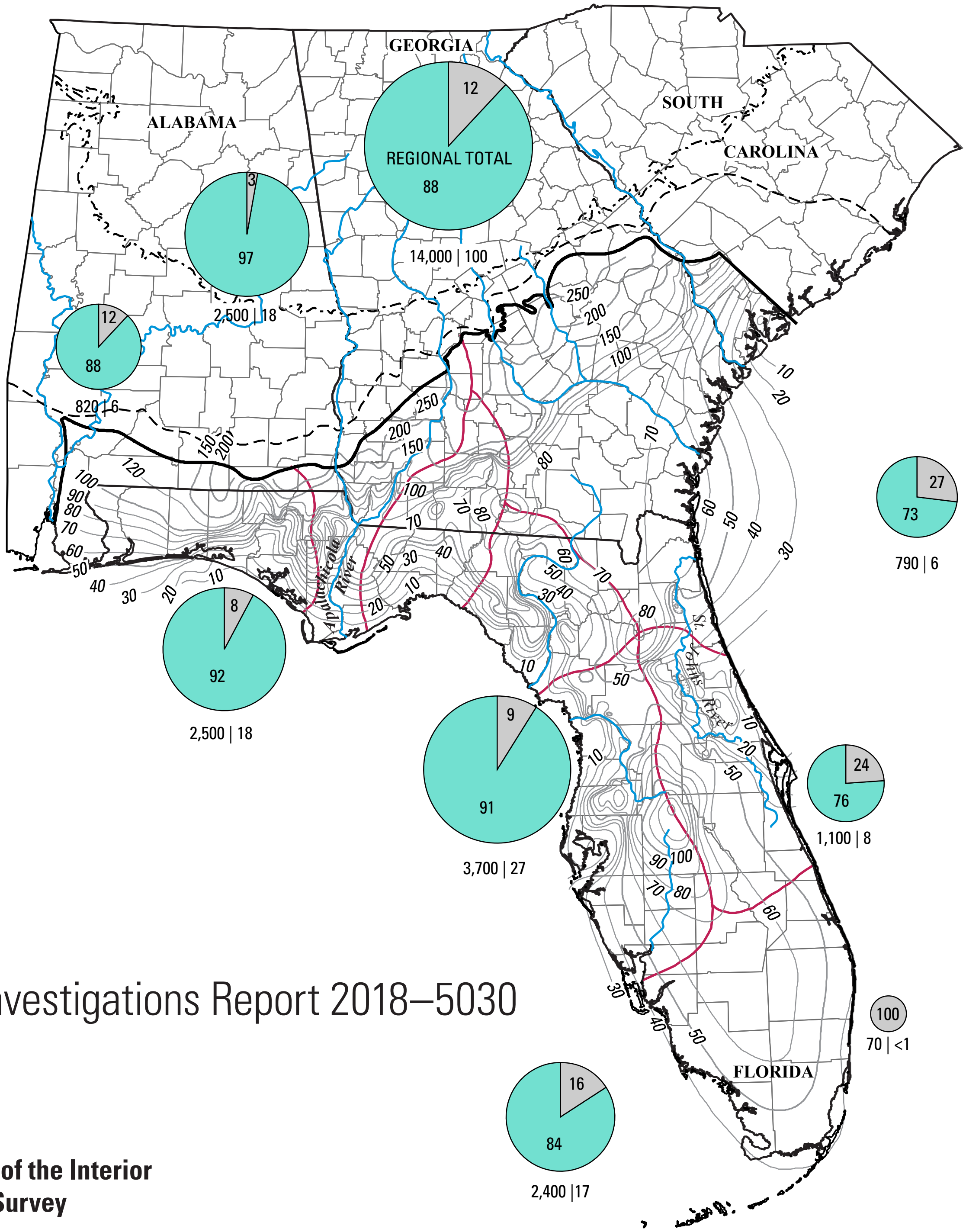
Water Availability and Use Science Program

Hydrogeologic Setting, Conceptual Groundwater Flow System, and Hydrologic Conditions 1995–2010 in Florida and Parts of Georgia, Alabama, and South Carolina



Scientific Investigations Report 2018–5030

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

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By Jason C. Bellino, Eve L. Kuniansky, Andrew M. O’Reilly, and Joann F. Dixon

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U.S. Department of the Interior
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Plate

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Figures

Tables

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
million gallons (Mgal)	3,785	cubic meter (m^3)
cubic mile (mi^3)	4.168	cubic kilometer (km^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
	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)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
	Area	
square meter (m^2)	0.0002471	acre
square kilometer (km^2)	247.1	acre
square meter (m^2)	10.76	square foot (ft^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic meter (m^3)	6.290	barrel (petroleum, 1 barrel = 42 gal)
liter (L)	33.81402	ounce, fluid (fl. oz)
liter (L)	2.113	pint (pt)
liter (L)	1.057	quart (qt)
liter (L)	0.2642	gallon (gal)
cubic meter (m^3)	264.2	gallon (gal)
cubic meter (m^3)	0.0002642	million gallons (Mgal)
liter (L)	61.02	cubic inch (in^3)
cubic meter (m^3)	35.31	cubic foot (ft^3)
cubic meter (m^3)	1.308	cubic yard (yd^3)
cubic kilometer (km^3)	0.2399	cubic mile (mi^3)
cubic meter (m^3)	0.0008107	acre-foot (acre-ft)
	Flow rate	
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
cubic meter per second (m^3/s)	22.83	million gallons per day (Mgal/d)
meter per day (m/d)	3.281	foot per day (ft/d)
	Mass	
kilogram (kg)	2.205	pound avoirdupois (lb)
	Density	
kilogram per cubic meter (kg/m^3)	0.06242	pound per cubic foot (lb/ft^3)

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

°F=(1.8×°C)+32

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

°C=(°F–32)/1.8

Datum

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

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

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

Supplemental Information

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

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

Abbreviations

DEM	digital elevation model
ET	evapotranspiration
FSUML	Florida State University Marine Laboratory
GNIS	Geographic Names Information System
HUC4	hydrologic unit code (four-digit)
MRLC	Multi-Resolution Land Characteristics Consortium
NLCD	National Land Cover Database
NRCS	Natural Resources Conservation Service
NWIS	National Water Information System
RASA	Regional Aquifer-System Analysis
RET	reference evapotranspiration
SCS	Soil Conservation Service
SFWMD	South Florida Water Management District
SGD	submarine groundwater discharge
SWB	Soil-Water-Balance (code)
USGS	U.S. Geological Survey

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By Jason C. Bellino,[1] Eve L. Kuniansky,[1] Andrew M. O'Reilly,[2] and Joann F. Dixon[1]

Abstract

The hydrogeologic setting and groundwater flow system in Florida and parts of Georgia, Alabama, and South Carolina is dominated by the highly transmissive Floridan aquifer system. This principal aquifer is a vital source of freshwater for public and domestic supply, as well as for industrial and agricultural uses throughout the southeastern United States. Population growth, increased tourism, and increased agricultural production have led to increased demand on groundwater from the Floridan aquifer system, particularly since 1950. The response of the Floridan aquifer system to these stresses often poses regional challenges for water-resource management that commonly transcend political or jurisdictional boundaries. To help water-resource managers address these regional challenges, the U.S. Geological Survey (USGS) Water Availability and Use Science Program began assessing groundwater availability of the Floridan aquifer system in 2009.

The current conceptual groundwater flow system was developed for the Floridan aquifer system and adjacent systems partly on the basis of previously published USGS Regional Aquifer-System Analysis (RASA) studies, specifically many of the potentiometric maps and the modeling efforts in these studies. The Floridan aquifer system extent was divided into eight hydrogeologically distinct subregional groundwater basins delineated on the basis of the estimated predevelopment (circa 1880s) potentiometric surface: (1) Panhandle, (2) Dougherty Plain-Apalachicola, (3) Thomasville-Tallahassee, (4) Southeast Georgia-Northeast Florida-South South Carolina, (5) Suwannee, (6) West-central Florida, (7) East-central Florida, and (8) South Florida. The use of these subregions allows for a more detailed analysis of the individual basins and the groundwater flow system as a whole.

The hydrologic conditions and associated groundwater budget were updated relative to previous RASA studies to include additional data collected since the 1980s and to reflect the entire groundwater flow system, including the surficial, intermediate, and Floridan aquifer systems for a contemporary period (1995–2010). Inflow to the groundwater flow system of 33,700 million gallons per day (Mgal/d) was assumed to be exclusively from net recharge (precipitation minus evapotranspiration and surface runoff). Outflow from the groundwater flow system included spring discharge (7,700 Mgal/d) and groundwater withdrawals (5,200 Mgal/d). Estimates for all components of the groundwater system were not possible because of large uncertainties associated with internal leakage, coastal discharge, and discharge to streams and lakes. A numerical modeling analysis is required to improve this hydrologic budget calculation and to forecast future changes in groundwater levels and aquifer storage caused by groundwater withdrawals, land-use change, and the effects of climate variability and change.

Introduction

The groundwater flow system in Florida and parts of Georgia, Alabama, and South Carolina is dominated by the highly transmissive Floridan aquifer system, which extends over approximately 100,000 square miles (mi^2) (fig. 1). The Floridan aquifer system—composed of the Upper Floridan aquifer and Lower Floridan aquifer—also is present in a small portion of southeastern Mississippi, but is saline in this area and not used for any purpose (Williams and Kuniansky, 2015). Groundwater withdrawals from the Floridan aquifer system in 2000 (4,020 million gallons per day [Mgal/d]; Bellino, 2017; Marella and Berndt, 2005) were ranked fifth largest among the 66 principal aquifers of the United States by the U.S. Geological Survey (USGS) (Maupin and Barber, 2005), and about 90 percent of the groundwater was obtained from the Upper Floridan aquifer (Marella and Berndt, 2005). Other sources of water in the region include the intermediate aquifer system and the surficial aquifer system (Miller, 1990; Williams and Kuniansky, 2015); these aquifer systems, however, are not as productive over as great an extent as is the Floridan aquifer system.

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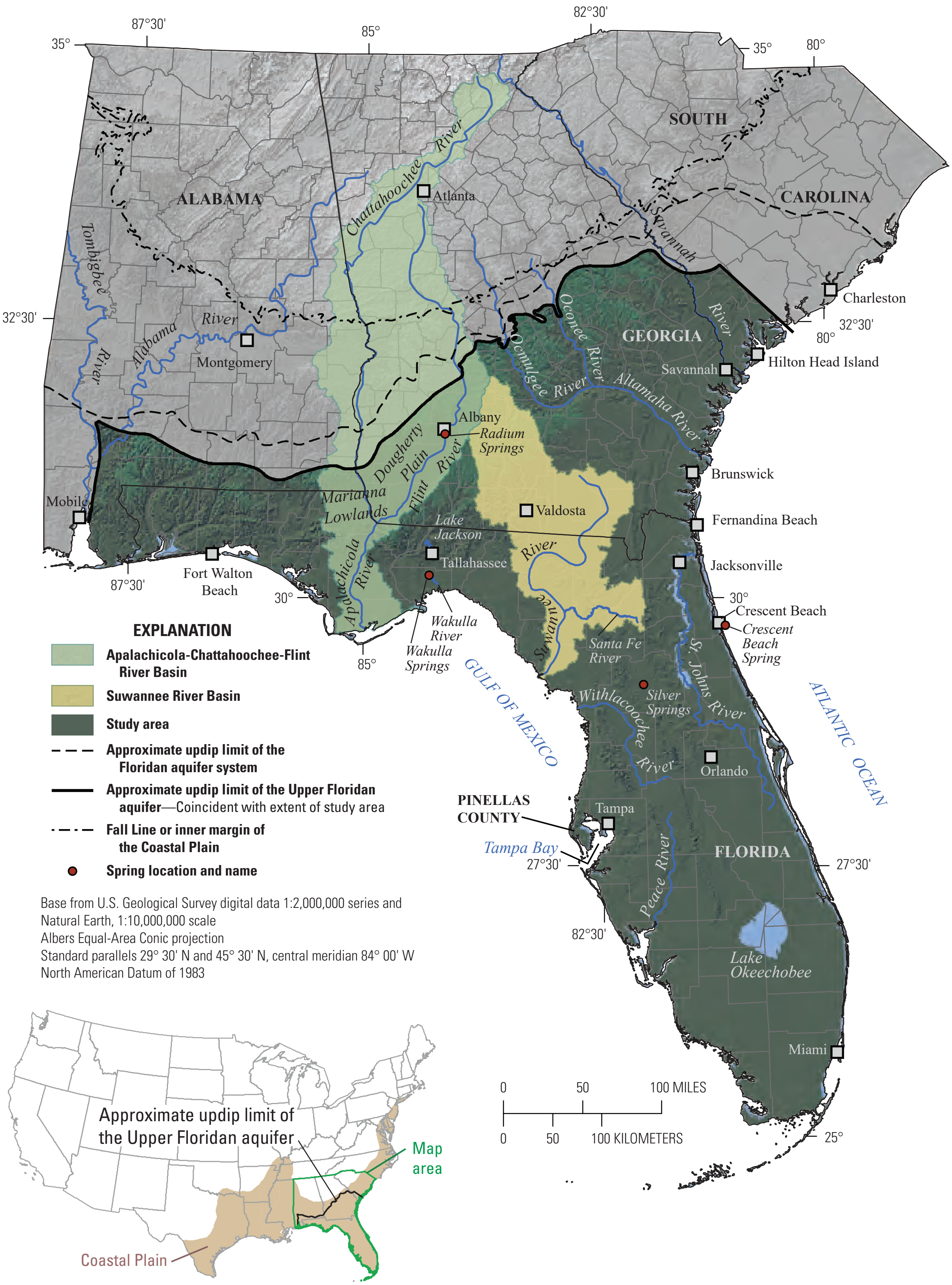


Figure 1. Location of the Floridan aquifer system; approximate updip limit of the Floridan aquifer system and Upper Floridan aquifer; location of the Fall Line (inner margin of the Coastal Plain); selected cities, rivers, river basins, lakes, and springs; and shaded relief in the study area, southeastern United States.

Groundwater development of the Floridan aquifer system began in 1887 when 14 artesian wells were constructed to supply drinking water for the city of Savannah, Ga. (fig. 1); by 1950, public-supply withdrawals had increased from 6 Mgal/d to about 13 Mgal/d (Bush and Johnston, 1988). Increases in population, tourism, and agricultural production resulted in a more than 500-percent increase in groundwater withdrawals from the Floridan aquifer system between 1950 and 2000 (Marella and Berndt, 2005), and as of 2000, the Floridan aquifer system was the primary source of drinking water for about 10 million people, mostly in Florida (Marella and Berndt, 2005). In response to pumping, groundwater levels have declined by as much as 35 feet (ft) per decade from 1970 to 2010 in the confined parts of the Floridan aquifer system (Williams and others, 2011), which has led to decreased aquifer storage, the draining of some lakes and wetlands, and saltwater intrusion (Beach and Kelley, 1998; HydroGeoLogic, Inc., 2005, 2007; Metz, 2011; Southwest Florida Water Management District, 2002; Spechler, 1994, 2001). As of 2010, total withdrawals from the Floridan aquifer system were 3,319 Mgal/d (Bellino, 2017).

Concerns that limit the availability of fresh groundwater from the Floridan aquifer system are varied, with different permitting and management strategies for each area or State in the study area (table 1). For example, saltwater intrusion is of great concern in Hilton Head Island, S.C. (fig. 1), where groundwater withdrawals have reversed the natural upward discharge from the Floridan aquifer system and where seawater now migrates downward along paleochannels that cut through the confining units between the Floridan aquifer system and the ocean (Falls and others, 2005; Krause and Clarke, 2001; Provost and others, 2006). In Brunswick, Ga., and Fernandina Beach, Fla. (fig. 1), upward migration of saline water from deeper zones through vertical fractures and horizontal vuggy or cavernous zones has been observed (Cherry and others, 2011; Williams and Spechler, 2011).

In other areas, reductions in spring discharge and (or) increases in nitrates in groundwater motivate permitting and management strategies. For example, Radium Springs, near Albany, Ga. (fig. 1), no longer flows during drought periods or during periods of intense pumping (Allums and others, 2009, 2012), and increased levels of nitrates have been documented at many springs in the Suwannee River groundwater basin, southeast of Tallahassee, Fla. (fig. 1) (Katz and Hornsby, 1998; Katz and others, 1999; Heffernan and others, 2010a, b). Silver Springs, approximately 100 miles (mi) north of Tampa, Fla. (fig. 1), has undergone decreases in discharge and increases in nitrates (Phelps, 2004; Harrington and others, 2010).

Groundwater withdrawals also have caused reductions in streamflow in the Apalachicola-Chattahoochee-Flint River Basin (fig. 1) and have affected the hydrology and ecology of this basin (Albertson and Torak, 2002; Jones and Torak, 2006). Partly in response to these effects, permits for agricultural withdrawals from the Floridan aquifer system in the lower Flint and Chattahoochee River Basins, Ga., were suspended as of July 30, 2012 (Judson H. Turner, Georgia Department of Natural Resources, written commun., 2012). In central Florida,

Table 1. State agencies that administer groundwater regulations within the study area, southeastern United States.

State	Doctrine of appropriation	Regulatory system	Administrating agency
Alabama	Riparian	Registering and reporting pumping greater than 100,000 gallons per day.	Alabama Department of Economic and Community Affairs–Water Management/ Water Use Reporting Program.
Florida	Regulated riparian	Permitting and reporting requirements vary per management area.	Northwest Florida Water Management District, Suwannee River Water Management District, St. Johns River Water Management District, Southwest Florida Water Management District, and South Florida Water Management District.
Georgia	Regulated riparian	Permitting and monitoring wells pumping more than 100,000 gallons per day.	Environmental Protection Division Watershed Protection Branch.
South Carolina	Regulated riparian	Registering and reporting groundwater withdrawals equal to or greater than 3 million gallons in any month requires permit in capacity use area (note Floridan aquifer system is within the Low Country Capacity Use area of South Carolina).	South Carolina Department of Health and Environmental Control and Capacity Use areas.

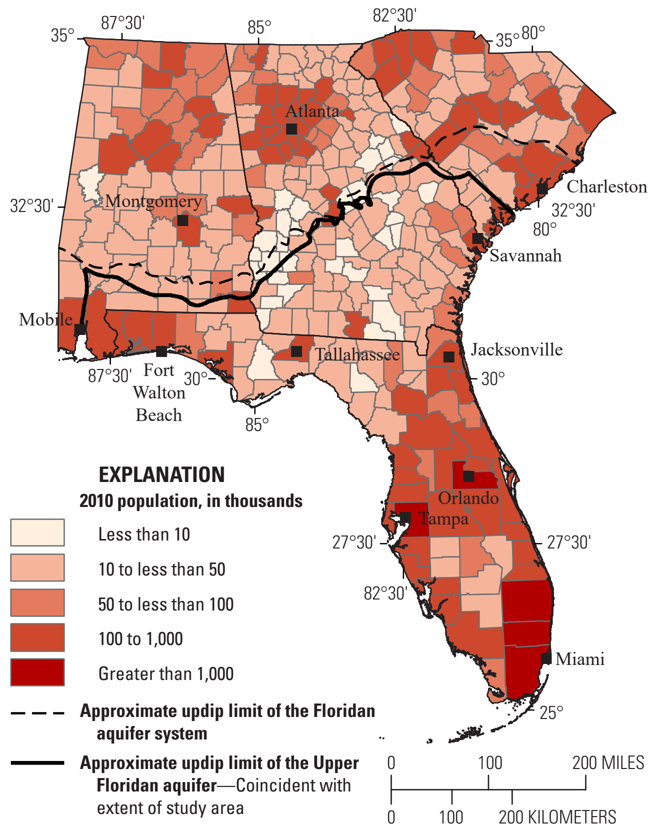
withdrawals from the Floridan aquifer system have induced downward leakage from shallow aquifers, resulting in lowered lake levels, reductions in wetland areas or hydroperiods, and increases in sinkhole development during droughts (Haag and Lee, 2006; Lee and others, 2009; Sepúlveda and others, 2012; Tihansky, 1999).

Concern persists that the widespread use of the Floridan aquifer system for multiple and sometimes competing uses will result in unforeseen hydrologic consequences. Competition for the Floridan aquifer system as a water resource became acutely apparent during the early 2000s when demands for potable groundwater resulted in disagreement over proposed groundwater withdrawals, water use, and land development (Goodnough, 2003). The response of the Floridan aquifer system to stresses often poses regional challenges for water-resources management that transcend political or jurisdictional boundaries.

Location and Physical Setting

The Floridan aquifer system underlies all of Florida and parts of Georgia, Alabama, and South Carolina (fig. 1); approximately 24 million people resided within the study area in 2010 (U.S. Census Bureau, 2011), with more densely populated counties associated with major cities (fig. 2). The Floridan aquifer system lies entirely within the Coastal Plain physiographic province (Fenneman and Johnson, 1946) (fig. 1). The topography is relatively flat over most of the extent, and altitudes generally range from sea level to 300 ft. Much of the land surface of Florida is at an altitude of less than 100 ft above sea level, although small areas of central Florida exceed 250 ft above sea level. Altitudes exceed 400 ft just south of the Fall Line where Coastal Plain sedimentary rocks are in contact with metamorphic and igneous rocks in central Georgia, north of Albany (fig. 1). The carbonate rocks of the Floridan aquifer system dissolve when exposed to mildly acidic rainwater (Miller, 1999), and much of the terrain of the study area is dominated by karst features such as sinkholes, circular sinkhole lakes, large springs, and sinking streams (Tobin and Weary, 2004; Veni and others, 2001).

Land use varies widely across the study area and consists of 22 percent wetlands and open water; 45 percent forest or scrub; 23 percent grassland, pasture, and cultivated crops; and 10 percent developed land (Multi-Resolution Land Characteristics Consortium, 2014) (fig. 3). In the less-populated counties of Georgia, much of the land use is agricultural. Large tracts of cropland are also present in central Florida, and extensive cropland is cultivated in the vicinity of Lake Okeechobee, the largest freshwater lake in Florida (more than 700 mi^2 in surface area). Large cities, such as Jacksonville, Orlando, Tampa, and Miami, Fla., are located within the developed areas (fig. 3). Extensive woody and herbaceous wetlands are present along the coast in low-lying areas and along major rivers and swamps. Some of the larger wetlands include The Everglades in south Florida and the Okefenokee Swamp in south Georgia.



Base from U.S. Geological Survey digital data 1:2,000,000 series and Natural Earth, 1:10,000,000 scale
Albers Equal-Area Conic projection
Standard parallels 29° 30' N and 45° 30' N, central meridian 84° 00' W
North American Datum of 1983

Figure 2. 2010 population by county in the study area, southeastern United States (data from U.S. Census Bureau, 2011).

The climate in the study area is primarily humid subtropical, with the exception of the southernmost part of Florida, which has a tropical climate (Kunkel and others, 2013). Average annual precipitation ranges from 44 to 68 inches (in.); the greatest average annual precipitation occurs in the panhandle of Florida, coastal Alabama, and southeast Florida (Kunkel and others, 2013). In general, monthly precipitation is greater during June–September than during the rest of the year, most notably in central and south Florida as recorded by Tampa and Miami weather stations, respectively (National Oceanic and Atmospheric Administration, 2014) (fig. 4); however, precipitation is distributed more evenly throughout the year, and there is less month-to-month variation at the Mobile, Ala., weather station than at the other weather stations (fig. 4). Average daily-minimum air temperatures for January range from about 36 degrees Fahrenheit (°F) to greater than 63 °F, and average daily-maximum air temperatures for July range from 88 °F to greater than 90 °F (Kunkel and others, 2013).

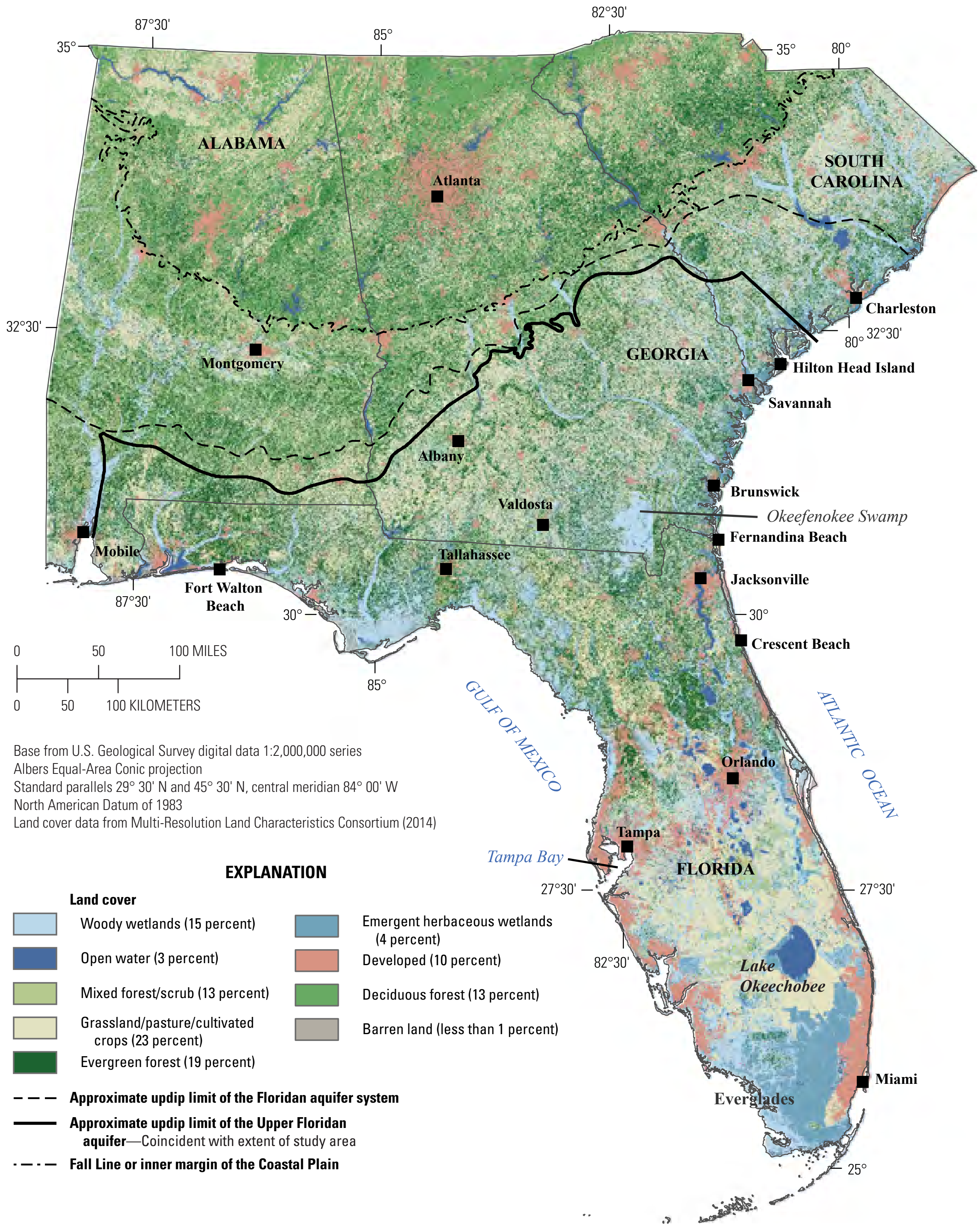


Figure 3. Land cover in 2011 in the study area, southeastern United States (data from Multi-Resolution Land Characteristics Consortium, 2014).

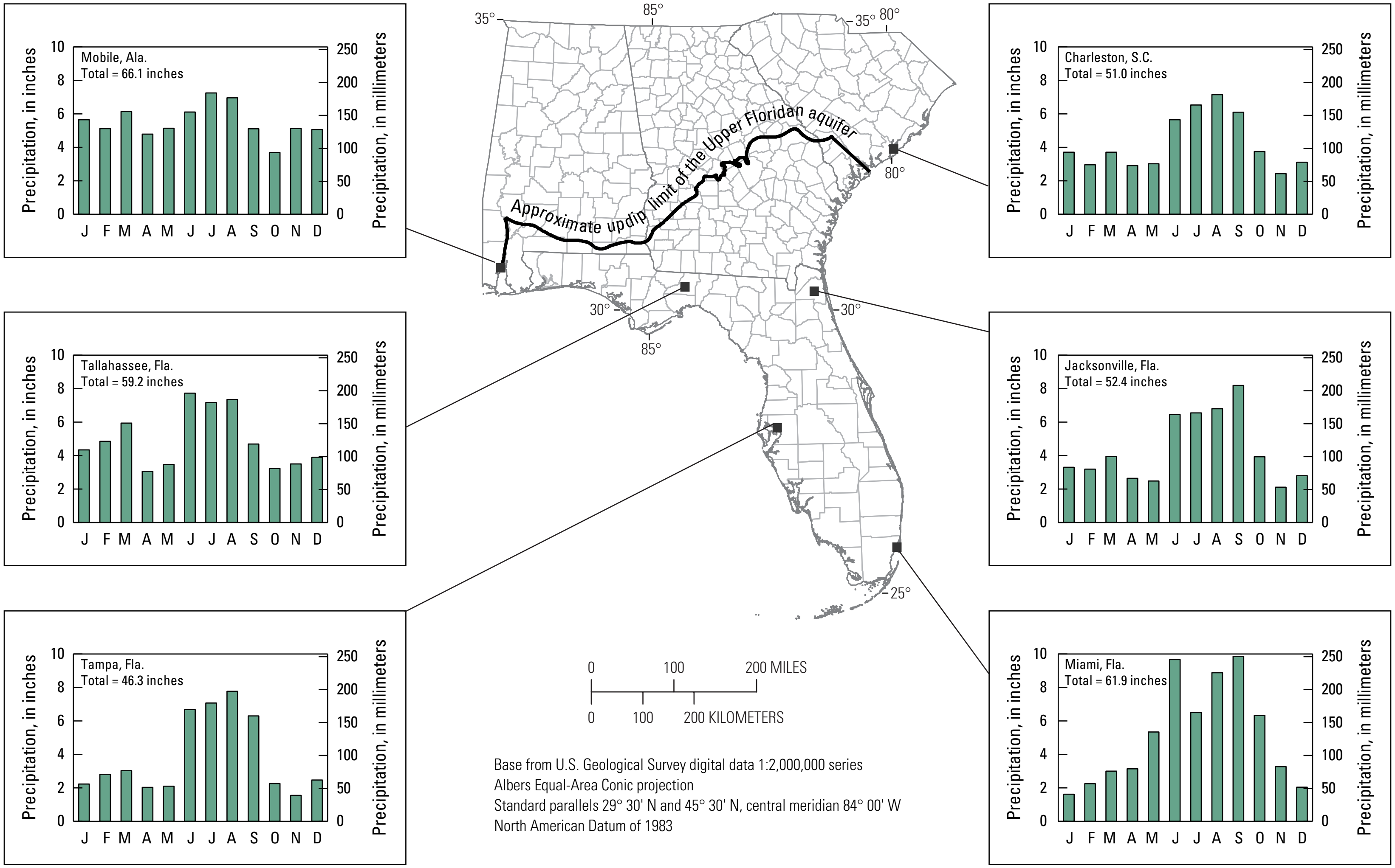


Figure 4. Monthly precipitation normals (1981–2010) for selected weather stations within the study area, southeastern United States (data from National Oceanic and Atmospheric Administration, 2014).

Despite substantial annual precipitation, the area is prone to short-term (1- to 3-year) droughts, although generally not the multidecadal droughts experienced in the Central and Western United States (Kunkel and others, 2013). The seasonal variations in precipitation, typical of the climate of central and south Florida, can result in seasonal groundwater shortages from approximately Tampa and Orlando southward. Groundwater shortages are exacerbated by drought conditions, population growth and related water use, high variability in summer precipitation, and high summer evapotranspiration (ET) rates. The 1998–2002 drought resulted in record low lake, reservoir, and groundwater levels; the 2007–8 drought resulted in more than $1 billion in agricultural losses in Georgia alone (Kunkel and others, 2013).

The study area is subject to extreme weather events such as tropical storms and hurricanes. The most intense storms mainly affect the coast; however, substantial effects can be felt further inland. The storms can replenish soil moisture, lakes, and groundwater, especially when flooding occurs over the outcrop or thinly confined areas of the Floridan aquifer system. Because of the short duration and intense nature of these systems, however, much of the water is lost to overland runoff that causes widespread flooding. Hurricanes of categories 3–5 are most frequent in south Florida, where they occur approximately once every 15 years, and along the northern Gulf of Mexico coast, where they occur approximately once every 20 years (Keim and others, 2007).

Purpose and Scope

The purpose of this report is to summarize the hydrogeologic setting, conceptual groundwater flow system, and hydrologic conditions over the extent of the Floridan aquifer system in Florida and parts of Georgia, Alabama, and South Carolina. The part of the Floridan aquifer system present in Mississippi is not discussed herein. A brief summary of the hydrogeologic framework and conceptual flow system is presented, along with the extent of the freshwater and brackish-water flow system (total dissolved solids concentrations less than 10,000 milligrams per liter [mg/L]). This report also provides a general description of the regional aquifer systems and shallower aquifers that exchange water through leakage to and from the Floridan aquifer system through the upper confining unit, where present. The groundwater flow system is characterized through analyses of water-budget components that are based, in part, on previous studies, on trends in hydrologic conditions (recharge, groundwater levels, and spring flow), and on water use. Hydrologic conditions for a contemporary period (1995–2010) are analyzed, and longer term trends are evaluated in cases where sufficient data are available. The 1995–2010 analysis includes periods of short-term drought (1998–2002 and 2007–8), average conditions, and wet conditions (2005 and 2009).

Hydrogeologic Setting

The two major groundwater flow systems in the study area are the surficial aquifer system and the Floridan aquifer system (fig. 5) (Miller, 1990). These systems are separated in most areas by the upper confining unit, which restricts flow between them (Miller 1986, 1990; Williams Kuniansky, 2015). The upper confining unit also contains productive water-bearing formations in southwest Florida (intermediate aquifer system) and southeast Georgia (Brunswick aquifer system) (Clarke and others, 1990; Parker and others, 1955; Stringfield, 1936, 1966; Torres and others, 2001).

Surficial Aquifer System

The surficial aquifer system is composed primarily of terrace and alluvial sands of Pliocene to Holocene age (Miller, 1986, 1990; Williams and Kuniansky, 2015). In south Florida, the surficial aquifer system consists of a thick and productive sequence of carbonate rocks and is referred to as the “Biscayne aquifer” (fig. 6). In the western panhandle of Florida, where sediments within the surficial aquifer system are thickest, some gravel is also present, and the surficial aquifer system there is referred to as the “sand and gravel aquifer” (Miller, 1990). The thickness of the surficial aquifer system ranges from less than 10 ft in parts of north-central Florida and updip areas in southeast Georgia and South Carolina to more than 1,200 ft in the western panhandle of Florida; however, the surficial aquifer system is generally between 25 and 200 ft thick over approximately half of the study area (Williams and Kuniansky, 2015). In some areas, such as west-central peninsular Florida and the central panhandle of Florida, the Floridan aquifer system crops out, and the surficial aquifer is absent (fig. 6).

The surficial aquifer system stores water and transmits it to and from surface-water features and underlying aquifers through the upper confining unit and where the upper confining unit is thin or breached. Bush and Johnston (1988) treated the surficial aquifer system as a source-sink layer in their model (groundwater levels specified for the surficial aquifer system in numerical model), but in recent studies it has been actively simulated (numerical model calculates groundwater levels in surficial aquifer system) because the water availability constraints on use of the underlying Floridan aquifer system depend on the dynamic response of the surficial aquifer system to Floridan aquifer system withdrawals (Sepúlveda and others, 2012).

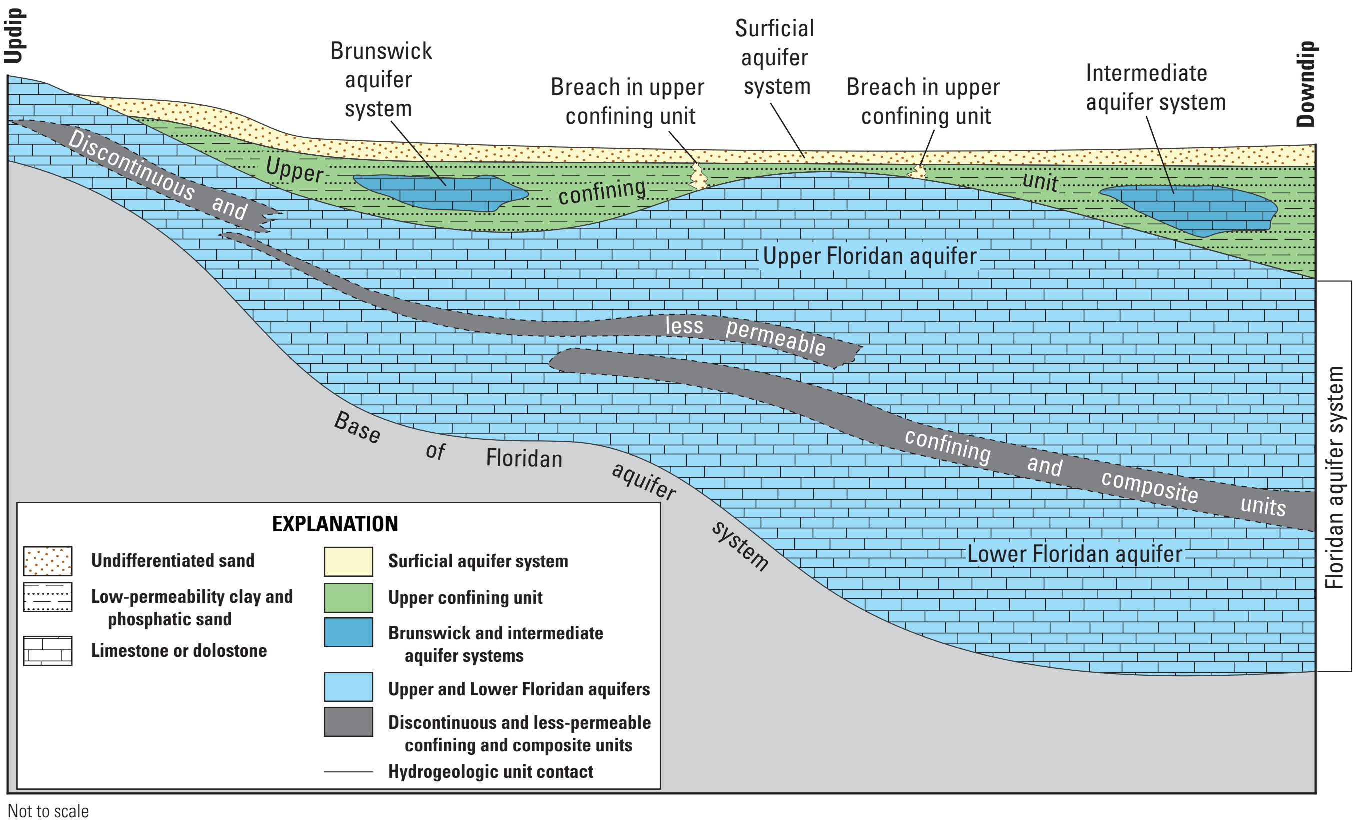


Figure 5. Groundwater flow systems in the study area, southeastern United States.

Upper Confining Unit

The upper confining unit underlies the surficial aquifer system and consists of beds of low-permeability clays, phosphatic sands, and dolomitic limestone of the late and middle Miocene age Hawthorn Group (Miller, 1986; Williams and Kuniansky, 2015). The upper confining unit ranges in thickness from less than 100 ft in thinly confined areas to more than 1,000 ft in confined areas and is absent or very thin in unconfined areas of the Floridan aquifer system (fig. 7) (Williams and Kuniansky, 2015). Vertical hydraulic conductivity of the upper confining unit is typically in the range of 1×10^{-3} foot per day (ft/d), but is highly variable; where clays are present, vertical hydraulic conductivity is very small (less than 1×10^{-4} ft/d), and leakage across the upper confining unit is negligible (Williams and Kuniansky, 2015). Locally, the upper confining unit may be breached by sinkholes or vertical joints and fractures, resulting in direct hydraulic connectivity between the overlying surficial aquifer system and underlying Floridan aquifer system, as conceptually illustrated in figure 5.

Intermediate and Brunswick Aquifer Systems

The upper confining unit thickens within some of the basins and embayments and contains local aquifer systems in two locations: one near Brunswick, Ga., called the Brunswick aquifer system and one in southwest Florida called the intermediate aquifer system (fig. 6). Both of these units are composed of several permeable beds within the Hawthorn Group (Arthur and others, 2008). The Brunswick aquifer system consists of poorly sorted fine- to coarse-grained phosphatic, slightly dolomitic sand or carbonate beds (Clarke and others, 1990). The intermediate aquifer system consists of a complex assemblage of carbonate and siliciclastic sediments that have permeable zones within indurated limestone and dolostone (Knochenmus, 2006). The Brunswick aquifer system is confined over its extent, and the intermediate aquifer system is unconfined over the northern part of its extent.

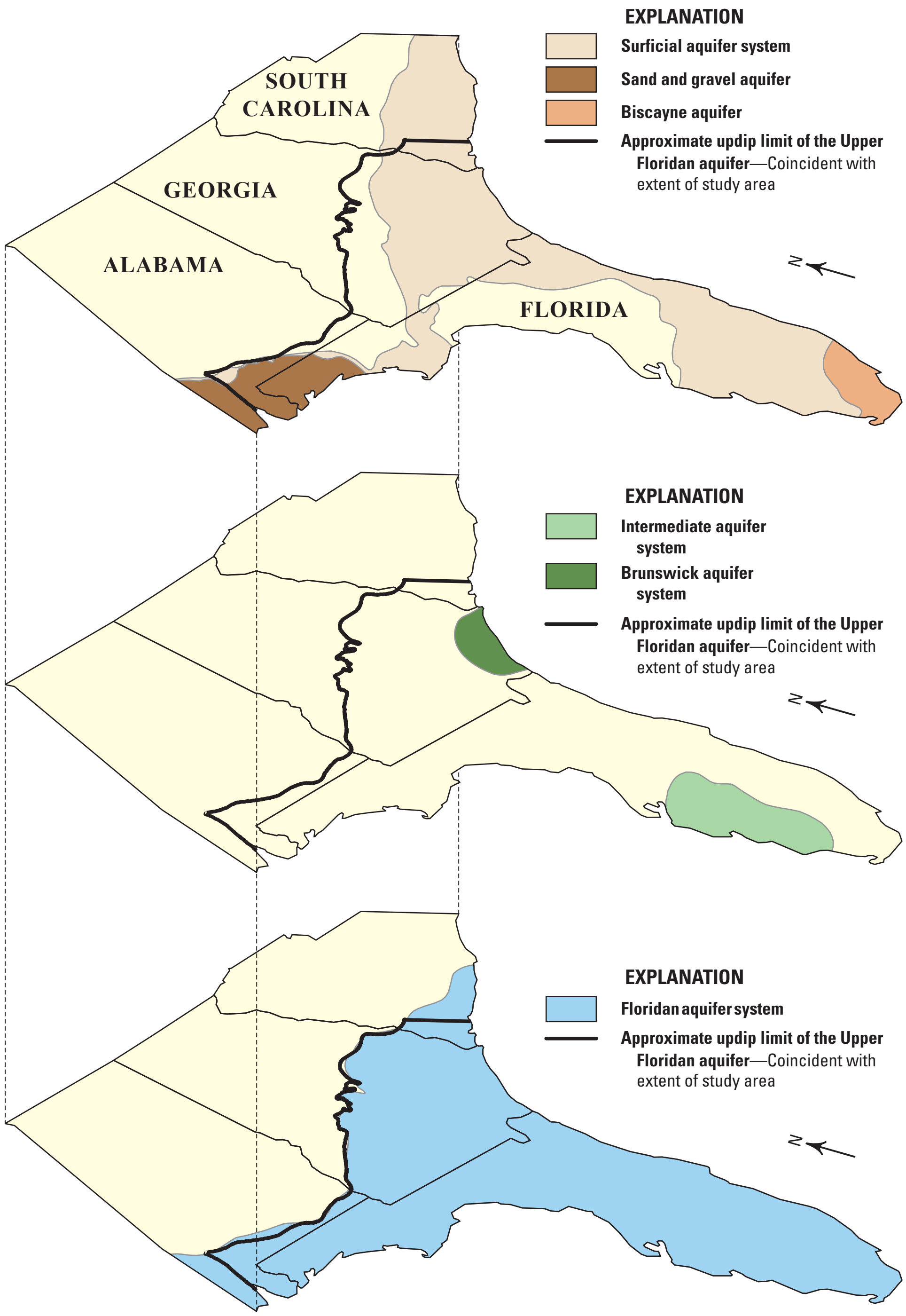
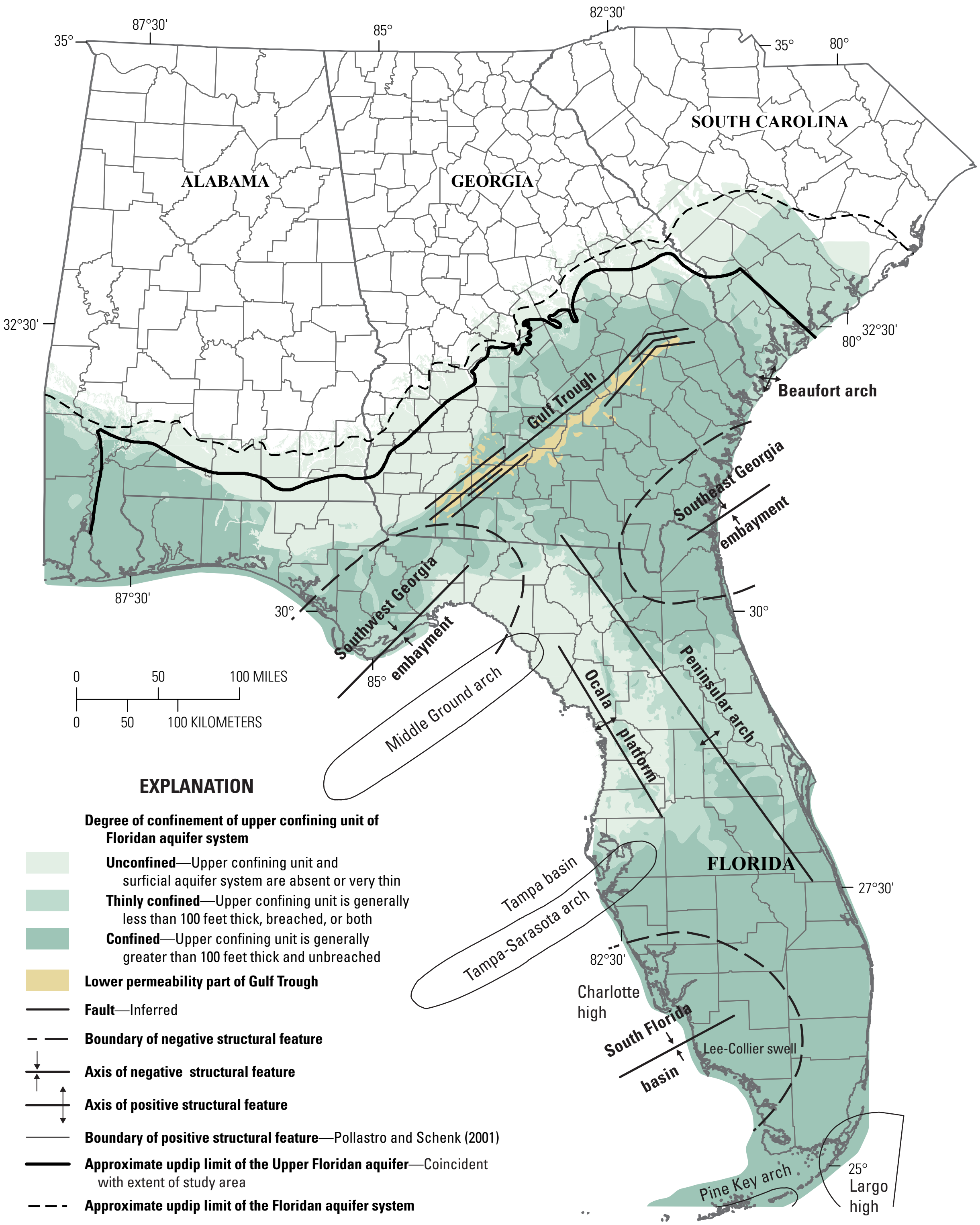


Figure 6. Floridan aquifer system extent and shallower aquifers, southeastern United States (modified from Marella and Berndt, 2005; Miller, 1990; Williams and Kuniansky, 2015).



