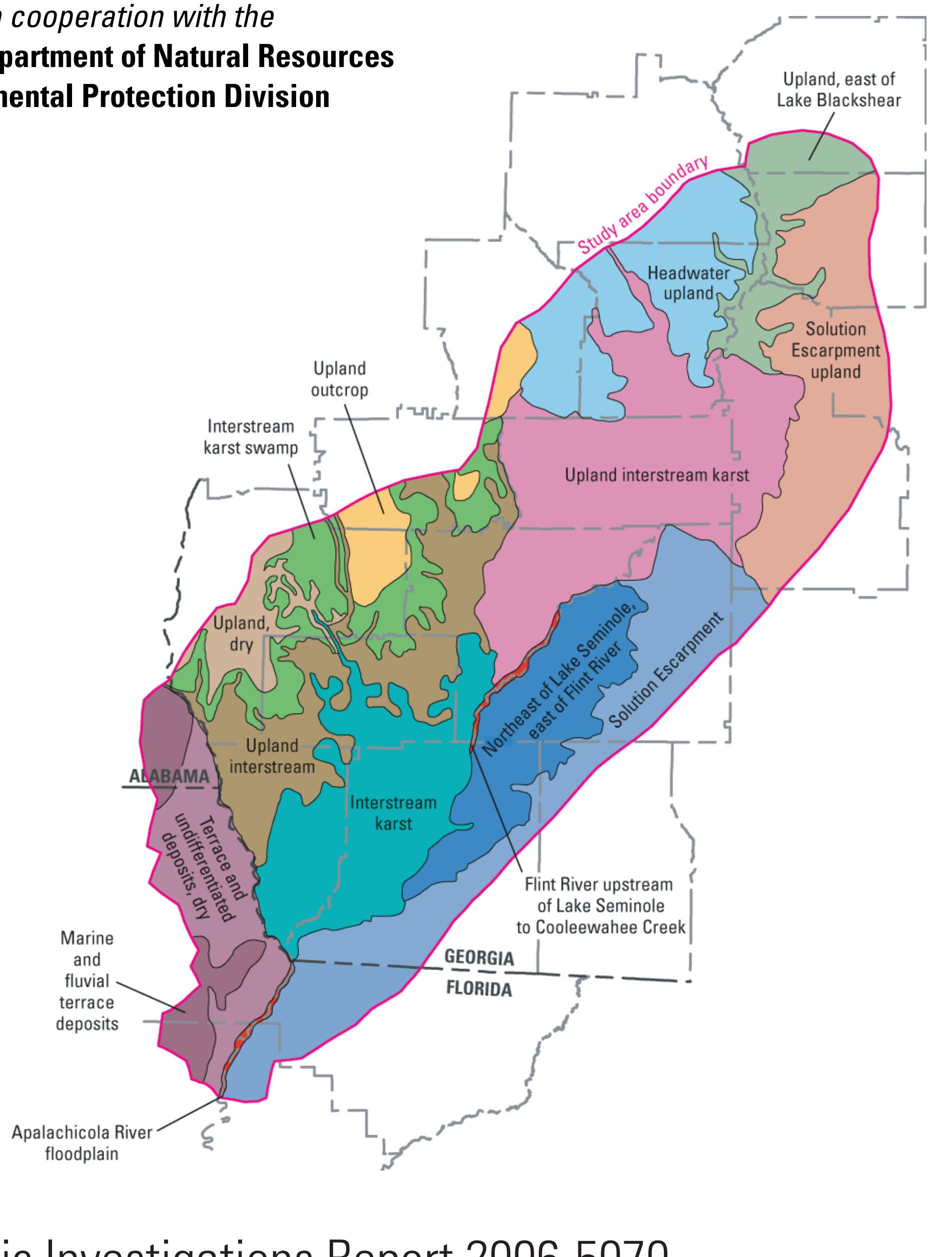
Geohydrology of the Lower Apalachicola–Chattahoochee–Flint River Basin, Southwestern Georgia, Northwestern Florida, and Southeastern Alabama

Prepared in cooperation with the
Georgia Department of Natural Resources
Environmental Protection Division



Scientific Investigations Report 2006-5070

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

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Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
cubic mile (mi^3)	4.168	cubic kilometer (km^3)
	Flow rate	
foot per day (ft/d)	0.3048	meter per day (m/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Transmissivity*	
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32) / 1.8$$

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

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

*Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [$(ft^3/d)/ft^2$]ft. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

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).

NOTE TO USGS USERS: Use of liter (L) as a special name for cubic decimeter (dm^3) is restricted to the measurement of liquids and gases. No prefix other than milli should be used with liter.

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By Lynn J. Torak and Jaime A. Painter

Abstract

The lower Apalachicola–Chattahoochee–Flint (ACF) River Basin contains about 4,600 square miles of karstic and fluvial plains and nearly 100,000 cubic miles of predominantly karst limestone connected hydraulically to the principal rivers and lakes in the Coastal Plain of southwestern Georgia, northwestern Florida, and southwestern Alabama. Sediments of late-middle Eocene to Holocene in hydraulic connection with lakes, streams, and land surface comprise the surficial aquifer system, upper semiconfining unit, Upper Floridan aquifer, and lower semiconfining unit and contribute to the exchange of ground water and surface water in the stream-lake-aquifer flow system. Karst processes, hydraulic properties, and stratigraphic relations limit ground-water and surface-water interaction to the following hydrologic units of the stream-lake-aquifer flow system: the surficial aquifer system, upper semiconfining unit, Upper Floridan aquifer, and lower confining unit. Geologic units corresponding to these hydrologic units are, in ascending order: Lisbon Formation; Clinchfield Sand; Ocala, Marianna, Suwannee, and Tampa Limestones; Hawthorn Group; undifferentiated overburden (residuum); and terrace and undifferentiated (surficial) deposits. Similarities in hydraulic properties and direct or indirect interaction with surface water allow grouping sediments within these geologic units into the aforementioned hydrologic units, which transcend time-stratigraphic classifications and define the geohydrologic framework for the lower ACF River Basin. The low water-transmitting properties of the lower confining unit, principally the Lisbon Formation, allow it to act as a nearly impermeable base to the stream-lake-aquifer flow system.

Hydraulic connection of the surficial aquifer system with surface water and the Upper Floridan aquifer is direct where sandy deposits overlie the limestone, or indirect where fluvial deposits overlie clayey limestone residuum. The water level in perched zones within the surficial aquifer system fluctuates independently of water-level changes in the underlying aquifer, adjacent streams, or lakes. Where the surficial aquifer system is connected with surface water and the Upper Floridan aquifer, water-table fluctuations parallel those in adjacent streams or the underlying aquifer.

The upper semiconfining unit ranges in thickness from a few feet in the northwestern part of the lower ACF River Basin near the outcrop areas of the Upper Floridan aquifer to about 400 feet to the south and east of Lake Seminole in the Tifton Upland and Tallahassee Hills. In some areas in Florida, several hundred feet of unconsolidated clay and sand or low-permeability sediments fill paleosinks and inhibit the exchange of water between land surface and the Upper Floridan aquifer. Sand and clay content of the upper semiconfining unit controls the vertical hydraulic conductivity and influences the rate of vertical leakage of ground water across the top of the Upper Floridan aquifer. Variations in the hydrologic and geologic settings of the lower ACF River Basin have created distinct local patterns of ground-water-level fluctuations that allowed the establishment of 14 geohydrologic zones for identifying local variations in the saturated proportion of total semiconfining-unit thickness basinwide. Differences in the saturated proportion of total thickness influences potential recharge to the Upper Floridan aquifer.

Ground-water levels in the upper semiconfining unit respond to infiltration of precipitation, dry climatic conditions, evapotranspiration, changes in surface-water level, and ground-water withdrawal and discharge (springflow). Drought conditions and heavy rainfall disrupt seasonal patterns of ground-water-level fluctuations by creating either unusually low or high levels, respectively, although water-level data do not indicate long-term declines.

The Upper Floridan aquifer is the principal water-bearing hydrologic unit of the stream-lake-aquifer flow system in the lower ACF River Basin. The diversity and complexity of thickness, lithology, and hydraulic properties within and among the geologic units constituting the Upper Floridan aquifer create equally diverse hydrologic characteristics depending on location in the basin. Hydraulic properties of aquifer transmissivity, hydraulic conductivity, storage coefficient, and specific yield have been enhanced in the Upper Floridan aquifer by limestone dissolution, resulting in increased ground-water flow to wells through interconnected systems of solution openings, fractures, and joints in the limestone, and increased storage capacity of the aquifer and its hydraulic connection with surface water. Stream-aquifer interaction varies in the basin according to the proximity of the aquifer to surface water and degree of hydraulic connection, or separation, of the aquifer from surface water by other hydrologic units. Seasonal ground-water-level response to natural and human-made stresses affects ground-water discharge to streams and reflects the local heterogeneity of hydraulic properties in the aquifer. Increased agricultural pumpage since the mid-1970s and drought conditions from the early to mid-1980s and from 1998 to 2002 caused noticeable declining trends in ground-water level along the Flint River and eastward across the Solution Escarpment into adjacent river basins.

Introduction

The Apalachicola–Chattahoochee–Flint (ACF) River Basin encompasses a narrow area of about 19,256 square miles (mi^2), mostly in western Georgia and partly in southeastern Alabama and northwestern Florida (fig. 1). About 17,230 mi^2 of the ACF River Basin are contained in Georgia and Alabama, and this area is nearly equally divided between the Chattahoochee and Flint Rivers. The remaining 2,026 mi^2 of drainage area in the ACF River Basin are tributary to the Apalachicola River in Florida (U.S. Army Corps of Engineers, 1973). Flow from the Chattahoochee and Flint Rivers is tributary to Lake Seminole, a human-made impoundment located at the Georgia–Florida State line that provides headwater to the Apalachicola River at Chattahoochee, Florida. The Apalachicola River flows about 107 miles (mi) southward from Lake Seminole through the panhandle of northwestern Florida to Apalachicola Bay and the Gulf of Mexico. Flow in the Apalachicola River is important to the ecology and economy of the region surrounding the floodplain and estuary, affecting navigation, flow regulation, and the supply of nutrients and detritus that are critical for sustaining a variety of aquatic biota including a diverse shellfish population in Apalachicola Bay.

The principal rivers and tributaries of the lower ACF River Basin drain karstic and fluvial plains that are connected hydraulically to the Upper Floridan aquifer, which is part of one of the most productive aquifers in the United States. The Upper Floridan aquifer contains nearly 100,000 cubic miles of predominantly karst limestone (Bush and Johnston, 1988) and is the primary source of ground water for agriculture, industry, and public supply in the lower ACF River Basin. Irrigation pumpage represents the major use of ground water in this predominately agricultural region. Ground water from about 4,000 wells completed in the Upper Floridan aquifer irrigates nearly one-half million acres (James E. Hook, National Environmentally Sound Production Agricultural Laboratory, The University of Georgia, Tifton, Georgia, written commun., November 2002). During 2002, ground-water withdrawal from the Upper Floridan aquifer in the Flint River Basin totaled about 123 billion gallons (Hook and others, 2005).

Hydraulic connection of the Upper Floridan aquifer with surface water in the lower ACF River Basin occurs directly through many karst sinks, sinkhole ponds, and conduits that expose limestone at the surface, and through incised streambeds where streams flow over the limestone. Indirect hydraulic connection of the aquifer with surface water occurs by leakage through undifferentiated overburden consisting of alluvium and chemically weathered limestone (residuum), which mantles the aquifer across much of the area. Many springs feed streams that flow directly on limestone of the Upper Floridan aquifer. Streams have gaining and losing characteristics that change seasonally and along relatively short distances. Some streams disappear into limestone sinks and caverns, flow underground, and reappear elsewhere, emanating from solution openings in the limestone.

During the early and mid-1990s, the ACF River Basin gained prominence as Georgia, Florida, and Alabama argued within the courts about the basin's finite water resources (U.S. Army Corps of Engineers, 1997). Increases in population, agriculture, and industry and the drought from 1998 to 2002 made water supply and use in the lower ACF River Basin a major concern for water managers in the three States. The three States signed the ACF River Basin Compact[1] during 1997, intending to ensure equitable use and availability of water resources in the region while protecting river ecology. After 6 years of negotiations, the States failed to reach a water-sharing agreement by the deadline of July 2003, and the tristate decision of water allocation in the ACF River Basin reverted to the courts (Shelton, 2005).

The Georgia Environmental Protection Division (GaEPD) is in the process of implementing a Regional Water Development and Conservation Plan for the Lower Flint River Conservation Reserve Area, an area roughly coincident with the study area in Georgia (fig. 1). The plan, termed *Flint River Basin*

[1]As adopted by the Alabama Legislature on February 18, 1997, and signed by the Governor of Alabama on February 25, 1997, as Alabama Acts 97-67, Alabama Code, Title 33-19-1 *et seq*.; the Florida Legislature on April 14, 1997, and signed by the Governor of Florida on April 24, 1997, as Chapter 97-25, Laws of Florida, Section 373.71, Florida Statutes (1997); the Georgia Legislature on February 11, 1997, as Georgia Acts No. 7, and signed by the Governor of Georgia on February 25, 1997, as Georgia Code Annual Section 12-10-100 *et seq*., and passed by the United States Congress on November 7, 1997, and signed by the President of the United States on November 20, 1997, as Public Law Number 105-104, 111 Statute 2219.

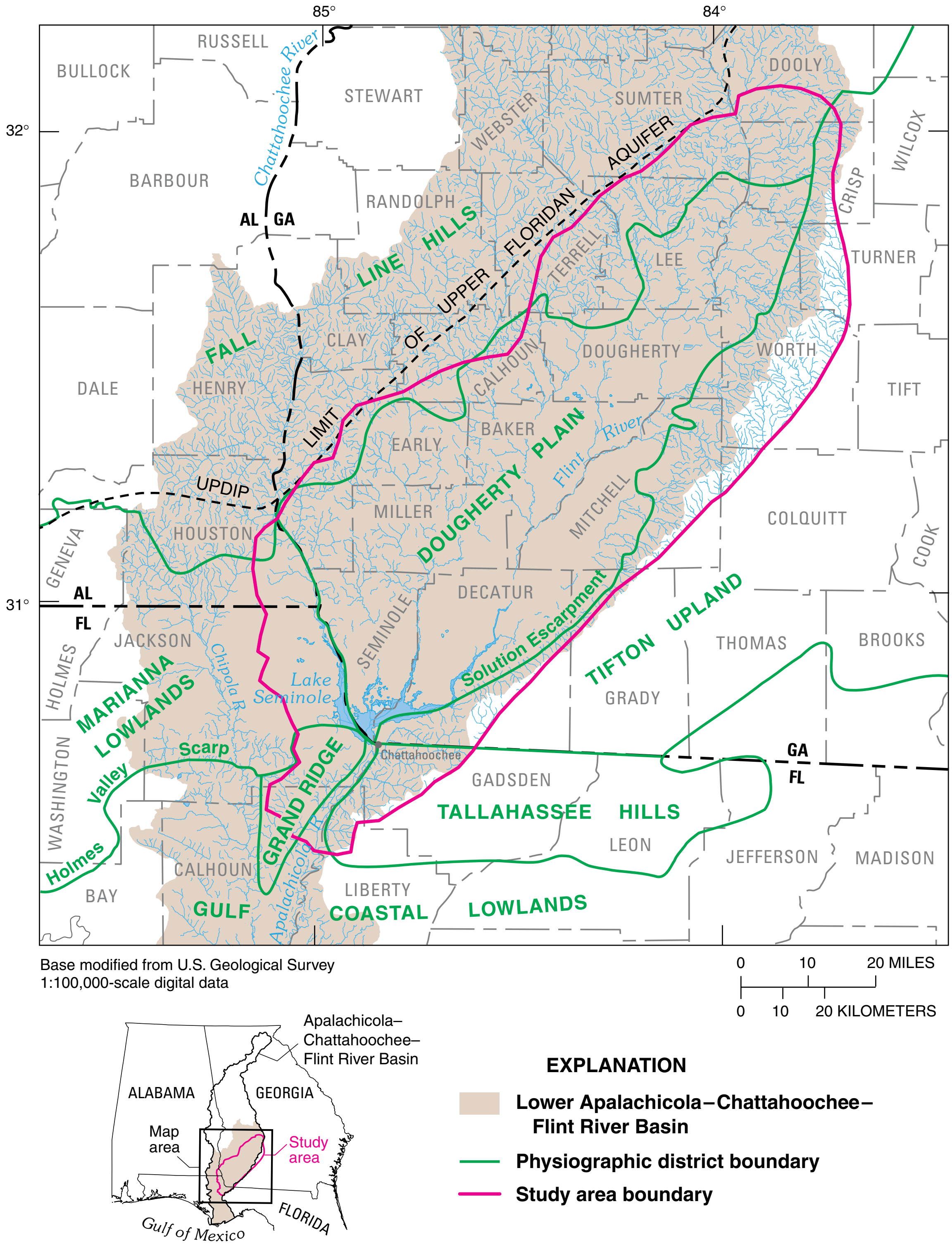


Figure 1. Location of study area, boundary of the lower Apalachicola–Chattahoochee–Flint River Basin, and physiographic districts of the Coastal Plain province, Georgia, Florida, and Alabama (modified from Torak and others, 2006).

Plan, is designed to "promote the conservation and reuse of water, guard against a shortage of water, and promote efficient use of the water resource" (Georgia Environmental Protection Division, 2005). Implementation of the plan includes a hydrologic assessment of the Upper Floridan aquifer in southwestern Georgia and an update of an existing digital model of ground-water flow (William H. McLemore, then-Georgia State Geologist, Georgia Department of Natural Resources, Environmental Protection Division, Geologic Survey, Atlanta, Ga., written commun., May 2000). During 1999, the GaEPD requested that the U.S. Geological Survey (USGS) engage in a cooperative investigation to "develop considerable new data" in support of the hydrologic assessment of the Upper Floridan aquifer. The investigation incorporated site-specific hydrologic measurements into an updated version of the digital model developed by Torak and McDowell (1996) to simulate time-variant (transient) ground-water flow and stream-aquifer interaction (Harold F. Reheis, then-Director, Georgia Environmental Protection Division, Atlanta, Ga., written commun., April 1999). State water officials most likely will use the model as a management tool to provide an early indication of low-streamflow and ground-water-level conditions that might occur within the basin, and as a predictor of low streamflow in the Apalachicola River at the Georgia–Florida State line at Chattahoochee, Fla. Analysis of model results most likely will provide the basis of a method to notify specific agricultural-water users of possible restrictions on irrigation withdrawal during an upcoming growing season (Harold F. Reheis, then-Director, Georgia Environmental Protection Division, Atlanta, Ga., written commun., April 1999).

The following study objectives represent the role of the USGS in assisting the State of Georgia to implement the Flint River Basin Plan:

- Increase current understanding of the hydrogeologic framework that controls stream-aquifer relations and flow-system processes in the lower ACF River Basin through analysis of recent subsurface data.

- Devise and direct a program of boring, well drilling and installation, and aquifer testing to acquire hydrogeologic information in areas where data are lacking.

- Establish a hydrologic data-collection network suitable for assessing stream-aquifer relations, recharge, and withdrawal from the Upper Floridan aquifer.

- Incorporate newly acquired and existing hydrologic data into a transient finite-element model of ground-water flow capable of simulating seasonal ground-water-level and streamflow conditions and pumpage-induced streamflow reduction (William H. McLemore, then-Georgia State Geologist, Georgia Department of Natural Resources, Environmental Protection Division, Georgia Geologic Survey, Atlanta, Ga., written commun., May 2000).

Purpose and Scope

This report is the second in a series of reports describing work performed by the USGS that contributes to a hydrologic assessment of the Upper Floridan aquifer in southwestern Georgia, as part of the State of Georgia's Flint River Basin Plan. A report by Mosner (2002) described stream-aquifer relations in the lower ACF River Basin, effects of drought on the ground-water level of the Upper Floridan aquifer, and ground-water discharge to (or baseflow of) streams, partially addressing the first study objective, listed previously. The current report addresses the first three objectives listed in the previous section by describing the geologic and hydrologic setting of the stream-aquifer flow system comprising the Upper Floridan aquifer, overlying and underlying hydrologic units, and surface water.

This report focuses on the *geohydrology* or fluid-flow aspects of ground water (Davis and DeWiest, 1966) contained in the Upper Floridan aquifer and in overlying and underlying hydrologic units. Thus, the report contains maps, tables, charts, and diagrams describing the areal and vertical extent of hydrologic units and corresponding hydraulic properties, aquifer-recharge mechanisms, interaction of hydrologic units with surface water, and ground-water-level fluctuations, which are assumed to govern ground-water flow and affect water-resource potential in the Upper Floridan aquifer. Discussions contained in the report use subsurface sections that depict geologic and hydrologic units in the southern part of the lower ACF River Basin, developed previously by Torak and others (2006), to increase current understanding of the hydrogeologic framework that controls stream-aquifer relations and flow-system processes. Geologic and hydrologic information from recent test boring, well drilling, and aquifer testing (Katherine H. Zitsch, Project Manager, Camp, Dresser & McKee Inc., Atlanta, Ga., written commun., October 2004) supplemented and refined current information and information that had become known during and since the investigation by Torak and McDowell (1996) (appendix A). These data aided in the development of geohydrologic descriptions and illustrations contained in this report. Illustrations and tables containing hydrologic data collected from a network of streamgaging stations and monitor wells describe the relation of monitor sites to ground-water-level fluctuations and streamflow.

Geologic nomenclature used herein is consistent with previous hydrologic investigations performed in the study area and described in reports by Wagner and Allen (1984), Miller (1986), Torak and McDowell (1996), Torak and others (1996), Albertson and Torak (2002), Mosner (2002), Jones and Torak (2004), and Torak and others (2006). Although other investigators have proposed different names for the geologic units described herein, use of an alternate geologic nomenclature would deter from the purpose of this report, which supports the first objective stated previously, namely, to increase current understanding of the hydrogeologic framework that controls stream-aquifer relations and flow-system processes. Alternate naming conventions of geologic units will be presented and cited for reference, where appropriate.

Previous Studies

Many investigators have studied the regional geology, physiography, geohydrology, and ground-water resources of the Upper Floridan aquifer in the lower ACF River Basin since the 1890s. A summary of these investigations appears in Torak and others (2006); some of these references are included herein. A study by McCallie (1898) first described the general geology and ground-water resources of the Coastal Plain; this study was followed by similar studies by Stephenson and Veatch (1915), Cooke (1939, 1943), and Herrick (1961).

Wait (1963), Sever (1965a, b), Pollard and others (1978), and Hicks and others (1981, 1987) described detailed investigations of geologic formations, water-bearing properties, and the hydrology of selected parts of the lower ACF River Basin. Moore (1955), Kwader and Schmidt (1978), Schmidt (1978, 1979, 1984), Schmidt and Coe (1978), Schmidt and Clark (1980), and Schmidt and others (1980) investigated the geology of parts of the lower ACF River Basin in Florida near Lake Seminole. Arthur and Rupert (1989) investigated details of basin physiography. A preimpoundment survey identified details of the geology, hydrogeology, and structural integrity of foundation material to Jim Woodruff Lock and Dam (U.S. Army Corps of Engineers, 1948). Hayes and others (1983) defined geohydrologic and hydraulic characteristics of the Floridan aquifer system (formerly called *principal artesian aquifer system*) in southwestern Georgia, and developed a hydrologic budget and digital model that quantified aquifer-system response to real and hypothetical increases in ground-water withdrawal. Torak and others (1993, 1996) and Torak and McDowell (1996) updated the geohydrology of parts of the lower ACF River Basin from that described by Hayes and others (1983), investigated stream-aquifer relations, and simulated the effects of ground-water withdrawal on streamflow and water levels in the Upper Floridan aquifer. Mosner (2002) described stream-aquifer relations and ground-water-level conditions in the lower ACF River Basin during the drought years of 1999 and 2000, and computed aquifer contribution to streamflow for specific reaches. Jones and Torak (2004) described the geohydrology of the area surrounding Lake Seminole in southwestern Georgia, and simulated the effects of impoundment on ground-water flow in the Upper Floridan aquifer. Torak and others (2006) cited physical and hydrochemical evidence of hydraulic connection between surface water and ground water beneath and around Lake Seminole and Jim Woodruff Lock and Dam, and documented the complex exchange of surface water and ground water between the lake, streams, and aquifer.

Well and Climatological-Station Identification and Surface-Water Station Numbering Systems

A system based on USGS topographic maps identifies wells in Georgia. Each 7½-minute topographic quadrangle map in Georgia has been given a number and letter designation beginning at the southwest corner of the State. Numbers increase eastward through 39; letters advance northward through “Z,” then double-letter designations “AA” through “PP” are used. The letters “I,” “O,” “II,” and “OO” are not used. Wells inventoried in each quadrangle are numbered sequentially beginning with “1.” Thus, the forty-eighth well inventoried in the Albany West quadrangle (designated 12L) in Dougherty County is designated 12L048. Wells in Florida are numbered with a four-digit code that is assigned by the Northwest Florida Water Management District, for example, 8038 (Christopher J. Richards, Senior Hydrogeologist, Northwest Florida Water Management District, Havana, Fla., written commun., April 2000).

Climatological stations are given a name that corresponds to the nearest city, town, or locality; figures and letters following the name indicate the distance in miles and direction from the post office or town community center, such as Albany 3 SE (National Oceanic and Atmospheric Administration, 2002). Exceptions to this naming convention are “Plains SW GA EXP STN” and “Bainbridge International Paper.”

Partial- and continuous-record surface-water stations are given an identification number that is assigned in “downstream order” (Stokes and others, 1990). No distinction is made between partial-record stations and other stations; therefore, the number for a partial-record station indicates downstream-order position in a list made up of both types of stations. The complete number for each station includes a 2-digit part number “02” plus the downstream-order number, which can contain from 6 to 12 digits.

Study Area

The study area is located in the lower ACF River Basin of the Coastal Plain physiographic province in parts of southwestern Georgia, northwestern Florida, and southeastern Alabama, and consists of the land area that contributes ground water and surface water to the Upper Floridan aquifer, about 4,632 mi^2 (fig. 1). In Georgia, the study area includes all or parts of the following counties: Baker, Calhoun, Colquitt, Crisp, Decatur, Dooly, Dougherty, Early, Grady, Lee, Miller, Mitchell, Seminole, Sumter, Terrell, Turner, and Worth. In Florida, the study area is contained within Calhoun, Gadsden, Jackson, and Liberty Counties; a small part of the study area is located in Houston County, Alabama.

Climate

The climate of the lower ACF River Basin is humid subtropical, defined by long summers and mild winters (Sever, 1965a). Temperature and precipitation vary seasonally and areally across the basin, due to the proximity of the basin to the Gulf of Mexico and the length of the basin, which spans about 150 mi in a northeast-to-southwest direction (fig. 2; tables 1 and 2). The coldest months, December and January, average about 51.4 degrees Fahrenheit (°F) in the southern part of the basin (near Colquitt, Ga.) and about 44.7°F to the north (near Plains, Ga.) (fig. 2); freezing temperatures, however, can occur during this time. The warmest months, July and August, average about 80°F at both locations, although temperatures near 100°F are common. The mean-annual air temperature at Colquitt is about 66.4°F (table 1) for the 47-year period from 1957 to 2003. The mean-annual air temperature is about 64°F at Plains (table 2), for the 48-year period from 1956 to 2003.

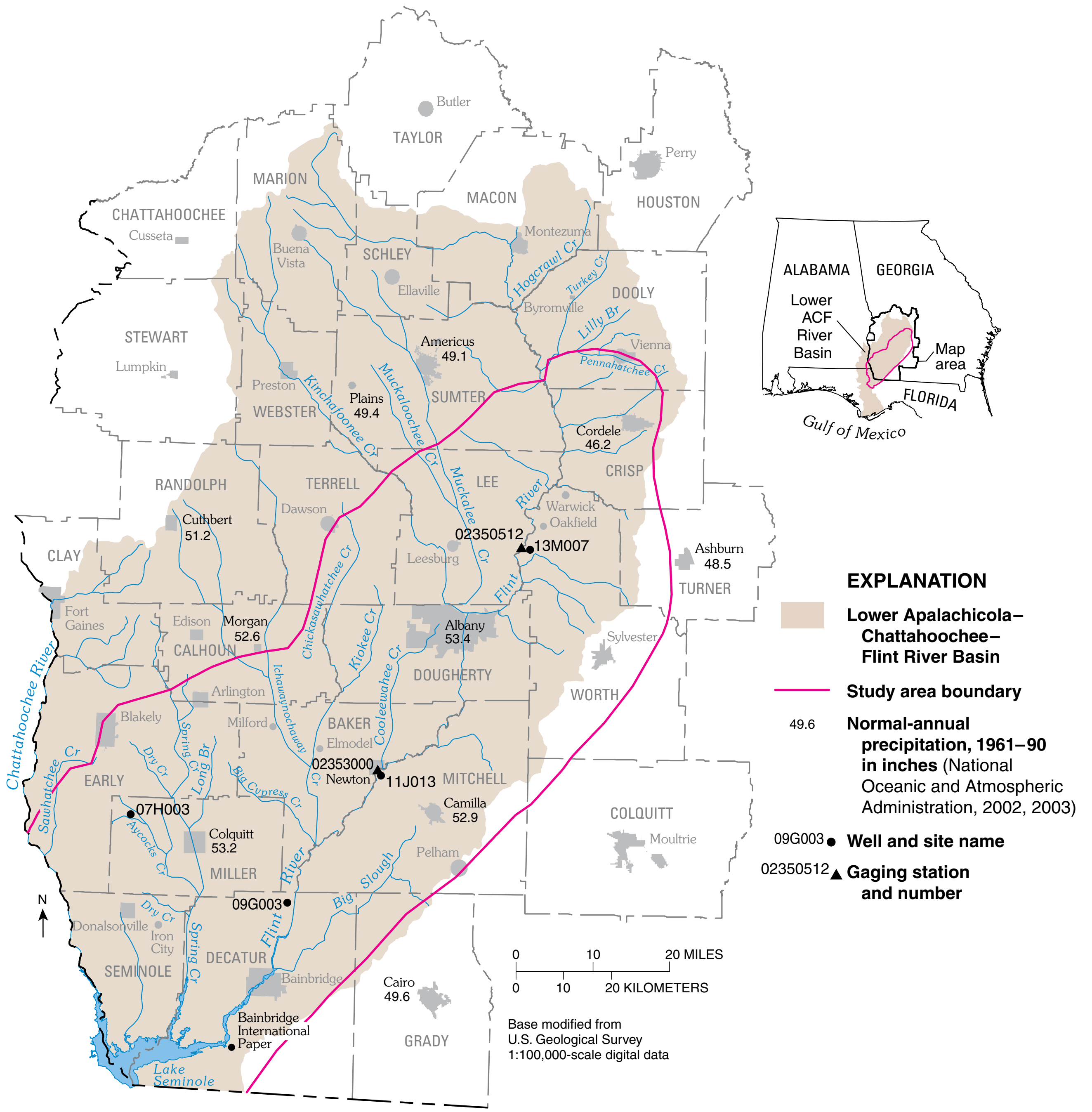


Figure 2. Normal annual precipitation at National Oceanic and Atmospheric Administration climatological stations for the averaging period 1961–90; selected climatological and streamgaging stations and wells where hydrologic data (stream and well hydrographs and rainfall graphs) are available interactively in and near the lower Apalachicola–Chattahoochee–Flint River Basin in Georgia. (Click on station name, location, or well to view graphs interactively or see Appendix B for all graphs. Precipitation data from National Oceanic and Atmospheric Administration, 2002, 2003.)

Table 1. Climate data for Colquitt, Georgia[1].

[°F, degree Fahrenheit]

Month	Average maximum temperature (°F)	Average minimum temperature (°F)	Average precipitation (inch)
January	61.2	38.1	5.29
February	65.3	41	4.7
March	72.1	46.9	6.14
April	79.7	53.4	3.83
May	85.6	60.4	3.58
June	90.1	67.3	5.36
July	91.9	70	5.41
August	91.2	69.6	4.96
September	88	65.7	4.44
October	80.1	54.5	2.6
November	71.8	46	3.38
December	64	39.9	4.23
Average	**78.4**	**54.4**	**Total = 53.92**

Mean-annual air temperature	66.4°F
Average air temperature	
July and August	80.7°F
December and January	51.4°F

[1]See figure 2 for location; data from National Oceanic and Atmospheric Administration climatological station "COLQUITT 2 W," index number 2153, Colquitt, Miller County, Ga., latitude 31°10'01"N, longitude 84°46'01"W, for the period 1957–2003. Source: Georgia Automated Environmental Monitoring Network, the University of Georgia, College of Agriculture and Environmental Sciences, Griffin Experiment Station, Griffin, Ga. (accessed March 23, 2005, at *http://georgiaweather.net*).

Table 2. Climate data for Plains, Georgia[1].

[°F, degree Fahrenheit]

Month	Average maximum temperature (°F)	Average minimum temperature (°F)	Average precipitation (inch)
January	56.8	34.7	5.00
February	61.3	37.6	4.63
March	68.2	44.2	5.43
April	76.5	51.6	3.48
May	83.5	59.7	3.31
June	88.3	66.2	4.76
July	90.5	69.1	5.33
August	89.6	68.4	4.04
September	85.5	63.5	3.47
October	77.4	52.5	2.38
November	68.4	43.9	3.3
December	60.1	37	3.92
Average	**75.5**	**52.4**	**Total = 49.06**

Mean-annual air temperature	64°F
Average air temperature	
July and August	79.4°F
December and January	44.7°F

[1]See figure 2 for location; data from National Oceanic and Atmospheric Administration climatological station "PLAINS SW GA EXP STN," index number 7087, Plains, Sumter County, Ga., latitude 31°03'N, longitude 84°22'W, for the period 1956–2003. Source: Georgia Automated Environmental Monitoring Network, the University of Georgia, College of Agriculture and Environmental Sciences, Griffin Experiment Station, Griffin, Ga. (accessed March 24, 2005, at *http://georgiaweather.net*).

Normal[2] annual precipitation ranges from about 46.2 inches at Cordele, Ga., in the northern part of the basin, to about 53.2 inches at Colquitt, Ga., to the south (fig. 2), for the climate-averaging period from 1961 to 1990 (National Oceanic and Atmospheric Administration [NOAA], 2003). Average annual precipitation for the period of record at these sites (47 years at Colquitt from 1957 to 2003; and 48 years at Plains from 1956 to 2003) (tables 1 and 2) varies slightly from the normal precipitation for the climate period from 1961 to 1990, established by the NOAA (National Oceanic and Atmospheric Administration, 2003). Although precipitation is fairly uniformly distributed throughout the year, most of the recharge to the aquifer occurs from December through March, when storms associated with frontal passages bring relatively long-duration (from 2 to 3 days), low-intensity rainfall to the study area, and evapotranspiration rates are low. Rainfall events of this type are conducive to high infiltration and low runoff, in contrast with summer rainfall, which is usually of short duration and high intensity, derived from convective-type thunderstorms that cause high runoff and low infiltration (Torak and others, 2006).

The extent and severity of the drought from 1998 to 2002 affected several parts of the lower ACF River Basin differently than others. In the northern and central parts of the study area near Americus, Camilla, Cuthbert, and Morgan, Ga., monthly precipitation and departure from normal precipitation recovered slightly from the drought during the first half of 2001 (interactive map, fig. 2. Click on location of climatological stations shown on figure 2 to view rainfall graphs. Subsequent references to interactive components of figure 2 [stream and well hydrographs and rainfall graphs] are indicated by the words "interactive map," which precedes the reference to figure 2 in the text for the interactive component, for example "interactive map, fig. 2." Appendix B has all interactive components.)

[2]Climate data normals: The average value of the meteorological element (for example, precipitation and temperature) during a period. Effective January 1, 1993, the averaging period is from 1961 to 1990. The normals for National Weather Service localities have been adjusted to be representative for the current observation site (National Oceanic and Atmospheric Administration, 2003).

In the southern part of the basin near Camilla, Cairo, and Colquitt, Ga., drought conditions persisted for the remainder of 2001 and through the first half of 2002 (interactive map, fig. 2). To the north of the study area in Plains, Ga., monthly rainfall deficits accumulated to a maximum of nearly 9 inches during August 2002 before surplus rainfall during the following 4 months nearly eliminated the yearly deficit (interactive map, fig. 2). Likewise, to the south and east of the study area in Cairo, Ga., the rainfall deficit reached a maximum of 10 inches during August before recovering about 9 inches with 4 months of above-normal rainfall (interactive map, fig. 2). Near Ashburn, Ga., along the northeastern boundary of the study area, the 6-inch rainfall deficit that had accumulated during the first 2 months of 2001 was eliminated by October; however, below-normal rainfall during 9 of the next 10 months caused a maximum rainfall deficit of nearly 14 inches to occur during August 2002 (interactive map, fig. 2). Normal to above-normal precipitation fell on the basin during the last half of 2002, although cumulative departures from normal precipitation remained negative during 2001 and 2002, with some locations indicating precipitation deficits from 12 to 13 inches (Albany and Morgan, Ga.) (interactive map, fig. 2). An exception to negative departures from normal precipitation for 2002 occurred in Colquitt, Ga., which overcame a 7-inch deficit during May to finish the year with a 15-inch surplus (interactive map, fig. 2).

Physiography and Drainage

The study area is located in the Coastal Plain physiographic province and contains three distinctive regions: a low-lying karstic region; a region of dissected remnant hills and sand-hill ridges; and a flat, low-lying, coastal-sediment region. The karstic region includes the Dougherty Plain, Marianna Lowlands, and Tifton Upland physiographic districts (fig. 1). In the Florida panhandle, the Dougherty Plain district is called the *Marianna Lowlands district*, and the Tifton Upland district is called the *Tallahassee Hills district* (fig. 1) (Puri and Vernon, 1964). The boundary between the Dougherty Plain and Tifton Upland districts in Georgia is a regionally prominent northwest-facing escarpment called the *Solution Escarpment* (MacNeil, 1947), or *Pelham Escarpment* (Hayes and others, 1983). In the southern part of the study area in Florida, the Holmes Valley Scarp separates the Marianna Lowlands district from the Grand Ridge region, a topographically high area containing dissected remnant hills and sand-hill ridges (Schmidt and Coe, 1978). The Gulf Coastal Lowlands contains the flat, low-lying coastal-sediment region in Florida (fig. 1).

The Dougherty Plain is nearly flat and consists of internally drained limestone that forms a low cuesta extending from the southeastern corner of Alabama into Florida and Georgia (fig. 1) (Fenneman, 1938). The infacing scarp of the Dougherty Plain is located in Georgia and Alabama along the northwestern study area boundary at land-surface altitudes ranging from about 400 to 500 feet (ft). The scarp is not well defined everywhere; however, it is deeply notched everywhere from stream-channel development (Fenneman, 1938). East of the Chattahoochee River, the plain slopes southeastward to the Flint River, with land-surface altitudes ranging from about 300 ft along parts of the northern boundary to about 150 ft along the southeastern boundary with the Tifton Upland, and to about 50 ft near Lake Seminole.

The most noticeable features of the Dougherty Plain are shallow, flat-bottomed or rounded depressions made by limestone dissolution (Fenneman 1938). Limestone dissolution exerts the greatest influence on shaping the landscape. Many shallow sinks and depressions—ranging in size from a few tens of feet in diameter to several hundred acres, with some containing water year round—dot the landscape and provide evidence of active solutioning in the limestone aquifer.

The Dougherty Plain contains subsurface, internal drainage (fig. 1), typical of karst topography (Herrick and LeGrand, 1964; LeGrand and Stringfield, 1966; Longwell and others, 1969). Surface-water drainage occurs where Eocene limestone crops out or subcrops beneath the overburden. Mainstem streams flow in terraced valleys and cut shallow channels through the overburden to the underlying limestone of the Upper Floridan aquifer.

Evidence of active limestone solutioning exists on and beneath the landscape in the form of sinkholes, sinkhole ponds, marshes, and underground channels, which capture surface drainage. Active solutioning of limestone interrupts the relatively flat terrane of the Dougherty Plain in western Baker and Early Counties, Ga., by forming a prominent ridge that separates surface-water drainage between Ichawaynochaway and Spring Creeks (fig. 2). Formed between two elongated depressions (uvalas) created by limestone sinks, this “interuvala” ridge represents topography that is physiographically younger than the remainder of the Dougherty Plain (Hendricks and Goodwin, 1952). Many sinkholes collect runoff from rainfall, providing direct recharge to the Upper Floridan aquifer; small tributary streams are scarce (Sever, 1965a).

