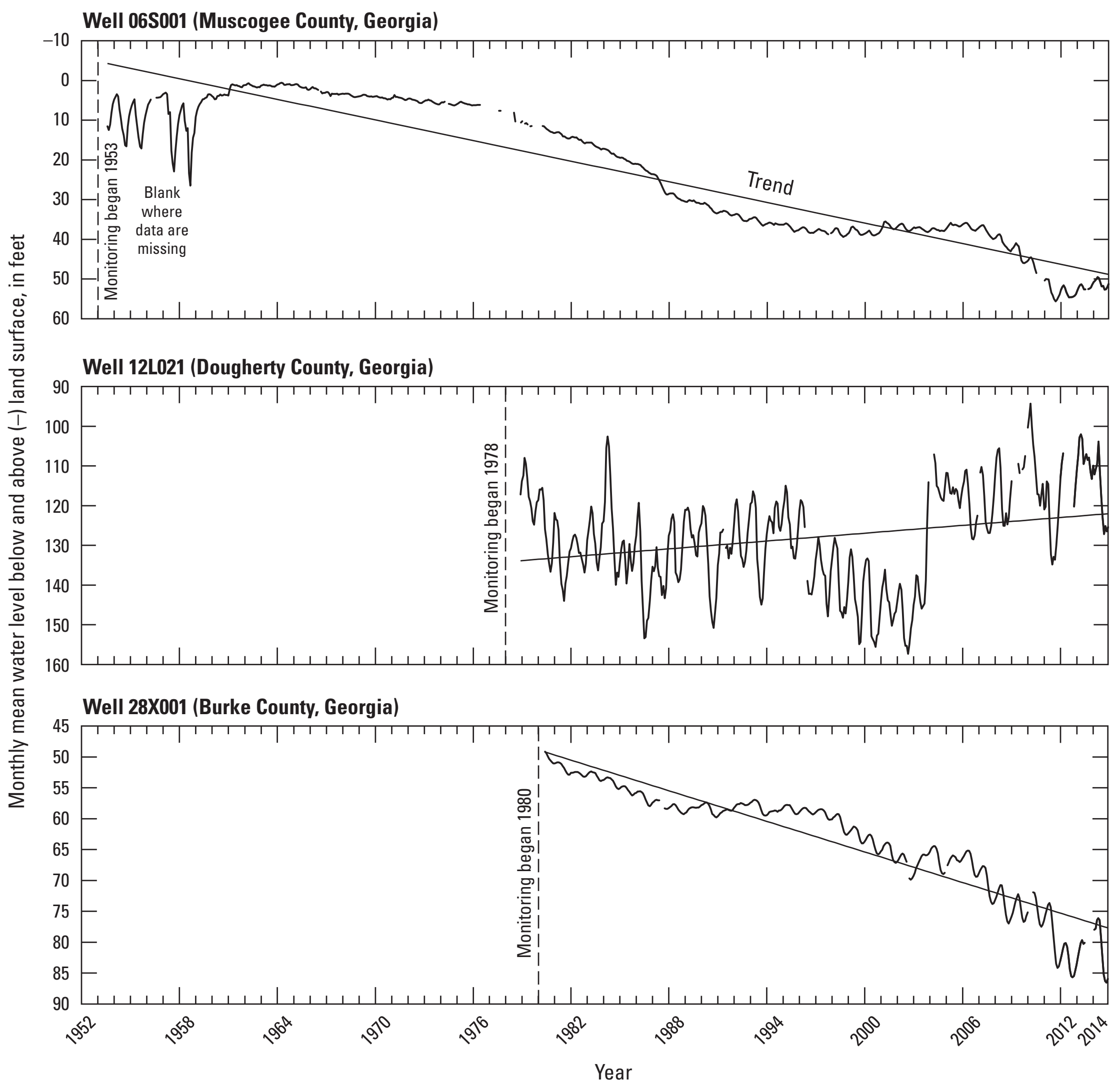
Groundwater Levels

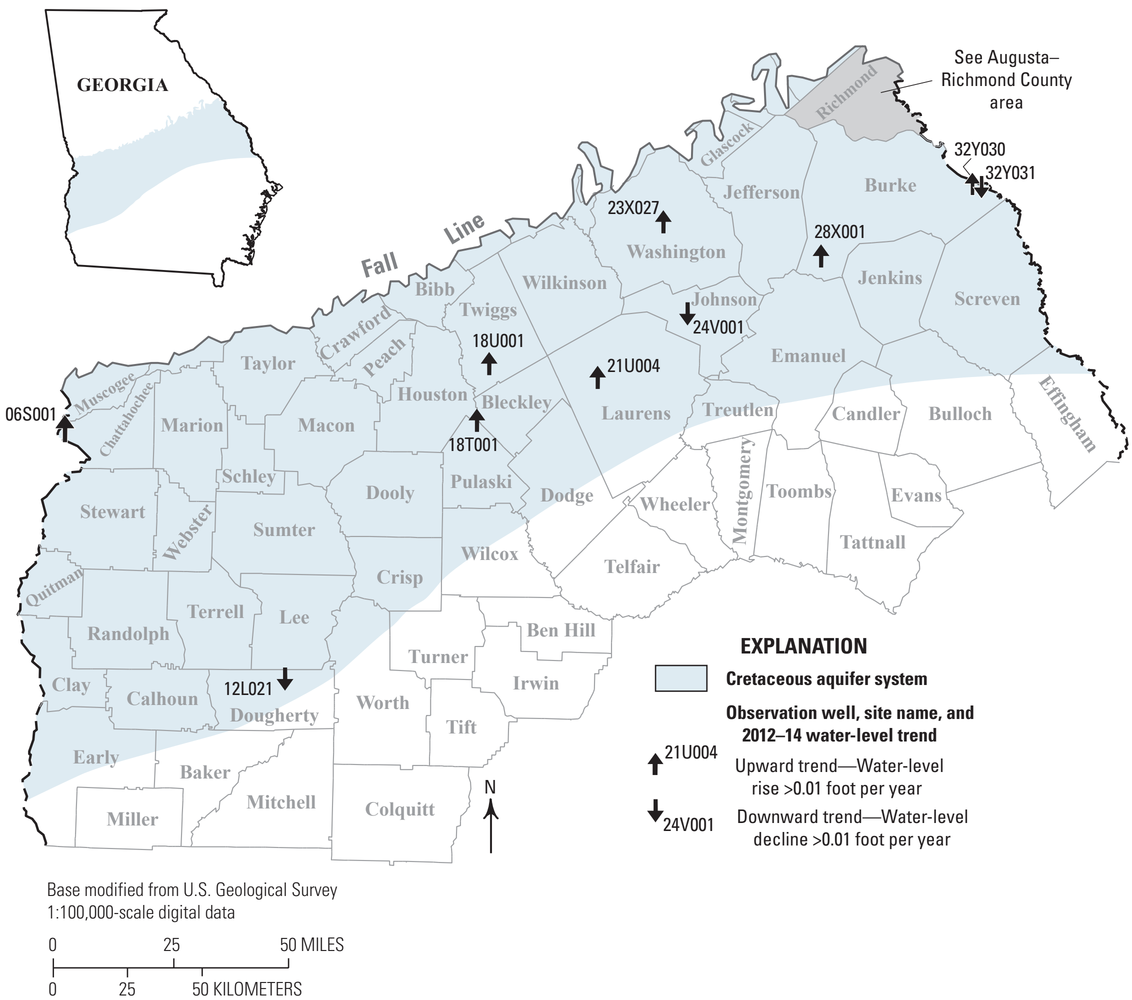
Cretaceous Aquifer System

Water levels in 10 wells in the Cretaceous aquifer system were used to define groundwater conditions throughout central and southwestern Georgia during 2012–14 (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 9 of the 10 wells declined at rates of 0.14 to 0.86 foot per year (ft/yr). The only water-level rise (0.33 ft/yr) during the period of record occurred in well 12L021 at Albany because of decreased pumping for public supply (Jim Stolze, City of Albany Utility Board, written commun., June 27, 2016)

During 2012–14, water levels in 7 of the wells rose at rates of 0.10 to 0.86 ft/yr and declined in 3 wells at rates of 0.01 to 4.60 ft/yr. The largest decline occurred in well 12L021 in Dougherty County, reflecting changes in local pumping.