Base from U.S. Geological Survey digital data 1:2,000,000 series
Albers Equal-Area Conic projection
Standard parallels 29° 30' N and 45° 30' N, central meridian 84° 00' W
North American Datum of 1983

Figure 7. Location of Floridan aquifer system, degree of confinement, and geologic structure, southeastern United States (from Williams and Kuniansky, 2015).

Floridan Aquifer System

The Floridan aquifer system is a sequence of Tertiary carbonate rocks that generally thickens seaward from the northern boundary of the system. The top of the Floridan aquifer system is confined by late and middle Miocene age rocks of the upper confining unit (where present), and the bottom is confined by early Paleocene age rocks (Miller, 1986; Williams and Kuniansky, 2015). Although the Floridan aquifer system consists of two major hydrogeologic units—the Upper Floridan aquifer and the Lower Floridan aquifer—it behaves as one aquifer over much of its extent even though rocks of relatively lower permeability create hydrologic separation between the Upper Floridan aquifer and Lower Floridan aquifer subregionally.

The relative degree of confinement of the Floridan aquifer system (fig. 7) ranges from unconfined or thinly confined in areas where the top of the system is at or near land surface (fig. 8) to thickly confined in areas where the upper confining unit consists of several hundred feet of low-permeability clastic sediments and fine-grained lower permeability limestone, mostly of the Hawthorn Group. In areas where carbonates of the Floridan aquifer system crop out, secondary porosity from the dissolution of rock is ongoing, and karst features are evident. In thickly confined areas, the upper confining unit restricts the exchange of water between the Floridan aquifer system and shallower aquifers within the upper confining unit or within the surficial aquifer system (figs. 6 and 7). Even in thickly confined areas, however, such as central Florida along the Peninsular arch (fig. 7), subsurface collapse sinkholes have been mapped under many of the circular lakes and were probably formed by subaerial weathering during times of lower sea level (Kindinger and others, 1994, 1999, 2000). Collapse features are also present at depth and within confined parts of the system in northeast Florida (Spechler, 1994, 2001) and south Florida (Cunningham, 2013).

The total thickness of the carbonate rocks that compose the Floridan aquifer system ranges from approximately 100 ft at the updip limit of the Upper Floridan aquifer to more than 3,600 ft in southwest Florida (fig. 9). The thickest sequence of carbonate rocks is in south Florida (fig. 9); however, much of the Floridan aquifer system in south Florida contains saline water, which is delineated by estimated total dissolved solids concentrations greater than 10,000 mg/L. Total thickness also increases within the Southeast and Southwest Georgia embayments, portions of which also contain saline water (figs. 7, 9, and 10). In the Florida panhandle and in southern Alabama, sediments thicken and dip southward as they grade from carbonate to fine-grained clastic rocks (Williams and Kuniansky, 2015).

In the updip area, Williams and Kuniansky (2015) mapped the extent of the Floridan aquifer system to include the upper Pearl River aquifer of the Southeastern Coastal Plain aquifer system (Renken, 1996), which grades laterally downdip from clastic material to the carbonate rocks of the Lower Floridan aquifer, as defined by Miller (1986). The approximate updip limit of the most productive part of the Floridan aquifer system is defined by the approximate updip extent of carbonate facies (Williams and Kuniansky, 2015). The updip clastic aquifers have been included in either the Floridan aquifer system or the Southeastern Coastal Plain aquifer system, or both, for different groundwater modeling studies (Barker and Pernik, 1994; Bush and Johnston, 1988; Campbell and Coes, 2010; Krause and Randolph, 1989; Maslia and Hayes, 1988; Payne and others, 2005). The deeper aquifers of the Southeastern Coastal Plain aquifer system become progressively more isolated from the Floridan aquifer system farther downdip. Herein, the approximate updip limit of the Upper Floridan aquifer as defined by Miller (1986) is used as the northern boundary of the area used to estimate preliminary groundwater-budget components in order to compare the current budget components with those reported in Johnston (1999).

The current regional hydrogeologic framework for the Floridan aquifer system presented in Williams and Kuniansky (2015) is not fundamentally different from that of Miller (1986) and Bush and Johnston (1988). More data have been collected over the intervening years, however, including data from packer tests, multiwell aquifer tests, flowmeter logs, and other previously unavailable geophysical logs. Miller (1986) mapped discontinuous confining units within the aquifer based on information available at the time. More recent multiwell aquifer tests and packer tests indicate that, although many of these previously mapped units are indeed of lower permeability than are the vuggy and cavernous higher permeability zones, they commonly have hydraulic properties similar to those of rocks within the Upper Floridan aquifer or Lower Floridan aquifer, being less than or equal to one order of magnitude less permeable. Some of these zones within the middle and lower parts of the Floridan aquifer system become more important sources of water as the system thickens to the south.

The revised hydrogeologic framework of Williams and Kuniansky (2015) abandons the numbered middle confining units (MCUI–VIII) convention of Miller (1986) and instead uses a stratigraphic naming convention for subregional zones of contrasting higher and lower permeability (fig. 11) similar to those adopted locally by the water management districts of Florida. Additionally, the revised framework uses three mappable and laterally extensive lithostratigraphic units to subdivide the Floridan aquifer system into the Upper Floridan aquifer and Lower Floridan aquifer over its entire extent. These generally less-permeable units, from shallowest to deepest, are the Bucatunna clay confining unit in the panhandle of Florida and southwestern Alabama; the Lisbon-Avon Park composite unit in Georgia, northern Florida, eastern Alabama, and western South Carolina; and the middle Avon Park composite unit in peninsular Florida (Williams and Kuniansky, 2015).

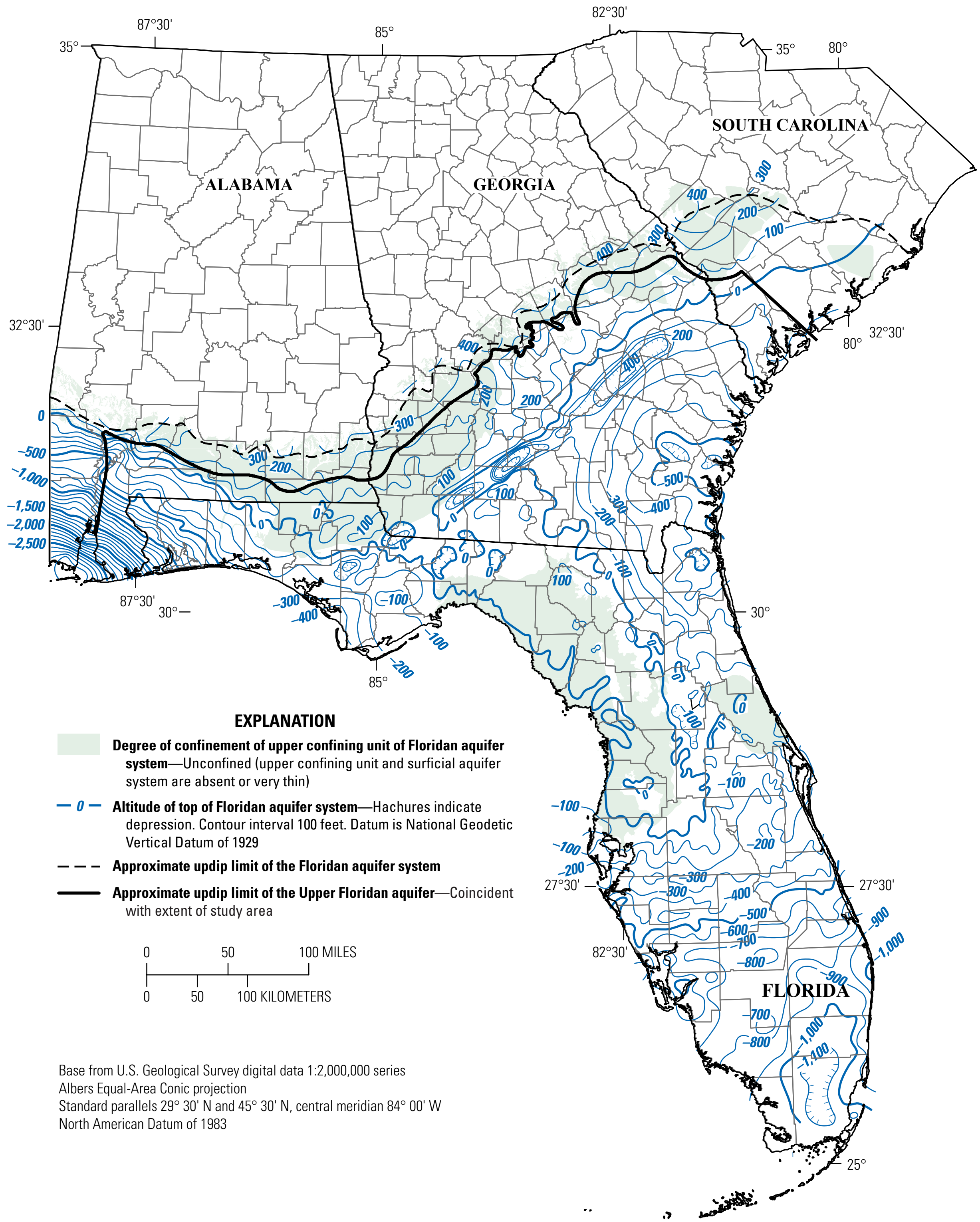


Figure 8. Altitude of the top of the Floridan aquifer system, southeastern United States (modified from Williams and Kuniansky, 2015).

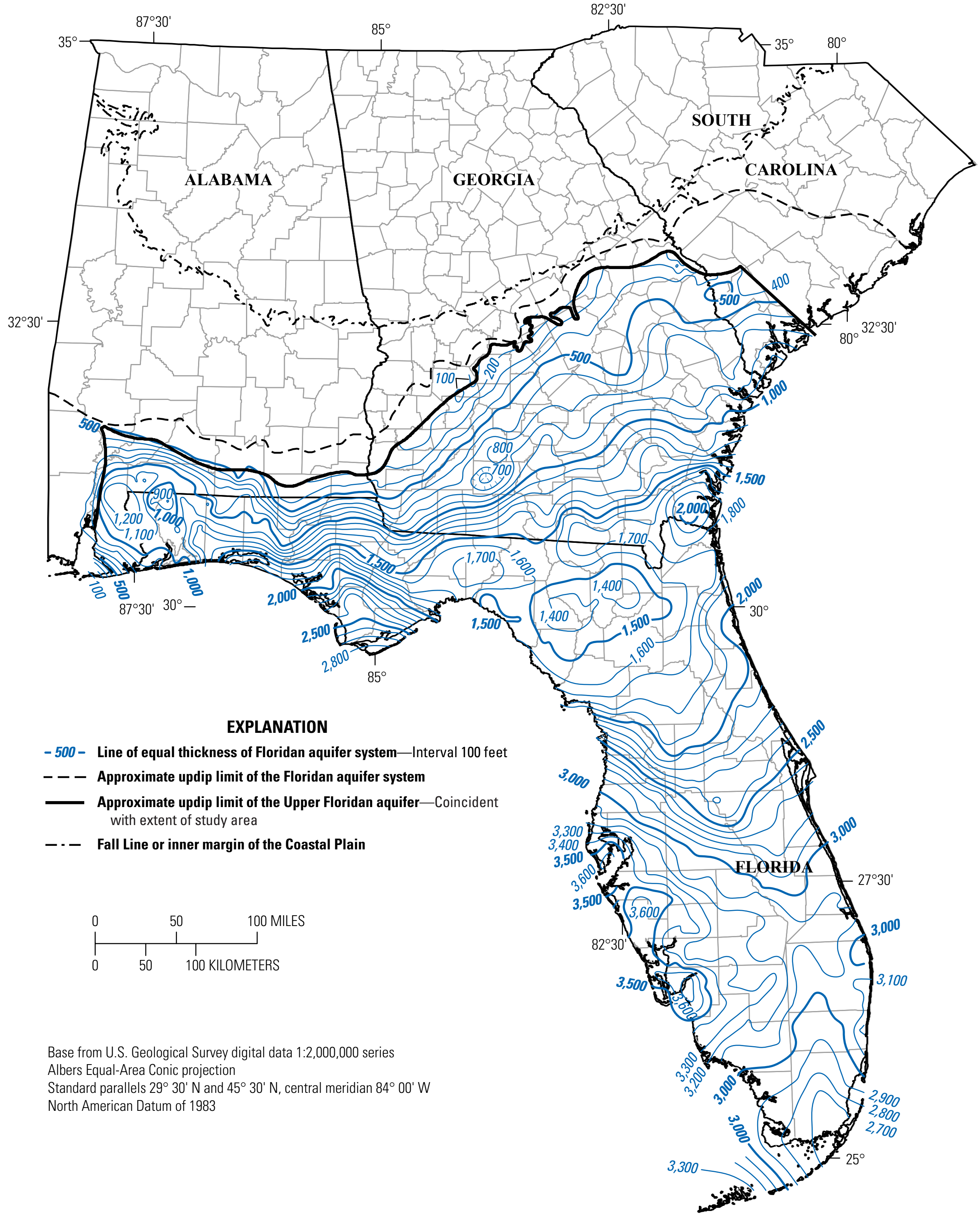


Figure 9. Thickness of the Floridan aquifer system, southeastern United States (modified from Williams and Kuniansky, 2015).

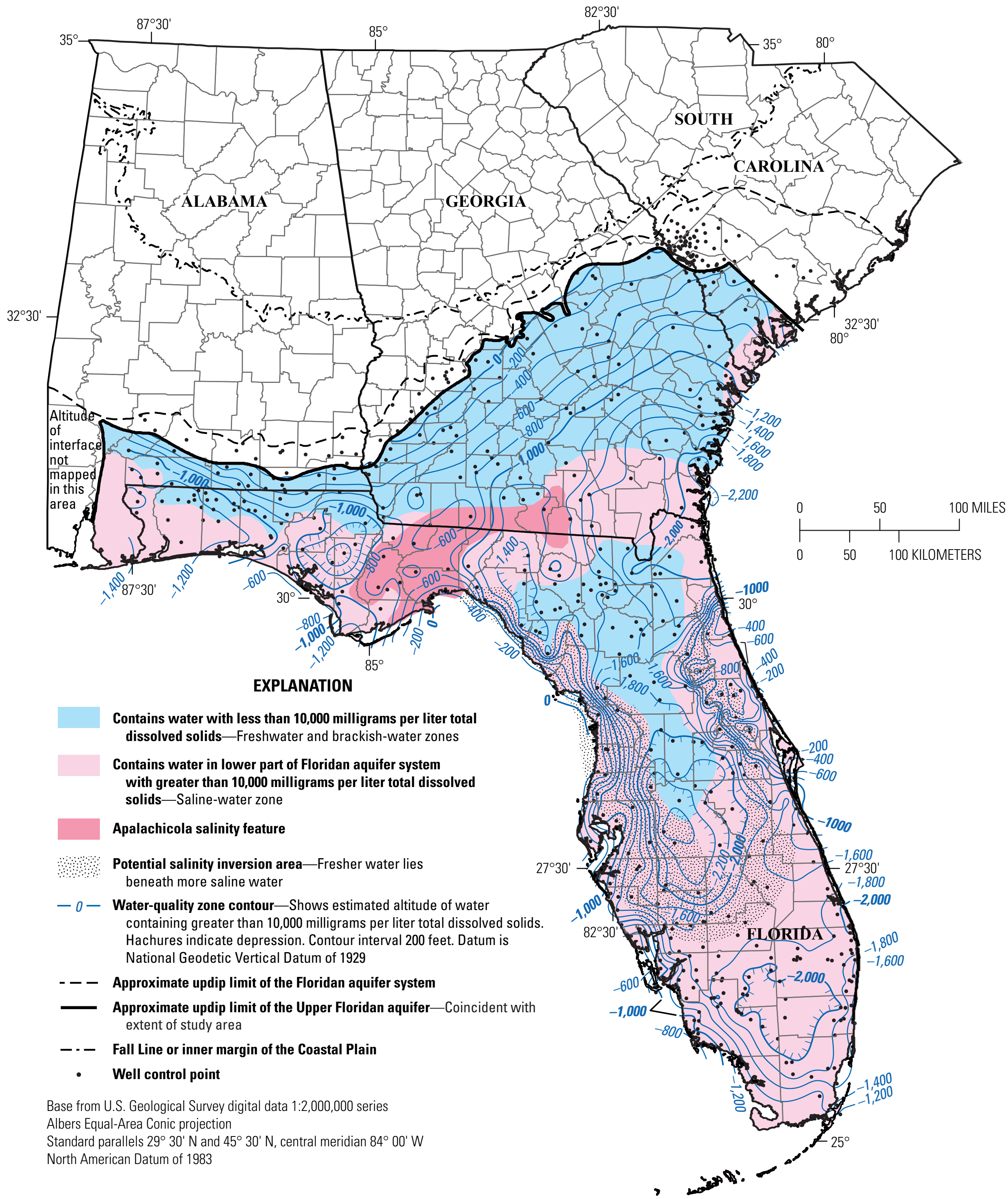


Figure 10. Estimated altitude of water containing greater than 10,000 milligrams per liter total dissolved solids within the Floridan aquifer system, southeastern United States (modified from Williams and Kuniansky, 2015).

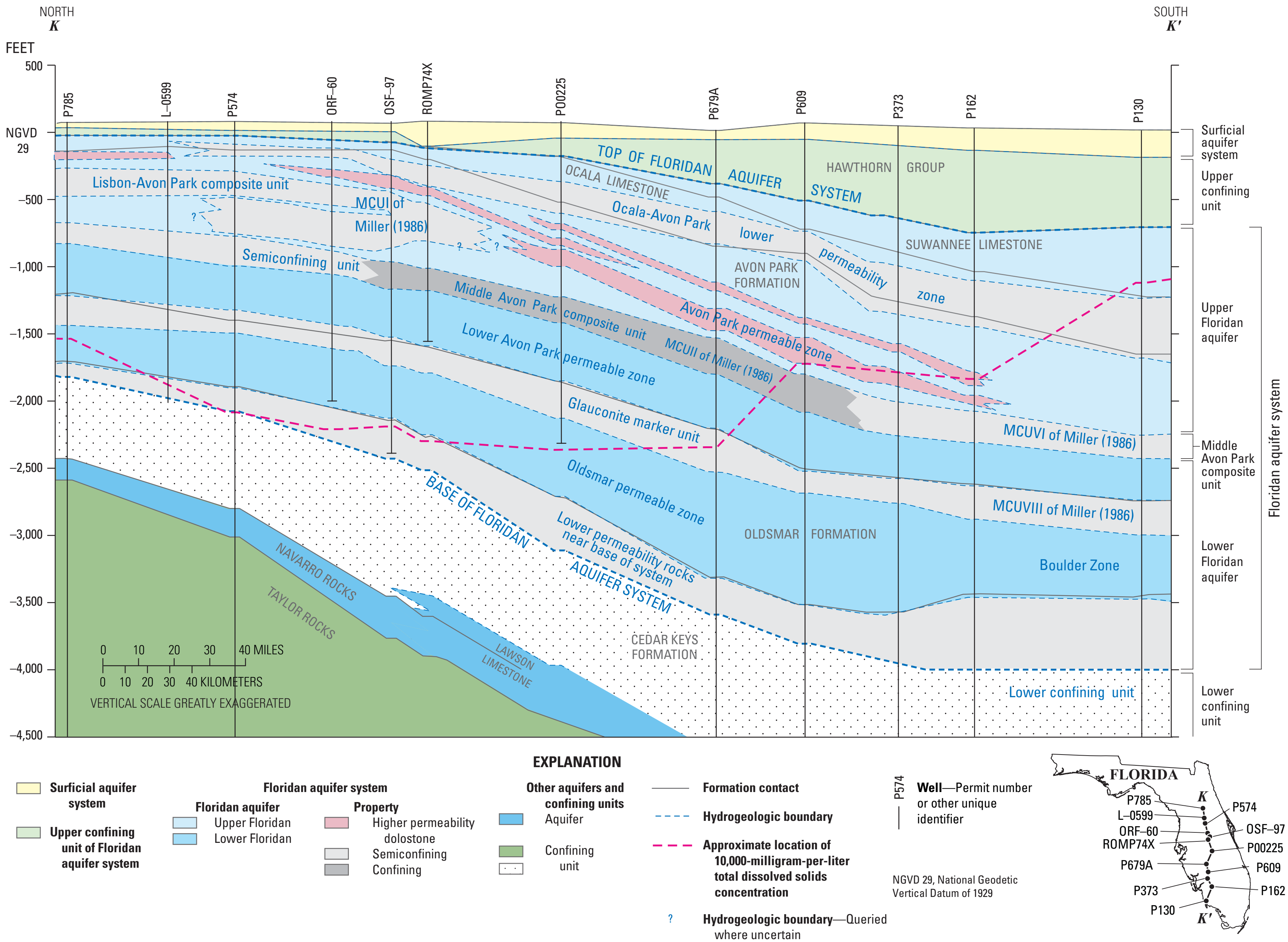


Figure 11. Generalized north to south hydrogeologic cross section *K–K′* in peninsular Florida, southeastern United States (modified from Williams and Kuniansky, 2015). The middle Avon Park composite unit separates the Upper and Lower Floridan aquifers along this cross section. The Lisbon-Avon Park composite unit is used to separate the Upper and Lower Floridan aquifers in regions to the north of this cross section.

In the previous framework published in Miller (1986), the entire Floridan aquifer system was designated as the Upper Floridan aquifer if no numbered confining unit was present. Where more than one numbered confining unit was present, the Floridan aquifer system was split into the Upper Floridan aquifer and Lower Floridan aquifer by using the least permeable unit as determined by Miller (1986). The disadvantage of this method was that detailed local mapping resulted in inconsistencies or ambiguity in the placement of time stratigraphic units in either the Upper Floridan aquifer or the Lower Floridan aquifer. In the revised framework (Williams and Kuniansky, 2015), the use of the three mappable lithostratigraphic units allows for consistency in subdividing the Floridan aquifer system into the Upper Floridan aquifer and Lower Floridan aquifer throughout the regional system. Older stratigraphic units become part of the Upper Floridan aquifer in central and south Florida. The two composite units, the middle Avon Park composite unit and Lisbon-Avon Park composite unit, do not confine the system everywhere, and regions within each unit having hydraulic properties similar to adjacent aquifers are delineated in Williams and Kuniansky (2015). The revised framework allows for finer delineation of permeability variations within the Floridan aquifer system than previously possible, which may be necessary for improved simulation of groundwater and surface-water interaction, saltwater intrusion, and offshore movement of fresh groundwater.

The Gulf Trough is a low-permeability structural feature that trends northeast to southwest from east-central Georgia to near the southwestern corner of Georgia (fig. 7). The Gulf Trough feature consists of an elongated, depressed area (submarine valley, strait, graben complex, syncline, or solution valley) that was infilled with finer grained, lower permeability sediment (Patterson and Herrick, 1971). This low-permeability feature has a great effect on groundwater flow within the Floridan aquifer system, especially in central and southwestern Georgia (Kellam and Gorday, 1990), where it creates a steep head gradient normal to its major axis that is evident on all potentiometric maps of the area (for example, Bush and others, 1987; Kinnaman and Dixon, 2011; pl. 1).

Parts of the Floridan aquifer system contain saline water, primarily in deeper parts of the aquifer system, but also in shallower parts near the coast (fig. 10) (Williams and Kuniansky, 2015). The Floridan aquifer system is bounded by saltwater in the Atlantic Ocean to the east and in the Gulf of Mexico to the west; some of this saltwater has migrated inland because of decreased groundwater levels in the aquifer caused by groundwater withdrawals. The carbonate rocks that form the aquifer were deposited in a marine or nearshore environment, resulting in trapped saline connate water in some parts of the aquifer system (Miller, 1986; Williams and Kuniansky, 2015).

Bush and Johnston (1988) assumed that the freshwater interface is stable, exists at depth, and rises seaward as freshwater floats buoyantly above the more dense saline water. This traditional interpretation of the interface holds true for much of the coastal area of the Floridan aquifer system, whereas in other areas the location of the interface is complicated by the generally horizontal zones of rocks with distinctly different permeability. Johnston and others (1982) mapped an offshore area of freshwater in Georgia between Brunswick and Savannah, where land-surface altitude in the updip recharge area is greater than 400 ft and downdip flow is not obstructed by the lower permeability sediments of the Gulf Trough. Williams and Kuniansky (2015) mapped areas where freshwater is present in deeper permeable zones beneath saline water (potential salinity inversion area shown on fig. 10). Freshwater is present across the entire thickness of the Floridan aquifer system within northern inland areas of peninsular Florida (beneath the central uplands in central Florida where the aquifer is unconfined and thinly confined) and part of extreme southern Georgia north of Valdosta (fig. 1). In the updip part of the system, freshwater is present across the vertical extent of the Floridan aquifer system in Alabama and Georgia, where direct recharge occurs in unconfined and thinly confined areas. The thickness of the freshwater part of the Floridan aquifer system ranges from 0 ft along the coast in east-central and west-central Florida and in updip areas where the Floridan aquifer system is thin to 2,600 ft in central Florida where the Floridan aquifer system is thick (figs. 12 and 13).

In extreme southwestern Georgia and the east-central portion of the Florida panhandle, Williams and Kuniansky (2015) informally named an area where brackish and saline water are present as the “Apalachicola salinity feature” (fig. 10), which may be incompletely flushed or trapped connate water within an area associated with fine-grained sediments of the Southwest Georgia embayment (fig. 7). The feature is merged with a newly mapped brackish to saline-water zone, which is also associated with low-permeability evaporitic rocks near the base of the aquifer system near Valdosta, Ga.

The transmissivity of the Upper Floridan aquifer ranges from 8 to 9,300,000 feet squared per day (ft^2/d) (median of 27,000 ft^2/d and standard deviation of 370,000 ft^2/d; Kuniansky and Bellino, 2012) because of its highly conductive network of dissolution features. The updated transmissivity map of the Upper Floridan aquifer, which includes the full thickness of the Floridan aquifer system where the middle confining units are leaky and the locations of first-magnitude springs, is shown in figure 13. Areas of relatively high transmissivity are present where the freshwater part of the system is thick or where the system is unconfined and karstification has increased secondary porosity features, such as first-magnitude springs. Transmissivity is generally lower along the Gulf Trough and Southwest Georgia embayment (figs. 7 and 13), where lower permeability sediments are present, and in south Florida, where the freshwater section thins.

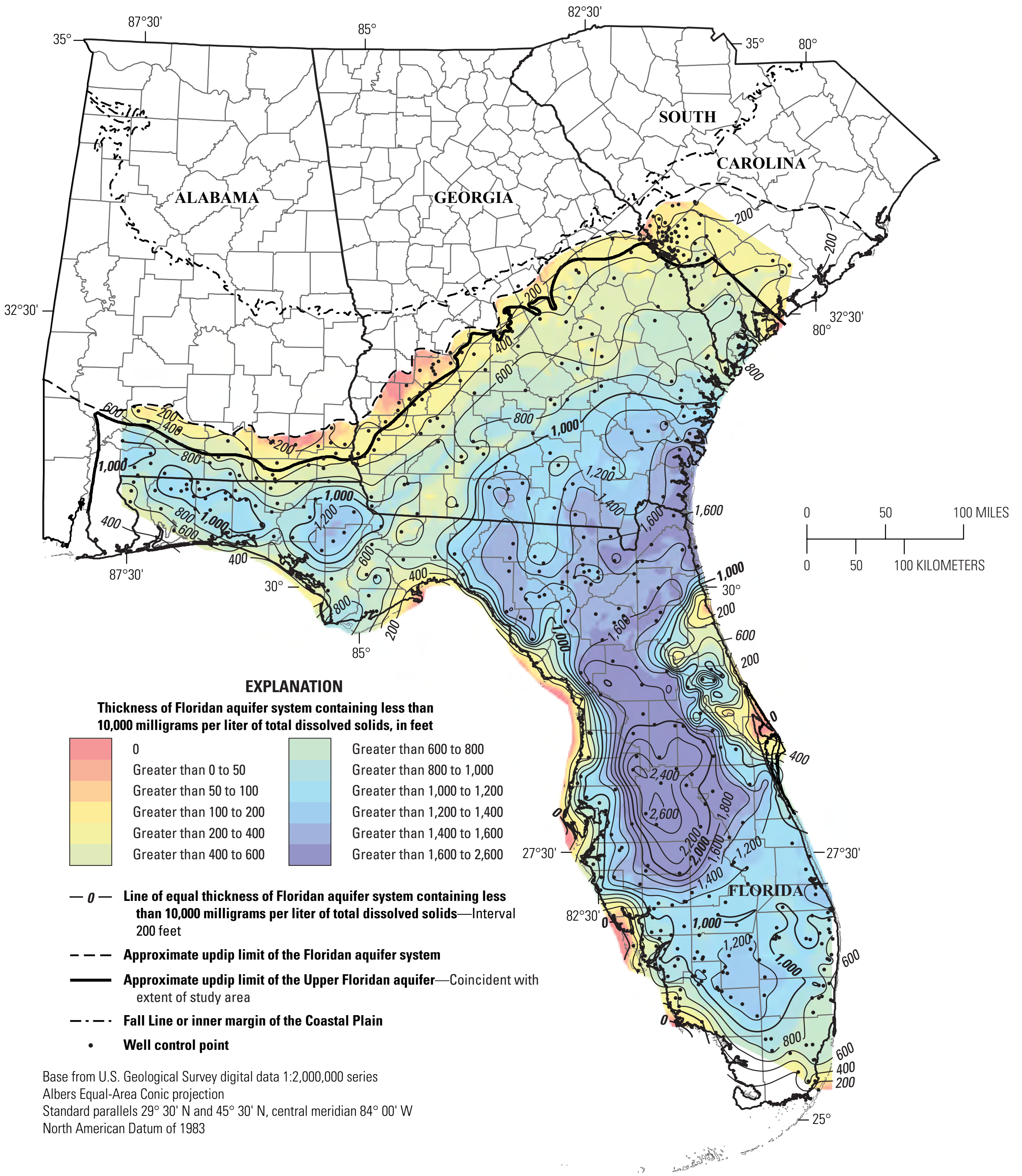


Figure 12. Thickness of Floridan aquifer system containing less than 10,000 milligrams per liter of total dissolved solids, southeastern United States (modified from Williams and Kuniansky, 2015).

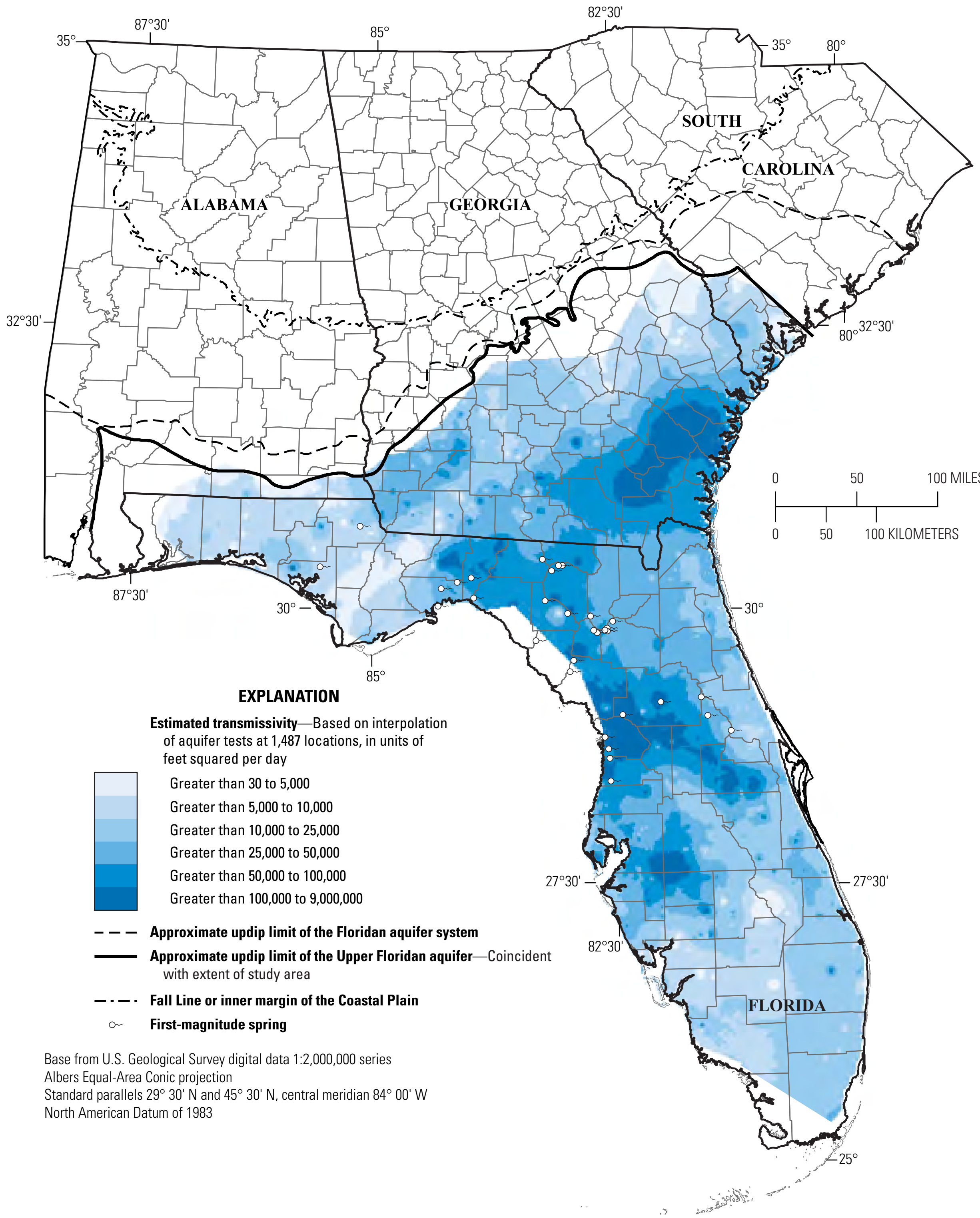


Figure 13. Estimated transmissivity of the Upper Floridan aquifer and locations of first-magnitude springs, southeastern United States (modified from Kuniansky and others, 2012; Williams and Kuniansky, 2015).

Conceptual Groundwater Flow System

The conceptual groundwater flow system presented herein is a combination of the hydrogeologic framework and a representation of how water moves into and out of the system. The current conceptual groundwater flow system was developed for the Floridan aquifer system and adjacent systems partly on the basis of previously published USGS RASA studies (Sun and others, 1997), specifically many of the potentiometric maps and the modeling efforts in these studies, and partly on the basis of the recent update of the hydrogeologic framework by Williams and Kuniansky (2015). This section provides background concerning the current understanding of how water enters and exits the system by summarizing previous work, including the predevelopment and 1980 groundwater budgets presented in Bush and Johnston (1988) and more recent potentiometric maps and hydrographs.

Factors that influence circulation of groundwater within the Floridan aquifer system are the altitude of the updip direct-recharge area and its distance to and altitude of discharge areas; degree of confinement; changes in transmissivity within the Floridan aquifer system; terrain, including uplands and lowlands or incision of streams; karst areas with internal subsurface drainage; groundwater withdrawals; and the presence of hydraulically connected saline groundwater. These factors are highly variable across the Floridan aquifer system extent, and for this reason, Bush and Johnston (1988) subdivided the system into the following eight hydrogeologically distinct subregional groundwater basins delineated on the basis of the estimated predevelopment (circa 1880s) potentiometric surface: (1) Panhandle; (2) Dougherty Plain-Apalachicola; (3) Thomasville-Tallahassee; (4) Southeast Georgia-Northeast Florida-South South Carolina; (5) Suwannee; (6) West-central Florida; (7) East-central Florida; and (8) South Florida (fig. 14). The estimated predevelopment potentiometric surface is a composite of several maps developed over many years, the details of which are documented in Johnston and others (1980). This surface reflects the system in dynamic equilibrium, where natural recharge is balanced by natural discharge, and thus also reflects the natural circulation pattern of groundwater based only upon the effects of geology and terrain. Bush and Johnston (1988) estimated the predevelopment discharge for each groundwater basin (fig. 14) by using a numerical model, noting that their simulated values are lower than independently estimated values because of the large scale of their model grid and inability to simulate local flow systems.

Bush and Johnston (1988) divided total discharge into two categories: (1) discharge to major springs and surface-water bodies (by means of a direct connection between the Floridan aquifer system and surface-water features) and (2) diffuse discharge (by means of upward leakage through adjacent units to low-lying areas) (fig. 14). For basins in unconfined or thinly confined areas, namely Dougherty Plain-Apalachicola, Thomasville-Tallahassee, Suwannee, and West-central Florida, total discharge is relatively large and dominated by flow to springs and surface-water bodies. For those basins in the more confined areas, namely Southeast Georgia-Northeast Florida-South South Carolina and East-central Florida, there is less total discharge from the system, and although springs and surface-water bodies are still the primary avenues for discharge, diffuse discharge composes a larger percentage of total discharge. For the South Florida basin, all discharge is diffuse because the system is deeply buried and thickly confined and springs are absent. Additionally, the overall predevelopment discharge from the South Florida basin is small because the freshwater part of the system is very thin (Bush and Johnston, 1988).

Groundwater withdrawals from the Floridan aquifer system have contributed to increases in the total flow through the system. Bush and Johnston (1988) provided a 1980 potentiometric map of the Floridan aquifer system and, through simulation, computed a 1980 water budget for the same groundwater basins. The simulated predevelopment and 1980 discharge from the steady-state model of Bush and Johnston (1988) is shown in table 2. In a steady-state model, there is no change in storage, and recharge equals discharge. After development, there was a 12-percent increase in total flow through the system because of groundwater withdrawals from pumpage, which (1) lowered groundwater levels and induced more recharge and leakage to the Floridan aquifer system from adjacent aquifers and (2) reduced diffuse upward leakage and discharge to springs. Table 3 summarizes reductions to spring and stream discharge, reductions in upward diffuse discharge, and increases in recharge and leakage to satisfy simulated groundwater withdrawals. It should be noted that the steady-state assumption does not allow for some of the groundwater withdrawals to be supplied by a change in storage; however, change in storage in the Floridan aquifer system is small (Konikow, 2013, 2015). Total simulated withdrawals in 1980 composed 18 percent of discharge from the Floridan aquifer system (compare total discharge in table 2 with total groundwater withdrawals from table 3).

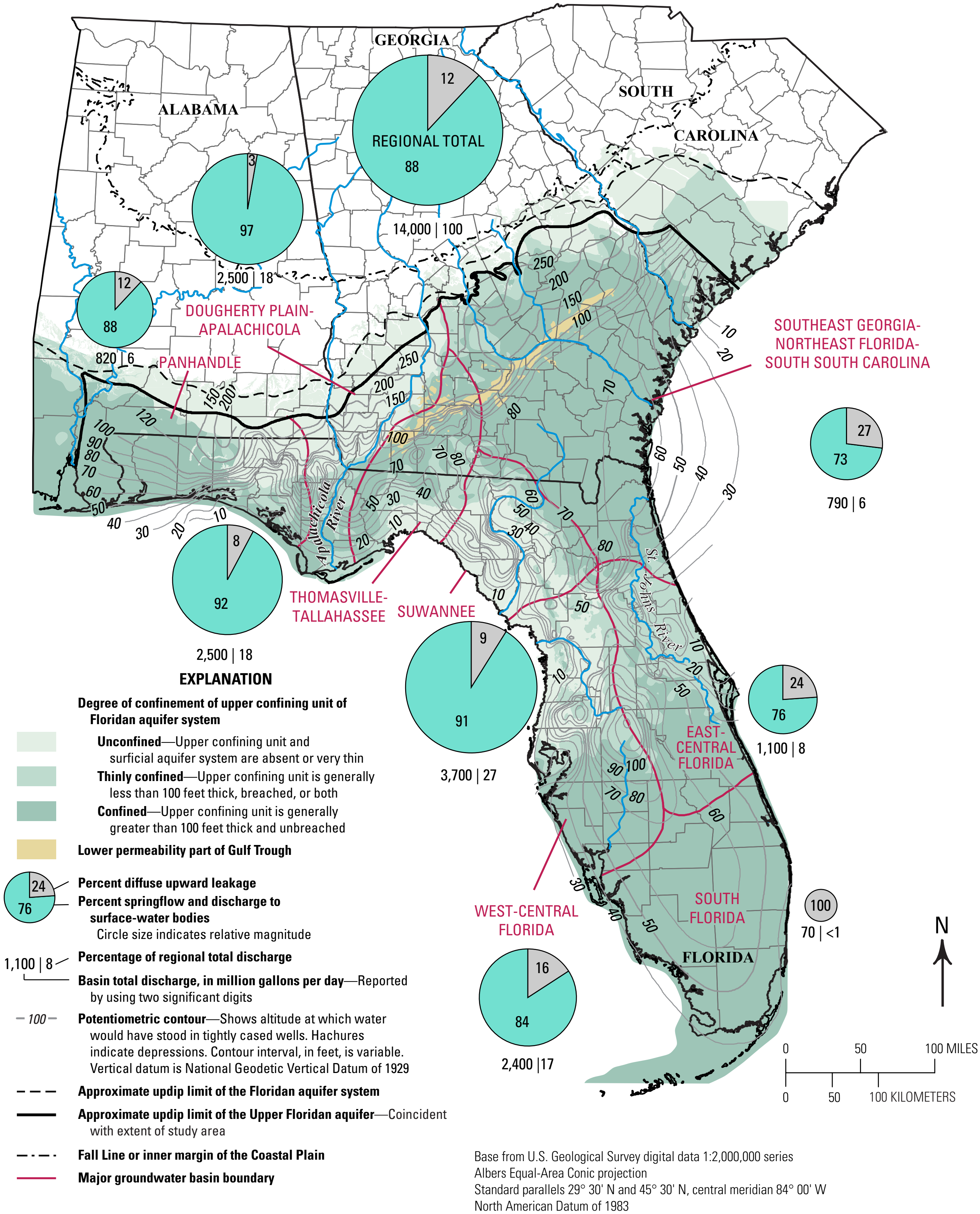


Figure 14. Estimated predevelopment potentiometric surface and discharge from major groundwater basins of the Floridan aquifer system, southeastern United States (modified from Bush and Johnston, 1988; Johnston and others, 1980).

Table 2. Comparison of predevelopment and 1980 simulated discharge from steady-state simulation of the Floridan aquifer system by subregion in the study area, southeastern United States.

[mi^2, square mile; ft^3/s, cubic foot per second; Mgal/d, million gallons per day; --, not applicable. Modified from Bush and Johnston, 1988, figs. 22 and 32; numbers may not sum to equivalent totals because of independent rounding; reported precision does not imply accuracy]

Subregion	Area, in mi^2	Predevelopment				1980					Difference
		Percent springflow and discharge to surface-water bodies	Percent diffuse upward leakage	Total discharge, in ft^3/s	Total discharge, in Mgal/d	Percent springflow and discharge to surface-water bodies	Percent diffuse upward leakage	Percent groundwater withdrawals	Total discharge, in ft^3/s	Total discharge, in Mgal/d	Percent change in total discharge
Groundwater basin											
Panhandle	10,029	88	12	1,265	818	87	3	10	1,290	834	+2.0
Dougherty Plain-Apalachicola	6,641	97	3	3,905	2,524	86	3	11	4,170	2,695	+6.8
Thomasville-Tallahassee	6,828	92	8	3,850	2,488	88	8	4	3,900	2,521	+1.3
Southeast Georgia-Northeast Florida-South South Carolina	26,338	73	27	1,225	792	44	4	52	1,995	1,289	+62.9
Suwannee	6,565	91	9	5,775	3,732	87	9	4	5,750	3,716	-0.4
West-central Florida	10,675	84	16	3,790	2,450	61	8	31	4,915	3,177	+29.7
East-central Florida	9,879	76	24	1,640	1,060	59	10	31	1,925	1,244	+17.4
South Florida	13,936	--	100	105	68	--	24	76	170	110	+61.9
Floridan aquifer system extent	**90,892**			**21,555**	**13,931**				**24,115**	**15,586**	**+11.9**

Table 3. Sources of water supplying simulated 1980 pumpage from the Floridan aquifer system by subregion in the study area, southeastern United States.

