Simulation of Regional Ground-Water Flow in the Suwannee River Basin, Northern Florida and Southern Georgia

By Michael Planert

Prepared in cooperation with the
Suwannee River Water Management District

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Conversion Factors, Sea Level Datum, and Acronyms

Multiply	By	To obtain
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
inch per year (in/yr)	25.4	millimeter per year
foot (ft)	0.3048	meter
foot squared per day (ft^2/d)	0.09290	meter squared per day
cubic foot per second (ft^3/s)	0.2832	cubic meters per day
gallons per day (gal/d)	0.003785	cubic meter per day
million gallons per day (Mgal/d)	0.4381	cubic meter per day

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows: °F = 1.8 x °C + 32

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD of 1929); horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

MODFLOW	Modular, three-dimensional finite-difference ground-water flow model code
NIR	Net irrigation requirement
SRWMD	Suwannee River Water Management District
USGS	U.S. Geological Survey

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By Michael Planert

Abstract

The Suwannee River Basin covers a total of nearly 9,950 square miles in north-central Florida and southern Georgia. In Florida, the Suwannee River Basin accounts for 4,250 square miles of north-central Florida. Evaluating the impacts of increased development in the Suwannee River Basin requires a quantitative understanding of the boundary conditions, hydrogeologic framework and hydraulic properties of the Floridan aquifer system, and the dynamics of water exchanges between the Suwannee River and its tributaries and the Floridan aquifer system.

Major rivers within the Suwannee River Basin are the Suwannee, Santa Fe, Alapaha, and Withlacoochee. Four rivers west of the Suwannee River are the Aucilla, the Econfina, the Fenholloway, and the Steinhatchee; all drain to the Gulf of Mexico. Perhaps the most notable aspect of the surface-water hydrology of the study area is that large areas east of the Suwannee River are devoid of channelized, surface drainage; consequently, most of the drainage occurs through the subsurface.

The ground-water flow system underlying the study area plays a critical role in the overall hydrology of this region of Florida because of the dominance of subsurface drainage, and because ground-water flow sustains the flow of the rivers and springs.

Three principal hydrogeologic units are present in the study area: the surficial aquifer system, the intermediate aquifer system, and the Floridan aquifer system. The surficial aquifer system principally consists of unconsolidated to poorly indurated siliciclastic deposits. The intermediate aquifer system, which contains the intermediate confining unit, lies below the surficial aquifer system (where present), and generally consists of fine-grained, unconsolidated deposits of quartz sand, silt, and clay with interbedded limestone of Miocene age. Regionally, the intermediate aquifer system and intermediate confining unit act as a confining unit that restricts

the exchange of water between the overlying surficial and underlying Upper Floridan aquifers. The Upper Floridan aquifer is present throughout the study area and is extremely permeable and typically capable of transmitting large volumes of water. This high permeability largely is due to the widening of fractures and formation of conduits within the aquifer through dissolution of the limestone by infiltrating water. This process has also produced numerous karst features such as springs, sinking streams, and sinkholes.

A model of the Upper Floridan aquifer was created to better understand the ground-water system and to provide resource managers a tool to evaluate ground-water and surface-water interactions in the Suwannee River Basin. The model was developed to simulate a single Upper Floridan aquifer layer. Recharge datasets were developed to represent a net flux of water to the top of the aquifer or the water table during a period when the system was assumed to be under steady-state conditions (September 1990). A potentiometric-surface map representing water levels during September 1990 was prepared for the Suwannee River Water Management District (SRWMD), and the heads from those wells were used for calibration of the model. Additionally, flows at gaging sites for the Suwannee, Alapaha, Withlacoochee, Santa Fe, Fenholloway, Aucilla, Ecofina, and Steinhatchee Rivers were used during the calibration process to compare to model computed flows. Flows at seven first-magnitude springs selected by the SRWMD also were used to calibrate the model.

Calibration criterion for matching potentiometric heads was to attain an absolute residual mean error of 5 percent or less of the head gradient of the system which would be about 5 feet. An absolute residual mean error of 4.79 feet was attained for final calibration. Calibration criterion for matching streamflow was based on the quality of measurements made in the field. All measurements used were rated “good,” so the desire was for simulated values to be within 10 percent of the field measurements. All river reaches and springs were calibrated to within 5 percent, less than the 10-percent criterion of the measured discharge. Simulated transmissivity values range from 1,000 to 2 million feet squared per day. All relatively high values of transmissivity are associated with springs where the probability of fractures and dissolution have enhanced the primary permeablity of the limestone. The lowest transmissivity values are generally associated with areas of poor drainage where swamps or wetlands are present.

Model-simulated recharge values range from 0.5 inch per year (in/yr) in the confined area of the Upper Floridan aquifer in the northeastern and eastern part of the study area to 20 in/yr near Wacissa Springs. The initial estimate of 7 in/yr proved to be appropriate for most of the unconfined part of the Suwannee River Basin.

Introduction

The Suwannee River Basin covers about 9,950 mi^2 in north-central Florida and southern Georgia (fig. 1). In Florida, most of the basin (4,250 mi^2) lies within the Suwannee River Water Management District, which covers 7,640 mi^2 in north-central Florida and includes all or parts of 14 counties. The defining natural feature of the region is the Suwannee River. From its source in the Okefenokee Swamp in southeastern Georgia (fig. 1), the Suwannee River winds its way to the Gulf of Mexico, 12 mi northwest of Cedar Key (fig. 1). Two major tributaries to the Suwannee River originate in Georgia—the Alapaha and Withlacoochee Rivers. The Santa Fe River in Florida flows west from its headwaters to join the Suwannee near Branford (fig. 2).

Florida's rapid population growth during the last several decades has had limited effect on the water resources of north-central Florida. The region's water-related problems are of a smaller scale and more localized than those in more urbanized and developed parts of the State and Nation. Ground-water withdrawals in the 14 counties within the SRWMD increased by 64 percent between 1975-2000 (Marella, 2004). Most of this increase (78 Mgal/d) occurred as a result of an increase in irrigation; demand has remained stable since 1990. This region, however, is becoming increasingly attractive to retirees and second-home developers, so demand for water is likely to increase. Populated areas to the south have also shown an interest in tapping into the water resources of this region for their growing needs. The SRWMD is presented with the challenge of protecting the quality and quantity of its water resources as growth and development continues. To do so requires a quantitative understanding of the boundary conditions, hydrogeologic framework, and hydraulic properties of the Floridan aquifer system, as well as the dynamics of water exchanges between the Suwannee River and its tributaries and the Floridan aquifer system. In 2002, a cooperative project was initiated between the U.S. Geological Survey (USGS) and the SRWMD to develop a method for evaluating the effects of current and potential withdrawals of water in the basin. The objective included integrating historic and newly collected ground- and surface-water data to better understand the hydrology of the aquifer and river, and their interaction. Development of a hydrologic model of the aquifer and river systems was an essential element of this integration.

Background

Ground-water flow modeling provides a valuable tool in understanding the hydrologic system, assessing the needs for additional data and information, and providing water managers a means to determine effects of changing hydrologic conditions. Modeling has been limited in this basin compared to other parts of the State. Bush and Johnston (1988) utilized computer simulation to analyze ground-water hydraulics, regional flow, and the effects of development on the Floridan aquifer system where the aquifer is present in Florida, Georgia, and South Carolina—modeling included the Suwannee River Basin. Because of the large model area in their study, a square cell size of 8 mi on each side was necessary to keep the model size manageable. This relatively large cell size precluded the inclusion of fine detail in the model. Motz (1995) simulated flow in the surficial, intermediate, and Upper and Lower Floridan aquifers, and the Fernandina Permeable Zone in most of Union County, all of Bradford County, and the eastern two-thirds of Alachua County within the SRWMD. That model, however, did not include much of the Suwannee River Basin. Krause and Randolph (1989) simulated predevelopment and 1980 hydrologic conditions in southeastern Georgia and northeastern Florida where ground-water development (declining heads) in Duval County had caused a westward shift in the position of an arch (high) in the potentiometric surface. Similarly, their model did not include the Suwannee River Basin, but did provide insight into adjacent hydrologic conditions. Davis (1996) simulated ground-water flow in the Upper Floridan aquifer in an area largely west of the Suwannee River Basin that included Leon County, and the surrounding counties in north-central Florida and southwestern Georgia. Recently, Sepulveda (2002) developed a model (informally known as the "Mega model") of ground-water flow in the intermediate and Floridan aquifer systems in the peninsular Florida system, including part of the Suwannee River Basin. The westward extent of the Mega model in the Suwannee River Basin reaches to a north-south line approximately 7 mi west of Suwannee County from the Gulf of Mexico to the Florida-Georgia line. The northern extent of the Mega model in the basin is approximately the Florida-Georgia line.

Presently, the scientific community and water managers need a better understanding of the ground-water system in the Suwannee River Basin, as well as tools to develop plans for population and agricultural growth in the area covered by the SRWMD. A ground-water flow model is a tool that can test scenarios of increased ground-water pumping. Currently, no single complete model has been constructed specific to the Suwannee River Basin that can answer water-resource management questions. To address this need, an aerially extensive model of the ground-water flow system in northern Florida and southern Georgia is needed.

Purpose and Scope

The objective of this report is to describe the development of a numerical model of the regional ground-water flow system in the Suwannee River Basin that will provide a comprehensive understanding of the regional ground-water system and the exchange of water between the Upper Floridan aquifer and the major streams in the Suwannee River Basin. This report describes the hydrology, hydrogeology, ground-water flow system boundaries, hydraulic properties, and ground-water withdrawals in the study area, which includes all of the SRWMD in Florida and parts of southern Georgia (fig. 2). The ground-water flow model of the Upper Floridan aquifer developed during this project is described in this report and simulates steady-state hydrologic conditions during a period of low river flow (September, 1990) in the basin in Florida and Georgia. The active model domain includes boundary conditions such as the Gulf of Mexico, ground-water divides in interior areas to the east and in Georgia, and major drainages such as the Suwannee, Santa Fe, Withlacoochee, Fenholloway, and Alapaha Rivers. Metered ground-water withdrawal rates used in the model simulation reflect rates occurring during the low-flow period.

Description of the Study Area

The study area lies within the Coastal Plain physiographic province (Fenneman, 1938). Puri and Vernon (1964) presented a detailed map of the physiographic divisions within Florida, and identified three major physiographic divisions that are present in or adjacent to the study area: the Northern Highlands, Central Highlands, and the Gulf Coastal Lowlands. Of these three divisions, the Northern Highlands and Gulf Coastal Lowlands comprise the bulk of the study area (fig. 3).

The Northern Highlands typically have broad, gently sloping, and generally continuous high-elevation plateaus in the interior regions with marginal slopes that are drained by dendritic streams. The Central Highlands are also characterized by broad, generally coast-parallel high-elevation areas, some of which have been divided into distinct areas of elongated ridges, separated by low-elevation uplands and broad valleys (Puri and Vernon, 1964). The Brooksville Ridge is the most prominent example (Puri and Vernon, 1964). Most of the study area lies within the Gulf Coastal Lowlands, which generally consists of coast-parallel terraces and ancient shorelines that slope gently from the Northern Highlands and Central Highlands toward the coast. Interior relict barrier islands (sand ridges) are commonly underlain by karst limestone in the Gulf Coastal Lowlands (Puri and others, 1967). Limestone is present at or near land surface over much of this area, and karst topographic features are quite common. Other features of the Gulf Coastal Lowlands include (1) extensive areas of poorly drained swamps and wet-pine flatwoods; (2) the Suwannee River and Santa Fe River valleys which, apart from the two main rivers and the numerous springs that feed them, are nearly devoid of surface drainage; and (3) coastal areas that are drained by a network of sluggish streams, coastal swamps, and salt marshes.

The boundary between the Northern Highlands and the Gulf Coastal Lowlands is defined by the Cody Scarp, which is the most persistent topographic break (escarpment) in Florida (Puri and Vernon, 1964). This escarpment also is roughly coincident with the boundary between confined and unconfined areas of the Upper Floridan aquifer (Miller, 1986). Many of the streams draining the Northern Highlands are captured by sinkholes near the margins of the Northern Highlands and re-emerge below the Cody Scarp (Burnson and others, 1984).

The climate of the study area is transitional temperate-humid subtropical. Temperatures typically range from 39-50 ºF in the winter and from 77-95 ºF in the summer. Average annual precipitation recorded across the study area ranges from about 51-59 in/yr, with about half of this amount typically falling from June to September. Summer precipitation is generally associated with localized thunderstorm activity that can produce intense rainfall. Winter precipitation is generally associated with the passage of cold fronts and is more evenly distributed geographically. Average-annual evapotranspiration estimates in the SRWMD range between 35-41 in/yr (Bush and Johnston, 1988, pl. 9; Knowles, 1996).

Most of the study area is sparsely populated. The most densely populated areas are the towns of Gainesville (95,447), Lake City (9,980), and Perry (6,847) (University of Florida, 2001). The primary economic activities in the study area are silviculture, the manufacture of forest products, and agriculture. Accordingly, forested and agricultural lands account for most of the land use in the study area.

Hydrology of the Study Area

The major drainages within the Suwannee River Basin are the Suwannee, Santa Fe, Alapaha, and Withlacoochee Rivers. Additionally, four large rivers are present west of the Suwannee River: the Aucilla, Econfina, Fenholloway, and Steinhatchee, all accepting ground-water discharge and draining to the Gulf of Mexico.

Perhaps the most notable aspect of the surface-water hydrology of the study area is that large areas of the Suwannee River Basin are devoid of channelized, surface drainage with most of the drainage occurring into the subsurface. Subsurface drainage occurs because of the karst topography of the area, which is generally flat and contains numerous sinkholes and closed topographic depressions. The porous nature of the rocks allows rainfall to easily move into and through the subsurface, discouraging the formation of surface drainage networks and allowing springs to be a source to streamflow in the basin. Many major springs have been identified in the study area (fig. 2).

The ground-water flow system underlying the study area plays a role in the overall hydrology of this region of Florida because of the dominance of subsurface drainage and because ground-water flow sustains the flow of the rivers and springs. Characterizing several key aspects of the ground-water flow system is essential to understanding the hydrology of the ground-water system. These include the hydrogeologic framework, hydrologic boundaries, and hydraulic properties of the system, and the nature and distribution of sources and sinks of water to the ground-water flow system. Collectively, each of the above characteristics of the ground-water flow system defines a conceptual model of the system.

The ground-water system is recharged by infiltrating rainfall and by seepage from streams and wetlands (when water levels in the streams and wetlands are higher than the water-table elevation). Discharge from the surficial aquifer system occurs as seepage to streams and wetlands (when the water-table elevation is higher than stream and wetland water levels), as evaporation and transpiration, and as leakage to the intermediate confining unit and Upper Floridan aquifer. In areas that lack surface drainage, recharge is equal to the difference between precipitation and evapotranspiration.

Hydrogeologic Framework

Three principal hydrogeologic units are present in and adjacent to the study area: the surficial aquifer system, the intermediate aquifer system, and the Floridan aquifer system. A generalized east-west hydrogeologic section of the study area is depicted in figure 4.

The surficial aquifer system is present throughout the Northern Highlands area and somewhat more locally in the Gulf Coastal Lowlands, where clay-rich sediments perch water. Where present, the surficial aquifer system is contiguous with the land surface and principally consists of unconsolidated to poorly indurated siliciclastic deposits (Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition, 1986). The surficial aquifer system consists of undifferentiated sands, silts, and clays of Pliocene and younger age. These sediments are generally less than 40 ft thick, although they may be 55 ft thick or more in areas of the high-elevation sand ridges and depressions in the top of the Upper Floridan aquifer (Hunn and Slack, 1983; Rupert, 1988a; Ron Ceryak, Suwannee River Water Management District, oral comm., 2004). The surficial aquifer system is unconfined and the water table is generally within 10 ft of land surface, although it may be deeper in areas of high elevation. The water table of this system is at or near the surface in areas of ground-water discharge (for example, in coastal areas and along river and stream corridors) and in the broad, wetland areas of Mallory Swamp, Waccassassa Flats, and the Okefenokee Swamp, where low permeability sediments in the surficial aquifer system (Col and others, 1997) and possibly the Upper Floridan aquifer impede the vertical flow of ground water. The presence of these sediments in the Waccasassa Flats is consistent with some evidence indicating that a closed basin or settling paleoenvironment existed during the formation of the surficial aquifer system (Col and others, 1997). The saturated thickness of the surficial aquifer system ranges 10-60 ft. The aquifer is generally thickest under sand ridges, such as the Brooksville Ridge, and thins toward the coast (Rupert, 1988b).

