

Section 5

Regional Groundwater Flow Model Development

5.1 Conceptual Groundwater Flow Model

There are numerous phases of work involved in developing a groundwater flow model. The modeling process starts with data collection and the development of a conceptual model and extends through groundwater model calibration.

The formulation of a conceptual model is one of the first steps in groundwater flow model development. The conceptual model provides a basic understanding of the general groundwater flow directions in the aquifer system in both the vertical and horizontal directions, and forms the basis for the establishment of the model dimensions and grid system, hydrogeologic units, and the boundary conditions that represent the aquifer system in the numerical groundwater flow model.

The Coastal Plain Aquifer System consists of numerous distinct aquifers and confining units that exist in the southern part of the State, extending from the land surface to an elevation of -4,700 ft NGVD (depths ranging from approximately 1,200 to 7,200 feet below land surface (Miller, 1990; Pollard and Vorhis, 1980). The vertical sequence of aquifers in the southeastern portion of the State is different than the south-central and southwestern portions. In addition, the geologic units composing the aquifers and confining units may vary from west to east given similar land surface elevations and depths. Therefore, a chronostratigraphic nomenclature is used to describe the sequential layering of aquifer systems and confining units in descending order based on depth:

- Surficial Aquifer System;
- Brunswick Aquifer;
- Upper (Hawthorn Group) Confining Unit;
- Upper Floridan Aquifer;
- Lisbon-McBean Confining Unit;
- Claiborne/Gordon/Lower Floridan Aquifers;
- Tusahoma-Fishburne Confining Unit;
- Clayton-Dublin Aquifers;
- Providence Sand-Peedee Confining Unit;
- Providence Sand-Peedee Aquifer;

- Ripley-Black Creek Confining Unit;
- Eutaw-Midville Aquifer;
- Eutaw-Cape Fear Confining Unit;
- Upper Atkinson-Upper Tuscaloosa Aquifers;
- Middle Atkinson Confining Unit; and
- Lower Atkinson-Upper Tuscaloosa Aquifers.
- Mitchell Confining Unit

Details on how these hydrogeologic units are represented in the project groundwater models are presented below. The surficial aquifer system is composed of primarily Quaternary age clastic sediments. The Brunswick, Upper Floridan, and Claiborne/Gordon/Lower Floridan Aquifers are composed of Tertiary age carbonate-based sediments. The upper portion of the Cretaceous age units begins with the Providence Sand-Peedee Aquifer and extends to the Lower Atkinson-Upper Tuscaloosa Aquifers. The deeper portions of the Cretaceous units (Lower Atkinson-Upper Tuscaloosa Aquifers) have poor water quality and are not used for water supply.

The long-term average groundwater elevations of the surficial aquifer and Upper Floridan Aquifer, Claiborne/Gordon/Lower Floridan Aquifers, Clayton-Dublin Aquifers, and Providence Sand-Peedee-Dublin Aquifers in the outcropping areas are likely to mimic the topographic surface. Water levels in these aquifers fluctuate in response to rainfall, evapotranspiration (ET), and recharge from nearby rivers. Recharge into the surficial aquifer system and the aquifers in the outcrop areas is primarily by rainfall. Discharge from the aquifer is mainly by ET, downward leakage to underlying aquifers, and lateral seepage to surface water bodies. In a normal rainfall year, the net natural recharge (i.e., rainfall minus ET and direct surface runoff) into the surficial aquifer system and the aquifers in the outcropping areas within the Georgia Coastal Plain is estimated to range from approximately one to five inches per year (Bush and Johnston, 1988).

Groundwater flow in the surficial aquifer system usually flows from higher topographic areas to lower topographic areas (i.e., to streams, rivers, lakes, and the ocean). Groundwater flow in each underlying aquifer occurs under confined conditions, except in the outcrop area just south of the Fall Line (see Section 2.5 for details about confinement of each aquifer in the Coastal Plain of Georgia) and responds to recharge, discharge and pumping. In the Upper Floridan Aquifer, groundwater flow occurs from the Fall Line to the southwest-southeast-south toward the Gulf of Mexico, the Atlantic Ocean, and into Florida (Figure 2-24). Based on limited data for the aquifers underlying the Upper Floridan Aquifer, groundwater in

these aquifers appears to be flowing from the higher elevations in the north toward the south-southeast-southwest (Figures 2-25 through 2-28).