[Mgal/d, million gallons per day; ft^3/s, cubic foot per second; --, not applicable. Modified from Bush and Johnston, 1988, fig. 33; reported precision does not imply accuracy]

Subregion	Percent from decreased springflow and discharge to surface-water bodies	Percent from reduced upward leakage	Percent from induced recharge and leakage	Groundwater withdrawals, in Mgal/d	Groundwater withdrawals, in ft^3/s
Groundwater basin					
Panhandle	--	38	62	83	128
Dougherty Plain-Apalachicola	40	2	58	300	464
Thomasville-Tallahassee	68	3	29	110	170
Southeast Georgia-Northeast Florida-South South Carolina	6	24	70	645	998
Suwannee	100	--	--	150	232
West-central Florida	12	15	73	985	1,524
East-central Florida	12	30	58	395	611
South Florida	--	50	50	85	132
Upper Floridan aquifer extent				**2,753**	**4,260**

The most recent potentiometric map of the Floridan aquifer system represents conditions in May–June 2010 (Kinnaman and Dixon, 2011), which is updated herein with contours added in south Florida by calculation of equivalent freshwater head where water-quality data were available (pl. 1 and app. 1; Kuniansky and others, 2017). Although groundwater development captures some of the water that would naturally discharge from the system and alters the potentiometric surface, boundaries of the major groundwater basins delineated from the estimated predevelopment map generally reflect conditions in 2010 as well. Maps showing change in groundwater level for the Floridan aquifer system (fig. 15) were derived by computing the difference between maps of groundwater levels for predevelopment and 1980 and for predevelopment and 2010. Large cones of depression are present on both groundwater-level change maps in the Savannah-Hilton Head Island area in Georgia and South Carolina, on the west coast of Florida near Tampa, and in the panhandle of Florida at Fort Walton Beach. The areal extent of lowered groundwater levels has increased from 1980 to 2010, and there are new areas of drawdown in southeast Alabama and southwest Georgia (pl. 1); however, groundwater levels in the center of the cone of depression in Savannah, which were more than 110 ft below the National Geodetic Vertical Datum of 1929 (NGVD 29) in 1980, increased by as much as 20–30 ft in some areas in 2010 because the city reduced withdrawals and increased its use of treated surface water (Georgia Department of Natural Resources, 2006).

Recharge to and discharge from the Floridan aquifer system occur through a variety of pathways, and the most dominant characteristic of the system controlling these processes is the degree of confinement (Bush and Johnston, 1988; Williams and others, 2011; Williams and Kuniansky, 2015). Recharge from precipitation enters the system, and aggressive dissolution of carbonates occurs where the Floridan aquifer system is unconfined or thinly confined (Miller, 1999). The resulting karst features allow for rapid infiltration of water into the Floridan aquifer system during rainy periods although there can be short periods of drawdown during drier months. Groundwater hydrographs generally indicate greater rates of regionally extensive, long-term removal of groundwater from storage in confined areas than in unconfined or thinly confined areas (fig. 16). Changes in groundwater levels were evaluated by using a linear least-squares regression; significance of trends was determined on the basis of the 99-percent confidence interval around the slope of the regression line. Statistically significant trends (99-percent confidence level) were identified for all but the hydrograph for Lake Alfred deep well near Lake Alfred, Fla. (fig. 16*C*). In the more confined parts of the Floridan aquifer system, permanent removal of groundwater from storage has occurred, as indicated by long-term declines in groundwater levels, with rates of groundwater-level declines ranging from -0.06 to -0.68 foot per year (ft/yr) (figs. 15 and 16) (Williams and others, 2011). Significant long-term increases in groundwater levels were indicated at four wells,

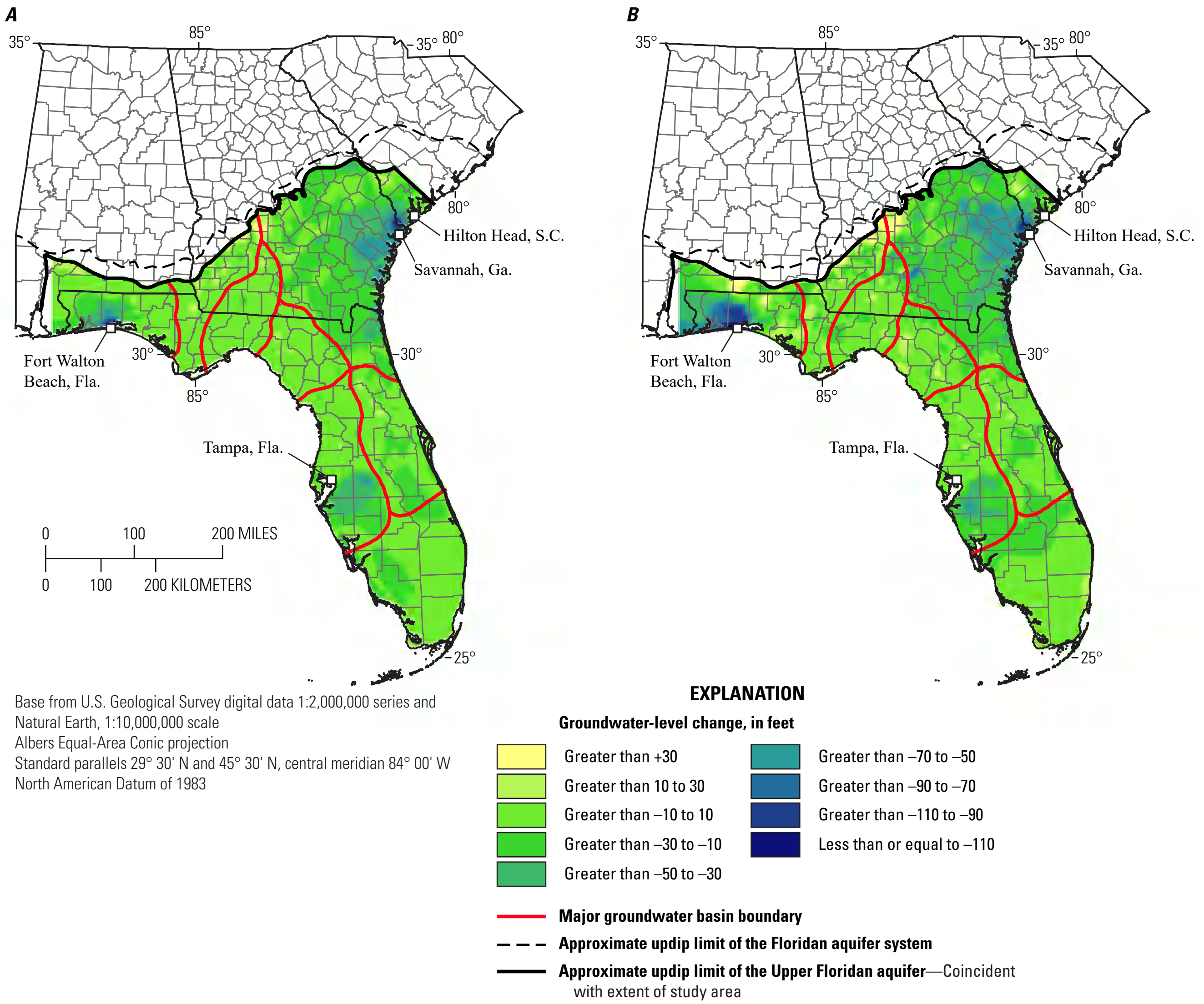


Figure 15. Groundwater-level change in the Floridan aquifer system from estimated predevelopment to *A*, May 1980 and *B*, May–June 2010, southeastern United States.

with rates as high as 0.15 and 0.14 ft/yr for two wells adjacent to the coastline near Brunswick and Fernandina Beach, Ga., respectively (fig. 16*B*). These groundwater-level increases are attributable to decreased groundwater withdrawals when a paper mill in St. Marys, Ga., was shut down in October 2002, which coincided with the end of a prolonged drought (Cherry and others, 2011; Peck and others, 2005). Where the Floridan aquifer system is unconfined and water-table conditions prevail, the Floridan aquifer system probably has a larger storage coefficient because of gravity drainage than in more confined areas, which may also contribute to observed differences between long-term hydrographs (fig. 16).

Groundwater Basins

The eight subregional groundwater basins delineated by Bush and Johnston (1988) are hydrogeologically distinct regions of the Floridan aquifer system whose boundaries may shift over time because of spatial and temporal differences in precipitation and groundwater withdrawals. In this section, characteristics of these basins are briefly discussed.

A

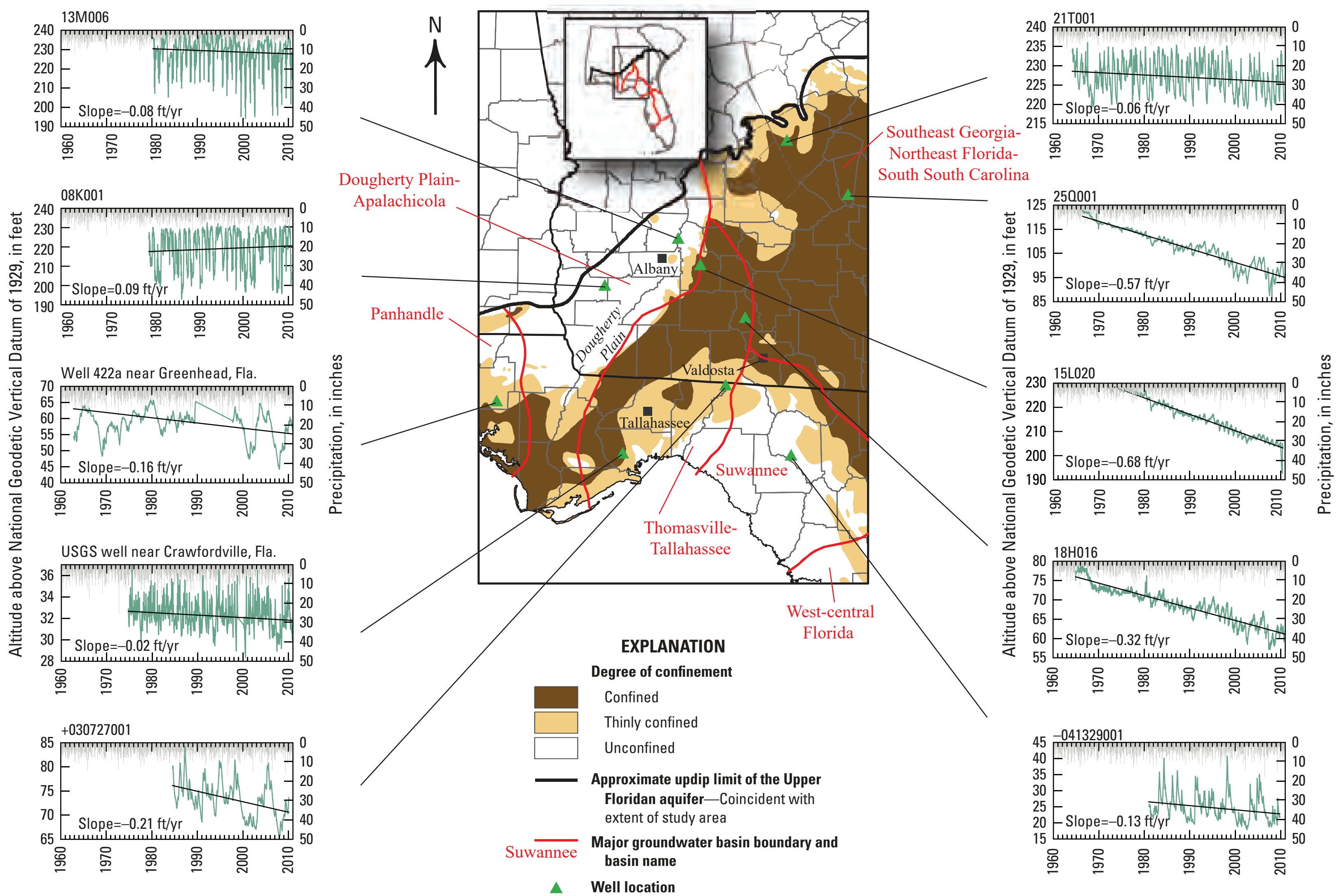


Figure 16. Groundwater-level hydrographs for selected wells in the Floridan aquifer system and degree of confinement for the *A*, north-central, *B*, northeast, and *C*, southern parts of the study area, southeastern United States. [ft/yr, foot per year]

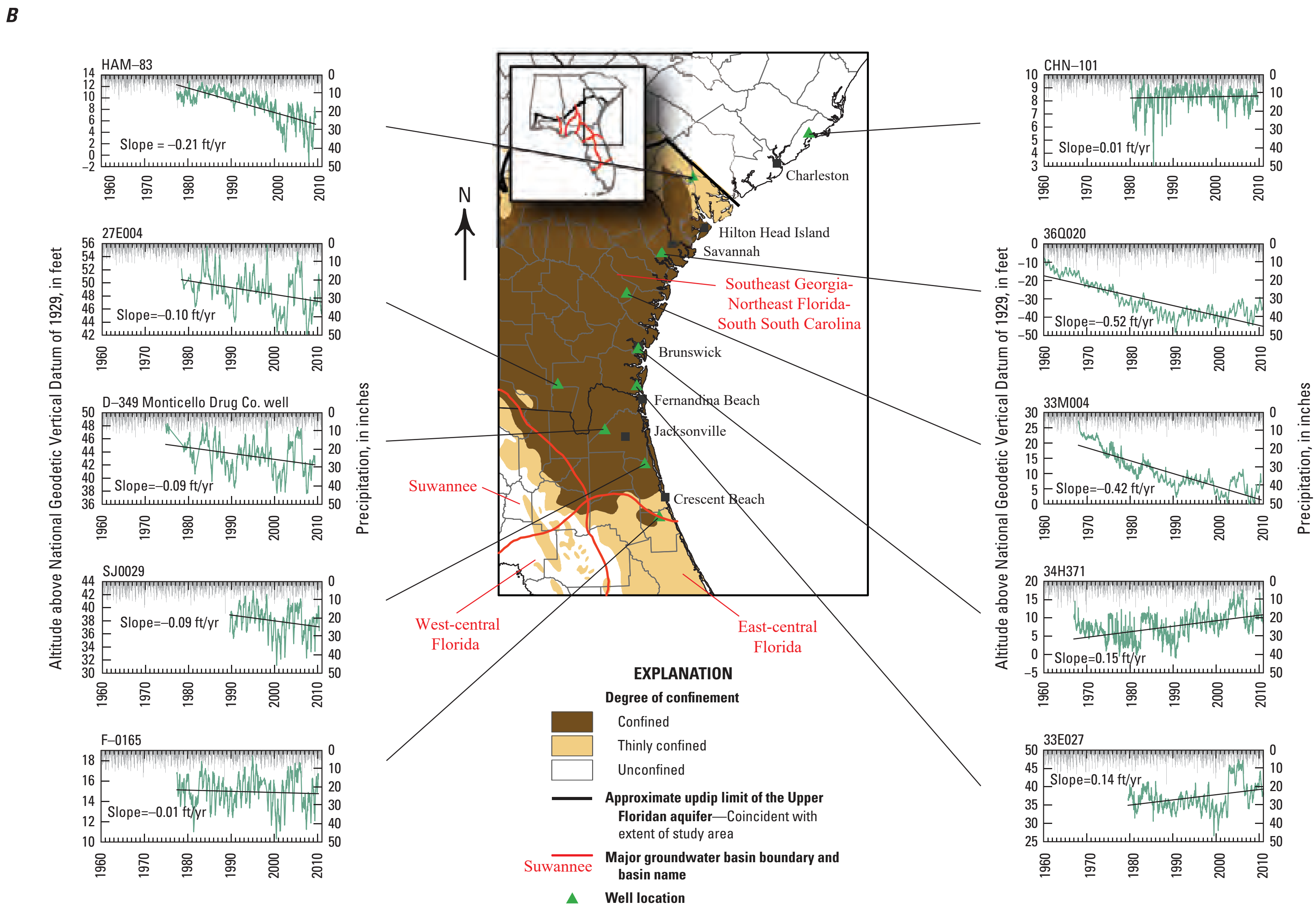


Figure 16. Groundwater-level hydrographs for selected wells in the Floridan aquifer system and degree of confinement for the *A*, north-central, *B*, northeast, and *C*, southern parts of the study area, southeastern United States. [ft/yr, foot per year]—Continued

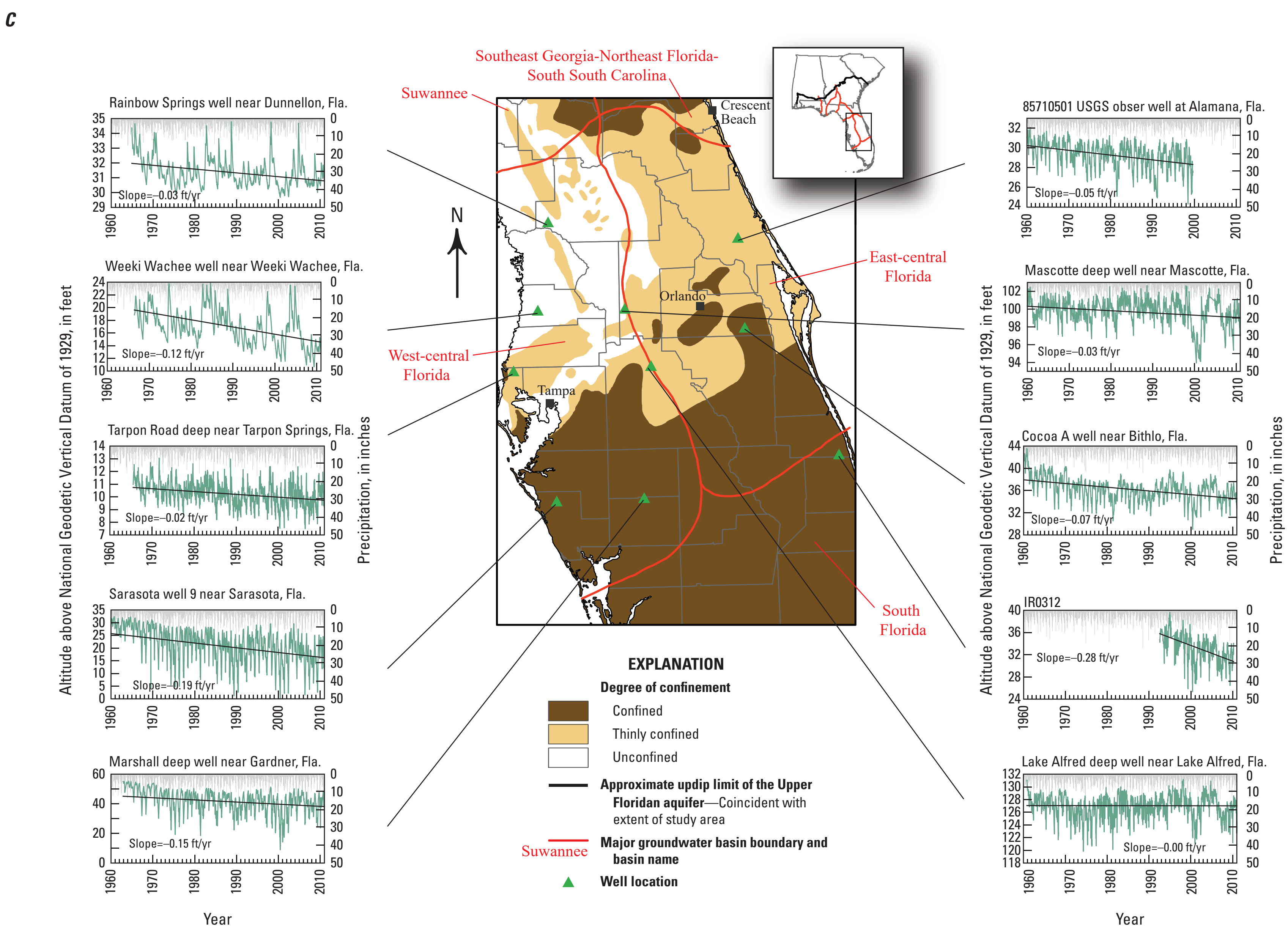


Figure 16. Groundwater-level hydrographs for selected wells in the Floridan aquifer system and degree of confinement for the *A*, north-central, *B*, northeast, and *C*, southern parts of the study area, southeastern United States. [ft/yr, foot per year]—Continued

Panhandle Groundwater Basin

Flow in the Panhandle groundwater basin, which includes the panhandle of Florida and part of southwest Alabama (pl. 1 and fig. 14), is influenced by the degree of confinement, changes in transmissivity, terrain, groundwater withdrawals, and the presence of saline water (Bush and Johnston, 1988; Miller, 1986; Williams and Kuniansky, 2015). The Floridan aquifer system is mostly confined in the groundwater basin and dips steeply toward the Gulf of Mexico. Freshwater is prevalent in the shallow updip part of the Floridan aquifer system, whereas the deeper downdip parts are mostly saline. Additionally, transmissivity decreases westward in the groundwater basin (fig. 13) as the rocks grade into finer grained clastic rocks from lower permeability carbonate rocks. Low transmissivity is indicated by the steep hydraulic gradients in this area (pl. 1 and fig. 14). The terrain is dissected by streams flowing to the Gulf of Mexico, incising the surficial aquifer system, but not the Floridan aquifer system. Curved potentiometric contours, however, indicate that there is some groundwater discharge from the Floridan aquifer system toward lower lying streams (pl. 1 and fig. 14). The upper confining unit is generally thick in this area and provides a large degree of hydraulic separation between the Floridan aquifer system and the overlying surficial aquifer system. Confinement of the Floridan aquifer system has allowed freshwater to extend offshore, as indicated by artesian heads that are shown as being well above sea level offshore in figure 14. Groundwater development in the Fort Walton Beach, Fla. (fig. 15), area has led to a substantial cone of depression in the potentiometric surface of the Floridan aquifer system (pl. 1 and fig. 14), reducing heads and altering flow within the system. Potentiometric heads, below sea level in some areas since the mid-1950s, have created the potential for saltwater intrusion in coastal areas (Barraclough and Marsh, 1962; HydroGeoLogic, Inc., 2005, 2007; Ryan and others, 1998)1962; HydroGeoLogic, Inc., 2005; HydroGeoLogic, Inc., 2007; Ryan and others, 1998. The Bucatunna clay confining unit divides the Floridan aquifer system into the Upper Floridan aquifer and Lower Floridan aquifer in this area and provides hydraulic separation between the two aquifers, except along its updip extent in the northern part of the groundwater basin where it grades into the main body of the Floridan aquifer system (Williams and Kuniansky, 2015). Potentiometric heads within the Lower Floridan aquifer were reported to be approximately 5 ft above sea level, whereas potentiometric heads within the Upper Floridan aquifer were reported to be approximately 50 ft below sea level, indicating a high degree of separation in coastal areas (Maslia and Hayes, 1988).

Dougherty Plain-Apalachicola Groundwater Basin

The Floridan aquifer system is unconfined to thinly confined in the Dougherty Plain-Apalachicola groundwater basin (pl. 1 and figs. 7 and 14), and flow in the system is dominated by degree of confinement, terrain, and karst features (Bush and Johnston, 1988; Miller, 1986; Williams and Kuniansky, 2015). Although groundwater withdrawals for agricultural irrigation are prevalent in this area (Bellino, 2017), the relatively high transmissivity (Kuniansky and others, 2012; Kuniansky and Bellino, 2012) and unconfined nature of the system (fig. 7) have prevented substantial long-term drawdown. The Dougherty Plain feature and its extension in Florida, the Marianna Lowlands (fig. 1), formed as a result of carbonate dissolution at land surface. This lower altitude, relatively level karst plain contains numerous circular depressions formed by sinkholes, and older ones are filled with lower permeability sediments forming ponds that exist year-round. The younger sinkholes provide recharge to the Floridan aquifer system and remain dry (Hendricks and Goodwin, 1952). The area contains subsurface internal drainage, which is typical of a karst plain and indicated by a lack of flowing tributaries to the Flint River (fig. 1) (LeGrand and Stringfield, 1966; Torak and Painter, 2006). In many places, a residuum consisting of sand and clay formed by the weathering and dissolution of the surficial limestone ranges from a few feet to 150 ft thick (Torak and Painter, 2006). For areas where the residuum is less than 10 ft thick, Jones and Torak (2006) assumed that direct recharge from precipitation occurs, and in areas of thick residuum, groundwater can be perched in the residuum and leak vertically into the Floridan aquifer system. In the Dougherty Plain part of the groundwater basin, there is a direct hydraulic connection between the Upper Floridan aquifer and surface water (Jones and Torak, 2006). Hydrographs from wells in the Dougherty Plain indicate both slight long-term (1980–2010) decreases (-0.08 ft/yr at well 13M006 [statistically significant on the basis of the 99-percent confidence interval]) and increases (+0.09 ft/yr at well 08K001 [statistically significant on the basis of the 99-percent confidence interval]) in groundwater levels (fig. 16*A*). The Apalachicola part of this groundwater basin extends along a divide mimicking the surface-water divide of the Apalachicola River part of the Apalachicola-Chattahoochee-Flint River Basin in Florida (fig. 1). This southernmost part of the groundwater basin is not part of the karst plain, so the Floridan aquifer system is confined here; however, the Apalachicola River is incised into the surficial aquifer system, creating a north-south linear topographic low. The predevelopment potentiometric map (fig. 14) indicates groundwater discharge from the Floridan aquifer system to the Apalachicola River in this confined part of the groundwater basin. Groundwater discharge to the Apalachicola River is also indicated on the May–June 2010 potentiometric map (pl. 1) by the upstream bending of potentiometric contours along the course of the river. The thinning of the Floridan aquifer system and thus lower transmissivity in the updip area are indicated by the steeper gradients in the updip limit in this groundwater basin on the present-day surface (pl. 1 and figs 13 and 14).

Thomasville-Tallahassee Groundwater Basin

Flow in the Thomasville-Tallahassee groundwater basin is dominated by degree of confinement, changes in transmissivity, terrain, and karst features (Bush and Johnston, 1988; Miller, 1986; Williams and Kuniansky, 2015). The groundwater basin extends north from the Gulf of Mexico near Tallahassee, Fla., to near Albany, Ga., and crosses the Gulf Trough, as well as an escarpment that formed above the less-permeable sediments within the Gulf Trough (pl. 1 and figs. 1, 7, and 14). Most of the groundwater basin is confined, and hydrographs indicate groundwater-level declines of between -0.32 and -0.68 ft/yr in the northern and eastern parts of the basin and -0.02 ft/yr in the thinly confined southern part of the basin (fig. 16*A*). The terrain is variable, with dissected hills in upland areas to the north and a relatively flat karst plain to the south that parallels the coast. The karst plain is in a thinly confined to unconfined area known for its large springs, such as Wakulla Springs, Fla., which provides most of the flow to the Wakulla River, Fla. (fig. 1) (Torak and others, 2010). On potentiometric maps of the Floridan aquifer system (for example, Johnston and others, 1980; Kinnaman and Dixon, 2011; pl. 1; fig. 14), contours are closely spaced along the Gulf Trough, indicating the lower transmissivity of the Floridan aquifer system along this feature. Groundwater flow is generally southward to the coast (pl. 1). Recharge to the Floridan aquifer system occurs by means of leakage from the surficial aquifer system through the upper confining unit in the confined area and by direct recharge into sinks within the karst plain or thinly confined area (Torak and others, 2010). Most discharge is to springs and surface-water bodies (figs. 13 and 14 and table 2).

Southeast Georgia-Northeast Florida-South South Carolina Groundwater Basin

Flow in the Southeast Georgia-Northeast Florida-South South Carolina groundwater basin is dominated by the altitude of recharge and discharge areas, degree of confinement, heterogeneity in transmissivity, groundwater withdrawals, and the presence of saline water (Bush and Johnston, 1988; Miller, 1986; Williams and Kuniansky, 2015). The groundwater basin is confined over nearly its entire extent (pl. 1 and figs. 7 and 14), and the overall flow through the predevelopment system is less than in unconfined or thinly confined groundwater basins (figs. 7 and 14 and table 2). The Coastal Plain is dissected by streams within the extent of this groundwater basin, creating rolling hills inland and flatter, lower terrain toward the coast. The Gulf Trough extends through the northwestern part of this area, and the hydrologic effect of the Gulf Trough is indicated by the steep hydraulic gradient across this feature (pl. 1 and figs. 7 and 14). Southeast of the Gulf Trough, however, the potentiometric surface is flat in the area of relatively higher transmissivity in southeastern Georgia (pl. 1 and figs. 13 and 14). The Gulf Trough does not extend through the entire northern part of the area and does not affect the potentiometric surface within South Carolina. The estimated predevelopment potentiometric surface (fig. 14) has smooth contours with no inflections related to topography or streams, as in the unconfined areas. The more recent surface, which has more data points, does indicate some inflection toward new pumping centers (pl. 1). Water enters the Floridan aquifer system by means of leakage from the surficial aquifer system through the upper confining unit and direct recharge in updip inland areas where the aquifer is unconfined. Diffuse upward leakage occurs in lowland areas along the coast and toward wells in developed areas. The land-surface altitude of the direct recharge area is more than 400 ft, and the system is fairly transmissive toward the coast where the entire aquifer thickens. The hydraulic gradient has pushed freshwater at least 55 mi offshore in the confined part of the system between Savannah and Brunswick, Ga. (Johnston and others, 1982). Most of the hydrographs shown in figure 16*A* and *B* indicate long-term declines in this confined part of the Floridan aquifer system; however, the hydrographs for wells 34H371 and 33E027 (fig. 16*B*) indicate substantial long-term increases in groundwater levels attributable to the shutdown of a paper mill in St. Marys, Ga., in October 2002, which was coincident with the end of a prolonged drought (Cherry and others, 2011; Peck and others, 2005).

Suwannee Groundwater Basin

The Suwannee groundwater basin lies mostly beneath an unconfined karst plain (pl. 1 and figs. 7 and 14), and flow is dominated by karst features (Bush and Johnston, 1988; Miller, 1986; Williams and Kuniansky, 2015). The groundwater basin lies southeast of the Thomasville-Tallahassee groundwater basin and southwest of the Southeast Georgia-Northeast Florida-South South Carolina groundwater basin. The northeastern boundary of the Suwannee groundwater basin parallels the Peninsular arch (fig. 7). Numerous first-, second-, and third-magnitude springs are present along the lower reaches of the Suwannee River and Santa Fe River (fig. 1), which are incised into the carbonates of the Floridan aquifer system (Grubbs and Crandall, 2007). Except for these rivers, much of this area is devoid of surface drainage, which is typical in a karst terrain having subsurface drainage. Potentiometric surface maps clearly indicate Floridan aquifer system discharge to both rivers (pl. 1 and fig. 14), and the study of Grubbs and Crandall (2007) indicated a strong hydraulic connection between the Floridan aquifer system and the rivers in this groundwater basin. Direct recharge occurs over the unconfined area. Most of the groundwater discharge is to the streams and springs, with diffuse discharge possibly to the coastal swamps (fig. 14 and table 2). A substantial decrease in groundwater levels of -0.13 ft/yr is indicated for well −041329001, located in the central part of this basin (fig. 16*A*), similar to trends in wells within the adjacent Thomasville-Tallahassee and Southeast Georgia-Northeast Florida-South South Carolina groundwater basins.

West-Central Florida Groundwater Basin

The West-central Florida groundwater basin lies south of the Suwannee groundwater basin and west of the East-central Florida groundwater basin, with the northeastern boundary also parallel to the Peninsular arch (pl. 1 and figs. 7 and 14). Flow in the West-central Florida groundwater basin is dominated by the degree of confinement, terrain, karst features, and groundwater withdrawals (Bush and Johnston, 1988; Miller, 1986; Williams and Kuniansky, 2015). The northern part of the groundwater basin is unconfined or thinly confined, and the southern part of the groundwater basin becomes confined as the Floridan aquifer system dips to the south. In the southern part of the groundwater basin, the intermediate aquifer system is present within the upper confining unit, and the surficial aquifer system overlies the intermediate aquifer system (fig. 6). The northern part of the groundwater basin is karstified and has high transmissivity and numerous first-magnitude springs (fig. 13). The overall estimated predevelopment discharge for this groundwater basin is smaller than that of the others having large unconfined areas, and a higher percentage of the discharge is diffuse (fig. 14 and table 2). Direct recharge occurs in the unconfined areas of the groundwater basin, and leakage between the Floridan aquifer system and the intermediate aquifer system or surficial aquifer system occurs in the confined areas. In the upland areas along the eastern boundary of the groundwater basin, leakage from the shallower aquifers recharges the Floridan aquifer system. Upward discharge occurs in the coastal swamps and wetlands under predevelopment and 2010 conditions (Bush and Johnston, 1988; Knochenmus, 2006; Miller, 1986; Williams and Kuniansky, 2015).

A regional potentiometric high along the eastern boundary of the West-central Florida groundwater basin drives flow from the uplands toward the coastal lowlands on both the predevelopment and 2010 surfaces (pl. 1 and fig. 14). Water levels in this groundwater basin show a downward trend; declines in confined areas of the system are greater than those in the unconfined and thinly confined areas (fig. 16*C*). Groundwater withdrawals in the groundwater basin, particularly in the greater Tampa Bay region (fig. 1), have had effects such as the drying of lakes, streams, and wetlands, as well as saltwater intrusion (Barcelo and others, 2003; Beach and Kelley, 1998; Dooris and others, 1990; Lee and others, 2009; Metz, 2011; Metz and Sacks, 2002; Rochow, 1998; Yager and Metz, 2004)1998; Dooris and others, 1990; Lee and others, 2009; Metz, 2011; Metz and Sacks, 2002; Rochow, 1998; Yager and Metz, 2004.

East-Central Florida Groundwater Basin

The East-central Florida groundwater basin lies east of the Peninsular arch and the West-central Florida groundwater basin (pl. 1 and figs. 7 and 14), and flow within this basin is dominated by the degree of confinement and by karst features (Bush and Johnston, 1988; Miller, 1986; Tibbals, 1990; Williams and Kuniansky, 2015). Most of this groundwater basin is thinly confined, and the surficial aquifer system is present over much of its extent (fig. 7). The area is notable for having a large number of surface-collapse sinkhole lakes (Tihansky, 1999). Water enters the Floridan aquifer system in this groundwater basin by means of leakage from the surficial aquifer system through the upper confining unit. The converging potentiometric contours on both the predevelopment and 2010 potentiometric surfaces indicate discharge to the St. Johns River (pl. 1 and fig. 14). The general direction of groundwater flow is from the west upland area where the Floridan aquifer system potentiometric surface is high toward the coastal lowlands. The simulated predevelopment discharge for this basin is slightly greater than that of the Southeast Georgia-Northeast Florida-South South Carolina groundwater basin, and the percentage of diffuse discharge is higher than in unconfined groundwater basins (fig. 14 and table 2). Hydrographs for wells in the confined area also indicate a slight (less than 0.1 ft/yr) long-term lowering of groundwater levels since 1960 (statistically significant on the basis of the 99-percent confidence interval) (fig. 16*C*).

South Florida Groundwater Basin

The Floridan aquifer system is deeply buried and thickly confined in the South Florida groundwater basin (pl. 1 and figs. 7 and 8), and flow is controlled by the degree of confinement and presence of saline water (Bush and Johnston, 1988; Miller, 1986; Williams and Kuniansky, 2015). Here the Lower Floridan aquifer contains saline water, and much of the Upper Floridan aquifer contains brackish water (Williams and Kuniansky, 2015). Overall flow through this groundwater basin is relatively small, and diffuse upward leakage is the primary avenue of discharge from the system (Bush and Johnston, 1988). Williams and Kuniansky (2015) indicated that fresher water lies beneath some of the saline water at the northern boundary of the groundwater basin, although the extent of this resource is unknown (figs. 10 and 14).

Hydrologic Conditions

Estimates of fluxes to and from the groundwater system, including the surficial aquifer system, intermediate aquifer system, and Floridan aquifer system, are summarized herein for current conditions. The summaries are based on measured or estimated meteorological (Daymet; Thornton and others, 2012), streamflow (USGS National Water Information System [NWIS]; U.S. Geological Survey, 2016), and water-use (Bellino, 2017) datasets. The 16-year period from 1995 through 2010 was chosen to represent current hydrologic conditions (referred to as “current conditions”) and includes a range of meteorological conditions, including two short-term droughts (1998–2002 and 2007–8) and two wet years (2005 and 2009). The 2000 calendar year, during which most areas underwent extreme deficits in precipitation, was chosen to represent dry hydrologic conditions (referred to herein as “dry conditions”), and the 2005 calendar year, during which some areas underwent above-normal precipitation, was chosen to represent wet hydrologic conditions (referred to herein as “wet conditions”). Although 2005 was not the wettest year between 1995 and 2010, it was chosen because it coincides with availability of the water-use data (Bellino, 2017) described in this section.

A potentiometric surface map of the Upper Floridan aquifer for May–June 2010 is presented in plate 1 and updates Kinnaman and Dixon (2011). Additional contours were drawn in South Florida where equivalent freshwater altitudes were computed from water-level measurements taken in wells containing brackish water (app. 1). Digital datasets associated with plate 1 are available in Kuniansky and others (2017).

Sources of Water to the Groundwater Flow System

Recharge from precipitation is the primary source of water to the Floridan aquifer system in outcrop and other unconfined areas. ET and surface runoff are processes that control the amount of precipitation that becomes available to recharge the aquifer and can be estimated by using soil water budgets and watershed characteristics. Where the Floridan aquifer system is confined, it receives water primarily through leakage from adjacent aquifers and lateral inflow from upgradient areas. Estimates of leakage and lateral inflow under these conditions have been made previously in various studies (for example, Bush and Johnston, 1988; Clarke and others, 2010; Payne and others, 2005; Robertson and Mallory, 1977; Ryder, 1982). Other sources of water to the Floridan aquifer system include irrigation-return flow, drainage-well recharge, and wastewater-return flow. Anthropogenic sources of water, such as irrigation- and wastewater-return flows, are considered separately, even though both are generated at land surface, subject to ET, and able to mix with water from net recharge. Lateral inflow is discussed briefly but does not contribute substantial quantities of water to the Floridan aquifer system.

Net Recharge

Estimates of net recharge provided herein are made concomitantly with estimates of processes such as ET and surface runoff and are therefore equivalent to net recharge. Net recharge was estimated as a function of precipitation. Precipitation data for this study were from the Daymet model output (Thornton and others, 2012), which interpolates daily weather station data to a 1-kilometer (km) grid. Average annual precipitation for the 1995–2010 period was 53.6 in. and ranged from a minimum of 47.8 in. within the Southeast Georgia-Northeast Florida-South South Carolina groundwater basin to a maximum of 63.1 in. within the Panhandle groundwater basin (table 4). Net recharge to the groundwater flow system was estimated (Bellino, 2018) by using the Soil-Water-Balance (SWB) code (Westenbroek and others, 2010), which uses a modified Thornthwaite-Mather soil-water-balance empirical accounting method to estimate precipitation minus ET (actual ET in table 4) (Thornthwaite and Mather, 1955, 1957), combined with the Soil Conservation Service (SCS) runoff curve number method (Cronshey and others, 1986) that estimates surface runoff on a cell-by-cell basis over a rectangular grid of regularly spaced cells. The SCS runoff curve number method is known to work poorly in karst terrain because a large portion of flow enters the subsurface through sinks, swallets, and other karst features that are not accounted for by the SCS runoff curve number method, resulting in overestimation of surface runoff (Woodward and others, 2002). An overestimation of surface runoff results in an underestimation of net recharge in unconfined areas of the Floridan aquifer system. Additionally, the SCS runoff curve number method was originally designed to estimate runoff from individual storm events and was found by Fennessey and Hawkins (2001) to predict peak runoff within 30 percent at best for large, ungaged watersheds. A uniform multiplier of 1.6 was applied to net recharge grids derived from the SWB model to bring the estimates in line with those from hydrograph separation (see app. 2) and other groundwater flow model studies, which were found to be about 60 percent greater than SWB-derived estimates. Further details about the methodology, sensitivity, and limitations of the SWB model are provided in appendix 2. Rates of net recharge in excess of 60 inches per year (in/yr) were estimated in areas of the Florida panhandle and south Florida, where precipitation is generally highest. Areally, these estimated values are relatively isolated, often present in clusters of five or fewer model cells, and generally located near the edge of the model domain. These high rates of net recharge are considered anomalous and probably artifacts of model sensitivity to a number of input parameters or a consequence of limitations of the SWB model, as outlined in appendix 2. Net recharge rates were capped at 40 in/yr, the 97th percentile of the wettest year (2009), in this analysis. Estimated results were also postprocessed to limit values to the lesser of recharge or precipitation. Average annual net recharge for current conditions (1995–2010) was estimated to be 7.5 in/yr and ranged from 3.9 to 9.3 in/yr during dry (2000) and wet (2005) conditions, respectively (fig. 17 and table 4). Comparison of average annual net recharge with average annual precipitation indicates that much (86 percent) of the precipitation in the study area is lost to actual ET and runoff.

Table 4. Estimated average annual precipitation, actual and reference evapotranspiration, and net recharge by subregion for current conditions (1995–2010), dry conditions (2000), and wet conditions (2005) in the study area, southeastern United States.

[Mgal/d, million gallons per day; in/yr, inch per year. Precipitation data from Thornton and others, 2012; reference evapotranspiration, actual evapotranspiration, and net recharge estimated by using a modified Thornthwaite-Mather soil-water-balance numerical code (Westenbroek and others, 2010); numbers may not sum to equivalent totals because of independent rounding; reported precision does not imply accuracy]

Subregion	Precipitation, in Mgal/d			Reference evapotranspiration, in Mgal/d			Actual evapotranspiration, in Mgal/d			Net recharge, in Mgal/d		
	1995–2010	2000	2005	1995–2010	2000	2005	1995–2010	2000	2005	1995–2010	2000	2005
Groundwater basin												
Panhandle	31,900	21,900	35,800	27,800	29,100	27,300	18,300	15,100	19,800	8,600	3,800	10,000
Dougherty Plain-Apalachicola	18,000	14,900	20,900	18,400	19,400	17,900	11,400	10,400	12,800	3,400	1,400	4,600
Thomasville-Tallahassee	17,600	15,400	21,400	19,000	19,900	18,500	11,500	10,800	12,800	2,800	1,600	4,700
Southeast Georgia-Northeast Florida-South South Carolina	61,600	52,300	71,600	71,800	74,000	69,100	41,400	38,000	47,300	6,200	3,600	6,700
Suwannee	17,100	14,400	20,200	18,700	19,500	18,000	11,100	9,900	12,600	3,000	1,900	4,000
West-central Florida	27,900	20,000	30,400	31,000	32,100	29,700	17,300	13,500	19,500	4,000	2,300	3,900
East-central Florida	26,000	17,700	31,900	27,500	28,400	26,600	15,600	12,400	18,500	3,000	1,300	3,900
South Florida	40,000	31,400	45,200	36,800	37,200	35,500	23,100	19,300	24,400	2,600	1,600	3,400
Surficial or intermediate aquifer												
Present	167,800	131,200	194,700	173,000	178,200	167,400	103,600	89,600	115,800	19,200	9,800	23,800
Absent	72,300	56,800	82,600	78,000	81,500	75,300	46,200	39,800	51,800	14,500	7,700	17,800
Upper Floridan aquifer extent	**240,100**	**187,900**	**277,300**	**251,000**	**259,700**	**242,700**	**149,700**	**129,400**	**167,700**	**33,700**	**17,500**	**41,600**

Table 4. Estimated average annual precipitation, actual and reference evapotranspiration, and net recharge by subregion for current conditions (1995–2010), dry conditions (2000), and wet conditions (2005) in the study area, southeastern United States.—Continued

[Mgal/d, million gallons per day; in/yr, inch per year. Precipitation data from Thornton and others, 2012; reference evapotranspiration, actual evapotranspiration, and net recharge estimated by using a modified Thornthwaite-Mather soil-water-balance numerical code (Westenbroek and others, 2010); numbers may not sum to equivalent totals because of independent rounding; reported precision does not imply accuracy]

Subregion	Precipitation, in in/yr			Reference evapotranspiration, in in/yr			Actual evapotranspiration, in in/yr			Net recharge, in in/yr		
	1995–2010	2000	2005	1995–2010	2000	2005	1995–2010	2000	2005	1995–2010	2000	2005
Groundwater basin												
Panhandle	63.1	43.3	70.8	54.9	57.5	53.9	36.1	29.8	39.1	17.0	7.5	20.2
Dougherty Plain-Apalachicola	55.0	45.6	63.9	56.3	59.4	54.8	34.9	31.7	39.0	10.4	4.3	14.1
Thomasville-Tallahassee	53.4	46.6	64.7	57.5	60.3	56.1	34.9	32.7	38.9	8.5	4.8	14.2
Southeast Georgia-Northeast Florida-South South Carolina	47.8	40.6	55.6	55.7	57.4	53.7	32.1	29.5	36.7	4.8	2.8	5.2
Suwannee	53.6	45.1	63.5	58.8	61.3	56.5	34.9	31.0	39.5	9.3	5.9	12.7
West-central Florida	53.3	38.2	57.9	59.1	61.3	56.7	32.9	25.8	37.2	7.7	4.5	7.5
East-central Florida	53.1	36.1	65.1	56.3	58.1	54.3	31.9	25.3	37.7	6.2	2.7	8.1
South Florida	57.3	45.0	64.8	52.7	53.3	50.9	33.1	27.7	35.0	3.8	2.3	4.9
Surficial or intermediate aquifer												
Present	53.7	42.0	62.3	55.4	57.0	53.6	33.2	28.7	37.1	6.2	3.1	7.6
Absent	53.2	41.8	60.8	57.4	60.0	55.4	34.0	29.3	38.1	10.7	5.7	13.1
Upper Floridan aquifer extent	**53.6**	**41.9**	**61.9**	**56.0**	**57.9**	**54.2**	**33.4**	**28.9**	**37.4**	**7.5**	**3.9**	**9.3**

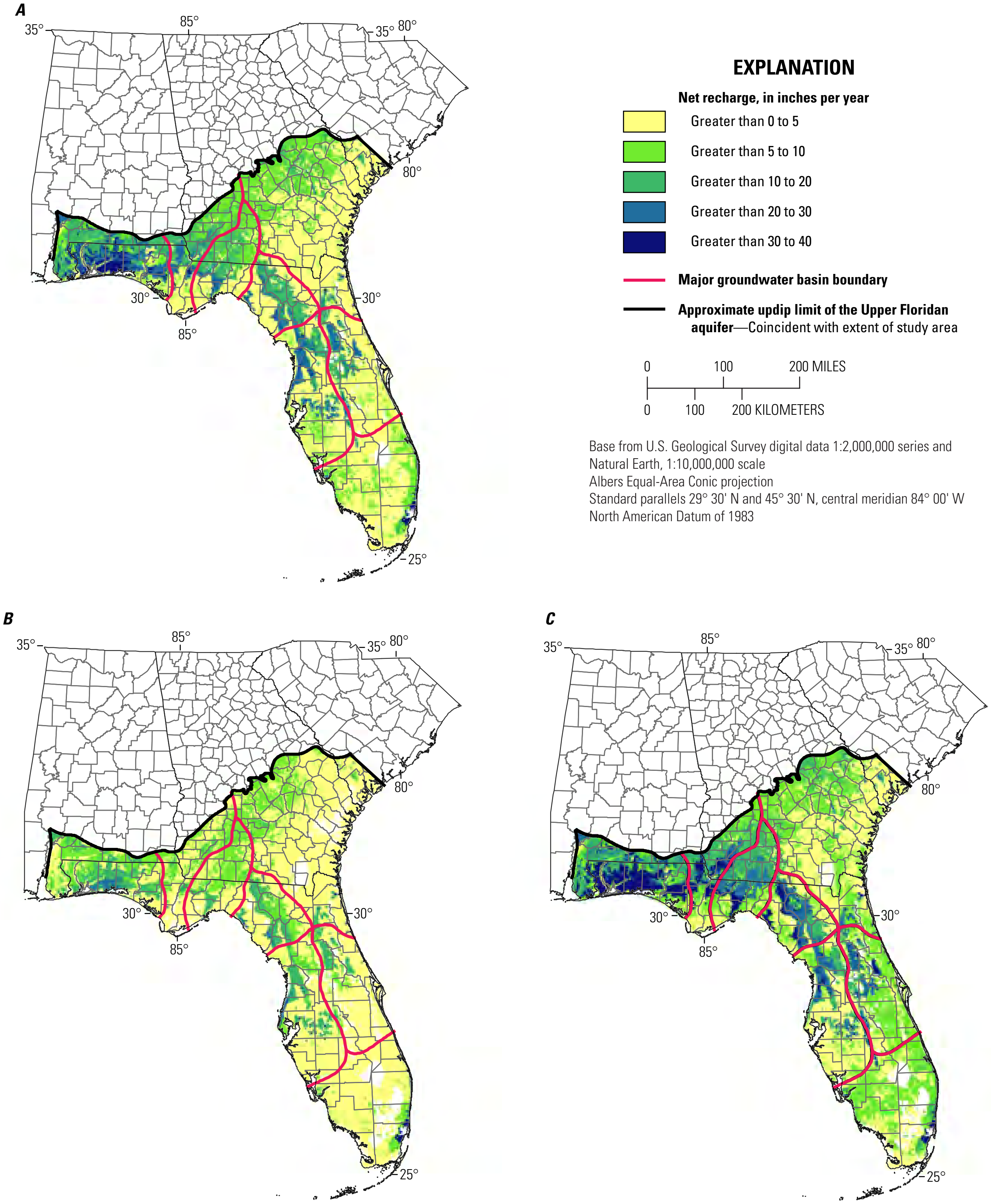


Figure 17. Estimated net recharge in the study area, southeastern United States, for *A*, current conditions (1995–2010), *B*, dry conditions (2000), and *C*, wet conditions (2005).