Between the Dougherty Plain and Tifton Upland districts lies the Solution Escarpment, a steeply-sloping escarpment along the southeastern shore of the Flint River impoundment arm to Lake Seminole that extends northeastward across Decatur, Grady, and Mitchell Counties, Ga. (fig. 1). The escarpment provides as much as 125 ft of local relief, and the ridge of the escarpment forms a topographic and surface-water divide between the Flint River Basin and the Ochlockonee River and Withlacoochee River Basins to the east (Torak and others, 1996). The slope of the Solution Escarpment faces west to northwest, and small streams flow northwestward down the escarpment into caves and sinkholes along the eastern edge of the Dougherty Plain (Sever, 1965a). The base of the escarpment contains cavities and sinkholes, but solution features that exist are more narrow and deeper than features contained on the Dougherty Plain (Hicks and others, 1987).

Vernon (1951) subdivided the Coastal Plain province in northwestern Florida into a minor geomorphic unit called the Marianna River Valley Lowlands, or, as Cooke (1939) proposed, the Marianna Lowlands (fig. 1). Like the Dougherty Plain, the Marianna Lowlands contains low, generally flat or rolling topography, which resulted from a complicated sequence of stream erosion, deposition, and capture by several streams, including the Apalachicola and Chattahoochee Rivers, and to a lesser extent from lowering of the surface by limestone dissolution. During recent times, however, processes related to the dissolving of limestone have modified the surface (Schmidt and Coe, 1978). The lowland has been formed since early Pleistocene time by removal and dissection of Miocene clastic sediments, exposing underlying limestone units at the surface. Normal cuestaform topography of a coastal plain rather than karst topography resulted from this erosion (Moore, 1955); well-developed sinkholes and gentle depressions indicative of internal drainage, however, are common (Schmidt and Coe, 1978).

The Marianna Lowlands extends eastward in the panhandle of Florida to the Chattahoochee River and is bounded in southeastern Jackson County, Fla., by the Grand Ridge region, a topographically high section similar in structure and relief to the Tifton Upland and Tallahassee Hills (fig. 1). Land surface in the Grand Ridge region rises above 250 ft altitude and consist of a series of remnant hills and sand-hill ridges dissected by stream valleys (Puri and Vernon, 1964). The ridges are composed of clayey sand, probably Miocene to Pleistocene, that cover the underlying limestone to depths ranging from 100 to 200 ft below the surface (Schmidt and Coe, 1978). The transition from the Marianna Lowlands to the Grand Ridge occurs across an abrupt north-facing slope, termed the *Holmes Valley Scarp* (Schmidt and Coe, 1978), much like in Georgia where the Solution Escarpment separates the Dougherty Plain from the Tifton Upland. Small tributary streams to the Chipola River to the west of the study area extend eastward and northeastward across Jackson County, Fla., producing a north-facing escarpment, which forms the southern boundary to the Marianna Lowlands.

The Tifton Upland in Georgia and Tallahassee Hills in Florida contain gently-rolling hills having broad rounded summits and are situated between the low-lying Dougherty Plain and Gulf Coastal Lowlands. These regions contain high hills largely composed of resistant clayey sand, silt, and clay (Arthur and Rupert, 1989), which slope gently to the southeast. The Tifton Upland in southwestern Georgia is a distinct cuesta with an escarpment nearly 150 ft high overlooking the Flint River (fig. 1) (Fenneman, 1938). Land-surface altitudes in the Tifton Upland and Tallahassee Hills range from about 330 ft near the Florida–Georgia State line to about 100 ft at the southern edge of the region. The higher altitudes of the Tifton Upland contain solution features, some of which are abundant in a broad east-west strip along the Georgia–Florida State line (Fenneman, 1938).

Dendritic drainage of many surface streams dissects the hills and forms deeply incised valleys and ravines (Rupert, 1990) in the otherwise broad, flat plain. Sinkholes and other solution features are absent (Sever, 1965a). The Tifton Upland and Tallahassee Hills end abruptly at the Flint and Apalachicola Rivers, respectively, in steep bluffs, which provide relief ranging from about 150 to 200 ft above the floodplain (Torak and others, 1996) and expose Miocene to Holocene sediments. The Grand Ridge region of southeastern Jackson County, Fla., however, extends the hilly region of the Tallahassee Hills westward into Jackson County, Fla.

The Gulf Coastal Lowlands (fig. 1) consists of sandy, flat, seaward-sloping features shaped mostly by wave and current activity from high sea-level stands during the Pleistocene Epoch (Arthur and Rupert, 1989). Land surface in the lowlands contains relic Pleistocene marine bars, terraces, spits, and sandbar dunes (Leitman and others, 1984). The floodplain of the Apalachicola River occupies the lowlands and separates the Grand Ridge region to the west of the river in Jackson County, Fla., from the Tallahassee Hills to the east in Liberty County, Fla.

Geohydrology

The unique geologic and hydrologic settings of the Upper Floridan aquifer, overlying and underlying hydrologic units, and surface-water features in the lower ACF River Basin control the movement of ground water in the stream-lake-aquifer flow system. Hydrologic characteristics of geologic units that compose the aquifer system combine with natural and human-made stresses to affect the resource and development potential of the Upper Floridan aquifer. Assimilation of relevant geohydrologic data with newly acquired information since the previous investigation by Torak and others (1996) regarding the geology, lithology, and hydrology of the stream-lake-aquifer flow system has refined previous knowledge and understanding of ground-water movement in the Upper Floridan aquifer, stream-aquifer relations, and flow-system processes.

The following sections contain detailed descriptions of the geologic and hydrologic aspects of the stream-lake-aquifer flow system, with emphasis on geohydrologic information acquired since the investigations by Torak and others (1996, 2006). Cited references contain additional details of the geohydrology of the flow system.

Geologic Setting

Geologic units of the stream-lake-aquifer flow system in the lower ACF River Basin consist of late-middle Eocene to Holocene Coastal Plain sediments hydraulically connected with lakes, streams, and land surface that contribute to the exchange of ground water and surface water in the study area. Sediments contained in this flow system include cross-bedded clayey sand, sand, gravel, clay, limestone, dolomite, and limestone residuum, which occur in an off-lapping sequence dipping gently and thickening gradually to the southeast. Geologic units corresponding to these sediments are, in ascending order: Lisbon Formation; Clinchfield Sand; Ocala, Marianna, Suwannee, and Tampa Limestones; Hawthorn Group; undifferentiated overburden (residuum), and terrace and undifferentiated (surficial) deposits (fig. 3).

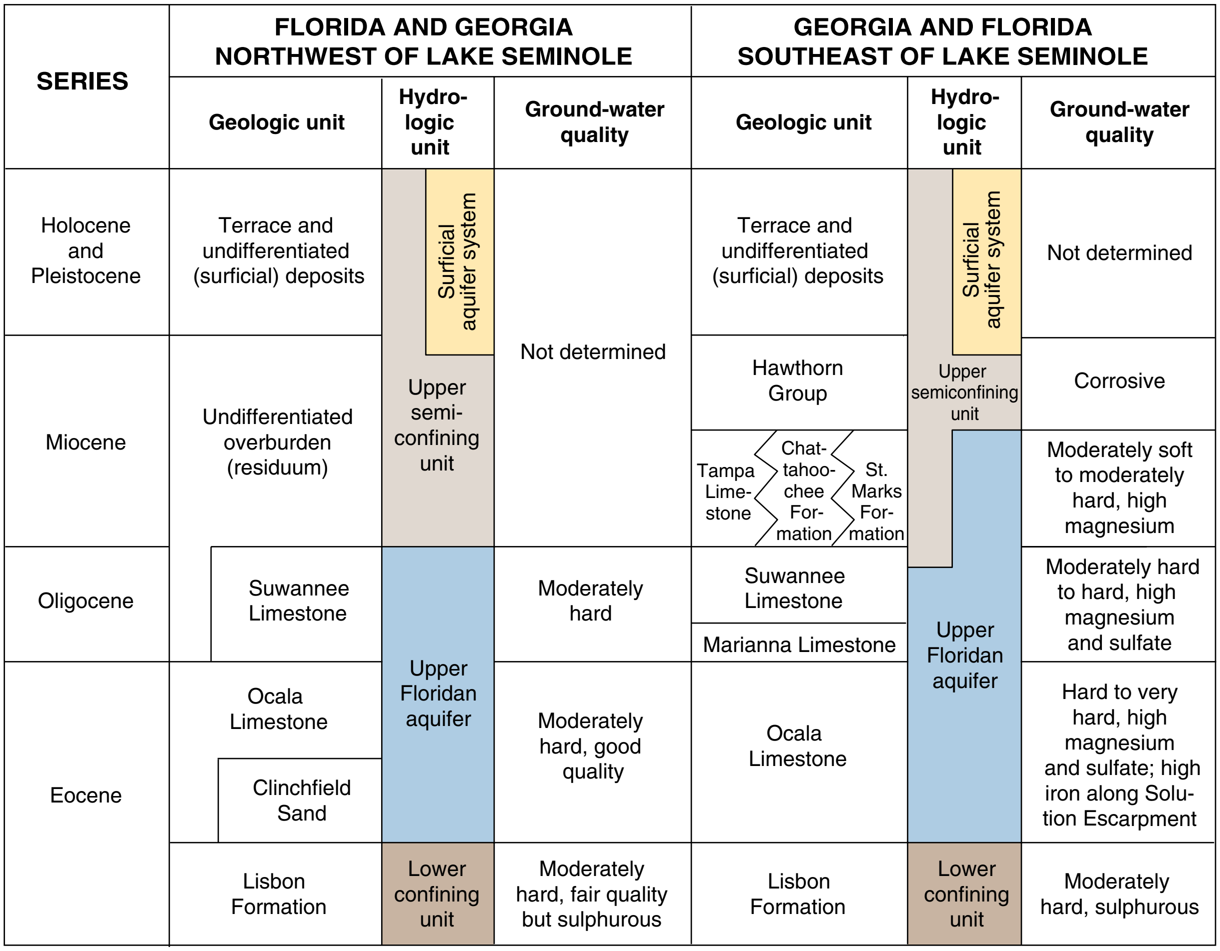


Figure 3. Geologic and hydrologic units and ground-water quality in the lower Apalachicola–Chattahoochee–Flint River Basin (modified from Torak and others, 2006).

The Lisbon Formation defines the lower boundary of the stream-lake-aquifer flow system and consists mainly of gray, interbedded calcareous, glauconitic sand, marl, sandy clay, and clay of late-middle Eocene (Chen, 1965). These sediments crop out north of the study area in western and southern Alabama and southwestern Georgia, where permeable zones in the Lisbon Formation function as aquifers. In northwestern Seminole County, Ga., the Lisbon Formation is about 120 ft thick and consists of gray, sandy, pyritic, glauconitic marl, which yields little water (Sever, 1965a). Downdip, the Lisbon Formation grades into calcareous, glauconitic clay and contains thin-to-thick beds of fine, calcareous, glauconitic sand, and hard, sandy, glauconitic limestone (Miller, 1986). These sediments function as a nearly impermeable base to the Upper Floridan aquifer. A highly glauconitic, sandy, and fossiliferous limestone marks the top of the Lisbon Formation upon which younger, middle-Eocene sediments lie unconformably (Chen, 1965).

The Clinchfield Sand overlies the Lisbon Formation (fig. 3) and crops out in a narrow (less than 5 mi) band through Crisp, Dooly, Lee, and Sumter Counties, Ga., less than 1 mi beyond the updip limit of the overlying Ocala Limestone (Vorhis, 1972). The Clinchfield Sand is an ancient beach deposit consisting of fine- to medium-quartz sand to the east of the study area and a limestone matrix near the Flint River. Huddlestun and Hetrick (1986) have correlated the Clinchfield Sand with deposits in eastern Georgia; however, those deposits are more lithologically variable than the Clinchfield Sand in the study area. Huddlestun and Hetrick (1986) grouped both of these lithologic occurrences into one nomenclature convention by "... expanding the original definition and concept of the formation …" and by "… changing the sense of the formation from Clinchfield Sand to Clinchfield Formation …" (Huddlestun and Hetrick, 1986, p. 22). The Clinchfield Sand is an important aquifer for agricultural use in the lower ACF River Basin, despite its nominal 20-ft thickness. Downdip, the sand grades into the Ocala Limestone (Herrick, 1972).

The late-Eocene Ocala Limestone overlies the Lisbon Formation and the Clinchfield Sand (fig. 3) and consists of a "white bioclastic limestone that is honeycombed with solution cavities" (Sever, 1965a). The Ocala Limestone crops out along the northern half of Jackson County, Fla. (Schmidt and Coe, 1978), and along a southwest-to-northeast trend in Georgia, which forms the northwestern study area boundary (fig. 2). In Jackson County, Fla., the lithology of the Ocala Limestone consists of light yellow to cream to white, granular, permeable, and highly fossiliferous pure limestone with minor amounts of dolomite and calcareous shale, which grade into a highly fossiliferous limestone dominated by large foraminifera. Recrystallization and silicification hardens weathered surfaces locally (Chen, 1965). The lower part of the Ocala Limestone, which is not exposed in Jackson County, Fla., is slightly glauconitic, sandy, and greenish gray (Schmidt and Coe, 1978).

The Florida Bureau of Geology considers the Ocala Limestone to be a group consisting of, in ascending order, the Inglis, Williston, and Crystal River Formations, as Puri (1953b) proposed (Miller, 1986). As Miller noted, however, "Puri's three formations cannot be recognized lithologically even at their type sections and cannot be differentiated in the subsurface" (Miller, 1986, p. B30). Applin and Applin (1944), however, recognized two different rock types in the Ocala Limestone; lithologic distinctions between each rock type are described as they affect the fluid-flow aspects of the Ocala Limestone. Because of the lack of recognition of the Inglis, Williston, and Crystal River Formations within the Ocala Limestone, these names are not used in this report, and subsequent elevation of the Ocala Limestone to group status (creating the Ocala Group), as proposed by Puri (1953b), has not been used herein.

Limestone dissolution and development of karst topography has formed an irregular surface of the Ocala Limestone, and the upper few feet of limestone in the subsurface consists of soft, clayey residuum (Miller, 1986). In extreme southeastern Alabama, the Ocala Limestone thickens to about 300 ft (Torak and others, 1996, pl. 3). The Ocala Limestone is about 250 ft thick at Bainbridge, Ga., thins to about 100 ft to the northwest near Donalsonville, Ga., and is absent farther to the northwest at the Chattahoochee River (fig. 2) (Torak and others, 2006). In Florida, thickness of the Ocala Limestone varies from less than 100 ft in Jackson County to more than 400 ft to the south near the Gulf of Mexico (Chen, 1965). Beneath the Tifton Upland, the Ocala Limestone thickens to about 750 ft and becomes a brown, sacchroidal dolomitic limestone, containing gypsum (Sever, 1965a).

Descriptions of lithologic characteristics by Applin and Applin (1944) and Miller (1986) enabled subdividing the Ocala Limestone into lower and upper units that contain distinct patterns of ground-water movement, or flow regimes (Torak and others, 1996). The upper unit consists of a white, soft, friable, porous coquina composed of large foraminifera, bryozoan fragments, and whole-to-broken echinoid remains, all loosely bound by a matrix of micritic limestone. In the northern part of the study area, the upper unit of the Ocala Limestone is dense, and supplies ground water to the lower unit of the Ocala Limestone through vertical flow. Near Lake Seminole, the upper 10–20 ft of Ocala Limestone yield abundant water to uncased wells (Torak and others, 2006).

The lower unit of the Ocala Limestone consists of fine-grained, soft to semi-indurated, micritic limestone (Miller, 1986). In the northern part of the study area, the lower unit contains recrystallized dolomitic limestone that is very hard, but fractured (David W. Hicks, then-Hydrologist, U.S. Geological Survey, Atlanta, Ga., written commun., 1994); thus, the limestone can transmit ground water horizontally as well as vertically. In a small region to the southeast of the study area on the Tifton Upland, however, wells have penetrated the entire thickness of Ocala Limestone and reported yields of less than 30 gallons per minute (Sever, 1965a).

Lithological and paleontological variations in the Ocala Limestone in northwestern Florida, adjacent to Lake Seminole, affect ground-water flow and have led to local naming of the limestone, which is not discussed herein, but Moore (1955) described in detail. In this area, the Ocala Limestone consists of white to cream, generally soft, granular, permeable, fossiliferous pure limestone, composed almost wholly of the tests of foraminifera and bryozoa (Moore, 1955). In some places, however, the Ocala Limestone has been recrystallized into a hard, dense limestone with local silicification that reduces its ability to transmit ground water (Torak and others, 2006). A local member of the Ocala Limestone is softer and whiter than the surrounding limestone and slightly glauconitic (Moore, 1955), which also might impede ground-water flow. Another member of the Ocala Limestone, described by Moore (1955), is buff to white in color, soft, porous, and fine-grained, and differs paleontologically from the Ocala Limestone in Georgia by the scarcity of large foraminifera. A zone of dense, brown chert is present near the top of the limestone, along with selenite gypsum, which may impede ground-water movement (Torak and others, 2006). The Oligocene Marianna and Suwannee Limestones unconformably overlie the Ocala Limestone in the southern part of the study area. To the north, surficial deposits and residuum conformably and unconformably overlie the Ocala Limestone (fig. 3).

The early Oligocene Marianna Limestone crops out in a narrow band through central Jackson County, Fla., directly south of the Ocala exposures and north of the Suwannee Limestone outcrops (Schmidt and Coe, 1978). The Marianna Limestone is light gray to cream white, generally massive, and much less permeable than the underlying Ocala Limestone, and tends to case-harden as it weathers (Schmidt and Coe, 1978). In Liberty County, Fla., the Marianna Limestone consists of gray to very light orange, chalky, fossiliferous marine limestone (Rupert, 1991). Although only one core penetrated the Marianna Limestone in northwestern Liberty County (well 6901, fig. A1), the Marianna Limestone probably underlies western Liberty County at depths greater than 400 ft below land surface, but pinches out to the east (Rupert, 1991). Outcrops of the Marianna Limestone are not recognized in Georgia; the Suwannee Limestone, however, overlies the Marianna in Florida and is exposed in a narrow band extending eastward from central Jackson County, Fla., through Lake Seminole, and northeastward into Georgia along the Solution Escarpment on the Tifton Upland (fig. 2) (Sever, 1964, fig. 1; Sever, 1965a, pl. 2).

The Oligocene Suwannee Limestone consists of cavernous, cream, fossiliferous limestone (fig. 3), which crops out at the base of the Solution Escarpment and in the coastal terraces in Georgia but is absent from most of the Dougherty Plain (Sever, 1965a). In northwestern Florida, the Suwannee Limestone crops out to the west of Lake Seminole and consists of tan to buff limestone, dolomitic limestone, and dolomite, which are porous and fossiliferous (Schmidt and Coe, 1978). The limestone forms part of the bed of Lake Seminole at the dam and extends about 9 mi up the Chattahoochee River impoundment arm and about 16 mi up the Flint River impoundment arm, bordering the Solution Escarpment (fig. 1) (Sever, 1965a, pl. 2). The limestone contains many silicified masses that also are present in the residual clays and sandy clays (Schmidt and Coe, 1978). Thickness of the Suwannee Limestone varies from about 10 ft in the western part of the study area in Florida, to about 115 ft in Florida to the west of Lake Seminole near the dam, to about 210 ft south of the lake (Moore, 1955). The cavernous nature of the Suwannee Limestone permits it to yield abundant water to wells that are completed in this unit and provides good hydraulic connection with streams and the lake (Torak and others, 2006). Early Miocene sandy clay, clay, and marl or the Tampa Limestone overlies the Suwannee Limestone (Moore, 1955).

The early Miocene Tampa Limestone overlies the Suwannee Limestone and is overlain either by clayey sand and gravel of terrace and undifferentiated deposits or by the Hawthorn Group (fig. 3). The Tampa Limestone is exposed in nearly the entire southern part of Jackson County, Fla., cropping out in a narrow band around the southern margin of the Marianna Lowlands at the Solution Escarpment where it is from about 20 to 40 ft thick. The limestone is absent from the Dougherty Plain and much of the coastal terraces. The Tampa Limestone underlies the high-relief region of the Tifton Upland and southern part of the study area in Florida. The Tampa Limestone exists south of the Tifton Upland and to the east of the study area in Georgia where it attains a maximum thickness of nearly 250 ft. Jim Woodruff Lock and Dam is emplaced in the Tampa Limestone, which is about 170 ft thick, and thins to about 100 ft in the western part of the study area in Florida (Reves, 1961). The upper 130 ft of Tampa Limestone is above the altitude of the Apalachicola River at the dam (about 44 ft above North American Vertical Datum of 1988 [NAVD 88]), and about 97 ft of Tampa Limestone is above the altitude of Lake Seminole (about 77 ft above NAVD 88). Near the dam, the Tampa Limestone composes the valley walls, although the appearance is chalky (U.S. Army Corps of Engineers, 1948). Large streams that dissect the Tifton Upland expose the limestone in valleys and channel bottoms (Sever, 1965a).

The Tampa Limestone generally consists of white to light-gray, sandy, hard-to-soft, locally clayey, fossiliferous limestone (Miller, 1986) containing white, gray, and green clay, which commonly are calcareous (Moore, 1955). Near Jim Woodruff Lock and Dam, the Tampa Limestone consists of white, sandy, and shaly limestone, with beds of green "plastic" clay, fine sandy to clayey marl, and fine beds of scattered quartz sand interbedded within the upper 110 ft of thickness (Moore, 1955). Ground-water levels in limestone layers interspersed with clay are higher than either Lake Seminole or the Apalachicola River because the clay impedes vertical ground-water movement from land surface to the limestone below. Most domestic and some industrial wells are completed in the Tampa Limestone because the depth to limestone of the Upper Floridan aquifer beneath the Tifton Upland is greater than 400 ft (Sever, 1965a).

Fine quartz sand within shaly limestone, which typically weathers to gray and white sandy clay, characterizes the Tampa Limestone (Schmidt and Coe, 1978). Lithology of the Tampa Limestone grades from being calcareous in the southeastern part of Jackson County, Fla., to shaly in the western and northwestern parts of the county (Reves, 1961). Puri (1953a) called these gradational components, or facies, formations in the Florida panhandle, where a calcareous downdip facies is termed the *St. Marks Formation*, and an updip silty facies is termed the *Chattahoochee Formation*. The Tampa Limestone is the westward gradation of sediments in the central panhandle called the *Chattahoochee Formation* (Scott, 1992). Northward into Georgia, the Chattahoochee Formation grades into the basal Hawthorn Group (fig. 3) (Huddlestun, 1988); and eastward, the Chattahoochee Formation grades into the St. Marks Formation (Puri and Vernon, 1964; Scott, 1986). Each facies contains a distinct ground-water level and flow pattern and functions uniquely in the Upper Floridan aquifer system.

Two distinct, areally segregated facies in the Tampa Limestone affect water-bearing properties of the formation and stream-lake-aquifer interaction. East of the Apalachicola River and downdip of the Solution Escarpment in Gadsden County, Fla., a transitional area exists where the calcareous St. Marks Formation on the east and south interfingers with the siliciclastic and dolomitic Chattahoochee Formation to the west (Rupert, 1990). In this area, clay layers are interspersed with limestone in the Tampa Limestone and are quite resistant, blocky, and tough, impeding the movement of ground water between the overlying Hawthorn Group and the underlying limestone of the Upper Floridan aquifer. The clays are eroded effectively only by stream abrasion (Moore, 1955), and land surface in this area has greater relief than in areas underlain by pure limestone. West of the Apalachicola River, the Tampa Limestone is calcareous and highly dissected by streams, and water levels in the Tampa Limestone are similar to those in the underlying limestone of the Upper Floridan aquifer.

The middle-Miocene Hawthorn Group is a complex series of phosphate-bearing sediments that overlies the Tampa Limestone (fig. 3), and consists of interbedded varicolored clay, clayey sand, and sandy clay in the upper part, and thin beds of calcareous sand and sandy limestone in the lower part (Sever, 1965a). Carbonate sediments of the Hawthorn Group are primarily fine-grained and contain varying proportions of clay, silt, and phosphate. Siliciclastic sediments comprise fine- to coarse-quartz sand, quartz silt, and clay minerals in widely varying proportions and form an effective confining unit. The carbonate sediments may be permeable enough locally to form the upper part of the Upper Floridan aquifer (Scott, 1992). Sands in the upper part of the formation yield water to dug and bored wells (Sever, 1965a).

The top of the Hawthorn Group is a highly irregular erosional and karstic surface with distinct local relief in the study area (Scott, 1992). The Hawthorn Group crops out in the valleys of large streams in the Tifton Upland (Sever, 1965a). The Hawthorn Group contains lenses of green-to-gray fuller's earth (U.S. Army Corps of Engineers, 1948, p. II-2-1), which is commercial-grade palygorskite clay that is mined just east of the study area in Gadsden County, Fla., and north into Georgia (Rupert, 1990). Near Jim Woodruff Lock and Dam, the Hawthorn Group is about 40 ft thick and consists of sandy clay and fine to medium sand.

An unnamed late-Miocene sand-and-gravel deltaic deposit overlies the Hawthorn Group to the east of Lake Seminole on the Tifton Upland and contains up to 100 ft of red clayey sand and gravel with hematite concretions (Sever, 1965a). This deposit consists of a series of cross-bedded coarse sand and gravel, which is visible at the surface on the tops of hills in the Tifton Upland. Although this deposit can supply water to dug and drilled wells, the water is corrosive and contains high iron concentrations (Sever, 1965a).

Undifferentiated overburden (residuum) consisting of late-Miocene and younger alluvial deposits and chemically weathered limestone remnants overlies the Hawthorn Group and limestone units of the Upper Floridan aquifer (fig. 3). The residuum consists of unsorted to interbedded sand, silt, and clay with local inclusions of silicified limestone boulders, and ranges in thickness from a few feet to as much as 100 ft (Torak and others, 2006). Although the thickness of the residuum is quite variable, in areas where it overlies the calcareous parts of the Marianna, Suwannee, and Tampa Limestones, the irregular topographic surface conforms to the surface of the underlying limestone, a result of dissolution of the underlying soluble limestone (Reves, 1961).

In the Marianna Lowlands of northern Jackson County, Fla., a red sand-silt-clay mantle covers the limestone surface and represents, in part, the insoluble residue of the eroded limestone and the extent of filling of low spots in the uneven limestone surface. In some places, dark organic clay fills solution irregularities in the limestone, forming lenticular and vertical pockets from 20 to 30 ft long (or deep) and from 3 to 4 ft thick (or in diameter) (Reves, 1961). The occurrence of clay-filled solution cavities in the limestone impedes the vertical movement of ground water or infiltration of precipitation to recharge the Upper Floridan aquifer.

In the Dougherty Plain, Hayes and others (1983) and Hicks and others (1987) noted that approximately the lower-half thickness of residuum is more clayey than the sandy, upper part, perhaps owing to its origin as a weathering product of the underlying limestone. The clayey lower part of the residuum semiconfines the underlying Upper Floridan aquifer, and, where present, the upper sandy part can contain a water table, although it is laterally discontinuous. Hydraulic connection of the Upper Floridan aquifer with the water table in the sandy upper part of the overburden, where present, or with terrace and undifferentiated deposits, is indirect by vertical leakage through clayey residuum above the limestone. In contrast, lithologic logs of wells drilled for aquifer testing in upland, interstream areas of the Dougherty Plain and on the Solution Escarpment indicate the presence of clay interspersed with sand and silt layers throughout the residuum thickness (Katherine H. Zitsch, Project Manager, Camp, Dresser & McKee Inc., Atlanta, Ga., written commun., October 2004). The clay impedes the downward flow of ground water through the residuum and inhibits vertical leakage from the residuum to the Upper Floridan aquifer.

Terrace and undifferentiated (surficial) deposits of Holocene and Pleistocene (fig. 3) exist in the Marianna Lowlands to the south and west of Lake Seminole and represent marine-terrace deposits and alluvial terraces and floodplains along the principal streams, namely the Apalachicola and Chattahoochee Rivers. These deposits directly overlie the residuum and limestone units of the Upper Floridan aquifer, which have been exposed in river valleys by dissection and removal of the Miocene clastic formations (Moore, 1955) . The terrace and undifferentiated deposits consist of clayey sand, sand, and gravel that vary laterally and vertically within short distances. Most deposits are cross-bedded, and locally, "limonite" cements the sands and gravels into a hard, dense, ferruginous sandstone (Moore, 1955). Where stream terraces have dissected the underlying limestone, some residual boulders are incorporated into the deposits. Thickness of terrace deposits ranges from 30 to 50 ft (Moore, 1955). Near Jim Woodruff Lock and Dam, erosion and dissolution of the Tampa Limestone have deeply incised former channels of the Apalachicola River. Alluvium, which varies in thickness from at least 30 ft to nearly 80 ft in some places, has filled these ancient incisions (U.S. Army Corps of Engineers, 1948).

Hydrologic Setting

Similarities in hydraulic properties permit grouping sediments in the lower ACF River Basin into distinct hydrologic units according to their ability to transmit or impede ground-water flow and according to their direct or indirect interaction with surface water. This grouping transcends time-stratigraphic classifications and defines the hydrogeologic framework for the stream-lake-aquifer flow system in the study area that, in descending order, consists of the following hydrologic units: surficial aquifer system, upper semiconfining unit, Upper Floridan aquifer, and lower confining unit (figs. 3 and 4). Differences in lithology and hydrologic characteristics within a geologic unit create boundaries between hydrologic units. Karst processes, hydraulic properties, and stratigraphic relations limit stream-lake-aquifer interaction to these aforementioned hydrologic units.

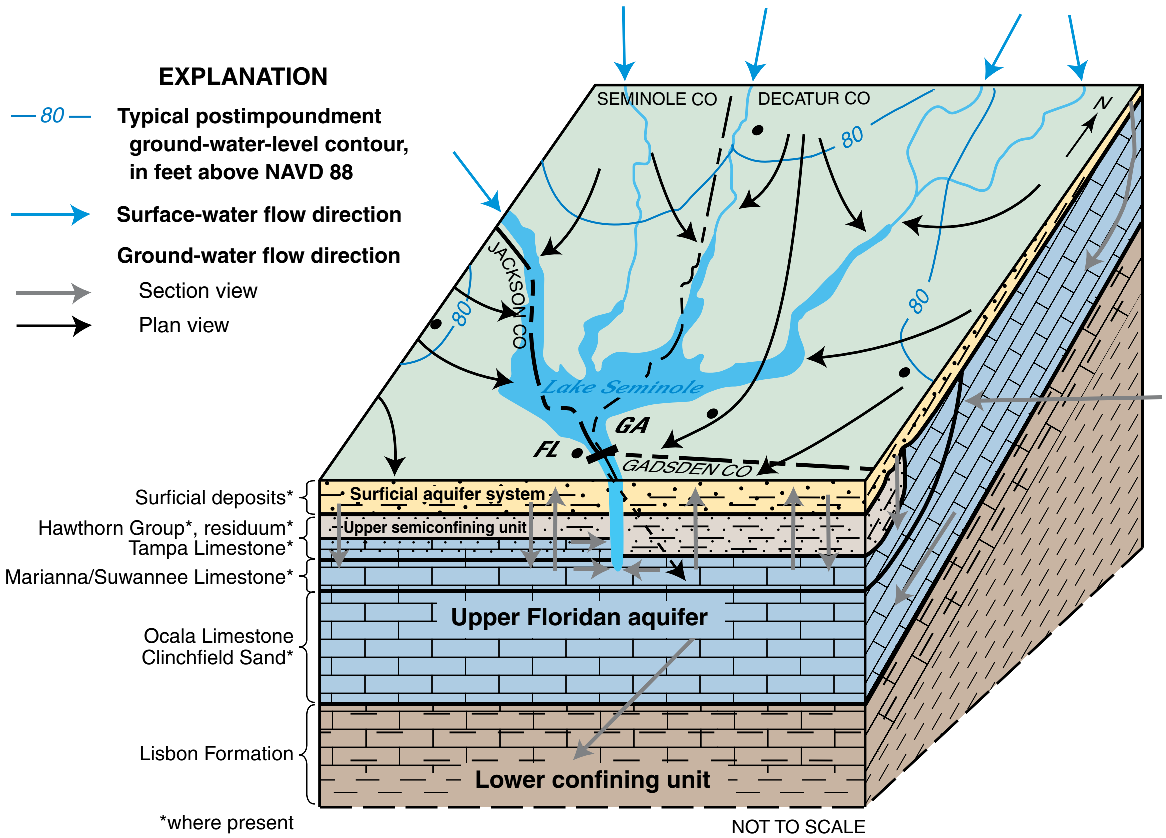


Figure 4. Diagram of idealized hydrogeologic section and conceptualization of ground-water and surface-water flow in the lower Apalachicola–Chattahoochee–Flint River Basin (modified from Torak and others, 1996).

The Upper Floridan aquifer in the lower ACF River Basin contains a stepped sequence of carbonate sediments comprising the Ocala, Suwannee, and Tampa Limestones and, locally, the Chattahoochee and St. Marks Formations (facies of the Tampa Limestone), Marianna Limestone, and Clinchfield Sand (fig. 3). The older sediments extend to the surface at the northernmost outcrop area of the sequence; younger sediments crop out successively to the south. Surficial deposits, residuum, and Hawthorn Group sediments overlie the limestone in extreme southeastern Alabama and southwestern Georgia, and in the western and central parts of the study area in Florida, creating a semiconfined aquifer (fig. 5). In the Dougherty Plain, the Upper Floridan aquifer primarily consists of the Ocala Limestone, but includes the Clinchfield Sand in parts of Crisp, Dooly, Lee, and Sumter Counties, Ga. The Upper Floridan aquifer includes the Suwannee Limestone near Lake Seminole and on the Tifton Upland and Tallahassee Hills in Florida and Georgia, and the Marianna and Suwannee Limestones in Jackson County, Fla. West of the Apalachicola River, the Upper Floridan aquifer includes the Tampa Limestone, which overlies the Marianna and Suwannee Limestones.

The geographic relation of the Tampa Limestone with the Apalachicola River, incidence of surface-water drainage, lithologic variations, and small areal extent influence the function of this geologic unit in the Upper Floridan aquifer (fig. 4). West of the Apalachicola River, the Tampa Limestone is hydrologically similar to the underlying Ocala and Suwannee Limestones because of the combination of sparse areal extent, sandy lithology, and well-developed surface-water drainage; thus, the Upper Floridan aquifer includes the Tampa Limestone in this area. East of the Apalachicola River, however, the Tampa Limestone functions more as a semiconfining unit or source layer than as part of the underlying Upper Floridan aquifer because of its ubiquitous occurrence, large thickness, dense, clayey lithology, and poorly developed surface-water drainage. The Tampa Limestone east of the Apalachicola River contains a higher hydraulic head than the underlying limestone and, because of its less transmissive hydraulic characteristics compared with the deeper units, impedes vertical leakage to the Upper Floridan aquifer from the overlying Hawthorn Group or surficial deposits.

Alluvial processes, chemical weathering, and limestone dissolution have created a highly active and complex flow system in the Upper Floridan aquifer, which is connected with surface water through many leakage mechanisms (fig. 6). Direct recharge to, and discharge from, the aquifer occurs through karst features such as sinkholes, swallow holes, or similar depressions where limestone is located at or near land surface. These karst features can collect precipitation and runoff, and where sinkhole ponds are formed, the collected water and ground water can either infiltrate to the aquifer or evaporate. Vertical leakage through the upper semiconfining unit from land surface or the surficial aquifer system, where present, provides indirect recharge to the Upper Floridan aquifer.

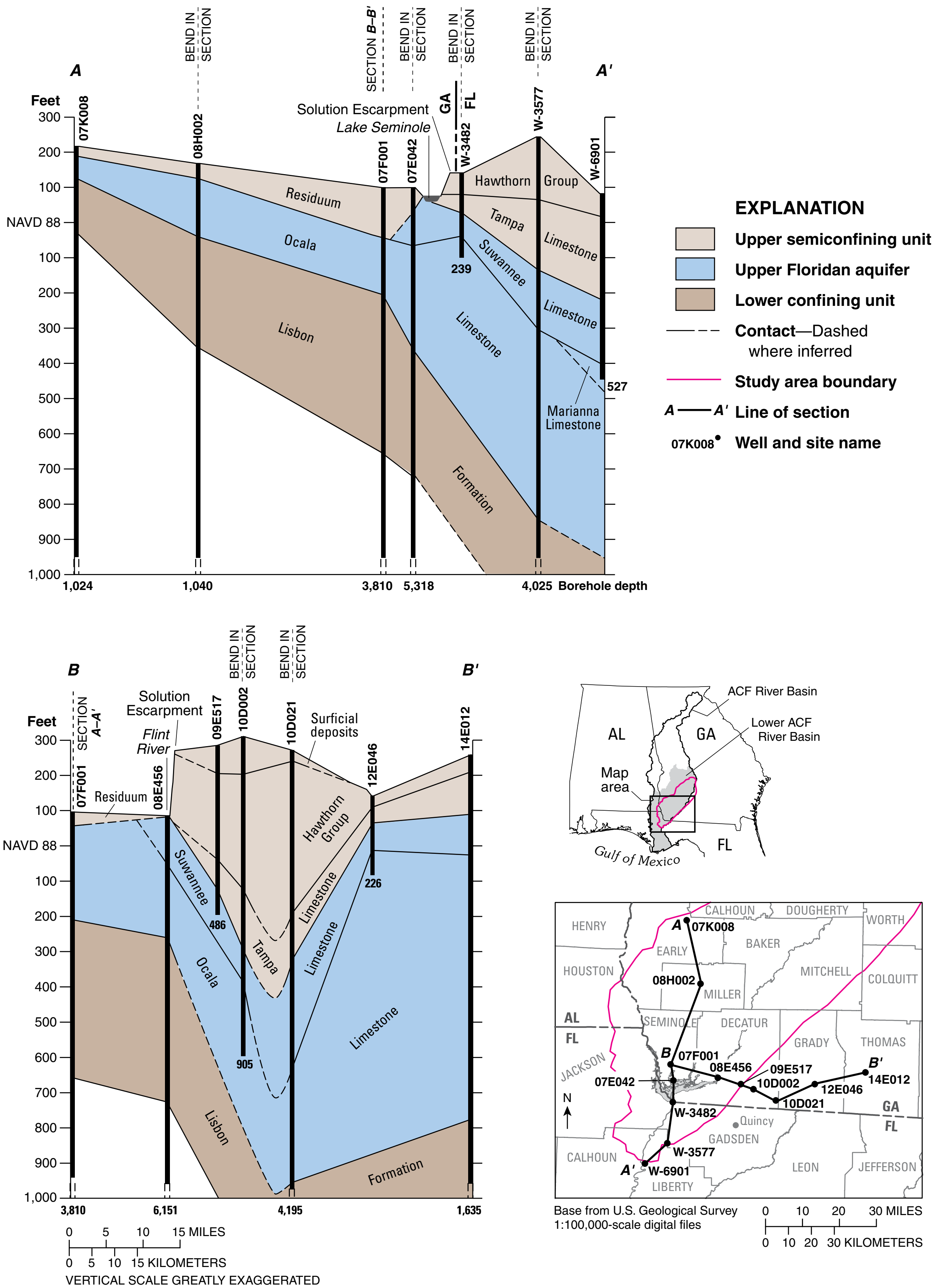
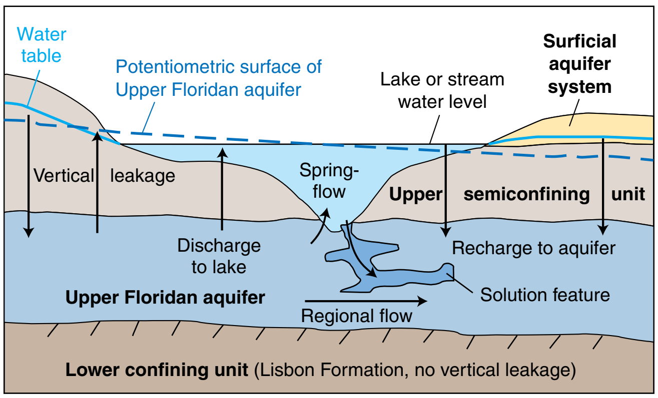


Figure 5. Hydrogeologic sections *A–A*' and *B–B*' and locations of wells used to construct sections through the southern part of the study area in the lower Apalachicola–Chattahoochee–Flint (ACF) River Basin (modified from Sever, 1964, 1965b; Torak and others, 2006).

Ground-water discharge from the Upper Floridan aquifer occurs near streams or lakes where overlying residuum is thin or absent, and where the ground-water level is above lake or stream stage. Streams flowing directly over the limestone of the Upper Floridan aquifer, and in-channel and in-lake springs, provide a means of direct-water exchange between the atmosphere, land surface, streams and lakes, and the aquifer.



