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NORTH-CENTRAL FLORIDA ACTIVE WATER-TABLE REGIONAL GROUNDWATER FLOW MODEL

FINAL REPORT

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

NORTH-CENTRAL FLORIDA ACTIVE WATER-TABLE REGIONAL GROUNDWATER FLOW MODEL

(Final Report)

by

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EXECUTIVE SUMMARY

The north-central Florida active water-table regional groundwater flow model simulates the effects that increased groundwater pumpage in north-central Florida from 1995 to 2020 and 2025 will have on water levels in the surficial aquifer system and upper Floridan aquifer, groundwater system water budgets, and spring flows. This model, which was developed by modifying a previously completed model (Motz and Dogan 2002) in which the water table was treated as a specified-head layer, was developed as part of an investigation authorized by the St. Johns River Water Management District (SJRWMD) in October 1999. This investigation consisted of six tasks: characterizing the hydrogeology in a study area that is approximately 30 percent larger than the study area in the specified-head water-table model; revising the specified-head water-table model by activating the water table and calibrating to average 1995 conditions; simulating the impacts of pumping in 2020; simulating the impacts of pumping in 2025; preparing a draft report; and preparing the final technical report. This report represents the final technical report, which has been prepared in response to SJRWMD's review of the draft report.

The study area for this investigation covers approximately 5,650 square miles in north-central Florida, extending from 28° 45′ N to 29° 54′ N latitude and from 81° 19′ W to 82° 30′ W longitude. Altogether, parts of fourteen counties are included in the study area, i.e., parts of Alachua, Bradford, Citrus, Clay, Flagler, Lake, Marion, Putnam, Sumter, St. Johns, and Volusia counties and small parts of Levy, Orange, and Seminole counties. The study area contains parts of three physiographic divisions of Florida known as the Coastal Lowlands, Central Highlands, and Northern Highlands divisions. The Coastal Lowlands landform is characterized by nearly level plains or terraces formed during Pleistocene time by invasions of the sea. The Central Highlands landform is characterized by alternating uplands and lowlands, which form high hills and swampy plains, and thousands of sinkholes and sinkhole lakes. The Northern Highlands landform, which also is characterized by uplands and lowlands, is separated from the Central Highlands by the Cody Scarp, a persistent topographic break in the northern part of the study area. The climate in north-central Florida is subtropical and characterized by warm, humid summers and mild, dry winters. The mean annual rainfall at Ocala, which is centrally located from north to south in the study area, is approximately 52 inches, and more than fifty percent of the annual rainfall occurs during the four-month rainy season from June to September.

The groundwater system in north-central Florida generally consists of a surficial aquifer system that overlies a low permeability confining unit, which in turn overlies the Floridan aquifer system, a regionally extensive aquifer system. The surficial aquifer system, which consists of Pliocene, Pleistocene, and Holocene deposits, is under water-table conditions. The confining unit between the surficial aquifer and Floridan aquifer systems, which is called the intermediate confining unit, is comprised of rocks of the Miocene age Hawthorn Group and, locally, deposits of Pliocene age. The Floridan aquifer system in north-central Florida consists of the Oligocene Suwannee Limestone (where it is present), the late Eocene Ocala Limestone, the middle Eocene Avon Park Formation, the early Eocene Oldsmar Formation, and the Paleocene Cedar Keys Formation. In most of the study area, the Floridan aquifer system is comprised of two zones called the upper and lower Floridan aquifers that are separated by a relatively low permeability unit called the middle semiconfining unit. The upper Floridan aquifer is a zone of high permeability in the Ocala Limestone and the upper third of the Avon Park Formation, and the lower Floridan aquifer occurs within the lower half of the Avon Park Formation, the Oldsmar Formation, and the upper third of the Cedar Keys Formation. The base of the Floridan aquifer system occurs at the top of low permeability anhydrite beds within the Cedar Keys Formation, which are considered to be the lower, or sub-Floridan, confining unit of the Floridan aquifer system.

The Floridan aquifer system occurs under both confined and unconfined conditions in the study area. In the eastern part of the study area, the upper Floridan aquifer is overlain and confined by the intermediate confining unit. In some areas in the western part of the study area, the water table occurs in surficial deposits that directly overlie the upper Floridan aquifer or in the upper Floridan aquifer itself, and the upper Floridan aquifer generally is unconfined. Hydraulic heads in the upper Floridan aquifer are greatest in the northern part of the study area in Alachua, Bradford, Clay, and Putnam counties and in the south in Lake and Sumter counties, and heads are lowest along the St. Johns River and to the east. In the study area, recharge to the upper Floridan aquifer occurs directly via rainfall where the aquifer is at or near the surface and by downward leakage from the surficial aquifer system through the intermediate confining unit, particularly in areas where the confining unit is breached by sand-filled sinkholes. Discharge occurs by means of spring flow from the upper Floridan aquifer, direct discharge to streams and lakes, and diffuse upward leakage in areas where the upper Floridan aquifer is confined.

Groundwater use was compiled for the study area, which falls within three water management districts, i.e., SJRWMD, Southwest Florida Water Management District (SWFWMD), and Suwannee River Water Management District (SRWMD). The year 1995 was selected as a base year to represent present groundwater use conditions, and projections were made for the years 2020 and 2025 to represent future use. Groundwater pumpage was estimated for seven water-use categories, i.e., public supply, domestic self-supplied, commercial-industrial self-supplied, agricultural self-supplied, recreational irrigation (i.e., golf courses), free-flowing wells, and artificial recharge from drainage and injection wells. Based on U.S. Geological Survey (USGS) files and data and SJRWMD and SWFWMD water-use surveys, the total net pumpage (i.e., discharge minus recharge) in the study area for 1995 was estimated to be 255.8 million gallons per day (mgd). Based on water-supply assessment plans of the water management districts, water-use data for 1995, and USGS estimates, the total net pumpage for 2020 was projected to be 401.2 mgd. In addition, revised pumping data for part of the study area obtained from SJRWMD were combined with the USGS pumping data to obtain a modified database for 1995 pumpage. In the modified database for 1995, the total net pumpage was estimated to be 230.5 mgd. Pumpage in the modified database for 1995 was used to estimate a projected net pumpage of 330.9 mgd in 2025.

The USGS modular three-dimensional finite-difference code MODFLOW was used to simulate the groundwater flow system in north-central Florida. A groundwater flow model was assembled and calibrated to average 1995 conditions in the surficial aquifer system and upper Floridan aquifer. The hydrogeologic system simulated by the model consists of three layers, or aquifer units, separated by confining units. Layer one represents the surficial aquifer system in the eastern part of the study area. Layer two represents the upper Floridan aquifer, and layer three represents the lower Floridan aquifer. Layer one is inactive in the areas in the western part of the study area where the upper Floridan aquifer is the uppermost hydrogeologic unit. Layer two is unconfined in these areas in the western part of the study area and confined or partially confined elsewhere. Confining units (where present) between layers one and two and layers two and three are represented in the model by vertical conductances between the layers.

The model domain was discretized into 150 columns and 168 rows that are all equally spaced at 2,500 ft. Layer one is an active layer in the area where it represents the uppermost hydrogeologic unit, and it was assigned no-flow, or inactive, cells in the western parts of the model area where the upper Floridan aquifer is the uppermost hydrogeologic unit. All of the cells in layer two are active cells. Layer three was assigned inactive cells in the southwestern and eastern parts of the model in areas where groundwater with a high chloride concentration (> 5,000 mg/L) occupies the full thickness of the lower Floridan aquifer. The simulation for average 1995 conditions was run as a steady-state simulation with one stress period and one time step arbitrarily set to 1.0 day. The value for hydraulic conductivity in layer one was treated as a calibration parameter and adjusted during the calibration process. The vertical conductance for layer one, which represents the leakance of the intermediate confining unit, and the transmissivity for layer two, which represents the upper Floridan aquifer, also were adjusted as calibration parameters. Similarly, the vertical conductance for layer two, which represents the leakance of the middle semiconfining unit, and the transmissivity of the active cells in layer three, which represents the lower Floridan aquifer, also were adjusted as calibration parameters.

Based on groundwater-use data and well location information compiled from SJRWMD, SRWMD, and SWFWMD, the pumpage in the study area was assigned to 11,757 cells in the model, with 11,721 cells in layer two and 36 cells in layer three. For average 1995 conditions (and all of the other simulations as well), essentially all of the net pumpage accounted for is from layer two, which represents the upper Floridan aquifer. Recharge to the water table was computed by considering rainfall, irrigation, septic tank inflow, runoff, and a minimum value of evapotranspiration from the unsaturated zone. The resulting net recharge was applied to layer one, where it is present, and to the unconfined parts of layer two where it is the uppermost hydrologic unit. In addition to accounting for the minimum evapotranspiration that occurs from the unsaturated zone in the net recharge calculations, the evapotranspiration package in MODFLOW was used to simulate the effects of evapotranspiration in removing water from the saturated regime. Forty-six drain cells in layer two were used to represent springs that discharge from the upper Floridan aquifer. Areas where direct discharge occurs between the groundwater system and parts of the surface-water system are represented by 3,105 cells in the MODFLOW river package. General head boundary conditions were assigned to 632 cells around the periphery of layer two and to 418 active cells around the periphery of layer three.

The groundwater flow model was calibrated by comparing simulated head values for layers one and two to corresponding heads that represented average 1995 conditions in 81 target wells and other locations in the surficial aquifer system and 278 target wells in the upper Floridan aquifer in the model domain. For the model simulation that was considered calibrated, the mean of the differences between the simulated and observed heads in layer one is –0.80 ft, and the root mean square error of the head differences is 4.51 ft. In layer two, the mean of the differences between the simulated and observed heads is –0.07 ft, and the root mean square error is 3.27 ft. The calibrated values for hydraulic conductivity in layer one, representing the surficial aquifer system, range from 5 to 125 ft/day, and the calibrated values of vertical conductance in layer one, representing the leakance of the intermediate confining unit, range from 1.0×10^{-6} to 4.0×10^{-3} day^{-1}. The calibrated values of transmissivity in layer two, representing the upper Floridan aquifer, range from 5,000 to 1.0×10^{7} ft^{2}/day, and the calibrated values of vertical conductance in layer two, representing the leakance of the middle semiconfining unit, range from 1.0×10^{-6} to 5.0×10^{-3} day^{-1}. The calibrated values for transmissivity in layer three, representing the lower Floridan aquifer, range from 280,000 to 2.0×10^6 ft^2/day. In the 1995 simulation, spring flows from the upper Floridan aquifer total 1.77×10^8 ft^3/day [2,046 cubic feet per second (cfs)].

The calibrated arrays and boundary conditions for average 1995 conditions and pumpage and recharge projected for 2020 were used to simulate the water table in the surficial aquifer system and the potentiometric surface in the upper Floridan aquifer for average 2020 conditions. In the simulation for average 2020 conditions, the total net pumpage (401.2 mgd) is 57 percent greater than the average 1995 pumpage (255.8 mgd), and spring flows from the upper Floridan aquifer total 1.73×10^8 ft^3 /day (2,002 cfs). Estimated changes in the water table due to the projected changes in pumpage and recharge are negligible (less than 1.0 ft) over a large part of the model domain but approximately 2 to 3 ft in the northwestern part of the model domain in the Gainesville Regional Utilities (GRU) wellfield near Gainesville. Estimated changes in the potentiometric surface of the upper Floridan aquifer are negligible (less than 1.0 ft) over a large part of the model domain. Drawdowns of approximately 2 to 5 ft are simulated in the potentiometric surface in the southern and northeastern parts of the model domain, and drawdowns of approximately 16 ft are simulated in the GRU wellfield.

The calibrated arrays and boundary conditions for average 1995 conditions also were used to simulate the water table in the surficial aquifer system and the potentiometric surface in the upper Floridan aquifer for average 2025 conditions, using the revised 1995 pumpage and pumpage and recharge projected for 2025. In the simulation for average 2025 conditions, the total net pumpage (330.9 mgd) is 44 percent greater than the revised 1995 pumpage (230.5 mgd), and spring flows from the upper Floridan aquifer total 1.74×10^8 ft^3 /day (2,019 cfs). Estimated changes in the water table due to the projected changes in pumpage and recharge are negligible (less than 1.0 ft) over a large part of the model domain. Drawdowns in the water table of approximately 2 to 3 ft are simulated in the southeastern part of the model domain in Seminole County, and drawdowns of approximately 1 to 2 ft are simulated in the GRU wellfield. Estimated drawdowns in the potentiometric surface of the upper Floridan aquifer are negligible (less than 1.0 ft) over a large part of the model area. Drawdowns of approximately 10 to 15 ft are simulated in the potentiometric surface in the southeastern part of the model domain, and drawdowns of approximately 15 ft are simulated in the GRU wellfield.

Based on the groundwater model results, the impacts that increased groundwater pumping from the upper Floridan aquifer in north-central Florida from 1995 to 2020 and 2025 will have on water levels in the surficial aquifer system and upper Floridan aquifer, groundwater system water budgets, and spring flows generally will be negligible on a regional basis. Some localized drawdowns in Alachua, Lake and Seminole counties may be significant, however. The north-central Florida active water-table regional groundwater flow model, calibrated for average 1995 conditions, provides a means for water managers to evaluate groundwater pumping options for this region. The calibrated groundwater flow model developed in this study can be used to predict the effects that pumping from the upper Floridan aquifer will have on water levels in the surficial aquifer system and upper Floridan aquifer. Also, the simulated water-table and upper Floridan aquifer drawdowns can be used to estimate the impacts that increased pumping will have on lakes and wetlands in the study area.

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1.0 INTRODUCTION

1.1 BACKGROUND AND OBJECTIVES

The St. Johns River Water Management District (SJRWMD 2000) currently is developing groundwater flow models of the surficial and Floridan aquifer systems to simulate the effects of present and future groundwater pumping in SJRWMD as part of a 20-year district-wide water-supply plan. Models that cover east-central Florida (McGurk and Presley 2002), northeast Florida (Durden 1997), and Volusia County (Williams 2002) will be used to help assess water-supply needs and sources in these areas. In order to complete the areal coverage in the southern part of Marion County and parts of adjacent counties, the north-central Florida regional groundwater flow model (Motz et al. 1995), developed for SJRWMD by the University of Florida, was revised by expanding the study area to include areas not completely covered in other existing or proposed models. The revised groundwater model (Motz and Dogan 2002), calibrated for May 1995 conditions, was used to simulate the increased groundwater pumpage projected for May 2020 and the effects this pumpage will have on groundwater levels in the upper Floridan aquifer. As described in this report, the domain of the revised model was increased by approximately 30 percent, the water table in the model was activated, and the resulting new model was calibrated for average 1995 conditions. This new model was then used to simulate the increased pumpage projected for 2020 and 2025 and the effects this pumpage will have on the water table in the surficial aquifer system and groundwater levels of the upper Floridan aquifer.

1.2 TASKS

The investigation described in this report consists of six tasks:

- Characterizing the hydrogeology in the expanded study area;
- Revising the steady-state calibration;
- Simulating the effects of pumpage projected in 2020;
- Simulating the effects of pumpage projected in 2025;
- Preparing a draft interim report; and
- Preparing the final report.

In the first task, additional data that characterize the hydrology, hydrogeology, and groundwater use in the expanded study area were acquired and compiled. In the second task, the existing groundwater flow model domain of Motz and Dogan (2002) was expanded to accommodate the revised study area, and layer one of the expanded flow model was made an active layer. The resulting new groundwater flow model was developed for the expanded study area, utilizing the U.S. Geological Survey (USGS) code MODFLOW (McDonald and Harbaugh 1988). Using this model, the water table in the surficial aquifer and groundwater levels in the upper Floridan aquifer were simulated for average 1995 conditions. In the third task, this new model was utilized to simulate the effects that increased pumpage projected for 2020 will have on the water table in the surficial aquifer system and groundwater levels in the upper Floridan aquifer, utilizing pumpage developed from USGS groundwater pumpage data for 1993-1994 and projections for 2020 (Sepulveda 2002). In the fourth task, the new model was utilized to simulate the effects that increased pumpage projected in 2025 will have on the water table in the surficial aquifer system and groundwater levels in the upper Floridan aquifer, utilizing revised pumpage data and projections provided by SJRWMD (written communication, 2003). In the fifth task, a draft interim report was submitted for peer review to SJRWMD. The sixth task is represented by this final report, which has been prepared and submitted based on review comments and suggested revisions resulting from SJRWMD's review of the draft interim report.

2.0 REGIONAL SETTING

2.1 LOCATION

The study area covers approximately 5,650 square miles (mi^2) in north-central Florida, extending from 28° 45′ N to 29° 54′ N latitude and from 81° 19′ W to 82° 30′ W longitude (see Figure 1). Rainbow Springs and Silver Springs are the dominant hydrologic features in the western part of the study area, and the St. Johns River and numerous springs along the river are the dominant hydrologic features in the eastern part of the study area. Fourteen counties are included in the study area, i.e., parts of Alachua, Bradford, Citrus, Clay, Flagler, Lake, Marion, Putnam, Sumter, St. Johns, and Volusia counties and small parts of Levy, Orange, and Seminole counties.

2.2 PREVIOUS INVESTIGATIONS

2.2.1 Regional and State-wide Investigations

A number of statewide and regional reports have included descriptions of the physiography, geology, hydrogeology, and hydrology of north-central Florida. MacNeil (1950) described Pleistocene shorelines in Florida and Georgia, including those that occur in north-central Florida. Puri and Vernon (1964) summarized the geology of Florida, and White (1970) described the geomorphology of the Florida peninsula. Stringfield (1966) described artesian conditions in the Tertiary limestone in the southeastern U.S., which included the Floridan aquifer system in Florida. Scott (1983 and 1988) studied and mapped the Hawthorn Group in north-eastern Florida. Rosenau et al. (1977) published a comprehensive report describing the springs of Florida, and Fernald and Patton (1984 and 1998) edited comprehensive summaries of the water resources of Florida. As part of the USGS regional aquifer system analysis (RASA) program, Johnston and Bush (1988) summarized aspects of the Floridan aquifer system in Florida and parts of Georgia, South Carolina, and Alabama, including the hydrogeologic framework, hydraulic properties of aquifers, regional groundwater flow, effects of groundwater development, and geochemistry. Miller (1986) described in detail the hydrogeologic framework of the regional aquifers and confining units that comprise the Floridan aquifer system.

2.2.2 Investigations in North-Central Florida

Clark et al. (1964) investigated the water-resources of Alachua, Bradford, Clay, and Union counties, parts of which are in the northern part of the study area. Hunn and Slack (1983) investigated the water resources of the Santa Fe River basin, including parts of Alachua and Bradford counties. Yobbi and Chappell (1979) described the hydrology of the Upper Etonia Creek basin, a 165 mi^2 area mostly in Clay and Putnam counties noted for numerous lakes and karst features. Bermes et al. (1963) investigated the geology and groundwater resources of Flagler, Putnam, and St. Johns counties. Faulkner (1973) investigated the geohydrology of the proposed Cross-Florida Barge Canal area, including part of Marion County and the southern parts of Alachua and Putnam counties. Phelps (1987) studied the effects of surface runoff and

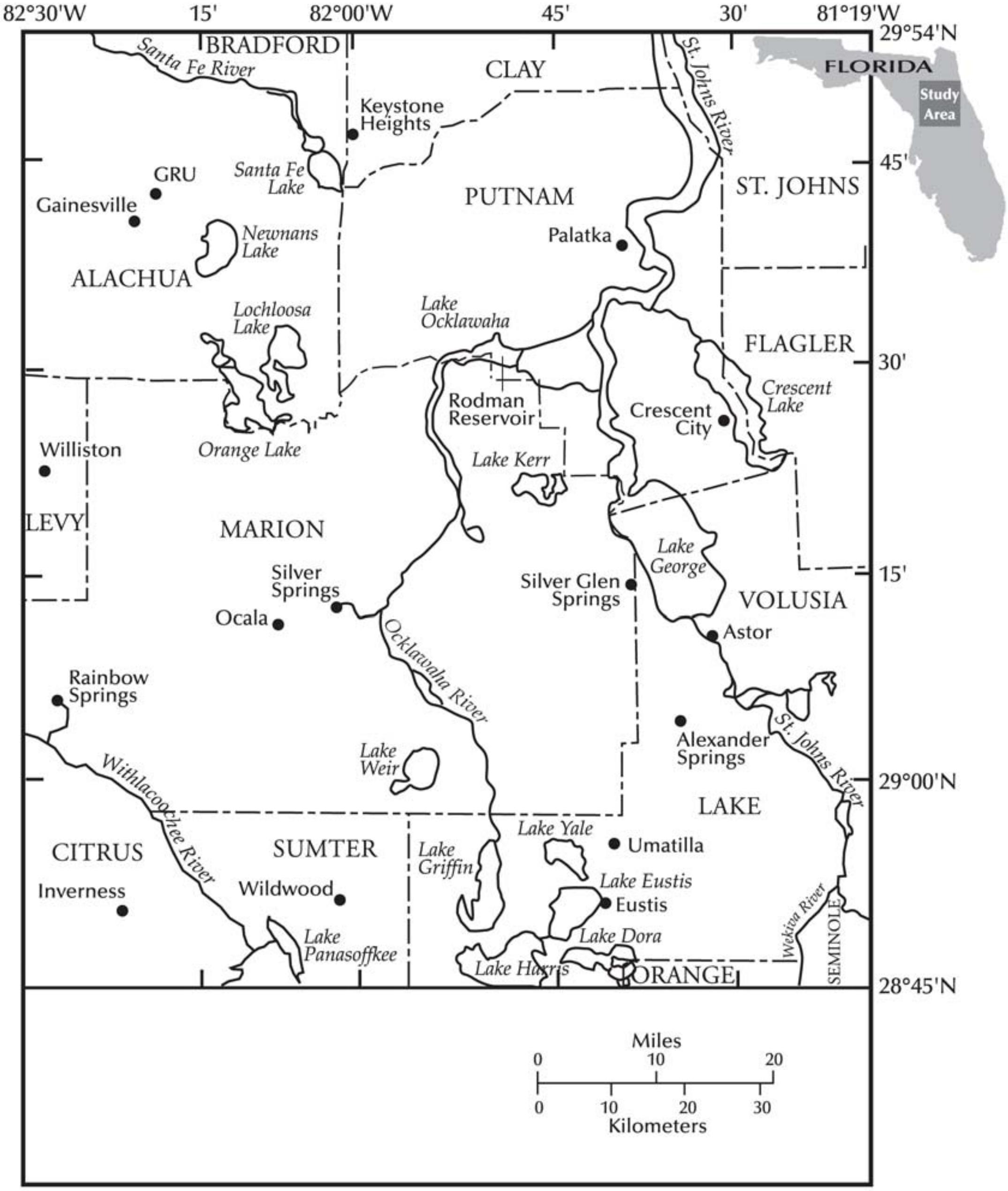

Figure 1. Study area in north-central Florida (Source: Compiled from USGS 1:500,000 scale State of Florida map)

treated wastewater recharge on the quality of water in the Floridan aquifer system in the Gainesville area in Alachua County. Also, Phelps (1994) investigated the hydrology and water quality and the potential for contamination of the upper Floridan aquifer in the Silver Springs groundwater basin in Marion County. Knowles (1996) estimated evapotranspiration from the Rainbow Springs and Silver Springs groundwater basins using a regional water-budget approach. Knochenmus (1971) described groundwater features in Lake County, and Campbell (1989) described groundwater conditions in Sumter County.

2.2.3 Groundwater Models

As part of the RASA program, a regional groundwater flow model and three sub-regional groundwater flow models of the Floridan aquifer system were developed by the USGS (see Figures 2 and 3). Bush and Johnston (1988) simulated the regional groundwater hydraulics of the Floridan aquifer system in Florida and parts of Georgia, South Carolina, and Alabama. In related investigations, Ryder (1985) simulated the Floridan aquifer system in west-central Florida, and Krause and Randolph (1989) simulated the Floridan aquifer system in southeastern Georgia, including adjacent parts of South Carolina and northeast Florida. Also, Tibbals (1990) simulated the Floridan aquifer system in east-central Florida.

Groundwater flow models of the Floridan aquifer system in and adjacent to the north-central Florida study area also have been developed (see Figure 4). Recent studies include the investigations by Motz et al. (1995) and Motz and Dogan (2002), which simulate water levels in the upper Floridan aquifer in the north-central Florida area. The latter of these models is the basis for the revised model described in this report. The northeast Florida groundwater model (Durden 1997) includes northeast Florida and parts of southern Georgia. The east-central Florida groundwater model (McGurk and Presley 2002) and the Volusia County model (Williams 2002) cover areas to the south and east of the north-central Florida area. In addition to these model studies, many other model investigations in and adjacent to north-central Florida have been conducted. These include, for example, groundwater model studies in the Orange Lake vicinity in Alachua and Marion counties (Motz et al. 1997) and in the greater Orlando area in east-central Florida (Murray and Halford 1996 and 1999).

The U.S. Geological Survey (USGS) "mega model" (Sepulveda 2002) simulates the intermediate and Floridan aquifer systems over about 40,800 mi^2 of peninsular Florida, including parts of northern and central Florida (see Figure 4). This model, which utilizes the results of fourteen existing flow models for initial estimates of the spatial distribution of hydraulic properties, will be used to evaluate the effects that projected 2020 groundwater withdrawals will have on groundwater levels and to support sub-regional groundwater flow modeling in peninsular Florida.

2.3 PHYSIOGRAPHY AND TOPOGRAPHIC FEATURES

2.3.1 Physiographic Regions

The study area contains parts of three physiographic divisions of Florida, e.g., the Coastal Lowlands, Central Highlands, and Northern Highlands divisions (Puri and Vernon 1964,

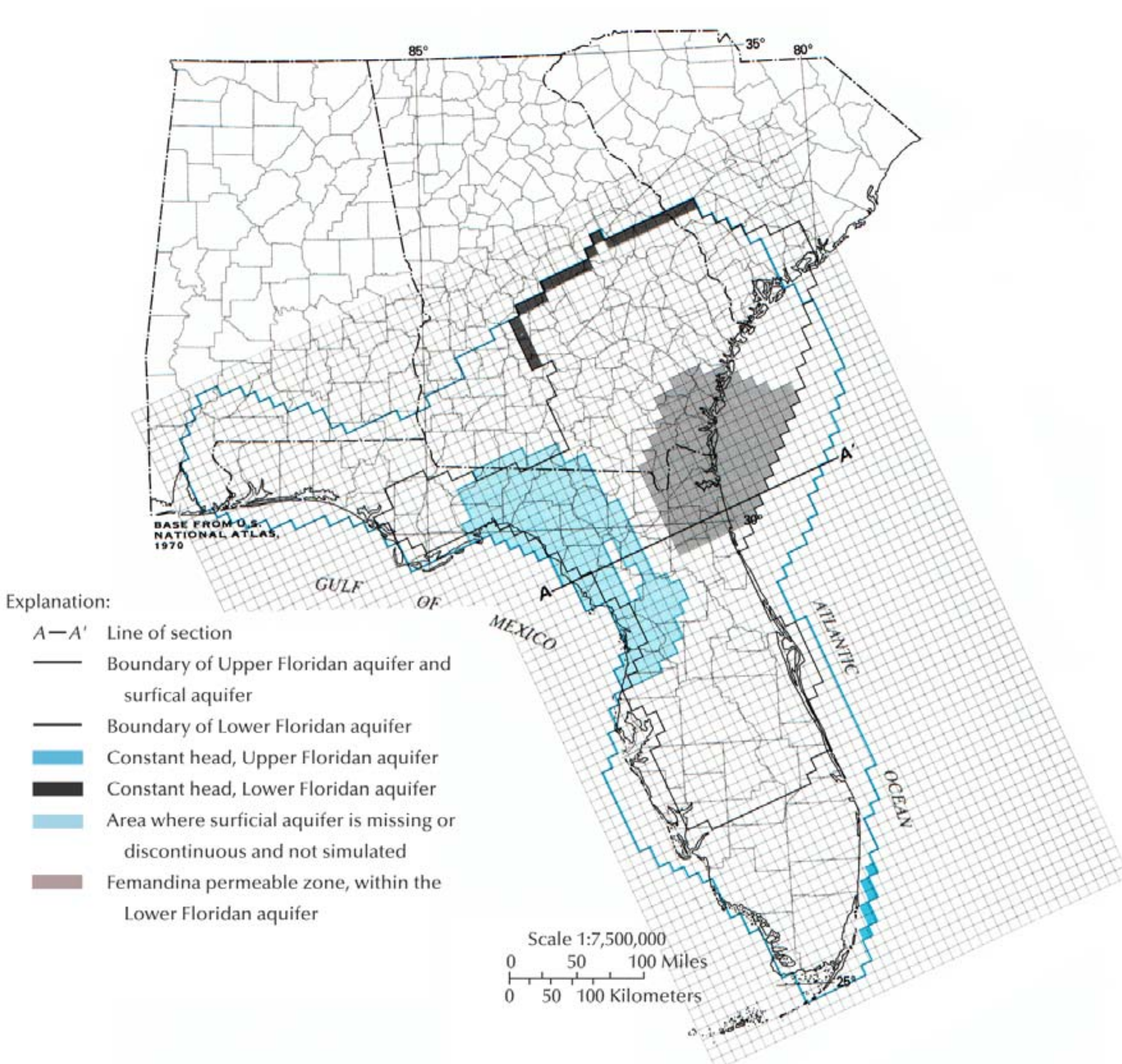

Figure 2. Grid configuration and areal extent of USGS RASA regional groundwater flow model (Source: Bush and Johnston 1988)

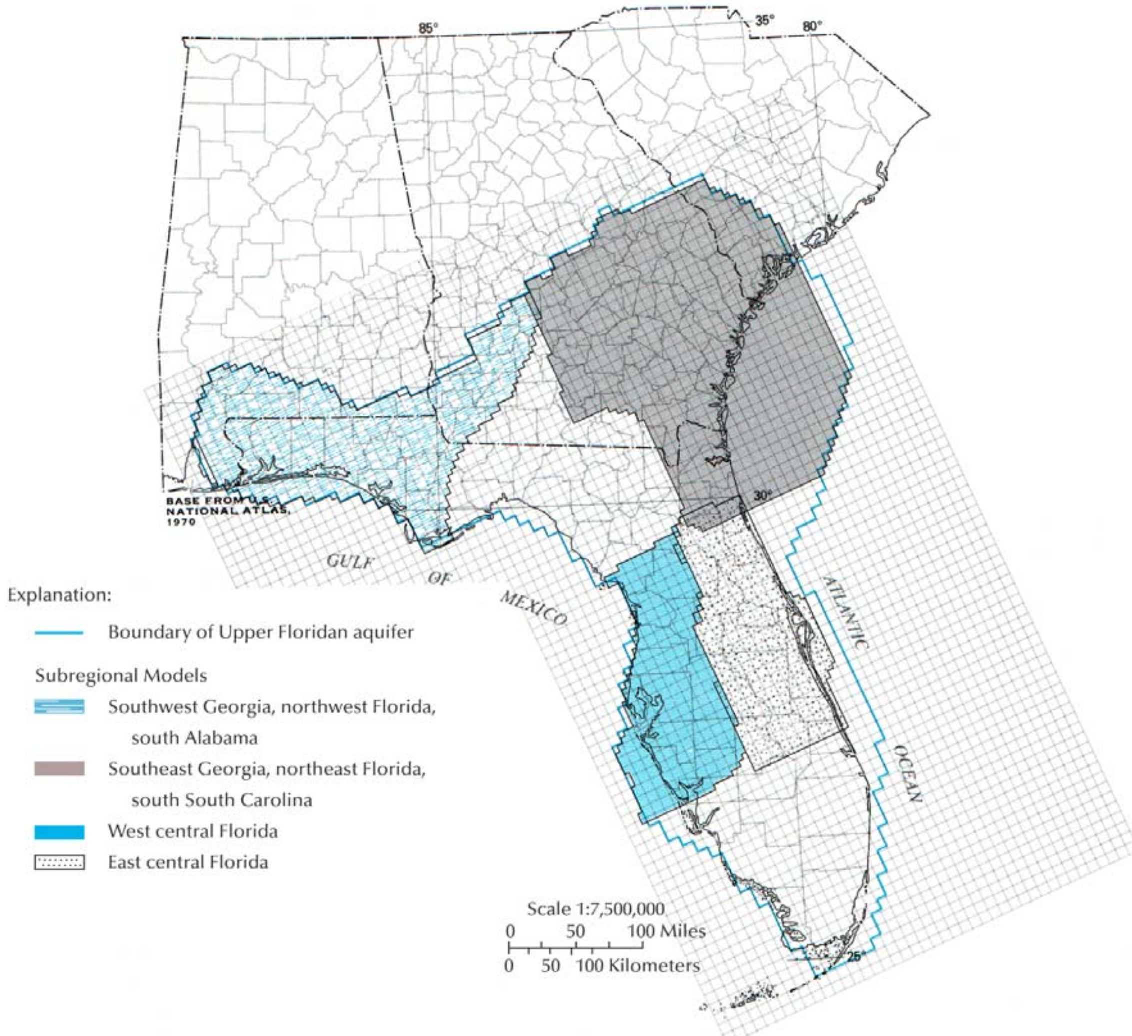

Figure 3. Grid configuration and areal extent of USGS RASA sub-regional groundwater flow models (Source: Bush and Johnston 1988)

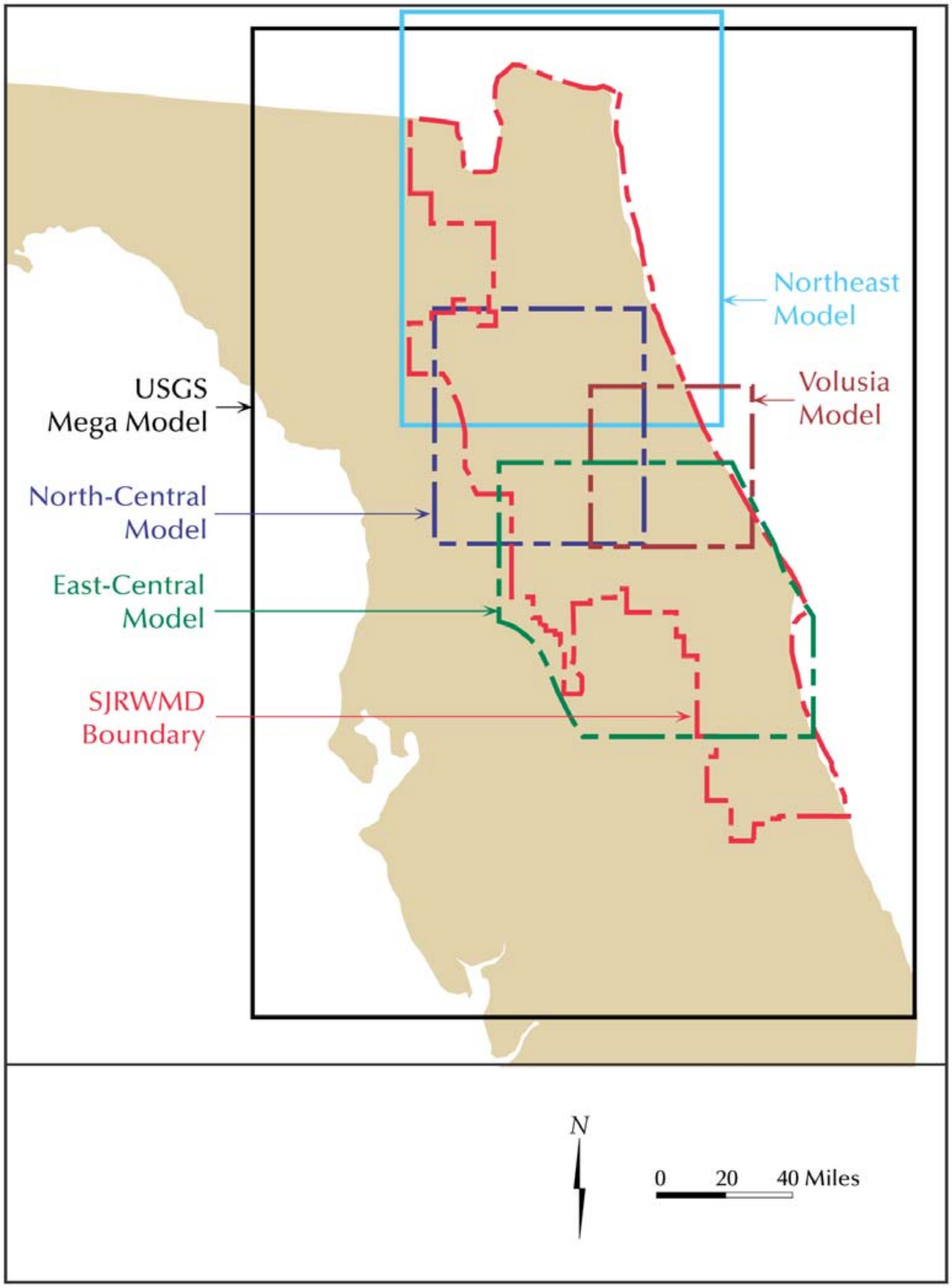

Figure 4. Areal extent of groundwater flow models in and adjacent to the north-central Florida study area (Source: SJRWMD [written communication 2000])

Stringfield 1966, and White 1970) (see Figure 5). The land-surface altitude of the Coastal Lowlands ranges from sea level to about 100 feet, National Geodetic Vertical Datum of 1929 (ft, NGVD, formerly called mean sea level). This part of the study area is characterized by nearly level plains or terraces formed during Pleistocene time by invasions and subsequent regressions of the sea that left shorelines at approximately 100, 70, 42, 25, and 6 feet above the present sea level. The principal topographic features of the Coastal Lowlands are the Atlantic Coastal Ridge, Duval Upland, Palatka Hill, Eastern Valley, the St. Johns River, which flows northward through a river valley, and lakes such as Lake George, which are remnants of a former estuary (White 1970) (see Figure 6). The land-surface altitude of the Central Highlands ranges from less than 40 ft, NGVD, in some valleys to more than 200 ft, NGVD, in the western part of the study area.

The Central Highlands landform is characterized by alternating uplands and lowlands that form high hills and swampy plains, and thousands of sinkholes and sinkhole lakes (see Figure 6). The topographically higher areas include the Crescent City Ridge in the east, the Mount Dora Ridge in the center of the study area, the Fairfield Hills and Sumter Upland in the west, and the Brooksville Ridge in the southwest (White 1970). The topographically lower areas include the Marion Upland between the Crescent City and Mount Dora ridges, the Central Valley between the Mount Dora Ridge and the Fairfield Hills and Sumter Upland, and the Tsala Apopka Plain and Western Valley west of the Fairfield Hills and Sumter Upland. The Northern Highlands landform, including Florahome Valley and Trail Ridge, is separated from the Central Highlands by the Cody Scarp, a persistent topographic break from 150 to 200 ft, NGVD, in the northern part of the study area (Puri and Vernon 1964).

2.3.2 Lakes in the Central and Northern Highlands

Karst solution-formed lakes that occur in the study area include lakes Harris, Griffin, Dora, Eustis, and Yale, which are part of the Ocklawaha chain of lakes (Schiffer 1998) (see Figure 1). Other lakes include Lake Panasoffkee in Sumter County (Taylor 1977), Lake Weir in Marion County, Lochloosa and Newnans lakes in Alachua County, and Santa Fe Lake in Bradford County. Orange Lake in Alachua County is located in a flat-bottomed karst depression called a polje (Davis 1996 and Kindinger et al. 1999). Lake Ocklawaha in Putnam County is a man-made lake that was formed when Rodman Reservoir was built in 1968 on the Ocklawaha River (Schiffer 1998).

2.4 CLIMATE

2.4.1 Temperature and Precipitation

The climate in north-central Florida is subtropical and characterized by warm, humid summers and mild, dry winters (Knowles 1996). In Ocala, which is centrally located from north to south in the study area, the mean annual air temperature is 71.1 ºF (EarthInfo 2001). Rainfall patterns are characterized by a rainy season from June to September and a dry season from October through May. Approximately 53 percent of the annual rainfall occurs during the four-month rainy season, mostly in the form of isolated showers and thunderstorms. During the

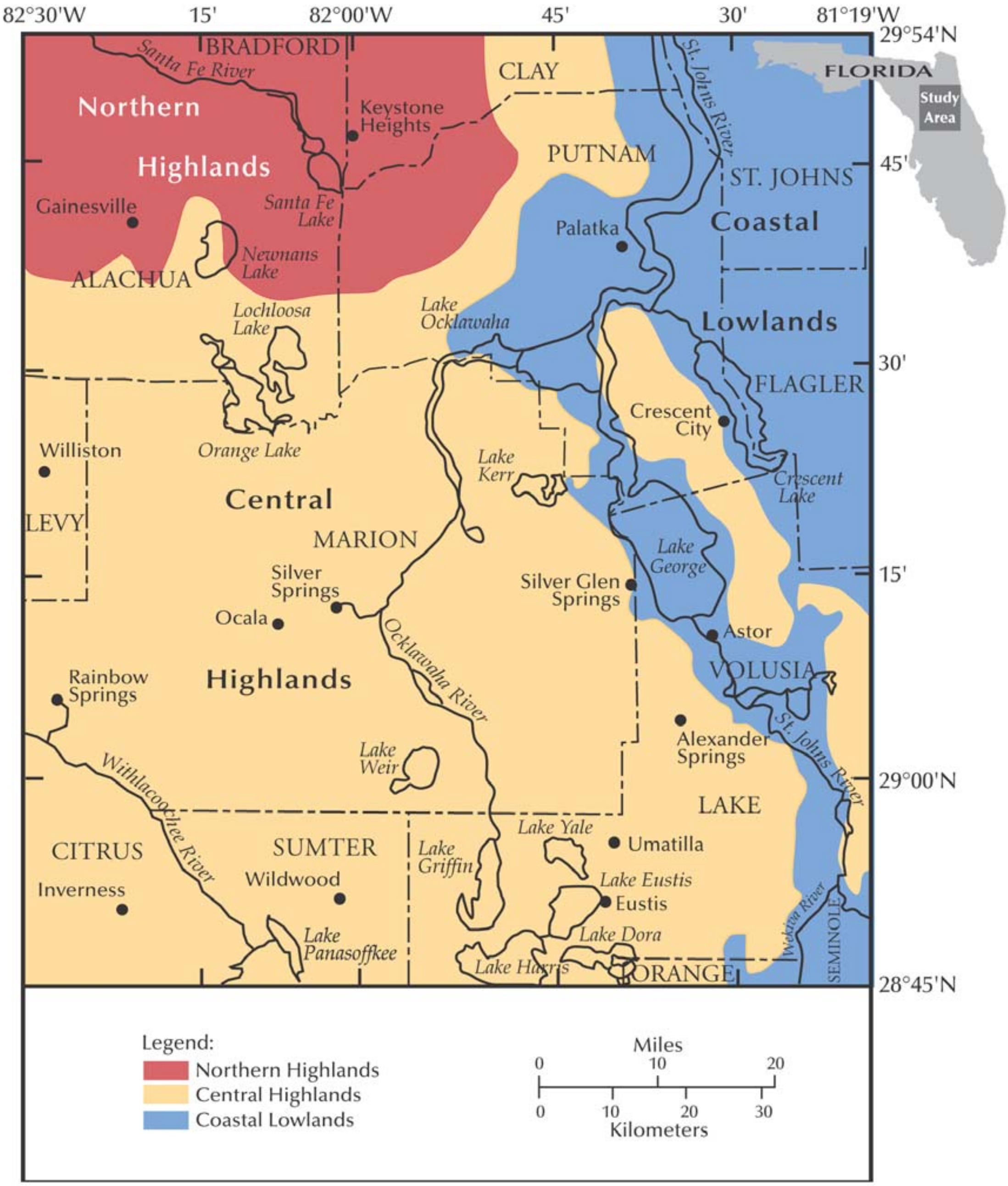

Figure 5. Major physiographic divisions in north-central Florida (Source: Puri and Vernon 1964; White 1970)

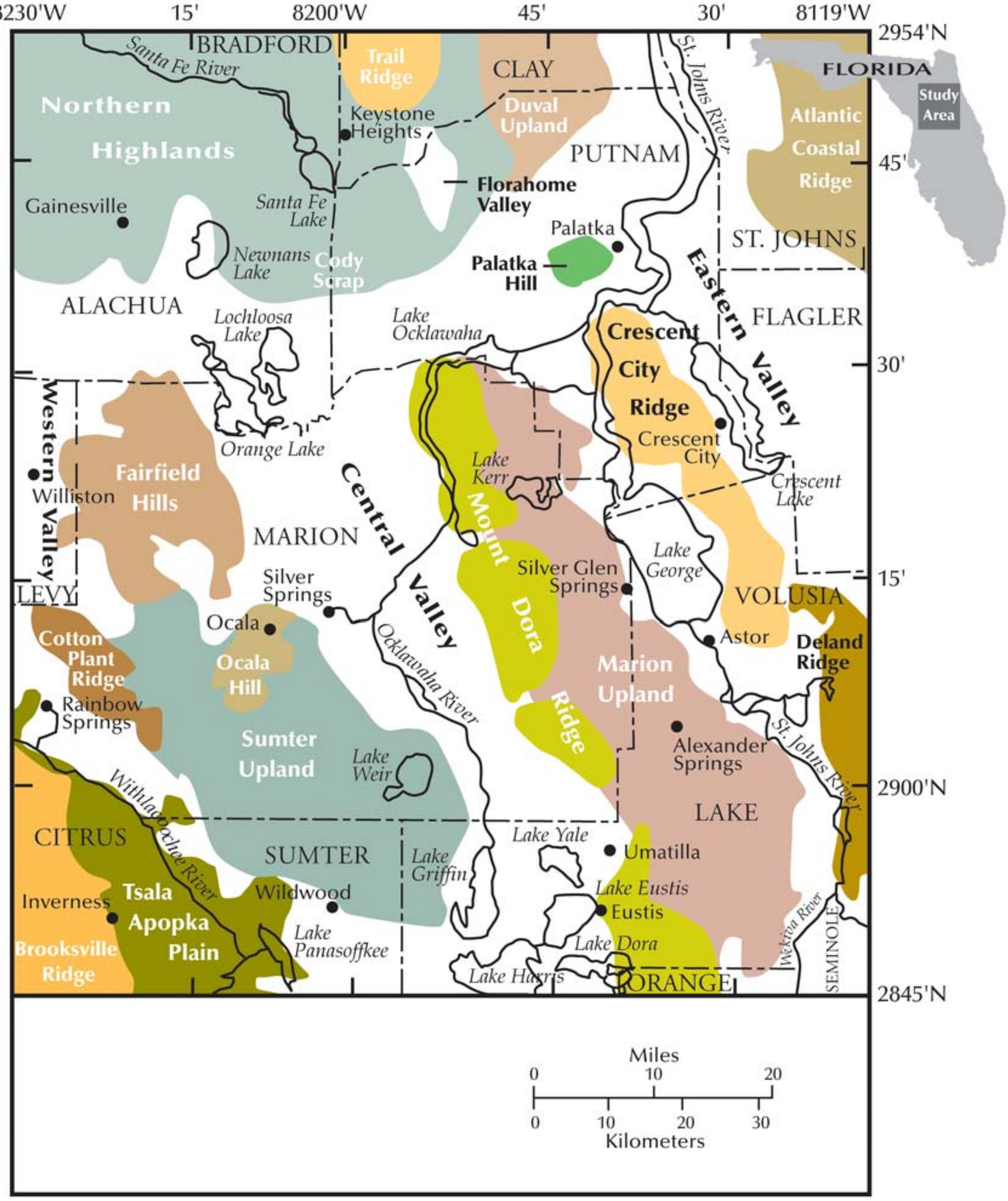

Figure 6. Physiographic subdivisions in north-central Florida (Source: Puri and Vernon 1964; White 1970)

winter and early spring, precipitation is more widespread and usually associated with frontal activity. The mean annual rainfall for Ocala for 1949 – 2000 is 52.22 inches (see Figure 7). At Ocala, the driest year in the 1949 – 2000 period of record is 2000 with 28.58 inches, and the wettest year is 1982 with 74.71 inches of rainfall.

Including the station at Ocala, precipitation data are available for 1995 at eleven stations in and adjacent to the study area in north-central Florida (see Table 1 and Figure 8). The annual rainfall in 1995 at these stations ranged from 44.13 inches at Crescent City to 59.32 inches at Sanford. The spatially averaged rainfall in the study area for 1995 is 52.45 inches, based on the Thiessen polygon method [described by Viessman and Lewis (2003)] to obtain a weighted average of the 1995 rainfall from the eleven stations (see Table 1 and Figure 8).

2.4.2 Evaporation and Evapotranspiration

Pan evaporation data are available in the study area at two stations, i.e., Gainesville and Lisbon (see Table 2 and Figure 1). Based on these two stations, the annual pan evaporation in the study area for 1995 was 54.05 inches. The annual pan coefficient that relates pan evaporation to potential evapotranspiration for north-central Florida is approximately 0.845, based on Irmak et al. (2002), who used pan coefficients to estimate evapotranspiration using data from Gainesville as representative of a humid region. Multiplying the annual pan evaporation by the pan coefficient yields 45.7 inches, which represents an estimate of the annual potential evapotranspiration (PET) for the study area, based on Shuttleworth (1993). In north-central Florida, the actual annual evapotranspiration ranges from approximately 33.5 to 35.4 inches (Fernald and Patton 1984).