Site name	Water-bearing unit[1]	County	Year monitoring began	Water-level trend, in feet, per year[2]	
				Period of record	From 2012 to 2014
28X001	M	Burke	1980	–0.82	0.31
32Y030	LM	Burke	1995	–0.49	0.10
32Y031	LD	Burke	1995	–0.56	–0.01
12L021	P	Dougherty	1978	0.33	–4.60
24V001	M	Johnson	1980	–0.60	–0.21
21U004	M	Laurens	1982	–0.34	0.48
06S001	T	Muscogee	1953	–0.86	0.86
18T001	M	Pulaski	1981	–0.27	0.46
18U001	D	Twiggs	1975	–0.14	0.67
23X027	DM	Washington	1985	–0.46	0.41

[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.

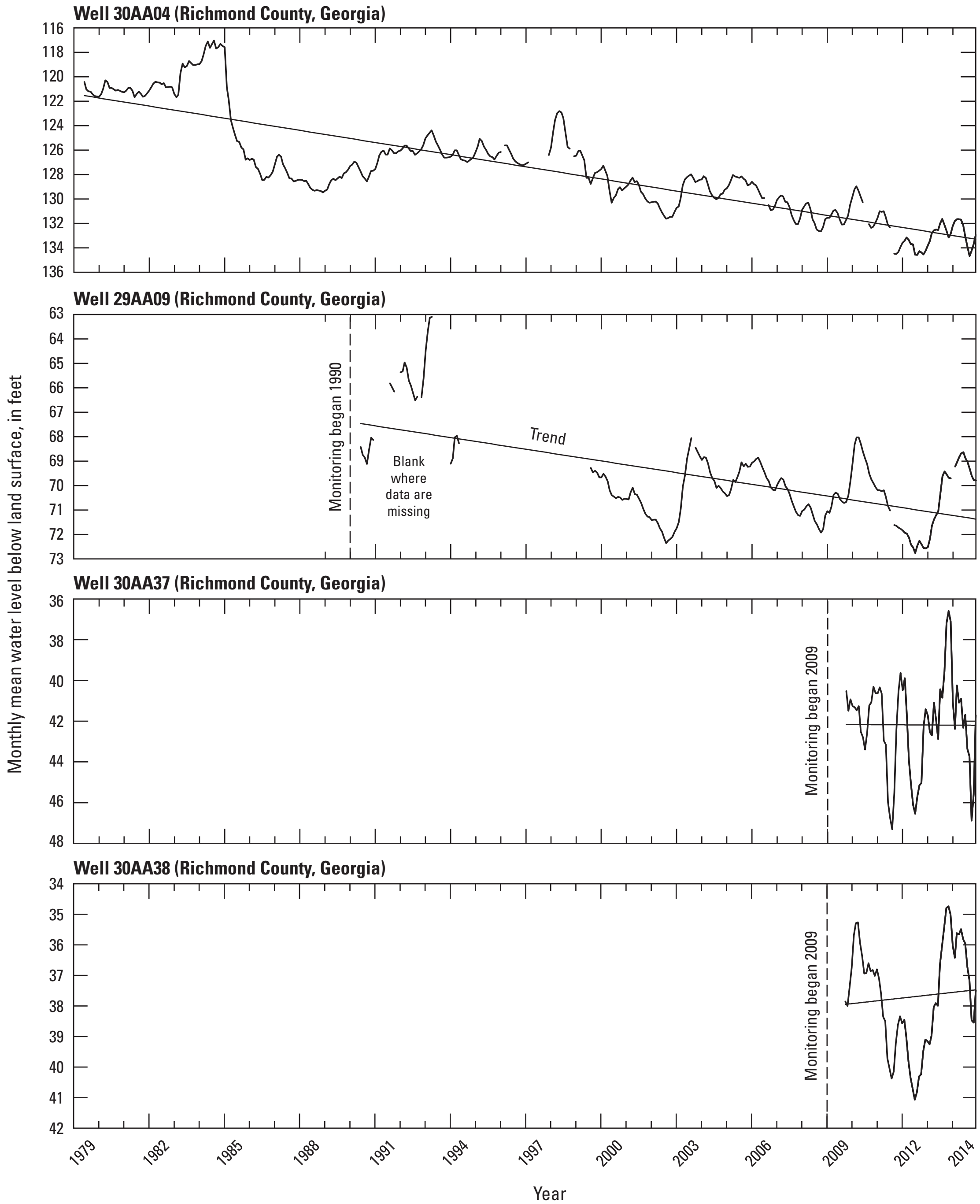
Groundwater Levels

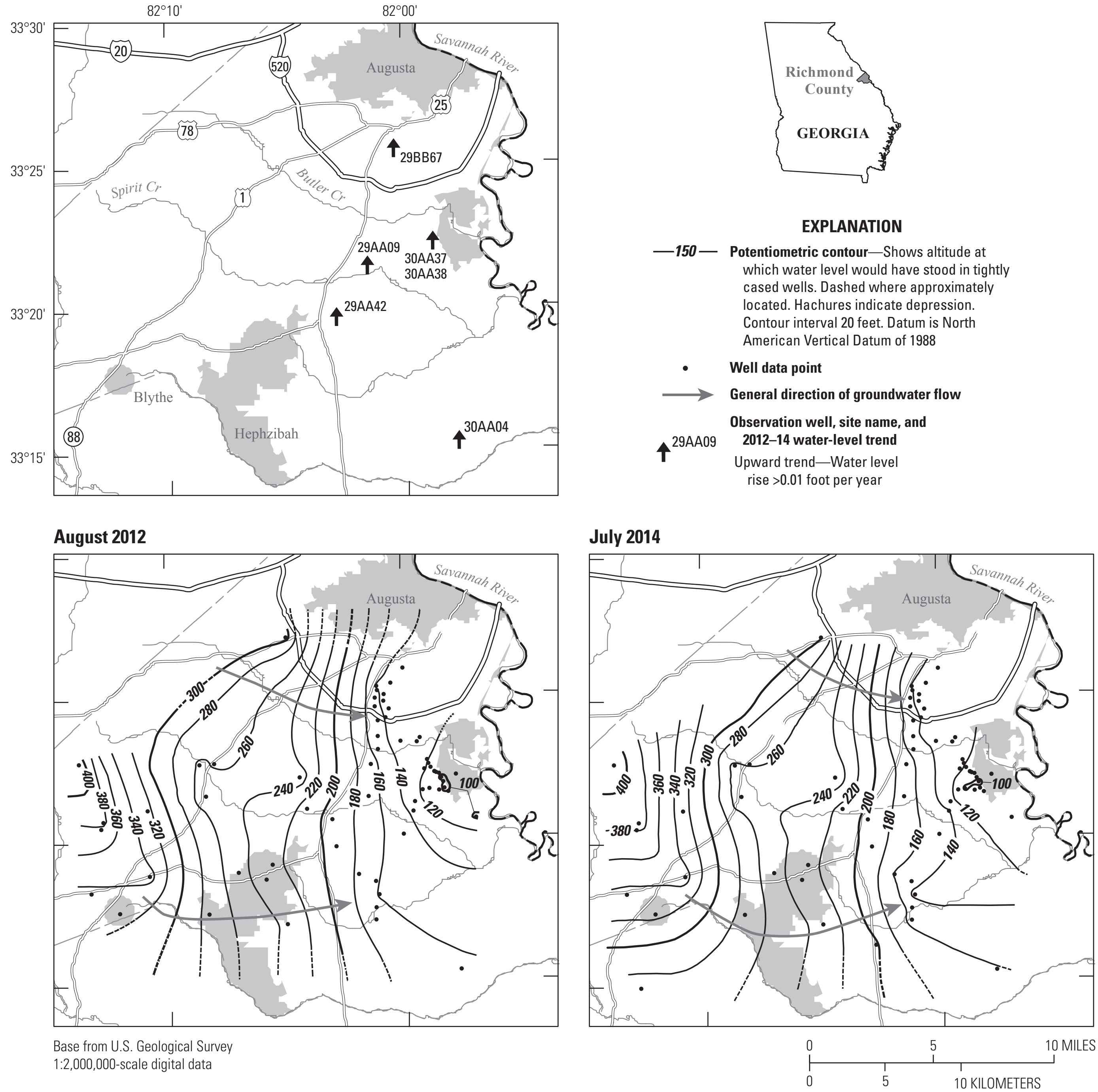
Cretaceous Aquifer System

Augusta–Richmond County Area

Water levels were continuously monitored in six wells in the Cretaceous aquifer system in the Augusta–Richmond County area (maps and table, facing page). During the period of record, water levels declined in 3 wells at rates of 0.10 to 0.33 ft/yr, rose in 2 wells at rates of 0.09 and 0.16 ft/yr, and remained about the same in 1 well (below). During 2012–14, water levels rose in all six wells at rates of 0.08 to 1.49 ft/yr.