Estimated rates of net recharge are correlated with the ability of the underlying soil to transmit water from the land surface to the water table; those areas with well-drained soils typically have higher rates of net recharge than do areas with poorly drained soils. Net recharge rates for current conditions (1995–2010) (fig. 17*A* and table 4) were highest in the Panhandle groundwater basin (17.0 in/yr) and lowest in the South Florida groundwater basin (3.8 in/yr). Both areas generally receive large quantities of precipitation; average annual precipitation values for the current conditions (1995–2010) period were 63.1 and 57.3 in/yr for the Panhandle and South Florida groundwater basins, respectively (table 4). Soils in south Florida are poorly drained (Natural Resources Conservation Service, 2014) and remain saturated all or part of the year, however, which increases surface runoff and reduces the amount of recharge that occurs. The Southeast Georgia-Northeast Florida-South South Carolina groundwater basin also has a low average net recharge rate (4.8 in/yr), which is probably related to the relatively lower quantities of precipitation received by that region (annual average of 47.8 in/yr) (table 4). The areal distribution of net recharge rates over the study area was as follows: 58 percent of the study area received less than 5 in/yr; 16 percent received 5–10 in/yr; 16 percent received 10–20 in/yr; 8 percent received 20–30 in/yr; and 2 percent received 30–40 in/yr (fig. 17*A*).

Net recharge rates for dry (2000) conditions (fig. 17*B* and table 4) were highest in the Panhandle groundwater basin (7.5 in/yr) and lowest in the South Florida groundwater basin (2.3 in/yr). During this period, 72 percent of the study area had net recharge rates of less than 5 in/yr, including much of peninsular Florida and coastal Georgia (fig. 17*B*). About 18 percent of the study area had net recharge rates between 5 and 10 in/yr, and the remaining 10 percent had net recharge rates greater than 10 in/yr.

Net recharge rates for wet (2005) conditions (fig. 17*C* and table 4) were generally much higher than for dry conditions and ranged from 20.2 in/yr in the Panhandle groundwater basin to 4.9 in/yr in the South Florida groundwater basin. During this time, 46 percent of the study area received less than 5 in/yr of net recharge, while those areas receiving 5–10 in/yr accounted for 26 percent of the study area (fig. 17*C*). Areas receiving 10–20 in/yr of net recharge accounted for 14 percent of the study area, and those receiving greater than 20 in/yr accounted for the remaining 14 percent.

Rates of net recharge as a percentage of precipitation for both current and wet conditions ranged from about 7 to about 28 percent for individual groundwater basins (table 4). For dry conditions, the range was about 5–17 percent for individual groundwater basins.

The Panhandle groundwater basin contributed the most net recharge to the groundwater flow system (8,600 Mgal/d) because of its approximately 10,000-mi^2 (table 2) extent and high average net recharge rate of 17.0 in/yr (table 4). The largest of the groundwater basins, the Southeast Georgia-Northeast Florida-South South Carolina groundwater basin (approximately 26,300 mi^2) (table 2), is nearly three times the size of the Panhandle groundwater basin, but contributed an average of only about three-quarters (6,200 Mgal/d) as much recharge. The remaining groundwater basins each contributed from about 2,600 to 4,000 Mgal/d.

Predevelopment recharge and leakage rates for the Floridan aquifer system were simulated by Bush and Johnston (1988) by using a groundwater flow model with 64-mi^2 grid cells. These recharge values are considered to be “slightly lower” than actual values because of the inability of that model to simulate local recharge and discharge that occur entirely within a model cell (Bush and Johnston, 1988, p. C38). This may be particularly true for areas dominated by local flow systems, such as the hilly outcrop region of the Floridan aquifer system (Bush and Johnston, 1988; Tóth, 1963). Estimates of current net recharge can be compared to simulated predevelopment discharge from Bush and Johnston (1988) (equivalent to recharge under steady-state conditions) by comparing tables 2 and 4; however, current net recharge is estimated for the entire groundwater flow system (surficial aquifer system, intermediate aquifer system, and Floridan aquifer system), whereas simulated predevelopment discharge is for the Floridan aquifer system only. The estimated rate of current net recharge to the whole groundwater flow system over the study area (33,700 Mgal/d) is about two and a half times greater than the predevelopment regional total discharge from the Floridan aquifer system alone (13,931 Mgal/d; fig. 14 and tables 2 and 4). Current net recharge to the groundwater flow system is greater by 3–38 times predevelopment rates of discharge in those groundwater basins where the Floridan aquifer system is overlain by another aquifer and (or) is confined to semiconfined (Panhandle, Southeast Georgia-Northeast Florida-South South Carolina, East-central Florida, and South Florida groundwater basins). Current net recharge to the groundwater flow system is approximately the same (86–176 percent of predevelopment rates) in relatively unconfined groundwater basins where the Floridan aquifer system is near land surface or is otherwise better connected hydraulically with overlying aquifers (Dougherty Plain-Apalachicola, Thomasville-Tallahassee, Suwannee, and West-central Florida groundwater basins). These findings are as expected because (1) current estimates include recharge to the entire groundwater flow system at land surface, which may not be indicative of the rate of recharge to the Floridan aquifer system individually where overlain by the surficial aquifer system and intermediate aquifer system; (2) rates of recharge to the surficial aquifer system in areas where the Floridan aquifer system is confined should be greater than rates of leakage through lower permeability sediments to the Floridan aquifer system; and (3) rates of net recharge are underestimated by the SWB model in areas where karst features such as sinkholes provide avenues for inflow of surface runoff to the aquifer but are not represented by corresponding mechanisms in the SWB model (app. 2).

Anthropogenic Recharge

Artificial, or anthropogenic, recharge represents a small part of the overall hydrologic budget, even though it can locally be an important part of the groundwater flow system. Although it is beyond the scope of this report to develop detailed estimates of anthropogenic recharge, approximations of irrigation-return flow, drainage-well recharge, and wastewater-return flow are presented.

Irrigation-Return Flow

Depending on the irrigation method and crop and soil type, some irrigation water may infiltrate to the saturated zone of the aquifer and is referred to herein as "irrigation-return flow." As a percentage of applied irrigation water, irrigation-return flow ranges from 0 percent for microdrip irrigation to as much as 50 percent for rice cultivation, wherein fields are flooded for extended periods (Dewandel and others, 2008) i.e. the ratio between the quantity of water returned from the cultivated area to the groundwater system and the amount of abstraction, vary by more than 50% for rice cultivation using standing water irrigation to 0% in the case of drip irrigation technique. This component of the groundwater budget plays an important role, particularly in intensively irrigated areas. Thus, to avoid any inaccurate aquifer budgeting, modelling and consequently any erroneous watershed management, this component needs to be accurately assessed for a particular time-step (e.g. weekly, seasonally. Studies in Colorado concluded that about 24–30 percent of the irrigation water applied by surface-water canals or furrows (referred to as seepage irrigation) returns to the groundwater system and that no water is returned by center-pivot sprinkler systems (Cain, 1985; Gates and others, 2012). These sprinkler systems are common across Alabama, Georgia, and South Carolina, whereas microdrip systems are less common, and flood irrigation is negligible (U.S. Department of Agriculture, 2009). Although some amount of irrigation-return flow to the groundwater system is likely in the humid southeastern United States, such flow is considered to be a small fraction of the overall water budget and is probably within the uncertainty of estimates of net recharge from precipitation. For example, Jones and Torak (2006) considered irrigation-return flow to be negligible in their model of part of the Floridan aquifer system in the Dougherty Plain, and no adjustments to recharge were deemed necessary.

Within Florida, approximately 1.960 million acres were irrigated in 1995, including four major crop types: fruit (45 percent), field (29 percent), ornamentals and grasses (12.5 percent), and vegetable (12 percent) (Marella, 1999). Total irrigation was 3,244 Mgal/d from surface-water and groundwater sources; 52 percent of the irrigated crop acreage used flood or subsurface irrigation systems, 30 percent used microdrip irrigation systems, and 18 percent used sprinkler irrigation systems (Marella, 1999). In 2010, 1.734 million acres were irrigated, and total irrigation from surface-water and groundwater sources was 2,551 Mgal/d. Use of microdrip irrigation systems increased to 40 percent of irrigated crop acreage, whereas flood or subsurface irrigation systems decreased to 42 percent, and sprinkler irrigation systems remained at 18 percent (Marella, 2014). Irrigation-return flow cannot be accurately estimated by using the statewide summaries by Marella (1999, 2014) because total volumes by irrigation method are not available. An approximation of the upper limit of this flux can be calculated, however, by multiplying the total irrigation volume by the percentage of acres irrigated by flood methods—the only form of irrigation used in the study area that returns appreciable quantities of water to the groundwater system—and then by a factor of 30 percent (Gates and others, 2012), which yields 506 and 321 Mgal/d for 1995 and 2010, respectively. These estimates represent about 3 percent of the estimated 1980 inflow (recharge and leakage) to the Floridan aquifer system (Bush and Johnston, 1988), which is negligible in terms of the overall groundwater budget and will not be discussed further.

Drainage-Well Recharge

Drainage wells are the primary mechanism used to remove excess surface water at some locations in central and north Florida where suitable hydrogeologic conditions exist (Kimrey and Fayard, 1984). Estimated recharge to the groundwater flow system by way of drainage wells was estimated in the 1980s to be between about 45 and 75 cubic feet per second (ft^3/s) in the Orlando area, where a majority of the wells are located (Kimrey and Fayard, 1984). Recharge from drainage wells in the 1980 groundwater budget was assumed to be 45 ft^3/s (0.2 percent of the groundwater budget) according to Bush and Johnston (1988, fig. 34). This recharge component is considered negligible for the purposes of this report.

Wastewater-Return Flow

Some proportion of treated wastewater is returned to the groundwater flow system, mainly by land-application techniques or onsite septic wastewater-treatment systems. Land-application techniques include irrigation, overland flow, and infiltration-percolation ponds (Pound and Crites, 1973); in 1996, only 3 percent (1,421 Mgal/d) of the 42,225 Mgal/d of wastewater treated daily in the United States was applied to the land surface (Tchobanoglous and others, 2002). Few estimates of the amount of wastewater applied to the land surface in the study area were available. O'Reilly and others (2014) surmised, however, that this source of water could be substantial locally and that about a third (151 Mgal/d) of the water withdrawn for public supply in central Florida is applied to the land surface, much of which is thought to percolate to the water table. Given the lack of estimates for other areas, a rough estimate can be made by assuming that, if the 1,421 Mgal/d representing all wastewater applied to the land surface in the United States in 1996 were applied evenly over the study area, it would amount to roughly 0.3 in/yr. Onsite septic wastewater-treatment systems are a common method for disposing of domestic wastewater in rural areas or in urban areas that are not served by public sewer systems. Liquid effluent discharged from the septic system is absorbed by the surrounding soil and becomes available to recharge the groundwater flow system. Recharge derived from septic-system effluent can be substantial locally and may be particularly important during drought conditions (Landers and Ankcorn, 2008). In 1990, there were an estimated 3.8 million septic systems in Alabama, Florida, Georgia, and South Carolina, representing about 37 percent of households (U.S. Census Bureau, 2011). Statewide estimates of recharge from septic systems were made for each State in the study area by using the equation

$$R_{septic} = \frac{H_n P_n Q}{A} \quad (1)$$

where

R_{septic} is groundwater recharge from septic systems [LT^{-1}],

H_n is the number of households with septic systems [unitless],

P_n is the population per household for the State [unitless],

Q is the effluent discharge volume per person per household per day [L^3T^{-1}], and

A is the area over which the septic systems are distributed [L^2].

Recharge estimates range from 0.03 in/yr in Alabama to 0.08 in/yr in Florida, and the area-weighted average across the study area is 0.06 in/yr, representing less than 1 percent of the water budget for the overall groundwater flow system. A detailed estimate of recharge from septic systems was beyond the scope of this study because of a lack of specific knowledge about the location and status of individual septic systems across the entire study area. Given the small part of the groundwater budget composed of both land-application techniques and onsite septic wastewater-treatment systems, recharge from wastewater-return flow will not be discussed further herein.

Lateral Inflow

Lateral inflow to the Floridan aquifer system from the updip area was simulated as 340 and 350 ft^3/s in the predevelopment and 1980 simulations, respectively, of Bush and Johnston (1988), which is about 1 percent of the total flow through the system. Jones and Torak (2006) simulated part of the Floridan aquifer system in the Dougherty Plain and simulated 140 Mgal/d (22 ft^3/s) of inflow on the updip limit of the Floridan aquifer system for this part of the system. As a result, lateral inflow is not a major component to the overall groundwater budget and will not be discussed further herein.

Losses of Water from the Groundwater Flow System

The major losses of water from the groundwater flow system (aside from ET, which is accounted for in the estimate of net recharge) are discharge to springs, discharge to streams and lakes, diffuse upward leakage in low-lying areas, groundwater withdrawals, and coastal discharge. Diffuse upward leakage from the Floridan aquifer system to other aquifers as determined by Bush and Johnston (1988) was previously discussed for predevelopment and 1980 conditions in the “Conceptual Groundwater Flow System” section, along with their total estimate of spring discharge and discharge to surface-water bodies. This section provides estimates of spring discharge, discharge to streams and lakes, groundwater withdrawals, and coastal discharge.

Discharge to Springs

Most of the large springs in the study area have been inventoried and are classified according to discharge magnitude by local, State, and Federal agencies. Springs classified as first magnitude have an average discharge greater than 100 ft^3/s, springs classified as second magnitude have an average discharge between 10 and 100 ft^3/s, and springs classified as third magnitude have an average discharge between 1 and 10 ft^3/s (Meinzer, 1927). Miscellaneous discharge measurements and water-quality data for the springs of Florida are published in Scott and others (2004), for Alabama in Chandler and Moore (1987), and for Georgia in Callahan (1964) and Stringfield (1966). Additional discharge measurements for the springs of Florida are from the Florida Geological Survey (Debra Harrington, written commun., 2014). The Florida Geological Survey compiled a database of Florida springs that contained 751 inventoried springs as of 2010 (Harrington and others, 2010; Scott and others, 2004), of which 48 springs or spring groups were classified as first magnitude, 155 were second magnitude, and 118 were third magnitude. In Alabama, 17 springs that discharge water from the Floridan aquifer system have been inventoried by the USGS and the Geological Survey of Alabama; none were classified as first- or second-magnitude springs, but three were classified as third magnitude. In Georgia, 56 springs that originate in the Floridan aquifer system have been inventoried within NWIS (https://waterdata.usgs.gov/nwis) and the USGS Geographic Names Information System (GNIS) (https://geonames.usgs.gov/). Of these, Radium Springs, near Albany, Ga., is the only historical first-magnitude spring, three springs are second magnitude, and eight are third magnitude. Radium Springs, which flows into the Flint River, is the largest natural spring in Georgia and historically had a peak discharge of approximately 150 ft^3/s, but in recent years it no longer flows during drought conditions. There are no third-magnitude or larger springs in South Carolina. In summary, 824 Floridan aquifer system springs have been inventoried across the study area, of which 35 are classified historically as first-magnitude springs or associated with a first-magnitude spring group, and 302 are classified as second and third magnitude.

Continuous discharge measurements are not available for all springs, and most springs do not have long-term datasets (Harrington and others, 2010). Estimates of flow based on magnitude classification are used herein if no continuous discharge data are available for first- through third-magnitude springs. The minimum flow for the discharge magnitude class is used for dry conditions (2000), maximum flow for the discharge magnitude class multiplied by an arbitrary coefficient of 0.3 is used for wet conditions (2005), and the average of the dry and wet year values is used for current conditions (1995–2010) (table 5). The 0.3 coefficient was used to decrease the estimate of spring discharge for wet conditions because existing data show that many springs flow at rates near the minimum of their magnitude class and only temporarily flow at higher rates following precipitation events. Appendix 3 is a list of all Floridan aquifer system springs with discharge greater than 1 ft^3/s compiled for this study. Spring discharge for each subregion in the study area, computed on the basis of data in appendix 3, is listed in table 5. Direct comparisons of spring discharge estimates in table 5 should not be made with estimates from earlier reports because the number of inventoried springs has changed over time. In an effort to use the most current knowledge to develop groundwater budgets for this report, many more springs were included in the current analysis of spring discharge than in Bush and Johnston (1988), thereby resulting in a greater volume of discharge from springs than was previously estimated. Average spring flow for the current conditions period (1995–2010) was 12,000 ft^3/s (7,700 Mgal/d) and ranged from 6,200 ft^3/s (4,000 Mgal/d) during dry (2000) conditions to 17,000 ft^3/s (11,000 Mgal/d) during wet (2005) conditions.

Discharge to Streams and Lakes

Total groundwater discharge to streams and lakes includes both spring discharge and diffuse discharge predominantly from the aquifer present at land surface. Diffuse groundwater discharge to streams and lakes is difficult to separate from spring discharge. Bush and Johnston (1988) combined streamflow and spring discharge from the Floridan aquifer system in all published water budgets and did not actively simulate the surficial aquifer system. Hydrograph separation analysis has been applied, however, to determine base flow, as an estimate of groundwater discharge, in the confined part of the Floridan aquifer system in coastal Georgia (Priest, 2004), and an analysis using the Groundwater Toolbox software (Barlow and others, 2015) was conducted as an independent validation of recharge estimated by the SWB model across the entire study area (app. 2).

Table 5. Total spring discharge by subregion for springs discharging 1 cubic foot per second or greater in the study area, southeastern United States.

[ft^3/s, cubic foot per second; --, not applicable. Spring discharge values were compiled and aggregated from Bush and Johnston, 1986; Callahan, 1964; Champion and Starks, 2001; Chandler and Moore, 1987; Meinzer, 1927; Rosenau and others, 1977; St. Johns River Water Management District, 2014; Scott and others, 2004; Stringfield, 1966; U.S. Geological Survey, 2016; Debra Harrington, Florida Geological Survey, written commun., 2014; numbers may not sum to equivalent totals because of independent rounding; reported precision does not imply accuracy]

Subregion	Number of springs or spring groups	Discharge, in ft^3/s		
		2000	2005	1995–2010
Groundwater basin				
Panhandle	22	220	660	440
Dougherty Plain-Apalachicola	16	260	650	450
Thomasville-Tallahassee	13	550	2,480	1,640
Southeast Georgia-Northeast Florida-South South Carolina	11	30	90	40
Suwannee	149	2,530	7,870	5,350
West-central Florida	48	1,850	3,930	2,840
East-central Florida	32	750	1,680	1,210
South Florida	--	--	--	--
Upper Floridan aquifer extent	[1]**291**	**6,200**	**17,000**	**12,000**

[1]Total number of springs is less than total spring inventory because some individual springs may be assigned to one spring group.

Base flow is essentially the low-flow part of a hydrograph attributable to groundwater discharge, but may not always represent the true groundwater discharge in the study area, especially in Florida because of the confounding effects of spring discharge, slow surface-water drainage from swamps, and excessive bank storage (Halford and Mayer, 2000). For example, river stage along the lower Suwannee River remains high over the entire rainy season, and groundwater levels in the Floridan aquifer system, into which the river channel is incised, can rise for many miles away from the river channel resulting in a slow, long-term release of water from bank storage as river stage decreases. Additionally, Kinzelbach and others (2002) found that hydrograph separation methods of partitioning streamflow into surface runoff and base flow provide an estimate of groundwater discharge (approximately equal to recharge) within a factor of 2 of the actual discharge. Stewart and others (2007) used a form of chemical mass balance to calibrate hydrograph separation to obtain a better estimate of groundwater discharge to streams; their data indicate that the estimate of groundwater discharge from hydrograph separation alone is within a factor of 2 of the groundwater discharge estimated with chemical mass-balance hydrograph separation. Base flow, determined by hydrograph separation, is considered a reasonable method to estimate recharge to the groundwater flow system (Risser and others, 2005; Rutledge, 1998, 2000).

Bush and Johnston (1988) found that 12,000 Mgal/d discharged to springs and streams during predevelopment and in 1980 from the Floridan aquifer system alone (calculated from data in table 2). The current estimate of average spring discharge for 1995–2010 from the Floridan aquifer system is 7,800 Mgal/d or 65 percent of the total discharge to springs and streams from Bush and Johnston (1988). This estimate does not, however, represent the base flow (groundwater discharge) over the study area from other parts of the groundwater flow system (surficial aquifer system and intermediate aquifer system) and is less than the direct recharge of 15,000 Mgal/d estimated by the SWB model for 1995–2010 on the unconfined Floridan aquifer system.

Priest (2004) estimated that groundwater discharge to streams in coastal Georgia (surficial aquifer system predominantly at land surface) for the period 1971–2001 was between 39 and 70 percent of total streamflow. When the area-weighted average runoff for the entire Floridan aquifer system of 15.1 in/yr (U.S. Geological Survey, 2014) is used in the analysis, groundwater discharge to streams could range from 5.9 in/yr (26,300 Mgal/d) to 10.6 in/yr (47,300 Mgal/d) with an average of 8.2 in/yr (36,800 Mgal/d). A second analysis, using the Groundwater Toolbox software (Barlow and others, 2015), estimated base flow more broadly across the study area at 156 streamflow gaging stations from the GAGES–II database (Falcone, 2011). The average base-flow contribution to streamflow for 1995–2010 was 11.5 in/yr (51,600 Mgal/d) and ranged from 9.3 in/yr (41,500 Mgal/d) to 13.3 in/yr (59,800 Mgal/d). Of the 156 gaging stations used in the analysis, 13 had average base-flow contribution rates greater than 80 percent, and of these many were located in drainage basins affected by swamp drainage and (or) spring discharge including the Weeki Wachee River and the Withlacoochee and Wekiva River Basins, Fla. Removal of these sites from the analysis resulted in rates of base flow that more closely agree with results using the Priest (2004) values: average base flow is 8.0 in/yr (36,000 Mgal/d), minimum base flow is 6.1 in/yr (27,300 Mgal/d), and maximum base flow is 9.7 in/yr (43,400 Mgal/d).

Groundwater Withdrawals

The USGS National Water Use Program has published estimates of water use for the Nation every 5 years since 1950. According to these estimates, groundwater withdrawals in the United States more than doubled between 1950 and 1980, increasing from 34,000 to 84,000 Mgal/d (Maupin and others, 2014). During the same time period, withdrawals from the Floridan aquifer system grew by about 375 percent from 630 to 2,990 Mgal/d (Marella and Berndt, 2005) (figs. 18 and 19 and table 6). From 1980 to 1990, when total groundwater withdrawals across the Nation decreased slightly (Maupin and Barber, 2005), withdrawals from the Floridan aquifer system increased slightly from 2,990 to 3,430 Mgal/d (15 percent) (Marella and Berndt, 2005). From 1985 through 2010, the rate of water withdrawals from the Floridan aquifer system became relatively stable at about 3,100–3,300 Mgal/d with the exception of 2000, when the amount of groundwater withdrawn peaked at 4,020 Mgal/d (Bellino, 2017; Marella and Berndt, 2005) (figs. 18 and 19 and table 6). This withdrawal rate was the fifth largest of the principal aquifers in the United States and is attributed to high irrigation demand caused by low rates of precipitation during that year (Marella and Berndt, 2005; Maupin and Barber, 2005).

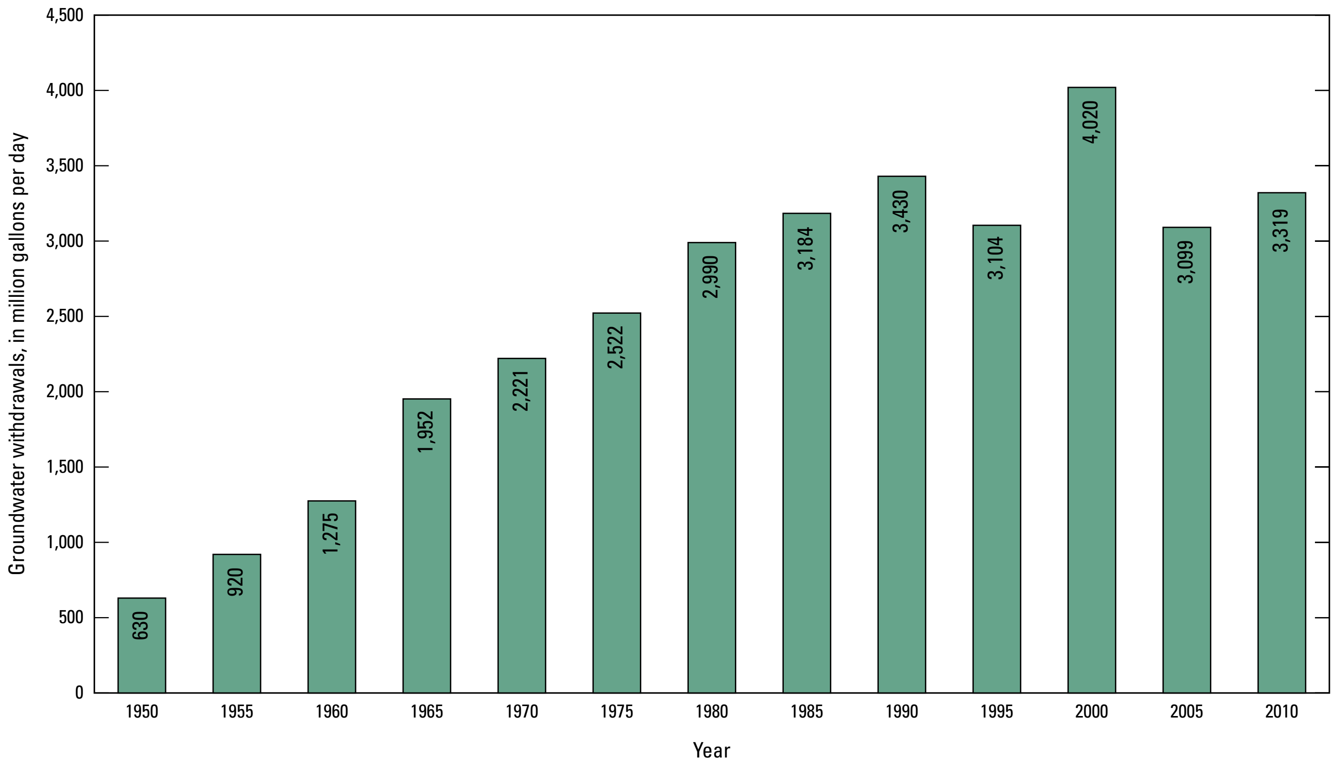


Figure 18. Total groundwater withdrawals from the Floridan aquifer system, southeastern United States, 1950–2010 (data for 1950–1990 from Marella and Berndt, 2005; data for 1995, 2000, 2005, and 2010 from Bellino, 2017).

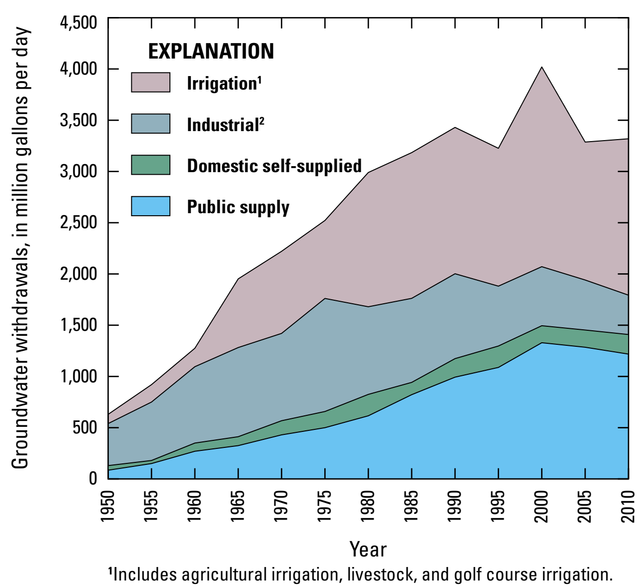


Figure 19. Groundwater withdrawals from the Floridan aquifer system by category, southeastern United States, 1950–2010 (data for 1950–1990 from Marella and Berndt, 2005; data for 1995, 2000, 2005, and 2010 from Bellino, 2017).

Table 6. Water withdrawals from the Floridan aquifer system in the study area, southeastern United States, by water-use category, 1950–2010.

[Units are million gallons per day. Data for 1950–90 from Marella and Berndt, 2005; 1995, 2000, 2005, and 2010 data and 1995–2010 average data from Bellino, 2017; reported precision does not imply accuracy]

Category	1950	1955	1960	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010	1995–2010 average
Public supply	85	150	270	325	430	500	616	822	993	1,104	1,329	1,291	1,286	1,253
Domestic self-supplied	45	30	80	87	138	158	209	120	181	198	166	172	202	185
Irrigation[1]	90	170	180	670	801	761	1,310	1,422	1,428	1,388	1,949	1,327	1,540	1,551
Industrial[2]	410	570	745	870	852	1,103	855	820	828	414	576	309	290	397
Totals	**630**	**920**	**1,275**	**1,952**	**2,221**	**2,522**	**2,990**	**3,184**	**3,430**	**3,104**	**4,020**	**3,099**	**3,319**	**3,386**

[1]Includes agricultural irrigation, livestock, and golf course irrigation.

[2]Includes commercial, mining, and power generation.

Groundwater withdrawals from the Floridan aquifer system in 2000 were taken from table 1 of Marella and Berndt (2005). Other groundwater withdrawals from the Floridan aquifer system were estimated by multiplying the gross groundwater withdrawals for each county by a coefficient representing the proportion of total groundwater withdrawals coming from the Floridan aquifer system (Bellino, 2017). Coefficients for each county and water-use category were back-calculated from data presented in Marella and Berndt (2005) and applied to the 1995, 2000, 2005, and 2010 USGS Aggregate Water-Use Data System groundwater withdrawal data (Kenny and others, 2009; Maupin and others, 2014), with the exception of Georgia, for which previously calculated coefficients were obtained (Stephen Lawrence, U.S. Geological Survey, written commun., June 4, 2014).

It is estimated that about 90 percent of the water withdrawn from the Floridan aquifer system is obtained from the Upper Floridan aquifer, which is highly transmissive and yields potable water in most locations north of Lake Okeechobee, Fla. (Berndt and others, 1998; Marella and Berndt, 2005). Water in the Lower Floridan aquifer is generally brackish to saline; however, in parts of central Florida the Lower Floridan aquifer is used for water supply and yields potable water (O'Reilly and others, 2002; Williams and Kuniansky, 2015). In central Florida, the Lower Floridan aquifer is being explored for further development as an alternative source of water that can be used to meet future demand (Drumm, 2013; Gilmer, 2011; Spear, 2011, 2015). For the period 1995–2010, the average total withdrawals from the Floridan aquifer system were 3,386 Mgal/d, of which Florida accounted for 75 percent (2,531 Mgal/d), Georgia accounted for 23 percent (785 Mgal/d), and South Carolina and Alabama combined accounted for about 2 percent (70 Mgal/d) of the average total withdrawals (fig. 20 and table 7).

Average withdrawals from the Floridan aquifer system for 1995–2010 were 100 Mgal/d or greater for seven counties, all of which are in Florida: Duval, Highlands, Hillsborough, Orange, Osceola, Pasco, and Polk (Bellino, 2017) (fig. 21*A*). Public supply was the dominant use of groundwater in Duval, Orange, and Pasco Counties, whereas irrigation was the dominant use in Polk and Osceola Counties. Groundwater use in Hillsborough County was divided mainly between public supply and irrigation (Bellino, 2017). Groundwater used for irrigation and public supply together accounted for 83 percent (2,804 Mgal/d) of the average total withdrawals (fig. 22 and tables 6 and 7). Industrial and domestic self-supplied withdrawals accounted for 12 (397 Mgal/d) and 5 (185 Mgal/d) percent of the total, respectively (fig. 22 and tables 6 and 7).

Normalization of withdrawals by the area over which they occur provides a better basis for comparisons of withdrawals between counties, whose areas differ by an order of magnitude. The resulting measure is called withdrawal intensity (Bellino, 2017) (fig. 21*B*). A similar concept, depletion intensity, was used in the context of long-term groundwater depletion in Konikow (2015). The top 10 withdrawal intensities are for counties that account for only 6 percent (6,353 mi^2) of the total area, but 31 percent (1,045 Mgal/d) of the withdrawals (Bellino, 2017). Summary statistics for withdrawal intensity are provided in table 8.

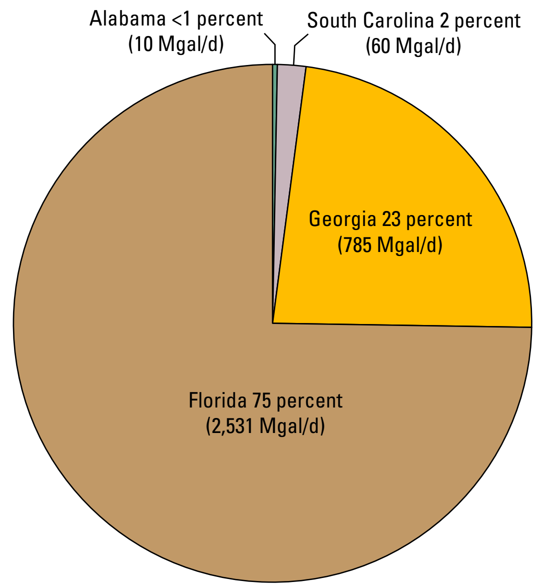


Figure 20. Average groundwater withdrawals from the Floridan aquifer system by State, southeastern United States, 1995–2010 (data from Bellino, 2017; numbers may not sum to equivalent totals because of independent rounding; Mgal/d, million gallons per day).

Table 7. Average groundwater withdrawals from the Floridan aquifer system in the study area, southeastern United States, by water-use category and State, 1995–2010.

[Units are million gallons per day. Data from Bellino, 2017; numbers may not sum to equivalent totals because of independent rounding; reported precision does not imply accuracy]

State	Water-use category				Total
	Public supply	Domestic self-supplied	Irrigation	Industrial	
Alabama	1	2	8	0	10
Florida	1,074	136	1,115	205	2,531
Georgia	152	38	407	188	785
South Carolina	26	9	21	4	60
Totals	**1,253**	**185**	**1,551**	**397**	**3,386**

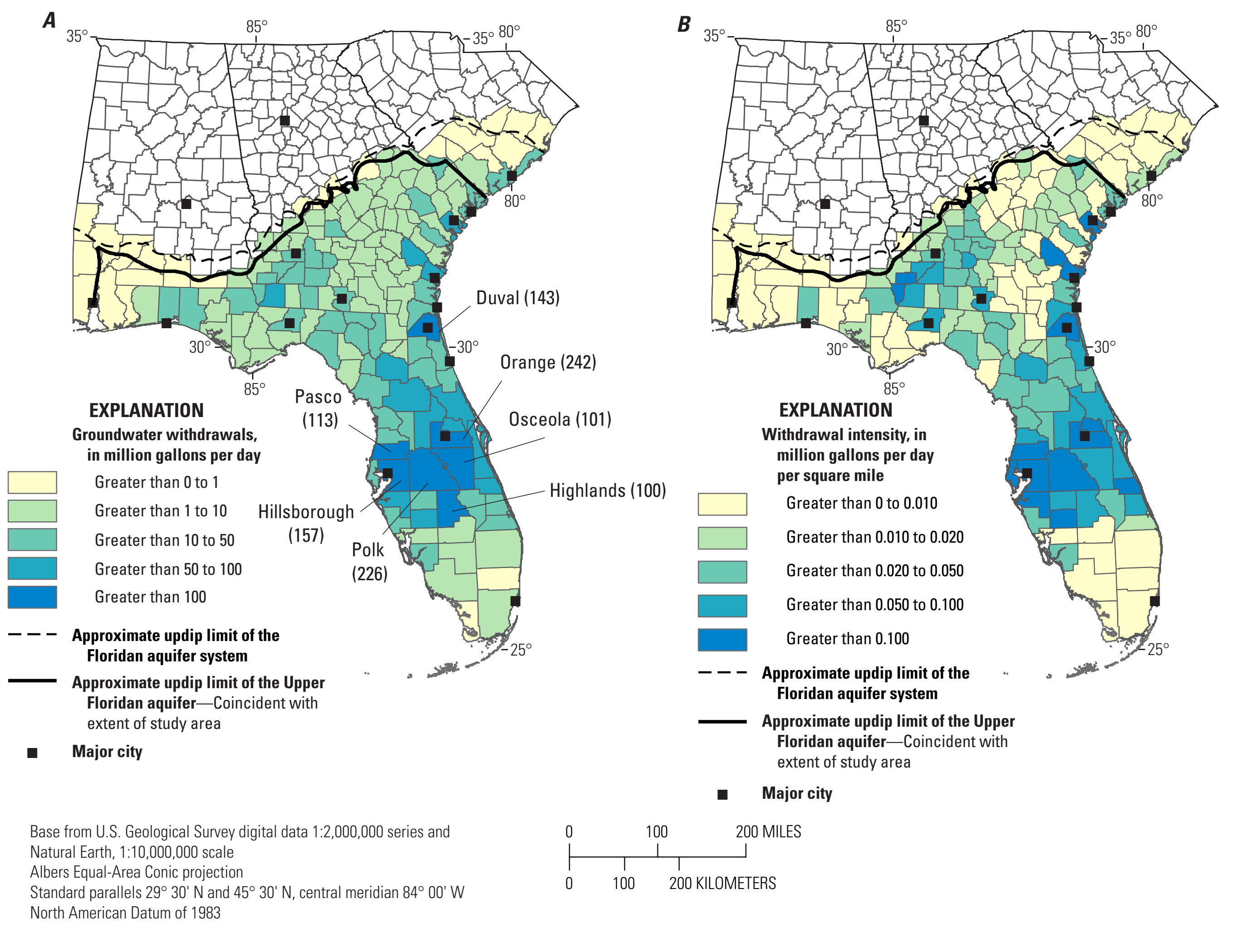
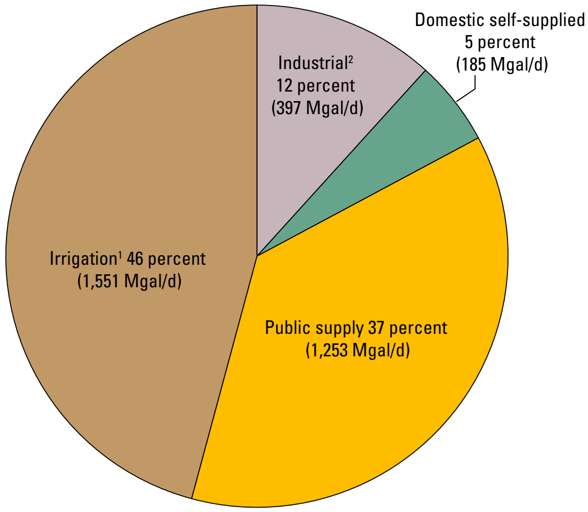


Figure 21. *A*, Average groundwater withdrawals and *B*, withdrawal intensity from the Floridan aquifer system by county, southeastern United States, 1995–2010 (data from Bellino, 2017).



[1]Includes agricultural irrigation, livestock, and golf course irrigation.

[2]Includes commercial, mining, and power generation.

Figure 22. Average groundwater withdrawals from the Floridan aquifer system by category, southeastern United States, 1995–2010 (data from Bellino, 2017; numbers may not sum to equivalent totals because of independent rounding; Mgal/d, million gallons per day).

Public Supply

The Floridan aquifer system is the primary source of drinking water throughout most of Florida north of Lake Okeechobee and in parts of southern Georgia (Marella and Berndt, 2005; Miller, 1990)1990. From 1995 through 2010, withdrawals for public supply increased by 16 percent (182 Mgal/d; table 6). Water use peaked at 1,329 Mgal/d in 2000, an increase of 20 percent (225 Mgal/d) over 1995 water use, and then decreased to 1,291 Mgal/d in 2005 and further to 1,286 Mgal/d in 2010 (table 6).

Average public-supply withdrawals from the Floridan aquifer system for the period from 1995 through 2010 (fig. 23*A*) totaled 1,253 Mgal/d (tables 6 and 7), and counties with the 10 largest withdrawals accounted for 60 percent of the water withdrawn for public supply (749 Mgal/d); of those counties, all withdrew more than 30 Mgal/d on average, and all but one were located in Florida (Bellino, 2017). Two counties, Orange and Duval, withdrew more than 100 Mgal/d and represent 25 percent (313 Mgal/d) of withdrawals (Bellino, 2017) (fig. 23*A*). The counties with the 20 largest withdrawals accounted for 77 percent (961 Mgal/d) of the water withdrawn for public supply (Bellino, 2017). Seventy-nine counties reported less than 1 Mgal/d and constitute 2 percent (29 Mgal/d) of withdrawals (Bellino, 2017). The population served by public supply was greater than 500,000 in three counties—Pinellas, Orange, and Duval (Bellino, 2017) (fig. 23*B*).

Table 8. Summary statistics for groundwater withdrawal intensity computations for the study area, southeastern United States, from Bellino (2017).

[Units are million gallons per day per square mile]

Statistic	1995–2010 average	1995–2010 average, irrigation only
Number of nonzero values	145	137
Minimum	0.000	0.000
Maximum	0.238	0.156
Mean	0.031	0.015
Median	0.013	0.006
Standard deviation	0.043017	0.024654

Domestic Self-Supplied

Many of the withdrawals for domestic self-supplied use are concentrated in central Florida north of Tampa Bay (fig. 24*A*), where population centers coincide with areas in which the Floridan aquifer system is at or near land surface (Bellino, 2017). Use of the Floridan aquifer system in south Florida for domestic self-supplied purposes is restricted by aquifer depth and water quality (Marella and Berndt, 2005; Miller, 1990; Parker and others, 1955). Average domestic self-supplied withdrawals from the Floridan aquifer system for the period 1995–2010 totaled 185 Mgal/d (tables 6 and 7). Two counties, Marion and Orange (fig. 24*A*), each withdrew 10 Mgal/d or more and accounted for 14 percent (25 Mgal/d) of domestic self-supplied withdrawals (Bellino, 2017). One hundred and seventeen counties reported withdrawals of less than 1 Mgal/d and constituted 21 percent (39 Mgal/d) of domestic self-supplied withdrawals (Bellino, 2017). The population served by domestic self-supplied was greater than 100,000 in Marion County, Fla. (Bellino, 2017) (fig. 24*B*).

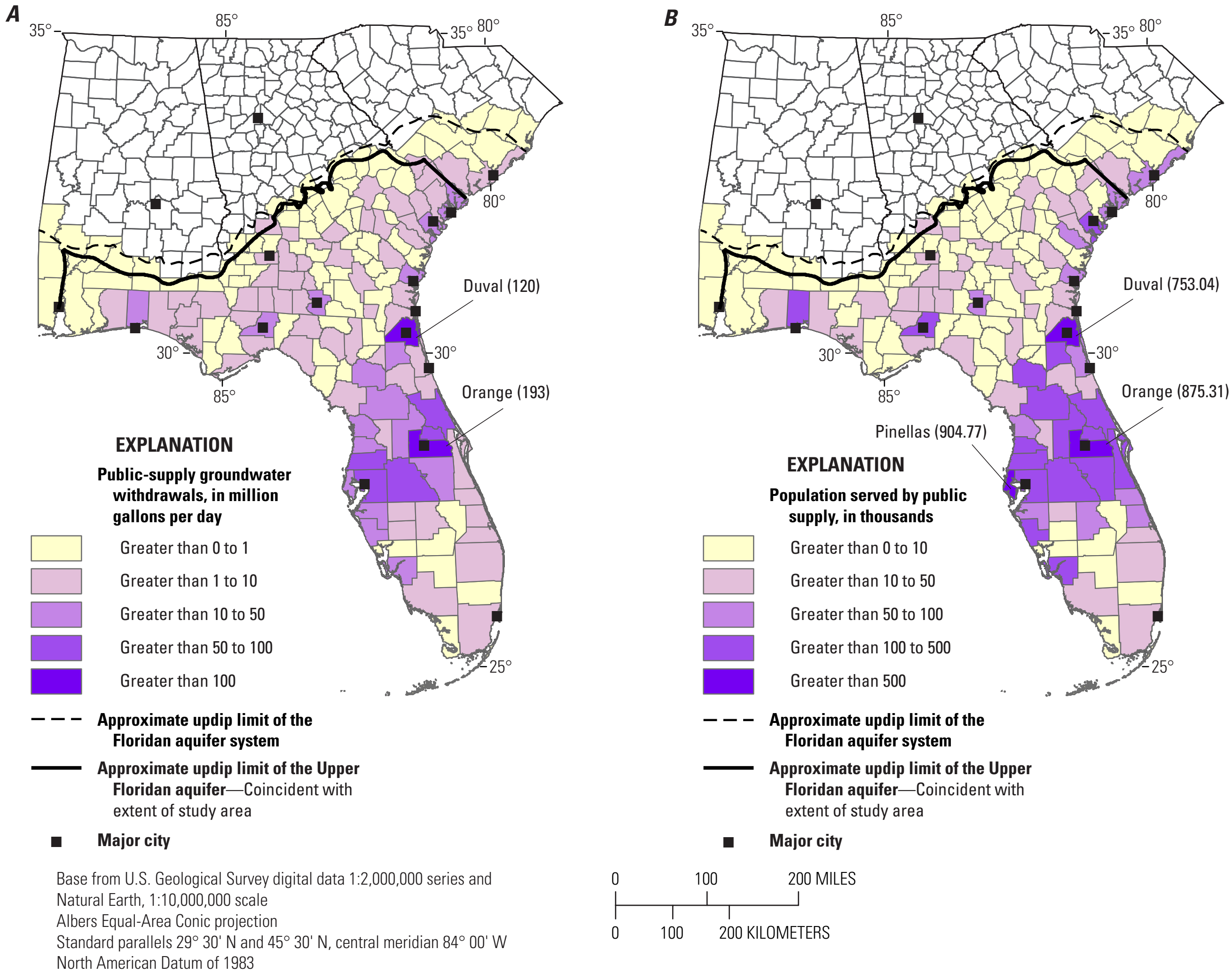


Figure 23. *A*, Average public-supply groundwater withdrawals from the Floridan aquifer system by county and *B*, population served by public supply from the Floridan aquifer system, southeastern United States, 1995–2010 (data from Bellino, 2017).

