DATA AVAILABILITY FOR DEVELOPMENT OF THE NORTH FLORIDA SOUTHEAST GEORGIA (NFSEG) REGIONAL GROUNDWATER FLOW MODEL IN THE AREA OF ITS POTENTIAL DOMAIN

by

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for

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INTRODUCTION

The North Florida Southeast Georgia (NFSEG) regional groundwater flow model will encompass portions of Florida, Georgia, and possibly South Carolina. It will be used in evaluations of both inter-district (e.g., SJRWMD/SRWMD) and inter-state (e.g., Florida/Georgia) aquifer drawdowns. As with other regional-scale, numerical groundwater flow models, the development and application of the NFSEG regional groundwater flow model will require a considerable variety and amount of data. In view of the essential role of data in model development and application, an assessment of the availability of required data within the potential domain of the NFSEG model is necessary prior to specifying the locations of the model spatial boundaries and the time frames to be represented in model calibration runs. Where data deficiencies are identified, they may, in some cases, be addressed through data collection performed during model development. However, if essential data are not available in areas of interest and cannot be obtained in a manner that is consistent with the model-development schedule, then the feasibility of including such areas in the model domain will need to be given special consideration.

Data types needed for the model development and application include the following: water-use data (i.e., well-discharge rates, well locations, well casing lengths, and well open-hole or screened intervals); rainfall amounts and distribution; evapotranspiration rates and distribution; aquifer water levels; surface-water levels; stream-flow rates; groundwater chemistry (e.g., concentrations of total-dissolved solids, chlorides, and sulfates); land use; and soils data. Hydrogeologic data are required also, including aquifer identification and extent, aquifer and confining-unit top and bottom elevations (i.e, stratigraphy), and aquifer hydraulic properties, such as transmissivity or hydraulic conductivity. Multiple observations or estimates of time-varying data, such as water levels and evapotranspiration, are preferred to better support transient simulations. In some cases, required data types must be derived based on other, observed data types. An example is the rate of aquifer recharge, the estimation of which involves land-use data, soils data, evapotranspiration data, and stream-flow data.

The potential domain of the NFSEG regional groundwater model includes portions of north Florida and southeast Georgia. This area is bounded roughly on the west by the Apalachicola and Chattahoochee rivers, on the east by the Atlantic coast, and on the north by the Fall Line, the boundary between the outcrop areas of the Coastal Plain clastic sediments and the crystalline formations of the Piedmont. The southern boundary will likely lie far enough south to at least enable the inclusion of Marion County, Florida. A portion of South Carolina is included as well because drawdowns created by withdrawals from the FAS in Savannah, Georgia, extend into South Carolina, resulting in potential lateral boundary-constraint considerations. Hence, the Savannah River may be considered another potential boundary (Figure 1). The selection of these boundaries is not intended to exclude consideration of areas outside of them, but, rather, to provide a reasonable starting point for the process of discussing and ultimately determining the exact spatial and temporal boundaries of the model domain.

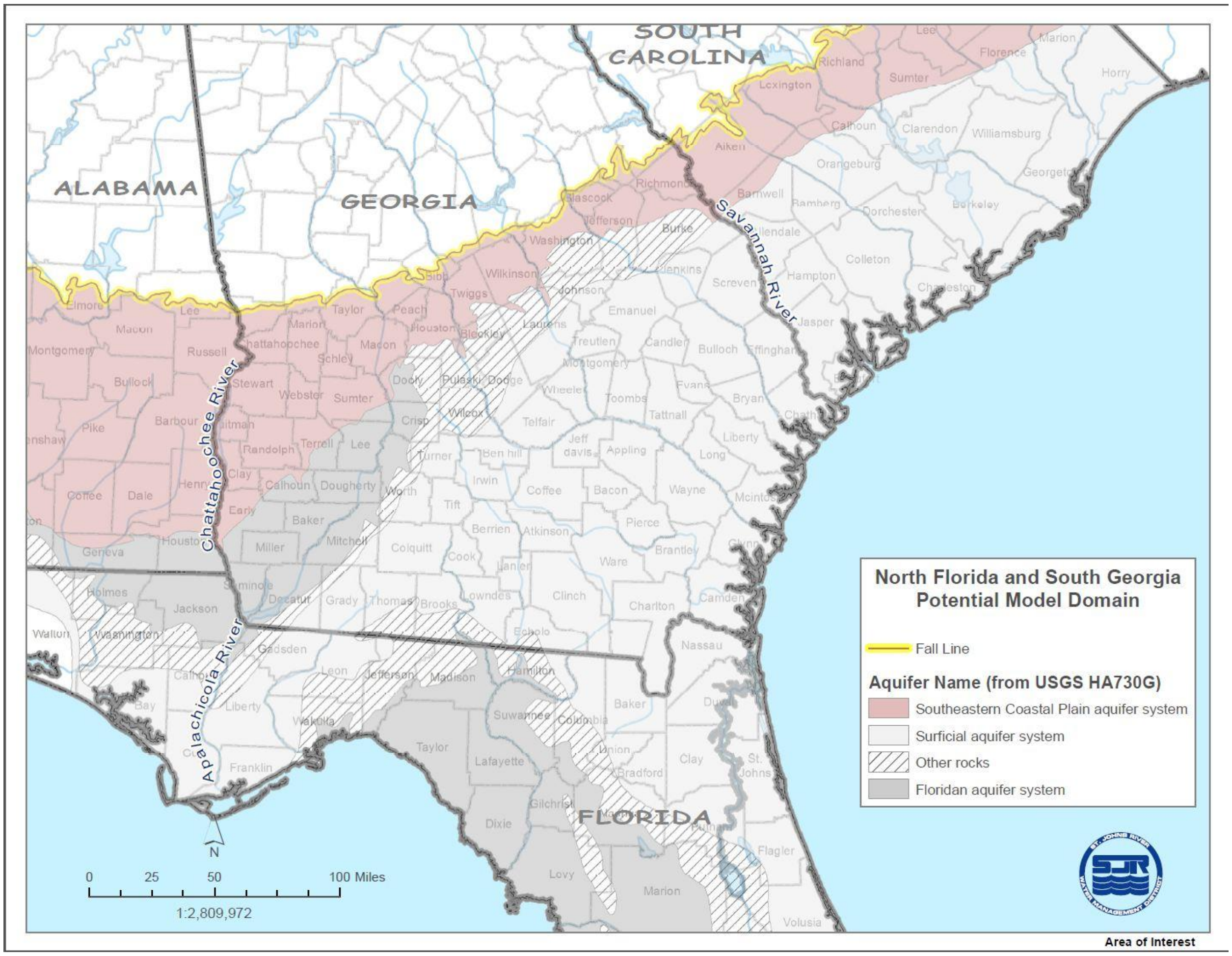


Figure 1. Area of Interest

DESCRIPTION OF STUDY AREA

Physiography

The area of the interest lies within the Coastal Plain physiographic province of Florida, Georgia, and South Carolina. Within the area of interest, the Coastal Plain province is subdivided into the Sea Island, East Gulf Coastal Plain, and Floridian Sections

(Fenneman and Johnson, 1946; Figure 2). The Coastal Plain province extends from the Fall Line southward towards the Atlantic and Gulf coasts. The topography of the Coastal plain within the area of interest varies from low-lying flat plains to rounded foothills of the Piedmont region (Renken, 1996). Karstic landscapes prevail in areas where limestone is near land surface. Low-lying coastal terraces occupy much of the area and reflect changes in Pleistocene sea-level stands (Renken, 1996)

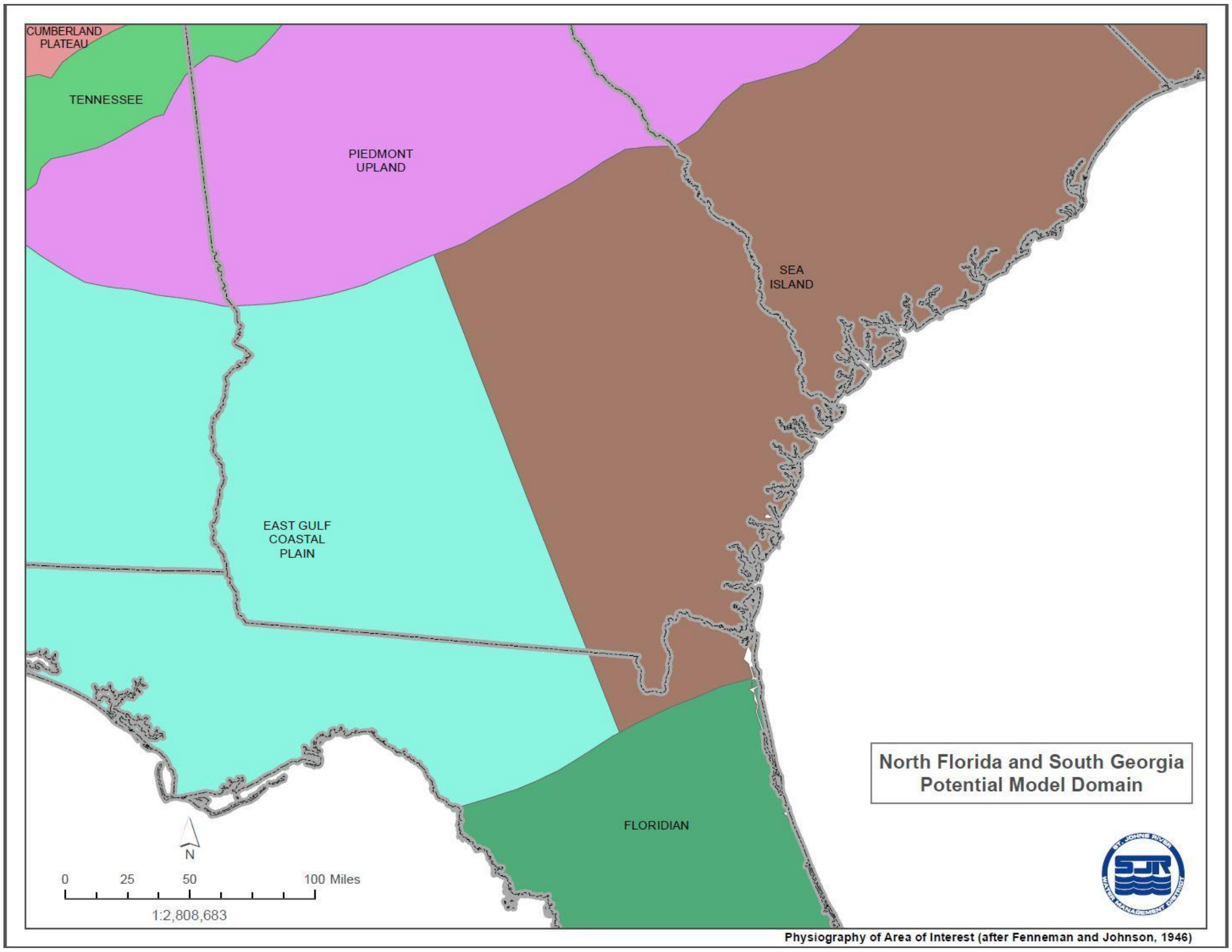


Figure 2. Physiography of Area of Interest (after Fenneman and Johnson 1946)

Drainage Basins

Major drainage basins within the area of interest include the St. Johns River, the Suwannee River, Apalachicola River, the Altamaha River, the Ogeechee River, and the Savannah River basins (Figure 3). With the notable exception of the St. Johns River, the headwaters of the larger rivers tend to be located north of the Fall Line (Figure 3).

Figure 3. Major Surface-Water Drainage Basins

Pumping Centers

Major pumping centers tend to be located in larger cities, where municipal, commercial, and industrial water requirements are concentrated. Such areas include Jacksonville, Gainesville, and Tallahassee, Florida, and Savannah, Brunswick, and Albany, Georgia (Figure 4). Fernandina Beach, Florida, is another area of concentrated pumpage. Until recently, St. Marys, Georgia, was as well. Areas of concentrated agricultural withdrawals include the Flint-River basin of southwest Georgia, southern St. Johns and Flagler counties, Florida, and the Suwannee River basin in Florida (Figure 4).

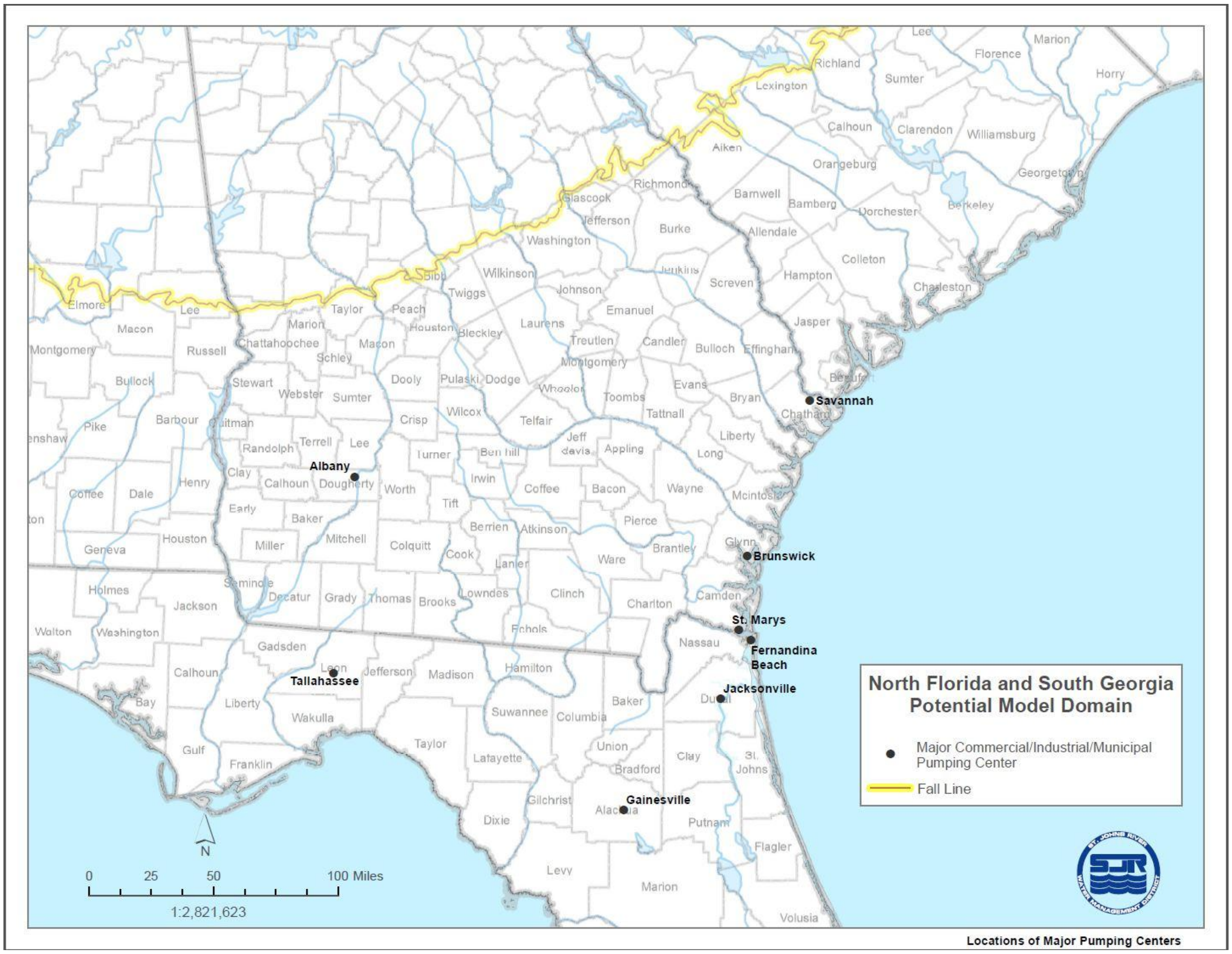


Figure 4. Locations of Major Pumping Centers

Climate

The climate of the area is characterized as humid subtropical, with hot, humid summers and mild winters. Temperatures in the summer range approximately from the low 70's to low 90's ^{o}F on average. Temperatures in the winter range approximately from the low 30's to the low 70's ^{o}F on average ('Climate of Florida', 2012, 'Climate of Georgia', 2012). Rainfall amounts range from somewhat less than 50 inches per year in the north to as high as 60 inches per year or more in the south (Miller, 1990). Winter rainfall patterns tend towards widespread frontal activity, while summer rainfall patterns tend towards afternoon thundershowers ('Climate of Florida', 2012, 'Climate of Georgia', 2012).

GENERALIZED HYDROGEOLOGY

The potential domain of the NFSEG regional groundwater flow model includes large areas of both Florida and Georgia and a portion of South Carolina. Major aquifer systems in this area include the surficial aquifer system, the intermediate aquifer system, the Floridan aquifer system, and the Southeastern Coastal Plain aquifer system (Miller, 1990). The following is a brief description of the aforementioned aquifers.

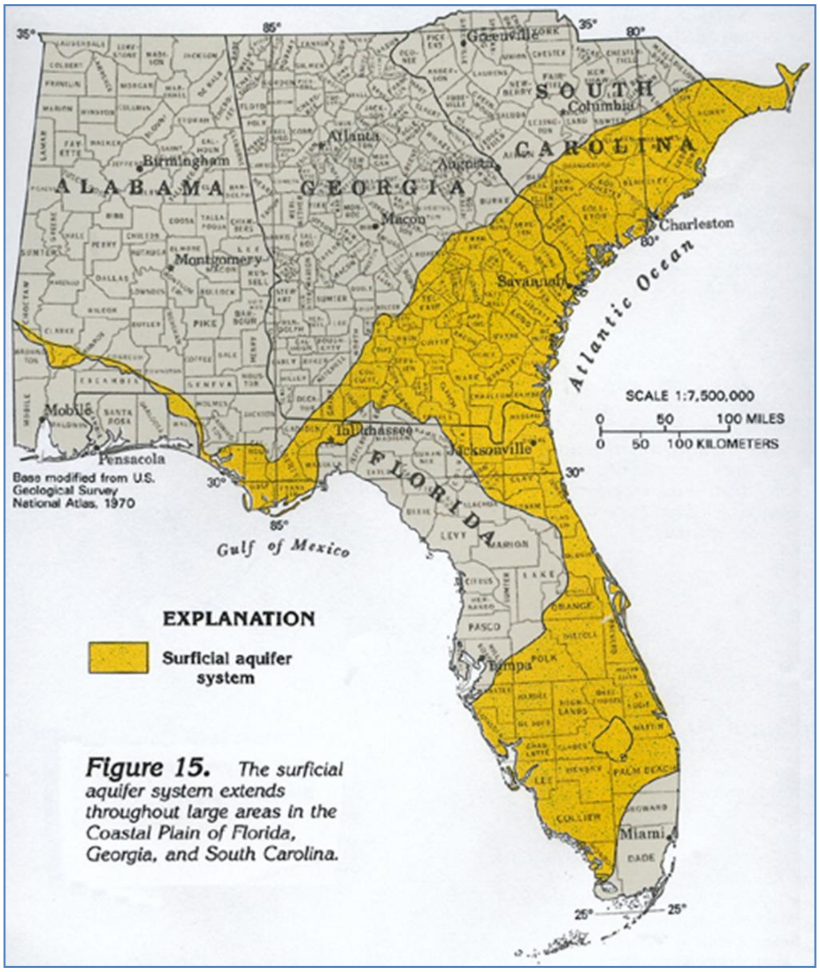


Figure 5. Extent of the Surficial Aquifer System (after Miller 1990)

Surficial Aquifer System

General Description of the Surficial Aquifer System

The surficial aquifer system (SAS) is the uppermost aquifer system within the area of interest. The SAS occupies a large portion of the potential study area (Figure 5; Miller, 1990). The SAS is generally unconfined and is comprised of sediments and rocks that range in age from Pliocene to Holocene (Miller, 1986). It is comprised primarily of unconsolidated beds of sand, shelly sand, and shell, and its thickness is generally less than 50 feet (Miller, 1990). In some locales, the SAS is comprised of an upper unconfined and a lower semiconfined zone. An example is the SAS of Volusia County, Florida, where the SAS is comprised of an upper unconfined zone consisting primarily of sand separated by clay or silt layers from a lower semiconfined zone consisting primarily of sand and shell (Phelps, 1990). From a hydraulic perspective, the SAS serves as a “source-sink” bed for the underlying Floridan aquifer system (Miller, 1986).

<u>Hydraulic Properties of the SAS</u>

Generalized regional maps of the hydraulic properties of the SAS are not available, probably because the SAS has typically been characterized on a localized or subregional basis. Aquifer performance tests have been performed on the SAS (e.g., Hayes, 1981), and the SAS has been actively modeled in recent years (Figure 6). The transmissivity of the SAS has been estimated as ranging generally from 1,000 to 10,000 feet squared per day (ft^2/d) with a maximum range of 25,000 to 50,000 ft^2/d within its area of extent (Miller, 1990). In St. Johns County, Florida, estimates of the transmissivity of the lower permeable zone of the SAS ranged from 6,500 to 7,000 ft^2/d (Hayes, 1981). In Volusia County, Florida, SAS transmissivity estimates ranged from 100 to 9,300 ft^2/d (Phelps, 1990).

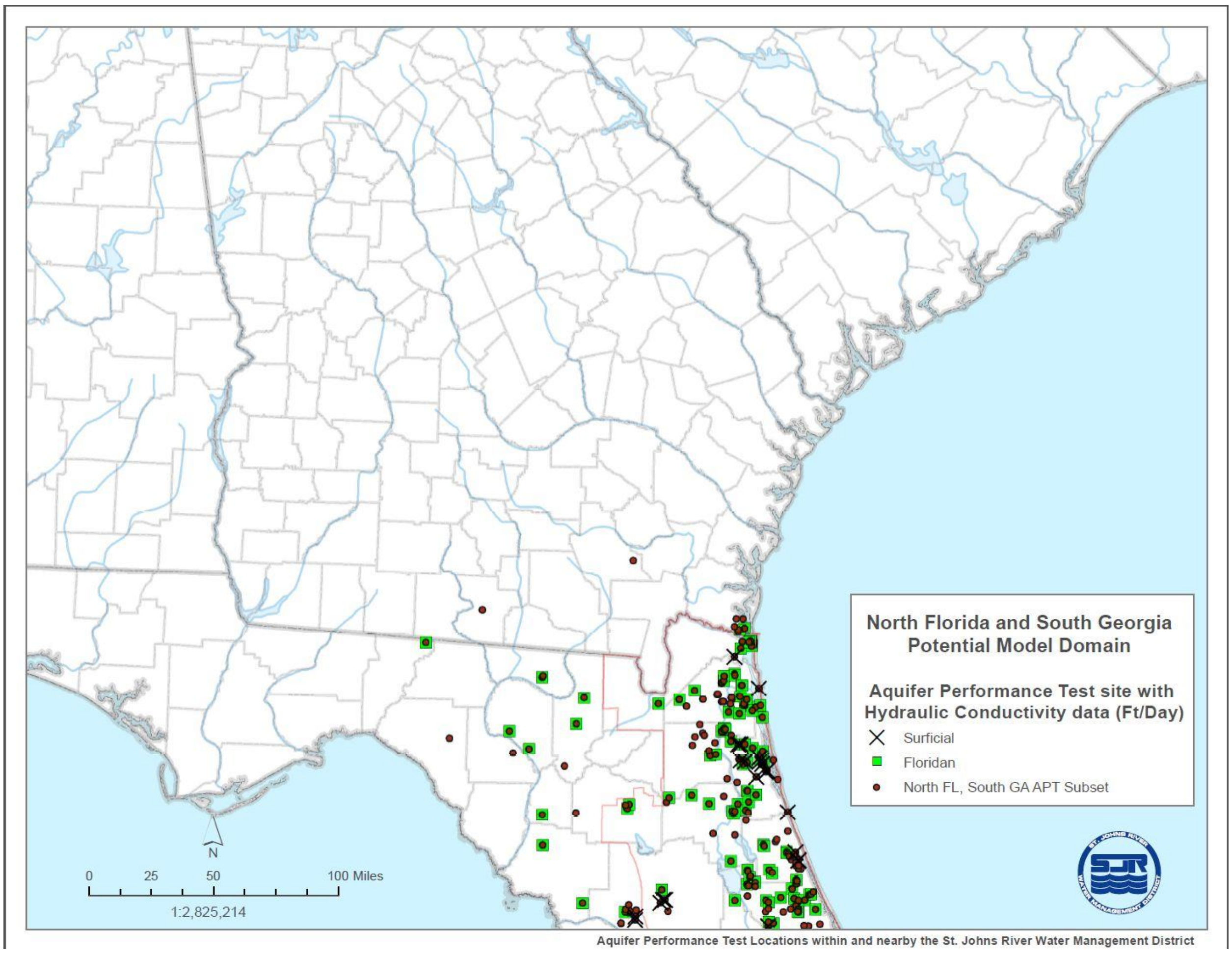


Figure 6. Aquifer Performance Test Locations within and nearby the St. Johns River Water Management District

<u>Stratigraphy of the SAS</u>

The top of the SAS coincides with land surface (Figure 7). The bottom of the SAS coincides with the top of the intermediate aquifer system, where it is present (Miller, 1990; Davis and Boniol, In Progress; Figure 8). The thickness of the SAS is generally

50 feet (ft) or less, but it can range up to approximately 400 ft in parts of east-central Florida (Miller, 1990).

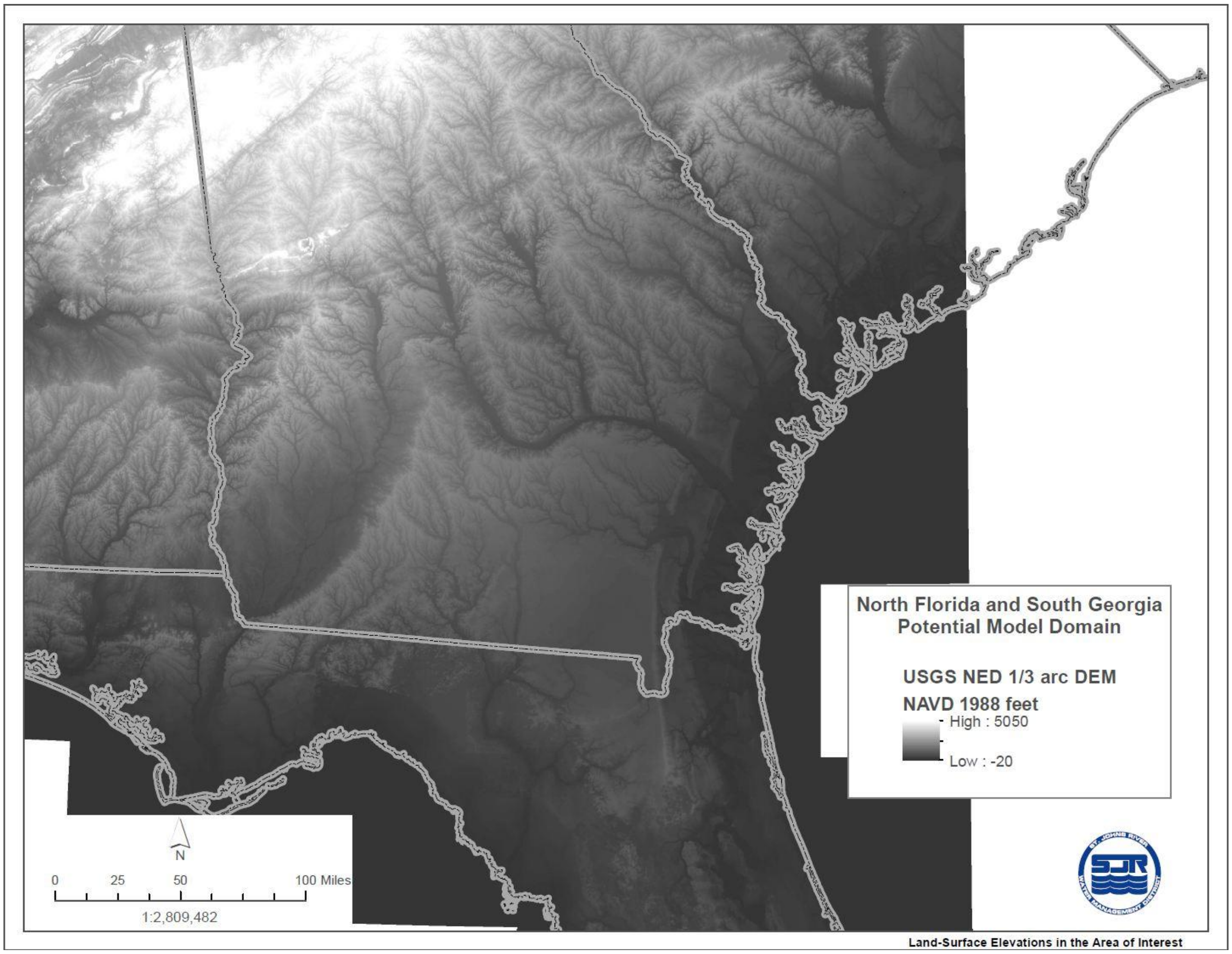


Figure 7. Land-Surface Elevations in the Potential Area of Interest

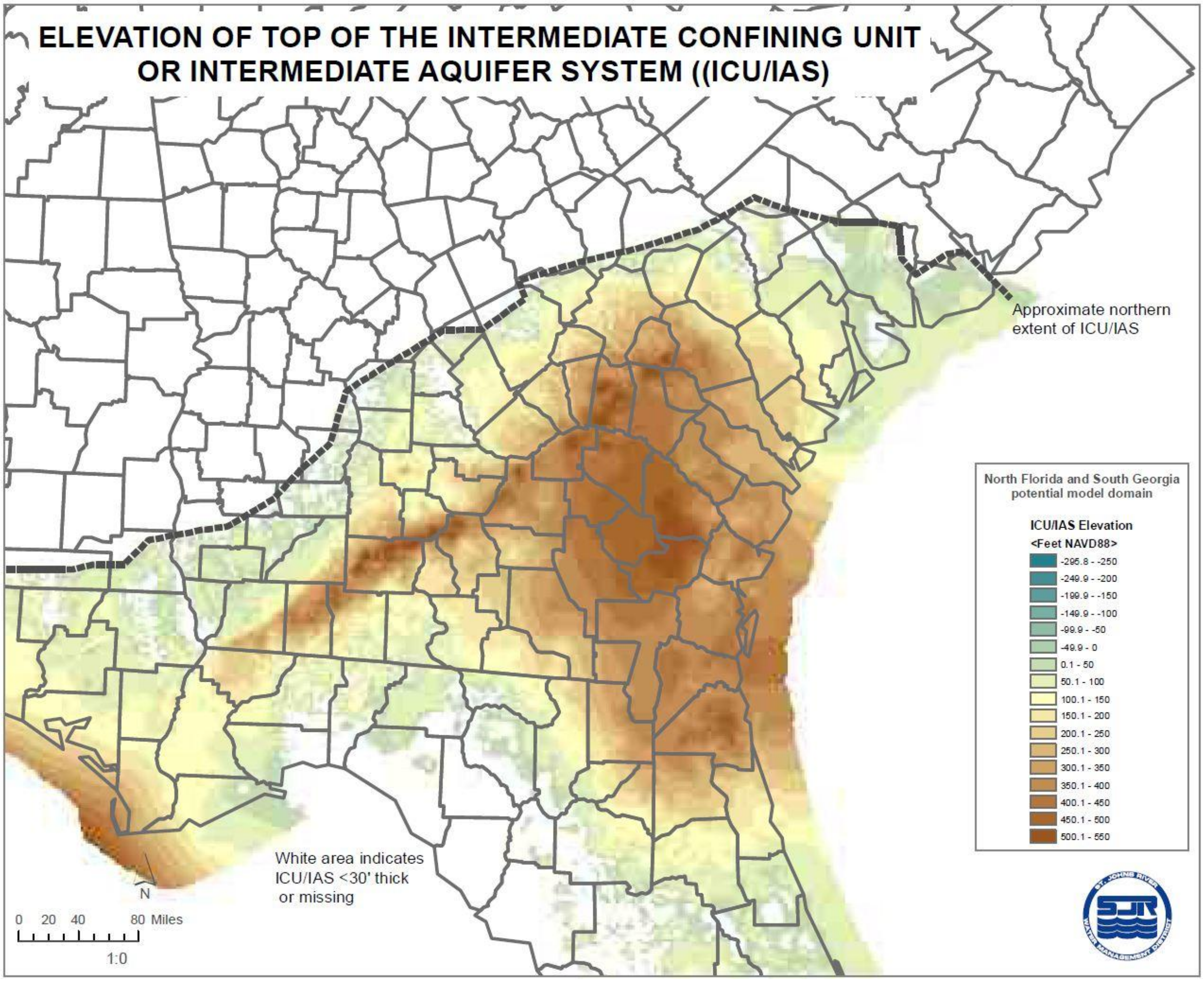


Figure 8. Elevation of the Top of the Intermediate Aquifer System (after Davis and Boniol, in Progress; NAVD 1988)

<u>Water Levels in the SAS</u>

The water table of the SAS is a subdued reflection of land surface (Miller, 1986). Currently, a regional-scale map of the water table that encompasses the entire area of interest is not available. However, a regional-scale water-table map will be produced as a result of the present study, probably for multiple points in time.

Intermediate Aquifer System

General Description of the Intermediate Aquifer System

Throughout most of its extent, the Floridan aquifer system is overlain by thick middle Miocene- (i.e., Hawthorn Group) to post-Miocene-age, clay-rich units that form its upper confining unit (Miller, 1986; Bush and Johnston, 1988; Figure 9). The clays of the upper confining unit are interbedded with sand, shell, and carbonate lenses that in some cases are extensive enough to constitute aquifers of limited vertical and lateral extent

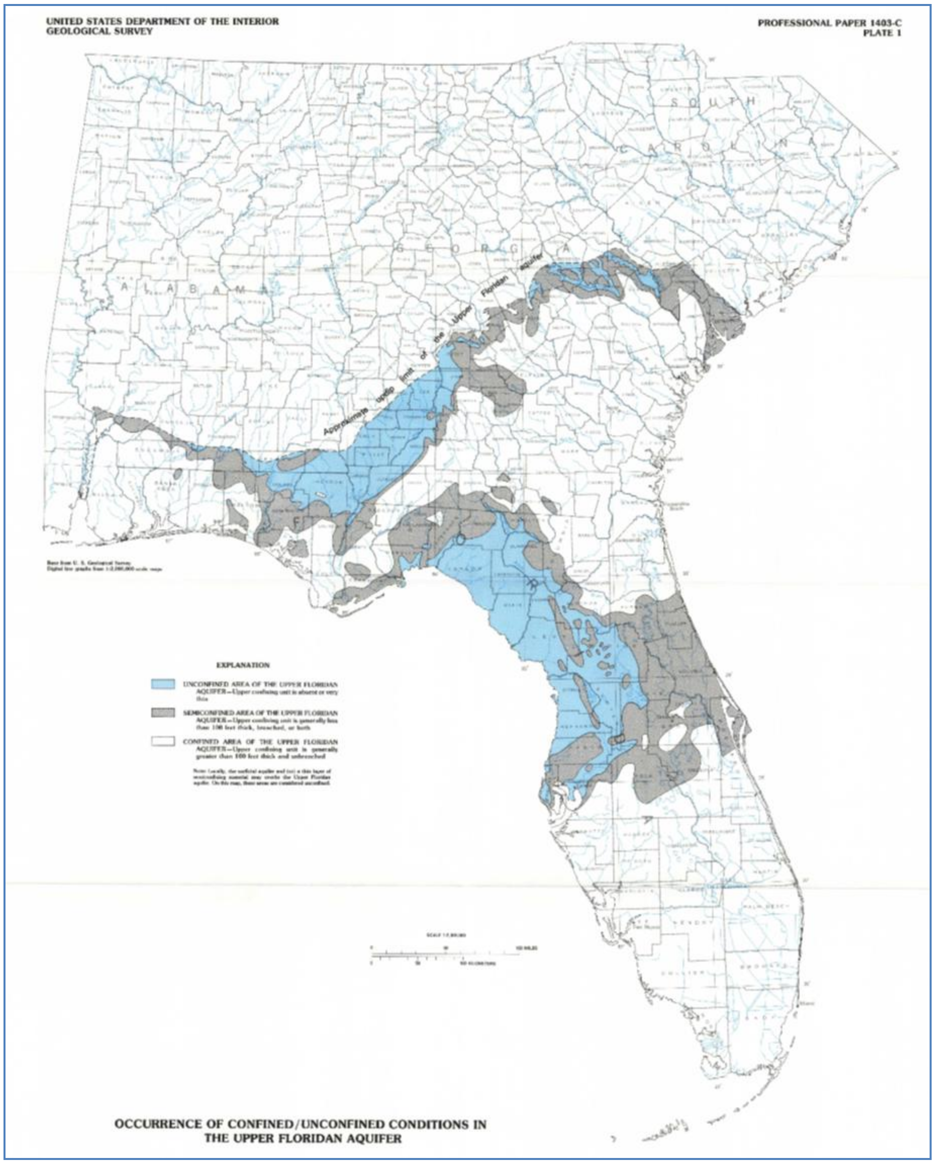


Figure 9. Extent of the Intermediate Aquifer System (after Bush and Johnston 1988)

(Miller, 1986). Perhaps the most notable and well known of such aquifers is the Brunswick aquifer system in the Brunswick area of southeast Georgia (Steele and McDowell, 1998). The upper confining unit and its various internal aquifers of limited areal and vertical extent are referred to collectively as the intermediate aquifer system (IAS) or intermediate confining unit. The IAS separates the underlying Floridan aquifer system from the overlying SAS throughout most of the extent of the SAS (Figure 5).

In some areas, the Floridan aquifer system is unconfined due to the complete absence of the IAS (Bush and Johnston, 1988; Figure 9). Examples of such areas are the lower Suwannee River basin in the Suwannee River Water Management District (SRWMD) of north-central Florida and the lower Flint River basin of southwest Georgia (Bush and Johnston, 1988). By contrast, the IAS can also be quite thick. In Duval and Nassau counties, Florida, and Camden County, Georgia, for instance, its thickness is in the hundreds of feet; hence, in those areas, the Floridan aquifer system is heavily confined.

Stratigraphy of the IAS

Within the area of interest, the thickness of the IAS ranges from 0 ft in areas where the Floridan aquifer system is unconfined to as much as 600 ft in southeast Georgia (Davis and Boniol, In Progress; Figure 10). The IAS is not present in areas in which the Floridan aquifer system is unconfined.

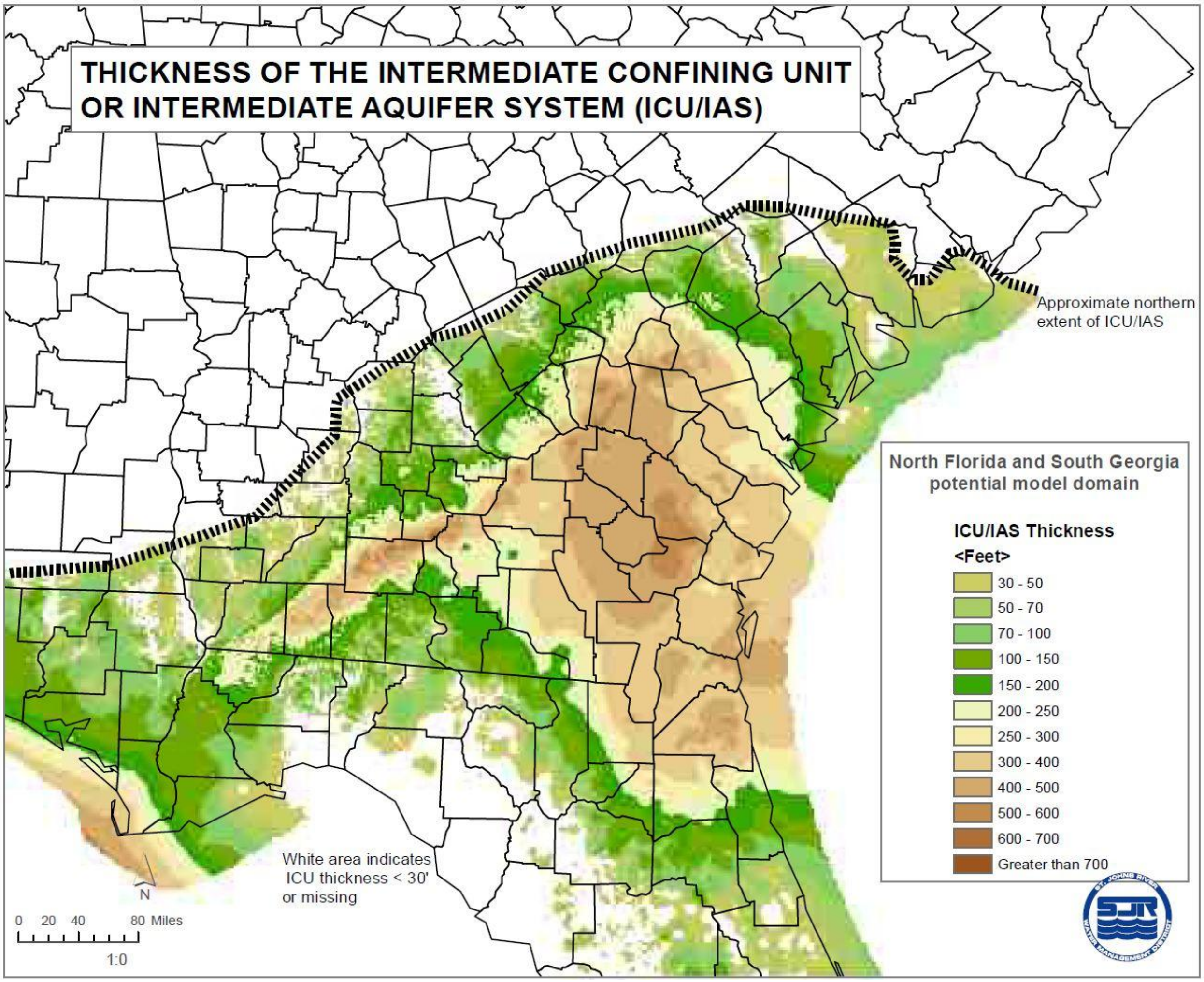


Figure 10. Thickness of the Intermediate Aquifer System (after Davis and Boniol, in Progress)

Hydraulic Properties of the IAS

Hydraulic Conductivity and Transmissivity. While generally of limited water-supply potential, the aquifers of the IAS are, in some cases, capable of supplying relatively large volumes of water. An example is the Brunswick aquifer system of southeast Georgia (Steele and McDowell, 1998). Aquifer-performance tests performed on the Lower Brunswick aquifer in Glynn County, Georgia, indicated an average hydraulic conductivity of about 20 to 57 feet/day (ft/day) and average of about 38 ft/day. These estimates translate to a range in transmissivity of 2,000 to 4,700 ft2/d (Clarke et al., 1990).

Leakance. The leakance of the IAS has been determined from aquifer-performance tests and model calibration. Estimates vary widely depending on location; however, they tend to be lower in areas where the thickness of the IAS is greater. In areas where the IAS is thick, leakance estimates may be on the order of 10^{-6} per day or lower (Bush and Johnston, 1988; Figure 11). In areas where the IAS is thin, leakance estimates may be on the order of 10^{-4} per day or higher (Bush and Johnston, 1988; Figure 11). Leakance estimates would be expected to be generally lower in areas of higher clay content also.

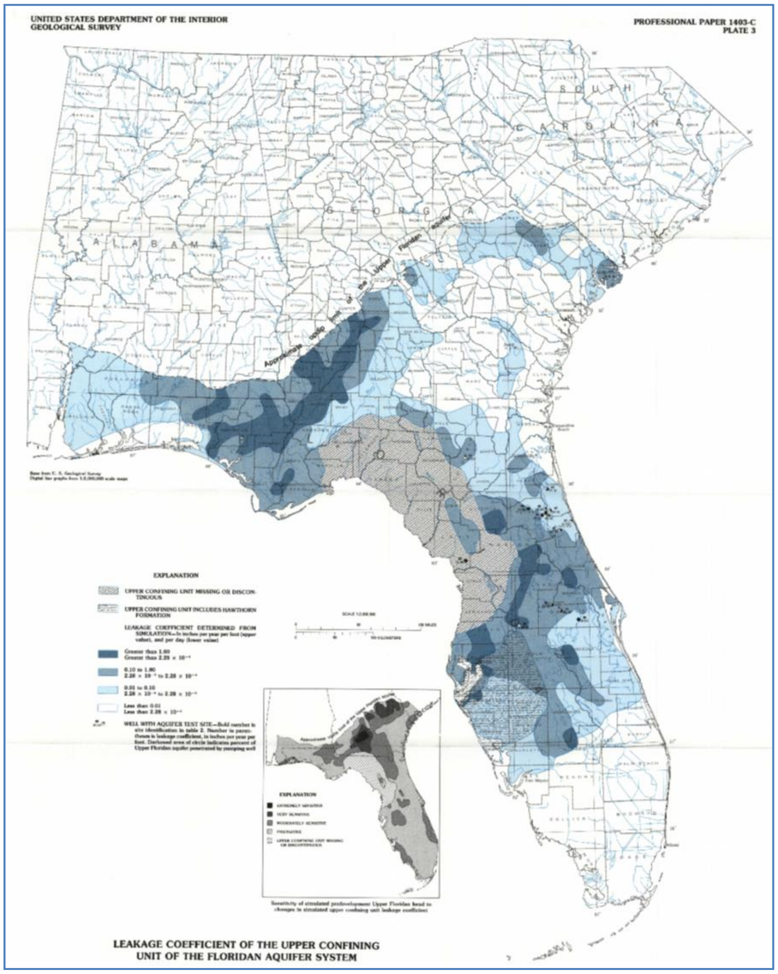


Figure 11. Estimated Leakance Distribution of the Intermediate Aquifer System (after Bush and Johnston 1988)

Floridan Aquifer System

General Description of the Floridan Aquifer System

The Floridan aquifer system (FAS) is comprised primarily of carbonate rocks of Paleocene to Oligocene age. The FAS underlies the entire state of Florida, southeastern Georgia, and parts of Alabama and South Carolina (Miller, 1990). The FAS is highly productive and has become an essential source of water wherever water quality permits (Miller, 1990). In many areas, water within the FAS is brackish or saline (Miller, 1990).