The intermediate aquifer system and intermediate confining unit (where present) lie below the surficial aquifer system, and generally consist of fine-grained, unconsolidated deposits of quartz sand, silt, and clay with interbedded limestone and dolostone of Miocene age (Scott, 1992, p. 55). Regionally, the intermediate aquifer system and intermediate confining unit act as a confining unit that restricts the exchange of water between the overlying surficial and underlying Upper Floridan aquifer. Accordingly, the term, ”intermediate confining unit,” is used in this report to refer to the intermediate aquifer system and intermediate confining unit. The intermediate confining unit generally is present in the Northern Highlands, coinciding with the

Hawthorn Group sediments, and is generally absent in the Gulf Coastal Lowlands (fig. 3). The top of the intermediate confining unit is at an elevation ranging from about 50 to 150 ft above NGVD of 1929 and coincides with the base of the surficial aquifer system (Scott, 1992, p. 44). The base of the intermediate confining unit coincides with the top of the Upper Floridan aquifer and is at an elevation ranging from about 200 ft below to 100 ft above NGVD of 1929 (Miller, 1986, pl. 26). The unit pinches out along the Cody Escarpment and thickens to nearly 250 ft in Baker County.

The Floridan aquifer system consists of a thick sequence of carbonate (limestone and dolomite) rocks of mostly Paleocene to early Miocene age, and is subdivided into the Upper and Lower Floridan aquifers (Miller, 1986). The maps presented by Miller (1986) pertain to the thickness of rocks associated with the Floridan aquifer system and not necessarily the thickness of the potable zone of the aquifer system, nor the system simulated and described later in this report.

The Lower Floridan aquifer is present only where a middle confining unit separates the more permeable Upper and Lower Floridan aquifers. In areas where the middle confining unit is absent, the total thickness reflects the Upper Florida aquifer only. In the study area, the Lower Floridan aquifer is not used for water supply, presumably because of poor quality of water (Miller, 1986), and is present only in the northern part of the SRWMD from Jefferson County east to Columbia County, and in the southern half of Levy County.

The Upper Floridan aquifer is present throughout the study area, is extremely permeable, and typically capable of transmitting large volumes of water. This high permeability largely is due to the widening of fractures and formation of conduits within the aquifer through dissolution of the limestone by infiltrating water and the development of dispersed secondary porosity. This process has also produced numerous karst features such as springs, sinking streams, and sinkholes. The Upper Floridan aquifer is generally at or near land surface and, therefore, unconfined in the Gulf Coastal Lowlands, but is generally covered by surficial sediments and confined in the Northern Highlands. Elevation of the top of the aquifer generally ranges from about 160 ft below to nearly 100 ft above NGVD of 1929 (fig. 5; Ron Ceryak, Suwannee River Water Management District, written commun., 1996; Miller, 1986, plate 26). The elevation of rocks that are associated with the base of the Floridan aquifer ranges from about 2,000 ft below NGVD of 1929 in the coastal areas of Jefferson County to 400 ft below NGVD of 1929 in Lowndes County, Ga. (fig. 6, Miller, 1988, plate f).

Ground-Water Flow System Boundaries

Defining the location and type of boundaries of the ground-water flow system is a necessary step for developing a conceptual model of this system. The following section describes the location of the horizontal (lateral), and vertical (upper and lower) boundaries of the ground-water flow system. These sections also describe the direction of water movement along and across these boundaries, including any spatial and temporal variability in water movement at some of the boundaries.

Lateral Boundaries

The lateral boundaries of the study area were defined partly by the geographic scope of the project and partly by key features of the regional ground-water flow system. These features include areas of relatively high ground-water levels on the potentiometric surface (potentiometric ”highs”), areas of low ground-water levels near important areas of ground-water discharge (such as major rivers or the Gulf of Mexico), and points where ground-water flow paths parallel the boundary (Jefferson and Citrus Counties). Together, these features define the location of five key lateral boundaries: the northern potentiometric high near Valdosta, Ga., the southeastern discharge boundary, the boundary represented by the Gulf of Mexico coastline, and the eastern and northwestern no-flow boundaries. These boundaries define the lateral limits of the model domain and determine whether water flows into or out of the model.

The northern specified-head boundary is defined by a prominent dome-shaped potentiometric high centered near Valdosta, Ga., (fig. 7) that is caused by a sinking stream. The eastern no-flow boundary is defined by a potentiometric high that occurs in the Keystone Heights area on the eastern side of the study area along the border between Clay, Putnam, Alachua, and Bradford Counties in Florida (fig. 7). This potentiometric high is the result of high topographic relief.

A comparison of the 1990 potentiometric surface (fig. 7) with historic ground-water level data and estimated predevelopment potentiometric surface (fig. 8, modified from Bush and Johnston, 1988) indicates that the location of the eastern no-flow boundary has migrated southwestward over the last century. Before substantial withdrawals occurred from the Upper Floridan aquifer, the study area was completely enclosed by the bounding flowlines that originate at the highest points of the Valdosta and Keystone Heights highs (fig. 8). Large ground-water withdrawals from the Upper Floridan aquifer in the Jacksonville and Fernandina Beach areas of northeastern Florida, however, began during the late 1800s and have increased since then. These ground-water withdrawals have caused large, regional drawdowns in the Upper Floridan aquifer in the northeastern part of the study area, resulting in the southwestward migration of the northeastern ground-water divide. Movement of the northeastern ground-water divide has reduced the area of the Upper Floridan aquifer that contributes water to the study area (fig. 7), and has increased the area of the Upper Floridan aquifer that flows toward the pumping centers near Jacksonville and Fernandina Beach. Historic water-level data from long-term observation wells along the northeastern boundary indicate that the rate of drawdown has slowed and perhaps stopped in recent years, and that the movement of this boundary has also slowed or that the boundary may have reached a new equilibrium (fig. 9).

The southeastern boundary is controlled by the Oklawaha River, which is east of the study area (fig. 1). This river controls ground-water flow in the southeastern part of the study area and is the main control for ground-water discharge in this area.

The lateral boundary near the Gulf of Mexico coastline defines a key external boundary for the study area and its location is defined by the line of intersection of two surfaces, the interface between freshwater and saltwater in the Upper Floridan aquifer. Because only a few direct observations of saline ground water are available in the study area, insufficient data are available to map the elevation and location of the freshwater-saltwater interface. Heads slightly above mean sea level in a few shallow wells near the coast indicate that freshwater is discharging to the Gulf of Mexico near the coast and, therefore, the western boundary is a discharge boundary which allows the head in the Upper Floridan aquifer to naturally diffuse to the Gulf at some distance offshore.

Upper and Lower Flow-System Boundaries

The top of the ground-water flow system was conceptualized to be the top of the Upper Floridan aquifer or the top of the surficial aquifer system, if present, in areas where the intermediate confining unit is absent (fig. 4). Thus, in areas where the Upper Floridan aquifer is unconfined and overlain directly by the surficial aquifer system, both of these aquifers are treated as a single flow system. This conceptualization is supported by data from collocated wells tapping both aquifers, which indicate that the water levels in both aquifers are similar in patterns of fluctuation (fig. 10).

Although Miller (1986) mapped the base of the rocks associated with the Floridan aquifer system, the base of the fresh ground-water flow system has not been defined, because there are no fully penetrating water wells in the Upper Floridan aquifer within the study area. Therefore, a total thickness of freshwater is not known in the study area.

Hydraulic Properties

The hydraulic properties that govern ground-water flow in aquifers are the conductive and storage properties. Conductive properties are expressed as hydraulic conductivity or transmissivity (conductivity multiplied by aquifer thickness) and are a function of the degree of intergranular connections of the subsurface rocks and sediments and any secondary dissolution of the subsurface rocks. Storage properties are a function of the compressibility of water and the elasticity and water-retentive characteristics of the subsurface rocks and sediments. Estimates of hydraulic properties can be made from aquifer tests, numerical (simulation) models, and by making inferences from other hydrologic and hydrogeologic data.

Twenty-three aquifer tests have been performed in and adjacent to the study area, and values for transmissivity ranged from 1,600 to 650,000 ft^2/d for tests conducted within the study area and from 9,100 to 2,700,000 ft^2/d for tests conducted in areas adjacent to the study area (table 1 and fig. 11). These tests were conducted on wells that generally penetrated only 200 ft of the Upper Floridan aquifer, so these values do not characterize the entire thickness of the aquifer. Consequently, these values can only be used as a guide to estimate transmissivities and should be considered as a relatively low estimate for a particular area.

Ground-Water Withdrawals

Monthly water withdrawal values were collected for public suppliers, self-supplied commercial, industrial (including mining), and power plants that withdrew at least 200,000 gal/mo or used a daily average of at least 10,000 gal/d. Data were obtained for each user based on the total amount of water withdrawn per facility (wellfield or plant); data for individual wells within a wellfield or plant were not differentiated. Water-use data were collected for the following counties in Florida: Alachua, Baker, Bradford, Columbia, Dixie, Gilchrist, Hamilton, Jefferson, Lafayette, Levy, Madison, Suwannee, Taylor, and Union. Similar data were collected for parts of the following counties in Georgia: Brooks, Clinch, Echols, and Lowndes. Data were obtained from the permit compliance files at the SRWMD and the Southwest Florida Water Management District, from the water-use database at the St. Johns River Water Management District and at the USGS Georgia Water Science Center, and from water-use files at the Florida Department of Environmental Protection and the Georgia Environmental Protection Division of the Department of Natural Resources. Additional data were obtained directly from several individual users. (Richard Marella, U.S. Geological Survey, written commun., 2004).

Agricultural water-use estimates were calculated by multiplying the acres irrigated by an average net monthly irrigation requirement per crop type. Acreage data for 1990 for Florida were obtained from the USGS water-use files (Richard Marella, U.S. Geological Survey, written commun., 2004). Acreage data for Georgia were obtained from the Georgia Cooperative Extension Service Offices in Brooks, Clinch, Echols, and Lowndes Counties. Data were reported for fruit crops, field crops, vegetables, ornamentals and grasses. Water-use values were estimated by using a net irrigation requirement (NIR) coefficient per crop type obtained from the Florida Irrigation Guide (U.S. Soil Conservation Service, 1982) for climatic zone 2 (Suwannee River Basin). The NIR provides an estimated amount of water needed to supplement rainfall to grow an acre based on a monthly average rainfall for the 30-year period 1941-70. The NIR was then multiplied by 1.3 to account for system efficiencies. It was assumed that all irrigated acreage was irrigated using a sprinkler system (center pivot, traveling gun, cable tow, and stationary), which is rated at about 70-percent efficient (Marella, 1999).

Crops were categorized into the following: vegetables (spring), fruit crops, melons (watermelons and cantaloupes), cotton, corn, peanuts, soybeans, sorghum, tobacco, ornamentals (field grown and container grown), turf grass (golf course), sod, and improved pasture. Vegetables included carrots, cucumbers, pepper, potatoes, tomatoes, and other miscellaneous vegetables. The NIR used for all vegetables assumed a 100-day growing season beginning March 1 and ending June 8. Fruit crops included blueberries, grapes, peaches, and pecans, and the monthly NIR for these crops used the growing season of grapes (108 days beginning March 15 and ending June 30). Field-grown ornamentals used the monthly NIR for corn; container ornamentals used the monthly NIR for orchards; turf grass and sod used the monthly NIR for improved pasture. All other crops used the appropriate monthly NIR. Estimates of water use for golf courses were made using the monthly NIR for pasture grasses.

The withdrawal data described above were then merged with data describing the location of the wells that were the source of the withdrawals. To simplify the process of merging two types of information (withdrawal data and location data), data were merged if a user withdrew more than 100,000 gal/d (a daily average of about 69 gal/min).

The geographic distribution of withdrawals from the Upper Floridan aquifer (fig. 12) shows that most withdrawals occur in agricultural areas along the Suwannee River. Agricultural withdrawal calculations for 1990 were not adjusted for demands caused by low rainfall conditions during that year. However, because agricultural withdrawals generally occur in the spring and summer (Marella, U.S. Geological Survey, oral commun., 2004) and low-flow conditions generally occur in the fall, it was unneccessary to make adjustments for low-flow conditions. Major public-supply withdrawals occur at Gainesville, Lake City, Perry, Cross City, and Chiefland. A major industrial withdrawal is associated with a pulp and paper mill in Taylor County. The cumulative withdrawal rate represented in the model for all water uses within the study area was about 700 Mgal/d.

As described above, pumpage in the model included withdrawals for public supply, commercial, industrial, power generation, and agriculture. Withdrawals from the aquifer for all categories were calculated on an annual basis and were simulated as a daily rate. All agricultural pumpage was estimated as a daily pumping value even though pumping did not occur throughout the year.

Ground-Water Flow Modeling

The Upper Floridan aquifer in the Suwannee River Basin and adjacent areas was modeled under low-flow conditions to provide a management tool to evaluate ground- and surface-water interactions. September 1990 was the period of lowest water level recorded since 1960 (fig. 9) in the eastern part of the study area. The later part of 1990 had stable water levels, as shown in the inset on figure 9, reflecting a period that approximates equilibrium. Therefore, September 1990 was deemed to be a suitable period for modeling under steady-state conditions. The model was used to test boundary condition assumptions discussed in the conceptual model section and was formulated around a rectangular grid of 163 rows and 148 columns (fig. 13) with a uniform spacing of 5,000 ft for the width of each row and column. Visual MODFLOW (Waterloo Hydrogeologic, Inc., 2002) was used to simulate two-dimensional movement of ground water in the Upper Floridan aquifer.

The boundaries (fig. 14) tested by the model were:

- The (southwestern) diffuse-flow boundary coincident with the shoreline of the Gulf of Mexico where the freshwater part of the Upper Floridan aquifer thins because of the saltwater underlying the coastward-moving freshwater.
- The (northwestern) no-flow boundary coincident with a flow line near the St. Marks River in Wakulla, Leon, and Jefferson Counties, Florida. This boundary extends northeastward into Georgia along the flow line.
- The (eastern) no-flow boundary coincident with the flow line and potentiometric high south of the constant-head boundary (described above) in eastern Bradford and Alachua Counties and through Marion County.
- The (northern) specified-head boundary coincident with a potentiometric high in Lowndes County, Ga. (Valdosta potentiometric high).
- The (southeastern) general-head boundary coincident with low potentiometric heads in the southeastern corner of the model domain indicating ground-water flow to the Oklawaha River.

The lateral boundaries to the north and east correspond to flow paths that originate at the Valdosta and Keystone Heights potentiometric highs on the 1990 potentiometric-surface map (fig. 7). No-flow was used as a boundary condition for all but the northern part of this area (fig. 14), where the boundary was simulated using specified-head cells with head values set equal to the ground-water levels that were interpolated (spatially) for September 1990 conditions. The model simulated the Upper Floridan aquifer layer as a single layer. Recharge represented a net flux of water to the top of the aquifer during a period when the system was assumed to be in equilibrium (September 1990). The model was calibrated to water levels measured in September

1990. Flows during September 1990 at gaging sites on the Suwannee, Aucilla, Econfina, and Steinhatchee Rivers were used during the calibration process to compare to model-computed flows. Flows at seven springs—Wacissa, Madison Blue, Manatee, Ichetucknee, Troy, Rainbow, and Fanning—also were used to calibrate the model.

The sources and sinks used in the ground-water flow models are identical to those described in the previous discussion of ground-water hydrology of the study area. A variety of MODFLOW packages (Harbaugh and McDonald, 1996a) were used to represent recharge, well pumpage, and exchanges between the Upper Floridan aquifer and rivers, springs, and wetlands.

The zone along the coast of the Gulf of Mexico, where diffuse freshwater discharge from the Upper Floridan aquifer is likely to occur, was represented in the model using the River Package of MODFLOW (Harbaugh and McDonald, 1996a, p. 6-1). The coastal "river" model cells have a stage that is set equal to 0.00 ft NGVD of 1929. The river bottom was set at -50 ft NGVD of 1929. The river conductance value was calculated using a vertical conductivity value of 100 ft/d (medium sand, Lohman, 1972) and a streambed thickness of 50 ft. Model-simulated flow values between cells on the landward side of the coastline and the coastal cells in the Gulf represent discharge from the Upper Floridan aquifer to the Gulf of Mexico.