Irrigation

Irrigation withdrawals, as defined herein, include livestock and golf course irrigation in addition to agricultural irrigation. The southeastern United States is a substantial producer of many important agricultural crops, such as cotton, corn, peanuts, citrus, nuts, soybeans, strawberries, blueberries, sugarcane, melons, and tomatoes (U.S. Department of Agriculture, 2009). Many of these crops are irrigated with groundwater from the Floridan aquifer system to supplement precipitation.

The period from 1995 to 2010 is characterized by relatively stable groundwater withdrawals, with a spike in 2000 (table 6) caused by a 5-year drought from 1998 through 2002. In 2000, irrigation withdrawals increased by 40 percent (561 Mgal/d) from 1995 to 1,949 Mgal/d (table 6). Average irrigation withdrawals from the Floridan aquifer system for the period 1995–2010 totaled 1,551 Mgal/d (tables 6 and 7). Polk County, Fla. (fig. 25*A*), withdrew 108 Mgal/d and accounted for 7 percent of all irrigation withdrawals (Bellino, 2017). The 10 counties with the greatest average withdrawals, 9 of which are in Florida, accounted for 42 percent (651 Mgal/d) of all withdrawals for irrigation (Bellino, 2017). Forty-six counties reported less than 1 Mgal/d and constituted less than 1 percent (8 Mgal/d) of all withdrawals for irrigation (Bellino, 2017).

The 10 counties with the greatest average withdrawal intensity accounted for 5 percent (5,662 mi^2) of the total area, but for more than 33 percent of the irrigation withdrawals (516 Mgal/d) (Bellino, 2017). Of these counties, half are in Georgia, and the other half are in Florida. Withdrawal intensity of these 10 counties ranged from 0.156 Mgal/d per square mile (Seminole County, Ga.) to 0.069 Mgal/d per square mile (Hardee County, Fla.) (Bellino, 2017) (fig. 25*B*). It is notable that Seminole County, Ga., the largest user in terms of withdrawal intensity, was the 11th largest user in terms of actual withdrawals (41 Mgal/d) (Bellino, 2017) (fig. 25*A*).

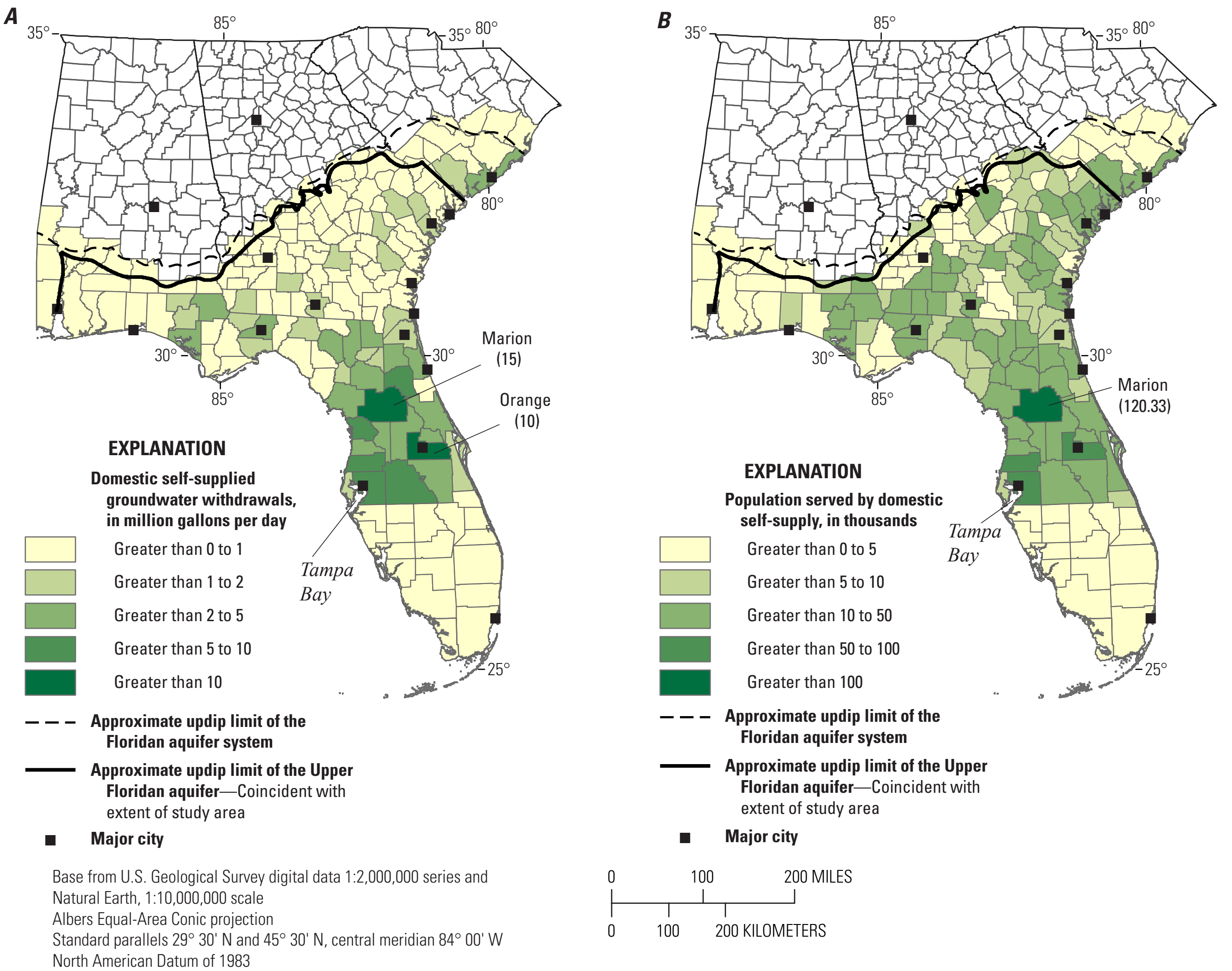


Figure 24. *A*, Average domestic self-supplied groundwater withdrawals from the Floridan aquifer system by county and *B*, population served by domestic self-supply from the Floridan aquifer system, southeastern United States, 1995–2010 (data from Bellino, 2017).

Industrial

Industrial groundwater withdrawals include water used for transportation and in the production of food, paper, chemicals, refined petroleum, or metals (Hutson and others, 2004). Herein, industrial withdrawals also include water used for mining, commercial uses, and power generation. Between 1995 and 2010, industrial withdrawals decreased by 30 percent (124 Mgal/d) (table 6). The single largest decrease over that period was a 34-Mgal/d reduction in Camden County, Ga., mostly as a result of the shutdown of the St. Mary's paper plant in October 2002 (Peck and others, 2005).

Average industrial withdrawals from the Floridan aquifer system for the period 1995–2010 totaled 397 Mgal/d (tables 6 and 7). Wayne County, Ga., withdrew 60 Mgal/d and accounted for 15 percent of industrial withdrawals (Bellino, 2017) (fig. 26). Ten counties each withdrew more than 10 Mgal/d and accounted for 78 percent (308 Mgal/d) of industrial withdrawals (Bellino, 2017). One hundred and thirty-five counties reported less than 1 Mgal/d and accounted for 5 percent (19 Mgal/d) of industrial withdrawals (Bellino, 2017).

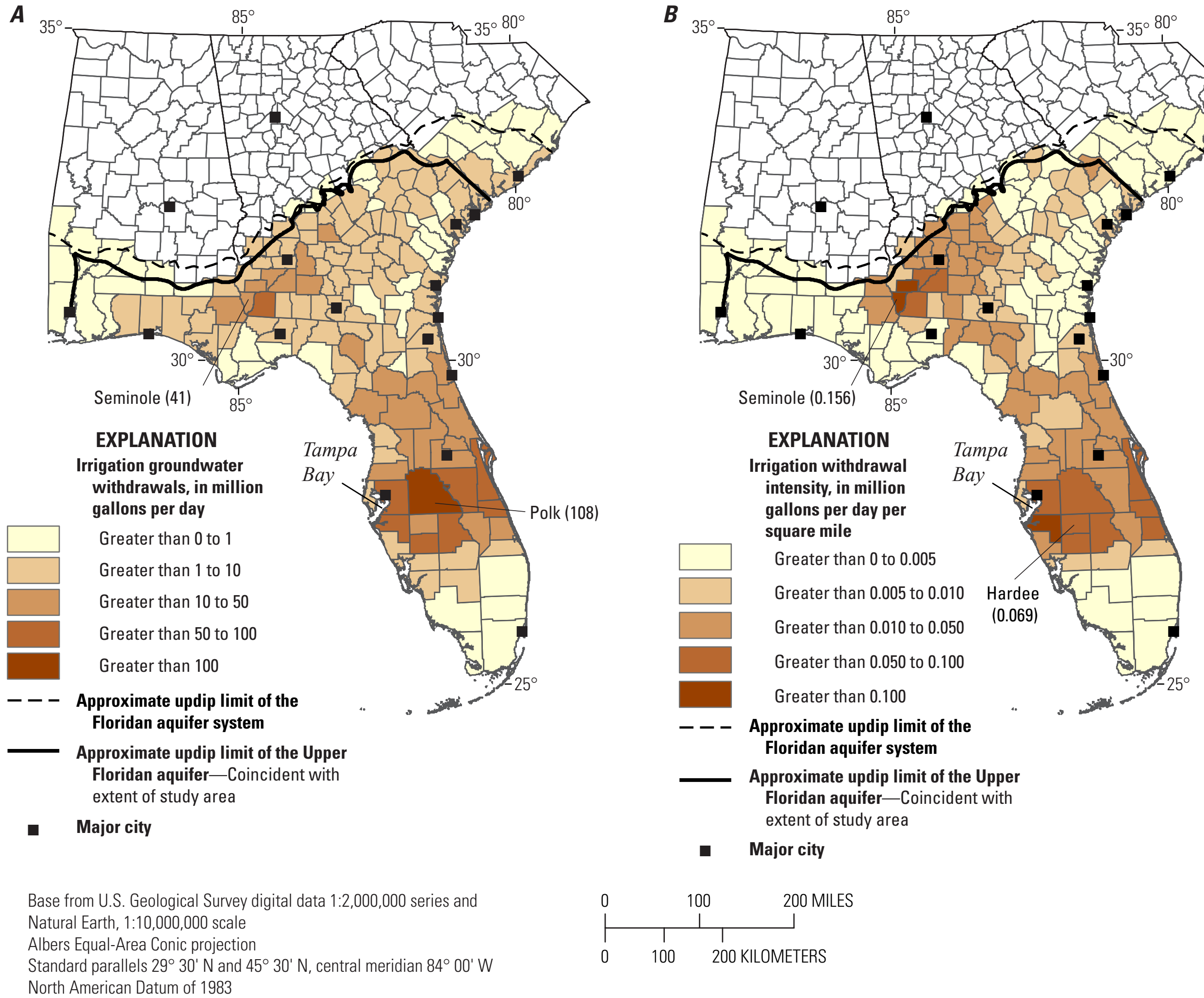


Figure 25. *A*, Average irrigation groundwater withdrawals from the Floridan aquifer system by county and *B*, irrigation withdrawal intensity from the Floridan aquifer system by county, southeastern United States, 1995–2010 (data from Bellino, 2017).

Coastal Discharge

Groundwater that discharges offshore is referred to as “coastal discharge” or “submarine groundwater discharge” (SGD) and remains a largely unknown component of the groundwater budget for the groundwater flow system. Although some SGD may issue from submerged springs, most occurs as diffuse upward leakage through the seafloor and varies throughout the year according to heads in the aquifer and tidal variations on both short-term (semidiurnal) and long-term (seasonal, spring, and neap) timeframes (Burnett and others, 2003; Chanton and others, 2003; Lambert and Burnett, 2003; Li and others, 2009). SGD is often a mix of fresh or brackish water from the groundwater system (surficial aquifer system, intermediate aquifer system, and Floridan aquifer system) and recirculated seawater but may also be composed almost entirely of water from one source or the other depending on the local geology and hydraulic head conditions (Li and others, 2009; Smith and Zawadzki, 2003; Taniguchi and others, 2002).

Various measurement methods indicate that (1) SGD rates are high close to shore and decrease exponentially with distance from shore with some variation related to heterogeneity of sediments, (2) SGD rates vary widely through the tidal cycle, and (3) SGD derived from fresh groundwater is a small percentage of the total SGD (Burnett and others, 2002; Lambert and Burnett, 2003; Li and others, 2009; Moore, 2003; Smith and Robbins, 2012; Smith and Zawadzki, 2003; Taniguchi and others, 2002, 2003).

Studies of SGD within the study area have mostly been conducted in Florida on the gulf coast where the Floridan aquifer system is relatively close to land surface. The range of SGD rates in Tampa Bay estimated from multiple surface-water samples collected during two separate periods (June 2003 and August 2003) with a geochemical model of the mass balance of excess radium-226 by Swarzenski and others (2007,

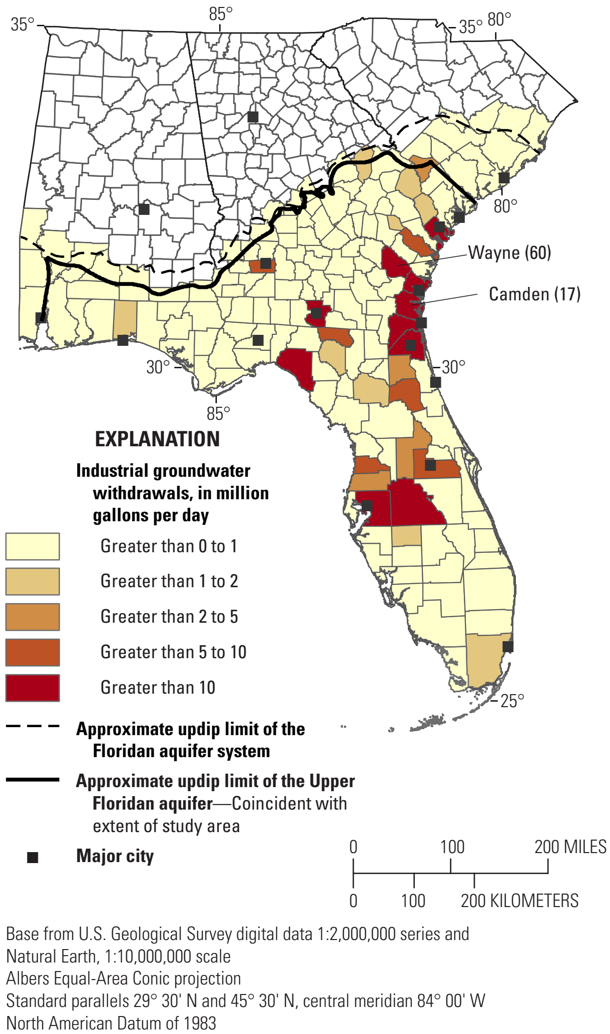


Figure 26. Average industrial groundwater withdrawals from the Floridan aquifer system by county, southeastern United States, 1995–2010 (data from Bellino, 2017).

table 5) was 2.2–14.5 liters per square meter per day (0.09–0.6 inch per day [in/d]) over the entire bay (1.03×10^9 square meters [m^2]). Smith and Swarzenski (2012) estimated SGD rates at the Pinellas County coast ranging from 1.0 to 5.9 in/d, and Smith and Robbins (2012) estimated SGD rates ranging from 0.0 to 1.7 centimeters per day (0 to 0.67 in/d) along the coast of west-central Florida. SGD was studied extensively at a research site near the Florida State University Marine Laboratory (FSUML) southwest of Tallahassee, Fla., during August 2000 by using multiple methods including seepage meters (Lambert and Burnett, 2003; Taniguchi and others, 2003), radium isotopes (Moore, 2003), radon-222 (Lambert and Burnett, 2003), and a variable-density groundwater flow model (Smith and Zawadzki, 2003). The daily averaged SGD, based on field-based measurements, agreed well and ranged from 1.5 to 2.5 cubic meters per minute (m^3/min) (4.3 to 7.1 in/d) over a 20,000-square-foot (ft^2) area encompassing two shore-normal transects, each 200 meters (m) long and separated by a distance of 100 m (Lambert and Burnett, 2003). Smith and Zawadzki (2003), however, reported rates of SGD that were two to three orders of magnitude lower as indicated by a groundwater flow model of the site and concluded that circulation of seawater through the surficial aquifer system via tidal pumping may be an important process contributing to overall SGD. Li and others (2009) developed another variable-density groundwater flow model of the study site and reported that rates of SGD ranged from 2.7 to 5.6 cubic meters per meter per day (m^3/m/d) (1.1 to 2.2 in/d) over a 13,000-ft^2 (1,200-m^2) area, similar to those of Lambert and Burnett (2003), Moore (2003), and Taniguchi and others (2003). Additionally, Li and others (2009) found that the freshwater component of SGD accounted for 5–49.6 percent of total SGD (0.09–1.9 m^3/m/d [0.4–0.7 in/d]). Cable and others (1996) collected a total of 206 water samples across a study area of 620 square kilometers (240 mi^2) in the northeastern Gulf of Mexico near the FSUML study site. Based on an analysis of radon-222, total SGD flux was estimated to be between 180 and 710 cubic meters per second (1.0 and 3.9 in/d).

These studies represent measurements over a snapshot in time at only a few transects or sample locations, which makes them difficult to use for estimation of average total SGD over the entire coastline or the freshwater contribution to the total. Coastal discharge from the Floridan aquifer system is thought to be characterized primarily by diffuse upward leakage that is limited to nearshore areas where the Floridan aquifer system is unconfined and extending farther offshore where hydraulic heads in the confined portions of the aquifer have pushed the freshwater-saltwater interface seaward, though rates may be small because of low-permeability confining units restricting vertical leakage (Bush and Johnston, 1988). Although measurements of SGD derived from the Floridan aquifer system are not available, if it is assumed that all SGD emanating along the 236-mi coastline from Tallahassee to Tampa (where the Floridan aquifer system is unconfined) and within 1 mi of the shoreline is derived from the Floridan aquifer system, a rough estimation of freshwater SGD along the west-central Florida coast may be obtained by multiplying the area over which SGD may occur (236 mi^2) by a nominal seepage rate of 0.8 in/d and a correction factor of 0.05 to account for recirculating seawater (Li and others, 2009). This rate, approximately 300 ft^3/s (200 Mgal/d), is about 2 percent of the combined average rates of recharge for the Thomasville-Tallahassee, Suwannee, and West-central Florida groundwater basins, described earlier.

Rates of SGD from the Floridan aquifer system may be much greater where submerged spring vents focus groundwater discharge from the aquifer system. Many such springs have been anecdotally reported by fishermen, but few have been verified or studied. The hydrogeology of Crescent Beach Spring, however, located about 2.5 mi east of Crescent Beach, Fla. (fig. 1), was studied in detail and was estimated to flow at a rate as high as 1,500 ft^3/s (970 Mgal/d) (Brooks, 1961; Swarzenski and Reich, 2000). Freshwater is known to exist 55 mi east of Fernandina Beach, Fla. (fig. 1), at a depth of about 1,100 ft (Johnston and others, 1982, p. 82), and although the upper confining unit is thicker in this area, the potential for additional focused SGD from the Floridan aquifer system exists.

In total, the estimated coastal discharge from the Floridan aquifer system (diffuse upward leakage along the coast between Tampa and Tallahassee [fig. 1] plus measured discharge at Crescent Beach Spring) equals 1,800 ft^3/s (1,170 Mgal/d), which is about 3 percent of the recharge to the Floridan aquifer system where the surficial aquifer system and intermediate aquifer system are absent (table 4).

Change in Groundwater Storage

Although groundwater development first occurred in the late 1800s, large withdrawals from the Floridan aquifer system did not begin until after 1950 (Miller, 1986). The surficial aquifer system is a less-developed source of fresh groundwater over most of its area, having large withdrawals in the Biscayne aquifer of 812 Mgal/d in 2000 and 650 Mgal/d over other parts of the surficial aquifer system area in 2000 (Maupin and Barber, 2005). Williams and others (2011) examined rates of groundwater-level decline in the Floridan aquifer system and were able to quantitatively demonstrate long-term groundwater-level declines (also referred to as “groundwater mining”) in confined areas with small declines in unconfined areas. The volumetric change in storage associated with changes in groundwater levels is estimated as the product of the storage coefficient, the estimated change in groundwater levels, and the area over which the changes occur (Konikow, 2013); the storage coefficient represents the amount of water released per unit area of aquifer given a unit change in head and is dimensionless. Long-term changes in storage for the Floridan aquifer system were estimated by using computed groundwater-level changes for predevelopment (assumed to end December 31, 1884) to May 1980 and for predevelopment to May–June 2010 (fig. 15).

Representative storage properties from aquifer tests compiled in Kuniansky and Bellino (2012) were used to compute change in storage for confined parts of the Floridan aquifer system, which have an average storage coefficient of 0.0004. Only 54 aquifer tests within the unconfined areas of the Upper Floridan aquifer have available estimates of storage properties, most of which were very small and similar to those for confined parts of the Upper Floridan aquifer. It is thought that the duration of these tests was not sufficient to determine specific yield, and a representative storage coefficient of 0.004 was applied for unconfined parts of the Floridan aquifer system (Leonard Konikow, U.S. Geological Survey, written commun., October 16, 2014). The surficial aquifer system is generally composed of unconsolidated sediments, where specific-yield values typically range from 0.01 to 0.35 (Johnson, 1967).

No potentiometric surface map exists for the entire Floridan aquifer system for 1995. Change in storage in the Floridan aquifer system for the current conditions (1995–2010) period was therefore approximated as the difference in storage changes calculated for the periods from predevelopment to May 1980 and predevelopment to May–June 2010. The estimated change in storage for the unconfined, confined, and total area of the Upper Floridan aquifer is shown in table 9 by each groundwater basin for predevelopment to May 1980, from May 1980 to May–June 2010, and from predevelopment to May–June 2010. Negative values in table 9 indicate a decrease in storage within the aquifer (declining groundwater level). The rates of change in storage in the Floridan aquifer system are generally very low, although there is a fairly wide range in the change in storage rates among basins and within basins (driven primarily by differences in the degree of aquifer confinement) with some areas having positive rates indicating a groundwater-level rise; the range for individual basins and areas and time periods is from -3.0 to 0.7 Mgal/d. The change in storage over the entire area from predevelopment to May–June 2010 was -3.7 Mgal/d (-0.10 in/yr; -0.64 cubic kilometer [km^3]), and all of the storage loss is attributable to thinly confined and confined parts of the Floridan aquifer system where recharge to the groundwater flow system was outpaced by groundwater withdrawals. The Southeast Georgia-Northeast Florida-South South Carolina groundwater basin accounted for 59 percent (-2.2 Mgal/d; -0.02 in/yr; -0.38 km^3) of the total change; decreases in groundwater levels in excess of 100 ft from predevelopment to May–June 2010 have been recorded in these areas (fig. 15). The highest rates of storage loss occurred from May 1980 to May–June 2010 when the rate of storage change was -6.5 Mgal/d (-0.14 in/yr; -0.27 km^3) and the Southeast Georgia-Northeast Florida-South South Carolina groundwater basin accounted for 46 percent (-3.0 Mgal/d; -0.03 in/yr; -0.12 km^3) of the change. Although groundwater levels change seasonally in the unconfined and thinly confined parts of the system, as indicated by the hydrographs in figure 16, long-term declines are not as pronounced in these areas. When compared to net recharge for current conditions (33,700 Mgal/d; table 4), the estimated change in storage in the Floridan aquifer system for predevelopment to May–June 2010 (-3.7 Mgal/d) is relatively small; these changes, however, can be a locally important issue for resource managers.

Change in storage in the surficial and intermediate aquifer systems varies between wet and dry periods and could be substantial. Estimated changes in storage were computed by using the groundwater-level-change and storativity method described in Konikow (2013) for the period 1995–2010, as there are no predevelopment or postdevelopment potentiometric maps for the surficial aquifer system and even fewer groundwater-level data for comparison over time. A range of specific-yield values (0.1–0.3) for similar

Table 9. Estimated changes in storage in the Upper Floridan aquifer in the study area, southeastern United States, by subregion, predevelopment to May–June 2010.

[Units are million gallons per day. Predevelopment is assumed to end December 31, 1884, for computational purposes. Negative values indicate decreases in storage. Reported precision does not imply accuracy; --, not applicable]

Subregion	Unconfined areas			Thinly confined areas			Confined areas			All areas		
	[1]Predev-elopment to May 1980	[2]May 1980 to May–June 2010	[3]Predev-elopment to May–June 2010	[1]Predev-elopment to May 1980	[2]May 1980 to May–June 2010	[3]Predev-elopment to May–June 2010	[1]Predev-elopment to May 1980	[2]May 1980 to May–June 2010	[3]Predev-elopment to May–June 2010	[1]Predev-elopment to May 1980	[2]May 1980 to May–June 2010	[3]Predev-elopment to May–June 2010
Groundwater basin												
Panhandle	0.0	-0.3	-0.1	0.0	0.0	0.0	-0.2	-1.2	-0.5	-0.3	-1.6	-0.6
Dougherty Plain-Apalachicola	0.6	-1.0	0.2	0.1	0.0	0.1	0.0	0.0	0.0	0.7	-1.0	0.3
Thomasville-Tallahassee	0.0	0.1	0.0	-0.1	0.1	0.0	0.0	-0.2	-0.1	0.0	-0.1	-0.1
Southeast Georgia-Northeast Florida-South South Carolina	-0.2	-0.4	-0.2	-0.6	-1.4	-0.8	-1.2	-1.2	-1.2	-2.0	-3.0	-2.2
Suwannee	0.2	0.0	0.1	0.0	-0.8	-0.2	0.0	0.0	0.0	0.1	-0.8	-0.1
West-central Florida	-0.1	0.0	-0.1	-0.3	0.2	-0.1	-0.3	0.0	-0.2	-0.6	0.2	-0.4
East-central Florida	0.0	-0.1	0.0	-0.4	-0.4	-0.4	-0.1	0.0	-0.1	-0.5	-0.4	-0.5
South Florida	--	--	--	--	--	--	-0.2	0.1	-0.1	-0.2	0.1	-0.1
Upper Floridan aquifer extent	**0.5**	**-1.7**	**0.0**	**-1.4**	**-2.2**	**-1.6**	**-1.9**	**-2.6**	**-2.1**	**-2.8**	**-6.5**	**-3.7**

[1]Computed by potentiometric map subtraction (May 1980 minus predevelopment).

[2]Computed as the difference between potentiometric map subtraction for (a) May 2010 minus predevelopment and (b) May 1980 minus predevelopment.

[3]Computed by potentiometric map subtraction (May 2010 minus predevelopment).

aquifers (Johnson, 1967) and the estimated area over which groundwater-level changes occurred (41,500–83,000 mi^2) were used to bracket estimates of surficial and intermediate aquifer systems storage changes. A limited analysis of groundwater-level data from NWIS (U.S. Geological Survey, 2016) was undertaken by using 24 wells with aquifer codes corresponding to the surficial aquifer system, most of which were located in central and south Florida. Groundwater-level change was computed by subtracting water levels measured on January 1, 1995, from those measured on December 31, 2010 (table 10). The analysis indicated that groundwater levels in the surficial aquifer system changed by -3.26 ft (1995–2010) and that the associated bracketed estimate of the rate of change in storage was -500 to -2,900 Mgal/d (-11 to -64 km^3) for 1995–2010, which is 1.5 to 8.6 percent of net recharge (33,700 Mgal/d), respectively.

Table 10. Computed groundwater-level differences for January 1, 1995, to December 31, 2010, for selected surficial aquifer system wells in the study area, southeastern United States.

[Data from U.S. Geological Survey, 2016. USGS, U.S. Geological Survey]

USGS site identification number	Water-level altitude difference, in feet
261957081432202	-2.66
315950081161201	-6.45
261000080520001	-1.83
263251081452802	-8.93
264005080233501	-3.41
263138081545801	-0.80
264123080053801	-2.02
263041081433102	-4.85
263850081365401	-4.54
311009084495503	-15.54
263524080124301	-1.90
274240082212702	-0.49
271134082092202	-1.93
263251081452803	-1.43
314330084005403	-4.76
283204081544902	-3.75
263328080085201	-1.47
280058082202202	-3.74
262549082035301	-1.26
282210081352601	-2.61
261124081470101	-0.08
262218080070101	-1.68
262228081361901	-1.44
260111081243901	-0.64

Preliminary Groundwater Budget

The primary groundwater-budget components for the current conditions (1995–2010) of the groundwater flow system are net recharge, discharge to springs, discharge to streams and lakes, groundwater withdrawals, and coastal discharge. The control volume is the freshwater part of all aquifers from land surface to the base of the Floridan aquifer system within the extent of the Upper Floridan aquifer in the study area; therefore, the control volume combines the surficial aquifer system, intermediate aquifer system, and Floridan aquifer system. The inflow component (net recharge) minus the outflow components (discharge to springs, discharge to streams and lakes, groundwater withdrawals, and coastal discharge) equals the change in storage, as indicated by the following equation used to balance the groundwater budget:

$$R_n - (Q_{springs} + Q_{sl} + Q_{wells} + Q_{coastal}) = \Delta S \quad (2)$$

where

R_n is net recharge [L^3T^{-1}],
$Q_{springs}$ is discharge to springs [L^3T^{-1}],
Q_{sl} is discharge to streams and lakes [L^3T^{-1}],
Q_{wells} is discharge from wells [L^3T^{-1}],
$Q_{coastal}$ is coastal discharge [L^3T^{-1}], and
ΔS is change in storage [L^3T^{-1}].

Not all components of the groundwater budget (such as discharge of groundwater to streams and lakes and coastal discharge from the surficial aquifer system) were estimated because there were uncertainties and lack of information, as discussed in previous sections. Internal fluxes of water within the groundwater system (control volume) include upward and downward leakage between the Floridan aquifer system and surficial and intermediate aquifer systems; however, it was beyond the scope of this study to independently estimate these exchanges, and the preliminary groundwater budget presented herein was estimated by using leakage values from Bush and Johnston (1988) and Johnston (1999). A negative change in storage reported in table 9 implies a groundwater-level decline. As water is removed from “storage” it is conceptually another source of inflow to the water budget; it is therefore considered positive in this section. The preliminary groundwater budgets come from the information provided in the previous sections of the report.

Errors associated with the preliminary groundwater-budget components presented herein may be considerable because of the lack of detailed information about the past and current states of individual flow components. Net recharge estimated by the SWB model is sensitive to multiple input parameters (app. 2), and uncertainty could be ±50 percent or more. Where measurements were unavailable, estimates of spring flow were made on the basis of the magnitude class assigned to each spring, and uncertainty is also assumed to be ±50 percent or more. The 1995–2010 rate of change in storage (-3.8 Mgal/d) was estimated for the Floridan aquifer system by using the groundwater-level-change and storativity method described in Konikow (2013) using potentiometric map subtraction with available maps for 1980 and 2010 and assumed to be the same rate for the 1995–2010 period. The change in storage for 1995–2010 in the surficial and intermediate aquifer systems cannot be accurately estimated because of a lack of potentiometric maps and could range from -500 to -2,900 Mgal/d. The uncertainty in storage change for the Floridan aquifer system is assumed to be at least ±50 percent because of the lack of data; however, the total is relatively small (negligible part of the overall water budget). The estimated change in storage for the surficial and intermediate aquifer systems, however, is large (1–6 percent of the net recharge), and the uncertainty is more than ±100 percent.

These preliminary groundwater budgets are presented as tools used to understand the relative magnitudes of sources and sinks in the groundwater system and should be used with caution; they are not intended for use in any regulatory context. A three-dimensional numerical model of the groundwater flow system that explicitly simulates flow within the surficial aquifer system, upper confining unit, intermediate aquifer system, and Floridan aquifer system and is calibrated to hydrologic measurements such as groundwater levels and streamflows would provide more detailed insight into the magnitude and distribution of the groundwater-budget components and how they have changed over time.

Predevelopment

For the predevelopment period (assumed to end December 31, 1884), it is assumed that flows to and from the groundwater system were balanced and the system was in a state of dynamic equilibrium with no long-term net changes in storage. Net recharge was the sole source of inflow to the system, and outflows included spring discharge and coastal discharge. It is assumed herein that the average rate of net recharge to the groundwater system has not changed substantially over time, and therefore the SWB-simulated average rate of net recharge for current conditions also was used for predevelopment (fig. 27*A*). Net recharge (current) to the Floridan aquifer system (which only occurs where the surficial aquifer system and intermediate aquifer system are absent) estimated by the SWB model is 14,500 Mgal/d and to the surficial and intermediate aquifer systems 19,200 Mgal/d for a total inflow of 33,700 Mgal/d (table 4). Net recharge to the Floridan aquifer system (14,500 Mgal/d) is greater than the 13,900 Mgal/d of recharge derived from the steady-state simulation of the Floridan aquifer system by Bush and Johnston (1988) (reported in table 2 of Johnston, 1999) partly because of the large size (8 mi by 8 mi) of the grid cells in the Bush and Johnston model—any recharge and discharge occurring entirely within the 64-mi^2 area of a given model cell is not simulated and therefore not included in their water budget—and because different methods were used to compute the rate of recharge.

Current Conditions

Most of the flow into the current groundwater system (fig. 27*B*) for the current conditions period (1995–2010) comes from net recharge and is assumed to be the same as estimated for predevelopment (fig. 27*A*), with only a minor amount (approximately 1,000 Mgal/d) coming from anthropogenic recharge (not shown), which is within the margin of error of the water budget. Net storage loss could be 500–2,100 Mgal/d and is primarily from the surficial and intermediate aquifer systems; the conservative estimate of storage loss (500 Mgal/d) is used in the preliminary groundwater budget. Net storage loss in the Floridan aquifer system was less than 100 Mgal/d. Spring discharge (-7,700 Mgal/d or -12,000 ft^3/s) was estimated on the basis of available measurements, as described earlier and listed in table 5. Groundwater withdrawal data for the Floridan aquifer system (-3,400 Mgal/d) and surficial and intermediate aquifer systems (-1,800 Mgal/d) are from Bellino (2017).

This analysis indicates that flow through the groundwater system has changed over time from predevelopment to current conditions primarily because of groundwater withdrawals. These withdrawals are balanced by removal of water from storage, reductions in discharge to streams and lakes, and reductions in discharge to springs. It should be noted, however, that other variables that affect the water budget, such as reductions in coastal discharge, reduced ET due to a lowering of the water table, and changes in meteorological conditions and (or) climate, may be partly responsible for changes in the groundwater flow system, but were not explored in depth for this report.

Conceptual water budgets of the groundwater flow system were not developed for dry (2000) and wet (2005) conditions; however, a summary of conditions and select budget components are presented for context. The southeastern United States underwent a multiyear drought from 1998 through 2002; the 12-month period from September 1999 through August 2000 was the driest on record during that drought, and most of the study area ranked from severe to extreme on the Palmer Drought Index (National Oceanic and Atmospheric Administration, 2000). From January through December 2000, precipitation was 41.9 in., and net recharge was 3.9 in. (78 and 52 percent, respectively, of average current conditions computed for 1995–2010). Groundwater withdrawals from the Floridan aquifer system increased, mainly for irrigation purposes, and were 17 percent greater than the period average computed for 1995–2010. Estimates for change in storage in the surficial aquifer system during the 12-month dry period range from -10,500 Mgal/d to -1,800 Mgal/d, depending on the specific yield and area.

The wet conditions analysis reflects a period of record-breaking tropical activity in the Atlantic basin (National Weather Service, 2007), during which time several tropical storms affected parts of the study area, including Hurricanes Cindy, Dennis, Katrina, Rita, and Wilma. In 2005, precipitation was 61.9 in., and net recharge

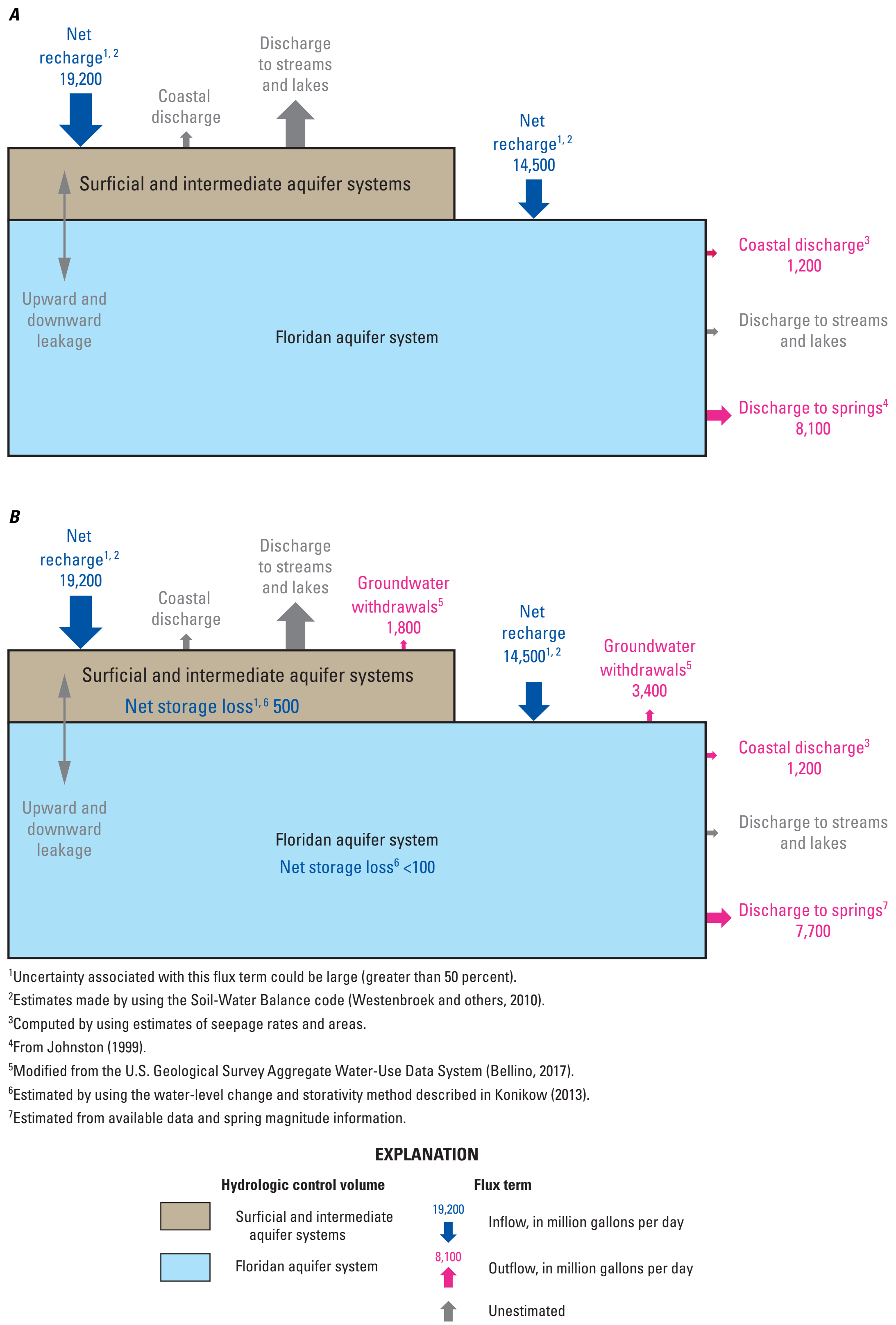


Figure 27. Preliminary groundwater budget for *A*, predevelopment and *B*, current conditions (1995–2010) (budget terms are reported to the nearest 100 million gallons per day).

was 9.3 in. (113 and 124 percent, respectively, of average current conditions computed for 1995–2010). Groundwater withdrawals from the Floridan aquifer system were 8 percent lower than the period average computed for 1995–2010. Estimates for change in storage in the surficial aquifer system during dry conditions range from an increase of 4,400 Mgal/d to an increase of 26,300 Mgal/d, depending on the specific yield and area.

Variability in Precipitation and Evapotranspiration

Precipitation in the study area varies considerably from year to year; annual precipitation rates over the entire study area were computed by using monthly precipitation data from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) (Daly and others, 1994). Output from the PRISM is available at a 2.5-arc-minute grid spacing for the conterminous United States (PRISM Climate Group, 2013). Median precipitation for the study area from PRISM output ranged from about 35 to 70 in/yr between 1900 and 2010 (fig. 28). During 2000, about 94 percent of the study area received less than the computed 1900–2010 average precipitation of 52.7 in., whereas during 2005, only about 16 percent of the study area received less than the long-term average. The period average for 1995–2010 was below the 1900–2010 PRISM output average throughout 36 percent of the study area. The Daymet model (Thornton and others, 1997) data were at a finer, 1-km resolution than the PRISM output, but output from Daymet extends as far back as only 1980. Daymet output was used for SWB calculations (1995–2010) and to illustrate spatial variability in the study area. On average, the wettest parts of the study area are generally the panhandle region and south Florida south of Lake Okeechobee, with relatively drier areas in north-central peninsular Florida and inland Georgia and South Carolina (fig. 29*A*). The annual total Daymet precipitation output (Thornton and others, 2012) used for the soil-water-budget computations agreed with annual precipitation estimates from PRISM output for the study area (average annual difference = +4.7 percent; standard deviation = 3.4 percent). Thornton and others (1997, p. 235), however, indicated that "[mean absolute errors] obtained from simple differences in annual totals and from percentages of observed annual totals are 13.4 cm and 19.3%, respectively," for the northwestern United States during validation of the Daymet algorithm. The error in precipitation can propagate into substantial error in estimated net recharge.

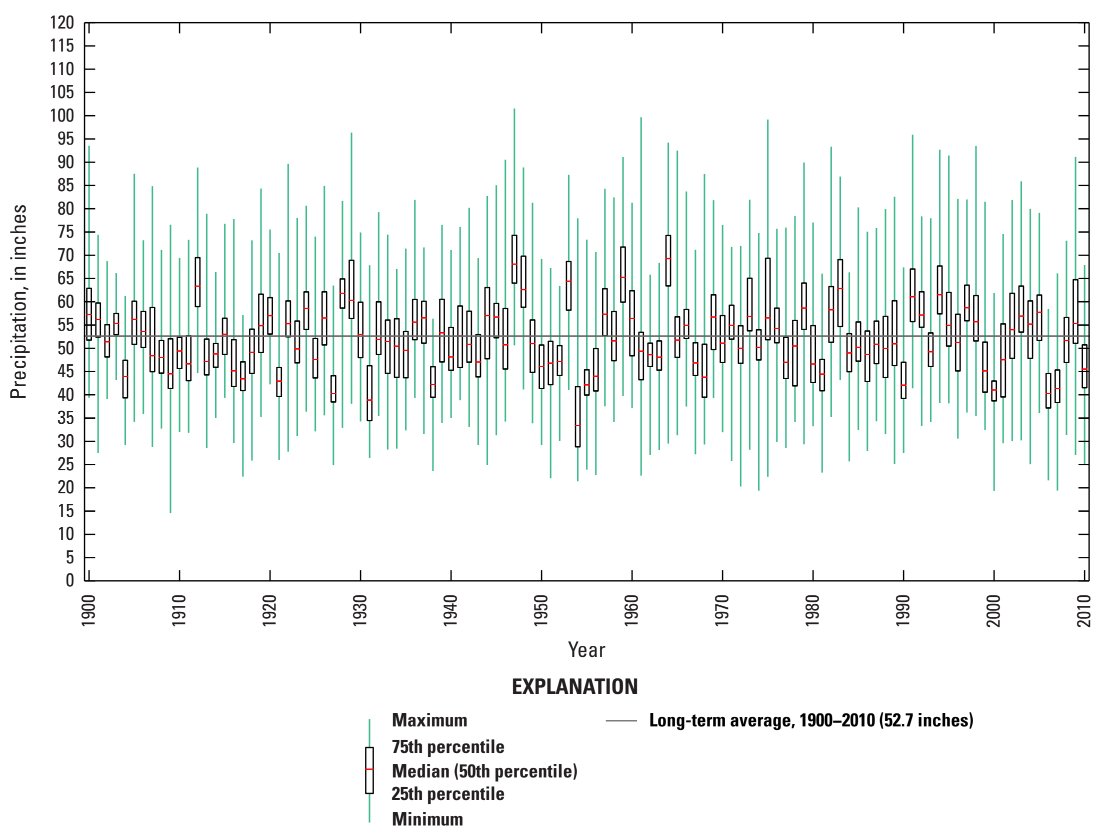


Figure 28. Variability of annual precipitation in the study area, southeastern United States, 1900 through 2010 (computed from monthly data from PRISM Climate Group, 2013).