The thickness of the FAS increases from a thin edge along its northern updip limit, which is located south of the Fall Line, towards the Gulf of Mexico and Atlantic Ocean (Miller, 1990). Generally, the FAS is comprised of an upper aquifer, the Upper Floridan aquifer, and a lower aquifer, the Lower Floridan aquifer (Miller, 1986). The Upper Floridan and Lower Floridan aquifers are separated by a semiconfining interval referred to as the middle semiconfining unit (MSCU) herein. Regionally the unit varies in lithologic composition and hydraulic characteristics. As Miller (1986) stated, “Any or all of the subregional low-permeability units may locally contain thin zones of moderate to high permeability.” He also stated that “The vertical hydraulic conductivity of the rocks that comprise the base of the Upper Floridan, however, is everwhere at least two orders of magnitude less than that of the aquifer material itself." The MSCU extent has been expanded from what Miller (1990) mapped due to new data availability and a review of geophysical logs that indicate the presence of confining material that extends westward from where Miller originally mapped the unit. Though the rocks and sediments that comprise the MSCU are regionally extensive, the confinement of the MSCU may be highly variable locally as Miller stated. Core permeability tests at a recently drilled site in Columbia County (SJRWMD well CO0133) indicate rocks of the MCU I are less than 1E-07 cm/sec, and from the Upper and Lower Floridan are greater than 1E-04 cm/sec. It is recognized that dissolution enlarged fractures can greatly affect local conditions and therefore a detailed drilling and testing program is needed to assess the degree of confinement at specific sites.

In northeast Florida and Camden and Glynn counties, Georgia, the Lower Floridan aquifer is further subdivided into an upper zone and a lower zone called the Fernandina permeable zone (Miller, 1986). A major geological feature that appears to affect flow within the FAS significantly is the Gulf Trough (Kellam and Gorday, 1990) of southeast Georgia. The Gulf Trough is hypothesized as a system of fault-induced grabens into which lower-permeability Miocene sediments have downdropped (Miller, 1986). This feature is oriented generally along a southwesterly-northeasterly alignment (Figure 24). Permeability of the FAS appears to be significantly lower in the Gulf Trough region than in adjacent updip and downdip areas, as evidenced by the bunching of FAS potentiometric-surface contours in the area of the Gulf Trough (Miller, 1986;Figure 24; Figure 25; Figure 27).

Stratigraphy of the FAS

<u>Top of the Upper Floridan Aquifer.</u> The top of the Upper Floridan aquifer ranges in elevation from -800 feet, NAVD88 (ft NAVD88), to more than 550 ft NAVD88 within the area of interest (Davis and Boniol, In Progress; Figure 12).

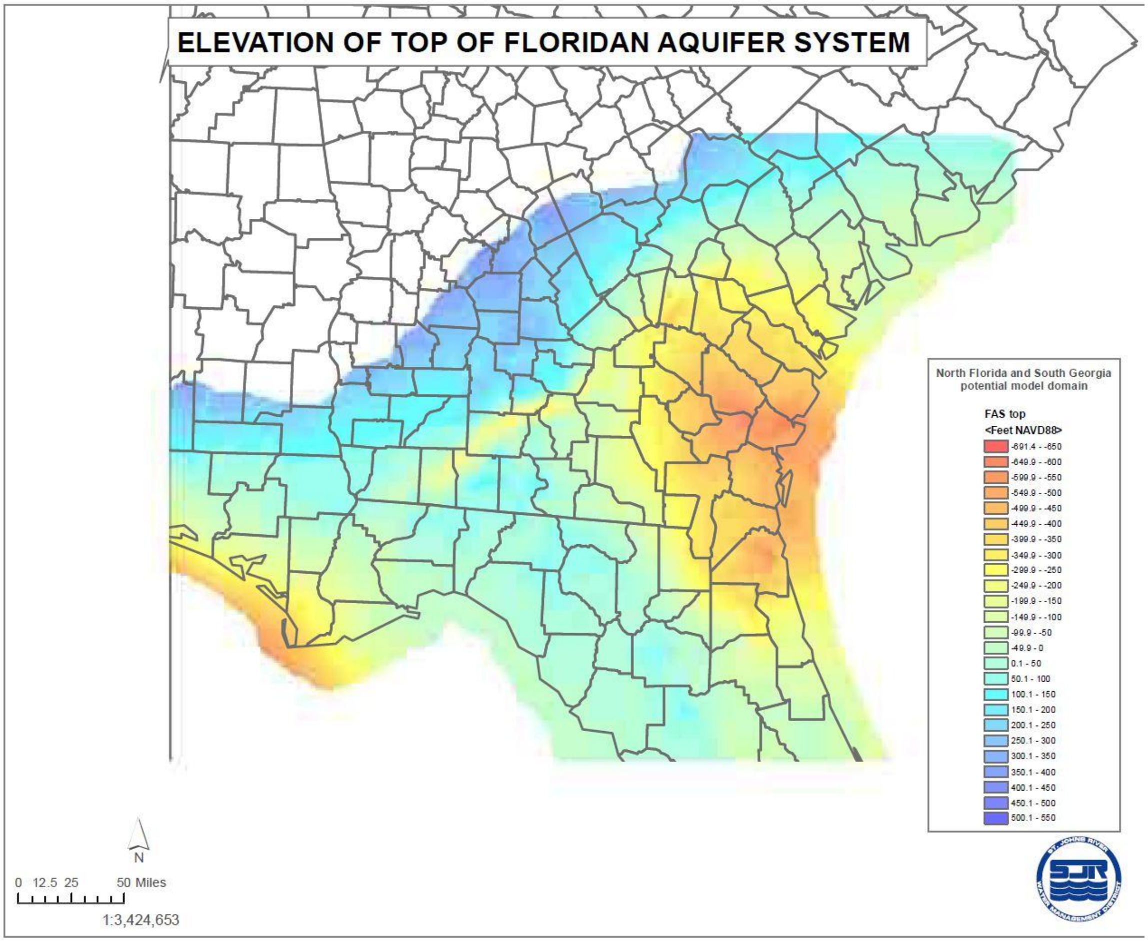


Figure 12. Elevation of the Top of Upper Floridan Aquifer (after Davis and Boniol, in Progress; NAVD88)

<u>Bottom of the Upper Floridan Aquifer.</u> The bottom of the Upper Floridan aquifer ranges in elevation from approximately -1,200 ft NAVD88 in central Florida to over 350 ft NAVD88 at the updip limit of the FAS in central Georgia (Davis and Boniol, In Progress; Figure 13).

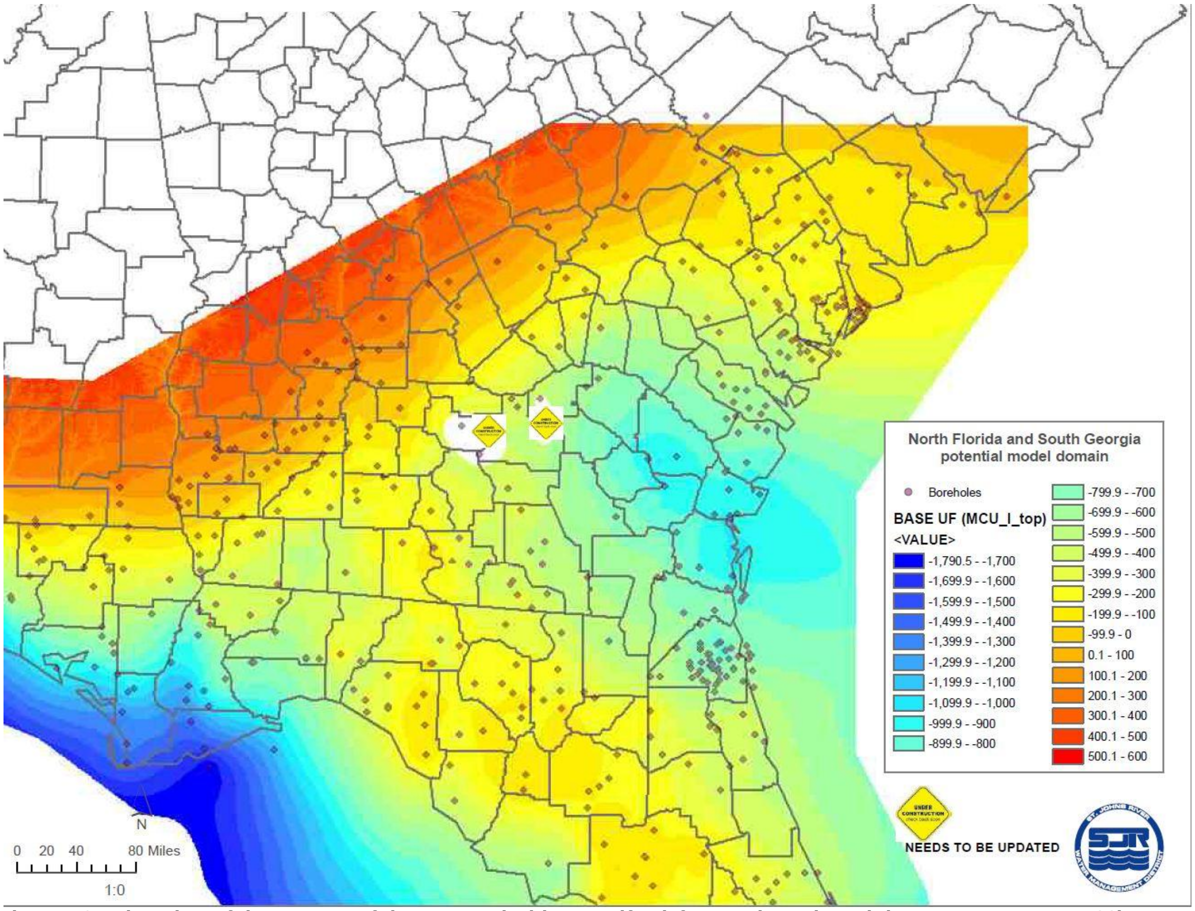


Figure 13. Elevation of the Bottom of the Upper Floridan Aquifer (after Davis and Boniol, In Progress; NAVD88)

Thickness of the Upper Floridan Aquifer. The thickness of the Upper Floridan aquifer ranges from approximately 1,800 ft near Apalachicola in the Florida Panhandle to 0 ft at the updip limit of the FAS in central Georgia and southeastern South Carolina (Davis and Boniol, in Progress;Figure 14).

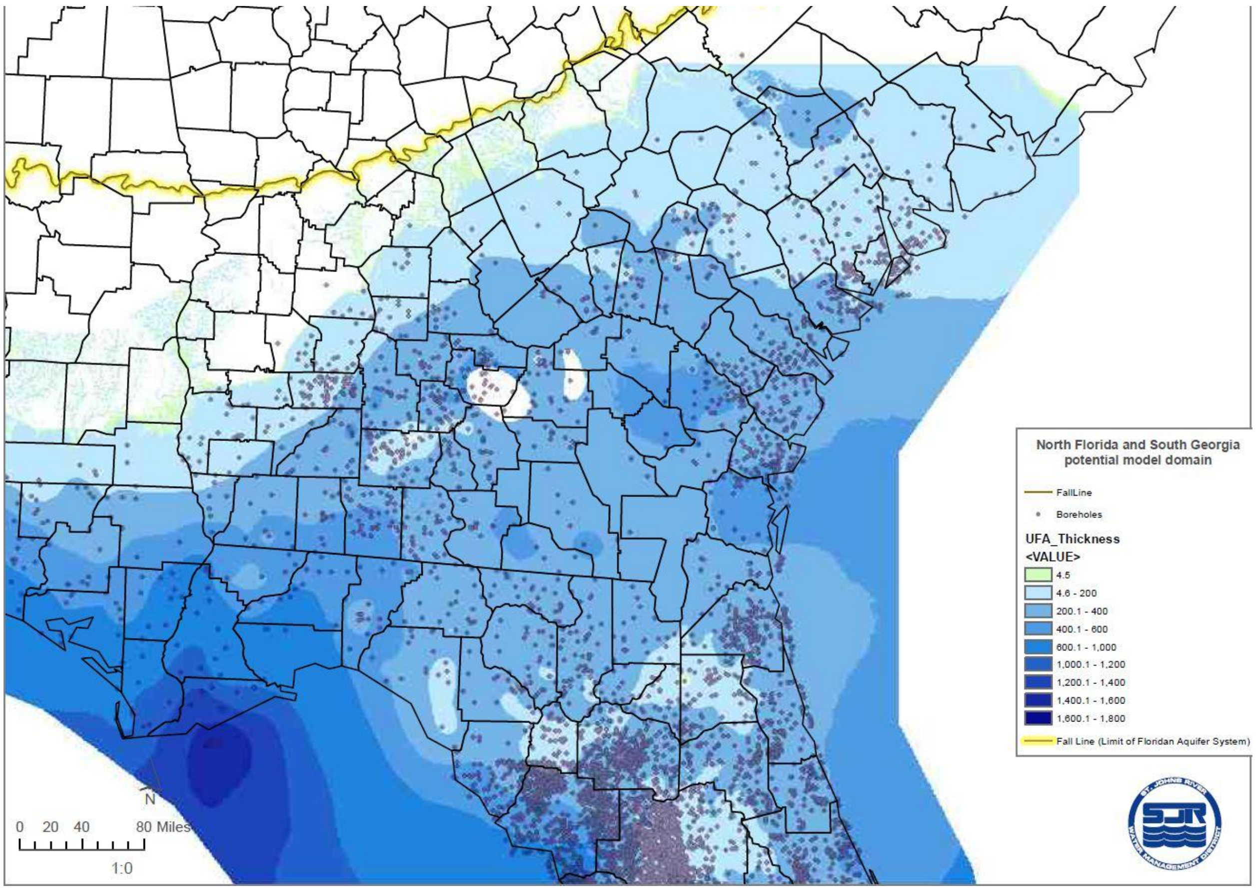


Figure 14. Thickness of the Upper Floridan Aquifer (after Davis and Boniol, In Progress)

Top of the Lower Floridan Aquifer. The top of the Lower Floridan aquifer ranges in elevation from approximately -1,800 ft NAVD88 near Apalachicola in the Florida Panhandle to 350 ft NAVD88 at its updip limit in southeastern South Carolina (Davis and Boniol, In Progress; Figure 15).

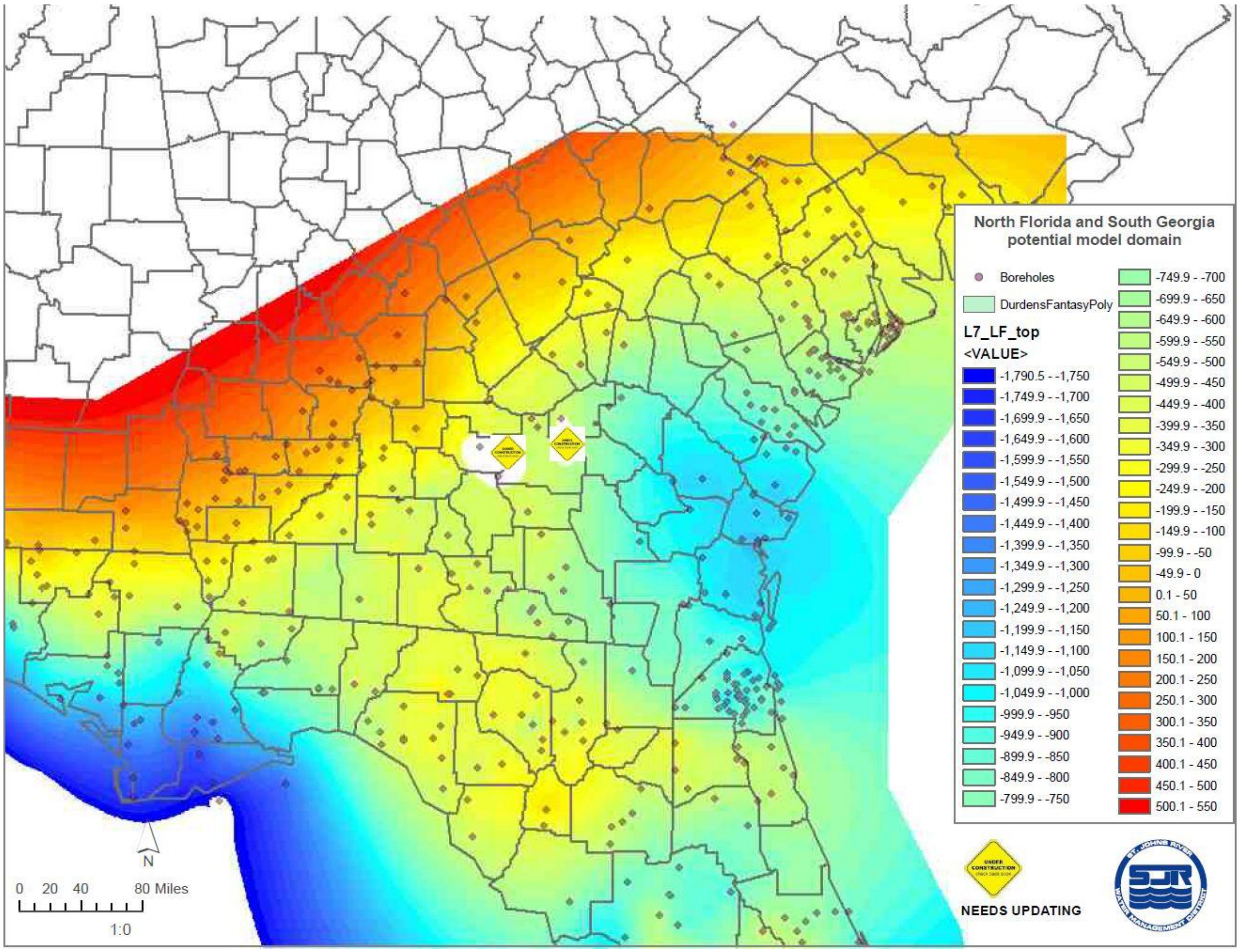


Figure 15. Elevation of the Top of the Lower Floridan Aquifer (after Davis and Boniol, In Progress; NAVD88)

<u>Bottom of the Floridan Aquifer System.</u> The bottom of the Floridan aquifer system ranges in elevation from -3,100 ft NAVD88 at Apalachicola in the Florida Panhandle to 300 ft NAVD88 near its updip limit (Davis and Boniol, in Progress; (Figure 16).

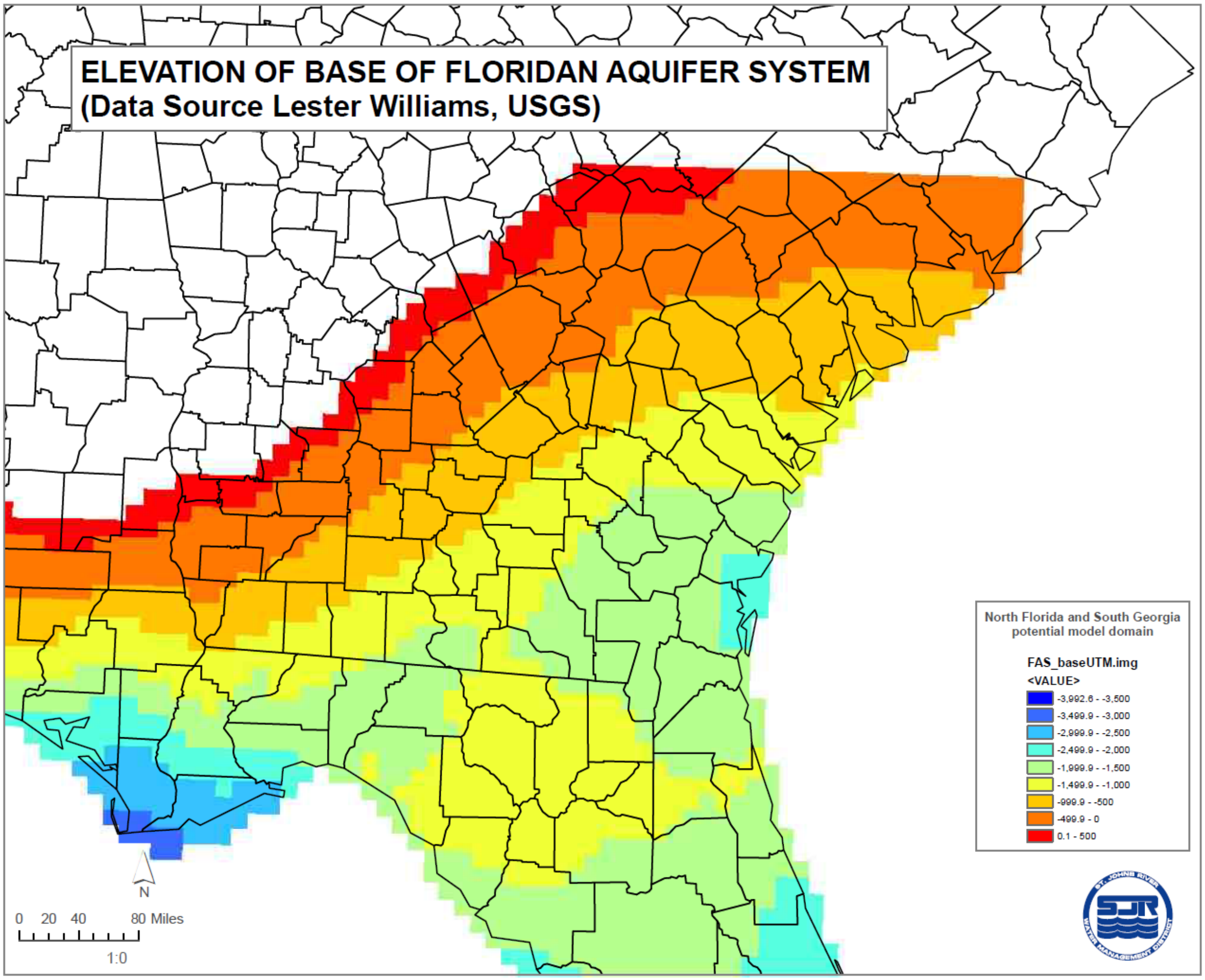


Figure 16. Elevation of the Bottom of the Floridan Aquifer System (after Davis and Boniol, In Progress; NAVD88)

Thickness of the Lower Floridan Aquifer. The thickness of the Lower Floridan aquifer ranges from approximately 1,600 ft near Apalachicola to 0 ft near its updip limit in southeastern South Carolina (Davis and Boniol, In Progress; Figure 17).

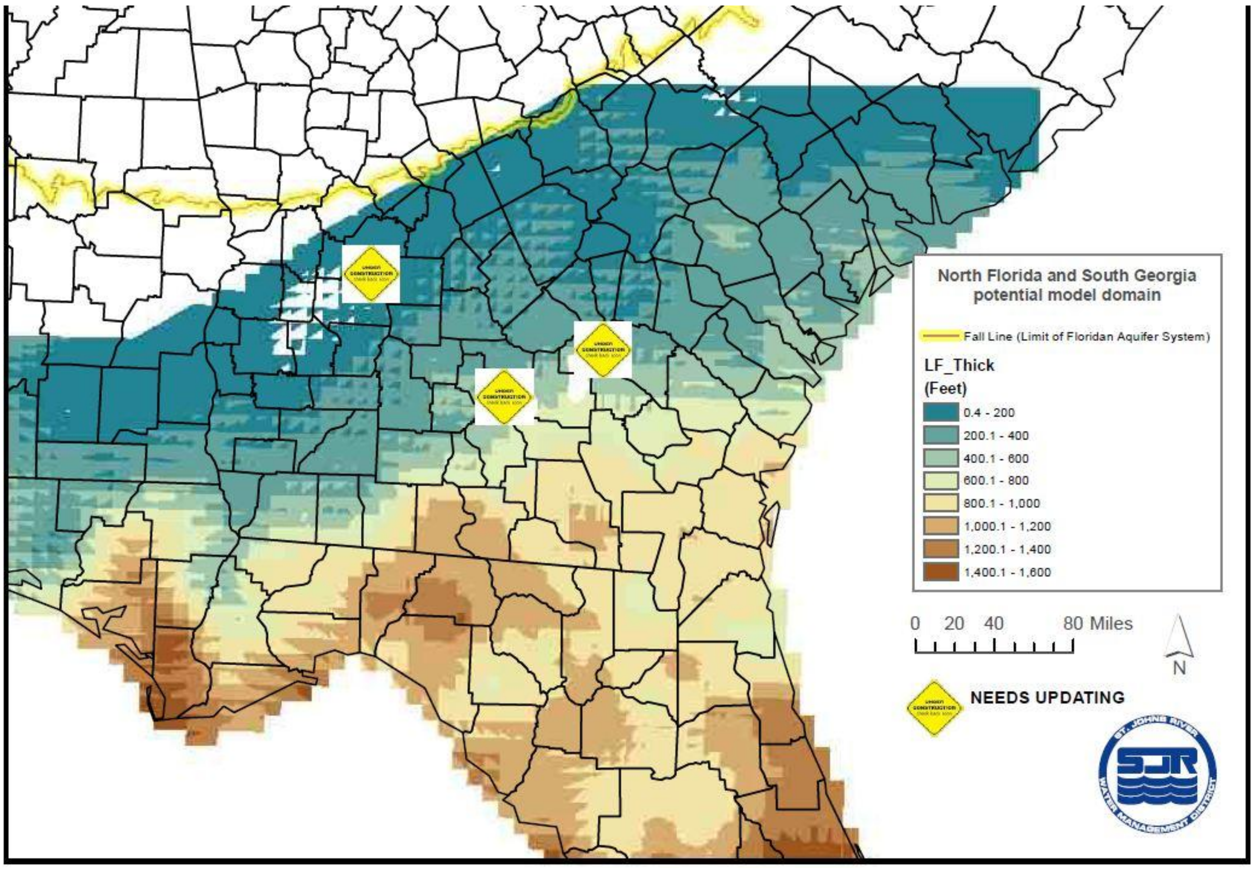


Figure 17. Thickness of the Lower Floridan Aquifer (after Davis and Boniol, In Progress)

Hydraulic Properties of the FAS

Transmissivity. The transmissivity of the Upper Floridan aquifer varies widely within the potential study area (Figure 18), ranging from less 10,000 ft^2/d to more 1,000,000 ft^2/d (Bush and Johnston, 1988). Transmissivity magnitudes appear to be influenced by the degree of confinement (i.e., degree of near-surface karstic development) and also by factors such as aquifer thickness and the degree of dolomitization (Bush and Johnston, 1988; Figure 18).

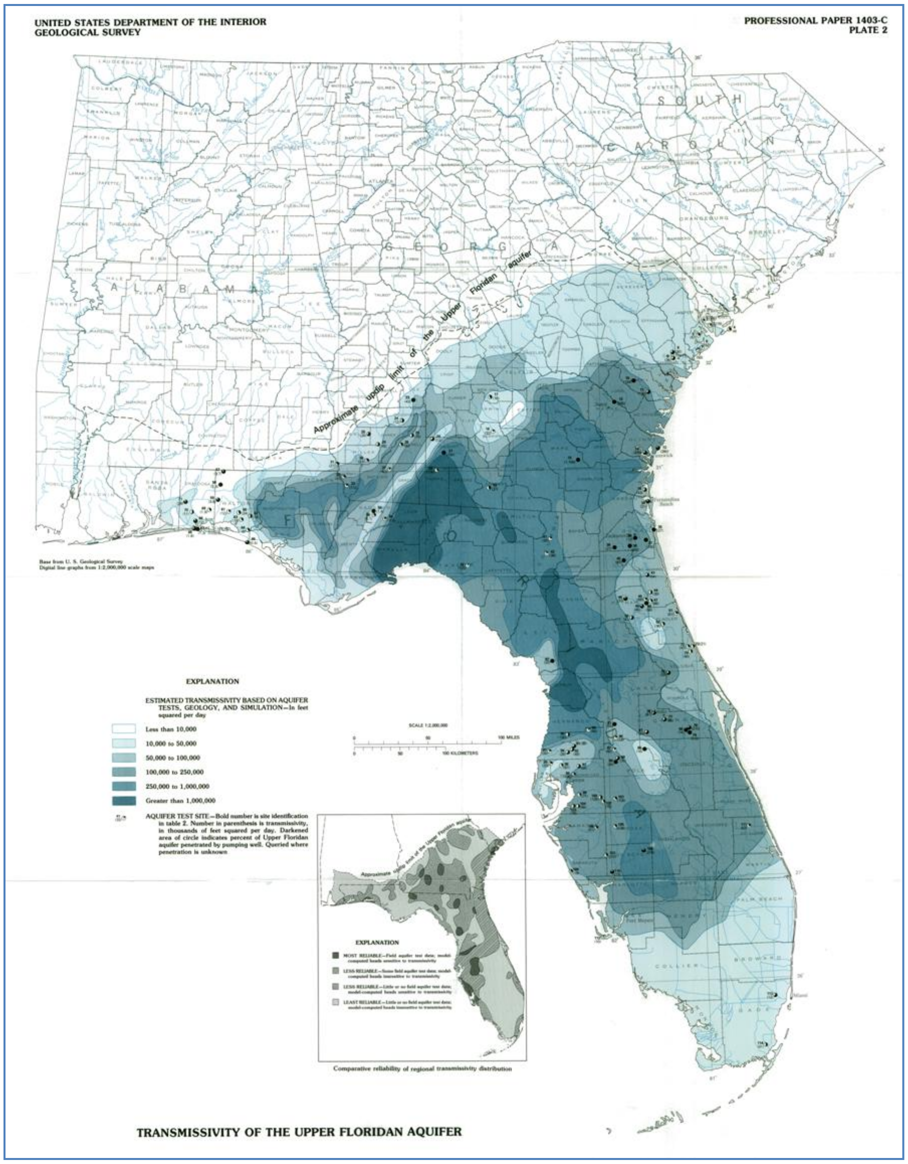


Figure 18. Estimated Transmissivity Distribution of the Upper Floridan Aquifer (after Bush and Johnston 1988)

<ins>Leakance.</ins> See the discussion of the IAS above for a description of the leakance of the FAS upper confining unit. The leakance distribution of the middle semiconfining unit is not well not known, having been determined primarily by model calibration to date.

<ins>Storage Coefficient.</ins> Values of storage coefficient in the Upper Floridan aquifer generally fall within the range of 10^{-3} to 10^{-4} (Bush and Johnston, 1988); however, aquifer-test data have resulted in lower and higher values--10^{-5} to 0.02 (Bush and Johnston, 1988).

FAS Recharge and Discharge Rates and Related Factors

Recharge and discharge rates are determined generally through mass-balance considerations, the primary factors of which are rainfall, runoff, and evapotranspiration, discussed as follows.

Rainfall. Average rainfall amounts within the potential study area tend to increase from north to south and from east to west (Bush and Johnston, 1988; Figure 19), ranging from about 43 inches per year (in/yr) in north-central Georgia to 56 in/yr in north-central Florida to 59 in/yr in the eastern Florida panhandle (Bush and Johnston, 1988; Figure 19).

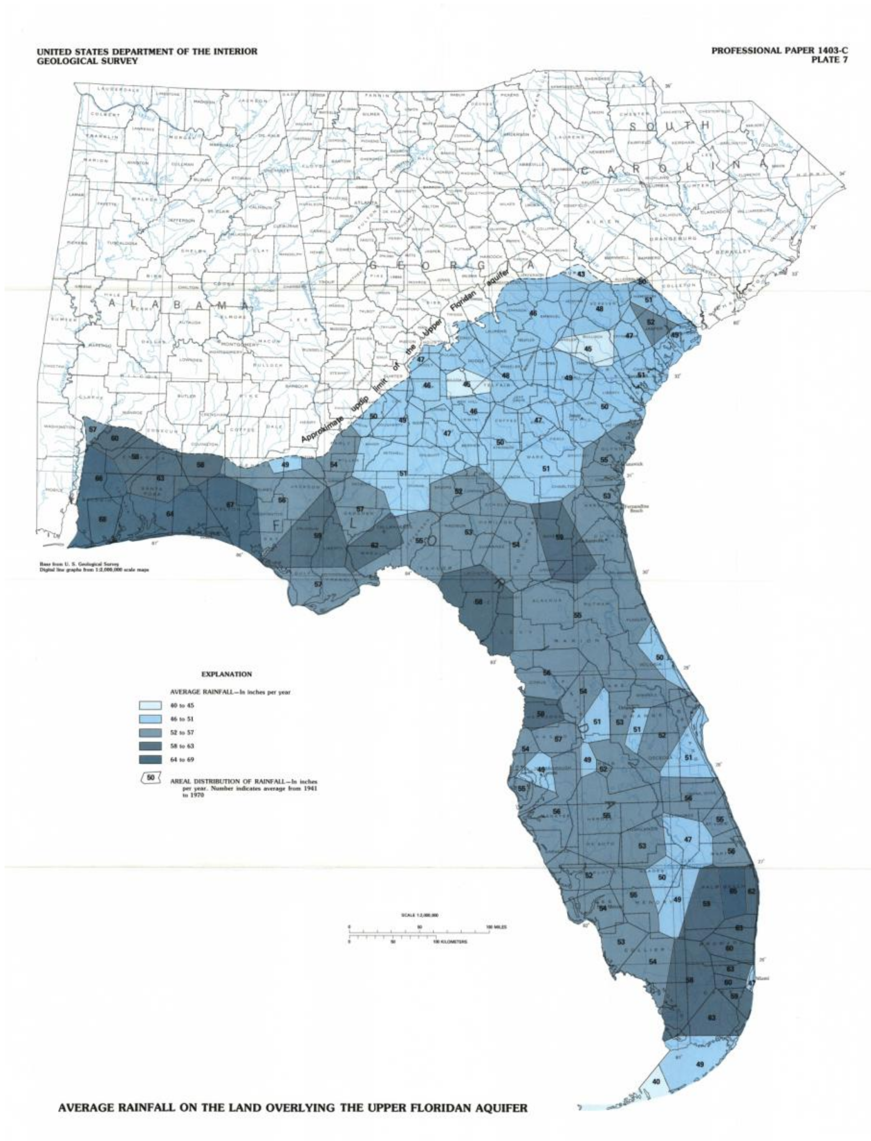


Figure 19. Rainfall Distribution (after Bush and Johnston 1988)

Runoff. Estimates of basin runoff within the potential study area range from about 4 in/yr up to about 38 in/yr (Bush and Johnston, 1988; Figure 20).

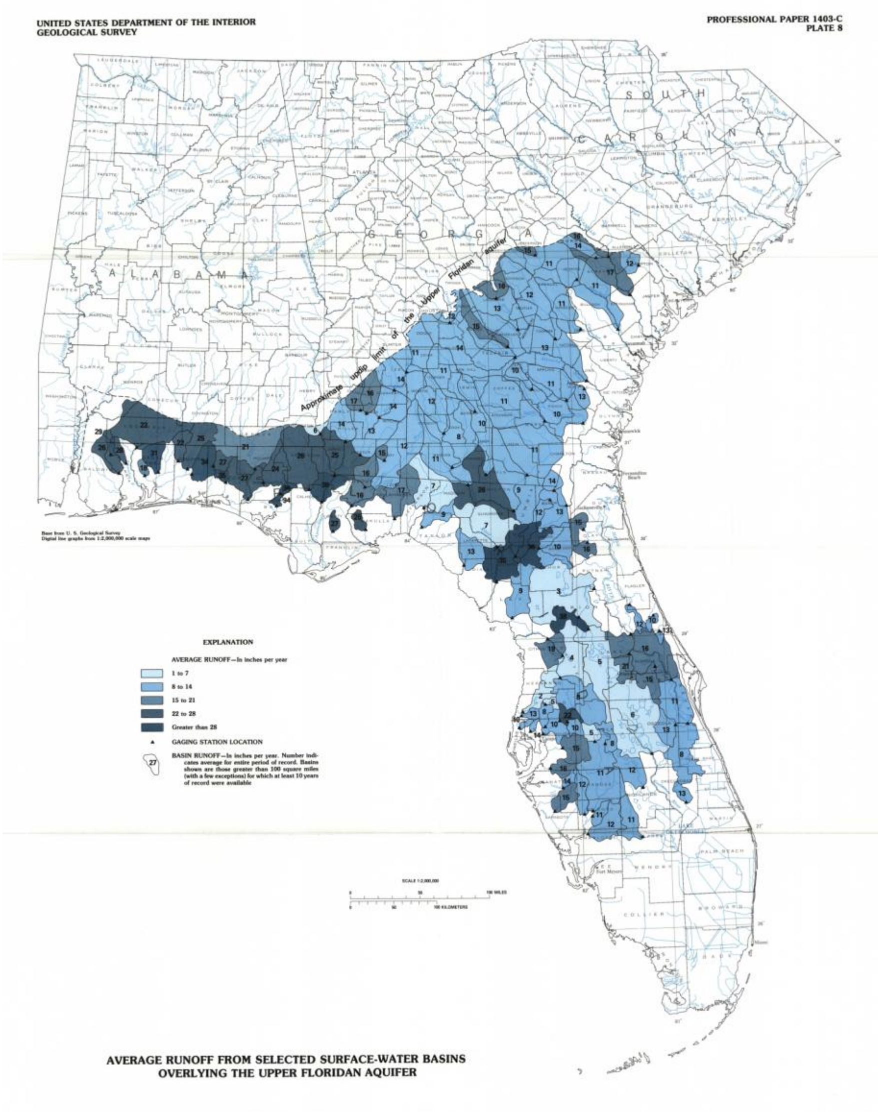


Figure 20. Estimated Runoff in the Area of Interest (after Bush and Johnston 1988)

<u>Evapotranspiration.</u> Estimates of evapotranspiration range from about 31 in/yr to about 41 in/yr (Bush and Johnston, 1988; Figure 21).

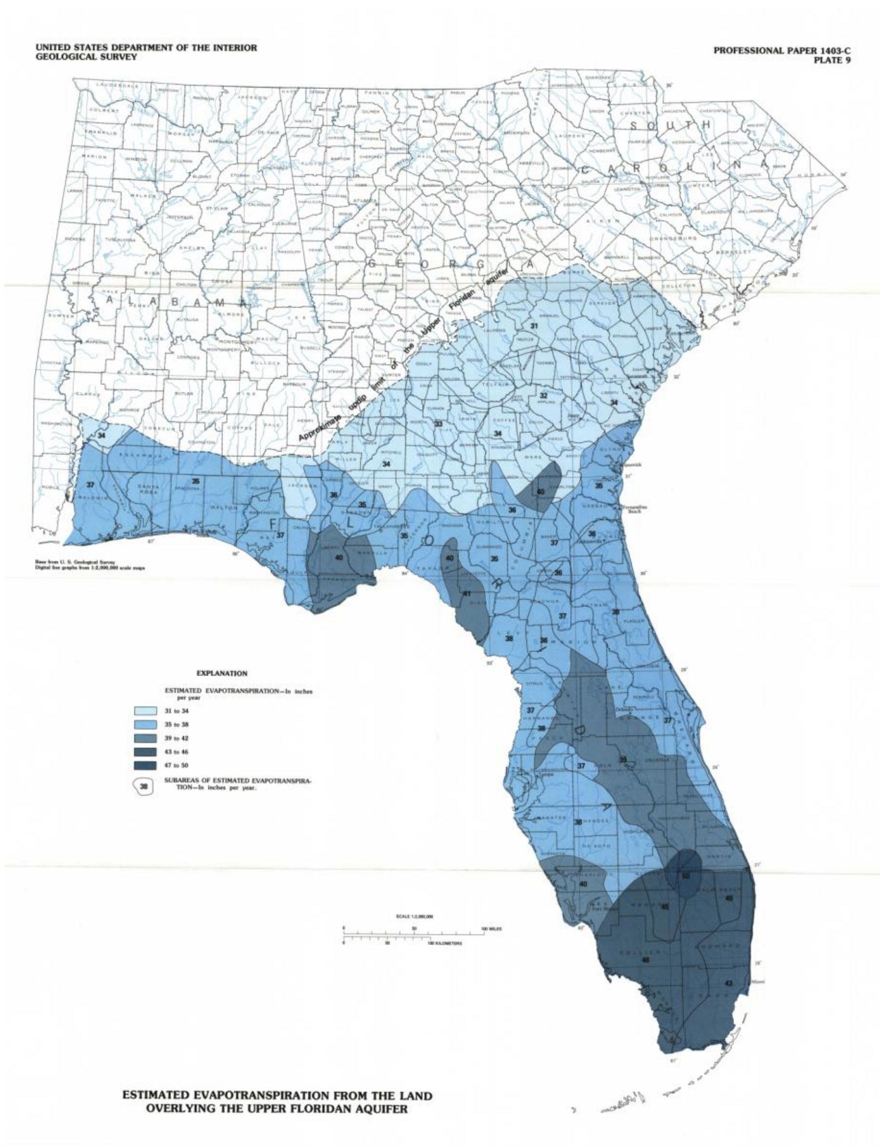


Figure 21. Estimated Evapotranspiration in the Area of Interest (after Bush and Johnston 1988)

Recharge to and Discharge from the FAS. Estimates of recharge to the predevelopment Upper Floridan aquifer within the potential study area range from 0 to 20 in/yr. Estimates of discharge range from 0 to 10 in/yr (Bush and Johnston, 1988; Figure 22; Figure 23).

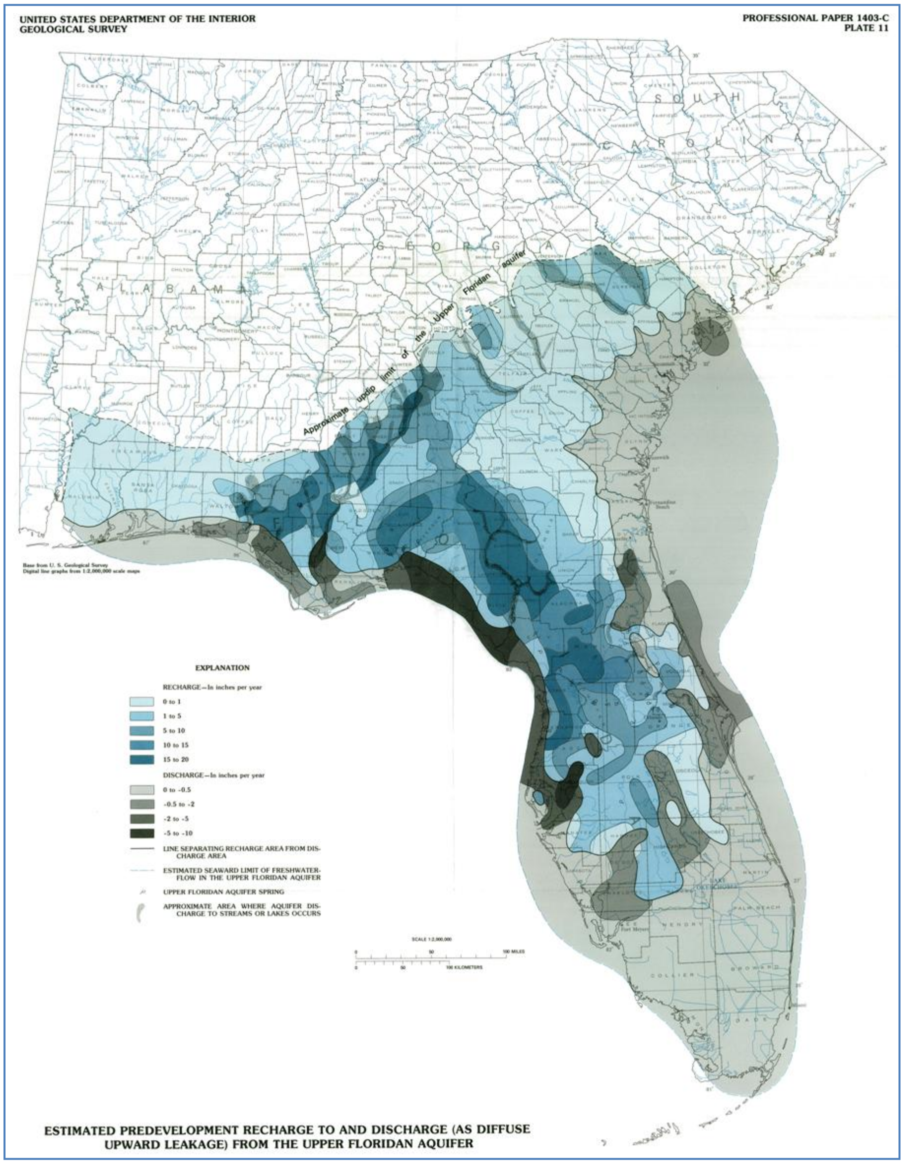


Figure 22. Estimated Predevelopment Recharge to and Discharge from the Upper Floridan Aquifer (after Bush and Johnston 1988)

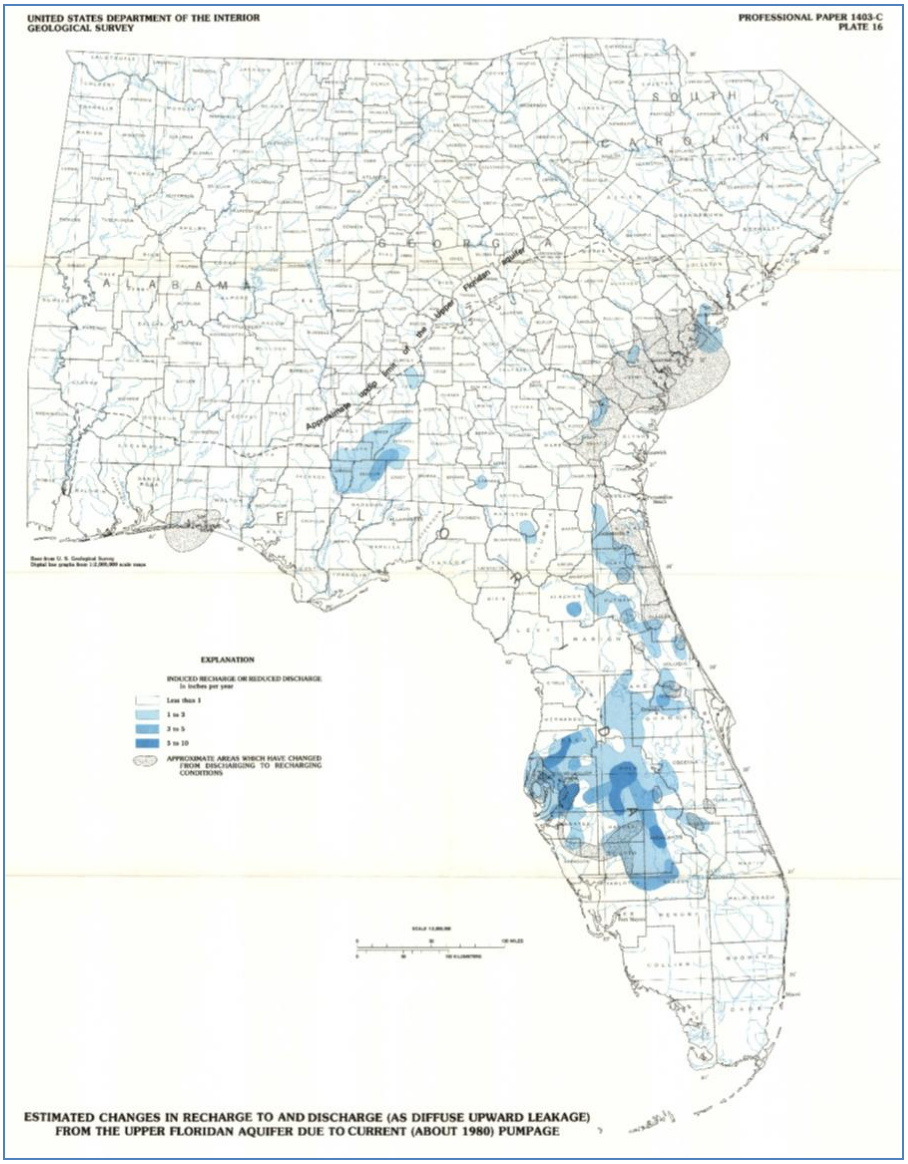


Figure 23. Estimated Change in Recharge to and Discharge from the Upper Floridan Aquifer, Predevelopment to 1980

Upper Floridan Aquifer Predevelopment Water Levels. The Upper Floridan aquifer estimated predevelopment potentiometric surface is a representation of water levels in the Upper Floridan aquifer prior to significant anthropogenic influences, primarily major pumping effects (Bush and Johnston, 1988; Figure 24).