Recharge was represented in the ground-water model using the Recharge Package of MODFLOW (Harbaugh and McDonald, 1996a, p. 7-1). Recharge to the aquifer was estimated by calculating a unit rate of infiltration based on the 90-percent duration discharge of the Suwannee River near Wilcox. Nelms and others (1997) stated that flow statistics are commonly used to evaluate baseflow and related that a 90-percent duration is a relatively stable flow-duration statistic used as a conservative estimate to analyze aquifer systems. The 90-percent duration discharge from the beginning of record (from 1930 to September 1990) is 4,823 ft3/s, and the drainage area is 9,640 mi^2, yielding an infiltration rate of about 7 in/yr, which was used as an initial estimate of total recharge to the basin. Figure 15 shows that flow in the Suwannee River at Branford (upstream from Wilcox) was nearly all baseflow during September 1990.

Exchanges between the Upper Floridan aquifer and the major river was simulated using the River Package (Harbaugh and McDonald, 1996a, p. 6-1). Estimates of river water levels and riverbed conductance were required for each cell modeled by this package. The water level at each grid cell was estimated by interpolating stream elevations between gaging stations using conditions at the end of September 1990. The river bottoms were set approximately as the stream depths at the gaging stations and interpolated between the stations. Initial river conductance values were calculated using a vertical hydraulic conductivity value of 100 ft/d, a streambed thickness of 10 ft, and an estimated area of the streambed.

The Drain Package (Harbaugh and McDonald, 1996a, p. 9-1) was used to estimate discharge from minor rivers where headwater conditions may require solely gaining flow conditions that, had the River Package been used, would have allowed nonexistent stream leakage to be simulated that would have resulted in higher than appropriate computed heads. The same techniques were used in estimating the drain cells' stage and streambed conductance where gaging stations could define these parameters. Initial river conductance values were calculated using a vertical hydraulic conductivity value of 50 ft/d, a streambed thickness of 1 ft, and an estimated area of the streambed. The headwater stream stage was estimated from topographic maps; therefore, from the upstream gaging station to the headwater drain cell, the stream stage is less reliable.

The Block-Centered Flow Package (Harbaugh and McDonald, 1996a, p. 5-1) was used to simulate hydraulic properties in the regional ground-water flow model. A confined/unconfined layer type was specified where transmissivity was determined by the thickness of the saturated aquifer under unconfined conditions or the total aquifer thickness under confined conditions. An arbitrary thickness of 1,000 ft was chosen for the aquifer thickness, which allows the hydraulic conductivity matrix to be multiplied by 1,000 to provide final estimates of transmissivity. Adjustments to hydraulic conductivity during the model calibration process, however, do not solely reflect variability in hydraulic properties of the rock but also reflect the variability in aquifer thickness, despite that the aquifer thickness was set arbitrarily at 1,000 ft.

Model Calibration

Calibration accuracy was evaluated by matching measured water-level elevations in September 1990 to simulated heads for cells where observation wells (fig. 16) are located. Also, measured stream discharge (fig. 16) for selected reaches was used to match model-simulated stream discharge, and measured discharge from springs was used to match model-simulated spring discharge.

To evaluate a particular calibration, a plot was made of the measured elevations and the simulated elevations. If there was a perfect match, all data points would fall on a 45-degree line. A second evaluation of model calibration was the absolute residual mean error for the measured and simulated elevations. This statistic is determined by calculating the absolute value of the difference between the measured and simulated elevations, adding the differences, and dividing by the number of observations. The calibration is better as the absolute residual mean error diminishes in magnitude. Calibration criterion was to attain an absolute residual mean error of 5 percent or less of the head gradient of the system, which would be about 5 ft.

Water-level measurements for 190 observation wells (fig. 16) were available for matching during calibration. Also used for calibraton were discharge values from ground water to five stream reaches: the Aucilla River, the Econfina River, Steinhatchee River, and an upper and middle reach of the Suwannee River (fig. 16). The lowest reach of the Suwannee River (from Branford to the Gulf of Mexico) is tidally affected and could not be used for calibration. Measurements for seven springs were available for calibration: Wacissa, Troy, Madison Blue, Manatee, Ichetucknee, Fanning, and Rainbow Springs (fig. 16). Calibration criterion for matching streamflow is based on the quality of measurements made in the field. All measurements used were rated “good,” meaning the measurements had no more than a 10-percent error. Taking this into account, a goal was set for simulated values to be within 10 percent of the field measurements.

Modeling began with a simplified conceptualization of the ground-water flow system. Initial estimates for the model paramerters were:

- Hydraulic conductivity, Upper Floridan aquifer, horizontal = 500 ft/d.
- Hydraulic conductivity, river streambed, vertical = 100 ft/d.
- Hydraulic conductivity, Gulf of Mexico bed, vertical = 100 ft/d.
- Recharge = 7 in/yr.

The initial simulated heads were generally too high, and the difference between measured and simulated heads varied greatly in magnitude. The first change made to the model was along the southeast corner of the model. A general-head boundary representing the Oklawaha River to the east of the study area had to be added to lower heads that were too high in that area. The next adjustment of parameters for model calibration was along the coast, where emphasis was placed on matching simulated and measured flows of the minor rivers that discharge to the Gulf of Mexico. Matching simulated and measured heads between the Gulf and the Suwannee River in this area was also included in this step. Several zones of hydraulic conductivity and recharge were added and adjusted until heads and streamflow fell within the calibration criterion. Changes to streambed conductivity for certain reaches of the rivers were also necessary to obtain the proper discharge to aquifer head relations. Finally, areas in the northern, eastern, and southern parts of the study area were evaluated, and modifications to hydraulic conductivity, recharge, or streambed conductance were made to match measured heads and discharges, using the same calibration strategy as in the western area of the model. Discharge to springs was controlled by adjusting transmissivity in wells surrounding their respective constant-head cells and adjusting the simulated pool elevation.

The final match of measured and simulated heads is presented in figure 17. The distribution of residuals between simulated and measured water levels is shown on figure 18. The simulated potentiometric-surface map of the Upper Floridan aquifer for September 1990 is shown in figure 19. Final distributions of transmissivity and recharge are presented in figures 20 and 21, respectively. Table 2 compares simulated and measured discharges of river reaches and springs following model calibration; the percent error between simulated and measured values for each river reach and spring is also given. The absolute residual mean error for the match of simulated and measured heads was 4.79 ft (fig. 17). All river reaches and springs were calibrated to within 5 percent, less than the 10-percent criterion of the measured discharge. Simulated transmissivity values ranged from 1,000 to 20 million ft^2/d (fig. 20), and the majority of the area east of the Suwannee River was 1.5 million ft^2/d. The value of 20 million ft^2/d is for a limited area near Wacissa Springs, reflecting the conditions simulated in an adjacent model (Davis, 1996). Other relatively high values are associated with springs where the probability of fractures and dissolution have enhanced the primary permeablity of the limestone. The lowest transmissivity values simulated are associated with the Mallory Swamp area west of the Suwannee River, the Waccassassa Flats area east of the Suwannee River and south of the Santa Fe River, and the Keystone Heights area.

Simulated recharge values range from 0.5 in/yr in the confined area of the Upper Floridan aquifer in the northeastern and eastern parts of the study area to 20.0 in/yr near Wacissa Springs (Davis, 1996). The initial estimate of 7 in/yr proved to be appropriate for most of the unconfined parts of the Suwannee River Basin.

Streambed conductance values ranged from 100,000 to 350,000 ft^2/d for the Suwannee River and from 500 to 50,000 ft^2/d for the minor rivers that discharge to the Gulf of Mexico. The streambed conductance for the Gulf of Mexico was not altered during calibration.

Water Budget

The water budget for the model included inputs from constant heads that represent flow from the northern boundary, wells that represent discharge from swallow holes along streams (represented by injection wells), recharge, river cells that represent losing reaches of the river, and general-head cells that represent the Oklawaha River. Outputs from the model included (1) constant-head cells that represent springs; (2) wells; (3) river and drain cells for gaining river reaches and discharge to the Gulf of Mexico; and (4) a general-head boundary representing the southeastward flow out of the model. The inputs to the model are as follows:

- 1,272 ft^3/s from constant-head cells,
- 52 ft^3/s for wells (swallow holes),
- 4,548 ft^3/s from recharge,
- 556 ft^3/s as river cell leakage, and
- 6 ft^3/s across the southeastern general-head boundary.

The total flow of water into the model was 6,434 ft^3/s. The outputs from the model are as follows:

- 1,939 ft^3/s for constant heads representing the springs,
- 577 ft^3/s from wells,
- 3,913 ft^3/s from rivers and drains (of which about 2,000 ft^3/s discharges to the Gulf of Mexico), and
- 7 ft^3/s for the general-head boundary to the southeast.

The total flow of water out of the model was 6,436 ft^3/s.

Sensitivity Analysis

The final result of model calibration is a representation of the aquifer system that incorporates a blend of measured and estimated parameter values. Starting with more than one estimated parameter, the modeled solution can never be considered unique. Varying each parameter over its probable value range can determine which parameters are most sensitive to the model. Table 3 lists the changes made to the parameter values, the results the changes had to river and spring discharges, and the effect of the changes on the absolute mean error for head matches.

The results of the sensitivity analysis show that reducing the hydraulic conductivity by one-half and doubling the recharge rate produced the same effects on the system—increasing the flows of the rivers and springs. The absolute mean residual error increased to 11.10 ft and 15.47 ft, respectively. Doubling the hydraulic conductivity decreased flow in the rivers along the coast and increased flow in all other rivers and springs, which produced an absolute mean residual error for this run of 6.78 ft. Decreasing the recharge rate by one-half produced lower flows in the streams and springs, which produced an absolute mean residual error for this run of 8.34 ft. Decreasing the riverbed conductance by one-half reduced river flows and increased springs flows associated with river reaches, which produced an absolute mean residual error increase of 5.21 ft. Doubling the riverbed conductance improved the absolute mean error to 4.35 ft, but the flows were not within the calibration criterion. Only two springs were within the 10-percent flow criterion for this simulation.

Model Limitations

Because of the regional scale of the modeling application, certain limitations must be noted for future use of this model:

- The large cell size prohibits direct analysis of indiviual well pumping effects. Additional analyses would require finer discretization of the model grid in the area of interest.
- Impacts from pumping should be measured as changes to the system, either as head changes or streamflow changes, not as absolute values of head or flow. This is necessary because the model was calibrated to one set of hydrologic conditions assumed to be at steady state. Any conditions not reflecting those of September 1990 will alter the heads and flows of that time period.
- Impacts to springs must be simulated with a transient model using a general-head boundary for the spring instead of a specified-head boundary. Transient calibration would use several combinations of stage and discharge for the spring and the conductance for the specified head would be the calibration parameter. The conductance has no physical meaning other than allowing the correct relation of stage and flow to be repeated in the model.
- Agricultural pumpage was not simulated because of the lack of information regarding withdrawals for agricultural usage, both agricultural totals and site-specific locations. Updating pumpage data in the model if site-specific withdrawal rates become available could influence ground-water levels in the south Georgia part of the model depending on the magnitude of those withdrawals.
- Increased pumpage in the Jacksonville area may cause further ground-water level declines in the northeastern corner of the model. Because this model simulates steady-state conditions of September 1990 when ground-water levels had stabilized in that area, a no-flow boundary was used. When the model is used to simulate increased pumpage inside or outside of the model area, a general-head boundary condition should replace the no-flow boundary currently used in the model.

Summary

The Suwannee River Basin covers a total of about 9,950 mi^2 in north-central Florida and southern Georgia. In Florida, the Suwannee River Basin (4,250 mi^2) lies within the SRWMD, covering 7,640 mi^2 and including all or parts of 14 counties. The ground- and surface-water resources of the Suwannee River Basin represent a substantial water supply and provide a variety of important economic, recreational, ecological, and aesthetic benefits. Although these resources have not been highly developed, demand is likely to increase from users within the basin, within the SRWMD, and possibly from more populated areas of Florida. Evaluating the impacts of increased development in the lower Suwannee River Basin requires a quantitative understanding of the boundary conditions, hydrogeologic framework and hydraulic properties of the Floridan aquifer system, as well as the dynamics of water exchanges between the Suwannee River and its tributaries and the Floridan aquifer system.

Three major physiographic divisions are present in or adjacent to the study area: the Northern Highlands, Central Highlands, and the Gulf Coastal Lowlands. Of these three divisions, the Northern Highlands and Gulf Coastal Lowlands make up most of the study area. The boundary between the Northern Highlands and the Gulf Coastal Lowlands is defined by the Cody Scarp, which is the most persistent topographic break (escarpment) in Florida. This escarpment is also roughly coincident with the boundary between the confined and unconfined areas of the Upper Floridan aquifer.

Major rivers within the Suwannee River Basin are the Suwannee, Santa Fe, Alapaha, and Withlacoochee. Four rivers west of the Suwannee River are the Aucilla, the Econfina, the Fenholloway, and the Steinhatchee; all drain to the Gulf of Mexico. Perhaps the most notable aspect of the surface-water hydrology of the study area is that large areas east of the Suwannee River are devoid of channelized, surface drainage; consequently, most of the drainage occurs through the subsurface.

The ground-water flow system underlying the study area plays a critical role in the overall hydrology of this region of Florida because of the dominance of subsurface drainage and because ground-water flow sustains the flow of the rivers and springs.

Three principal hydrogeologic units are present in and adjacent to the study area: the surficial aquifer system, the intermediate aquifer system, and the Floridan aquifer system. The surficial aquifer system is present throughout the Northern Highlands area and somewhat more locally in the Gulf Coastal Lowlands. Where present, the surficial aquifer system is contiguous with land surface and principally consists of unconsolidated to poorly indurated siliciclastic deposits. The intermediate aquifer system and intermediate confining unit lie below the surficial aquifer system (where present), and generally consists of fine-grained, unconsolidated deposits of quartz sand, silt, and clay with interbedded limestone of Miocene age. Regionally, the intermediate aquifer system and intermediate confining unit act as a confining unit that restricts the exchange of water between the overlying surficial and underlying Upper Floridan aquifers. The Upper Floridan aquifer is present throughout the study area and is extremely permeable, typically capable of transmitting large volumes of water. This high permeability largely is due to the widening of fractures and formation of conduits within the aquifer through dissolution of the limestone by infiltrating water. This process has also produced numerous karst features such as springs, sinking streams, and sinkholes.

The lateral boundaries of the ground-water flow system in the study area define horizontal limits of the system. There are five key lateral boundaries: the northern specified-head boundary, the southeastern head-dependent boundary, the boundary represented by the Gulf of Mexico coastline, and the eastern and northwestern no-flow boundaries. These boundaries define the lateral limits of the area that contribute water to the Suwannee River Basin.

A model of the Upper Floridan aquifer was created to better understand the ground-water system and to provide water-resource managers with a tool to evaluate ground-water and surface-water interactions in the Suwannee River Basin. The model was developed to simulate a single Upper Floridan aquifer layer. Recharge datasets were developed to represent a net flux of water to the top of the aquifer or the water table during a period when the system was assumed to represent steady-state conditions (September 1990). A potentiometric-surface map representing water levels during September 1990 was prepared for the study area, and the heads from those wells were used for calibration of the model. Water-level measurements for 190 observation wells were available for matching during calibration. Additionally, flows at gaging sites in the Suwannee, Santa Fe, Fenholloway, Aucilla, Econfina, and Steinhatchee Rivers were used during the calibration process to compare to model computed flows. Flows at seven springs (Wacissa, Madison Blue, Manatee, Ichetucknee, Troy, Rainbow, and Fanning) also were used to calibrate the model.

Calibration criterion for matching potentiometric heads was to attain an absolute residual mean error of 5 percent or less of the head gradient of the system, which would be about 5 ft. An absolute residual mean error of 4.79 ft was attained for final calibration. Calibration criterion for matching streamflow is based on the quality of measurements made in the field. All measurements used were rated “good,” so a goal was set for model-simulated values to be within 10 percent of the field measurements. All river reaches and springs were calibrated to within 5 percent, less than the 10-percent criterion of the measured discharge.