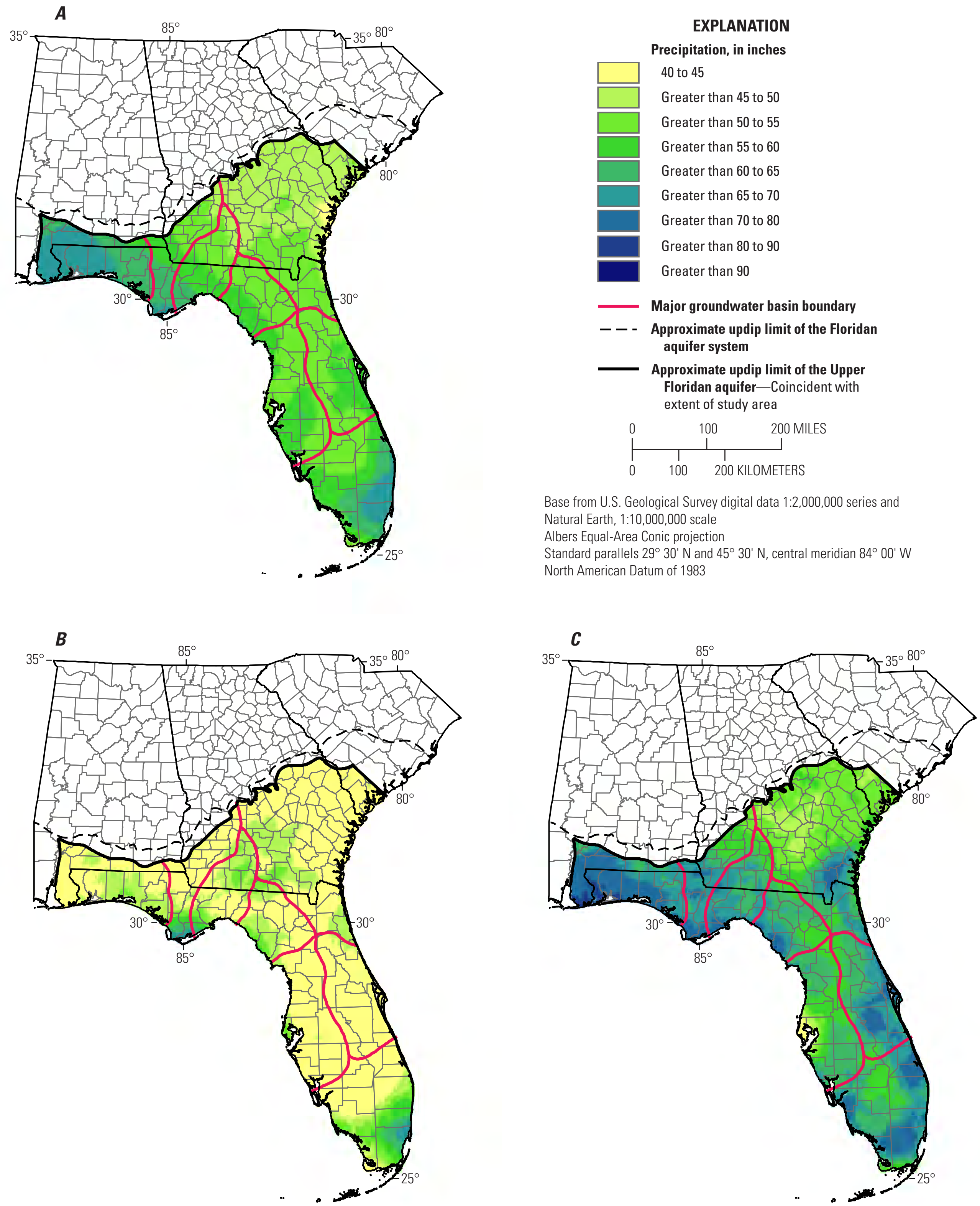


Figure 29. Precipitation for *A*, current conditions (1995–2010), *B*, dry conditions (2000), and *C*, wet conditions (2005), southeastern United States (data from Thornton and others, 2012).

Reference evapotranspiration (RET) is an estimate of evaporation and transpiration from a well-water grass surface, computed by using methods such as described by Mecikalski and others (2011). Estimates of RET are available for Florida at a 2-km grid spacing from U.S. Geological Survey (2015). For dry conditions (2000), the average annual rate of RET simulated by SWB (59.9 in., fig. 30*B*) in Florida is 5.8 in. greater than the RET computed from the Florida-wide USGS RET product for 2000 (54.1 in.). The RET was lower for wet conditions than for dry conditions (SWB-estimated RET was 56.1 in., and Florida-wide USGS RET product was 52.5 in.), and the difference between the two estimates (3.6 in.) was relatively small. Differences in RET estimates between the SWB model and the Florida-wide USGS RET product where coincident are likely due to differences in the methods used to compute RET. The Hargreaves-Samani equation (Hargreaves and Samani, 1985) was used by the SWB model, although it can overestimate RET in humid climates (Raziei and Pereira, 2013), because it was the only method for which SWB provides spatially distributed RET estimates, whereas the USGS RET product was computed by using the Penman-Monteith equation (Allen and others, 1998; Monteith, 1965; Penman, 1948). Differences may also be related to average absolute errors in daily-minimum and daily-maximum air temperature in the Daymet air temperature data used by the SWB model. Data validation results for the northwestern United States show that the average absolute errors were 0.7 and 1.2 degrees Celsius (°C), with biases of +0.1 and –0.1 °C for average daily-maximum and daily-minimum air temperatures, respectively (Thornton and others, 1997). The error in RET can propagate into error in estimated net recharge. Overall, the SWB model estimate is approximately 10 percent different from the RET computed from the Florida-wide USGS RET product.

Climate Change and Groundwater Resources

Climate projections indicate increasing air temperature, changes in precipitation patterns, hurricanes of greater intensity, increased drought frequency, and sea-level rise in the study area (Heimlich and others, 2009; Heimlich and Bloetscher, 2011; Karl and others, 2009; Strzepek and others, 2010; Thieler, 2000; Thieler and Hammar-Klose, 1999). If these projections are realized, the resulting changes would have an effect on groundwater availability.

From 1970 to 2008, average annual air temperatures in the southeastern United States increased by 1.6 °F, and winters have become warmer (Karl and others, 2009). Average annual air temperatures are projected to increase by 4.5 to 9.0 °F by 2080 (Karl and others, 2009). Over much of the study area, average precipitation is projected to increase slightly, with the exception of south Florida, which is projected to become drier (Ingram and others, 2013). Most climate models indicate that the increased precipitation will be more frequently in the form of heavy thunderstorms and hurricanes with increased dry periods, increasing the frequency of floods and droughts (Karl and others, 2009). Notably, autumn precipitation has increased since 1901, whereas spring and summer precipitation has decreased, resulting in seasonal drought (Karl and others, 2009).

Even if average precipitation increases slightly, rising air temperatures will increase ET, potentially resulting in less net groundwater recharge to the aquifers. If spring and summer become drier, then more water will be required for irrigation of crops, increasing agricultural water demand, which is already a large component of groundwater withdrawals. The more confined areas of the Floridan aquifer system have lost water from storage as expressed by long-term groundwater-level declines. In south Florida, groundwater levels drop substantially during the dry season, affecting wetlands. South Florida is expected to undergo a longer dry season and more severe droughts, with a 10- to 15-percent reduction in annual precipitation and more flooding during storms (Heimlich and Bloetscher, 2011).

Stronger hurricanes (increased storm surge) along with rising sea level increase the risk of flooding, beach erosion, and property damage along the coast (Thieler, 2000; Thieler and Hammar-Klose, 1999). Sea-level rise over the past 80 years has already increased the amount of time that coastal land is inundated in storm surge at Atlantic City, New Jersey (Zhang and others, 1997). Sunny-day street flooding is becoming a common occurrence at high tide in Miami, Fla., in recent years because of the current increase in sea level (Davenport, 2014). Wigley and Raper (1992) expected sea level to rise globally another 0.5 to 3 ft by 2100. In Miami, Fla., the expected rise by 2100 is projected to be 2–5 ft (Heimlich and Bloetscher, 2011). Higher sea level affects coastal infrastructure, safety, and coastal ecosystems; moreover, over time it will increase saltwater intrusion into the aquifers in the study area, especially the Biscayne aquifer, which is composed of high-porosity limestone (Heimlich and others, 2009).

In summary, the projected effect of climate change is a reduction in fresh groundwater in the Floridan aquifer system. At the same time, freshwater demands will increase, especially in agricultural areas. With drier weather projected for the growing season, it is possible that lowered groundwater levels during the dry season will increase the likelihood of formation of sinkholes, a unique effect for this karst aquifer system. An increase in the formation of sinkholes in the Floridan aquifer system during droughts is well documented, and some of the cover-collapse sinkhole lakes, such as Lake Jackson near Tallahassee, Fla., have drained into sinkholes during droughts (Kuniansky and others, 2015; Rupert and Spencer, 2004; Tihansky, 1999).

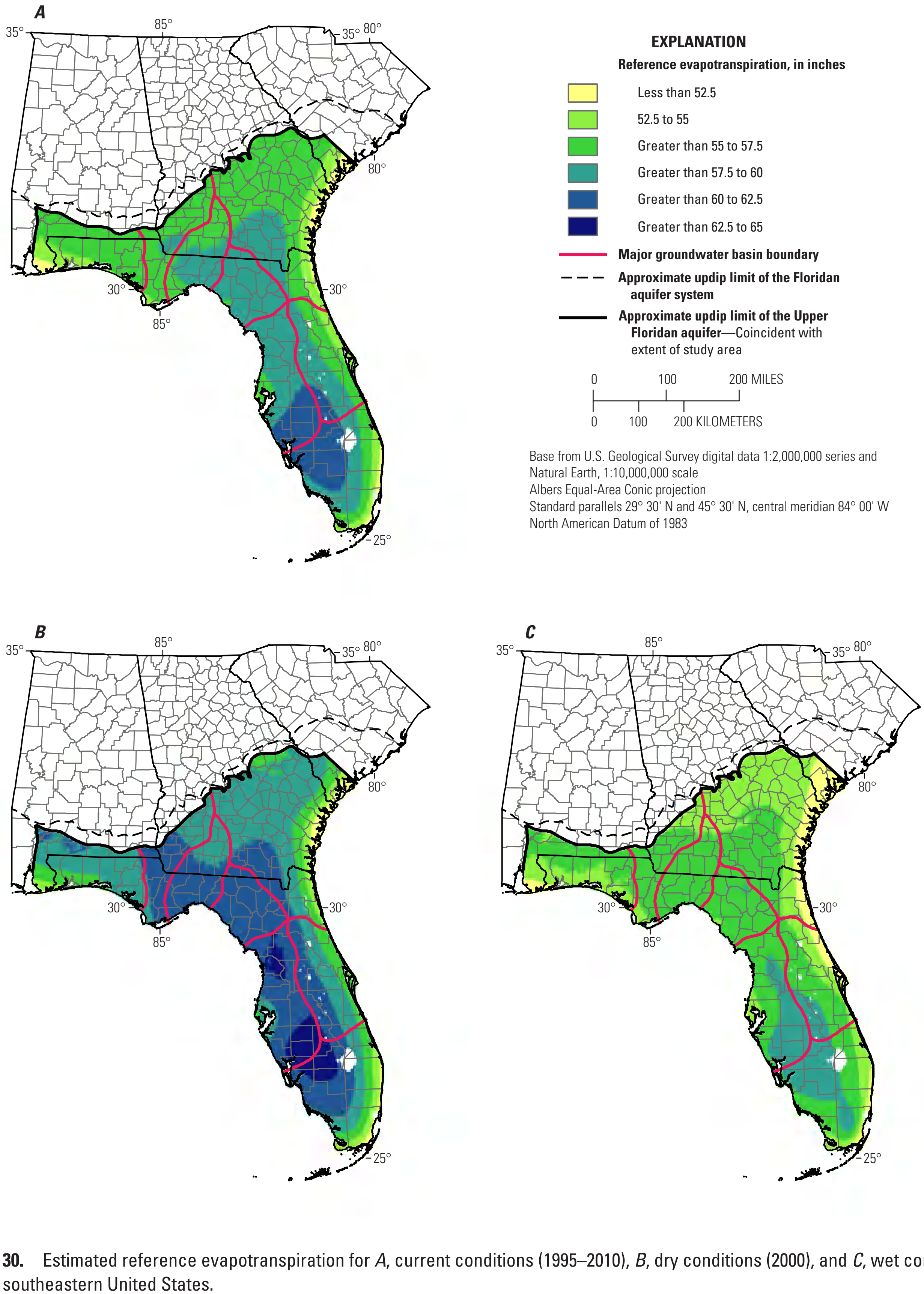


Figure 30. Estimated reference evapotranspiration for *A*, current conditions (1995–2010), *B*, dry conditions (2000), and *C*, wet conditions (2005), southeastern United States.

Summary

The groundwater flow system in Florida and parts of Georgia, Alabama, and South Carolina is dominated by the highly transmissive Floridan aquifer system, which extends over approximately 100,000 square miles. The Floridan aquifer system consists of a sequence of Tertiary carbonate rocks that thickens seaward from the northern boundary of the system. Permeability of the limestones composing the Floridan aquifer system is mainly due to secondary porosity from dissolution of the rock; in areas where the Floridan aquifer system crops out, this dissolution is ongoing, and karst features are evident.

Population growth, increased tourism, increased agricultural production, and variability in precipitation and evapotranspiration have led to increased demand on groundwater from the Floridan aquifer system, particularly since 1950. Increases in groundwater withdrawals to meet increases in demand have caused decreases in aquifer storage, the draining of lakes and wetlands, and saltwater intrusion. The response of the Floridan aquifer system to these stresses often poses regional challenges for water-resource management that commonly transcend political or jurisdictional boundaries.

Concerns that limit the availability of fresh groundwater from the Floridan aquifer system are varied, and there are different permitting and management strategies for each area or State in the study area. Saltwater intrusion is an issue of great concern in Hilton Head Island, S.C., where seawater migrates downward through paleochannels in the seafloor and into the Floridan aquifer system. In other areas, such as Brunswick, Ga., and Fernandina Beach, Fla., saltwater has migrated upward from deeper zones through vertical fractures. Reduced spring discharge, increased nitrates in groundwater, reduced wetland water levels, and reduced streamflow also are key factors in driving management decisions in other parts of the study area.

To help resource managers address these regional challenges, the U.S. Geological Survey (USGS) Water Availability and Use Science Program began assessing groundwater availability of the Floridan aquifer system in 2009. As part of this assessment, the USGS Floridan Aquifer System Groundwater Availability Study will update information provided by the USGS Regional Aquifer-System Analysis (RASA) study of the Floridan aquifer system completed in the 1980s.

The current conceptual groundwater flow system was developed for the Floridan aquifer system and adjacent systems partly on the basis of previously published USGS RASA studies, specifically many of the potentiometric maps and the modeling efforts in these studies, and partly on the basis of the recent update of the hydrogeologic framework. The factors that influence circulation of groundwater within the Floridan aquifer system are highly variable across the Floridan aquifer system extent.

The Floridan aquifer system extent was divided into eight hydrogeologically distinct subregional groundwater basins delineated on the basis of the estimated predevelopment (circa 1880s) potentiometric surface and hydrogeology: (1) Panhandle, (2) Dougherty Plain-Apalachicola, (3) Thomasville-Tallahassee, (4) Southeast Georgia-Northeast Florida-South South Carolina, (5) Suwannee, (6) West-central Florida, (7) East-central Florida, and (8) South Florida. The use of these subregions allows for a more detailed analysis of the individual basins and the groundwater flow system as a whole.

The groundwater budget was updated to reflect the entire groundwater flow system for a contemporary period (1995–2010) and to include additional data collected since the 1980s. The budget, however, does not include estimates for all flow components because of large uncertainties associated with some flow components. The average annual rate of precipitation for current conditions (1995–2010) was 53.6 inches per year (in/yr) and resulted in 7.5 in/yr (33,700 million gallons per day [Mgal/d]) of total recharge to all aquifers in the study area. Anthropogenic sources of water to the groundwater flow system (irrigation-return flow, drainage-well recharge, and wastewater-return flow) and lateral inflow to the Floridan aquifer system from the updip area compose a relatively small part of the overall water budget; these components, however, can locally be an important part of the groundwater flow system.

Spring discharge from the groundwater flow system was 23 percent (7,700 Mgal/d) of total recharge and was the single largest of the estimated outflow components. More springs have been documented since the predevelopment groundwater budget was produced, and one-to-one comparisons of spring discharge from predevelopment to current conditions (1995–2010) may be misleading.

Groundwater withdrawals accounted for 15 percent (5,200 Mgal/d) of total recharge with 65 percent (3,400 Mgal/d) coming from the Floridan aquifer system and the remaining 35 percent (1,800 Mgal/d) from the surficial and intermediate aquifer systems. Ninety-eight percent of all withdrawals from the Floridan aquifer system were obtained in Florida (75 percent) and Georgia (23 percent). Most (83 percent) of the groundwater withdrawn from all sources was used to irrigate crops (46 percent) or for public supply (37 percent). Groundwater withdrawal intensity is a measure of the rate of withdrawals over a specified area, and the 10 counties with the greatest average withdrawal intensity accounted for 6 percent (6,353 square miles) of the land area and 31 percent (1,045 Mgal/d) of actual withdrawals.

The rates of change in storage in the Floridan aquifer system are generally very low, although there is a fairly wide range in rates among and within basins, driven primarily by differences in the degree of aquifer confinement. Total change in storage for the Floridan aquifer system from predevelopment to May–June 2010 was -3.7 Mgal/d, and the Southeast Georgia-Northeast Florida-South South Carolina groundwater basin accounted for 59 percent (-2.2 Mgal/d)

of the change. The highest rates of storage loss occurred from May 1980 to May–June 2010 when the rate of storage change was -6.5 Mgal/d, and the Southeast Georgia-Northeast Florida-South South Carolina groundwater basin accounted for 46 percent (-3.0 Mgal/d) of the change. These rates of change, when compared to net recharge (33,700 Mgal/d), are relatively small; storage loss, however, can be a locally important issue for resource managers.

The primary groundwater-budget components for the current conditions (1995–2010) of the groundwater flow system are net recharge, discharge to springs, discharge to streams and lakes, groundwater withdrawals, and coastal discharge. The control volume of the groundwater budget encompasses the freshwater part of the surficial, intermediate, and Floridan aquifer systems. The errors associated with the preliminary groundwater-budget components may be considerable because of the lack of detailed information aboutthe past and current states of individual flow components.

For the predevelopment period (assumed to end on December 31, 1884), it is assumed that flows to and from the groundwater system were balanced and the system was in a state of dynamic equilibrium with no long-term net changes in storage. Net recharge was the sole source of inflow to the system, and outflows included spring discharge, discharge to streams and lakes, and coastal discharge. It is assumed herein that the average rate of net recharge to the groundwater system has not changed substantially over time, and therefore the simulated average rate of net recharge for current conditions (33,700 Mgal/d; simulated with the Soil-Water-Balance [SWB] code) also was used for predevelopment. Net recharge to the surficial and intermediate aquifer systems was 19,200 Mgal/d, and net recharge to the Floridan aquifer system was 14,500 Mgal/d.

Groundwater withdrawals accounted for 15 percent (5,200 Mgal/d) of net recharge during current conditions (1995–2010). Decreases in storage and discharge to springs are attributed to groundwater withdrawals in this analysis; interannual variability in precipitation and evapotranspiration, however, also are likely to have played a role in some areas. Discharge to springs was estimated to have decreased from predevelopment (8,100 Mgal/d) to current conditions (7,700 Mgal/d). Coastal discharge was assumed to be unchanged from predevelopment to current conditions (1,200 Mgal/d).

Climate projections indicate increasing air temperature, increased precipitation from heavy thunderstorms and hurricanes, and more frequent floods and droughts. These changing patterns could result in less net groundwater recharge and require more groundwater withdrawals for irrigation of crops. Higher sea level affects coastal infrastructure, safety, and coastal ecosystems; over time, higher sea level will also increase saltwater intrusion into the aquifers in the study area, especially the Biscayne aquifer, which is composed of high-porosity limestone.

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Appendixes 1–3

Appendix 1. Equivalent Freshwater-Altitude Calculations for South Florida Wells, May–June 2010

Equivalent freshwater altitudes are used when comparing groundwater levels in wells in the same aquifer where some of the wells contain freshwater and some of the wells contain brackish water. Equivalent freshwater altitude is defined as the height of freshwater that would create the equivalent pressure exerted by denser water of a specific height. When determining the equivalent freshwater altitude between adjacent wells for potentiometric mapping, it is important to measure the height of water relative to a common vertical datum, Z_d. Equivalent freshwater altitude can be computed by using equations 1–1 and 1–2 based on the diagram shown in figure 1–1.

$$H_f = \frac{\rho}{\rho_f} H \qquad (1\text{–}1)$$

$$WLEQ_{alt} = WL_{alt} + (H_f - H) \qquad (1\text{–}2)$$

where

- H_f is the equivalent freshwater height of water referenced to datum Z_d [L],
- ρ is the density of the water in the well [M/L^3],
- ρ_f is the density of freshwater [M/L^3],
- H is the height of water in the well referenced to datum Z_d [L],
- $WLEQ_{alt}$ is the equivalent freshwater altitude referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29) [L], and
- WL_{alt} is the altitude of water in the well referenced to NGVD 29 [L].

When computing equivalent freshwater altitudes, several assumptions are made: (1) water density in the aquifer at the well location is constant above datum Zd; (2) seawater density is 1,025 kilograms per cubic meter (kg/m^3), and freshwater density is 1,000 kg/m^3; (3) the chloride concentration of seawater is 19,400 milligrams per liter (mg/L); (4) the specific conductance of seawater is 50,000 microsiemens per centimeter (µS/cm) at 25 degrees Celsius; (5) the total dissolved solids concentration of seawater is 35,999 mg/L; (6) the density of the water in the well is less than that of seawater; and (7) linear density relations among chloride concentration, specific conductance, and total dissolved solids concentration are applicable. Specific conductance and total dissolved solids concentration are two commonly measured water-quality properties and are often used as surrogates for chloride concentration. Linear relations between these properties and chloride concentration are assumed so that water density can be computed directly from measurements

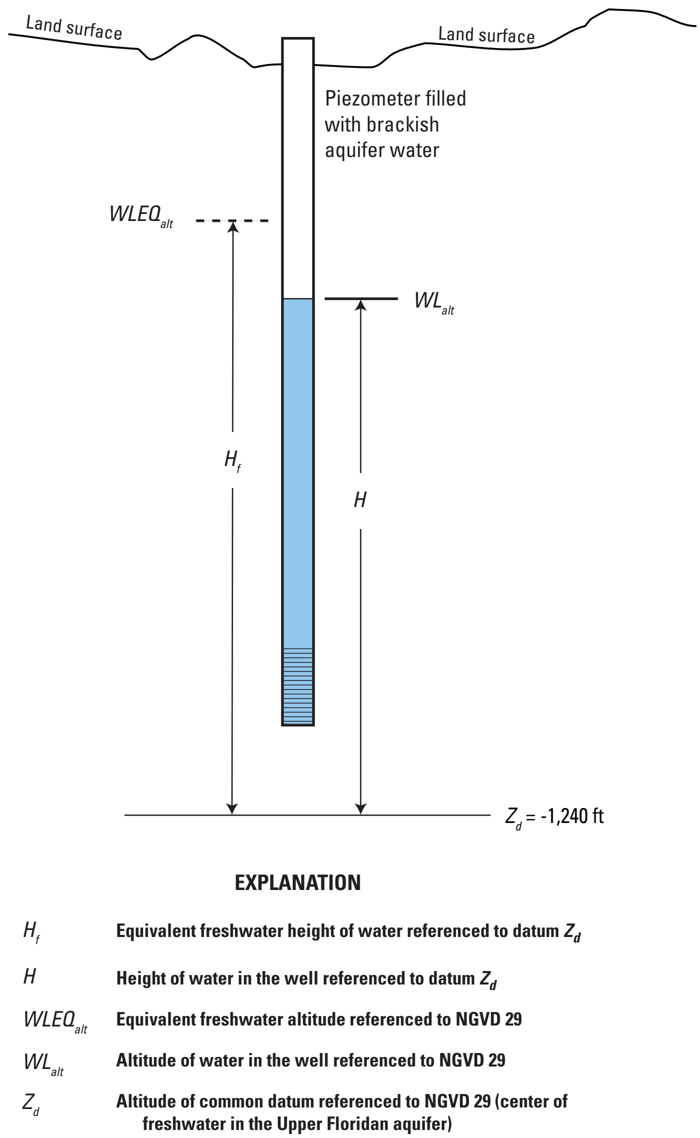

Figure 1–1. Equivalent freshwater-altitude computation for the Upper Floridan aquifer, south Florida. [NGVD 29, National Geodetic Vertical Datum of 1929]

of specific conductance or total dissolved solids concentration and used to calculate equivalent freshwater heads by using equation 1–1. Water temperature can also affect the density of water; however, temperature corrections were not applied because temperature variations within the freshwater part of the Upper Floridan aquifer in south Florida are small. Figure 1–1 shows the computation of equivalent freshwater altitude diagrammatically. Further details about equivalent freshwater-altitude calculations and theory are provided in Cooper (1964), Guo and Langevin (2002), and Lusczynski (1961).

During May–June 2010, the South Florida Water Management District (SFWMD) collected groundwater levels and water-quality data for 17 wells and stored these data in their database (https://www.sfwmd.gov/science-data/dbhydro). Water-quality data consisted of specific conductance measured in the field, in microsiemens per centimeter; chloride concentration, in milligrams per liter; and total dissolved solids concentration, in milligrams per liter. Computations of water density were made by using each of the water-quality properties, and the average density was used to compute equivalent freshwater head. Water-quality data for SFWMD well BF–4S are presented in table 1–1. The common datum, Z_d, for the 2010 potentiometric surface map was computed as the average altitude of the center of the freshwater part of the Upper Floridan aquifer in south Florida (-1,240 feet [ft] referenced to NGVD 29) by using the data in table 1–2.

Table 1–3 provides the estimated equivalent freshwater altitudes used in the updated potentiometric surface map for 2010. Because of the uncertainty associated with Z_d over the region and the assumption that density is constant above Z_d at each well, equivalent freshwater altitudes are reported to the nearest foot. For example, using water-quality data in table 1–1 and a Z_d = -1,240 ft NGVD 29, the computed equivalent freshwater altitude for SFWMD well BF–4S is 51.35 ft NGVD 29; however, using Z_d = -1,340 ft NGVD 29, the computed equivalent freshwater altitude is 51.97 ft NGVD 29. In south Florida, the main source of error in the computation of equivalent freshwater altitudes is the difference between the true center of the freshwater part of the aquifer at each well and the computed common datum, Z_d (table 1–2).

Table 1–1. Water-quality data for South Florida Water Management District well BF–4S.

[kg/m^3, kilogram per cubic meter; mg/L, milligram per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius. Data from Emily Richardson, South Florida Water Management District, written commun., 2011]

Parameter	Concentration	Calculated density, in kg/m^3
Chloride[1]	4,116 mg/L	1,005.304
Specific conductance[2]	14,103 µS/cm	1,007.052
Total dissolved solids[3]	8,731 mg/L	1,006.236
Average		**1,006.197**

[1]U.S. Environmental Protection Agency method 300.0.

[2]U.S. Environmental Protection Agency method SM2540C.

[3]Field measurement.

Table 1–2. Data used to determine average altitude of the center of freshwater in the Upper Floridan aquifer in south Florida.

[Units are feet referenced to the National Geodetic Vertical Datum of 1929 unless otherwise noted]

County	Top of the Floridan aquifer system[1]	Base of the freshwater part of the Upper Floridan aquifer[2]	Center of the freshwater part of the Upper Floridan aquifer[3]	Difference between the center of the freshwater part of the Upper Floridan aquifer and a common vertical datum, Z_d, in feet
Broward	-1,000	-1,900	-1,450	210
Charlotte	-700	-1,100	-900	-340
Collier	-800	-1,500	-1,150	-90
Glades	-700	-1,800	-1,250	10
Hendry	-800	-2,000	-1,400	160
Lee	-600	-1,600	-1,100	-140
Martin	-650	-1,800	-1,225	-15
Miami-Dade	-1,100	-1,600	-1,350	110
Monroe	-950	-1,600	-1,275	35
Palm Beach	-900	-1,900	-1,400	160
St. Lucie	-500	-1,700	-1,100	-140
Average	**-800**	**-1,700**	**-1,240**	**-5**

[1]Average altitude of top of Floridan aquifer for county from Williams and Kuniansky (2015).

[2]Average altitude of 10,000-milligram-per-liter total dissolved solids concentration boundary for county from Williams and Kuniansky (2015).

[3]Average altitude of land surface for county from Williams and Kuniansky (2015).

Table 1–3. Groundwater-level and water-quality data for selected South Florida Water Management District wells, May–June 2010.

[USGS, U.S. Geological Survey; NGVD 29, National Geodetic Vertical Datum of 1929; ddmmss, degrees, minutes, seconds; mg/L, milligram per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, not applicable. Data (except equivalent freshwater altitudes) from Emily Richardson, South Florida Water Management District, written commun., 2011]

Local agency unique site identifier	USGS site identification number	County	Latitude (ddmmss)	Longitude (ddmmss)	Date of measurement	Water-level altitude, in feet above NGVD 29	Chloride concentration, in mg/L	Total dissolved solids, in mg/L	Specific conductance, in µS/cm	Equivalent freshwater altitude, in feet above NGVD 29
BF-4S	--	Broward	261024	801047	5/30/2010	43.4	4,116	8,731	14,103	51
BICY-MZ2	--	Collier	255337	811833	5/25/2010	38.79	2,501	5,679	9,553	44
BOYRO_EPXU	--	Palm Beach	262938	800530	5/30/2010	45.69	2,014	4,136	7,241	50
DF-4	255434080280901	Miami-Dade	255436	802807	5/30/2010	51.49	1,651	3,601	6,296	55
ENP-100	252255080361101	Miami-Dade	252257	803611	5/30/2010	37.78	1,682	4,943	8,592	42
G-2618	261016080492601	Broward	261017	804919	5/30/2010	58.46	613	1,590	2,763	60
I75-MZ2	261012081435101	Collier	261013	814350	5/30/2010	32.17	3,682	7,610	12,890	39
IWSD-MZ2	262448081255401	Collier	262450	812553	5/30/2010	55.49	1,082	2,854	4,790	58
L2-PW2	263627080565802	Hendry	263629	805658	5/30/2010	58.2	636	1,630	2,845	60
MF-37U	265928080362801	Martin	265926	803617	5/30/2010	52.46	563	1,490	2,657	54
MF-40U	--	Martin	271221	802832	5/30/2010	49.1	1,283	2,248	3,863	51
PB-747	265604080082601	Palm Beach	265606	800824	5/30/2010	47.62	1,230	2,553	4,704	50
PBF-15U	--	Palm Beach	264416	802149	5/30/2010	51.93	1,472	3,395	5,739	55
PBF-3	264033080061101	Palm Beach	264034	800609	6/8/2010	45.92	2,300	4,646	8,246	50
PBF-7U	264158080425701	Palm Beach	264159	804257	5/30/2010	55.01	1,275	2,839	4,966	58
SLF-75	272015080292402	St. Lucie	272016	802923	5/30/2010	40.61	922	1,852	3,605	42
SLF-76	272015080292403	St. Lucie	272016	802623	5/30/2010	41.21	1,304	2,708	4,526	44

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Appendix 2. Soil-Water-Balance Methodology and Analysis

The soil-water-balance model developed for the southeastern United States used the numerical Soil-Water-Balance (SWB) code (Westenbroek and others, 2010) to estimate net recharge. SWB uses a modified Thornthwaite-Mather soil-water accounting method to compute recharge (*R*) on a cell-by-cell basis over a rectangular grid of regularly spaced cells by using the equation

$$R = [p + M + Q_{in}] - [i + Q_{out} + ET] - \Delta soilmoisture \qquad (2–1)$$

where

- p is precipitation [L];
- M is snow melt [L];
- Q_{in} is surface inflow [L];
- i is interception of precipitation [L];
- Q_{out} is surface outflow [L];
- ET is estimated actual evapotranspiration [L]; and
- $\Delta soilmoisture$ is the change in soil moisture [L].

Computations are made by using daily climate data (precipitation and maximum and minimum air temperature), gridded datasets containing an eight-direction (D8) flow-direction grid, latitude of the grid cell, soil-water capacity information, hydrologic soil groups, and land-use data. The model parameters related to land-use type and hydrologic soil group were Soil Conservation Service (SCS) runoff curve number, maximum allowable recharge rate, canopy interception, and root-zone depth. A D8 flow-direction grid specifies the direction of steepest downward slope on a block-centered grid by using eight equal triangular facets and is used to route overland runoff (Tarboton, 1997). Westenbroek and others (2010) provided further details about the theory and application of SWB. The SWB model input datasets described herein are available in Bellino (2017).

Climate data for this study were obtained from the Daymet model (Thornton and others, 2012). The D8 flow-direction grid was derived from a 30-meter digital elevation model (DEM) from the NHDPlus Version 2 dataset (McKay and others, 2012) and subsequently modified to reflect the highly managed surface-water system in south Florida. The hydrologic soil group and soil-water capacity data were obtained from the U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS) SSURGO and STATSGO soil databases (U.S. Department of Agriculture, 2014). Land-use classifications were obtained from the Multi-Resolution Land Characteristics Consortium National Land Cover Database (NLCD) (Homer and others, 2007; Fry and others, 2011; Jin and others, 2013). The sources of parameter values associated with land use and hydrologic soil group are as follows: SCS curve numbers were obtained from Cronshey and others (1986) and Suphunvorranop (1985), maximum allowable recharge rates were obtained from the SWB documentation (Westenbroek and others, 2010), canopy interception values for forested and wetland areas were obtained from the SWB documentation (Westenbroek and others, 2010, table 9), and root-zone depth values were modified from Thornthwaite and Mather (1957).

SWB uses land-use codes and hydrologic soil groups to define combinations of variables used by the model (SCS runoff curve number, maximum allowable recharge rate, root-zone depth, and canopy interception) to calculate the various parts of the soil-water budget. A custom land-use lookup table was developed for this study to better reflect the average conditions within each 5,000-square-foot grid cell in the SWB model. SCS runoff curve numbers, maximum allowable recharge rate, and root-zone depth were assigned to each of the hydrologic soil groups and (or) NLCD land-use codes, and average values for each of these variables were then calculated for each cell. Each of 77,621 unique combinations of these parameter values was assigned arbitrary land-use codes that were then distributed to the SWB model grid accordingly.

Simulated output from SWB was checked against independent U.S. Geological Survey (2014) estimates of runoff for four-digit hydrologic unit codes (HUC4) representing 13 watersheds in the study area (fig. 2–1). Runoff from the HUC4 units is equivalent to total streamflow and was generated by using historical streamflow data combined with drainage basin information. Total streamflow should equal precipitation minus the calculated actual evapotranspiration from the SWB model on an annual basis. Results of the analysis show that, on average, the SWB model overestimates streamflow by 69 percent (6.2 inches per year [in/yr]) relative to estimates of runoff at the HUC4 level obtained from the U.S. Geological Survey (USGS) WaterWatch web portal (U.S. Geological Survey, 2014). Calculations by the SWB model overestimated runoff by 167 percent (7.7 inches [in.]) during the dry conditions of 2000 and by 21 percent (3.5 in.) during the wet conditions of 2005. Differences in runoff within the nine HUC4 units (0305–0307 and 0312–0317 [northern group]) (fig. 2–1) that drain hilly areas (average mean slope of 8.9 degrees) in the northern part of the study area ranged from 2.7 to 5.6 in/yr (15 to 63 percent) with an average of 4.2 in/yr (36 percent) (fig. 2–2). Conversely, differences in the four HUC4 units (0308–0311 [southern group]) that drain relatively flat areas (average mean slope of 1.6 degrees) in the southern part of the study area were much greater and ranged from 7.7 to 15.0 in/yr (93 to 215 percent) with an average of 10.6 in/yr (142 percent). Regression analysis indicated a negative linear correlation between the computed average slope of each HUC4 unit and the percent difference between SWB-estimated runoff and USGS WaterWatch values for both groups (fig. 2–2).

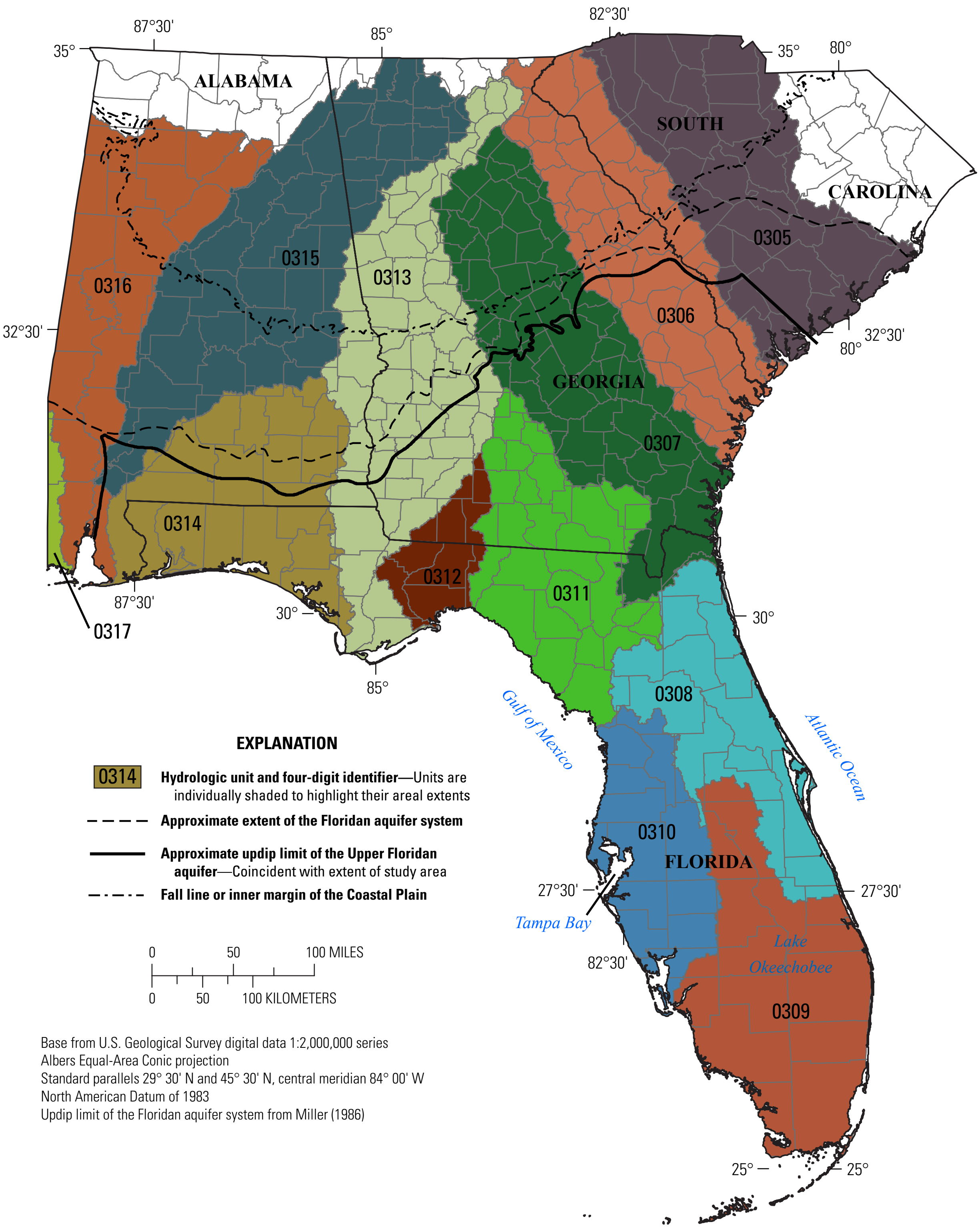

Figure 2–1. Four-digit hydrologic units in the study area, southeastern United States.

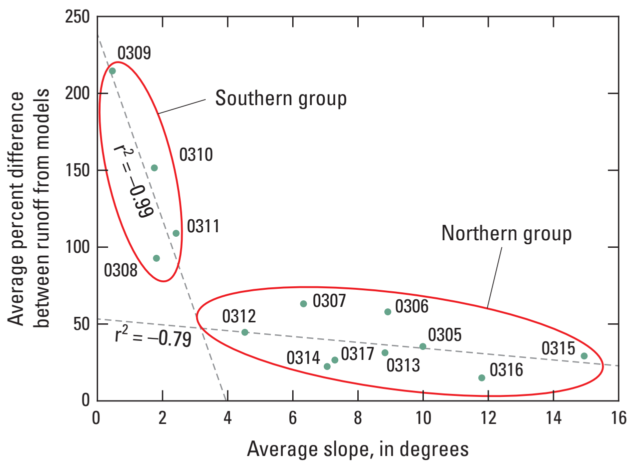

Figure 2–2. Relation between average slope of four-digit hydrologic units shown in figure 2–1 and 1995–2010 average percent difference between runoff estimated by using the Soil-Water-Balance code and U.S. Geological Survey WaterWatch runoff data (U.S. Geological Survey, 2014).

The correlation between average slope and percent difference between observed and estimated runoff is probably the result of two key factors related to the limitations and assumptions of the SWB model and their effects on the principal components of the runoff calculation. First, rejected recharge that does not infiltrate into a downslope cell is routed out of the model domain on the same day in which it was generated, which may lead to underestimation of recharge in flat areas that may drain over the course of days or weeks allowing more time for infiltration. Second, the SCS runoff curve number method used by SWB for internal calculations of runoff was developed to evaluate low-frequency flooding events and may not accurately simulate high-frequency flows of typical magnitude. One complicating factor is the inability of the SWB model to simulate groundwater/surface-water interactions. In areas where the top of the water table is located at or near land surface, excessive recharge may be simulated because SWB has no mechanism to reject recharge based on saturation excess. Another complicating factor is that recharge may be underestimated in karst areas where surface water is routed directly to the water table by sinkholes and other geologic features rather than running off as in more traditional watersheds for which the SCS runoff curve number method was designed (White, 1976).

Base flow, the part of streamflow composed of groundwater discharge, is sometimes used to approximate long-term net recharge to the groundwater flow system. Net recharge estimates were compared to base-flow estimates from two hydrograph separation analyses—one in coastal Georgia and the other of 156 streamflow gaging stations across the study area (table 2–1). Discharge from groundwater to streams in coastal Georgia for the period 1971–2001 was estimated to be between 39 and 70 percent of total streamflow (Priest, 2004). By using the area-weighted average runoff for the whole study area of 15.1 in/yr (U.S. Geological Survey, 2014), it was estimated that groundwater discharge to streams could range from 5.9 in/yr (26,300 million gallons per day [Mgal/d]) to 10.6 in/yr (47,300 Mgal/d) with an average of 8.2 in/yr (36,800 Mgal/d). The second analysis, using the Groundwater Toolbox software (Barlow and others, 2015), estimated base flow more broadly across the study area at 156 streamflow gaging stations from the GAGES–II database (Falcone, 2011). The average base-flow contribution to streamflow for 1995–2010 was estimated to be 11.5 in/yr (51,600 Mgal/d) and ranged from 9.3 in/yr (41,500 Mgal/d) to 13.3 in/yr (59,800 Mgal/d). Of the 156 gaging stations used in the analysis, 13 had average base-flow contribution rates greater than 80 percent, and of these, many are located in drainage basins affected by swamp drainage and (or) spring discharge including the Weeki Wachee River and the Withlacoochee and Wekiva River Basins. Removal of these sites from the analysis resulted in rates of base flow that more closely agree with results using the Priest (2004) values: average base flow is 8.0 in/yr (36,000 Mgal/d), minimum is 6.1 in/yr (27,300 Mgal/d), and maximum is 9.7 in/yr (43,400 Mgal/d). Average estimates of net recharge from the hydrograph separation analyses were about 60 percent greater than the unadjusted SWB-derived estimate (4.8 in/yr).

Net recharge estimates from the SWB model were also compared to recharge rates used in the Southwest Florida Water Management District Northern District Model (NDM) (HydroGeoLogic, Inc., 2008). The NDM covers a karstified area of coastal west-central Florida, and recharge values were taken from the steady-state calibrated version of the model that simulates conditions for 1995. A grid was produced from the SWB-derived estimates of net recharge that was of the same size and extent as the NDM recharge grid, and the two were compared. Average NDM recharge over the model domain was estimated to be 12.6 in/yr, about 60 percent greater than the SWB-derived estimate of 7.9 in/yr.

Based on results from the hydrograph separation analyses and comparison with recharge rates used in the NDM, a uniform multiplier of 1.6 was applied to net recharge grids derived from the SWB model. Although there are issues related to performing hydrograph separation analyses in flat and karstified areas and because the uncertainty associated with such analyses is probably large, increasing estimates of net recharge by using a multiplier should provide a better estimate of the magnitude of the value.

Table 2–1. Streamflow gaging stations used to estimate base flow in the study area, southeastern United States.