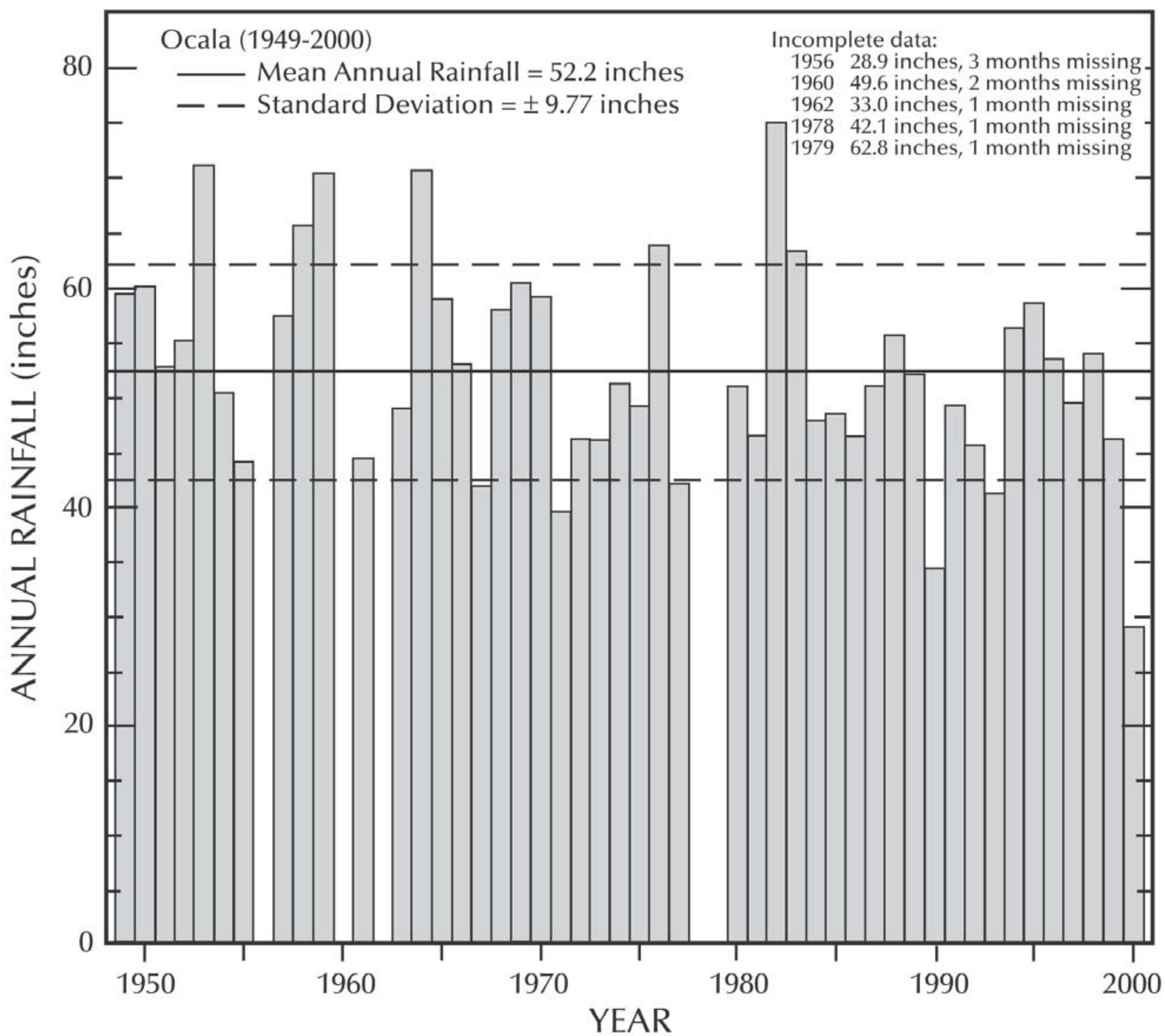

Figure 7. Annual rainfall at Ocala for 1949-2000 (Source: EarthInfo 2001)

Table 1. Rainfall at selected stations in north-central Florida

Station	Latitude Longitude	Annual Rainfall			Period of Record	Percent of Study Area in Thiessen Polygon
		1995 (inches)	Historical Mean (inches)	Standard Deviation (inches)		
High Springs	29 49 43 N 82 35 50 W	53.52	52.54	8.16	1949-2000	1.5
Gainesville Regional Airport	29 41 31 N 82 16 32 W	51.22	49.9	7.91	1961-2000	19.7
Hasting ARC	29 43 19 N 81 29 40 W	55.83	53.3	10.32	1978-2000	12.7
St Augustine WFOY	29 54 30 N 81 18 50 W	52.65	48.17	9.13	1974-2000	1.5
Ocala	29 12 21 N 82 05 15 W	58.07	52.22	9.77	1949-2000	20.2
Crescent City	29 25 42 N 81 30 29 W	44.13	52.01	8.93	1932-2000	14.6
Inverness 3 SE	28 48 11 N 82 18 45 W	51.52	53.54	10.76	1949-2000	8.4
Bushnell 2 E	28 39 43 N 82 04 58 W	55.04	50.35	9.23	1950-2000	1.7
Lisbon	28 52 22 N 81 47 11 W	52.12	48.56	8.93	1959-2000	11.7
Deland 1 SSE	29 01 05 N 81 18 38 W	48.6	54.32	8.71	1931-2000	5.7
Sanford	28 48 09 N 81 16 07 W	59.32	51.02	9.43	1956-2000	2.3

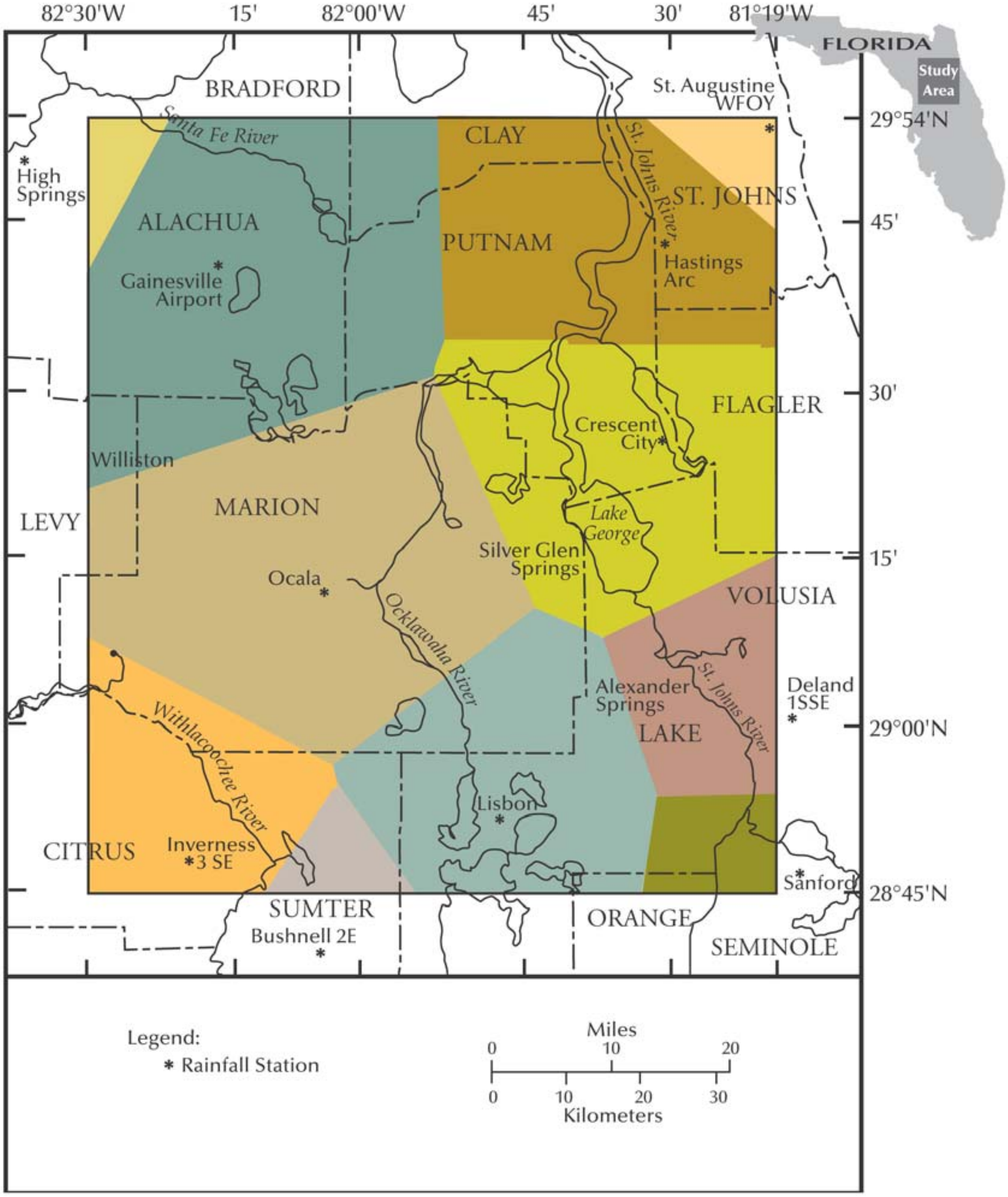

Figure 8. Rainfall stations and corresponding Thiessen polygons in north-central Florida in and adjacent to the study area

Table 2. Pan evaporation at selected stations in north-central Florida

Station	Latitude Longitude	Annual Pan Evaporation					Period of Record
		1995 (inches)	Average (inches)	Standard Deviation (inches)	Maximum (inches)	Minimum (inches)	
Gainesville 11 WNW	29 40 53 N 82 29 39 W	56.77	59.06	5.31	65.90 (1990)	52.38 (1996)	1990-2000
Lisbon	28 52 22 N 81 47 11 W	51.33	56.97	3.21	61.11 (1990)	45.68 (1999)	1960-2000

Source: EarthInfo 2001.

3.0 GEOLOGY

3.1 INTRODUCTION

The geologic units in the north-central Florida area can be divided into pre-Hawthorn Tertiary carbonate formations, the Hawthorn Group, and post-Hawthorn deposits (see Table 3). The pre-Hawthorn formations consist of five units that range in age from Paleocene to Oligocene (Miller 1986). The units from oldest to youngest are the Paleocene Cedar Keys Formation, the early Eocene Oldsmar Formation, the middle Eocene Avon Park Formation, the late Eocene Ocala Limestone, and the Oligocene Suwannee Limestone. The Miocene age Hawthorn Group is a very complex formation, consisting of clay, sand, carbonates, and phosphates in heterogeneous patterns and thicknesses throughout the study area (Scott 1983 and 1988). The post-Hawthorn deposits range in age from Pliocene (or late Miocene) to Holocene. These formations generally consist of sand, clay, sandy clay, shell marl, and peat and mud originally deposited in stream and lake bottoms (Faulkner 1973). The ages of these units range from 55 to 65 million years before present for the Paleocene Cedar Keys Formation to 11,000 years before present for the Pleistocene and Holocene units (Batten 1987) (see Table 4).

Table 3. Geologic units in north-central Florida

Geologic Age	Stratigraphic Unit	Approximate Thickness (feet)	Lithology
Pleistocene and Holocene	post-Hawthorn deposits	10-100	Discontinuous beds of loose sand, clayey sand, sandy clay, marl, and shell
Pliocene	post-Hawthorn deposits	10-110	Clay, clayey sand, sandy clay, shell and limestone
Miocene	Hawthorn Group	0-200	Interbedded clay, quartz, sand, carbonate, phosphate
Oligocene	Suwannee Limestone	0-100	Carbonate and clastic rocks
Late Eocene	Ocala Limestone	100-300	Porous limestone
Middle Eocene	Avon Park Formation	700-1,200	Interbedded limestone and dolomite
Early Eocene	Oldsmar Formation	300-700	Interbedded limestone and dolomite
Paleocene	Cedar Keys Formation	>2,400	Interbedded limestone and anhydrite

Source: Bermes et al. 1963; Clark et al. 1964; Hoenstine and Lane 1991; Leve 1966; Miller 1986; Scott 1983, 1988.

Table 4. Time before present of various geologic ages

Geologic Epoch	Time Before Present (years $\times 10^6$)
Pleistocene and Holocene	0.011 to 1.5
Pliocene	1.5 to 12
Miocene	12 to 20
Oligocene	20 to 35
Eocene	35 to 55
Paleocene	55 to 65

Source: Batten 1987.

3.2 PRE-HAWTHORN TERTIARY CARBONATE FORMATIONS

3.2.1 Paleocene Series

The Cedar Keys Formation contains rocks of Paleocene age, which consist predominantly of interbedded dolomite and anhydrite. Extensive anhydrite beds, which are relatively impermeable, occur at the base of the upper third of this formation (Miller 1986). The top of the Cedar Keys Formation slopes downward from the northwest in the study area. The altitude at the top of the Cedar Keys Formation ranges from approximately –1,200 ft, NGVD, in Alachua County to approximately –1,900 ft, NGVD, in Flagler and Seminole counties. Based on a test well in Marion County that penetrated part of the Cedar Keys Formation, its thickness is at least 2,400 ft (Miller 1986).

3.2.2 Eocene Series

3.2.2.1 Early Eocene Oldsmar Formation.

Rocks of early Eocene age comprise the Oldsmar Formation, a unit that consists of interbedded limestone and dolomite. The lower part of the unit contains gypsum and thin beds of anhydrite, and it is usually more extensively dolomitized than the upper part. The dolomite beds within the unit vary greatly in thickness and contain many cavities. The designation of the Oldsmar Formation as a "Formation" rather than "Limestone" is due to the presence of significant amounts of dolomite, anhydrite, and other rocks along with the limestone (Miller 1986). The altitude at the top of the Oldsmar Formation ranges from approximately –900 ft, NGVD, in the western part of the study area to approximately –1,500 ft, NGVD, in the eastern part of the study area, and its thickness ranges from 300 to 700 ft (Miller 1986).

3.2.2.2 Middle Eocene Avon Park Formation.

The rocks of middle Eocene age beneath the study area formerly were separated into two limestone units that consisted of the "Lake City Limestone" and the Upper "Avon Park Limestone." It is now recognized that the rocks of these units are indistinguishable lithologically and faunally, except locally (Miller 1986). Because of this, the two units of the middle Eocene age are designated as the Avon Park Formation, which is composed of limestone of highly variable hardness interbedded with dolomite. The dolomite beds vary in texture and occasionally contain cavities and fractures. In many places, the Avon Park Formation is composed almost entirely of dolomite instead of limestone. Because of this, the Avon Park Formation is referred to as a "Formation" rather than "Limestone" (Miller 1986).

The Avon Park Formation is approximately 700 ft thick in Alachua County. In a southeasterly direction across the study area, the thickness of the Avon Park Formation increases to about 1,200 ft along the southern and eastern boundaries of the area. The altitude at the top of the Avon Park Formation ranges from approximately -100 ft, NGVD, in parts of Marion, Sumter, and Lake counties to approximately –400 ft, NGVD, in part of Alachua County and nearly –500 ft, NGVD, in the northeastern part of the study area (Miller 1986).

3.2.2.3 Late Eocene Ocala Limestone.

The rocks of the late Eocene age comprise the Ocala Limestone. This formation consists of two parts, an upper unit and lower unit. The lower unit consists of fine-grained limestone that is of variable hardness and contains an abundance of marine fossils. In places, the lower unit contains variable amounts of dolomite. The upper unit is a soft, porous coquina composed of shells and other marine fossils that are loosely bound into a limestone matrix (Miller 1986).

The top of the Ocala Limestone is a highly irregular surface. These irregularities are due primarily to the dissolution of carbonate rocks caused by contact with slightly acidic ground-water. As a result, cavities and even large caverns have been observed within the carbonate units (Schultz and Cleaver 1955). The dissolution of the limestone has greatly enhanced the primary porosity of the unit, making it among the most permeable rock units in the Floridan aquifer system (Miller 1986).

The thickness of the Ocala Limestone ranges from 200 to 300 ft in most of the study area. In southern Marion County, its thickness is approximately 100 ft. The top surface of the Ocala Limestone occurs at an altitude of about +0 ft, NGVD, or higher, in most of Marion County, and its altitude generally decreases from west to east across the study area. In the northeastern part of the study area, the altitude at the top of the Ocala Limestone is approximately -200 ft, NGVD (Miller 1986).

3.2.3 Oligocene Series

The Suwannee Limestone of Oligocene age consists of carbonate and clastic rocks that occur at or near land surface in the southwestern part of the study area in Citrus County and in areas that are northwest of the study area (Miller 1986). Subsurface outliers that are the remnants of Oligocene age rocks removed by erosion occur in the study area in parts of Alachua and Citrus counties.

3.3 HAWTHORN GROUP

The Hawthorn Group of Miocene age consists of highly variable mixtures of clay, quartz sand, carbonate, and phosphate (Scott 1983 and 1988). This unit is very heterogeneous, consisting of many discontinuous lenses of components. In north Florida, the Hawthorn Group can be subdivided into four separate units, or, from oldest to youngest, the Penney Farms Formation, Marks Head Formation, Coosawhatchie Formation, and Statenville Formation. However, contacts and boundaries of the separate units of the Hawthorn Group are difficult to identify due to their highly variable lithology (Scott 1988).

The western limit of the Hawthorn Group occurs in Alachua, Marion, and Sumter counties in the study area (Scott 1988) (see Figure 9). The Hawthorn Group generally is not present as a laterally extensive or continuous formation in southwestern Alachua or Marion counties, in Citrus or Sumter counties, or east of the St. Johns River in part of Volusia County. In the study area, the altitude of the top of the Hawthorn Group ranges from more than 150 ft, NGVD, in Alachua County to approximately –50 ft, NGVD, in the northeastern part of the study area (Scott

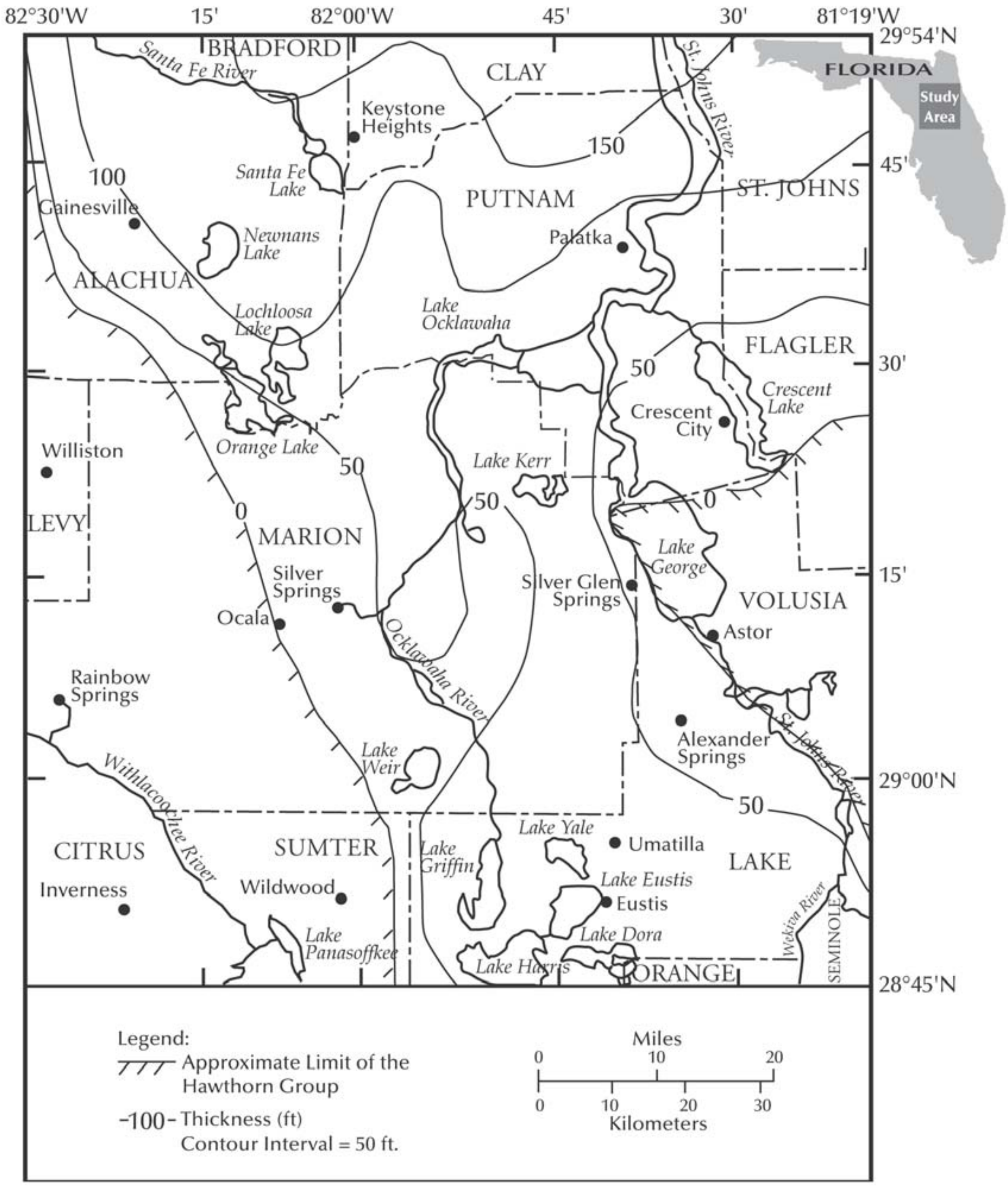

Figure 9. Approximate limits and thickness of the Hawthorn Group in north-central Florida (Source: Scott 1988)

1988). The thickness of the Hawthorn Group generally increases from south to north. Its thickness is approximately 50 ft in Lake and Marion counties and ranges from 100 to nearly 200 ft in Clay County. Where it is present, the Hawthorn Group comprises most of the upper confining unit of the Floridan aquifer system (Miller 1986).

3.4 POST-HAWTHORN DEPOSITS

The post-Hawthorn deposits range in age from Pliocene (or late Miocene) to Pleistocene and Holocene (Bermes et al. 1963, Faulkner 1973, Hoenstine and Lane 1991, Miller 1986, and Scott 1988). The thickness of the post-Hawthorn deposits generally ranges from a few tens of feet of sand and clayey sand in Marion County (Faulkner 1973) to 150 feet or more in Putnam County (Miller 1986). A thesis by Kane (1984) describes the origin of the Grandin Sands in western Putnam County and includes a lithostratigraphic description of the post-Hawthorn deposits.

3.4.1 Pliocene Deposits

The Pliocene deposits are differentiated from the Hawthorn Group by the absence or near absence of phosphate (Leve 1966). These deposits are comprised of interbedded clay and clayey sand, fine to medium grained, well-sorted sand, shell, and soft limestone. The transition between the underlying Hawthorn Group into the overlying Pliocene deposits is evident in gamma-ray logs, because the gamma-ray activity in the Hawthorn Group generally is significantly higher than the activity in the underlying and overlying formations (Scott 1988). The transition usually is marked by an unconformity consisting of coarse sands and phosphates. No distinct lithostratigraphic boundary occurs between the Pliocene and the overlying Pleistocene and Holocene deposits (Leve 1966).

3.4.2 Pleistocene and Holocene Deposits

Pleistocene and Holocene deposits generally occur throughout the study area. These deposits generally contain fine to course grained, loose sand, clayey sand, sandy clay, marl, shell, and clay. Beds within the Pleistocene and Holocene deposits vary in lithology and texture over short distances, both horizontally and vertically (Bermes et al. 1963 and Fairchild 1972).

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4.0 HYDROGEOLOGIC FRAMEWORK

4.1 INTRODUCTION

The hydrogeologic framework in the north-central Florida area generally consists of a surficial aquifer system that overlies a low permeability confining unit, which in turn overlies the Floridan aquifer system, a regionally extensive aquifer system (Miller 1986 and Sepulveda 2002) (see Table 5 and Figures 10 and 11). The water table generally occurs in the uppermost part of the surficial aquifer system; and it also occurs in the uppermost part of the Floridan aquifer system where the top of this system occurs at or near land surface. The confining unit between the surficial and Floridan aquifer systems is the uppermost confining unit for the Floridan aquifer system. This unit, called the intermediate confining unit, consists mostly of clastic rocks of the Hawthorn Group. Locally, low permeability beds of Pliocene age deposits are considered part of the intermediate confining unit. The Floridan aquifer system occurs under both confined and unconfined conditions within the study area. In the areas where it is confined, the Floridan aquifer system is overlain by the intermediate confining unit. In most of the study area, the Floridan aquifer system is comprised of two zones called the upper and lower Floridan aquifers,

Table 5. Hydrogeologic units in north-central Florida

Geologic Age	Geologic Unit	Hydrogeologic Unit		Lithologic Description
Pleistocene and Holocene	Pleistocene and Holocene deposits	Surficial aquifer system		Sand, clayey sand, and shell. Thickness ranges from 0 to more than 150 ft
Pliocene	Pliocene deposits	Intermediate confining unit		Clay, marl, and discontinuous beds of sand, shell, dolomite, and limestone. Thickness generally ranges from 0 to 200 ft
Miocene	Hawthorn Group			
Oligocene and Late Eocene	Suwannee Limestone (where present) and Ocala Limestone	Floridan Aquifer System	Upper Floridan Aquifer	Mainly limestone of high primary and secondary porosity. Thickness ranges from 200 to 1,900 ft
Middle Eocene	Avon Park Formation		Middle Semiconfining Unit	Leaky, low permeability limestone and dolomite. Thickness ranges from 0 to 400 ft
Early Eocene	Oldsmar Formation		Lower Floridan Aquifer	Primarily interbedded limestone and dolomite. Thickness ranges from 1,300 to 1,500 ft. The Fernandina permeable zone, overlain by the lower semi-confining unit, occurs at the base of this unit in a small part of the study area in northeastern Alachua County
Paleocene	Cedar Keys Formation	Sub-Floridan confining unit		Low permeability anhydrite beds

Source: Clark et al. 1964; Hoenstine and Lane 1991; Miller 1986; Ryder 1985; Scott 1988; Sepulveda 2002; South-eastern Geological Society 1986; Tibbals 1990.

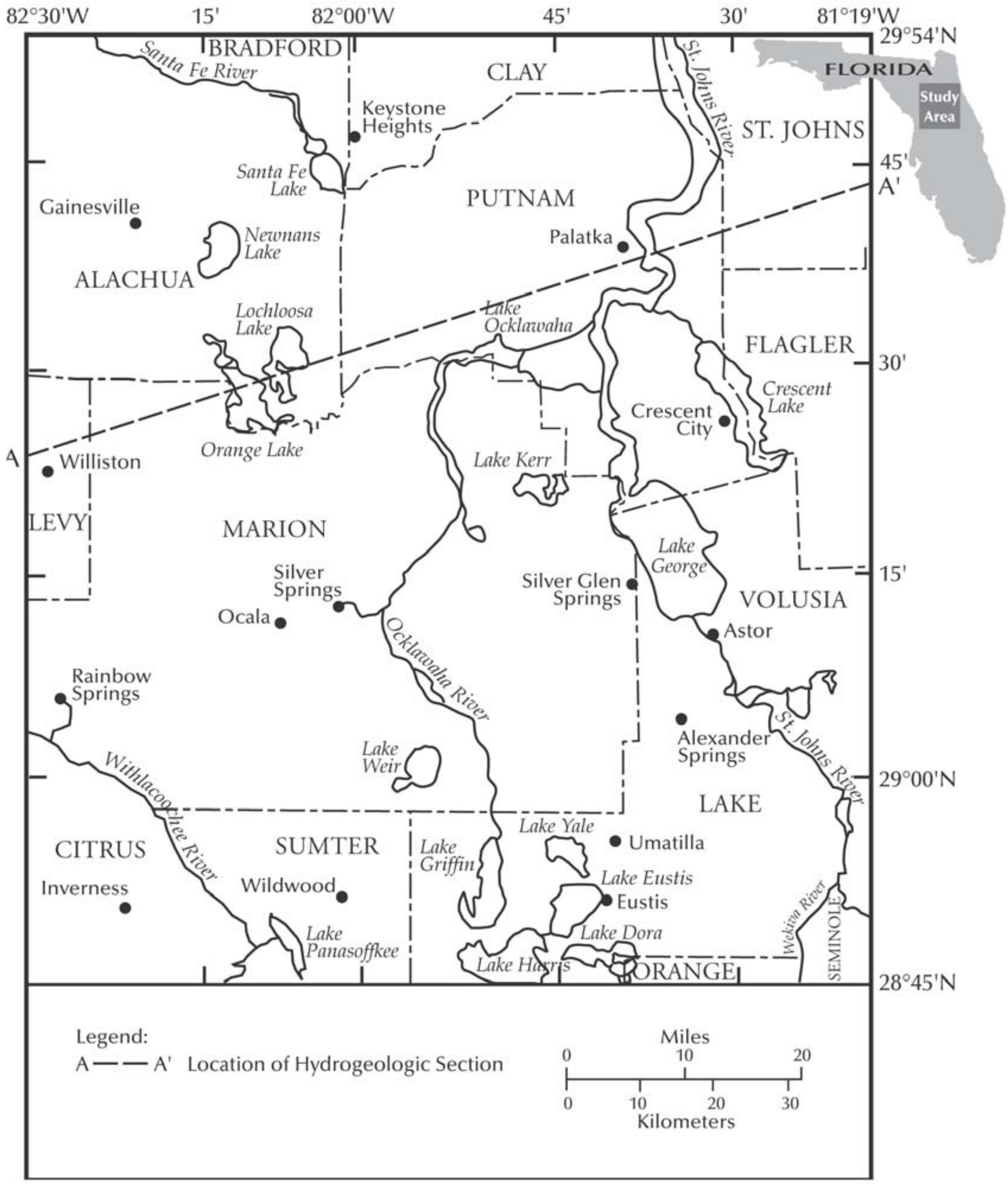

Figure 10. Location of line of hydrogeologic section A-A′ in north-central Florida

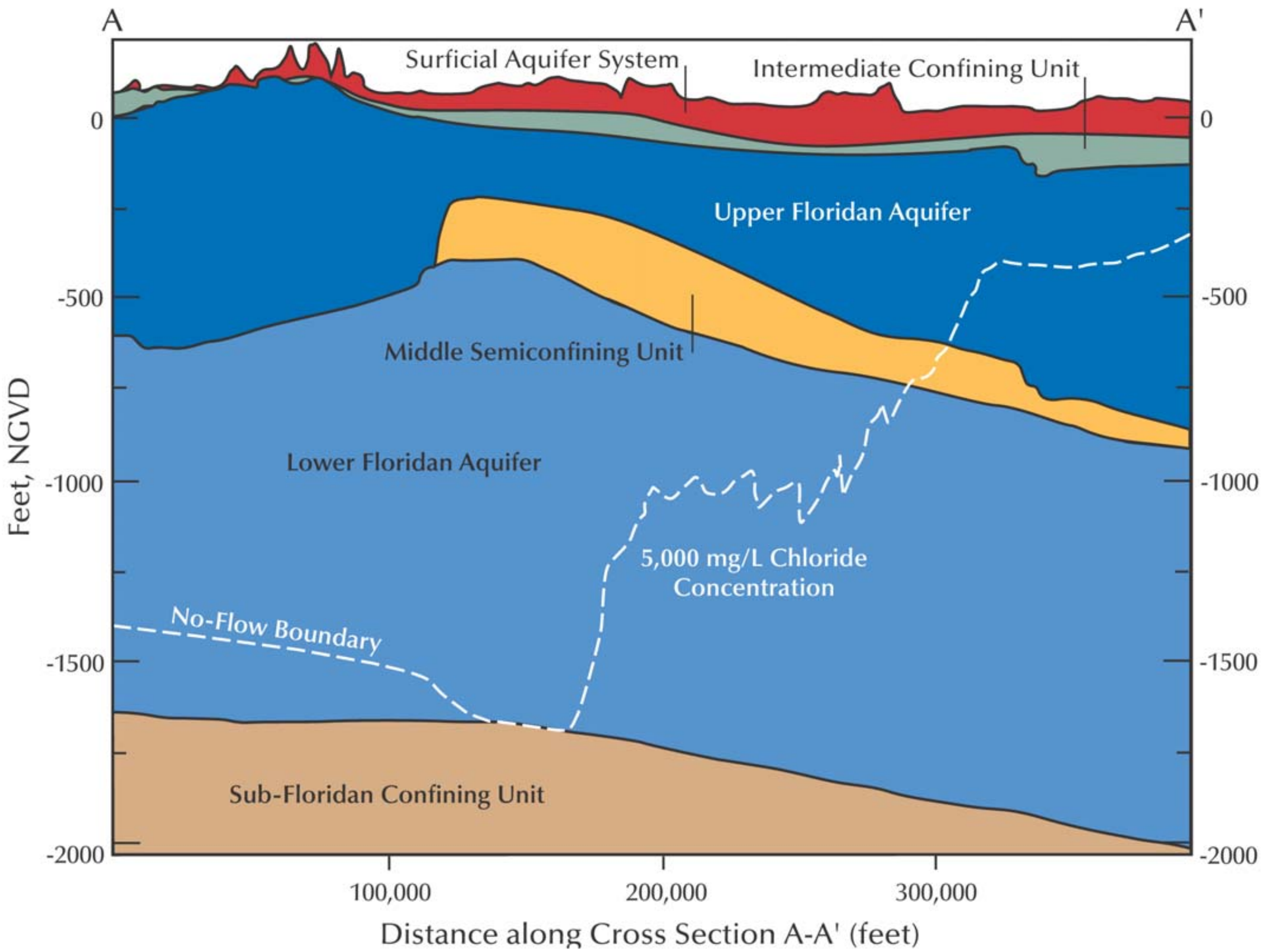

Figure 11. Hydrogeologic section A-A′ in north-central Florida (modified from Miller 1986 and Sepulveda 2002)

which are separated by a relatively low permeability unit called the middle semiconfining unit. The base of the Floridan aquifer system occurs at the top of low permeability anhydrite beds within the Cedar Keys Formation, which generally serves as the lower, or sub-Floridan, confining unit of the Floridan aquifer system.

4.2 SURFICIAL AQUIFER SYSTEM

The surficial aquifer system is contained in the sand, clayey sand, and shell of the Pliocene, Pleistocene, and Holocene deposits (Clark et al. 1964; Kane 1984; and Southeastern Geological Society 1986) (see Table 5). In the northeastern part of the study area, the thickness of the surficial aquifer system ranges from approximately 50 to 150 ft or more (Miller 1986). In parts of Alachua and Marion counties, the surficial deposits are very thin or absent, and the water table occurs in the underlying Hawthorn Group or within the upper Floridan aquifer. In parts of southwestern Alachua County and Marion County, the Hawthorn Group is not present, and the water table occurs in the surficial deposits that directly overlie the upper Floridan aquifer in these areas or in the upper Floridan aquifer (Clark et al. 1964 and Faulkner 1973). The water-table configuration generally conforms to the local topography throughout the study area (Miller 1986).

4.3 INTERMEDIATE CONFINING UNIT

The intermediate confining unit of the Floridan aquifer system consists of deposits of clay, clayey sand, sandy clay, marl, limestone and dolomite of the Hawthorn Group, and, locally, low permeability beds of post-Miocene age. The competence of the confining unit depends largely on its thickness, its local lithology, and whether it is breached due to karst features in the underlying limestone units of the upper Floridan aquifer. Vertical leakage through the confining unit is less in areas that are thick with high clay content compared to areas where the confining unit is thin with low clay content (Miller 1986). The thickness of the intermediate confining unit generally is the same as the thickness of the Hawthorn Group, i.e., 0 to 200 ft (see section 3.3, Hawthorn Group). Locally, low permeability units of post-Miocene age are included in the thickness of the intermediate confining unit. In the northern part of the study area, the intermediate confining unit is generally greater than 100 ft thick and unbreached, and the upper Floridan aquifer is considered to be confined (Bush and Johnston 1988). In the western part of the study area, the confining unit is absent or very thin, and the upper Floridan aquifer is considered to be unconfined. In other parts of the study area, the intermediate confining unit is generally less than 100 ft thick and/or breached, and the aquifer is considered to be semiconfined.

4.4 FLORIDAN AQUIFER SYSTEM

The Floridan aquifer system in north-central Florida consists of the Oligocene Suwannee Limestone (where it is present), the late Eocene Ocala Limestone, the middle Eocene Avon Park Formation, the early Eocene Oldsmar Formation, and the Paleocene Cedar Keys Formation (Miller 1986) (see Table 5). The altitude of the top of the Floridan aquifer system varies from approximately 100 ft, NGVD, in Marion County to nearly –300 ft, NGVD, in Clay County (Miller 1986). In the study area, the thickness of the Floridan aquifer system ranges from approximately 1,500 to 2,300 ft generally from north to south, and its base occurs at –1,500 to –2,200 ft, NGVD. The Floridan aquifer system generally can be divided into an upper zone of high permeability, a middle semiconfining unit of low permeability, and a lower zone of low to high permeability, all of which overlie the sub-Floridan confining unit. The boundaries of these hydrogeologic units do not coincide necessarily with the boundaries of time, stratigraphic units, or rock types, because the differentiation of the units is based on vertical variations in permeability (Miller 1986).

4.4.1 Upper Floridan Aquifer

The upper Floridan aquifer is a zone of high permeability principally contained within the Ocala Limestone and the upper third of the Avon Park Formation. The high permeability is attributed to the combination of high primary and secondary porosity of the limestone that comprises this unit (Miller 1986). The high secondary porosity is the result of the formation of dissolution cavities within the limestone of the upper Floridan aquifer. In the northwestern part of the study area, the middle semiconfining unit is not present, and the upper Floridan aquifer is considered by Miller (1986) to extend to the base of the Floridan aquifer system and to include the permeable rocks of early middle Eocene to late Paleocene ages. Based on this convention, the thickness of the upper Floridan aquifer ranges from approximately 1,500 to 1,900 ft in the northwestern part of the study area and from 200 to 800 ft in the other parts of the study area, where the middle semiconfining unit separates the Floridan aquifer system into upper and lower units.

4.4.2 Middle Semiconfining Unit

The middle semiconfining unit, which is comprised mainly of beds of limestone and dolomite that are of lower permeability than those beds above and below it, occurs in most of the study area (see Figure 12). The middle semiconfining unit extends approximately from the middle to the upper third of the Avon Park Formation, although at some locations it extends upward to the base of the Ocala Limestone (Durden 1990). In the areas where it is present, the thickness of the middle semiconfining unit ranges from approximately 100 ft to nearly 400 ft in the southeastern part of the study area (Miller 1986).

4.4.3 Lower Floridan Aquifer

The lower Floridan aquifer generally is contained within the lower half of the Avon Park Formation and upper third of the Cedar Keys Formation (see Table 5). The permeability of rocks in the lower Floridan aquifer generally is much less than that of rocks in the upper Floridan aquifer (Miller 1986). The thickness of the lower Floridan aquifer ranges from nearly 1,300 ft in St. Johns County to more than 1,500 ft in Marion and Sumter counties. The altitude of the top of the lower Floridan aquifer varies from –400 ft, NGVD, in Marion and Sumter counties to –900 ft, NGVD, in Flagler and St. Johns counties.

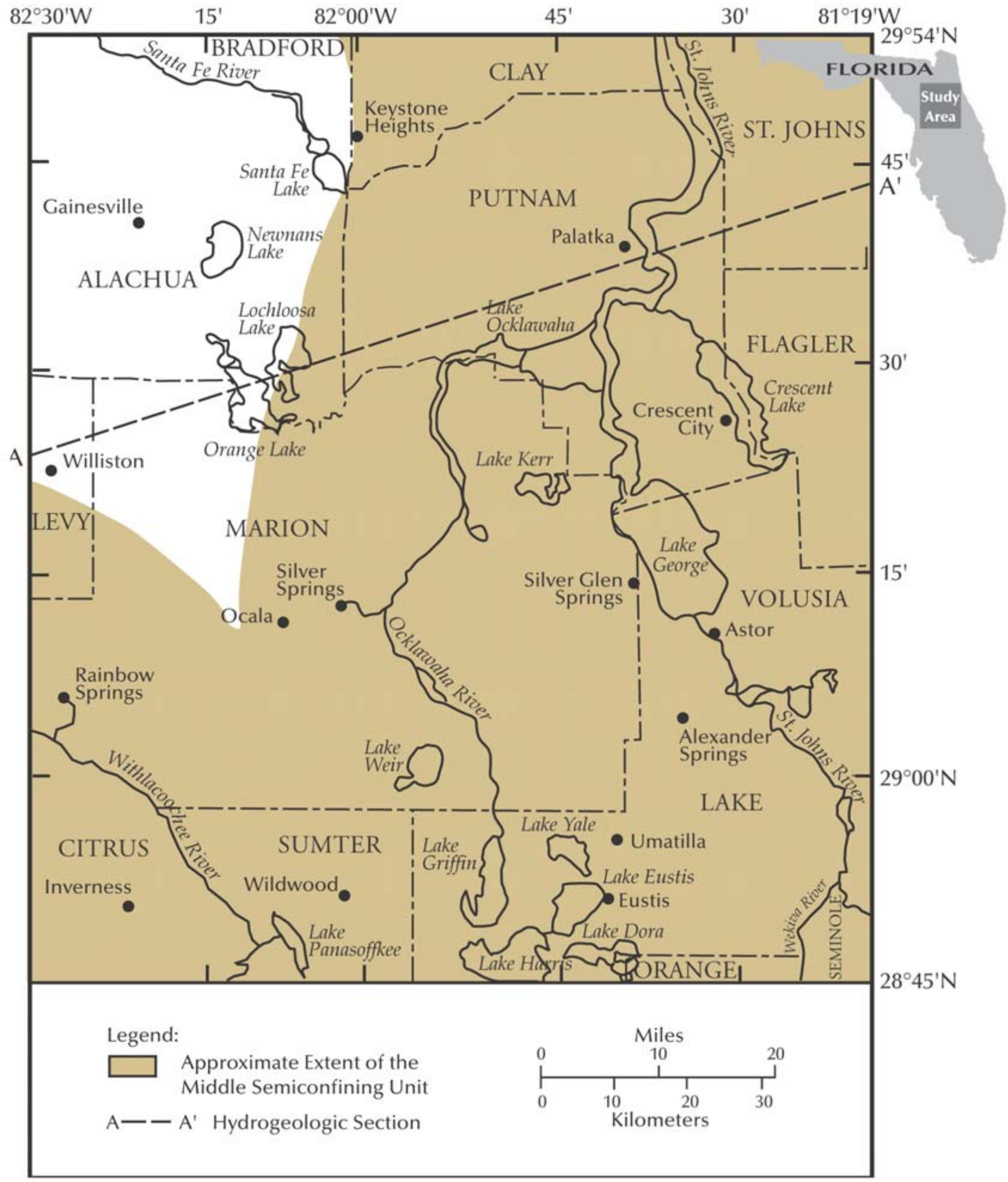

Figure 12. Area in which the middle semiconfining unit occurs in north-central Florida (Source: Miller 1986)

4.4.4 Sub-Floridan Confining Unit

The sub-Floridan confining unit of the Floridan aquifer system is comprised of thick anhydrite beds at the base of the upper third of the Cedar Keys Formation. The hydraulic conductivity of these beds is very low compared to the hydraulic conductivity of the carbonate rocks that are above them (Miller 1986). The top of this unit generally is considered to be the bottom of the Floridan aquifer system.

4.4.5 Chloride Concentrations

Chloride concentrations in the upper Floridan aquifer generally range from 0 to 250 mg/L in most of the study area and to more than 1,000 mg/L along the St. Johns River and toward the east coast of Florida (Sprinkle 1989). These high chloride concentrations may be the result of incomplete flushing of Pleistocene seawater by the modern-day flow system (Stringfield 1966). Similarly, chloride concentrations in the lower Floridan aquifer range from less than 250 mg/L in most of the study area to more than 5,000 mg/L along the St. Johns River. In the valley of the St. Johns River, high chloride concentrations were mapped by Sprinkle (1989) on the assumption that the lower Floridan aquifer also has been incompletely flushed of seawater that invaded the aquifer system during Pleistocene times. The estimated altitude of water containing a chloride concentration of 5,000 mg/L ranges from less than –200 ft, NGVD, beneath the St. Johns River to deeper than –2,000 ft, NGVD, in the southern part of the study area (see Figure 13). Generally, freshwater extends to below the base of the Floridan aquifer system in only part of study area near its center, and saltwater occurs in part of the upper Floridan aquifer along the St. Johns River and toward the east coast and in part or all of the lower Floridan aquifer (see Figure 11).

4.5 RECHARGE AND DISCHARGE

4.5.1 Surficial Aquifer System

Rainfall, runoff, and evapotranspiration are the principal processes that affect groundwater recharge and discharge in the region underlain by the Floridan aquifer system. Overall, in the region that includes Florida, southeast Georgia, and small parts of adjoining Alabama and South Carolina, approximately 53 inches/year of rainfall is balanced by approximately 37 inches/year of evapotranspiration and 16 inches/year of runoff (Bush and Johnston 1988). Recharge to the surficial aquifer system occurs by means of rainfall and diffuse upward leakage from the upper Floridan aquifer in areas where the altitude of the hydraulic head in the upper Floridan aquifer is greater than the altitude of the water table. Other relatively smaller amounts of recharge to the surficial aquifer system include irrigation return flows and infiltration of septic tank discharges. Discharge from the surficial aquifer system occurs by means of evapotranspiration, flow to streams, lakes, and drains, and diffuse downward leakage to the upper Floridan aquifer in areas where the altitude of the water table is greater than the altitude of the hydraulic head in the upper Floridan aquifer. Relatively small amounts of discharge occur via pumping from domestic self-supplied wells and also from wells in local aquifers within the intermediate confining unit in areas where the intermediate aquifer is present.

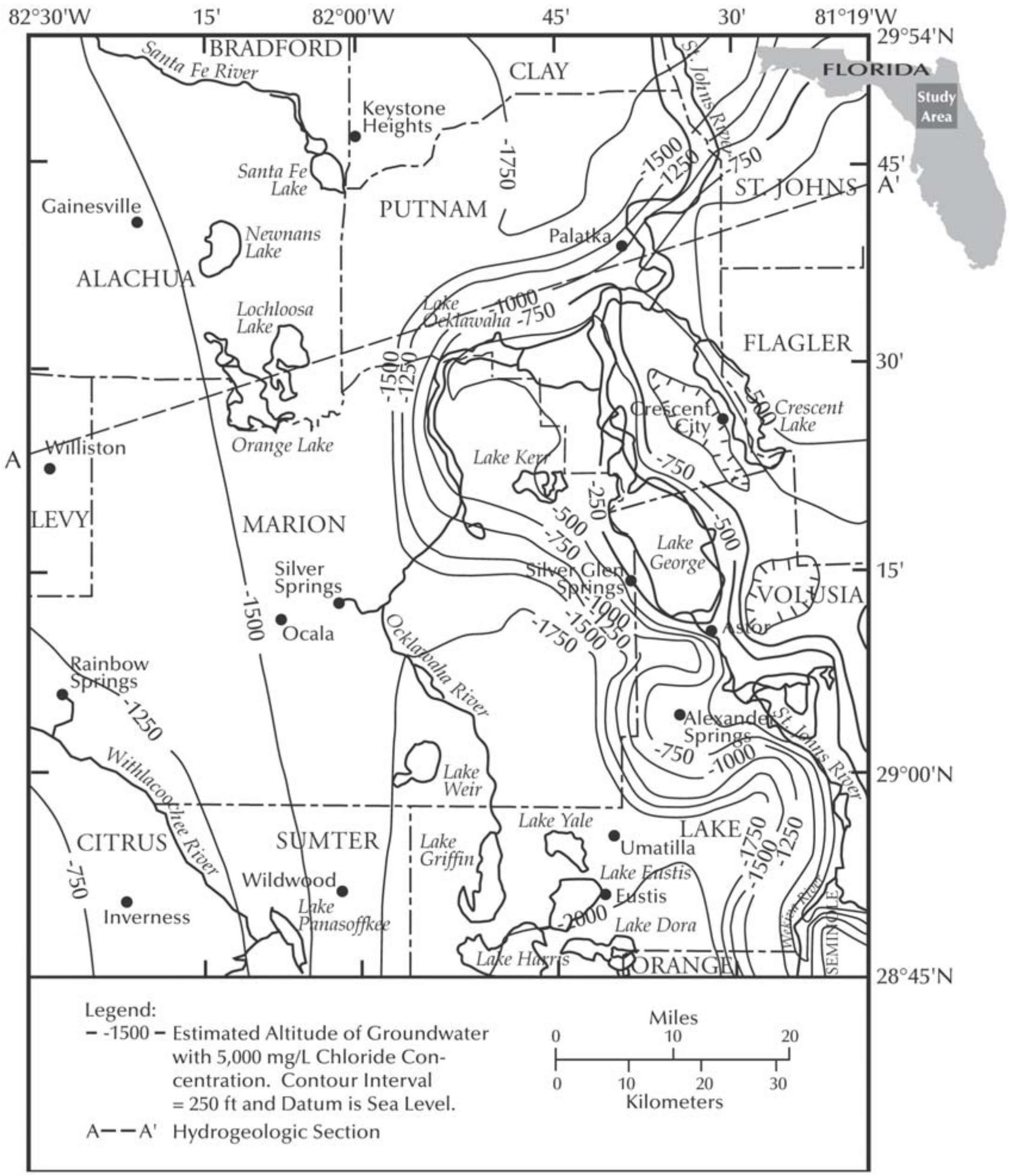

Figure 13. Estimated altitude of water containing a chloride concentration of 5,000 milligrams per liter in the Floridan aquifer system in north-central Florida (Source: Sepulveda 2002)

4.5.2 Floridan Aquifer System

Recharge to the upper Floridan aquifer occurs by means of direct recharge via rainfall and surface runoff in areas where the aquifer is at or near land surface. Recharge also occurs in the areas where the aquifer is overlain by the intermediate confining unit through the confining unit and, in some areas, through sand-filled sinkholes that extend from land surface through the intermediate confining unit to the upper Floridan aquifer (Stringfield 1966). The dominant component of discharge from the upper Floridan aquifer is spring flow (Bush and Johnston 1988). Discharge also occurs by means of direct discharge from the upper Floridan aquifer to streams and lakes and by diffuse upward leakage in areas where the upper Floridan aquifer is confined. Under present, developed conditions, discharge also occurs by means of groundwater pumping in the study area (Marella 1999). Based on water budgets simulated by Bush and Johnston (1988), in areas where the upper Floridan aquifer is directly recharged or where the surficial aquifer system directly overlies the upper Floridan aquifer, approximately 53 inches/year of rainfall is balanced by approximately 36 inches/year of evapotranspiration, 12 inches/year of runoff, and 5 inches/year of net recharge to the upper Floridan aquifer. In areas where discharge occurs from the upper Floridan aquifer, relative to the surficial aquifer, approximately 53 inches/year of rainfall and 16 inches/year of recharge from the upper Floridan aquifer are balanced by approximately 40 inches/year of evapotranspiration and 29 inches/year of runoff.

4.5.3 Groundwater Levels in the Surficial and Floridan Aquifer Systems

Hydraulic heads in the upper Floridan aquifer in the study area were compiled based on water-level data for 278 upper Floridan aquifer monitoring wells (see Figure 14). Continuously recorded groundwater levels for 1995 were available for 88 of these upper Floridan aquifer wells; at each of these wells, the continuous water levels were averaged to obtain the average 1995 heads for these wells. The average 1995 heads at these 88 wells were linearly regressed with the May 1995 and September 1995 heads at these wells to obtain a multiple linear regression equation that relates the average 1995 head to May and September heads for 1995:

$$h_{avg\ 1995} = 0.051 + 0.486\ h_{May\ 1995} + 0.516\ h_{September\ 1995} \tag{4-1}$$

The standard error calculated for Equation 4-1 is 0.31 ft and the correlation coefficient r^2 is 1.00. Equation 4-1 was used to estimate average 1995 heads at the remaining 190 upper Floridan aquifer wells for which only May and September 1995 water levels were available. The average 1995 heads at the 279 wells were then used to construct a potentiometric surface map representing the average 1995 heads in the upper Floridan aquifer in the study area (see Figure 15).