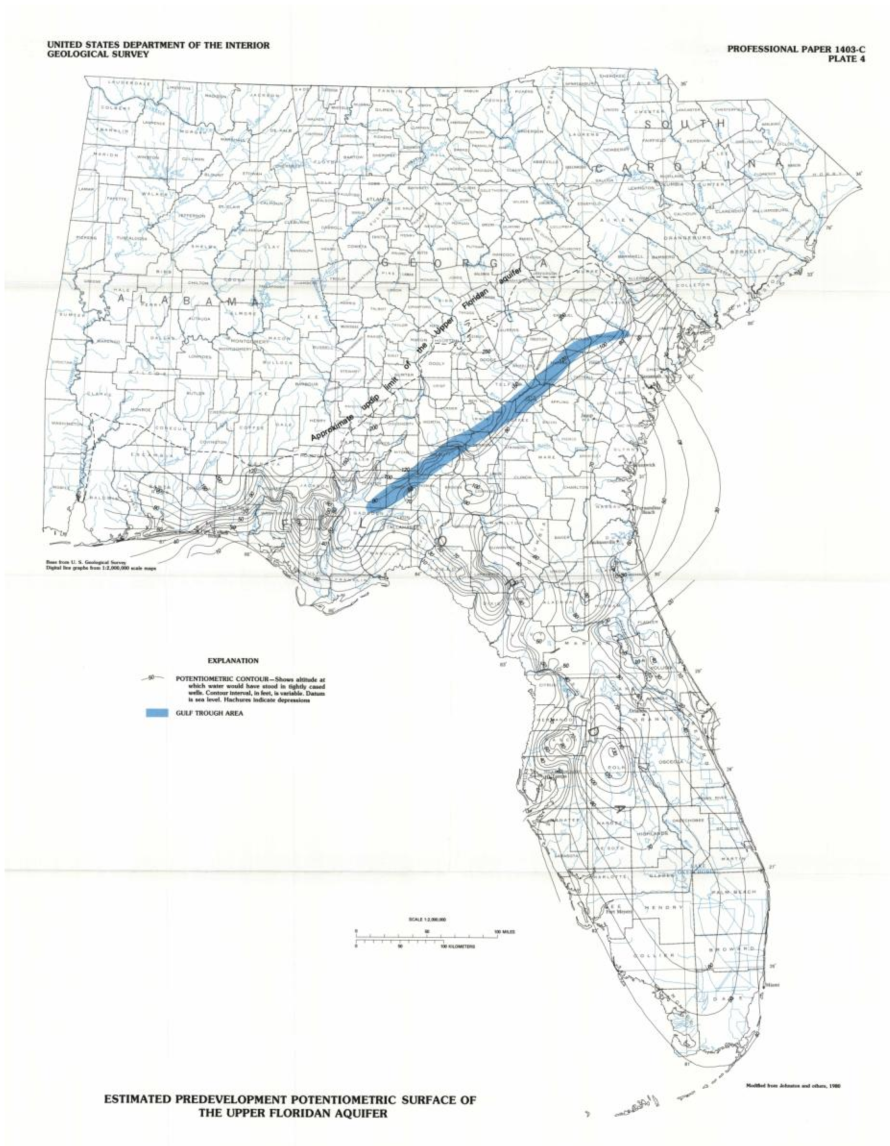


Figure 24. Estimated Predevelopment Potentiometric Surface of the Upper Floridan Aquifer (after Bush and Johnston 1988)

Upper Floridan Aquifer May 1980 Water Levels. The May 1980 Upper Floridan aquifer estimated potentiometric surface is based on observation data obtained from numerous water-level monitoring wells. Comparison of this potentiometric surface to the estimated predevelopment potentiometric surface shows many broad similarities in configuration and levels. In general, however, water levels in May 1980 were lower in many places, particularly in areas of major pumping centers, such as northeast Florida. In some places, the configuration of the potentiometric surface was altered significantly as well (Bush and Johnston, 1988; Figure 25). In general, the direction of ground-water flow may be inferred as perpendicular to the contour lines representing the potentiometric surface.

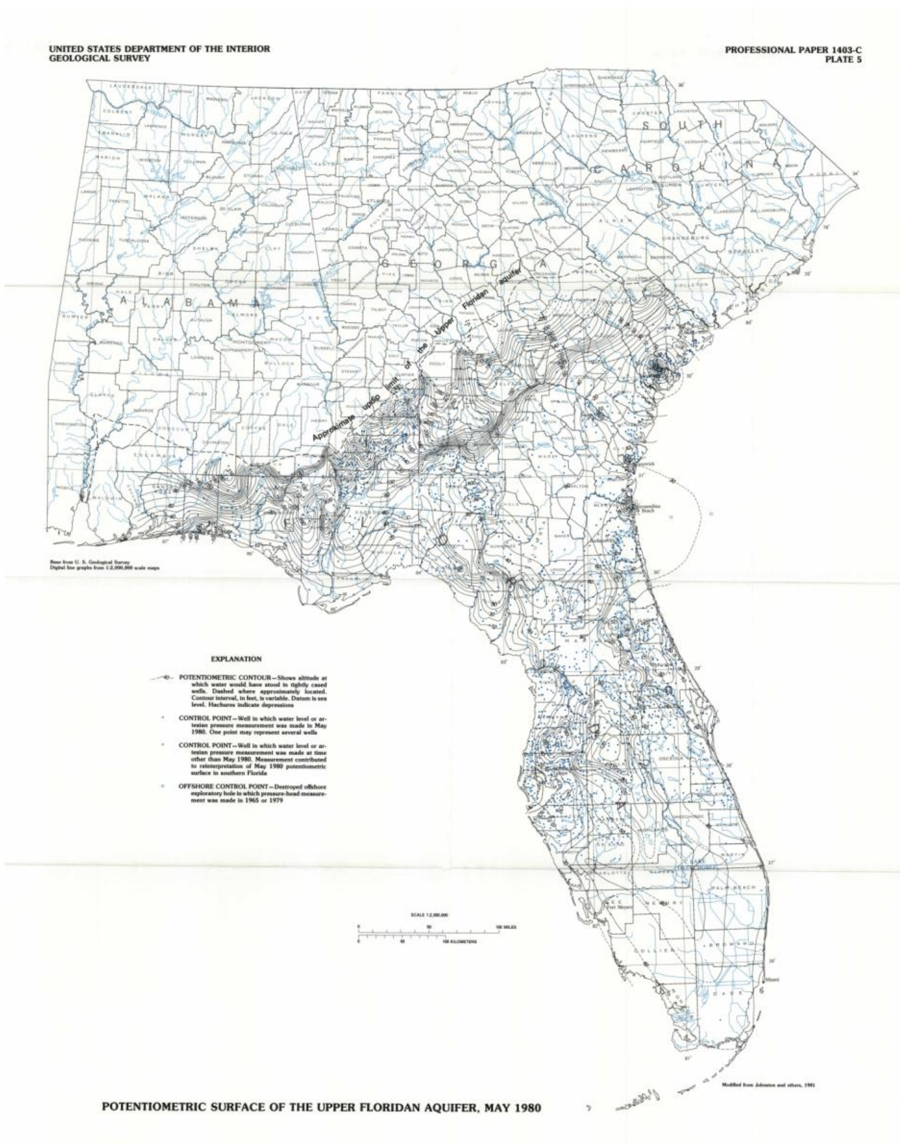


Figure 25. May 1980 Potentiometric Surface of the Upper Floridan Aquifer (after Bush and Johnston 1988)

Upper Floridan Aquifer Estimated Water-Level Drawdowns, Predevelopment-May 1980. The difference between the estimated predevelopment potentiometric surface and May 1980 potentiometric surface of the Upper Floridan aquifer indicates the degree of decline in the water levels of the Upper Floridan aquifer since predevelopment times, due primarily to pumping effects. The differences are greatest where pumping is most concentrated (Bush and Johnston, 1988; Figure 26). Although the May 1980 potentiometric surface is now 32 years old, the basic configuration of the Upper Floridan aquifer potentiometric surface is still the same in most places, as comparison to the May 2010 Upper Floridan aquifer potentiometric surface shows (Kinnaman and Dixon, 2011; Figure 27).

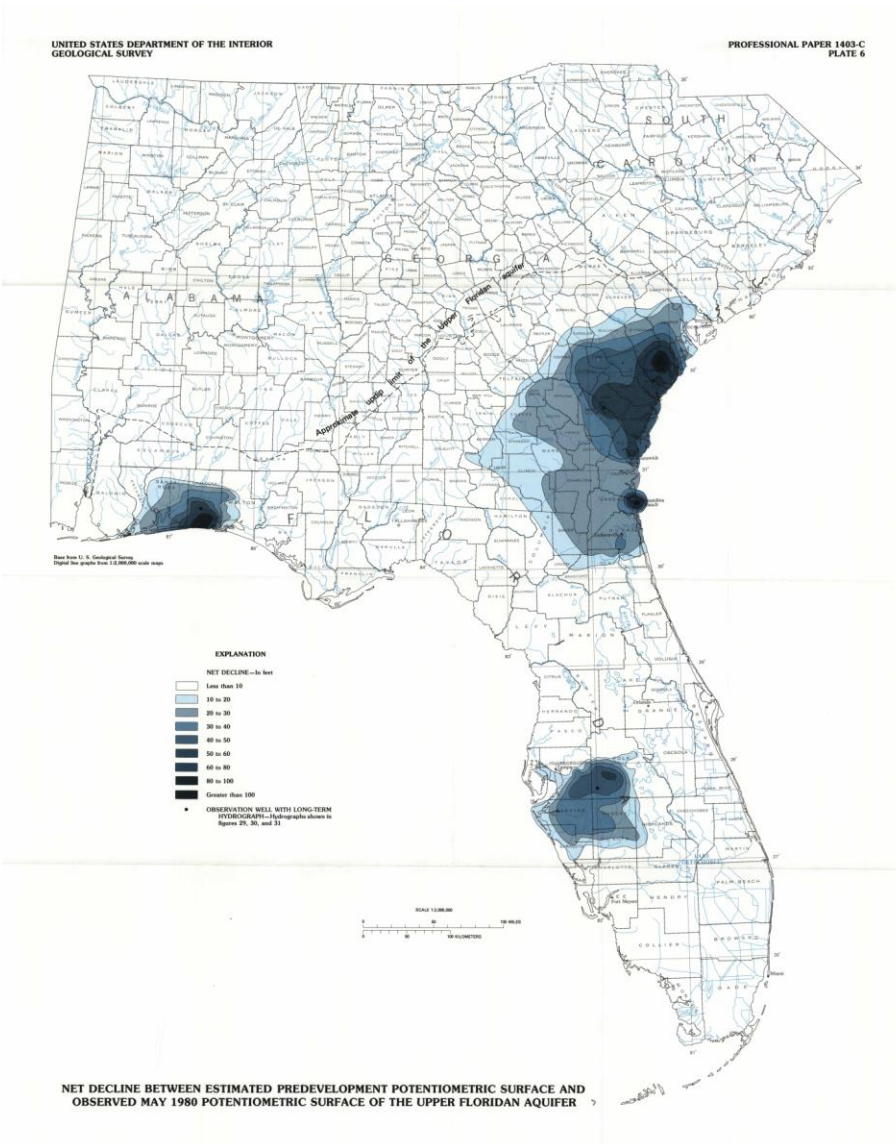


Figure 26. Drawdown in the Upper Floridan Aquifer Potentiometric Surface--Predevelopment to May 1980 (after Bush and Johnston 1988)

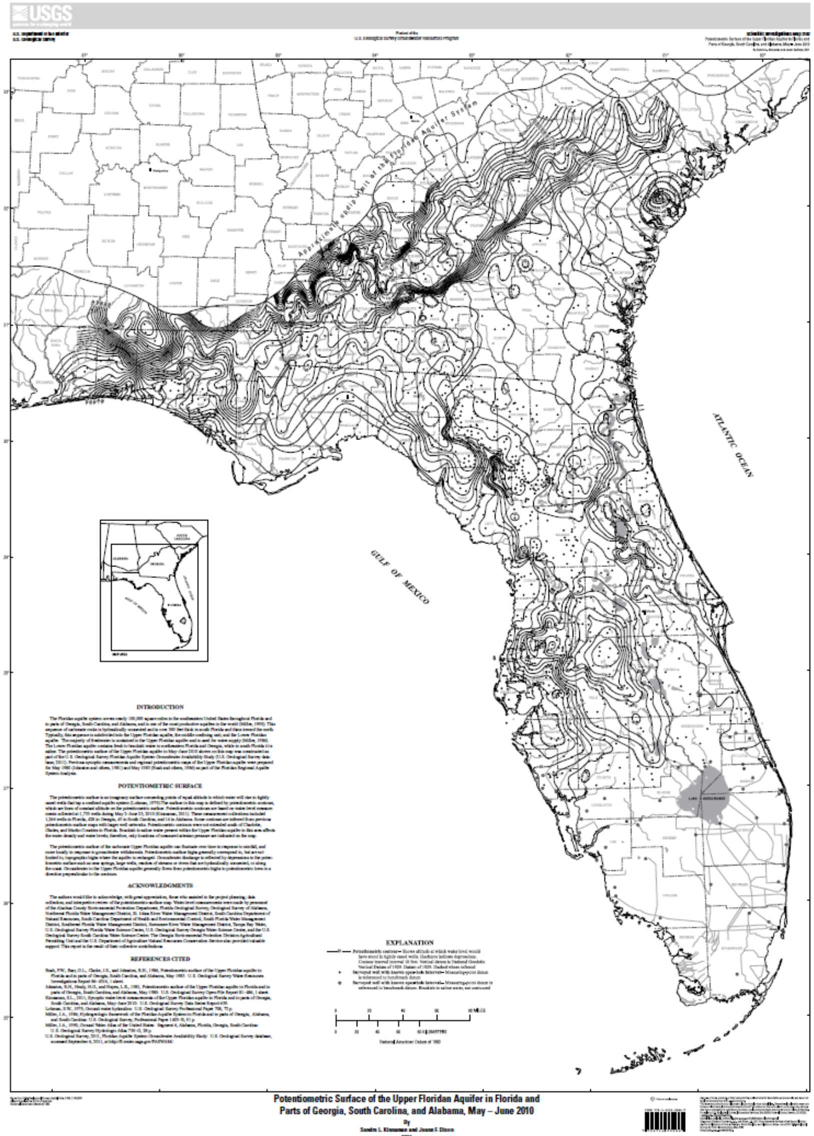


Figure 27. May-June 2010 Potentiometric Surface of the Upper Floridan Aquifer (after Kinnaman and Dixon, 2011)

1980 FAS Pumpage Distribution

The distribution of well withdrawals by county in 1980 is, of course, somewhat out of date. Nevertheless, it is still a useful guide to the relative magnitude of groundwater withdrawals from the FAS, as the relative magnitudes of withdrawals have not changed generally (Bush and Johnston, 1988; Figure 28).

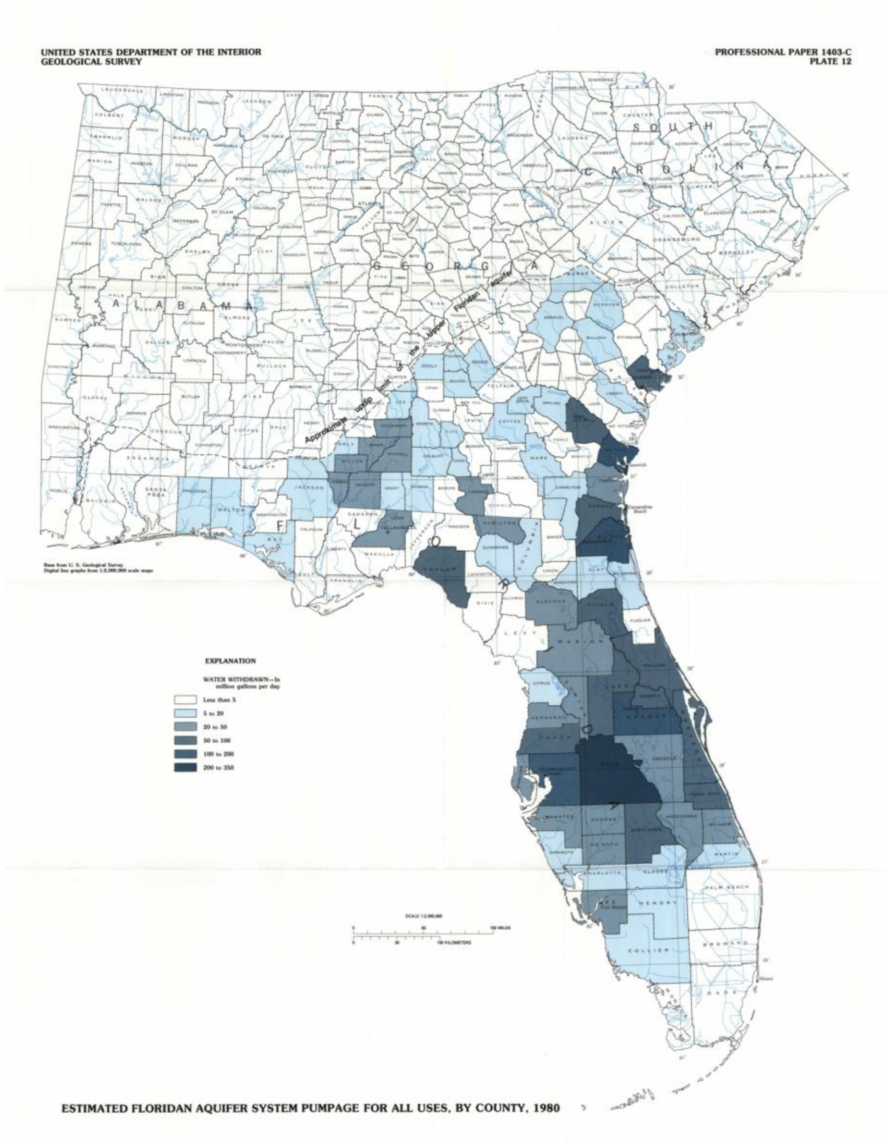


Figure 28. Estimated Pumpage from the Floridan Aquifer System in 1980 by County (after Bush and Johnston 1988)

In general, the ambient water quality of Upper Floridan aquifer water is better in upgradient recharge areas than in downgradient discharge areas. This is because the removal of relict seawater through the rinsing process of influxing recharge has naturally had greater effect at points of entry (i.e., recharge areas) than in downgradient areas where aquifer discharge predominates (Miller, 1990). Furthermore, the process is an ongoing one and is exceedingly slow, occurring over millennia (Toth, personal communication).

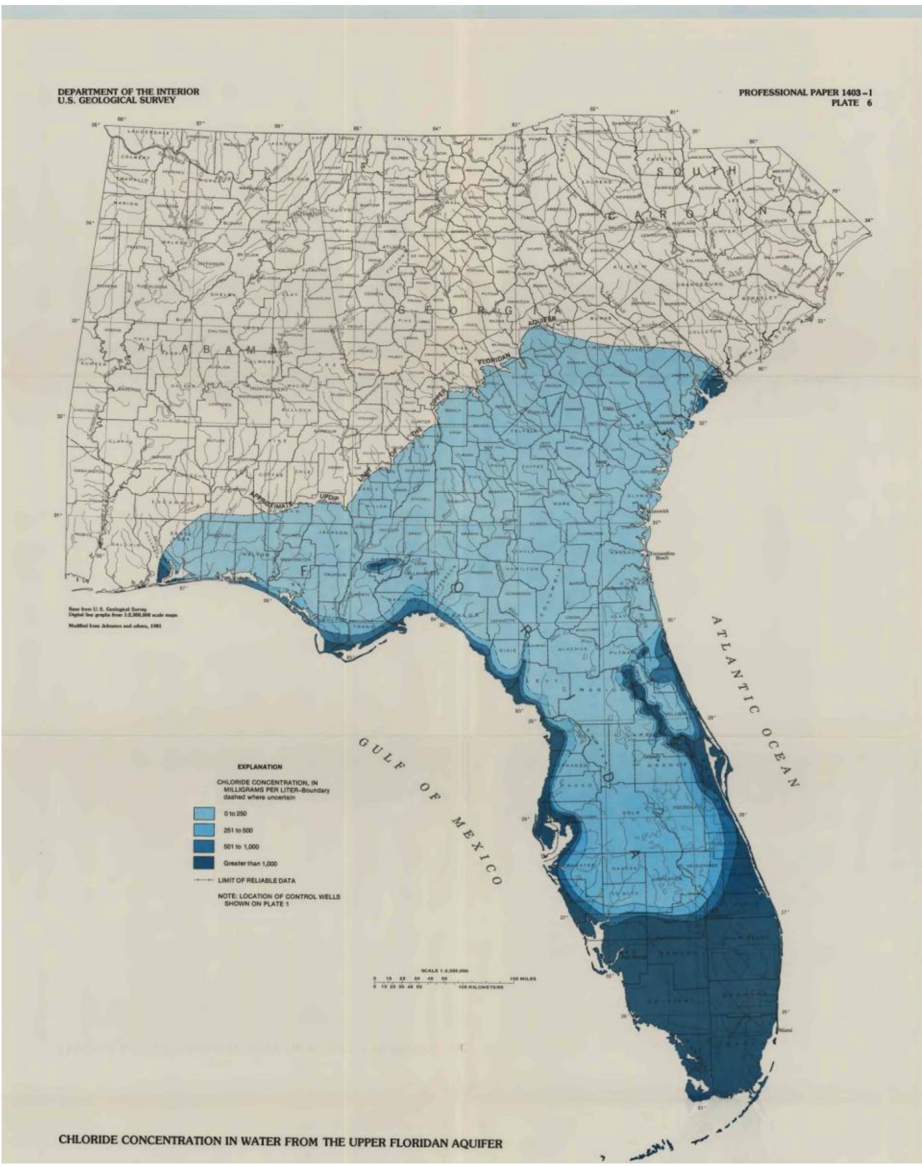


Figure 29. Estimated Concentration of Chloride in the Upper Floridan Aquifer (after Sprinkle 1989)

<u>Chlorides.</u> Concentrations of chloride are generally less than 250 milligrams per liter (mg/l) in the Upper Floridan aquifer within the area of interest (Sprinkle, 1989; Figure 29). Chloride concentrations tend to be higher, however, in downgradient, discharge areas (Sprinkle, 1989; Figure 29).

Sulfates. Concentrations of sulfates range between 0 and 250 mg/l throughout most of the area of interest (Sprinkle, 1989; Figure 30), although they are higher in downgradient areas along the coast and the southern extent of the St. Johns River (Sprinkle, 1989; Figure 30).

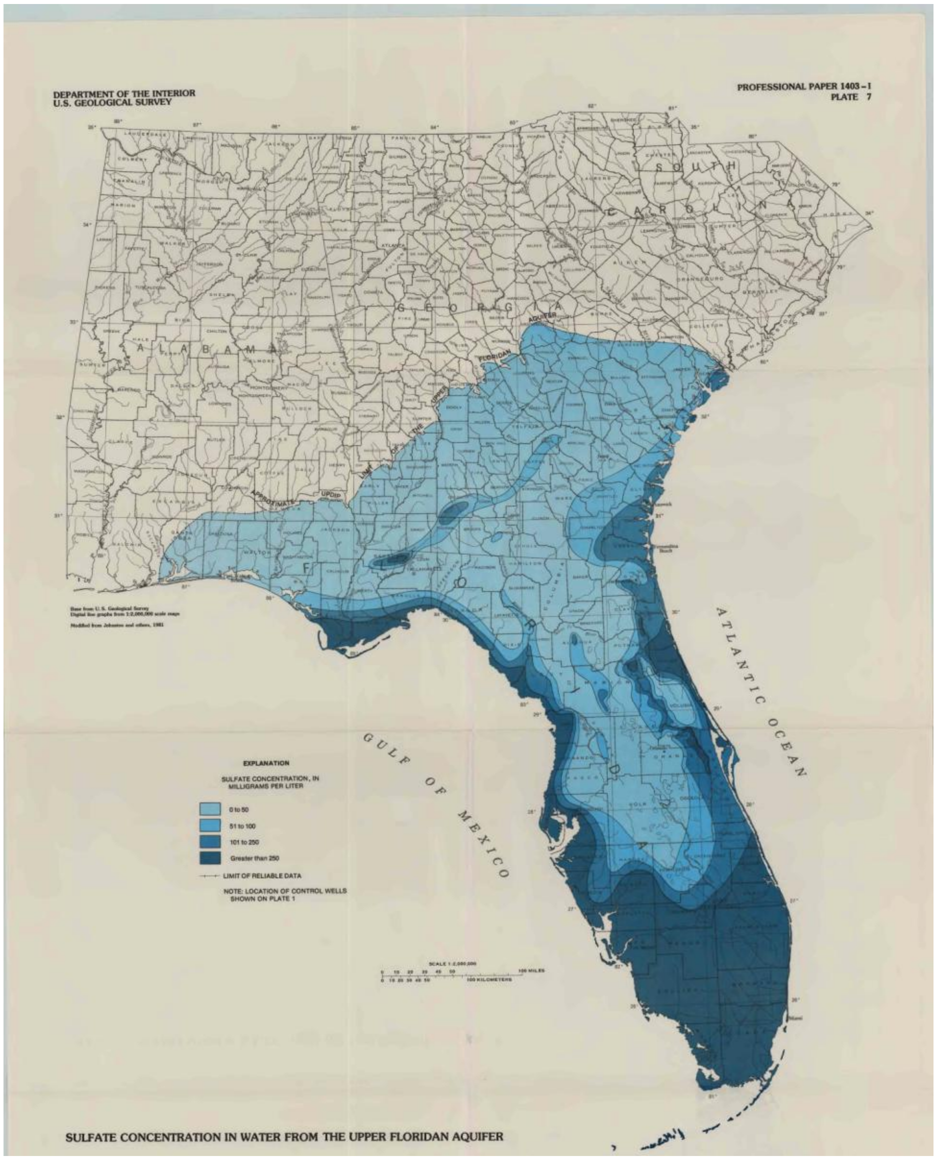


Figure 30. Estimated Concentration of Sulfate in the Upper Floridan Aquifer (after Sprinkle 1989)

<u>Total Dissolved Solids.</u> Total dissolved solids concentrations range from 0 to 250 mg/l throughout most of the area of interest also (Sprinkle, 1989; Figure 31). They are also higher in downgradient areas along the coast (Sprinkle, 1989; Figure 31).

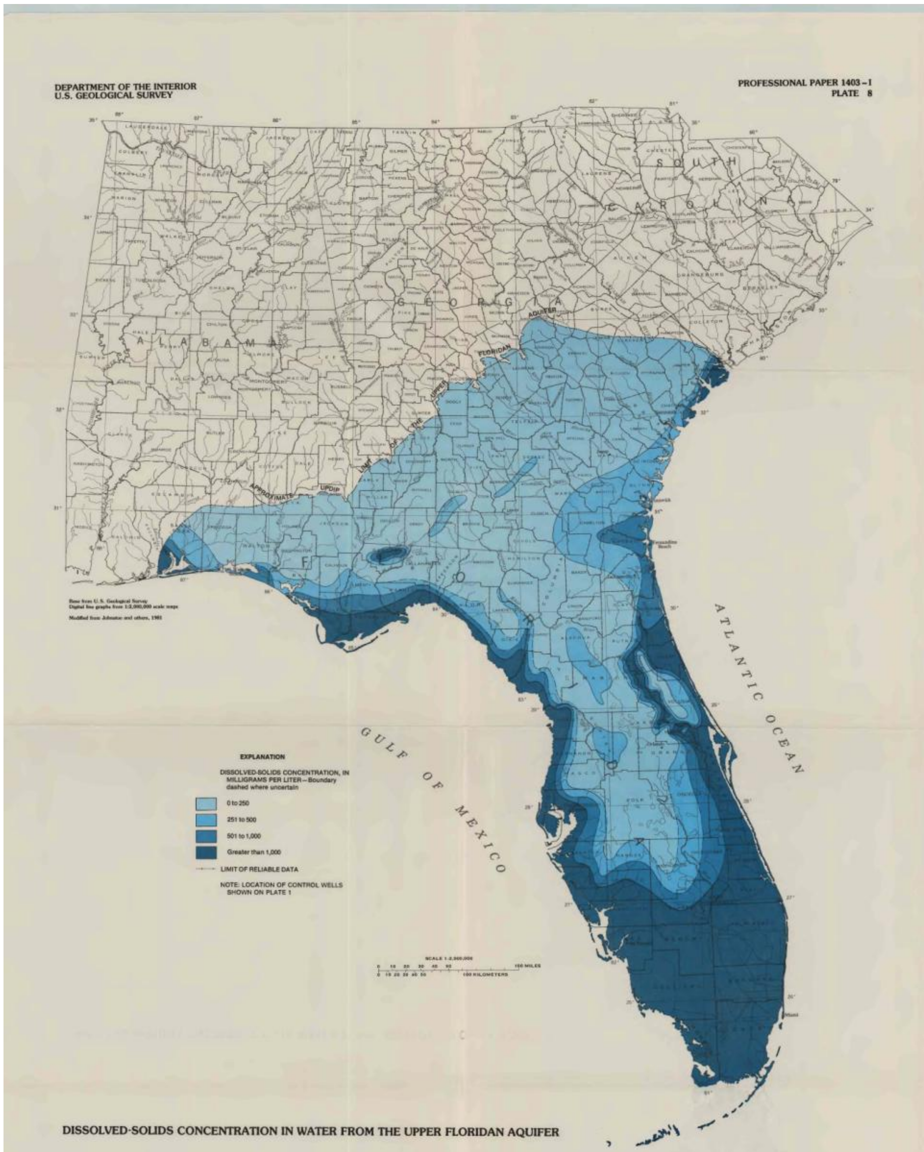


Figure 31. Estimated Concentration of Total Dissolved Solids in the Upper Floridan Aquifer (after Sprinkle 1989)

Southeastern Coastal Plain Aquifer System

General Description of the Southeastern Coastal Plain Aquifer System

The Southeastern Coastal Plain aquifer system (SECPAS) is included within the potential model domain because of interaction between it and the FAS in Georgia and South Carolina. The materials that comprise the SECPAS are predominantly clastic in nature--i.e., interbedded clay, sand, silt, marl, mudstone, sandstone, chalk, etc., (Miller, 1992; Renken, 1996), though carbonate units, such as the Clayton aquifer of southwest Georgia are also present (McFadden and Perriello, 1983).

The SECPAS is comprised of a number of aquifers and semiconfining units of generally subregional extent and ranging in age from Cretaceous to Miocene (Miller, 1992; Renken, 1996). Other examples are the Gordon aquifer of east-central Georgia and the Claiborne aquifer of southwestern Georgia (Clarke *et al.*, 1985; McFadden and Perriello; 1983; Renken, 1996). The SECPAS thickens in a wedge-like shape from the Fall Line, its line of pinch-out, towards the Gulf-of-Mexico and Atlantic coasts. Its maximum penetrated thickness is at least 21,000 feet (Miller, 1992).

The U.S. Geological Survey (USGS) has modeled groundwater flow in the SECPAS on both regional and subregional scales (e.g., Barker and Pernik, 1994; Aucott, 1996; Faye and Mayer, 1997). To facilitate the regional-scale modeling process, local-scale or subregional-scale aquifers and confining units that comprise the SECPAS were grouped by the USGS into regional aquifers separated by regional semiconfining units (Miller, 1992; Renken, 1996). These regional aquifers and semiconfining units were mapped primarily on the basis of permeability considerations, and the various aquifers were named after major rivers that transect their outcrop areas (Miller, 1992). Within the area of interest, these aquifers and confining units include, from the uppermost to the lowermost, the Pearl River aquifer confining unit, the Pearl River aquifer, the Chattahoochee River aquifer confining unit, the Chattahoochee River aquifer, the Black Warrior River aquifer confining unit, and the Black Warrior River aquifer (Renken, 1996). A fourth USGS-defined SECPAS regional aquifer, which is outside of the likely study area, is the Chickasawhay River aquifer (Renken 1996; Figure 32; Figure 33).

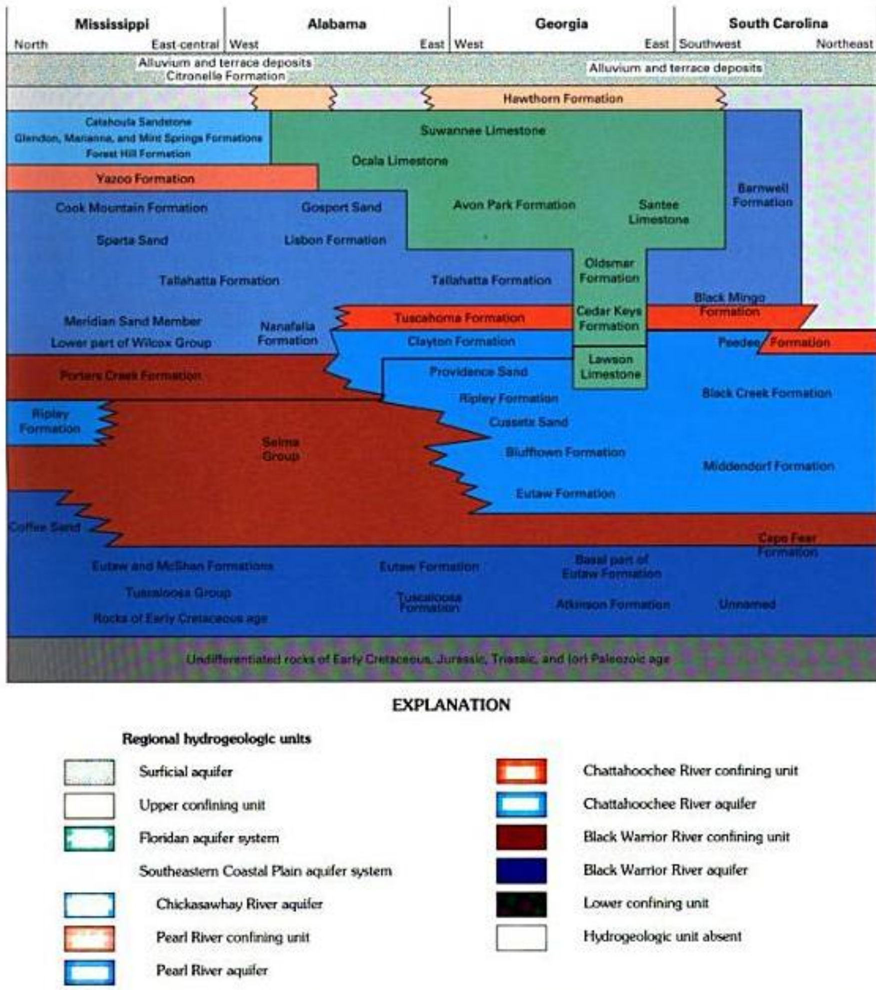


FIGURE 18.—Relations among regional hydrogeologic units and selected rock-stratigraphic units in the Southeastern Coastal Plain (modified from Renken, 1984). Exact correlation of geologic units is not implied.

Figure 32. Relations Among Regional Hydrogeologic Units in the Southeastern Coastal Plain--A (after Renken 1996)

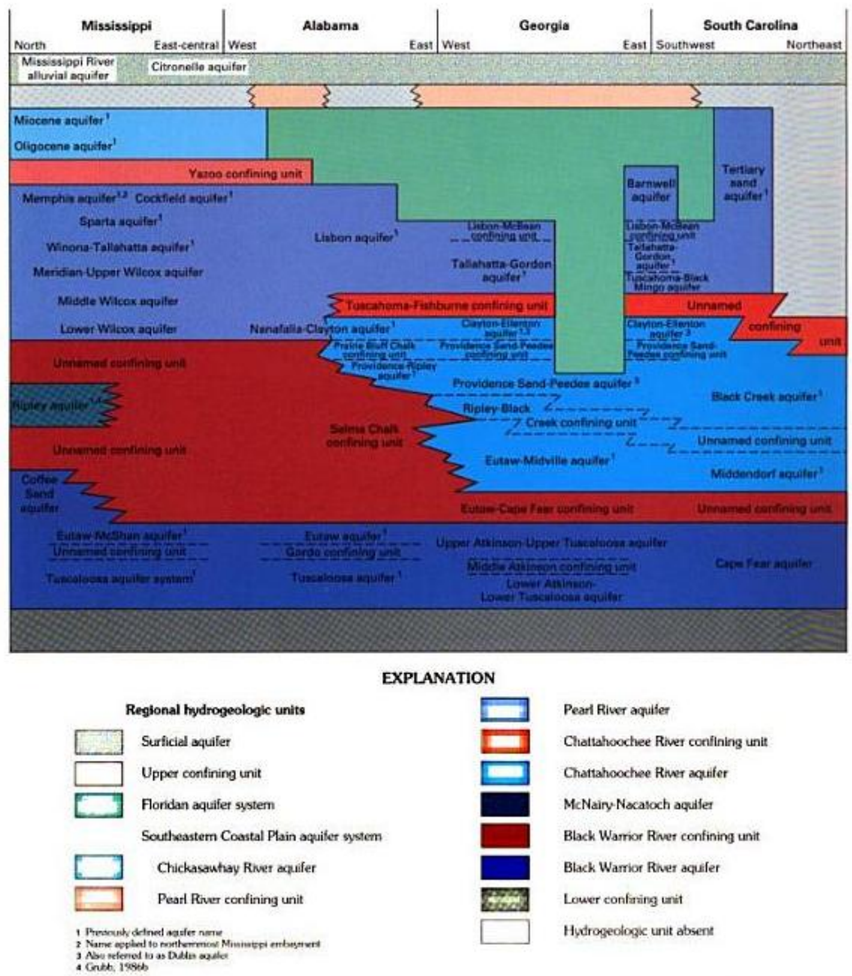


FIGURE 19.—Relations among regional and subregional hydrogeologic units in the Southeastern Coastal Plain aquifer system (modified from Miller and Renken, 1988).

Figure 33. Relations Among Regional Hydrogeologic Units in the Southeastern Coastal Plain--B (after Renken 1996)

The clastic rocks of the SECPAS grade by facies change both laterally and vertically into the carbonate rocks of the FAS in western South Carolina, south Georgia, and southeastern Alabama (Barker and Pernik, 1994), resulting in a direct hydraulic connection between the two aquifer systems at such boundaries (Figure 34). Down gradient of such boundaries, the hydraulic connection between the SECPAS and the FAS is manifested in the form of diffuse vertical leakage across the semiconfining units that separate the SECPAS from the FAS (McFadden and Perriello, 1983).

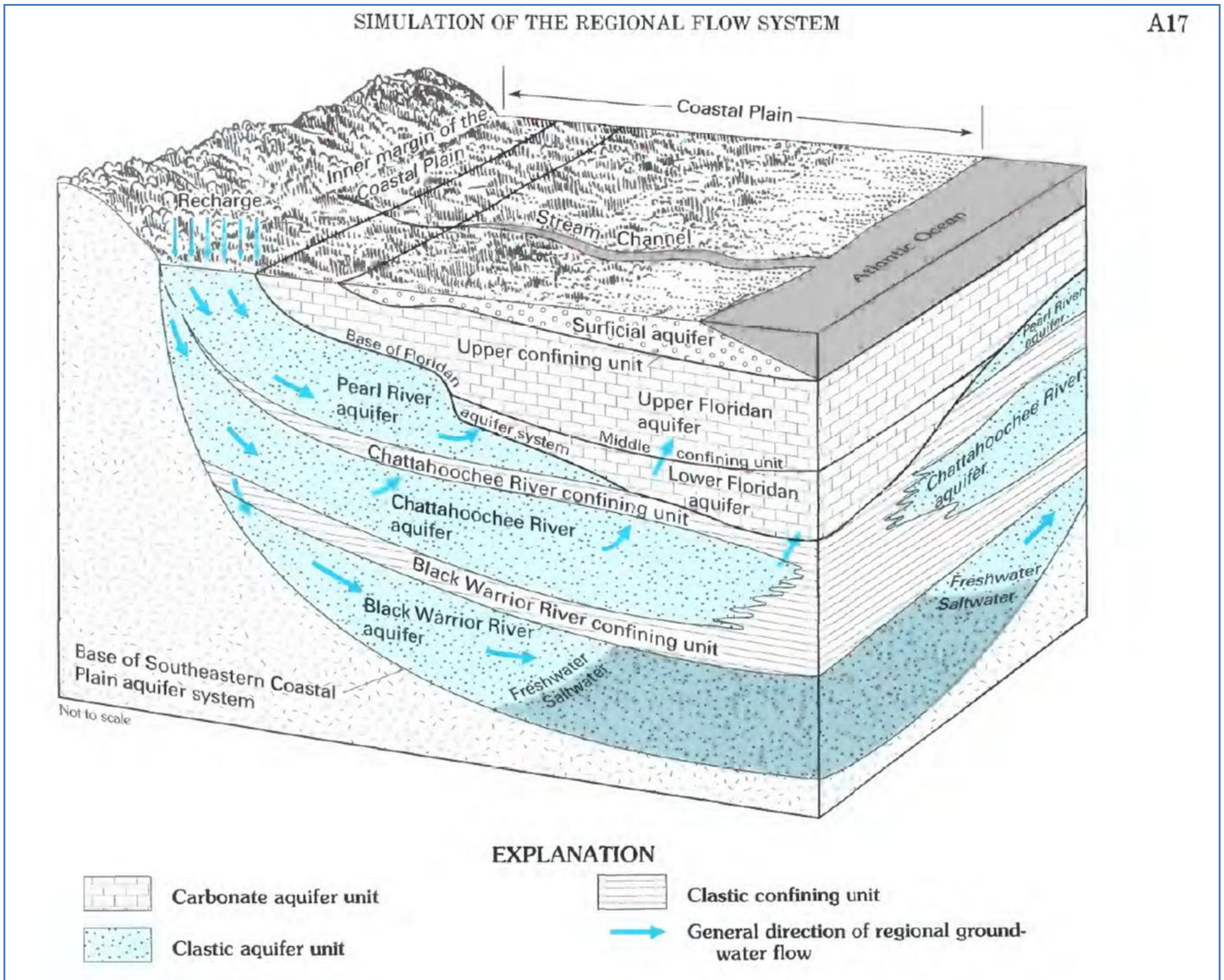


FIGURE 10.—Relation between hydrogeologic framework and simulated flow directions along a hypothetical dip section through Georgia (modified from Barker, 1986).

Figure 34. Hydrogeologic Relation between the Floridan Aquifer System and the Southeastern Coastal Plain Aquifer System along a Hypothetical Section in Georgia (after Miller 1992)

Stratigraphy of the SECPAS

As stated previously, the SECPAS within the area of interest has been delineated into three aquifers and overlying semiconfining units. These are, from top to bottom, the Pearl River aquifer confining unit, the Pearl River Aquifer, the Chattahoochee River aquifer confining unit, the Chattahoochee River aquifer, the Black Warrior River aquifer confining unit, and the Black Warrior River Aquifer (Renken,1996; Figure 32; Figure 33; Figure 34).

<u>Top of the Pearl River Aquifer.</u> Within the area of interest, the top of the Pearl River aquifer ranges in elevation from approximately -1,700 ft NGVD in southern Georgia to 400 ft NGVD near the intersection of the Fall Line with the Georgia-South Carolina state line (Renken, 1996;Figure 35).

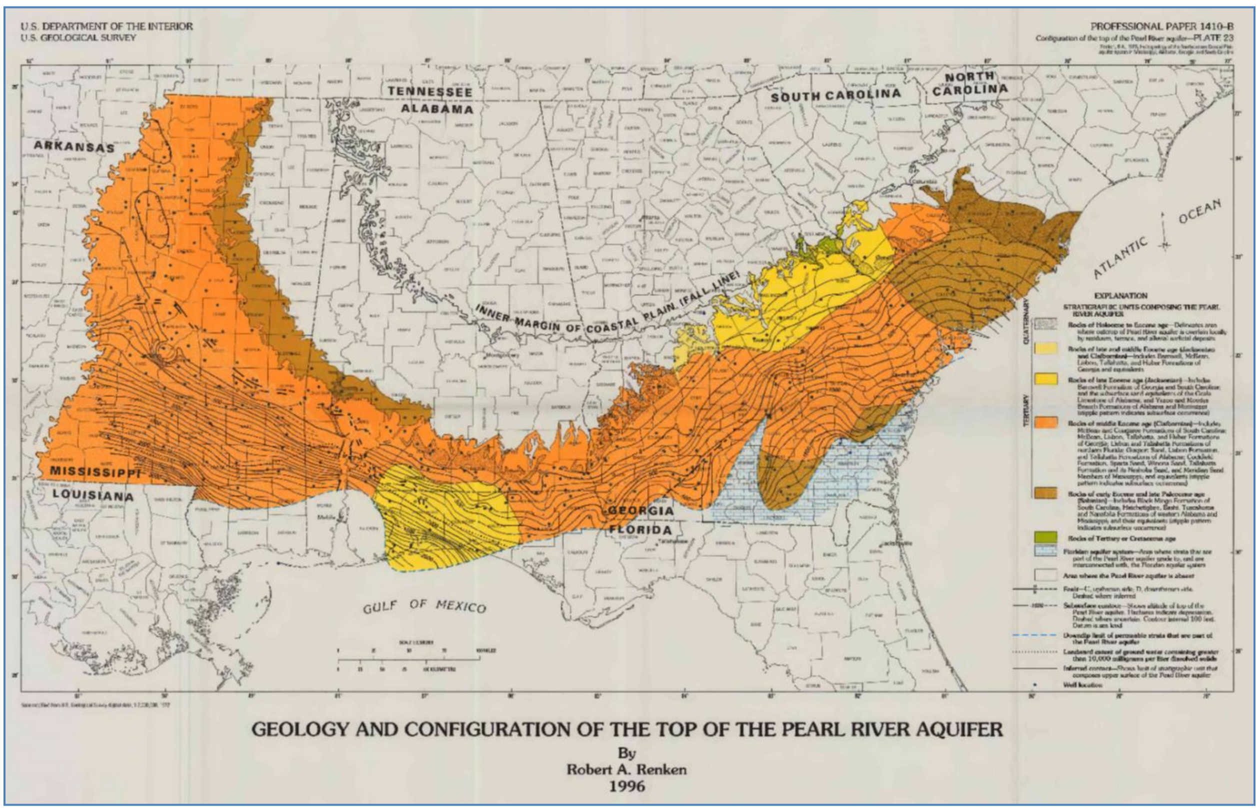


Figure 35. Elevation of the Top of the Pearl River Aquifer (after Renken 1996)

Bottom of the Pearl River Aquifer. Within the area of interest, the bottom of the Pearl River aquifer ranges in elevation from approximately -2,220 ft NGVD in southern Georgia to 400 ft NGVD near the intersection of the Fall Line with Georgia-South Carolina state line (Renken, 1996; Figure 36).