NOT TO SCALE

Figure 6. Conceptual diagram of ground-water and surface-water flow in the interconnected stream-lake-aquifer flow system of the lower Apalachicola–Chattahoochee–Flint River Basin (modified from Torak and others, 2006).

Hydrochemistry

Ground water in the hydrologic units of the stream-lake-aquifer flow system contains chemical constituents derived from atmospheric gases, precipitation, and minerals from the rocks through which the water flows (fig. 3). Ground water is partially confined in the Upper Floridan aquifer, making it open to gas exchange with atmospheric oxygen and carbon dioxide (Katz, 1992). Precipitation generally is dilute with respect to ions; however, precipitation with the highest specific conductance and the lowest pH occurs during spring and summer (table 3), and can influence the chemical composition of water that infiltrates to the aquifer. Limestone, dolomite, and gypsum are present in abundance in the Upper Floridan aquifer and can supply ground water with ions derived from dissolution of calcium carbonate, magnesium carbonate, and calcium sulfate, respectively (Torak and others, 2006). Glauconite and pyrite, which are present in sediments comprising the residuum and Upper Floridan aquifer, can contribute potassium, iron, silica, and sulfate ions to the chemical composition of ground water through dissolution.

The chemical composition of ground water in the Upper Floridan aquifer varies throughout the lower ACF River Basin. Hard, calcium-magnesium-bicarbonate-type water exists in the Dougherty Plain. In the Tifton Upland, however, very hard water containing sulfate occurs in some places. High iron concentration exists in a 100-mi^2 region that trends roughly parallel with the Solution Escarpment and Flint River, southeast of Bainbridge, Ga. (Sever, 1965a, fig. 2).

Table 3. Monthly weighted-mean concentrations of selected chemical constituents in precipitation at Quincy, Gadsden County, Florida, for 2001[1].

[mg/L, milligram per liter; µS/cm, microsiemens per centimeter]

Month	Field water-quality constituents		Laboratory water-quality constituents							
	pH, field (standard unit)	Specific conductance, field (µS/cm)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO_4 (mg/L)	Cl (mg/L)	NH_4 (mg/L)	NO_3 (mg/L)
January	4.81	14.0	0.06	0.06	0.55	0.03	0.89	0.92	0.08	0.58
February	4.82	12.6	.11	.09	.77	.09	1.17	1.33	.1	.68
March	4.91	19.2	.11	.05	.4	.06	1.11	.7	.18	.59
April	4.9	11.5	.16	.04	.28	.04	1.02	.49	.23	.88
May	4.57	18.6	.16	.06	.53	.06	1.39	.9	.21	1.44
June	4.92	8.9	.08	.03	.23	.02	.57	.41	.05	.54
July	4.51	19.5	.12	.02	.14	.02	1.56	.24	.23	1.23
August	4.69	11.9	.04	.02	.17	.01	.69	.32	.04	.64
September	4.79	9.1	.03	.01	.06	.01	.56	.12	.05	.54
October	5.56	4.3	.03	.03	.2	.05	.23	.38	.06	.12
November	4.99	7.3	.04	.02	.17	.01	.41	.29	.06	.4
December	4.91	17.5	.09	.13	1.16	.05	.88	2.12	.09	.67
Average	**4.87**	**12.9**	**1.03**	**.05**	**.39**	**.04**	**.87**	**.69**	**.12**	**.69**

[1]See figure 5 for location; data from Quincy, Fla., latitude 30°32'53"N, longitude 84°36'3"W, for 2001 (U.S. Geological Survey National Atmospheric Depositional Program/National Trends Network, accessed April 19, 2005, at *http://nadp.sws.uiuc.edu*).

Extensive chemical analyses of ground water, surface water, and springflow in the Lake Seminole area (Torak and others, 2006) indicate enrichment of ground water with naturally-occurring isotopes of hydrogen and oxygen resulting from surface water mixing with ground water in the Upper Floridan aquifer. Water in geologic units underlying the Upper Floridan aquifer in the southeastern part of the study area emits a moderate hydrogen-sulfide odor, attributed to pyrite and gypsum that are contained in these rocks; the water probably contains high sodium and chloride concentrations as well as high concentrations of iron and sulfur (Sever, 1965a).

Hydrologic Characteristics

Variations in thickness, areal extent, and hydraulic properties of geologic units comprising the surficial aquifer system, upper semiconfining unit, Upper Floridan aquifer, and lower confining unit govern the degree of interconnection of ground water to surface water in the lower ACF River Basin. Heterogeneity of hydrologic characteristics within the Upper Floridan aquifer and overlying and underlying hydrologic units determines the relative contribution of each hydrologic unit to the water resources of the basin.

Surficial Aquifer System

The Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition (Ad Hoc Committee) has identified terrace and undifferentiated (surficial) deposits in Florida as belonging to the surficial aquifer system (Florida Geological Survey, 1986) (fig. 3). These sediments represent “the permeable hydrogeologic unit contiguous with land surface that is comprised principally of unconsolidated to poorly indurated clastic deposits” (Florida Geological Survey, 1986). In Jackson County, Fla., these deposits are relatively thin and finer than elsewhere in the State and have low permeability; thus, they are of minor importance as a source of water (Pratt and others, 1996). In southern Jackson County and northern Liberty County, Fla., the surficial aquifer system consists of a series of marine and fluvial-terrace deposits that range in thickness from about 30 to 50 ft (Moore, 1955; Scott, 1992). In other parts of Jackson County, however, Reves (1961) reported the occurrence of less than 15 ft of “overburden” at 36 of 38 limestone exposures that were investigated for economic feasibility of mining the underlying limestone.

Hydraulic connection of the surficial aquifer system with surface water and the Upper Floridan aquifer can be direct where sandy deposits overlie the limestone units, or indirect where fluvial deposits overlie clayey limestone residuum. In some places, the surficial aquifer system is connected with surface water and the Upper Floridan aquifer and contains a water table that fluctuates with the adjacent stream stage or the Upper Floridan aquifer. In other places, clay or residuum separate the surficial aquifer system from surface water and the Upper Floridan aquifer forming a perched water table in the surficial aquifer system. The water level in the perched zones fluctuates independently of water-level changes in the underlying aquifer or in adjacent streams or lakes.

Upper Semiconfining Unit

The upper semiconfining unit overlies the Upper Floridan aquifer and consists of surficial deposits, residuum, Hawthorn Group, and Tampa Limestone depending on location in the lower ACF River Basin (fig. 3). Weathered limestone residuum mantles the underlying limestone almost everywhere, with the exception of stream channels, and constitutes the upper semiconfining unit, as would-be exposures of limestone at the surface weather quickly into soil (David W. Hicks, Scientist, Joseph W. Jones Ecological Research Center at Ichauway, Newton, Ga., written commun., October 2005). In extreme southeastern Alabama and southwestern Georgia, and in most of Jackson County, Fla., the upper semiconfining unit contains surficial deposits, residuum, and Hawthorn Group. In southeastern Jackson County and northern Liberty County, Fla., and east of the Apalachicola River in Gadsden and Calhoun Counties, Fla., the upper semiconfining unit includes the dense clay lithology of the lower part of the Tampa Limestone. The surficial aquifer system in Florida is considered part of the upper semiconfining unit because of its low permeability.

The naming convention of *upper semiconfining unit* differs from that established by the Ad Hoc Committee (Florida Geological Survey, 1986), which recognizes an *intermediate confining unit* as all sediments that collectively retard the exchange of water between the overlying surficial aquifer system and the Floridan aquifer system (or Upper Floridan aquifer in the lower ACF River Basin). Pratt and others (1996) combined the *intermediate confining unit* with hydrostratigraphically equivalent water-bearing units, called the *intermediate aquifer system* by the Ad Hoc Committee, into one unit termed the *Intermediate System*. According to this nomenclature, “the complex series of confining and water-bearing lithologies comprising the intermediate confining unit/aquifer system are combined and elevated to system status” (Pratt and others, 1996). For this report and for consistency in nomenclature, however, confining lithology in the Intermediate System of Florida is identified with sediments containing similar lithology and hydrologic characteristics in Georgia and Alabama and termed the *upper semiconfining unit*.

Thickness

Thickness of the upper semiconfining unit ranges from nearly absent in the northwestern, upland-outcrop areas of the lower ACF River Basin and in some stream valleys to about 400 ft to the south and east of Lake Seminole on the Tifton Upland and Tallahassee Hills (fig.7). The detailed thickness distribution of the upper semiconfining unit shown on figure 7 was obtained by subtracting the estimate for the altitude of the top of the Upper Floridan aquifer (fig. 8) from the USGS National Elevation Dataset digital-elevation model of land surface (accessed May 11, 2005, at *http://ned.usgs.gov/*).

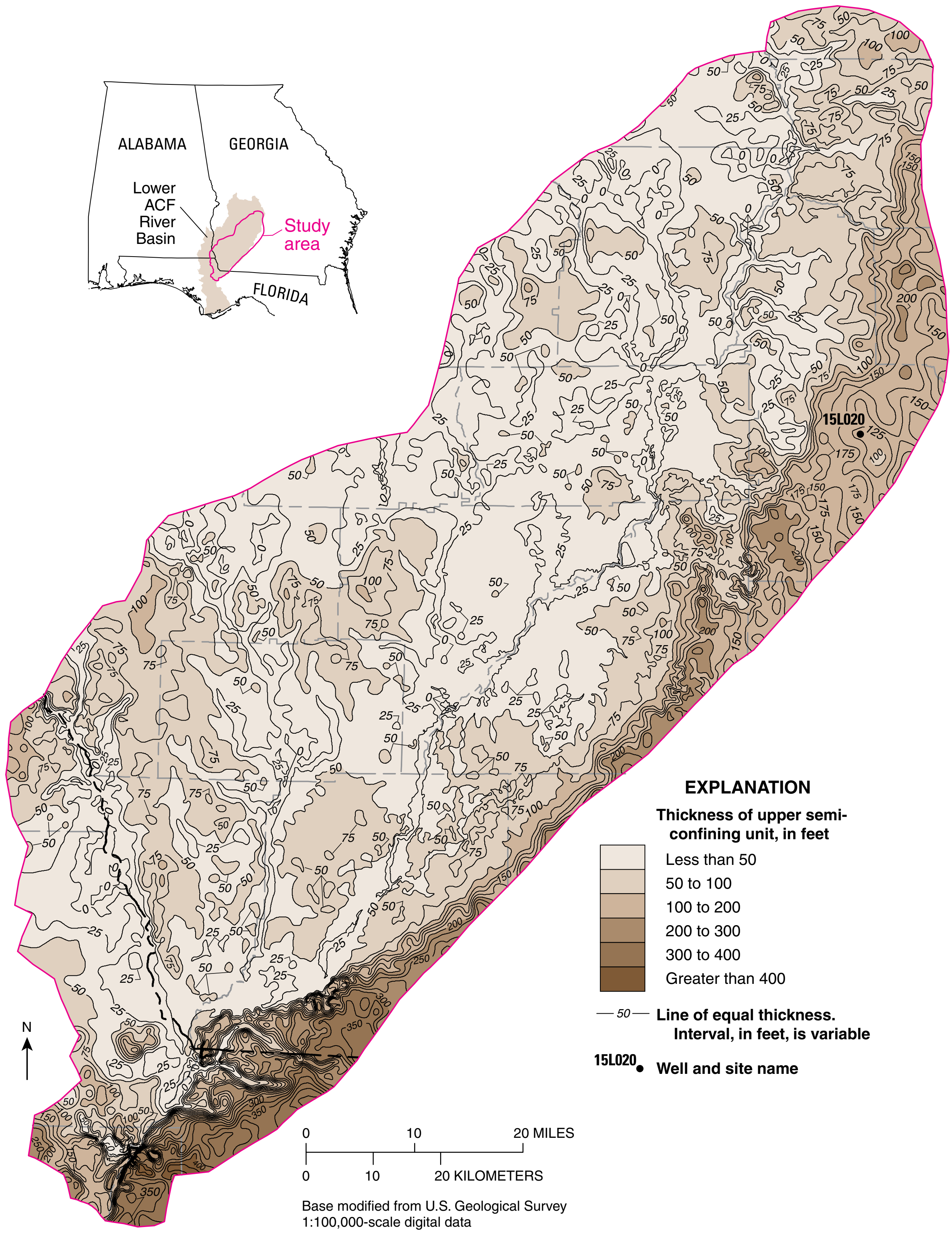


Figure 7. Approximate thickness of the upper semiconfining unit to the Upper Floridan aquifer in the lower Apalachicola–Chattahoochee–Flint (ACF) River Basin, southwestern Georgia and adjacent parts of Florida and Alabama.

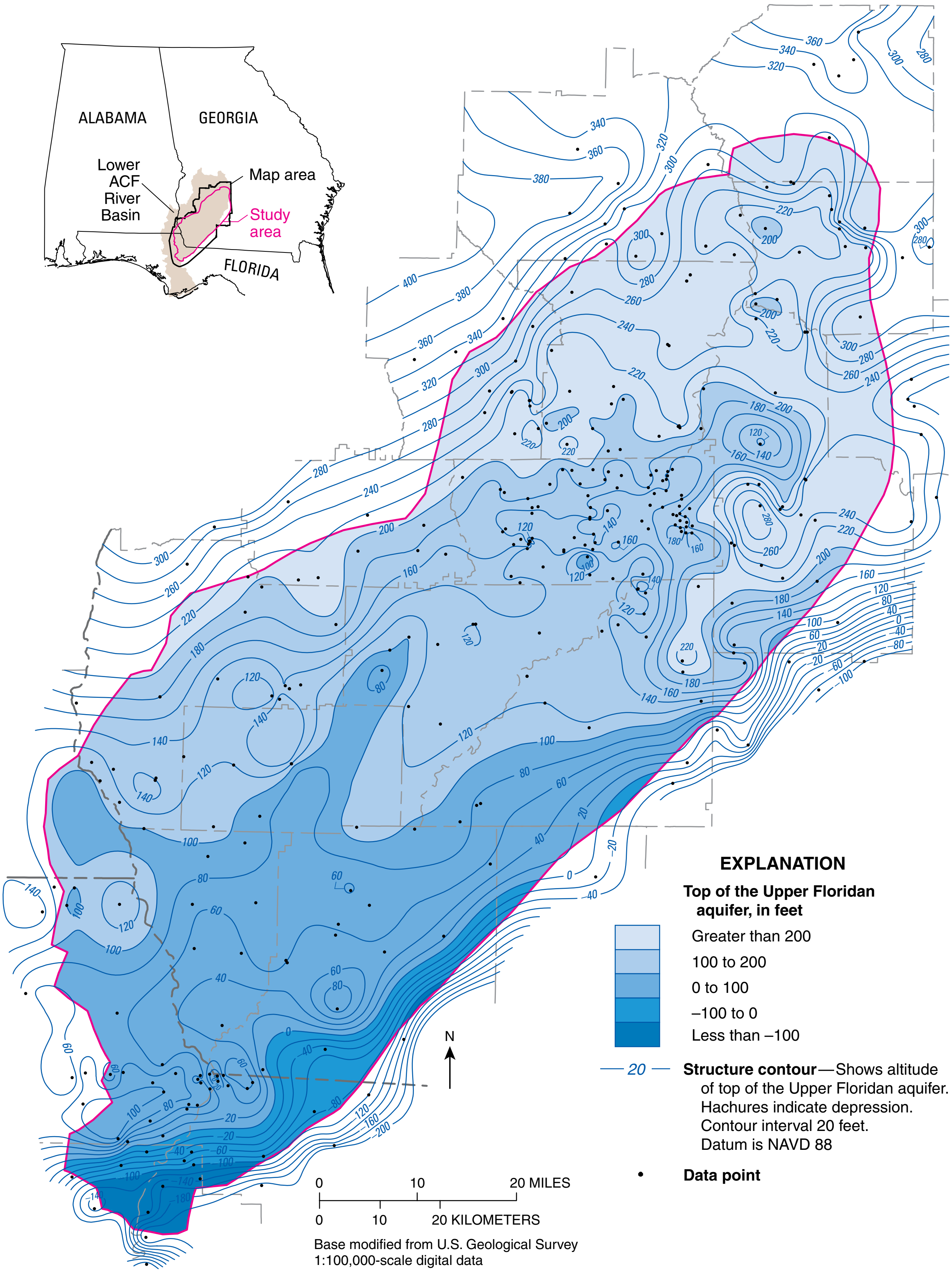


Figure 8. Approximate altitude of the top of the Upper Floridan aquifer in the lower Apalachicola–Chattahoochee–Flint (ACF) River Basin, southwestern Georgia and adjacent parts of Florida and Alabama.

The result was adjusted to refine thickness estimates in stream channels and valleys where the upper semiconfining unit is nearly absent. In some areas, several hundred feet of unconsolidated clay and sand or low-permeability sediments fill paleosinks inhibiting the exchange of water between land surface and the Upper Floridan aquifer (Pratt and others, 1996). In southwestern Georgia, the upper semiconfining unit averages about 90 ft thick (Camp, Dresser & McKee Inc., 2001); however, in much of the Dougherty Plain, the thickness of the upper semiconfining unit generally is less than 50 ft (David W. Hicks, Scientist, Joseph W. Jones Ecological Research Center at Ichauway, Newton, Georgia, written commun., October 2005). Thickness of the upper semiconfining unit in southeastern Alabama ranges from about 40 to 120 ft in upland areas of the lower ACF River Basin and is nearly absent near the Chattahoochee River.

Vertical Hydraulic Conductivity and Leakage Potential

Sand and clay content of the upper semiconfining unit controls the vertical hydraulic conductivity and influences the rate of vertical leakage of ground water into or out of the Upper Floridan aquifer. Vertical hydraulic conductivity of 16 relatively undisturbed core samples from wells in the Albany, Ga., area ranged from about 0.0004 feet per day (ft/d) for silty clay to about 23 ft/d for fine to medium sand (Charles A. Turner, Geologist, S & ME, Inc., written commun., 1988). Regional estimates of vertical hydraulic conductivity range from about 0.0001 to about 9 ft/d and have a median value of about 0.003 ft/d (Hayes and others, 1983). Permeable zones in the upper semiconfining unit are laterally and vertically discontinuous; the permeable zones, however, create a high potential for vertical leakage by facilitating water exchange between the Upper Floridan aquifer, surface water, and land surface. The upper semiconfining unit generally contains thick sequences of clay and silt, which, in contrast to the permeable zones, create an effective hydraulic barrier to vertical leakage, thereby decreasing recharge rates to the aquifer from infiltration of precipitation and impeding potential downward migration of surface-applied chemicals.

Ground-Water-Level Fluctuations

Ground-water levels in the upper semiconfining unit respond to recharge from infiltration of precipitation to drought, evapotranspiration, changes in surface-water level, springflow, and ground-water withdrawal. The magnitude of water-level fluctuations is affected by the thickness and lithology of residuum contained in the upper semiconfining unit and by the proximity of water-bearing zones to surface water and aquifers, which are connected hydraulically by varying degrees to the upper semiconfining unit.

Ground-water levels in the upper semiconfining unit fluctuate seasonally, generally reaching a yearly high in late winter through early spring, declining during summer and fall, and reaching a yearly low during late fall through early winter (figs. 9 and 10). Seasonal recharge by infiltration of precipitation causes water levels to rise during January and February in years that receive normal or above-normal rainfall. Dry climatic conditions cause dewatering of the sandy and silty lithology of the upper semiconfining unit within a relatively short period following seasonal-high water levels in the spring. Continued dry conditions during spring and fall result in large water-level changes in the sandy and silty layers, while the clayey lithology in the lower-half thickness of the residuum (Hayes and others, 1983) dewaters slowly and remains saturated. Long-term water-level records do not indicate declining trends in the upper semiconfining unit; most ground-water levels tend to recover to about the same level each year.

During drought conditions—such as occurred during 1980 and 1981, 1986, and from 1998 to 2002—ground-water levels in the upper semiconfining unit did not recover completely during late winter and early spring from low levels of the previous season before declining further during the following summer and fall in response to low rainfall, evapotranspiration, and pumping in the Upper Floridan aquifer (figs. 9 and 10). Water levels in well 09G003 were lower at the beginning of 2002 than during 2001, defining a low water-level trend that continued throughout the year as a result of lower-than-normal rainfall during the fall and winter of 2001 (interactive map, fig. 2).

Low rainfall during early 2001 caused lower-than-normal ground-water levels during January and February in well 07H003; that is, monthly mean ground-water levels for January and February 2001 were below the corresponding then-period-of-record (1980–2000) monthly means by about 1.4 and 3.8 ft, respectively (Coffin and others, 2002). Ground-water levels in well 07H003 recovered somewhat by late March to a yearly high of about 1.2 ft below land surface, but declined nearly 18 ft by the end of the year to about 20 ft below land surface, which is nearly 7.5 ft below the then-period-of-record monthly mean for December (interactive map, fig. 2). Higher-than-normal rainfall during 2002 more than compensated for the soil-moisture deficit that most likely was created in the unsaturated zone during 2001 and the first half of 2002. By August 2002, the monthly mean ground-water level in well 07H003 exceeded the then-period-of-record monthly mean by about 3.5 ft, establishing a trend of high ground-water levels that was maintained for the remainder of the year.

During 2001 and 2002, the water level in wells 13M007 and 11J013 responded to local rainfall, as did the stage of the Flint River, which is located less than a mile to the west of these wells. The ground-water-level response to rainfall in well 13M007 is characteristic of the upper semiconfining unit located in the northern part of the lower ACF River Basin in Worth County and neighboring Crisp and Dooly Counties, Ga., where relatively thin (50 ft or less) residuum overlies the Upper Floridan aquifer near the Flint River. The sandy clay residuum composing the upper semiconfining unit in this part of the basin, together with relatively dry antecedent-moisture conditions in the sediment, damped ground-water-level response to local rainfall, although the water level in well 13M007 generally was less than 12 ft below land surface.

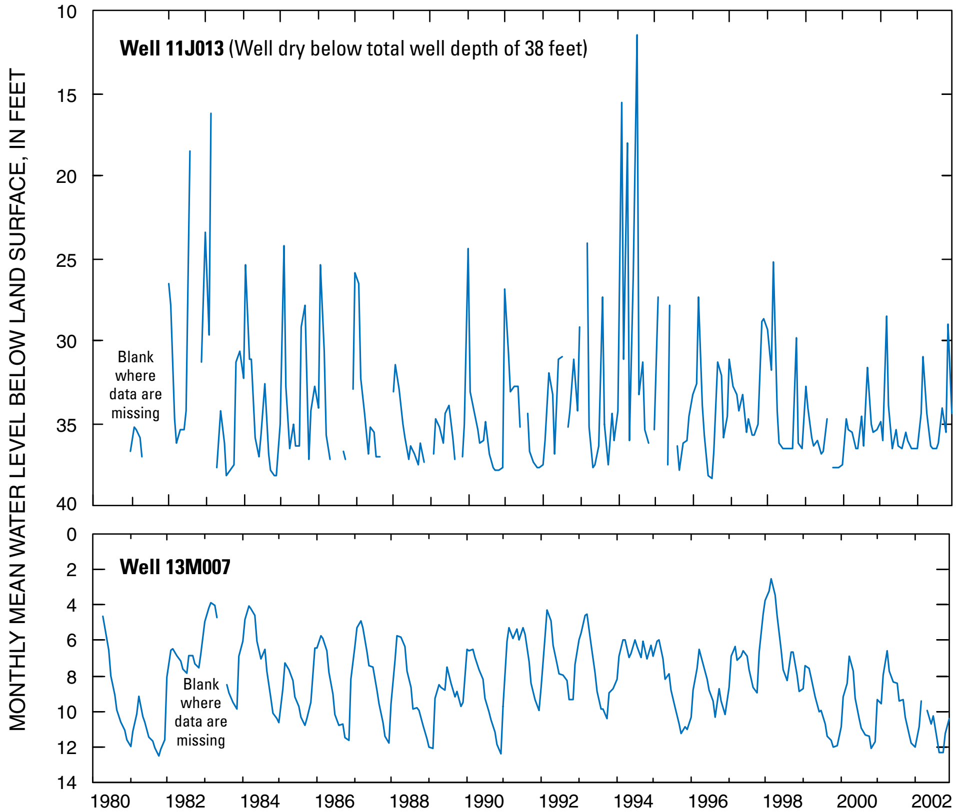


Figure 9. Monthly mean water levels in wells 11J013 and 13M007 in the upper semiconfining unit overlying the Upper Floridan aquifer in the lower Apalachicola–Chattahoochee–Flint River Basin, 1980–2002 (modified from Coffin and others, 2003; see figure 2 for well locations).

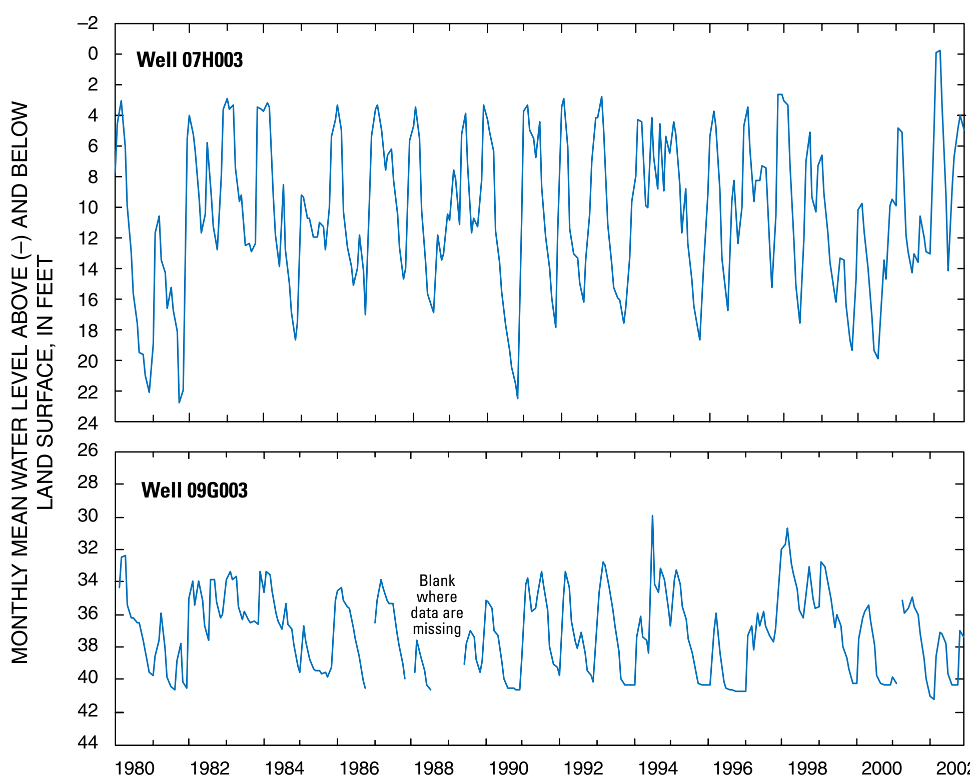


Figure 10. Monthly mean water levels in wells 07H003 and 09G003 in the upper semiconfining unit overlying the Upper Floridan aquifer in the lower Apalachicola–Chattahoochee–Flint River Basin, 1980–2002 (modified from Coffin and others, 2003; see figure 2 for well locations).

Ground-water-level fluctuation in well 13M007 totaled about 6 ft during the drought year 2001 (interactive map, fig. 2). During March, local rainfall totaled about 9.9 and 9.6 inches, respectively, at Albany and Cordele, Ga., causing slightly less than a 3-ft rise in ground-water level in well 13M007 and an 11-ft rise in stage of the Flint River near Oakfield, Ga. (streamgaging station 02350512, interactive map, fig. 2). The precipitation-induced ground-water-level rise is independent of the rise in Flint River stage because the well is not connected hydraulically to the river. Dry conditions throughout the remainder of the year caused a steady decline in ground-water level of about 6 ft in the upper semiconfining unit. Recharge by infiltration of precipitation during the first quarter of 2002 resulted in a 3-ft rise in water level in well 13M007; continued dry conditions during April through October, however, caused ground-water levels to decline slightly more than 3 ft during summer and into fall.

The precipitation-induced rise in ground-water level in well 11J013 seemed to lag behind a similar rise in Flint River stage by several days (interactive map, fig. 2), perhaps a result of the clayey lithology of the upper semiconfining unit at the well taking longer to respond to recharge by infiltrating precipitation than a sandy or silty lithology (table 4). The lower 22 ft of well 11J013 penetrated dense, pliable, "plastic" clay; the upper 16 ft of the well penetrated sand and clay. The upper sandy zone probably is capable of readily transmitting precipitation from land surface to the lower zone, which would not saturate as readily as the upper zone because of the relatively low water-transmitting ability of the clay. During March 2001, the ground-water level increased about 20 feet in response to rainfall; stream stage during this time increased about 12 feet. The "flat" sections of hydrograph between episodes of increased ground-water level indicate that the well was dry during most of 2001 and during most of the first 8 months of 2002.

In some upland interstream karst regions in the northwestern parts of the Dougherty Plain, the upper semiconfining unit contains a sandy clay to clay lithology (table 4); however, lithology alone does not seem to control ground-water-level fluctuations or the hydrologic function of the upper semiconfining unit in each region. As discussed previously, ground-water levels in well 07H003 (Miller County, Ga.) respond quickly to precipitation and pumping, sometimes fluctuating nearly 20 ft annually as during 2001 (interactive map, fig. 2). In this region, the variably sandy clay lithology provides adequate hydraulic connection for water levels in the upper semiconfining unit to fluctuate in response to precipitation and stresses in the Upper Floridan aquifer, perhaps permitting recharge by vertical leakage to the underlying Upper Floridan aquifer.

In other upland interstream regions, ground-water levels at or near land surface create an interstream karst swamp in the upper semiconfining unit. The lithology of the residuum in these swampy areas consists of dense, plastic clay (Katherine H. Zitsch, Project Manager, Camp Dresser & McKee, Inc., written commun., 2002) that inhibits ground-water fluctuations and limits hydraulic connection of the upper semiconfining unit with the underlying aquifer. Other factors besides lithology—such as proximity to streams and lakes, pumped wells, topography, and rainfall distribution—might contribute directly or indirectly to ground-water-level fluctuations in the upper semiconfining unit and its hydrologic function in the stream-lake-aquifer flow system. These factors uniquely combine at each location in the study area; thus, yielding uncertain results with regard to vertical leakage and recharge from through the upper semiconfining unit to the Upper Floridan aquifer.

Ground-water levels in the upper semiconfining unit in Calhoun and Gadsden Counties, and in southern Jackson County, Fla., and on the Tifton Upland southeast of Lake Seminole in Georgia, range from about 5 to 150 ft higher than water levels in the underlying Upper Floridan aquifer (Maloney and others, 1998). These ground-water levels are associated with the siliciclastic and dolomitic Chattahoochee Formation facies of the Tampa Limestone, which separates the overlying Hawthorn Group from the Ocala and Suwannee Limestones. Substantial clay fractions interspersed with water-bearing carbonate layers in the upper semiconfining unit result in low water-yielding properties (Pratt and others, 1996) and isolate this unit somewhat from hydraulic connection with the overlying surficial aquifer system and underlying Upper Floridan aquifer. The limited hydraulic connection of the upper semiconfining unit with either the surficial aquifer system or Upper Floridan aquifer, coupled with a low demand for domestic, municipal, or industrial water use in this part of the lower ACF River Basin, causes slight seasonal water-level fluctuations to occur.

Geohydrologic Zones and Potential Recharge to the Upper Floridan Aquifer

Variations in the hydrologic and geologic settings of the lower ACF River Basin create distinct local patterns of ground-water-level fluctuations in wells completed in the upper semiconfining unit. These local variations affect vertical leakage and infiltration of precipitation, which ultimately affect recharge to the Upper Floridan aquifer. The relative scarcity of ground-water-level data for the upper semiconfining unit in the study area makes exact quantification of recharge from or through this hydrologic unit to the Upper Floridan aquifer impossible. Useful information about vertical leakage and recharge to the Upper Floridan aquifer is gleaned, however, from sparse upper semiconfining-unit data from wells (table 4) by inferring that ground-water-level fluctuations associated with a unique combination of hydrologic and geologic settings apply to other areas containing the same or similar hydrologic and geologic settings where ground-water-level data are scarce or absent.

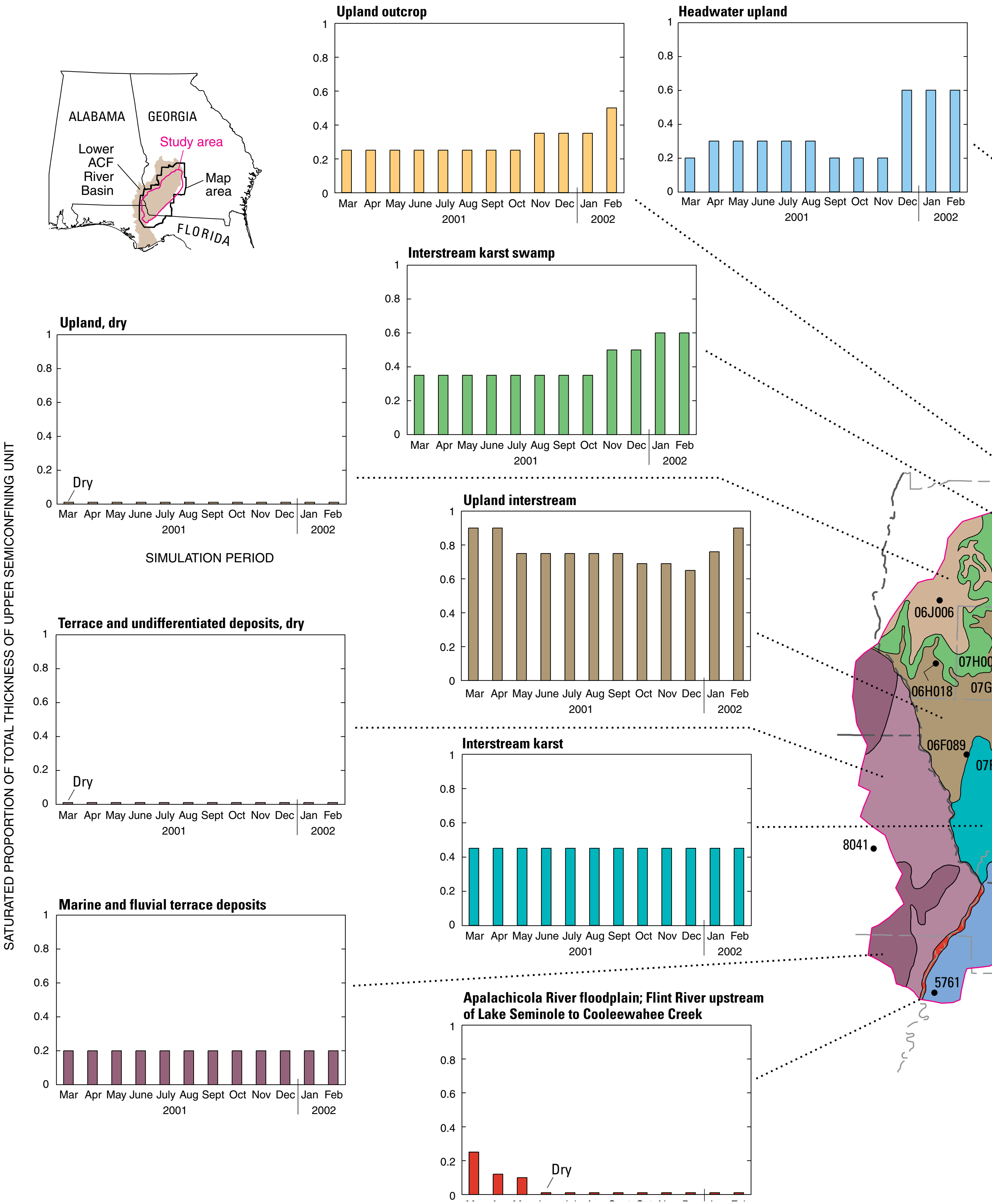
Table 4. Hydrologic and geologic characteristics of wells penetrating the upper semiconfining unit to the Upper Floridan aquifer.

[See figure 11 for location of wells; land-surface altitude in feet above North American Vertical Datum of 1988; na, not applicable; —, no data available]

Well name	Latitude (degree)	Longitude (degree)	Land-surface altitude (foot)	Hydrologic and geologic setting	Total thickness (foot)	Lower-thickness lithology	Lower thickness (foot)	Upper-thickness lithology	Upper thickness (foot)
06H018	31.1458	84.9678	185.0	Karst upland to Chattahoochee River	50	Sandy, silty clay, plastic[1] clay	50	na	na
06F089	30.9653	84.896	160	Upland interstream karst	[2]95	Sandy clay, clay	43	Clayey silt	42
06J006	31.2696	84.96	220	Upland outcrop, dry	40	Plastic[1] clay	20	Dense, sandy clay	20
07H003	31.1691	84.8317	165	Interstream upland	55	Sandy clay	55	na	na
07D015	30.7183	84.7796	280	Solution Escarpment upland, southeast	[2]100	Sandy clay	30	Clayey sand	70
07F008	30.9668	84.7937	125	Interstream karst	40	Soft sandy-clay, plastic[1] clay	10	Sand silt, sandy clay	30
08K020	31.4514	84.6844	255	Upland outcrop	50	Sandy clay	50	na	na
08J017	31.2823	84.7354	185	Interstream karst swamp	54	Sandy clay, plastic[1] clay	29	Silty clay, sand	25
08F499	30.9337	84.6497	120	Interstream karst	32	Silt-sand-clay mixture	26	Clayey silt, clayey sand	6
08D092	30.7472	84.6744	290	Solution Escarpment upland, southeast	[2]100	Sandy clay	30	Clayey sand sandy clay	70
09G003	31.0744	84.5181	145	West of Flint River, karst	40	Sand, dense clay	40	na	na
09G016	31.0772	84.6183	142	Interstream karst	[2]40	Sandy clay	20	Clayey sand	20
09J017	31.3096	84.5748	195	Upland interstream karst	[2]120	Sandy clay	120	na	na
10K007	31.3781	84.4122	178	Interstream karst swamp	51	Plastic[1] clay	19	Very dense clay	32
10F161	30.9161	84.4675	135	Karst, adjacent to Solution Escarpment	117	Sandy clay	117	na	na
10G315	31.1099	84.4107	140	Interstream karst east of Flint River	63	Sand, clayey sand	18	Clayey sand, silt	45
11J013	31.3008	84.3231	165	East of Flint River, karst	38	Plastic[1] clay	22	Sand clay	16
11M033	31.7065	84.3199	297	Interstream karst upland	[2]63	Chalky clay, limestone	31	Silty sand	32
13M007	31.7253	84.0142	235	Flint River floodplain	50	Clayey sand	30	Poorly sorted quartz sand	20
13P013	31.8839	84.0425	290	Interstream upland near Lake Blackshear	[2]70	Limestone and clay	50	Silty clay, limestone	20
13N012	31.7908	84.0764	270	Karst swamp 2 miles west of Flint River	28	Sandy clay	28	na	na
13J010	31.3225	84.0533	340	Solution Escarpment upland	48	Clayey sand	29	Silty clay	19
14K055	31.4931	83.9619	310	Solution Escarpment upland, northeast	87	Clayey sand, clay	19	Fine clayey sand	68
15L033	31.5908	83.8384	415	Solution Escarpment upland	[2]170	Clayey sand	80	Sandy clay, dense clay	90
15Q017	32.0297	83.8594	330	Upland outcrop east of Lake Blackshear	51	Plastic[1] clay with limestone	20	Sand silt, clayey sand	31
15N003	31.8072	83.8364	342	Solution Escarpment upland	60	Red soft clay	50	Clayey sand	10
5761	30.496	84.9677	202	Terrace deposits	58	—	—	—	—
8025	30.5041	84.7096	255	Terrace deposits; incised dendritic drainage	20	—	—	—	—
8038	30.6656	84.8154	285	Solution Escarpment upland	44	—	—	—	—
8041	30.7792	85.1082	123.6	Terrace deposits	65	—	—	—	—

[1]Dense, pliable clay having low water-yielding capability.

[2]Inferred from lithologic logs of nearby wells used for aquifer performance test (Katherine H. Zitsch, Project Manager, Camp, Dresser & McKee Inc., written commun., October 2004).