The potentiometric surface map of the average 1995 heads in the upper Floridan aquifer (Figure 15) and the altitude at the top of the upper Floridan aquifer (based on Miller 1986) were used to delineate the areas in which the upper Floridan aquifer could be considered confined and unconfined. In most of the study area, and generally coincident with the presence of the intermediate confining unit that overlies the upper Floridan aquifer, the altitude of the average 1995

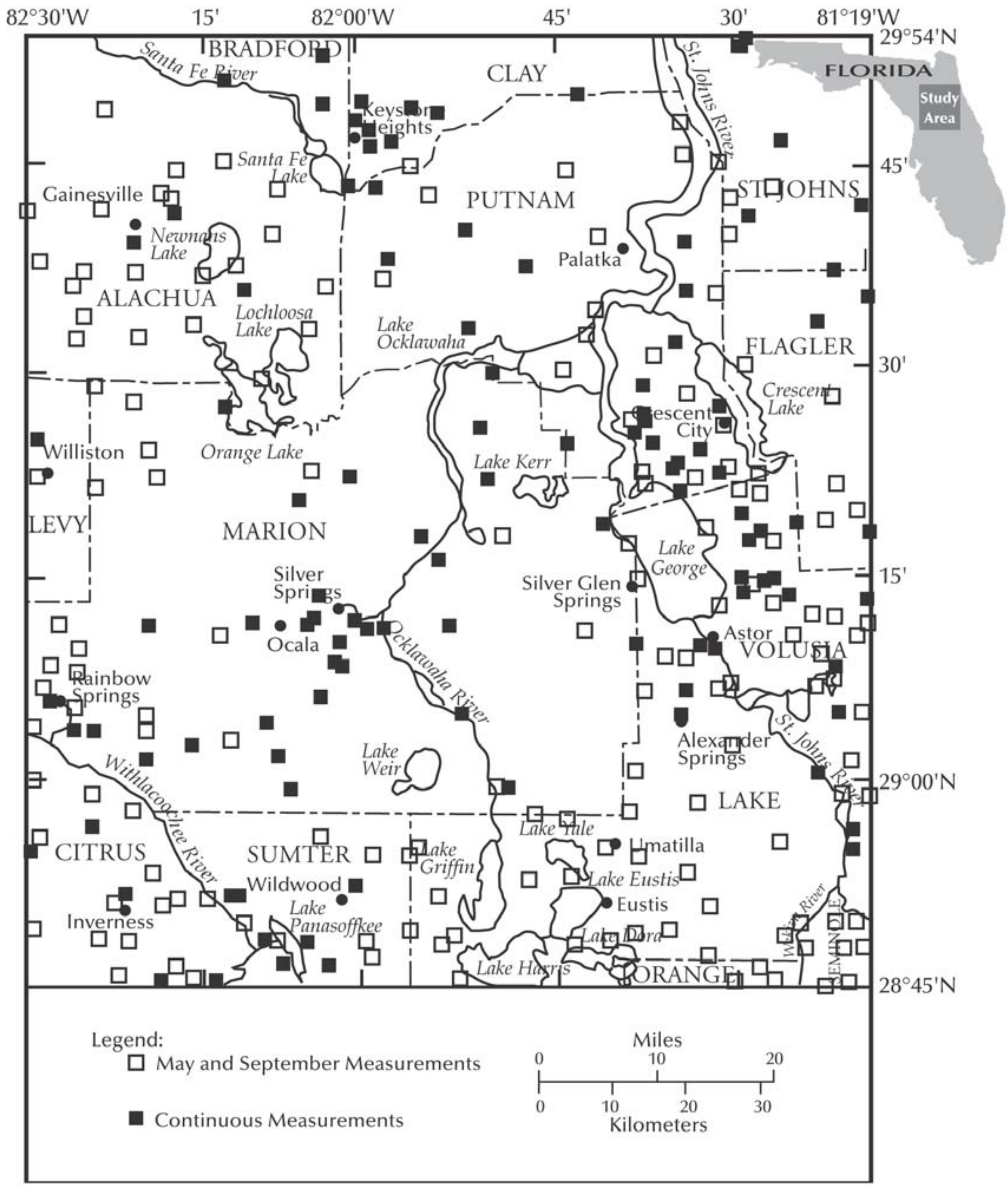

Figure 14. Locations of 278 monitoring wells used to construct the average 1995 potentiometric surface map of the upper Floridan aquifer in north-central Florida

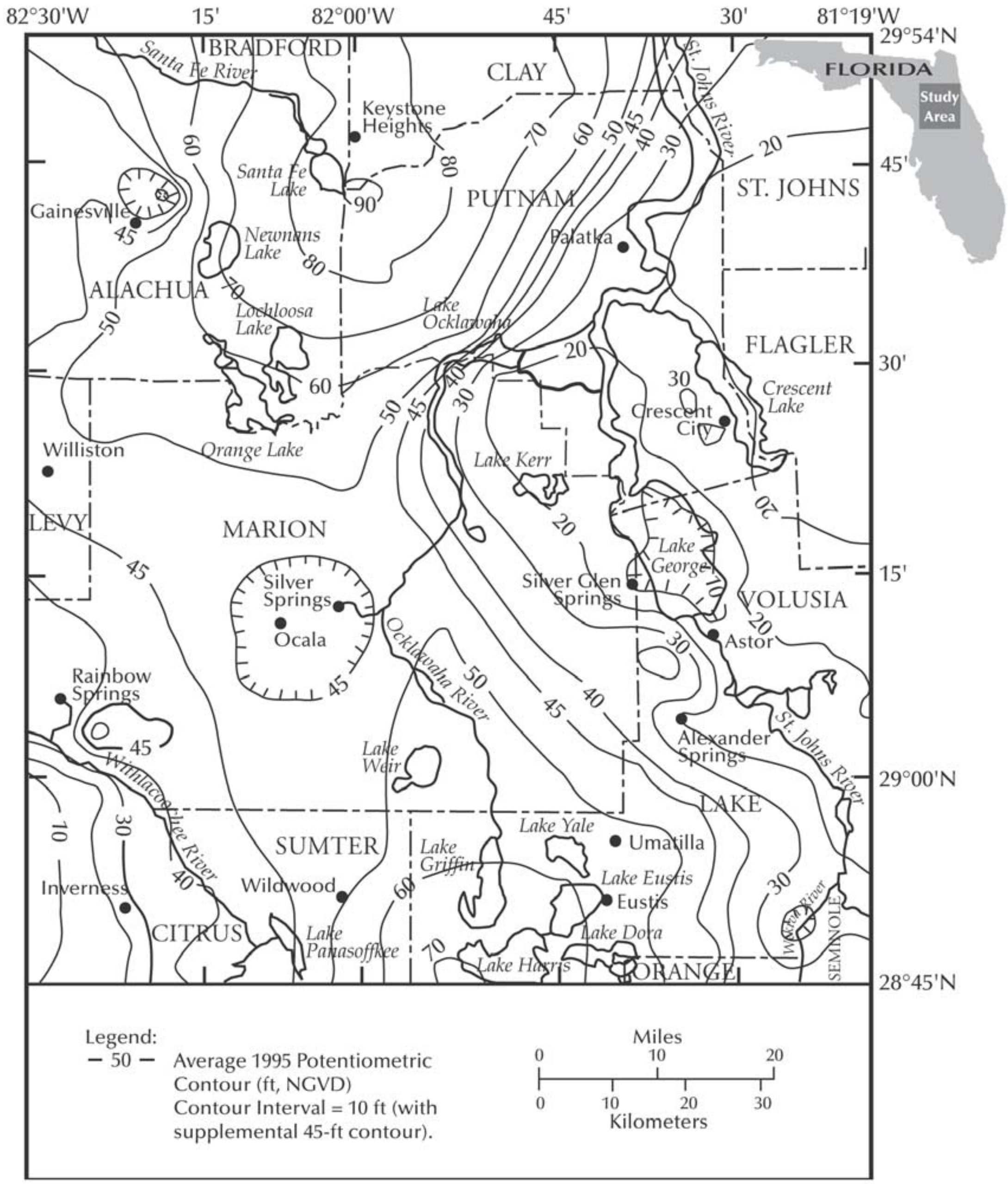

Figure 15. Estimated average 1995 potentiometric surface of the upper Floridan aquifer in north-central Florida

potentiometric surface is greater than the altitude at the top of the upper Floridan aquifer, and the aquifer is confined in these areas (see Figure 16). In some areas in the western part of the study area, the altitude of the average 1995 head in the upper Floridan aquifer is less than the altitude at the top of the upper Floridan aquifer, and in these areas the upper Floridan aquifer is unconfined (see Figure 16).

The altitude of the water table in the surficial aquifer system was compiled based on water-level data for 42 surficial aquifer system monitoring wells in the parts of the study area in which the upper Floridan aquifer is confined and in which a separate water table exists in the surficial aquifer system (see Figure 17). Continuously recorded groundwater levels for 1995, which were available for 32 of these shallow wells, were averaged to obtain the average 1995 heads at these wells. The average 1995 heads at these 32 wells were linearly regressed with the May 1995 and September 1995 heads at these wells to obtain a multiple linear regression equation that relates the average 1995 head to the May and September heads for 1995:

$$h_{avg\ 1995} = 0.050 + 0.470\ h_{May\ 1995} + 0.531\ h_{September\ 1995} \qquad (4\text{-}2)$$

The standard error calculated for Equation 4-2 is 0.35 ft and the correlation coefficient r^2 is 1.00. Equation 4-2 was used to estimate average 1995 heads at the remaining 10 shallow wells for which only May and September 1995 water levels were available. The average 1995 heads at these 42 wells, along with supplemental water-level data for 39 small lakes and wetlands that also represented the water table in the surficial aquifer (Figure 17), were used to construct a water-level map representing the average altitude of the water table in the surficial aquifer system in the study area in 1995 (see Figure 18).

Based on the potentiometric surface of the upper Floridan aquifer (Figure 15), hydraulic heads in the upper Floridan aquifer are greatest in the northern part of the study area in Alachua and Putnam counties and in the south in Lake County. The lowest heads in the upper Floridan aquifer occur along the St. Johns River and to the east. The direction of groundwater flow is downgradient and approximately perpendicular to contours of equal altitude of head on the potentiometric surface. Thus, in the northwestern part of the study area, groundwater flow occurs predominantly toward the Gainesville Regional Utilities (GRU) Murphree Well Field near Gainesville (see Figure 1 for location), south toward Silver Springs, and southeast toward the St. Johns River. In the southern part of the study area, flow occurs to the west toward Rainbow Springs and beyond the study area, northwest toward Silver Springs, and northeast toward the St. Johns River. In the eastern part of the study area, flow is toward the springs and areas of direct discharge along the St. Johns and Ocklawaha rivers. In the northeast part of the study area in St. Johns and Flagler counties, groundwater flow occurs to the east beyond the study area.

4.5.4 Spring Discharge from the Upper Floridan Aquifer

Forty-seven named springs that discharge from the upper Floridan aquifer were located in the study area as part of this investigation (see Figure 19). In 1995, the average discharge from these springs totaled approximately 2,223 cubic feet per second (cfs) (see Table 6).

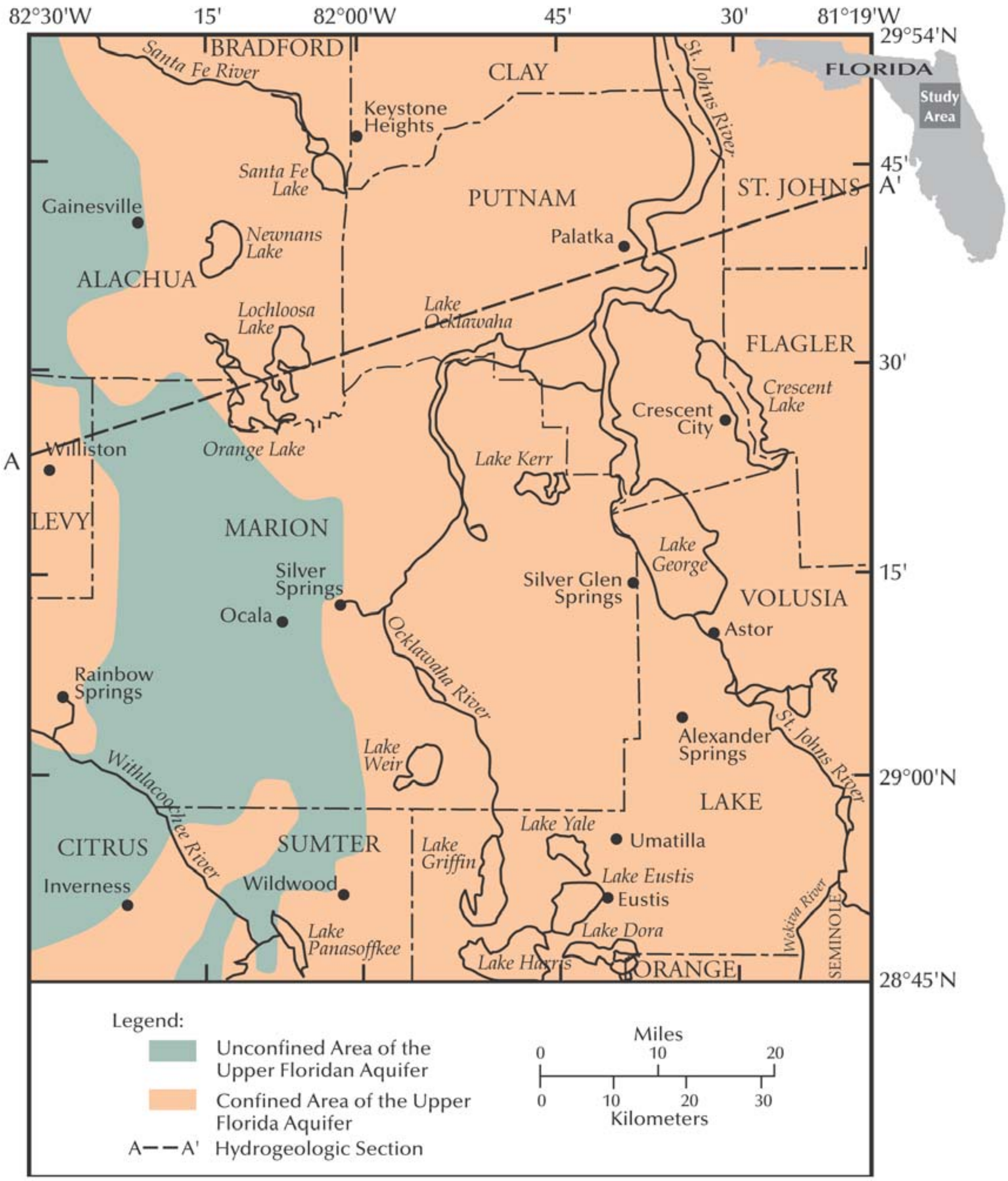

Figure 16. Areas in which the upper Floridan aquifer occurs under confined and unconfined conditions in north-central Florida

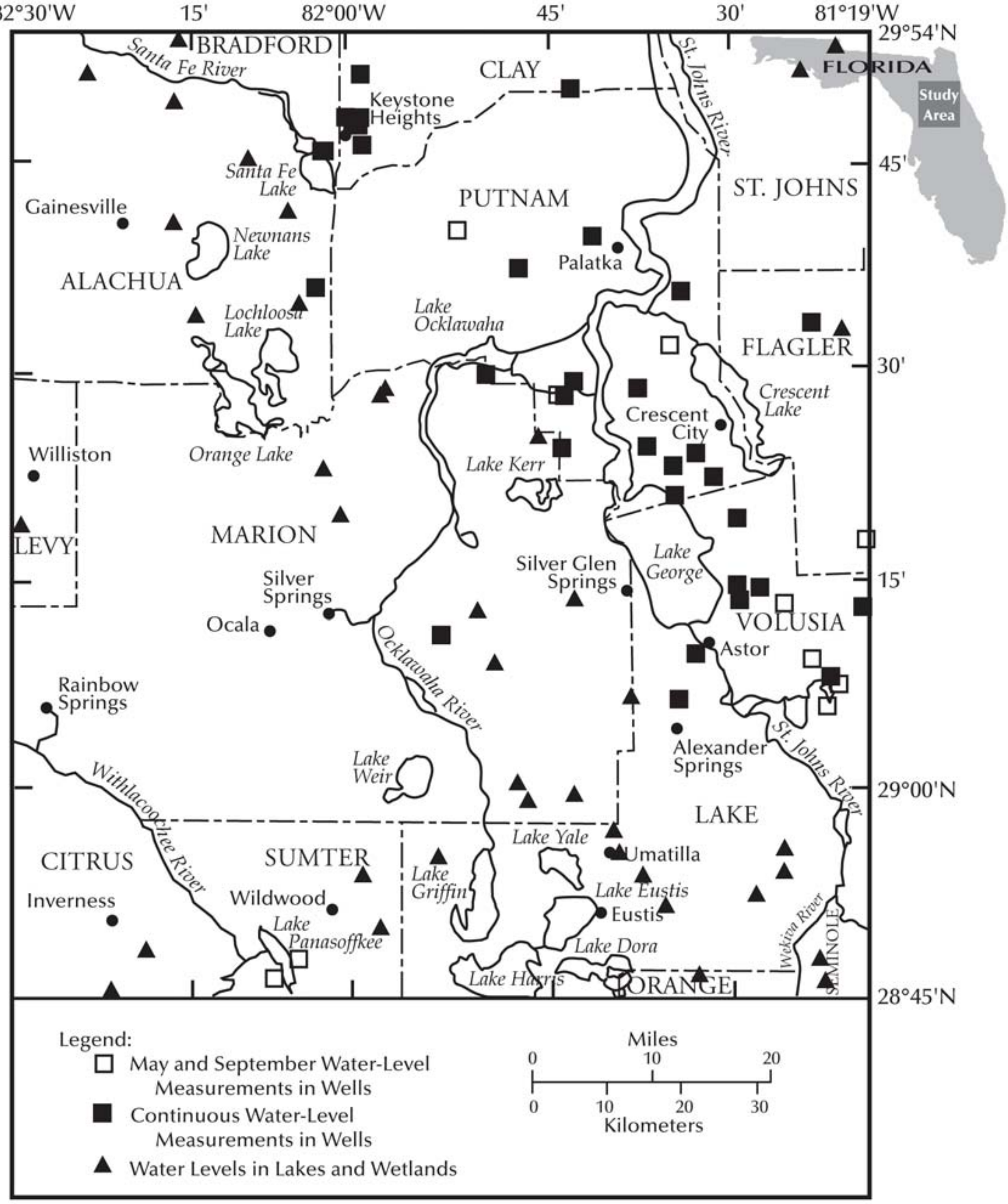

Figure 17. Locations of 81 monitoring wells and other control points used to construct the average 1995 water table of the surficial aquifer system in north-central Florida

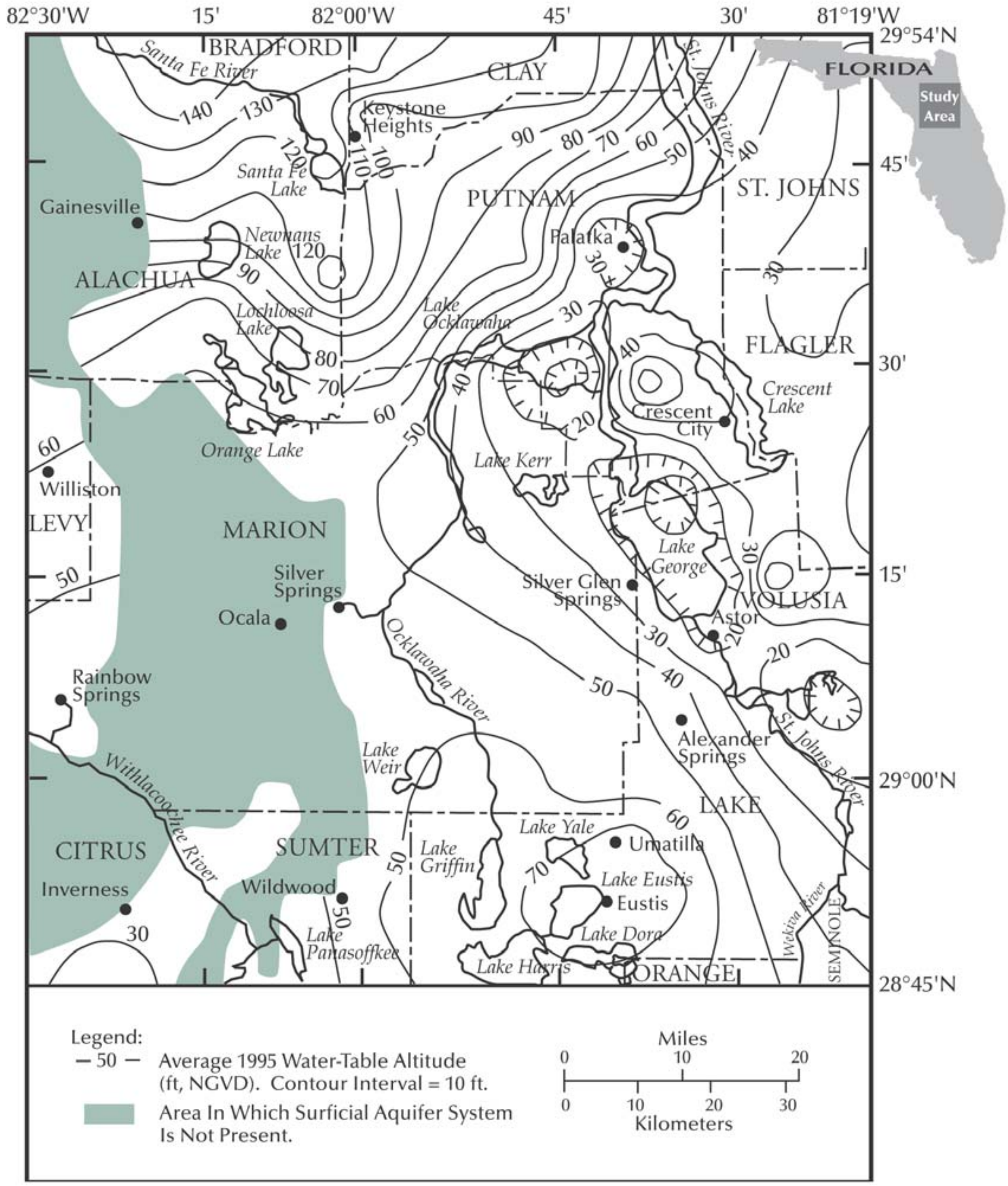

Figure 18. Estimated average 1995 water table of the surficial aquifer system in north-central Florida

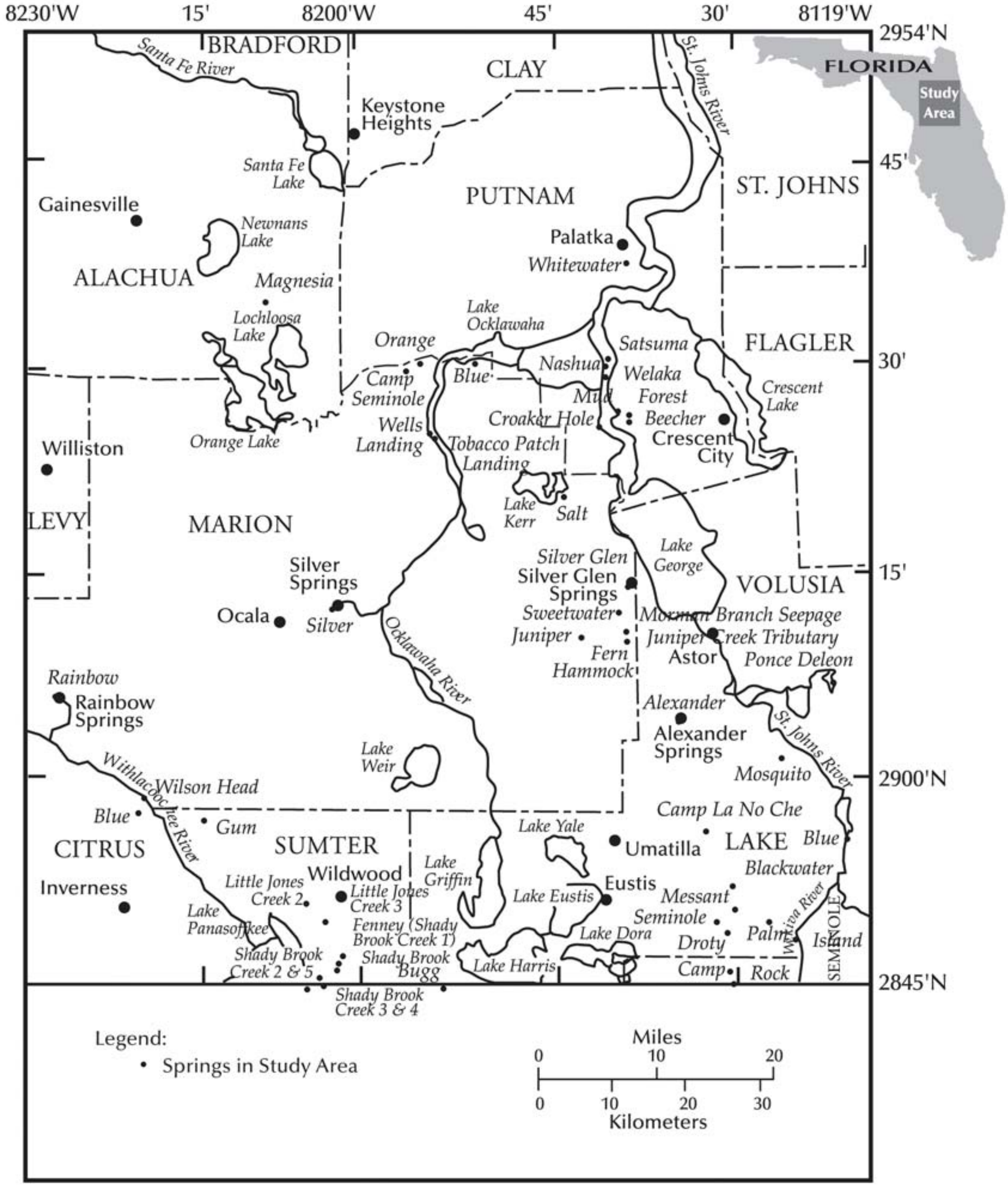

Figure 19. Locations of selected springs in north-central Florida (Source: Bush and Johnston 1988; SJRWMD [written communication, November 11, 1997]; Rosenau et al. 1977; Sepulveda 2002; Tibbals 1990)

Table 6. Discharge measurements at selected springs in north-central Florida

County	Spring	Latitude	Longitude	Measured or Estimated Average 1995 Discharge (cfs)	Date(s) of Measure-ment(s)	Source of Data
Alachua	Magnesia Spring	29 34 58	82 09 00	0.8		EE
Citrus	Blue Springs	28 58 09	82 18 52	11.9	May-72	B
Lake	Alexander Springs	29 04 50	81 34 30	98.1	Ave-1995	M
	Camp La No Che Spring	28 57 02	81 32 24	1.0	Jun-97	A
	Messant Spring	28 51 21	81 29 56	15.5	9-92, 5-94	S
	Seminole Springs	28 50 44	81 31 22	47.8	9-93, 5-94	S
	Droty Spring	28 49 40	81 30 38	0.8	Jun-97	A
	Bugg Spring	28 45 07	81 54 06	8.6	9-93, 5-94	S
	Blackwater Springs near Cassia	29 11 04	81 38 45	1.8	Jun-97	A
	Mosquito Springs Run	28 50 38	81 27 01	1.6	Jun-97	A
	Palm Springs Seminole State Forest	28 50 11	82 03 49	0.5		E
Marion	Orange Spring	29 30 38	81 56 38	2.1	May-99	A
	Salt Springs	29 21 00	81 43 58	74.1	Ave-1995	M
	Silver Glen Springs	29 14 43	81 38 37	106	Ave-1995	M
	Silver Springs	29 12 57	82 03 11	708	Ave-1995	M
	Sweetwater Spring	29 13 07	81 39 36	13.0	Ave-1995	M
	Juniper Springs	29 11 01	81 42 46	11.7	Ave-1995	M
	Fern Hammock Springs	29 11 00	81 42 29	12.9	Ave-1995	M
	Wilson Head Springs	28 58 40	82 19 08	2.1	Jun-72	B
	Rainbow Springs	29 06 08	82 26 16	652	Ave-1995	M
	Blue Spring near Orange City	29 30 51	81 51 25	0.4	May-99	A
	Camp Seminole Spring at Orange Springs	29 30 21	81 57 06	0.8	May-99	A
	Tobacco Patch Landing Spring Fort McCoy	29 25 42	81 55 26	1.4	May-99	A
	Wells Landing Springs near Fort McCoy	29 25 21	81 55 12	6.9	May-99	A
	Juniper Creek Tributary near Astor	29 11 29	81 38 58	1.6	Jun-97	A
	Morman Branch Seepage into Juniper Creek	28 51 34	82 05 18	1.0		E
Orange	Camp Spring	28 46 34	81 30 10	0.8	Jun-97	A
	Rock Springs	28 45 21	81 30 04	60.6	Ave-1995	M
Putnam	Whitewater Springs	29 38 06	81 38 53	1.2	Apr-72	B
	Satsuma Spring	29 30 45	81 40 32	0.9	Mar-72	B
	Nashua Spring	29 30 33	81 40 34	0.3		EE
	Welaka Spring	29 29 35	81 40 25	1.0		E
	Mud Spring	29 27 35	81 39 45	0.6	Ave-1995	M
	Forest Springs	29 27 25	81 39 35	0.3		EE
	Beecher Springs	29 26 54	81 38 49	4.9	Sep-93	S
	Croaker Hole Spring	29 26 18	81 41 21	70.9	Sep-93	S
Seminole	Island Springs	28 49 22	81 25 03	8.3	4-97, 8-97	A

Table 6–*Continued*

County	Spring	Latitude	Longitude	Measured or Estimated Average 1995 Discharge (cfs)	Date(s) of Measure-ment(s)	Source of Data
Sumter	Fenney Springs (Shady Brook Creek Spring No.1)	28 47 42	82 02 19	15.9	Mar-72	B
	Gum Springs	28 57 31	82 13 54	75.9	Jun-72	B
	Little Jones Creek Spring No. 2	29 02 20	81 26 04	5.3	Jun-97	A
	Little Jones Creek Spring No. 3	28 53 18	81 29 52	3.0		E
	Shady Brook Creek Spring No. 2	28 47 08	82 02 46	2.9		E
	Shady Brook Creek Spring No. 3	28 46 46	82 02 38	2.9		E
	Shady Brook Creek Spring No. 4	28 46 12	82 04 20	2.9		E
	Shady Brook Creek Spring No. 5	28 45 15	82 05 01	2.9		E
Volusia	Ponce De Leon Springs	29 08 02	81 21 47	23.8	Ave-1995	M
	Blue Spring	28 56 50	81 20 23	156	Ave-1995	M
			Total (cfs)	2,223		

Note: A = estimated as the product of measured flow in indicated year and ratio of 1995 rainfall and rainfall that occurred in actual flow measurement year
B = estimated as the product of measured flow from Rosenau and others (1977) and the ratio of 1995 rainfall and the rainfall that occurred during actual flow measurement year
E = estimated
EE = estimated from Motz and Dogan (2002)
M = measured in 1995
S = from Sepulveda (2002)

4.5.5 Discharges Between the Surficial and Upper Floridan Aquifers and Major Streams in the Study Area

In addition to the spring discharges, direct discharge occurs between the surficial and upper Floridan aquifers and the major streams in the study area. Based on Bush and Johnson (1988), direct discharge from the upper Floridan aquifer occurs along the St. Johns River and into Lake George and along part of the Ocklawaha River in Marion and Putnam counties. Along part of the Santa Fe River in Alachua County, discharge occurs from the surficial aquifer into the river. Based on Sepulveda (2002), direct discharge from the upper Floridan aquifer also occurs along part of the Withlacoochee River in Citrus County. Surface-water runoff also occurs into the St. Johns, Ocklawaha, Santa Fe, and Withlacoochee rivers and into other rivers and streams in the study area.

Based on a water-budget approach that considered inflows, outflows, and changes in storage between stream gauging stations, it was estimated as part of this study that the discharge from surface-water runoff and direct discharge from the upper Floridan aquifer into the St. Johns River between USGS gauging station 02234500 (St. Johns River near Sanford) and USGS gauging station 02244040 (St. Johns River at Buffalo Bluff near Satsuma) averaged 1,384 cfs in 1995 (see Figure 20 and Table 7). Also, it was estimated that the discharge from surface-water runoff and direct discharge from the upper Floridan aquifer into the Ocklawaha River between USGS gauging station 02238500 (Ocklawaha River at Moss Bluff) and two downstream USGS gauging stations 02243960 (Ocklawaha River at Rodman Dam near Orange Springs) and 02244032 (Cross-Florida Barge Canal at Buckman Lock, near Palatka) averaged 309 cfs in 1995 (see Figure 20 and Table 7). In the study area, the average surface-water runoff is 8.27 inches/year, and the average direct discharge is 2.78 inches/year [see section 6.3.4]. Thus, surface-water runoff comprises 75 percent of the total stream flow, and direct discharge comprises 25 percent. On this basis, the average direct discharge into this part of the St. Johns River in 1995 was (0.25)(1,384 cfs), or 346 cfs, and the average direct discharge into this part of the Ocklawaha River in 1995 was (0.25)(309 cfs), or 77.3 cfs.

Direct discharges from the surficial and upper Floridan aquifers into parts of the Santa Fe and Withlacoochee rivers for 1995 were estimated by attributing the increases in base flows that occurred in parts of these rivers to direct discharges from groundwater (see Table 8). For the Withlacoochee River calculation, the measured spring discharge was subtracted from the difference in base flow entering and leaving the gaged reach of the river to estimate the direct discharge. The direct discharge from the surficial aquifer into the Santa Fe River between upstream USGS gauging station 02320700 (Santa Fe River near Graham), which had 2.0 cfs base flow (inflow) (see Figure 21), and gaging station 02321000 (New River near Lake Butler), which had 3.1 cfs base flow (inflow) (see Figure 22), and downstream gauging station 02321500 (Santa Fe River at Worthington Springs), which had 29.6 cfs base flow (outflow) (see Figure 23), was estimated to be 24.5 cfs in 1995 (see Table 8). The direct discharge from the upper Floridan aquifer into the Withlacoochee River between USGS gauging stations 02312720 (Withlacoochee River at Wysong Dam at Carlson), which had 93.8 cfs base flow (inflow) (see Figure 24), and gaging station 02313000 (Withlacoochee River near Holder), which had 246.9 cfs base flow (outflow) (see Figure 25), was estimated to be 73.0 cfs in 1995 upon subtracting the spring discharge of 80.1 cfs (see Table 8).

4.6 HYDRAULIC CHARACTERISTICS

Hydraulic characteristics of the surficial aquifer system, intermediate confining unit, and upper Floridan aquifer vary widely throughout north-central Florida. Sources of data for hydraulic characteristics include pumping test results and regional and sub-regional groundwater flow models.

4.6.1 Surficial Aquifer

Transmissivity estimates for the surficial aquifer system range from 60 to 1,000 square feet per day (ft^2/day) in eastern Nassau County (Brown 1984). Other estimates are 950 ft^2/day along the Crescent City Ridge in Putnam County (Ross and Munch 1980), 2,400 ft^2/day near Mayport in Duval County (Franks 1980), 6,500 to 7,000 ft^2/day in the Tillman Ridge area of east-central St. Johns County (Hayes 1981), and 625 ft^2/day in the Keystone Heights area in the

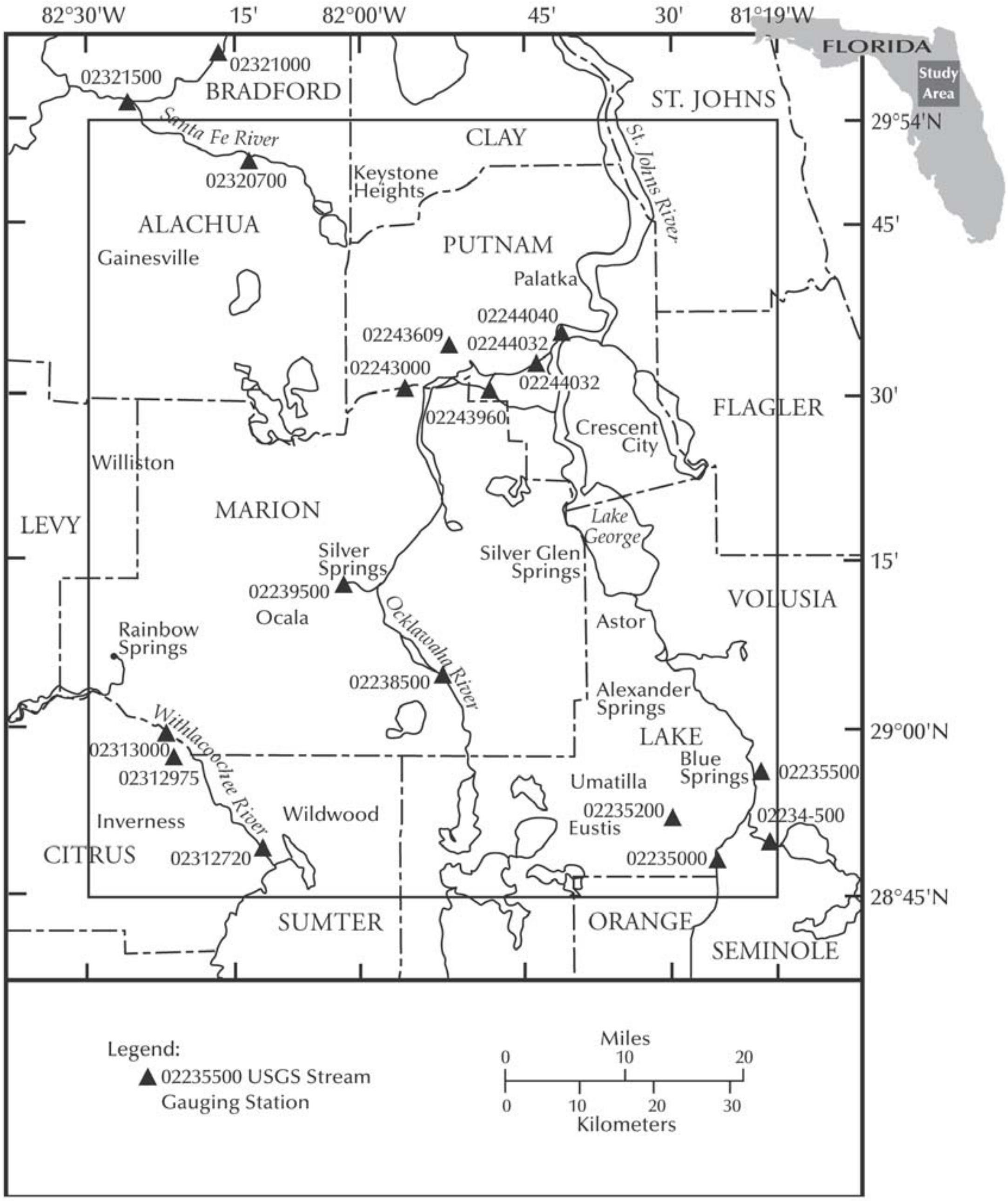

Figure 20. Locations of selected stream gauging stations used to estimate direct discharges from the surficial and upper Floridan aquifers into parts of the St. Johns, Ocklawaha, Santa Fe, and Withlacoochee rivers (Source: USGS 1996)

Table 7. Water-budget analysis for parts of the St. Johns and Ocklawaha rivers

Component	St. Johns River (cfs)	Component	Ocklawaha River (cfs)
Change in storage (dS/dt)	-75	Change in storage (dS/dt)	-76
Evapotranspiration (ET)	502	Evapotranspiration (ET)	150
Surface-water outflow (SW_{out}):		Surface-water outflow (SW_{out}):	
USGS 02244040 (St. Johns River at Buffalo Bluff near Satsuma, Florida (FL))	7,318	USGS 02244032 (Cross-Florida Barge Canal at Buckman Lock near Palatka, FL)	31
		USGS 02243960 (Ocklawaha River at Rodman Dam near Orange Springs, FL)	1,458
Rainfall (P)	515	Rainfall (P)	176
Surface-water inflow (SW_{in}):		Surface-water inflow (SW_{in}):	
USGS 02234500 (St. Johns River near Sanford, FL)	3,339	USGS 02238500 (Ocklawaha River near Moss Bluff, FL)	286
USGS 02235000 (Wekiva River near Sanford, FL)	337	USGS 02243960 (Deep Creek near Kenwood, FL)	24
USGS 02235200 (Blackwater Creek near Cassia, FL)	95	USGS 02243000 (Orange Creek at Orange Springs, FL)	50
USGS 02244032 (Cross-Florida Barge Canal at Buckman Lock near Palatka, FL)	31		
USGS 02243960 (Ocklawaha River at Rodman Dam near Orange Springs, FL)	1,458		
Spring discharge (Q_{spring}):	586	Spring discharge (Q_{spring}):	718
Surface-water runoff + direct discharge from the Upper Floridan Aquifer	1,384	Surface-water runoff + direct discharge from the Upper Floridan Aquifer	309
Direct discharge from the Upper Floridan aquifer	346	Direct discharge from the Upper Floridan aquifer	77.3

Note: dS/dt = (change in lake stage for 1995)(surface area) = (-1.16 ft/year)(2.04×10^9 ft^2) = 74.95 cfs for Lake George for the St. Johns River and change in lake volume for 1995 = -54,900 ac-ft/year = -75.83 cfs for Lake Ocklawaha for the Ocklawaha River

ET = (1995 pan evaporation) (pan coefficient)(surface area of river and adjacent wetlands between gauges) = (54.05 inches/year) (0.845) (4.16×10^9 ft^2) = 502 cfs for the St. Johns River and (54.05 inches/year)(0.845)(1.24×10^9 ft^2) = 150 cfs for the Ocklawaha River

P = (1995 rainfall)(surface area of river and adjacent wetlands between gauges) = (46.84 inches/year)(4.16×10^9 ft^2) = 515 cfs for the St. Johns River and (53.64 inches/year)(1.24×10^9 ft^2) = 176 cfs for the Ocklawaha River

Q_{spring} = sum of 1995 measured and estimated spring discharges at Alexander, Beecher, Blue, Croaker Hole, Fern Hammock, Forest, Island Springs, Juniper, Juniper Creek Tributary near Astor, Morman Branch Seepage into Juniper Creek, Mosquito Springs Run, Mud, Nashua, Ponce de Leon, Salt, Satsuma, Silver Glenn, Sweetwater, and Welaka springs for the St. Johns River and Silver Springs for the Ocklawaha River

Direct discharge + surface-water runoff = $dS/dt + ET + SW_{out} - P - SW_{in} - Q_{spring}$

Direct discharge = (0.25)(1,384 cfs) = 346 cfs for the St. Johns River and (0.25)(309 cfs) = 77.3 cfs for the Ocklawaha River

Locations of stream gauges are shown in Figure 20.

Table 8. Base flow separation for parts of the Santa Fe and Withlacoochee rivers

Component	Santa Fe River Average Base Flow in 1995 (cfs)	Component	Withlacoochee River Average Base Flow in 1995 (cfs)
Outflow (BF_{out}): USGS 02321500 (Santa Fe River at Worthington Springs, FL)	29.6	Outflow (BF_{out}): USGS 02313000 (Withlacoochee River near Holder, FL)	246.9
Inflow (BF_{in}): USGS 02320700 (Santa Fe River near Graham, FL)	2.0	Inflow (BF_{in}): USGS 02312720 (Withlacoochee River at Wysong Dam at Carlson, FL)	93.8
USGS 02321000 (New River near Lake Butler, FL)	3.1		
Spring discharge (Q_{spring}):	—	Spring discharge (Q_{spring}):	80.1
Direct discharge from surficial aquifer	24.5	Direct discharge from Upper Floridan aquifer	73.0

Note: — = 0 (no springs) for the Santa Fe River

Q_{spring} = sum of 1995 measured and estimated spring discharges at Gum, Blue, and Wilson Head springs for the Withlacoochee River

Direct discharge from underlying aquifer = BF_{out} - BF_{in} - Q_{spring}

Locations of stream gauges are shown in Figure 20.

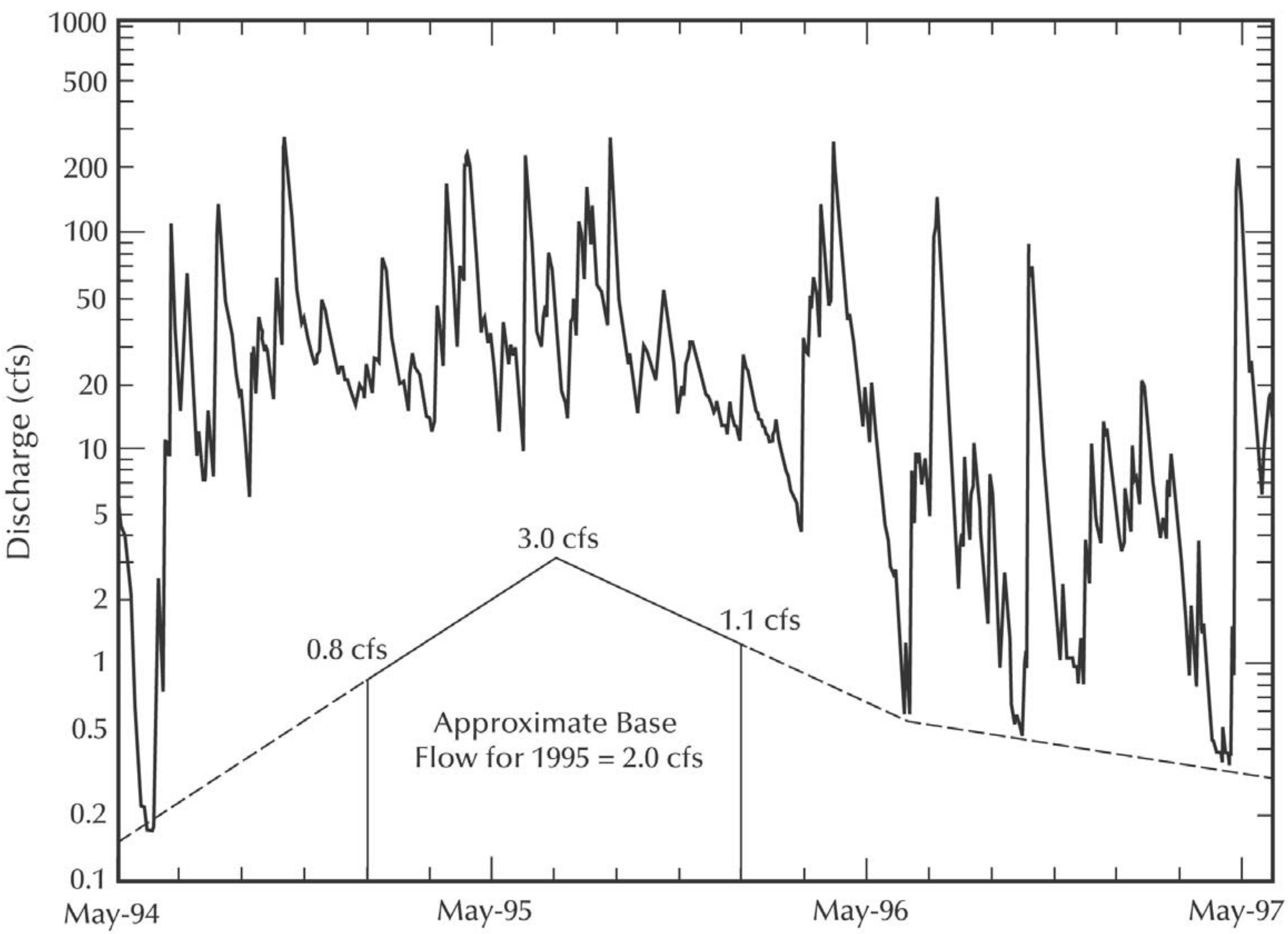

Figure 21. Approximation of base flow from mean monthly stream flow at USGS station 02320700 (Santa Fe River near Graham, Florida) (Source: http://waterdata.usgs.gov/nwis/discharge)

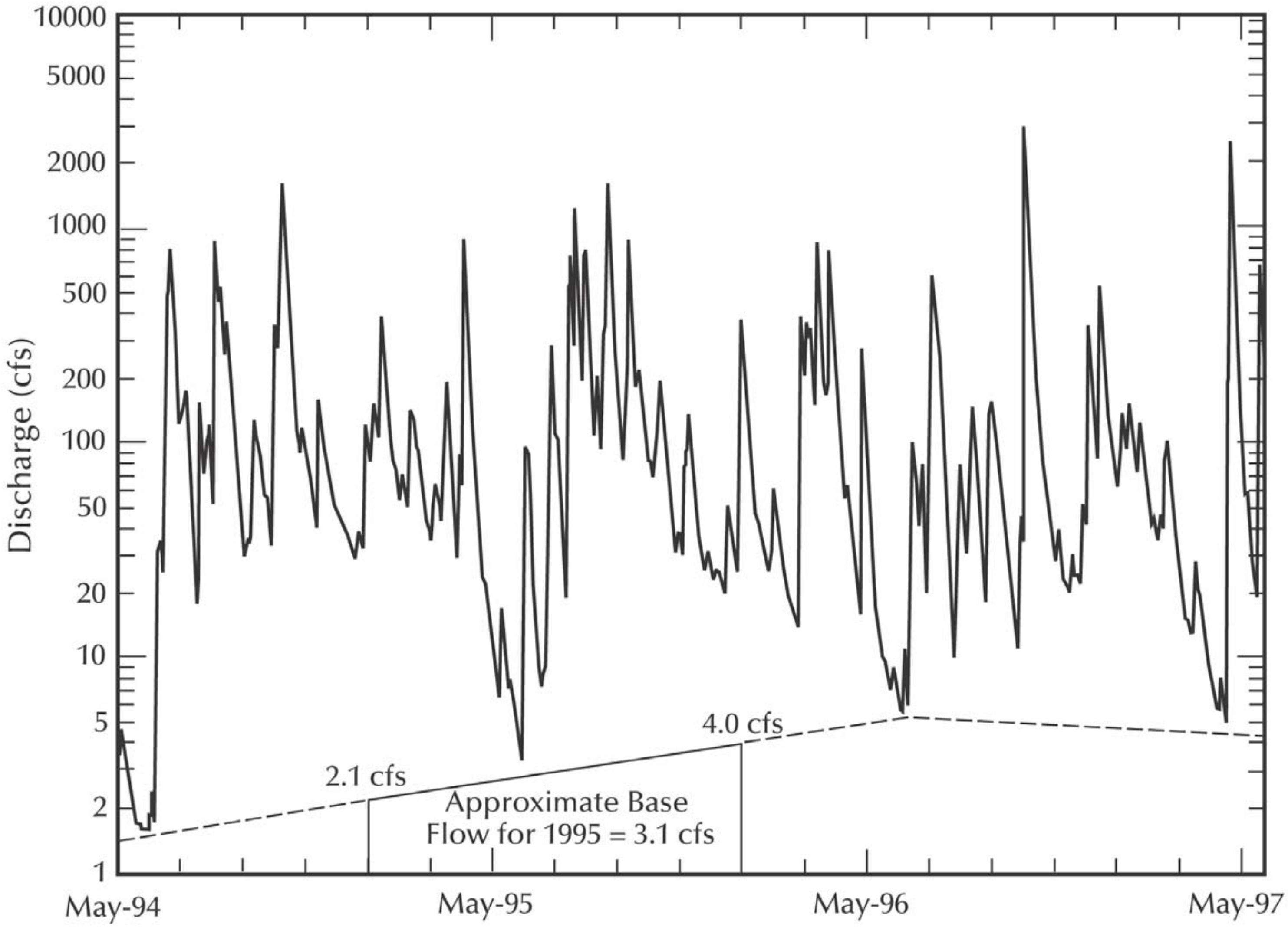

Figure 22. Approximation of base flow from mean monthly stream flow at USGS station 02321000 (New River near Lake Butler, Florida) (Source: http://waterdata.usgs.gov/nwis/discharge)

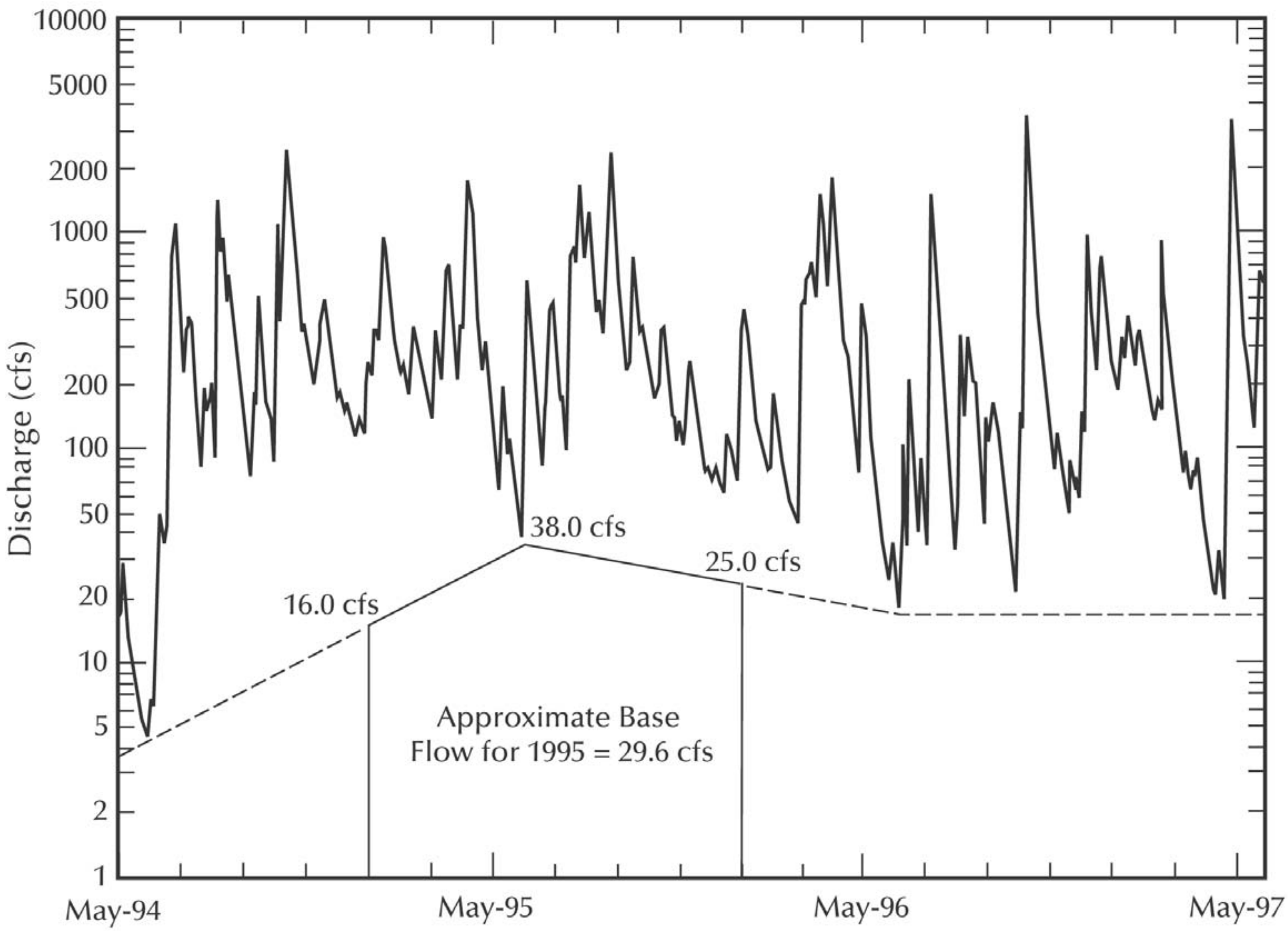

Figure 23. Approximation of base flow from mean monthly stream flow at USGS station 02321500 (Santa Fe River at Worthington Springs, Florida) (Source: http://waterdata.usgs.gov/nwis/discharge)