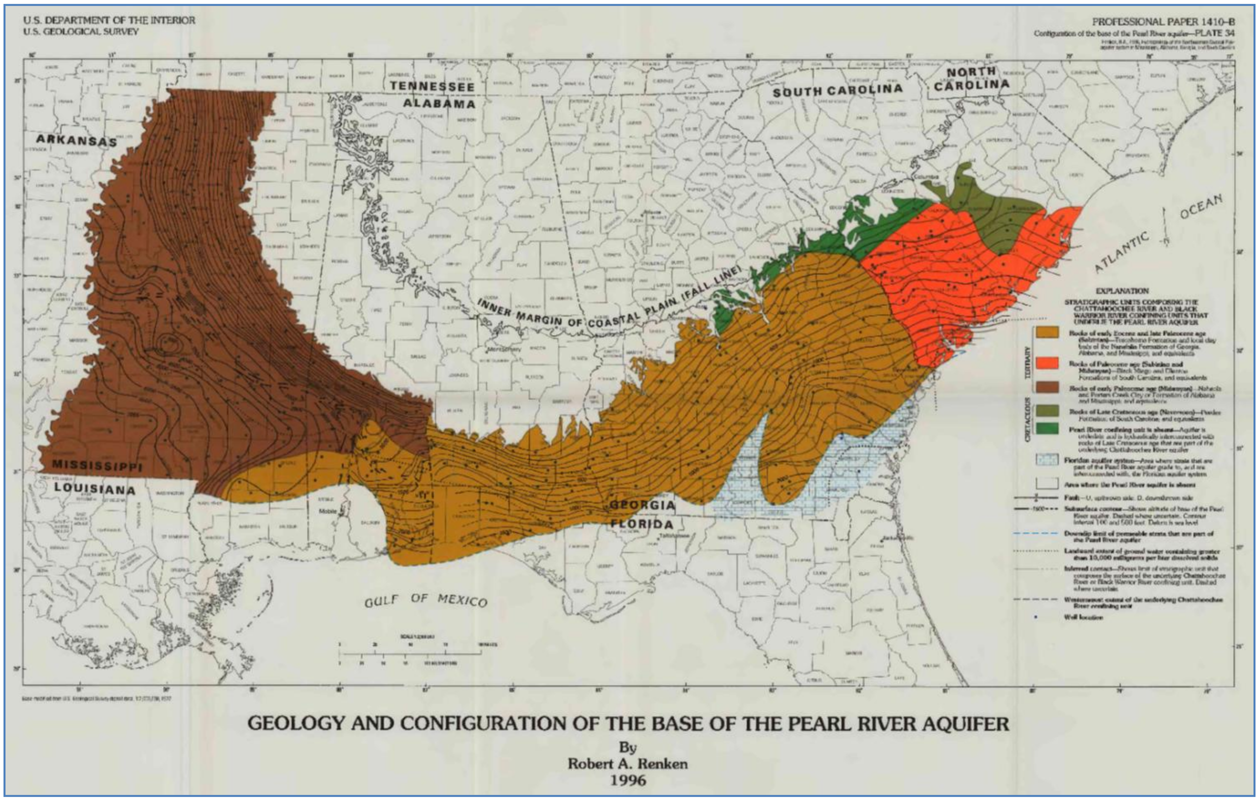


Figure 36. Elevation of the Bottom of the Pearl River Aquifer (after Renken 1996)

Thickness and Extent of the Pearl River Aquifer. Within the area of interest, the thickness of the Pearl River aquifer ranges from approximately 0 ft at its updip limit near the Fall Line to more 700 ft in southern Georgia (Renken, 1996; Figure 37).

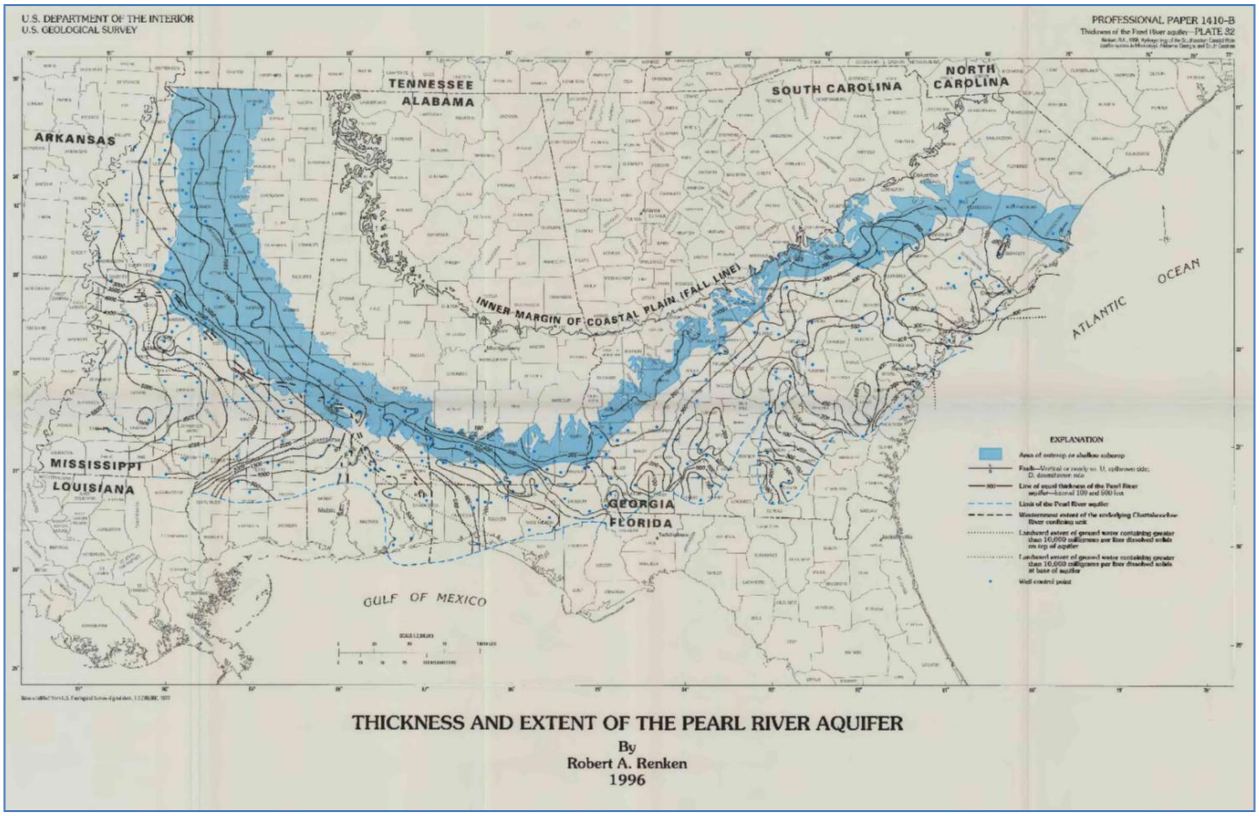


Figure 37. Thickness of the Pearl River Aquifer (after Renken 1996)

Thickness of the Chattahoochee River Confining Unit. Within the area of interest, the thickness of the Chattahoochee River aquifer confining unit ranges approximately from 0 ft at its updip limit to more than 800 ft in southeastern Georgia (Renken, 1996; Figure 38).

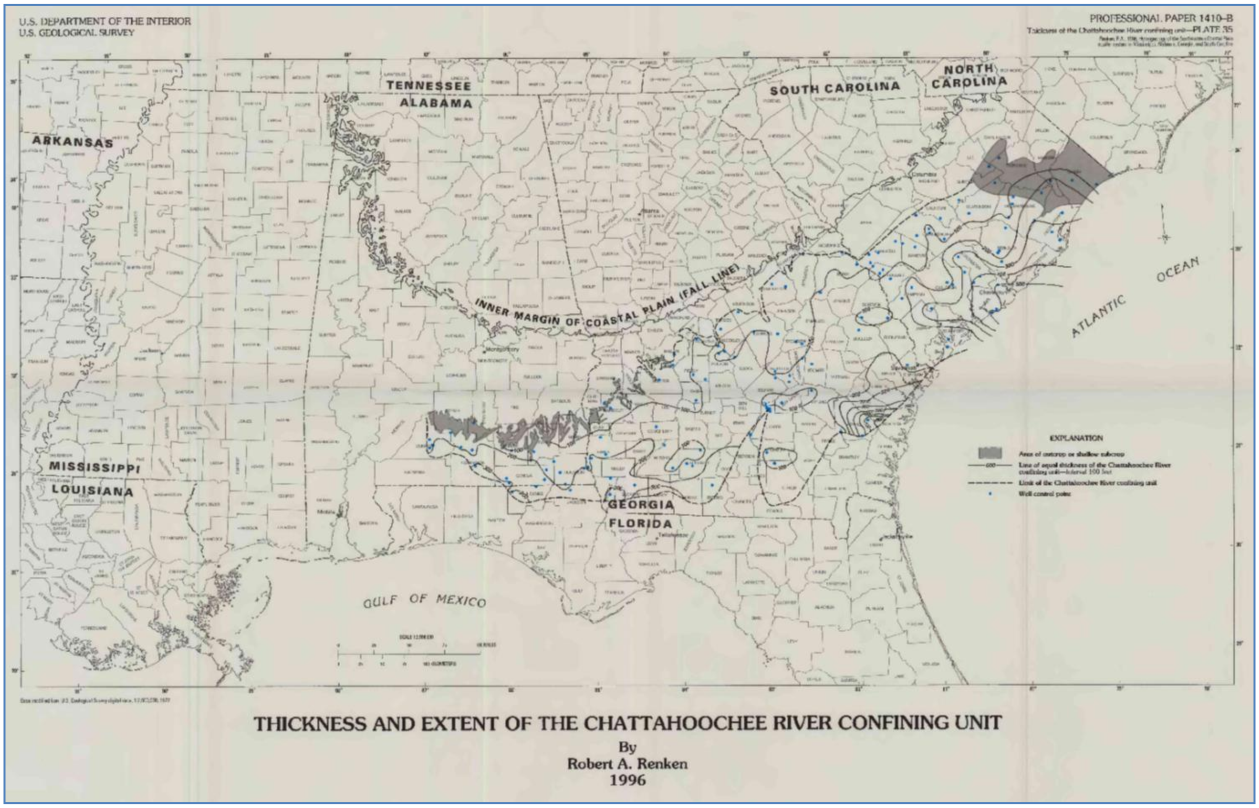


Figure 38. Thickness of the Chattahoochee River Aquifer Confining Unit (after Renken 1996)

Top of the Chattahoochee River Aquifer. Within the area of interest, the top of the Chattahoochee River aquifer ranges in elevation from approximately -2,500 ft NGVD in southeastern Georgia to 0 ft NGVD at its updip limit in central Georgia (Renken, 1996; Figure 39).

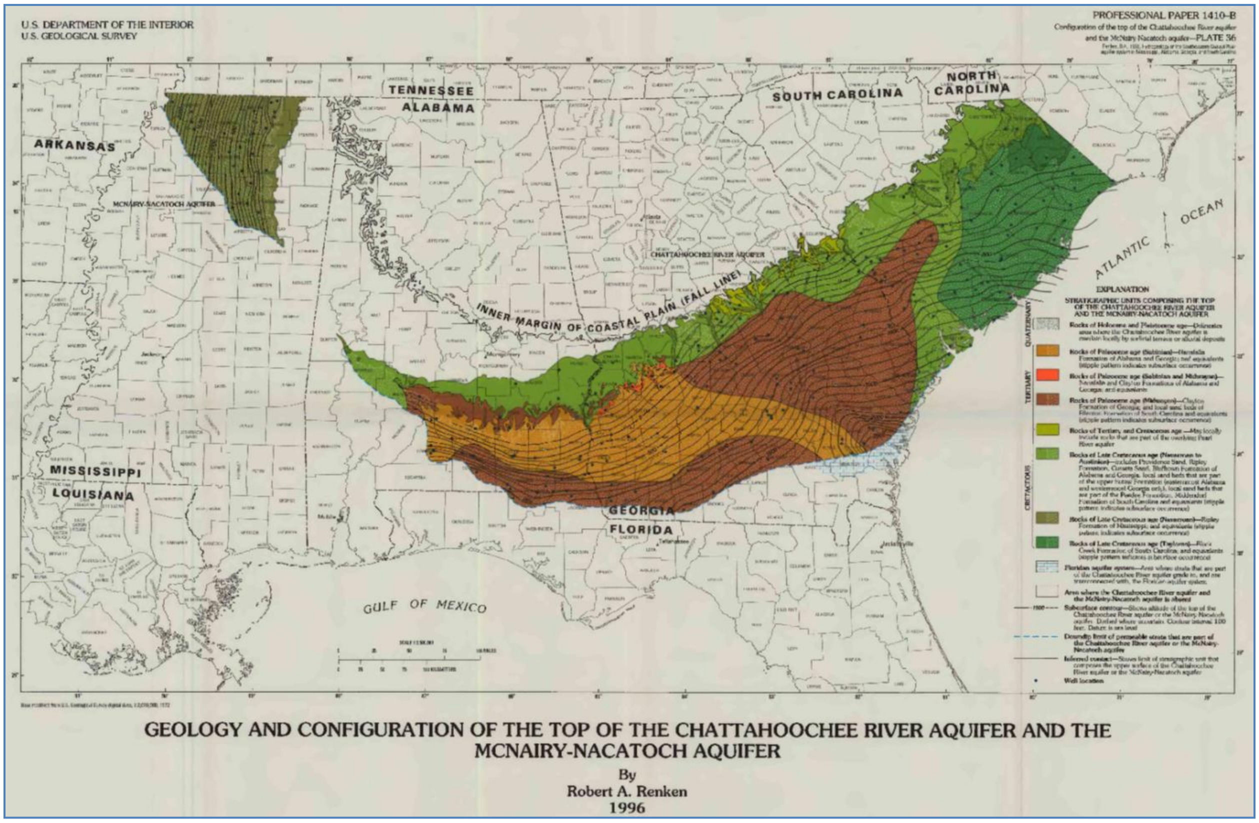


Figure 39. Elevation of the Top of the Chattahoochee River Aquifer (after Renken 1996)

Bottom of the Chattahoochee River Aquifer. Within the area of interest, the bottom of the Chattahoochee River aquifer ranges in elevation from approximately -3,300 ft NGVD in southeastern Georgia to 400 ft NGVD at its updip limit in central Georgia (Renken, 1996; Figure 40).

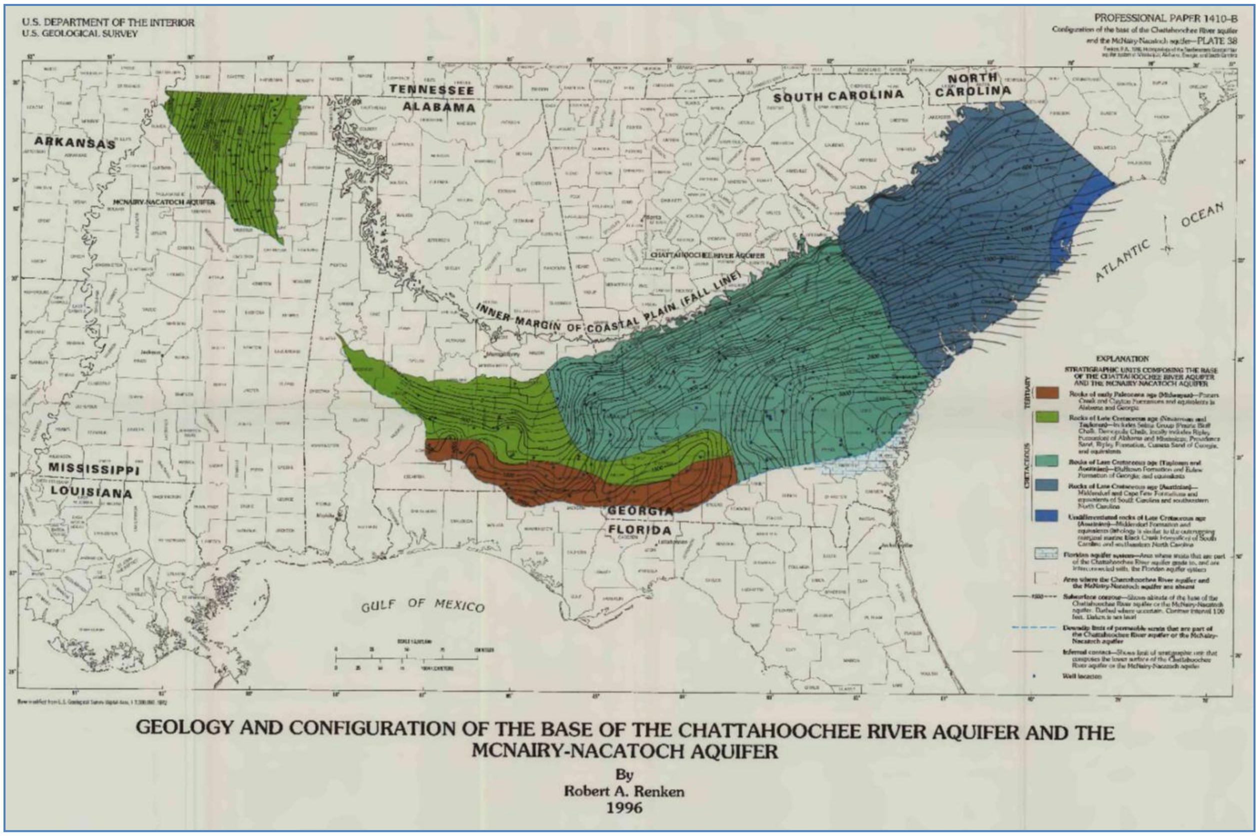


Figure 40. Elevation of the Bottom of the Chattahoochee River Aquifer (after Renken 1996)

Thickness of the Chattahoochee River Aquifer. The thickness of the Chattahoochee River aquifer ranges less than 250 ft in southern Georgia to more than 1500 ft in central Georgia (Renken, 1996; Figure 41).

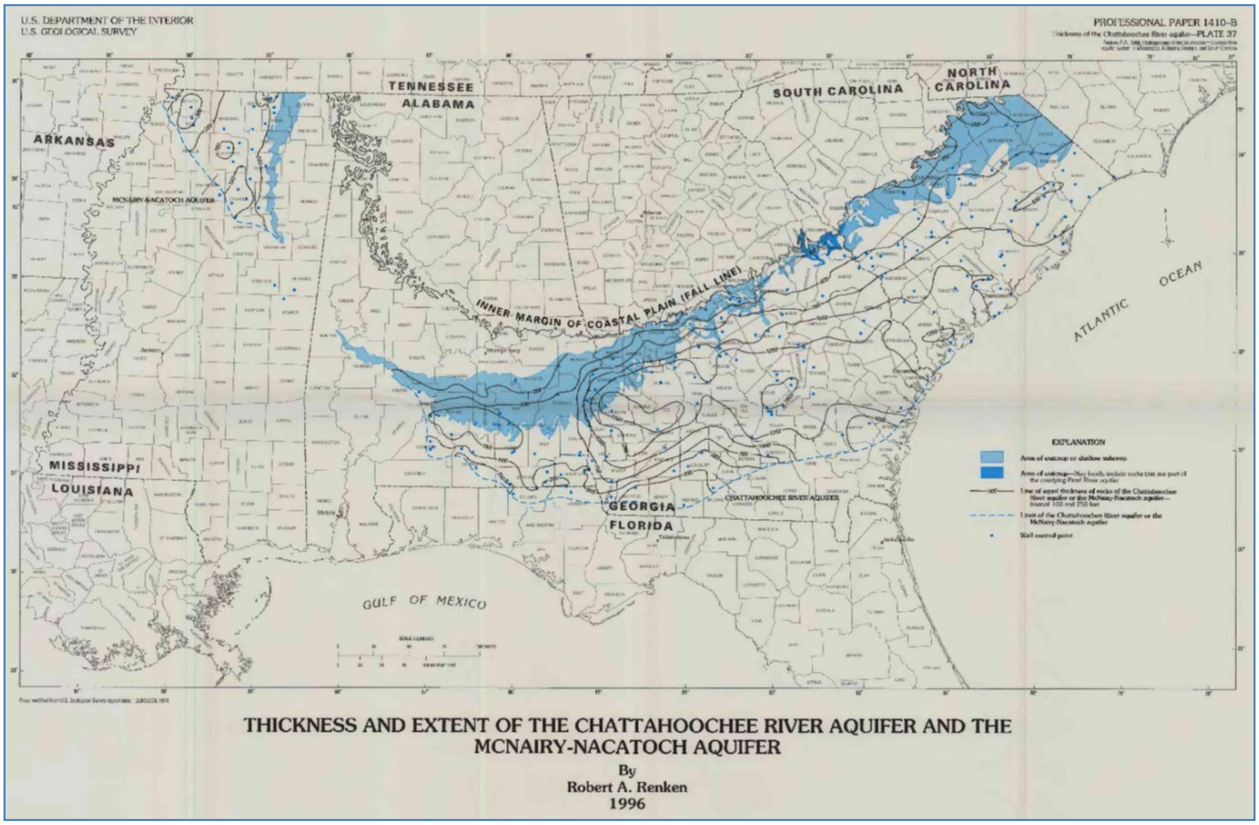


Figure 41. Thickness of the Chattahoochee River Aquifer (after Renken 1996)

Thickness of the Black Warrior River Aquifer Confining Unit. Within the area of interest, the thickness of the Black Warrior River aquifer confining unit ranges from approximately 0 ft to more 1,250 ft thick (Renken, 1996; Figure 42).

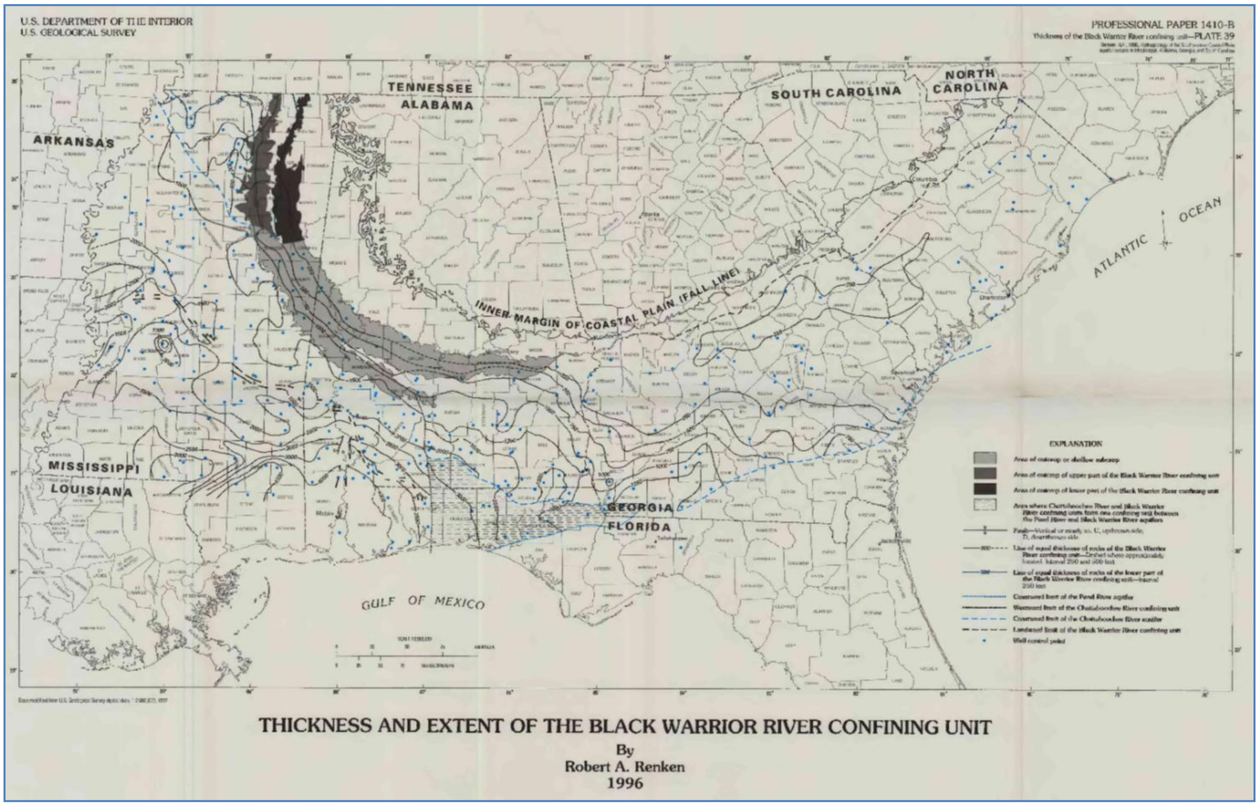


Figure 42. Thickness of the Black Warrior River Aquifer Confining Unit (after Renken 1996)

<u>Top of the Black Warrior River Aquifer.</u> Within the area of interest, the top of the Black Warrior River aquifer ranges in elevation from approximately -5,000 ft NGVD near Apalachicola in the Florida Panhandle to 0 ft NGVD at its updip limit in northwestern Georgia (Renken, 1996; Figure 43). Although the Black Warrior River aquifer extends into the Florida Panhandle, the limit of freshwater flow, taken as the 10,000 mg/l total dissolved solids contour, is located near the Florida-Georgia state line (Figure 43).

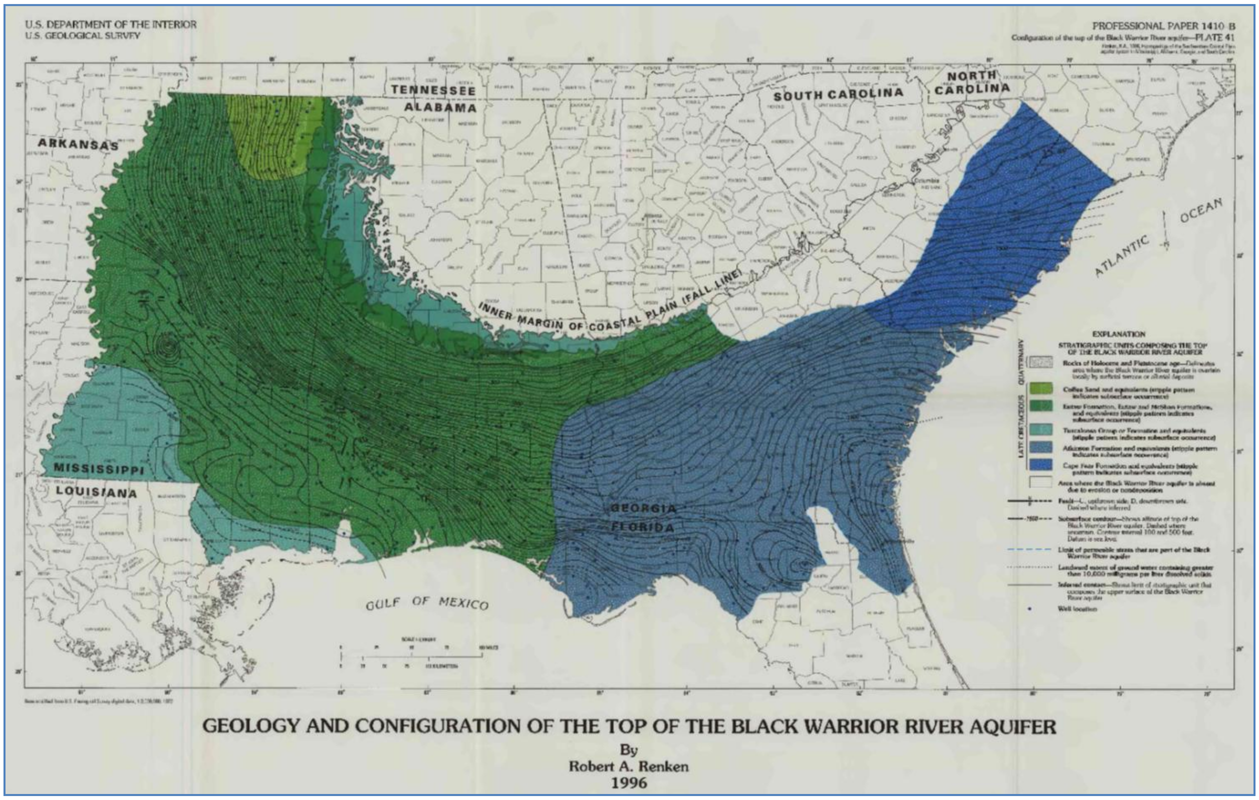


Figure 43. Elevation of the Top of the Black Warrior River Aquifer (after Renken 1996)

<u>Bottom of the Black Warrior River Aquifer.</u> The bottom of the Black Warrior River aquifer coincides with the bottom of the SECPAS (Renken, 1996; Figure 44). Within the area of interest, the bottom of the SECPAS ranges in elevation from -7,000 ft NGVD to 0 ft NGVD (Miller, 1990; Figure 44).

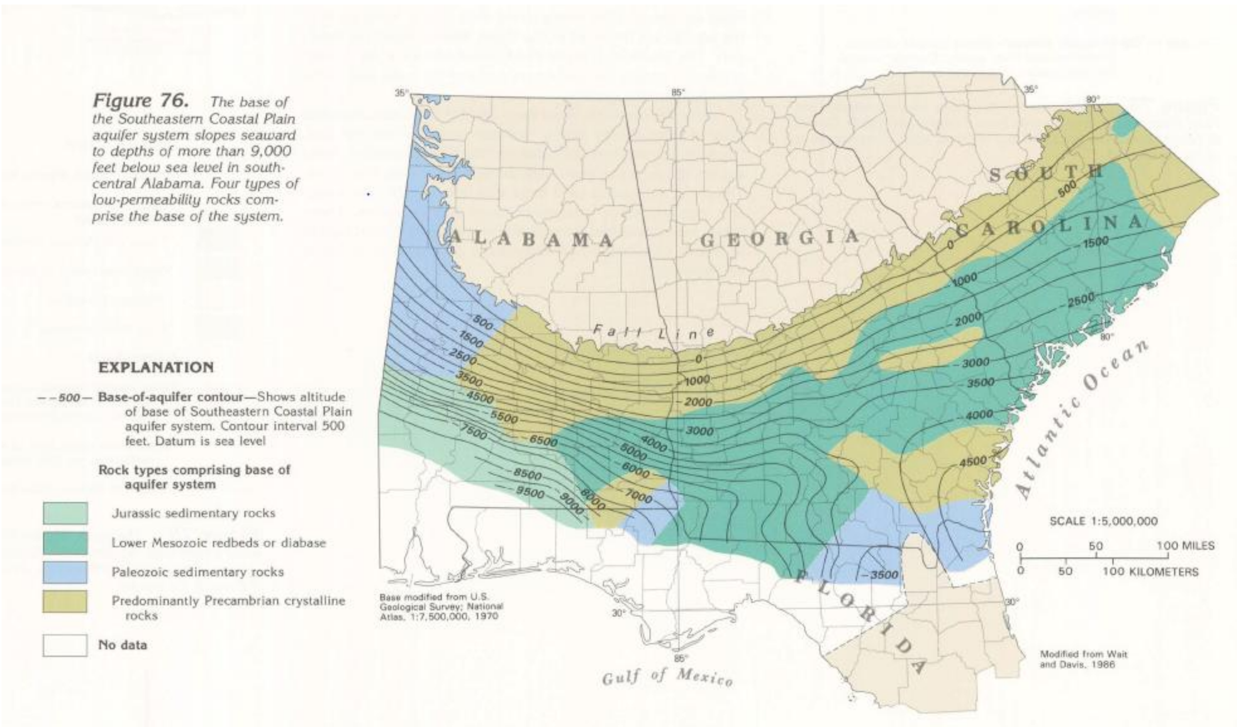


Figure 44. Elevation of the Bottom of the Black Warrior River Aquifer (after Miller 1990)

Thickness of the Black Warrior River Aquifer. Within the area of interest, the thickness of the Black Warrior River aquifer ranges from 0 ft at its updip limit to approximately 4,000 ft in southwest Georgia (Renken, 1996; Figure 45).

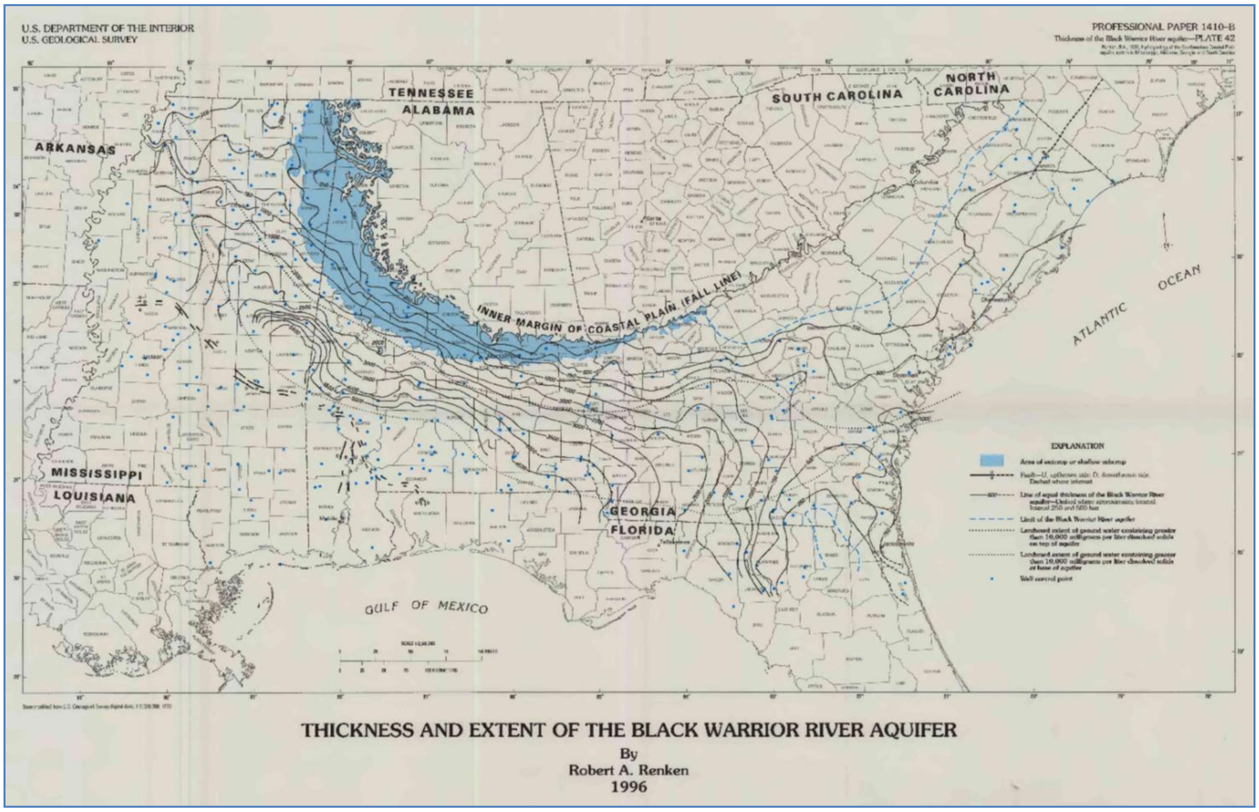


Figure 45. Thickness of the Black Warrior River Aquifer (after Renken 1996)

Hydraulic Properties of the SECPAS

Hydraulic properties of the SECPAS aquifers and semiconfining units were estimated as a result of model calibration (Barker and Pernik1994).

Transmissivity. Within the area of interest, the calibration-derived transmissivity of the aquifers of the SECPAS range approximately from 0 to 52,000 ft^2/d (Barker and Pernik, 1994; Figure 46).

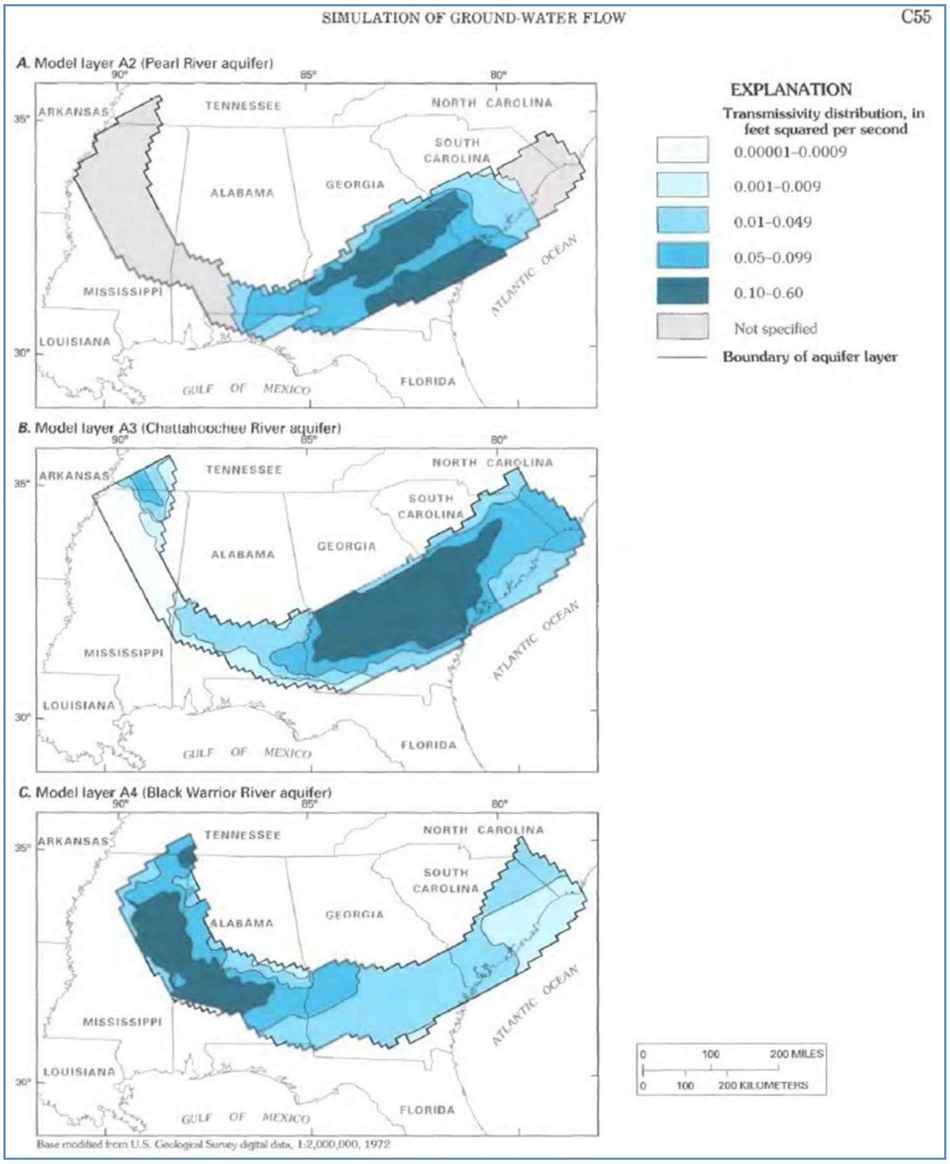


Figure 46. Calibration-Derived Transmissivity Distributions of the Southeastern Coastal Plain Aquifers (after Barker and Pernik 1994)

Leakance. Within the area of interest, the calibration-derived leakance of the confining units of the SECPAS range approximately from 8.6X10^{-12} per day (day^{-1}) to 8.6X10^{-5} day^{-1} (Barker and Pernik, 1994; Figure 47).

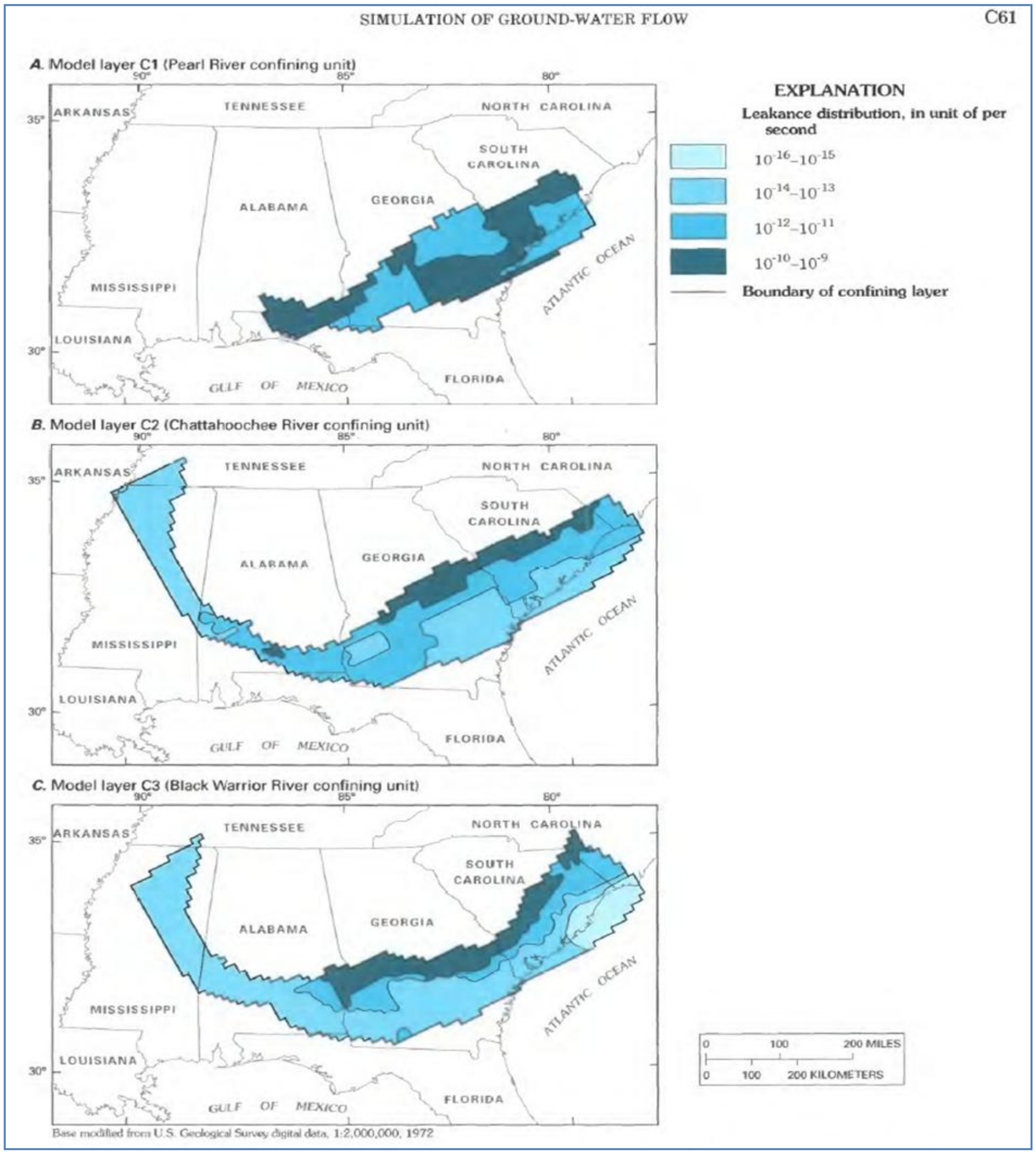


Figure 47. Calibration-Derived Leakance Distributions of the Southeastern Coastal Plain Aquifer Semiconfining Units (after Barker and Pernik 1994)

Storage Coefficient. Within the area of interest, the calibration-derived storage coefficient of the aquifers of the SECPAS ranges approximately from $1.0X10^{-4}$ to $1.0X10^{-1}$ (Barker and Pernik, 1994; Figure 48).

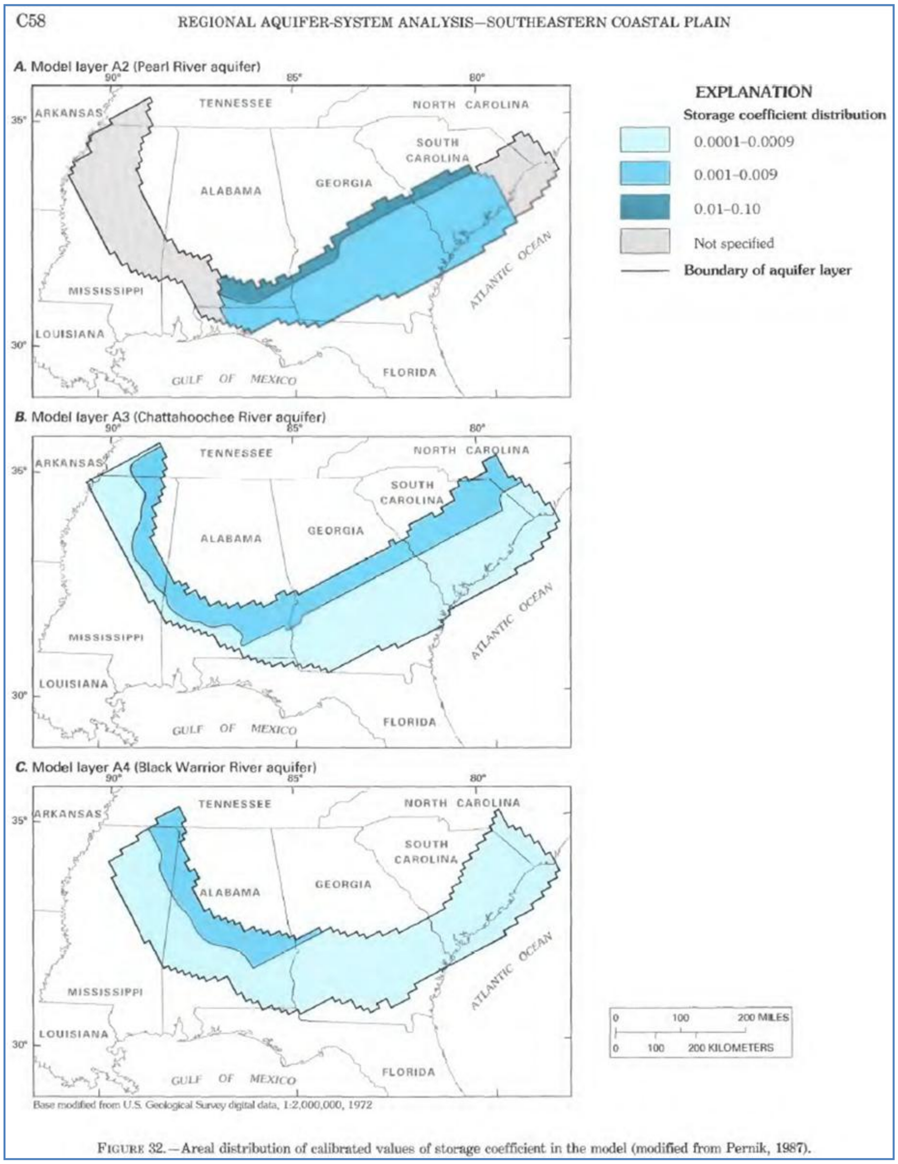


Figure 48. Calibration-Derived Storage Coefficient Distribution of the Southeastern Coastal Plain Aquifers (after Barker and Pernik 1994)

Recharge to the SECPAS Deep Flow System and Major Streams

Recharge to the deep-flow, semiconfined portion of the SECPAS and to major streams transecting the SECPAS outcrop areas was simulated by the USGS (Barker and Pernike 1994). The resulting calibrated recharge distribution did not include recharge that discharges to smaller tributaries and other relatively small streams. That portion of the recharge, however, is the great majority of the recharge, as most aquifer recharge to the outcrop areas of the SECPAS is lost locally as baseflow to streams (Barker and Pernik 1994). Nevertheless, the amount required to recharge the deeper portions of the SECPAS is instructive in the present study, as it is that part of the system that tends to be more intimately connected to the overlying and adjacent FAS. Recharge rates resulting from the calibration of the USGS model thus ranged approximately from 0 in/yr up to 5 in/yr (Barker and Pernik, 1994; Figure 49).