In addition to continuous water-level monitoring, synoptic water-level measurements were made in 64 wells during August 2012 and 66 wells during July 2014 to map the potentiometric surface of the Dublin-Midville aquifer system (Cretaceous) in Augusta-Richmond County. During both years, the general direction of groundwater flow was eastward toward the Savannah River.





Site name	Water-bearing unit[1]	County	Year monitoring began	Water-level trend, in feet, per year[2]	
				Period of record	From 2012 to 2014
29AA09	UM	Richmond	1990	–0.16	1.46
29AA42	MD	Richmond	2010	0.16	0.08
29BB67	LM	Richmond	2011	–0.10	0.22
30AA04	DM	Richmond	1979	–0.33	0.39
30AA37	LM	Richmond	2009	<0.01	0.44
30AA38	DM	Richmond	2009	0.09	1.49

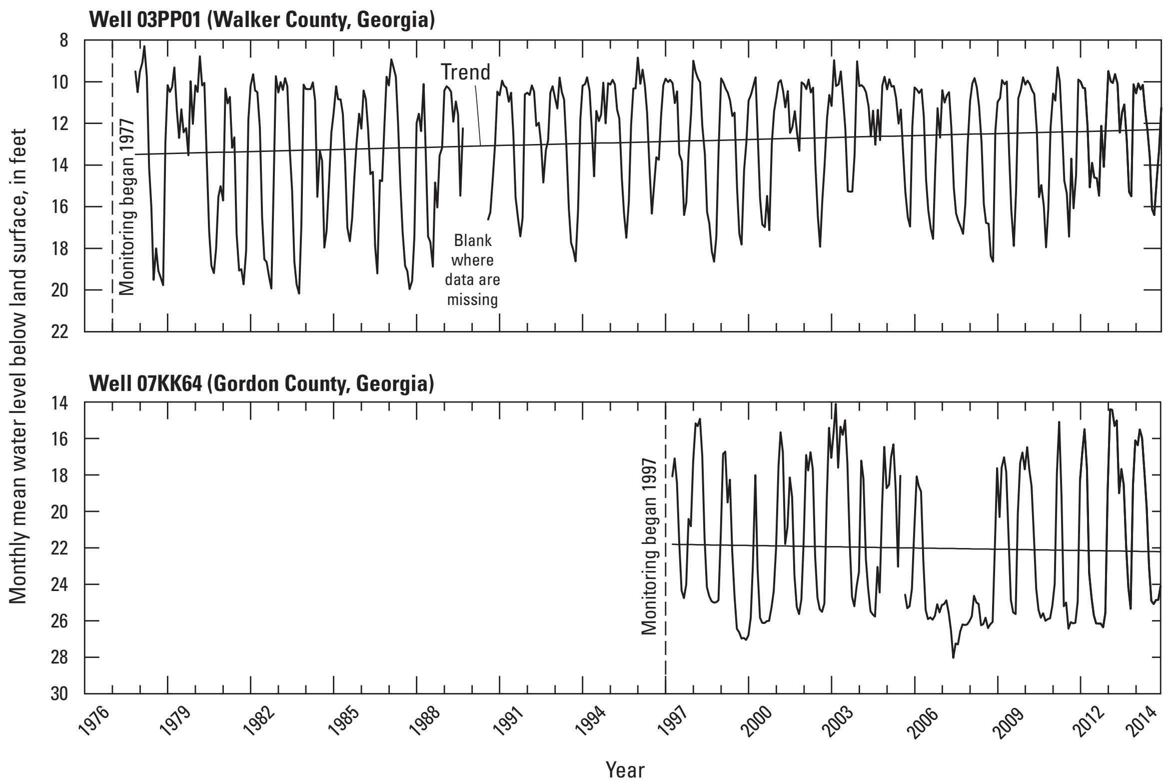
[1]UM, upper Midville aquifer; MD, Midville aquifer system; LM, lower Midville aquifer; DM, Dublin-Midville aquifer system.

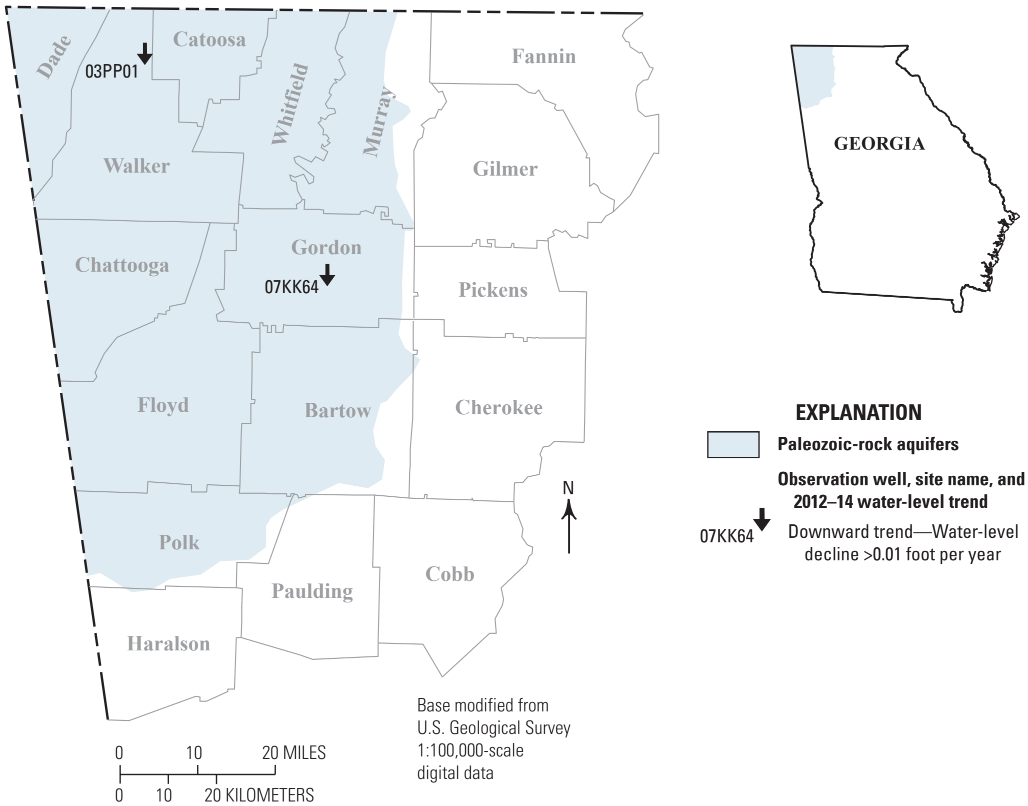
[2]See appendix for summary statistics.

Groundwater Levels

Paleozoic-Rock Aquifers

Water levels were measured in two wells in the Paleozoic-rock aquifers of northwestern Georgia during 2012–14 (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. During the period of record, the water level in well 07KK64 declined 0.02 foot per year (ft/yr) because of pumping from a nearby public-supply well. Conversely, the water level in well 03PP01 increased during the period of record, rising 0.03 ft/yr. During 2012–14, water levels in both wells declined at rates of 0.32 to 0.35 ft/yr.