Model-simulated transmissivity values range from 1,000 to 20 million ft^2/d. The value of 20 million ft^2/d is for a limited area near Wacissa Springs. All relatively high transmissivity values are associated with springs where the probability of fractures and dissolution have enhanced the primary permeablity of the limestone. The lowest transmissivity values are generally associated with wetland areas.

Model-simulated recharge values range from 0.5 in/yr in the confined area of the Upper Floridan aquifer to the northeastern and eastern part of the study area to 20.0 in/yr near Wacissa Springs. The initial estimate of 7 in/yr proved to be appropriate for most of the unconfined parts of the study area.

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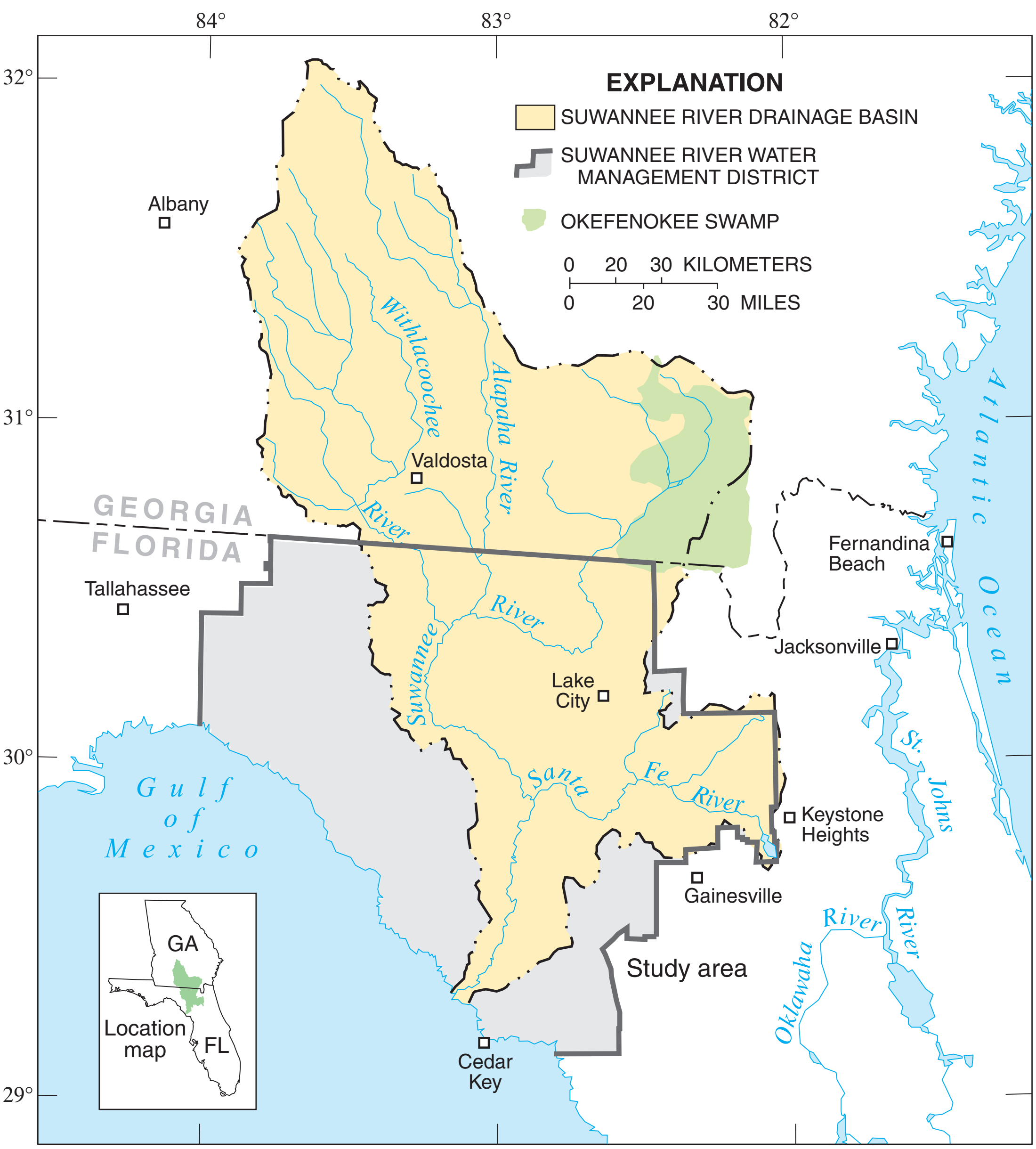
Figures 1–21



Base from U.S. Geological Survey digital data, 1972
Albers Equal-Area Conic Projection,
Standard parallels 29°30′ and 45°30′, central meridian -83°00′

Figure 1. Location of the Suwannee River drainage basin.

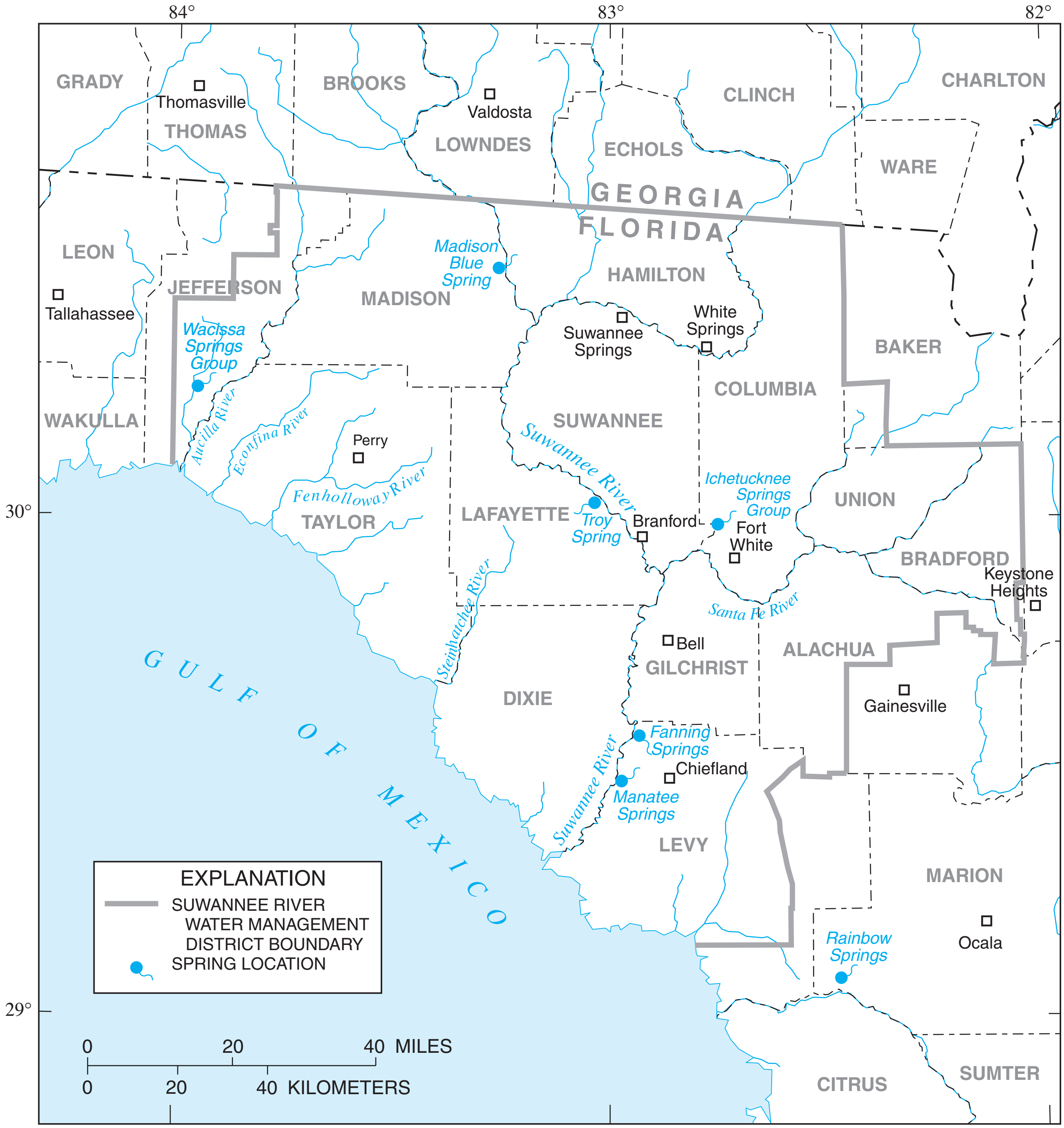


Figure 2. Location of the Suwannee River Water Management District within the study area.

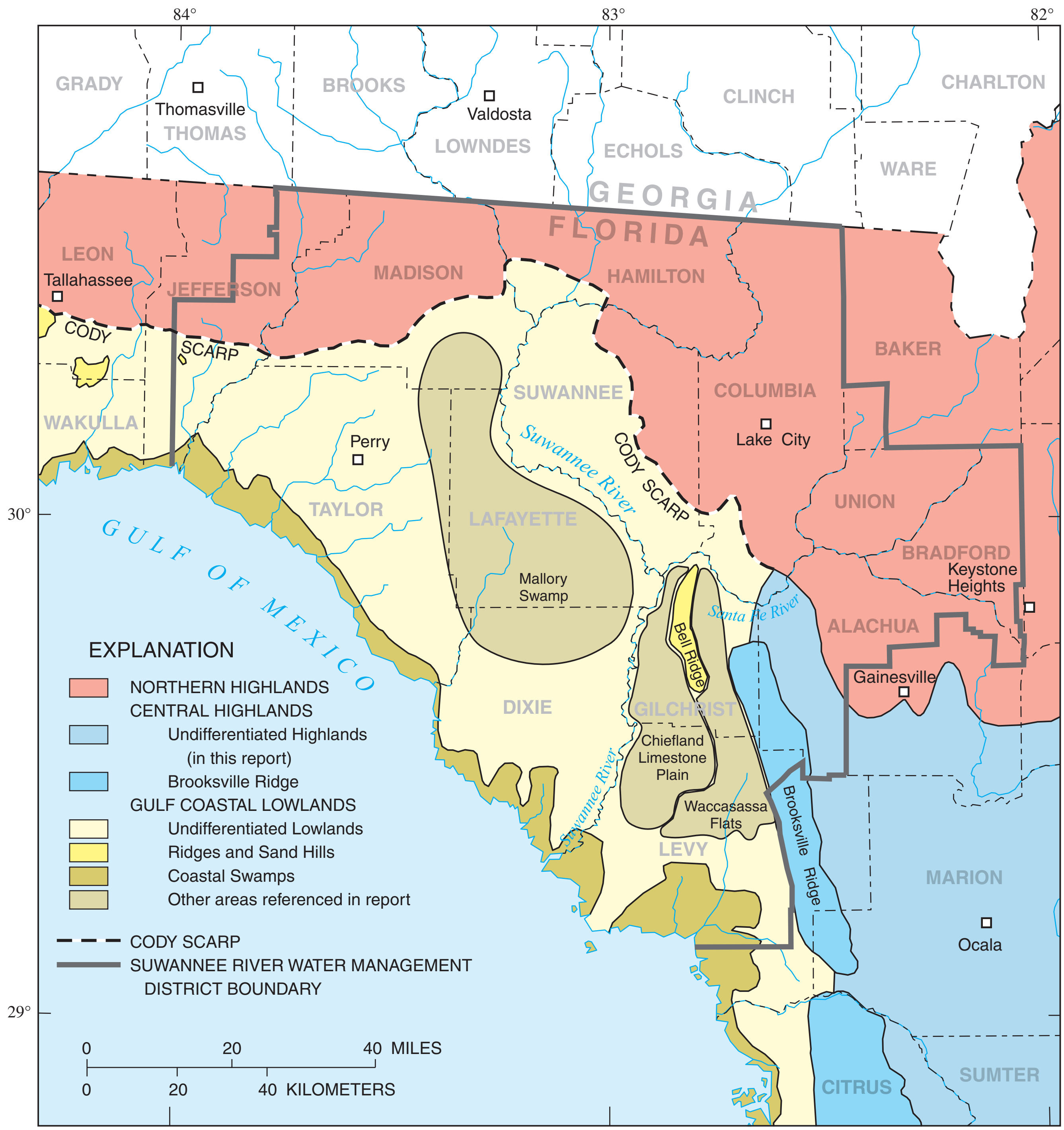


Figure 3. Physiographic areas in and adjacent to the Suwannee River Water Management District.

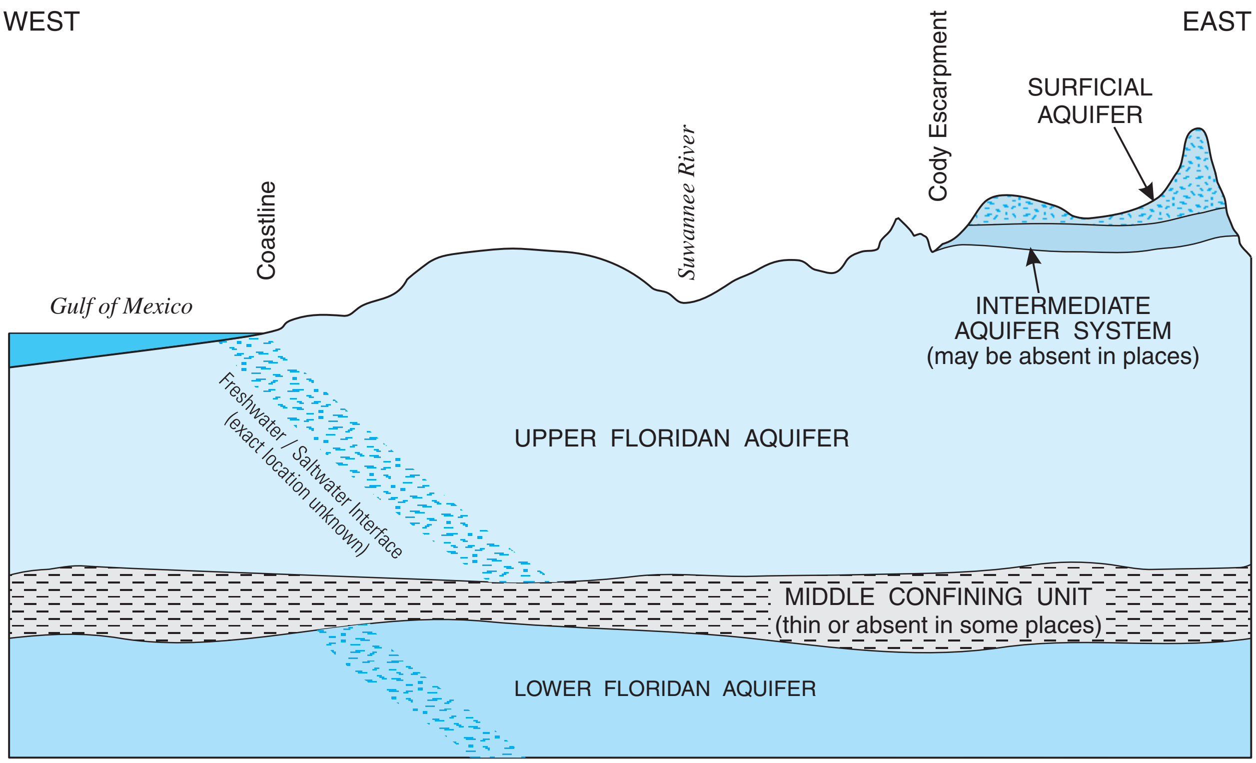


Figure 4. Generalized east-west hydrogeologic section.