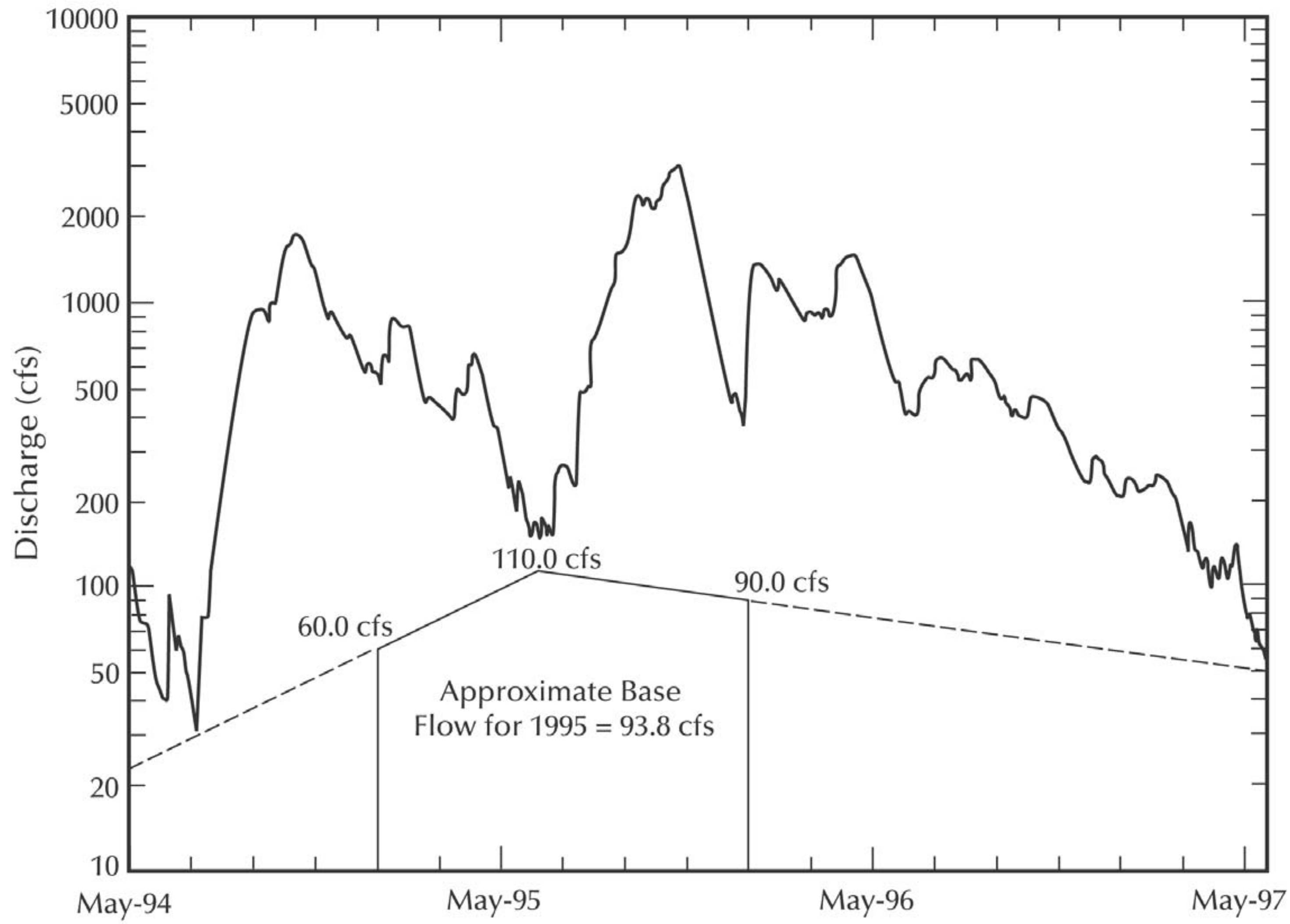

Figure 24. Approximation of base flow from mean monthly stream flow at USGS station 02312720 (Withlacoochee River at Wysong Dam at Carlson, Florida) (Source: http://waterdata.usgs.gov/nwis/discharge)

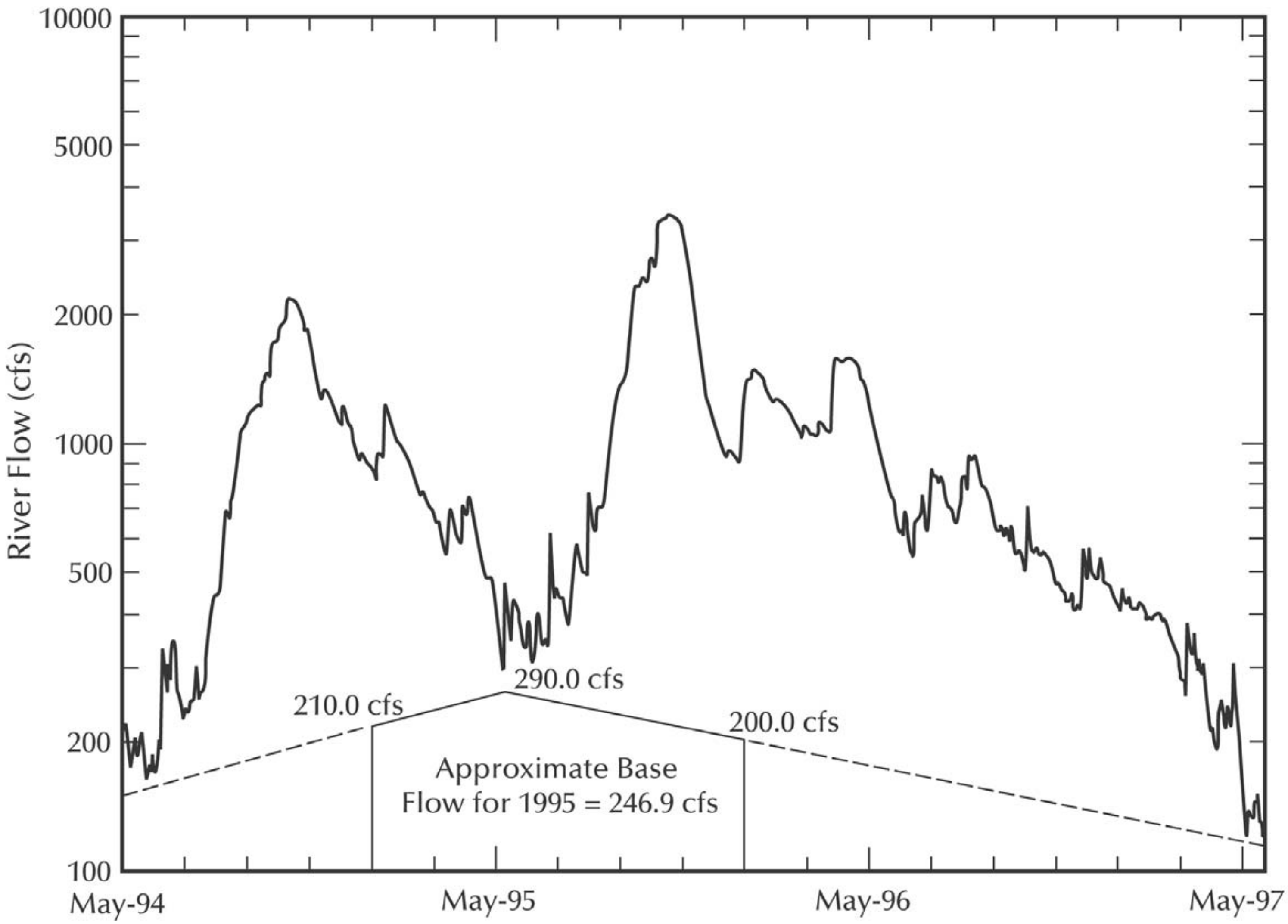

Figure 25. Approximation of base flow from mean monthly stream flow at USGS station 02313000 (Withlacoochee River near Holder, Florida) (Source: http://waterdata.usgs.gov/nwis/discharge)

Upper Etonia Creek Basin (Motz et al. 1993). Estimates for the storativity, or specific yield, of the surficial aquifer range from 0.1 at Mayport (Franks 1980) to 0.2 in eastern Nassau County (Brown 1984).

4.6.2 Intermediate Confining Unit

Based on a regional-scale numerical groundwater flow model of the upper Floridan aquifer (Bush and Johnston 1988), values for leakance of the intermediate confining unit range from 2.28×10^{-6} day^{-1} to 2.28×10^{-5} day^{-1} in the northeast part of the study area, where the Hawthorn Group is thickest, to greater than 2.28×10^{-4} day^{-1} in southeastern Alachua County and southeastern Marion County, where the upper Floridan aquifer is considered to be semiconfined. In Putnam County and other parts of the study area, values for leakance of the intermediate confining unit range from 2.28×10^{-5} day^{-1} to 2.28×10^{-4} day^{-1} (Bush and Johnston 1988). In the north-central Florida groundwater flow model, values for leakance of the intermediate confining unit were determined to range from 1.0×10^{-6} day^{-1} to 2.5×10^{-2} day^{-1} (Motz and Dogan 2002). An approximate range of 3.14×10^{-4} to 1.34×10^{-3} day^{-1} for leakance of the intermediate confining unit was determined from an aquifer test conducted on the south shore of Lake Swan in Putnam County (Yobbi and Chappell 1979). Also, leakance values determined from two pumping test at the Florida Rock Industries Gold Head sand mine near Keystone Heights range from 6.59×10^{-5} day^{-1} (Motz 1989) to 1.74×10^{-3} day^{-1} (Missimer and Associates 1991).

4.6.3 Upper Floridan Aquifer

Transmissivity values in the upper Floridan aquifer generally range from 10,000 to 50,000 ft^2/day in the northeastern past of the study area, where the upper Floridan aquifer is confined and occurs at its greatest depth, to more than 1,000,000 ft^2/day in part of Marion County, where the upper Floridan aquifer is unconfined and at or near land surface (Bush and Johnston 1988 and Motz and Dogan 2002). A region in which the transmissivity is less than 10,000 ft^2/day is located northeast of Lake George in parts of Flagler, Putnam, and Volusia counties (Bush and Johnston 1988). In the Silver Springs groundwater basin in Marion County, transmissivity values range from 1,000,000 to 10,000,000 ft^2/day, and values have been estimated to be as large as 25,000,000 ft^2/day in the vicinity of the spring vents (Faulkner 1973, Knowles 1996, Motz and Dogan 2002, and Ryder 1985). An approximate range of 80,500 to 132,000 ft^2/day for transmissivity of the upper Floridan aquifer was determined from the pumping test conducted at Lake Swan (Yobbi and Chappell 1979). The two pumping tests at the Gold Head sand mine near Keystone Heights indicated transmissivities of 497,000 ft^2/day (Motz 1989) and 468,000 ft^2/day (Missimer and Associates 1991). Estimates for the storativity of the upper Floridan aquifer typically range from 0.0001 to 0.001 (Johnston and Bush 1988; Missimer and Associates 1991; and Motz 1989).

4.6.4 Middle Semiconfining Unit and Lower Floridan Aquifer

The leakance of the middle semiconfining unit, which occurs in most of the study area, is approximately 5.0×10^{-5} day^{-1}, based on groundwater model studies in east-central and north-central Florida (Tibbals 1990 and Motz et al. 1995). Reliable estimates of the hydraulic characteristics of the lower Floridan aquifer generally are not available because the lower Floridan aquifer has not been tapped by wells to any significant extent (Durden and Motz 1991). Based on the north-central Florida groundwater model study (Motz et al. 1995), the transmissivity of the lower Floridan aquifer in the study area is approximately 200,000 ft^2/day.

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5.0 GROUNDWATER USE IN STUDY AREA

5.1 COMPILATION OF GROUNDWATER USE

Groundwater use was compiled for the study area, which falls within three water management districts, i.e., SJRWMD, Southwest Florida Water Management District (SWFWMD), and Suwannee River Water Management District (SRWMD) (see Figure 26). The year 1995 was selected as a base year to represent present conditions, and the year 2020 was selected for a 25-year projection of future use. Also, the year 2025 was selected for additional projections to meet changes in SJRWMD'S water-supply planning needs. As a result, two databases were developed to represent groundwater use. First, a database was developed based on established 1993-1994 and projected 2020 well locations and pumping rates published by the USGS (Sepulveda 2002). Second, a revised database was developed for 1995 and 2025 based on new information obtained from SJRWMD (written communication, 2003).

5.2 PUMPAGE FOR 1993-1994, 1995, AND 2020 BASED ON SEPULVEDA (2002)

5.2.1 Pumpage for 1993-1994

In Sepulveda's (2002) investigation, groundwater withdrawals for August 1993 – July 1994 for public water supply, commercial and industrial use (including thermoelectric power generation and recreational uses), and agricultural purposes were compiled or estimated, depending on the water-use type. Most of the groundwater withdrawals were compiled from consumptive use permits and groundwater-use data files from the SJRWMD, South Florida Water Management District (SFWMD), and SWFWMD. Other discharges such as self-supplied domestic discharges and discharge rates from free-flowing wells were estimated as described by Sepulveda (2002). Based on these data, which were developed for a larger area that includes the north-central Florida study area, the total estimated pumpage in the north-central Florida study area for August 1993 - July 1994 was 248.2 mgd (see Table 9). Of the total, approximately 89.4 mgd was public supply, 51.0 mgd was domestic self-supplied use, 38.0 mgd was commercial and industrial use, 80.1 mgd was agricultural use, and 5.6 mgd was recreational (golf course) irrigation (see Table 9 and Figure 27). Also, the estimated discharge from free-flowing wells was 0.1 mgd, and artificial recharge from drainage and injection wells was approximately 15.9 mgd.

5.2.2 Pumpage for 1995

The pumpage database for 1995 was developed from Sepulveda's (2002) August 1993 – July 1994 data as follows. First, the total groundwater use for the period August 1993 – July 1994 was determined for each groundwater-use category for each county in the study area using SJRWMD and SWFWMD water-use surveys. Next, the total groundwater use for 1995 was determined for each groundwater-use category for each county using water-use surveys available

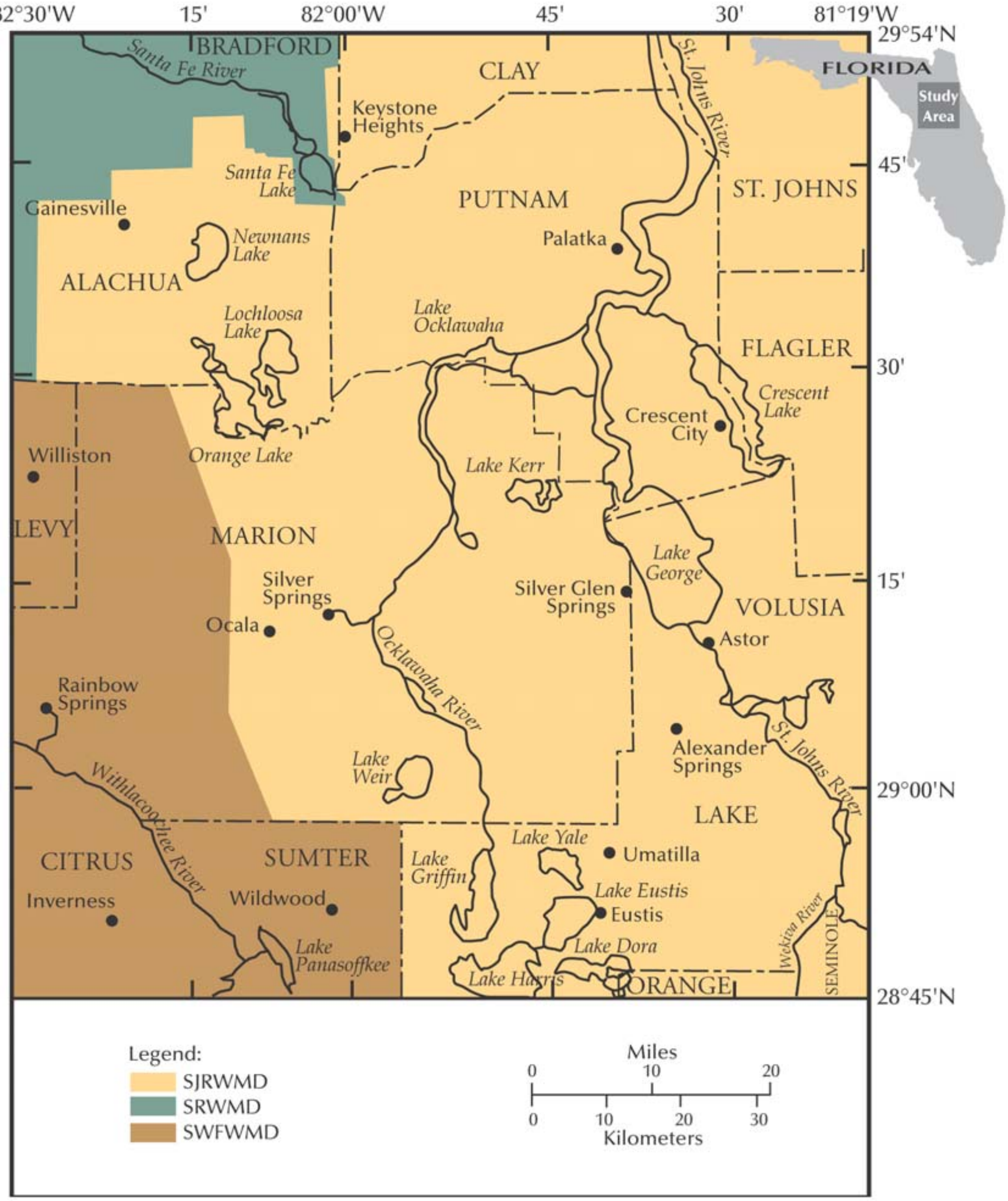

Figure 26. Water management districts in north-central Florida study area (Source: Fernald and Patton 1984)

Table 9. Estimated groundwater use in north-central Florida by category in 1993-1994 and 1995 and projected use in 2020 (in million gallons per day)

Category	1993-1994	1995	2020
Public supply	89.4	98.4	212.4
Domestic self-supplied	51.0	54.2	64.5
Commercial-industrial self-supplied	38.0	43.0	45.9
Agricultural self-supplied	80.1	74.0	90.6
Recreational irrigation	5.6	4.3	7.2
Free-flowing wells	0.1	0.0	0.0
Artificial recharge from drainage and injection wells	-15.9	-18.0	-19.3
Total	248.2	255.8	401.2

Source: Sepulveda 2002.

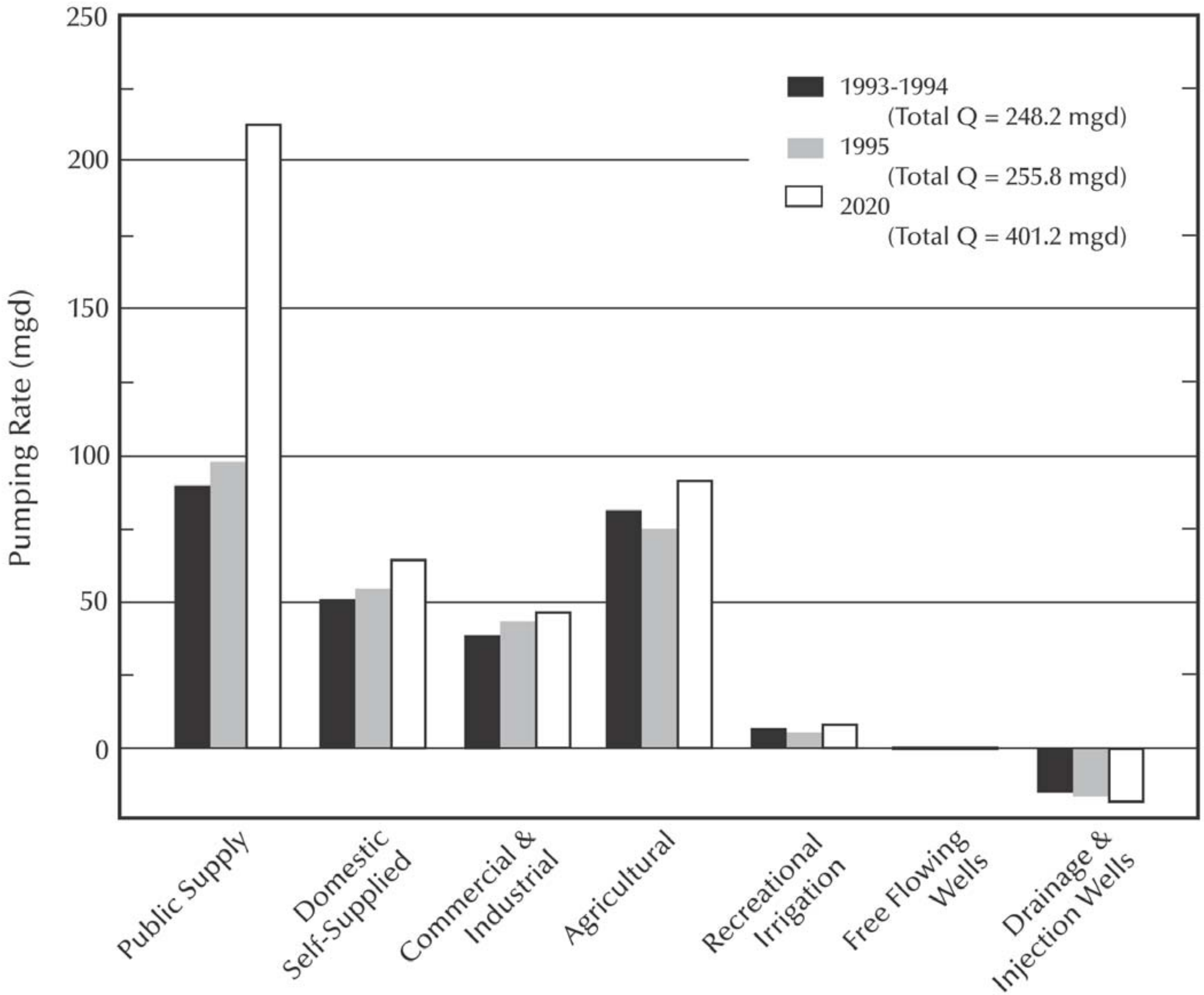

Figure 27. Groundwater use in north-central Florida by category in 1993-1994 and 1995 and projected use in 2020 (based on Sepulveda 2002)

from SJRWMD and SWFWMD. Ratios of increases (or decreases) were calculated by dividing the 1995 groundwater use for each county for each groundwater-use category by the corresponding value for August 1993 – July 1994. These ratios were then applied to the groundwater use for each county or part of a county in the study area for each category of groundwater use. Based on this procedure, the total estimated pumpage in the north-central Florida study area for 1995 was 255.8 mgd (see Table 9). Of this total, approximately 98.4 mgd was public supply, 54.2 mgd was domestic self-supplied use, 43.0 mgd was commercial and industrial use, 74.0 mgd was agricultural use, and 4.3 mgd was recreational (golf course) irrigation (see Table 9 and Figure 27). Also, the estimated discharge from free-flowing wells was 0.03 mgd, and artificial recharge from drainage and injection wells was approximately 18.0 mgd.

5.2.3 Projected Pumpage for 2020

Projected groundwater withdrawals for 2020 were estimated from water-supply assessment plans of the water management districts, water-use data for 1995, and USGS estimates (Sepulveda 2002). Based on this information, the total projected pumpage in the north-central Florida study area for 2020 is 401.2 mgd (see Table 9). Of this total, approximately 212.4 mgd is public supply, 45.9 mgd is domestic self-supplied use, 45.9 mgd is commercial and industrial use, 90.6 mgd is agricultural use, and 7.2 mgd is recreational (golf course) irrigation (see Table 9 and Figure 27). Also, artificial recharge from drainage and injection wells is approximately 19.3 mgd. The estimated discharge from free-flowing wells is negligibly small and thus not included in the 2020 projection.

5.3 PUMPAGE FOR 1995 AND 2025 BASED ON REVISED DATA

5.3.1 Pumpage for 1995

A modified database for pumpage for 1995 was obtained by combining revised pumping data for part of the model area with the 1995 pumpage derived from Sepulveda's (2002) August 1993 – July 1994 data. Specifically, public-supply, commercial and industrial, and agricultural pumpage for 1995 obtained from SJRWMD (written communication, 2003) was used to represent these categories of pumpage in the part of the model area within SJRWMD. For the other parts of the model area that are in SRWMD and SWFWMD, the public-supply, commercial and industrial, and agricultural pumpage is the same as the pumpage for these categories in the 1995 database derived from Sepulveda (2002). Also, in all of the model area, pumpage for the other categories, i.e., domestic self-supplied, recreational irrigation, free-flowing wells, and drainage and injection wells, was unchanged relative to the 1995 database derived from Sepulveda (2002). In the modified database, the total estimated pumpage in the north-central Florida study area for 1995 was 230.5 mgd (see Table 10). Of the total, approximately 84.1 mgd was public supply, 54.2 mgd was domestic self-supplied use, 22.5 mgd was commercial and industrial use, 83.5 mgd was agricultural use, and 4.3 mgd was recreational (golf course) irrigation (see Table 10 and Figure 28). Also, the estimated discharge from free-flowing wells was 0.03 mgd, and artificial recharge from drainage and injection wells was approximately 18.0 mgd.

Table 10. Estimated groundwater use in north-central Florida by category in 1995 and projected use in 2025 (in million gallons per day)

Category	1995	2025
Public supply	84.1	155.3
Domestic self-supplied	54.2	70.6
Commercial-industrial self-supplied	22.5	26.6
Agricultural self-supplied	83.5	90.5
Recreational irrigation	4.3	7.2
Free-flowing wells	0.0	0.0
Artificial recharge from drainage and injection wells	-18.0	-19.3
Total	230.5	330.9

Source: Sepulveda 2002; SJRWMD (written communication, 2003).

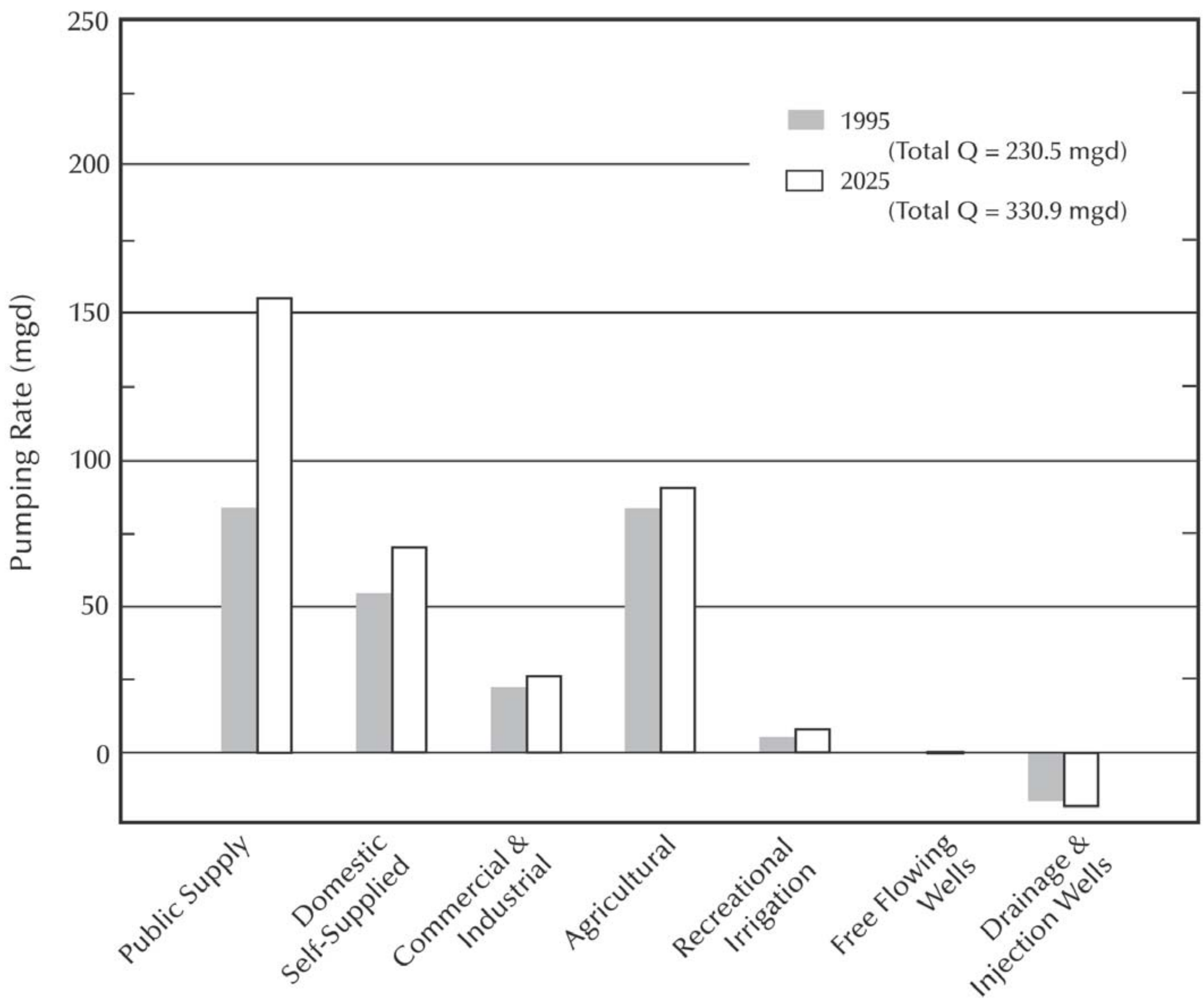

Figure 28. Estimated groundwater use in north-central Florida by category in 1995 and projected use in 2025 (based on revised database)

5.3.2 Projected Pumpage for 2025

Projected groundwater withdrawals for 2025 were obtained by combining pumping projections available for part of the model area for 2025 with the 2020 pumpage that was projected from the 1995 pumpage derived from Sepulveda (2002). Specifically, public-supply, domestic self-supplied, and commercial and industrial projections for 2025 obtained from SJRWMD (written communication, 2003) were used to represent these categories of pumpage in the part of the model area within SJRWMD. For the other parts of the model area that are in SRWMD and SWFWMD, public-supply, domestic self-supplied, and commercial and industrial projections for 2025 are the same as the corresponding projections for 2020. Also, in all of the model area, 2025 projections for agricultural, recreational irrigation, and drainage and injection wells were unchanged relative to the corresponding projections for 2020. In this database, the total projected pumpage in the north-central Florida study area for 2025 is 330.9 mgd (see Table 10). Of this total, approximately 155.3 mgd is public supply, 70.6 mgd is domestic self-supplied use, 26.6 mgd is commercial and industrial use, 90.5 mgd is agricultural use, and 7.2 mgd is recreational (golf course) irrigation (see Table 10 and Figure 28). Also, artificial recharge from drainage and injection wells is approximately 19.3 mgd. The estimated discharge from free-flowing wells is negligibly small and not included in the 2025 projection.

6.0 CALIBRATION OF THE GROUNDWATER FLOW MODEL

6.1 GROUNDWATER MODEL

6.1.1 Selection of Code and Calibration Strategy

The USGS modular three-dimensional finite-difference code MODFLOW (McDonald and Harbaugh 1988) was used to simulate the groundwater system in north-central Florida. As described in this chapter, a groundwater flow model was assembled and calibrated to represent average 1995 conditions. The primary objectives of the calibration were simulating water levels in selected (i.e., "target") wells in the upper Floridan aquifer, simulating water levels in target wells and selected water bodies in the surficial aquifer system, and simulating the measured (and estimated) spring discharges in the study area. Secondary objectives included simulating the direct discharges that occur from the upper Floridan aquifer into parts of the St. Johns, Ocklawaha, Santa Fe, and Withlacoochee rivers. Also, water-budget components for the surficial aquifer system and the upper and lower Floridan aquifers were simulated, along with rates of recharge and discharge relative to the upper Floridan aquifer and the surficial aquifer system. It was assumed that the average ground-water levels, streamflows, and pumping and other stresses for 1995 were approximately in equilibrium, and, accordingly, it was assumed that the average 1995 conditions in the groundwater system could be approximated by a steady-state calibration.

Model calibration was achieved by selecting starting values for hydraulic parameter arrays assigned as input to the model and then adjusting by trial the values in the model that represent the hydraulic conductivity of the surficial aquifer system, the transmissivity of the upper and lower Floridan aquifers, the leakance of the intermediate confining unit and middle semiconfining unit, and conductance of the springs and rivers that discharge from the upper Floridan aquifer. This adjustment of calibration parameters was done to minimize the differences between simulated and observed (or estimated) heads and discharges.

6.1.2 MODFLOW

In MODFLOW, an aquifer system is discretized with a mesh of blocks called cells, the locations of which are described in terms of rows, columns, and layers (see Figure 29). An i, j, k indexing system is used, and within each cell, the hydraulic head is calculated at a point called a node, which is at the center of each block. Version 5.1 of Processing MODFLOW for Windows (Chiang and Kinzelbach 2001), a Windows-based code that serves as a pre- and post-processor for MODFLOW, was used to prepare input files, run simulations, and prepare output files. Version 8.0 of Surfer® was used to analyze and plot output files for simulated and observed heads and drawdowns that were calculated as the differences between the simulated and observed heads. The basic (BAS1), block-centered flow, version 2 (BCF2), well (WEL1), drain (DRN1), general-head boundary (GHB1), recharge (RCH1), evapotranspiration (EVT1), preconditioned conjugate gradient solver (PCG2), and output control (OC) packages in MODFLOW were selected in assembling the groundwater flow model. The convergence criterion for hydraulic head in the model was set equal to 0.001 ft.

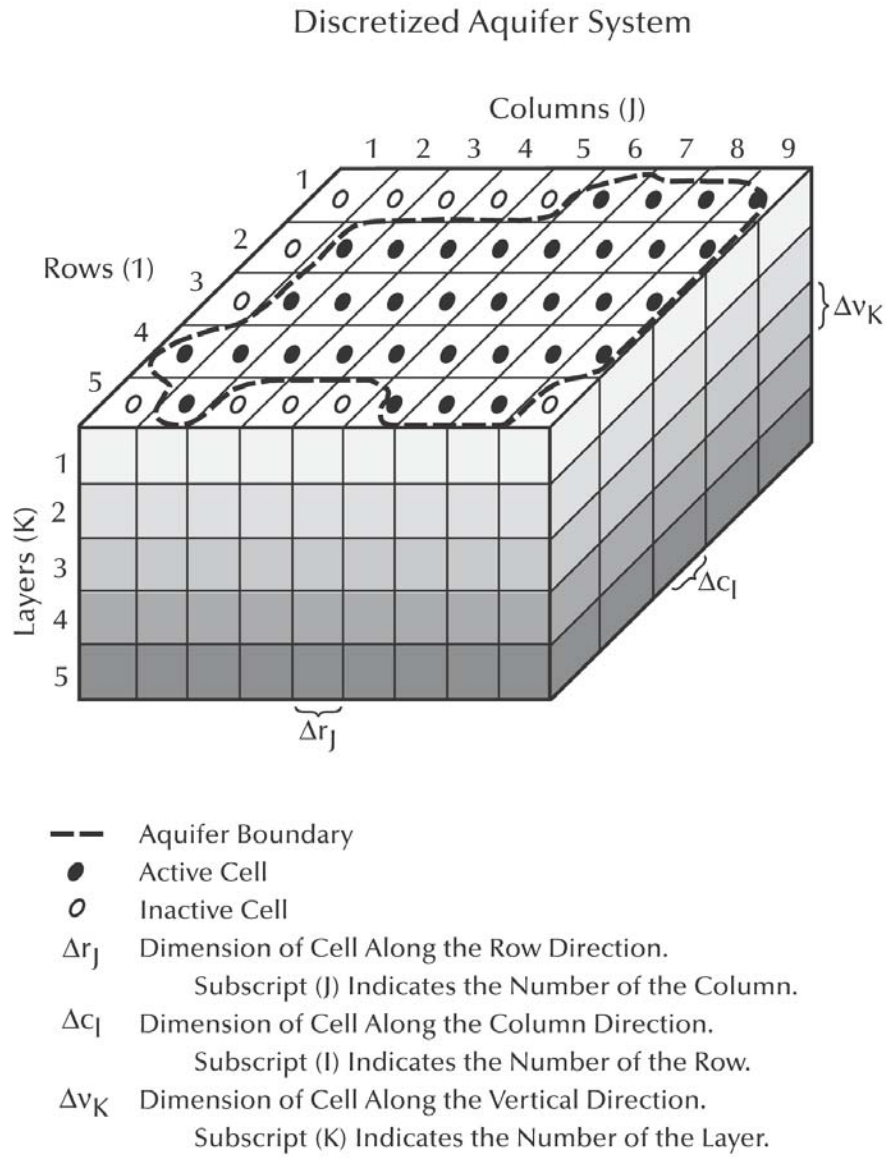

Figure 29. Discretized hypothetical aquifer system (Source: McDonald and Harbaugh 1988)

6.2 MODEL CONCEPTUALIZATION AND AQUIFER PARAMETERS

6.2.1 Hydrogeologic Units and Discretization

The hydrogeologic system within the model domain was considered to consist of three layers, or aquifer units, separated by confining units (see Figure 30). Layer one represents the surficial aquifer system, layer two represents the upper Floridan aquifer, and layer three represents the lower Floridan aquifer. Layer one is inactive in western parts of the study area where the upper Floridan aquifer is the uppermost hydrogeologic unit. Layer two is unconfined in the western parts of the study area where layer one is inactive and confined or partially confined elsewhere. Layer three is inactive in parts of the study area where brackish or salty water occupies the entire thickness of the aquifer. The intermediate confining unit between layers one and two and the middle semiconfining unit between layers two and three are represented implicitly by vertical conductances between the layers. The base of layer three coincides with the sub-Floridan confining unit, which is impermeable in the groundwater model.

The model area was discretized into 150 columns and 168 rows of cells that are all equally spaced at 2,500 ft (see Figure 31). The model domain is rectangular, and its dimensions represent distances of 375,000 ft east to west and 420,000 ft south to north. The total area represented by the model is approximately 5,650 mi^2. Layer one is an active layer in the area where it represents the uppermost hydrogeologic unit, and it was assigned no-flow, or inactive, cells in the western parts of the model area where the upper Floridan aquifer is the uppermost hydrogeologic unit (see Figure 32).

The part of the model area in which layer one is inactive and layer two is unconfined was determined by delineating the area in which the average altitude of the potentiometric surface for 1995 was less than the altitude of the top of the upper Floridan aquifer (Figure 16). This area is smaller than the area Bush and Johnston (1988, plate 1) identify as an area in which the upper confining unit is absent or very thin, and it is also smaller, but closer, in size to the area Bush and Johnston (1988, plate 3) identify in the same report as an area in which the upper confining unit is missing or discontinuous. However, this part of the model area is in close agreement with a similar area delineated by Ryder (1985) in which the upper Floridan aquifer is generally unconfined and the upper confining unit is absent. In addition, with some differences, it generally coincides with the area beyond the western limit of the Hawthorn Group delineated by Scott (1988) (see Figure 9). The inconsistencies in the size of the area in which the upper Floridan aquifer is unconfined between Ryder (1985) and Bush and Johnston (1988) and the differences that would result if Scott's (1988) Hawthorn Group boundary were used to define the unconfined area apparently result from differences in the geologic and hydrogeologic definitions that are used to delineate it. In this study, delineating the unconfined area as the area in which the altitude of the potentiometric surface of the upper Floridan aquifer is less than the altitude of the top of the upper Floridan aquifer is considered to be the approach that represents this area best in a hydrogeologic sense in the groundwater flow model.

Inactive cells were assigned to layer three in the southwest and eastern parts of the model area (see Figure 33) where water with a chloride concentration of 5,000 mg/L or greater occupies the full thickness of the layer (Figure 13).

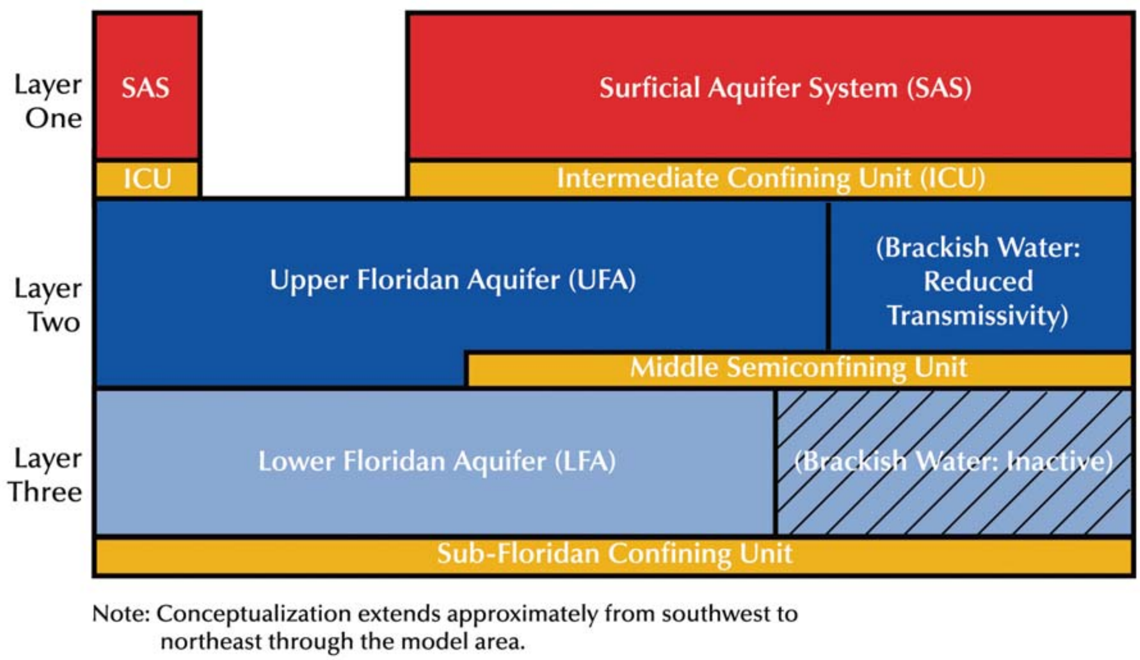

Figure 30. Conceptualization of the hydrogeologic system in north-central Florida

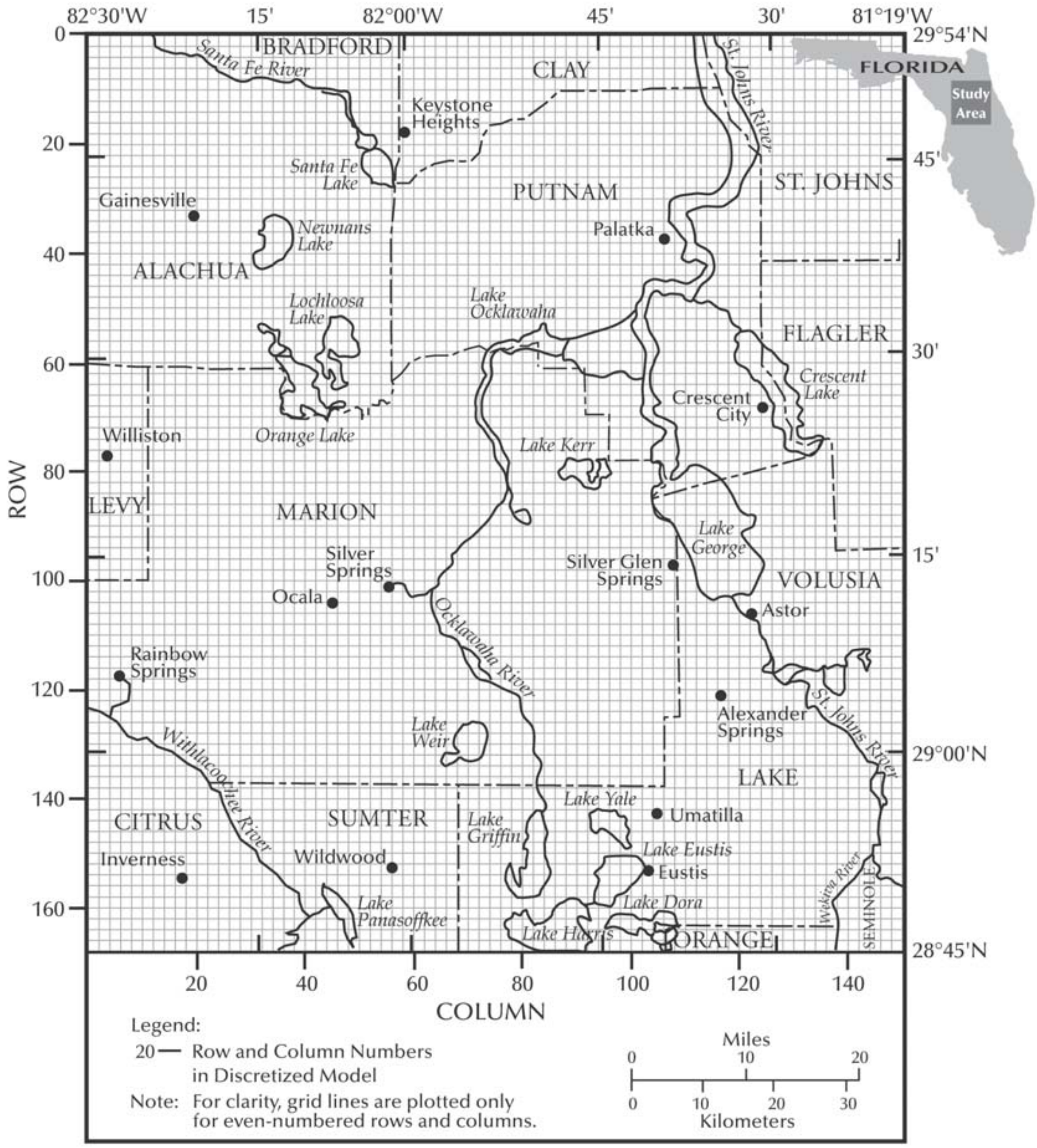

Figure 31. Discretization of the model area

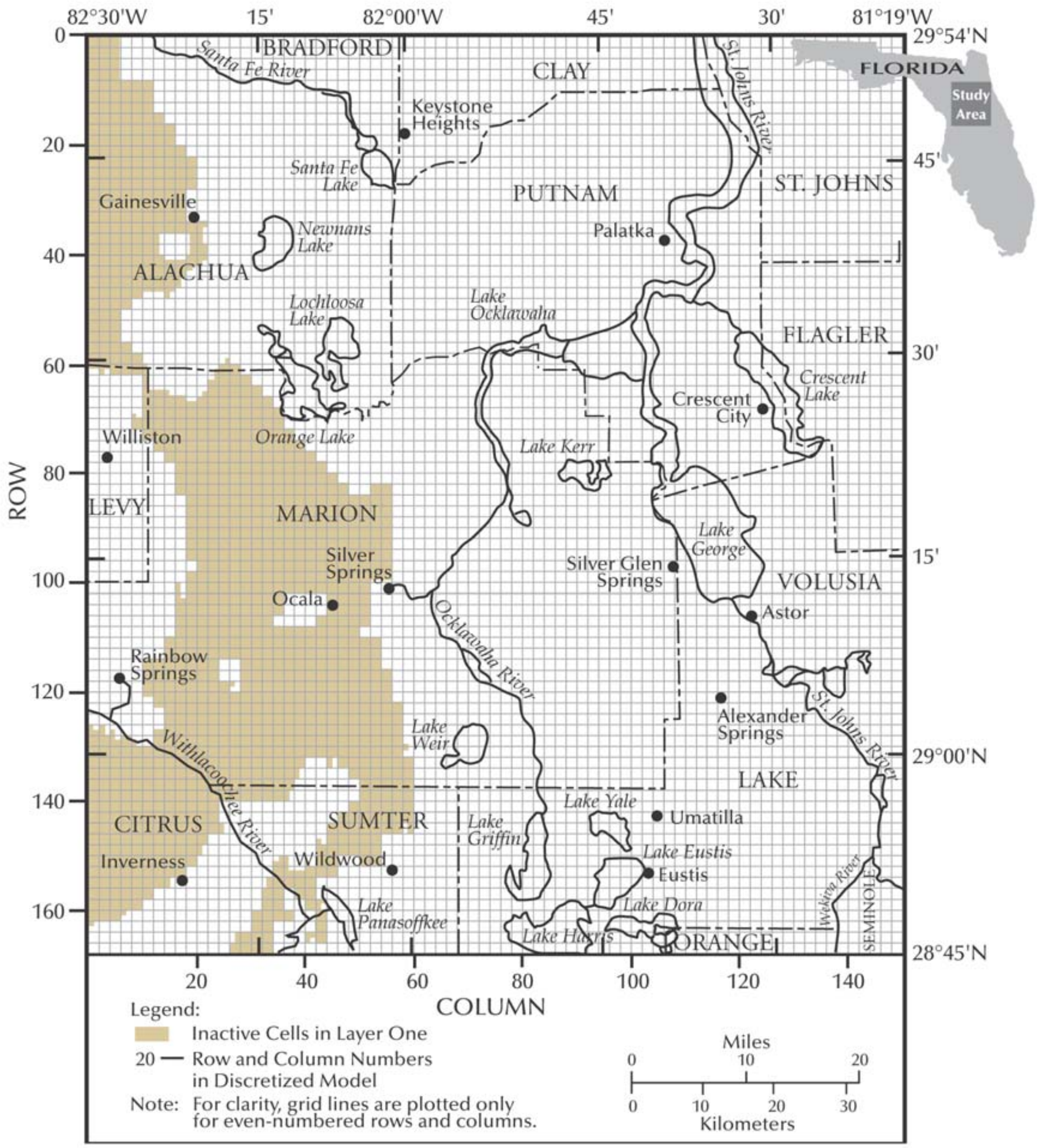

Figure 32. Active and inactive cells in layer one of the groundwater flow model

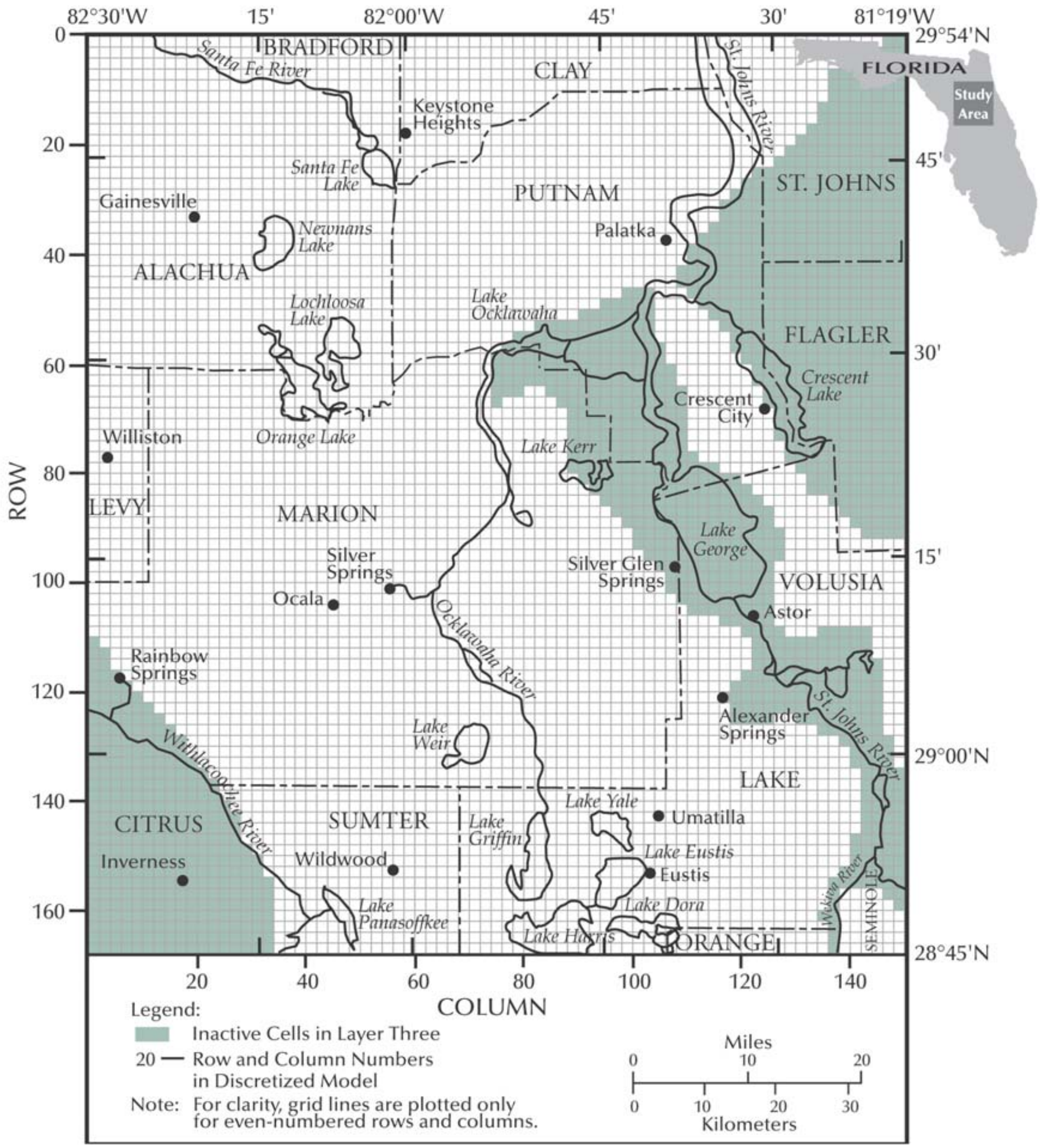

Figure 33. Active and inactive cells in layer three of the groundwater flow model

6.2.2 Starting Heads in the Surficial and Floridan Aquifer Systems

Starting heads that were input to layer one of the MODFLOW simulation were obtained for the center of each cell from the 1995 average water-table map of the surficial aquifer system (Figure 18). Similarly, starting heads for layer two were obtained for the center of each cell from the 1995 average potentiometric surface map of the upper Floridan aquifer (Figure 15). In the absence of water-level data for the lower Floridan aquifer, starting heads in layer three were assigned the same values as the corresponding heads in overlying layer two.