Site name	County	Year monitoring began	Water-level trend, in feet, per year[1]	
			Period of record	From 2012 to 2014
07KK64	Gordon	1997	–0.02	–0.35
03PP01	Walker	1977	0.03	–0.32

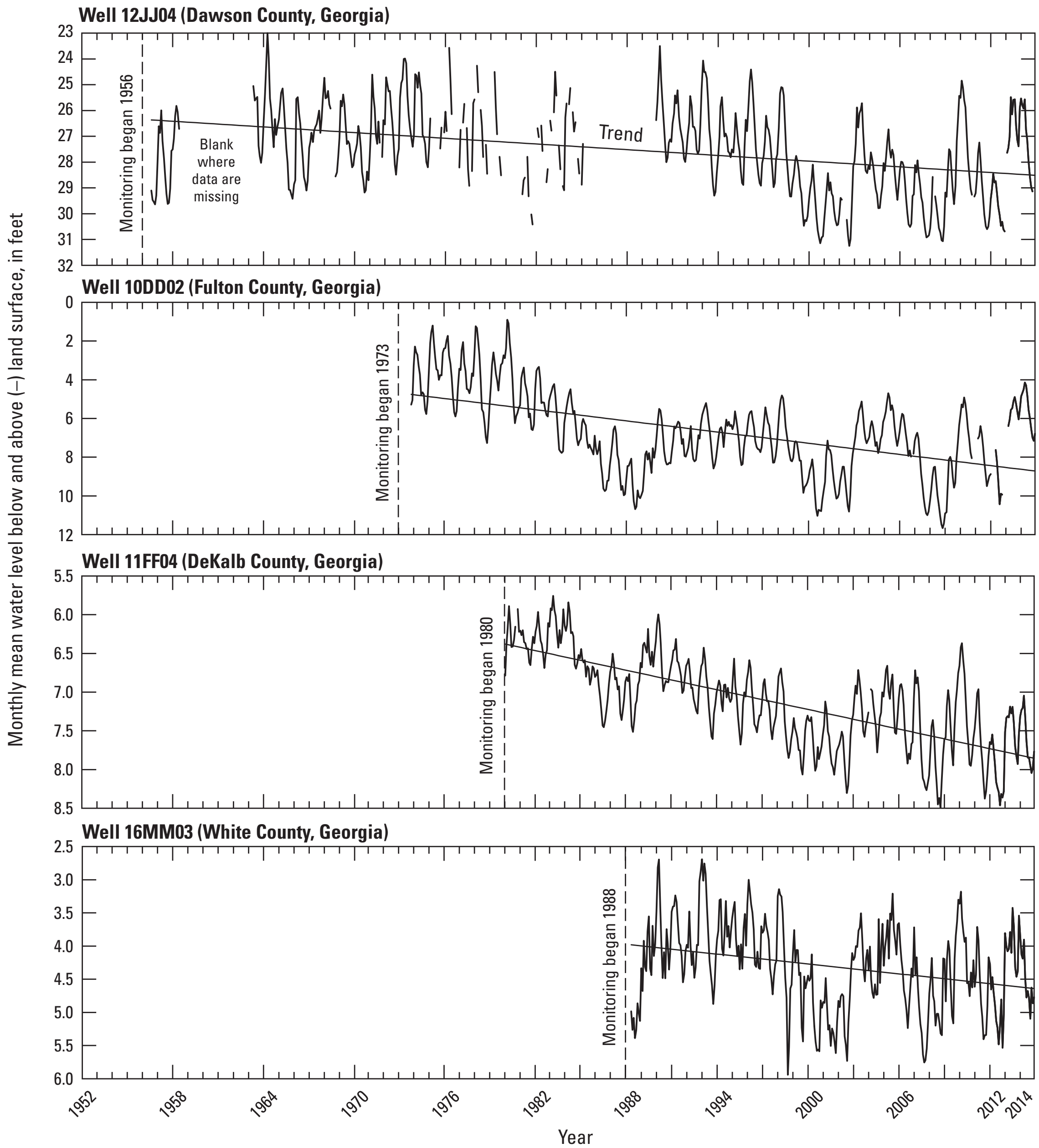
[1]See appendix for summary statistics.

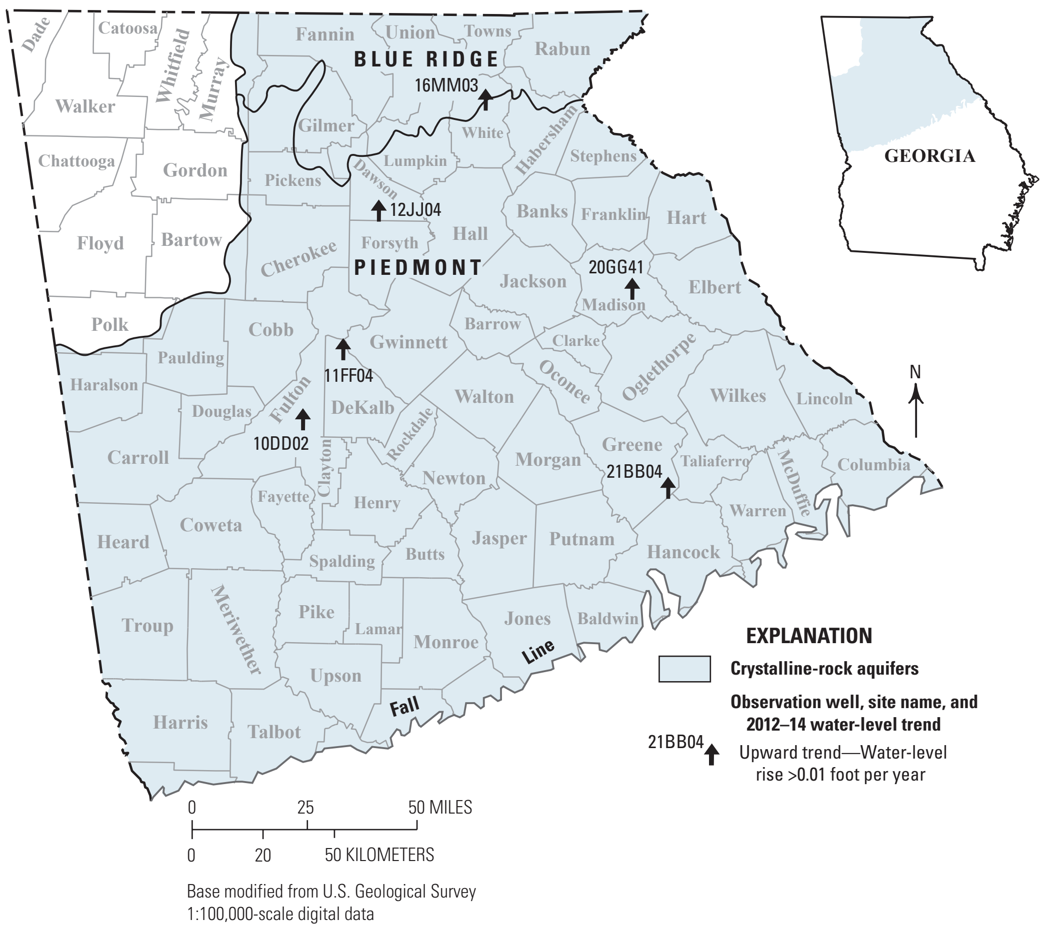
Groundwater Levels

Crystalline-Rock Aquifers

Water levels in six wells were measured in crystalline-rock aquifers in the Piedmont and Blue Ridge Physiographic Provinces of Georgia during 2012–14 (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 are local in 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 5 of the wells declined at rates of 0.02 to 0.19 foot per year (ft/yr) and rose in 1 well at a rate of 0.36 ft/yr. During 2012–14, water levels in all six wells rose at rates of 0.11 to 2.21 ft/yr.