ALABAMA
GEORGIA
Study area
Lower ACF River Basin
Map area
FLORIDA
Upland outcrop
Headwater upland
Interstream karst swamp
Upland, dry
Dry
Upland interstream
Terrace and undifferentiated deposits, dry
Dry
Interstream karst
Marine and fluvial terrace deposits
Apalachicola River floodplain; Flint River upstream of Lake Seminole to Cooleewahee Creek
Dry
Mar Apr May June July Aug Sept Oct Nov Dec Jan Feb
2001
2002
SIMULATION PERIOD
SATURATED PROPORTION OF TOTAL THICKNESS OF UPPER SEMICONFINING UNIT
06J006
06H018
06F089
8041
5761

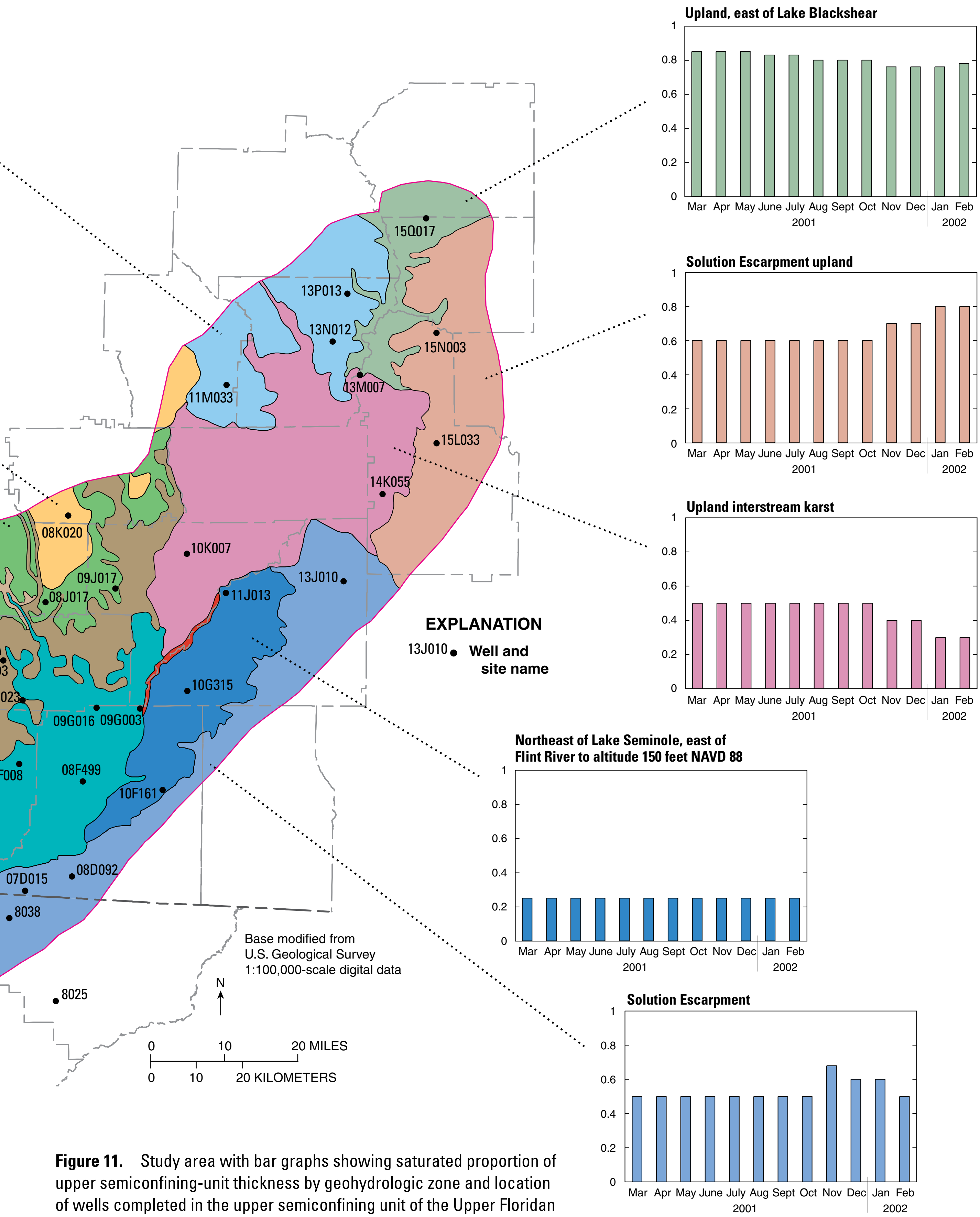


Figure 11. Study area with bar graphs showing saturated proportion of upper semiconfining-unit thickness by geohydrologic zone and location of wells completed in the upper semiconfining unit of the Upper Floridan aquifer in the lower Apalachicola–Chattahoochee–Flint (ACF) River Basin.

Expressing ground-water-level fluctuations in each well as a saturated proportion of total semiconfining-unit thickness (tables 5 and 6) and associating these fluctuations with specific factors of the hydrologic and geologic settings that characterize the well location provides a basis to categorize the study area into 14 geohydrologic zones (fig. 11) for identifying potential recharge to the Upper Floridan aquifer. Factors considered in establishing each geohydrologic zone include topography, altitude, physiography, proximity to surface-water features (wetlands, streams, and lakes), rainfall distribution, residuum thickness and lithology, and underlying geologic unit. Each geohydrologic zone defines a representative temporal distribution of proportional saturation of total semiconfining-unit thickness from March 2001 to February 2002 (fig. 11, table 7) derived from ground-water-level fluctuations and formation thickness for wells penetrating the upper semiconfining unit (tables 4–6). Miscellaneous water-level measurements from periods other than from March 2001 to February 2002 (table 6) supplement water-level data within this period in areas lacking ground-water-level data.

Potential recharge to the Upper Floridan aquifer by vertical leakage and/or direct infiltration of precipitation varies within each geohydrologic zone according to the total thickness of the upper semiconfining unit (fig. 7) and the proportional saturation of total thickness (fig. 11). Areas where the total upper semiconfining-unit thickness is less than 10 ft, such as in the upland-outcrop area, do not contain enough ground water in storage for the release of this water from storage and subsequent vertical downward leakage to represent an important source of recharge to the underlying aquifer.

Table 6. Proportional saturation of total upper semiconfining-unit thickness for miscellaneous dates, 1994, 2001–2003.

[See figure 11 for location of wells; saturated proportion expressed as fraction of total thickness of upper semiconfining unit; —, no data available]

Well name	Proportional saturation	Date	Proportional saturation	Date
06H018	0.817	Nov. 23, 2002	0.802	Dec. 10, 2002
07F008	.416	Dec. 5, 2002	.428	Dec. 18, 2002
08D092	.743	Nov. 22, 2002	—	—
08J017	.83	Dec. 11, 2002	.879	Dec. 26, 2002
08K020	.48	Nov. 21, 2002	—	—
10F161	.684	Dec. 5, 2002	.659	Mar. 23, 2002
10K007	.611	Nov. 29, 2002	—	—
11M033	.73	Nov. 20, 2002	.715	Dec. 2, 2002
13J010	.752	Dec. 13, 2002	.762	Dec. 27, 2002
15L033	.99	Dec. 11, 2002	—	—
15N003	.803	Apr. 25, 2003	—	—
15Q017	.707	Dec. 4, 2002	—	—
8038	.829	July 9, 1994	—	—
8041	.198	June 19, 2001	—	—

Table 5. Proportional saturation of total semiconfining-unit thickness in wells, March 2001 through February 2002.

[See figure 11 for location of wells; saturated proportion expressed as fraction of total thickness of upper semiconfining unit; —, no data available; 0, dry well]

Well name	Proportional saturation of total upper semiconfining-unit thickness by month											
	2001										2002	
	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.
06F089	—	—	—	—	—	—	—	—	—	0.5	0.5	—
06J006	—	—	—	—	—	—	—	—	—	—	.068	—
07G023	—	—	—	—	—	—	—	–	—	.6	.606	—
07H003	.903	.906	.785	.765	.741	.763	.752	.714	.678	.648	.761	.908
09G003	—	.122	.102	.109	.127	.111	.099	.069	.031	0	0	0
09J017	—	—	—	—	—	—	—	—	—	—	.89	.89
10F161	—	.46	—	—	—	—	—	—	—	.681	—	—
10G315	—	—	—	—	—	—	—	—	—	—	.256	—
10K007	—	—	—	—	—	—	—	—	—	—	.314	—
11J013	.249	.109	.039	.034	.042	.038	.062	.051	.038	.038	.039	.093
11M033	—	.302	—	—	—	—	—	—	—	—	—	—
13M007	.841	.869	.846	.833	.831	.811	.813	.793	.744	.764	.76	.783
13N012	—	—	—	—	—	—	—	—	—	.616	—	—
14K055	—	—	—	—	—	—	—	—	—	—	.311	—
8041	—	—	—	.198	—	—	—	—	—	—	—	—

Table 7. Geohydrologic zones in the upper semiconfining unit of the Upper Floridan aquifer and generalized saturated proportion of total semiconfining-unit thickness, March 2001 through February 2002.

[Saturated proportion expressed as a fraction of total thickness of upper semiconfining unit; altitude in feet above North American Vertical Datum of 1988]

Upper semiconfining unit geohydrologic zone (see fig. 11)	Proportional saturation of total semiconfining-unit thickness by month											
	2001										2002	
	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.
Upland outcrop	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.35	0.35	0.35	0.5
Upland, dry	0	0	0	0	0	0	0	0	0	0	0	0
Interstream karst swamp	.35	.35	.35	.35	.35	.35	.35	.35	.5	.5	.6	.6
Upland interstream	.9	.9	.75	.75	.75	.75	.75	.69	.69	.65	.76	.9
Interstream karst	.45	.45	.45	.45	.45	.45	.45	.45	.45	.45	.45	.45
Apalachicola River floodplains; Flint River upstream of Lake Seminole to Cooleewahee Creek	.25	.12	.1	0	0	0	0	0	0	0	0	0
Northeast of Lake Seminole, east of Flint River to altitude 150 feet	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25
Solution Escarpment	.5	.5	.5	.5	.5	.5	.5	.5	.68	.6	.6	.5
Upland interstream karst	.5	.5	.5	.5	.5	.5	.5	.5	.4	.4	.3	.3
Headwater upland	.2	.3	.3	.3	.3	.3	.2	.2	.2	.6	.6	.6
Upland, east of Lake Blackshear	.85	.85	.85	.83	.83	.8	.8	.8	.76	.76	.76	.78
Solution Escarpment upland	.6	.6	.6	.6	.6	.6	.6	.6	.7	.7	.8	.8
Terrace and undifferentiated deposits, dry	0	0	0	0	0	0	0	0	0	0	0	0
Marine and fluvial terrace deposits	.2	.2	.2	.2	.2	.2	.2	.2	.2	.2	.2	.2

Despite the low potential for recharge to the Upper Floridan aquifer by vertical leakage from ground water stored in the upper semiconfining unit in these areas, a high potential for recharge actually exists by direct infiltration of precipitation on the aquifer where the upper semiconfining unit is thin or nearly absent (fig. 12, light-shaded areas). Similarly, to the west of the Chattahoochee River (fig. 12), geohydrologic zones containing small or zero proportional saturation of total semiconfining-unit thickness (dark-shaded areas) or a relatively thin or nearly absent unit (light-shaded areas) also would not contain enough ground water to represent an important source of recharge to the aquifer by vertical leakage. A high potential for direct recharge to the Upper Floridan aquifer, however, may exist in these areas.

Geohydrologic zones containing less than 30 ft of total upper semiconfining unit thickness (fig. 7) and having a proportional saturation of total thickness that corresponds to less than 10 ft of saturated thickness (that is, less than about 0.3) indicate a low potential for recharge to the Upper Floridan aquifer by vertical leakage through the upper semiconfining unit or by the release of water in storage from this unit (fig. 12, medium-shaded areas). In the upland interstream, interstream karst swamp, and upland outcrop areas (fig. 11), the combination of relatively high proportional saturation of total upper semiconfining unit thickness (from 0.6 to 0.7, fig. 11) and relatively small total thickness (less than 30 ft) corresponds to a saturated thickness of less than about 21 ft that can dewater rapidly during dry climatic conditions, especially where the upper semiconfining unit contains a silty and sandy lithology (table 4). Although these areas probably would not contain enough ground water to represent a source of recharge to the underlying aquifer if dewatering by downward vertical leakage occurred, a potential for recharge could exist in these areas following sufficient rainfall to increase or maintain the saturated thickness of the upper semiconfining unit during vertical leakage. Therefore, these areas define a transition zone that, on a seasonal basis, can recharge the Upper Floridan aquifer by vertical leakage during wet periods.

In the interstream karst area between the Flint River and Spring Creek, and east of the Flint River along the Solution Escarpment (fig. 12, dark-shaded areas), the high proportional saturation of total upper semiconfining-unit thickness and relatively large thickness (greater than 30 ft) indicates a high potential for recharge to the Upper Floridan aquifer by vertical leakage. The possibility of a low potential for recharge exists in these areas; however, during dry climatic conditions, when the sandy and silty top half of the upper semiconfining-unit thickness dewaters. The lower-half thickness, which contains layers of clay and clayey silt (Hayes and others, 1983), is saturated but transmits little water by vertical leakage.

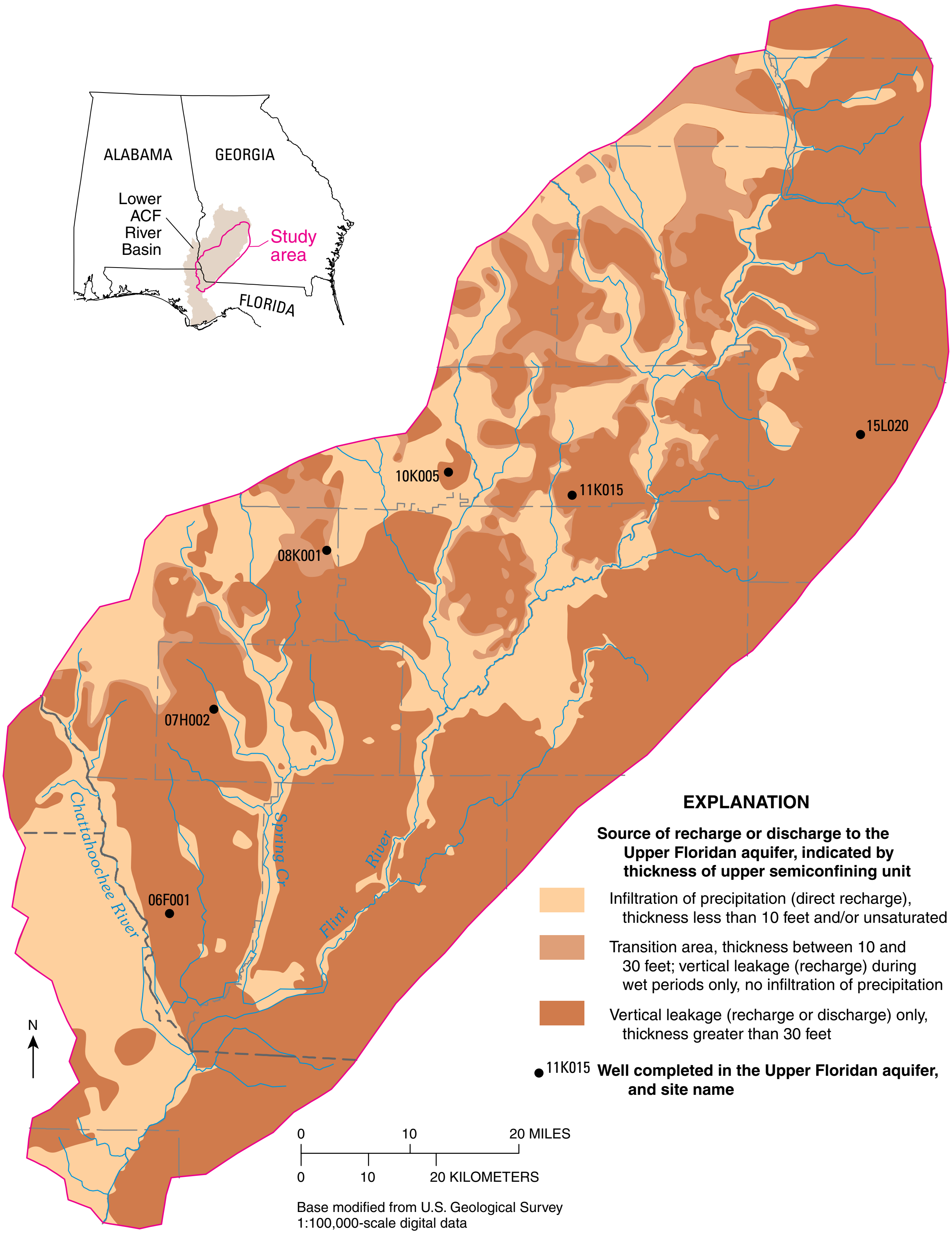


Figure 12. Sources of recharge or discharge to the Upper Floridan aquifer in the lower Apalachicola–Chattahoochee–Flint (ACF) River Basin.

Upper Floridan Aquifer

The Upper Floridan aquifer is the principal water-bearing unit of the stream-lake-aquifer flow system and is in hydraulic connection with surface water in much of the lower ACF River Basin. The aquifer consists of a complex off-lapping sequence of the following geologic units, in descending order: Tampa Limestone; Chattahoochee and St. Marks Formations; Suwannee, Marianna, and Ocala Limestones; and Clinchfield Sand. These units are confined below by the Lisbon Formation and generally semiconfined above by undifferentiated overburden (mostly in Georgia) and the Hawthorn Group (mostly in Florida) (fig. 3). The diversity and complexity of thickness and hydraulic properties within and among these geologic units creates equally diverse hydrologic characteristics of the Upper Floridan aquifer, depending on location in the lower ACF River Basin. Stream-aquifer interaction varies within the basin according to the proximity of the aquifer to surface water and degree of hydraulic connection to, or separation from, surface water by other hydrologic units. Development of secondary flow features in the Upper Floridan aquifer—such as joints, faults, fractures, and conduits—enhances stream-aquifer interaction in areas where hydraulic connection exists. Seasonal ground-water-level response to natural and human-made stresses affects ground-water discharge to streams and reflects the local heterogeneity of hydraulic properties in the aquifer.

Thickness

Thickness of the Upper Floridan aquifer in the lower ACF River Basin ranges from a few feet along the northwestern study area boundary, near the updip limit of the Clinchfield Sand, to more than 700 ft downdip along the southeastern boundary (fig. 13) where the aquifer consists mostly of Suwannee and Ocala Limestones. Thickness values were obtained by subtracting the altitude of the base of the Upper Floridan aquifer (fig. 14) from the altitude of the top (fig. 8) and confirmed by data (table A1) and published information (Pratt and others, 1996; Torak and others, 1996). Thickness increases greatly to the south and east along the Solution Escarpment and Holmes Valley Scarp where the Tampa, Suwannee, and Marianna Limestones overlie the Ocala Limestone in a stepped sequence, and the aquifer dips more sharply than in the central part of the study area on the Dougherty Plain (fig. 1). Along the southeastern study area boundary, the altitude of the base of the aquifer lowers to more than 800 ft below NAVD 88 (well W-3577, fig. 5; fig. 14). Thickness of the Upper Floridan aquifer increases from less than 50 ft in the Alabama part of the basin to more than 700 ft to the south and east of Lake Seminole (fig. 5, section *B–B′*). Aquifer thickness ranges from about 100 to 300 ft along the southwest-to-northeast-trending midsection of the lower ACF River Basin (fig. 13), between the outcrop area to the northwest and Solution Escarpment and Tifton Upland to the southeast.

Hydraulic Properties and the Effect of Limestone Dissolution on Ground-Water Flow

Limestone dissolution in the Upper Floridan aquifer has caused local variations in hydraulic properties of aquifer transmissivity, hydraulic conductivity, storage coefficient, and specific yield, facilitating ground-water flow to wells through interconnected systems of solution openings, fractures, and joints. The distribution of solution cavities from limestone dissolution has created local patterns of high transmissivity and a potential for preferential ground-water flow in the Upper Floridan aquifer such as those inferred in the Albany, Ga., area (Torak and others, 1993). Solution enlargement of interconnected pore space into cavities has increased storage properties of the Upper Floridan aquifer, causing storage coefficient and specific yield to vary locally depending on the amount of dissolution. Limestone dissolution has increased the hydraulic connection of the aquifer with surface water.

Transmissivity and Hydraulic Conductivity

Transmissivity values in the Albany, Ga., area derived from diffusivity analyses and multiwell aquifer-performance tests range from about 700 to about 283,000 feet squared per day (ft^2/d) and vary considerably within short distances (Hicks and others, 1987) owing to limestone dissolution. Other aquifer-performance tests conducted in the study area yielded a larger range in transmissivity values—from about 2,000 to about 1,300,000 ft^2/d (Sever, 1965a, b; Hayes and others, 1983; Wagner and Allen, 1984)—than those obtained in Albany, Ga., further indicating the effects of limestone dissolution on aquifer heterogeneity. Aquifer-performance tests conducted during this study by a private contractor to the State of Georgia yielded transmissivity values that range from about 1,600 to about 145,000 ft^2/d (fig. 15), and hydraulic conductivity values that range from about 10 to about 600 feet per day (ft/d) (Katherine H. Zitsch, Project Manager, Camp, Dresser & McKee Inc., written commun., 2003). Transmissivity values near the high end of this range generally occur where the aquifer is thick (fig. 13) or altered by limestone dissolution, such as near streams and Lake Seminole; low transmissivity values generally occur in areas where the limestone is thin or where ground water flows through unaltered limestone. High values of hydraulic conductivity indicate alteration of limestone by dissolution; low hydraulic-conductivity values represent unaltered limestone.

The largest transmissivity value listed in the ranges previously mentioned, 1,300,000 ft^2/d, was obtained from an aquifer-performance test on a well located in Bainbridge, Ga. (Sever, 1965b). Current-meter tests indicated that nearly 90 percent of the well yield during this test was derived from a 6-ft-thick zone located near the top of the Upper Floridan aquifer, within 130 ft of land surface. Two other zones of 2 and 23 ft in length, respectively, supplied the remaining well yield, with the 23-ft-thick zone supplying about 3 percent of the total well yield (Sever, 1965b, table 3).

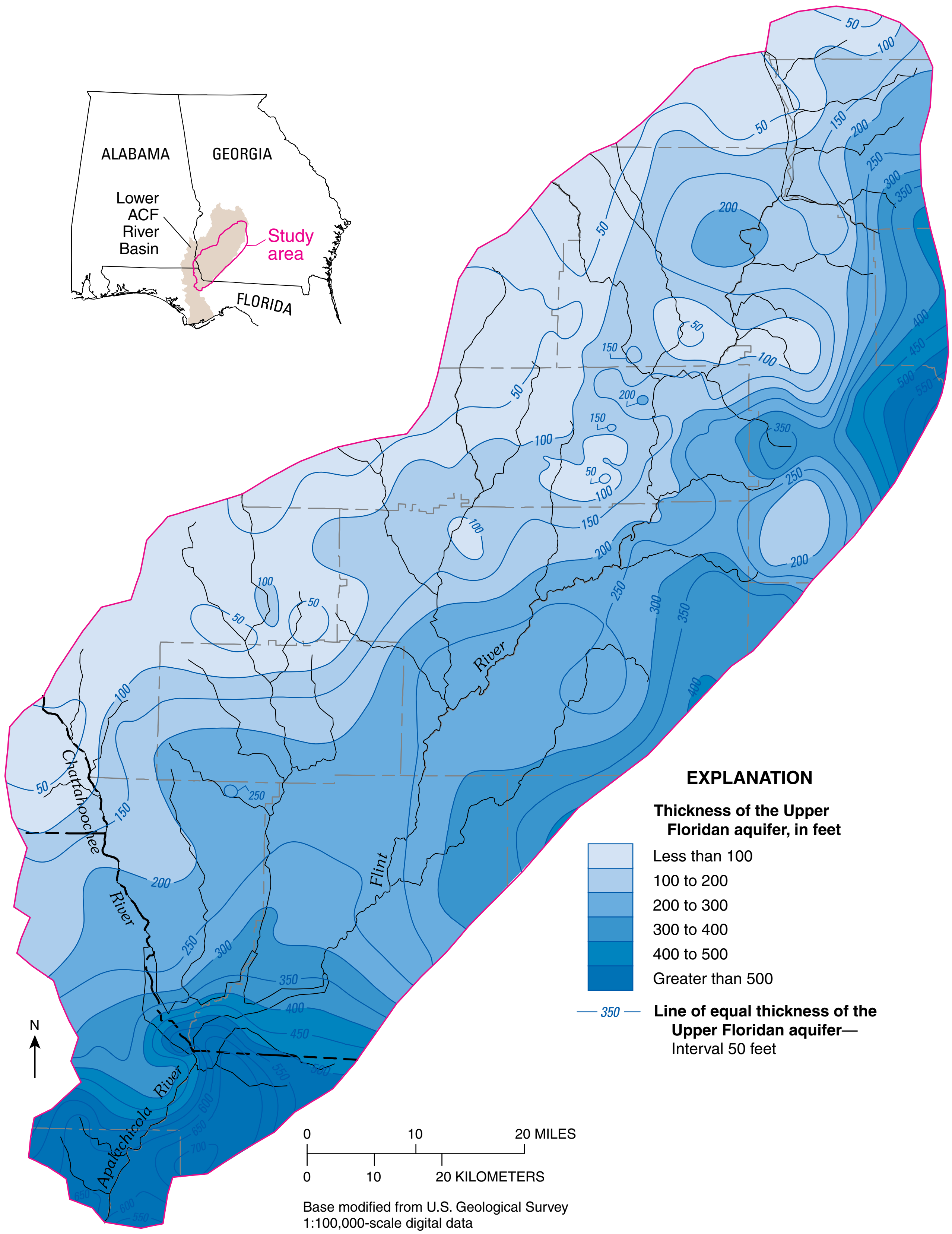


Figure 13. Approximate thickness of the Upper Floridan aquifer in the lower Apalachicola–Chattahoochee–Flint (ACF) River Basin.

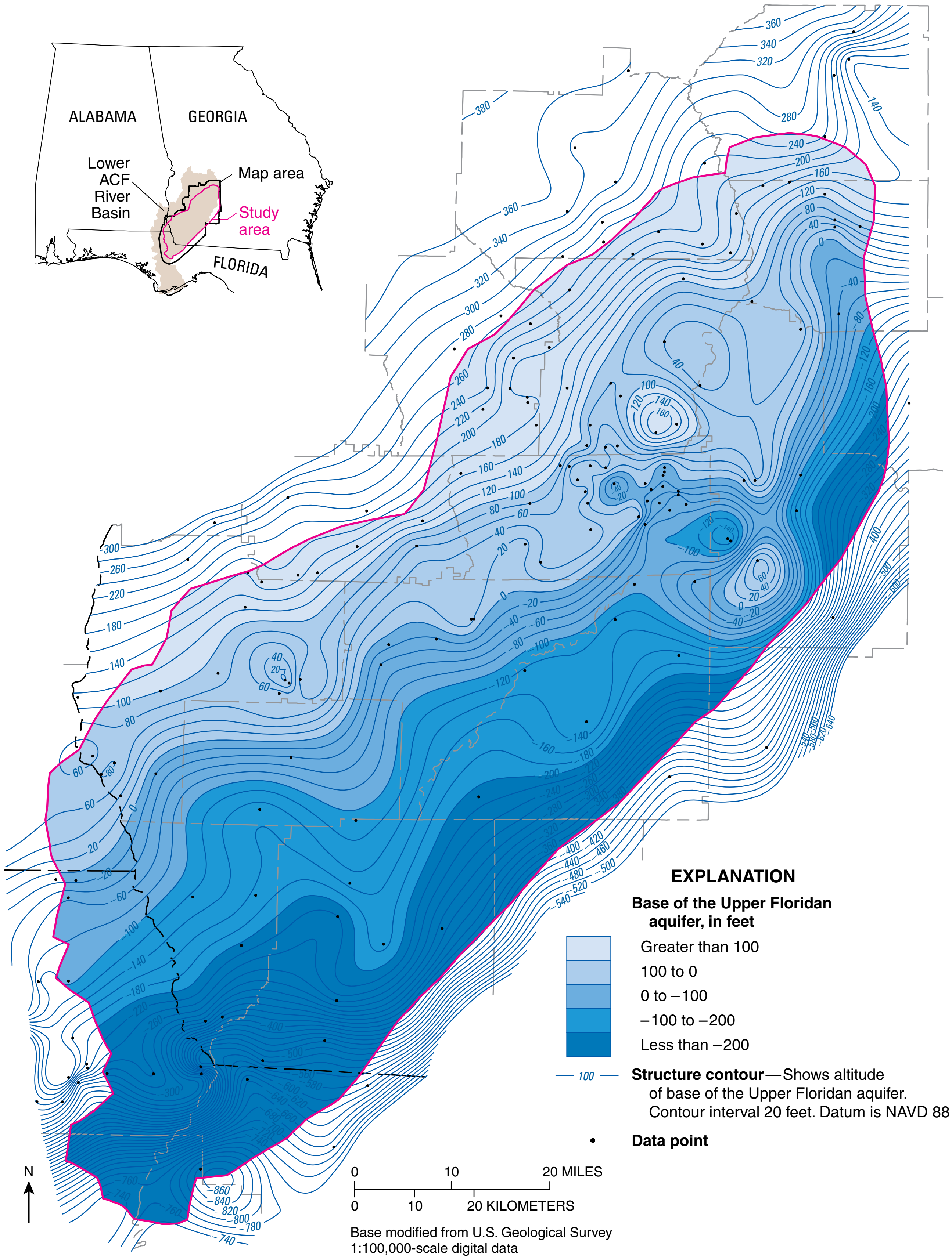


Figure 14. Approximate altitude of the base of the Upper Floridan aquifer in the lower Apalachicola–Chattahoochee–Flint (ACF) River Basin, southwestern Georgia and adjacent parts of Florida and Alabama.

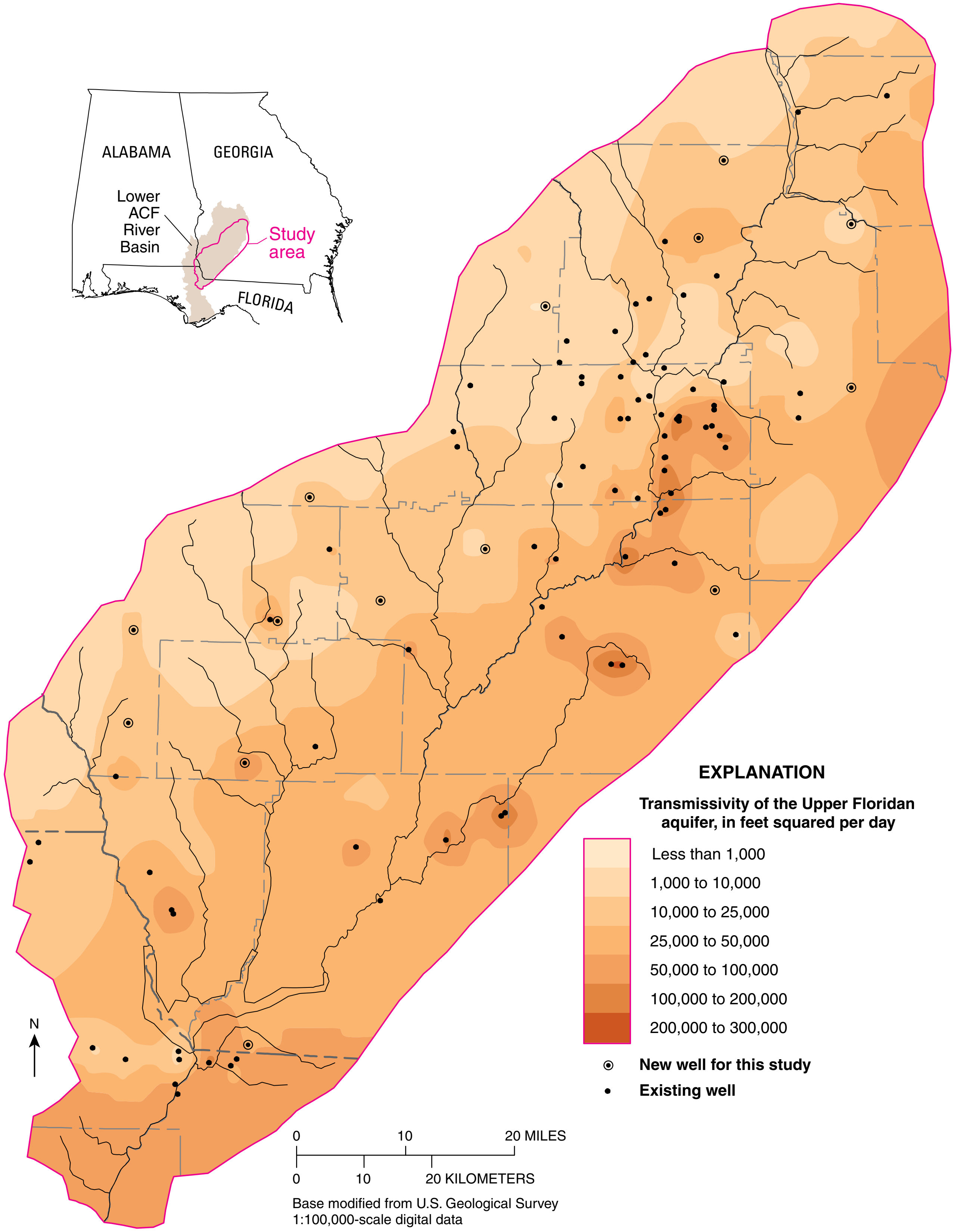


Figure 15. Regional estimates of transmissivity for the Upper Floridan aquifer in the lower Apalachicola–Chattahoochee–Flint (ACF) River Basin.

Therefore, out of about 350 ft of Upper Floridan aquifer thickness penetrated by the well, about 8 ft of the aquifer in two zones supplied nearly the entire well yield during the test (Sever, 1965b), and provided the highest transmissivity value in the study area.

Transmissivity values derived from aquifer-performance tests give an indication of the potential for the aquifer to produce water *within the immediate area of the test* and may not be indicative of aquifer-development potential or ground-water movement on a regional scale. Results of the aquifer-performance test in Bainbridge, Ga., described above, and the wide range of variation in transmissivity values obtained from similar tests performed throughout the study area underscore the effect of aquifer heterogeneity caused by limestone dissolution on hydraulic properties of the Upper Floridan aquifer. Hydraulic conductivity values from wells that derive high percentages of total well yield from relatively small percentages of aquifer thickness can lead to overestimation of regional transmissivity if total aquifer thickness is used with the hydraulic conductivity values to estimate transmissivity. Because wells are completed in the most productive zones of geologic units that constitute the entire aquifer thickness, applying hydraulic conductivity values obtained from aquifer-performance tests of these production zones to the entire aquifer thickness will lead to overestimation of transmissivity. On a regional scale, where aquifer-performance tests are sparse, overestimation of transmissivity leads to overestimating lateral and vertical ground-water movement into or out of the aquifer, and overestimating aquifer-development potential.

Overestimation of aquifer transmissivity on a local scale would give a false indication that the aquifer is highly productive, that is, capable of supplying large volumes of water to wells while producing only small water-level declines from pumping (drawdown) and small changes in regional hydraulic gradients, when in reality the opposite might occur. Projecting less drawdown from new wells by overestimating transmissivity could result in a failure to adequately account for interference from nearby wells when setting pumps in new wells, thereby causing unexpected well interference in new or existing wells in the form of excessive drawdown; nearby well pumps could break suction and pump dry, requiring pumps to be set lower than current depths. Similarly, minimizing pumpage effects on regional gradients resulting from overestimation of transmissivity could result in unanticipated pumpage-induced streamflow loss and possible habitat degradation for aquatic biota.

The large range in transmissivity and hydraulic conductivity values obtained from aquifer-performance tests reflects the importance of limestone dissolution on the ability of the Upper Floridan aquifer to transmit ground water to wells, surface water, and other hydrologic units. Results of aquifer-performance tests indicate that large variations in hydraulic conductivity exist at a regional scale, across several miles. Local variations in hydraulic conductivity, although unknown because of data limitations, are inferred to be equally as large as the regional variability, based on lithologic heterogeneities in limestone penetrated by closely spaced wells (Katherine Zitsch, Project Manager, Camp, Dresser & McKee Inc., written commun., 2003). Quantifying the magnitude of local variation in hydraulic conductivity throughout the study area using detailed local-scale aquifer-performance tests would be impractical and cost-prohibitive given the size of the study area and complexity of limestone-dissolution processes. Even the most thorough sampling and aquifer-testing program would yield little useful results because of the inability to define hydraulic conductivity and the physical extent of limestone dissolution everywhere in the subsurface.

Geostatistics use spatial-correlation structures of spatial functions to process hydraulic conductivity values that are averaged from different volumes and sizes (American Society of Civil Engineers Task Committee on Geostatistical Techniques in Geohydrology, 1990a, b). The results are used to estimate the regional distribution and local variations of hydraulic conductivity (Matheron, 1971; Journel and Huijbregts, 1989). Geostatistical techniques were applied to hydraulic conductivity data to obtain the regional distribution for the Upper Floridan aquifer and local variations in the lower ACF River Basin. Previous work in the Albany, Ga., area involving geostatistical co-estimation of hydraulic head and transmissivity of the Upper Floridan aquifer (Rouhani and Torak, 1991) was extended to the remainder of the study area to evaluate statistical relations and spatial trends among hydraulic conductivity values derived from aquifer-performance tests (David C. Leeth, U.S. Geological Survey, written commun., September 2004). Log-kriging, a geostatistical-estimation technique (Matheron, 1971; Journel and Huijbregts, 1989; and American Society of Civil Engineers Task Committee on Geostatistical Techniques in Geohydrology, 1990a, b) applied to hydraulic conductivity values, preserved the heterogeneity of the hydraulic conductivity, and, hence, transmissivity distributions (Matheron, 1967) that were caused by limestone dissolution. The log-transformed hydraulic conductivity values produced better-defined and stronger correlation structures among the “regionalized” transmissivity values than if ordinary kriging were performed using non-log-transformed data (De Marsily, 1986).

Regional estimates of transmissivity for the Upper Floridan aquifer (fig. 15) were obtained by combining the spatial distribution of hydraulic conductivity, derived from log-kriging (fig. 16), with aquifer thickness (fig. 13). Geostatistics provided unbiased estimates for the spatial distribution and variation in hydraulic conductivity and transmissivity, and was well suited for making inferences about these hydraulic-property distributions from “incomplete,” or sparse, spatial information provided by aquifer-performance-test results.

Storage Coefficient and Specific Yield

Values of storage coefficient derived from aquifer-performance tests range from about 0.0001 to about 0.04 (Katherine H. Zitsch, Project Manager, Camp, Dresser & McKee Inc., written commun., October 2003), and compare well with similar values reported by Hayes and others (1983), which range from about 0.0002 to about 0.03.

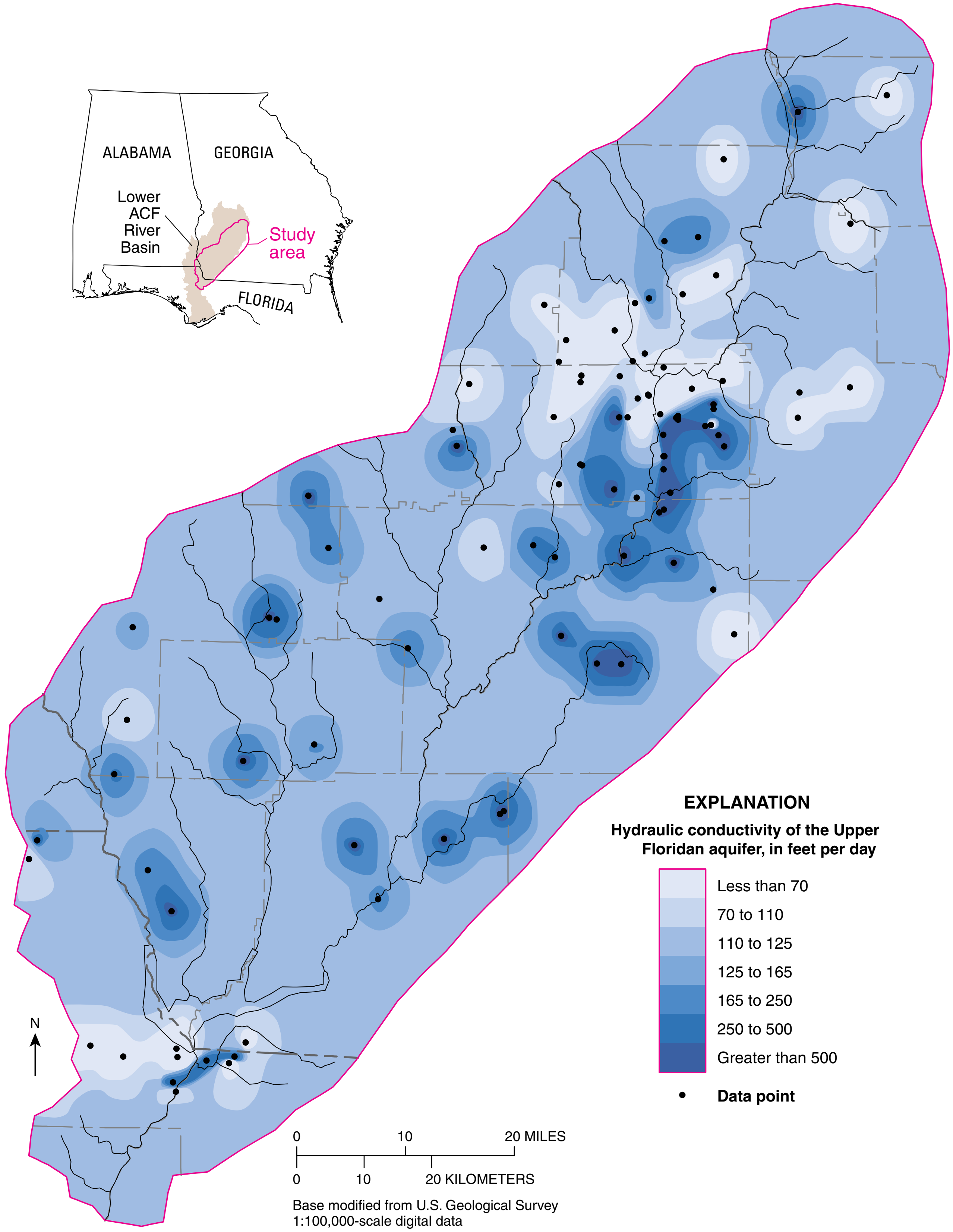


Figure 16. Kriged distribution of hydraulic conductivity of the Upper Floridan aquifer in the lower Apalachicola–Chattahoochee–Flint (ACF) River Basin.