6.2.3 Assigned Aquifer Parameters

The average 1995 conditions were obtained by running a steady-state simulation with one stress period and one time step equal to 1.0 day. Layer one was treated as an unconfined layer in the area where it is present. The value for the horizontal hydraulic conductivity in layer one, K_1, was treated as a calibration factor and adjusted during the calibration process. Starting values for K_1 were based on physiographic subdivisions (Brooks 1981 and White 1970) (see Figure 6) and Soil Conservation Service (SCS) county soil maps. The bottom altitude of layer one, which includes both the surficial aquifer system and the intermediate confining unit, is an array developed by SJRWMD based on Miller (1986) to represent the top of the upper Floridan aquifer. The spatially variable array for the vertical leakance of the intermediate confining unit, or V_{cont1} in MODFLOW, for layer one was treated as a calibration parameter and adjusted during the calibration process. Starting values for V_{cont1} were based on Bush and Johnston (1988) and Motz and Dogan (2002).

Layer two was treated as a confined/unconfined layer with a constant transmissivity (with respect to time) at each cell location. Layer two represents the upper Floridan aquifer, and the spatially variable transmissivity (T_2) array for this layer was a calibration parameter adjusted during the calibration process. Starting values were based on Bush and Johnston (1988) and Motz and Dogan (2002). The altitude of the top of the aquifer in layer two is the same array as the bottom of layer one that is based on Miller (1986). The spatially variable array for the vertical leakance of the middle semiconfining unit, or V_{cont2} in MODFLOW, for layer two was a calibration parameter that was adjusted during the calibration process.

Layer three is a completely confined layer that represents the lower Floridan aquifer. The spatially variable transmissivity (T_3) array for this layer was a calibration parameter adjusted during the calibration process.

6.2.4 Groundwater Pumpage

Based on groundwater-use data and well location information compiled from SJRWMD, SRWMD, and SWFWMD, the pumpage in the study area (described in Chapter 5) was assigned to 11,757 cells in the groundwater model, with 11,721 cells in layer two and 36 cells in layer three. The net pumpage (i.e., discharge minus recharge) totals 255.8 mgd (3.419×10^7 ft^3/day) for 1995, with 252.2 mgd (3.371×10^7 ft^3/day) from layer two, which represents the upper Floridan aquifer, and 3.6 mgd (4.818×10^5 ft^3/day) from layer three, which represents the lower Floridan aquifer.

6.2.5 Recharge and Evapotranspiration

Recharge to the water table was computed by considering rainfall, irrigation, septic tank inflow, runoff, and evapotranspiration. The resulting net recharge was applied using the MODFLOW recharge package (RCH1) to layer one, where it is present, and to the unconfined parts of layer two, where it is the uppermost hydrogeologic unit. Daily rainfall was calculated using rainfall data collected at the eleven stations in and adjacent to the study area and the Thiessen polygon method (Table 1 and Figure 8). Irrigation and septic tank inflows were calculated from water-use data. It was assumed that 100 percent of agricultural and recreational (golf course) irrigation was applied to the land surface. Also, it was assumed that irrigation from industrial and commercial self-supplied sources was negligible. Lawn irrigation to the land surface from public-supply sources was estimated by assuming that outdoor household use derived from public supply was that part of the demand greater than the minimum demand required for indoor household use, which was taken to be the lowest monthly water use, generally in January. Ratios of lawn irrigation relative to total pumpage were calculated in this manner using county-by-county water-use data where it was available. In addition, it was assumed that 100 percent of the domestic self-supplied pumpage was applied as either lawn irrigation or septic tank inflow. The distribution of lawn irrigation and septic tank inflow from domestic self-supplied pumpage was assumed to be the same as the county-by-county ratios for outdoor and indoor use determined for public-supply pumpage. Treated effluent from wastewater treatment plants that is applied to the land by means of spray irrigation and percolations ponds was also considered as an inflow in calculating net recharge, but the overall contribution of this discharge in the model area is negligible.

Daily runoff was calculated by assuming that the total daily rainfall and irrigation could be treated as separate storm events and by applying the SCS (1972) method to estimate direct runoff for each day. SCS curve numbers, which characterize the runoff potential, were assigned for each uppermost cell in layer one or two from a SJRWMD database that considered soil types and land use. These curve number (CN) values, which represent average runoff conditions [i.e., antecedent moisture condition (AMC)-II], were adjusted, as required, for lower and higher runoff potential using antecedent rainfall. The adjusted CN values, for AMC-I and -III, respectively, were determined by calculating the five-day antecedent rainfall. Rainfall limits of less than 1.4 inches for AMC-I, 1.4 – 2.1 inches for AMC-II, and greater than 2.1 inches for AMC-III were used during the growing season, and rainfall limits of less than 0.5 inches for AMC-I, 0.5 – 1.1 inches for AMC-II, and greater than 1.1 inches for AMC-III were used during the dormant season. Based on average evapotranspiration distributions for Florida (Smajstrla et al. 1984), it was assumed that the growing season coincided with the spring and summer months of April through September and that the dormant season coincided with the autumn and winter months of October through March. The daily runoff was calculated from:

$$\mathrm{Ru} = \frac{\left[\left(\mathrm{P}+\mathrm{IR}\right) - 0.2\,\mathrm{S}\right]^2}{\mathrm{P}+\mathrm{IR}+0.8\,\mathrm{S}} \tag{6-1}$$

where Ru = runoff
P = precipitation
IR = irrigation rate; and
S = potential maximum retention, and where:

$$S = \frac{1000}{CN} - 10 \tag{6-2}$$

and where CN = curve number.

Potential evapotranspiration was calculated by multiplying pan evaporation data by monthly pan coefficients, the yearly average of which is 0.845 (Irmak et al. 2002). A value of 30 inches/year was assumed to be the minimum evapotranspiration rate, based on Sumner (1996) and Tibbals (1990), in cells in which irrigation and septic tank inflow did not occur. As described below, this value was adjusted upward in cells in which irrigation and septic tank inflow occurred.

Values for net recharge (R_{net}) to the water table were calculated as follows:
For cells in which there was no irrigation or septic tank inflow, evapotranspiration was assumed equal to the minimum evapotranspiration, or:

$$ET_{min} = 30 \text{ inches/year} \tag{6-3}$$

and net recharge was calculated as:

$$R_{net} = P + IR - Ru - ET_{min} \tag{6-4}$$

For cells in which the net irrigation and septic tank inflow were less than or equal to the difference between the potential and maximum evapotranspiration, the minimum evapotranspiration was equal to 30 inches/year plus net irrigation and septic tank inflow, or:

$$\text{If } IR_{net} + SEP \leq PET - ET_{min} \tag{6-5}$$

$$ET_{min} = 30 + IR_{net} + SEP \tag{6-6}$$

and recharge was calculated as:

$$R_{net} = P + IR - Ru - ET_{min} \tag{6-7}$$

For cells in which the net irrigation and septic tank inflow were greater than the difference between the potential and maximum evapotranspiration, the minimum evapotranspiration was equal to the potential evapotranspiration, or:

$$\text{If } IR_{net} + SEP > PET - ET_{min} \tag{6-8}$$

$$ET_{min} = PET \tag{6-9}$$

and recharge was calculated as:

$$R_{net} = P + IR - Ru + IR_{net} + SEP - ET_{min} \tag{6-10}$$

In addition, during calibration, recharge rates at some cells were decreased slightly to prevent the water table from rising unrealistically above land surface. In these cells, the decrease in recharge was added to the runoff from the cell.

In addition to accounting for the minimum evapotranspiration in the net recharge calculations, the evapotranspiration (EVT1) package in MODFLOW was used to simulate the effects of transpiration and evaporation in removing water from the saturated regime. In the EVT1 package, the loss of water due to evapotranspiration decreases linearly as a function of the depth of the water table from a water-surface elevation at which the evapotranspiration is a maximum (ET surface elevation) to a maximum, or extinction, depth below which evapotranspiration does not occur (McDonald and Harbaugh 1988). It was assumed that the land-surface elevation in each cell represented the ET surface elevation and that the extinction depth was 5.0 feet. The maximum evapotranspiration in the EVT1 package was the potential evapotranspiration minus the minimum evapotranspiration already accounted for in the net recharge calculations, or:

$$ET_{max} = PET - ET_{min} \tag{6-11}$$

where ET_{max} = maximum evapotranspiration rate in each cell in the EVT1 package.

6.2.6 Springs

The forty-seven named springs that discharge from the upper Floridan aquifer in the study area (Figure 19 and Table 6) are represented in the model by forty-six cells in the MODFLOW drain (DRN1) package (see Figure 34 and Table 11). Juniper and Fern Hammock springs are located in the same cell. In MODFLOW, spring discharges are calculated from:

$$QD = CD\,(HS - HD) \tag{6-12}$$

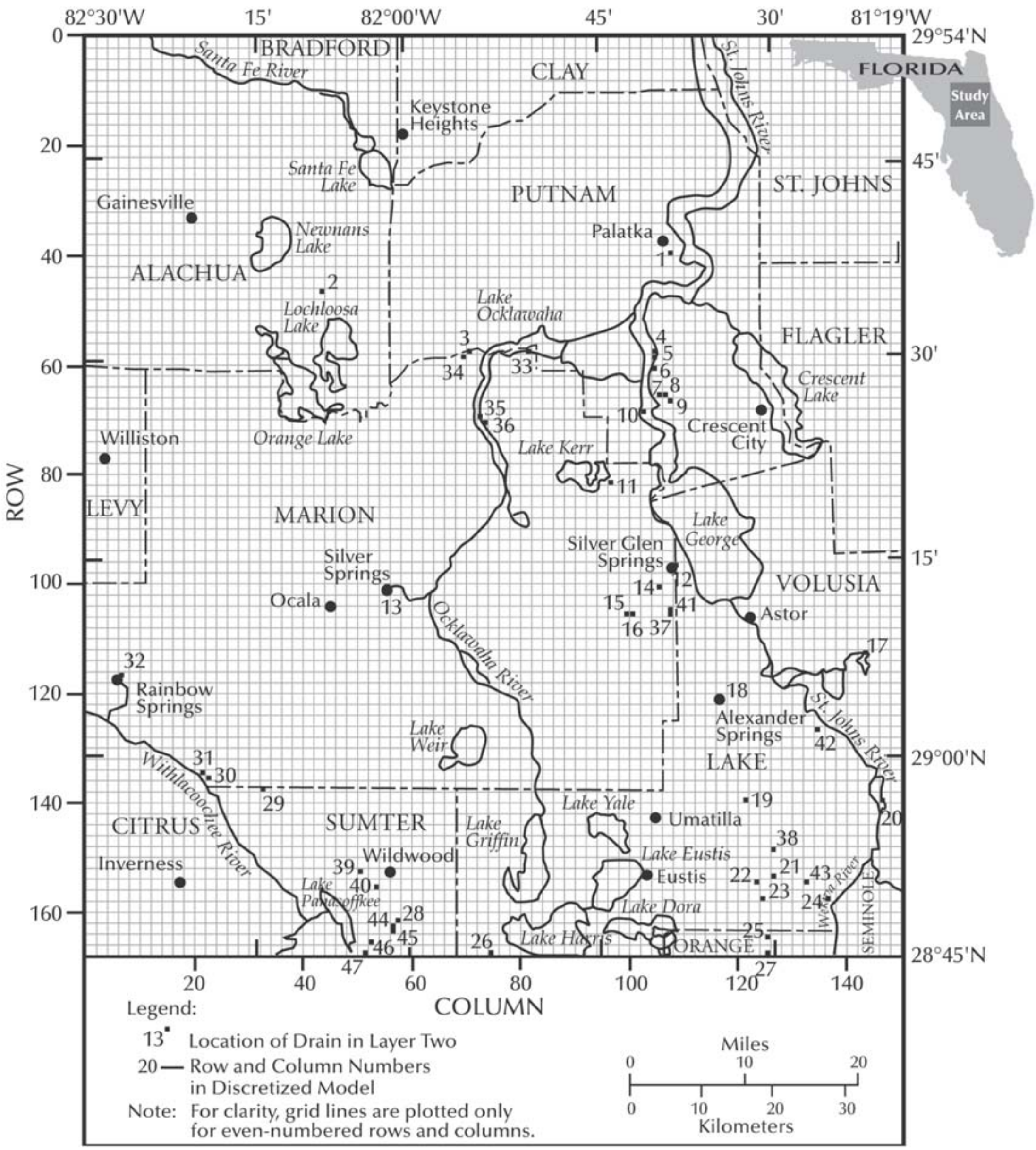

Figure 34. Locations of drain cells in layer two that represent springs discharging from the upper Floridan aquifer in north-central Florida

Table 11. Simulation results for springs and drains in the average 1995 simulation

Spring	Drain Number	Row	Column	Spring Conductance (ft^2/day)	Simulated Head in Cell (ft, NGVD)	Spring Pool Altitude (ft, NGVD)	Simulated Discharge (ft^3/day)	Measured (or Estimated) Discharge (ft^3/day)
Whitewater	1	40	108	2.55×10^4	24.6	20.68	1.00×10^5	1.00×10^5
Magnesia	2	47	44	5.42×10^3	72.6	60	6.83×10^4	6.83×10^4
Orange	3	58	71	4.36×10^3	65.5	24	1.81×10^5	1.81×10^5
Satsuma	4	58	105	2.67×10^4	12.8	10	7.47×10^4	7.46×10^4
Nashua	5	59	105	9.66×10^3	12.7	10	2.59×10^4	2.59×10^4
Welaka	6	61	105	5.15×10^4	12.7	11	8.65×10^4	8.64×10^4
Mud	7	66	106	6.00×10^3	11.6	3	5.19×10^4	5.18×10^4
Forest	8	66	107	3.27×10^3	11.9	4	2.59×10^4	2.59×10^4
Beecher	9	67	108	4.42×10^4	11.7	2	4.27×10^5	4.27×10^5
Croaker Hole	10	69	103	1.77×10^6	7.45	4	6.13×10^6	6.13×10^6
Salt	11	82	97	6.16×10^5	11.8	1.37	6.40×10^6	6.40×10^6
Silver Glen	12	97	109	5.33×10^6	3.17	1.45	9.17×10^6	9.13×10^6
Silver	13	101	56	2.79×10^7	42.6	40.39	6.12×10^7	6.11×10^7
Sweetwater	14	101	106	2.24×10^5	12.7	7.69	1.12×10^6	1.12×10^6
Juniper and Fern Hammock	15	106	100	4.92×10^5	27.7	23.4	2.13×10^6	2.13×10^6
Ponce de Leon*	17	113	144	1.52×10^5	12.8	2	1.64×10^6	1.64×10^6
Alexander	18	121	117	1.33×10^6	16.7	10.38	8.47×10^6	8.48×10^6
Camp La No Che	19	140	122	7.35×10^3	40.7	29	8.62×10^4	8.62×10^4
Blue (Volusia)**	20	140	147	5.15×10^5	9.39	4.16	2.69×10^6	2.69×10^6
Messant	21	154	127	2.16×10^5	33.2	27	1.34×10^6	1.34×10^6
Seminole	22	155	124	6.05×10^5	31.8	25	4.13×10^6	4.13×10^6
Droty	23	158	125	2.93×10^3	37.9	15	6.70×10^4	6.70×10^4
Island	24	158	137	6.20×10^4	20.5	9	7.15×10^5	7.15×10^5
Camp	25	165	126	3.95×10^3	40.0	23	6.70×10^4	6.70×10^4
Bugg	26	168	75	9.10×10^4	67.2	59	7.42×10^5	7.42×10^5
Rock***	27	168	126	1.18×10^5	37.3	26.17	1.31×10^6	1.31×10^6

Table 11–*Continued*

Spring	Drain Number	Row	Column	Spring Conductance (ft^2/day)	Simulated Head in Cell (ft, NGVD)	Spring Pool Altitude (ft, NGVD)	Simulated Discharge (ft^3/day)	Measured (or Estimated) Discharge (ft^3/day)
Fenney	28	162	58	1.54×10^5	53.9	45	1.37×10^6	1.37×10^6
Gum	29	138	33	1.92×10^6	37.4	34	6.56×10^6	6.56×10^6
Blue (Citrus County)	30	136	23	2.17×10^5	34.8	30	1.03×10^6	1.03×10^6
Wilson Head	31	135	22	4.00×10^4	34.6	30	1.84×10^5	1.84×10^5
Rainbow	32	117	7	1.40×10^7	34.6	30.6	5.64×10^7	5.63×10^7
Blue (near Orange City)	33	58	82	4.20×10^3	39.1	31	3.39×10^4	3.39×10^4
Camp Seminole	34	59	70	6.58×10^3	65.5	54.5	7.24×10^4	7.24×10^4
Wells Landing	35	70	73	1.69×10^4	37.8	30.8	1.19×10^5	1.19×10^5
Tobacco Patch	36	71	74	1.01×10^5	36.7	30.8	5.93×10^5	5.93×10^5
Juniper Creek Tributary	37	106	108	8.58×10^3	19.8	4	1.36×10^5	1.36×10^5
Blackwater	38	149	127	1.27×10^4	37.3	25	1.56×10^5	1.56×10^5
Little Jones Creek No. 2	39	153	51	1.41×10^5	47.2	44	4.57×10^5	4.57×10^5
Little Jones Creek No. 3	40	156	54	6.55×10^4	48.0	44	2.59×10^5	2.59×10^5
Morman Branch Seepage	41	105	108	6.24×10^3	16.9	3	8.64×10^4	8.64×10^4
Mosquito	42	127	135	8.10×10^4	17.7	16	1.40×10^5	1.40×10^5
Palm	43	155	133	1.23×10^4	32.0	28.5	4.32×10^4	4.32×10^4
Shady Brook Creek No. 2	44	163	57	2.65×10^4	54.0	44.5	2.51×10^5	2.51×10^5
Shady Brook Creek No. 3	45	164	57	5.98×10^4	54.2	50	2.51×10^5	2.51×10^5
Shady Brook Creek No. 4	46	166	53	4.54×10^4	51.5	46	2.51×10^5	2.51×10^5
Shady Brook Creek No. 5	47	168	52	2.30×10^4	50.9	40	2.51×10^5	2.51×10^5
						Total (ft^3/day)	1.77×10^8	1.77×10^8

Note: * = discharge from model area represents approximately 80% of total discharge
** = discharge from model area represents approximately 20% of total discharge
*** = discharge from model area represents approximately 25% of total discharge

where QD = spring discharge [$L^3 T^{-1}$]
CD = spring conductance [$L^2 T^{-1}$]
HS = the model-simulated head for the upper Floridan aquifer at the node in the cell in layer two in which the spring is located [L]; and
HD = the spring-pool altitude [L].

Equation 6-12 is equivalent to the drain discharge equation in MODFLOW (Equation 69 in McDonald and Harbaugh 1988). For twelve of the springs, the spring-pool altitude was reported by SJRWMD or the USGS (see Table 6). For the other springs, the altitude at which the spring discharged was estimated from the USGS 7.5-minute topographic quadrangle map that contains the spring. Conductance values, which are treated as lumped parameters in MODFLOW, were adjusted individually during calibration of the model.

6.2.7 Direct Discharge

The areas where direct discharge occurs between the groundwater system and parts of the surface-water system are represented by 3,105 cells in the MODFLOW river (RIV) package (see Figure 35). In layer one, 878 cells are located along the St. Johns River, 225 cells along the Ocklawaha River, and 56 cells along the Santa Fe River. Lakes larger than approximately one square mile are represented by 1,035 cells in layer one. Also, several relatively small areas that contain tributaries of rivers and streams and/or in which the water table in the model was unrealistically above land surface during calibration are represented by 688 river cells in layer one. The areas where direct discharge occurs between the groundwater system and the Withlacoochee River are represented by 223 river cells in layer two. Of these, 82 cells are located along the river, and 141 cells represent lakes and wetlands along the river (see Figure 35). Conductance values for the river cells were adjusted during calibration to match the simulated and estimated direct discharges for the zones in which direct discharge could be estimated from available stream-flow data (Tables 7 and 8 and Figures 20 through 25).

6.2.8 General Head Boundary Conditions

In MODFLOW, at a general head boundary (GHB), flow into or out of a boundary cell from an external source is proportional to the difference between the head in the cell and the head assigned to the external source. The external source can be considered to represent a specified head boundary located some distance from the boundary cell, and flow occurs to or from the boundary cell if heads in the boundary cell and at the external source are different. If heads in the boundary cell and at the external source are the same, then flow does not occur between the boundary cell and the external source, and a no-flow boundary, or streamline, can be considered to exist between the boundary cell and the external source. In MODFLOW, the lateral flow rate across each boundary-cell face is calculated from (Equation 78, McDonald and Harbaugh 1988):

$$QGHB = TW \frac{(HB - HS)}{L} \qquad (6\text{-}13)$$

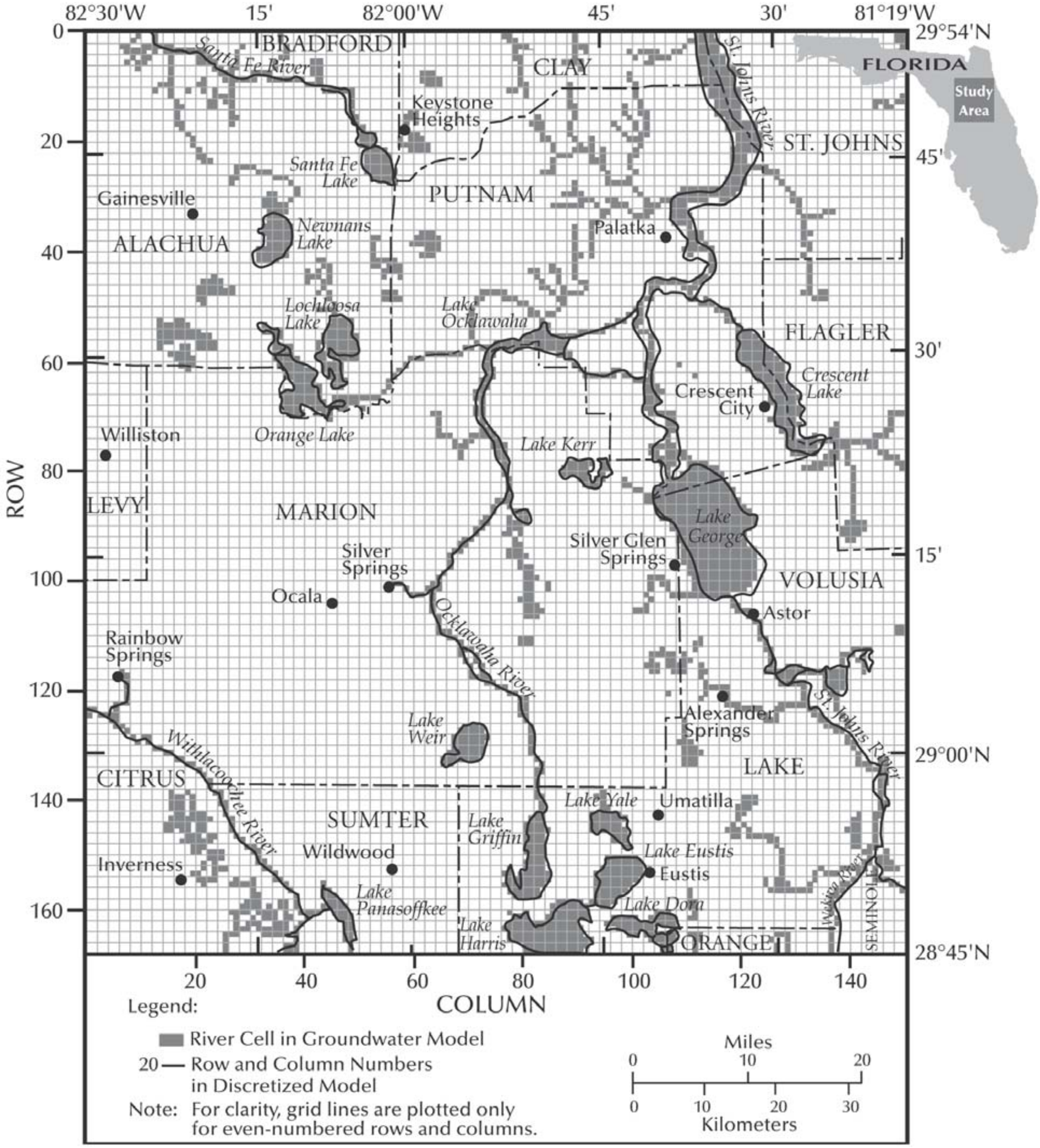

Figure 35. Locations of river cells in layers one and two that represent areas of direct discharge between the groundwater system and parts of the surface-water system

where QGHB = lateral flow rate [$L^3 T^{-1}$]
T = aquifer transmissivity between HS and HB [$L^2 T^{-1}$]
W = width of the cell face perpendicular to the flow [L]; and
HB = specified GHB head [L]
HS = model-specified head at the boundary node [L]
L = distance from HS to HB [L].

The quantity TW/L is equal to the boundary conductance [$L^2 T^{-1}$]. In the model area, the Floridan aquifer system generally is a regionally extensive aquifer that does not have physical or hydraulic boundaries that result in constant-head or no-flow boundaries. Thus, in a simulation, it is more realistic to allow for the effects of pumping and other stresses to extend beyond the boundaries represented in the model. By using GHB conditions instead of constant head or no-flow boundaries in simulating this system, the effects of pumping and other stresses near the model boundaries can be included without creating unrealistic flow or head conditions near the boundaries.

In the north-central Florida groundwater flow model, GHB conditions were assigned to 632 cells around the periphery of layers two and 418 cells around the periphery of layer three for a total of 1,050 GHB's. The conductance for each GHB cell was obtained from the product of the transmissivity and width of the boundary cell divided by the length of the flow path between the specified-head source and the adjacent boundary cell. The distance to the specified-head source from the center of the adjacent boundary cell was arbitrarily assigned a value of 10,000 ft. Head values at each external source were average heads for 1995 based on data obtained from SJRWMD for the May and September 1995 potentiometric surfaces in the upper Floridan aquifer.

6.3 CALIBRATION RESULTS FOR AVERAGE 1995 CONDITIONS

6.3.1 Comparison of Observed and Simulated Water Levels

Hydraulic heads simulated for layers one and two were compared to corresponding heads that represented average 1995 conditions at the target wells and other locations in the model area (Figures 15 and 18). Values for the hydraulic conductivity in layer one (K_1), vertical leakance in layer one (V_{cont1}), transmissivity in layer two (T_2), vertical leakance in layer two (V_{cont2}), transmissivity in layer two (T_2), and the conductance at the drain cells in layers one and two were adjusted until the simulated heads in layers one and two were within reasonable agreement with the observed heads.

For the model simulation that was considered calibrated, the mean of the differences between the simulated and observed heads in layer one is –0.80 ft and the root mean square error of the head differences is 4.51 ft (see Figures 36 through 38). The differences between the simulated and observed heads at the target wells and other locations in the surficial aquifer system range from –9.75 to 9.53 ft (see Figure 39). In layer two, the mean of the differences

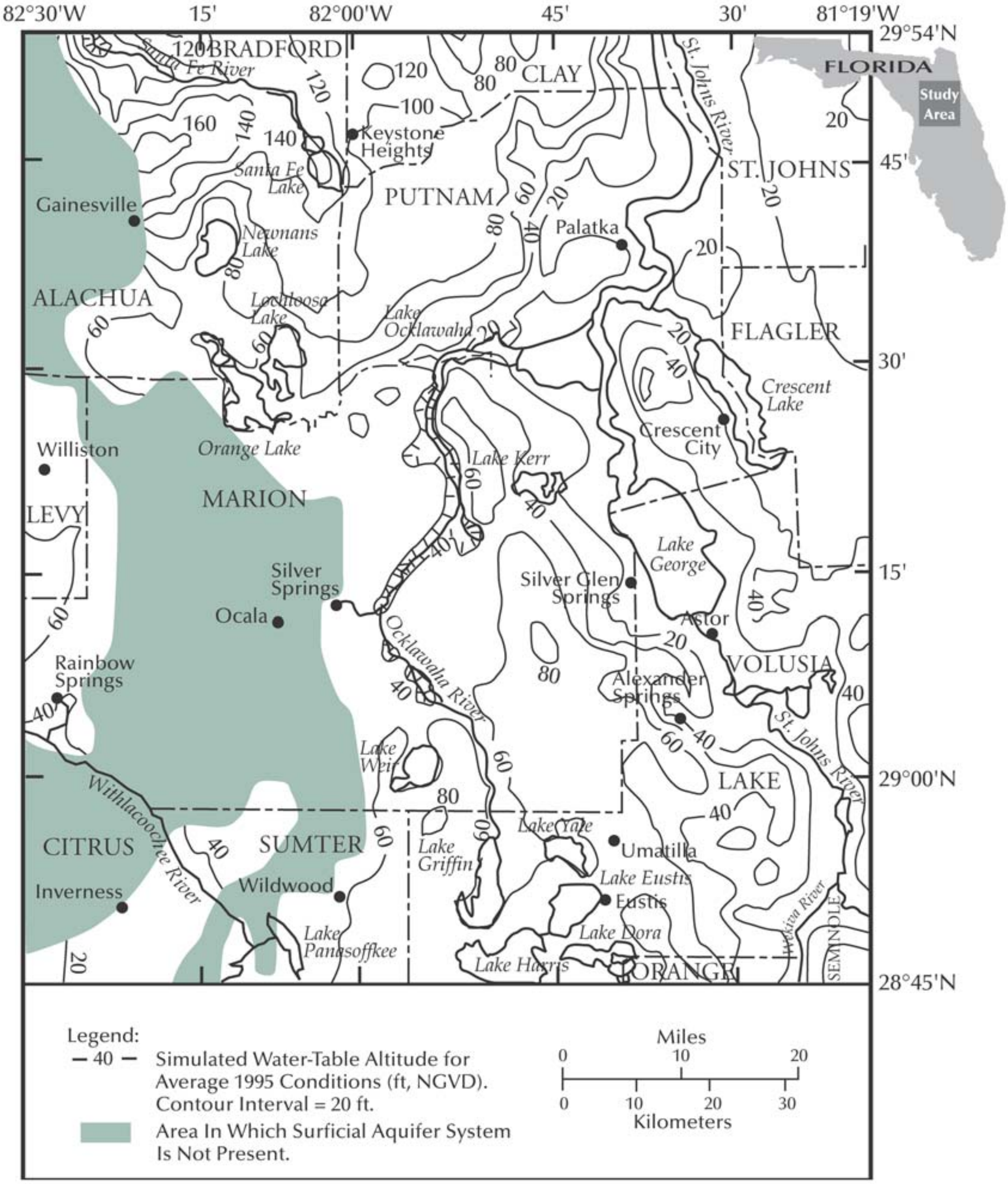

Figure 36. Simulated water table in the surficial aquifer system in north-central Florida for average 1995 conditions

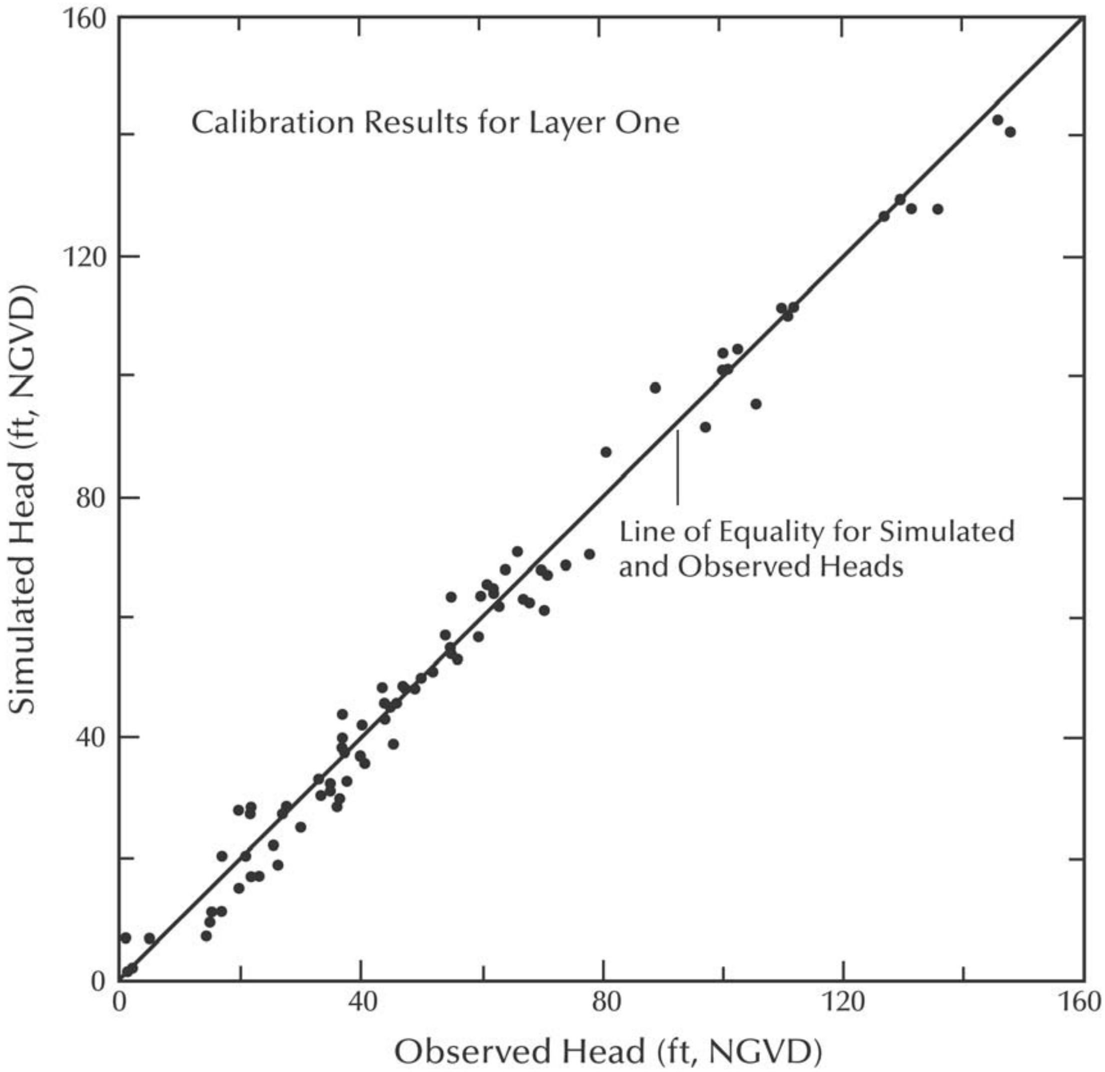

Figure 37. Scatter diagram of simulated heads in layer one and heads observed in target wells and other locations in the surficial aquifer system in north-central Florida for average 1995 conditions

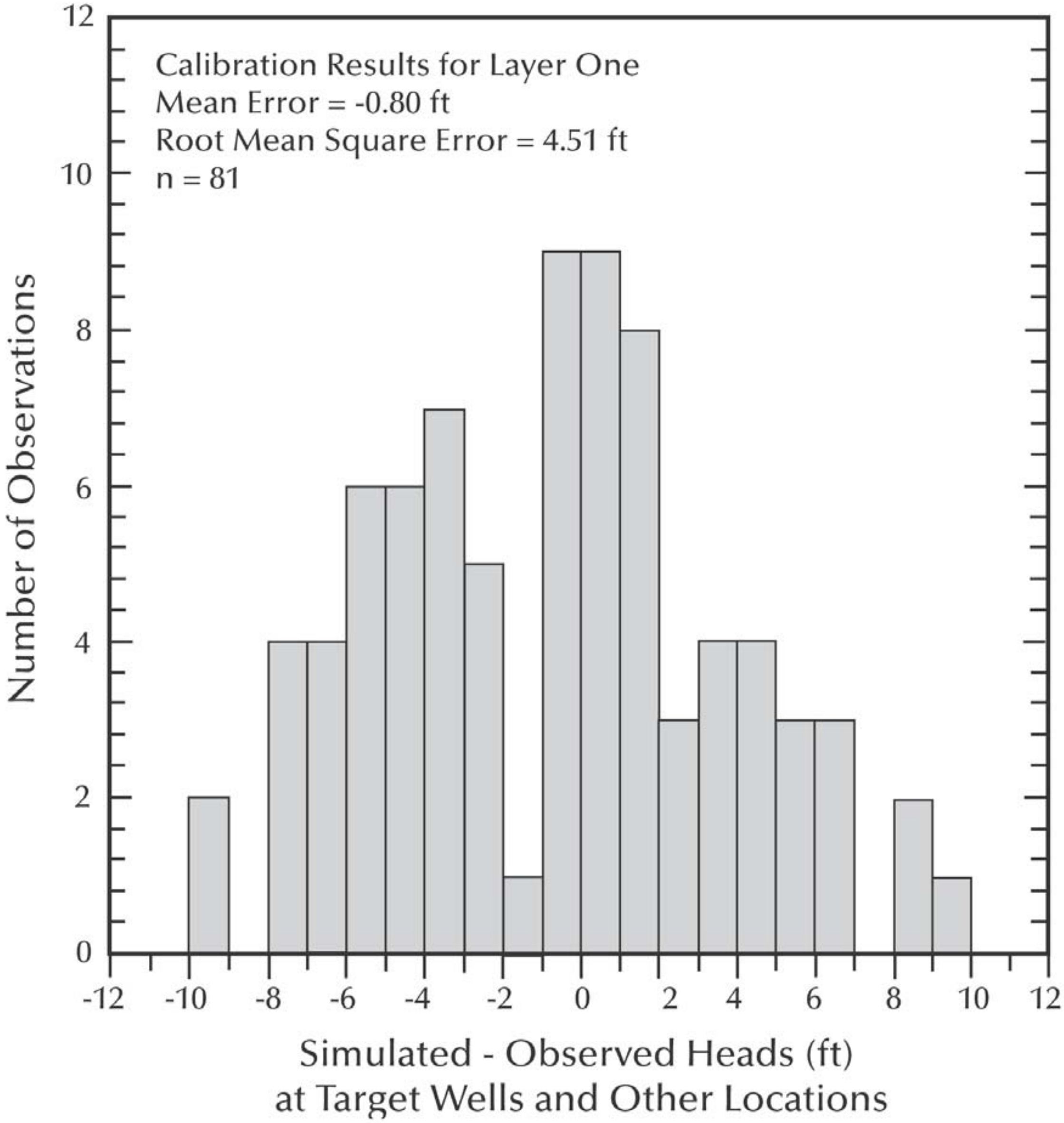

Figure 38. Histogram of residuals between simulated heads in layer one and heads observed in target wells and other locations in the surficial aquifer system in north-central Florida for average 1995 conditions

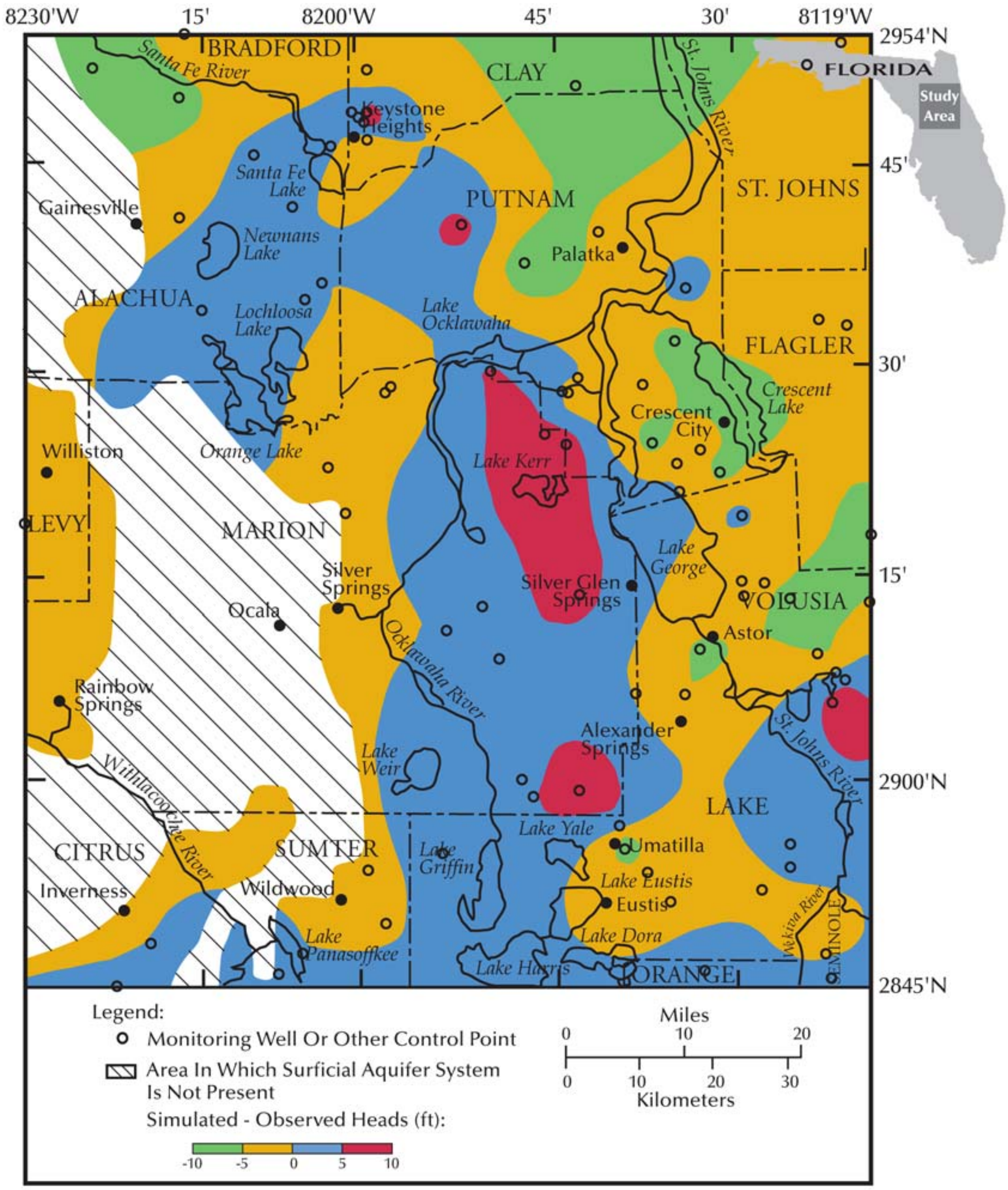

Figure 39. Spatial distribution of residuals between simulated heads in layer one and heads observed in target wells and other locations in the surficial aquifer system in north-central Florida for average 1995 conditions

between the simulated and observed heads is -0.07 ft and the root mean square error is 3.27 ft (see Figures 40 through 42). The differences between the simulated and observed heads at the target wells in the upper Floridan aquifer range from –7.39 to 7.05 ft (see Figure 43).

The calibrated values for K_1 in layer one, representing the horizontal hydraulic conductivity of the surficial aquifer system, range from 5 to 125 ft/day (see Figure 44), and the calibrated values for V_{cont1} in layer one, representing the leakance of the intermediate confining unit, range from 1.0×10^{-6} to 4.0×10^{-3} day^{-1} (see Figure 45). The calibrated values for transmissivity in layer two, representing the upper Floridan aquifer, range from 5,000 to 1.0×10^{7} ft^2/day (see Figure 46), and the calibrated values for V_{cont2} in layer two, representing the leakance of the middle semiconfining unit, range from 1.0×10^{-6} to 5.0×10^{-3} day^{-1} (see Figure 47). The calibrated values for transmissivity in layer three, representing the lower Floridan aquifer, range from 280,000 to 2.0×10^{6} ft^2/day (see Figure 48).

6.3.2 Springs

At each drain location, the simulated spring discharge was obtained in MODFLOW by multiplying the calibration adjusted conductance value by the difference between the simulated average 1995 head in the cell and the spring discharge water-surface altitude (see Table 11). Overall, the simulated spring discharges total 2,046 cfs, which matches the total observed and estimated discharges. Also, there is close agreement between individual simulated spring discharges and the measured (and estimated) average 1995 spring discharges (see Table 11 and Figure 49).

6.3.3 Direct Discharge

The simulated net discharge into the 666 river cells that represent the part of the St. Johns River for which direct discharge was estimated (see Figure 50) is 376 cfs, which is approximately 9 percent greater than the 346 cfs estimated for the direct discharge into this part of the river (Table 7). The simulated net discharge into the 199 cells that represent the part of the Ocklawaha River for which direct discharge was estimated (see Figure 50) is 99.2 cfs, which is approximately 30 percent greater than the 73.7 cfs estimated for the direct discharge into this part of the river (Table 7). The simulated net discharge into the 38 cells that represent the part of the Santa Fe River for which direct discharge was estimated (see Figure 50) is 24.2 cfs, which is nearly the same as the 24.5 cfs estimated for the direct discharge into this part of the river (Table 8). Also, the simulated net discharge into the 34 cells that represent the part of the Withlacoochee River for which direct discharge was estimated (see Figure 50) is 73.9 cfs, which is nearly the same as the 73.0 cfs estimated for the direct discharge into this part of the river (Table 8).

6.3.4 Water Budget

For the simulated average 1995 conditions, rainfall is 52.45 inches/year, irrigation is 0.47 inches/year, septic tank inflow is 0.17 inches/year, runoff is 8.27 inches/year, minimum evapotranspiration is 30.72 inches/year, and net recharge to the water table is 14.09 inches/year (see Figure 51).