Site name	County	Year monitoring began	Water-level trend, in feet, per year[1]	
			Period of record	From 2012 to 2014
12JJ04	Dawson	1956	–0.04	1.04
11FF04	DeKalb	1980	–0.04	0.11
20GG41	Madison	2007	0.36	1.62
10DD02	Fulton	1973	–0.10	1.35
21BB04	Madison	1987	–0.19	2.21
16MM03	White	1988	–0.02	0.11

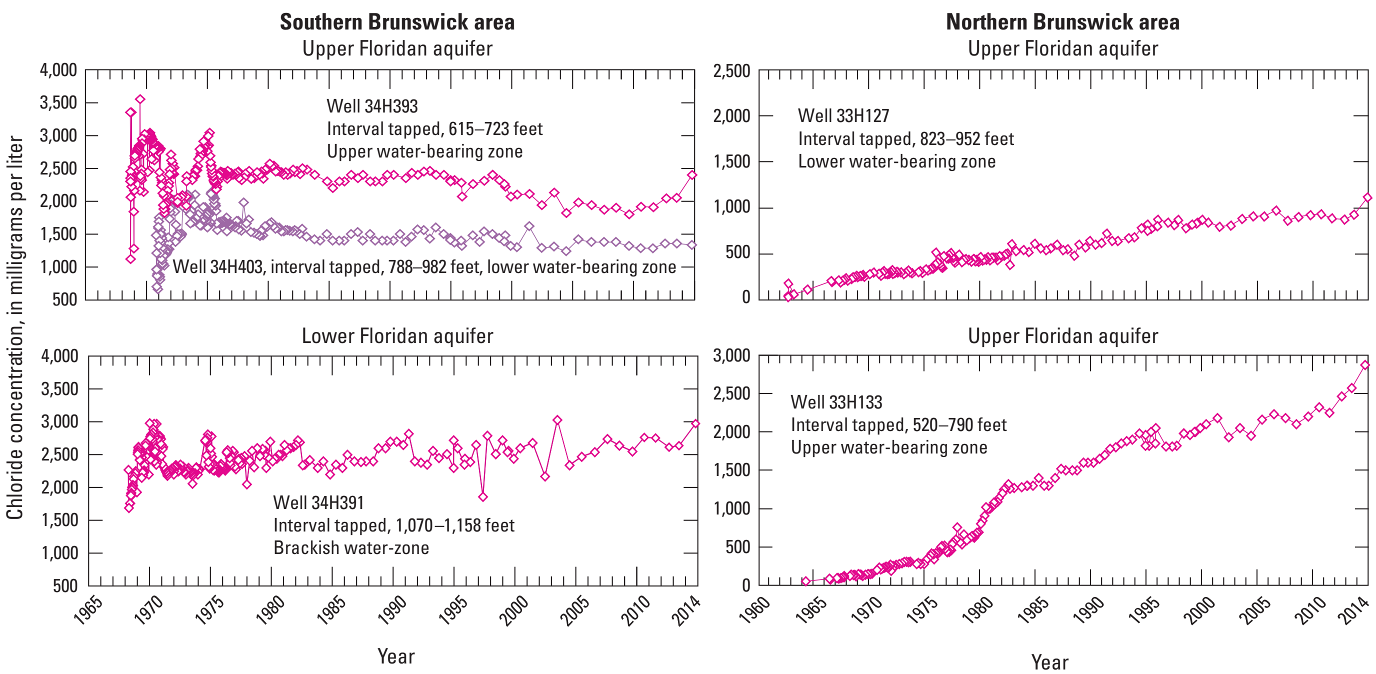
[1]See appendix for summary statistics.

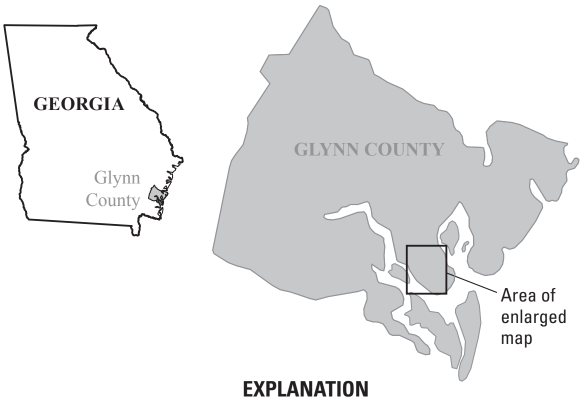
Groundwater Quality in the Upper and Lower Floridan Aquifers—City of Brunswick Area

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; Cherry and others, 2011). 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 2012–14, 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 (mi^2) area and exceeded 2,250 mg/L in part of the area. More information on monitoring groundwater quality in the Brunswick area is available at http://ga.water.usgs.gov/projects/brunswick/.

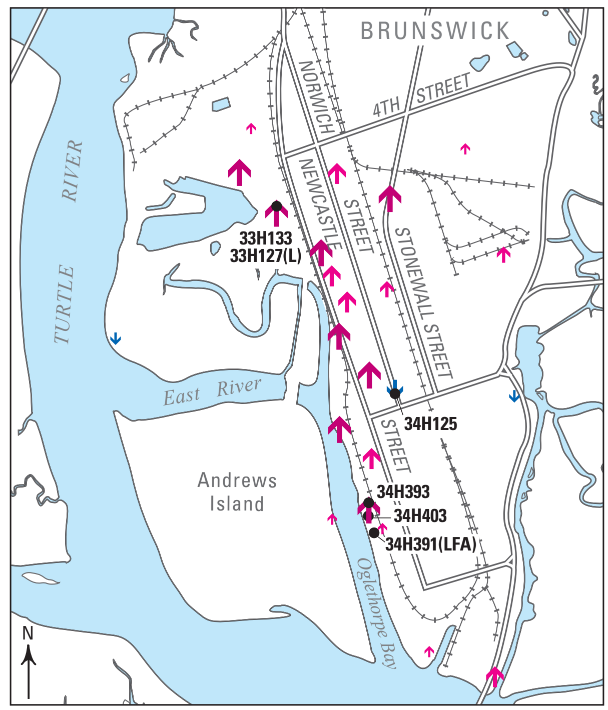
Dissolved chloride concentrations in the upper water-bearing zone of the Upper Floridan aquifer at Brunswick were mapped for August 2012 using data from 25 wells, and for October 2014 using data from 32 wells (facing page). The 2012 and 2014 maps are similar to previously published maps for 2010 and 2011 (Peck and others, 2013) and show that areas having the 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.

Changes in chloride concentration during 1960–2014 are illustrated on graphs from selected wells in the southern and northern Brunswick areas (below), and on a map showing changes during 2012–14. Chloride concentrations within the plume area increased in 20 of 23 wells sampled during 2012–14 (facing page). The greatest decrease in concentration was 60 mg/L at well 34H125 in the southern part of the plume. Chloride concentrations in five wells increased more than 250 mg/L during 2012–14; the largest increase, 410 mg/L, occurred in well 33H133 in the northern part of the plume, and concentrations increased 350 mg/L near one of the source areas in the southern part of the chloride plume area. These changes probably reflect seasonal fluctuations and shifts in local pumping patterns.





Change in chloride concentration from August 2012 to October 2014



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

EXPLANATION

MAPS BELOW

Chloride concentration in water from wells completed in upper water-bearing zone of Upper Floridan aquifer— In milligrams per liter

- 250
- 750
- 1,250
- 1,750
- 2,250

• **Well**

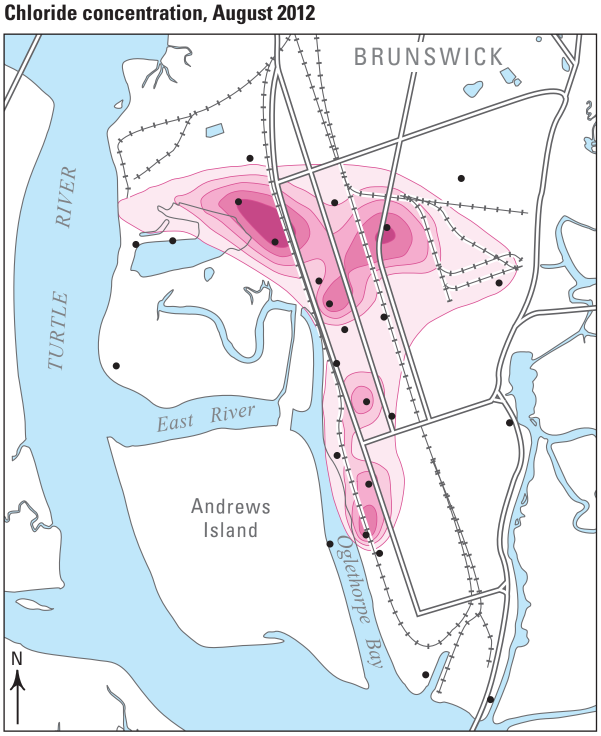
MAP AT RIGHT

Change in chloride concentration in water from wells completed in upper water-bearing zone of Upper Floridan aquifer from 2012 to 2014, in milligrams per liter