These values indicate confined or semiconfined (artesian) aquifer conditions and support the conceptualization of the Upper Floridan aquifer as semiconfined from above by the residuum or Hawthorn Group. A relatively high storage-coefficient value, 0.1, obtained from an aquifer-performance test in Bainbridge, Ga. (Sever, 1965a), indicates that unconfined aquifer, or water-table aquifer conditions existed at some locations in the Upper Floridan aquifer. The potential exists for water-table aquifer conditions to occur in the Upper Floridan aquifer because of heavy seasonal agricultural withdrawal, discharge to streams, or a dry climate.

The occurrence of water-table aquifer conditions together with interconnected-solution features (conduits) indicates a potential for the Upper Floridan aquifer to accumulate or release large volumes of water with small changes in the ground-water level. For a given change in the water table, partially filled conduits in the Upper Floridan aquifer have a much larger capacity to accumulate or release ground water than the same conduits flowing full under artesian conditions. The large storage capacity of the Upper Floridan aquifer under water-table conditions results from the water-table storage term, or *specific yield*, being several orders of magnitude larger than the artesian storage term, or *storage coefficient*. The specific yield represents the ability of the water-table aquifer to accumulate or release ground water by draining or saturating interconnected pore space in the aquifer, such as partially filled flow conduits, cavities, and solution-enlarged joints and fractures. The artesian storage (storage coefficient) term represents the ability of the aquifer to accumulate or release ground water due to changes in the pressure potential of hydraulic head according to the compressibility of the aquifer and ground water (Davis and DeWiest, 1966), while the aquifer maintains complete saturation during these aquifer-storage processes. Although more ground water can be derived from storage in the Upper Floridan aquifer under water-table conditions than under artesian conditions for a given decline in ground-water level, excessive ground-water-level declines in a water-table aquifer result in considerable loss of saturated thickness and can cause aquifer dewatering, which would severely impede ground-water flow to wells and surface water.

Seasonal and Long-Term Ground-Water-Level Fluctuations

Ground-water levels in the Upper Floridan aquifer respond seasonally and in the long term to climatic effects caused by drought, infiltration of precipitation, and evapotranspiration, and to ground-water withdrawal and changes in stream stage and lake level (fig. 17). The extent to which these hydrologic factors affect ground-water levels varies throughout the lower ACF River Basin. The proximity and degree of hydraulic connection of the aquifer with land surface, overlying hydrologic units, and surface water—and the spatial and temporal distribution of pumpage—affect ground-water levels.

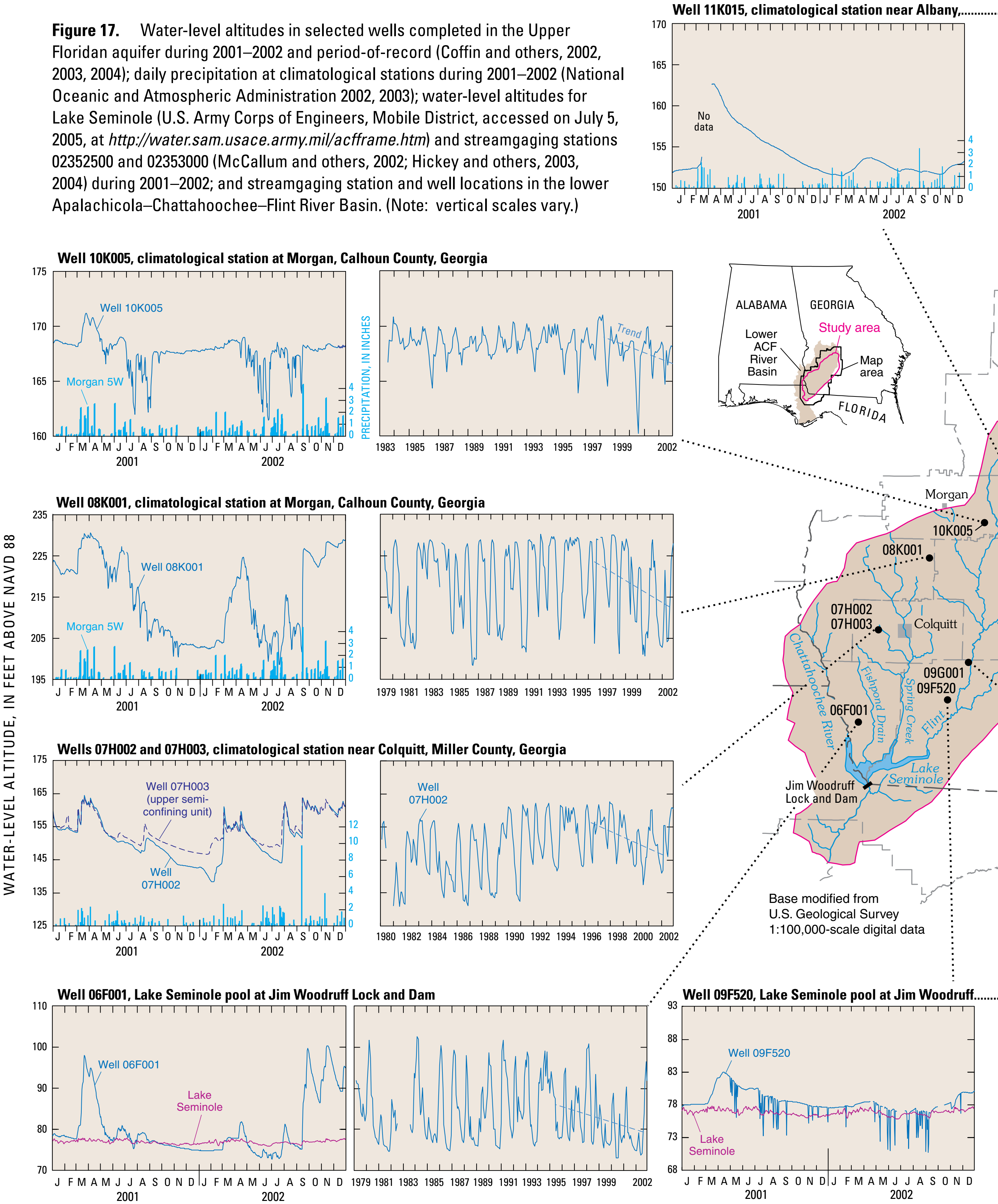
Ground-water levels in the Upper Floridan aquifer usually reach a yearly maximum from late winter to early spring (fig. 17) when evapotranspiration and agricultural pumping are low and when long-duration, moderate-intensity storms, associated with frontal passages, bring steady rain to large areas of the basin. Rainfall enters the Upper Floridan aquifer by infiltration through the upper semiconfining unit. During the growing season, from mid-spring to early winter, ground-water levels gradually decline in response to reduced recharge, irrigation pumping, other agricultural water use, and increased evapotranspiration. Recharge from infiltration of precipitation decreases during the growing season and contributes to the seasonal decline of ground-water levels as summertime, convective-type thunderstorms supplant the longer-duration rainfall that occurred during the previous winter and spring. Thunderstorms create isolated rainfall patterns across small areas of the basin, generating more runoff to streams than recharge to the aquifer because of their high intensity but short duration. Ground-water levels reach yearly lows during early to mid-fall and usually recover to seasonal high levels again during the following winter and spring with the return of normal seasonal precipitation.

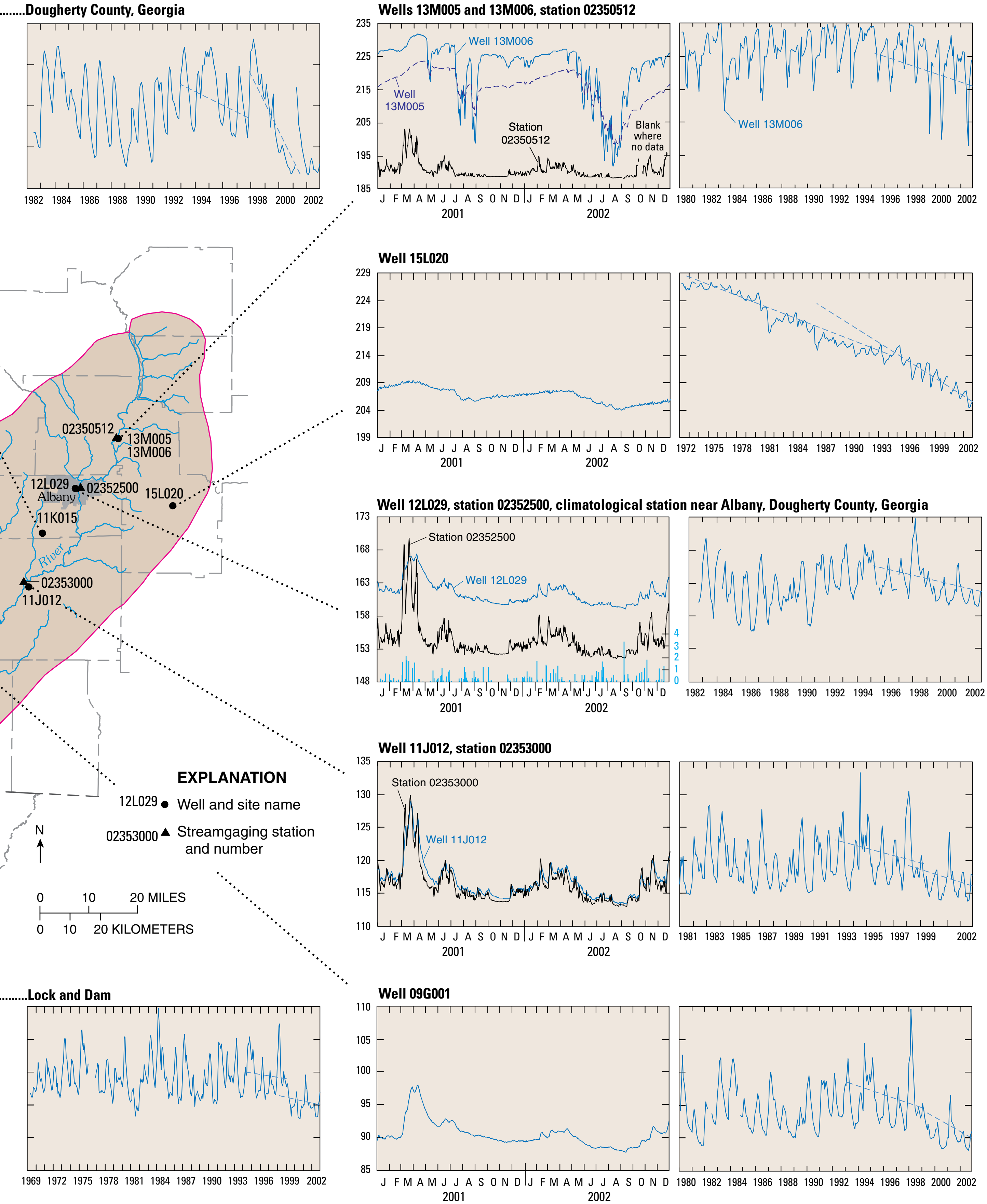
Seasonal ground-water-level fluctuations in the Upper Floridan aquifer vary throughout the basin according to the amount of water that recharges the aquifer, either directly from infiltration or indirectly from vertical leakage through the upper semiconfining unit or from surface-water sources. Downdip of the outcrop area where the upper semiconfining unit is thin or absent (fig. 7), ground-water levels fluctuate seasonally by nearly 30 ft (wells 07H002 and 08K001, fig. 17) in response to infiltration. During 2001 and 2002, water-level fluctuations in well 07H002 closely paralleled those in well 07H003, completed nearby in the upper semiconfining unit, indicating that precipitation infiltrated readily through the relatively thin upper semiconfining unit (about 40 ft) to recharge the underlying Upper Floridan aquifer by vertical leakage. Good hydraulic connection of the upper semiconfining unit with the underlying aquifer facilitated near-identical water-level response to recharge in both hydrologic units.

Near the central part of the lower ACF River Basin, seasonal ground-water-level fluctuations from about 10 to 15 ft occurred in the Upper Floridan aquifer in wells 10K005, 11K015, and 12L029 (fig. 17). A relatively thick upper semiconfining unit (greater than about 50 ft, fig. 7), overlies the Upper Floridan aquifer at these well locations, preventing direct recharge into the aquifer and promoting recharge by vertical leakage. Vertical leakage through the upper semiconfining unit damps seasonal ground-water-level fluctuations, replacing the large, precipitation-driven, seasonal ground-water-level fluctuations associated with direct recharge to the outcrop areas of the aquifer with a more subdued response.

Along the Solution Escarpment and Tifton Upland, the ground-water level in well 15L020, completed in the Upper Floridan aquifer, has fluctuated no more than about 5 ft annually since the early 1970s (fig. 17). The advent of heavy agricultural pumpage in the mid-1970s (Harrison and Tyson, 1999) and drought conditions during the 1980s and from 1998 to 2002, however, have prevented complete recovery of the ground-water level from previous growing-season declines.

Figure 17. Water-level altitudes in selected wells completed in the Upper Floridan aquifer during 2001–2002 and period-of-record (Coffin and others, 2002, 2003, 2004); daily precipitation at climatological stations during 2001–2002 (National Oceanic and Atmospheric Administration 2002, 2003); water-level altitudes for Lake Seminole (U.S. Army Corps of Engineers, Mobile District, accessed on July 5, 2005, at *http://water.sam.usace.army.mil/acfframe.htm*) and streamgaging stations 02352500 and 02353000 (McCallum and others, 2002; Hickey and others, 2003, 2004) during 2001–2002; and streamgaging station and well locations in the lower Apalachicola–Chattahoochee–Flint River Basin. (Note: vertical scales vary.)




........Dougherty County, Georgia
1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002
Wells 13M005 and 13M006, station 02350512
235 225 215 205 195 185
Well 13M006
Well 13M005
Station 02350512
Blank where no data
J F M A M J J A S O N D J F M A M J J A S O N D
2001 2002
1980 1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002
Well 15L020
229 224 219 214 209 204 199
1972 1975 1978 1981 1984 1987 1990 1993 1996 1999 2002
Well 12L029, station 02352500, climatological station near Albany, Dougherty County, Georgia
173 168 163 158 153 148
Station 02352500
Well 12L029
4 3 2 1 0
1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002
Well 11J012, station 02353000
135 130 125 120 115 110
Station 02353000
Well 11J012
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2002
Well 09G001
110 105 100 95 90 85
1980 1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002
........Lock and Dam
1969 1972 1975 1978 1981 1984 1987 1990 1993 1996 1999 2002
02350512
13M005
13M006
12L029
Albany
02352500
15L020
11K015
River
02353000
11J012
EXPLANATION
12L029 ● Well and site name
02353000 ▲ Streamgaging station and number
N
0 10 20 MILES
0 10 20 KILOMETERS

A thick layer of the upper semiconfining unit ranging from 150 to 200 ft mantles the Upper Floridan aquifer along the eastern boundary of the lower ACF River Basin with residuum having low water-bearing properties (fig. 7). The combination of large thickness and low water-bearing properties of the upper semiconfining unit limits recharge to the underlying aquifer in this area, contributing to a steady annual decline in water levels of slightly less than 1 ft since the mid-1970s in well 15L020 (fig. 17). Since the mid-1990s, several hydrologic factors caused increases in rate of decline in the ground-water level in well 15L020, which are apparent from the hydrograph:

- increased use of the Upper Floridan aquifer;
- reduced recharge to the aquifer by infiltration of precipitation and vertical leakage; and
- reduced regional (intrabasin) flow to this area from updip areas that have sustained irrigation-pumpage increases.

Ground-water-level declines in this area limit ground-water availability along the eastern boundary of the lower ACF River Basin and flow downdip to adjacent river basins (inter-basin flow) located to the east and south of the well.

Climatic Effects

Climatic effects on ground-water-level fluctuations in the Upper Floridan aquifer vary throughout the lower ACF River Basin, but in general, are relatively short term. That is, drought and rainfall usually affect ground-water levels for the length of time that those events occur and for a short time thereafter until precipitation and/or the cessation of pumping during the nongrowing season restores ground-water levels to seasonal or near-seasonal average conditions. Ground-water levels showed record or near-record lows during the drought years of 1980, 1981, and 1986, but returned to predrought levels the following years when precipitation resumed at average to above-average rates in wells 08K001, 07H002, 06F001, 11K015, 12L029, and 09G001 (fig. 17).

For the sustained drought conditions that began during 1998 and extended through 2002, new minimum-monthly mean ground-water levels were established for specific months during 2001 and 2002 in wells 06F001, 09G001, 10K005, 11K015, 13M006, and 15L020 (fig. 17). In well 06F001, located near the Chattahoochee River impoundment arm of Lake Seminole, the ground-water level declined to new monthly lows during February, March, and May 2002. By the end of the year, however, the ground-water level in well 06F001 recovered by nearly 21 ft with the return of rainfall and subsequent recharge. The ground-water level in well 09G001 declined to new monthly mean lows during each of the first 9 months of 2002, surpassing previously established minimum-mean ground-water levels during January, February, and March 2001, and signifying the severity of drought conditions that existed in the south-central part of the lower ACF River Basin.

In the north-central part of the lower ACF River Basin, downdip from the outcrop area of the Upper Floridan aquifer, the ground-water level in well 10K005 responded to low rainfall. Ground-water levels declined to new minimum-monthly mean levels during the first quarter of 2001, fluctuated near monthly mean water levels during the summer, and declined to near minimum-monthly mean levels by the end of the year in (fig. 17). The water level in well 10K005 responded to low precipitation by declining to new minimum-monthly mean levels during February through June 2002, recovered nearly 6.5 ft during July in response to precipitation during that month, and ended the year within about 0.5 ft of the long-term (from 1983 to 2002), monthly mean ground-water level for December. East and downdip of well 10K005, drought conditions caused new minimum-monthly mean ground-water levels in well 11K015 during at least the first 2 months of 2001 and during the following year except during December 2002, when seasonal precipitation recharged the aquifer.

Effects of Ground-Water Withdrawal

Ground-water withdrawal for agricultural, municipal, and industrial use creates seasonal and long-term water-level declines (drawdown) in the Upper Floridan aquifer that vary locally in magnitude and duration throughout the lower ACF River Basin. Near areas of heavy agricultural pumpage to the north of Lake Seminole, seasonal ground-water-level fluctuations of nearly 30 ft occurred during 2001 and 2002 in well 06F001 (fig. 17). In the outcrop area, ground-water pumpage combined with low hydraulic properties of the Upper Floridan aquifer (fig. 15) and recharge caused seasonal ground-water-level fluctuations that ranged from 25 to 30 ft in well 08K001 (fig. 17). Annual ground-water-level fluctuations in the northern part of the basin generally range from 20 to 25 ft in well 13M006 in response to agricultural pumpage. Seasonal ground-water-level fluctuations exceeding 30 ft can occur near centers of heavy agricultural and industrial pumpage; however, Hicks and others (1987) noted these fluctuations do not form distinct cones of depression in the water-level surface of the Upper Floridan aquifer, but rather uniformly raise and lower water levels in the aquifer across large areas.

Ground-water levels respond readily to agricultural pumpage during the growing season, which usually spans early spring through summer. During the growing seasons of 2001 and 2002, hydrographs of wells 10K005, 08K001, 09F520, and 13M006, located near irrigation pumpage, recorded cyclic-drawdown patterns (fig. 17). Local drawdown of as much as 30 ft in well 13M006 resulted from irrigation pumpage in the Upper Floridan aquifer during the 2001 and 2002 growing seasons. Water-level fluctuations in well 09F520 indicated that cyclic-irrigation pumpage nearby continued into the fall of 2001 and 2002 and created local drawdown effects ranging from about 5 to 10 ft for days or weeks at a time. Pumpage-induced drawdown of ground-water levels during the drought conditions of 1998 through 2002 exacerbated seasonal-low water-level conditions and created record- or near-record low water levels in most wells.

Since the early 1990s, increased demand for ground water (wells) to supply agricultural irrigation, together with drought during 1998 to 2002, have contributed to slight but steady declines in ground-water levels of the Upper Floridan aquifer in some areas of the lower ACF River Basin. To understand the effects of increased agricultural irrigation on ground-water levels in the Upper Floridan aquifer, a brief discussion of agricultural water use since the 1970s and since the 1990s is given below, followed by a description of the effects of increased agricultural irrigation on water levels in the Upper Floridan aquifer.

Results of the University of Georgia Cooperative Extension Service (CES) Irrigation Surveys indicate that irrigation acreage increased more than tenfold statewide from 1970 to 2000, from about 145,000 acres during 1970 to more than 1.5 million acres during 2000. Irrigated acreage in the lower ACF River Basin accounted for about half of the statewide total during 2000, or about 745,000 acres; about 80 percent of the total irrigation acreage in the basin, or about 597,000 acres, was supplied by ground water (Hook and others, 2005, tables E-14 and E-20). From 1998 to 2000, a 5.4-percent increase in irrigated acreage occurred statewide (Harrison, 2001); in the lower ACF River Basin, irrigated acreage increased about 7 percent during this period, slightly greater than the statewide increase.

New irrigation systems installed since 1970 generally relied on wells to meet the increased irrigation demand because most systems supplied by surface water utilize farm ponds, which are not adequate to supply some of the larger systems that were being installed (Harrison, 2001). While the number of irrigation systems utilizing surface water (ponds, streams, and rivers) statewide remained fairly constant during the 1990s, at about 6,000 systems, the number of irrigation systems supplied by wells increased by about 39 percent, from about 7,300 systems during 1989 to about 10,100 systems during 2000 (Harrison, 2001, table 1). CES survey data indicate that, between 1992 and 1998, the number of wells supplying water to irrigation systems in the lower ACF River Basin increased by about 17 percent, from 4,418 to 5,158 wells, and total pumping capacity increased by 13 percent (Dr. James E. Hook, National Environmentally Sound Production Agricultural Laboratory, The University of Georgia, Tifton, Ga., written commun., January 2006). This pumpage increase represents about an 11-percent net growth in agriculture in the lower ACF River Basin from 1992 to 1998 (Dr. James E. Hook, National Environmentally Sound Production Agricultural Laboratory, The University of Georgia, Tifton, Ga., written commun., January 2006).

Use of center-pivot and drip irrigation increased steadily from the mid-1970s, with the highest increasing trends since the 1970s occurring during the mid- to late 1990s (Harrison, 2001, fig. 3). Most of the water demand corresponding to the new center-pivot systems was met by using wells tapping the Upper Floridan aquifer. Although non-center-pivot systems (such as cable-tow, hose reel, lateral move, solid-set sprinkler, traveling gun, and portable pipe with sprinklers) increased during the 1970s and early 1980s, their total number has declined slightly since then because of the high labor requirement and cost of operation (Harrison, 2001).

Agricultural acreage served by center-pivot irrigation increased by about 37 percent from 1993 to 1999, from about 330,302 acres to about 452,230 acres, in Georgia counties encompassing the lower ACF River Basin (table 8) (Litts and others, 2001). Because the remote-sensing methods used to account for center-pivot irrigation were incapable of accounting for increases in non-center-pivot irrigation during 1993 to 1999 (Litts and others, 2001), the increase in total irrigation acreage during this period is unavailable. Results of the CES survey from 1992 to 1998, however, indicate that irrigated acreage in the lower ACF River Basin increased by about 11.6 percent, from 622,000 acres to 690,000 acres (Dr. James E. Hook, National Environmentally Sound Production Agricultural Laboratory, The University of Georgia, Tifton, Ga., written commun., January 2006). CES survey data also indicate that from 1992 to 1998, the number of non-center-pivot systems statewide decreased by about 48 percent, and the number of center-pivot systems increased by about 49 percent, with an 11-percent net increase in total irrigated acres (Harrison, 2001, table 1).

Table 8. Center-pivot-irrigation acreage in lower Apalachicola–Chattahoochee–Flint River Basin, 1993 and 1999 (modified from Litts and others, 2001).

[See figure 2 for county location; —, not applicable]

County[1]	Center-pivot irrigation		1993–1999 increase (acre)	Percent increase
	1993 (acre)	1999 (acre)		
Baker	32,904	38,739	5,835	18
Calhoun	18,167	24,416	6,249	25
Crisp	3,895	11,951	8,056	207
Decatur	47,870	59,579	11,709	24
Dooly	6,984	12,487	5,503	79
Dougherty	8,123	11,116	2,993	37
Early	18,037	30,265	12,228	68
Grady	2,828	3,254	426	15
Lee	26,691	33,651	6,960	26
Miller	30,762	45,982	15,220	49
Mitchell	47,610	58,425	10,815	23
Seminole	35,116	45,831	10,715	31
Sumter	29,161	39,634	10,473	36
Terrell	12,391	19,841	7,450	60
Turner	211	1,384	1,173	556
Worth	9,552	15,675	6,123	64
Total	**330,302**	**452,230**	**121,928**	—

[1]Colquitt County had no center-pivot irrigation systems in the study area.

The CES survey data seem to indicate a shift toward greater dependence on ground water than surface water in the lower ACF River Basin during the 1990s (Dr. James E. Hook, National Environmentally Sound Production Agricultural Laboratory, The University of Georgia, Tifton, Ga., written commun., January 2006). The combination of these factors—increase in center-pivot irrigation systems, decrease in non-center-pivot systems, and net increase in total irrigated acres (11.6 percent)—could indicate a replacement of some surface-water (and ground-water) supplied non-center-pivot systems with center-pivot systems supplied mostly by ground water from the Upper Floridan aquifer, in addition to the installation of new systems on fields that previously had no irrigation.

From 1993 to 1999, the largest percentage increases to center-pivot-irrigation acreage of all counties in the lower ACF River Basin occurred in Crisp, Dooly, Early, Turner, and Worth Counties, Ga. (table 8). Center-pivot-irrigation acreage increased in these counties by a total of 33,083 acres, which represents about 27 percent of the total-acreage increase attributed to center-pivot irrigation in the basin (121,928 acres, table 8). Although other counties sustained larger acreage increases related to center-pivot irrigation during 1993 to 1999 than the five counties mentioned previously, four of these counties (Crisp, Dooly, Turner, and Worth) are located along the northern and northeastern boundaries of the lower ACF River Basin where the Upper Floridan aquifer is relatively thin (fig. 13), and transmissivity is relatively low (fig. 15). Early County is in and near the outcrop area of the Upper Floridan aquifer along the northwestern boundary of the lower ACF River Basin where the aquifer is thin and less transmissive than downdip to the southeast. Increased pumping in these areas could cause declines in the ground-water level of the Upper Floridan aquifer if recharge by infiltration of precipitation, vertical leakage through the upper semiconfining unit, or regional flow from outcrop areas are limited or reduced substantially.

Ground-water pumping to supply increased demands for center-pivot irrigation in the outcrop area of the Upper Floridan aquifer, where the aquifer is thin and less transmissive than downdip, makes these areas susceptible to large pumpage-induced drawdown and long-term ground-water-level decline. Center-pivot-irrigation acreage increased by about 46,353 acres from 1993 to 1999 in counties containing outcrop areas, namely, Calhoun, Dougherty, Early, Lee, Sumter, and Terrell Counties, Ga. (table 8). Combined with similar increases to center-pivot-irrigation acreage in the northern and northeastern parts of the lower ACF River Basin (20,855 acres in Crisp, Dooly, Turner, and Worth Counties, Ga.), more than half (55 percent) of the increased-irrigation acreage supplied by center-pivot systems is contained in the outcrop area of the Upper Floridan aquifer and along the northern and northeastern parts of the lower ACF River Basin. Lowered ground-water levels in the outcrop area could lead to long-term trends of declining ground-water-levels, aquifer dewatering, and reduced intrabasin flow downdip, where the aquifer is thick and highly transmissive, and reduced interbasin flow to adjacent basins to the south and east.

Downdip areas in the basin could sustain long-term water-level declines as increased irrigation pumpage in the outcrop area depletes intrabasin flow needed to restore ground-water conditions to prepumped levels during the nongrowing season. Ground-water levels in parts of the aquifer located along the Solution Escarpment and northeastern and eastern basin boundaries have the potential to decline in response to increased ground-water pumping in the outcrop areas as well as in the immediate area because a thick upper semiconfining unit overlies the Upper Floridan aquifer in these areas, limiting recharge by vertical leakage (figs. 1, 7, and 12). The inability of pumpage increases in downdip areas of the basin to induce additional intrabasin ground-water flow from the outcrop area, or induce vertical leakage into the aquifer through a thick upper semiconfining unit could cause long-term ground-water-level decline in the downdip areas. Pumpage increases in the outcrop area could cause local ground-water-level decline that reduces regional hydraulic gradients and transmissivity, thus reducing intrabasin flow to downdip areas of the basin.

Well 15L020, located along the Solution Escarpment in Worth County, Ga., downdip from the recharge area, has experienced long-term ground-water-level decline since the mid- to late 1970s (fig. 17). About 125–175 ft of upper semiconfining unit (fig. 7) overlies the area around well 15L020, making recharge by infiltration and vertical leakage through these overlying units difficult. The location of this well along the northeastern boundary of the lower ACF River Basin places it at least 30 mi downdip of outcrop areas to the Upper Floridan aquifer located in Dougherty, Lee, Sumter, and Terrell Counties, Ga. These counties have undergone increases in center-pivot-irrigation acreage of about 27,900 acres from 1993 to 1999; while during the same period (table 8), center-pivot-irrigation acreage increased in Worth County by about 64 percent, or about 6,100 acres. Increased pumpage from the Upper Floridan aquifer to supply center-pivot irrigation in these counties has the potential to reduce intrabasin flow from the outcrop area to downdip areas and to cause ground-water-level decline along the eastern boundary of the lower ACF River Basin and in neighboring basins to the east and south. Ground-water-level decline in the outcrop area to the west and northwest of well 15L020 during the mid- to late 1990s can be inferred from hydrographs of wells 10K005, 12L029, and 13M006, and could signify the onset of a long-term trend of declining ground-water levels.

Fluctuations in seasonal high and low water levels on long-term hydrographs of selected wells located in the lower ACF River Basin indicate slight trends in ground-water-level decline for the Upper Floridan aquifer during the mid- to late 1990s, exclusive of the ground-water-level decline attributed to drought during 1998 to 2002 (fig. 17). Drought conditions from 1998 to 2002 lowered ground-water levels to record or near-record lows, compounding ground-water-level declines that, from hydrographs, can be inferred to have begun about 5 years previously. Tropical Storm Alberto, an extreme-rainfall event during July 1994, raised ground-water levels during the last half of that year, reducing the possibility of identifying long-term declines in ground-water levels during the years preceding the storm.

In the central part of the basin along the Flint River and along the eastern lower ACF River Basin boundary, ground-water-level decline from 1993 to 2002, possibly in response to increased irrigation pumpage and drought, can be inferred from long-term hydrographs of wells 13M006, 12L029, 11J012, 09G001, and 15L020 (fig. 17). Hydrographs of wells 06F001, 07H002, 08K001, 10K005 and 11K015, located to the west of the Flint River near the updip limit or outcrop area of the Upper Floridan aquifer, indicate slight declines in ground-water-level, possibly in response to increased agricultural pumpage since 1993, in addition to drought-related ground-water-level declines from 1998 to 2002. Water levels in wells 06F001, 07H002, and 08K001, located near the outcrop area of the Upper Floridan aquifer, indicate slight recovery at the end of 2002 in response to rainfall during December. Increases in center-pivot irrigation pumpage from 1993 to 1999 seemed to affect ground-water levels less in this part of the basin than in other parts, perhaps because of the proximity of these wells to recharge from vertical leakage through the upper semiconfining unit (fig. 12) and because of water-table conditions that exist in the outcrop area.

Surface-Water Influence

Major surface-water bodies in the lower ACF River Basin affect ground-water levels in the Upper Floridan aquifer and upper semiconfining unit by raising and lowering ground-water levels in close proximity to these features commensurate with changes in surface-water stage. The Flint River incises the upper semiconfining unit and top part of the Upper Floridan aquifer, exposing limestone in the streambed as it courses through the center of the basin. Ground-water hydrographs of wells 09G001, 11J012, and 12L029 during 2001 and 2002 resemble stream hydrographs of the Flint River at Newton, Ga. (streamgaging station 02353000, near well 11J012), and at Albany, Ga. (streamgaging station 02352500, near well 12L029) (fig. 17). These wells are located less than a mile from the Flint River. Although located about 20 mi downstream from the streamgaging station at Newton, Ga., and about 0.5 mi west of the Flint River, the ground-water level in well 09G001 resembles stream stage as both responded to seasonal fluctuations (compare hydrograph of well 09G001 with stream stage at streamgaging station 02353000, fig. 17).

The ground-water level in well 12L029 and the Flint River stage at streamgaging station 02353000 seemed to respond to precipitation recorded in the Albany, Ga., area during 2001 and 2002 (fig. 17), making it difficult, if not impossible, to distinguish between ground-water-level fluctuations caused by changes in stream stage and those fluctuations caused by precipitation. The hydraulic connection of the Upper Floridan aquifer with the Flint River, however, causes the Flint River to affect ground-water levels in well 12L029 during periods of little or no rainfall, thus making the effects of surface water on ground-water levels discernable from precipitation effects.

Differences in stage of the Flint River and ground-water level in the Upper Floridan aquifer up to about 1 mi from the river establish the potential for interchange of water between the Upper Floridan aquifer and the river. The direction of hydraulic gradient between the river and aquifer governs the direction of ground-water flow. Relative differences between stream stage and ground-water level fluctuate in magnitude and direction during the year and indicate changes to leakage characteristics that define stream-aquifer relations. Ground water discharges from the Upper Floridan aquifer to the Flint River when aquifer water level exceeds stream stage; the Flint River discharges to the aquifer when river stage exceeds aquifer water level. Both of these leakage conditions occur during the year at wells 11J012, and 12L029 (fig. 17) and probably occur along the course of the Flint River upstream and downstream of these wells.

Lake Seminole influences ground-water levels in the Upper Floridan aquifer across a large area in the lower ACF River Basin in southern Georgia and northwestern Florida (fig. 17) because of its nearly constant lake stage of about 77 ft and hydraulic connection with the aquifer. Impoundment of the natural channels of the Chattahoochee and Flint Rivers, Fishpond Drain, and Spring Creek during 1957 by Jim Woodruff Lock and Dam created Lake Seminole, and raised ground-water levels in the Upper Floridan aquifer by about 30 ft near the dam and by smaller amounts upstream from the dam (Torak and others, 2006). The impoundment causes backwater conditions to extend upstream from the dam nearly 50 mi along the Chattahoochee River and about 47 mi along the Flint River (U.S. Army Corps of Engineers, 1948). Backwater conditions elevate not only stream (or lake) stage, but also ground-water levels, as the Upper Floridan aquifer interacts hydraulically with the nearly constant lake level.

During 2001 and 2002, between the impoundment arms and surrounding the lake, backwater conditions caused ground-water levels in the Upper Floridan aquifer to approach lake stage during periods of little or no hydrologic stress (irrigation pumpage or infiltration of precipitation). About 15 mi north of the dam, adjacent to the Chattahoochee River impoundment arm, the ground-water level in well 06F001 fluctuated near lake stage during the drought conditions of 2001 and 2002 (fig. 17). The ground-water level in well 06F001 deviated from lake stage, rising in response to precipitation during March, April, and June 2001 and 2002, and declining in response to irrigation pumpage during the growing season and drought conditions during the winter (compare well 06F001 hydrograph and Lake Seminole stage with precipitation record at climatological station near Colquitt, Ga.). During fall and winter 2001, the ground-water level in well 06F001 approached lake stage and declined a few feet below lake stage by winter as a result of the drought conditions that continued until spring 2002.

Water exchange between Lake Seminole and the Upper Floridan aquifer during the drought years of 2001 and 2002 controlled ground-water-level fluctuations and damped seasonal pumpage-induced ground-water-level decline. Despite below-normal precipitation during fall 2001 through spring 2002, when recharge to the Upper Floridan aquifer usually would occur, seasonal declines in already low ground-water levels attributed to irrigation pumpage were not as large near Lake Seminole during 2002 as during 2001, as indicated by the hydrograph of well 06F001 (fig. 17). Ground-water levels in well 06F001 exceeded lake stage by about 20 ft at the beginning of the 2001 growing season and declined to within lake stage (which is about 77 ft) by May 2001. Ground-water levels then stabilized for the remainder of the year, owing to the exchange of water between the Upper Floridan aquifer and Lake Seminole, fluctuating to within 5 ft of lake stage through the remaining months of the growing season (June through September 2001).

Below-normal precipitation during late fall 2001 through spring 2002 prevented ground-water levels from recovering prior to the 2002 growing season; consequently, ground-water levels in well 06F001 during April 2002 were about 5 ft above lake stage, which is about 20 ft lower than the ground-water level at the beginning of the 2001 growing season (fig. 17). Instead of expected ground-water-level declines of at least 20 ft during the 2002 growing season, the ground-water level declined about 10 ft, fluctuating about 5 ft above and below lake stage, because of water exchange between Lake Seminole and the Upper Floridan aquifer. Ground-water levels that fluctuate near lake stage reverse leakage conditions between the lake and aquifer. Lake water leaks into the aquifer when ground-water levels drop below lake stage, and ground water flows to the lake when ground-water levels exceed lake stage.

Cyclic patterns of irrigation pumpage between the Flint River and Spring Creek impoundment arms of Lake Seminole caused the ground-water level in well 09F520 to fluctuate above and below lake stage during the drought of 2001 and 2002, reversing the usual condition of ground-water inflow to the lake during times of no pumping (fig. 17). Irrigation pumpage caused daily water-level decline in the Upper Floridan aquifer in well 09F520, occasionally more than 5 ft below lake stage, and established the potential for lake leakage into the Upper Floridan aquifer. The potential for ground-water inflow to Lake Seminole resumed during no-pumping cycles, which lasted from several days to weeks, when the ground-water level recovered to heights that ranged from about 1 to 5 ft above lake stage. Water levels measured in other wells located to the north of Lake Seminole indicated similar leakage conditions where ground-water levels fluctuated above and below lake stage during 2000, reversing hydraulic gradients between the lake and the aquifer (Torak and others, 2006).

Lower Confining Unit

The lower confining unit underlies the Upper Floridan aquifer and consists of the Lisbon Formation (fig. 3). The hard, sandy, clayey limestone of the Lisbon Formation contains distinctly lower water-yielding characteristics than the Ocala Limestone (Watson, 1981) of the Upper Floridan aquifer. The low water-transmitting properties of the lower confining unit permit the Lisbon Formation to act as a nearly impermeable base to the aquifer (Hayes and others, 1983). Results of a regional ground-water flow analysis by Faye and Mayer (1996) indicated that upward vertical leakage from the lower confining unit to the Upper Floridan occurs at a rate of about 10 cubic feet per second (ft^3/s) in the northern part of the basin. Downward vertical leakage from the Upper Floridan aquifer to the lower confining unit occurs in the southern part of the basin at a rate of about 5 ft^3/s, and no leakage occurs in the central part of the Dougherty Plain.