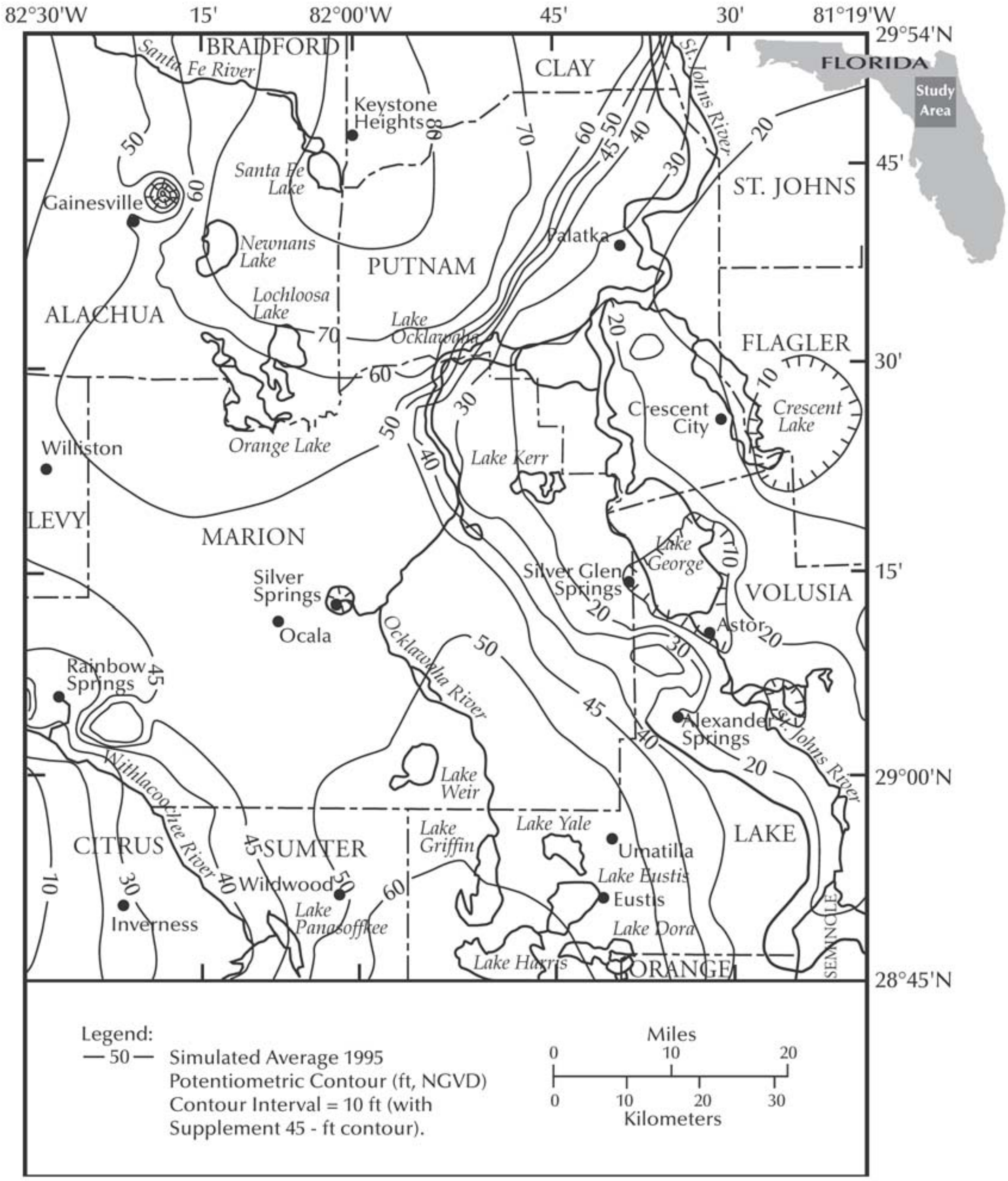

Figure 40. Simulated potentiometric surface in the upper Floridan aquifer in north-central Florida for average 1995 conditions

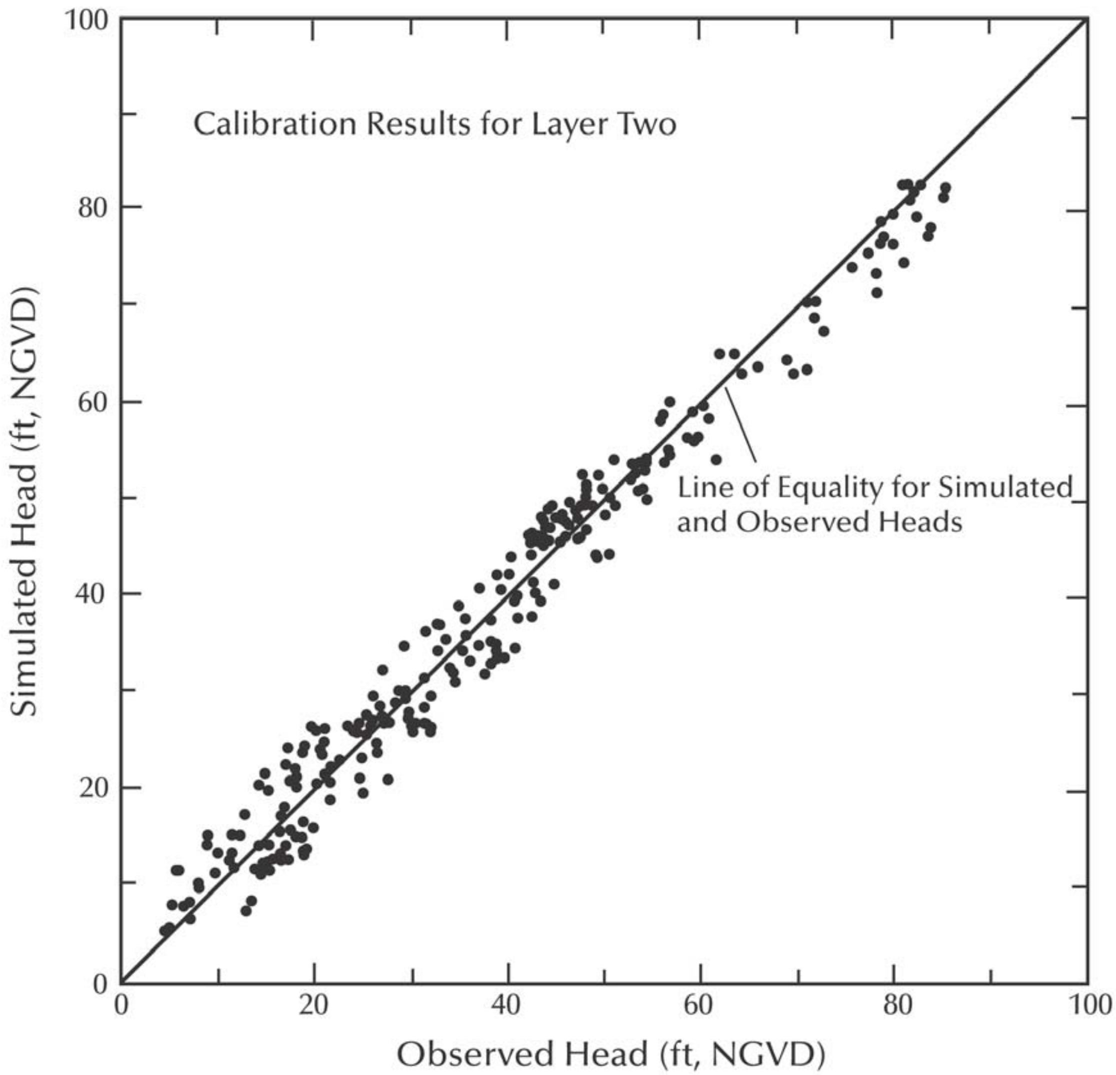

Figure 41. Scatter diagram of simulated heads in layer two and heads observed in target wells in the upper Floridan aquifer in north-central Florida for average 1995 conditions

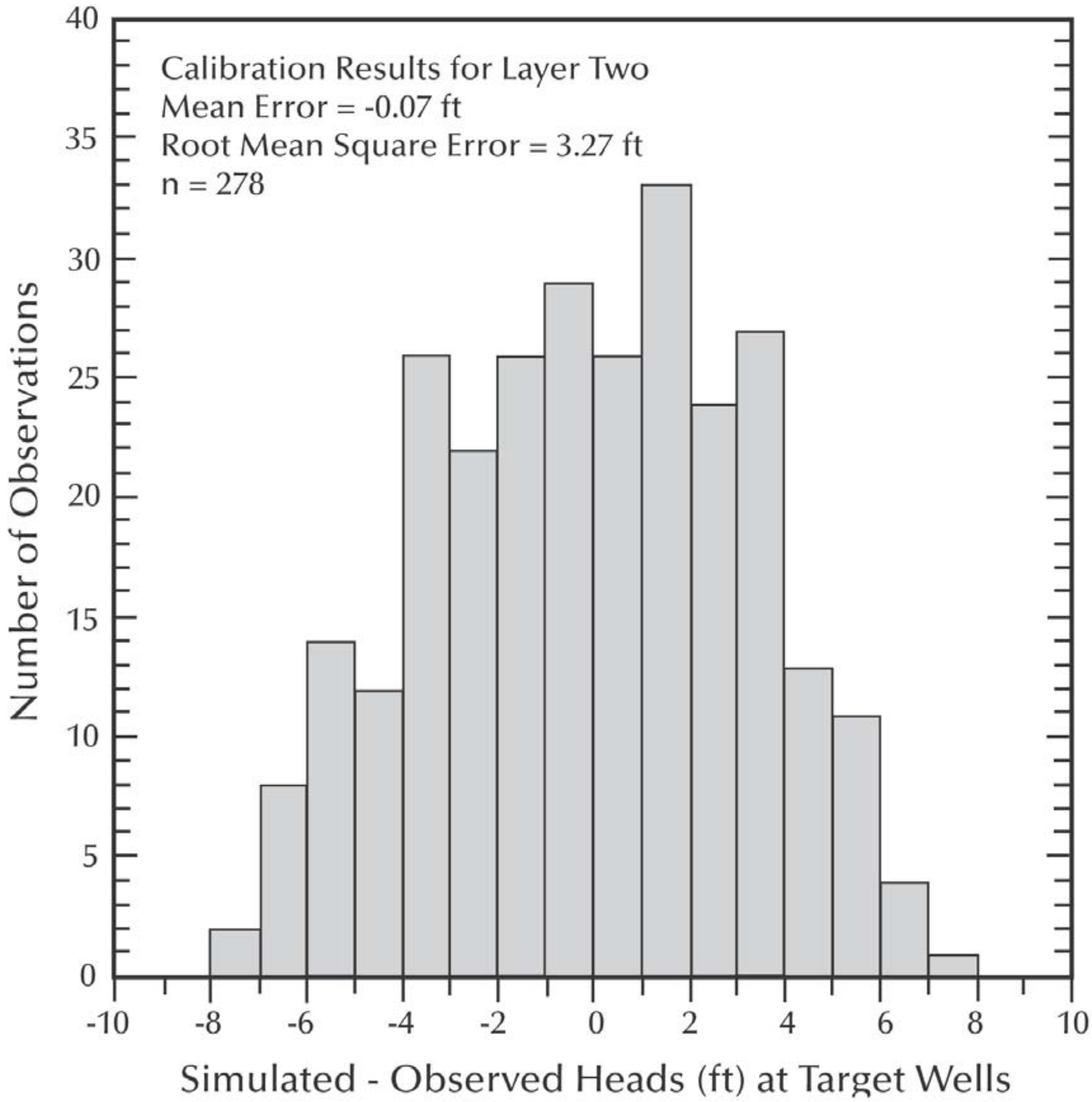

Figure 42. Histogram of residuals between simulated heads in layer two and heads observed in target wells in the upper Floridan aquifer in north-central Florida for average 1995 conditions

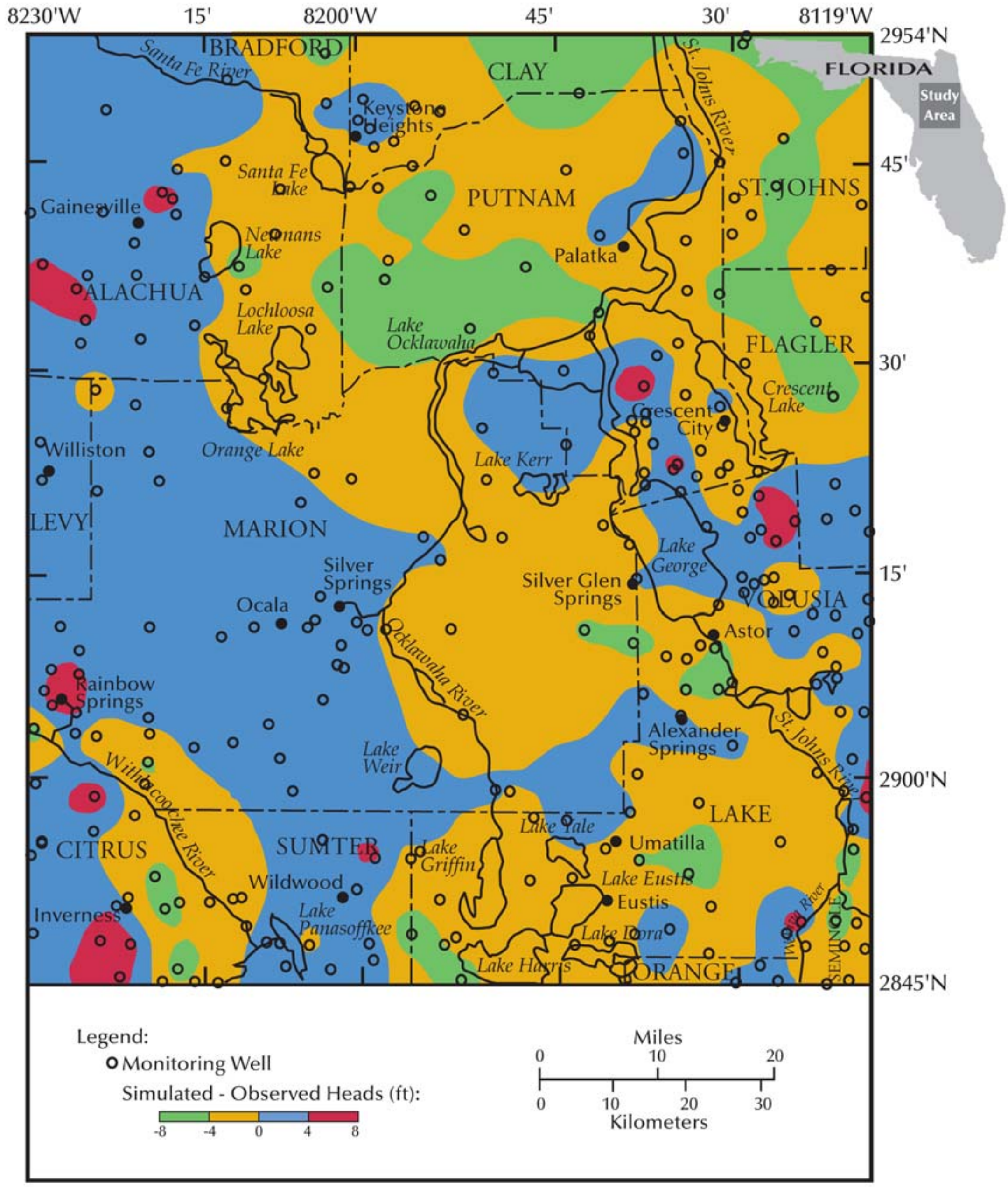

Figure 43. Spatial distribution of residuals between simulated heads in layer two and heads observed in target wells in the upper Floridan aquifer in north-central Florida for average 1995 conditions

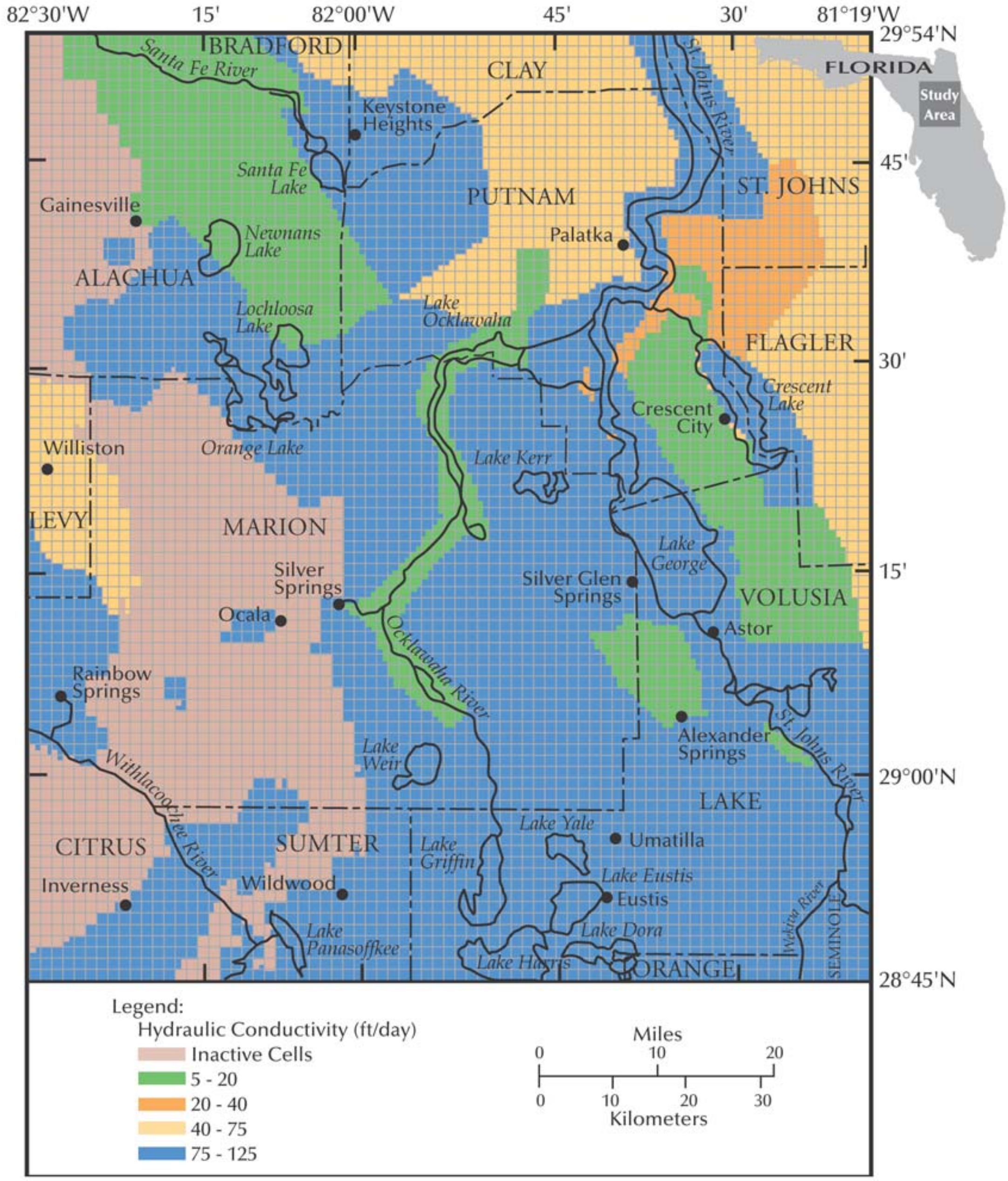

Figure 44. Calibrated hydraulic conductivity array of the surficial aquifer system in north-central Florida in the average 1995 simulation

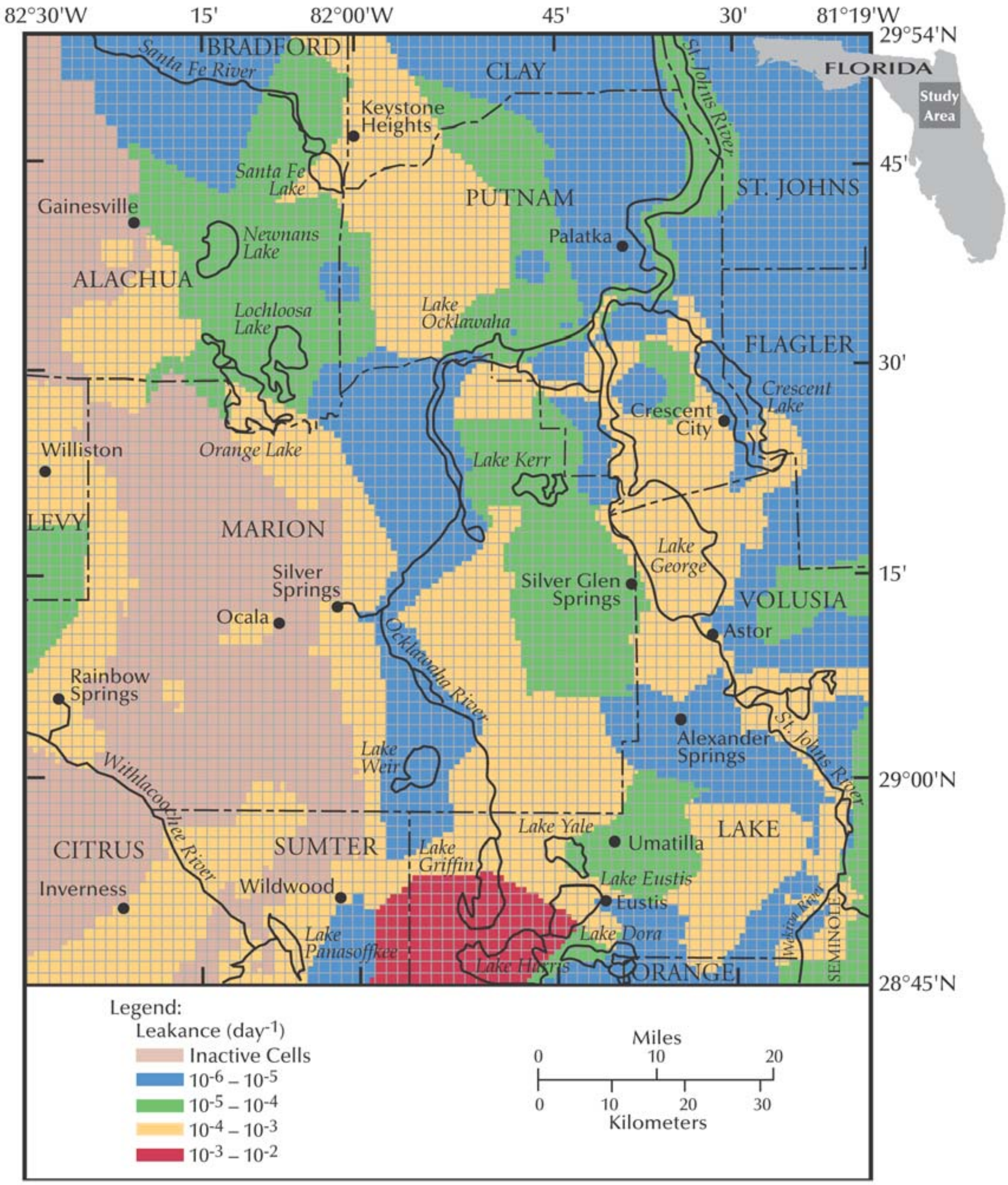

Figure 45. Calibrated leakance array of the intermediate confining unit in north-central Florida in the average 1995 simulation

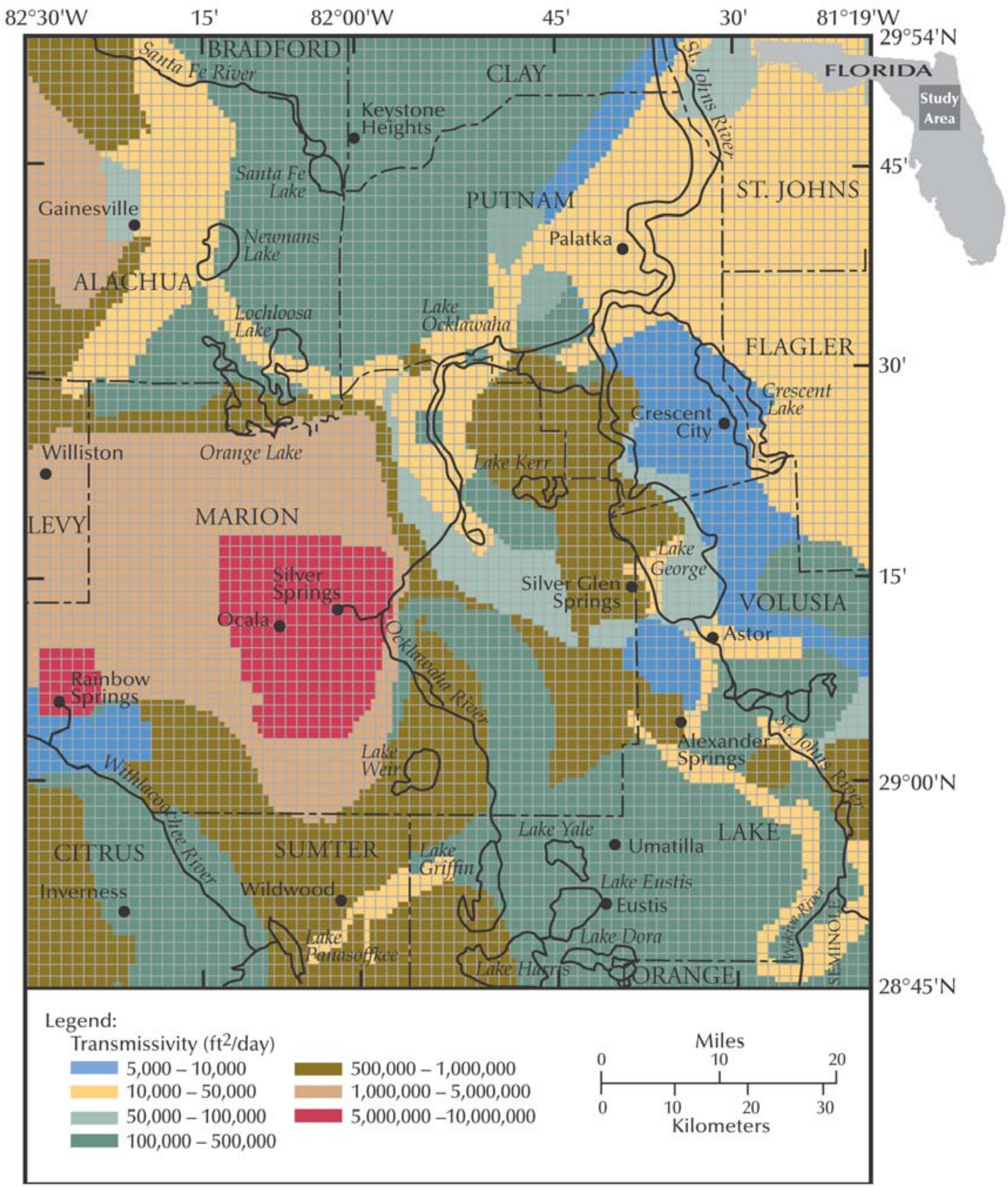

Figure 46. Calibrated transmissivity array of the upper Floridan aquifer in north-central Florida in the average 1995 simulation

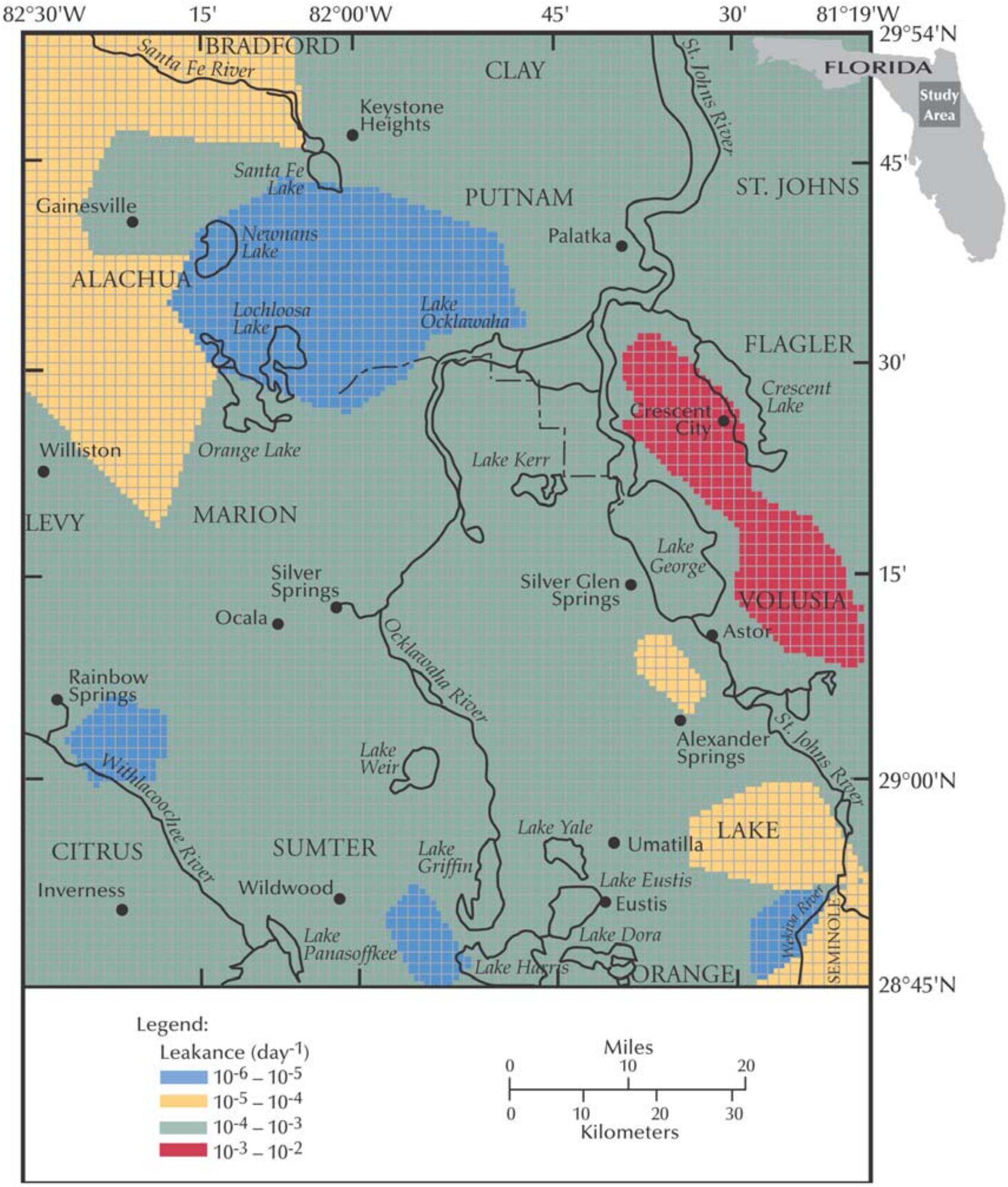

Figure 47. Calibrated leakance array of the middle semiconfining unit in north-central Florida in the average 1995 simulation

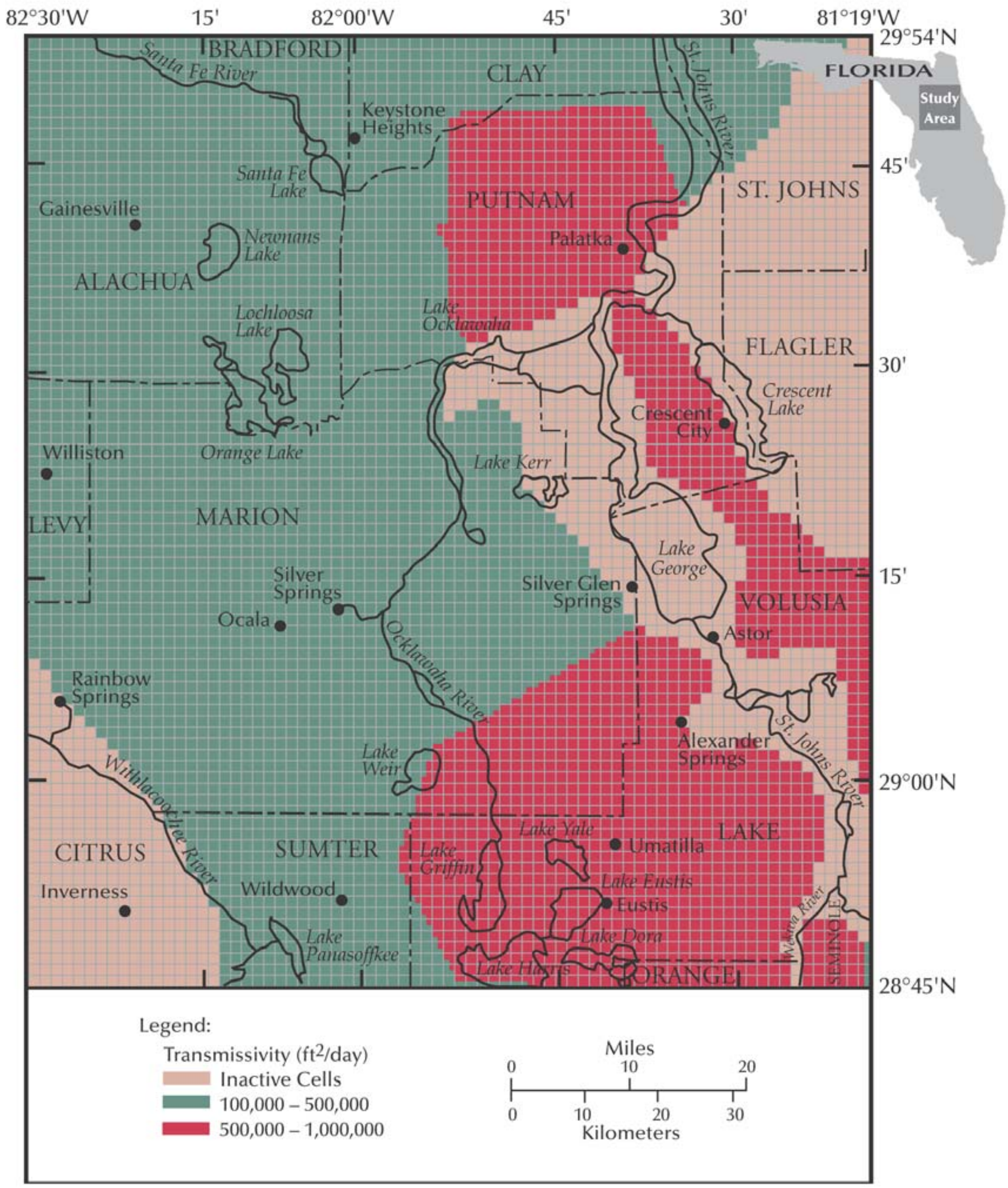

Figure 48. Calibrated transmissivity array of the lower Floridan aquifer in north-central Florida in the average 1995 simulation

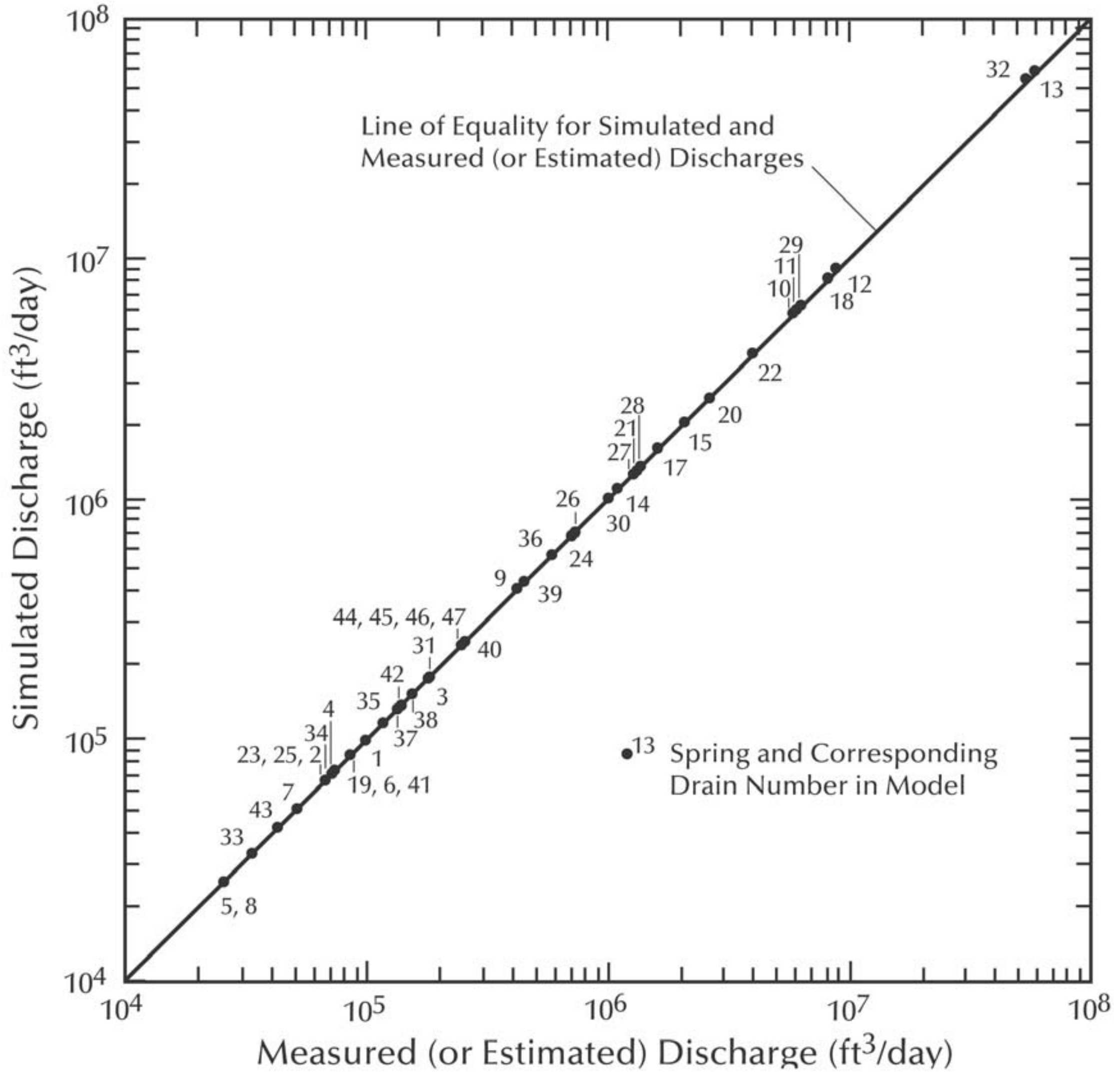

Figure 49. Scatter diagram of the simulated and measured (or estimated) average 1995 spring discharges from the upper Florida aquifer in north-central Florida

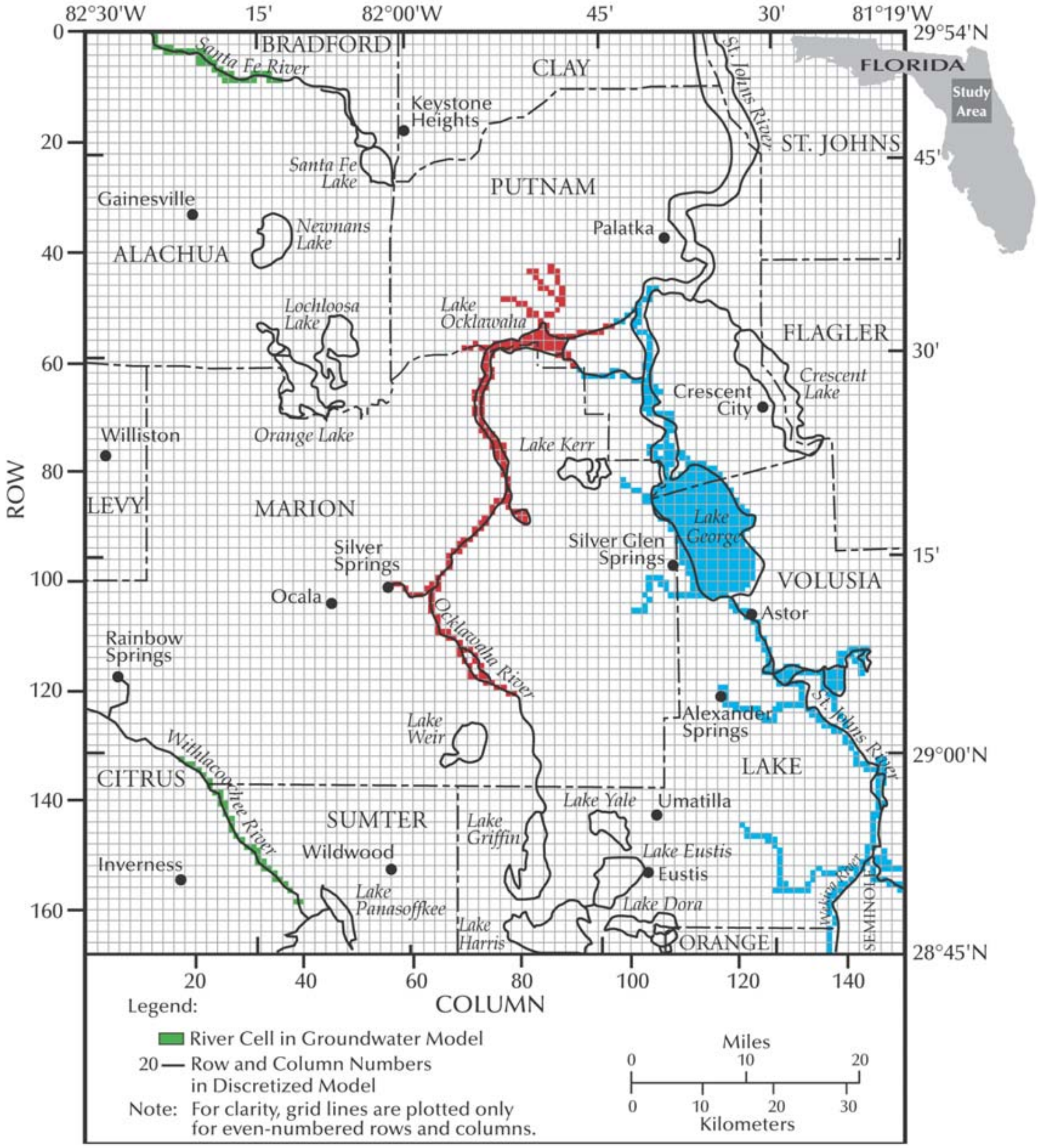

Figure 50. Locations of river cells in layers one and two that represent areas of direct discharge between the groundwater and surface-water systems estimated from available stream-flow data

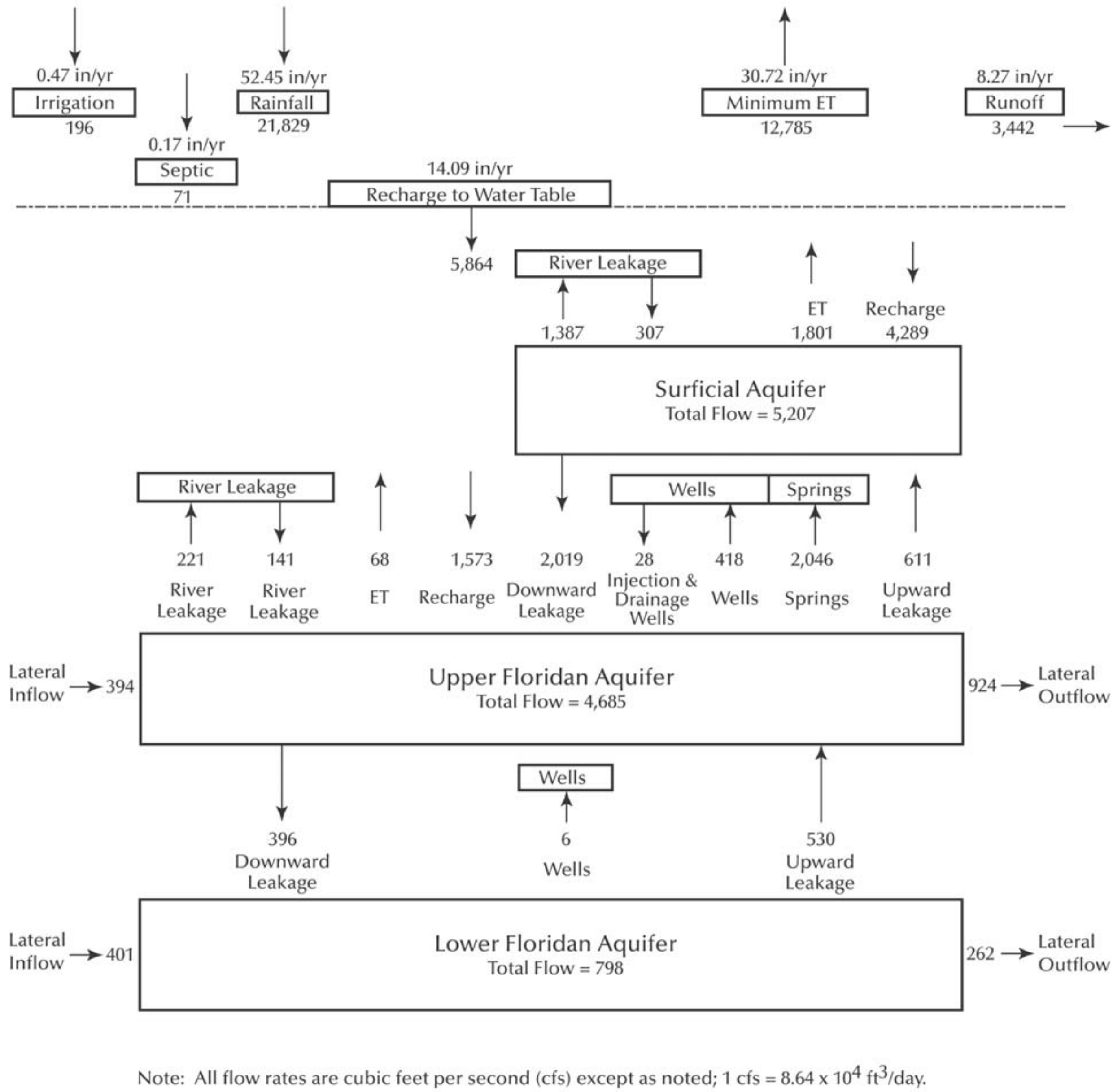

Figure 51. Simulated hydrologic budgets representing the surficial aquifer system and upper and lower Floridan aquifers in north-central Florida for average 1995 conditions

The simulated water budget for average 1995 conditions indicates that the total flow in layer one, which represents the surficial aquifer system, is 5,207 cfs (see Figure 51). Direct recharge (4,289 cfs) accounts for 82 percent of the inflow, and upward leakage from the upper Floridan aquifer (611 cfs) accounts for 12 percent of the inflow. Inflow from river cells in layer one (307 cfs) accounts for 6 percent of the inflow. Evapotranspiration (1,801 cfs) accounts for 35 percent of the outflow, and downward leakage to the upper Floridan aquifer (2,019 cfs) accounts for 39 percent of the outflow. Outflow to river cells in layer one (1,387 cfs) accounts for 27 percent of the outflow from the surficial aquifer system.

The total flow in layer two, which represents the upper Floridan aquifer, is 4,685 cfs (see Figure 51). Direct recharge (1,573 cfs), which occurs in the area where the upper Floridan aquifer is unconfined, accounts for 34 percent of the inflow, and downward leakage from the surficial aquifer system (2,019 cfs) accounts for 43 percent of the inflow to the upper Floridan aquifer. Lateral inflow from GHB's (394 cfs) and upward leakage from the lower Floridan aquifer (530 cfs) account for 8 and 11 percent of the inflow, respectively. Inflow from river cells in layer two (141 cfs) and injection and drainage wells (28 cfs) account for 3 and 1 percent of the inflow, respectively. The discharge from the forty-seven springs (2,046 cfs) accounts for 44 percent of the outflow from the upper Floridan aquifer, and groundwater pumping (418 cfs) accounts for 9 percent. Diffuse upward leakage to the surficial aquifer system (611 cfs) is 13 percent of the outflow, and direct discharge to river cells in layer two (221 cfs) is 5 percent of the outflow. Lateral outflow to GHB's (924 cfs) and downward leakage to the lower Floridan aquifer (396 cfs) account for 20 and 8 percent of the outflow, respectively. Evapotranspiration (68 cfs) in the area where the upper Floridan aquifer is unconfined accounts for 1 percent of the outflow from the upper Floridan aquifer.

The total flow in layer three, which represents the lower Floridan aquifer, is 798 cfs (see Figure 51). Downward leakage from the upper Floridan aquifer (396 cfs) and lateral inflow from GHB's (401 cfs) each account for 50 percent of the inflow. Lateral outflow to GHB's (262 cfs) and upward leakage to the upper Floridan aquifer (530 cfs) account for 66 and 33 percent of the outflow, respectively. Groundwater pumping (6 cfs) from layer three accounts for approximately 1 percent of the outflow.

<u>6.3.5 Recharge and Discharge Areas</u>

In the average 1995 simulation, recharge from the surficial aquifer system to the upper Floridan aquifer occurs in 14,499 cells in the model, which is approximately 57.5 percent of the model domain (see Figure 52). The recharge rate from the surficial aquifer system to the upper Floridan aquifer ranges from 0 to 24 inches/year in 13,337 of these cells (52.9 percent of the area), from 24 to 30 inches/year in 803 of these cells (3.2 percent of the area), and from 30 inches/year to a maximum value of 85 inches/year in 359 cells (1.4 percent of the area). Direct recharge to the upper Floridan aquifer where it is unconfined occurs in 4,581 cells (18.2 percent of the model area). Discharge from the upper Floridan aquifer to the surficial aquifer system occurs in 6,120 cells (24.3 percent of the model area).

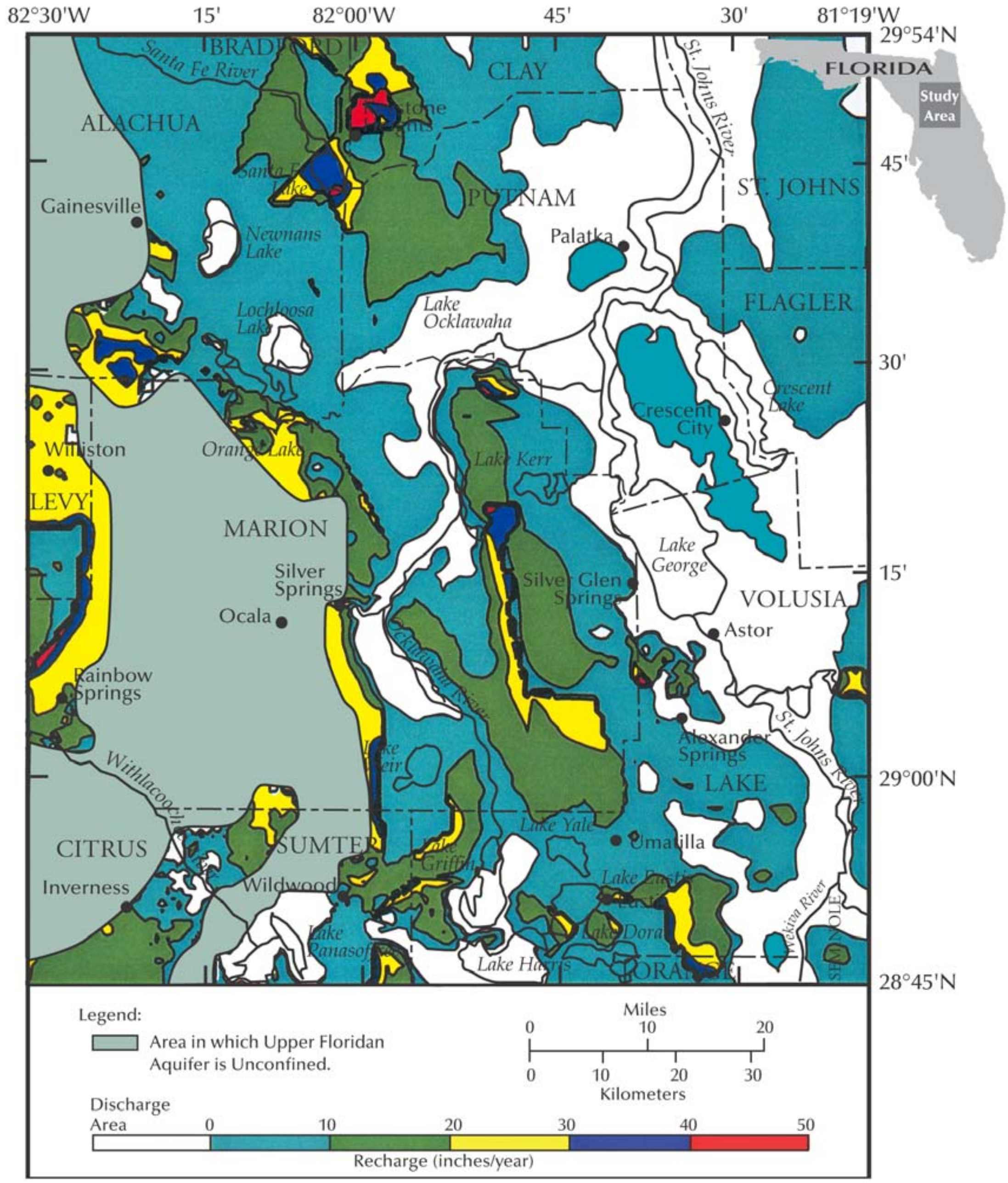

Figure 52. Areas of recharge to and discharge from the upper Floridan aquifer in north-central Florida in the average 1995 simulation

6.3.6 Sensitivity Analysis

A sensitivity analysis was performed to determine the degree to which the calibrated model results are affected by changes in model parameters and aquifer stresses. The model parameters and stresses representing the hydraulic conductivity of the surficial aquifer system (K_1), transmissivities of the upper and lower Floridan aquifers (T_2 and T_3), leakances of the intermediate confining unit (V_{cont1}) and the middle semiconfining unit (V_{cont2}), pumpage, spring, river, and general head boundary conductances, direct recharge, and general head boundary heads were selected for the sensitivity analysis. The parameters and stresses were varied uniformly, one at a time, over a range judged equal to or greater than the estimated error related to the calibration parameter or stress. The resulting changes in the root mean square errors in the residuals between simulated and observed heads in the surficial aquifer system and the upper Floridan aquifer in the model calibrated for average 1995 conditions were calculated and plotted (see Figures 53 through 58).

The simulated heads in the surficial aquifer system are most sensitive to changes in the intermediate confining unit leakance, upper Floridan aquifer transmissivity, and surficial aquifer system hydraulic conductivity (Figure 53). The simulated heads in the surficial aquifer system are relatively insensitive to changes in the lower Floridan aquifer transmissivity and middle semiconfining unit leakance (Figure 53). The simulated heads in the upper Floridan aquifer are very sensitive to changes in the upper Floridan aquifer transmissivity and moderately sensitive to changes in the intermediate confining unit leakance, middle semiconfining unit leakance, and lower Floridan aquifer transmissivity (Figure 54). The simulated heads in the upper Floridan aquifer are relatively insensitive to changes in the surficial aquifer system hydraulic conductivity (Figure 54). The simulated heads in the surficial aquifer system are sensitive to increases in pumpage from the upper and lower Floridan aquifers and relatively insensitive to changes in spring, river, and general head boundary (Figure 55). The simulated heads in the upper Floridan aquifer are very sensitive to increases in pumpage from the upper and lower Floridan aquifers, somewhat sensitive to decreases in pumpage and changes in spring and general head boundary conductances, and relatively insensitive to changes in river conductance (Figure 56). The simulated heads in the surficial aquifer system are sensitive to changes in direct recharge and relatively insensitive to changes in general head boundary heads (Figure 57). The simulated heads in the upper Floridan aquifer are slightly sensitive to changes in direct recharge and general head boundary heads (Figure 58).