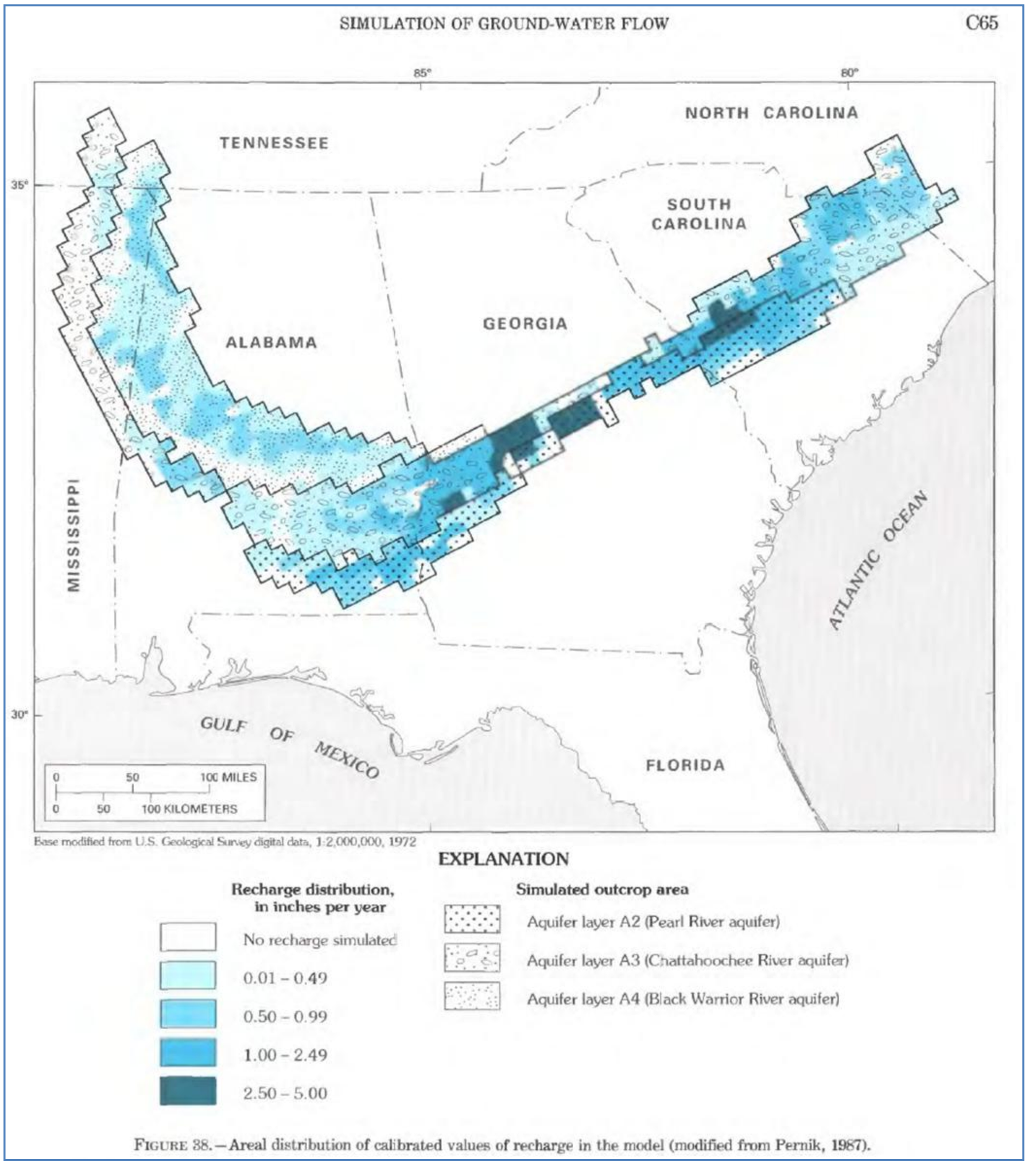


FIGURE 38.—Areal distribution of calibrated values of recharge in the model (modified from Pernik, 1987).

Figure 49. Calibration-Derived Distribution of Recharge to the Southeastern Coastal Plain Aquifer System Outcrop Area (after Barker and Pernik 1994)

Leakage Patterns through SECPAS Semiconfining Units and Estimated Rate of Exchange between the SECPAS and FAS

The leakage patterns resulting from the USGS simulation of the SECPAS show a pattern of discharge into and out of the three aquifers that comprise the SECPAS within the area of interest (Barker and Pernik, 1994; Figure 50). The results of the USGS simulation showed a net influx of water from the SECPAS into the postdevelopment FAS of about 110 cfs or 71 mgd (Barker and Pernik, 1994; Figure 51).

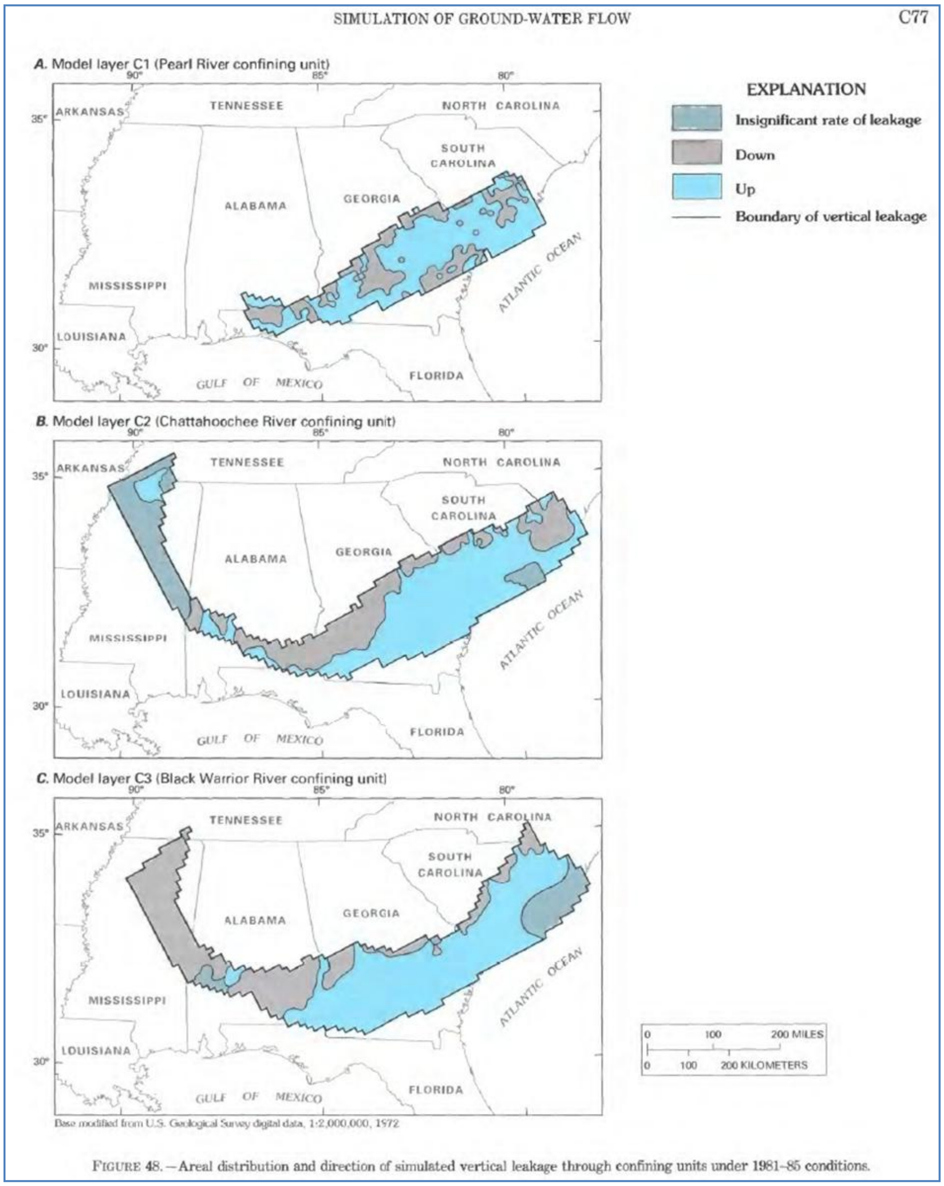


Figure 50. Simulated Pattern of Recharge to and Discharge from Aquifers Comprising the Southeastern Coastal Plain Aquifer System (after Barker and Pernik 1994)

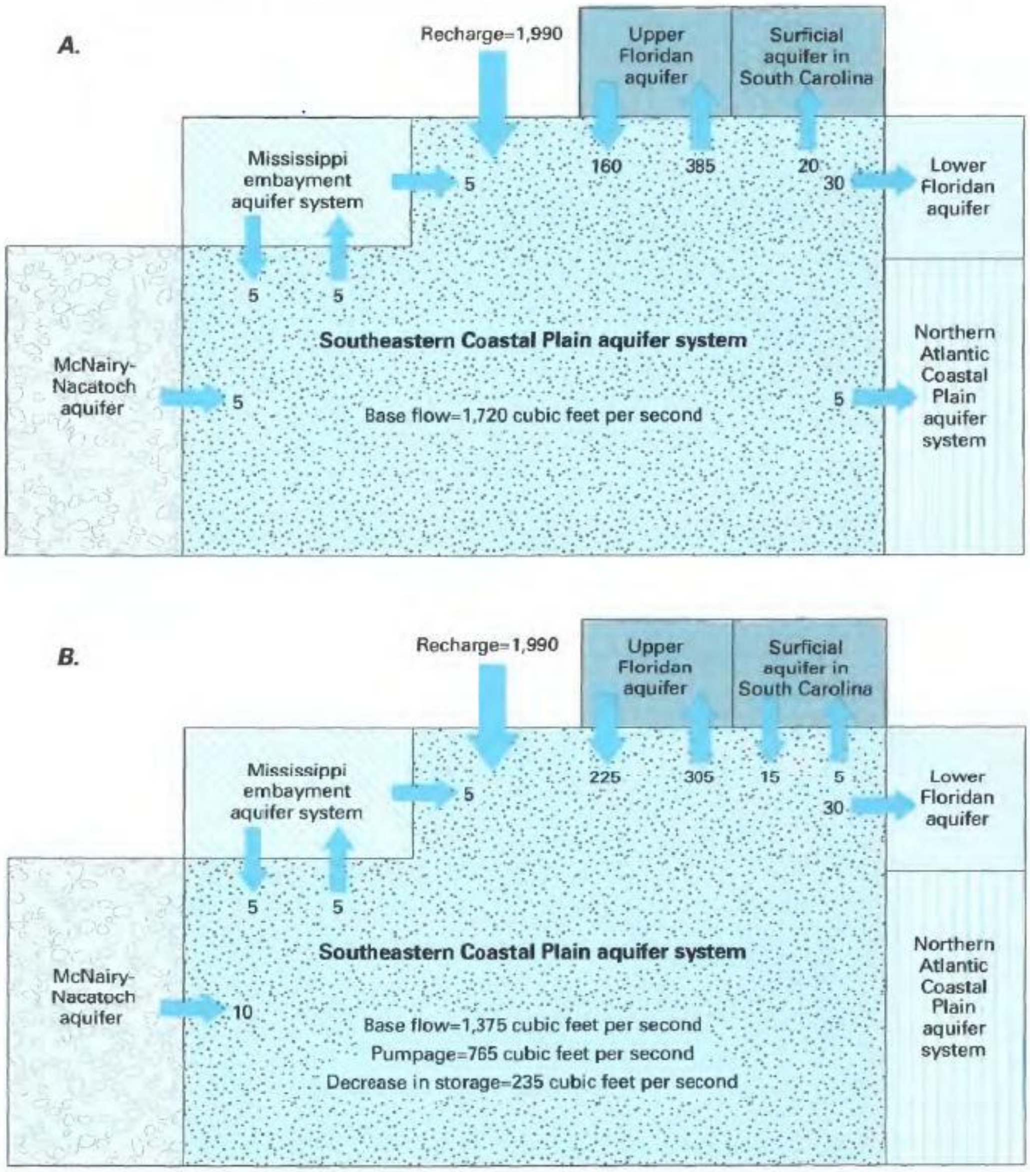


FIGURE 49.—Simulated rates of ground-water flow between the Southeastern Coastal Plain aquifer system and adjacent regional aquifers and aquifer systems, under (*A*) predevelopment (pre-1900) and (*B*) 1981–85 conditions (modified from Miller, 1992). (Units are rounded to the nearest 5 cubic feet per second.)

Figure 51. Simulated Rates of Groundwater Flow between the Southeastern Coastal Plain Aquifer System and Adjacent Aquifers (after Barker and Pernik 1994)

Pumpage Distribution in the SECPAS

The pumpage distribution for the period 1981 through 1985 was compiled by the USGS for modeling purposes (Barker and Pernik, 1994; Figure 52). Pumpage in the SECPAS is concentrated primarily in outcrop areas (Barker and Pernik, 1994; Figure 52), but this is not the case in all instances. In southwest Georgia, the semiconfined Claiborne aquifer, which is part of the USGS-defined Pearl River aquifer, and the semiconfined Clayton aquifer, which is part of the USGS-defined Chattahoochee River Aquifer (Renken, 1996), are primary sources of water to the city of Albany (McFadden and Perriello, 1983).

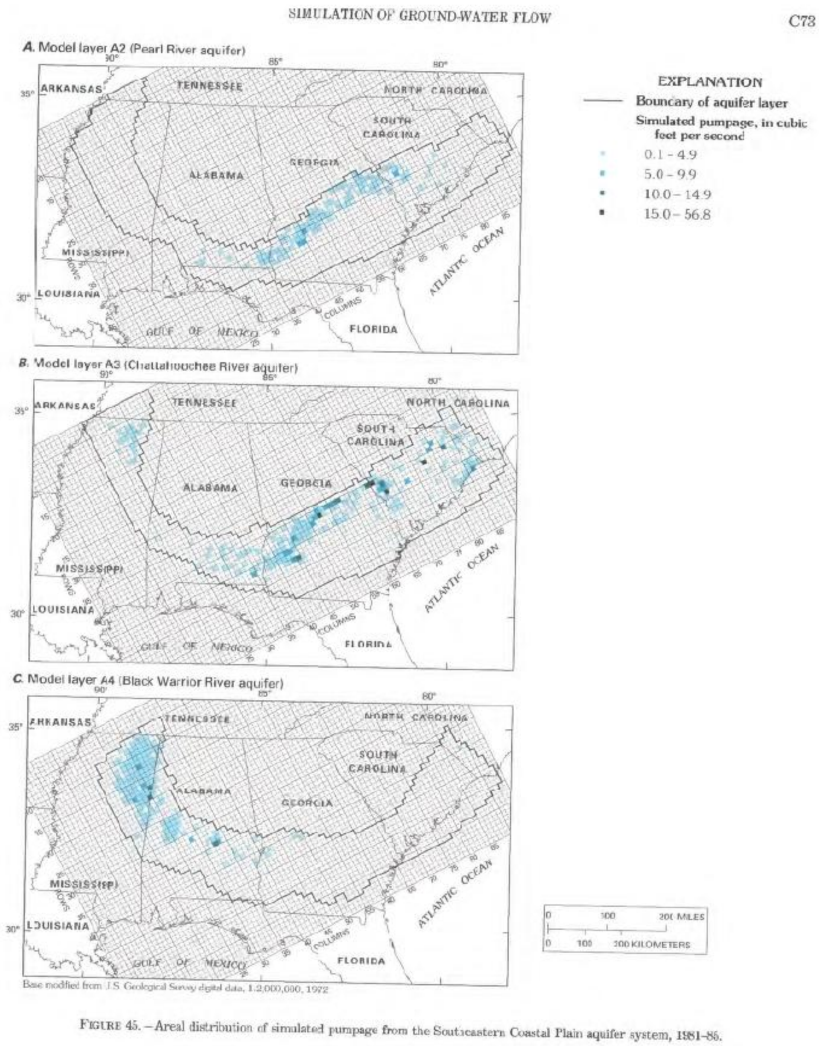


Figure 52. Estimated Pumpage Distribution in the Southeastern Coastal Plain Aquifer System (after Barker and Pernik 1994)

Ambient chloride and dissolved concentrations in the SECPAS, as well as other water-quality constituents, have been mapped for all three aquifers (Lee, 1993; Figure 53; Figure 54; Figure 55).

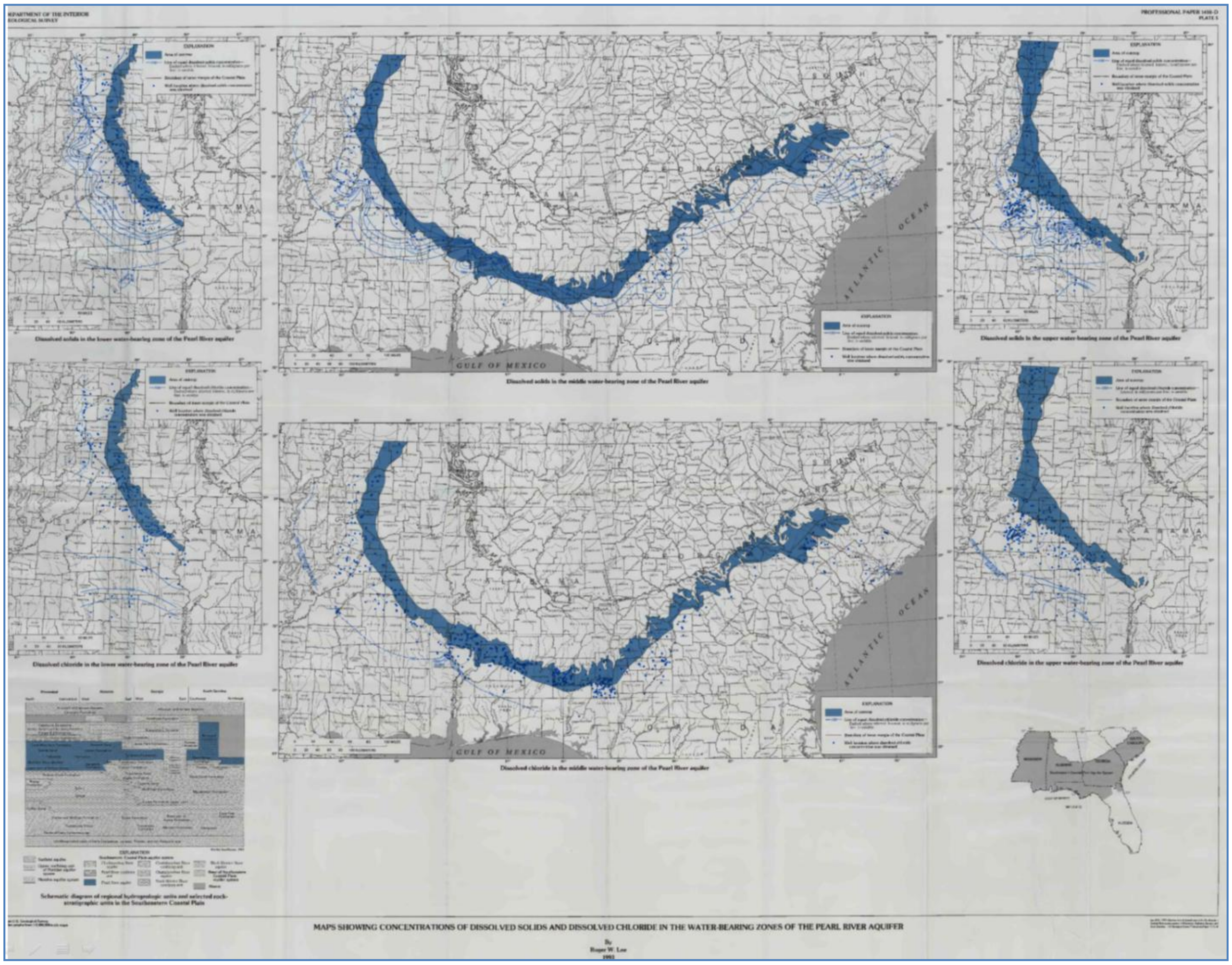


Figure 53. Concentrations of Dissolved Solids and Chloride in the Pearl River Aquifer (after Lee 1993)

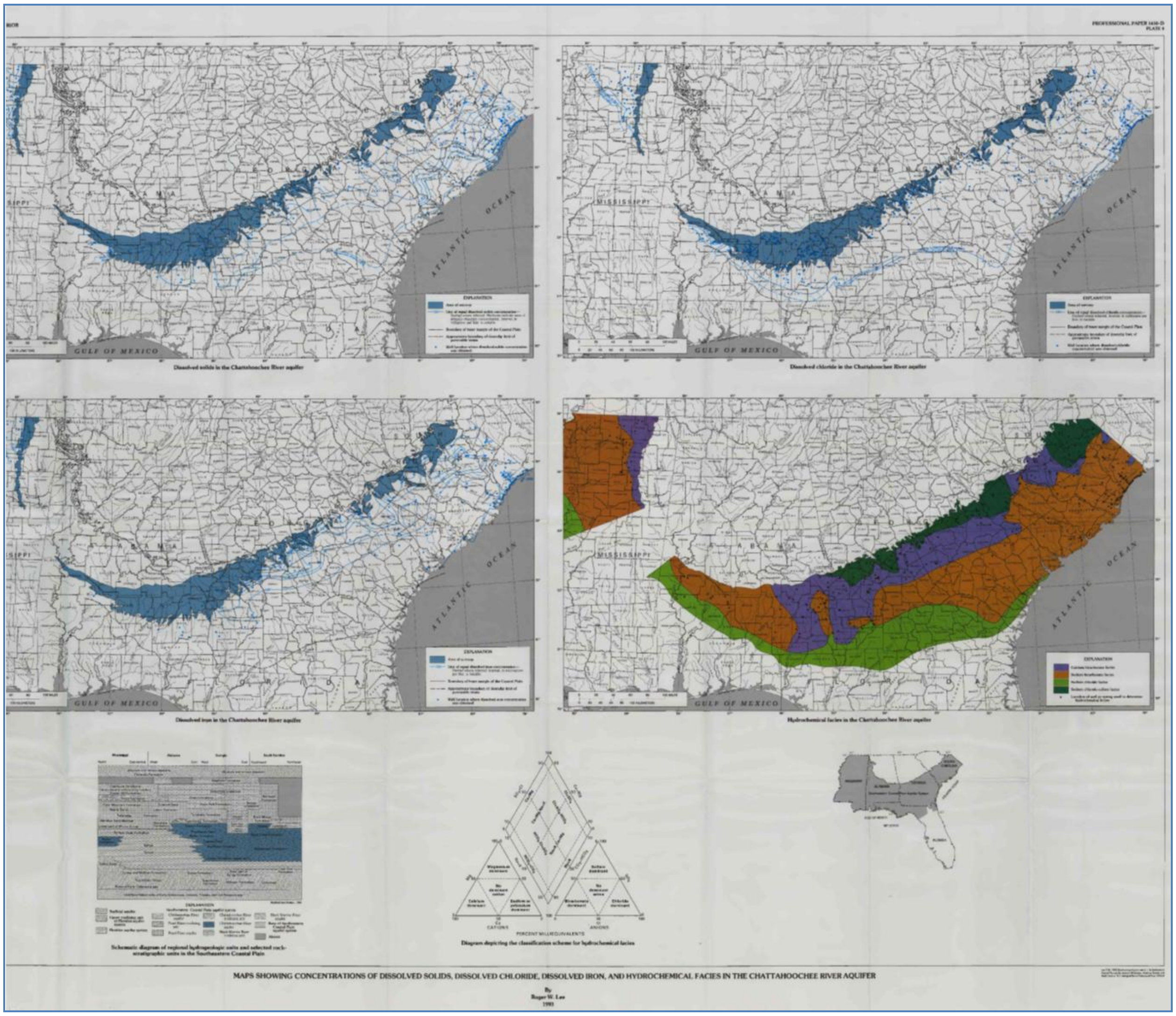


Figure 54. Concentrations of Dissolved Solids and Chloride in the Chattahoochee River Aquifer (after Lee 1993)

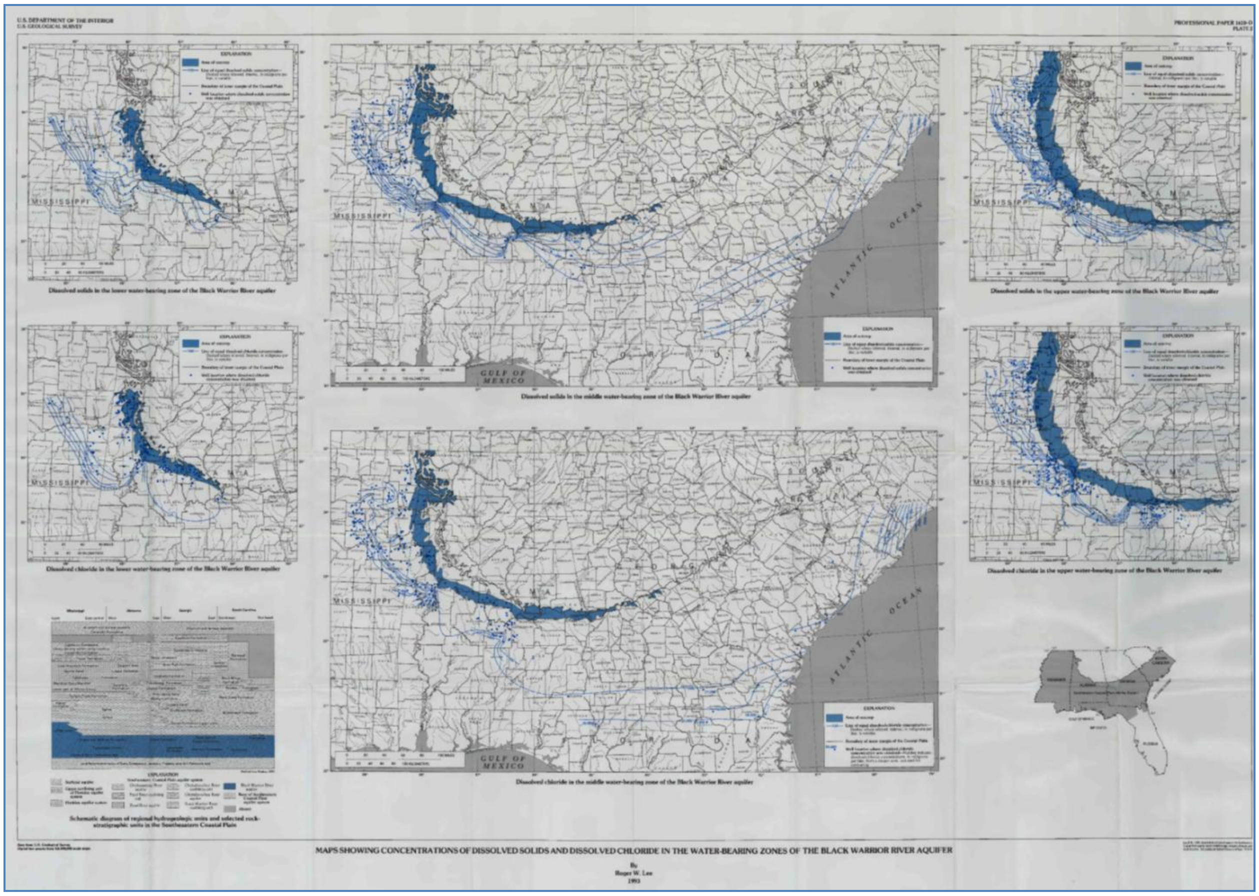


Figure 55. Concentrations of Dissolved Solids and Chlorides in the Black Warrior River Aquifer (after Lee 1993)[i]

DATA REQUIREMENTS AND AVAILABILITY

The preceding discussion helps to demonstrate the necessity of a number of different data types, including stratigraphic, pumpage, water-level, recharge and discharge, and water quality data types, as these and other types of data are necessary for the assessment of aquifer characteristics. The maps used in the preceding sections are somewhat dated but are, nevertheless, still relevant to an accurate conceptualization of the present-day groundwater system of north Florida and southeast Georgia. Furthermore, the very existence of such maps implies that the collection and observation of the data they represent was of adequate interest to warrant collection up until the fairly recent past at least. Generally, however, such data are still being collected and updated on an ongoing basis, and, in some cases, through the use of techniques that were not available or at least not widely available until more recent years.

The purpose of the present section, then, is to show the locations of data-collection stations of various data types and their periods of record. In some cases, the data type in question is, by its nature, not collected by station, so a map of the distribution of the data is shown instead. An example of such a data type is land use. Some discussion of the necessity and application of the various data types to the model development and/or application will be included also.

Pumping-Well Locations

Well withdrawals within the FAS are large enough and widespread enough to affect the FAS flow system significantly throughout the region. Therefore, accurate knowledge of the locations of withdrawals, of the aquifer(s) from which they are obtained, of the magnitudes of the withdrawals, and of the timing of the withdrawals is essential to model calibration and application. The following maps show the locations of known, permitted pumping wells. They do not include non-permitted well points, such as domestic self-supply well points. Most of the points in Georgia are also not shown, as data supplied by the Georgia EPD is not in point form but rather in a much more generalized format. Data in the Suwannee River Water Management District are not available throughout the entire Suwannee River Water Management District. Clearly, then, much work remains in accurately locating pumping well locations within the area of interest.

SAS Pumping Well Locations

A number of wells withdraw water from the SAS within the area of interest (Figure 56). Withdrawals, in some cases, are for municipal supplies (e.g., in Palm Coast, Florida).

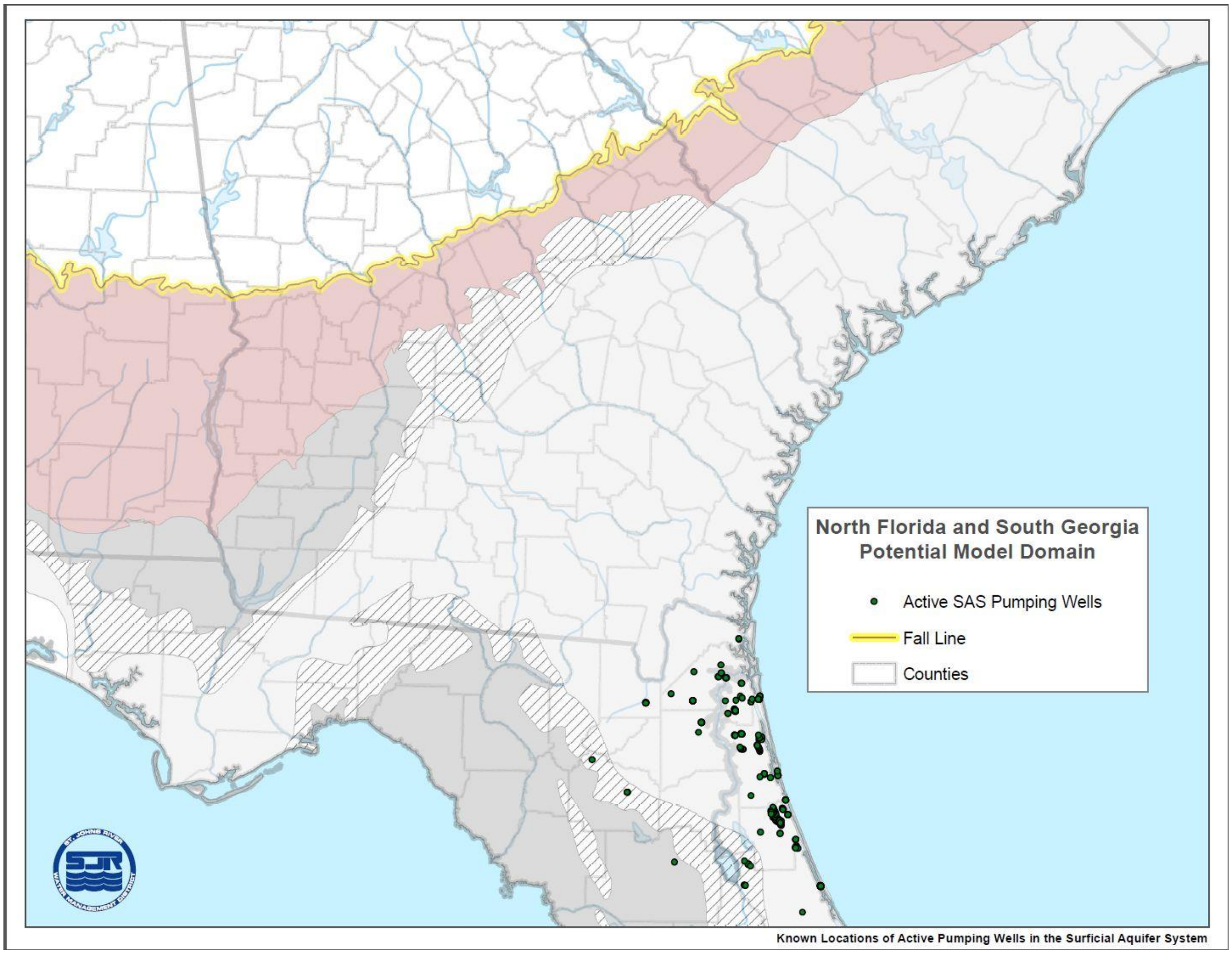


Figure 56. Known Locations of Active Pumping Wells in the Surficial Aquifer System

IAS Pumping-Well Locations

Although of limited water-supply potential in general, pumping from the permeable lenses of the IAS does occur outside of the Brunswick aquifer system (Figure 57). In some cases, pumping wells are open to both the IAS and the FAS (Figure 58).

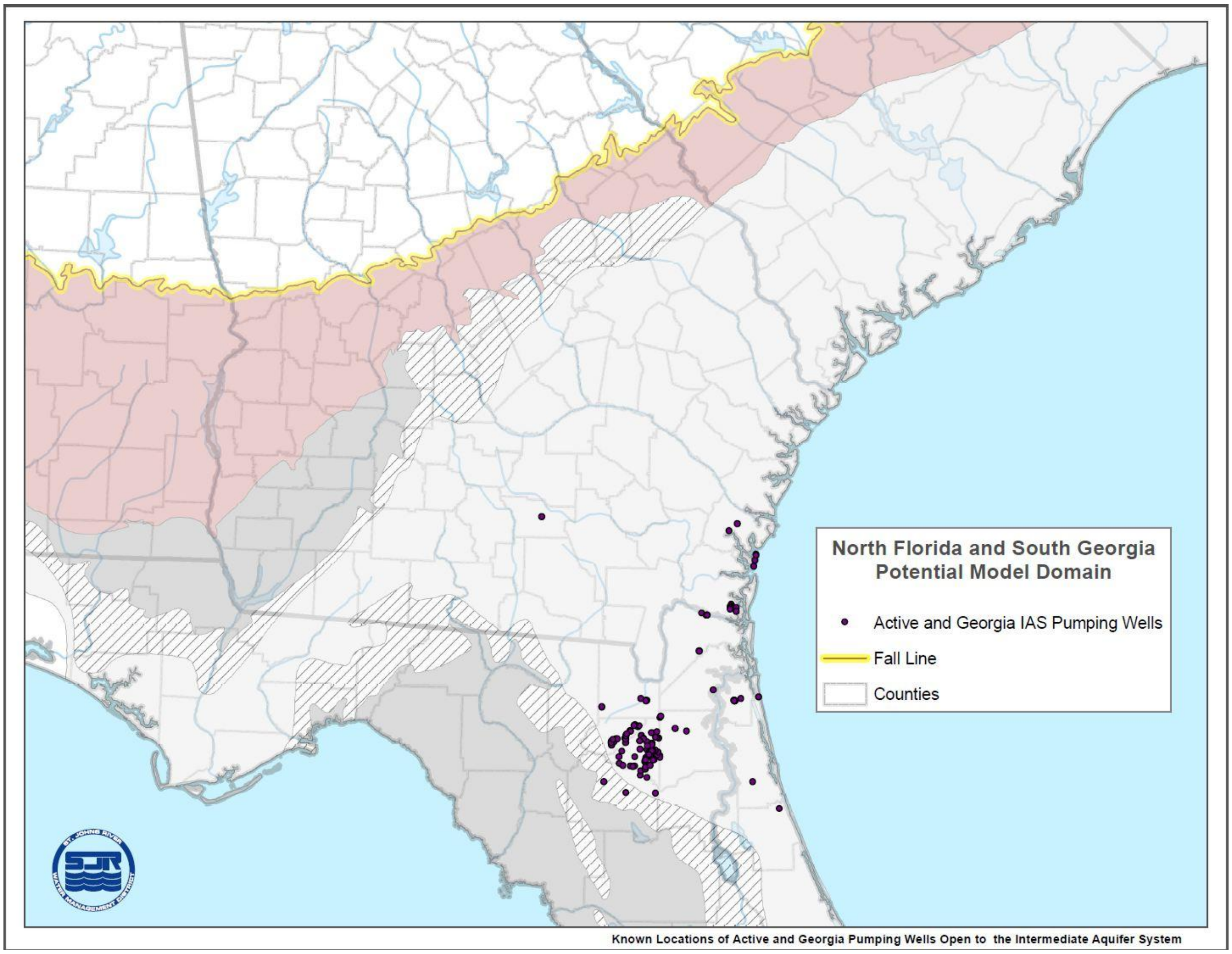


Figure 57. Known Locations of Active and Georgia Pumping Wells Open to the Intermediate Aquifer System

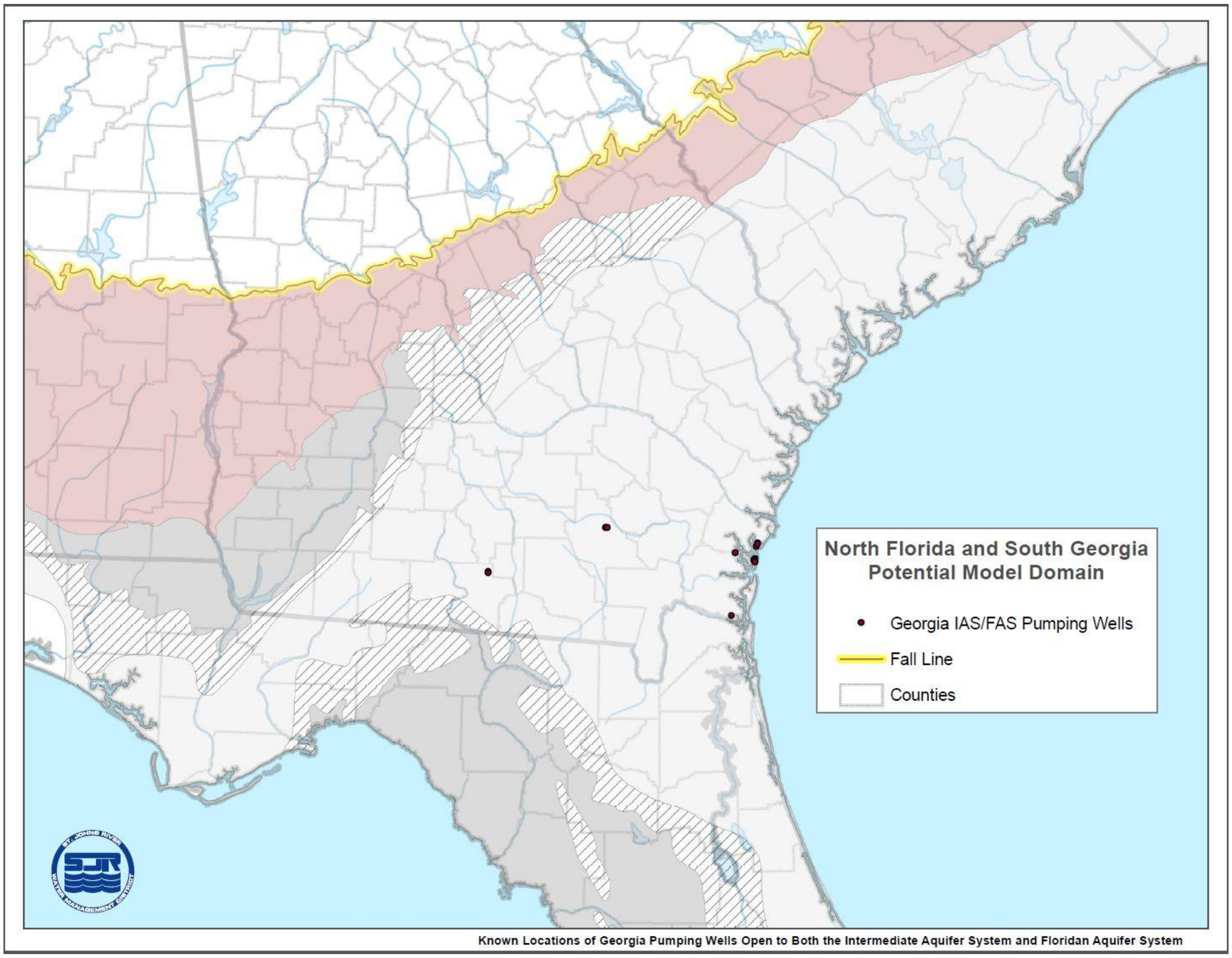


Figure 58. Known Locations of Georgia Pumping Wells in Both the Intermediate Aquifer System and Floridan Aquifer System

Upper Floridan Aquifer Pumping-Well Locations

Known locations of Upper Floridan aquifer withdrawal wells within the area of interest are shown (Figure 59). Withdrawal locations in Georgia, as supplied to date by the Georgia EPD, are highly generalized and, therefore, not represented.

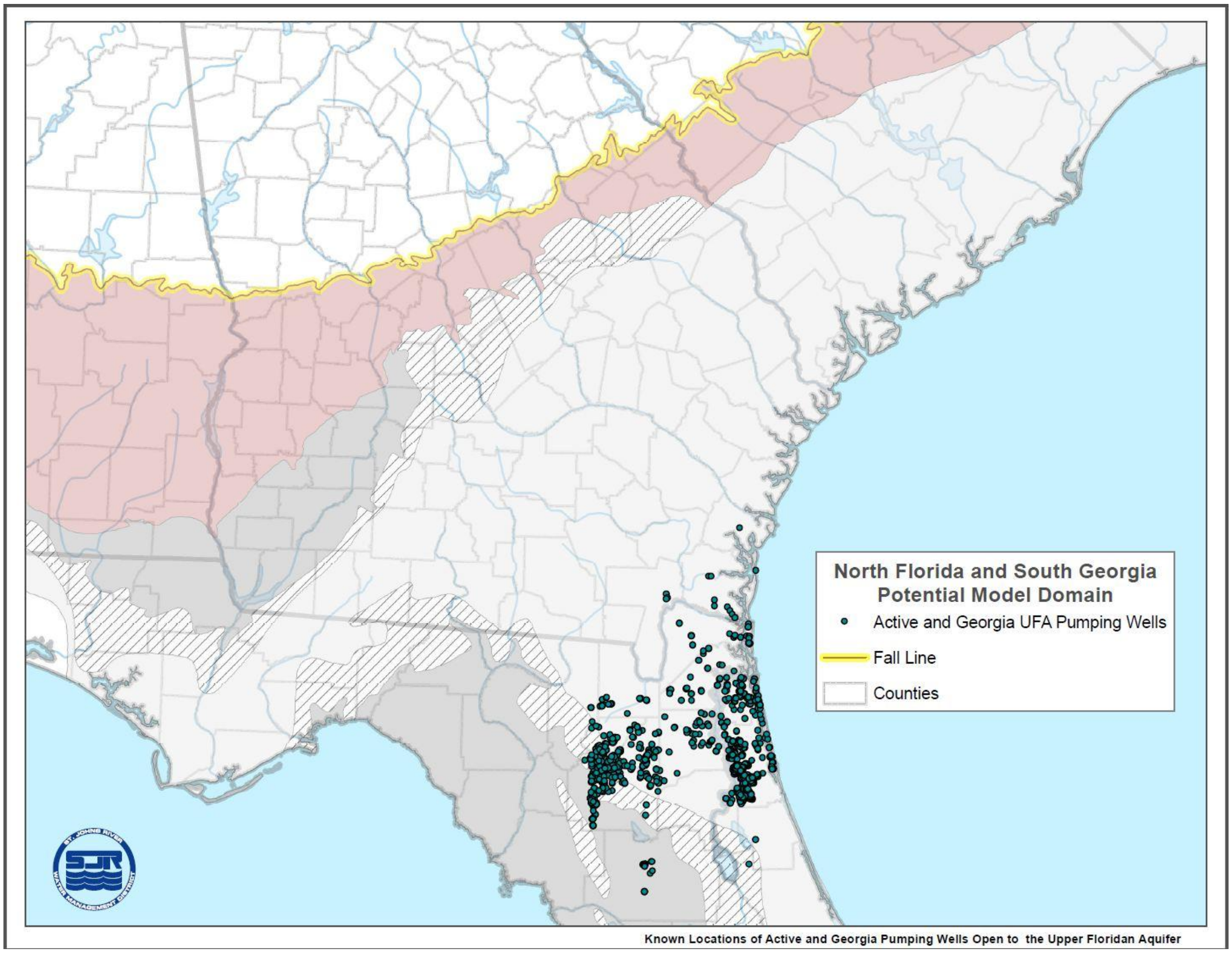


Figure 59. Known Locations of Active and Georgia Pumping Wells Open to the Upper Floridan Aquifer

Upper/Lower Floridan Aquifer Pumping-Well Locations

A fair number of withdrawal wells are open to both the Upper and Lower Floridan aquifers, particularly in Duval and Clay counties, Florida (Figure 60).