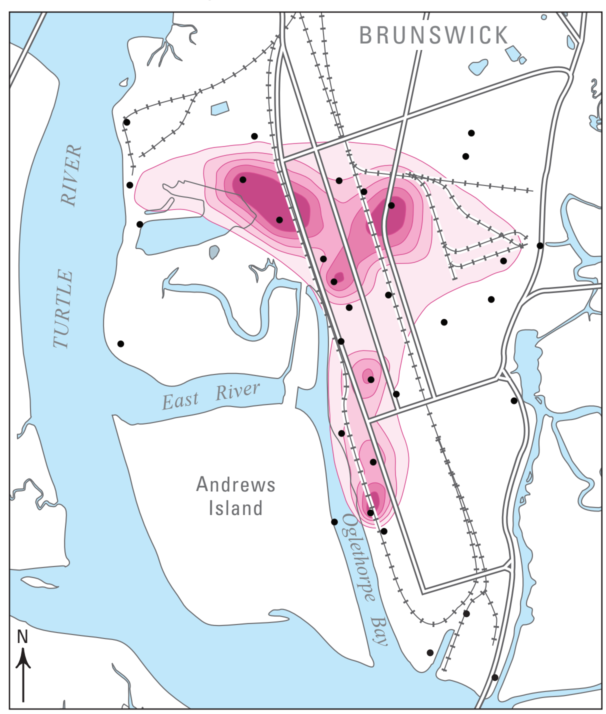
Decrease	Increase
> –10	0 to 10
–10 to 0	>10 to 50
	>50 to 100
	>100

34H391 ● **Location and site name of wells shown in cloride graphs on facing page**—L, lower water-bearing zone of Upper Floridan aquifer; LFA, Lower Floridan aquifer

Chloride concentration, August 2012



Chloride concentration, October 2014



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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 2012–14. Although the LMA typically is used for nonlinear fitting, it also can be used for deriving linear fits that are very near values derived using ordinary least squares fitting. The LMA optimizes a mathematical function—the merit function—that measures how well the results represent 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 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). Missing periods of data, where present, could affect the goodness of fit and statistical strength of the reported trend. Users of the trend results presented in this report can apply the following statistics to inform interpretation:

- The degrees of freedom represent the number of data points minus the variables used. For these trend evaluations, two variables are used—slope (m) and intercept (b). For example, there are 34 degrees of freedom if 3 years of monthly mean water-level measurements in the 3-year period from 2012–14 are available for statistical calculations. The number of degrees of freedom decreases by one for each month of missing mean monthly water-level measurements.
- The root mean square error (RMSE) is a measure of the sample standard deviation of differences between the values predicted by the trend line and the observed data. RMSE units are the same units as the quantity being estimated (in this report, feet). In general, a lower RMSE is better as it suggests the water level estimated is very close to the actual water-level measurements.
- The χ^2 value is the sum of squared residuals (differences) between the monthly mean water level and the monthly mean water-level 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. 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). These exceptions include but are not limited to: data that are modeled linearly, but are not linear (having a strong curvature); outliers in the data that exert inordinate leverage; residuals that are not normally distributed; or variables that are serially correlated. For long periods of data that were examined—none to few of these exceptions apply. For the shorter time spans, all of these exceptions apply, but trend line statistical calculations are included so that the reader can draw their own conclusions.
- 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 (dispersion) around the regression line.

References

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Moré, J., 1978, The Levenberg-Marquardt algorithm—Implementation and theory, *in* Watson, G.A., ed., Numerical analysis, v. 630: Berlin, Springer-Verlag, p. 105.

Table 1–1. Regression summary statistics.

Well name	Period of record summary statistics					2012–14 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	435	2.93775	8.6304	–40.66%	–1.16%	34	2.16308	4.67892	–130.90%	–70.07%
06F001	409	7.61261	57.9519	–40.05%	–1.46%	34	7.92984	62.8824	–37.17%	–25.26%
06G006	250	8.96665	80.4007	–81.15%	–1.07%	34	8.25696	68.1773	–24.43%	–15.28%
06K009	348	8.32142	69.2461	–3.43%	–0.26%	30	8.38445	70.299	–53.18%	–9.63%
06K010	354	1.34843	1.81826	–9.08%	–0.09%	34	0.703458	0.494853	–8.88%	–1.86%
06S001	695	6.0877	37.0601	–1.49%	–0.85%	33	1.14153	1.30309	–25.43%	–4.64%
07H002	405	7.63558	58.3021	–15.05%	–2.79%	33	5.94876	35.3877	–82.06%	–48.75%
07H003	415	5.08395	25.8465	–79.11%	–2.39%	34	5.18605	26.8951	–232.80%	–79.25%
07KK64	210	3.97207	15.7774	–232.80%	–1.93%	34	4.31837	18.6483	–239.50%	–70.13%
07N001	589	3.78337	14.3139	–1.39%	–0.12%	34	2.48363	6.16839	–165.60%	–3.78%
08E038	149	0.780083	0.60853	–52.91%	–0.65%	34	0.483965	0.234223	–16.77%	–4.15%
08E039	149	1.20695	1.45673	–279%	–1.81%	32	1.10534	1.22177	–43.54%	–14.86%
08G001	453	8.76055	76.7472	–26.50%	–1.37%	34	8.91581	79.4916	–23.76%	–17.66%
08K001	422	10.0739	101.484	–65.39%	–4.26%	34	10.527	110.819	–30.48%	–26.21%
09F520	537	3.03869	9.23366	–16.27%	–0.32%	34	2.49047	6.20244	–21.28%	–8.30%
09FF18	142	0.524054	0.274633	–7.23%	–0.46%	31	0.325213	0.105764	–57.16%	–3.69%
09G001	409	3.48461	12.1425	–23.55%	–0.34%	33	2.73858	7.49984	–18.64%	–7.87%
09G003	391	2.44328	5.96963	–114%	–0.35%	34	1.295	1.67703	–32.34%	–7.28%
09M007	354	24.5695	603.659	–7.47%	–0.74%	33	26.5541	705.119	–83.78%	–25.18%
09M009	356	1.56446	2.44753	–569%	–0.30%	30	1.20342	1.44821	–16.67%	–6.99%
10DD02	481	1.84018	3.38626	–7.41%	–1.29%	27	1.42678	2.03571	–23.66%	–17.60%
10G313	523	5.46533	29.8698	–16.71%	–0.51%	34	3.81073	14.5216	–12.57%	–7.37%
10H009	196	6.44677	41.5608	–177.20%	–2.03%	34	6.20553	38.5086	–19.94%	–13.45%
10K005	365	2.06546	4.26613	–12.38%	–0.48%	33	1.86546	3.47994	–57.17%	–15.44%
11AA01	818	2.8409	8.07073	–72.10%	–0.92%	32	2.82599	7.98619	–26.63%	–17.01%
11FF04	415	0.405009	0.164032	–4.65%	–0.28%	34	0.390593	0.152563	–68.66%	–11.05%
11J011	405	3.8297	14.6666	–11.26%	–0.47%	34	2.8882	8.3417	–14.39%	–7.77%
11J012	401	3.62891	13.169	–27.84%	–0.40%	33	3.16278	10.0032	–32.81%	–11.50%
11K003	426	6.35922	40.4397	–24.79%	–1.10%	34	4.95658	24.5677	–10.62%	–8.47%
11K005	410	4.36634	19.0649	–1.39%	–0.34%	22	1.19651	1.43163	–272.70%	–5.99%
11L002	478	16.2673	264.627	–3.89%	–0.70%	28	15.7677	248.621	–62.12%	–23.07%
11P014	348	16.5311	273.278	–8.07%	–0.85%	34	3.459	11.9647	–131.70%	–8.89%
11P015	356	1.79655	3.22759	–11.87%	–0.25%	34	0.968638	0.938259	–12.48%	–4.13%
12F036	577	5.85586	34.2911	–8.76%	–0.21%	34	1.34312	1.80396	–13.45%	–2.06%
12JJ04	520	1.55571	2.42023	–10.88%	–0.29%	31	1.49641	2.23924	–30.09%	–10.10%
12K014	390	4.06746	16.5442	–24.64%	–0.49%	34	4.00628	16.0503	–27.22%	–12.68%
12K141	215	7.37118	54.3343	–39.26%	–2.14%	29	3.99556	15.9645	–7.95%	–6.49%
12K180	144	4.18265	17.4945	–87.37%	–3.83%	34	3.75488	14.0991	–27.10%	–16.06%
12L019	420	8.73146	76.2384	–7.05%	–0.61%	34	5.70478	32.5445	–65.13%	–17.34%
12L020	411	14.4446	208.648	–13.40%	–0.56%	32	11.548	133.356	–103.60%	–32.22%
12L021	412	12.1708	148.129	–17.66%	–0.50%	27	6.34161	40.216	–31.77%	–40.69%