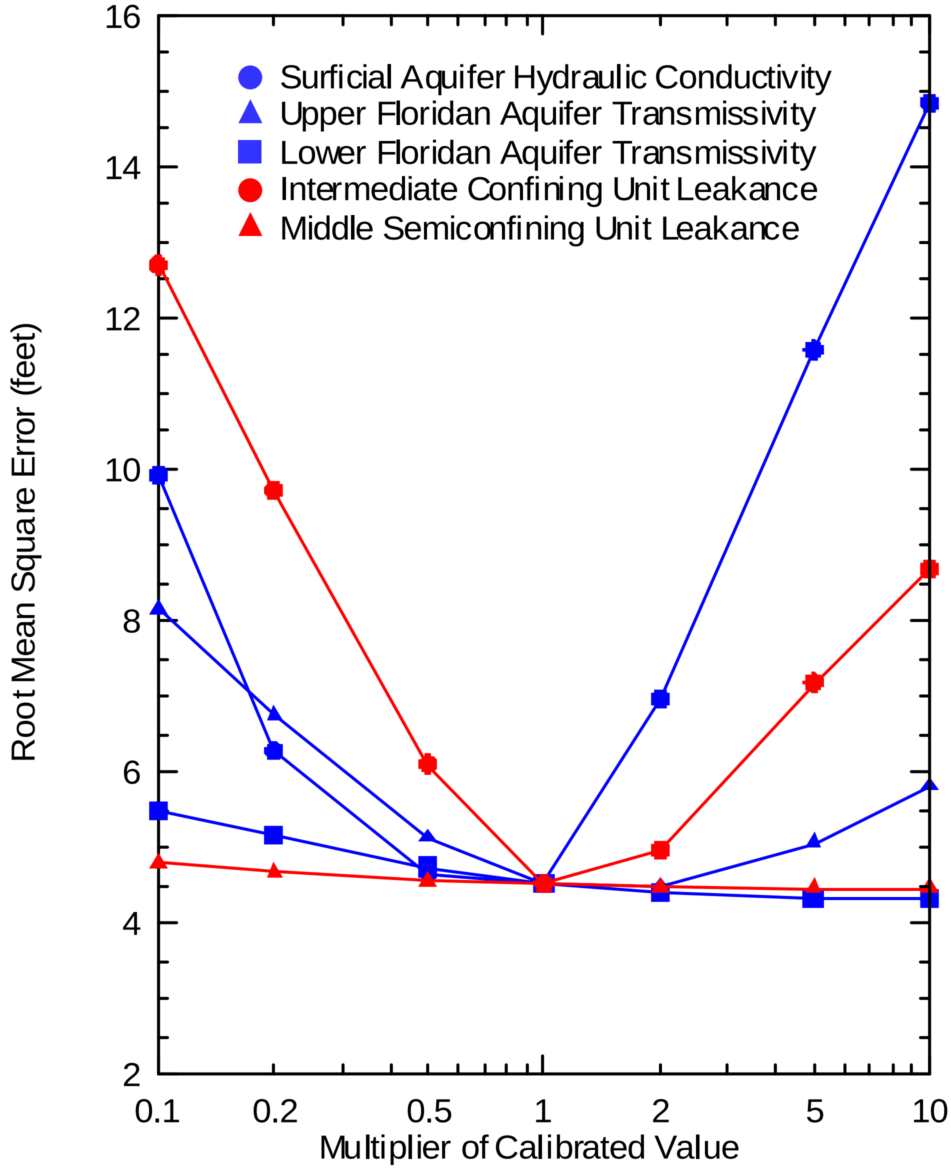

Figure 53. Sensitivity of simulated heads in the surficial aquifer system to changes in surficial aquifer system hydraulic conductivity, upper and lower Floridan aquifer transmissivities, and intermediate confining unit and middle semiconfining unit leakances

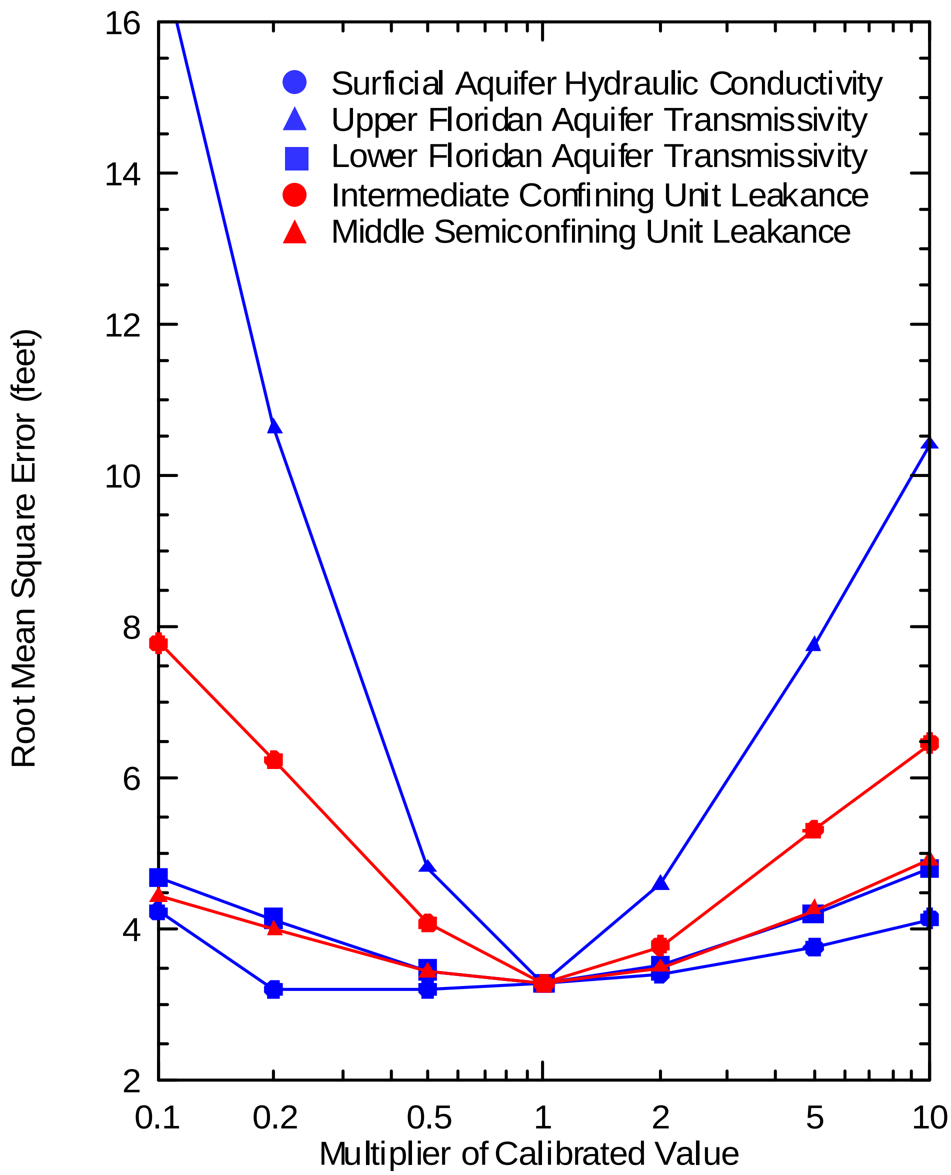

Figure 54. Sensitivity of simulated heads in the upper Floridan aquifer to changes in surficial aquifer system hydraulic conductivity, upper and lower Floridan aquifer transmissivities, and intermediate confining unit and middle semiconfining unit leakances

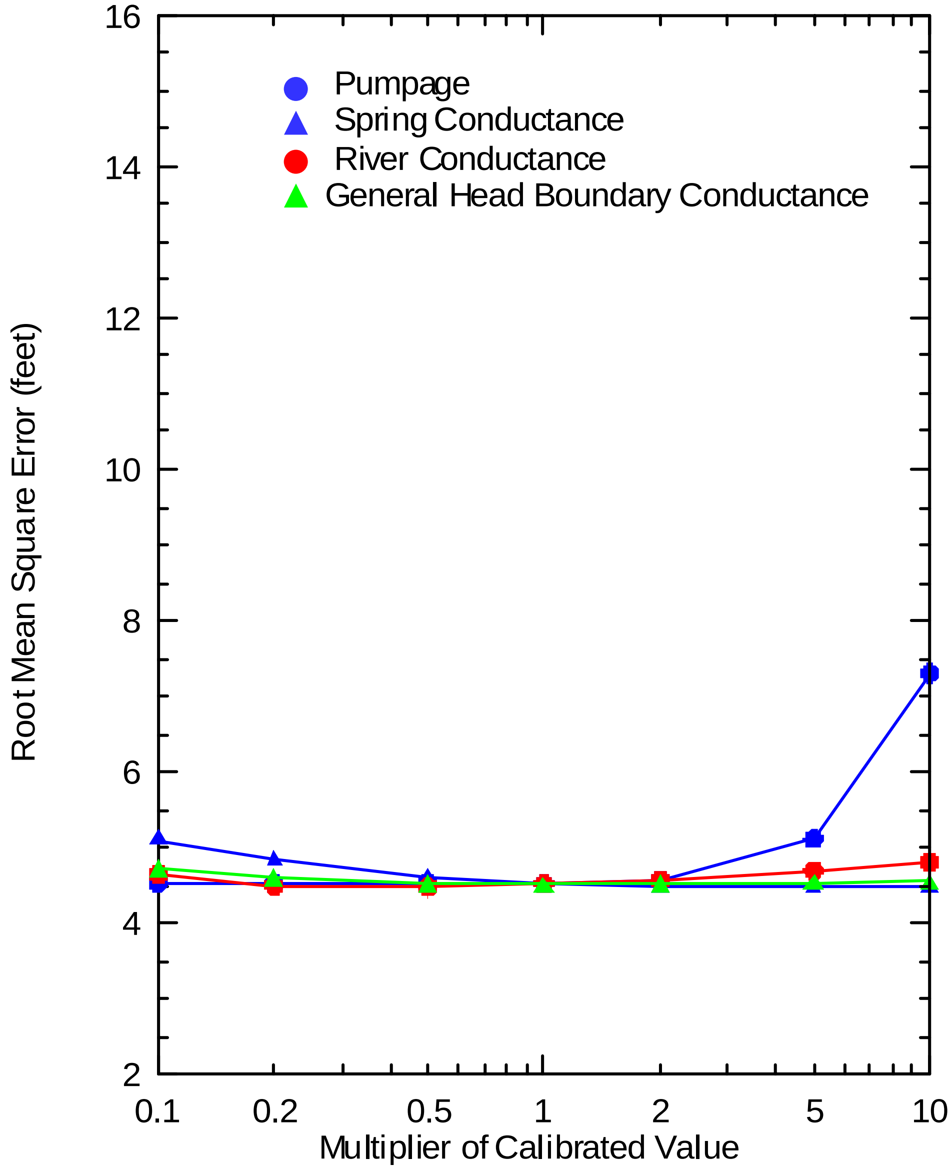

Figure 55. Sensitivity of simulated heads in the surficial aquifer system to changes in pumpage and spring, river, and general head boundary conductances

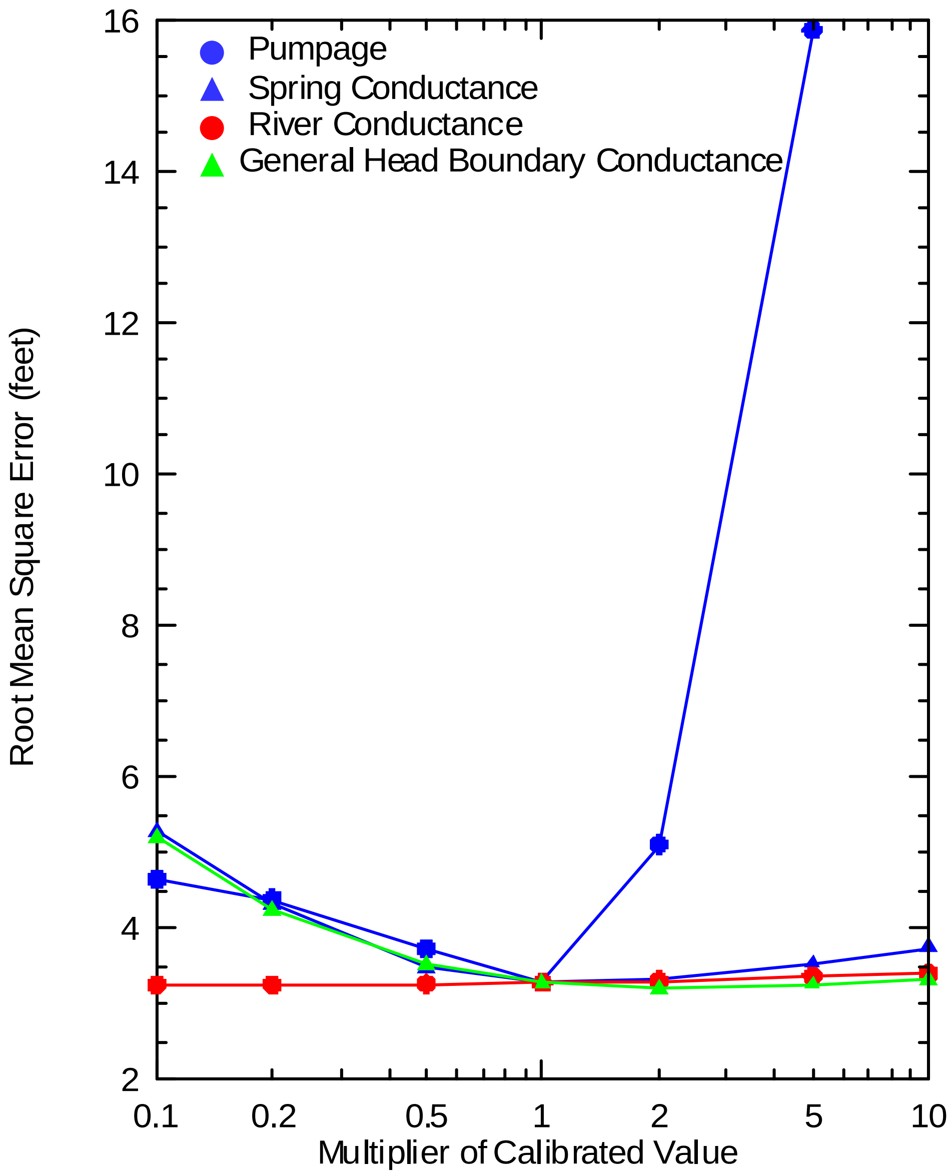

Figure 56. Sensitivity of simulated heads in the upper Floridan aquifer to changes in pumpage and spring, river, and general head boundary conductances

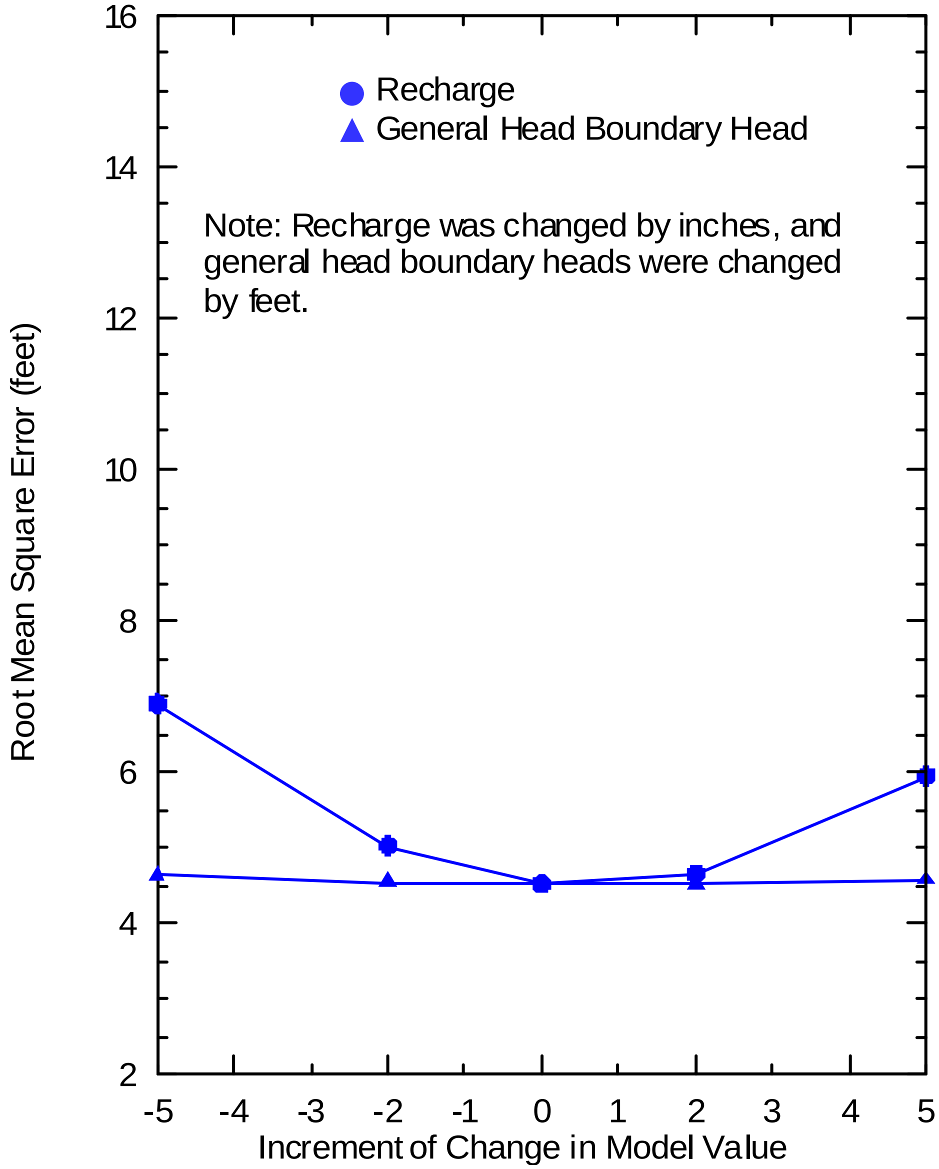

Figure 57. Sensitivity of simulated heads in the surficial aquifer system to changes in recharge and general head boundary heads

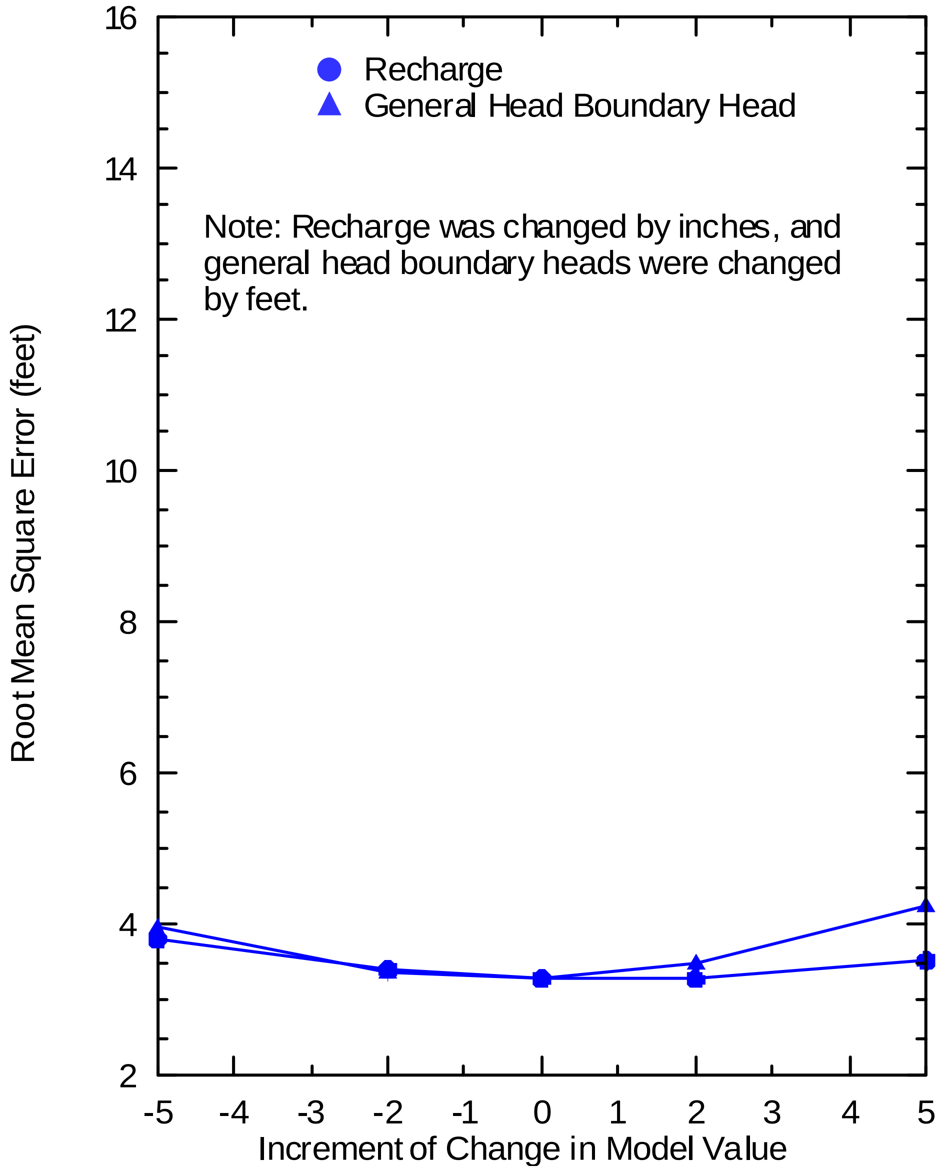

Figure 58. Sensitivity of simulated heads in the upper Floridan aquifer to changes in recharge and general head boundary heads

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7.0 PREDICTION OF WATER-TABLE AND UPPER FLORIDAN AQUIFER CONDITIONS IN 2020

7.1 SIMULATION OF THE WATER TABLE AND POTENTIOMETRIC SURFACE OF THE UPPER FLORIDAN AQUIFER FOR AVERAGE 2020 CONDITIONS

7.1.1 MODFLOW Input Files and Groundwater Pumpage

The MODFLOW input files for the calibrated simulation of average 1995 conditions (described in Chapter 6) representing the hydrogeologic units, aquifer discretization, aquifer hydraulic characteristics, spring conductances and discharge heads, and maximum evapotranspiration rates and extinction depth were used to simulate average 2020 conditions. Pumpage for 2020 was adjusted from 1995 conditions based on the water-use projections derived from the 1995 database developed from Sepulveda's (2002) August 1993 – July 1994 data, as described in Chapter 5. In the 2020 simulation, the total groundwater pumpage (401.2 mgd) is 56.8 percent greater than the total pumpage (255.8 mgd) estimated for 1995. Net recharge to the water table, a function of rainfall, irrigation, septic tank inflow, runoff, and evapotranspiration, will increase approximately 1 percent over the study area as a result of the increased pumpage and associated increases in lawn and agricultural irrigation and septic tank inflows.

7.1.2 Simulated Water Table, Potentiometric Surface, and Hydrologic Budgets Representing Average 2020 Conditions

The calibrated 1995 model and projected pumpage and recharge for 2020 were used to simulate the water table in the surficial aquifer system and the potentiometric surface in the upper Floridan aquifer for average 2020 conditions (see Figures 59 and 60). For simulated average 2020 conditions, rainfall is 52.45 inches/year, irrigation is 0.65 inches/year, septic tank inflow is 0.20 inches/year, runoff is 8.29 inches/year, minimum evapotranspiration is 30.84 inches/year, and net recharge to the water table is 14.17 inches/year (see Figure 61). In the 2020 simulation, the total flow in the surficial aquifer system (layer one) is 5,214 cfs (see Figure 61). Direct recharge (4,310 cfs) accounts for 83 percent of the inflow, and upward leakage from the upper Floridan aquifer (580 cfs) accounts for 11 percent of the inflow. Inflow from river cells in layer one (324 cfs) accounts for 6 percent of the inflow. Evapotranspiration (1,781 cfs) accounts for 34 percent of the outflow, and downward leakage to the upper Floridan aquifer (2,071 cfs) accounts for 40 percent of the outflow. Outflow to river cells in layer one (1,362 cfs) accounts for 26 percent of the outflow from the surficial aquifer system.

The total flow in the upper Floridan aquifer (layer two) is 4,797 cfs (see Figure 61). Direct recharge (1,586 cfs) in the area where the upper Floridan aquifer is unconfined accounts for 33 percent of the inflow, and downward leakage from the surficial aquifer system (2,071 cfs) accounts for 43 percent of the inflow to the upper Floridan aquifer. Lateral inflow from GHB's (424 cfs) and upward leakage from the lower Floridan aquifer (543 cfs) account for 9 and 11 percent of the inflow, respectively. Inflows from river cells in layer two (145 cfs) and injection and drainage wells (30 cfs) account for 3 and 1 percent of the inflow, respectively. The discharge

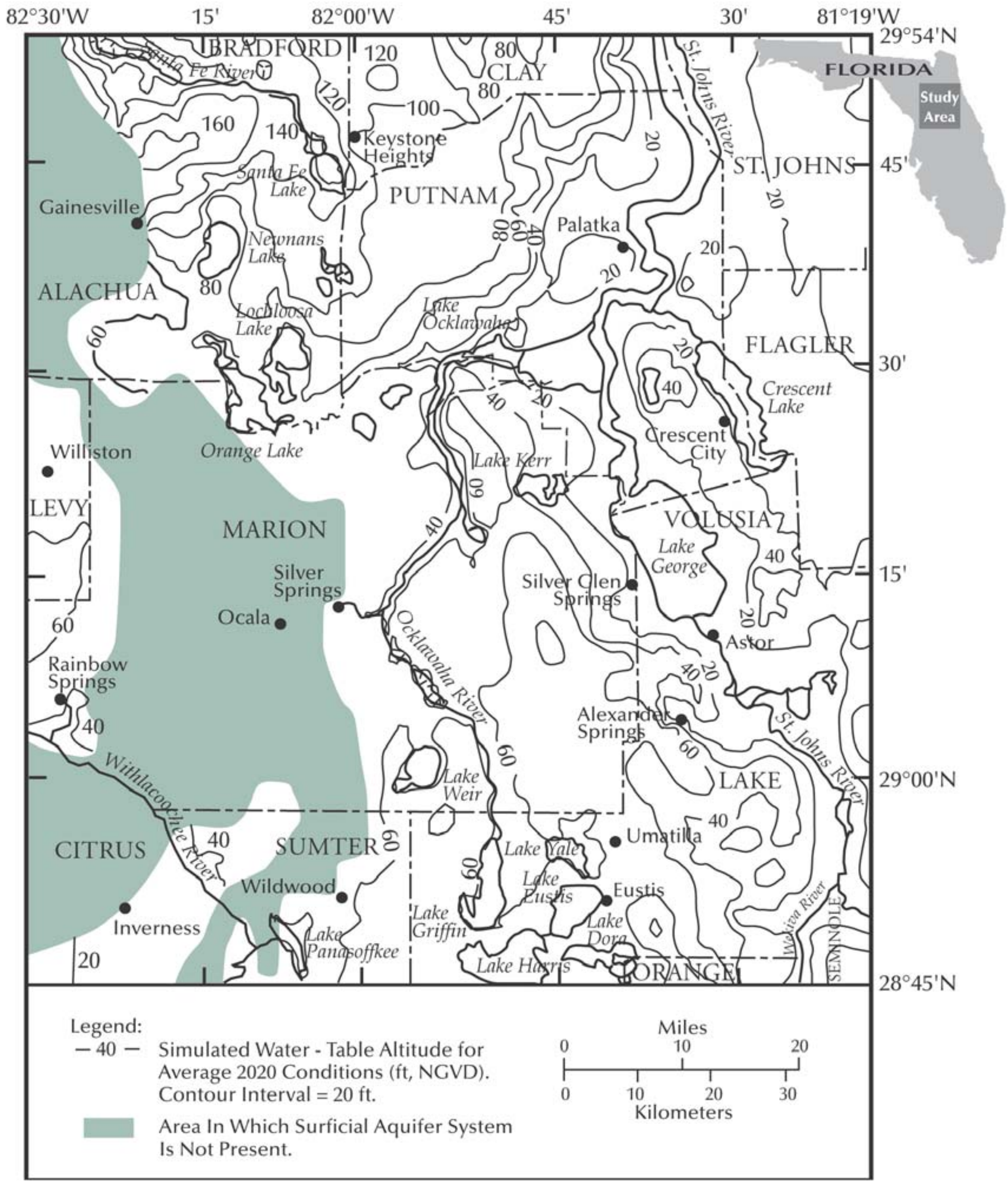

Figure 59. Simulated water table of the surficial aquifer system in north-central Florida for average 2020 conditions

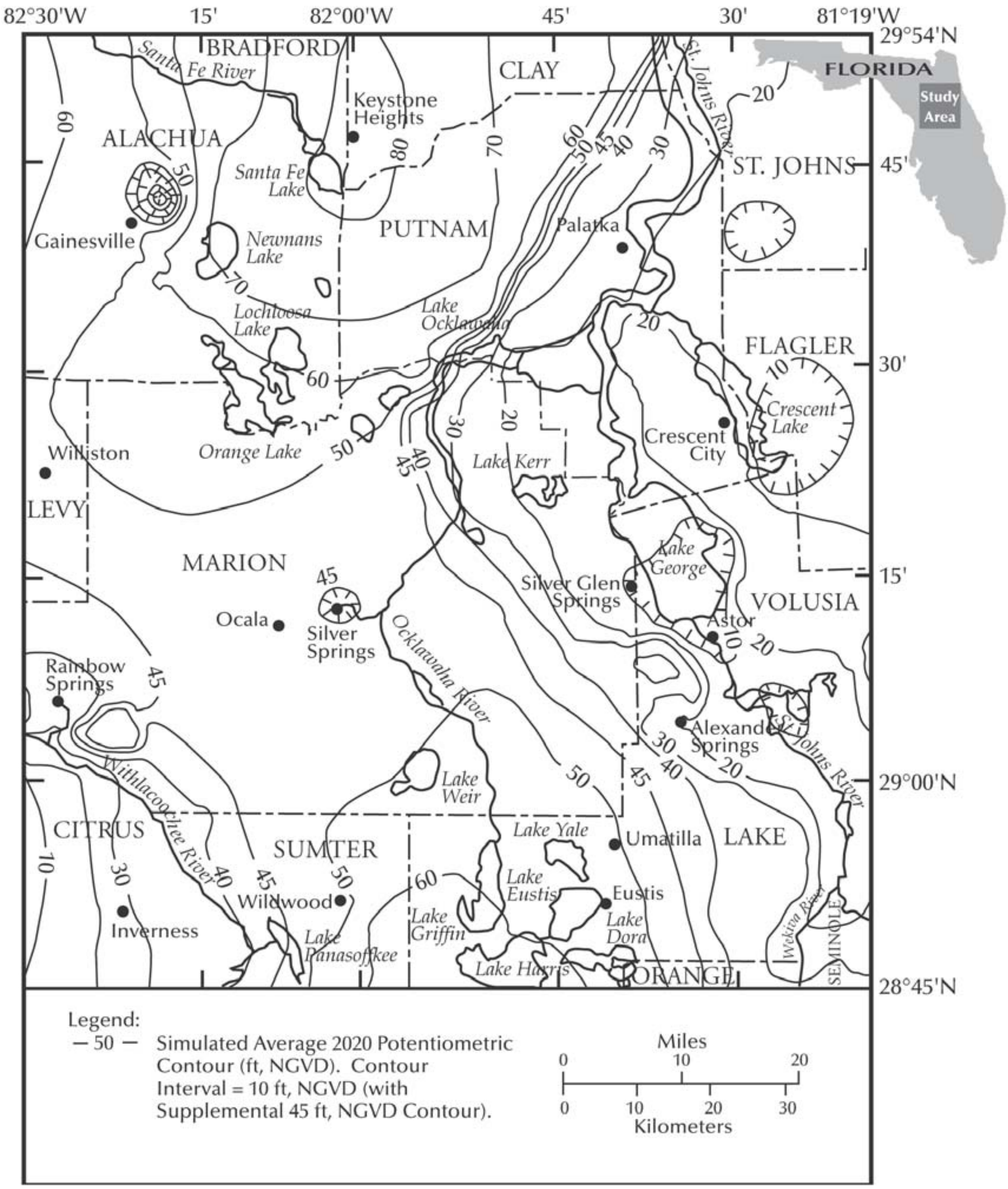

Figure 60. Simulated potentiometric surface of the upper Floridan aquifer in north-central Florida for average 2020 conditions

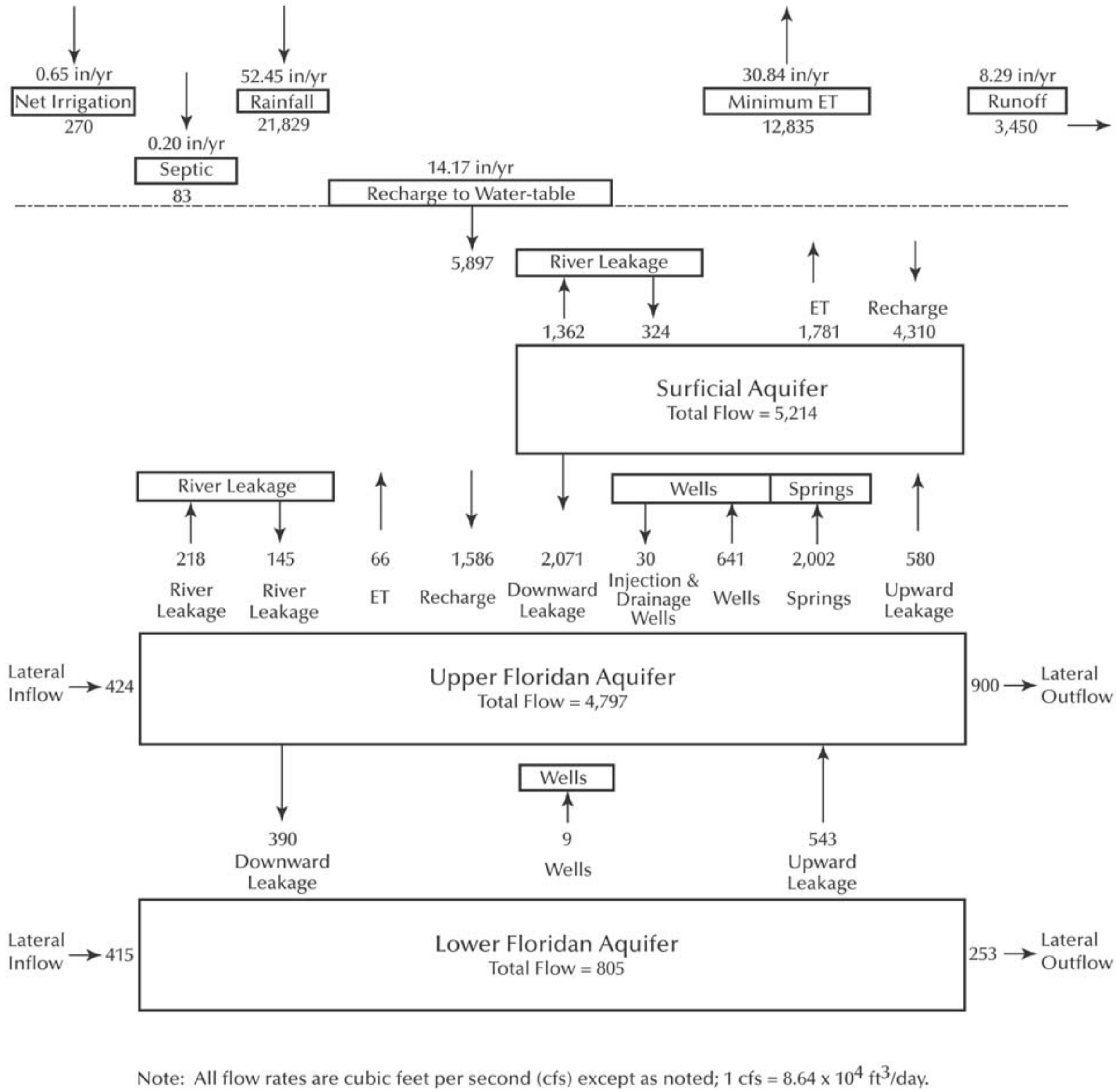

Figure 61. Simulated hydrologic budgets representing the surficial aquifer system and the upper and lower Floridan aquifers in north-central Florida for average 2020 conditions

from the forty-seven springs (2,002 cfs) accounts for 42 percent of the outflow from the upper Floridan aquifer, and groundwater pumping (641 cfs) accounts for 13 percent. Diffuse upward leakage to the surficial aquifer system (580 cfs) is 12 percent of the outflow, and direct discharge to river cells in layer two (218 cfs) is 5 percent of the outflow. Lateral outflow to GHB's (900 cfs) and downward leakage to the lower Floridan aquifer (390 cfs) account for 19 and 8 percent of the outflow, respectively. Evapotranspiration (66 cfs) in the area where the upper Floridan aquifer is unconfined accounts for 1 percent of the outflow from the upper Floridan aquifer.

The total flow in the lower Floridan aquifer (layer three) is 805 cfs (see Figure 61). Downward leakage from the upper Floridan aquifer (390 cfs) and lateral inflow from GHB's (415 cfs) account for 49 and 51 percent of the inflow, respectively. Lateral outflow to GHB's (253 cfs) and upward leakage to the upper Floridan aquifer (543 cfs) account for 31 and 68 percent of the outflow, respectively. Groundwater pumping (9 cfs) from layer three accounts for approximately 1 percent of the outflow.

7.2 DRAWDOWN AND CHANGES IN THE HYDROLOGIC BUDGETS

7.2.1 Estimated Drawdown from 1995 to 2020

The water tables in the surficial aquifer system simulated for average 1995 and 2020 conditions (Figures 36 and 59) were compared to estimate the changes that will occur in the water table due to the changes in pumpage and recharge that are projected to occur in the study area from 1995 to 2020. Estimated changes in the water table are negligible (less than 1.0 ft) over a large part of the model area. Water-table drawdowns of approximately 2 to 3 ft are simulated in the northwestern part of the model area in the GRU wellfield near Gainesville (see Figure 62).

The potentiometric surfaces simulated for average 1995 and 2020 conditions (Figures 40 and 60) also were compared to estimate the water-level changes that will occur in the upper Floridan aquifer due to the changes in pumpage and recharge that are projected in the study area from 1995 to 2020. Estimated changes in the potentiometric surface are negligible (less than 1.0 ft) over a large part of the model area. Drawdowns of approximately 2 to 5 ft are simulated in the southern and northeastern parts of the model area, and drawdowns of approximately 16 ft are simulated in the GRU wellfield near Gainesville (see Figure 63).

7.2.2 Estimated Changes in Hydrologic Budgets from 1995 to 2020

In response to the increase in groundwater pumpage and recharge projected from 1995 to 2020, the total inflow and outflow in the surficial aquifer system are predicted to increase by approximately 0.1 percent (see Table 12). Inflow from direct recharge and rivers and streams will increase, and upward leakage from the upper Floridan aquifer will decrease. Evapotranspiration and discharge to rivers will decrease, and downward leakage to the upper Floridan aquifer will increase. In the upper Floridan aquifer, the total inflow and outflow are predicted to increase by approximately 2.4 percent. Inflows from direct recharge, river leakage, injection and

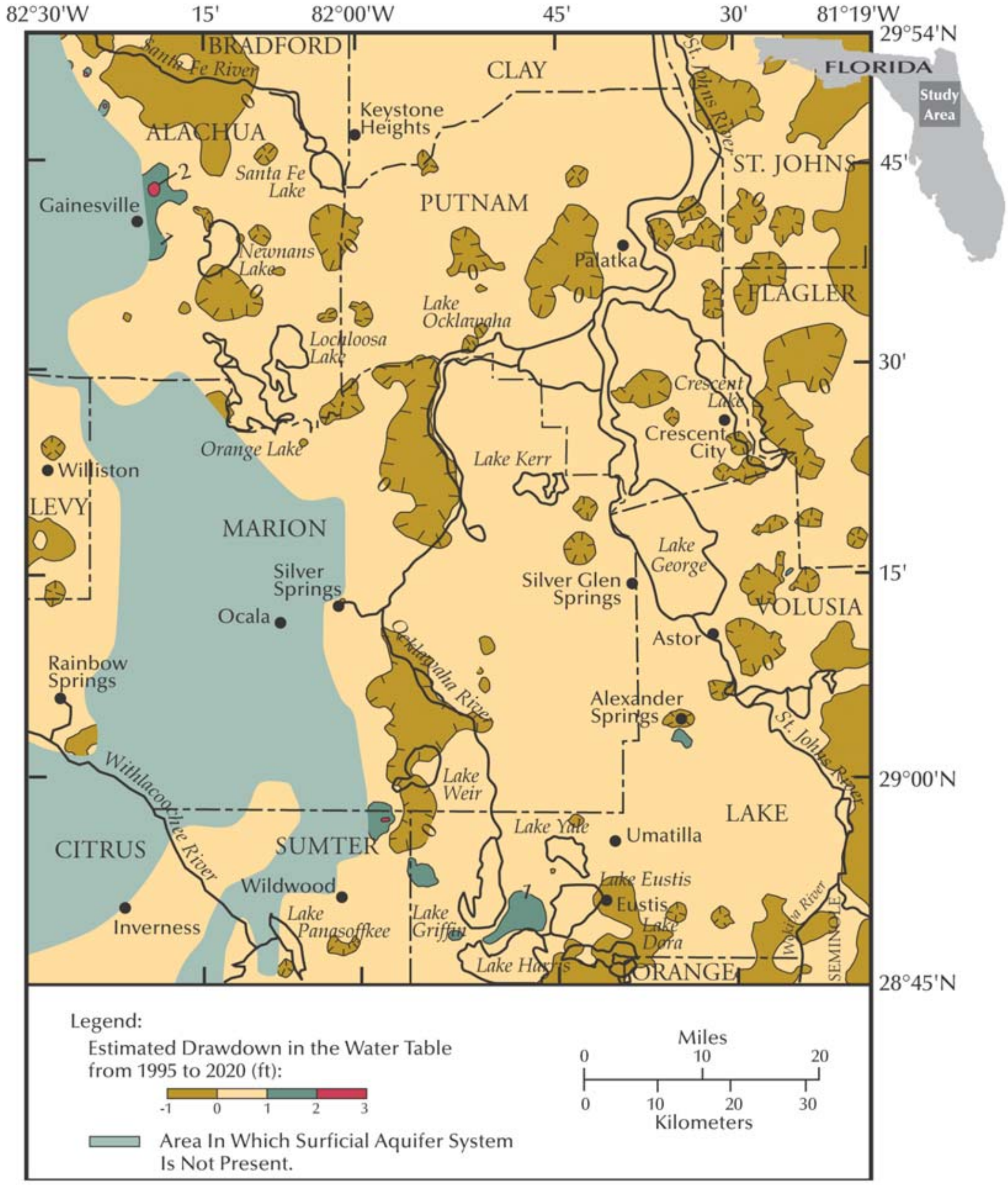

Figure 62. Estimated water-table drawdown in north-central Florida due to changes in pumpage and recharge from 1995 to 2020

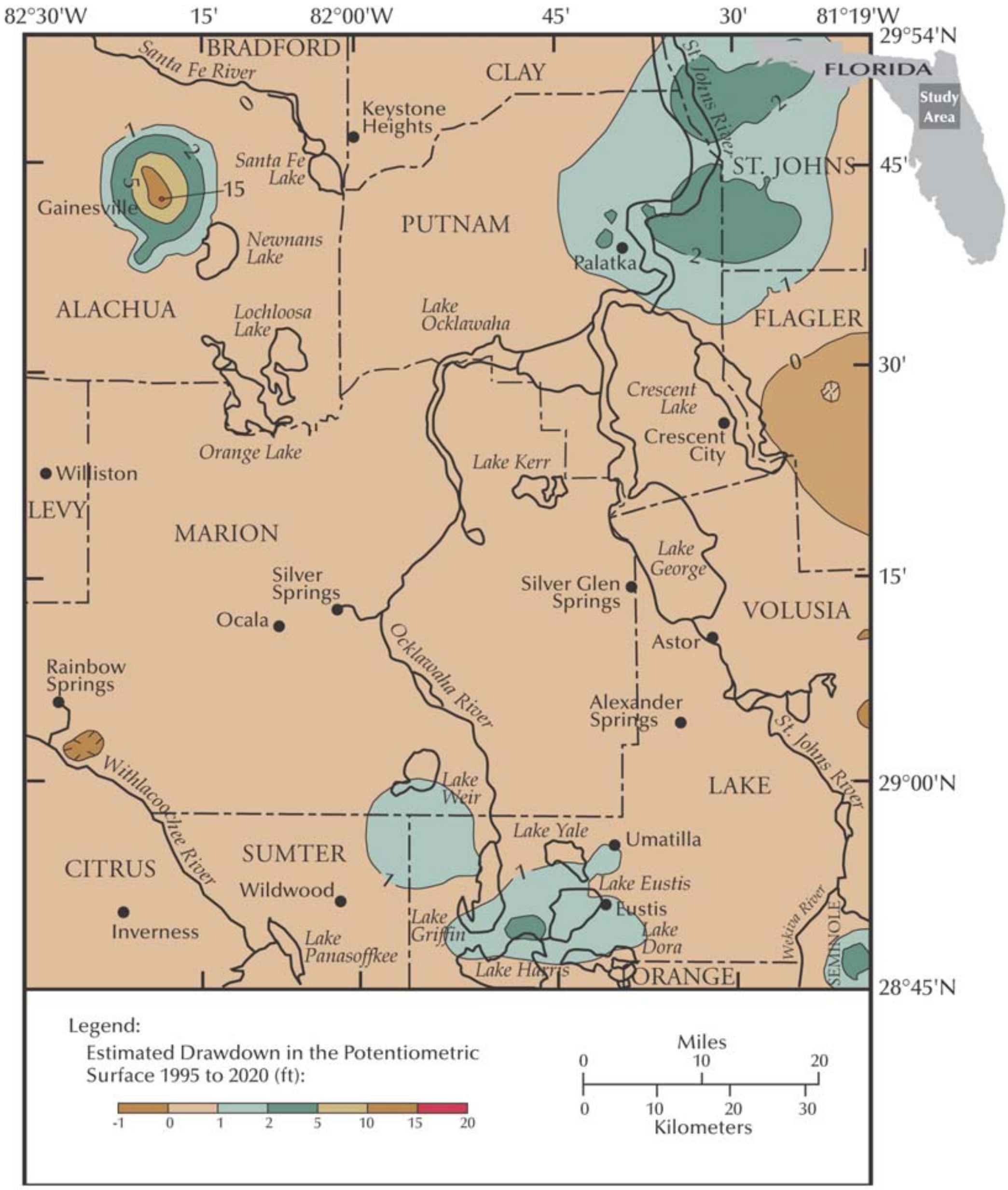

Figure 63. Estimated drawdowns in the potentiometric surface of the upper Floridan aquifer in north-central Florida due to changes in pumpage and recharge from 1995 to 2020

Table 12. Estimated changes in the hydrologic budgets of the surficial aquifer system and the upper and lower Floridan aquifers due to changes in pumpage and recharge from 1995 to 2020

Aquifer and Hydrologic Budget Component	1995 (cfs)	2020 (cfs)	Change from 1995 to 2020	
			(cfs)	%
Surficial Aquifer				
Direct Recharge	4289	4310	20	0.5
River Leakage	307	324	18	5.8
Upward Leakage	611	580	-32	-5.2
TOTAL INFLOW	5207	5214	6	0.1
Evapotranspiration	1801	1781	-21	-1.2
River Leakage	1387	1362	-25	-1.8
Downward Leakage	2019	2071	52	2.6
TOTAL OUTFLOW	5207	5214	6	0.1
Upper Floridan Aquifer				
Direct Recharge	1573	1586	13	0.8
River Leakage	141	145	3	2.3
Injection and Drainage Wells	28	30	2	7.0
Downward Leakage	2019	2071	52	2.6
Upward Leakage	530	543	13	2.5
Lateral Inflow	394	424	30	7.6
TOTAL INFLOW	4685	4797	113	2.4
Evapotranspiration	68	66	-2	-3.2
River Leakage	221	218	-3	-1.5
Wells	418	641	224	53.5
Springs	2046	2002	-43	-2.1
Upward Leakage	611	580	-32	-5.2
Downward Leakage	396	390	-6	-1.5
Lateral Outflow	924	900	-24	-2.6
TOTAL OUTFLOW	4685	4797	113	2.4
Lower Floridan Aquifer				
Downward Leakage	396	390	-6	-1.5
Lateral Inflow	401	414	13	3.3
TOTAL INFLOW	798	805	7	0.9
Wells	6	9	3	57.2
Upward Leakage	530	543	13	2.5
Lateral Outflow	262	253	-9	-3.5
TOTAL OUTFLOW	798	805	7	0.9

drainage wells, leakage from the surficial and lower Floridan aquifers, and lateral inflow are predicted to increase, and outflows from evapotranspiration, river leakage, springs, leakage to the surficial and lower Floridan aquifers, and lateral outflow are predicted to decrease. In the lower Floridan aquifer, the total inflow and outflow are predicted to increase by approximately 0.9 percent. Lateral inflow and upward leakage to the upper Floridan aquifer will increase, and downward leakage from the upper Floridan aquifer and lateral outflow will decrease.

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8.0 PREDICTION OF WATER-TABLE AND UPPER FLORIDAN AQUIFER CONDITIONS IN 2025

8.1 SIMULATION OF THE WATER TABLE AND POTENTIOMETRIC SURFACE OF THE UPPER FLORIDAN AQUIFER FOR REVISED 1995 CONDITIONS

8.1.1 MODFLOW Files and Revised Groundwater Pumpage

The MODFLOW input files for the calibrated simulation for average 1995 conditions (described in Chapter 6) representing the hydrogeologic units, aquifer discretization, aquifer hydraulic characteristics, spring conductances and discharge heads, and maximum evapotranspiration rates and extinction depth were used to simulate another set of conditions for 1995. In this simulation, the net groundwater pumpage was 230.5 mgd, which is based on the revised 1995 pumpage for SJRWMD (written communication, 2003), as described in Chapter Five. Net recharge to the water table was re-calculated, taking into account a small reduction in the amount of water returned to the water table from lawn and agricultural irrigation and septic tank inflows using the revised 1995 pumpage.

8.1.2 Simulated Water Table, Potentiometric Surface, and Hydrologic Budgets Representing Revised 1995 Conditions

The calibrated model with the revised pumpage and recharge for 1995 was used to simulate the water table in the surficial aquifer system and the potentiometric surface in the upper Floridan aquifer (see Figures 64 and 65). For the revised 1995 simulation, rainfall is 52.45 inches/year, irrigation is 0.40 inches/year, septic tank inflow is 0.17 inches/year, runoff is 8.33 inches/year, minimum evapotranspiration is 30.68 inches/year, and net recharge to the water table is 14.0 inches/year (see Figure 66). In the revised 1995 simulation, the total flow in the surficial aquifer system (layer one) is 5,184 cfs (see Figure 66). Direct recharge (4,257 cfs) accounts for 82 percent of the inflow, and upward leakage from the upper Floridan aquifer (621 cfs) accounts for 12 percent of the inflow. Inflow from river cells in layer one (305 cfs) accounts for 6 percent of the inflow. Evapotranspiration (1,792 cfs) accounts for 35 percent of the outflow, and downward leakage to the upper Floridan aquifer (2,005 cfs) accounts for 39 percent of the outflow. Outflow to river cells in layer one (1,387 cfs) accounts for 27 percent of the outflow from the surficial aquifer system.