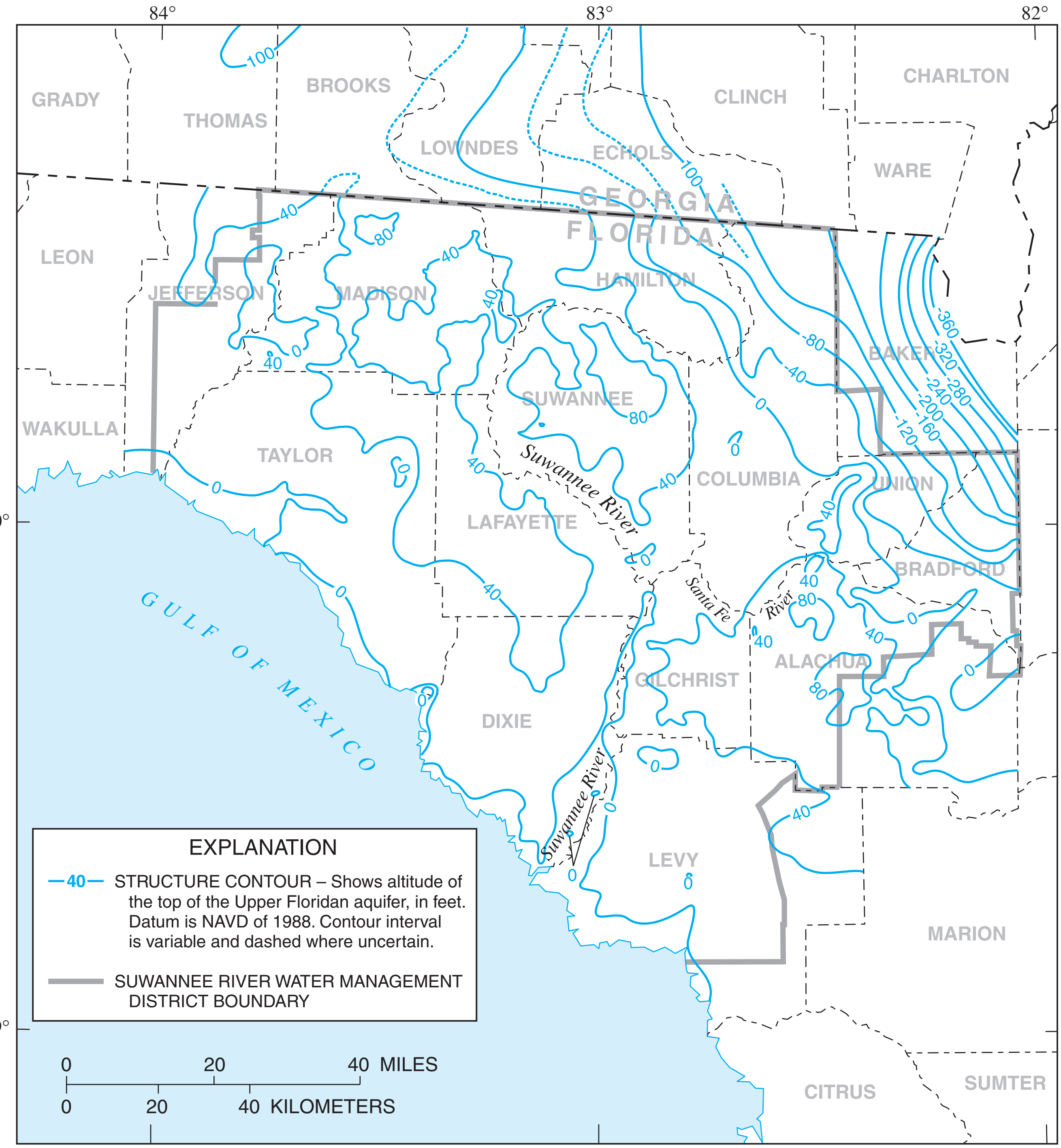


Figure 5. Elevation of the top of the rocks associated with the Upper Floridan aquifer.

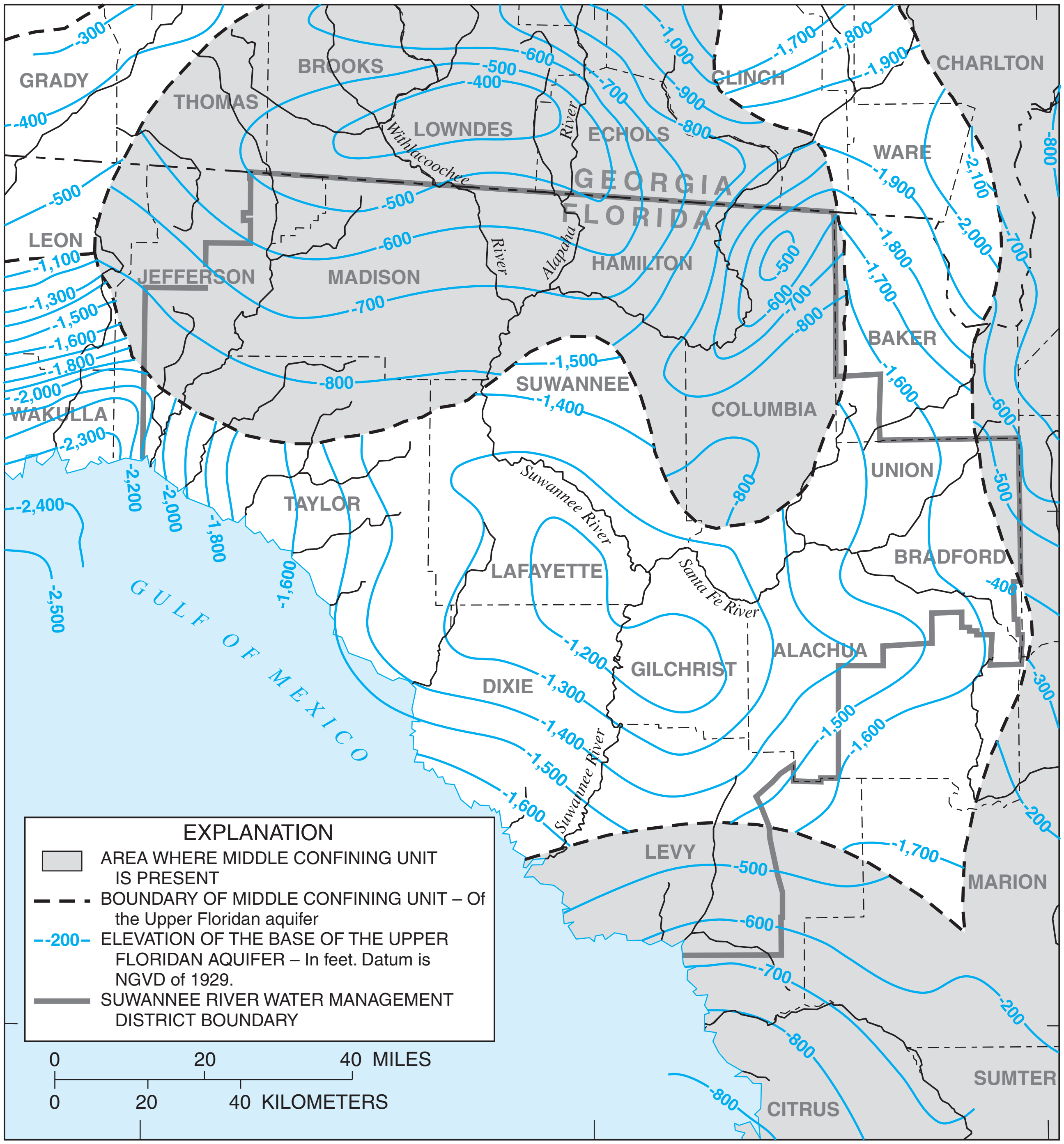


Figure 6. Elevation of the base of the rocks associated with the Upper Floridan aquifer.

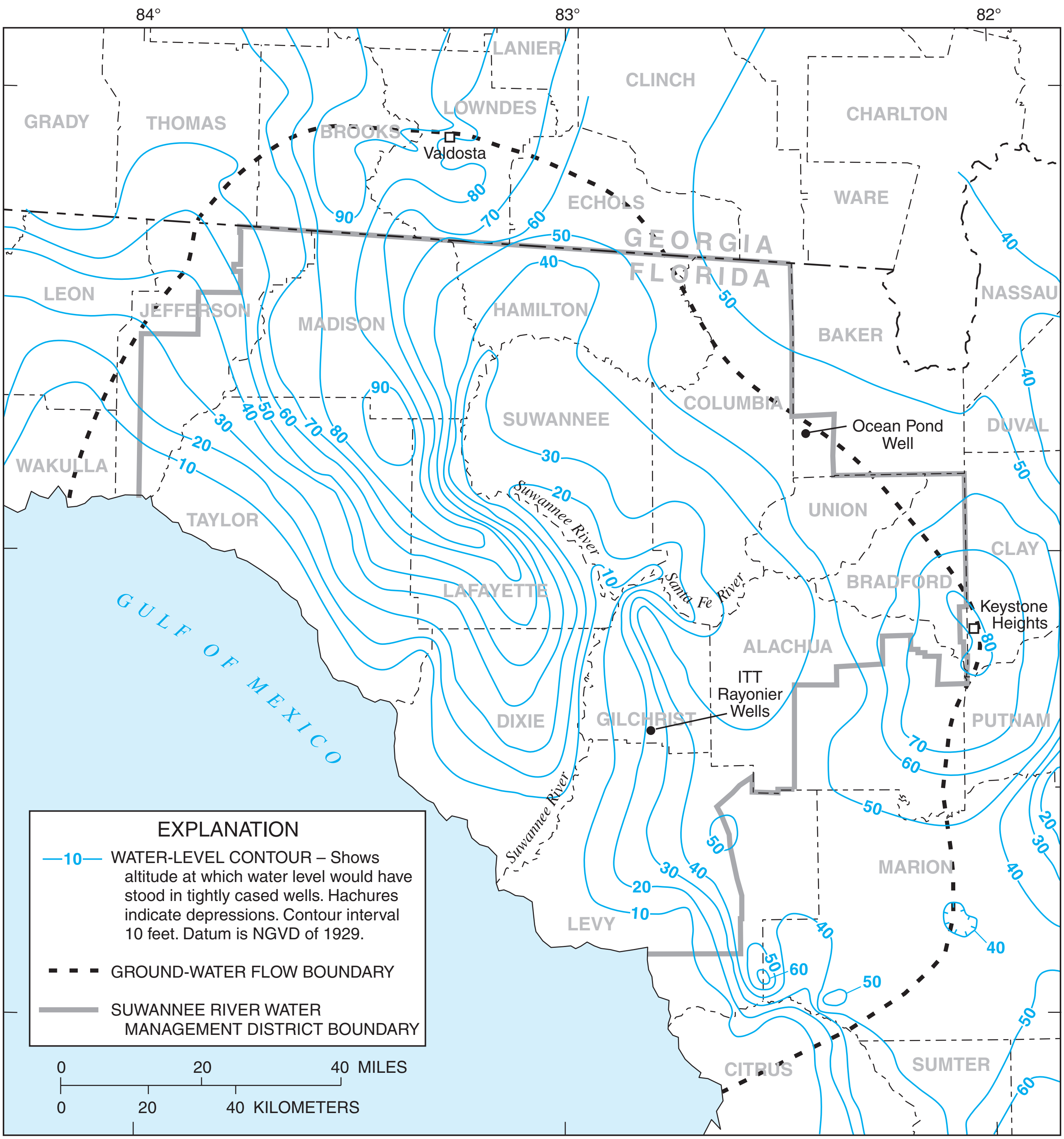


Figure 7. Potentiometric surface for the Upper Floridan aquifer, September 1990.

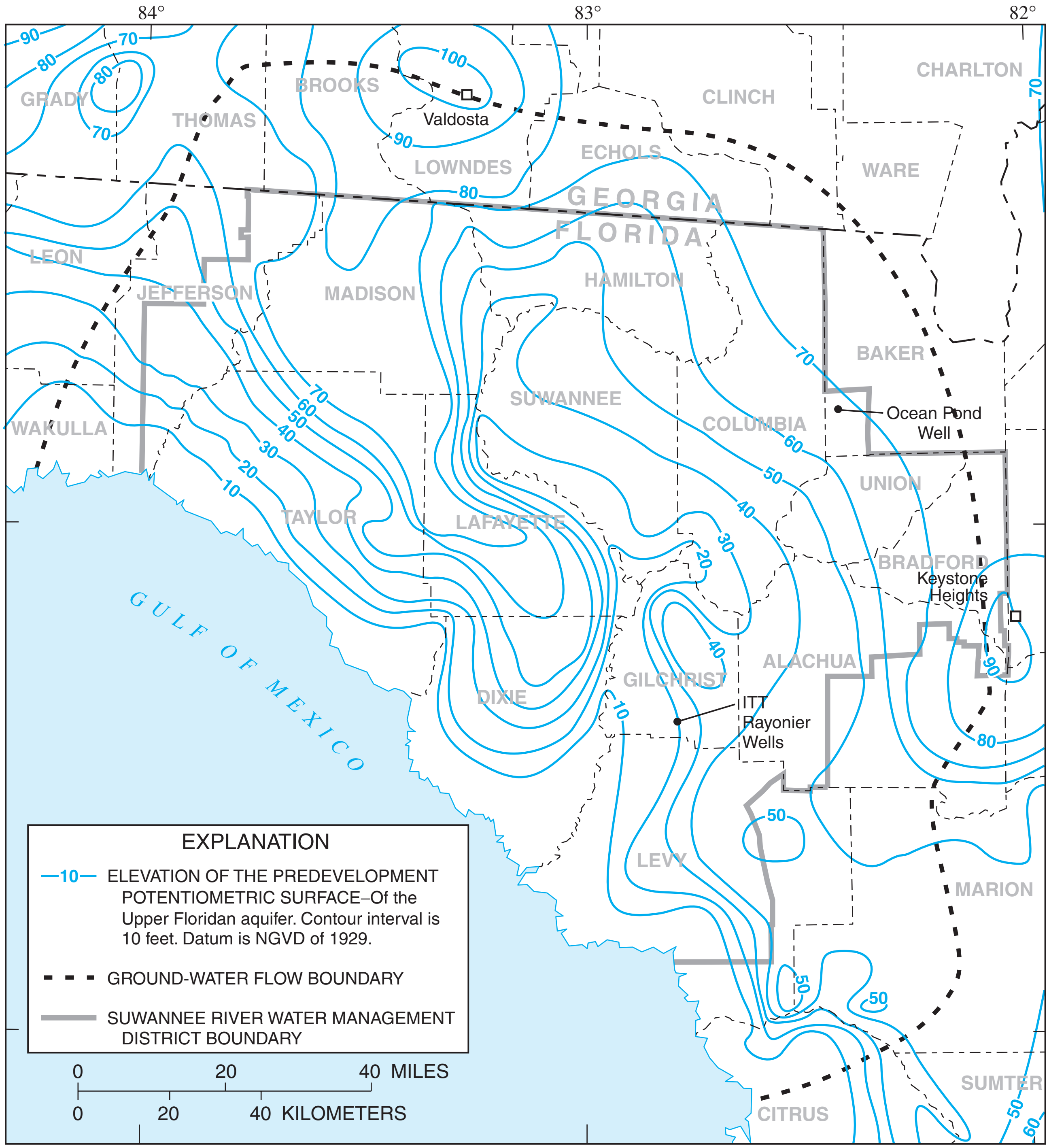


Figure 8. Predevelopment potentiometric surface of the Upper Floridan aquifer.