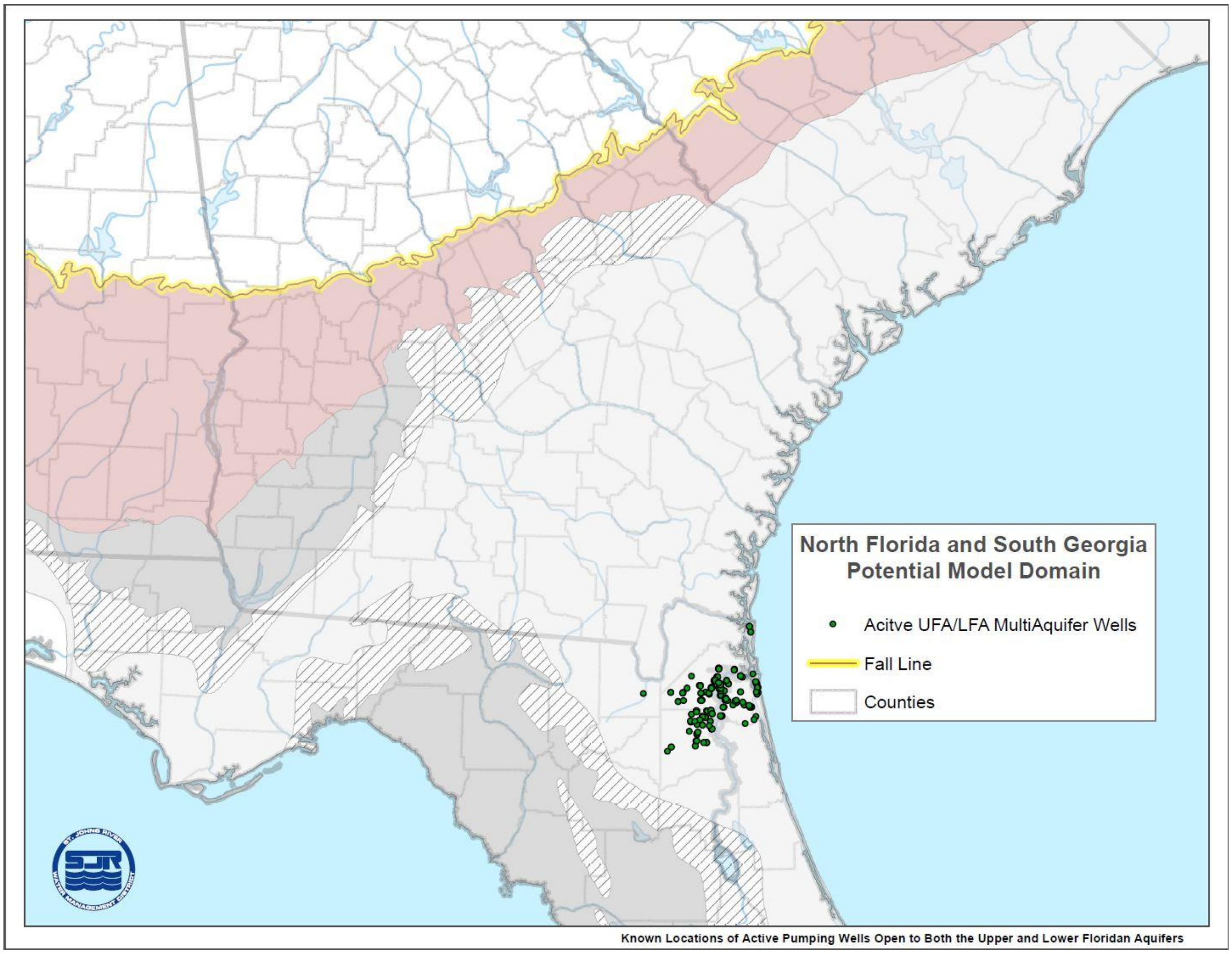


Figure 60. Known Locations of Pumping Wells Open to Both the Upper and Lower Floridan Aquifers

Lower Floridan Aquifer Pumping-Well Locations

Pumping wells open exclusively to the Lower Floridan aquifer are rare. Know cases of such wells are shown (Figure 61).

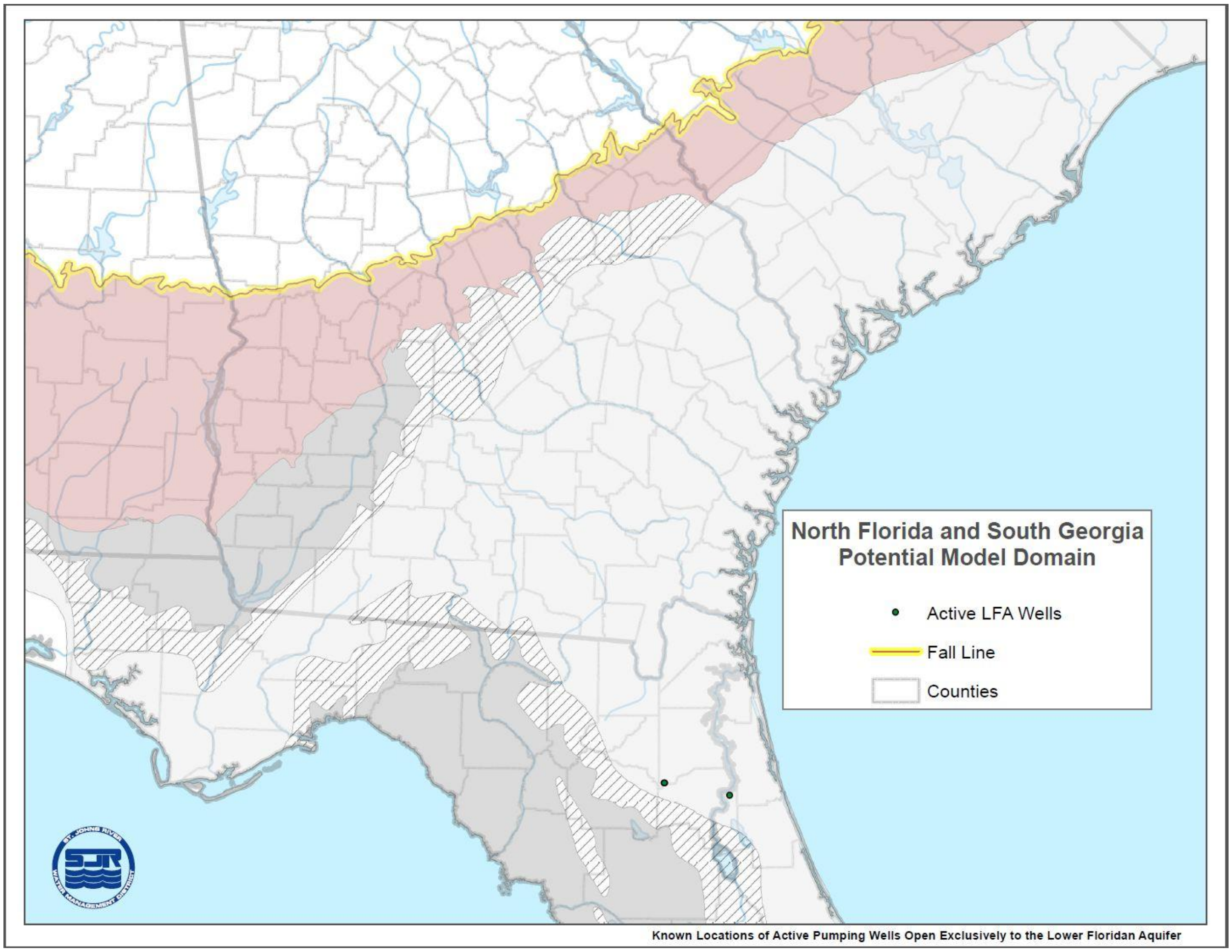


Figure 61. Known Locations of Active Pumping Wells Open Exclusively to the Lower Floridan Aquifer

Other Pumping-Well Categories

In many cases, pumping wells are designated as being open to the FAS, but the specific aquifer in the FAS (i.e., Upper Floridan or Lower Floridan) is not specified (Figure 62). In many of such cases, the total depth and casing length of the well are known, thus enabling the determination of the aquifer to which the well is open by comparison to hydrogeologic data. If not, then the aquifer can usually be assumed to be the Upper Floridan aquifer only, as this is in fact the case in most instances. Sometimes, other information regarding the well will enable a more definite determination. In other cases, the aquifer to which a pumping well is open is not specified at all. Again, knowledge of the total depth and casing length can enable the determination of the aquifer in question possible by comparing to hydrogeologic data (Figure 63). In other cases, the aquifer to which the well is open is unspecified and the depth information is not known (Figure 64). In some of these cases, other information may be available to help inform us concerning the source aquifer.

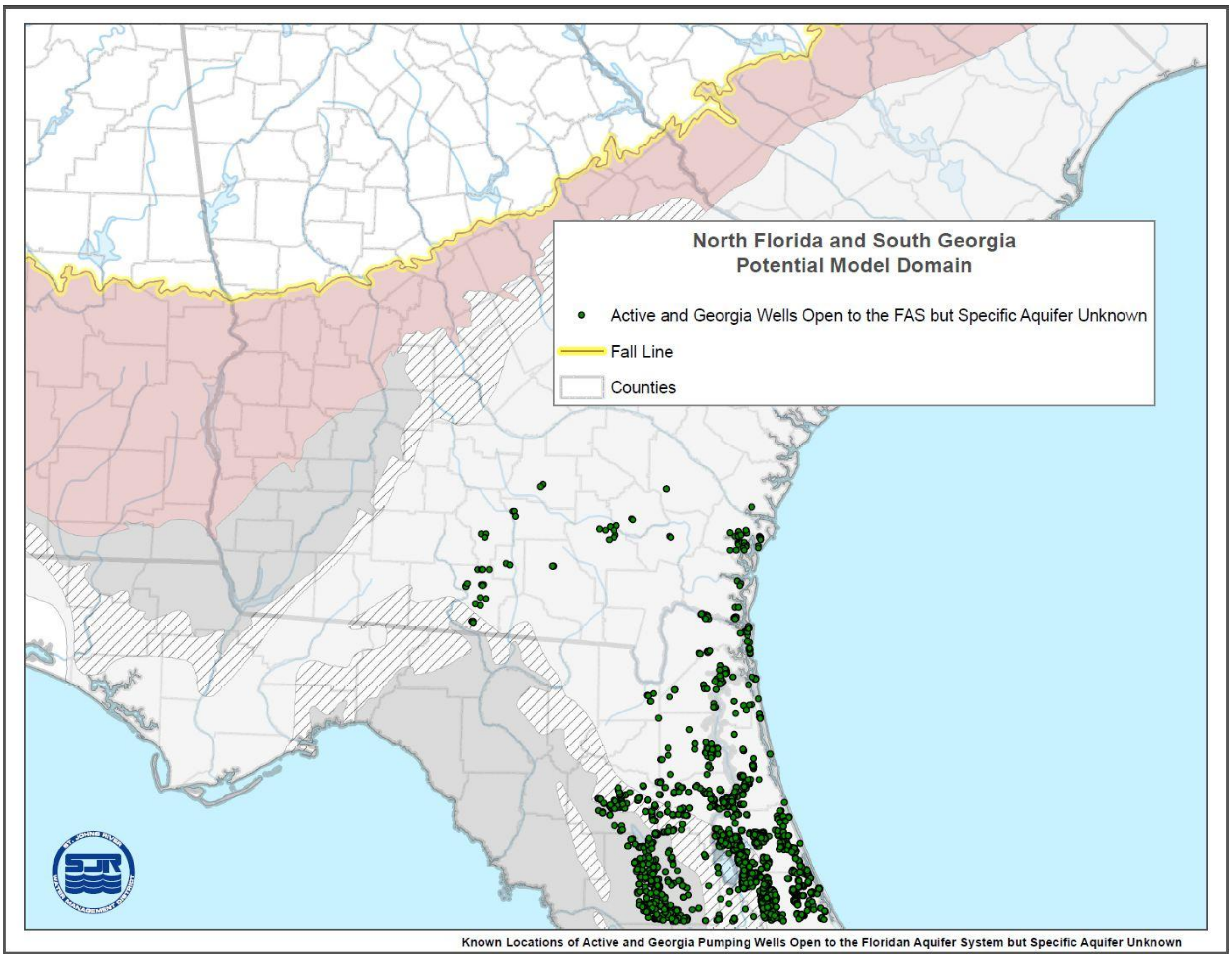


Figure 62. Known Locations of Active Pumping Wells Open to the Floridan Aquifer System, Component Aquifer Unknown

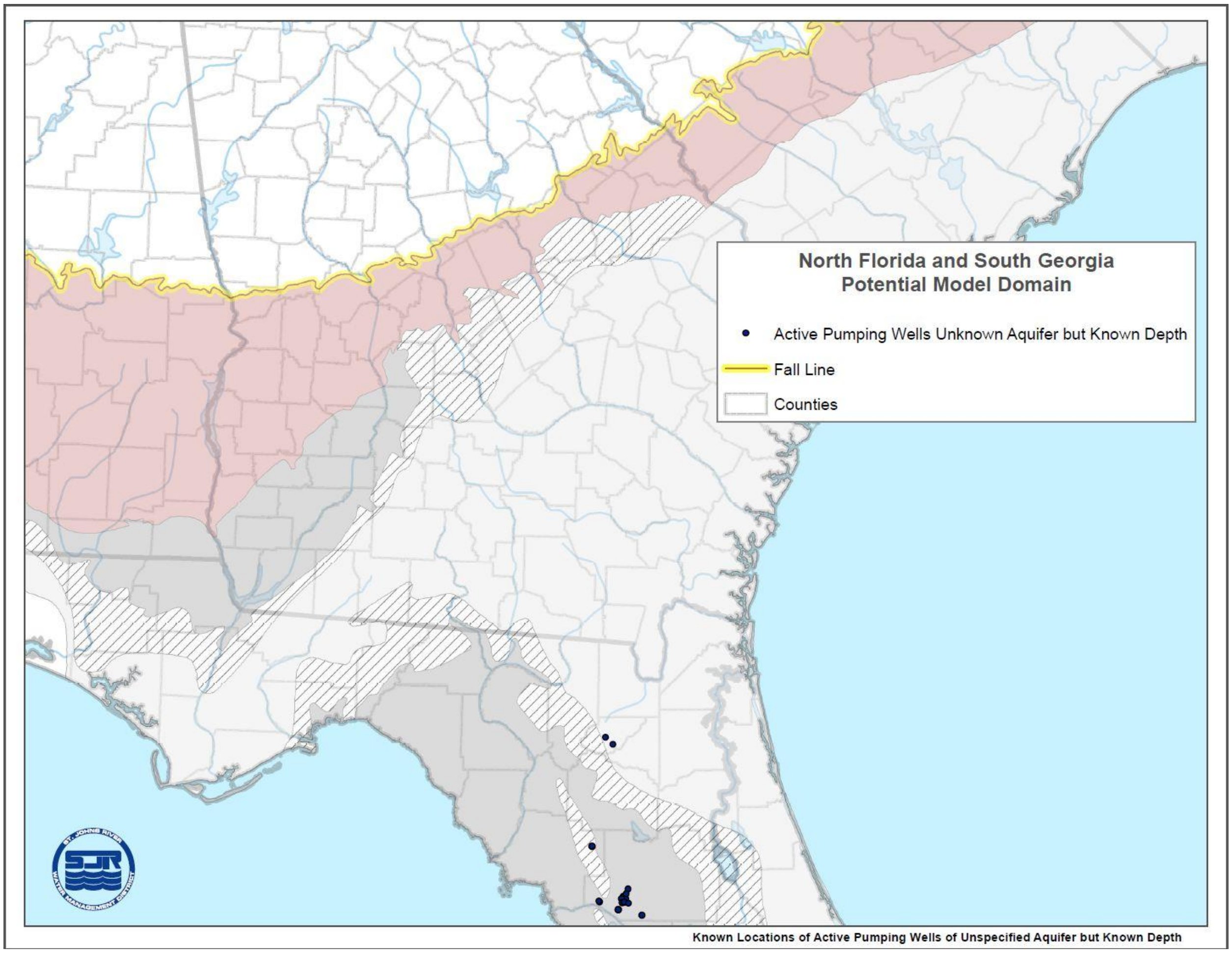


Figure 63. Known Locations of Active and Georgia Pumping Wells of Unspecified Aquifer but Known Depth

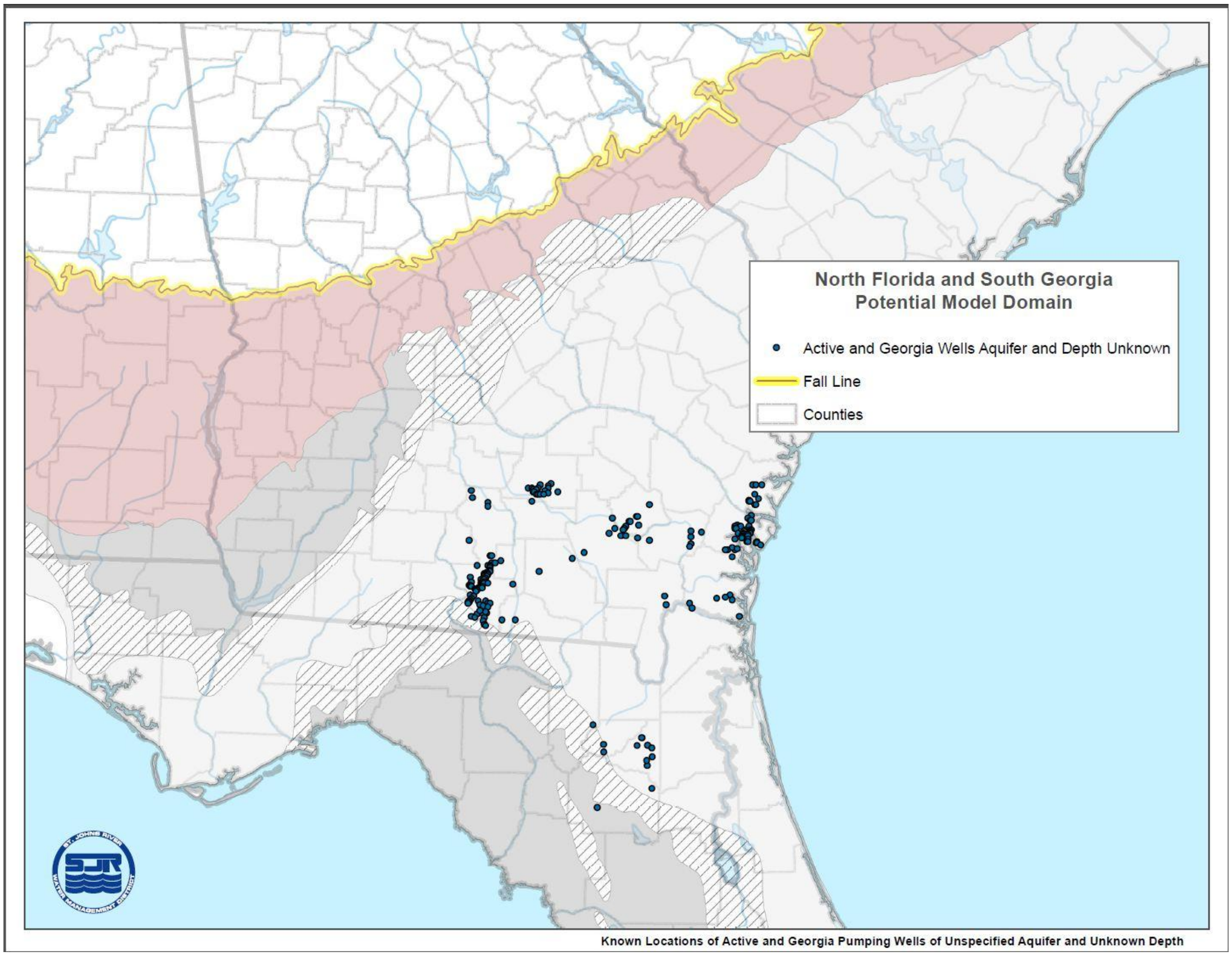


Figure 64. Known Locations of Active and Georgia Pumping Wells of Unspecified Aquifer and Unknown Depth

Water-Level Monitoring-Well Locations

The water levels observed in groundwater monitoring wells are necessary for model calibration, as simulated water levels are compared directly to observed water levels to help ascertain the ability of the model to simulate the flow system. Transient simulations require observations over periods of time. Hence, monitoring wells with longer periods of record are generally more valuable to model development.

SAS Monitoring-Well Locations

A number of SAS monitoring wells are present within the area of interest (Figure 65). These points will be used to map the water table within the area of interest, most likely at multiple points in time.

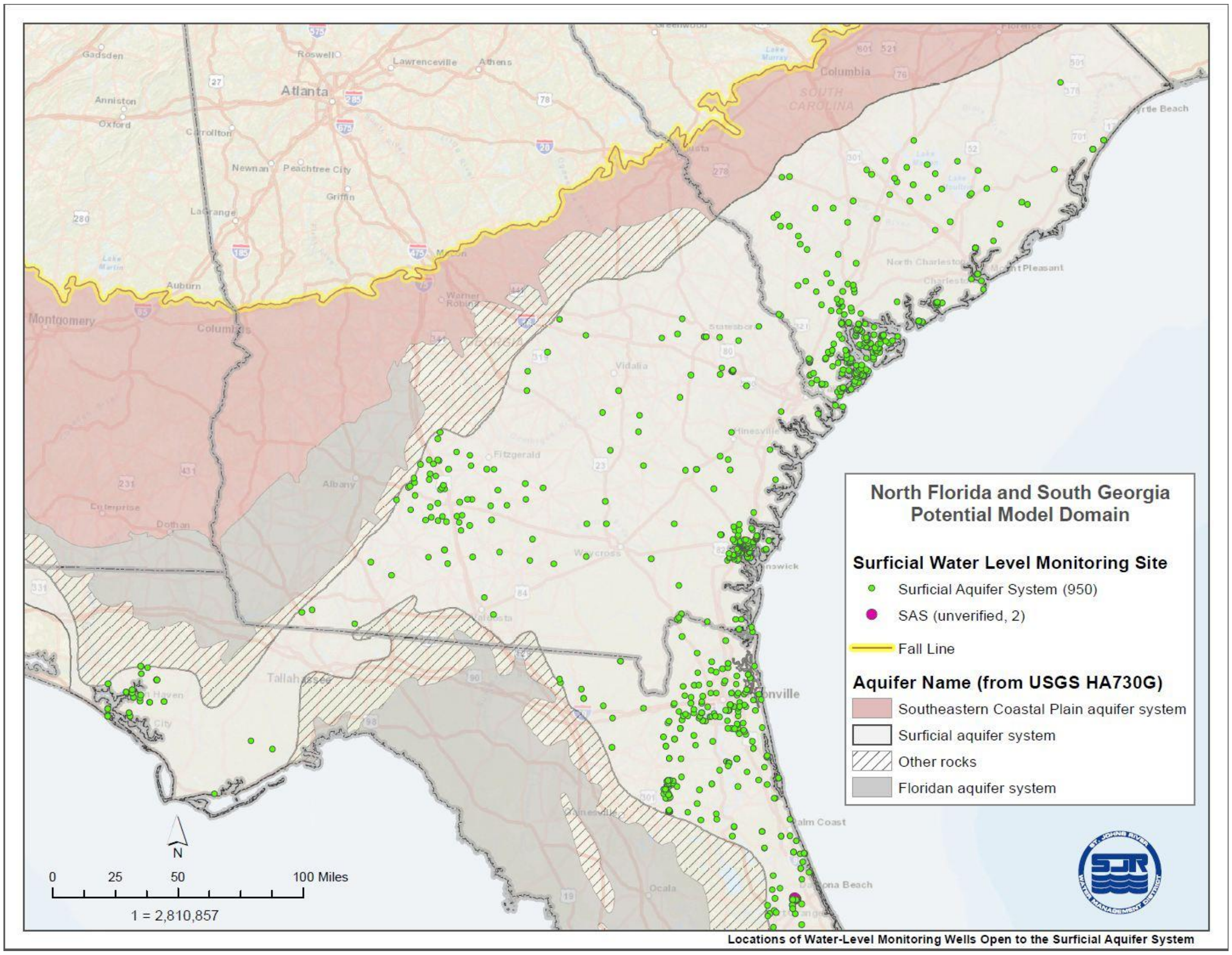


Figure 65. Locations of Water-Level Monitoring Wells Open to the Surficial Aquifer System

Intermediate Aquifer System Water-Level Monitoring-Well Locations

A fair number of water-level monitoring wells are open to the Intermediate Aquifer System (Figure 66).

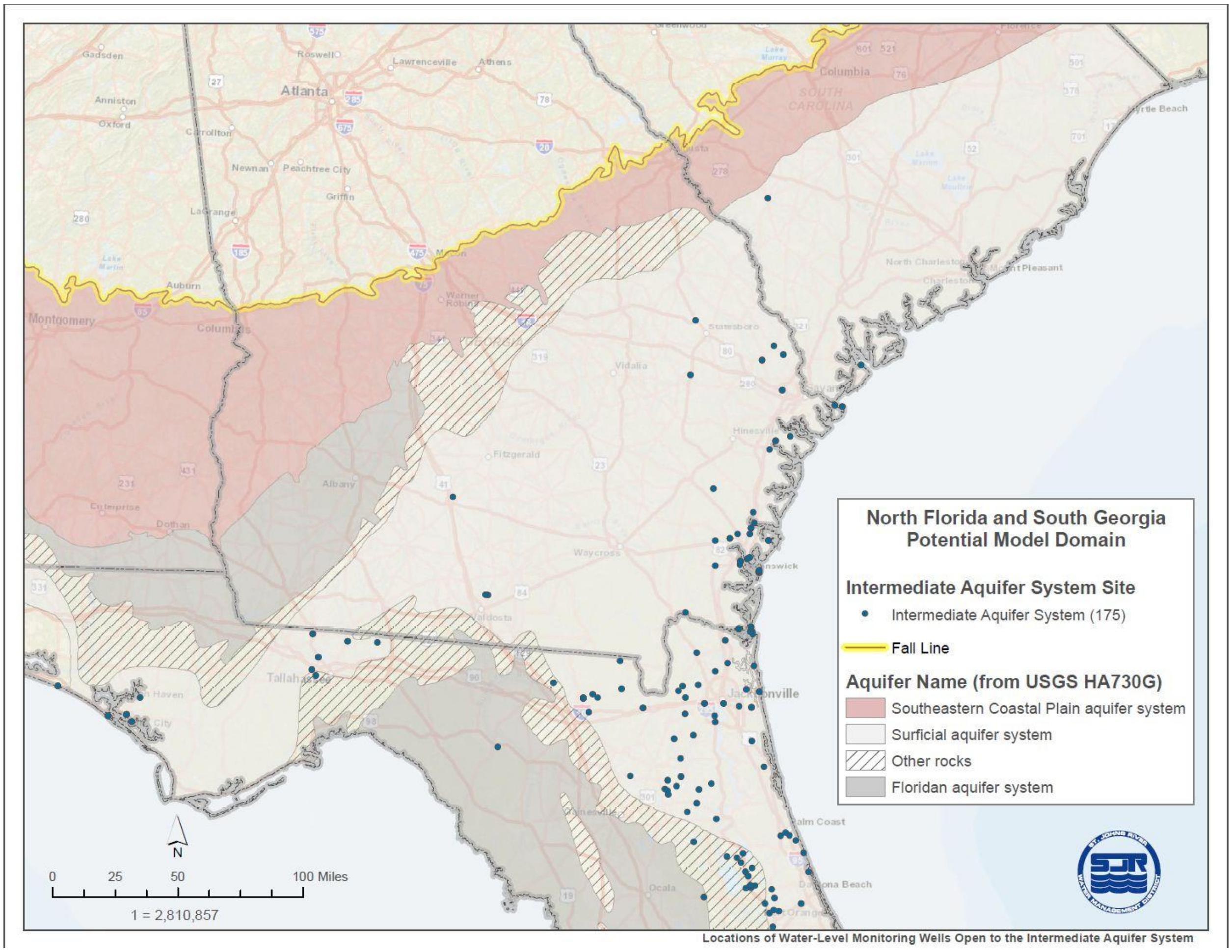


Figure 66. Locations of Water-Level Monitoring Wells Open to the Intermediate Aquifer System

Upper Floridan Aquifer Water-Level Monitoring-Well Locations

A relatively large number of water-level monitoring wells are open exclusively to the Upper Floridan aquifer within the area of interest (Figure 67).

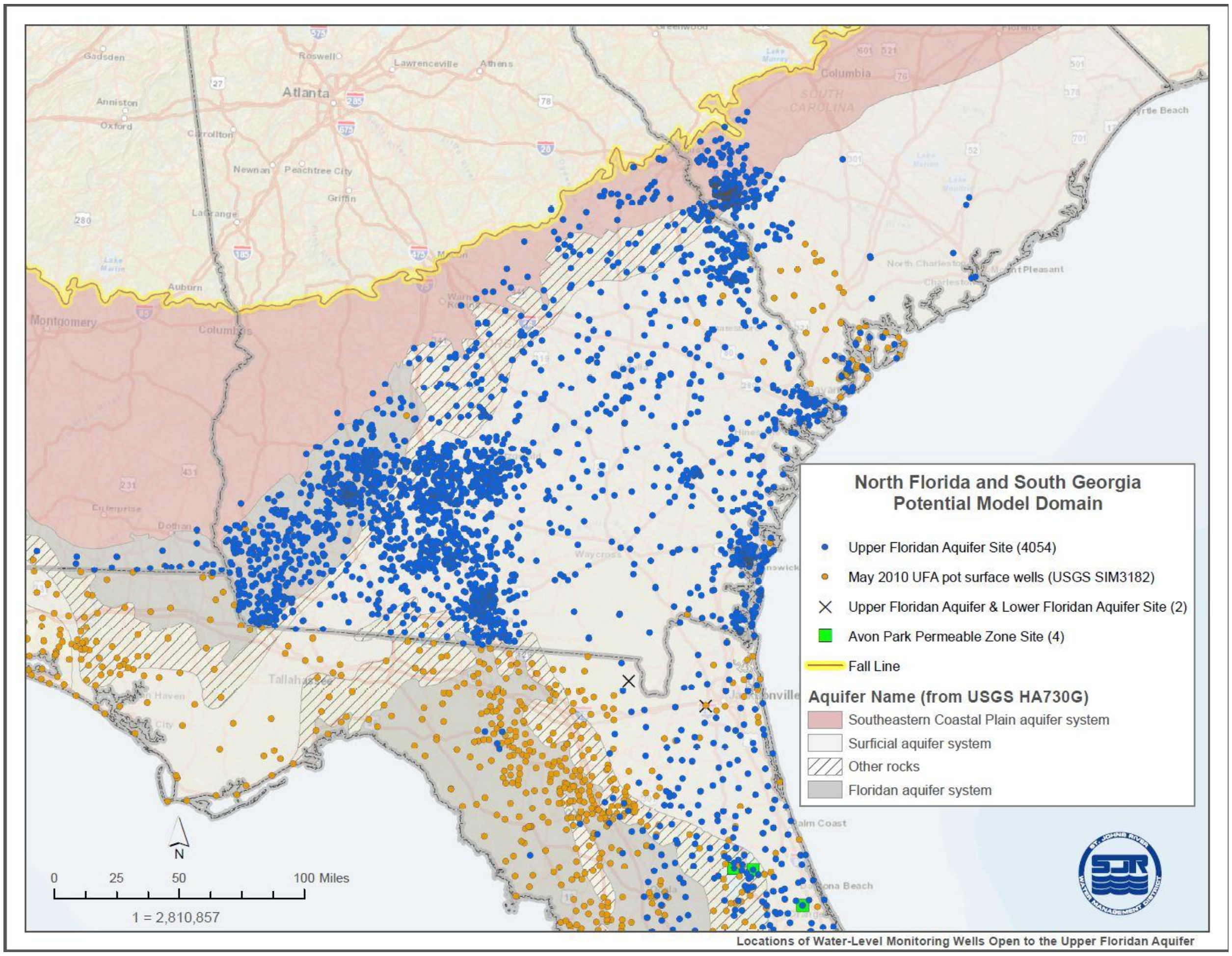


Figure 67. Locations of Water-Level Monitoring Wells Open to the Upper Floridan Aquifer

Lower Floridan Aquifer Water-Level Monitoring-Well Locations

A smaller number of water-level monitoring wells are open to the upper zone of the Lower Floridan aquifer due to the added expense of constructing such wells. These wells are quite valuable as they provide data for use in gaging the ability the model to simulate water levels in the Lower Floridan aquifer (Figure 68).

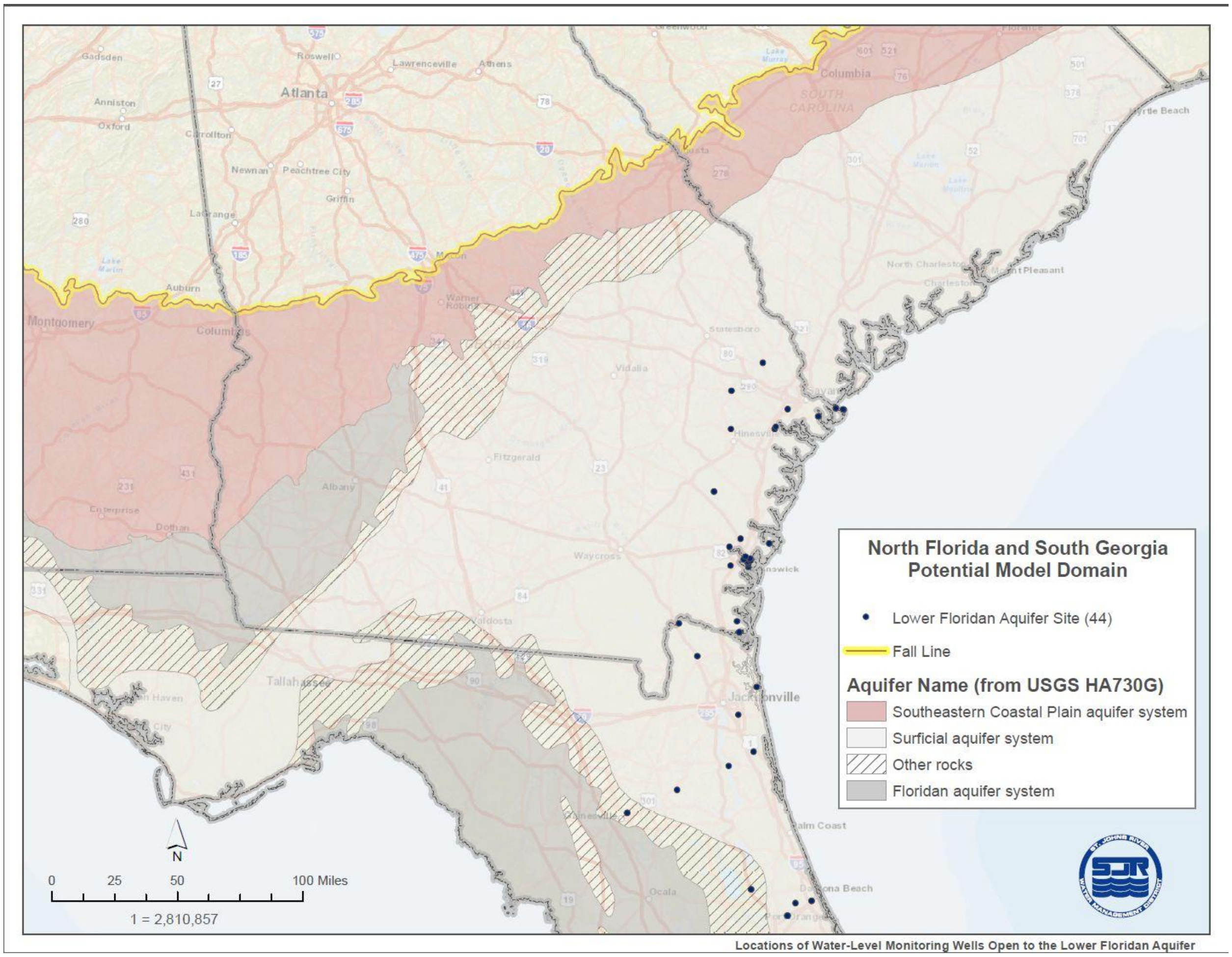


Figure 68. Locations of Water-Level Monitoring Wells Open to the Lower Floridan Aquifer

Fernandina Permeable Zone Water-Level Monitoring-Well Locations

Water-level monitoring wells open exclusively to the Fernandina Permeable zone are few in number (Figure 69).

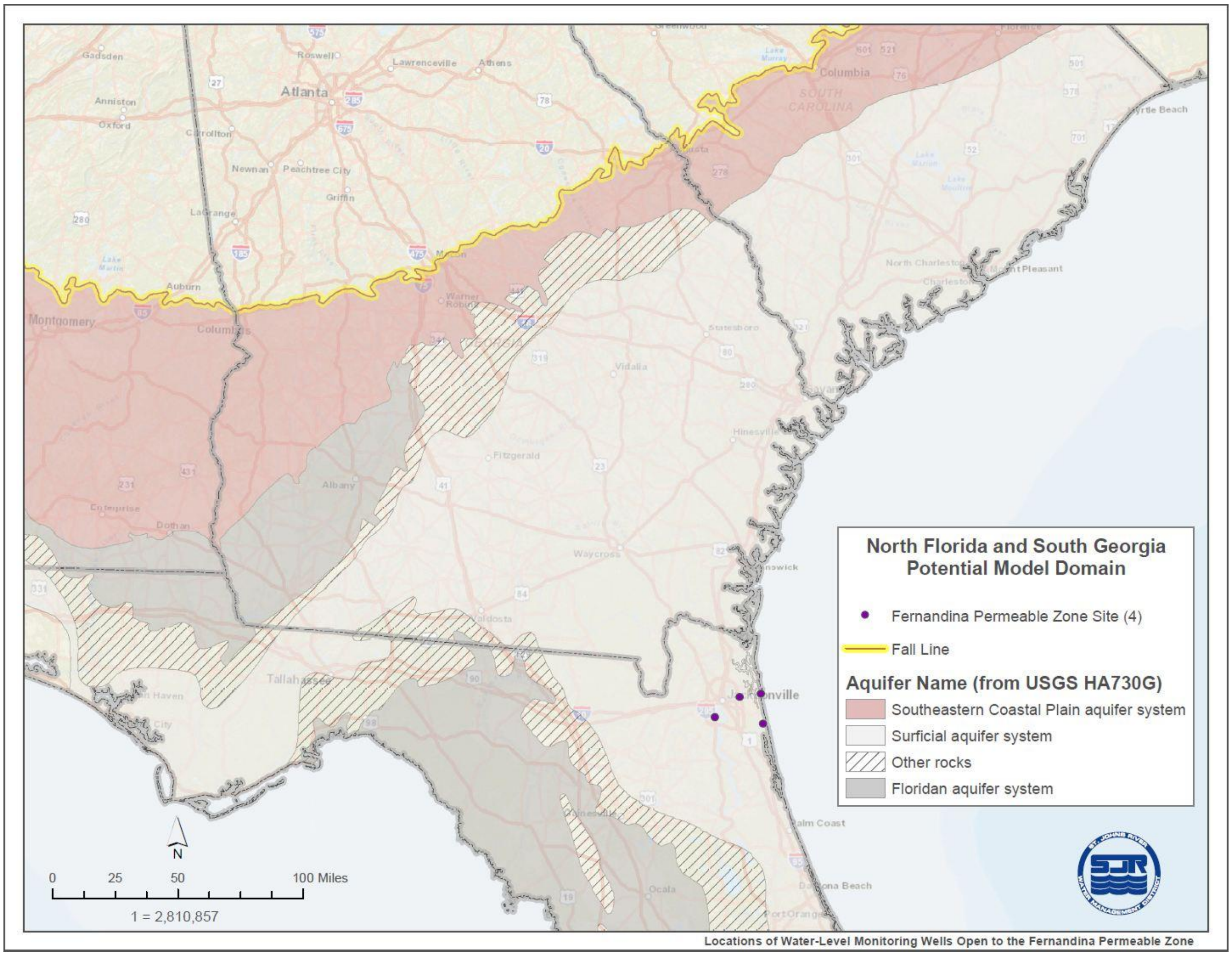


Figure 69. Locations of Water-Level Monitoring Wells Open to the Fernandina Permeable Zone

Floridan Aquifer System Water-Level Monitoring-Well Locations

In many cases, water-level monitoring wells are not specified by a particular component aquifer but rather as being open simply to the FAS. Additional investigation will be required to determine which of the component aquifers that comprise the FAS a given well is open (Figure 70).

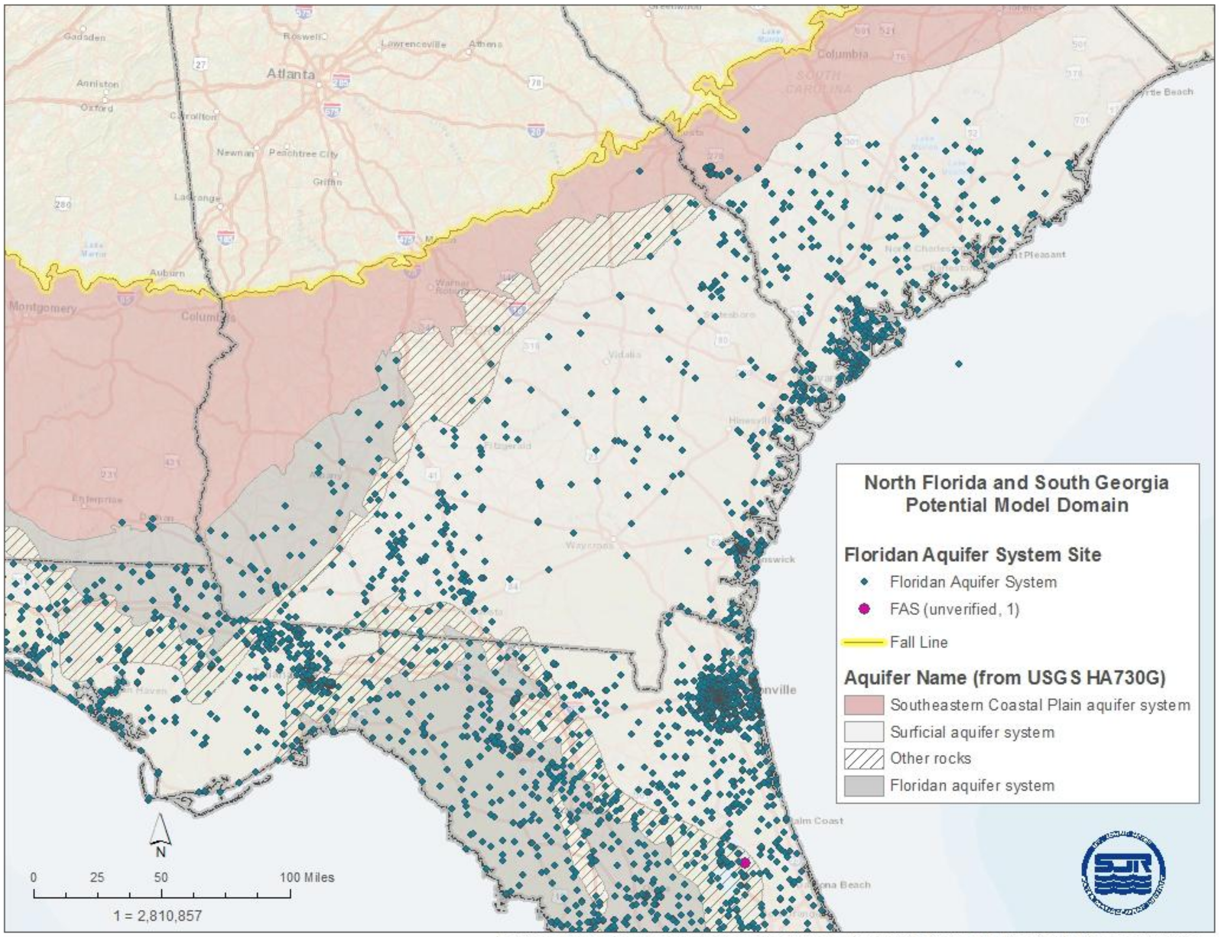


Figure 70. Locations of Water-Level Monitoring Wells Open to the Floridan Aquifer System, Not Specified by Component Aquifer

Pearl River Aquifer Water-Level Monitoring-Well Locations

Pearl River aquifer water-level monitoring-well locations are shown (Figure 71).