Table 1–1. Regression summary statistics.—Continued

Well name	Period of record summary statistics					2012–14 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)
12L029	365	5.78769	33.4974	–77.81%	–0.69%	23	3.76126	14.1471	–26.08%	–15.01%
12L030	335	4.6669	21.7799	–35.90%	–1.10%	23	3.32719	11.0702	–15.16%	–11.92%
12L277	189	6.72381	45.2096	–115.60%	–2.67%	33	4.60315	21.189	–9.88%	–7.92%
12L373	148	4.65408	21.6605	–120.70%	–2.70%	34	4.09238	16.7476	–21.34%	–12.15%
12M001	389	12.9248	167.051	–8.15%	–0.62%	34	10.2544	105.152	–255.30%	–22.59%
12M002	385	14.4154	207.804	–12.26%	–0.52%	17	10.9529	119.965	–39.86%	–21.55%
12M017	386	5.43979	29.5913	–150.70%	–0.88%	34	6.43973	41.4701	–28.93%	–18.57%
12Z001	537	2.14827	4.61506	–12.21%	–0.95%	30	1.8616	3.46555	–27.39%	–17.17%
13FF31	114	1.22487	1.50031	–137.70%	–1.58%	22	0.435357	0.189536	–12.60%	–4.24%
13J004	437	4.59932	21.1537	–7.86%	–0.47%	34	2.68868	7.229	–13.78%	–6.59%
13K014	382	4.64624	21.5875	–23.27%	–0.73%	34	4.16868	17.3779	–28.98%	–15.25%
13L002	651	18.5076	342.53	–3.36%	–0.71%	26	6.44338	41.5172	–169.70%	–17.01%
13L011	431	6.40765	41.058	–18.37%	–0.45%	23	3.4768	12.0881	–19.70%	–10.13%
13L012	435	3.76899	14.2053	–30.70%	–0.46%	21	2.99569	8.97416	–24.88%	–13.72%
13L013	403	8.55984	73.2709	–33.84%	–0.43%	18	0.697062	0.485895	–8.94%	–2.20%
13L015	415	9.09319	82.6861	–10.30%	–0.50%	34	5.79149	33.5413	–17.09%	–8.23%
13L049	344	6.00237	36.0284	–26.53%	–0.96%	34	4.48984	20.1586	–14.49%	–10.01%
13L180	197	5.90266	34.8414	–34.15%	–1.27%	34	4.10928	16.8862	–10.61%	–6.75%
13M005	406	5.43854	29.5777	–11.55%	–1.93%	31	5.99668	35.9602	–35.28%	–25.66%
13M006	410	6.83481	46.7147	–25.38%	–3.39%	34	7.88575	62.1851	–41.99%	–33.38%
13M007	411	2.27368	5.16964	–77.61%	–1.37%	34	2.4517	6.01084	–19.61%	–15.53%
14P014	358	3.76442	14.1708	–5.78%	–0.41%	32	2.4902	6.2011	–14.83%	–6.85%
14P015	359	10.1697	103.424	–18.53%	–2.29%	34	12.8448	164.989	–1151%	–115.30%
15L020	500	1.17256	1.3749	–0.65%	–0.03%	34	0.857918	0.736024	–41.52%	–1.05%
15Q016	136	9.75885	95.2351	–38.48%	–4.27%	34	11.4595	131.32	–84.16%	–29.65%
16MM03	318	0.6336	0.40145	–18.56%	–0.85%	34	0.543891	0.295818	–93.57%	–23.61%
18H016	587	1.59336	2.53881	–1.41%	–0.04%	34	1.55314	2.41224	–33.93%	–2.08%
18K049	427	3.45205	11.9167	–1.74%	–0.14%	34	3.83072	14.6744	–110.60%	–6.68%
18T001	394	1.41735	2.00889	–2.69%	–0.12%	33	1.04334	1.08856	–43.37%	–3.79%
18U001	465	1.19896	1.4375	–3.45%	–0.04%	33	1.019	1.03836	–29.42%	–1.50%
19E009	673	6.96673	48.5354	–15.42%	–0.27%	34	6.71043	45.0299	–30.84%	–9.39%
20GG41	78	2.1029	4.42218	–32.56%	–7.53%	33	1.67902	2.81911	–20.24%	–12.38%
21BB04	316	2.12758	4.5266	–7.94%	–2.76%	22	2.00929	4.03725	–26.79%	–21.81%
21T001	596	4.04736	16.3811	–14.03%	–0.61%	34	4.43516	19.6707	–28.91%	–15.46%
21U004	386	0.768976	0.591324	–1.24%	–0.10%	28	0.712938	0.508281	–32.97%	–4.02%
23X027	349	5.89611	34.7641	–8.04%	–0.13%	34	1.99291	3.97167	–93.56%	–2.05%
24V001	392	1.10056	1.21123	–0.95%	–0.04%	28	1.17459	1.37967	–119.20%	–2.25%
25Q001	569	2.5743	6.62701	–1.30%	–0.15%	33	3.8573	14.8788	–145.20%	–9.76%
26R001	486	3.46219	11.9868	–1.69%	–0.10%	34	4.08067	16.6519	–46.60%	–5.12%
27E004	421	2.59623	6.74041	–11.90%	–0.19%	34	1.76181	3.10396	–14.06%	–4.47%
27G003	399	2.73792	7.49619	–7.33%	–0.14%	34	2.22776	4.96293	–20.14%	–4.37%