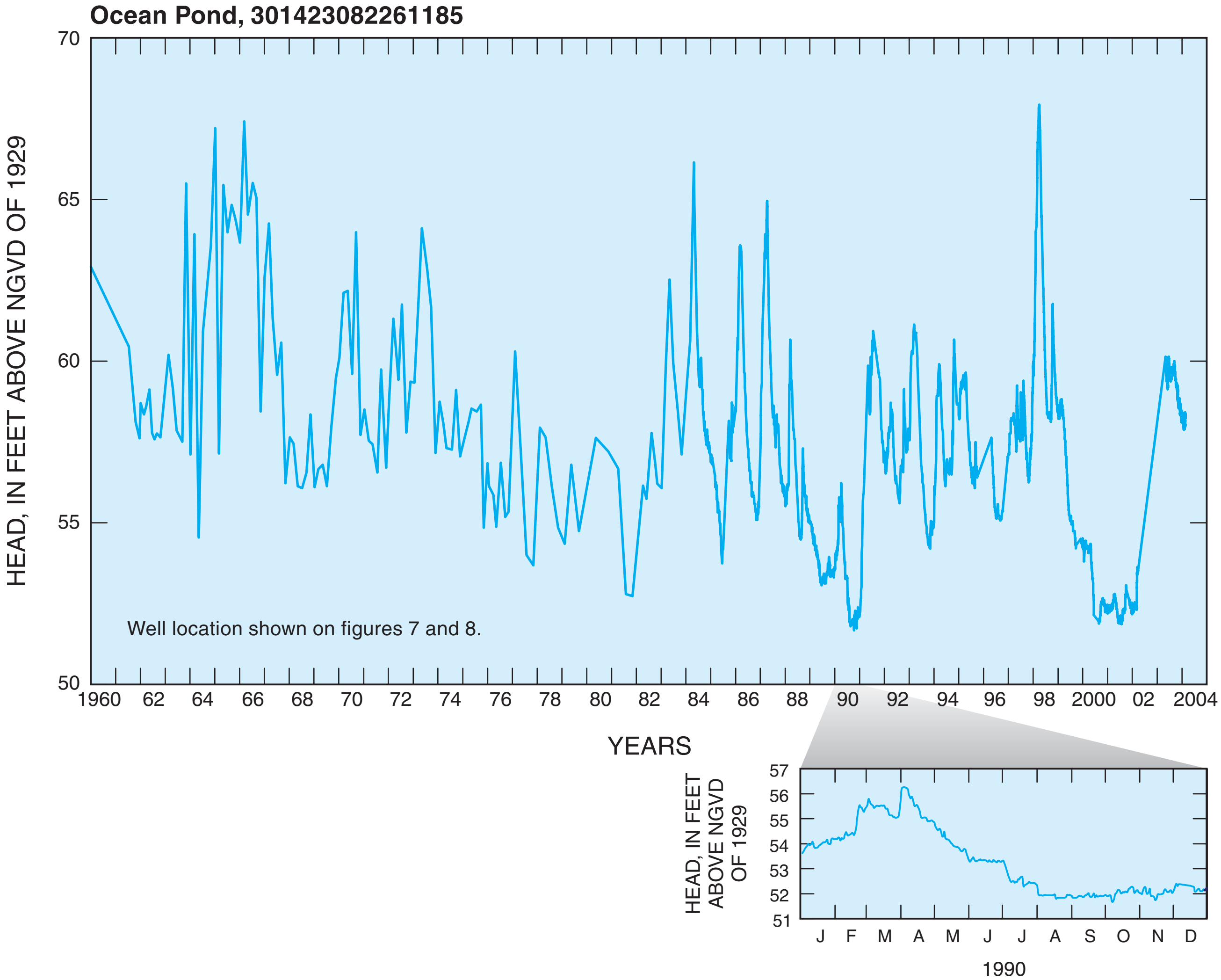


Figure 9. Long-term water levels of a well along eastern border of the study area.

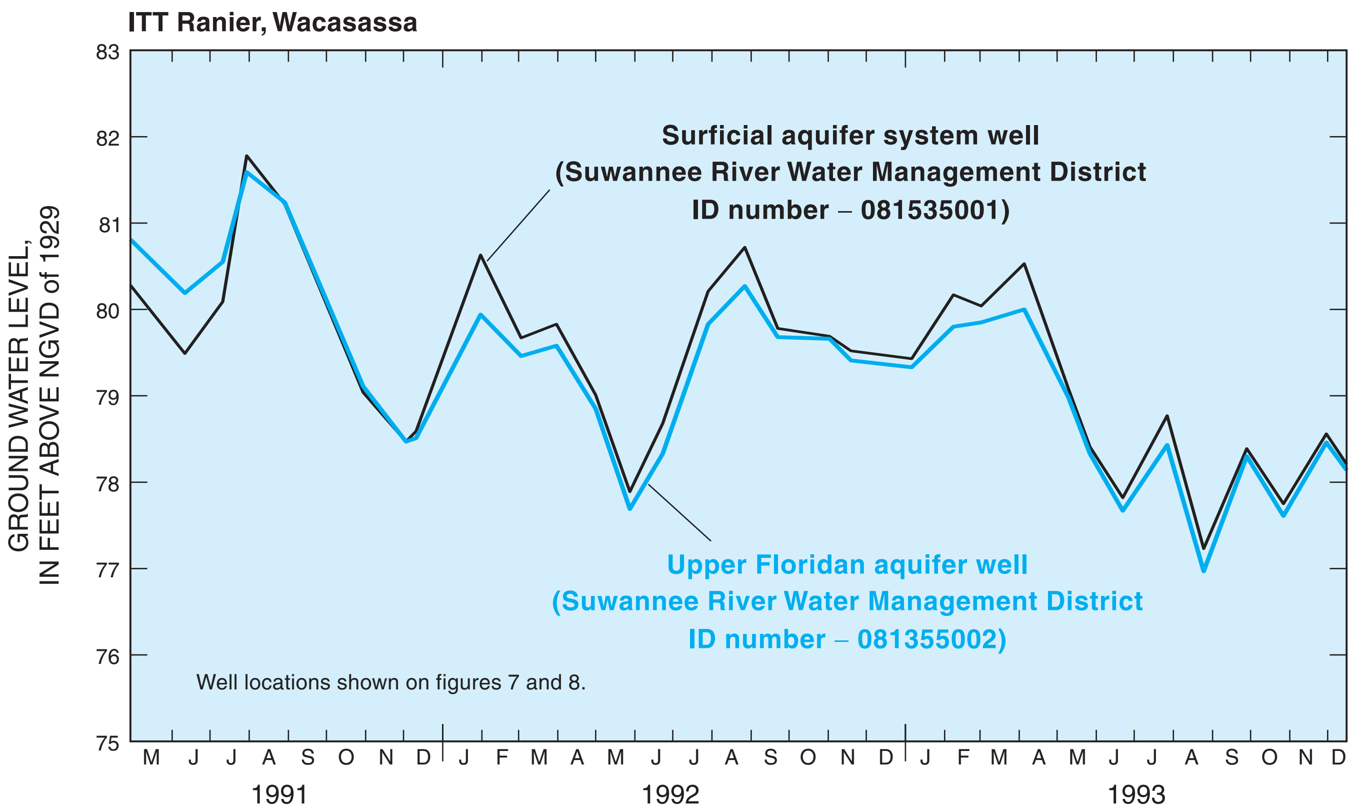
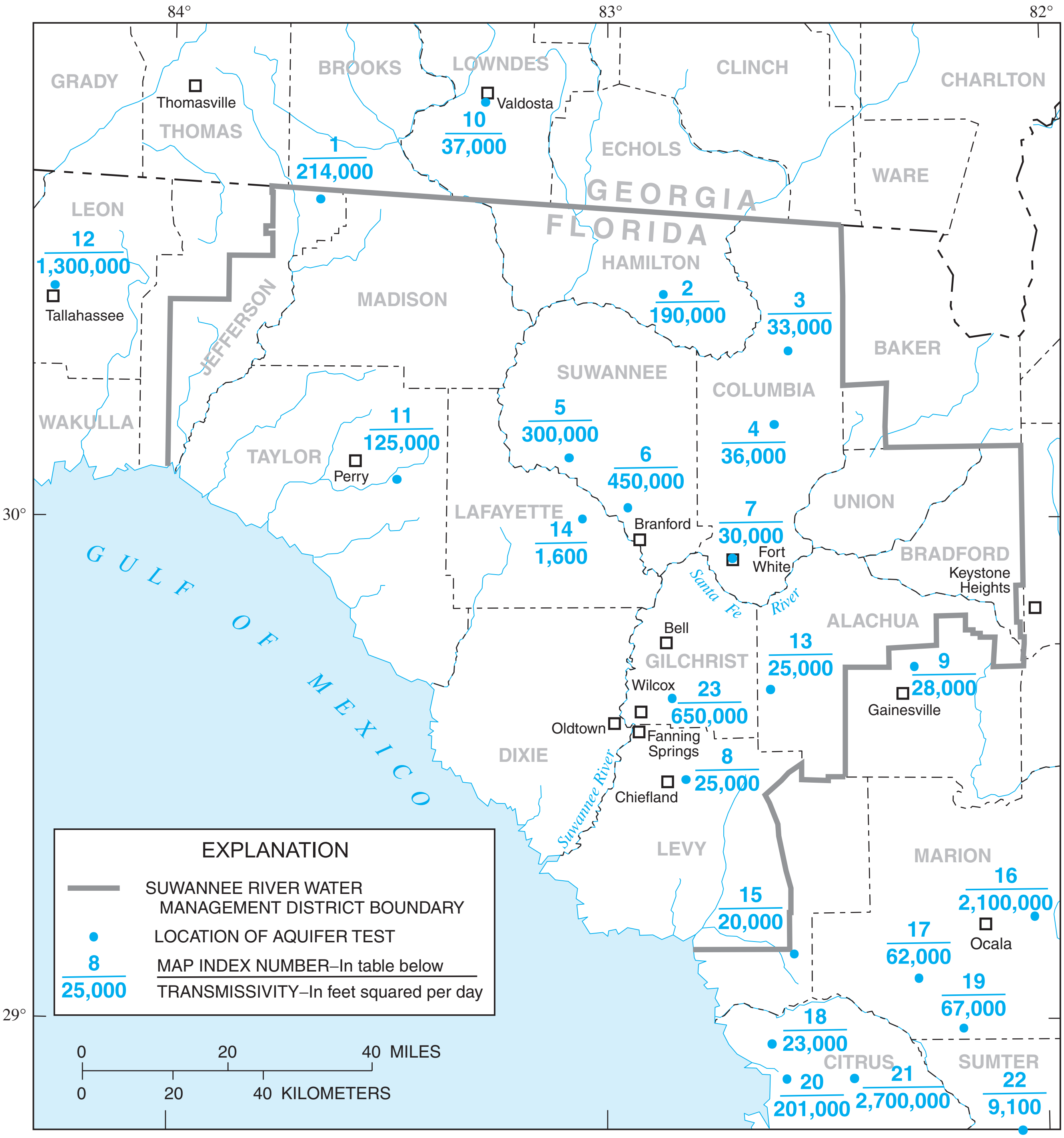


Figure 10. Water-level fluctuations of the surficial aquifer system and Upper Floridan aquifer from collocated wells in unconfined areas of the Upper Floridan aquifer. Map locations of these wells are shown in figure 8.



MAP INDEX NUMBER	WELL NAME	MAP INDEX NUMBER	WELL NAME
1	Finlayson	13	R.D. Williams
2	Oxy	14	John Folks, Division of Forestry, Midway, FL
3	Osceola National Forest	15	Tidewater
4	Lake City	16	Silver Springs
5	Boatright	17	Circle Square
6	Wet Farms	18	Florida Power - Crystal River
7	City of Fort White	19	Marion Oaks
8	Andrews Nursery	20	Crystal River
9	City of Gainesville	21	Hampton Hills
10	City of Valdosta, #4	22	Tompkin Park ROMP 111
11	Proctor and Gamble Foley Plant	23	Piedmont Farms
12	City of Tallahassee, #2		

Figure 11. Location of aquifer tests in the study area.

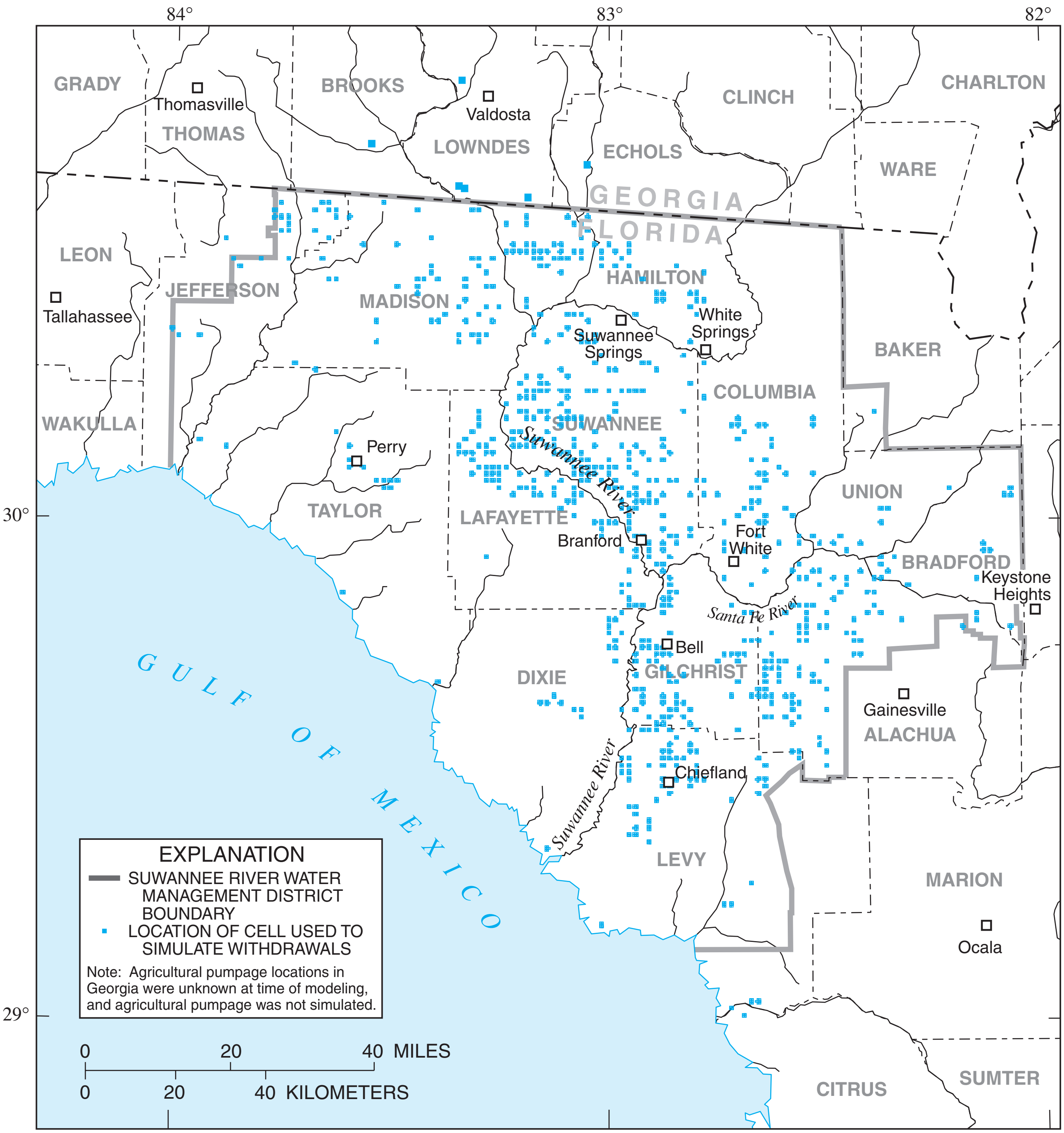


Figure 12. Geographic distribution of withdrawals from the Upper Floridan aquifer.

Figure 13. Model grid.