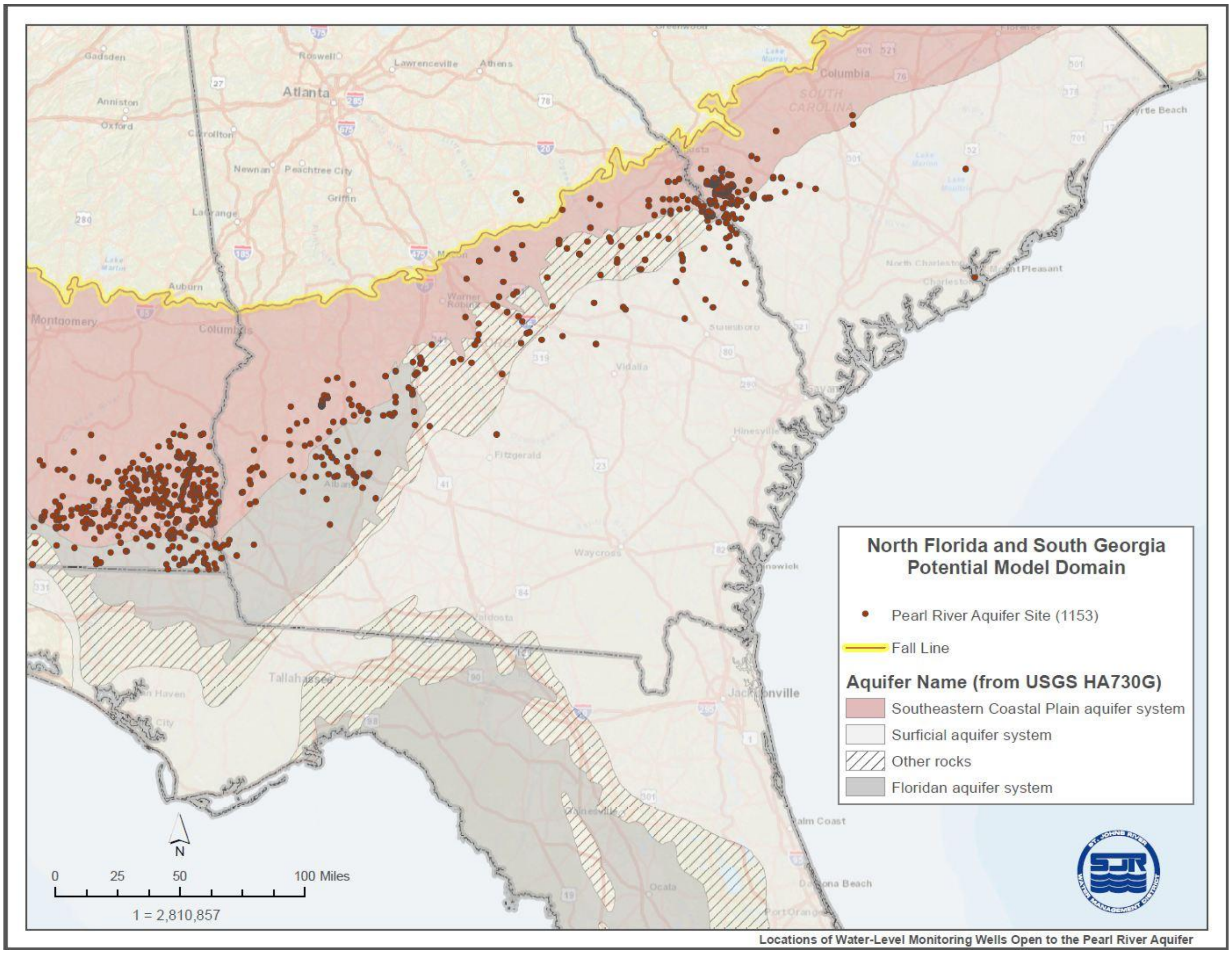


Figure 71. Locations of Water-Level Monitoring Wells Open to the Pearl River Aquifer

Chattahoochee River Aquifer Water-Level Monitoring-Well Locations

Chattahoochee River aquifer water-level monitoring-well locations are shown (Figure 72).

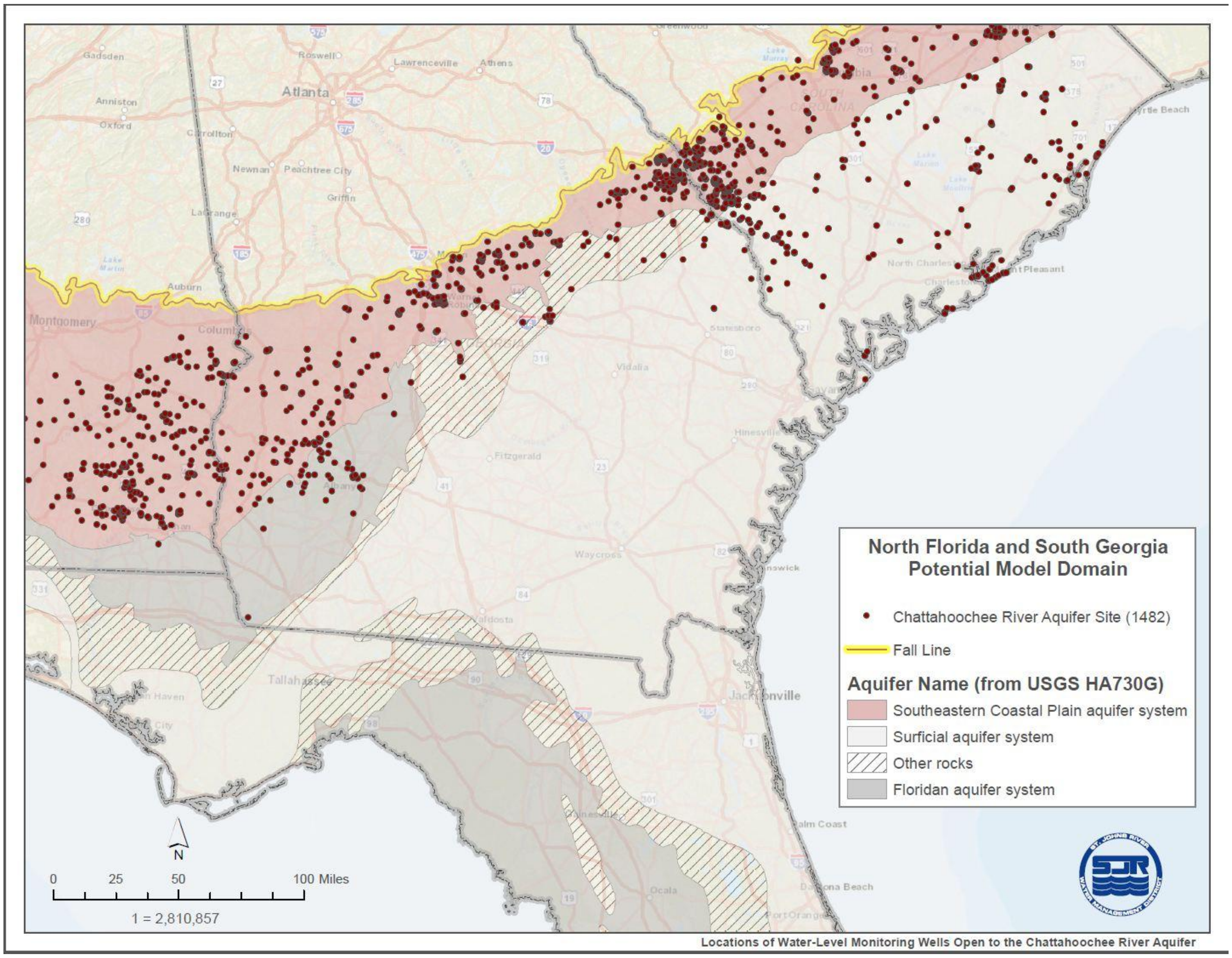


Figure 72. Locations of Water-Level Monitoring Wells Open to the Chattahoochee River Aquifer

Black Warrior River Aquifer Water-Level Monitoring-Well Locations

Black Warrior River aquifer water-level monitoring-well locations are shown (Figure 73).

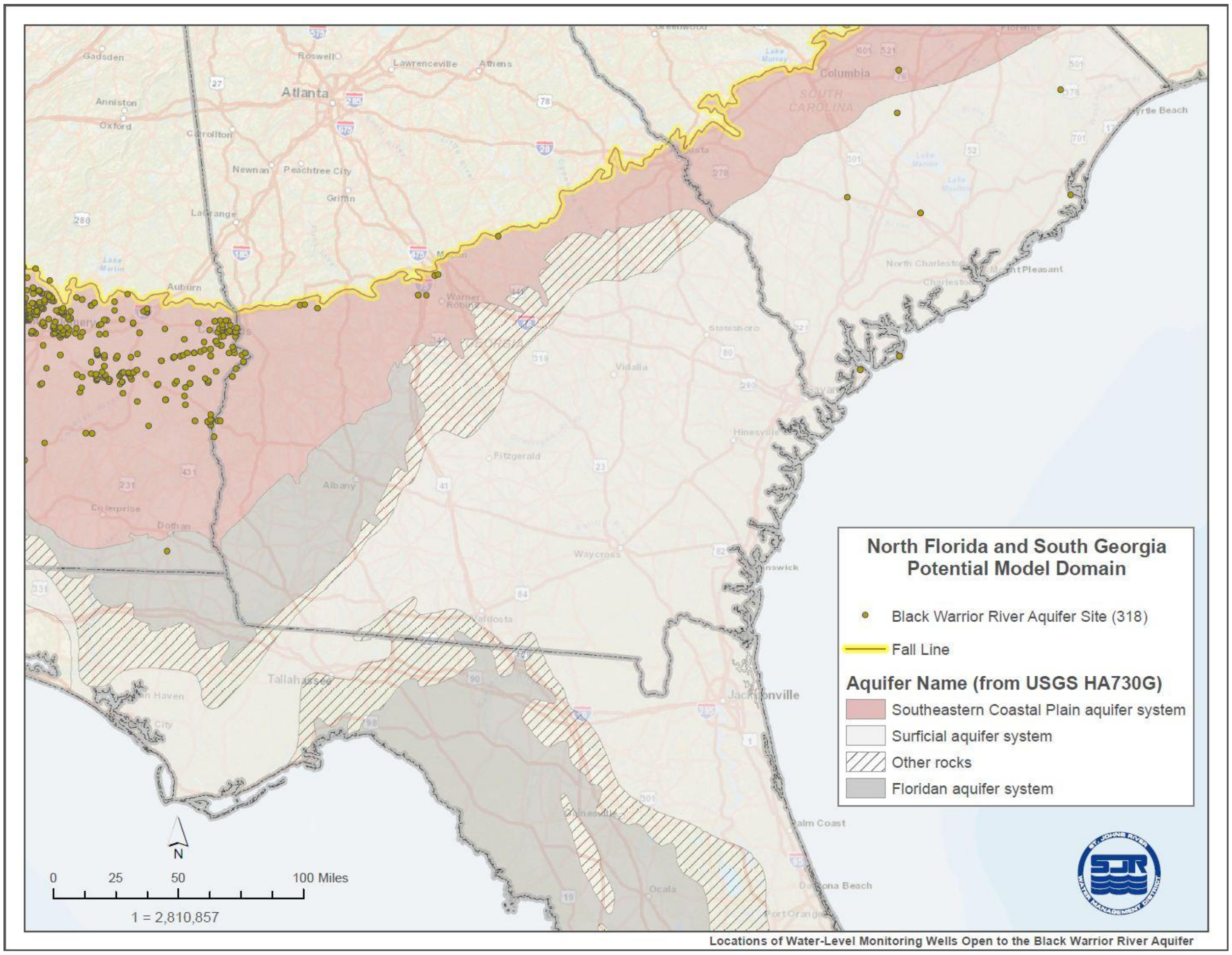


Figure 73. Locations of Water-Level Monitoring Wells Open to the Black Warrior River Aquifer

Coastal Plain Aquifer System Water-Level Monitoring-Well Locations

Wells open to the Coastal Plain Aquifer System but not specified by component aquifer are shown (Figure 74).

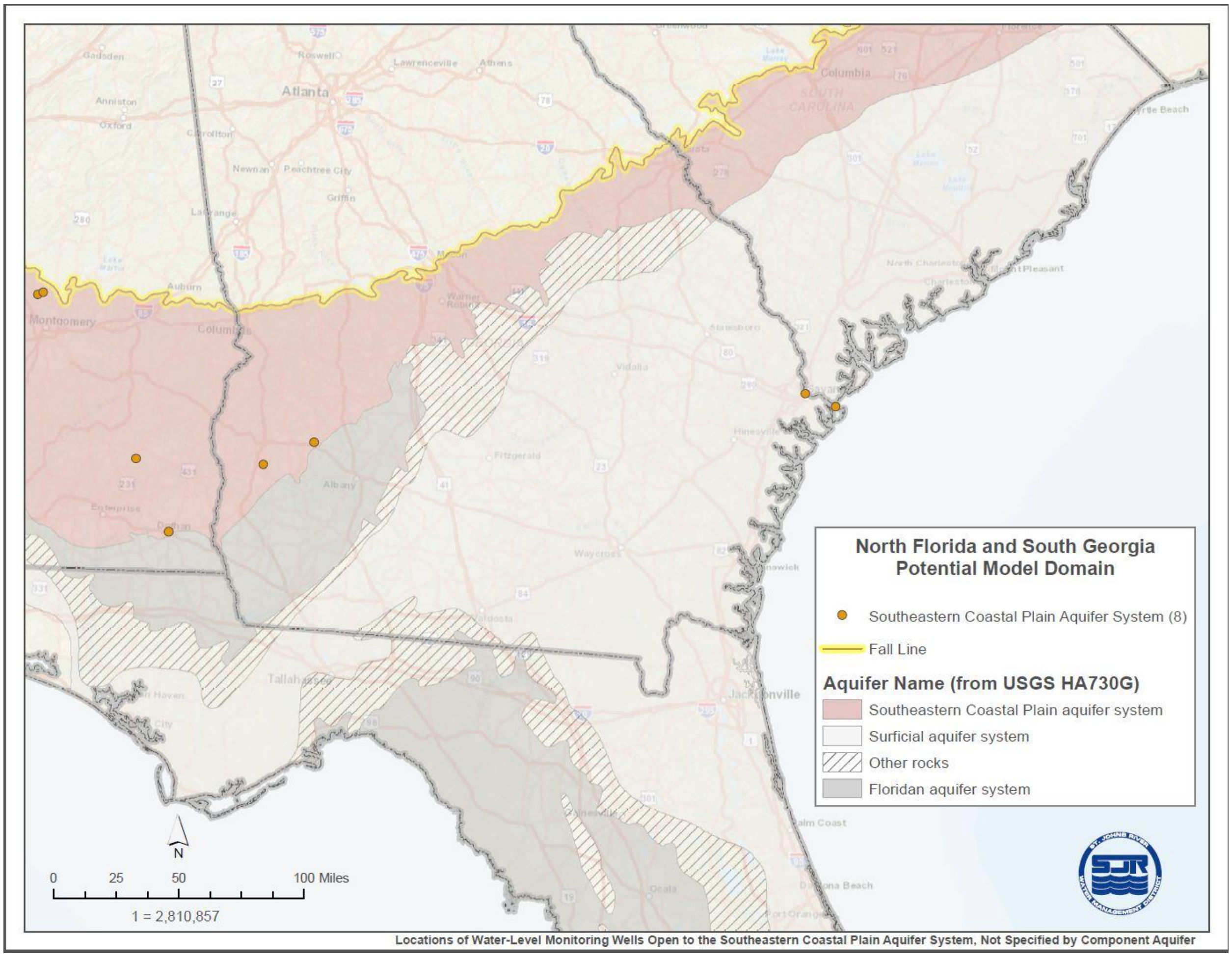


Figure 74. Locations of Water-Level Monitoring Wells Open to the Southeastern Coast Plain Aquifer System, Not Specified by Component Aquifer

Multi-Aquifer Water-Level Monitoring-Well Locations

In some cases, water-level monitoring wells are open to more than one aquifer (Figure 75, Figure 76).

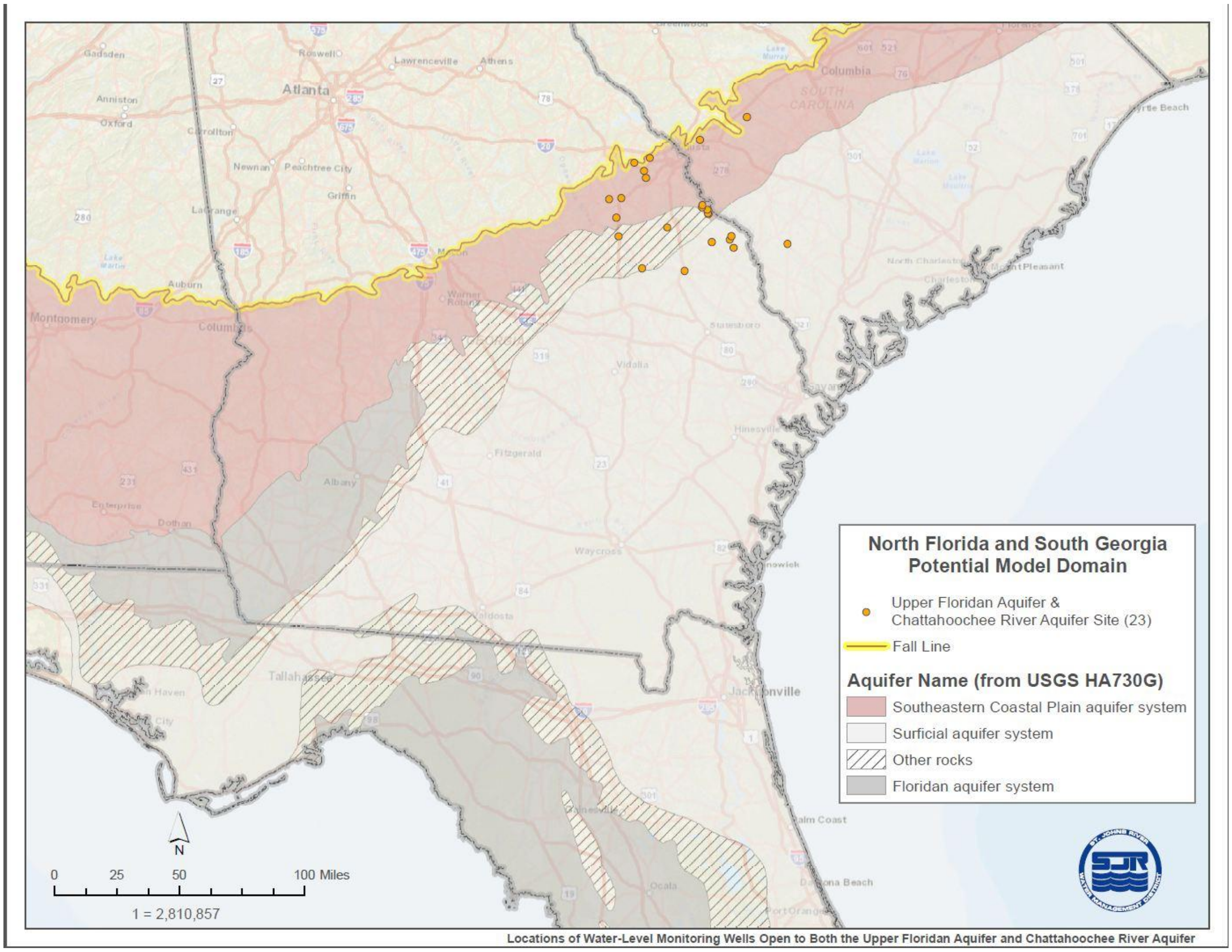


Figure 75. Locations of Water-Level Monitoring Wells Open to Both the Upper Floridan Aquifer and Chattahoochee River Aquifer

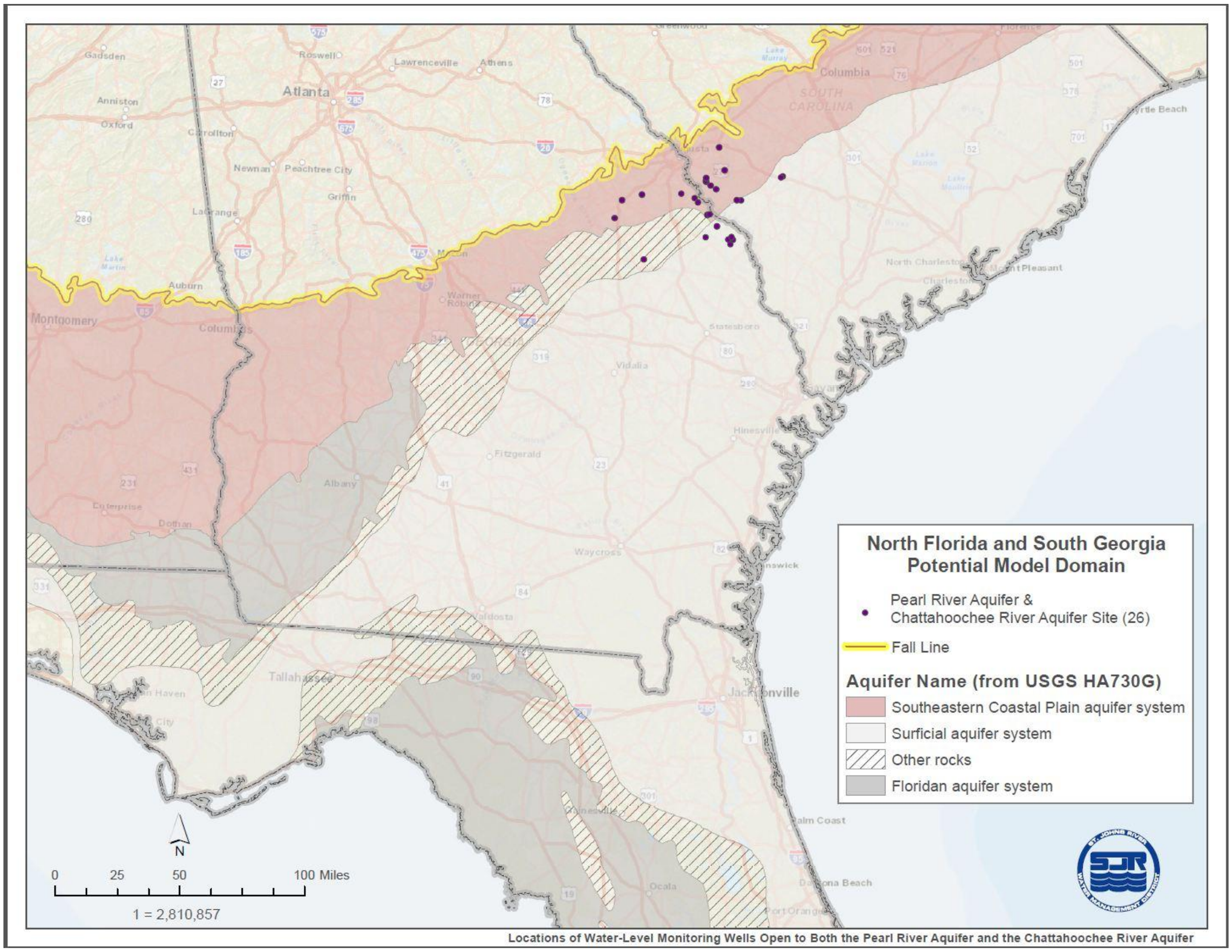


Figure 76. Locations of Water-Level Monitoring Wells Open to Both the Pearl River Aquifer and the Chattahoochee River Aquifer

Aquifer Water-Level Monitoring-Well Locations, Aquifer Not Specified

In some cases, the particular aquifer or aquifers to which a given well is open is not noted in the monitoring-well data base explicitly (Figure 77). In cases in which the casing depth and open-hole interval of such wells are known, however, the monitored aquifer can and will be determined in the present study. In some cases, the wells may be open to more than one aquifer. In such cases, the observed water levels will be assigned a lower level of influence in the calibration process but may, nevertheless, prove to be useful.

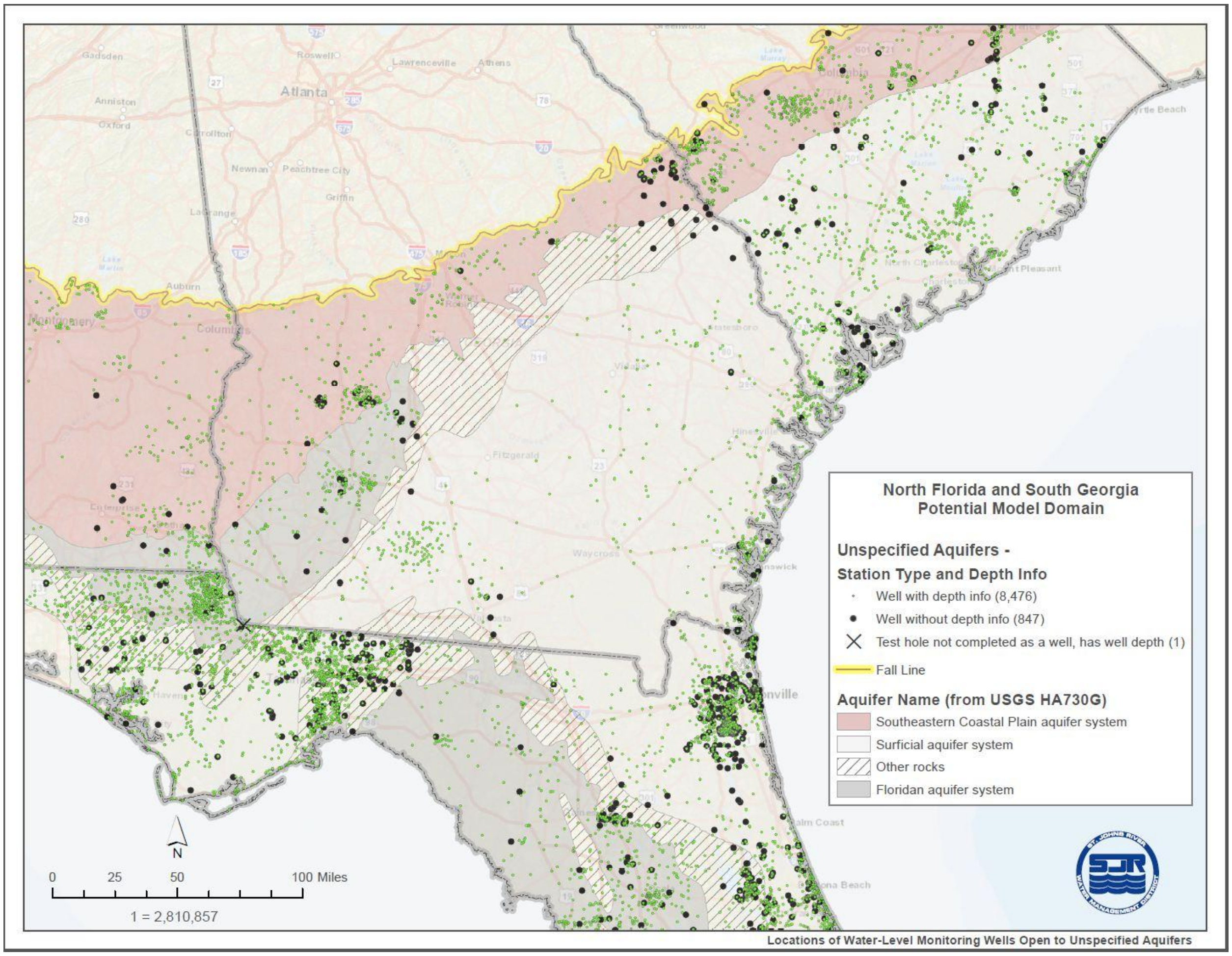


Figure 77. Locations of Water-Level Monitoring Wells Open to Unspecified Aquifers

Well Cluster Sites

Well clusters enable the comparison of water levels in different aquifers at the same location (Figure 78) because each of the wells that comprise a well cluster is dedicated to monitoring a specific aquifer exclusively at the same geographic location. Well clusters therefore enable an appraisal of the ability of the model to simulate vertical hydraulic gradients between aquifers at specific locations. Typically, well clusters include, at least, a dedicated SAS, IAS, and FAS monitoring well.

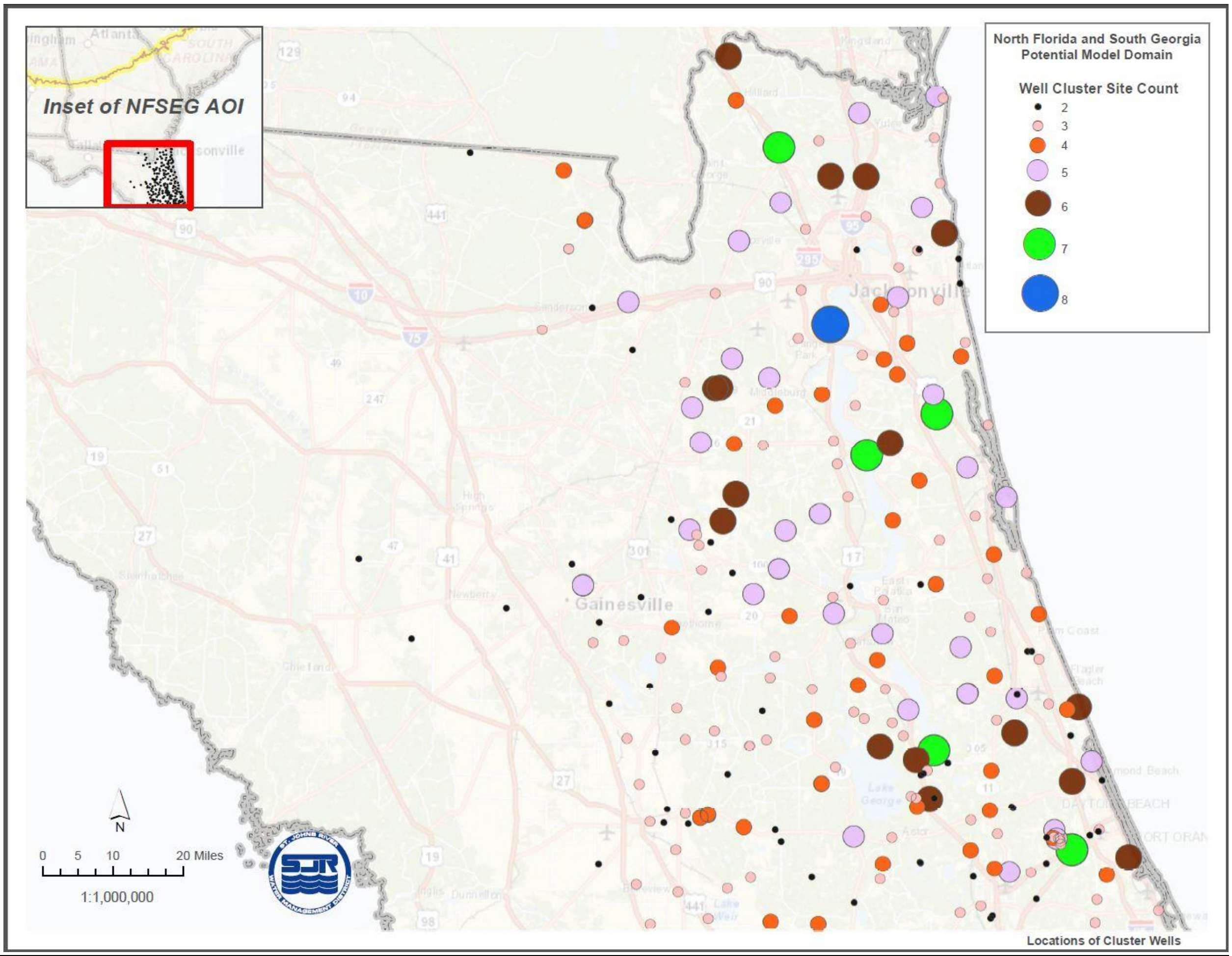


Figure 78. Locations of Well Clusters

Surface-Water Monitoring Sites

Surface-water monitoring sites are used to monitor lake, river, and spring-pool surface elevations. They are also used to monitor stream discharge as well (Figure 79; Figure 80; Figure 81; Figure 82). Stream-gage data can be used to estimate basin-runoff amounts, which, in turn, can be used in estimating recharge amounts, as well as base-flow amounts. Base-flow amounts are necessary for calibrating model aquifer layers that are in hydraulic connection to streams. Locations of stream centerlines and wetland areas will be based on the National Hydrography Dataset (i.e., NHD dataset; Figure 81), a highly detailed representation of stream centerlines and other surface-water bodies.

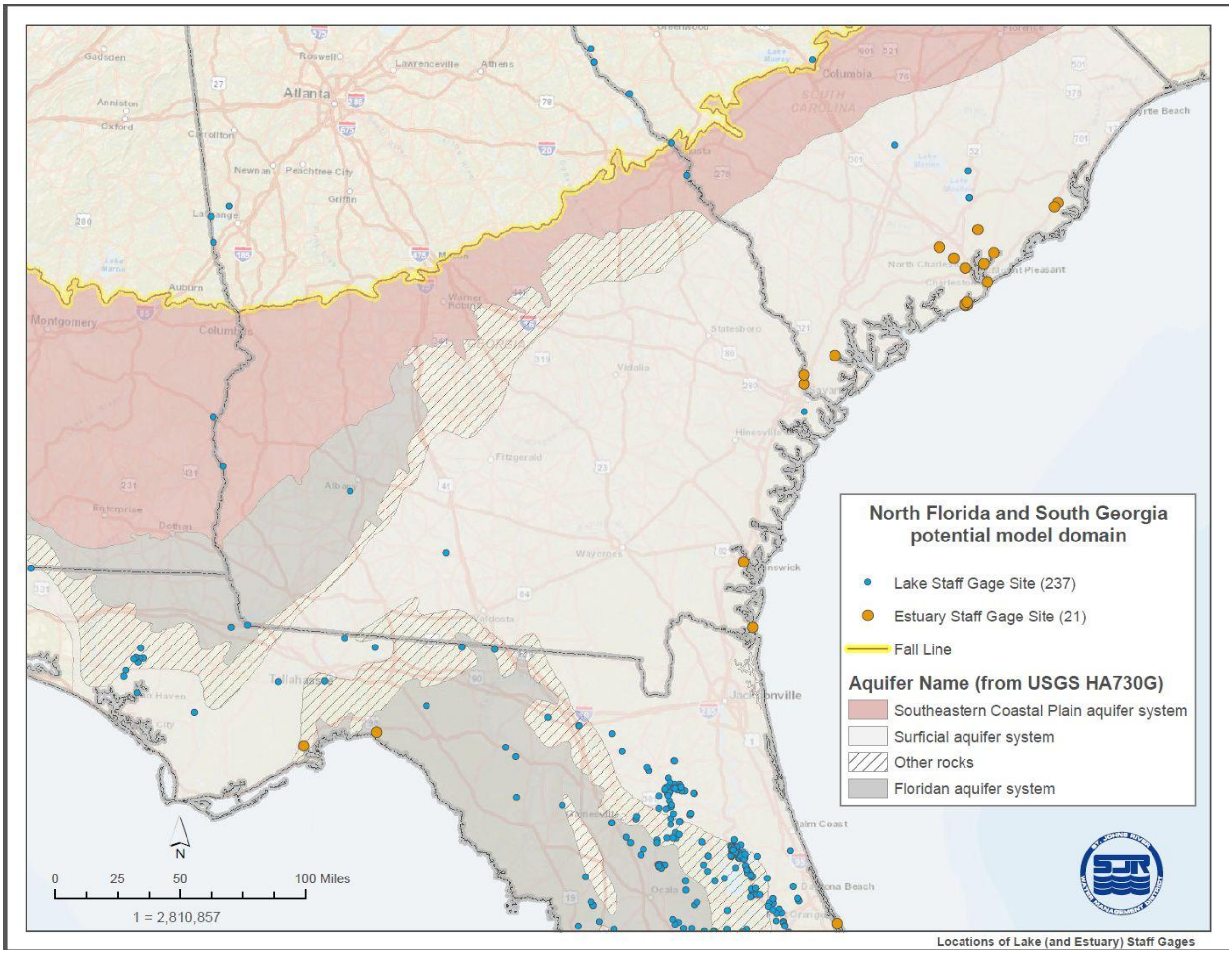


Figure 79. Locations of Lake (and Estuary) Staff Gages

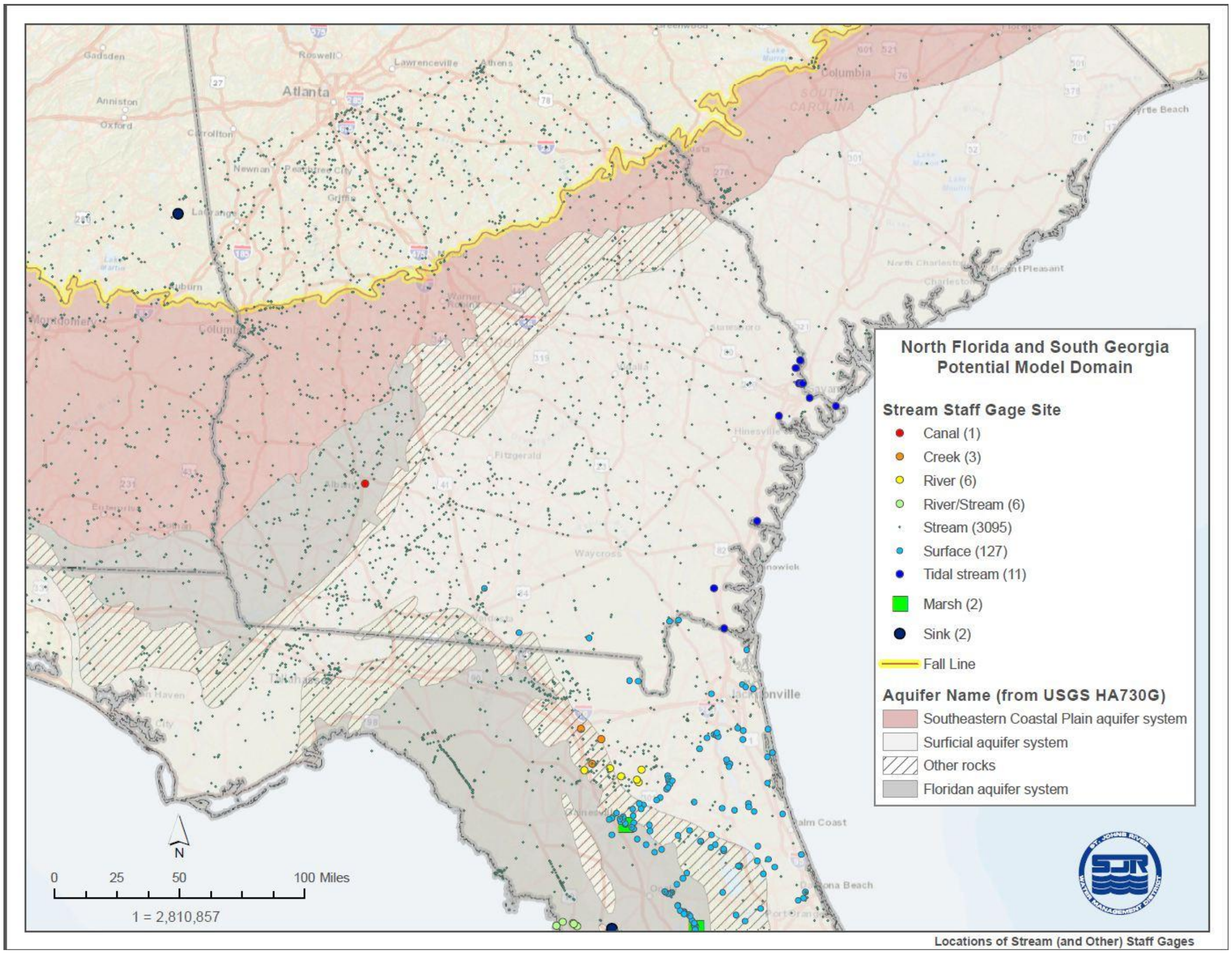


Figure 80. Locations of Stream (and Other) Staff Gages

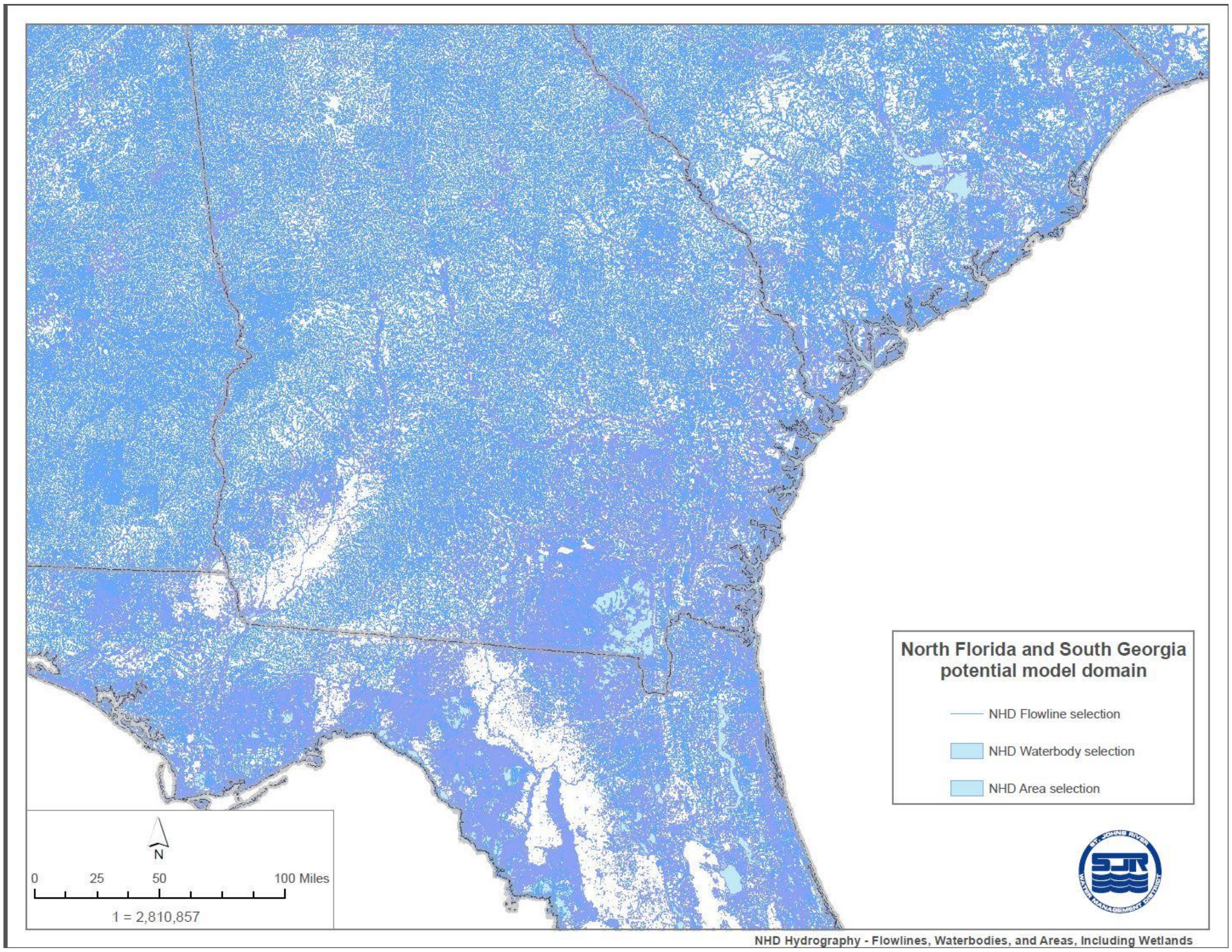


Figure 81. NHD Flowlines, Waterbodies, and Areas, Including Wetlands

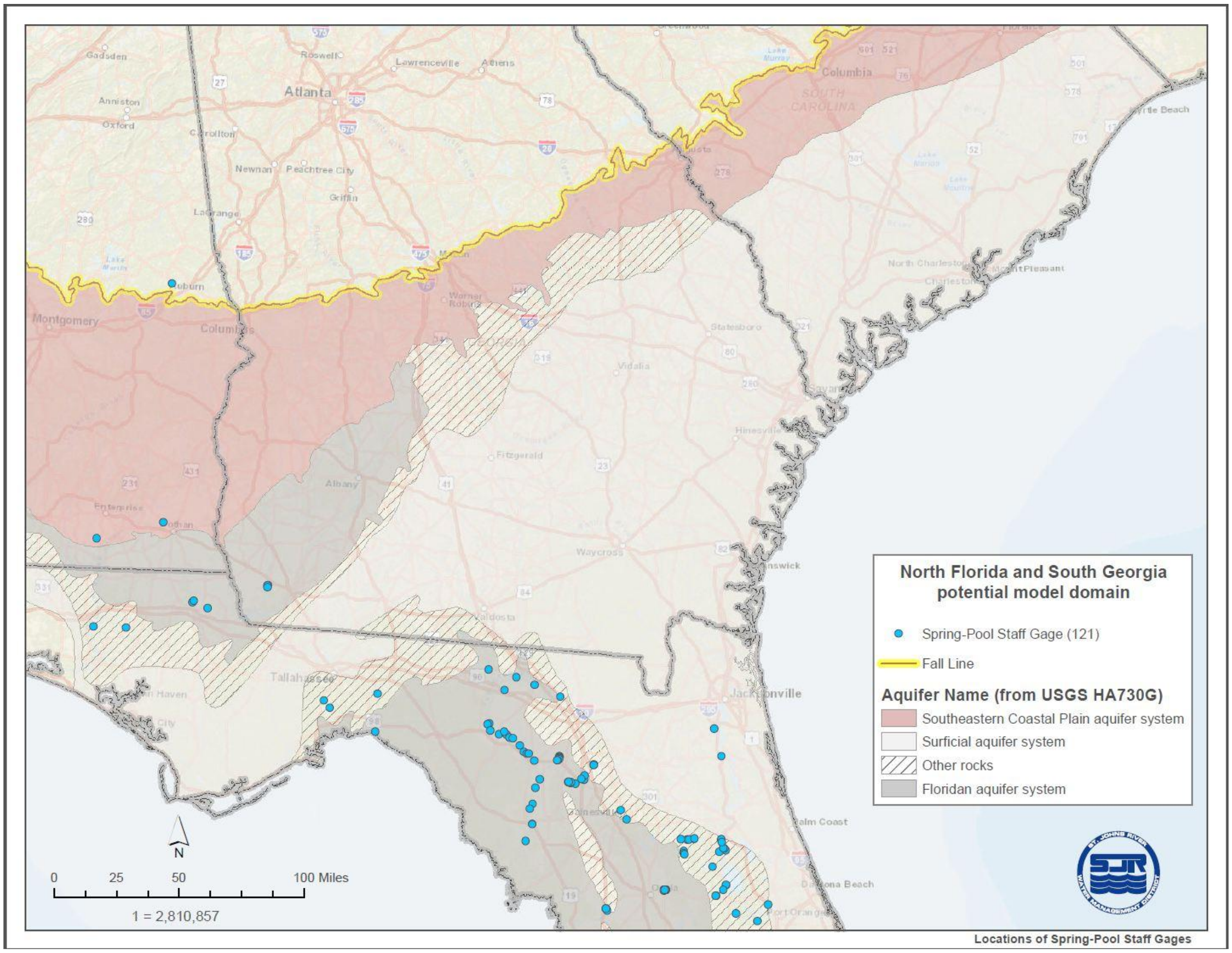


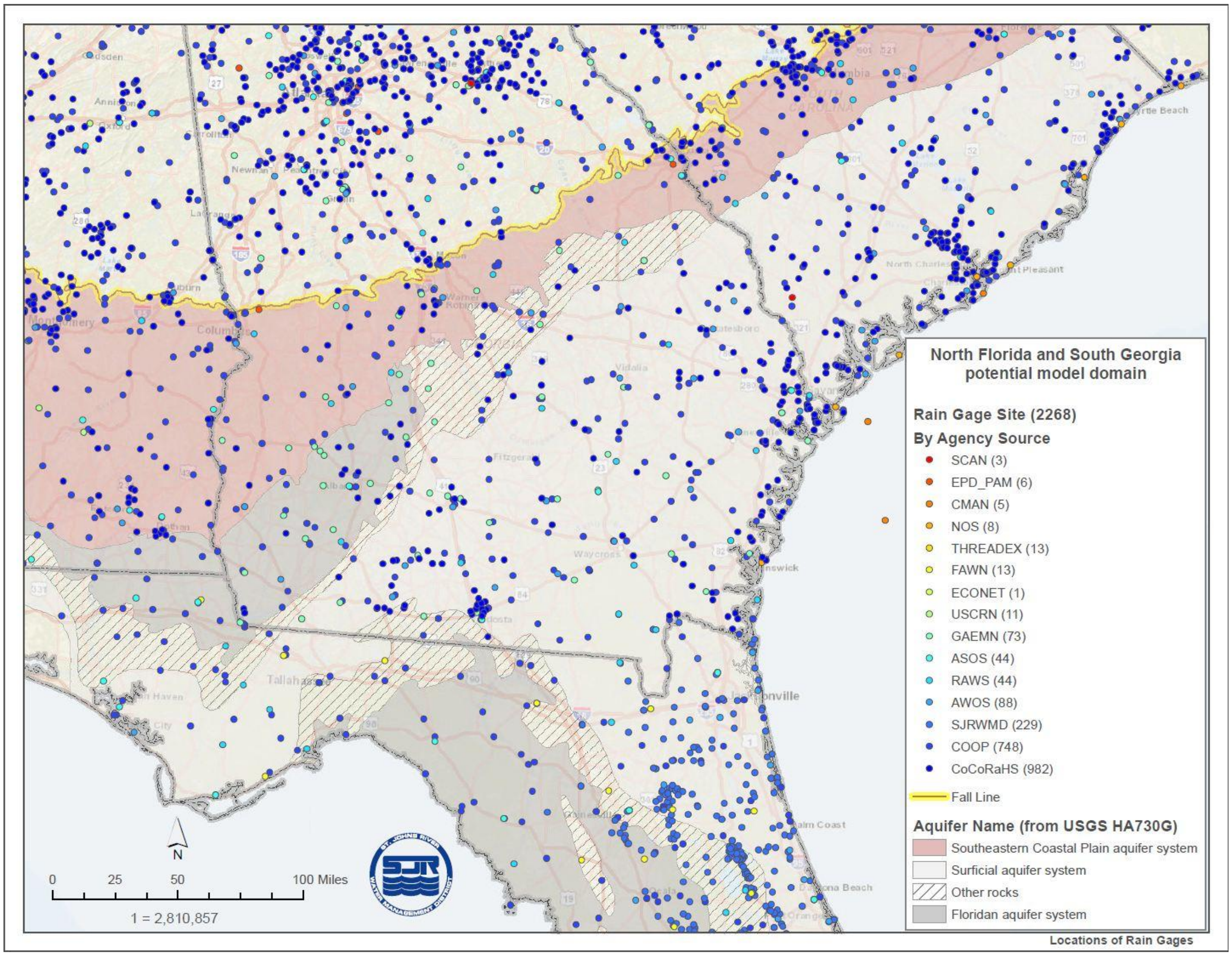
Figure 82. Locations of Spring-Pool Staff Gages

Recharge-Related Data Types

As stated previously, recharge estimates are derived based on a number of other data types, including rainfall amounts, evapotranspiration estimates, soils data, land-use data, and stream-discharge data.