Comparison of ground-water levels between wells completed in the Upper Floridan aquifer (13M006) and in a water-bearing unit (Claiborne aquifer) of the Lisbon Formation (13M005) (fig. 17) indicates that the potential exists for leakage through the lower confining unit. Ground-water levels defining vertical hydraulic gradients between the Upper Floridan aquifer and lower confining unit had reversed cyclically during the growing seasons of 2001 and 2002, indicating a response to irrigation pumpage in both units. Conditions for potential upward vertical leakage through the lower confining unit to the Upper Floridan aquifer existed briefly during May, July, August, and September 2001, and during May through September 2002, when the ground-water level in the lower unit was higher than the ground-water level in the Upper Floridan aquifer. Conditions for potential downward leakage from the Upper Floridan aquifer to the lower confining unit existed during the remaining months of those years.

Little information exists about the water-yielding properties of the lower confining unit. Results of regional cross-section simulations by Faye and Mayer (1996) indicated a 200-to-1 anisotropy ratio of horizontal hydraulic conductivity for the Upper Floridan aquifer to vertical hydraulic conductivity for the lower confining unit. This represents a sufficient contrast in lateral-to-vertical flow properties for the lower confining unit to function as an impermeable boundary to the Upper Floridan aquifer. Geophysical data indicate a strong possibility of hydraulic connection of the Claiborne and Upper Floridan aquifers through the lower confining unit (David W. Hicks, Scientist, Joseph W. Jones Ecological Research Center at Ichauway, Newton, Ga., written commun., October 2005). Lithologic logs of wells drilled during this study for aquifer-performance tests describe the presence of relatively thin (from 30 to 40 ft) confining zones separating the Upper Floridan aquifer from water-bearing units of the Lisbon Formation in some parts of the basin (Katherine H. Zitsch, Project Manager, Camp, Dresser & McKee Inc., Atlanta, Ga., written commun., October 2004).

Wells yield only a few gallons per minute from the lower confining unit throughout most of the study area, although this unit supplies water for domestic use to wells located southeast of the Dougherty Plain (Hayes and others, 1983). In southeastern Alabama, wells developed solely in the lower confining unit (Lisbon Formation) yield about 10 gallons per minute (gal/min) (Scott and others, 1967).

Summary

An area of about 4,632 square miles in the Coastal Plain physiographic province in parts of southwestern Georgia, northwestern Florida, and southeastern Alabama contributes ground water and surface water to the stream-lake-aquifer flow system in the lower ACF River Basin. Late-middle Eocene to Holocene sediments hydraulically connected with lakes, streams, and land surface comprise the surficial aquifer system, upper semiconfining unit, Upper Floridan aquifer, and lower semiconfining unit and contribute to the exchange of ground water and surface water in the stream-lake-aquifer flow system.

Limestone dissolution exerts the greatest influence on shaping the landscape and altering hydraulic properties and drainage patterns in the Dougherty Plain physiographic district of the lower ACF River Basin. Ongoing dissolution occurs where the limestone crops out beneath the residuum or thin surficial deposits and forms sinkholes, sinkhole ponds, marshes, and underground channels that capture surface drainage. Limestone dissolution enlarges fractures and joints in the Upper Floridan aquifer, increasing hydraulic conductivity and storage properties nonuniformly throughout the basin and creating preferential, subsurface-flow paths. The absence of sinkholes and solution features in the Tallahassee Hills and Tifton Upland indicates that less limestone dissolution and alteration of hydraulic properties is occurring there than in the Dougherty Plain.

Recharge to the Upper Floridan aquifer occurs in the outcrop areas of the Upper Floridan aquifer along the northwestern basin boundary and in the northern and central parts of the Dougherty Plain by vertical leakage through a thin veneer of residuum or surficial deposits. Removal and dissection of Miocene clastic sediments in the Marianna Lowlands physiographic district in parts of Jackson County, Fla., exposes underlying limestone units and facilitates recharge to the Upper Floridan aquifer by infiltration of precipitation. A thick sequence, up to 200 ft, of clayey sand and other resistant sediment inhibits recharge to the Upper Floridan aquifer in the Grand Ridge, Tallahassee Hills, and Tifton Upland regions, except where incised by streams, and provides an effective hydraulic barrier to vertical leakage from land surface. The potential for pumpage-induced recharge by vertical leakage upward through the lower confining unit exists during the growing season in the northern part of the basin along the Flint River, as irrigation pumpage reverses the usual downward hydraulic gradient and leakage potential from the aquifer to the lower confining unit.

Heterogeneity in the physical characteristics of hydrologic units in the stream-lake-aquifer flow system affects the relative contribution of each unit to the water resources in the lower ACF River Basin. Sand and clay content of residuum in the upper semiconfining unit controls the hydraulic conductivity and storage properties; thick sequences of clay and silt create an effective hydraulic barrier to vertical leakage and reduce recharge to the aquifer by infiltration. Substantial clay deposits in the Chattahoochee Formation isolate and effectively confine the aquifer from overlying water-bearing carbonate layers and the surficial aquifer system. Permeable zones in the upper semiconfining unit, although laterally and vertically discontinuous, create a high potential for vertical leakage by facilitating water exchange between the Upper Floridan aquifer, surface water, and land surface. Thickness and lithology of residuum and the proximity of permeable zones to surface water, the surficial aquifer system, and Upper Floridan aquifer affect the magnitude of ground-water level fluctuations in the upper semiconfining unit.

Total thickness and proportional saturation of total thickness of the upper semiconfining unit affect recharge to the Upper Floridan aquifer by vertical leakage and/or infiltration and forms the basis for establishing geohydrologic zones in the upper semiconfining unit. Sparse data defining the lithology, hydraulic properties, and ground-water level of the upper semiconfining unit prevents a more detailed description of this hydrologic unit and its role in providing recharge to the Upper Floridan aquifer, other than the delineation of 14 geohydrologic zones and a general temporal distribution of saturated proportions of total thickness. Zones containing less than 10 ft of thickness, such as in the upland-outcrop area, transmit water directly to the Upper Floridan aquifer by infiltration and are not a large source of vertical leakage. Zones containing a thick unsaturated sequence of sediments, or a small or zero proportional saturation of total semiconfining-unit thickness, such as areas located to the west of the Chattahoochee River, do not represent a large source of recharge to the aquifer by either infiltration or vertical leakage.

Aquifer-performance tests indicate large variations in hydraulic conductivity of the Upper Floridan aquifer at regional scales in the lower ACF River Basin; equally large variations in hydraulic conductivity at the local scale are inferred from descriptions of lithologic heterogeneity of limestone penetrated by closely spaced wells. Geostatistics provided unbiased estimates of the spatial distribution and variation (regionalization) of hydraulic conductivity and transmissivity given sparse aquifer-performance test results and thickness data from wells. Additional aquifer-performance tests performed in upland areas and in areas where hydraulic-property data do not exist would improve the spatial-correlation structure of the kriged estimates of hydraulic conductivity and lead to improving the level of detail and definition of hydrologic heterogeneity in the Upper Floridan aquifer.

Ground-water levels in the Upper Floridan aquifer respond seasonally and in the long term to climatic effects, infiltration of precipitation, evapotranspiration, ground-water withdrawal, discharge to springs, and changes in stream stage and lake level. The areal extent and magnitude to which ground-water levels are affected by these hydrologic factors vary throughout the lower ACF River Basin, being governed by proximity and hydraulic connection of the aquifer with land surface, overlying hydrologic units, surface water, spatial and temporal distribution of pumpage and springs, and heterogeneity of hydraulic properties.

Overpumping the Upper Floridan aquifer in specific areas of the lower ACF River Basin could cause irreversible hydrologic effects on the Upper Floridan aquifer basinwide, such as ground-water-level decline, aquifer dewatering, reduced regional (intrabasin) flow, and reduced interbasin flow to adjacent basins to the east and south. Well hydrographs indicate ground-water-level decline in the Upper Floridan aquifer, as increased irrigation demand was met with increased ground-water pumping basinwide. Irreversible effects of increased pumping could occur where ground-water resources are limited or inadequate to sustain pumpage increases, such as in outcrop areas of the aquifer and downdip, along the Solution Escarpment, where diminished recharge from the outcrop area reduces intrabasin flow.

Water exchange between Lake Seminole and the Upper Floridan aquifer controls ground-water-level fluctuations and damps seasonal ground-water-level decline caused by irrigation pumpage. Ground-water levels fluctuate above and below lake stage during the year. Lake water leaks into the aquifer when ground-water levels drop below lake stage, and ground water flows to the lake when ground-water levels exceed lake stage. Backwater conditions to the lake elevate not only stream (or lake) stage but also ground-water levels, as the Upper Floridan aquifer interacts hydraulically with the nearly constant lake level.

Long-term ground-water-level decline in wells located along the Solution Escarpment and in neighboring river basins to the east and south correspond to increased irrigation pumpage in the lower ACF River Basin during the mid-1970s. Declining ground-water levels further indicate that reductions to intra- and interbasin ground-water flow began immediately with increased irrigation pumpage and that reduced-flow conditions have been ongoing ever since. Reduced intra- and interbasin flow signifies that less ground water is available for development than before flow reduction occurred, thereby limiting the water-resource potential downdip of the outcrop area in the lower ACF River Basin and in adjacent river basins to the east and south.

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Appendixes

Appendix A. Geologic and Hydrologic Data for Selected Wells in the Lower Apalachicola–Chattahoochee–Flint River Basin

Table A1. Geologic and hydrologic data for selected wells in the lower Apalachicola–Chattahoochee–Flint River Basin.

[See figure 2 for well location; °, degree; ', minute; ", second; ft, foot; BLS, below land surface; NAVD 88, North American Vertical Datum of 1988; —, no data]

Well name	Latitude (North)	Longitude (West)	Well depth (ft)	Casing diameter (inch)	Casing depth (ft BLS)	Top altitude of Upper Floridan aquifer (NAVD 88) (ft)	Bottom altitude of Upper Floridan aquifer (NAVD 88) (ft)	Hydraulic conductivity (ft per day)
05G001	31°06'46"	–85°01'44"	—	—	—	113	39	—
05H004	31°10'18"	–85°04'39"	7,320	—	—	108	54	—
05H006	31°08'40"	–85°03'45"	494	10	432	105	80	—
05H007	31°09'42"	–85°02'23"	455	8	455	124	80	—
05J002	31°15'34"	–85°06'16"	276	—	20	173	115	—
06E013	30°46'37"	–84°52'45"	4,500	16	1,423	—	–317	—
06F001	30°53'49"	–84°53'54"	99	4	62	55	—	1,287
06F085	30°56'48"	–84°55'58"	225	6	118	—	—	383
06F090	30°57'45"	–84°54'06"	310	4	102	65	–124	—
06G006	31°04'27"	–84°59'10"	123	4	58	100	—	—
06G013	31°02'00"	–84°52'31"	174	12	73	95	—	—
06H002	31°10'51"	–84°55'04"	—	—	—	132	—	—
06H017	31°08'45"	–84°58'02"	245	4	70	140	–20	—
06H018	31°08'45"	–84°58'02"	41	2	26	144	—	—
06H019	31°08'57"	–84°57'57"	140	4	70	132	—	—
06J006	31°16'09"	–84°57'34"	38	2	23	180	—	—
06J007	31°16'09"	–84°57'34"	130	4	50	178	100	—
06K002	31°27'57"	–84°54'48"	574	6	109	274	239	—
07D014	30°43'05"	–84°46'45"	785	6	275	—	–520	—
07D016	30°43'05"	–84°46'45"	790	4	310	10	—	—
07E042	30°47'00"	–84°51'00"	5,318	—	—	28	–362	—
07F001	30°53'25"	–84°49'02"	3,810	10	311	56	–205	—
07F011	30°57'55"	–84°47'33"	310	4	61	66	–165	—
07G003	31°03'13"	–84°48'41"	—	—	—	95	—	—
07G019	31°04'39"	–84°51'58"	150	4	51	103	—	—
07G022	31°05'35"	–84°47'09"	290	4	71	86	–150	—
07H002	31°10'08"	–84°49'53"	75	4	64	120	—	—
07J001	31°17'46"	–84°51'34"	1,120	10	650	136	88	—
07J007	31°16'17"	–84°45'56"	97	16	44	119	—	—
07J008	31°15'59"	–84°45'08"	160	16	45	145	70	—
07K007	31°25'57"	–84°47'01"	670	20	41	193	168	—
07K008	31°23'43"	–84°48'45"	1,024	19	770	189	124	—
07K011	31°26'50"	–84°48'27"	675	20	59	209	162	—
07L007	31°31'15"	–84°51'59"	555	6	480	285	267	—
08D093	30°44'53"	–84°40'18"	300	4	310	–50	–475	—
08E456	30°48'30"	–84°39'05"	6,220	—	—	87	–258	—

Table A1. Geologic and hydrologic data for selected wells in the lower Apalachicola–Chattahoochee–Flint River Basin.—Continued

[See figure 2 for well location; °, degree; ', minute; ", second; ft, foot; BLS, below land surface; NAVD 88, North American Vertical Datum of 1988; —, no data]

Well name	Latitude (North)	Longitude (West)	Well depth (ft)	Casing diameter (inch)	Casing depth (ft BLS)	Top altitude of Upper Floridan aquifer (NAVD 88) (ft)	Bottom altitude of Upper Floridan aquifer (NAVD 88) (ft)	Hydraulic conductivity (ft per day)
08F001	30°52'47"	–84°44'24"	185	4	76	62	—	—
08F002	30°52'35"	–84°44'15"	145	4	60	55	—	—
08F005	30°52'47"	–84°44'23"	39	4	39	65	—	—
08F494	30°59'00"	–84°37'42"	425	10	165	59	–154	—
08F499	30°52'58"	–84°38'04"	120	4	114	—	—	—
08F500	30°56'01"	–84°38'59"	357	2	40	72	–220	—
08F501	30°55'02"	–84°39'15"	93	4	73	48	—	—
08G011	31°06'53"	–84°40'33"	—	—	—	—	—	221
08H002	31°10'16"	–84°43'53"	1,050	8	785	126	–39	—
08J001	31°17'16"	–84°42'56"	131	6	91	130	84	—
08J007	31°17'11"	–84°44'32"	153	16	45	139	20	—
08J009	31°17'01"	–84°44'49"	90	16	50	—	—	2,390
08J016	31°16'55"	–84°44'06"	132	4	83	130	31	—
08J017	31°16'56"	–84°44'07"	48	2	33	131	—	—
08K001	31°22'38"	–84°39'16"	—	—	—	190	—	—
08K002	31°26'35"	–84°43'12"	700	18	52	210	166	—
08K021	31°26'48"	–84°41'08"	130	4	38	218	145	—
08L001	31°33'31"	–84°44'17"	515	8	395	267	240	—
09E517	30°45'47"	–84°32'12"	486	—	—	–135	—	—
09F003	30°58'53"	–84°36'45"	240	12	100	—	—	700
09F007	30°57'42"	–84°35'45"	27	4	17	76	—	—
09F016	30°53'33"	–84°34'11"	485	20	147	51	–175	—
09F486	30°54'36"	–84°34'29"	464	12	464	—	—	246
09G002	31°04'28"	–84°31'04"	90	4	54	96	—	—
09G015	31°04'38"	–84°37'05"	260	2	40	110	–108	—
09H015	31°14'38"	–84°31'51"	—	—	—	—	—	416
09J001	31°21'31"	–84°31'40"	115	6	68	101	—	—
09J006	31°20'22"	–84°33'39"	—	—	—	100	–14	—
09J007	31°15'21"	–84°31'42"	158	4	9	124	—	—
09J018	31°18'33"	–84°34'28"	250	4	183	75	–40	—
09K001	31°29'12"	–84°30'44"	776	6	594	177	61	—
09K002	31°29'09"	–84°36'59"	556	4	475	190	147	—
09L002	31°31'27"	–84°30'07"	676	6	534	190	129	—
09L004	31°32'20"	–84°35'59"	657	6	485	218	208	—
09N001	31°46'09"	–84°31'06"	433	4	333	351	—	—
10F002	30°59'27"	–84°28'22"	—	—	—	—	—	860
10F160	30°54'57"	–84°28'04"	420	2	160	23	–290	—
10F162	30°55'11"	–84°27'43"	—	—	—	—	—	—
10G001	31°01'22"	–84°23'13"	160	4	88	56	—	—
10G004	31°05'07"	–84°26'21"	40	4	30	88	—	—
10G006	31°01'37"	–84°22'51"	—	—	—	—	—	870

Table A1. Geologic and hydrologic data for selected wells in the lower Apalachicola–Chattahoochee–Flint River Basin.—Continued

[See figure 2 for well location; °, degree; ', minute; ", second; ft, foot; BLS, below land surface; NAVD 88, North American Vertical Datum of 1988; —, no data]

Well name	Latitude (North)	Longitude (West)	Well depth (ft)	Casing diameter (inch)	Casing depth (ft BLS)	Top altitude of Upper Floridan aquifer (NAVD 88) (ft)	Bottom altitude of Upper Floridan aquifer (NAVD 88) (ft)	Hydraulic conductivity (ft per day)
10G314	31°06'44"	–84°24'13"	370	4	102	75	–210	—
10G315	31°06'34"	–84°24'38"	60	2	45	77	—	—
10H007	31°13'48"	–84°28'23"	169	4	158	130	—	—
10J001	31°20'52"	–84°28'40"	661	4.5	365	131	–22	—
10K005	31°28'53"	–84°27'50"	138	4	40	153	—	—
10K007	31°22'40"	–84°24'43"	40	2	25	125	—	—
10K008	31°22'44"	–84°24'55"	120	4	81	—	—	—
10K009	31°22'40"	–84°24'42"	210	4	84	120	18	—
10K010	31°22'40"	–84°24'59"	81	4	81	121	27	—
10L003	31°30'49"	–84°27'18"	—	—	104	—	—	576
10L008	31°35'42"	–84°26'04"	—	12	480	205	165	—
10L022	31°32'02"	–84°27'39"	—	—	—	—	—	85
10M007	31°43'21"	–84°23'14"	527	14	421	267	237	—
10M009	31°41'26"	–84°23'44"	430	—	—	254	213	—
10N001	31°46'50"	–84°26'46"	576	20	342	335	275	—
11J001	31°15'39"	–84°17'30"	190	4	50	120	—	—
11J011	31°18'02"	–84°19'22"	—	—	—	127	–123	643
11J012	31°18'02"	–84°19'22"	225	6	62	125	—	—
11J020	31°21'52"	–84°18'04"	196	—	42	126	—	401
11K003	31°29'14"	–84°15'30"	—	—	—	149	—	138
11K004	31°29'05"	–84°15'30"	150	4	60	145	—	—
11K005	31°26'54"	–84°21'00"	646	4	630	137	—	—
11K014	31°27'44"	–84°17'40"	—	12	79	131	41	—
11K026	31°29'46"	–84°19'11"	105	—	80	165	—	—
11K027	31°26'20"	–84°20'05"	100	4	63	148	—	—
11K028	31°29'44"	–84°20'44"	155	4	84	163	—	—
11K030	31°29'59"	–84°19'01"	180	6	76	120	—	—
11K031	31°29'22"	–84°19'19"	292	—	—	136	16	—
11K047	31°22'51"	–84°20'05"	—	—	—	—	—	417
11L015	31°36'22"	–84°15'36"	125	12	70	178	93	—
11L018	31°35'51"	–84°15'37"	—	—	70	—	—	21
11L020	31°33'00"	–84°18'48"	150	4	63	168	80	—
11L023	31°33'05"	–84°18'11"	109	—	40	165	—	—
11L025	31°30'11"	–84°19'59"	66	—	51	170	—	—
11L026	31°34'37"	–84°22'07"	76	3	58	179	—	—
11L029	31°32'30"	–84°18'49"	97	3	65	153	—	—
11L055	31°31'07"	–84°21'35"	99	4	66	145	—	—
11L070	31°34'21"	–84°21'42"	135	6	44	190	—	—
11L072	31°30'02"	–84°19'05"	120	4	60	122	—	—
11L073	31°30'52"	–84°21'53"	120	4	63	165	—	—

Table A1. Geologic and hydrologic data for selected wells in the lower Apalachicola–Chattahoochee–Flint River Basin.—Continued

[See figure 2 for well location; °, degree; ', minute; ", second; ft, foot; BLS, below land surface; NAVD 88, North American Vertical Datum of 1988; —, no data]

Well name	Latitude (North)	Longitude (West)	Well depth (ft)	Casing diameter (inch)	Casing depth (ft BLS)	Top altitude of Upper Floridan aquifer (NAVD 88) (ft)	Bottom altitude of Upper Floridan aquifer (NAVD 88) (ft)	Hydraulic conductivity (ft per day)
11L077	31°33'48"	–84°19'15"	130	4	60	180	—	—
11L078	31°30'17"	–84°18'48"	100	4	63	139	—	—
11L092	31°35'04"	–84°16'56"	125	4	63	187	—	—
11M001	31°43'18"	–84°20'53"	202	6	181	228	181	—
11M002	31°43'14"	–84°20'57"	620	8	475	229	95	—
11M004	31°40'01"	–84°18'08"	626	12	515	223	—	—
11M005	31°39'34"	–84°20'36"	20	4	10	215	—	—
11M008	31°40'30"	–84°17'17"	—	—	—	190	—	—
11M016	31°39'14"	–84°17'00"	150	—	40	—	—	66
11M018	31°37'32"	–84°17'41"	160	—	40	—	—	63
11M021	31°38'36"	–84°15'08"	—	—	—	227	—	—
11M031	31°42'02"	–84°19'00"	150	6	76	222	189	—
11M032	31°42'30"	–84°19'05"	160	6	75	227	181	—
11M034	31°42'30"	–84°19'02"	90	4	72	222	—	—
11N001	31°49'05"	–84°18'42"	130	—	—	272	232	—
11N002	31°49'47"	–84°21'49"	453	8	390	334	273	—
11N004	31°46'01"	–84°20'30"	—	—	—	279	189	—
11N008	31°46'57"	–84°16'44"	112	3	63	213	183	—
11P002	31°55'05"	–84°15'17"	110	—	—	303	273	—
12G028	31°00'13"	–84°12'18"	550	6	—	–13	—	—
12H008	31°13'27"	–84°12'55"	341	12	150	115	–125	1,183
12H018	31°13'22"	–84°11'52"	—	—	—	—	—	3,700
12J003	31°22'01"	–84°11'33"	82	—	62	123	—	—
12K002	31°22'35"	–84°09'52"	973	8	815	152	–123	—
12K003	31°25'46"	–84°07'46"	275	16	119	140	—	641
12K004	31°25'44"	–84°07'50"	280	4	63	135	–90	—
12K005	31°25'30"	–84°08'16"	250	16	110	—	—	800
12K006	31°29'57"	–84°07'45"	247	10	80	—	—	131
12K007	31°29'56"	–84°07'51"	79	10	79	—	—	833
12K015	31°29'53"	–84°12'14"	114	—	94	138	—	—
12K016	31°27'19"	–84°12'30"	131	4	84	—	—	2,400
12K017	31°28'53"	–84°07'52"	—	—	—	—	—	1,490
12K037	31°26'41"	–84°10'23"	200	8	69	133	—	—
12K094	31°29'55"	–84°09'48"	115	4	63	160	—	—
12K123	31°29'40"	–84°13'17"	242	4	55	155	—	—
12K126	31°27'01"	–84°12'48"	224	4	66	125	—	—
12K127	31°28'37"	–84°13'02"	—	4	—	86	—	—
12K129	31°29'17"	–84°12'29"	211	4	122	148	—	—
12L003	31°34'44"	–84°09'55"	768	12	653	163	–44	—
12L007	31°35'28"	–84°11'11"	725	26	80	182	—	—

Table A1. Geologic and hydrologic data for selected wells in the lower Apalachicola–Chattahoochee–Flint River Basin.—Continued

[See figure 2 for well location; °, degree; ', minute; ", second; ft, foot; BLS, below land surface; NAVD 88, North American Vertical Datum of 1988; —, no data]

Well name	Latitude (North)	Longitude (West)	Well depth (ft)	Casing diameter (inch)	Casing depth (ft BLS)	Top altitude of Upper Floridan aquifer (NAVD 88) (ft)	Bottom altitude of Upper Floridan aquifer (NAVD 88) (ft)	Hydraulic conductivity (ft per day)
12L010	31°36'10"	–84°10'49"	895	10	895	170	40	—
12L011	31°35'50"	–84°09'28"	928	10	860	168	—	—
12L012	31°36'21"	–84°12'26"	855	10	855	196	25	—
12L014	31°34'03"	–84°12'58"	891	12	865	170	46	—
12L016	31°35'06"	–84°13'47"	890	12	890	182	27	—
12L017	31°36'18"	–84°14'38"	820	12	820	187	49	—
12L023	31°32'43"	–84°10'56"	—	6	69	134	—	—
12L028	31°33'02"	–84°11'59"	100	10	43	—	—	1,140
12L029	31°34'50"	–84°09'17"	178	6	35	—	—	12
12L048	31°33'00"	–84°12'42"	85	6	40	158	23	—
12L055	31°33'20"	–84°08'08"	—	—	—	—	—	72
12L056	31°36'23"	–84°11'57"	—	—	—	—	—	75
12L058	31°31'39"	–84°07'50"	—	—	—	—	—	1,303
12L060	31°37'05"	–84°07'51"	—	—	—	—	—	9
12L061	31°30'20"	–84°14'24"	195	8	112	150	—	—
12L062	31°34'32"	–84°10'18"	—	4	85	—	—	91
12L063	31°34'49"	–84°09'14"	—	8	95	—	—	20
12L064	31°33'02"	–84°11'16"	—	—	—	—	—	64
12L269	31°33'00"	–84°12'42"	164	4	100	—	20	—
12L275	31°32'08"	–84°12'46"	—	—	—	173	—	—
12L276	31°31'58"	–84°12'47"	—	4	—	139	—	—
12L277	31°30'38"	–84°12'24"	203	4	—	140	52	—
12M002	31°38'10"	–84°12'48"	650	4	567	—	88	—
12M004	31°42'35"	–84°09'14"	190	4	64	196	85	—
12M009	31°38'01"	–84°10'50"	668	8	560	195	39	—
12M013	31°40'00"	–84°12'27"	158	6	120	200	75	—
12M014	31°43'44"	–84°10'15"	380	8	364	214	80	—
12M016	31°43'19"	–84°14'51"	510	—	—	206	151	—
12M017	31°38'08"	–84°09'35"	—	—	—	192	45	—
12M020	31°42'11"	–84°10'29"	—	6	85	205	—	—
12M021	31°37'33"	–84°10'45"	180	—	60	—	—	70
12N001	31°52'06"	–84°14'35"	—	—	—	270	240	—
12N007	31°47'09"	–84°07'44"	—	—	—	—	—	231
12P001	31°56'22"	–84°10'57"	100	3	93	270	250	—
12P003	31°59'29"	–84°09'03"	84	3	81	301	—	—
12P005	31°55'17"	–84°07'52"	163	3	138	313	203	—
12P006	31°59'07"	–84°14'47"	160	—	—	382	342	—
12P013	31°58'09"	–84°11'05"	99	3	95	322	272	—
12Q011	32°04'47"	–84°13'57"	259	—	128	348	338	—
12Q014	32°01'44"	–84°09'41"	148	—	—	369	322	—

Table A1. Geologic and hydrologic data for selected wells in the lower Apalachicola–Chattahoochee–Flint River Basin.—Continued

[See figure 2 for well location; °, degree; ', minute; ", second; ft, foot; BLS, below land surface; NAVD 88, North American Vertical Datum of 1988; —, no data]

Well name	Latitude (North)	Longitude (West)	Well depth (ft)	Casing diameter (inch)	Casing depth (ft BLS)	Top altitude of Upper Floridan aquifer (NAVD 88) (ft)	Bottom altitude of Upper Floridan aquifer (NAVD 88) (ft)	Hydraulic conductivity (ft per day)
12R002	32°11'41"	–84°08'16"	121	—	—	—	358	—
13H004	31°10'19"	–84°02'44"	316	6	—	12	—	—
13H008	31°08'30"	–84°04'15"	7,490	—	-41	–460	—	419
13J003	31°15'46"	–84°01'15"	575	10	242	130	—	9
13J004	31°21'29"	–84°06'56"	—	—	—	145	—	—
13J009	31°19'21"	–84°03'11"	497	4	83	227	–167	—
13J010	31°19'21"	–84°03'11"	43	2	28	224	—	—
13J012	31°18'22"	–84°03'09"	—	—	—	204	—	—
13K001	31°25'57"	–84°01'29"	382	10	116	218	–39	—
13K007	31°25'24"	–84°06'59"	285	16	92	131	—	—
13K008	31°23'32"	–84°07'09"	295	16	145	121	—	—
13K015	31°27'04"	–84°07'15"	235	—	212	109	—	—
13L002	31°35'51"	–84°06'23"	760	12	713	183	—	—
13L005	31°34'13"	–84°06'02"	965	10	965	145	–16	—
13L006	31°31'47"	–84°07'21"	1,000	—	1,000	158	23	—
13L007	31°34'28"	–84°04'48"	960	12	960	159	–27	—
13L008	31°36'15"	–84°05'49"	785	12	785	169	—	—
13L009	31°34'45"	–84°06'39"	940	12	940	178	7	—
13L010	31°31'05"	–84°06'40"	1,474	6	1,075	152	–55	—
13L015	31°36'21"	–84°04'08"	351	4	240	150	—	—
13L018	31°33'00"	–84°05'11"	900	—	—	160	–50	—
13L019	31°32'52"	–84°02'21"	997	—	920	188	–67	—
13L021	31°35'47"	–84°04'39"	560	12	560	153	–17	—
13L022	31°36'10"	–84°04'37"	550	12	550	166	–14	—
13L025	31°33'05"	–84°03'25"	940	—	—	168	—	—
13L026	31°35'28"	–84°04'46"	942	12	942	165	–17	—
13L028	31°30'42"	–84°02'08"	300	16	110	160	—	—
13L029	31°30'43"	–84°02'45"	310	16	75	167	—	—
13L030	31°31'15"	–84°02'42"	280	16	105	178	—	—
13L031	31°31'39"	–84°02'40"	290	16	70	171	—	—
13L032	31°32'09"	–84°02'49"	285	16	93	180	—	—
13L033	31°30'50"	–84°03'13"	310	16	70	198	—	—
13L034	31°31'11"	–84°03'20"	290	16	90	181	—	—
13L035	31°31'48"	–84°03'21"	295	12	148	175	—	—
13L036	31°32'26"	–84°03'23"	260	16	70	180	—	—
13L037	31°31'26"	–84°03'51"	275	16	118	178	—	—
13L038	31°32'15"	–84°03'43"	300	16	70	174	—	—
13L040	31°32'21"	–84°04'05"	940	6	940	177	–68	—
13L042	31°31'20"	–84°02'05"	275	6	209	190	—	—
13L043	31°33'11"	–84°06'28"	215	16	106	145	–30	—

Table A1. Geologic and hydrologic data for selected wells in the lower Apalachicola–Chattahoochee–Flint River Basin.—Continued

[See figure 2 for well location; °, degree; ', minute; ", second; ft, foot; BLS, below land surface; NAVD 88, North American Vertical Datum of 1988; —, no data]

Well name	Latitude (North)	Longitude (West)	Well depth (ft)	Casing diameter (inch)	Casing depth (ft BLS)	Top altitude of Upper Floridan aquifer (NAVD 88) (ft)	Bottom altitude of Upper Floridan aquifer (NAVD 88) (ft)	Hydraulic conductivity (ft per day)
13L044	31°33'11"	–84°06'29"	210	16	99	155	–30	—
13L045	31°34'03"	–84°03'11"	265	16	165	151	–30	—
13L046	31°33'43"	–84°03'11"	284	20	89	161	–60	—
13L049	31°35'21"	–84°05'09"	170	4	103	169	—	—
13L058	31°35'56"	–84°02'15"	173	—	62	—	—	12
13L245	31°32'20"	–84°03'57"	—	—	—	—	—	542
13M005	31°43'30"	–84°00'50"	345	3	330	198	38	—
13M008	31°39'18"	–84°05'30"	143	4	36	206	165	—
13M010	31°40'03"	–84°03'19"	215	4	41	217	150	—
13M012	31°40'13"	–84°03'24"	46	4	41	220	—	—
13M014	31°40'10"	–84°03'30"	185	4	47	218	—	—
13M027	31°42'52"	–84°06'00"	—	—	—	—	—	47
13M073	31°39'58"	–84°01'07"	100	—	—	194	—	—
13M087	31°44'23"	–84°02'52"	—	—	—	—	—	41
13N011	31°47'26"	–84°04'35"	225	6	60	248	40	—
13N012	31°47'21"	–84°04'26"	23	2	8	252	—	—
13P001	31°57'17"	–84°05'08"	234	6	210	290	218	—
13P002	31°56'09"	–84°00'31"	179	12	30	233	208	—
13P003	31°56'09"	–84°00'31"	175	12	34	223	—	—
13P012	31°53'03"	–84°02'33"	200	2	100	240	105	—
13P013	31°53'03"	–84°02'33"	33	2	18	256	—	—
13P014	31°53'36"	–84°02'10"	113	4	103	250	—	—
13P016	31°53'36"	–84°02'10"	130	6	82	254	—	—
13Q001	32°03'23"	–84°00'14"	—	—	—	265	219	—
14H001	31°11'05"	–83°54'03"	4,916	—	—	–170	–400	—
14H006	31°13'13"	–83°59'36"	426	4	—	11	—	—
14H013	31°11'52"	–83°56'24"	460	—	—	22	—	—
14J003	31°20'05"	–83°57'51"	280	4	228	162	—	—
14J011	31°19'08"	–83°56'43"	240	4	180	184	—	—
14K001	31°26'39"	–83°52'42"	454	—	214	226	—	—
14K003	31°27'48"	–83°54'53"	370	4	195	238	60	—
14K005	31°24'27"	–83°57'58"	—	4	240	189	—	—
14K054	31°29'48"	–83°58'01"	475	6	90	210	–150	—
14K055	31°29'35"	–83°57'42"	83	2	68	228	—	—
14K058	31°29'35"	–83°57'41"	—	—	—	224	–145	—
14L002	31°32'59"	–83°52'39"	460	4	260	210	—	—
14L003	31°35'00"	–83°56'15"	—	—	—	243	18	—
14L007	31°33'05"	–83°54'59"	180	3	73	285	—	—
14L009	31°34'59"	–83°55'05"	238	—	74	234	56	—
14L012	31°33'02"	–83°55'16"	—	—	—	—	—	57

Table A1. Geologic and hydrologic data for selected wells in the lower Apalachicola–Chattahoochee–Flint River Basin.—Continued

[See figure 2 for well location; °, degree; ', minute; ", second; ft, foot; BLS, below land surface; NAVD 88, North American Vertical Datum of 1988; —, no data]

Well name	Latitude (North)	Longitude (West)	Well depth (ft)	Casing diameter (inch)	Casing depth (ft BLS)	Top altitude of Upper Floridan aquifer (NAVD 88) (ft)	Bottom altitude of Upper Floridan aquifer (NAVD 88) (ft)	Hydraulic conductivity (ft per day)
14L030	31°32'45"	–83°52'54"	214	—	—	230	—	—
14M001	31°38'34"	–83°54'57"	215	4	160	119	—	—
14M008	31°43'06"	–83°53'19"	102	—	—	226	—	—
14N001	31°49'40"	–83°55'18"	325	6	160	225	—	—
14N005	31°51'55"	–83°55'22"	128	4	42	220	—	—
14N006	31°51'00"	–83°55'18"	—	4	175	187	77	—
14N007	31°51'23"	–83°53'05"	160	3	84	201	—	—
14P001	31°57'25"	–83°55'08"	124	6	50	—	—	519
14P002	31°57'41"	–83°54'15"	130	—	130	188	—	—
14P006	31°58'52"	–83°56'53"	140	3	75	211	171	—
14P007	31°55'22"	–83°57'32"	130	3	66	259	169	—
14Q001	32°01'20"	–83°54'04"	160	4	121	268	178	—
15J003	31°19'13"	–83°52'04"	380	4	300	13	—	—
15J013	31°16'43"	–83°49'01"	640	4	536	–86	—	—
15J017	31°20'45"	–83°57'47"	300	—	—	132	—	—
15K003	31°26'21"	–83°49'05"	—	4	206	179	—	—
15K004	31°22'40"	–83°46'58"	—	10	256	88	–339	12.7
15L020	31°31'46"	–83°49'15'	450	18	212	230	—	—
15L021	31°32'15"	–83°50'44"	536	18	146	250	–146	—
15L032	31°35'26"	–83°50'17"	520	2	160	230	–100	53.3
15L035	31°35'21"	–83°50'12"	430	4	180	240	—	—
15N001	31°49'50"	–83°46'08"	5,008	9	5,008	—	–41	—
15N003	31°48'27"	–83°50'10"	50	2	35	230	—	—
15N005	31°48'29"	–83°50'11"	260	6	96	228	70	—
15N006	31°48'28"	–83°49'56"	210	4	125	243	—	—
15P001	31°57'36"	–83°46'29"	540	10	530	241	30	—
15P003	31°56'02"	–83°45'53"	265	3	126	227	—	—
15P007	31°58'13"	–83°46'28"	600	12	600	281	61	—
15P009	31°58'40"	–83°46'44"	150	10	60	—	—	67
15P012	31°55'34"	–83°50'43"	80	3	75	225	—	—
15P020	31°59'20"	–83°47'18"	75	3	67	242	—	—
15Q003	32°05'41"	–83°47'28"	571	10	566	275	238	—
15Q011	32°00'33"	–83°47'30"	—	4	149	236	106	—
15Q016	32°01'39"	–83°51'15"	170	6	78	280	162	—
15Q017	32°01'47"	–83°51'33"	40	2	25	285	—	—
15R005	32°12'12"	–83°49'03"	130	3	113	329	—	—
15R007	32°11'10"	–83°46'26"	330	4	330	352	212	—
16J030	32°19'13"	–83°44'15"	5,568	7	1,050	–98	–718	—
16L011	31°31'35"	–83°39'14"	210	4	190	242	—	—
16M001	31°44'13"	–83°39'05"	350	4	120	199	—	—

Table A1. Geologic and hydrologic data for selected wells in the lower Apalachicola–Chattahoochee–Flint River Basin.—Continued

[See figure 2 for well location; °, degree; ', minute; ", second; ft, foot; BLS, below land surface; NAVD 88, North American Vertical Datum of 1988; —, no data]

Well name	Latitude (North)	Longitude (West)	Well depth (ft)	Casing diameter (inch)	Casing depth (ft BLS)	Top altitude of Upper Floridan aquifer (NAVD 88) (ft)	Bottom altitude of Upper Floridan aquifer (NAVD 88) (ft)	Hydraulic conductivity (ft per day)
16M008	31°39'18"	–83°38'06"	375	6	252	220	—	—
16M011	31°42'27"	–83°39'28"	648	12	250	180	—	—
16M013	31°42'53"	–83°38'48"	650	14	250	183	–268	—
16N003	31°49'47"	–83°44'23"	240	3	186	319	—	—
16P001	31°55'55"	–83°43'45"	290	4	212	231	—	—
16P006	31°55'01"	–83°39'54"	260	—	—	309	—	—
16P007	31°57'39"	–83°43'49"	610	12	580	329	80	—
16R001	32°12'35"	–83°44'51"	551	6	551	351	155	—
17L012	32°33'43"	–83°36'34"	280	6	95	201	—	—
17P002	31°55'55"	–83°37'05"	310	4	227	280	—	—
AT105	30°39'07"	–84°53'16"	—	—	—	—	—	98
AT106	30°41'38"	–84°50'24"	—	—	—	60	—	—
AT107	30°41'56"	–84°47'49"	—	—	—	60	—	—
AT108	30°42'32"	–84°53'13"	—	—	—	65	–494	—
AT110	30°39'53"	–84°53'31"	—	—	—	65	—	—
AT180	30°41'24"	–84°48'21"	—	—	—	60	–634	—
AT188	30°49'44"	–85°11'20"	—	—	—	70	–37	—
AT239	30°59'13"	–85°08'27"	—	—	—	115	–13	—
AT259	30°57'36"	–85°07'08"	—	—	—	100	–56	—
AT263	30°39'18"	–85°10'15"	—	—	—	90	–238	—
AT264	30°39'57"	–85°05'20"	—	—	—	95	—	—
AT265	30°41'52"	–84°58'08"	—	—	—	90	–260	—
AT266	30°41'52"	–84°53'09"	—	—	—	65	–376	—
AT267	30°42'43"	–85°05'05"	—	—	—	95	–205	—
AT269	30°42'46"	–85°01'11"	—	—	—	85	—	—
AT273	30°59'09"	–85°06'21"	—	—	—	100	–15	—
O-347	30°40'51"	–84°35'49"	—	—	—	–100	–600	—
PGOW1	31°33'06"	–84°06'33"	—	—	—	—	—	1,771
PGOW2	31°33'00"	–84°06'41"	—	—	—	—	—	1,006
PGOW3	31°32'50"	–84°06'29"	—	—	—	—	—	736
W-285	30°50'09"	–85°07'03"	—	—	—	—	–96	—
W-654	30°50'04"	–85°10'12"	—	—	—	—	–93	—
W-687	30°50'04"	–85°10'12"	—	—	—	—	–81	—
W-1352	30°42'21"	–85°05'00"	—	—	—	—	–212	—
W-1356	30°41'30"	–85°06'59"	—	—	—	—	–147	—
W-1357	30°41'03"	–85°05'58"	—	—	—	—	–284	—
W-1358	30°42'17"	–85°06'28"	—	—	—	45	—	—
W-1359	30°41'52"	–85°02'58"	—	—	—	—	–293	—
W-1360	30°39'18"	–85°07'38"	—	—	—	—	–264	—
W-1362	30°42'36"	–85°02'31"	—	—	—	50	—	—