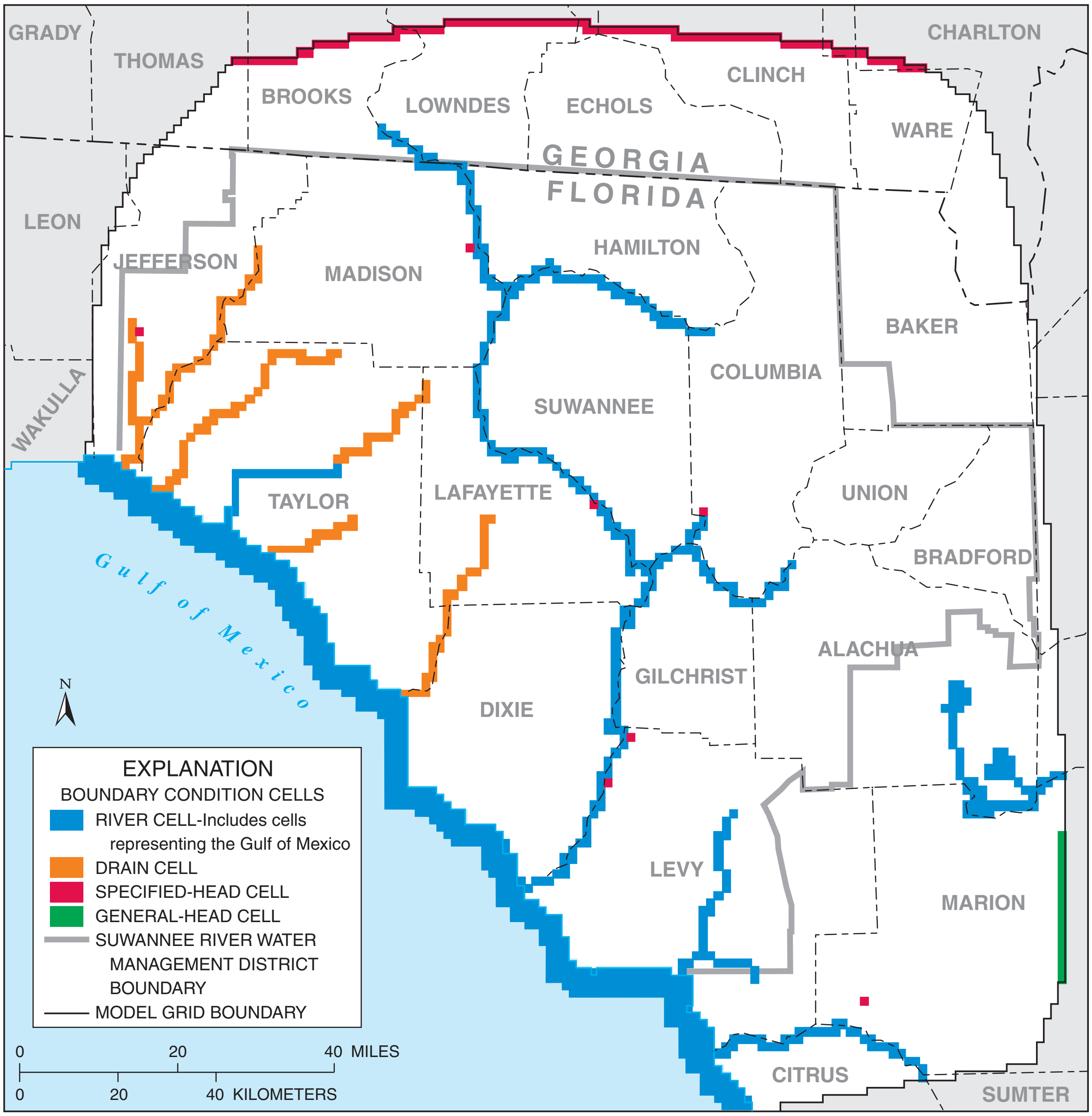


Figure 14. Boundary conditions used in the model.

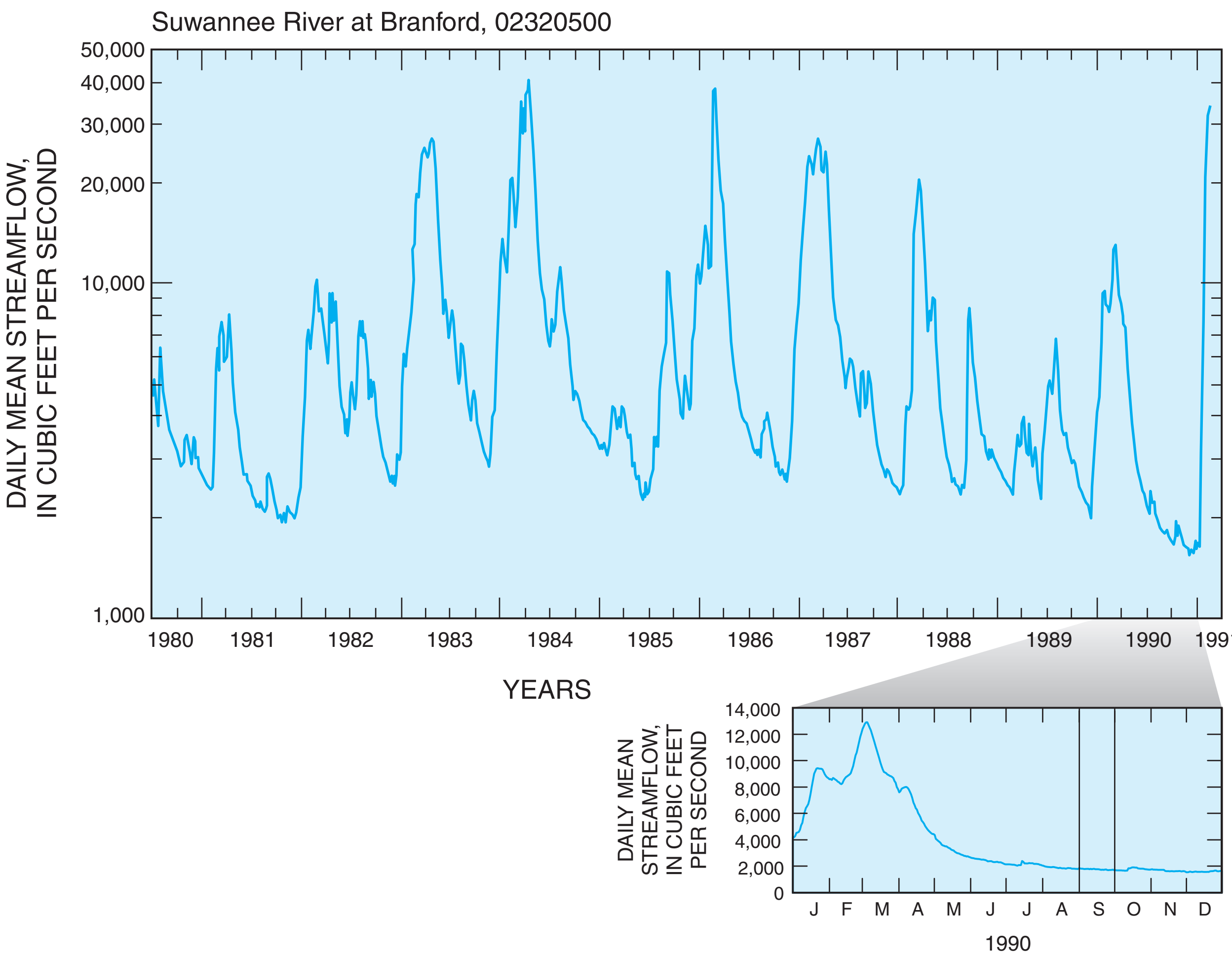


Figure 15. Daily mean streamflow in the Suwannee River at Branford, Florida.

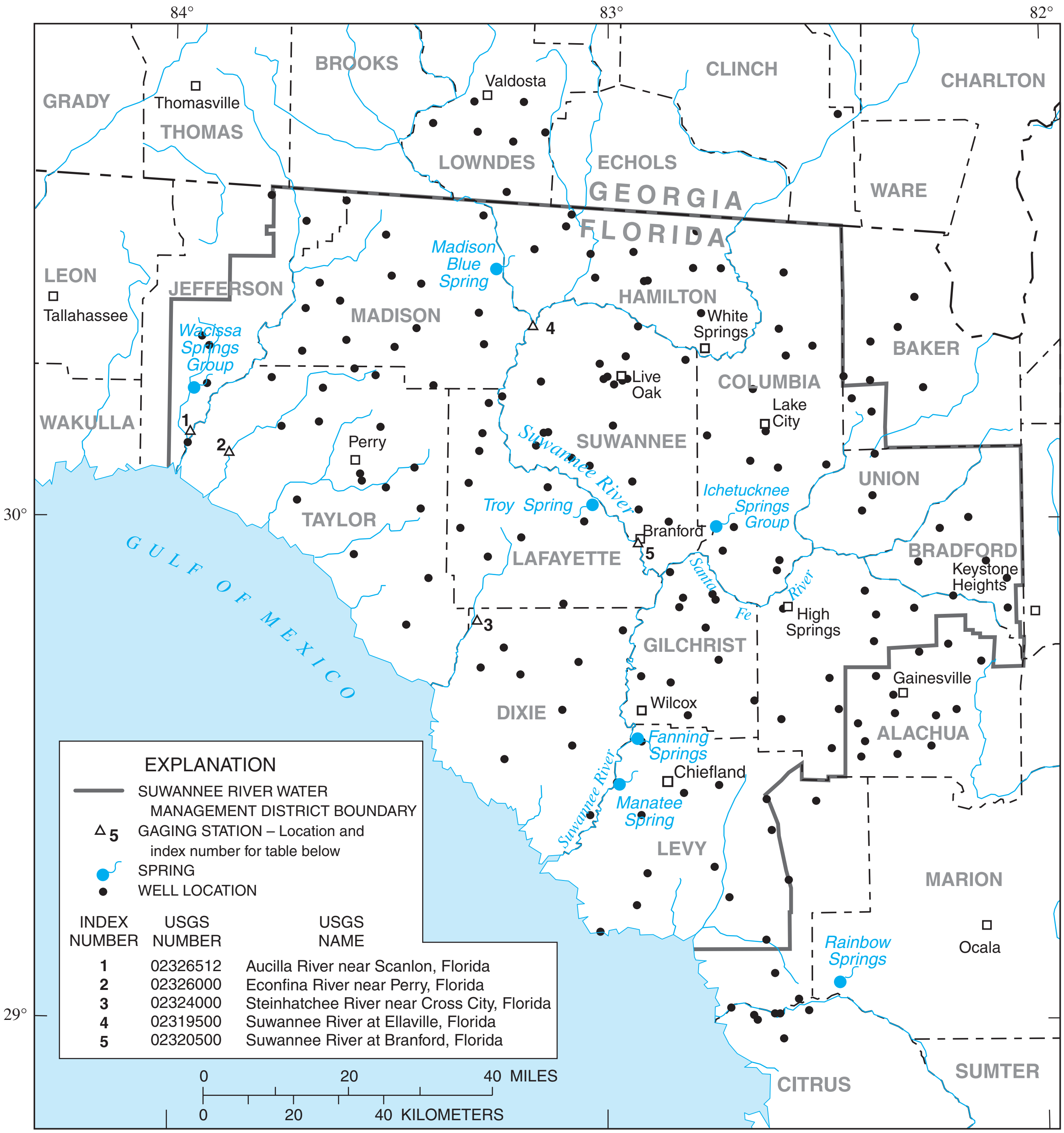


Figure 16. Observation wells, gaging stations, and springs used in model calibration.

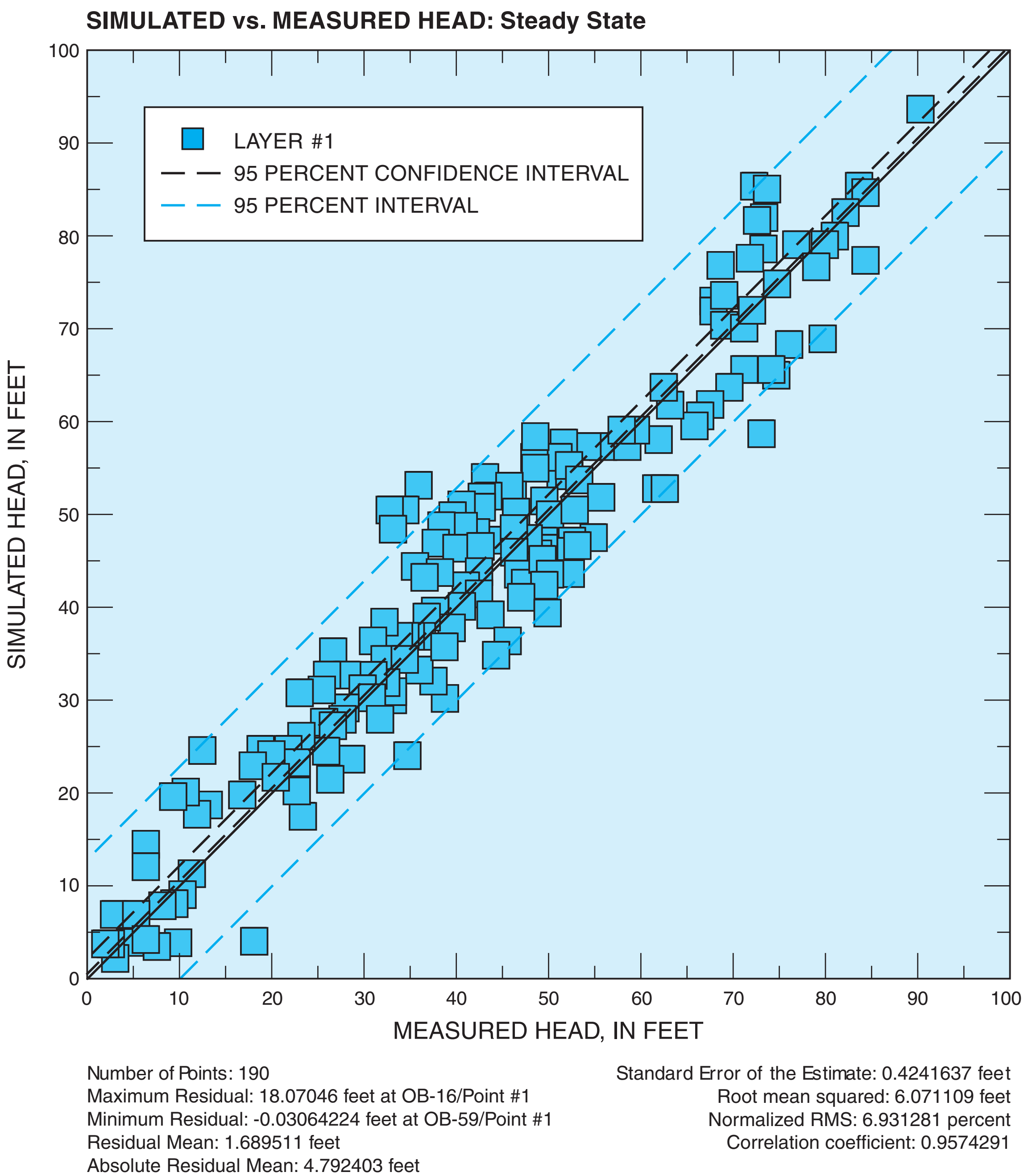


Figure 17. Calibration match of measured and model-simulated potentiometric heads.

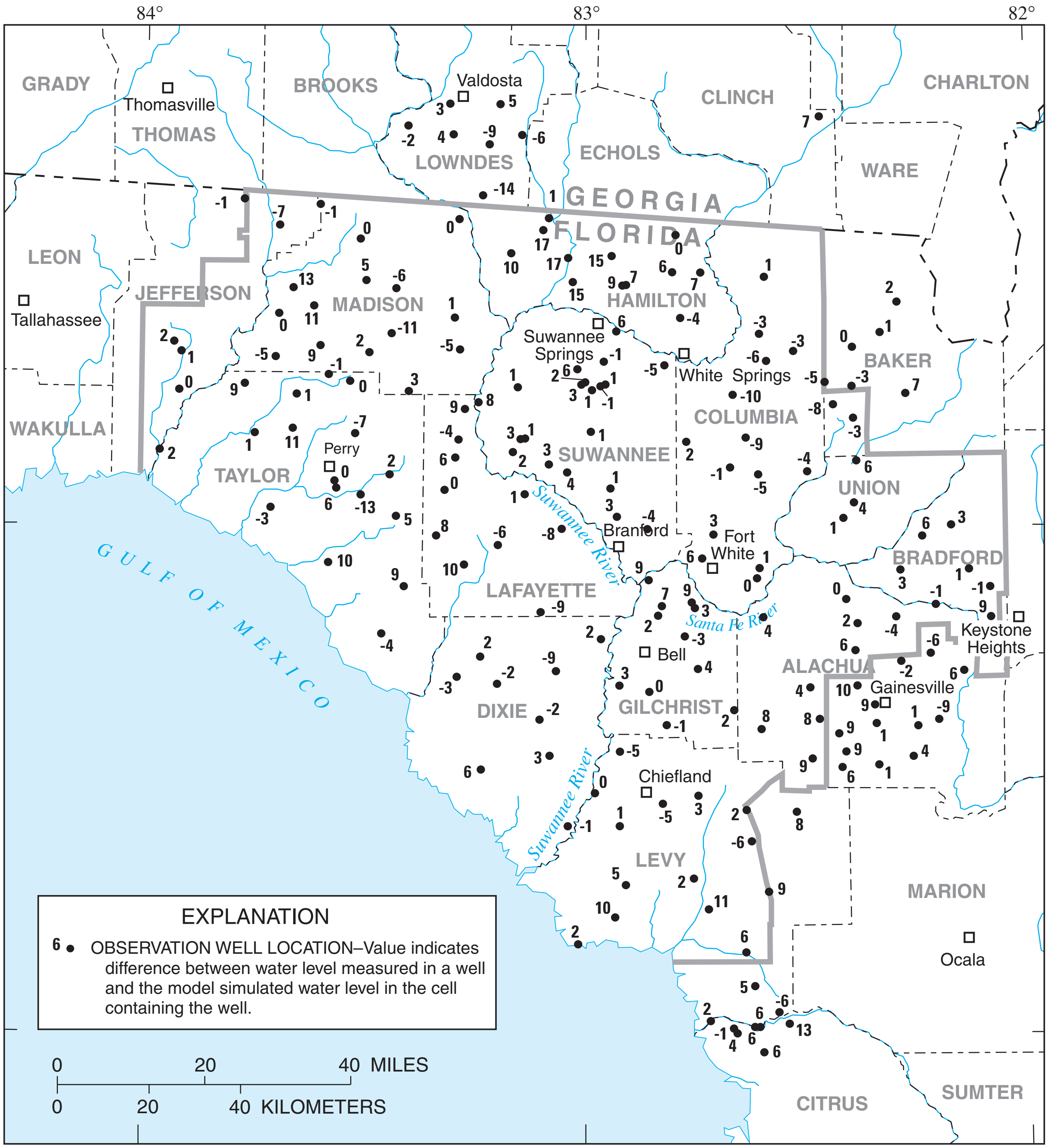


Figure 18. Residuals between simulated and measured water levels.