[FIPS, Federal Information Processing Standards; USGS, U.S. Geological Survey; NAD 83, North American Datum of 1983; HUC6, six-digit hydrologic unit code; Fl, Florida; Al, Alabama; Us, U.S. Highway; Hwy, Highway; Cr, Creek; Br, Branch; Nr, near; Fla., Florida; Sr, State Route; R, river; @, at; Sh, State Highway; Fcrr, Florida Central Railroad; Upst, upstream; Ck, Creek; Ft, Fort; St, Street; Pky, Parkway; Ab, above; Spr, Springs; Rd, Road; Blvd, Boulevard; Lt, Little; Ga, Georgia; Sc, South Carolina]

State	County	FIPS code	USGS site identification number	Station name	Longitude (decimal degrees, NAD 83)	Latitude (decimal degrees, NAD 83)	HUC6
Alabama	Baldwin	01003	02376500	Perdido River At Barrineau Park, Fl	-87.44025800	30.69046866	031401
Alabama	Baldwin	01003	02377570	Styx River Near Elsanor, Al.	-87.54720570	30.60574840	031401
Alabama	Baldwin	01003	02378300	Magnolia River At Us 98 Near Foley, Alabama	-87.73693230	30.40658669	031602
Alabama	Baldwin	01003	02378500	Fish River Near Silver Hill Al	-87.79860149	30.54547146	031602
Alabama	Escambia	01053	02369800	Blackwater River Near Bradley Al	-86.70995670	31.02767985	031401
Alabama	Escambia	01053	02374700	Murder Creek At State Hwy 41 At Brewton, Al.	-87.06885829	31.10101137	031403
Alabama	Escambia	01053	02374745	Burnt Corn Creek At State Hwy 41 Near Brewton, Al.	-87.08719280	31.12989910	031403
Alabama	Escambia	01053	02374950	Big Escambia Cr At Sardine Br Nr Stanley Crossroad	-87.37053530	31.12962115	031403
Florida	Alachua	12001	02240902	Prairie Creek Near Gainesville, Fl	-82.24871210	29.61163537	030801
Florida	Alachua	12001	02240954	Hogtown Creek Near Arredondo, Fl	-82.39232820	29.63830073	030801
Florida	Baker	12003	02228500	North Prong St. Marys River At Moniac, Ga	-82.23039540	30.51773125	030702
Florida	Baker	12003	02229000	Middle Prong St Marys River At Taylor, Fl	-82.28734020	30.43634185	030702
Florida	Baker	12003	02231000	St. Marys River Near Macclenny, Fl	-82.08150130	30.35884726	030702
Florida	Bay	12005	02359500	Econfina Creek Near Bennett, Fla.	-85.55659320	30.38464060	031401
Florida	Bradford	12007	02320700	Santa Fe River Near Graham, Fla.	-82.21954930	29.84635394	031102
Florida	Charlotte	12015	02298202	Shell Creek Near Punta Gorda Fl	-81.93564140	26.98478094	031001
Florida	Clay	12019	02246000	North Fork Black Creek Near Middleburg, Fl	-81.90649150	30.11329530	030801
Florida	Columbia	12023	02315500	Suwannee River At White Springs, Fla.	-82.73818260	30.32578120	031102
Florida	Columbia	12023	02322700	Ichetucknee R @ Hwy27 Nr Hildreth, Fl	-82.78595730	29.95273288	031102
Florida	De Soto	12027	02297100	Joshua Creek At Nocatee Fl	-81.87952820	27.16671794	031001
Florida	De Soto	12027	02297310	Horse Creek Near Arcadia Fl	-81.98841930	27.19949477	031001
Florida	De Soto	12027	02298110	Prairie Creek Upstream Of Sr 31 Near Ft Ogden Fl	-81.74316670	27.04155556	031001
Florida	De Soto	12027	02298123	Prairie Creek Near Fort Ogden Fl	-81.78452670	27.05199986	031001
Florida	Duval	12031	02231280	Thomas Creek Near Crawford, Fl	-81.83232750	30.46107070	030702
Florida	Duval	12031	02246150	Big Davis Creek At Bayard, Fl	-81.52619810	30.15163087	030801
Florida	Duval	12031	02246300	Ortega River At Jacksonville, Fl	-81.79676680	30.24746160	030801
Florida	Duval	12031	02246318	Ortega River At Kirwin Road Near Jacksonville,Fl	-81.76843150	30.19635087	030801

Table 2–1. Streamflow gaging stations used to estimate base flow in the study area, southeastern United States.—Continued

[FIPS, Federal Information Processing Standards; USGS, U.S. Geological Survey; NAD 83, North American Datum of 1983; HUC6, six-digit hydrologic unit code; Fl, Florida; Al, Alabama; Us, U.S. Highway; Hwy, Highway; Cr, Creek; Br, Branch; Nr, near; Fla., Florida; Sr, State Route; R, river; @, at; Sh, State Highway; Fcrr, Florida Central Railroad; Upst, upstream; Ck, Creek; Ft, Fort; St, Street; Pky, Parkway; Ab, above; Spr, Springs; Rd, Road; Blvd, Boulevard; Lt, Little; Ga, Georgia; Sc, South Carolina]

State	County	FIPS code	USGS site identification number	Station name	Longitude (decimal degrees, NAD 83)	Latitude (decimal degrees, NAD 83)	HUC6
Florida	Duval	12031	02246828	Pablo Creek At Jacksonville, Fl	-81.47814210	30.23551927	030801
Florida	Escambia	12033	02376115	Elevenmile Creek Near Pensacola, Fl.	-87.33580860	30.49825159	031401
Florida	Flagler	12035	02244420	Little Haw Creek Near Seville, Fl	-81.38527780	29.32194444	030801
Florida	Gadsden	12039	02329600	Little River Nr Midway, Fla.	-84.52352060	30.51241920	031200
Florida	Glades	12043	02256500	Fisheating Creek At Palmdale, Fl	-81.31479490	26.93255850	030901
Florida	Hardee	12049	02295420	Payne Creek Near Bowling Green Fl	-81.82563840	27.62059006	031001
Florida	Hardee	12049	02296260	Charlie Creek Near Crewsville Fl	-81.67841280	27.45948376	031001
Florida	Hardee	12049	02296500	Charlie Creek Near Gardner Fl	-81.79647080	27.37504297	031001
Florida	Hardee	12049	02297155	Horse Creek Near Myakka Head Fl	-82.02341970	27.48726130	031001
Florida	Hernando	12053	02310525	Weeki Wachee River Near Brooksville Fl	-82.58232150	28.51888454	031002
Florida	Hernando	12053	02312200	Little Withlacoochee River At Rerdell, Fl	-82.15536300	28.57277286	031002
Florida	Highlands	12055	02270000	Carter Creek Near Sebring Fl	-81.38757240	27.53225706	030901
Florida	Highlands	12055	02270500	Arbuckle Creek Near De Soto City, Fl	-81.29729280	27.44253750	030901
Florida	Highlands	12055	02271500	Josephine Creek Near De Soto City Fl	-81.39340620	27.37420780	030901
Florida	Hillsborough	12057	02300100	Little Manatee River Near Ft. Lonesome Fl	-82.19786720	27.70475366	031002
Florida	Hillsborough	12057	02300500	Little Manatee River Near Wimauma Fl	-82.35259250	27.67114344	031002
Florida	Hillsborough	12057	02300700	Bullfrog Creek Near Wimauma Fl	-82.35203690	27.79197208	031002
Florida	Hillsborough	12057	02301000	North Prong Alafia River At Keysville Fl	-82.10008689	27.88391480	031002
Florida	Hillsborough	12057	02301300	South Prong Alafia River Near Lithia Fl	-82.11758770	27.79669525	031002
Florida	Hillsborough	12057	02301500	Alafia River At Lithia Fl	-82.21120080	27.87224800	031002
Florida	Hillsborough	12057	02301750	Delaney Creek Near Tampa Fl	-82.36425950	27.92585640	031002
Florida	Hillsborough	12057	02302500	Blackwater Creek Near Knights Fl	-82.15000000	28.13972220	031002
Florida	Hillsborough	12057	02303000	Hillsborough River Near Zephyrhills Fl	-82.23175318	28.15029044	031002
Florida	Hillsborough	12057	02303205	Baker Creek At Mcintosh Road Near Antioch Fl	-82.24536780	28.02835317	031002
Florida	Hillsborough	12057	02303330	Hillsborough R At Morris Br Near Thonotosassa Fl	-82.31138889	28.09861110	031002
Florida	Hillsborough	12057	02303350	Trout Creek Near Sulphur Springs Fl	-82.36194440	28.13472220	031002
Florida	Hillsborough	12057	02303800	Cypress Creek Near Sulphur Springs Fl	-82.40916670	28.08888889	031002

Table 2–1. Streamflow gaging stations used to estimate base flow in the study area, southeastern United States.—Continued

[FIPS, Federal Information Processing Standards; USGS, U.S. Geological Survey; NAD 83, North American Datum of 1983; HUC6, six-digit hydrologic unit code; Fl, Florida; Al, Alabama; Us, U.S. Highway; Hwy, Highway; Cr, Creek; Br, Branch; Nr, near; Fla., Florida; Sr, State Route; R, river; @, at; Sh, State Highway; Fcrr, Florida Central Railroad; Upst, upstream; Ck, Creek; Ft, Fort; St, Street; Pky, Parkway; Ab, above; Spr, Springs; Rd, Road; Blvd, Boulevard; Lt, Little; Ga, Georgia; Sc, South Carolina]

State	County	FIPS code	USGS site identification number	Station name	Longitude (decimal degrees, NAD 83)	Latitude (decimal degrees, NAD 83)	HUC6
Florida	Hillsborough	12057	02306647	Sweetwater Creek Near Tampa Fl	-82.54509630	28.01390775	031002
Florida	Hillsborough	12057	02306774	Rocky Creek At St Hwy 587 At Citrus Park Fl	-82.56583330	28.06583333	031002
Florida	Hillsborough	12057	02306950	Brushy Creek Near Citrus Park Fl	-82.55537440	28.06501684	031002
Florida	Hillsborough	12057	02307000	Rocky Creek Near Sulphur Springs Fl	-82.57593040	28.03696237	031002
Florida	Holmes	12059	02365470	Wrights Creek At Sh 177-A Nr Bonifay,Fl	-85.76215450	30.85713010	031402
Florida	Indian River	12061	02231396	Blue Cypress Creek Near Fellsmere, Fl	-80.80505949	27.72808533	030801
Florida	Indian River	12061	02251000	South Prong St Sebastian River Near Sebastian,Fl	-80.50588680	27.76947258	030802
Florida	Lake	12069	02235200	Blackwater Creek Near Cassia, Fl	-81.48972220	28.87444444	030801
Florida	Lake	12069	02236500	Big Creek Near Clermont, Fl	-81.74007599	28.44778229	030801
Florida	Lake	12069	02237734	Wolf Branch At Fcrr Near Mount Dora, Fl	-81.60785149	28.79665898	030801
Florida	Lee	12071	02291500	Imperial River Near Bonita Springs, Fl	-81.74952979	26.33563940	030902
Florida	Lee	12071	02291580	North Branch Estero River At Estero, Fl	-81.79564100	26.44202474	030902
Florida	Liberty	12077	02330100	Telogia Creek Nr Bristol, Fla.	-84.92769349	30.42658500	031200
Florida	Liberty	12077	02330400	New River Near Sumatra, Fla	-84.84379900	30.03881356	031300
Florida	Manatee	12081	02298488	Myakka River Upst From Youngs Ck Nr Myakka City Fl	-82.13869970	27.42920840	031001
Florida	Manatee	12081	02298495	Maple Creek Near Myakka City Fl	-82.12981070	27.38448789	031001
Florida	Manatee	12081	02298530	Coker Creek Near Myakka City Fl	-82.17508930	27.40976480	031001
Florida	Manatee	12081	02298554	Myakka River Near Myakka City Fl	-82.14925550	27.36615530	031001
Florida	Manatee	12081	02298608	Myakka River At Myakka City Fl	-82.15675560	27.34365620	031001
Florida	Manatee	12081	02299950	Manatee River Near Myakka Head Fl	-82.21120100	27.47365137	031002
Florida	Manatee	12081	02300075	Frog Creek At Buffalo Road Near Rubonia Fl	-82.51338889	27.57991667	031002
Florida	Manatee	12081	02300210	South Fork Little Manatee River Near Parrish Fl	-82.21120090	27.60197978	031002
Florida	Nassau	12089	02231268	Alligator Creek At Callahan, Fl	-81.83344010	30.56662513	030702
Florida	Okaloosa	12091	02369000	Shoal River Nr Crestview, Fla.	-86.57078600	30.69741268	031401
Florida	Okaloosa	12091	02370000	Blackwater River Nr Baker, Fla.	-86.73467860	30.83351970	031401
Florida	Okeechobee	12093	02231342	Ft Drum Creek At Sunshine St Pky Near Ft Drum, Fl	-80.79617090	27.56864730	030801

Table 2–1. Streamflow gaging stations used to estimate base flow in the study area, southeastern United States.—Continued

[FIPS, Federal Information Processing Standards; USGS, U.S. Geological Survey; NAD 83, North American Datum of 1983; HUC6, six-digit hydrologic unit code; Fl, Florida; Al, Alabama; Us, U.S. Highway; Hwy, Highway; Cr, Creek; Br, Branch; Nr, near; Fla., Florida; Sr, State Route; R, river; @, at; Sh, State Highway; Fcrr, Florida Central Railroad; Upst, upstream; Ck, Creek; Ft, Fort; St, Street; Pky, Parkway; Ab, above; Spr, Springs; Rd, Road; Blvd, Boulevard; Lt, Little; Ga, Georgia; Sc, South Carolina]

State	County	FIPS code	USGS site identification number	Station name	Longitude (decimal degrees, NAD 83)	Latitude (decimal degrees, NAD 83)	HUC6
Florida	Okeechobee	12093	02274005	Otter Creek Near Okeechobee, Fl	-80.84533880	27.37754217	030901
Florida	Orange	12095	02233200	Little Econlockhatchee River Near Union Park, Fl	-81.24395600	28.52500210	030801
Florida	Orange	12095	02262900	Boggy Creek Near Taft, Fl	-81.31062470	28.37139699	030901
Florida	Orange	12095	02264000	Cypress Creek At Vineland, Fl	-81.51951730	28.39056323	030901
Florida	Orange	12095	02266200	Whittenhorse Creek Near Vineland, Fl	-81.61646320	28.38500749	030901
Florida	Osceola	12097	02231600	Jane Green Creek Near Deer Park, Fl	-80.88811550	28.07446200	030801
Florida	Osceola	12097	02232155	Pennywash Creek Near Deer Park, Fl	-80.89533730	28.18195808	030801
Florida	Osceola	12097	02232200	Wolf Creek Near Deer Park, Fl	-80.91089309	28.21306810	030801
Florida	Osceola	12097	02263800	Shingle Creek At Airport Near Kissimmee, Fl	-81.45090500	28.30417750	030901
Florida	Osceola	12097	02264100	Bonnet Creek Near Vineland, Fl	-81.52062840	28.32528785	030901
Florida	Osceola	12097	02266300	Reedy Creek Near Vineland, Fl	-81.57979600	28.33278738	030901
Florida	Osceola	12097	02266480	Davenport Creek Near Loughman, Fl	-81.59090740	28.27112300	030901
Florida	Osceola	12097	02266500	Reedy Creek Near Loughman, Fl	-81.53646200	28.26362340	030901
Florida	Palm Beach	12099	02277600	Loxahatchee River Near Jupiter,Fl	-80.17504440	26.93922405	030902
Florida	Pasco	12101	02301990	Hillsborough R Ab Crystal Spr Near Zephyrhills Fl	-82.18416670	28.18555556	031002
Florida	Pasco	12101	02309848	South Branch Anclote River Near Odessa Fl	-82.55336110	28.18544444	031002
Florida	Pasco	12101	02310000	Anclote River Near Elfers Fl	-82.66648820	28.21417784	031002
Florida	Pasco	12101	02310947	Withlacoochee River Near Cumpressco, Fl	-82.05591468	28.31195156	031002
Florida	Pasco	12101	02311500	Withlacoochee River Near Dade City, Fl	-82.12591619	28.35250420	031002
Florida	Pinellas	12103	02307359	Brooker Creek Near Tarpon Springs Fl	-82.68732190	28.09612675	031002
Florida	Pinellas	12103	02307668	Alligator Creek Below Belcher Rd At Clearwater Fl	-82.74232320	27.97974210	031002
Florida	Pinellas	12103	02308935	Saint Joe Creek At Pinellas Park Fl	-82.69565540	27.81419235	031002
Florida	Pinellas	12103	02310147	Hollin Creek Near Tarpon Springs Fl	-82.71037800	28.16251317	031002
Florida	Polk	12105	02267000	Catfish Creek Near Lake Wales, Fl	-81.49646319	27.96141068	030901
Florida	Polk	12105	02268390	Tiger Creek Near Babson Park Fl	-81.44368460	27.81141547	030901
Florida	Polk	12105	02269520	Livingston Creek Near Frostproof Fl	-81.44646260	27.70864100	030901

Table 2–1. Streamflow gaging stations used to estimate base flow in the study area, southeastern United States.—Continued

[FIPS, Federal Information Processing Standards; USGS, U.S. Geological Survey; NAD 83, North American Datum of 1983; HUC6, six-digit hydrologic unit code; Fl, Florida; Al, Alabama; Us, U.S. Highway; Hwy, Highway; Cr, Creek; Br, Branch; Nr, near; Fla., Florida; Sr, State Route; R, river; @, at; Sh, State Highway; Fcrr, Florida Central Railroad; Upst, upstream; Ck, Creek; Ft, Fort; St, Street; Pky, Parkway; Ab, above; Spr, Springs; Rd, Road; Blvd, Boulevard; Lt, Little; Ga, Georgia; Sc, South Carolina]

State	County	FIPS code	USGS site identification number	Station name	Longitude (decimal degrees, NAD 83)	Latitude (decimal degrees, NAD 83)	HUC6
Florida	Polk	12105	02294161	Peace Creek Near Bartow Fl	-81.79555560	27.92444444	031001
Florida	Polk	12105	02294491	Saddle Creek At Structure P-11 Near Bartow Fl	-81.85119270	27.93835785	031001
Florida	Polk	12105	02294781	Peace River Near Homeland Fl	-81.79952630	27.82113930	031001
Florida	Polk	12105	02295013	Bowlegs Creek Near Fort Meade Fl	-81.69535790	27.70003166	031001
Florida	Polk	12105	02301900	Fox Branch Near Socrum, Fl	-82.01250000	28.18194444	031002
Florida	Putnam	12107	02244473	Rice Creek Near Springside	-81.74203120	29.68830093	030801
Florida	Putnam	12107	02245140	Simms Creek Near Bardin, Fl	-81.70980879	29.73552280	030801
Florida	St. Johns	12109	02245255	Deep Creek Near Hastings, Fl	-81.44868600	29.68135917	030801
Florida	Santa Rosa	12113	02370500	Big Coldwater Creek Nr Milton, Fla.	-86.97218600	30.70852375	031401
Florida	Sarasota	12115	02298760	Howard Creek Near Sarasota Fl	-82.34009290	27.28838098	031001
Florida	Sarasota	12115	02298830	Myakka River Near Sarasota Fl	-82.31370350	27.24060500	031001
Florida	Sarasota	12115	02299450	Big Slough At Tropicaire Blvd Near North Port Fl	-82.19342390	27.12116517	031001
Florida	Sarasota	12115	02299472	Big Slough At West Price Blvd Near North Port Fl	-82.22033330	27.06933333	031001
Florida	Seminole	12117	02233475	Lt Econlockhatchee R At State Hwy434 Nr Oviedo, Fl	-81.20784299	28.61999870	030801
Florida	Seminole	12117	02233484	Econlockhatchee River Near Oviedo, Fl	-81.16978600	28.65555285	030801
Florida	Seminole	12117	02233500	Econlockhatchee River Near Chuluota, Fl	-81.11416670	28.67777778	030801
Florida	Seminole	12117	02234308	Howell Creek Near Altamonte Springs, Fl	-81.32312349	28.63249870	030801
Florida	Seminole	12117	02234344	Howell Creek At State Hwy 434 Near Oviedo, Fl	-81.24756560	28.68999664	030801
Florida	Seminole	12117	02234384	Soldier Creek Near Longwood, Fl	-81.30867800	28.71888466	030801
Florida	Seminole	12117	02234400	Gee Creek Near Longwood, Fl	-81.29062210	28.70416290	030801
Florida	Seminole	12117	02234990	Little Wekiva River Near Altamonte Springs, Fl	-81.39701380	28.68721920	030801
Florida	Seminole	12117	02235000	Wekiva River Near Sanford, Fl	-81.41923539	28.81527009	030801
Florida	Sumter	12119	02312667	Shady Brook Near Sumterville, Fl	-82.06369610	28.77026704	031002
Florida	Sumter	12119	02312700	Outlet River At Panacoochee Retreats, Fl	-82.15286580	28.80026510	031002
Florida	Taylor	12123	02324000	Steinhatchee River Near Cross City, Fla.	-83.32152620	29.78661294	031101
Florida	Taylor	12123	02324400	Fenholloway River Near Foley, Fla.	-83.47181120	30.09827057	031101
Florida	Taylor	12123	02324500	Fenholloway River At Foley, Fla.	-83.55792460	30.06549165	031101

Table 2–1. Streamflow gaging stations used to estimate base flow in the study area, southeastern United States.—Continued

[FIPS, Federal Information Processing Standards; USGS, U.S. Geological Survey; NAD 83, North American Datum of 1983; HUC6, six-digit hydrologic unit code; Fl, Florida; Al, Alabama; Us, U.S. Highway; Hwy, Highway; Cr, Creek; Br, Branch; Nr, near; Fla., Florida; Sr, State Route; R, river; @, at; Sh, State Highway; Fcrr, Florida Central Railroad; Upst, upstream; Ck, Creek; Ft, Fort; St, Street; Pky, Parkway; Ab, above; Spr, Springs; Rd, Road; Blvd, Boulevard; Lt, Little; Ga, Georgia; Sc, South Carolina]

State	County	FIPS code	USGS site identification number	Station name	Longitude (decimal degrees, NAD 83)	Latitude (decimal degrees, NAD 83)	HUC6
Florida	Taylor	12123	02326000	Econfina River Near Perry, Fla.	-83.82376790	30.17076448	031101
Florida	Union	12125	02321000	New River Nr Lake Butler Fla	-82.27399920	29.99829540	031102
Florida	Volusia	12127	02247510	Tomoka River Near Holly Hill, Fl	-81.10866870	29.21748099	030802
Florida	Volusia	12127	02248000	Spruce Creek Near Samsula, Fl	-81.04644550	29.05081845	030802
Florida	Wakulla	12129	02327100	Sopchoppy River Nr Sopchoppy, Fla.	-84.49434820	30.12936856	031200
Florida	Walton	12131	02365769	Bruce Creek At Sh 81 Nr Redbay, Fl	-85.94243580	30.62463630	031402
Florida	Walton	12131	02366996	Alaqua Creek Near Pleasant Ridge, Fl	-86.18660920	30.66908000	031401
Florida	Walton	12131	02368500	Shoal River Nr Mossy Head, Fla.	-86.30689060	30.79602050	031401
Georgia	Baker	13007	02354500	Chickasawhatchee Creek At Elmodel, Ga	-84.48250000	31.35055556	031300
Georgia	Brooks	13027	02318700	Okapilco Creek At Ga 333, Near Quitman, Ga	-83.56250000	30.82555556	031102
Georgia	Bryan	13029	02202600	Black Creek Near Blitchton, Ga	-81.48816698	32.16798030	030602
Georgia	Burke	13033	02198100	Beaverdam Creek Near Sardis, Ga	-81.81539160	32.93765809	030601
Georgia	Decatur	13087	02357000	Spring Creek Near Iron City, Ga	-84.74000000	31.04027778	031300
Georgia	Dooly	13093	02349900	Turkey Creek At Byromville, Ga	-83.90222220	32.19555556	031300
Georgia	Effingham	13103	02198690	Ebenezer Creek At Springfield, Ga	-81.29733230	32.36574688	030601
Georgia	Lee	13177	02350900	Kinchafoonee Creek At Pinewood Road, Nr Dawson, Ga	-84.25333330	31.76444444	031300
Georgia	Lee	13177	02351890	Muckalee Creek At Ga 195, Near Leesburg, Ga	-84.13944440	31.77611110	031300
Georgia	Lowndes	13185	023177483	Withlacoochee River At Mcmillan Rd,Near Bemiss, Ga	-83.26848650	30.95269980	031102
Georgia	Pulaski	13235	02215100	Tucsawhatchee Creek Near Hawkinsville, Ga	-83.50166670	32.23944444	030701
Georgia	Telfair	13271	02216180	Turnpike Creek Near Mcrae, Ga	-82.92194440	31.99138889	030701
Georgia	Washington	13303	02201000	Williamson Swamp Creek At Davisboro, Ga	-82.60985400	32.97570924	030602
Georgia	Wayne	13305	02226100	Penholoway Creek Near Jesup, Ga	-81.83816940	31.56688297	030701
South Carolina	Hampton	45049	02176500	Coosawhatchie River Near Hampton, Sc	-81.13177180	32.83627770	030502

Given the complexities of the study area, the limitations of using SWB for this study are that (1) groundwater/surface-water interactions cannot be simulated without a coupled groundwater flow model; (2) surface runoff is overestimated in karst areas because recharge by way of karst features is not taken into account; and (3) leakage to confined aquifers underlying the aquifer present at land surface is not calculated. As a consequence of these limitations, it is likely that the SWB model underestimates net recharge in karst areas and overestimates recharge in areas that have a shallow water table and receive large amounts of precipitation, such as low-lying coastal wetland areas. Much of the Florida panhandle, along with parts of central and south Florida, may be subject to overestimation of recharge in this manner. Additionally, the SWB model might underestimate recharge in unconfined or thinly confined areas where water might recharge the Floridan aquifer system through karst features such as in-stream sinks, sinkholes, or collapse features. Computation of leakage to the Floridan aquifer system is not possible for most of the study area where the Floridan aquifer system is overlain by the surficial and intermediate aquifer systems because SWB is unable to compute leakage through hydrogeologic units, as it is designed to estimate net recharge to the aquifer present at land surface.

A sensitivity analysis was completed to determine the potential for error in simulated recharge based on uncertainties associated with the input datasets. Parameter adjustment coefficients of 0.8, 0.9, 1.1, and 1.2 were used for precipitation, SCS runoff curve number, and maximum allowable recharge rate. Coefficients of 0.5, 0.75, 1.25, and 1.5 were used for available water content and root-zone depth. Air temperature was adjusted higher and lower by 1 and 5 degrees Fahrenheit. The percent change in simulated recharge (filtered) was computed for each groundwater basin (fig. 2–3). The analysis showed that recharge is most sensitive to changes in precipitation and least sensitive to maximum allowable recharge rate and air temperature. Results of a sensitivity analysis in Stanton and others (2011) indicated that actual evapotranspiration is similarly sensitive to precipitation, although less sensitive than recharge.

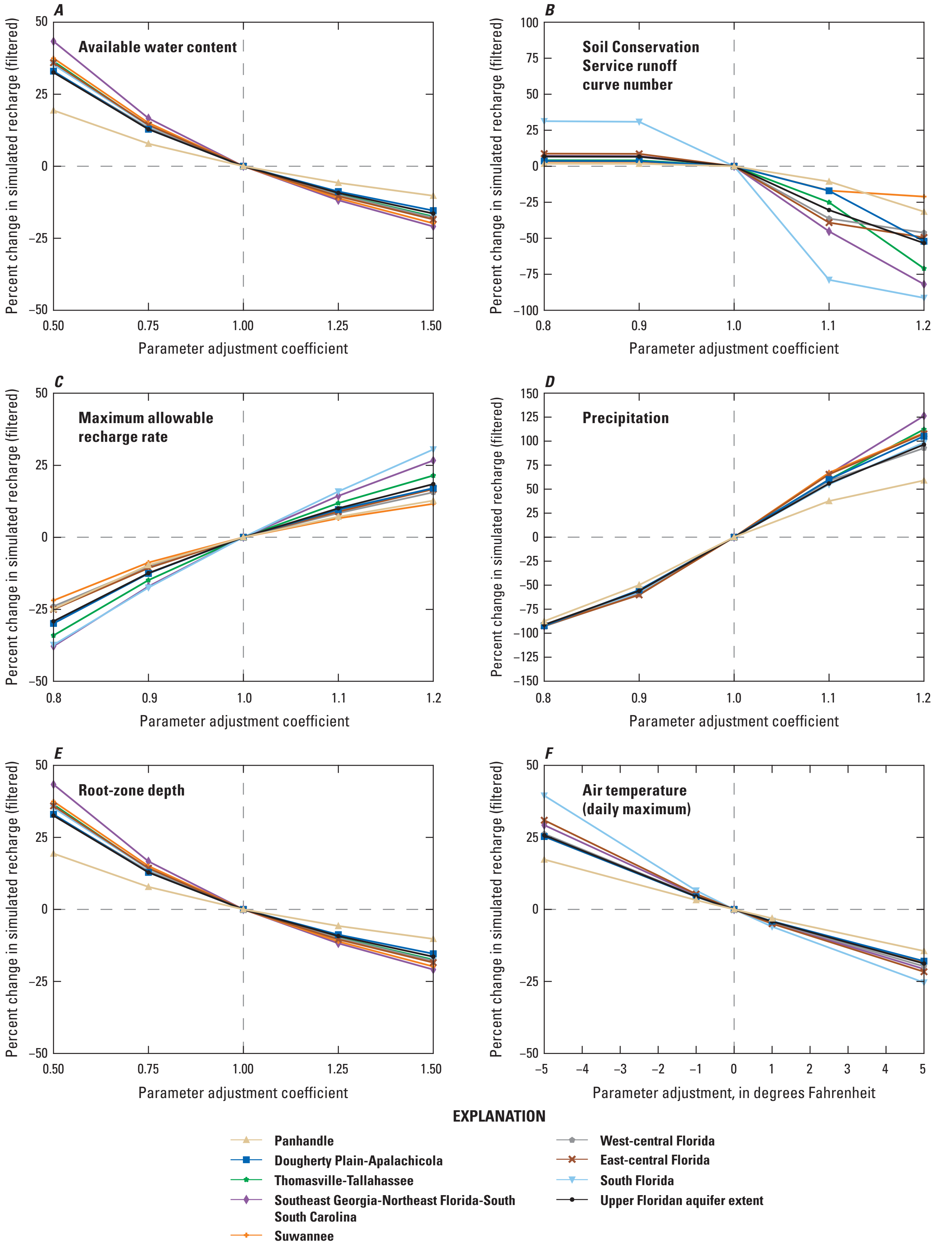

Figure 2–3. Percent change in simulated recharge (filtered) with respect to changes in parameter values used in the Soil-Water-Balance model in Bellino (2018) representing *A*, available water content, *B*, Soil Conservation Service runoff curve number, *C*, maximum allowable recharge rate, *D*, precipitation, *E*, root-zone depth, and *F*, air temperature (daily maximum).

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Appendix 3. Floridan Aquifer System Springs With Discharge Greater Than 1 Cubic Foot per Second

Table 3–1. Floridan aquifer system springs with discharge greater than 1 cubic foot per second in the study area, southeastern United States.

[Data from Bush and Johnston, 1986; Callahan, 1964; Champion and Starks, 2001; Chandler and Moore, 1987; Meinzer, 1927; Rosenau and others, 1977; St. Johns River Water Management District, 2014; Scott and others, 2004; Stringfield, 1966; U.S. Geological Survey, 2016; Debra Harrington, Florida Geological Survey, written commun., 2014. FIPS, Federal Information Processing Standards; ID, identification; USGS, U.S. Geological Survey; DEP FGS, Florida Department of Environmental Protection, Florida Geological Survey; GSA_ID, Geological Survey of Alabama identification; GNIS_ID, Geographic Names Information System identification; NGVD 29, National Geodetic Vertical Datum of 1929. "Group" indicates that the individual spring is part of a group of springs that, taken together, constitute the magnitude listed]

State	County	FIPS code	Spring group	Spring name	Other ID	USGS site identification number	Latitude, in decimal degrees	Longitude, in decimal degrees	Altitude, in feet above NGVD 29	Magnitude
Alabama	Clarke	01025	Gilmore Spring	Gilmore Spring	GSA_ID II-2		31.57405	-87.84361	135	3d
Alabama	Clarke	01025	Hoven Spring	Hoven Spring	GSA_ID HH-6		31.530441	-87.93639	34	3d
Alabama	Houston	01069	Bazemore Mill Spring	Bazemore Mill Spring	GSA_ID T-6		31.028795	-85.197154	141	2d
Florida	Alachua	12001	Ala930971	Ala930971	DEP FGS-1		29.827943	-82.640835	23	2d
Florida	Alachua	12001	Ala930972	Ala930972	DEP FGS-2		29.844662	-82.630856	26	2d
Florida	Alachua	12001	Darby Spring	Darby Spring	DEP FGS-93		29.852616	-82.605963	33	2d
Florida	Alachua	12001	Hornsby Spring	Hornsby Spring	DEP FGS-176	02321970	29.850355	-82.593201	35	1st
Florida	Alachua	12001	Magnesia Spring	Magnesia Spring	DEP FGS-246		29.583407	-82.149593	76	3d
Florida	Alachua	12001	Poe Spring	Poe Spring	DEP FGS-301	02322140, 294933082385800	29.825716	-82.648973	26	2d
Florida	Alachua	12001	Santa Fe River Rise	Santa Fe River Rise	DEP FGS-347		29.873894	-82.591636	36	1st
Florida	Alachua	12001	Treehouse Spring	Treehouse Spring	DEP FGS-412		29.854886	-82.602877	33	1st
Florida	Bay	12005	Gainer Spring Group	Gainer Spring No. 3 (Emerald)	DEP FGS-125	302536085325400, 302538085325500, 302540085325000	30.428973	-85.548787	21	1st (group)
Florida	Bay	12005	Gainer Spring Group	Gainer Spring No. 1 (McCormick Springs)	DEP FGS-123	302536085325400, 302538085325500, 302540085325000	30.427673	-85.546063	17	1st (group)
Florida	Bay	12005	Gainer Spring Group	Gainer Spring No. 2	DEP FGS-124	302536085325400, 302538085325500, 302540085325000	30.427392	-85.54832	21	1st (group)
Florida	Bay	12005	Pitt Spring	Pitt Spring	DEP FGS-300	302556085324700	30.432966	-85.546428	16	3d
Florida	Bay	12005	Sylvan Springs	Sylvan Springs			30.43176	-85.548223	22	2d (group)
Florida	Calhoun	12013	Grotto Springs	Grotto Springs	DEP FGS-145		30.599412	-85.164244	53	3d
Florida	Calhoun	12013	Hamilton Spring	Hamilton Spring	DEP FGS-155		30.519252	-85.163199	46	3d
Florida	Calhoun	12013	Sally Spring	Sally Spring	DEP FGS-340		30.570301	-85.17342	33	3d
Florida	Citrus	12017	Baird Spring Group	Baird Spring #4	DEP FGS-14	284230082344000	28.709259	-82.580274	0	3d (group)
Florida	Citrus	12017	Baird Spring Group	Baird Spring	DEP FGS-11	284230082344000	28.707476	-82.5782	0	3d (group)
Florida	Citrus	12017	Baird Spring Group	Baird Spring #2	DEP FGS-12	284230082344000	28.708301	-82.578556	0	3d (group)

Table 3–1. Floridan aquifer system springs with discharge greater than 1 cubic foot per second in the study area, southeastern United States.—Continued

[Data from Bush and Johnston, 1986; Callahan, 1964; Champion and Starks, 2001; Chandler and Moore, 1987; Meinzer, 1927; Rosenau and others, 1977; St. Johns River Water Management District, 2014; Scott and others, 2004; Stringfield, 1966; U.S. Geological Survey, 2016; Debra Harrington, Florida Geological Survey, written commun., 2014. FIPS, Federal Information Processing Standards; ID, identification; USGS, U.S. Geological Survey; DEP FGS, Florida Department of Environmental Protection, Florida Geological Survey; GSA_ID, Geological Survey of Alabama identification; GNIS_ID, Geographic Names Information System identification; NGVD 29, National Geodetic Vertical Datum of 1929. "Group" indicates that the individual spring is part of a group of springs that, taken together, constitute the magnitude listed]

State	County	FIPS code	Spring group	Spring name	Other ID	USGS site identification number	Latitude, in decimal degrees	Longitude, in decimal degrees	Altitude, in feet above NGVD 29	Magnitude
Florida	Citrus	12017	Baird Spring Group	Baird Spring #3	DEP FGS-13	284230082344000	28.709127	-82.579644	0	3d (group)
Florida	Citrus	12017	Kings Bay Spring Group	Three Sisters Springs	DEP FGS-408		28.888725	-82.589191	3	2d
Florida	Citrus	12017	Kings Bay Spring Group	Catfish Spring	DEP FGS-62		28.898	-82.599	0	2d
Florida	Citrus	12017	Kings Bay Spring Group	Hunter Spring	DEP FGS-180		28.89443	-82.592482	0	1st
Florida	Citrus	12017	Kings Bay Spring Group	Idiots Delight Spring	DEP FGS-182		28.887952	-82.589454	3	3d
Florida	Citrus	12017	Kings Bay Spring Group	Little Hidden Spring	DEP FGS-232		28.885782	-82.594062	0	3d
Florida	Citrus	12017	Kings Bay Spring Group	Millers Creek Spring	DEP FGS-259		28.9011	-82.6038	0	3d
Florida	Citrus	12017	Kings Bay Spring Group	Black Springs	DEP FGS-32		28.8773	-82.599	0	3d
Florida	Citrus	12017	Kings Bay Spring Group	Tarpon Hole Spring	DEP FGS-282		28.881844	-82.594815	0	1st
Florida	Citrus	12017	Chassahowitzka Spring Group	Chassahowitzka Spring Main	DEP FGS-68	02310650, 284254082343500	28.715518	-82.576203	0	1st
Florida	Citrus	12017	Chassahowitzka Spring Group	Chassahowitzka Spring #1	DEP FGS-66	02310650, 284254082343500	28.716178	-82.575089	3	2d
Florida	Citrus	12017	Chassahowitzka Spring Group	Chassahowitzka Spring #2	DEP FGS-67	02310650, 284254082343500	28.716018	-82.575451	3	2d
Florida	Citrus	12017	Citrus Blue Spring	Citrus Blue Spring	DEP FGS-70		28.969334	-82.31454	36	2d
Florida	Citrus	12017	Crab Spring	Crab Spring	DEP FGS-88		28.717199	-82.575852	0	2d
Florida	Citrus	12017	Homosassa Spring Group	Homosassa Spring #3	DEP FGS-174	02310678, 284758082352000	28.799065	-82.58852	0	1st (group)
Florida	Citrus	12017	Homosassa Spring Group	Homosassa Spring #2	DEP FGS-173	02310678, 284758082352000	28.799069	-82.588552	0	1st (group)

Table 3–1. Floridan aquifer system springs with discharge greater than 1 cubic foot per second in the study area, southeastern United States.—Continued

[Data from Bush and Johnston, 1986; Callahan, 1964; Champion and Starks, 2001; Chandler and Moore, 1987; Meinzer, 1927; Rosenau and others, 1977; St. Johns River Water Management District, 2014; Scott and others, 2004; Stringfield, 1966; U.S. Geological Survey, 2016; Debra Harrington, Florida Geological Survey, written commun., 2014. FIPS, Federal Information Processing Standards; ID, identification; USGS, U.S. Geological Survey; DEP FGS, Florida Department of Environmental Protection, Florida Geological Survey; GSA_ID, Geological Survey of Alabama identification; GNIS_ID, Geographic Names Information System identification; NGVD 29, National Geodetic Vertical Datum of 1929. “Group” indicates that the individual spring is part of a group of springs that, taken together, constitute the magnitude listed]

State	County	FIPS code	Spring group	Spring name	Other ID	USGS site identification number	Latitude, in decimal degrees	Longitude, in decimal degrees	Altitude, in feet above NGVD 29	Magnitude
Florida	Citrus	12017	Homosassa Spring Group	Homosassa Spring #1	DEP FGS-172	02310678, 284758082352000	28.799074	-82.588525	0	1st (group)
Florida	Citrus	12017	Potter Spring	Potter Spring	DEP FGS-305		28.7316	-82.596545	0	2d
Florida	Citrus	12017	Pumphouse Springs	Pumphouse Springs	DEP FGS-308		28.796495	-82.588293	0	3d
Florida	Citrus	12017	Ruth Spring	Ruth Spring	DEP FGS-338	02310660, 284357082354800	28.732465	-82.595059	0	2d
Florida	Citrus	12017	Trotter Main Spring	Trotter Main Spring	DEP FGS-413	284747082351000	28.796478	-82.586397	0	3d
Florida	Clay	12019	Green Cove Spring	Green Cove Spring	DEP FGS-143		29.9934	-81.67791	12	2d
Florida	Clay	12019	Lake Lowery Spring Group	Lake Lowery East	DEP FGS-214		29.861145	-81.980113	173	3d
Florida	Clay	12019	Lake Lowery Spring Group	Lake Lowery North	DEP FGS-215		29.871588	-81.988231	200	3d
Florida	Clay	12019	Lake Lowery Spring Group	Lake Lowry West	DEP FGS-216		29.866023	-81.995621	182	3d
Florida	Columbia	12023	Col1012971	Col1012971	DEP FGS-74		29.856912	-82.729995	20	2d
Florida	Columbia	12023	Col1012972	Col1012972	DEP FGS-75		29.856494	-82.731699	21	2d
Florida	Columbia	12023	Col101971	Col101971	DEP FGS-76		29.832211	-82.669364	26	3d
Florida	Columbia	12023	Col101974	Col101974	DEP FGS-77		29.833998	-82.676679	20	2d
Florida	Columbia	12023	Col428981	Col428981	DEP FGS-78		29.853536	-82.605521	33	3d
Florida	Columbia	12023	Col522981	Col522981	DEP FGS-79		30.321044	-82.755915	54	3d
Florida	Columbia	12023	Col522982	Col522982	DEP FGS-80		30.321462	-82.756528	54	3d
Florida	Columbia	12023	Col917971	Col917971	DEP FGS-81		29.924828	-82.77199	14	3d
Florida	Columbia	12023	Col928971	Col928971	DEP FGS-82		29.886163	-82.75153	16	3d
Florida	Columbia	12023	Col930971	Col930971	DEP FGS-83		29.831164	-82.65674	26	2d
Florida	Columbia	12023	Columbia Spring	Columbia Spring	DEP FGS-84	02321977	29.854111	-82.611953	33	1st
Florida	Columbia	12023	Jonathan Spring	Jonathan Spring	DEP FGS-194		29.83379	-82.675416	20	3d
Florida	Columbia	12023	July Spring	July Spring	DEP FGS-195	295010082414700	29.836175	-82.696396	23	1st
Florida	Columbia	12023	Mill Pond Spring	Mill Pond Spring	DEP FGS-258	02322695	29.966662	-82.759975	30	2d

Table 3–1. Floridan aquifer system springs with discharge greater than 1 cubic foot per second in the study area, southeastern United States.—Continued

[Data from Bush and Johnston, 1986; Callahan, 1964; Champion and Starks, 2001; Chandler and Moore, 1987; Meinzer, 1927; Rosenau and others, 1977; St. Johns River Water Management District, 2014; Scott and others, 2004; Stringfield, 1966; U.S. Geological Survey, 2016; Debra Harrington, Florida Geological Survey, written commun., 2014. FIPS, Federal Information Processing Standards; ID, identification; USGS, U.S. Geological Survey; DEP FGS, Florida Department of Environmental Protection, Florida Geological Survey; GSA_ID, Geological Survey of Alabama identification; GNIS_ID, Geographic Names Information System identification; NGVD 29, National Geodetic Vertical Datum of 1929. "Group" indicates that the individual spring is part of a group of springs that, taken together, constitute the magnitude listed]

State	County	FIPS code	Spring group	Spring name	Other ID	USGS site identification number	Latitude, in decimal degrees	Longitude, in decimal degrees	Altitude, in feet above NGVD 29	Magnitude
Florida	Columbia	12023	Rum Island Spring	Rum Island Spring	DEP FGS-335	294959082404900	29.83352	-82.679831	22	3d
Florida	Columbia	12023	Santa Fe Spring	Santa Fe Spring	DEP FGS-348		29.934804	-82.53042	41	1st
Florida	Columbia	12023	Sawdust Spring	Sawdust Spring	DEP FGS-350		29.840014	-82.70351	21	3d
Florida	Columbia	12023	Sunbeam Spring	Sunbeam Spring	DEP FGS-389		29.928094	-82.769814	13	3d
Florida	Columbia	12023	Wilson Spring	Wilson Spring	DEP FGS-457		29.90005	-82.758547	26	2d
Florida	Dixie	12029	Copper Spring	Copper Spring	DEP FGS-86	293650082582600	29.614014	-82.973858	10	2d
Florida	Dixie	12029	Dix95971	Dix95971	DEP FGS-99		29.704398	-82.952742	6	3d
Florida	Dixie	12029	Guaranto Spring	Guaranto Spring	DEP FGS-146	294646082562400	29.779797	-82.939958	33	2d
Florida	Dixie	12029	Little Copper Spring	Little Copper Spring	DEP FGS-229		29.633712	-82.966846	7	3d
Florida	Dixie	12029	Mccrabb Spring	Mccrabb Spring	DEP FGS-254		29.685488	-82.960204	3	3d
Florida	Dixie	12029	Pot Hole Spring	Pot Hole Spring	DEP FGS-303		29.810682	-82.935856	32	2d
Florida	Dixie	12029	Steinhatchee River Rise	Steinhatchee River Rise	DEP FGS-383		29.769912	-83.325035	8	1st
Florida	Duval	12031	Pottsburg Spring	Pottsburg Spring	DEP FGS-306		30.29	-81.5709	7	3d
Florida	Escambia	12033	Mystic	Mystic		305125087174800	30.858121	-87.3137	30	3d
Florida	Gilchrist	12041	Bell Spring	Bell Spring	DEP FGS-26	293550082563000	29.597444	-82.941172	12	3d
Florida	Gilchrist	12041	Campground Spring	Campground Spring	DEP FGS-59		29.89929	-82.866095	7	3d
Florida	Gilchrist	12041	Deer Spring	Deer Spring	DEP FGS-94		29.841165	-82.707324	24	3d
Florida	Gilchrist	12041	Devils Ear Spring	Devils Ear Spring	DEP FGS-96	02322402	29.835349	-82.6966	20	1st
Florida	Gilchrist	12041	Devil's Eye Spring	Devil's Eye Spring	DEP FGS-97		29.835159	-82.69659	21	1st, 2d
Florida	Gilchrist	12041	Dogwood Spring	Dogwood Spring	DEP FGS-100		29.838056	-82.701793	23	2d
Florida	Gilchrist	12041	Gil1012972	Gil1012972	DEP FGS-132		29.85605	-82.732709	17	3d
Florida	Gilchrist	12041	Gil1012973	Gil1012973			29.856187	-82.732895	16	1st
Florida	Gilchrist	12041	Gil107971	Gil107971			29.855901	-82.73219	16	2d
Florida	Gilchrist	12041	Gil84971	Gil84971	DEP FGS-134		29.829862	-82.89144	6	2d
Florida	Gilchrist	12041	Gil928971	Gil928971	DEP FGS-135		29.875598	-82.751892	22	3d
Florida	Gilchrist	12041	Gil99972	Gil99972	DEP FGS-136		29.930919	-82.802416	10	3d
Florida	Gilchrist	12041	Gilchrist Blue Spring	Gilchrist Blue Spring	DEP FGS-137		29.8299	-82.682851	25	2d

Table 3–1. Floridan aquifer system springs with discharge greater than 1 cubic foot per second in the study area, southeastern United States.—Continued

[Data from Bush and Johnston, 1986; Callahan, 1964; Champion and Starks, 2001; Chandler and Moore, 1987; Meinzer, 1927; Rosenau and others, 1977; St. Johns River Water Management District, 2014; Scott and others, 2004; Stringfield, 1966; U.S. Geological Survey, 2016; Debra Harrington, Florida Geological Survey, written commun., 2014. FIPS, Federal Information Processing Standards; ID, identification; USGS, U.S. Geological Survey; DEP FGS, Florida Department of Environmental Protection, Florida Geological Survey; GSA_ID, Geological Survey of Alabama identification; GNIS_ID, Geographic Names Information System identification; NGVD 29, National Geodetic Vertical Datum of 1929. "Group" indicates that the individual spring is part of a group of springs that, taken together, constitute the magnitude listed]