Table A1. Geologic and hydrologic data for selected wells in the lower Apalachicola–Chattahoochee–Flint River Basin.—Continued

[See figure 2 for well location; °, degree; ', minute; ", second; ft, foot; BLS, below land surface; NAVD 88, North American Vertical Datum of 1988; —, no data]

Well name	Latitude (North)	Longitude (West)	Well depth (ft)	Casing diameter (inch)	Casing depth (ft BLS)	Top altitude of Upper Floridan aquifer (NAVD 88) (ft)	Bottom altitude of Upper Floridan aquifer (NAVD 88) (ft)	Hydraulic conductivity (ft per day)
W-1363	30°45'02"	–85°06'34"	—	—	—	—	–181	—
W-1478	30°42'02"	–84°51'24"	118	—	—	0	—	—
W-1562	30°42'39"	–84°52'15"	—	—	—	22	—	—
W-1768	30°35'22"	–84°46'40"	—	—	—	–80	—	—
W-1777	30°42'11"	–84°53'29"	—	—	—	54	—	—
W-1780	30°42'30"	–84°51'28"	122	—	—	0	—	—
W-1781	30°57'43"	–85°01'40"	—	—	—	133	—	—
W-1786	30°35'22"	–84°39'21"	4,223	—	—	–286	–696	—
W-1796	30°41'03"	–84°57'00"	—	—	—	100	—	—
W-1813	30°48'02"	–85°01'51"	—	—	—	64	—	—
W-1872	30°36'53"	–85°01'41"	—	—	—	92	—	—
W-2260	30°42'42"	–84°55'46"	—	—	—	92	—	—
W-2406	30°57'00"	–85°09'39"	—	—	—	145	—	—
W-2409	30°41'21"	–84°52'12"	—	—	—	56	—	—
W-3482	30°41'39"	–84°50'21"	239	—	—	32	—	—
W-3577	30°33'21"	–84°53'12"	4,025	—	—	–135	–845	—
W-3776	30°32'47"	–84°46'51"	4,218	—	—	–208	—	—
W-4240	30°42'34"	–84°50'50"	200	—	—	49	—	—
W-4404	30°39'22"	–84°41'26"	420	—	—	–77	—	—
W-5201	30°36'20"	–84°39'21"	—	—	—	–179	—	—
W-6025	30°25'44"	–84°58'40"	—	—	—	–50	—	—
W-6901	30°28'08"	–84°58'45"	527	—	—	–218	—	—
W-15497	30°35'44"	–84°54'06"	—	—	—	–56	—	—
W-15498	30°34'36"	–84°53'52"	—	—	—	–98	—	—
W-15499	30°34'57"	–84°54'51"	—	—	—	–69	—	—
W-15500	30°30'21"	–84°58'33"	—	—	—	–136	—	—
W-15501	30°32'40"	–84°57'02"	—	—	—	–157	—	—
W-15502	30°35'44"	–84°58'44"	306	—	—	–21	—	—
W-15503	30°37'09"	–84°57'03"	—	—	—	16	—	—
W-15504	30°43'30"	–84°57'08"	—	—	—	58	—	—
W-15508	30°34'31"	–85°01'22"	553	—	—	–62	—	—
W-15509	30°36'38"	–85°00'42"	—	—	—	29	—	—
W-15510	30°39'33"	–84°54'35"	—	—	—	53	—	—
W-15511	30°33'28"	–85°06'25"	344	—	—	–53	—	—
W-15512	30°38'29"	–84°58'23"	555	—	—	70	—	—
W-15513	30°30'39"	–85°04'05"	285	—	—	–145	—	—
W-15514	30°39'57"	–84°54'24"	—	—	—	70	—	—

A. **Well distribution**

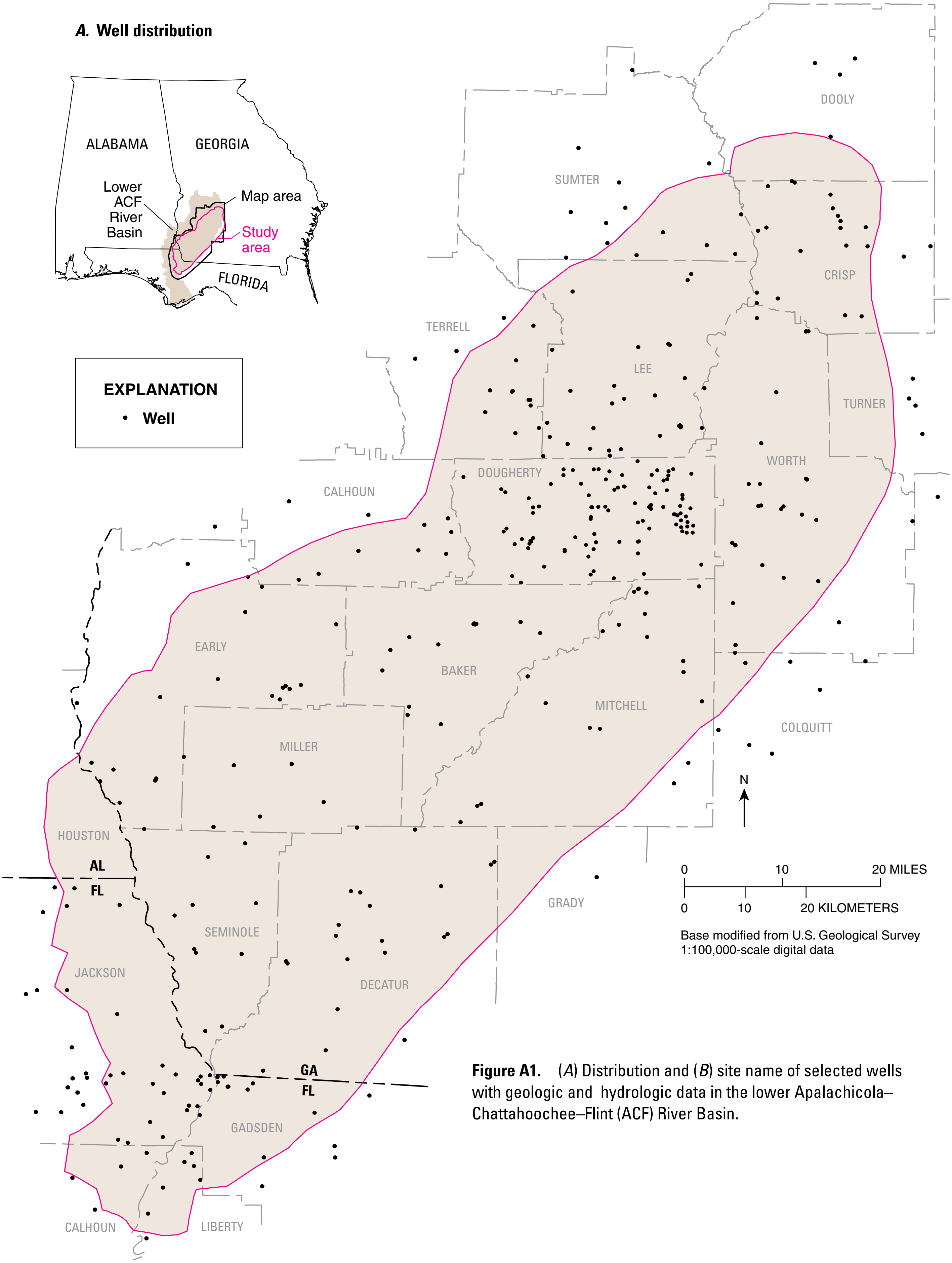


Figure A1. (*A*) Distribution and (*B*) site name of selected wells with geologic and hydrologic data in the lower Apalachicola–Chattahoochee–Flint (ACF) River Basin.

B. **Site names**

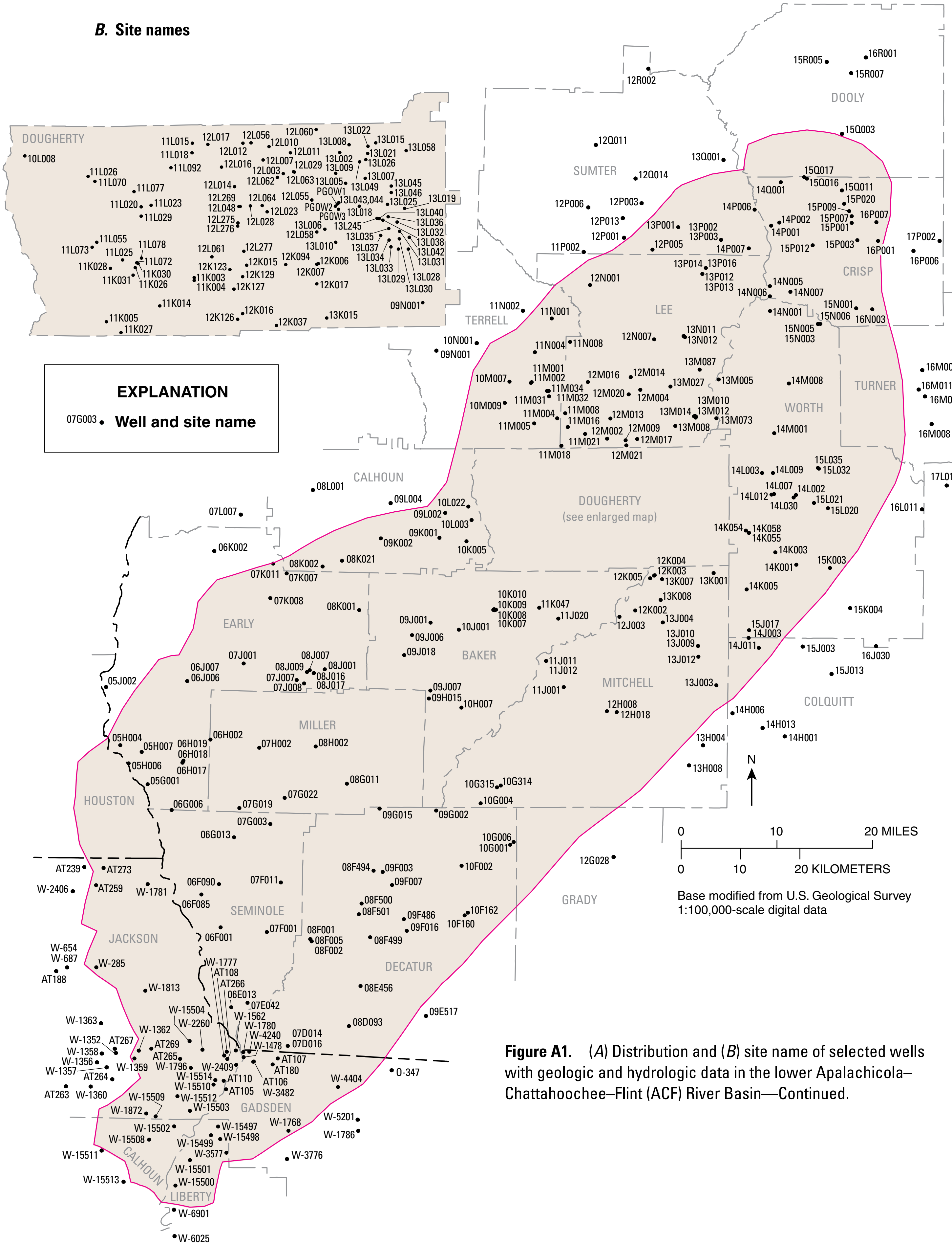
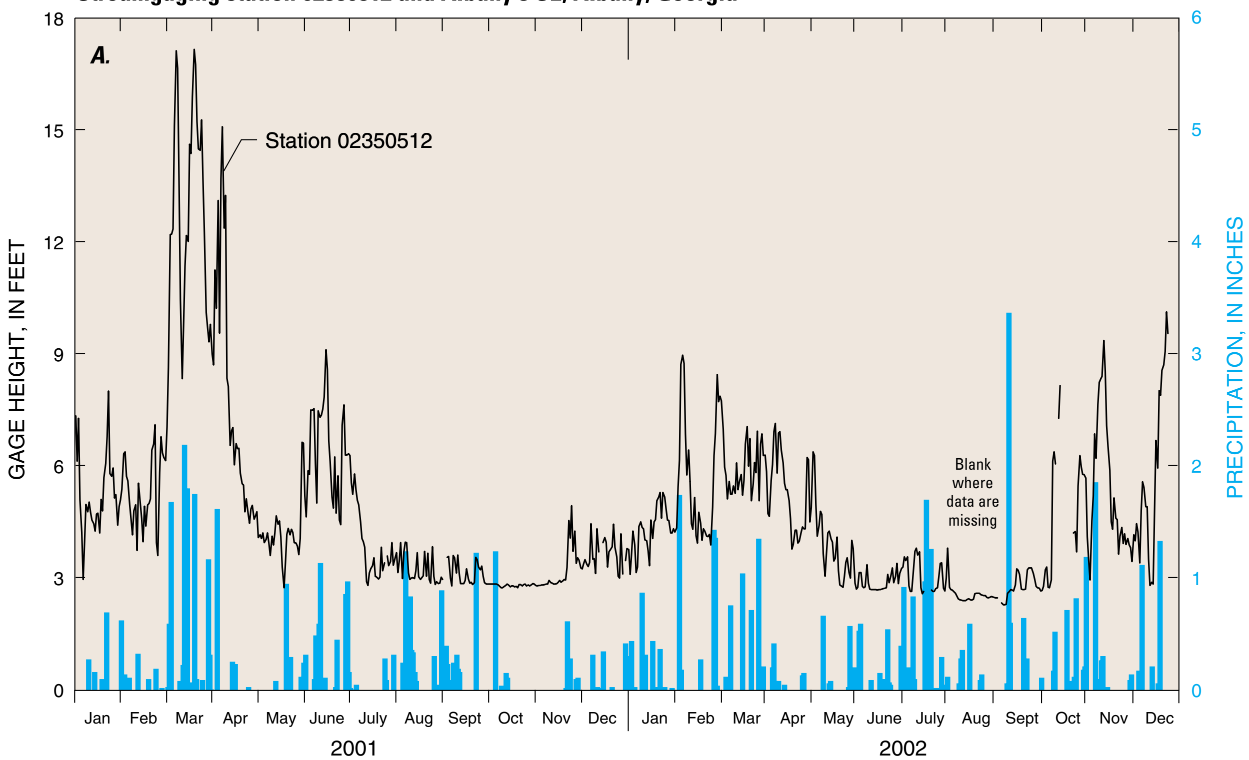


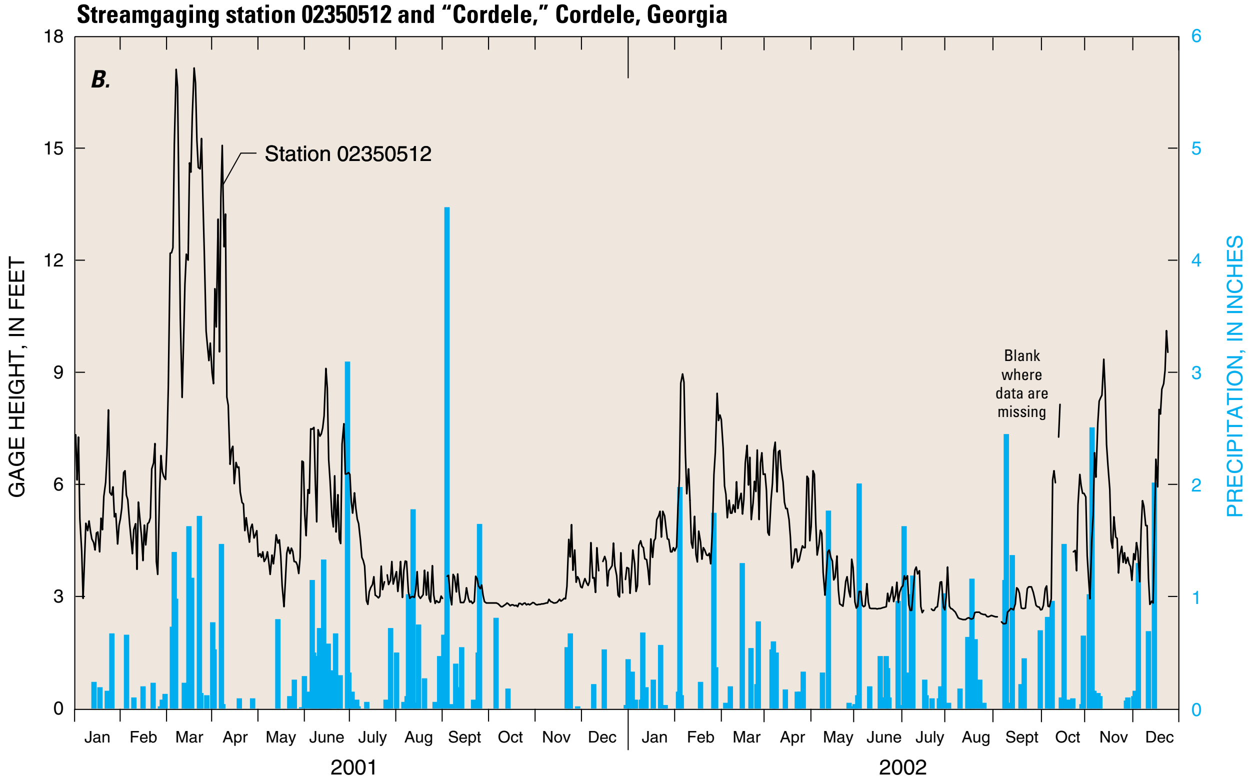
Figure A1. (*A*) Distribution and (*B*) site name of selected wells with geologic and hydrologic data in the lower Apalachicola–Chattahoochee–Flint (ACF) River Basin—Continued.

Appendix B. Stream and Well Hydrographs and Rainfall Graphs Accessed Interactively from Figure 2

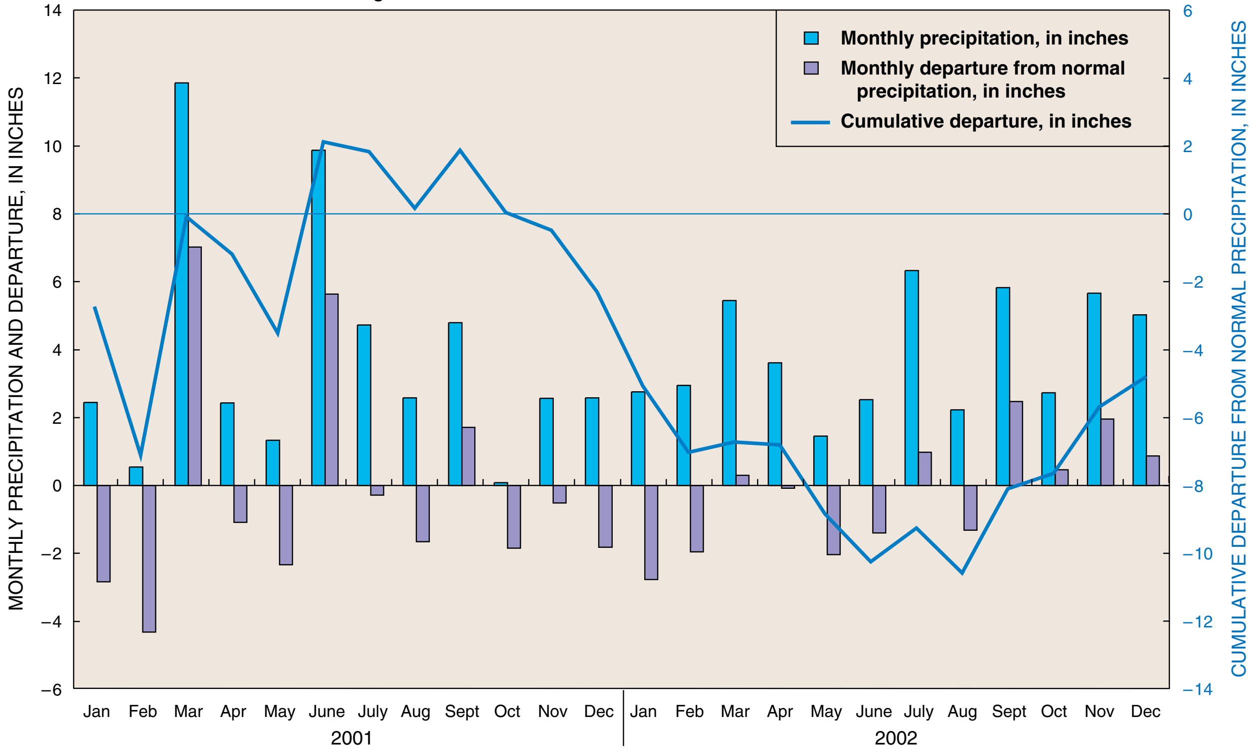
Streamgaging station 02350512 and Albany 3 SE, Albany, Georgia



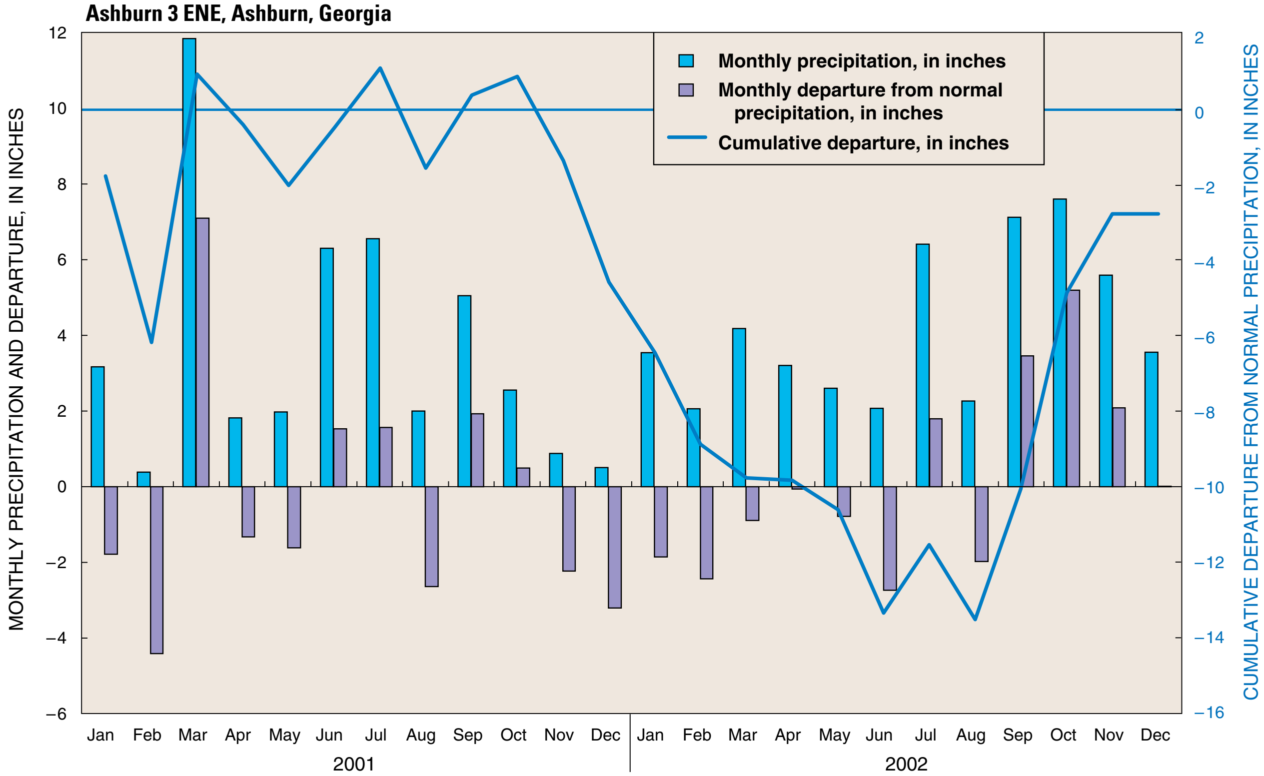
Streamgaging station 02350512 and "Cordele," Cordele, Georgia

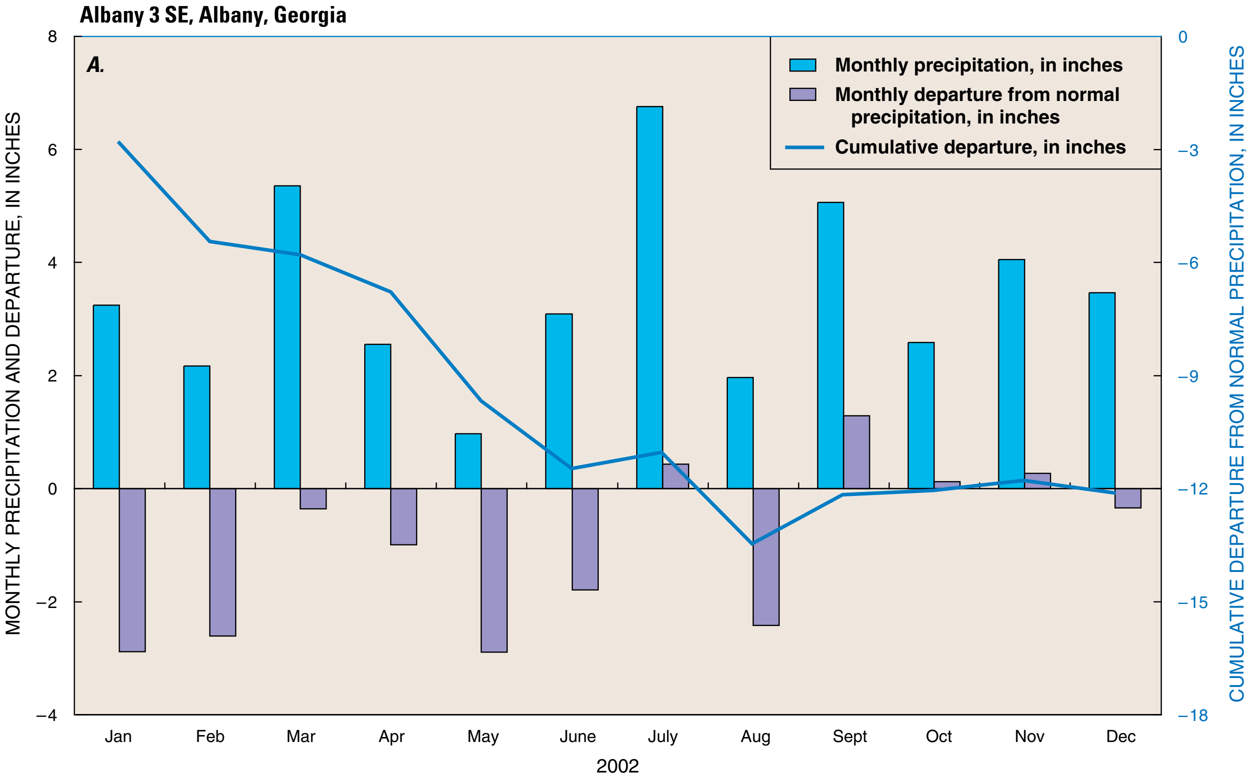


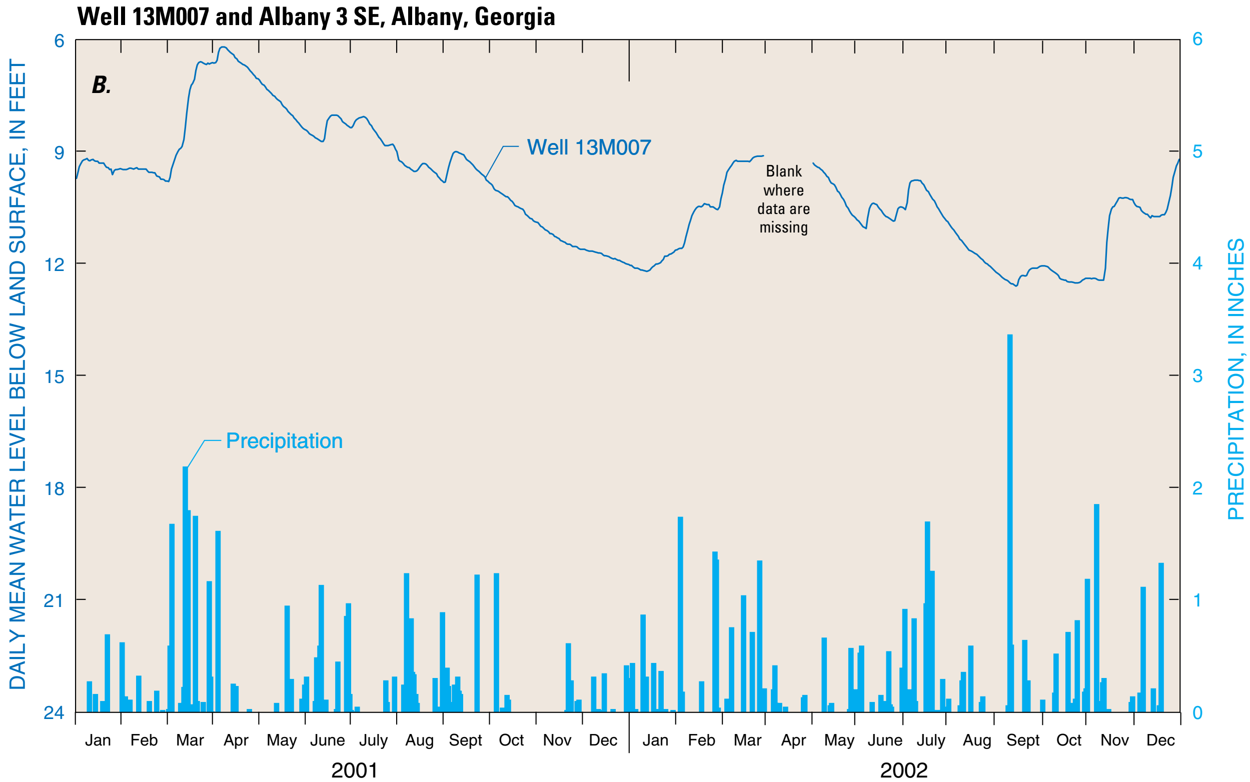
Americus 3 SW, Americus, Georgia

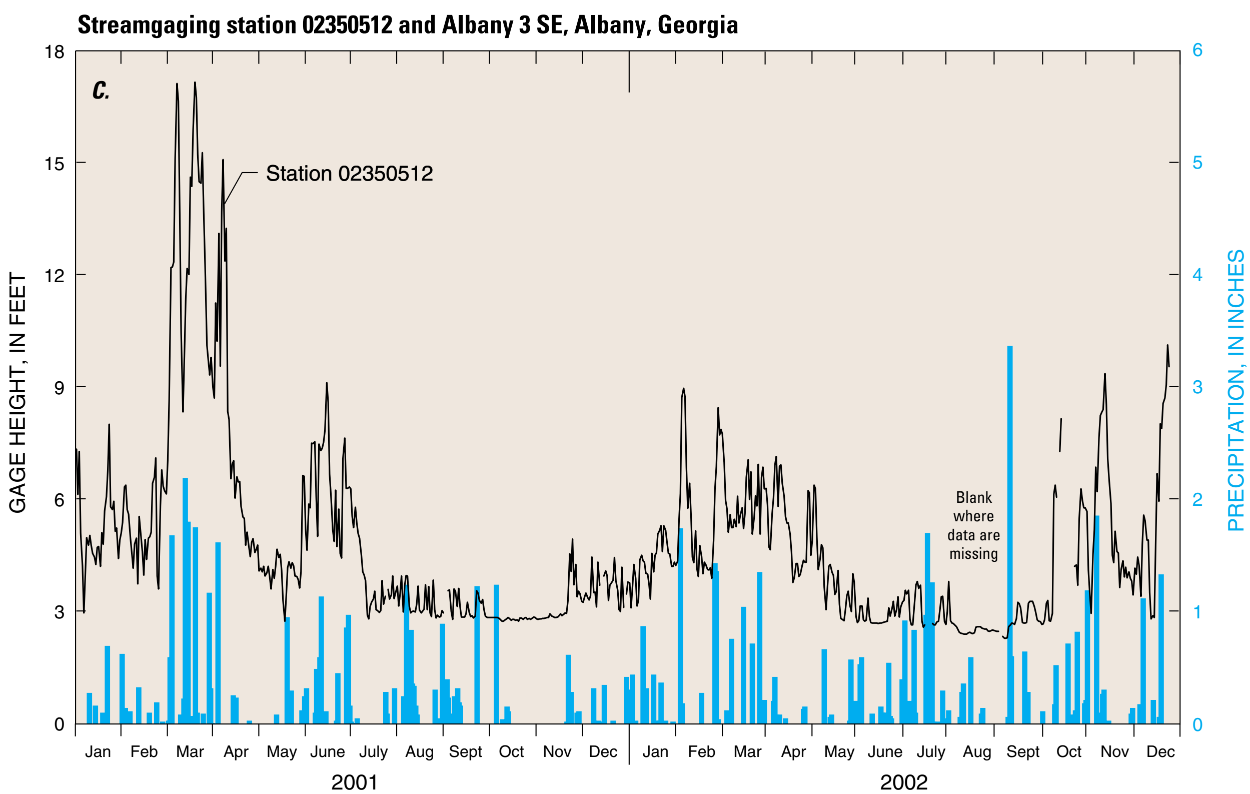


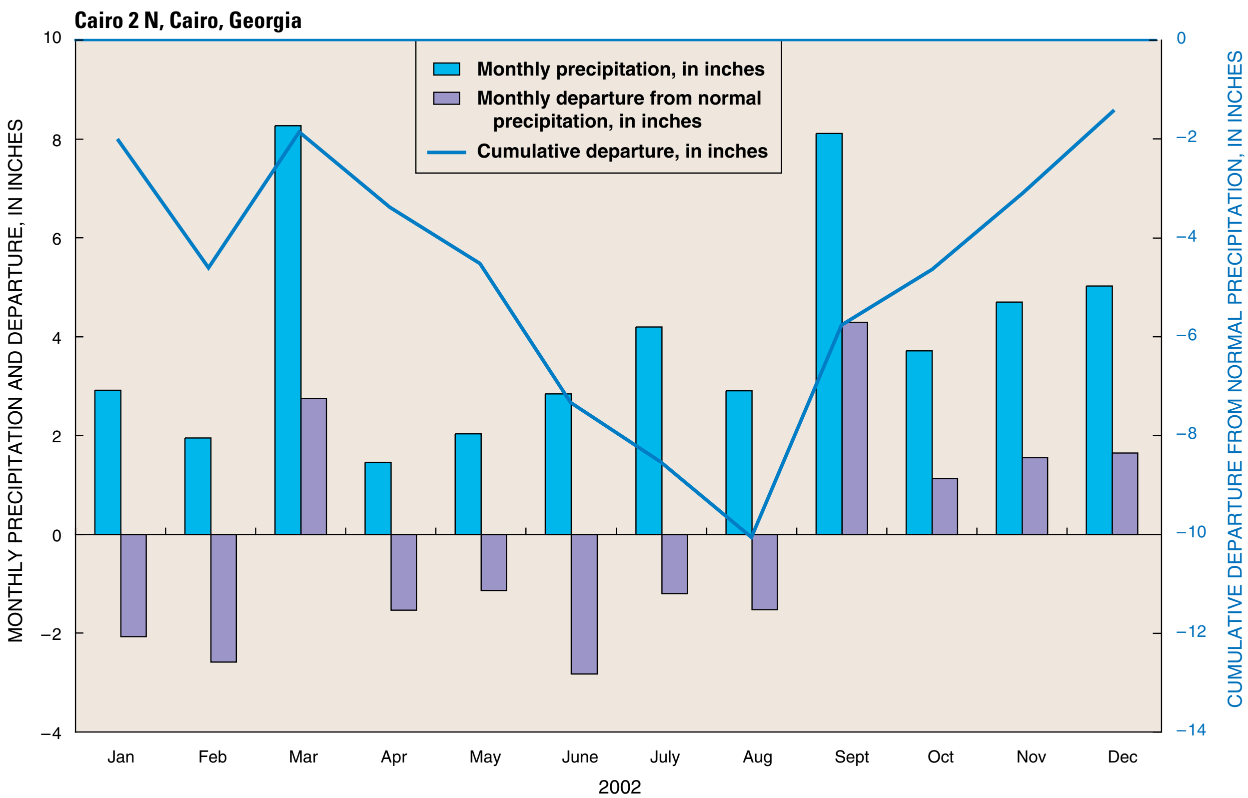
Ashburn 3 ENE, Ashburn, Georgia

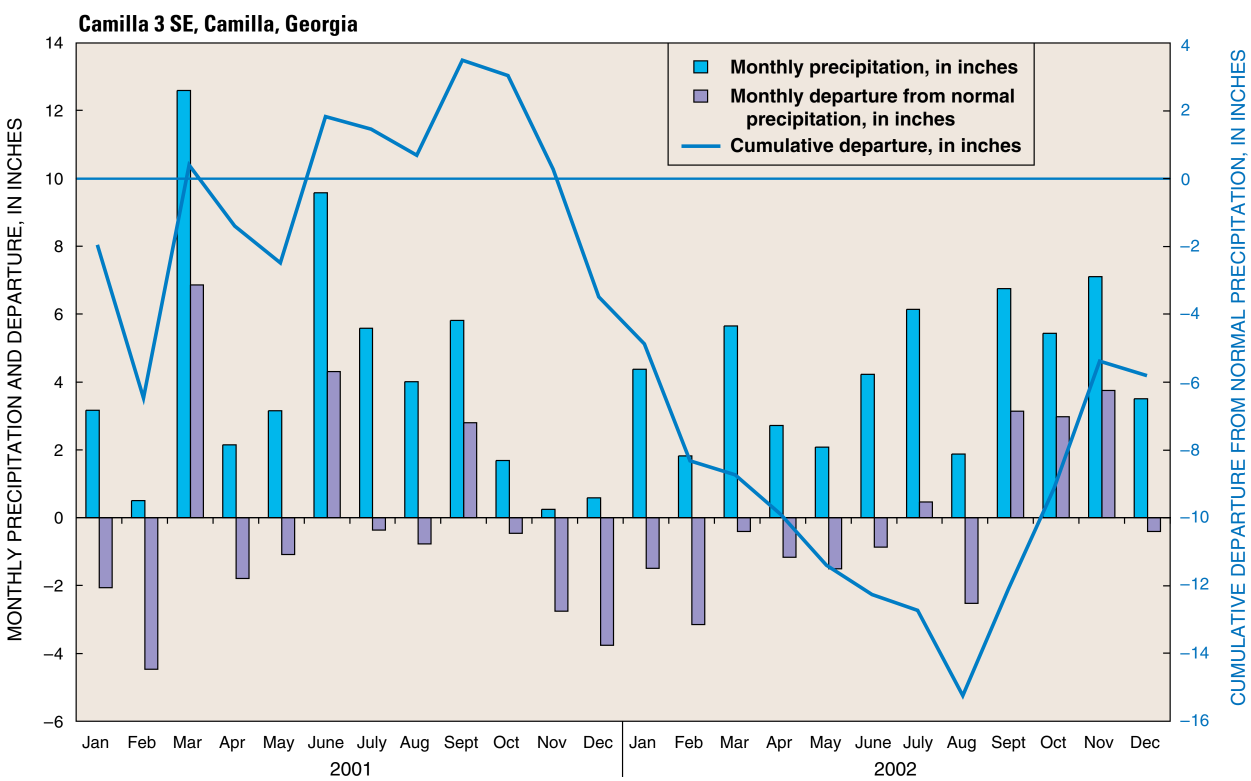



Albany 3 SE, Albany, Georgia
A.
Monthly precipitation, in inches
Monthly departure from normal precipitation, in inches
Cumulative departure, in inches
MONTHLY PRECIPITATION AND DEPARTURE, IN INCHES
CUMULATIVE DEPARTURE FROM NORMAL PRECIPITATION, IN INCHES
8
6
4
2
0
–2
–4
0
–3
–6
–9
–12
–15
–18
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec
2002