Table 1–1. Regression summary statistics.—Continued

Well name	Period of record summary statistics					2012–14 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)
28X001	399	3.01893	9.11394	–1.86%	–0.24%	28	3.16088	9.99118	–199.10%	–9.68%
29AA09	210	1.45515	2.11746	–9.45%	–0.18%	33	0.711513	0.50625	–9.44%	–2.05%
29AA42	53	0.583836	0.340864	–58.97%	–0.35%	34	0.53228	0.283322	–45.76%	–0.62%
29BB67	37	0.513371	0.263549	–55.82%	–13.43%	34	0.513787	0.263977	–117.30%	–17.31%
30AA04	410	2.14919	4.619	–3.08%	–0.09%	34	0.914401	0.836129	–45.52%	–1.72%
30AA37	61	2.34711	5.50893	–2279%	–5.76%	34	2.55066	6.50587	–111%	–13.76%
30AA38	61	1.73518	3.01084	–156.30%	–4.61%	34	1.43149	2.04915	–18.46%	–6.42%
30L003	485	3.62438	13.1361	–3.19%	–0.21%	34	2.8437	8.08664	–31.82%	–6.68%
31U008	367	3.6057	13.001	–4.02%	–0.22%	29	3.06845	9.41537	–17.50%	–6.26%
31U009	373	3.3207	11.027	–3.74%	–0.22%	33	2.80956	7.89363	–17.35%	–5.77%
32G047	105	2.09974	4.40891	–51.91%	–17.45%	14	0.934886	0.874011	–16.36%	–27.92%
32L005	171	0.98019	0.960772	–2.34%	–0.14%	13	0.530745	0.28169	–40.67%	–3.22%
32L015	371	2.64695	7.00636	–10.42%	–0.23%	33	2.27739	5.18653	–22.22%	–6.92%
32L016	376	1.51312	2.28952	–5.04%	–0.14%	34	0.54018	0.291795	–6.89%	–1.81%
32L017	369	1.59838	2.55481	–6.09%	–0.20%	34	0.950003	0.902505	–11.21%	–3.75%
32Y030	200	1.0544	1.11176	–2.66%	–0.10%	26	0.887982	0.788512	–168.20%	–2.75%
32Y031	216	1.47804	2.18459	–3.19%	–0.18%	28	1.54501	2.38706	–2234%	–6.05%
32Y033	212	5.98764	35.8518	–6.86%	–1.66%	28	8.16809	66.7177	–584.20%	–88.94%
33D069	242	6.18203	38.2174	–4.97%	–8.85%	33	1.17334	1.37673	–12.07%	–51.91%
33D071	194	5.20624	27.105	–5.73%	–11.07%	34	0.255489	0.0652746	–3.67%	–6.82%
33D072	190	1.47218	2.16732	–9.26%	–3.30%	28	0.532734	0.283806	–15.80%	–12.13%
33D073	176	7.33765	53.8411	–9.11%	–12.93%	34	0.924369	0.854459	–9.67%	–414.90%
33D074	137	1.68661	2.84465	–103.30%	–1.21%	34	0.615605	0.378969	–8.77%	–9.79%
33E027	409	3.29683	10.8691	–10.08%	–0.80%	22	1.02303	1.04659	–14.23%	–60.73%
33H127	592	4.40509	19.4048	–12.12%	–169.40%	30	1.447	2.0938	–25.10%	–43.48%
33H133	588	4.4298	19.6231	–4.08%	–4.31%	34	1.2879	1.65868	–15.65%	–17.26%
33H188	382	2.84707	8.10583	–10.16%	–2.13%	32	1.15684	1.33829	–177.80%	–54.83%
33H206	362	3.12336	9.75537	–7.12%	–2.97%	34	1.12899	1.27463	–15.99%	–34.04%
33H207	351	3.65	13.3225	–5.13%	–22.71%	22	0.999177	0.998354	–16.87%	–21.99%
33H208	363	1.30519	1.70351	–5.08%	–1.80%	34	0.438772	0.192521	–14.29%	–11.72%
33H324	87	1.65876	2.75148	–4.99%	–3.38%	34	1.10907	1.23004	–15.59%	–12.42%
33H325	87	8.69519	75.6063	–6.03%	–4.16%	34	6.5603	43.0375	–51.30%	–107.70%
33J044	423	2.54466	6.47532	–10.77%	–31.26%	34	0.959183	0.920032	–11.02%	–12.24%
33J062	158	2.64884	7.01637	–169.60%	–4.13%	33	1.20671	1.45614	–13.63%	–27.42%
33J065	148	1.08264	1.17211	–63.58%	–88.07%	27	0.330249	0.109064	–6.54%	–6.42%
33M004	556	3.16557	10.0208	–2.63%	–0.29%	34	1.80004	3.24016	–16.81%	–5.59%
33R045	149	3.38676	11.4702	–54.55%	–1.11%	34	2.08963	4.36656	–14.63%	–5.32%
34G033	119	2.66592	7.10711	–71.93%	–4.63%	34	0.863274	0.745242	–13.16%	–60.13%
34H334	548	3.33799	11.1422	–4.97%	–5.69%	30	0.969247	0.939439	–15.20%	–26.81%
34H371	556	2.82607	7.98665	–5.50%	–2.96%	28	0.901307	0.812355	–12.02%	–21.72%
34H391	453	2.73807	7.497	–6.48%	–2.25%	30	1.04966	1.10179	–14.74%	–30.90%

Table 1–1. Regression summary statistics.—Continued

Well name	Period of record summary statistics					2012–14 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)
34H436	370	2.7975	7.82602	–7.95%	–1.62%	34	1.10496	1.22093	–15.86%	–56.25%
34H437	353	2.13848	4.57312	–12.25%	–31.29%	33	0.713627	0.509264	–13.55%	–14.21%
34H495	148	2.65936	7.0722	–7.56%	–4.06%	34	0.598193	0.357835	–8.75%	–73.34%
34H500	162	3.1341	9.82257	–16.05%	–5.34%	34	0.877668	0.770301	–11.43%	–71.48%
34H504	90	1.5166	2.30008	–8.60%	–22.01%	31	0.969839	0.940588	–12.80%	–20.55%
34H505	89	1.70773	2.91636	–9.31%	–34.44%	30	1.12281	1.2607	–14.10%	–25.08%
34H514	93	1.78791	3.19661	–8.07%	–6.75%	34	1.10278	1.21612	–12.52%	–12.69%
34H515	107	0.504241	0.254259	–130.20%	–6.08%	34	0.334721	0.112038	–21.65%	–12.93%
34J077	191	4.17082	17.3958	–17.41%	–2.72%	29	2.79633	7.81947	–43.88%	–21.41%
34J080	150	2.36948	5.61443	–65.83%	–14.98%	34	1.0812	1.16898	–13.41%	–11.63%
34J081	146	1.77429	3.14809	–49.21%	–2.53%	32	1.20634	1.45525	–17.24%	–10.18%
34J082	149	0.870218	0.757279	–61.75%	–2.58%	33	0.387718	0.150325	–9.38%	–5.62%
34K104	101	2.2134	4.89916	–38.32%	–2.47%	25	0.971527	0.943865	–13.04%	–5.89%
34N089	566	3.34272	11.1738	–2.40%	–0.68%	32	1.35725	1.84212	–12.36%	–6.52%
34S008	158	1.59184	2.53395	–8.20%	–0.94%	34	0.746912	0.557877	–5.92%	–3.27%
34S011	148	3.19209	10.1895	–323.60%	–0.90%	34	1.67612	2.80938	–10.17%	–3.76%
35H068	89	1.66195	2.76208	–11.94%	–7.21%	34	1.03429	1.06975	–14.26%	–12.20%
35H076	65	0.567863	0.322468	–402.10%	–1.75%	12	0.38896	0.15129	–19.47%	–5.20%
35H077	104	7.03608	49.5065	–348.40%	–12.85%	26	6.87165	47.2195	–51.40%	–34.67%
35M013	561	2.81278	7.91175	–2.36%	–0.63%	33	1.01683	1.03394	–9.88%	–5.27%
35P094	862	2.19326	4.81037	–94.85%	–1.83%	30	1.32887	1.7659	–74.23%	–34.92%
35P110	169	2.89764	8.39634	–38.58%	–1.54%	32	1.36253	1.8565	–12.35%	–6.30%
35P125	95	2.25401	5.08056	–13.73%	–2.86%	34	1.41324	1.99724	–11.94%	–6.31%
35Q050	155	1.30025	1.69065	–23.82%	–1.39%	34	0.532304	0.283348	–7.51%	–3.92%
35Q070	5	0.982558	0.965421	–24.24%	–41.60%	5	0.982558	0.965421	–24.24%	–41.60%
35S008	175	1.32594	1.75811	–7.49%	–0.38%	34	0.59687	0.356254	–6.95%	–2.18%
36N012	172	2.31762	5.37136	–16.20%	–0.75%	28	1.1124	1.23743	–13.37%	–5.42%
36Q008	716	12.222	149.377	–409.70%	–0.64%	30	3.23325	10.4539	–29.94%	–8.17%
36Q020	659	5.27743	27.8513	–2.90%	–0.55%	30	2.03426	4.1382	–19.15%	–7.69%
37P114	363	3.08523	9.51867	–5.70%	–0.32%	30	1.82379	3.32621	–28.25%	–8.16%
37P116	364	0.312008	0.0973489	0.00%	–0.20%	34	0.244265	0.0596655	–26.66%	–5.85%
37Q016	707	9.26181	85.781	–17.92%	–0.58%	34	2.99221	8.9533	–31.71%	–8.84%
37Q185	287	5.50597	30.3157	–2.61%	–0.32%	16	6.56679	43.1227	–83.77%	–24.93%
38Q002	701	3.55053	12.6063	–3.75%	–0.54%	34	1.38037	1.90542	–21.91%	–7.84%
38Q208	187	0.423005	0.178933	–252.60%	–0.82%	24	0.469713	0.22063	–4309%	–28.86%
38Q209	197	0.327815	0.107463	–13.64%	–0.43%	34	0.223347	0.0498839	–18.06%	–4.96%
39Q003	603	2.96217	8.77444	–4.21%	–0.51%	34	1.14274	1.30584	–22.47%	–7.41%
39Q024	212	1.30056	1.69145	–7.07%	–0.33%	29	0.904882	0.818812	–18.01%	–5.63%
39Q026	207	0.473557	0.224256	–52.06%	–0.42%	29	0.265575	0.0705302	–23.89%	–5.61%
39Q029	185	0.962784	0.926952	–599.30%	–1.16%	31	0.591087	0.349384	–31.95%	–11.29%

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