State	County	FIPS code	Spring group	Spring name	Other ID	USGS site identification number	Latitude, in decimal degrees	Longitude, in decimal degrees	Altitude, in feet above NGVD 29	Magnitude
Florida	Gilchrist	12041	Ginnie Spring	Ginnie Spring	DEP FGS-139	02322400	29.836339	-82.700121	23	2d
Florida	Gilchrist	12041	Hart Springs	Hart Springs	DEP FGS-158	02323150, 294030082570500	29.675741	-82.951711	7	2d
Florida	Gilchrist	12041	Lilly Spring	Lilly Spring	DEP FGS-223		29.829717	-82.661212	23	2d
Florida	Gilchrist	12041	Little Devil Spring	Little Devil Spring	DEP FGS-230		29.834563	-82.697033	23	3d
Florida	Gilchrist	12041	Little Otter Spring	Little Otter Spring	DEP FGS-235		29.636417	-82.958427	7	2d
Florida	Gilchrist	12041	Lumbercamp Springs	Lumbercamp Springs	DEP FGS-241	294227082560800	29.706583	-82.938056	10	3d
Florida	Gilchrist	12041	Oasis Spring	Oasis Spring			29.925783	-82.780375	13	3d
Florida	Gilchrist	12041	Otter Spring	Otter Spring	DEP FGS-289		29.644802	-82.942753	7	2d
Florida	Gilchrist	12041	Pickard Spring	Pickard Spring	DEP FGS-298		29.830534	-82.662087	20	2d
Florida	Gilchrist	12041	Rock Bluff Springs	Rock Bluff Springs	DEP FGS-329	02322997, 294756082550800	29.799084	-82.91864	55	2d
Florida	Gilchrist	12041	Siphon Creek Rise	Siphon Creek Rise	DEP FGS-374		29.856191	-82.733051	16	1st
Florida	Gilchrist	12041	Sun Springs	Sun Springs	DEP FGS-388	02323095	29.704737	-82.933527	7	2d
Florida	Gilchrist	12041	Trail Spring	Trail Spring	DEP FGS-411		29.898358	-82.866713	3	3d
Florida	Gilchrist	12041	Twin Spring	Twin Spring	DEP FGS-417		29.840454	-82.705864	23	2d
Florida	Hamilton	12047	Alapaha River Rise	Alapaha River Rise	DEP FGS-3		30.438969	-83.089562	54	1st
Florida	Hamilton	12047	Ham1017974	Ham1017974	DEP FGS-149		30.417717	-82.965962	40	2d
Florida	Hamilton	12047	Ham610982	Ham610982	DEP FGS-150		30.417434	-83.207408	29	2d
Florida	Hamilton	12047	Ham610983	Ham610983	DEP FGS-151		30.420409	-83.214272	38	2d
Florida	Hamilton	12047	Ham610984	Ham610984	DEP FGS-152		30.440421	-83.219583	31	2d
Florida	Hamilton	12047	Ham612982	Ham612982	DEP FGS-153		30.474746	-83.243383	37	3d
Florida	Hamilton	12047	Ham923973	Ham923973	DEP FGS-154		30.418928	-83.149069	32	3d
Florida	Hamilton	12047	Holton Creek Rise	Holton Creek Rise	DEP FGS-169		30.43792	-83.057614	52	1st
Florida	Hamilton	12047	Morgan Spring	Morgan Spring	DEP FGS-264		30.420222	-83.207361	41	2d
Florida	Hamilton	12047	Pot Spring	Pot Spring	DEP FGS-304		30.470803	-83.234399	36	2d
Florida	Hamilton	12047	Seven Sisters Spring	Seven Sisters Spring	DEP FGS-352		30.4175	-83.155331	41	3d
Florida	Hamilton	12047	Tanner Spring	Tanner Spring	DEP FGS-280		30.464575	-83.217733	42	2d

Table 3–1. Floridan aquifer system springs with discharge greater than 1 cubic foot per second in the study area, southeastern United States.—Continued

[Data from Bush and Johnston, 1986; Callahan, 1964; Champion and Starks, 2001; Chandler and Moore, 1987; Meinzer, 1927; Rosenau and others, 1977; St. Johns River Water Management District, 2014; Scott and others, 2004; Stringfield, 1966; U.S. Geological Survey, 2016; Debra Harrington, Florida Geological Survey, written commun., 2014. FIPS, Federal Information Processing Standards; ID, identification; USGS, U.S. Geological Survey; DEP FGS, Florida Department of Environmental Protection, Florida Geological Survey; GSA_ID, Geological Survey of Alabama identification; GNIS_ID, Geographic Names Information System identification; NGVD 29, National Geodetic Vertical Datum of 1929. "Group" indicates that the individual spring is part of a group of springs that, taken together, constitute the magnitude listed]

State	County	FIPS code	Spring group	Spring name	Other ID	USGS site identification number	Latitude, in decimal degrees	Longitude, in decimal degrees	Altitude, in feet above NGVD 29	Magnitude
Florida	Hernando	12053	Aripeka Spring Group	Aripeka Spring #2	DEP FGS-10		28.435295	-82.658932	0	3d
Florida	Hernando	12053	Aripeka Spring Group	Aripeka Spring #1	DEP FGS-9		28.438531	-82.658784	0	3d
Florida	Hernando	12053	Blind Spring	Blind Spring	DEP FGS-34		28.657867	-82.634617	0	2d
Florida	Hernando	12053	Boat Spring	Boat Spring	DEP FGS-44	02310380, 282621082392900	28.43655	-82.65651	0	3d
Florida	Hernando	12053	Little Spring (Twin Dees Spring)	Little Spring (Twin Dees Spring)	DEP FGS-238		28.513464	-82.581028	13	2d
Florida	Hernando	12053	Ryles Spring	Ryles Spring	DEP FGS-339	284113082365000, 284114082365200	28.687165	-82.614118	0	2d
Florida	Hernando	12053	Salt Spring	Salt Spring	DEP FGS-342	02310562, 283245082371000	28.546319	-82.618965	3	2d
Florida	Hernando	12053	Weeki Wachee Springs	Weeki Wachee Springs	DEP FGS-448	02310500, 02310545, 283049082345100	28.517191	-82.573166	4	1st
Florida	Hernando	12053	Magnolia Spring	Magnolia Spring	DEP FGS-247	02310410, 282558082392600	28.43386944	-82.65248888	4	2d
Florida	Hillsborough	12057	Buckhorn Spring Group	Buckhorn East Spring		02301700, 275320082182000, 275322082181000	27.889075	-82.301442	9	2d
Florida	Hillsborough	12057	Buckhorn Spring Group	Buckhorn South Spring		02301700, 275320082182000, 275322082181000	27.886903	-82.305211	5	2d
Florida	Hillsborough	12057	Buckhorn Spring Group	Buckhorn West Spring		02301700, 275320082182000, 275322082181000	27.889206	-82.304672	13	2d
Florida	Hillsborough	12057	Buckhorn Spring Group	Buckhorn Spring	DEP FGS-53	02301700, 275320082182000, 275322082181000	27.889392	-82.302721	6	2d
Florida	Hillsborough	12057	Canal Spring	Canal Spring	DEP FGS-60		28.034786	-82.343023	13	2d

Table 3–1. Floridan aquifer system springs with discharge greater than 1 cubic foot per second in the study area, southeastern United States.—Continued

[Data from Bush and Johnston, 1986; Callahan, 1964; Champion and Starks, 2001; Chandler and Moore, 1987; Meinzer, 1927; Rosenau and others, 1977; St. Johns River Water Management District, 2014; Scott and others, 2004; Stringfield, 1966; U.S. Geological Survey, 2016; Debra Harrington, Florida Geological Survey, written commun., 2014. FIPS, Federal Information Processing Standards; ID, identification; USGS, U.S. Geological Survey; DEP FGS, Florida Department of Environmental Protection, Florida Geological Survey; GSA_ID, Geological Survey of Alabama identification; GNIS_ID, Geographic Names Information System identification; NGVD 29, National Geodetic Vertical Datum of 1929. "Group" indicates that the individual spring is part of a group of springs that, taken together, constitute the magnitude listed]

State	County	FIPS code	Spring group	Spring name	Other ID	USGS site identification number	Latitude, in decimal degrees	Longitude, in decimal degrees	Altitude, in feet above NGVD 29	Magnitude
Florida	Hillsborough	12057	Eureka Springs Group	Eureka Springs		280022082204000, 280023082203300, 280023082203700, 280023082203800	28.005956	-82.345875	16	2d (group)
Florida	Hillsborough	12057	Eureka Springs Group	Eureka Unnamed Spring No. #4 (TRIB #1)		280022082204000, 280023082203300, 280023082203700, 280023082203800	28.007424	-82.344055	14	2d (group)
Florida	Hillsborough	12057	Lettuce Lake Spring	Lettuce Lake Spring	DEP FGS-220		28.018202	-82.350071	13	3d
Florida	Hillsborough	12057	Lithia Springs	Lithia Springs	DEP FGS-226	02301600, 02301602	27.866278	-82.231471	6	2d
Florida	Hillsborough	12057	Sulphur Spring	Sulphur Spring	DEP FGS-386	02306000, 023060003	28.021134	-82.451635	4	2d
Florida	Holmes	12059	Holmes Blue Spring	Holmes Blue Spring	DEP FGS-168		30.851676	-85.885847	59	2d
Florida	Holmes	12059	Jackson Spring	Jackson Spring	DEP FGS-191		30.711676	-85.92806	46	3d
Florida	Holmes	12059	Ponce de Leon Spring	Ponce de Leon Spring	DEP FGS-302	304316085555100	30.721202	-85.930685	47	2d
Florida	Holmes	12059	Vortex Spring	Vortex Spring	DEP FGS-431	304614085565500	30.770552	-85.948474	69	2d
Florida	Jackson	12063	Baltzell Spring	Baltzell Spring	DEP FGS-15	304948085140501, 304950085140501	30.8306	-85.2344	73	2d
Florida	Jackson	12063	Barrel Spring	Barrel Spring	DEP FGS-18		30.592433	-85.17068	40	3d
Florida	Jackson	12063	Spring Lake Spring Group	Mill Pond Spring	DEP FGS-257	304153085174001, 304213085171801, 304213085181001, 304213085182701, 304225085182301	30.7037	-85.3075	79	2d
Florida	Jackson	12063	Spring Lake Spring Group	Black Spring	DEP FGS-31	304153085174001, 304213085171801, 304213085181001, 304213085182701, 304225085182301	30.698723	-85.294465	66	2d

Table 3–1. Floridan aquifer system springs with discharge greater than 1 cubic foot per second in the study area, southeastern United States.—Continued

[Data from Bush and Johnston, 1986; Callahan, 1964; Champion and Starks, 2001; Chandler and Moore, 1987; Meinzer, 1927; Rosenau and others, 1977; St. Johns River Water Management District, 2014; Scott and others, 2004; Stringfield, 1966; U.S. Geological Survey, 2016; Debra Harrington, Florida Geological Survey, written commun., 2014. FIPS, Federal Information Processing Standards; ID, identification; USGS, U.S. Geological Survey; DEP FGS, Florida Department of Environmental Protection, Florida Geological Survey; GSA_ID, Geological Survey of Alabama identification; GNIS_ID, Geographic Names Information System identification; NGVD 29, National Geodetic Vertical Datum of 1929. "Group" indicates that the individual spring is part of a group of springs that, taken together, constitute the magnitude listed]

State	County	FIPS code	Spring group	Spring name	Other ID	USGS site identification number	Latitude, in decimal degrees	Longitude, in decimal degrees	Altitude, in feet above NGVD 29	Magnitude
Florida	Jackson	12063	Spring Lake Spring Group	Springboard Spring	DEP FGS-380	304153085174001, 304213085171801, 304213085181001, 304213085182701, 304225085182301	30.7074	-85.3066	73	2d
Florida	Jackson	12063	Spring Lake Spring Group	Double Spring	DEP FGS-102	304153085174001, 304213085171801, 304213085181001, 304213085182701, 304225085182301	30.7038	-85.3031	79	2d
Florida	Jackson	12063	Spring Lake Spring Group	Gadsen Spring	DEP FGS-122	304153085174001, 304213085171801, 304213085181001, 304213085182701, 304225085182301	30.703357	-85.288451	67	2d
Florida	Jackson	12063	Blue Hole Spring	Blue Hole Spring	DEP FGS-37	304913085144201	30.820145	-85.244895	83	2d
Florida	Jackson	12063	Hays Spring	Hays Spring	DEP FGS-159	305335085133500	30.895092	-85.224485	89	2d
Florida	Jackson	12063	Jackson Blue Spring	Jackson Blue Spring	DEP FGS-189	02358795, 304725085082600	30.790515	-85.140088	78	1st
Florida	Jackson	12063	Maund Spring	Maund Spring	DEP FGS-252		30.74631	-85.2155	60	3d
Florida	Jackson	12063	Rooks Springs	Rooks Springs	DEP FGS-332		30.687899	-85.234388	66	3d
Florida	Jackson	12063	Sandbag Spring	Sandbag Spring	DEP FGS-344	304718085132000	30.788721	-85.221919	67	3d
Florida	Jackson	12063	Shangri-La Springs	Shangri-La Springs	DEP FGS-353		30.790166	-85.142885	90	3d
Florida	Jefferson	12065	Wacissa Spring Group	Garner Spring	DEP FGS-127	301804083584700	30.33031	-83.983116	30	2d
Florida	Jefferson	12065	Wacissa Spring Group	Brumbley Spring	DEP FGS-50	301804083584700	30.34483	-83.981009	33	2d
Florida	Jefferson	12065	Wacissa Spring Group	Horsehead Spring	DEP FGS-177	301804083584700	30.344861	-83.994543	33	2d
Florida	Jefferson	12065	Wacissa Spring Group	Cassidy Springs	DEP FGS-61	301804083584700	30.332721	-83.989037	28	1st, 2d
Florida	Jefferson	12065	Wacissa Spring Group	Wacissa Spring #3	DEP FGS-435	301804083584700	30.340593	-83.990744	33	3d
Florida	Jefferson	12065	Wacissa Spring Group	Thomas Spring	DEP FGS-407	301804083584700	30.339713	-83.992324	30	2d
Florida	Jefferson	12065	Wacissa Spring Group	Minnow Spring	DEP FGS-261	301804083584700	30.331534	-83.986593	27	2d

Table 3–1. Floridan aquifer system springs with discharge greater than 1 cubic foot per second in the study area, southeastern United States.—Continued

[Data from Bush and Johnston, 1986; Callahan, 1964; Champion and Starks, 2001; Chandler and Moore, 1987; Meinzer, 1927; Rosenau and others, 1977; St. Johns River Water Management District, 2014; Scott and others, 2004; Stringfield, 1966; U.S. Geological Survey, 2016; Debra Harrington, Florida Geological Survey, written commun., 2014. FIPS, Federal Information Processing Standards; ID, identification; USGS, U.S. Geological Survey; DEP FGS, Florida Department of Environmental Protection, Florida Geological Survey; GSA_ID, Geological Survey of Alabama identification; GNIS_ID, Geographic Names Information System identification; NGVD 29, National Geodetic Vertical Datum of 1929. "Group" indicates that the individual spring is part of a group of springs that, taken together, constitute the magnitude listed]

State	County	FIPS code	Spring group	Spring name	Other ID	USGS site identification number	Latitude, in decimal degrees	Longitude, in decimal degrees	Altitude, in feet above NGVD 29	Magnitude
Florida	Jefferson	12065	Wacissa Spring Group	Log Spring	DEP FGS-240	301804083584700	30.340533	-83.993004	30	2d
Florida	Jefferson	12065	Wacissa Spring Group	Little Blue Spring	DEP FGS-228	301804083584700	30.330842	-83.989037	30	2d
Florida	Jefferson	12065	Wacissa Spring Group	Big Spring (Big Blue Spring)	DEP FGS-28	301804083584700	30.327734	-83.984827	26	2d
Florida	Lafayette	12067	Wacissa Spring Group	Allen Mill Pond Spring	DEP FGS-5	02319915	30.162841	-83.243071	78	2d
Florida	Lafayette	12067	Convict Spring	Convict Spring	DEP FGS-85		30.08834	-83.095967	57	3d
Florida	Lafayette	12067	Laf57982	Laf57982	DEP FGS-201		30.061176	-83.05737	47	3d
Florida	Lafayette	12067	Laf718971	Laf718971	DEP FGS-202		29.959476	-82.953317	19	2d
Florida	Lafayette	12067	Laf718972	Laf718972	DEP FGS-203		30.011627	-83.004261	53	2d
Florida	Lafayette	12067	Laf919972	Laf919972	DEP FGS-204		30.092147	-83.113354	65	3d
Florida	Lafayette	12067	Laf922976	Laf922976	DEP FGS-206		30.260571	-83.249684	50	3d
Florida	Lafayette	12067	Laf924971	Laf924971	DEP FGS-207		30.102211	-83.166108	53	2d
Florida	Lafayette	12067	Laf929971	Laf929971	DEP FGS-208		30.21128	-83.245401	72	3d
Florida	Lafayette	12067	Laf929972	Laf929972	DEP FGS-209		30.190095	-83.250419	71	3d
Florida	Lafayette	12067	Laf929973	Laf929973	DEP FGS-210		30.18001	-83.247742	87	2d
Florida	Lafayette	12067	Lafayette Blue Spring	Lafayette Blue Spring	DEP FGS-211	02319950	30.125834	-83.226133	62	1st
Florida	Lafayette	12067	Mearson Spring	Mearson Spring	DEP FGS-255	02320240	30.041343	-83.025028	59	2d
Florida	Lafayette	12067	Owens Spring	Owens Spring	DEP FGS-290	300244083022901	30.045942	-83.04113	81	2d
Florida	Lafayette	12067	Perry Spring	Perry Spring	DEP FGS-297		30.096407	-83.18825	46	2d
Florida	Lafayette	12067	Ruth Spring	Ruth Spring	DEP FGS-337	02320260	29.995773	-82.976806	26	2d
Florida	Lafayette	12067	Troy Spring	Troy Spring	DEP FGS-414	02320250, 300021082595100	30.006026	-82.997503	53	1st
Florida	Lafayette	12067	Turtle Spring	Turtle Spring	DEP FGS-415	02322880	29.847393	-82.890286	30	2d
Florida	Lake	12069	Alexander Springs	Alexander Springs	DEP FGS-4	02236095	29.081301	-81.575884	13	1st
Florida	Lake	12069	Apopka Spring	Apopka Spring	DEP FGS-8		28.566601	-81.680669	66	2d
Florida	Lake	12069	Blackwater Springs	Blackwater Springs	DEP FGS-33		28.88809	-81.497454	26	3d
Florida	Lake	12069	Bugg Spring (Lake)	Bugg Spring (Lake)	DEP FGS-54		28.751987	-81.901517	61	2d

Table 3–1. Floridan aquifer system springs with discharge greater than 1 cubic foot per second in the study area, southeastern United States.—Continued

[Data from Bush and Johnston, 1986; Callahan, 1964; Champion and Starks, 2001; Chandler and Moore, 1987; Meinzer, 1927; Rosenau and others, 1977; St. Johns River Water Management District, 2014; Scott and others, 2004; Stringfield, 1966; U.S. Geological Survey, 2016; Debra Harrington, Florida Geological Survey, written commun., 2014. FIPS, Federal Information Processing Standards; ID, identification; USGS, U.S. Geological Survey; DEP FGS, Florida Department of Environmental Protection, Florida Geological Survey; GSA_ID, Geological Survey of Alabama identification; GNIS_ID, Geographic Names Information System identification; NGVD 29, National Geodetic Vertical Datum of 1929. "Group" indicates that the individual spring is part of a group of springs that, taken together, constitute the magnitude listed]

State	County	FIPS code	Spring group	Spring name	Other ID	USGS site identification number	Latitude, in decimal degrees	Longitude, in decimal degrees	Altitude, in feet above NGVD 29	Magnitude
Florida	Lake	12069	Holiday Spring	Holiday Spring	DEP FGS-167		28.740402	-81.817969	75	3d
Florida	Lake	12069	Lake Blue Springs	Lake Blue Springs	DEP FGS-212		28.74865	-81.827809	68	3d
Florida	Lake	12069	Mosquito Springs	Mosquito Springs	DEP FGS-267		29.03648	-81.43472	11	3d
Florida	Leon	12073	Horn Spring	Horn Spring	DEP FGS-175	301909084074400	30.319136	-84.128735	16	2d
Florida	Leon	12073	Leon Unnamed Spring #2	Leon Unnamed Spring #2			30.280983	-84.14733	10	2d
Florida	Leon	12073	Natural Bridge Spring	Natural Bridge Spring	DEP FGS-272	301706084085000	30.285185	-84.147123	13	1st
Florida	Leon	12073	Rhodes Spring Group	Rhodes Spring No. 1	DEP FGS-324	301651084085200, 301701084092100, 301701084092500, 301711084093600	30.283831	-84.155155	16	2d
Florida	Leon	12073	Rhodes Spring Group	Rhodes Spring No. 2	DEP FGS-325	301651084085200, 301701084092100, 301701084092500, 301711084093600	30.286461	-84.159955	13	2d
Florida	Leon	12073	Rhodes Spring Group	Rhodes Spring No. 4	DEP FGS-326	301651084085200, 301701084092100, 301701084092500, 301711084093600	30.283532	-84.157272	14	2d
Florida	Leon	12073	St Marks River Rise	St Marks River Rise	DEP FGS-381		30.276047	-84.148933	7	1st
Florida	Levy	12075	Big King Spring	Big King Spring	DEP FGS-29		29.116423	-82.642261	16	3d
Florida	Levy	12075	Fanning Springs (Big Fanning)	Fanning Springs (Big Fanning)	DEP FGS-115	02323502, 293515082560800	29.587589	-82.935304	7	1st
Florida	Levy	12075	Lancaster Spring	Lancaster Spring	DEP FGS-217		29.1907	-82.988172	1	3d
Florida	Levy	12075	Lev719991	Lev719991	DEP FGS-221		29.451028	-82.695365	43	2d
Florida	Levy	12075	Levy Blue Spring	Levy Blue Spring	DEP FGS-222	292702082415700	29.450746	-82.698966	36	3d
Florida	Levy	12075	Little Fanning Spring	Little Fanning Spring	DEP FGS-231	02323505, 293511082560700	29.586397	-82.935471	9	2d
Florida	Levy	12075	Little King Spring	Little King Spring	DEP FGS-233		29.110847	-82.647815	16	3d
Florida	Levy	12075	Manatee Spring	Manatee Spring		02323566	29.4895	-82.976872	4	1st
Florida	Levy	12075	Wekiva Springs	Wekiva Springs	DEP FGS-449		29.280415	-82.656083	23	2d

Table 3–1. Floridan aquifer system springs with discharge greater than 1 cubic foot per second in the study area, southeastern United States.—Continued

[Data from Bush and Johnston, 1986; Callahan, 1964; Champion and Starks, 2001; Chandler and Moore, 1987; Meinzer, 1927; Rosenau and others, 1977; St. Johns River Water Management District, 2014; Scott and others, 2004; Stringfield, 1966; U.S. Geological Survey, 2016; Debra Harrington, Florida Geological Survey, written commun., 2014. FIPS, Federal Information Processing Standards; ID, identification; USGS, U.S. Geological Survey; DEP FGS, Florida Department of Environmental Protection, Florida Geological Survey; GSA_ID, Geological Survey of Alabama identification; GNIS_ID, Geographic Names Information System identification; NGVD 29, National Geodetic Vertical Datum of 1929. "Group" indicates that the individual spring is part of a group of springs that, taken together, constitute the magnitude listed]

State	County	FIPS code	Spring group	Spring name	Other ID	USGS site identification number	Latitude, in decimal degrees	Longitude, in decimal degrees	Altitude, in feet above NGVD 29	Magnitude
Florida	Madison	12079	Fara Spring	Fara Spring	DEP FGS-116		30.276233	-83.235819	31	2d
Florida	Madison	12079	Laf922975	Laf922975	DEP FGS-205		30.261166	-83.246583	37	3d
Florida	Madison	12079	Mad610981	Mad610981	DEP FGS-243		30.414962	-83.201478	34	3d
Florida	Madison	12079	Madison Blue Spring	Madison Blue Spring	DEP FGS-244	02319302	30.480436	-83.244363	49	1st
Florida	Madison	12079	Suwanacoochee Spring	Suwanacoochee Spring	DEP FGS-399	302309083101800	30.386671	-83.171766	38	2d
Florida	Marion	12083	Blue Grotto Spring	Blue Grotto Spring	DEP FGS-36		29.514167	-81.856944	16	1st
Florida	Marion	12083	Fern Hammock Springs	Fern Hammock Springs	DEP FGS-119	02236132	29.183573	-81.708195	26	2d
Florida	Marion	12083	Geyser Spring	Geyser Spring			29.856187	-82.732895	16	1st
Florida	Marion	12083	Juniper Springs	Juniper Springs	DEP FGS-196	02236130	29.183706	-81.712411	31	2d
Florida	Marion	12083	Orange Spring	Orange Spring	DEP FGS-288		29.510651	-81.944072	23	3d
Florida	Marion	12083	Rainbow Springs Group	Rainbow Spring No. 1		02313100	29.102702	-82.437305	29	1st
Florida	Marion	12083	Rainbow Springs Group	Rainbow East Seep	DEP FGS-312	02313100	29.102475	-82.4376	31	3d
Florida	Marion	12083	Rainbow Springs Group	Rainbow Bubbling Spring	DEP FGS-52	02313100	29.10111111	-82.43472222	39	1st (group)
Florida	Marion	12083	Salt Springs	Salt Springs	DEP FGS-343	02236205	29.350655	-81.732792	12	2d
Florida	Marion	12083	Silver Glen Springs	Silver Glen Springs	DEP FGS-359	02236160	29.245844	-81.643473	0	1st
Florida	Marion	12083	Silver Springs Group	Silver Springs #11		02239500, 02239501	29.215833	-82.053056	43	1st
Florida	Marion	12083	Silver Springs Group	Silver Springs Main	DEP FGS-372	02239500, 02239501	29.216206	-82.052631	43	1st
Florida	Marion	12083	Sweetwater Spring	Sweetwater Spring	DEP FGS-277	02236147	29.218778	-81.659869	10	2d
Florida	Marion	12083	Tobacco Patch Springs	Tobacco Patch Springs	DEP FGS-410		29.428535	-81.923913	19	3d
Florida	Marion	12083	Waterfall Springs	Waterfall Springs	DEP FGS-446		29.10146	-82.435664	36	2d
Florida	Marion	12083	Wells Landing Springs	Wells Landing Springs	DEP FGS-452		29.421016	-81.919681	16	3d

Table 3–1. Floridan aquifer system springs with discharge greater than 1 cubic foot per second in the study area, southeastern United States.—Continued

[Data from Bush and Johnston, 1986; Callahan, 1964; Champion and Starks, 2001; Chandler and Moore, 1987; Meinzer, 1927; Rosenau and others, 1977; St. Johns River Water Management District, 2014; Scott and others, 2004; Stringfield, 1966; U.S. Geological Survey, 2016; Debra Harrington, Florida Geological Survey, written commun., 2014. FIPS, Federal Information Processing Standards; ID, identification; USGS, U.S. Geological Survey; DEP FGS, Florida Department of Environmental Protection, Florida Geological Survey; GSA_ID, Geological Survey of Alabama identification; GNIS_ID, Geographic Names Information System identification; NGVD 29, National Geodetic Vertical Datum of 1929. "Group" indicates that the individual spring is part of a group of springs that, taken together, constitute the magnitude listed]

State	County	FIPS code	Spring group	Spring name	Other ID	USGS site identification number	Latitude, in decimal degrees	Longitude, in decimal degrees	Altitude, in feet above NGVD 29	Magnitude
Florida	Marion	12083	Wilson Head Spring	Wilson Head Spring	DEP FGS-456		28.979762	-82.321466	36	3d
Florida	Orange	12095	Rock Springs	Rock Springs	DEP FGS-330	02234610	28.756445	-81.501735	41	2d
Florida	Orange	12095	Wekiwa Springs	Wekiwa Springs	DEP FGS-450	02234600	28.711887	-81.460421	23	2d
Florida	Orange	12095	Witherington Springs	Witherington Springs			28.731592	-81.489907	26	3d
Florida	Pasco	12101	Crystal Springs/ Composite	Crystal Springs/ Composite	DEP FGS-91	02302000	28.182201	-82.185147	50	2d
Florida	Pasco	12101	Horseshoe Spring	Horseshoe Spring	DEP FGS-178	282350082412100	28.397551	-82.689952	0	3d
Florida	Pinellas	12103	Crystal Beach Spring	Crystal Beach Spring	DEP FGS-90	280500082470700	28.08443446	-82.78475253	0	2d
Florida	Pinellas	12103	Health Spring	Health Spring	DEP FGS-160	02309494	28.106413	-82.772247	3	3d
Florida	Putnam	12107	Beecher Springs	Beecher Springs	DEP FGS-25		29.448658	-81.646863	10	2d
Florida	Putnam	12107	Mud Spring	Mud Spring	DEP FGS-268		29.461	-81.6615	3	3d
Florida	Putnam	12107	Satsuma Spring	Satsuma Spring	DEP FGS-349		29.5126	-81.6755	13	3d
Florida	Putnam	12107	Welaka Spring	Welaka Spring	DEP FGS-451		29.494554	-81.673249	3	3d
Florida	Putnam	12107	Whitewater Springs	Whitewater Springs	DEP FGS-454		29.6337	-81.6429	9	3d
Florida	Sarasota	12115	Warm Mineral Springs	Warm Mineral Springs	DEP FGS-443	02299260	27.059901	-82.259954	3	3d
Florida	Seminole	12117	Clifton Springs	Clifton Springs	DEP FGS-72		28.699872	-81.238118	3	3d
Florida	Seminole	12117	Miami Springs	Miami Springs	DEP FGS-256	02234650	28.710166	-81.443031	22	3d
Florida	Seminole	12117	Sanlando Springs	Sanlando Springs	DEP FGS-346	02234991	28.688701	-81.395296	29	2d
Florida	Seminole	12117	Starbuck Spring	Starbuck Spring	DEP FGS-382	02234997	28.697013	-81.391171	25	2d
Florida	Sumter	12119	Fenney Spring	Fenney Spring	DEP FGS-118	02312664	28.794998	-82.038114	53	2d
Florida	Sumter	12119	Gum Springs Main	Gum Springs Main	DEP FGS-147	02312764	28.958722	-82.231526	43	2d
Florida	Suwannee	12121	Anderson Spring	Anderson Spring	DEP FGS-7		30.35341	-83.189726	31	2d
Florida	Suwannee	12121	Bathtub Spring	Bathtub Spring	DEP FGS-19		30.091726	-83.098337	55	2d
Florida	Suwannee	12121	Betty Spring	Betty Spring	DEP FGS-27	295453082502400	29.914777	-82.839956	13	3d
Florida	Suwannee	12121	Blue Sink Spring	Blue Sink Spring	DEP FGS-40		30.33569	-82.808443	64	2d
Florida	Suwannee	12121	Bonnet Spring	Bonnet Spring	DEP FGS-45		30.124323	-83.138183	72	2d

Table 3–1. Floridan aquifer system springs with discharge greater than 1 cubic foot per second in the study area, southeastern United States.—Continued

[Data from Bush and Johnston, 1986; Callahan, 1964; Champion and Starks, 2001; Chandler and Moore, 1987; Meinzer, 1927; Rosenau and others, 1977; St. Johns River Water Management District, 2014; Scott and others, 2004; Stringfield, 1966; U.S. Geological Survey, 2016; Debra Harrington, Florida Geological Survey, written commun., 2014. FIPS, Federal Information Processing Standards; ID, identification; USGS, U.S. Geological Survey; DEP FGS, Florida Department of Environmental Protection, Florida Geological Survey; GSA_ID, Geological Survey of Alabama identification; GNIS_ID, Geographic Names Information System identification; NGVD 29, National Geodetic Vertical Datum of 1929. "Group" indicates that the individual spring is part of a group of springs that, taken together, constitute the magnitude listed]

State	County	FIPS code	Spring group	Spring name	Other ID	USGS site identification number	Latitude, in decimal degrees	Longitude, in decimal degrees	Altitude, in feet above NGVD 29	Magnitude
Florida	Suwannee	12121	Branford Springs	Branford Springs	DEP FGS-49	02320502, 295717082554400	29.954868	-82.928409	21	2d
Florida	Suwannee	12121	Brantley Spring	Brantley Spring			30.008283	-82.986518	62	2d
Florida	Suwannee	12121	Charles Spring	Charles Spring	DEP FGS-65	02319900, 301002083135000	30.167364	-83.230353	91	2d
Florida	Suwannee	12121	Coffee Springs	Coffee Springs	DEP FGS-73	02322699	29.959457	-82.775327	14	3d
Florida	Suwannee	12121	Devil's Eye Springs	Devil's Eye Springs	DEP FGS-98	02322694	29.973674	-82.760009	21	2d
Florida	Suwannee	12121	Ellaville Spring	Ellaville Spring	DEP FGS-109	302303083102100	30.384466	-83.172505	33	2d
Florida	Suwannee	12121	Falmouth Spring	Falmouth Spring	DEP FGS-114	02319520, 302140083080700	30.361163	-83.134992	46	1st
Florida	Suwannee	12121	Hidden	Hidden	DEP FGS-162		30.102604	-83.113999	65	3d
Florida	Suwannee	12121	Ichetucknee Spring Group	Ichetucknee Spring	DEP FGS-181	02322698, 02322700	29.984194	-82.761869	23	2d
Florida	Columbia	12023	Ichetucknee Spring Group	Blue Hole Spring	DEP FGS-38	02322698, 02322700	29.98053	-82.758439	23	1st
Florida	Columbia	12023	Ichetucknee Spring Group	Roaring Spring	DEP FGS-328	02322698, 02322700	29.976215	-82.757877	31	2d
Florida	Columbia	12023	Ichetucknee Spring Group	Cedar Head Spring	DEP FGS-63	02322698, 02322700	29.9833	-82.7587	26	2d
Florida	Suwannee	12121	Lime Run Spring	Lime Run Spring	DEP FGS-224		30.388997	-83.163366	40	1st
Florida	Suwannee	12121	Lime Spring	Lime Spring	DEP FGS-225		30.391219	-83.1687	30	2d
Florida	Suwannee	12121	Little River Spring	Little River Spring	DEP FGS-236	02320400	29.996864	-82.966318	22	2d
Florida	Suwannee	12121	Luraville Spring	Luraville Spring	DEP FGS-242		30.119556	-83.167125	86	3d
Florida	Suwannee	12121	Orange Grove	Orange Grove	DEP FGS-287		30.12726	-83.130763	87	2d
Florida	Suwannee	12121	Peacock Spring	Peacock Spring	DEP FGS-296	300718083075701	30.123226	-83.133154	79	3d, 2d
Florida	Suwannee	12121	Royal Spring	Royal Spring	DEP FGS-334	02320130	30.083712	-83.07478	61	3d
Florida	Suwannee	12121	Running Springs	Running Springs	DEP FGS-336	02320060	30.104464	-83.115923	59	2d
Florida	Suwannee	12121	Shingle Spring	Shingle Spring	DEP FGS-357		29.934393	-82.920451	21	2d
Florida	Suwannee	12121	Shirley Spring	Shirley Spring	DEP FGS-358		30.211008	-83.244819	89	3d

Table 3–1. Floridan aquifer system springs with discharge greater than 1 cubic foot per second in the study area, southeastern United States.—Continued

[Data from Bush and Johnston, 1986; Callahan, 1964; Champion and Starks, 2001; Chandler and Moore, 1987; Meinzer, 1927; Rosenau and others, 1977; St. Johns River Water Management District, 2014; Scott and others, 2004; Stringfield, 1966; U.S. Geological Survey, 2016; Debra Harrington, Florida Geological Survey, written commun., 2014. FIPS, Federal Information Processing Standards; ID, identification; USGS, U.S. Geological Survey; DEP FGS, Florida Department of Environmental Protection, Florida Geological Survey; GSA_ID, Geological Survey of Alabama identification; GNIS_ID, Geographic Names Information System identification; NGVD 29, National Geodetic Vertical Datum of 1929. "Group" indicates that the individual spring is part of a group of springs that, taken together, constitute the magnitude listed]

State	County	FIPS code	Spring group	Spring name	Other ID	USGS site identification number	Latitude, in decimal degrees	Longitude, in decimal degrees	Altitude, in feet above NGVD 29	Magnitude
Florida	Suwannee	12121	Suw1017971	Suw1017971			30.428454	-83.029601	31	2d
Florida	Suwannee	12121	Suw1017972	Suw1017972			30.423042	-83.015424	33	2d
Florida	Suwannee	12121	Suw718971	Suw718971	DEP FGS-393		30.064046	-83.061997	49	3d
Florida	Suwannee	12121	Suw725971	Suw725971	DEP FGS-394		30.062015	-83.057306	59	3d
Florida	Suwannee	12121	Suw917971	Suw917971	DEP FGS-395		29.932391	-82.800751	14	3d
Florida	Suwannee	12121	Suw919971	Suw919971	DEP FGS-396		30.083636	-83.087057	38	3d
Florida	Suwannee	12121	Suw922971	Suw922971	DEP FGS-397		30.285747	-83.231028	22	3d
Florida	Suwannee	12121	Suw923973 - Stevenson Spring	Suw923973 - Stevenson Spring	DEP FGS-398		30.417089	-83.15295	31	2d
Florida	Suwannee	12121	Suwannee Blue Spring	Suwannee Blue Spring	DEP FGS-400		30.081472	-83.069021	89	2d
Florida	Suwannee	12121	Suwannee Springs	Suwannee Springs	DEP FGS-276	02315600, 302339082560400	30.394478	-82.934538	39	2d
Florida	Suwannee	12121	Telford Springs	Telford Springs	DEP FGS-406	02320003, 300624083095700	30.10705	-83.165739	51	2d
Florida	Taylor	12123	Beaver Creek Spring	Beaver Creek Spring	DEP FGS-23		29.765947	-83.33505	14	2d
Florida	Taylor	12123	Big Spring	Big Spring	DEP FGS-30		29.974269	-83.738832	0	2d
Florida	Taylor	12123	Bradley Spring	Bradley Spring	DEP FGS-48		29.700047	-83.411131	13	3d
Florida	Taylor	12123	Camp Ground Spring	Camp Ground Spring	DEP FGS-56	300403083331400	30.067851	-83.553823	37	2d
Florida	Taylor	12123	Cedar Island Spring	Cedar Island Spring	DEP FGS-64		29.816314	-83.583882	3	2d
Florida	Taylor	12123	Eva Spring	Eva Spring	DEP FGS-113		29.677714	-83.399253	3	3d
Florida	Taylor	12123	Folsom Spring	Folsom Spring	DEP FGS-120		30.11385	-83.578147	35	3d
Florida	Taylor	12123	Jabo Spring	Jabo Spring	DEP FGS-187		29.882586	-83.622919	3	2d
Florida	Taylor	12123	Nutall River Rise	Nutall River Rise	DEP FGS-285		30.150479	-83.963284	0	1st
Florida	Taylor	12123	Spring Warrior Spring	Spring Warrior Spring	DEP FGS-379		29.935018	-83.609766	26	2d
Florida	Taylor	12123	Tay616992	Tay616992	DEP FGS-283		29.912531	-83.650817	3	2d
Florida	Taylor	12123	Tay622991	Tay622991	DEP FGS-401		29.873556	-83.625722	0	2d
Florida	Taylor	12123	Tay69991	Tay69991	DEP FGS-402		29.969909	-83.745409	0	3d

Table 3–1. Floridan aquifer system springs with discharge greater than 1 cubic foot per second in the study area, southeastern United States.—Continued

[Data from Bush and Johnston, 1986; Callahan, 1964; Champion and Starks, 2001; Chandler and Moore, 1987; Meinzer, 1927; Rosenau and others, 1977; St. Johns River Water Management District, 2014; Scott and others, 2004; Stringfield, 1966; U.S. Geological Survey, 2016; Debra Harrington, Florida Geological Survey, written commun., 2014. FIPS, Federal Information Processing Standards; ID, identification; USGS, U.S. Geological Survey; DEP FGS, Florida Department of Environmental Protection, Florida Geological Survey; GSA_ID, Geological Survey of Alabama identification; GNIS_ID, Geographic Names Information System identification; NGVD 29, National Geodetic Vertical Datum of 1929. "Group" indicates that the individual spring is part of a group of springs that, taken together, constitute the magnitude listed]

State	County	FIPS code	Spring group	Spring name	Other ID	USGS site identification number	Latitude, in decimal degrees	Longitude, in decimal degrees	Altitude, in feet above NGVD 29	Magnitude
Florida	Taylor	12123	Tay76991	Tay76991	DEP FGS-403		29.676364	-83.385353	7	3d
Florida	Taylor	12123	Tay924991	Tay924991	DEP FGS-404		30.107957	-83.627394	24	3d
Florida	Taylor	12123	Tay924993	Tay924993	DEP FGS-405		30.108326	-83.628178	23	3d
Florida	Taylor	12123	Waldo Spring	Waldo Spring	DEP FGS-441	300257083374700	30.049179	-83.629926	22	3d
Florida	Volusia	12127	Deleon Spring	Deleon Spring	DEP FGS-95		29.13428	-81.362748	0	2d
Florida	Volusia	12127	Gemini Springs	Gemini Springs	DEP FGS-130		28.862772	-81.311404	4	1st, 2d
Florida	Volusia	12127	Green Springs	Green Springs	DEP FGS-144		28.862789	-81.247479	13	3d
Florida	Volusia	12127	Volusia Blue Spring	Volusia Blue Spring	DEP FGS-430	02235500	28.947484	-81.339588	5	1st
Florida	Wakulla	12129	Cray's River Rise	Cray's River Rise	DEP FGS-89		29.9895	-84.408	1	1st
Florida	Wakulla	12129	Kini Spring	Kini Spring		301643084203400	30.278812	-84.342678	16	1st
Florida	Wakulla	12129	Mcbride Slough Spring	Mcbride Slough Spring	DEP FGS-253		30.239983	-84.269565	7	3d
Florida	Wakulla	12129	Newport Spring	Newport Spring	DEP FGS-273	301245084104300	30.212695	-84.17849	7	3d
Florida	Wakulla	12129	River Sink Spring	River Sink Spring		02326997, 301636084202800	30.276868	-84.341011	8	1st
Florida	Wakulla	12129	Sally Ward Spring	Sally Ward Spring	DEP FGS-341		30.241414	-84.3108	4	2d
Florida	Wakulla	12129	Sheppard Spring	Sheppard Spring	DEP FGS-356		30.1253	-84.2855	3	3d
Florida	Wakulla	12129	Spring Creek Rise Main	Spring Creek Rise Main	DEP FGS-378		30.08017706	-84.32980831	0	1st
Florida	Wakulla	12129	Wakulla Spring Group	Wakulla No Name Spring		02327000, 02327022	30.214815	-84.266505	7	3d
Florida	Wakulla	12129	Wakulla Spring Group	Wakulla Spring	DEP FGS-440	02327000, 02327022	30.235179	-84.30256	3	1st
Florida	Walton	12131	Ecuchee	Ecuchee	DEP FGS-106	304340086122300	30.737122	-86.193493	236	3d
Florida	Walton	12131	Morrison Spring	Morrison Spring	DEP FGS-266	02365580, 302928085541400	30.657884	-85.903938	26	2d
Florida	Washington	12133	Becton Springs	Becton Springs	DEP FGS-24	303853085413700	30.648647	-85.693663	30	2d
Florida	Washington	12133	Brunson Landing Spring	Brunson Landing Spring	DEP FGS-51		30.609229	-85.75858	26	3d

Table 3–1. Floridan aquifer system springs with discharge greater than 1 cubic foot per second in the study area, southeastern United States.—Continued

[Data from Bush and Johnston, 1986; Callahan, 1964; Champion and Starks, 2001; Chandler and Moore, 1987; Meinzer, 1927; Rosenau and others, 1977; St. Johns River Water Management District, 2014; Scott and others, 2004; Stringfield, 1966; U.S. Geological Survey, 2016; Debra Harrington, Florida Geological Survey, written commun., 2014. FIPS, Federal Information Processing Standards; ID, identification; USGS, U.S. Geological Survey; DEP FGS, Florida Department of Environmental Protection, Florida Geological Survey; GSA_ID, Geological Survey of Alabama identification; GNIS_ID, Geographic Names Information System identification; NGVD 29, National Geodetic Vertical Datum of 1929. "Group" indicates that the individual spring is part of a group of springs that, taken together, constitute the magnitude listed]

State	County	FIPS code	Spring group	Spring name	Other ID	USGS site identification number	Latitude, in decimal degrees	Longitude, in decimal degrees	Altitude, in feet above NGVD 29	Magnitude
Florida	Washington	12133	Clemmons Spring	Clemmons Spring	DEP FGS-71		30.641416	-85.692965	23	3d
Florida	Washington	12133	Cypress Springs	Cypress Springs	DEP FGS-92	02365986, 303929085410400	30.658746	-85.684372	26	2d
Florida	Washington	12133	Hightower Spring	Hightower Spring	DEP FGS-164		30.605052	-85.765419	20	3d
Florida	Washington	12133	Jack Paul Springs	Jack Paul Springs	DEP FGS-188		30.612859	-85.733739	23	2d
Florida	Washington	12133	Piney Wood Spring	Piney Wood Spring	DEP FGS-299		30.658551	-85.690639	31	3d
Florida	Washington	12133	Washington Blue Spring Choctawhatchee	Washington Blue Spring Choctawhatchee	DEP FGS-444	303048085504700	30.513259	-85.847185	15	2d
Florida	Washington	12133	Washington Blue Springs Econfina	Washington Blue Springs Econfina	DEP FGS-445	302712085315200	30.452823	-85.530369	29	2d
Florida	Washington	12133	Williford Spring	Williford Spring	DEP FGS-455	302621085325200	30.439552	-85.547581	22	2d
Georgia	Baker	13007	Blue Spring	Blue Spring	GNIS_ID 311554		31.382956	-84.471856	157	3d
Georgia	Brooks	13027	Blue or Wade Spring	Blue or Wade Spring			30.78922	-83.453795	98	2d
Georgia	Brooks	13027	McIntyre Spring	McIntyre Spring			30.641317	-83.365984	68	2d
Georgia	Dougherty	13095	Radium Spring	Radium Spring		02352650	31.526564	-84.136574	153	1st (historical)
Georgia	Jenkins	13165	Magnolia Spring	Magnolia Spring	GNIS_ID 334862		32.879326	-81.958171	167	2d
Georgia	Laurens	13175	Rock Springs	Rock Springs	GNIS_ID 346611		32.403503	-82.816806	157	3d
Georgia	Laurens	13175	Wells Spring	Wells Spring	GNIS_ID 346643		32.413503	-82.82764	154	3d
Georgia	Laurens	13175	Wilkes Spring	Wilkes Spring	GNIS_ID 346650		32.394337	-82.785416	148	3d
Georgia	Pulaski	13235	Blue Spring	Blue Spring	GNIS_ID 311558		32.168779	-83.478781	246	3d
Georgia	Pulaski	13235	Mock Spring	Mock Spring	GNIS_ID 318376		32.204887	-83.582396	295	3d
Georgia	Wilcox	13315	Osewichee Spring	Osewichee Spring	GNIS_ID 320106		31.869071	-83.199598	157	3d
Georgia	Wilcox	13315	Poor Robin Spring	Poor Robin Spring	GNIS_ID 321009		32.012677	-83.299046	177	3d

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