Rainfall Amounts

One method of estimating rainfall amounts throughout a model domain is to simply extrapolate the amounts measured at gage sites. Numerous rainfall gages are distributed throughout the area of interest, many with long periods of record (Figure 83). The technique employed for distributing rainfall amounts between rainfall gages are sometimes subject to question for various reasons, as is the degree of error in the measurements themselves.



Station System	Station, Full Atmospheric System Name	Supporting Agency
ASOS	Automated Surface Observing System	NWS
AWOS	Automated Weather Observing System	
COOP	Cooperative network	NWS
CoCoRaHS	Community Cooperative Rain, Hail, and Snow	
CMAN	Coastal marine Automated Network	
ECONET	North Carolina Environment and Climate Observing Network	
NOS	National Ocean Surface	
RAWS	Remote Automatic Weather Stations	
SCAN	Soil Climate Analysis Network	NRCS
THREADEX	Threaded Station Extremes	NOAA

USCRN	United States Climate Reference Network	NOAA
GAEMN	Georgia Automated Environmental Monitoring Network	
FAWN	Florida Automated Weather Network	
SJRWMD	St Johns River Water Management District	

Figure 83. Locations of Rain Gages

An alternative approach is radar rainfall, in which radar is used to sense the rainfall and map its distribution in real time as it falls. The distribution of rainfall in this approach is thought to be much more accurate, but the absolute amounts are sometimes questioned. To address this problem, rainfall gages are utilized to ground check the estimates obtained from the radar signals at the locations of the various gages. Radar rainfall mapping is available for all years since 1995 within the Florida portion of the area of interest. These values are stored by pixel (Figure 84). When accumulated by pixel for an entire year, the distribution of total rainfall for the year in question can be represented.

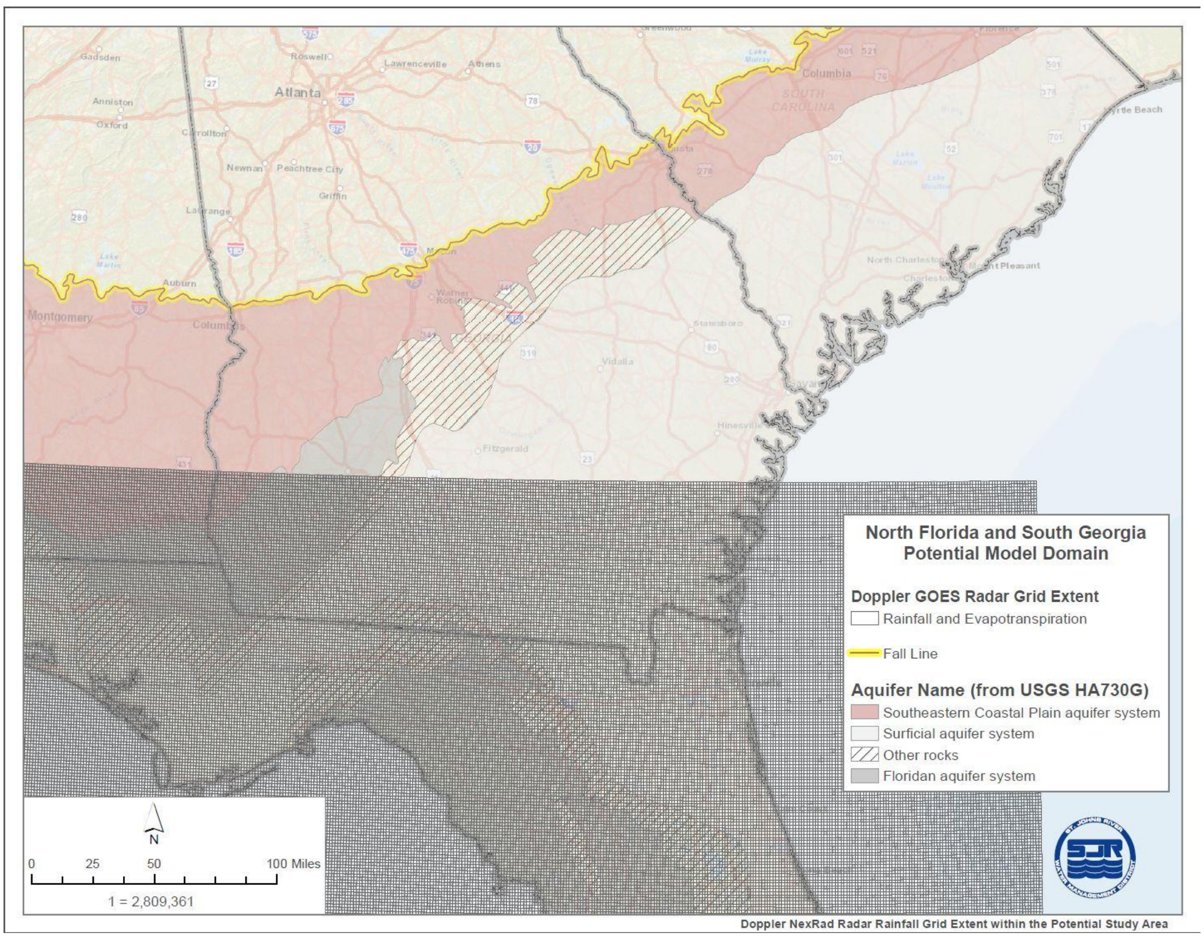


Figure 84. Doppler NexRad Radar Rainfall Grid Extent within the Potential Study Area

Evapotranspiration

In Georgia, evapotranspiration is calculated using the Priestly-Taylor method (Flitcroft personal communication 2012). Data supporting this method are collected at sites more or less evenly distributed throughout the state (Figure 85).

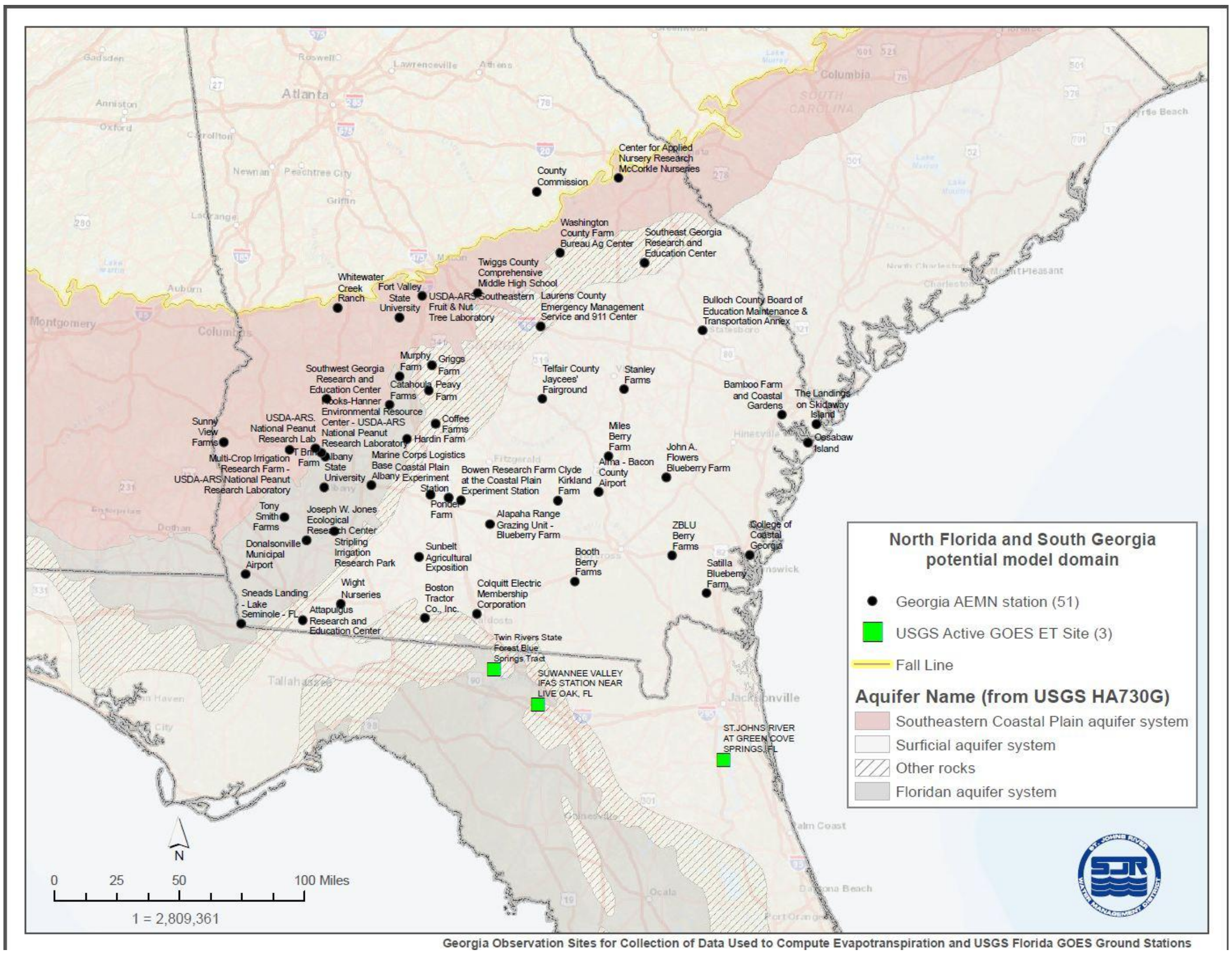


Figure 85. Observation Sites for Collection of Data Used to Compute Potential Evapotranspiration.

In Florida, the USGS GOES program is used to derive potential and reference evapotranspiration estimates. This is a satellite-based method that relies on various measurement stations for ground-truthing (Figure 85). Daily evapotranspiration data are available as a result of the GOES program for all years since 1995 and stored by pixel. The pixilated grid utilized for this purpose is the same as for the NexRad Radar Rainfall estimates (Figure 84). The daily amounts can be accumulated for any length of time greater than a day, including an entire year. An example is the distribution of total reference evapotranspiration for the year 1996 (Figure 86).

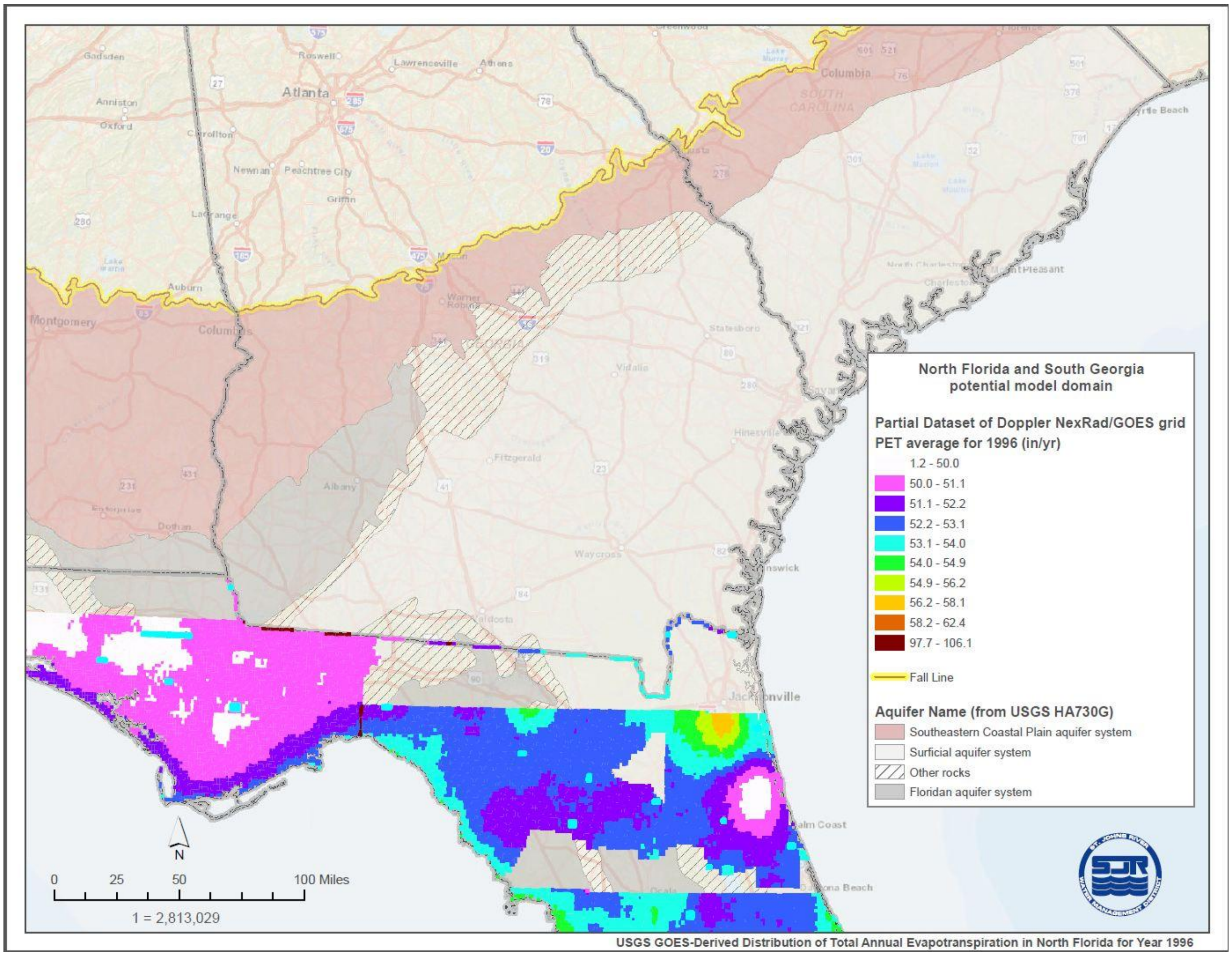


Figure 86. USGS GOES-Derived Distribution of Total Annual Reference Evapotranspiration in North Florida for Year 1996

Land-Use and Soils Data

Land-use and soils data are used as the basis of runoff computations, which, in turn, are used in recharge calculations. Detailed land-use and soils data are available for the area of interest. For the potential area of interest as whole, a less detailed dataset is available (Figure 87). In Florida, a highly detailed depiction of land use is available (Figure 88). The soils data are products of the Natural Resource Conservations Service of the Federal Government (NRCS). County-wide soils data sets are referred to as SSURGO. SSURGO data sets are available for most counties within the area of interest. In cases in which SSURGO data sets are not available, portions of statewide STATSGO data sets may be used instead (Figure 89).

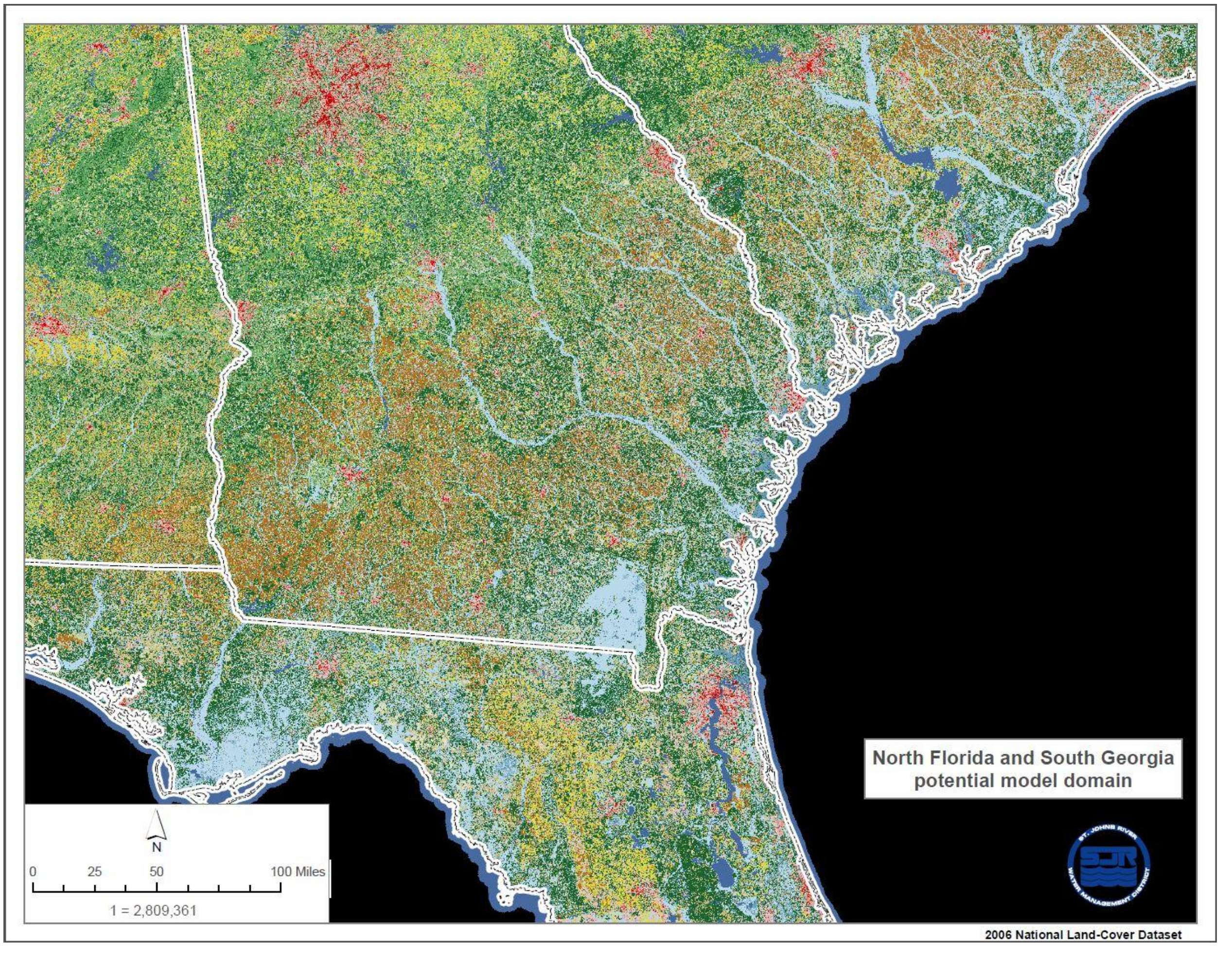


Figure 87. 2006 National Land-Cover Dataset

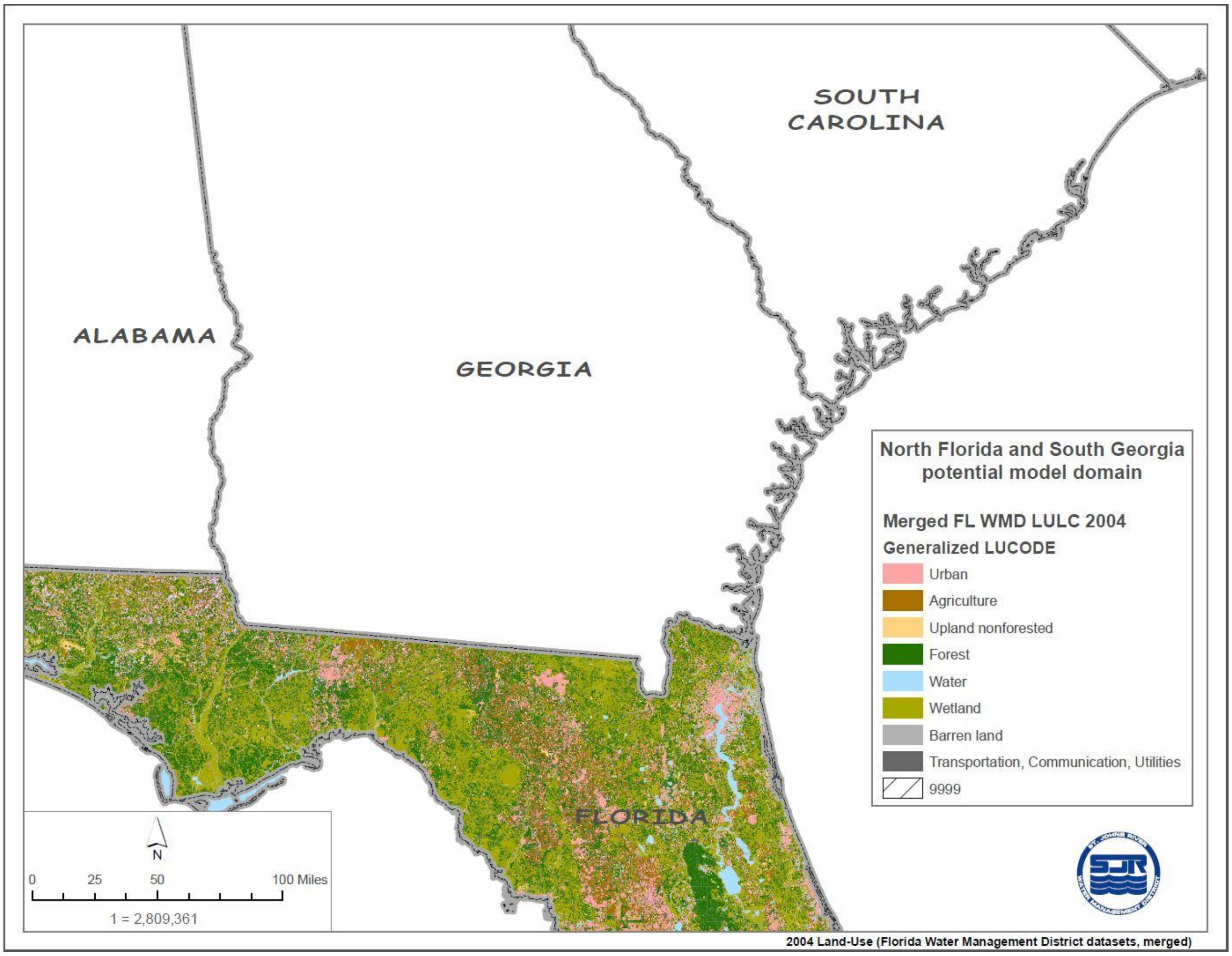


Figure 88. 2004 Land-Use (Florida Water Management District Datasets, Merged)

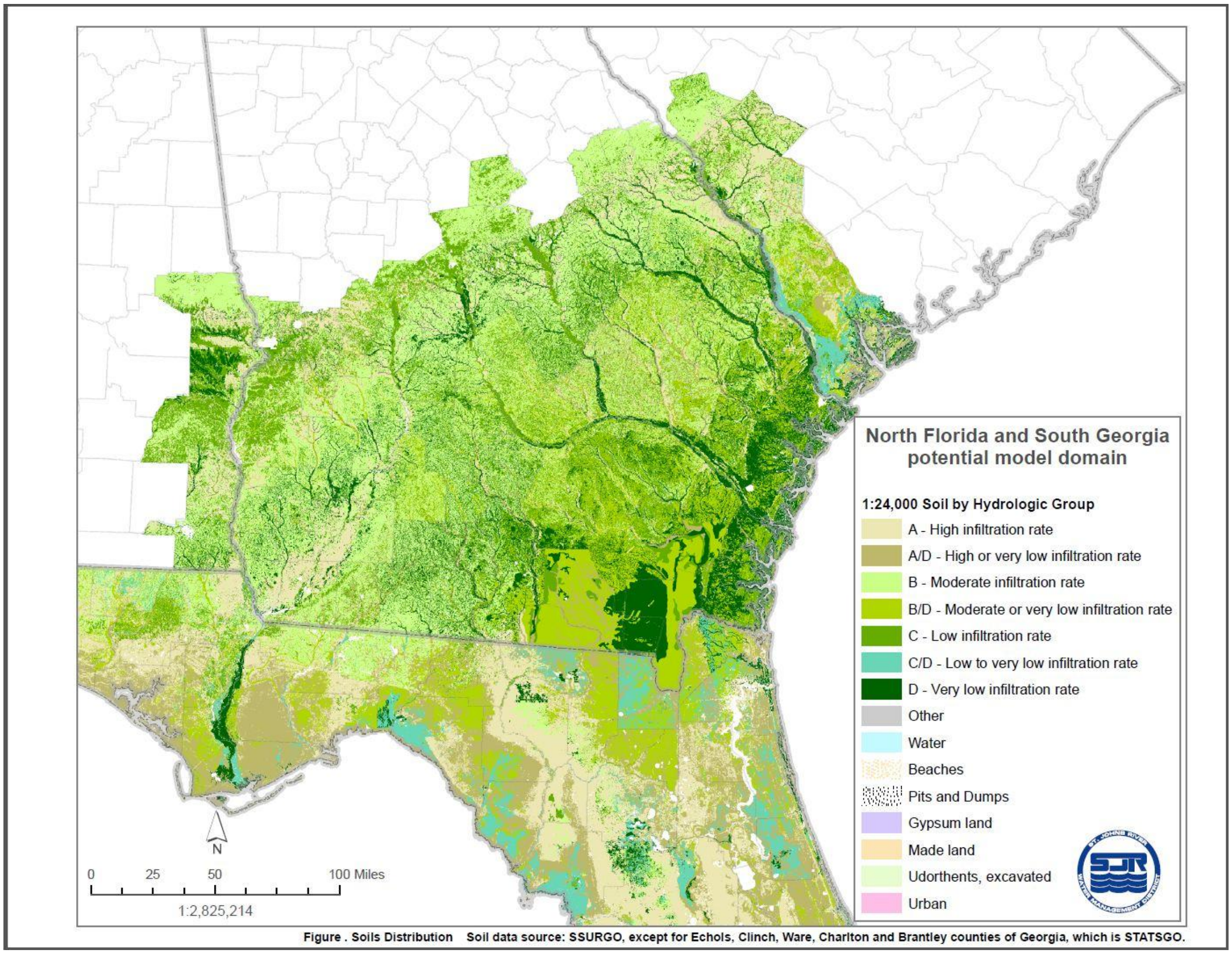


Figure 89. Soils Distribution

DISCUSSION

Lateral Boundaries

Taken together, the information and data presented in the preceding sections of the present report are intended to set the stage for consideration of the model lateral and temporal boundary conditions and other aspects of the model design. The description of the area of interest included the Coastal Plain province of Georgia and South Carolina so as to not limit consideration to areas entirely within or even just nearby the Florida-Georgia state line.

The subject hydrologic system is a regional flow system that is contained within several political jurisdictions, both water management districts and states. Well withdrawals and their associated impacts, however, are insensible to considerations of political boundaries, be they a state line or water-management district boundaries. It seems given that an important measure of success in regional groundwater modeling is the production of a model that is capable of simulating regional impacts. This entails the ability to represent drawdowns in a given subregion of the model domain that originate in some other subregion, perhaps even one that is relatively far away. Thus, in order to evaluate the impacts of pumping adequately, all subregions for which pumping is potentially of interest must be identified and represented, to the extent possible, with equal attention to detail. If data are lacking, then such deficiencies should be identified and addressed, perhaps resulting in areas of interest being excluded from the model domain and thus limiting the desired applicability of the model. However, a better approach would possibly be to include such areas anyway and represent them as well as possible in view of the data limitations. Presumably, as the Florida-Georgia state line is approached, the quality and availability of data will improve, thus enabling a steadily improving ability to represent the flow system.

The present modeling study appears to be motivated by a desire to evaluate pumping impacts originating in the St. Johns River Water Management District, the Suwannee River Water Management District, and the State of Georgia. Given that the State of Georgia is an area of concern, then the question of which areas of Georgia are of concern to the present undertaking must be addressed clearly. For instance, if pumping effects in Savannah, Georgia, are of concern, then, naturally, that location must be included within the model domain, and it must be included to the extent of fully encompassing the rather large cone of depression formed by pumping there, a cone of depression that also extends into South Carolina.

Regardless of how much of the State of Georgia is included, the inclusion of any significant amount of Georgia would appear to entail due consideration of the representations of both the SECPAS and the Gulf Trough. As stated in the preceding sections of the present report, the SECPAS underlies the FAS in Georgia and is in hydraulic connection with it. Barker and Pernik (1994) simulated a total outflow from the FAS to the SECPAS of 225 cfs (145.42 mgd) and a total inflow to the FAS from the SECPAS of 335 cfs (216.52 mgd) for a net influx of 110 cfs (71.10 mgd). In other regional models, the SECPAS equivalent of the Lower Floridan aquifer updip of the Gulf Trough, the Pearl River aquifer, was represented using the same layer as the Lower Floridan aquifer in areas downdip of the Gulf Trough, while the aquifers of the SECPAS that lie beneath the Lower Floridan aquifer (i.e., the Chattahoochee River aquifer and Black Warrior River aquifer) were ignored (e.g., Bush and Johnston, 1988; Krause and Randolph, 1989; Payne et al., 2005)

Groundwater flow lines within the Gulf Trough and north of it can be inferred as being oriented generally in a northwesterly-to-southeasterly direction (Figure 12; Figure 24; Figure 25; Figure 27). Whether this is due to widespread anisotropy in the FAS north of the Gulf Trough is not clear. However, most regional-scale models that encompass areas north of the Gulf Trough to date appear to have been oriented in deference to the southwesterly-northeasterly orientation of the Gulf Trough (e.g., Bush and Johnston, 1988; Krause and Randolph, 1989; Payne *et al.*, 2005; CDM, Inc., 2011). Also, it appears that a large, system-wide groundwater flow model of the FAS that is being considered by the USGS in Georgia will use this approach as well (Williams, In Progress).

Interestingly as well, most regional-scale models focused on areas within Georgia to date were extended to or even beyond the physical limits of the FAS north of the Gulf Trough (Bush and Johnston, 1988; Krause and Randolph, 1989; Payne *et al.*, 2005; CDM, Inc., 2011). Extension of the model domain to the physical limits of the FAS is advantageous because the lateral boundaries of the model at the FAS line of pinch-out can be treated realistically as a no-flow boundary at those locations, thus precluding the introduction of boundary-constraint error at those boundaries, a potentially significant source of error in predictive simulations. In regards to other potential lateral boundaries, use of the Apalachicola-Chattahoochee Rivers as the general demarcation of the western boundary is advantageous because these rivers, except for the lower third or so of the Apalachicola River, appear to be in close hydraulic connection to the FAS based on the shape of the FAS potentiometric surface in their vicinity (Figure 27). Hence, these rivers likely can be represented as no-flow boundaries, at least in regards to the Upper Floridan aquifer.

Other boundary considerations include the Atlantic-Ocean offshore boundary of the model. In the model study of Payne et al. (2005), this lateral boundary was represented as a no-flow boundary and made coincident with the onset of the Florida-Hatteras slope. Another boundary requiring due consideration is the southern boundary. If the Lower Suwannee River basin is to be represented to a high level of detail, then all areas of concentrated withdrawals that are affecting FAS water levels in the Lower Suwannee River basin should be included within the model domain. This potentially includes pumping from within the Southwest Florida Water Management District as well, so pumping considerations may dictate the location of the southern lateral boundary. Between Wakulla and Citrus counties, Florida, along the coast of the Gulf of Mexico, spring discharge and unconfined conditions imply use of a no-flow type boundary condition as well.

Temporal Boundaries

Regarding the temporal limits of the model, a more recent period is preferred. Hence, it is desirable to ascertain a steady-state period in the timeframe of the years 2000 through 2010 for purposes of conducting the steady-state calibration. Rainfall, aquifer water-level data, and flow data, such as spring flows, will need to be examined in greater detail than is presently possible to properly determine the best steady-state period for purposes of steady-state model calibration. Transient simulations will likely be conducted based on conditions in the period of 2000 through 2010 also.

CONCLUSIONS AND RECOMMENDATIONS

Modeling Approach

Inclusion of a significant portion of Georgia and the Lower Suwannee River basin may force inclusion of outlying areas that otherwise would not be of primary interest except for the potential for boundary-constraint error in model predictions. The full of impact of boundary-constraint error is difficult to evaluate because the source of the error lies outside of the model domain, and, regardless of where the model lateral boundaries are placed, some boundary-constraint error may occur. Nevertheless, this type of error can be minimized with careful planning.

The question of which aquifers should be included in the model domain is another major question to be addressed. For instance, extension of the model domain into Georgia appears to entail a degree of representation of the SECPAS. Other model studies of the FAS in Georgia, as mentioned previously, have done so, but to a minimal extent. This will probably prove to be a viable approach in the present case as well. The objective, then, is to include as much of the FAS and SECPAS as is necessary to produce a model that is capable of adequately representing inter-District and inter-state drawdowns but no more than that. This objective, however, may require including more of the hydrologic system, both laterally and vertically speaking, than might be imagined upon first consideration. Should this prove to be the case, then the additional area/aquifers should be included to enable the production of a technically sound model that is capable of meeting the objectives of the study in full.

Another consideration to bear in mind is the effect of the Gulf Trough feature of the FAS in Georgia. That feature is oriented generally along a southwesterly-northeasterly alignment, and the model grids of most major, regional-scale models of the FAS in Georgia have been oriented in deference to this feature at an angle to the orientation of north-south/east-west.

With these considerations in mind, then, a conservative approach is suggested as follows:

1. Consistent with other model studies of the FAS in Georgia, include the Pearl River aquifer but exclude the Chattahoochee River and Black Warrior River aquifers of the SECPAS (Figure 90);
2. Include the outcrop region of the Pearl River aquifer in order to adequately represent recharge to the deeper, confined zones of the Pearl River aquifer that are in intimate contact with the FAS at downdip locations. This implies that the NFSEG model within the State of Georgia will be extended somewhat beyond the pinch-out of the FAS into the direction of the Fall Line. Such an approach will greatly simplify lateral-boundary considerations and result in greater predictive accuracy;
3. The western model boundary should be coincident with the centerline of the Chattahoochee-Apalachicola Rivers, as this appears to be a hydraulic sink for the Upper Floridan aquifer based on inspection of the Upper Floridan aquifer potentiometric surface along this line. Between Wakulla and Citrus counties, Florida, a no-flow lateral boundary condition should be specified along the coast line to represent the limit of freshwater flow that occurs in that area due to spring discharge and unconfined conditions in the FAS;
4. On the east, the general area of the Georgia-South Carolina state line should be used as a lateral boundary to enable adequate representation of the pumping effects in Savannah, Georgia (Figure 91);
5. The Atlantic seaward boundary of the NFSEG model should be the onset of the Florida-Hatteras Slope, consistent with the approach of Payne et al. (2005);
6. The location of the southern lateral boundary of the model should be determined with due consideration of the influence of pumping on the Lower Suwannee River basin ((Planert, 2007); (Grubbs & Crandall, 2007)). All pumping centers that are influential to that area should be identified and considered for inclusion within the model domain;
7. The model grid should be oriented in deference to the orientation of the Gulf Trough. This has been the general approach taken in the development of regional-scale models of the FAS in Georgia;
8. If possible, nest the grid of the NFSEG regional groundwater flow model within the grid of the proposed system-wide USGS model (Williams, In Progress). To

the extent possible, coordinate the development of the NFSEG model with that of the system-wide USGS model. Also, coordinate the development of other SJRWMD models with that of the NFSEG model to enable a consistent representation of the FAS and to minimize duplication of efforts;

9. Given the regional focus of the NFSEG model, the grid-cell size may be on the order of 2,500 feet by 2,500 feet but not larger. For the sake of simplicity, the grid may be uniform, but a non-uniform grid should still have maximum grid-cell size of 2,500 feet by 2,500 feet, and the area of emphasis should the areas of the St. Johns River Water Management District and Suwannee River Water Management District within the model domain;
10. The temporal limits (i.e., calibration periods) of the model domain should be based on water-level, rainfall, and flow considerations within the proposed areal domain. An examination of the availability of water-level and discharge time series at well locations and other relevant points of interests should guide the determination of the calibration periods, both steady-state and transient. The period of 2000 through 2010 should be considered if data allow.

<table>
<tr><th colspan="4">Downdip of Gulf Trough</th></tr>
<tr><th>Series</th><th colspan="2">Hydrogeologic Unit</th><th>Model Layer</th></tr>
<tr><td>Post-Miocene</td><td colspan="2">Surficial Aquifer System</td><td>Layer 1[1]</td></tr>
<tr><td>Miocene</td><td colspan="2">Intermediate Aquifer System/Intermediate Confining Unit</td><td>Layer 2[1]</td></tr>
<tr><td>Oligocene</td><td rowspan="2">Upper Floridan Aquifer</td><td rowspan="6">Floridan Aquifer System</td><td rowspan="2">Layer 3[1]</td></tr>
<tr><td>Upper Eocene</td></tr>
<tr><td rowspan="2">Middle Eocene</td><td>Midle Semiconfining Unit; East: Lower Permeability; West: Higher Permeability or part of the transmissive system</td><td>Layer 4[1]</td></tr>
<tr><td>Lower Floridan Aquifer (Upper Zone)</td><td>Layer 5[1]</td></tr>
<tr><td>Lower Eocene</td><td>Lower Semiconfining Unit</td><td>Layer 6[1]</td></tr>
<tr><td>Paleocene</td><td>Lower Floridan Aquifer (Fernandina Permeable Zone)</td><td>Layer 7[1]</td></tr>
<tr><td>Upper Cretaceous</td><td colspan="2">Sub-Floridan Confining Unit</td><td>Inactive</td></tr>
</table>

<table>
<tr><th colspan="4">Updip of Gulf Trough</th></tr>
<tr><th>Series</th><th colspan="2">Hydrogelogic Unit</th><th>Model Layer</th></tr>
<tr><td>Post-Miocene</td><td colspan="2">Surficial Aquifer System1</td><td>Layer 1[1]</td></tr>
<tr><td>Miocene</td><td colspan="2">Intermediate Aquifer System/Intermediate Confining Unit1</td><td>Layer 2[1]</td></tr>
<tr><td>Oligocene</td><td colspan="2">Upper Floridan Aquifer</td><td>Layer3[1]</td></tr>
<tr><td>Upper Eocene</td><td>Pearl River Aquifer Confining Unit</td><td rowspan="4">Coastal Plain Aquifer System</td><td>Layer 4[1]</td></tr>
<tr><td>Middle Eocene
Lower Eocene</td><td>Pearl River Aquifer</td><td>Layer 5</td></tr>
<tr><td>Paleocene</td><td>Chattahoochee River Aquifer Confining Unit</td><td>Layer 6[2]</td></tr>
<tr><td>Upper Cretaceous</td><td>Chattahoochee River Aquifer</td><td>Layer 7[2]
Inactive</td></tr>
</table>

[1] Layer will be inactive where corresponding hydrogeologic layer is absent. [2] Layer will be inactive updip of the Gulf Trough.

Figure 90. Proposed Model Layering

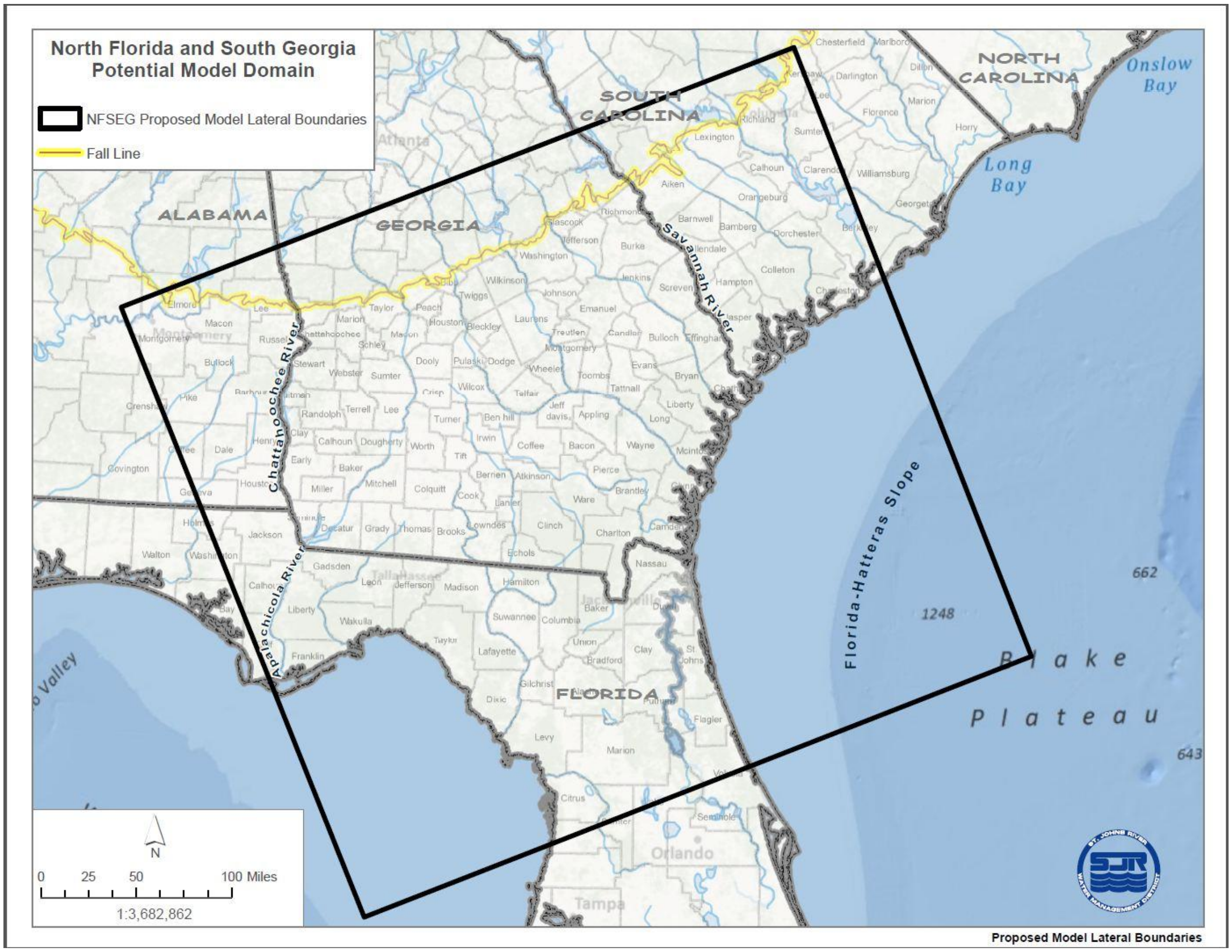


Figure 91. NFSEG Proposed Lateral Model Boundaries

Data Challenges

Review of available data indicates that attainment of adequately detailed water-use data will require the greatest level of additional effort. In particular, water-use data supplied to date by the State of Georgia are identified cumulatively by grid cell of the existing Georgia EPD ground-water flow model (CDM, Inc., 2011). The problem with the data lies not so much in the lack of specificity with regard to location but rather in the accumulation of the various uses corresponding to each grid cell into a single, lump-sum amount and to the lack of identification of the users of said amounts. This representation will make creating water-use data sets for periods other than that used in the existing Georgia EPD model difficult and perhaps even practically impossible. Difficulties regarding water use data are common to most ground-water modeling studies, and we expect the present study to be the same in this regard. We will work towards minimizing difficulties with regard to water-use data and the other required data types as well. A summary regarding data availability by institution/entity is presented in the following table.

	DATA Availability by Organization/Entity				
Data Type	**SJRWMD[1]**	**SRWMD[2]**	**GA[3]**	**NWFWMD[4]**	**SWFWMD[5]**
Water-Use	Good	Good	NAD	NE[7]	NE
Groundwater Levels	Good	Good	Good	Good	Good
Cluster Wells	Good	NAD	NE	NE	NE
Lake Stage	Good	Good	NAD	Good	Good
Stream Stage	Good	Good	Good	Good	Good
NHD Hydrography	Good	Good	Good	Good	Good
Spring-Pool Stage	Good	Good	NAD	Good	Good
Rainfall	Good	Good	Good	Good	Good
Evapotranspiration	Good	Good	Good	Good	Good
Land-Use/Land-Cover	Good	Good	Fair	Good	Good
Soils	Good	Good	Fair	Good	Good
Hydrostratigraphy	Good	Good	Good	Good	Good
Land-Surface Topography	Good	Good	Good	Good	Good
Prior Model Studies	Good	Good	Good	Good	Good

[1]St. Johns River Water Management District
[2]Suwannee River Water Management District
[3]State of Georgia
[4]Northwest Florida Water Management District
[5]Southwest Florida Water Management District
[6]Need Additional Data
[7]Not Evaluated

Table 1. Data Availability Summary

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