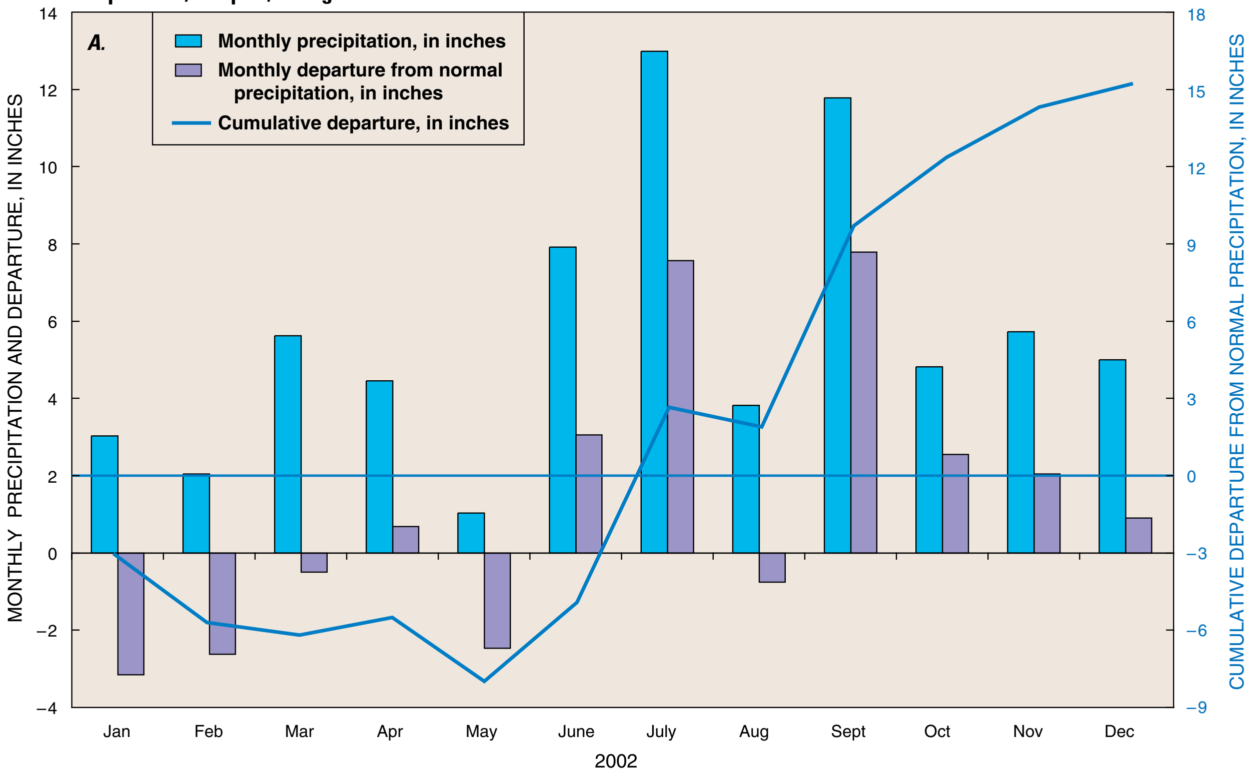

Well 13M007 and Albany 3 SE, Albany, Georgia
B.
Well 13M007
Precipitation
Blank where data are missing
DAILY MEAN WATER LEVEL BELOW LAND SURFACE, IN FEET
PRECIPITATION, IN INCHES
6
9
12
15
18
21
24
0
1
2
3
4
5
6
Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec
2001
2002


Streamgaging station 02350512 and Albany 3 SE, Albany, Georgia
C.
Station 02350512
Blank where data are missing
GAGE HEIGHT, IN FEET
PRECIPITATION, IN INCHES
18
15
12
9
6
3
0
6
5
4
3
2
1
0
Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec
2001
2002

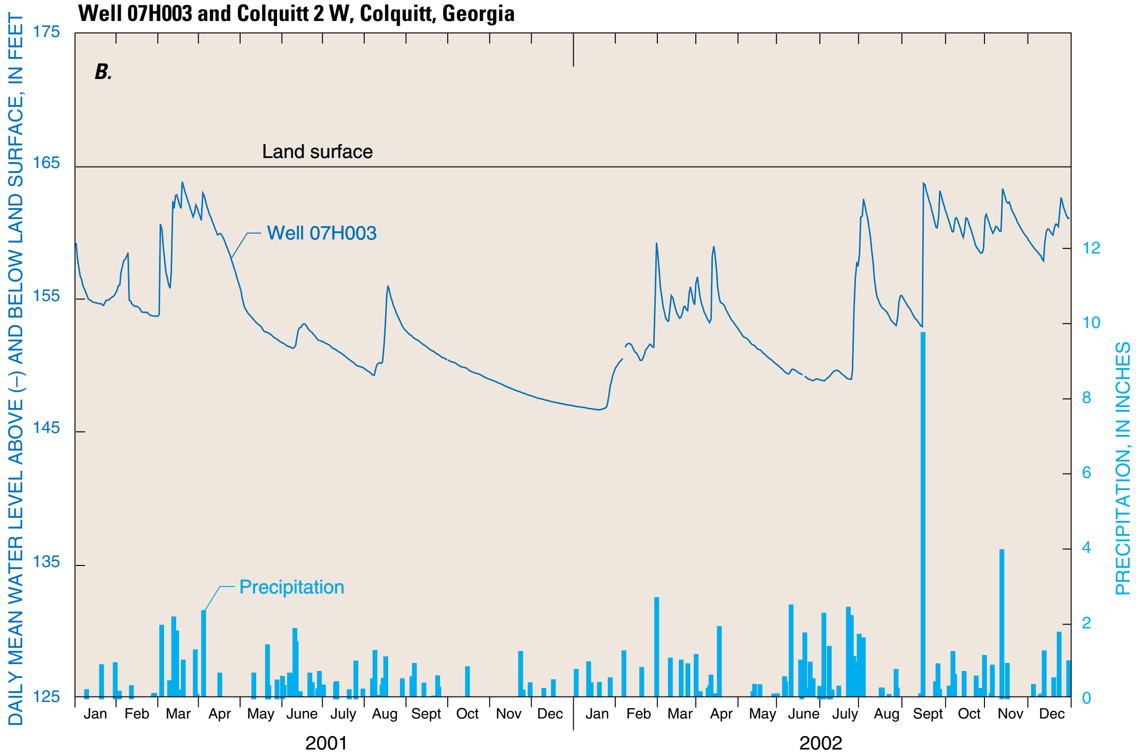

Cairo 2 N, Cairo, Georgia
Monthly precipitation, in inches
Monthly departure from normal precipitation, in inches
Cumulative departure, in inches
MONTHLY PRECIPITATION AND DEPARTURE, IN INCHES
CUMULATIVE DEPARTURE FROM NORMAL PRECIPITATION, IN INCHES
10
8
6
4
2
0
−2
−4
0
−2
−4
−6
−8
−10
−12
−14
Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec
2002

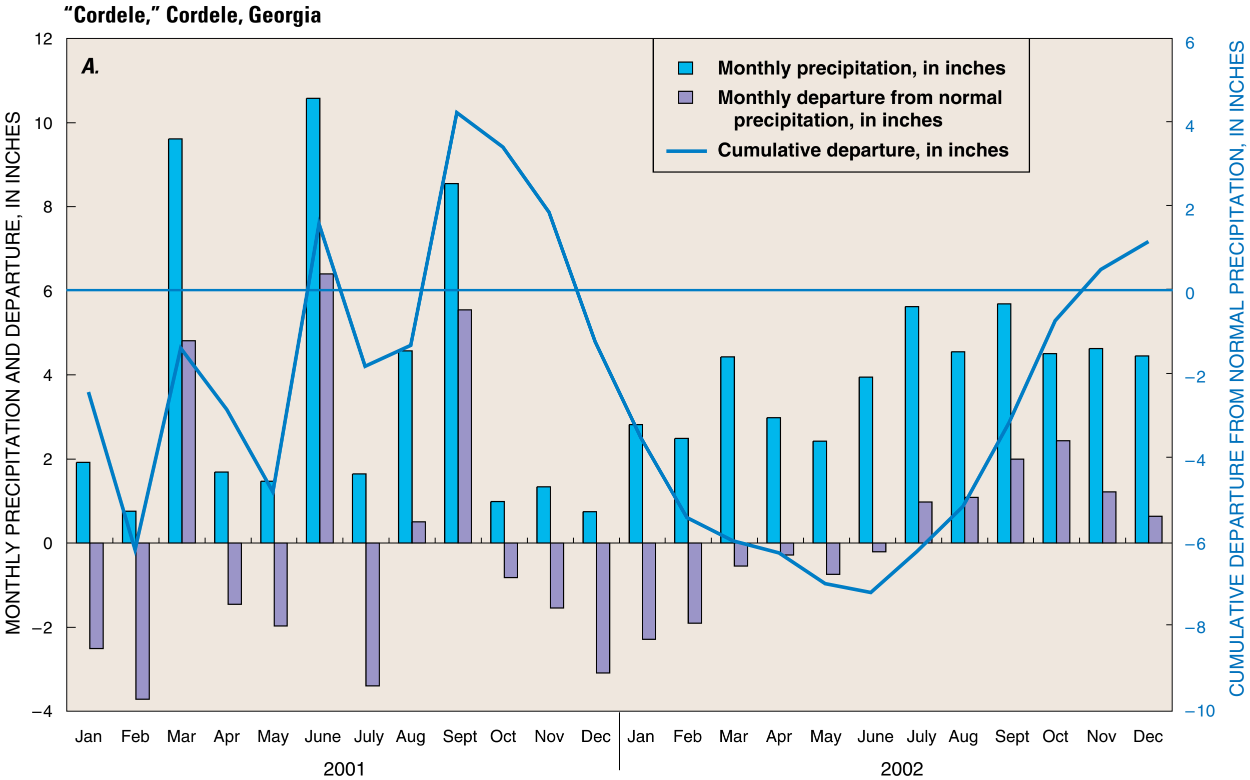

Camilla 3 SE, Camilla, Georgia
Monthly precipitation, in inches
Monthly departure from normal precipitation, in inches
Cumulative departure, in inches
MONTHLY PRECIPITATION AND DEPARTURE, IN INCHES
CUMULATIVE DEPARTURE FROM NORMAL PRECIPITATION, IN INCHES
14
12
10
8
6
4
2
0
−2
−4
−6
4
2
0
−2
−4
−6
−8
−10
−12
−14
−16
Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec
2001
2002

Colquitt 2 W, Colquitt, Georgia

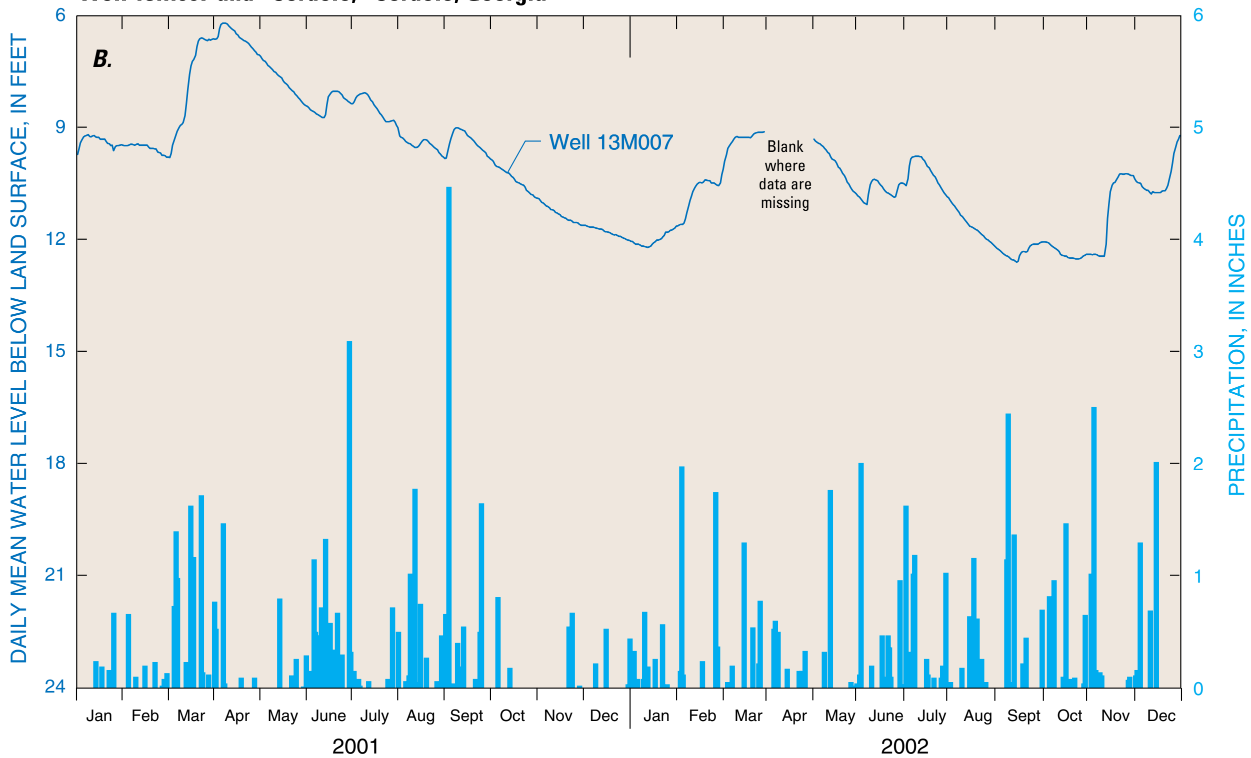


Well 07H003 and Colquitt 2 W, Colquitt, Georgia

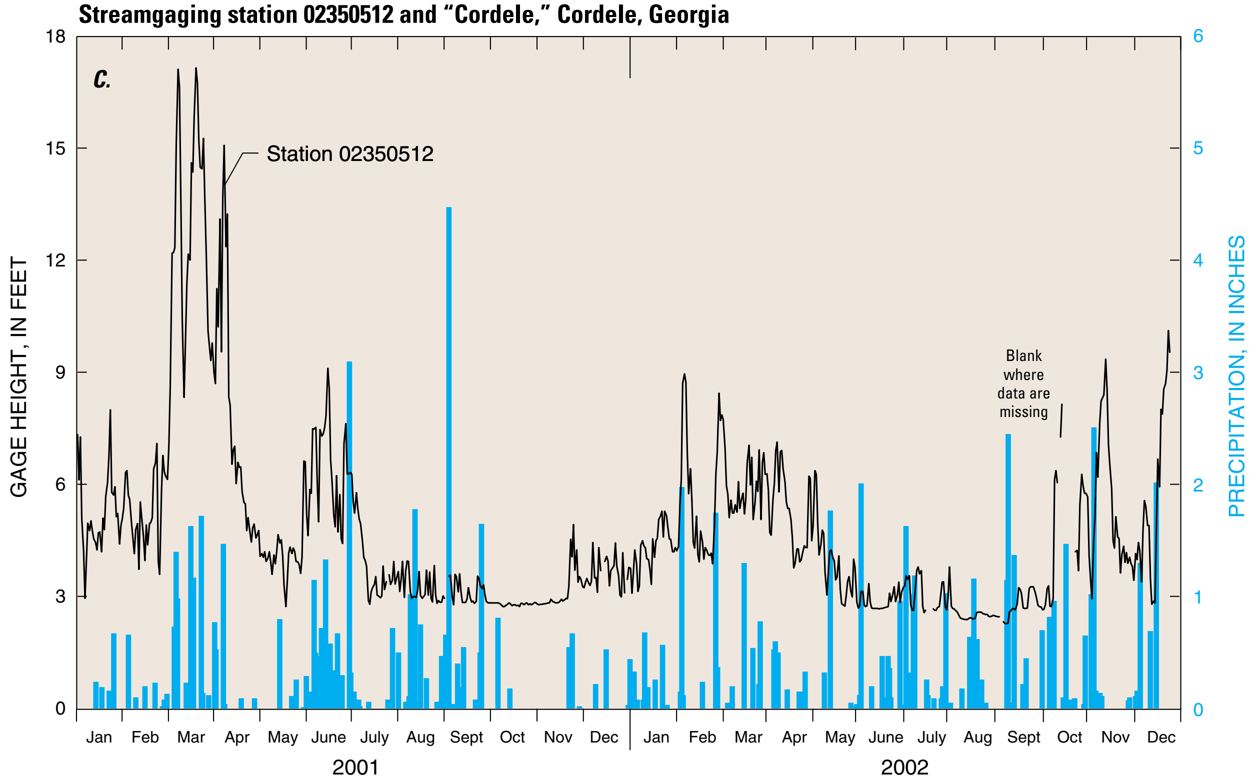


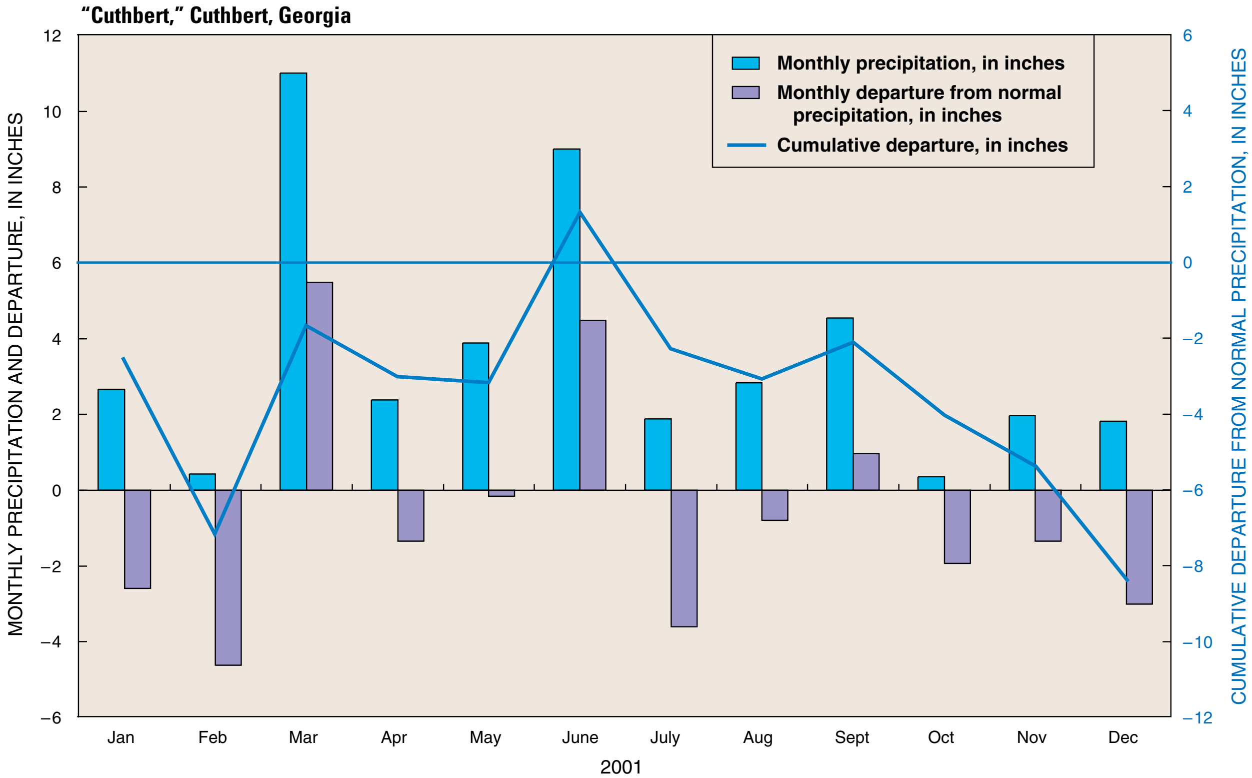

"Cordele," Cordele, Georgia
A.
Monthly precipitation, in inches
Monthly departure from normal precipitation, in inches
Cumulative departure, in inches
MONTHLY PRECIPITATION AND DEPARTURE, IN INCHES
CUMULATIVE DEPARTURE FROM NORMAL PRECIPITATION, IN INCHES
12
10
8
6
4
2
0
−2
−4
6
4
2
0
−2
−4
−6
−8
−10
Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec
2001
Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec
2002

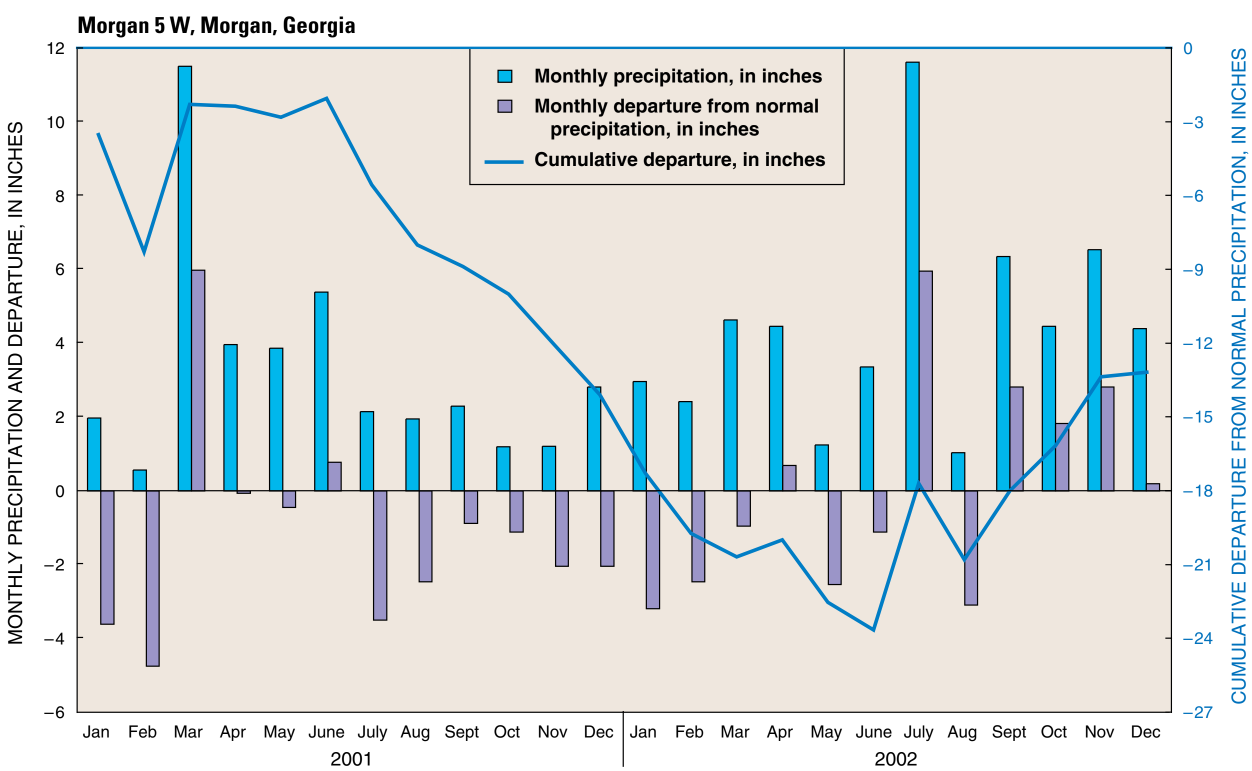
Well 13M007 and “Cordele,” Cordele, Georgia

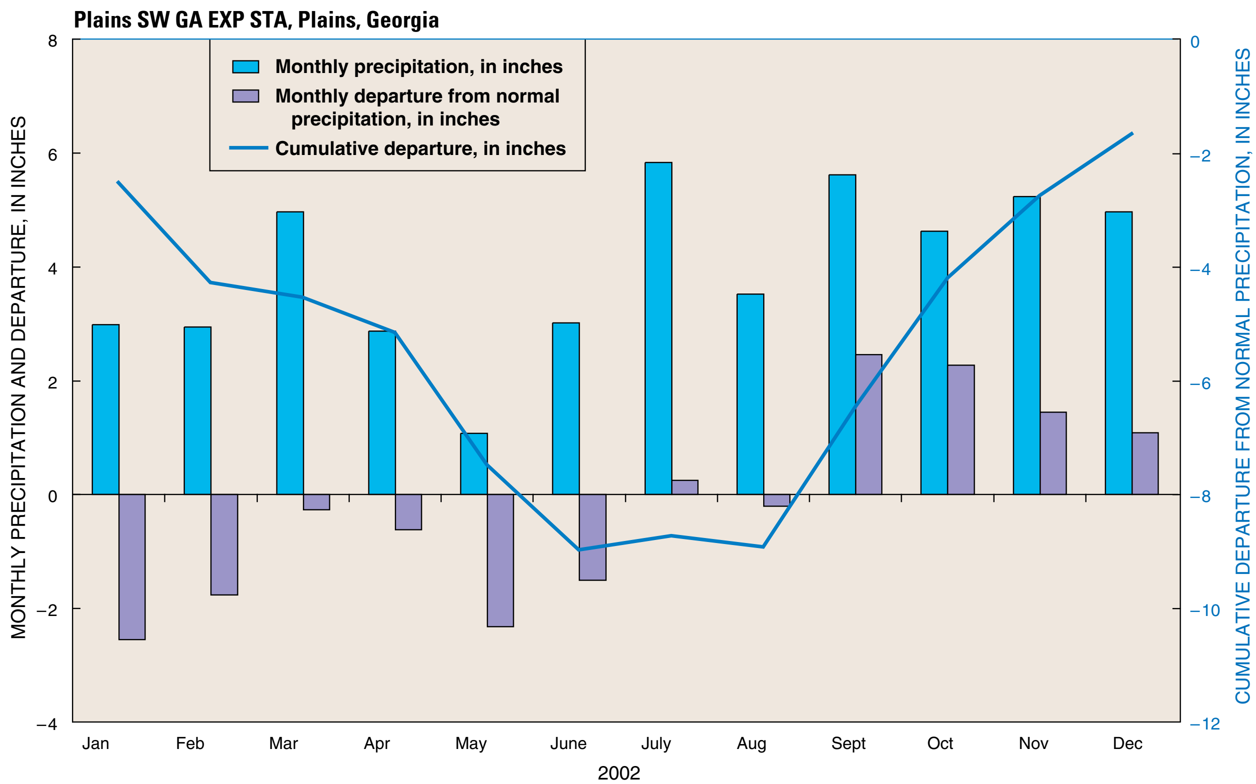


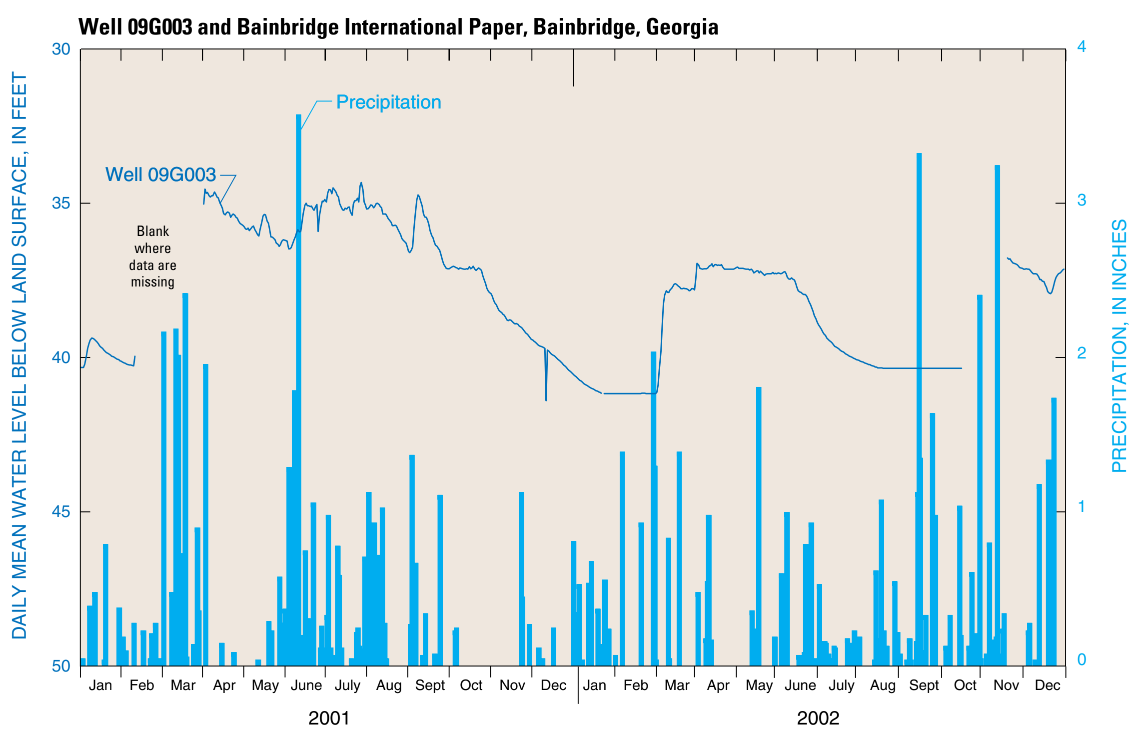
Streamgaging station 02350512 and “Cordele,” Cordele, Georgia

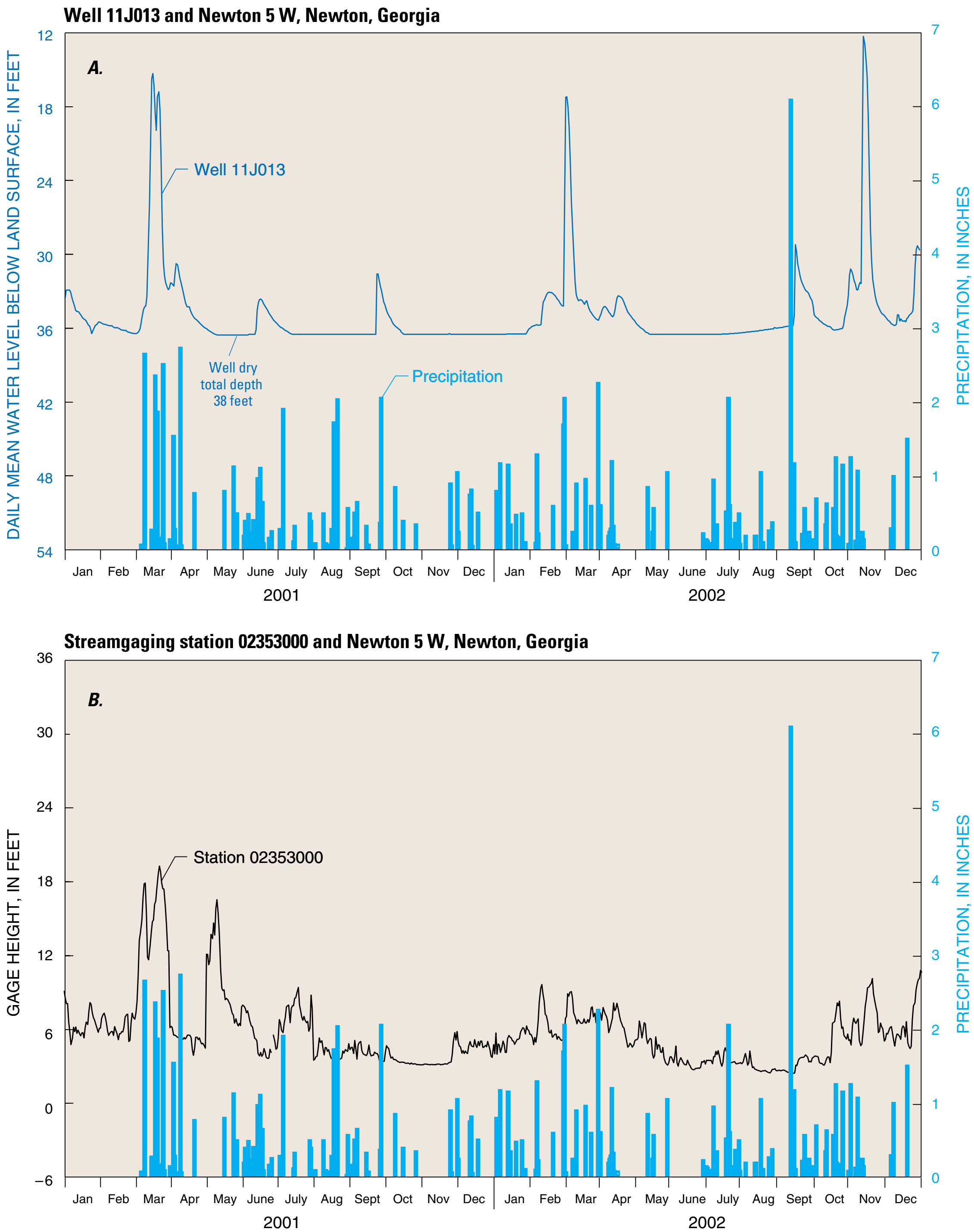



"Cuthbert," Cuthbert, Georgia
Monthly precipitation, in inches
Monthly departure from normal precipitation, in inches
Cumulative departure, in inches
MONTHLY PRECIPITATION AND DEPARTURE, IN INCHES
CUMULATIVE DEPARTURE FROM NORMAL PRECIPITATION, IN INCHES
12
10
8
6
4
2
0
−2
−4
−6
6
4
2
0
−2
−4
−6
−8
−10
−12
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec
2001


Morgan 5 W, Morgan, Georgia
Monthly precipitation, in inches
Monthly departure from normal precipitation, in inches
Cumulative departure, in inches
MONTHLY PRECIPITATION AND DEPARTURE, IN INCHES
CUMULATIVE DEPARTURE FROM NORMAL PRECIPITATION, IN INCHES
12
10
8
6
4
2
0
−2
−4
−6
0
−3
−6
−9
−12
−15
−18
−21
−24
−27
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec
2001
2002

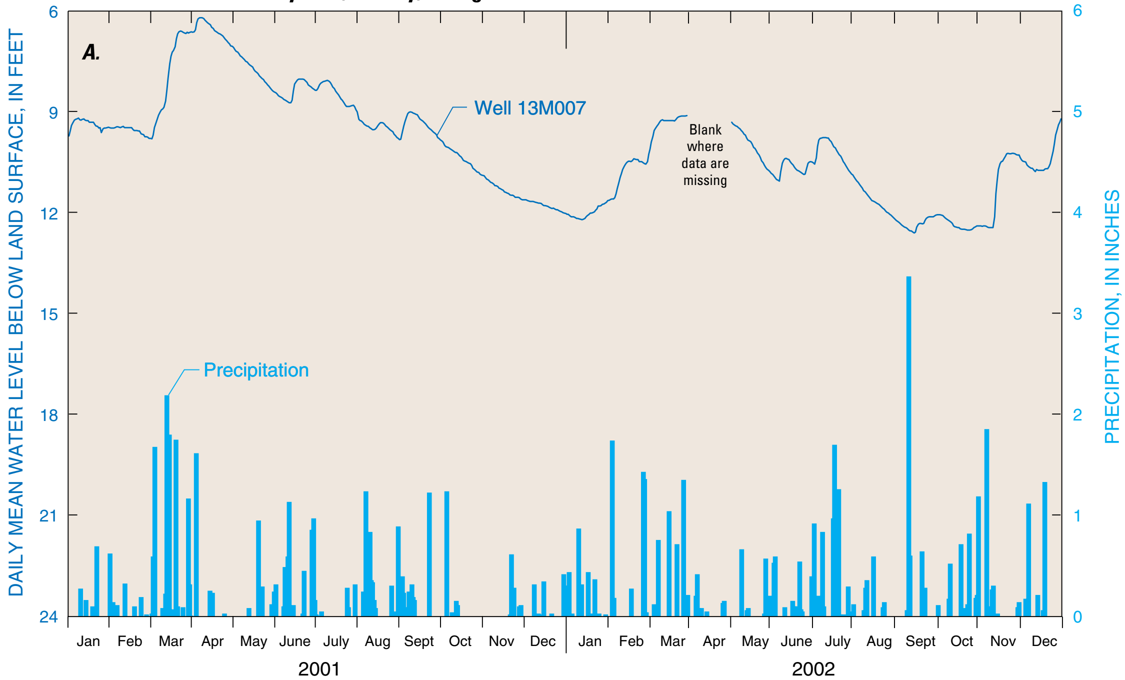

Plains SW GA EXP STA, Plains, Georgia
Monthly precipitation, in inches
Monthly departure from normal precipitation, in inches
Cumulative departure, in inches
MONTHLY PRECIPITATION AND DEPARTURE, IN INCHES
CUMULATIVE DEPARTURE FROM NORMAL PRECIPITATION, IN INCHES
8
6
4
2
0
−2
−4
0
−2
−4
−6
−8
−10
−12
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec
2002


Well 09G003 and Bainbridge International Paper, Bainbridge, Georgia
Precipitation
Well 09G003
Blank where data are missing
DAILY MEAN WATER LEVEL BELOW LAND SURFACE, IN FEET
PRECIPITATION, IN INCHES
30
35
40
45
50
4
3
2
1
0
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec
2001
2002

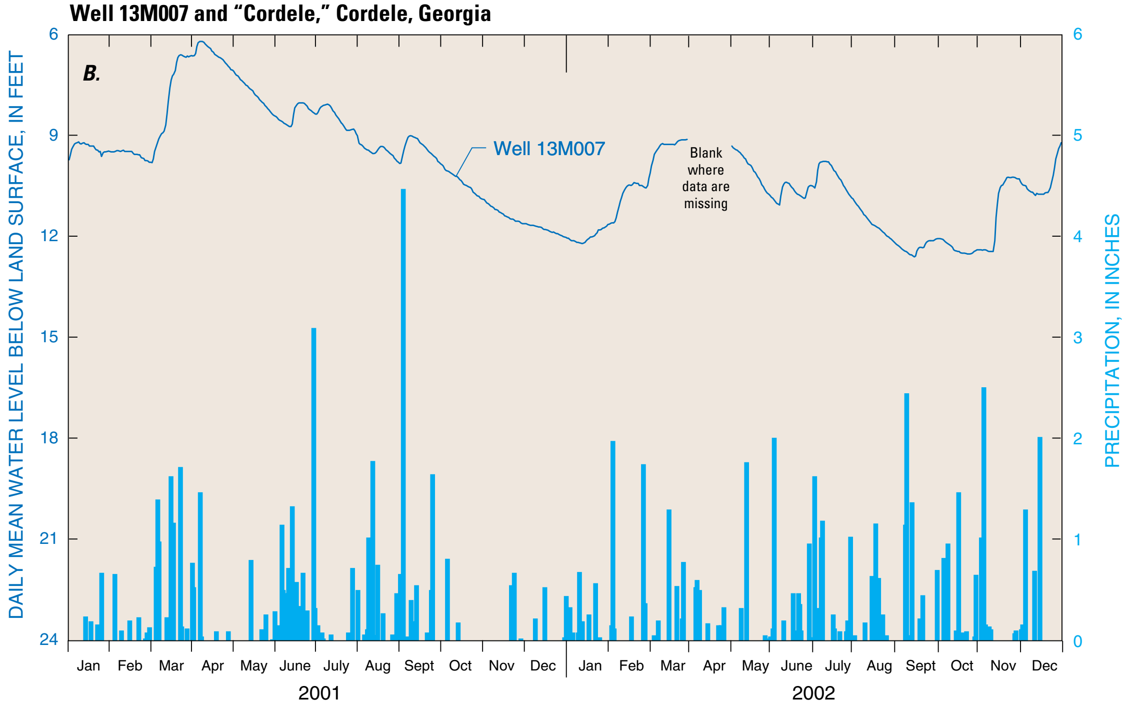


Well 11J013 and Newton 5 W, Newton, Georgia
A.
Well 11J013
Well dry
total depth
38 feet
Precipitation
DAILY MEAN WATER LEVEL BELOW LAND SURFACE, IN FEET
PRECIPITATION, IN INCHES
12
18
24
30
36
42
48
54
7
6
5
4
3
2
1
0
Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec
2001
2002
Streamgaging station 02353000 and Newton 5 W, Newton, Georgia
B.
Station 02353000
GAGE HEIGHT, IN FEET
PRECIPITATION, IN INCHES
36
30
24
18
12
6
0
−6
7
6
5
4
3
2
1
0
Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec
2001
2002

Well 13M007 and Albany 3 SE, Albany, Georgia



Well 13M007 and "Cordele," Cordele, Georgia



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