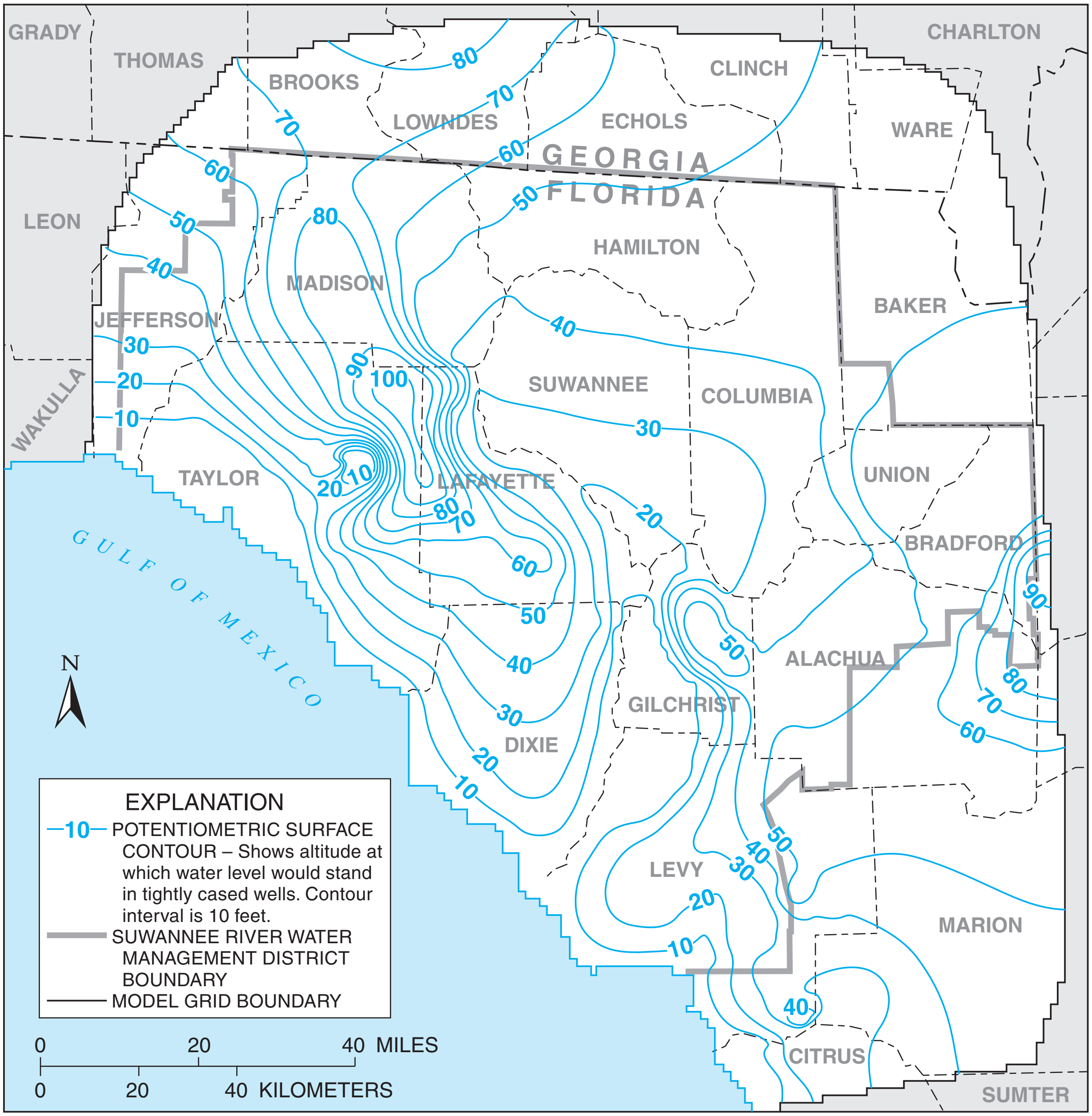


Figure 19. Simulated potentiometric suface of the Upper Floridan aquifer, September 1990.

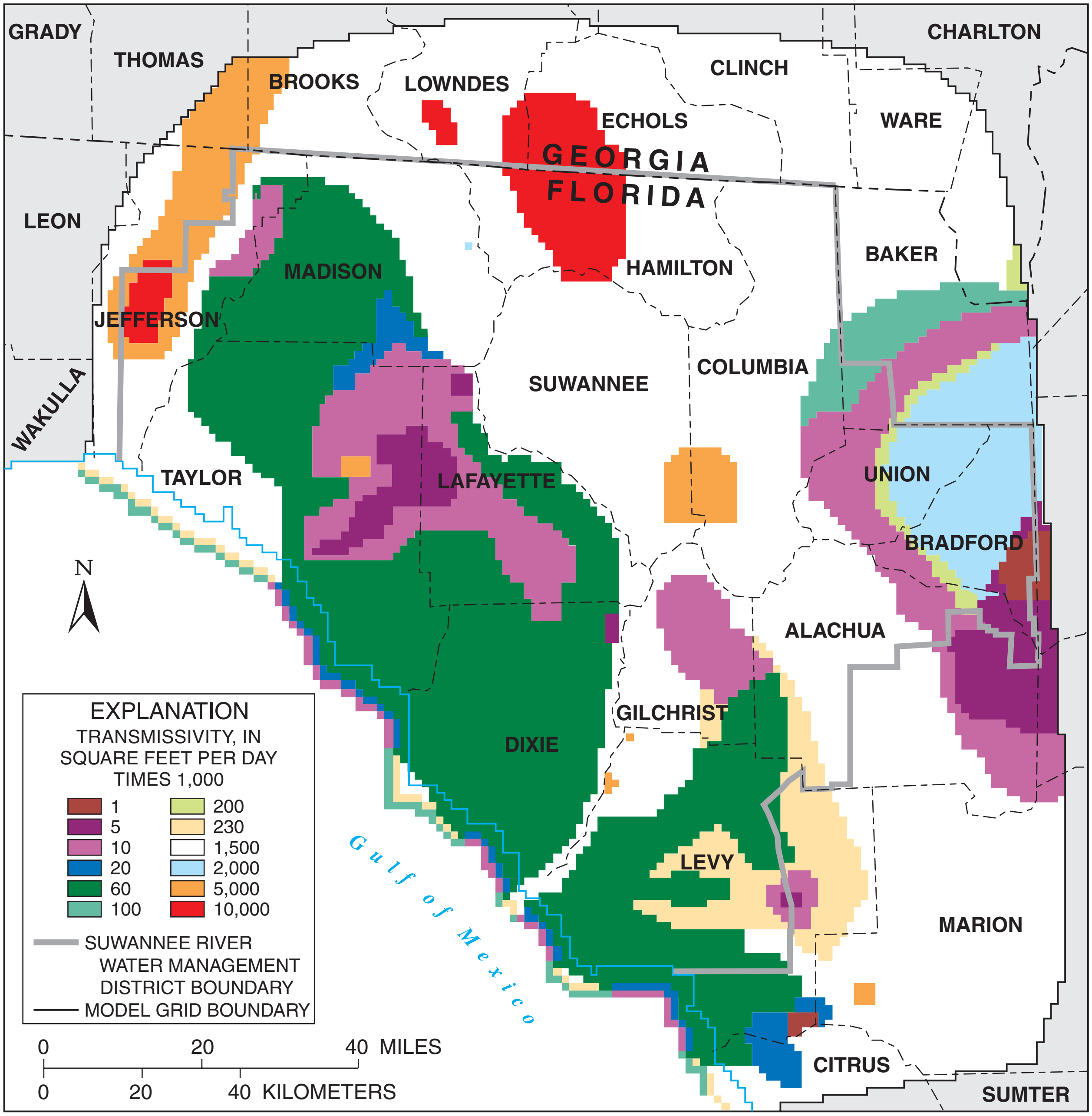


Figure 20. Distribution of simulated transmissivity.

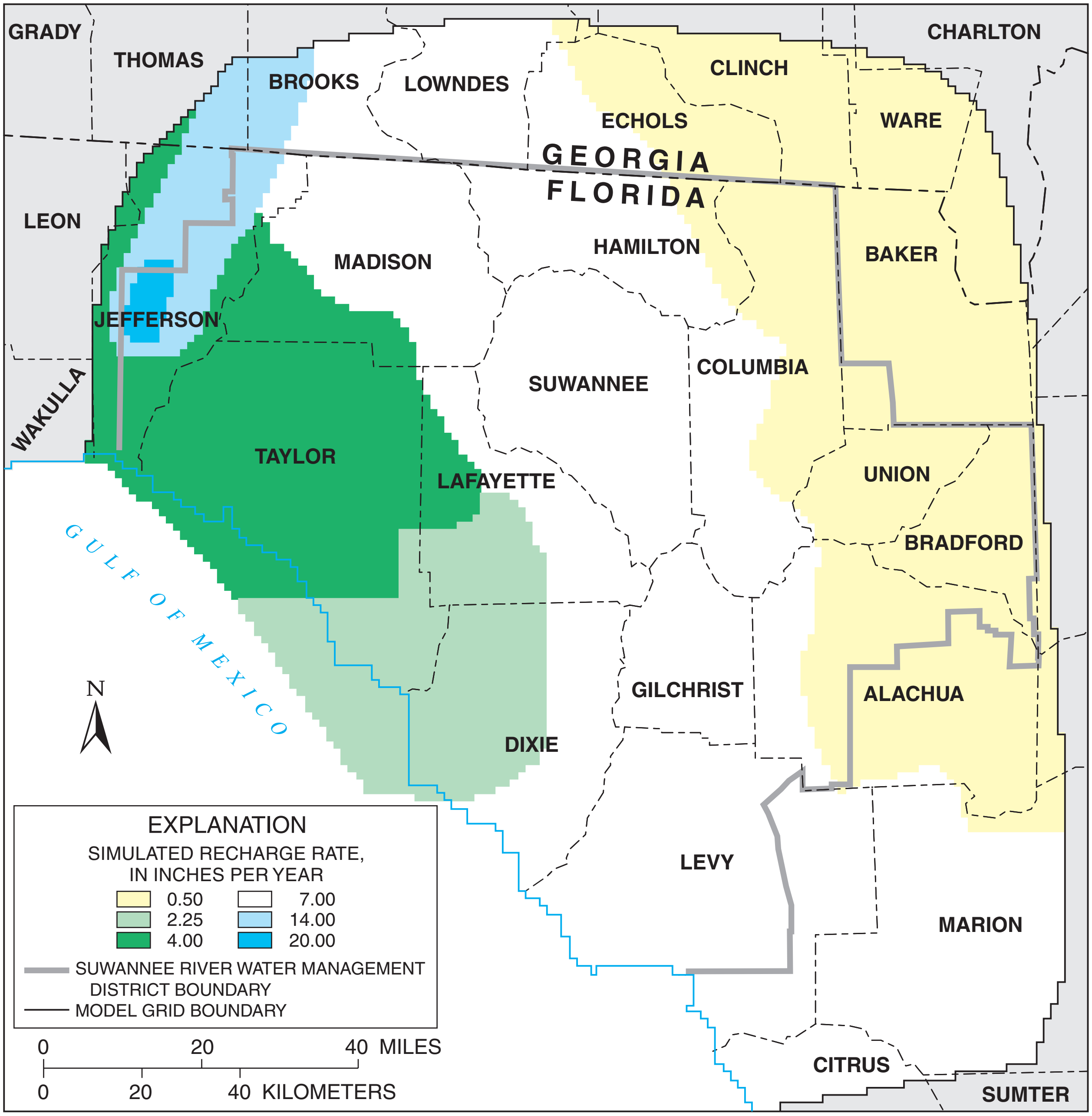


Figure 21. Distribution of simulated recharge.

Tables 1–3

Table 1. Aquifer tests in and adjacent to the study area.

Map index number (fig. 11)	Name	Transmissivity, in feet squared per day
1	Finlayson	214,000
2	Oxy	190,000
3	Osceola National Forest	33,000
4	Lake City	36,000
5	Boatright	300,000
6	Wet Farms	450,000
7	City of Fort White	30,000
8	Andrews Nursery	25,000
9	City of Gainesville	28,000
10	City of Valdosta #4	37,000
11	Proctor and Gable Foley Plant	125,000
12	City of Tallahassee #2	1,300,000
13	RD Williams	25,000
14	John Folks, Division of Forestry, Midway, Florida	1,600
15	Tidewater	20,000
16	Silver Springs	2,100,00
17	Circle Square	62,000
18	Florida Power—Crystal River	23,000
19	Marion Oaks	67,000
20	Crystal River	201,000
21	Hampton Hills	2,700,000
22	Tompkin Park Romp 111	9,100
23	Piedmont Farms	650,000

Table 2. Measured and model simulated river and spring flows in the study area.

[Discharge, in cubic feet per second; percent, ((simulated discharge - measured discharge) / measured dischrage) × 100 percent)]

	Aucilla River	Econfina River	Stein-hatchee River	Middle Suwannee River at Branford	Upper Suwannee River at Ellaville	Fanning Springs	Ichetuck-nee Springs	Madison Blue Spring	Manatee Springs	Rainbow Spring	Troy Spring	Wacissa Spring
Measured discharge	17.30	13.00	11.00	670.00	746.53	116.00	271.00	87.90	125.00	620.00	98.10	484.00
Simulated discharge	17.38	13.06	10.95	660.49	775.06	116.82	268.70	87.59	122.70	610.09	102.44	479.21
Percent error	0	0	0	-1	4	1	-1	0	-2	-2	4	-1

Table 3. Change in flow for rivers and springs in the model, and absolute mean error for head values during sensitivity analysis.

	Aucilla River	Econfina River	Stein-hatchee River	Middle Suwannee River at Branford	Upper Suwannee River at Ellaville	Fanning Springs	Ichetuck-nee Springs	Madison Blue Spring	Manatee Springs	Rainbow Spring	Troy Spring	Wacissa Spring	Absolute mean eror in head
Actual discharge													
	17.30	13.00	11.00	670.00	746.53	116.00	271.00	87.90	125.00	620.00	98.10	484.00	
Simulated discharge, in cubic feet per second													
Calibration	17.38	13.06	10.95	660.49	775.06	116.82	268.70	87.59	122.70	610.09	102.44	479.21	4.73
K*0.5	23.85	34.19	31.73	532.44	552.65	80.28	160.14	47.37	89.19	415.73	36.25	411.24	11.48
K*2.0	12.43	—	0.33	887.28	616.78	184.76	560.35	202.77	176.55	921.66	253.45	656.16	6.94
RCH*0.5	12.00	0.07	0.76	672.71	544.53	85.75	261.99	83.61	91.61	504.29	95.36	236.33	6.98
RCH*2.0	30.63	51.08	54.21	974.42	772.20	221.12	526.04	222.14	230.45	869.80	221.12	868.17	16.10
RIVK*0.5	10.10	8.20	8.53	536.34	379.28	146.20	410.42	182.71	142.97	606.97	158.59	510.68	5.63
RIVK*2.0	29.75	18.68	14.33	815.00	744.27	94.28	160.76	40.66	103.53	623.46	42.78	466.94	4.44