The total flow in the upper Floridan aquifer (layer two) is 4,660 cfs (see Figure 66). Direct recharge (1,571 cfs) in the area where the upper Floridan aquifer is unconfined accounts for 34 percent of the inflow, and downward leakage from the surficial aquifer system (2,005 cfs) accounts for 43 percent of the inflow to the upper Floridan aquifer. Lateral inflow from GHB's (387 cfs) and upward leakage from the lower Floridan aquifer (528 cfs) account for 8 and 11 percent of the inflow, respectively. Inflows from river cells in layer two (141 cfs) and injection and drainage wells (28 cfs) account for 3 and 1 percent of the inflow, respectively. The discharge from the forty-seven springs (2,053 cfs) accounts for 44 percent of the outflow from the upper Floridan aquifer, and groundwater pumping (375 cfs) accounts for 8 percent. Diffuse upward

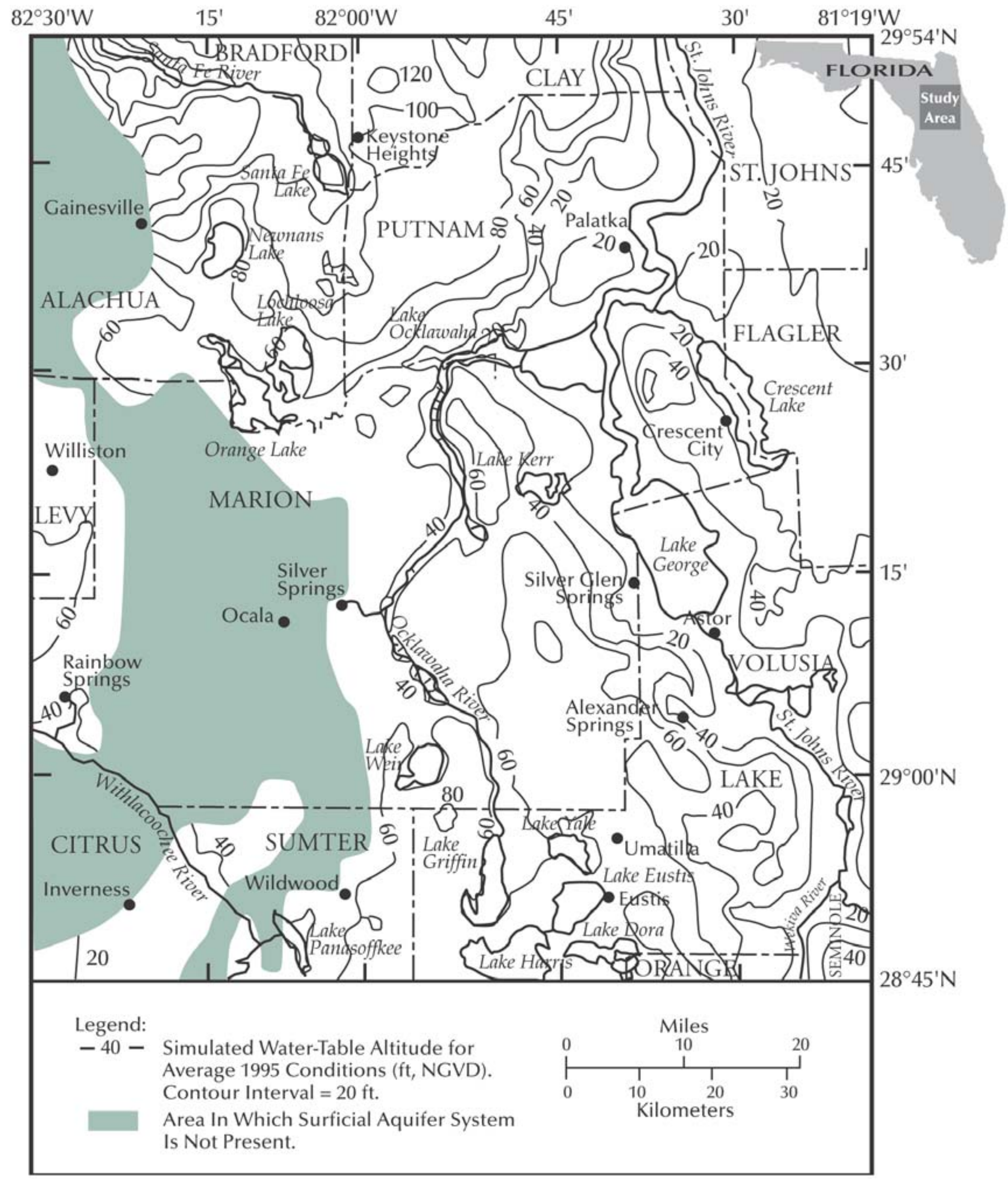


Figure 64. Simulated water table of the surficial aquifer system in north-central Florida for revised 1995 conditions

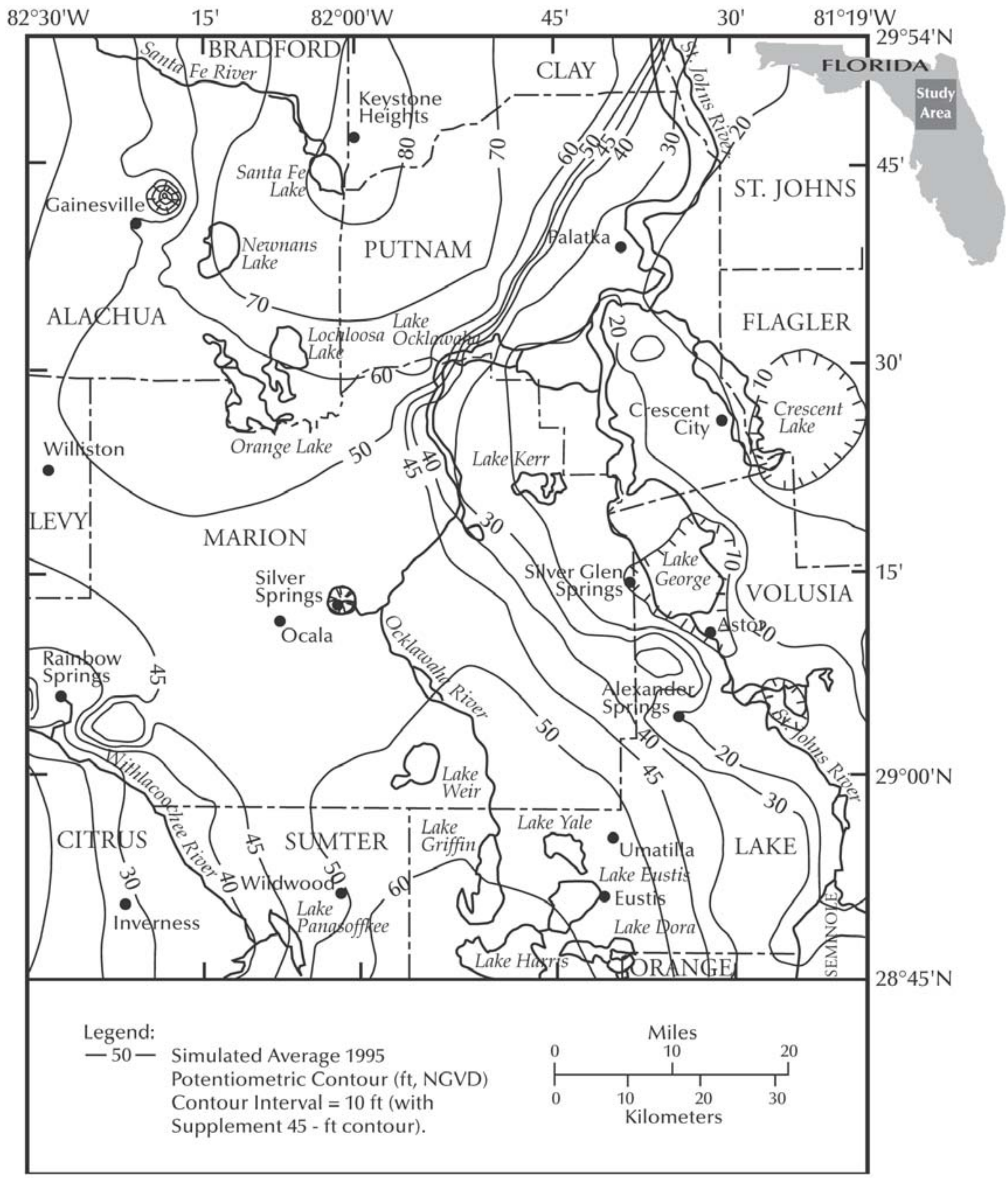
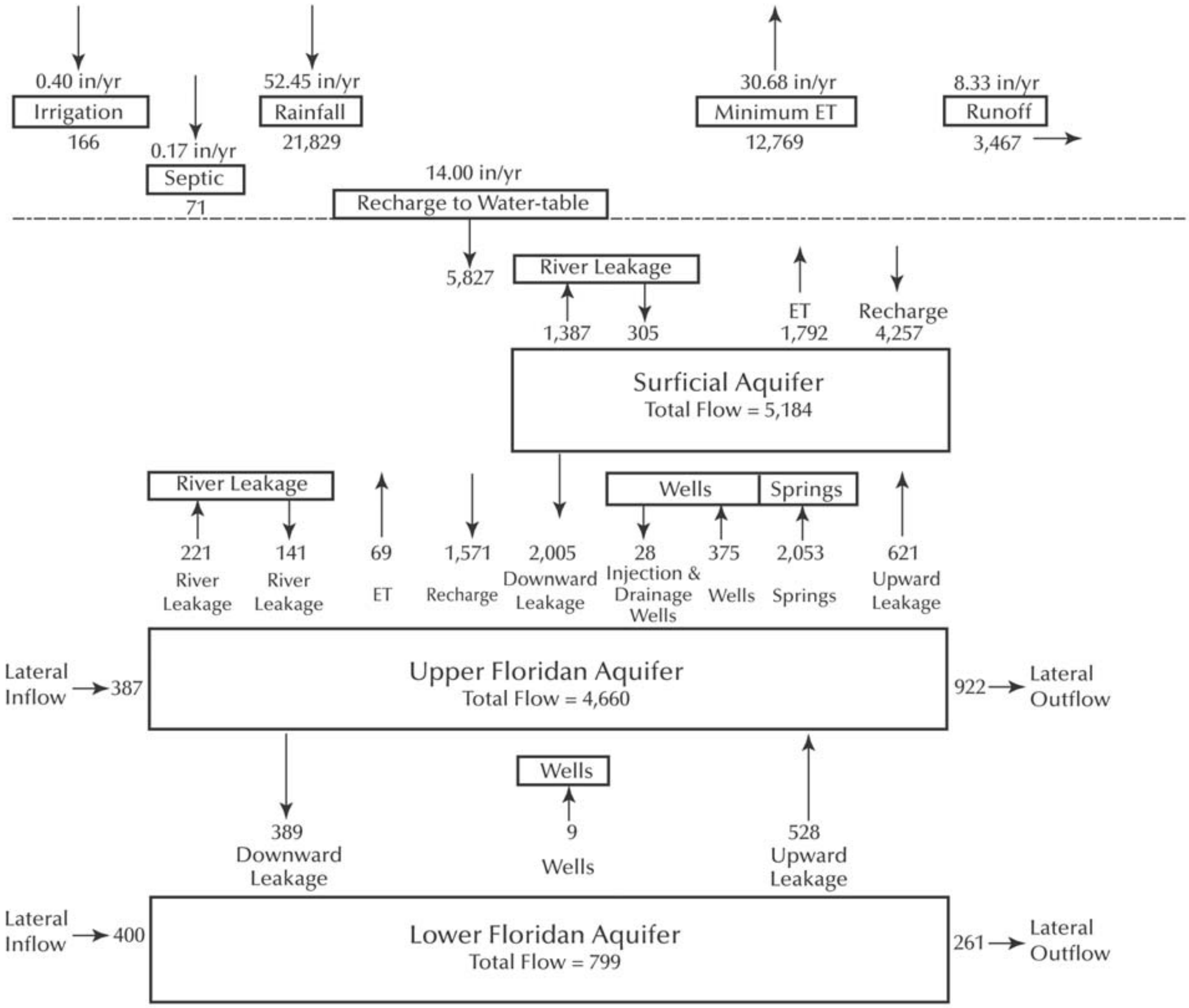


Figure 65. Simulated potentiometric surface of the upper Floridan aquifer in north-central Florida for revised 1995 conditions



Note: All flow rates are cubic feet per second (cfs) except as noted; 1 cfs = 8.64×10^4 ft^3/day.

Figure 66. Simulated hydrologic budgets representing the surficial aquifer system and the upper and lower Floridan aquifers in north-central Florida for revised 1995 conditions

leakage to the surficial aquifer system (621 cfs) is 13 percent of the outflow, and direct discharge to river cells in layer two (221 cfs) is 5 percent of the outflow. Lateral outflow to GHB's (922 cfs) and downward leakage to the lower Floridan aquifer (399 cfs) account for 20 and 9 percent of the outflow, respectively. Evapotranspiration (69 cfs) in the area where the upper Floridan aquifer is unconfined accounts for 1 percent of the outflow from the upper Floridan aquifer.

The total flow in the lower Floridan aquifer (layer three) is 799 cfs (see Figure 66). Downward leakage from the upper Floridan aquifer (399 cfs) and lateral inflow from GHB's (400 cfs) each account for 50 percent of the inflow. Lateral outflow to GHB's (261 cfs) and upward leakage to the upper Floridan aquifer (528 cfs) account for 33 and 66 percent of the outflow, respectively. Groundwater pumping (9 cfs) from layer three accounts for approximately 1 percent of the outflow.

The water table, potentiometric surface, and hydrologic budgets for the revised 1995 simulation (Figures 64 through 66) are very nearly the same as the water table, potentiometric surface, and hydrologic budgets simulated for 1995 conditions using the calibrated model (Figures 36, 40, and 45). Also, for the revised 1995 simulation, the mean of the differences between the simulated and observed heads in layer one is -0.83 ft, and the root mean square error of the head differences is 4.50 ft. The differences between the simulated and observed heads at the target wells and other locations in the surficial aquifer system range from -9.81 to 9.51 ft. In layer two, the mean of the differences between the simulated and observed heads is -0.07 ft, and the root mean square error is 3.36 ft. The differences between the simulated and observed heads at the target wells in the upper Floridan aquifer range from -7.52 to 10.56 ft. These results are nearly the same as the calibration results of the 1995 simulation described in Chapter Six. Accordingly, it was not necessary to re-calibrate the groundwater model for the revised 1995 simulation.

8.2 SIMULATED WATER TABLE, POTENTIOMETRIC SURFACE, AND HYDROLOGIC BUDGETS REPRESENTING 2025 CONDITIONS

The calibrated 1995 model and projected pumpage and recharge for 2025 were used to simulate the water table in the surficial aquifer system and the potentiometric surface in the upper Floridan aquifer for average 2025 conditions (see Figures 67 and 68). In this simulation, the net groundwater pumpage is 330.9 mgd, which is the 2025 pumpage based on the SJRWMD (written communication, 2003) projection described in Chapter Five. Net recharge to the water table for the 2025 simulation will increase slightly compared to the revised 1995 simulation due to an increase in water returned to the water table from lawn and agricultural irrigation and septic tank inflows.

For average 2025 conditions over the model area, rainfall is 52.45 inches/year, irrigation is 0.51 inches/year, septic tank inflow is 0.23 inches/year, runoff is 8.28 inches/year, minimum evapotranspiration is 30.80 inches/year, and net recharge to the water table is 14.11 inches/year (see Figure 69). In the 2025 simulation, the total flow in the surficial aquifer system (layer one) is 5,217 cfs (see Figure 69). Direct recharge (4,299 cfs) accounts for 82 percent of the inflow,

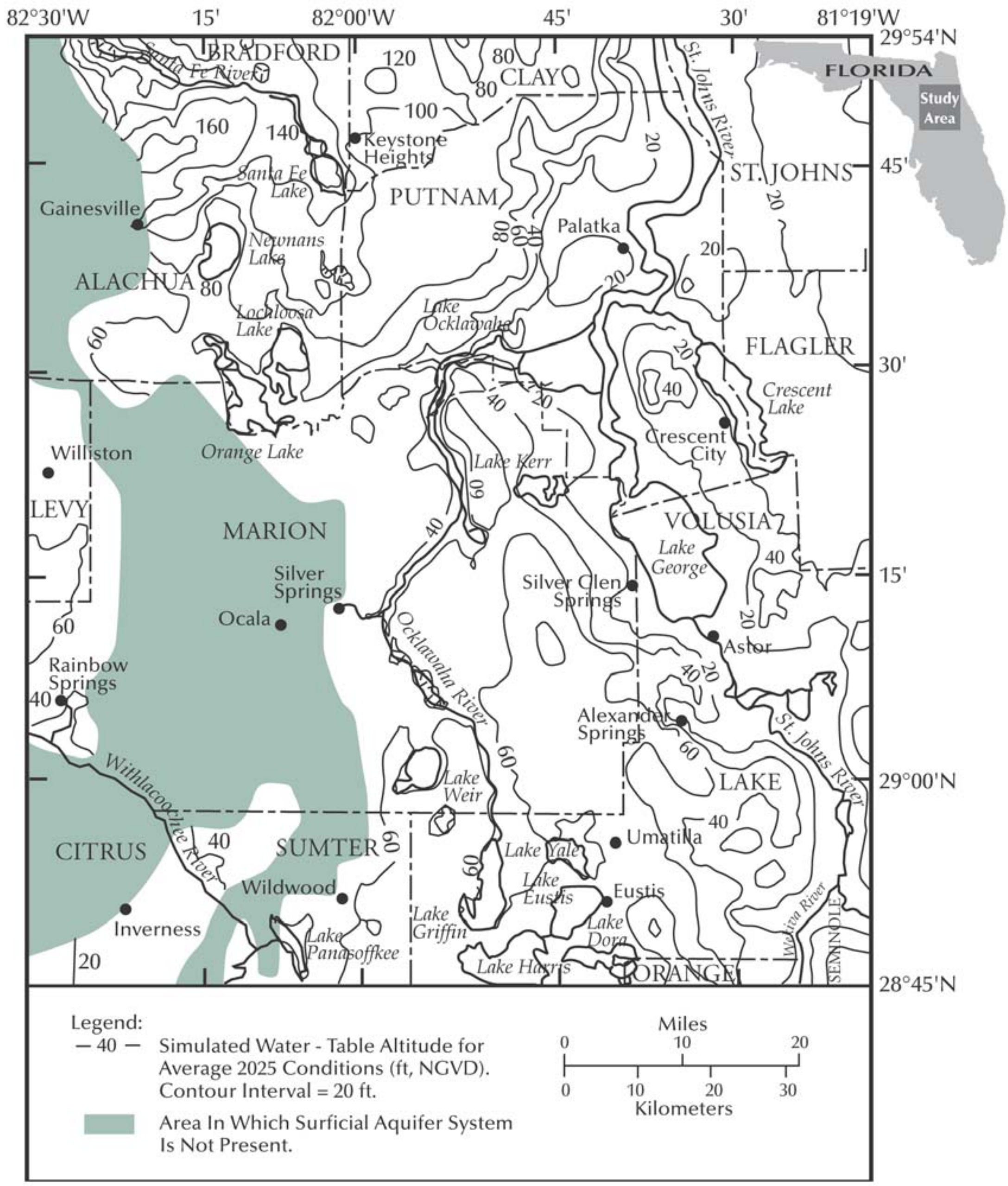


Figure 67. Simulated water table of the surficial aquifer system in north-central Florida for average 2025 conditions

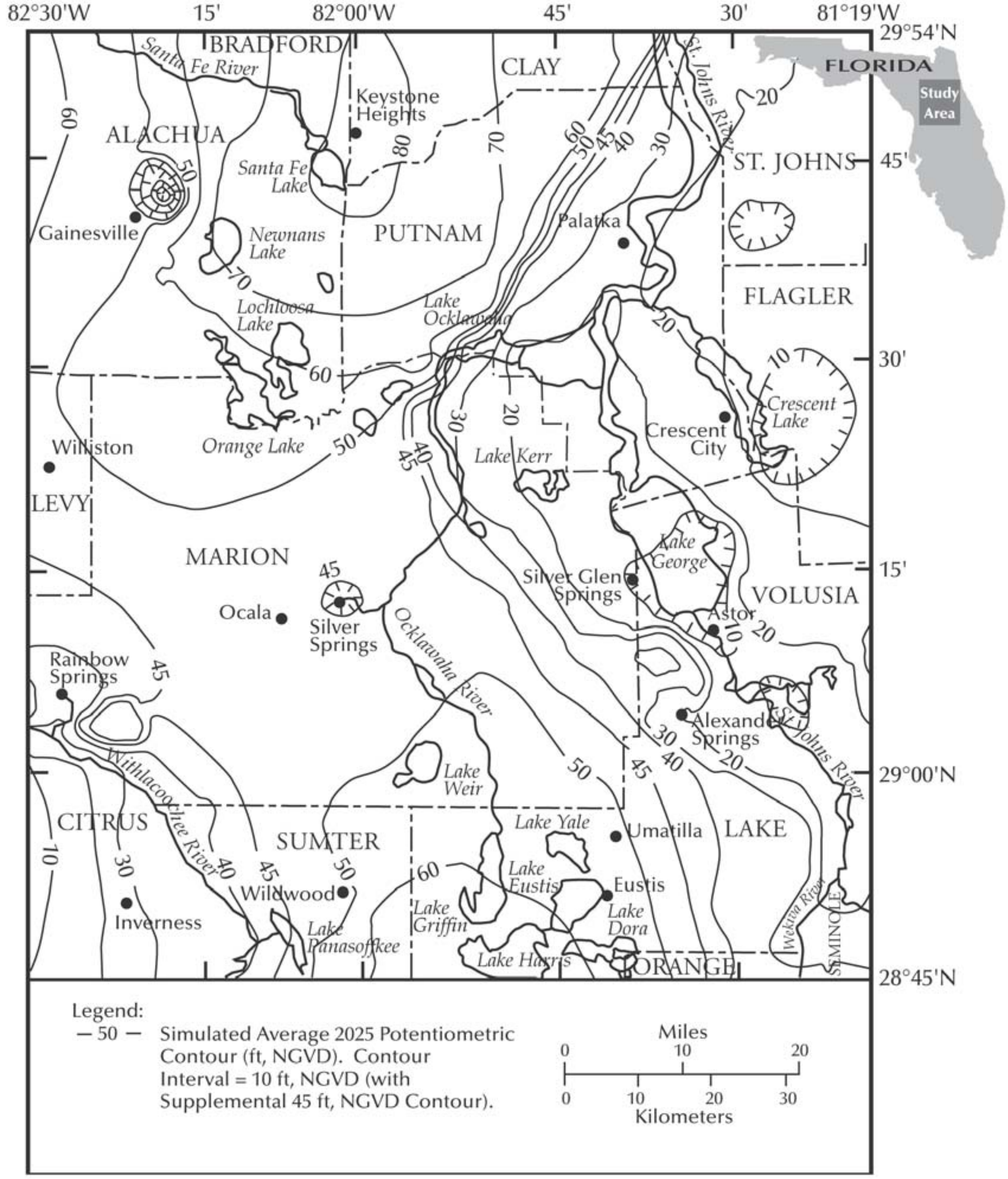


Figure 68. Simulated potentiometric surface of the upper Floridan aquifer in north-central Florida for average 2025 conditions

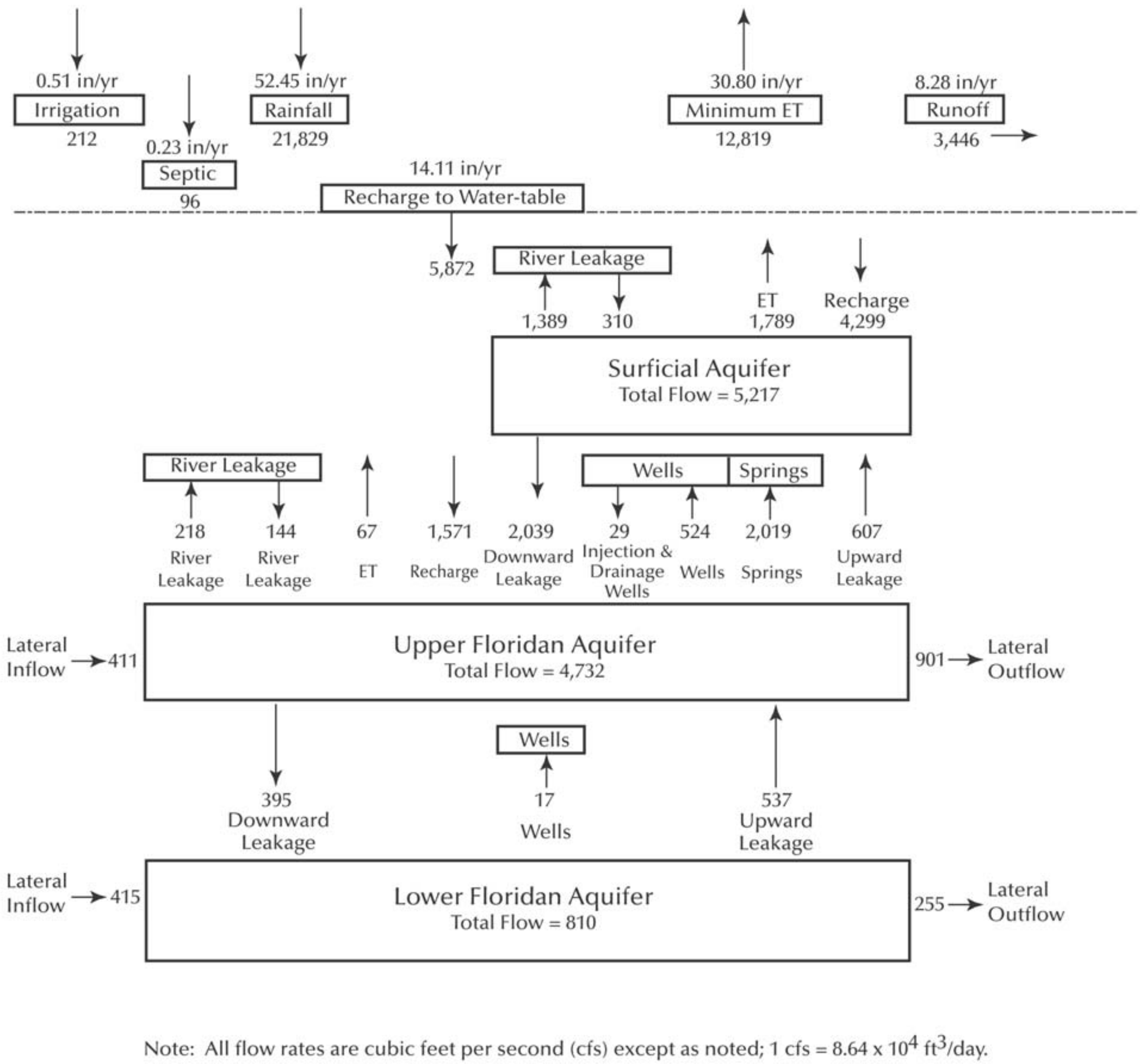


Figure 69. Simulated hydrologic budgets representing the surficial aquifer system and the upper and lower Floridan aquifers in north-central Florida for average 2025 conditions

and upward leakage from the upper Floridan aquifer (607 cfs) accounts for 12 percent of the inflow. Inflow from river cells in layer one (310 cfs) accounts for 6 percent of the inflow. Evapotranspiration (1,789 cfs) accounts for 34 percent of the outflow, and downward leakage to the upper Floridan aquifer (2,039 cfs) accounts for 39 percent of the outflow. Outflow to river cells in layer one (1,389 cfs) accounts for 27 percent of the outflow from the surficial aquifer system.

The total flow in the upper Floridan aquifer (layer two) is 4,732 cfs (see Figure 69). Direct recharge (1,571 cfs) in the area where the upper Floridan aquifer is unconfined accounts for 33 percent of the inflow, and downward leakage from the surficial aquifer system (2,039 cfs) accounts for 43 percent of the inflow to the upper Floridan aquifer. Lateral inflow from GHB's (411 cfs) and upward leakage from the lower Floridan aquifer (537 cfs) account for 9 and 11 percent of the inflow, respectively. Inflows from river cells in layer two (144 cfs) and injection and drainage wells (29 cfs) account for 3 and 1 percent of the inflow, respectively. The discharge from the forty-seven springs (2,019 cfs) accounts for 43 percent of the outflow from the upper Floridan aquifer, and groundwater pumping (524 cfs) accounts for 11 percent. Diffuse upward leakage to the surficial aquifer system (607 cfs) is 13 percent of the outflow, and direct discharge to river cells in layer two (218 cfs) is 5 percent of the outflow. Lateral outflow to GHB's (901 cfs) and downward leakage to the lower Floridan aquifer (395 cfs) account for 19 and 8 percent of the outflow, respectively. Evapotranspiration (67 cfs) in the area where the upper Floridan aquifer is unconfined accounts for 1 percent of the outflow from the upper Floridan aquifer.

The total flow in the lower Floridan aquifer (layer three) is 810 cfs (see Figure 69). Downward leakage from the upper Floridan aquifer (395 cfs) and lateral inflow from GHB's (415 cfs) account for 49 and 51 percent of the inflow, respectively. Lateral outflow to GHB's (255 cfs) and upward leakage to the upper Floridan aquifer (537 cfs) account for 32 and 66 percent of the outflow, respectively. Groundwater pumping (17 cfs) from layer three accounts for approximately 2 percent of the outflow.

8.3 DRAWDOWN AND CHANGES IN THE HYDROLOGIC BUDGETS

8.3.1 Estimated Drawdown from 1995 to 2025

The water tables in the surficial aquifer system simulated using the revised 1995 and projected 2025 conditions (Figures 64 and 67) were compared to estimate the changes that will occur in the water table due to the changes in pumpage and recharge that are projected to occur in the study area from 1995 to 2025. Estimated changes in the water table are negligible (less than 1.0 ft) over a large part of the model area. Drawdowns of approximately 2 to 3 ft are simulated in the southeastern part of the model area in Seminole County, and drawdowns of approximately 1 to 2 ft are simulated in the northwestern part of the model area in the GRU wellfield near Gainesville (see Figure 70).

The potentiometric surfaces simulated using the revised 1995 and projected 2025 conditions (Figures 65 and 68) also were compared to estimate the water-level changes that will

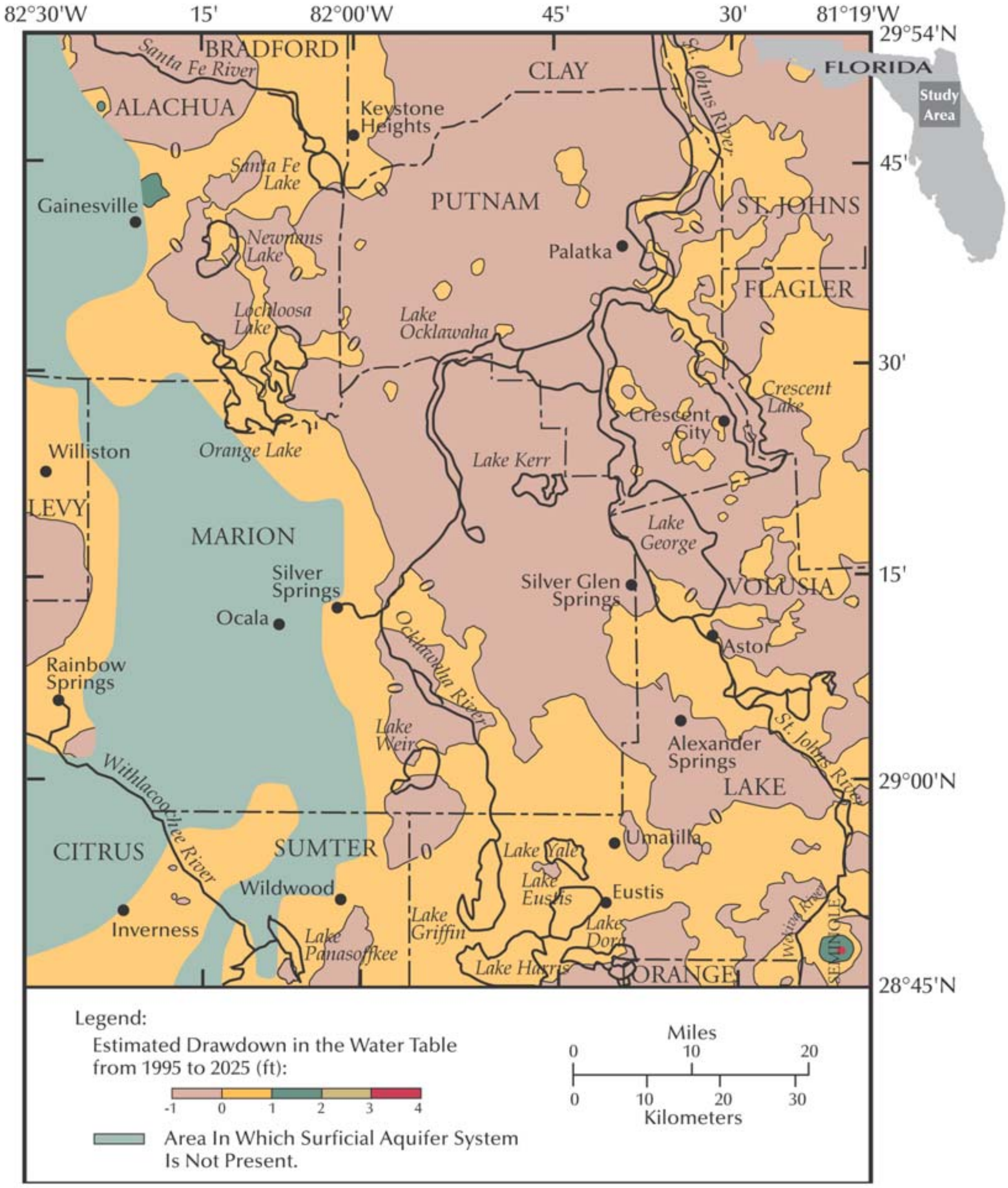


Figure 70. Estimated water-table drawdown in north-central Florida due to changes in pumpage and recharge from 1995 to 2025

occur in the upper Floridan aquifer due to the changes in pumpage and recharge that are projected in the study area from 1995 to 2025. Estimated changes in the potentiometric surface are negligible (less than 1.0 ft) over a large part of the model area. Drawdowns of approximately 10 to 15 ft are simulated in the southeastern part of the model area, and drawdowns of approximately 15 ft are simulated in the GRU wellfield near Gainesville (see Figure 71).

8.3.2 Estimated Changes in Hydrologic Budgets from 1995 to 2025

In response to the increase in groundwater pumpage and recharge projected from 1995 to 2025, the total inflow and outflow in the surficial aquifer system are predicted to increase by approximately 0.6 percent (see Table 13). Inflow from direct recharge and rivers and streams will increase, and upward leakage from the upper Floridan aquifer will decrease. Evapotranspiration will decrease, and discharge to rivers and downward leakage to the upper Floridan aquifer will increase. In the upper Floridan aquifer, the total inflow and outflow are predicted to increase by approximately 1.5 percent. Inflows from river leakage, injection and drainage wells, leakage from the surficial and lower Floridan aquifers, and lateral inflow are predicted to increase, and outflows from evapotranspiration, river leakage, springs, leakage to the surficial and lower Floridan aquifers, and lateral outflow are predicted to decrease. In the lower Floridan aquifer, the total inflow and outflow also are predicted to increase by approximately 1.3 percent. Lateral inflow and upward leakage to the upper Floridan aquifer will increase, and downward leakage from the upper Floridan aquifer and lateral outflow will decrease.

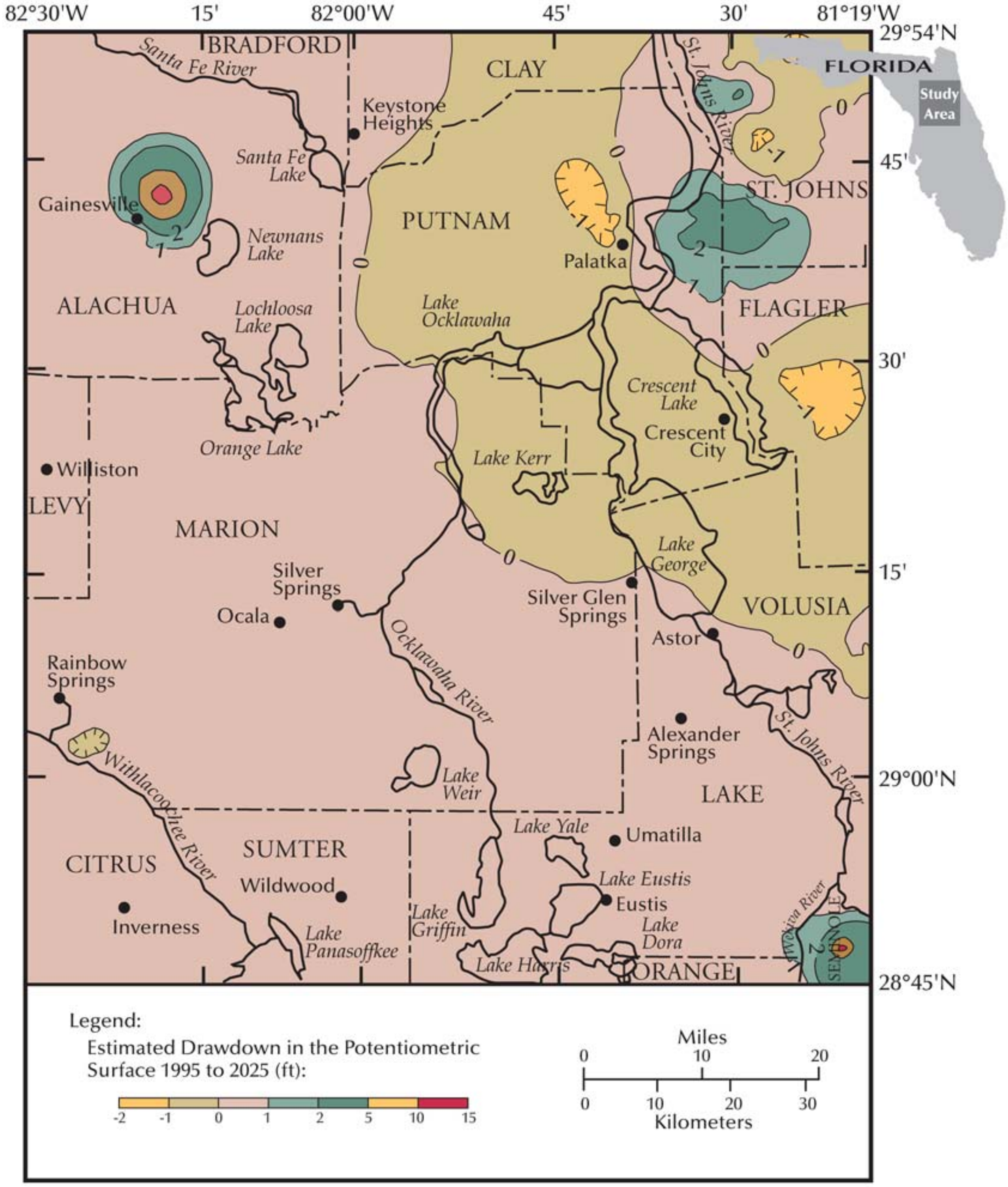


Figure 71. Estimated drawdown in the potentiometric surface of the upper Floridan aquifer in north-central Florida due to changes in pumpage and recharge from 1995 to 2025

Table 13. Estimated changes in the hydrologic budgets of the surficial aquifer system and upper and lower Floridan aquifers due to changes in pumpage and recharge from 1995 to 2025

Aquifer and Hydrologic Budget Component	1995 (cfs)	2025 (cfs)	Change from 1995 to 2025	
			(cfs)	%
Surficial Aquifer				
Direct Recharge	4257	4299	42	1.0
River Leakage	305	310	5	1.5
Upward Leakage	621	607	-14	-2.2
TOTAL INFLOW	5184	5217	33	0.6
Evapotranspiration	1792	1789	-3	-0.2
River Leakage	1387	1389	2	0.1
Downward Leakage	2005	2039	34	1.7
TOTAL OUTFLOW	5184	5217	33	0.6
Upper Floridan Aquifer				
Direct Recharge	1571	1571	0	0.0
River Leakage	141	144	3	2.2
Injection and Drainage Wells	28	29	2	7.0
Downward Leakage	2005	2039	34	1.7
Upward Leakage	528	537	9	1.7
Lateral Inflow	387	411	25	6.4
TOTAL INFLOW	4660	4732	72	1.5
Evapotranspiration	69	67	-2	-2.6
River Leakage	221	218	-3	-1.3
Wells	375	524	149	39.7
Springs	2053	2019	-34	-1.6
Upward Leakage	621	607	-14	-2.2
Downward Leakage	399	395	-4	-1.0
Lateral Outflow	922	901	-21	-2.3
TOTAL OUTFLOW	4660	4732	72	1.5
Lower Floridan Aquifer				
Downward Leakage	399	395	-4	-1.0
Lateral Inflow	400	414	15	3.6
TOTAL INFLOW	799	810	11	1.3
Wells	9	17	8	90.7
Upward Leakage	528	537	9	1.7
Lateral Outflow	261	255	-6	-2.5
TOTAL OUTFLOW	799	810	11	1.3

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9.0 DISCUSSION AND CONCLUSIONS

9.1 CALIBRATION RESULTS

9.1.1 Groundwater Levels and Springs

In the average 1995 simulation, the simulated water table (Figure 36) and potentiometric surface (Figure 40) match the observed water table (Figure 18) and potentiometric surface (Figure 15) very closely. In layer one, which represents the surficial aquifer system, the mean error of the differences between the simulated and observed heads (-0.80 ft) and the root mean square error (4.51 ft) (Figure 38) are relatively small, which indicates that the differences between the simulated and observed heads in layer one are relatively small. In layer two, which represents the upper Floridan aquifer, the mean error of the differences between the simulated and observed heads (-0.07 ft) and the root mean square error (3.27 ft) (Figure 42) also are relatively small, which indicates that the differences between simulated and observed heads in layer two are relatively small as well. Also, over large parts of the model domain, residuals between simulated and observed heads are within ±5 ft in layer one (Figure 39) and ±4 ft in layer two (Figure 43), which also indicates a good calibration.

The calibration results for the average 1995 simulation compare quite favorably with results reported for other, similar groundwater flow models (see Table 14). For example, McGurk and Presley (2002) obtained a mean error of 0.12 ft and a root mean square error of 4.32 ft in the surficial aquifer system and a mean error of 0.40 ft and a root mean square error of 3.04 ft in the upper Floridan aquifer in their simulation of the east-central Florida area. Murray and Halford (1996) obtained a mean head difference of 0.12 ft and an average absolute error of 1.8 ft in the upper Floridan aquifer in their simulation of the greater Orlando area, and Knowles et al. (2002) obtained a mean error of –1.78 ft and a root mean square error of 13.9 ft in the surficial aquifer system and a mean error of 0.53 ft and a root mean square error of 4.72 ft in the upper Floridan aquifer in their simulation of Lake County and the Ocala National Forest. Also, Motz and Dogan (2002) obtained a mean error of -0.13 ft and a standard deviation of 2.48 ft in the upper Floridan aquifer in their simulation of north-central Florida. The results for layer two also compare favorably with the results reported by Sepulveda (2002), who obtained a mean head difference of -0.19 ft and a root mean square error of 3.41 ft in the upper Floridan aquifer in his simulation of peninsular Florida.

In addition, the total of the simulated spring discharges (1.77×10^8 ft^3/day) exactly matches the total of the measured and estimated discharges for 1995. Also, the simulated discharges for each of the 47 springs closely match the corresponding measured and estimated discharges (Table 11 and Figure 49).

These results indicate that the primary objectives of minimizing the differences between the simulated and observed heads in the surficial aquifer system and upper Floridan aquifer and the differences between the simulated and measured (and estimated) discharges from springs discharging from the upper Floridan aquifer were achieved.

Table 14. Comparison of calibration statistics of selected groundwater flow models

Model	Investigator(s)	Surficial Aquifer System		Upper Floridan Aquifer		Lower Floridan Aquifer	
		Mean Error (feet)	Root-Mean Square Error (feet)	Mean Error (feet)	Root-Mean Square Error (feet)	Mean Error (feet)	Root-Mean Square Error (feet)
East-Central	McGurk and Presley (2002)	0.12	4.32	0.40	3.04	Not calibrated (variable head)	Not calibrated (variable head)
Greater Orlando Metropolitan Area	Murray and Halford (1996)	Not calibrated (specified head)	Not calibrated (specified head)	0.12	Average absolute error = 1.8 feet	Not calibrated (variable head)	Not calibrated (variable head)
Lake County and Ocala National Forest	Knowles et al. (2002)	– 1.78	13.9	0.53	4.72	2.33	4.6
North-Central (Revised)	Motz and Dogan (2002)	Not calibrated (specified head)	Not calibrated (specified head)	– 0.13	Standard deviation = 2.48 feet	Not calibrated (variable head)	Not calibrated (variable head)
North-Central Active Water-Table	Motz and Dogan (2004) (this investigation)	– 0.80	4.51	– 0.07	3.27	Not calibrated (variable head)	Not calibrated (variable head)
Peninsular Florida	Sepulveda (2002)	Not calibrated (specified head)	Not calibrated (specified head)	– 0.19	3.41	0.17	2.89

Note: Sepulveda (2002) also obtained a mean error = – 0.18 feet and a root-mean square error = 3.47 feet for the intermediate aquifer system, which is locally present within the intermediate confining unit in part of his model domain.

9.1.2 Direct Discharge

The simulated net discharge into the St. Johns River (376 cfs) compares favorably with the estimated direct discharge into the St. Johns River (346 cfs) (Table 7). The simulated net discharge into the Ocklawaha River (99.2 cfs) is approximately 30 percent greater than the 73.7 cfs estimated for the direct discharge into the Ocklawaha River (Table 7), which also is a reasonable result considering the approximations necessarily made in the water-budget calculations used to estimate the direct discharge. The simulated net discharge into the Santa Fe River (24.2 cfs) is nearly the same as the 24.5 cfs estimated for the direct discharge into the Santa Fe River (Table 8). Similarly, the simulated net discharge into the Withlacoochee River (73.9 cfs) is nearly the same as the 73.0 cfs estimated for the direct discharge into the Withlacoochee River (Table 8). These results indicate that the secondary objective of matching the estimated direct discharges from the surficial aquifer system and upper Floridan aquifer into the St. Johns, Ocklawaha, Santa Fe, and Withlacoochee rivers also was achieved.

9.2 LIMITATIONS AND UNCERTAINTIES

There are always limits and uncertainties associated with groundwater models, and the north-central Florida active water-table model described in this report is no exception. The need to represent a relatively large area in such a model limits the number of rows and columns to a practical maximum number and correspondingly sets the minimum cell size. In this model, for example, with a uniform cell size utilized over the model domain, the resulting 2,500-ft discretization may not be small enough to simulate many of the details in the surficial aquifer system in localized areas in which there is a relatively large spatial variability of the water table. Also, even though the model calibration resulted in relatively small residuals and seemingly good results, the non-uniqueness of the calibration should be acknowledged, i.e., other combinations of the hydraulic parameters and boundary conditions potentially could produce similar results.

In comparing the water tables simulated for average 1995 and 2020 conditions and for revised 1995 and 2025 conditions, relatively large areas can be noted in which the water table increases by 0 to 1 ft (Figures 62 and 70). These water-table increases are caused by increases in irrigation and septic tank discharges to the surficial aquifer system, which are associated with increases in public-supply, domestic self-supply, and agricultural pumpage projected from 1995 to 2020 and 2025. The water table is relatively sensitive to changes in recharge rates, and, in future model development, maximum water-table rise, ponding depths, and associated increases in surface-water runoff perhaps should be given more attention.

In nearly all of the recharge areas in the model domain, recharge from the surficial aquifer to the upper Floridan aquifer is equal to or less than 30 inches/year (Figure 52). In a very small number of cells in the model domain, recharge from the surficial aquifer system to the upper Floridan aquifer ranges from 30 to 85 inches/year. These high rates of recharge, which occur in approximately 1 percent of the model domain, are in areas that are recognized by Aucott (1988), Bonoil et al. (1993), Stewart (1980), and Yobbi and Chappell (1979) as areas of high recharge to the upper Floridan aquifer. These high values of recharge are consistent with values of vertical leakage on the order of 60 inches/year or more determined for lakes in the Upper Etonia Creek Basin (Motz 1998 and Motz et al. 2001), which occurs along the northern boundary of the model domain adjacent to and east of Lake Santa Fe.

Finally, assembling and calibrating a groundwater model often can indicate areas in which more data need to be collected in order to refine hydrogeologic concepts and/or improve predictions made by the model. For example, Miller's (1986) description of the hydrogeology in the northwestern part of the model domain indicates that the middle semiconfining unit (MSCU) is not present in this area (Figure 12). By contrast, results of the model calibration described in Chapter 6 indicate that the leakance of the MSCU may be relatively small in part of this area (Figure 47). This apparent contradiction indicates that leakance properties of the MSCU in the northwestern part of the model domain need to be defined better and that additional data collection may be needed to help resolve this.

9.3 CONCLUSIONS

As described in Chapter 7, the groundwater flow model calibrated for average 1995 conditions was used to simulate the water table in the surficial aquifer system and the potentiometric surface of the upper Floridan aquifer for 2020, using projected pumpage based on Sepulveda (2002). In this simulation, the groundwater pumpage for 2020 (401.2 mgd) is 57 percent greater than the pumpage estimated for 1995 (255.8 mgd) (Figure 27). The simulated water-level drawdowns due to the projected increases in pumpage from 1995 to 2020 are negligible (less than 1.0 ft) over a large part of the study area in both the surficial aquifer system and upper Floridan aquifer (Figures 62 and 63). Drawdowns in the water table in the surficial aquifer system will be approximately 1 to 2 ft in the southern part of the study area and approximately 2 to 3 ft in Alachua County at the GRU wellfield near Gainesville (Figure 62). Drawdowns in the potentiometric surface in the upper Floridan aquifer will be approximately 2 to 5 ft in the southern and northeastern parts of the model area and approximately 16 ft in Alachua County at the GRU wellfield near Gainesville (Figure 63). The simulated decrease in total flow in the surficial aquifer system (0.1 percent) and simulated increases in total flow in the upper and lower Floridan aquifers (2.4 and 0.9 percent, respectively) (Table 12), are insignificant. The 2.1 percent decrease in total spring discharge from the upper Floridan aquifer simulated for average 1995 conditions (2,046 cfs), compared to the total spring discharge simulated for 2020 (2,002 cfs), also is relatively small.

Similarly, as described in Chapter 8, the groundwater flow model calibrated for average 1995 conditions was used to simulate the water table in the surficial aquifer system and the potentiometric surface of the upper Floridan aquifer for 2025, using revised pumpage for SJRWMD (written communication, 2003) for 1995 and projections for 2025. In this simulation, the groundwater pumpage for 2025 (330.9 mgd) is 44 percent greater than the pumpage estimated for 1995 (230.5 mgd) (Figure 28). The simulated water-level drawdowns due to the projected increases in pumpage from 1995 to 2025 are negligible (less than 1.0 ft) over a large part of the study area in both the surficial aquifer system and upper Floridan aquifer (Figures 70 and 71). In this simulation, drawdowns in the water table in the surficial aquifer system will be approximately 2 to 3 ft in the southeastern part of the study area in Seminole County and approximately 1 to 2 ft in Alachua County at the GRU wellfield near Gainesville (Figure 70).

Drawdowns in the potentiometric surface in the upper Floridan aquifer will be approximately 10 to 15 ft in the southeastern part of the study area in Seminole County and approximately 15 ft in Alachua County at the GRU wellfield near Gainesville (Figure 71). The simulated increases in total flow in the surficial aquifer system (0.6 percent) and upper and lower Floridan aquifers (1.5 and 1.3 percent, respectively) (Table 13) are insignificant. The 1.9 percent decrease in total spring discharge from the upper Floridan aquifer simulated for average 1995 conditions (2,053 cfs), compared to the total spring discharge simulated for 2025 (2,014 cfs), also is relatively small.

Based on the model results, the effects that increased groundwater pumpage in north-central Florida from 1995 to 2020 and 2025 will have on water levels in the surficial aquifer system and upper Floridan aquifer, groundwater system water budgets, and spring flows generally will be small on a regional basis. However, some localized drawdowns in Alachua, Lake and Seminole counties may be significant. The newly revised north-central Florida regional groundwater flow model, calibrated for average 1995 conditions with an active water table, provides a means for water managers to evaluate groundwater pumping options for this region. The calibrated groundwater flow model developed in this study can be used to predict the effects that pumping from the upper Floridan aquifer will have on water levels in the surficial aquifer system and upper Floridan aquifer. Also, the simulated water-table and upper Floridan aquifer drawdowns can be used to estimate the effects that increased pumping will have on lakes and wetlands in the study area.

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