For this project, seven model layers are used to represent the hydrogeologic aquifer units within the Coastal Plain of Georgia. The model layers and corresponding hydrogeologic units are:

- Layer 1 - Surficial Aquifer System and Brunswick Aquifer;
- Layer 2 - Upper Floridan Aquifer;
- Layer 3 - Claiborne/Gordon/Lower Floridan Aquifers;
- Layer 4 - Clayton-Dublin Aquifers;
- Layer 5 - Providence Sand-Peedee-Dublin Aquifers;
- Layer 6 - Eutaw-Midville Aquifer; and
- Layer 7 - Upper Atkinson-Upper Tuscaloosa Aquifers.

Both the Surficial and Brunswick Aquifers are treated as one layer in the model and applied as a constant head in the model. The Providence Sand -Peedee-Dublin Aquifers, Eutaw-Midville Aquifer, and Upper Atkinson-Upper Tuscaloosa Aquifers comprise the upper units of the Cretaceous Aquifer. The bottom of the model corresponds to the top of the Middle Atkinson confining unit, which is a no flow boundary. The Lower Atkinson-Lower Tuscaloosa Aquifer, which is the lowest member of the Cretaceous Aquifer System, is not included in the model since there is no pumping from this aquifer and water quality is poor, as stated earlier. **Table 5-1** correlates geologic units, hydrogeologic units to the GaEPD Coastal Plain model layers.

Given the low horizontal hydraulic conductivity of the sediments and typical low hydraulic gradients (typically less than 0.1) in the horizontal direction there is negligible horizontal flow through confining units. However, given large cross sectional flow areas and higher vertical hydraulic gradients across confining units (typically ≥ 1), the majority of groundwater flow through confining units is in the vertical direction. Within the MODFLOW code, confining units can be defined explicitly as a layer with a defined top and bottom elevation, horizontal and vertical hydraulic conductivities, and appropriate storage coefficients. Another more common approach to modeling flow through confining units is to consider the horizontal flow to be negligible and to model the vertical flow as leakage. For this alternative, the confining unit leakance is specified (V_{cont} in MODFLOW) and the vertical leakage across the unit is calculated by the model. For the Georgia Coastal Plain groundwater modeling, the confining units between these aquifers are represented as leakance (i.e., vertical hydraulic conductivity divided by the confining

unit thickness) between the model layers. This approach provides equivalent results in the aquifers to the first approach of specifying confining units as a model layer.

5.2 Regional Groundwater Flow Model Code Selection

In accordance with Georgia EPD requirements, groundwater modeling software must be commercially available and/or obtained by or readily transferred to Georgia EPD for training and future use.

In selecting the numerical flow model for this project, considerations were given to the following factors:

- Availability - The modeling software should be available commercially or be in the public domain (i.e., the code is open to review and modification for all users);
- Documentation - The background theory, usage, and limitations of the modeling software should be well documented;
- Capability - The modeling software should be capable of providing realistic representations of the groundwater systems at the project site; and
- Acceptability - The modeling software should be widely accepted and used by the professional community and regulatory agencies.

Based on Georgia EPD's guidance and the above considerations, the USGS MODFLOW model software was selected for the Coastal Plain models.

MODFLOW is a three-dimensional Modular Finite-Difference Groundwater Flow Model that was originally developed by the USGS in 1985 (McDonald and Harbaugh, 1988). It is available in the public domain and has been rigorously peer reviewed. Since its inception, the model has been improved and updated by the USGS and other program developers. MODFLOW solves the partial differential equation describing the three-dimensional movement of groundwater of constant density through porous material using an iterative finite-difference approximation technique. Three iterative solution techniques, the Strongly Implicit Procedure, Slice Successive Over Relaxation and the Pre-Conditioned Conjugate 2, are contained within MODFLOW to solve the finite-difference equations (McDonald and Harbaugh, 1988; Hill, 1990).

The MODFLOW software can simulate a wide variety of hydrogeologic and hydrologic systems and can incorporate to varying degrees various elements such as rivers, drains, wells, streams, recharge, ET, etc. It can simulate groundwater flow under steady-state or transient conditions. Model input includes geometric and hydraulic properties of the aquifer system, as well as hydrologic boundary conditions within a specified model area. Model output includes piezometric heads, groundwater level drawdown, and cell-to-cell flow rates.

Table 5-1 Correlation between Geologic Units, Hydrogeologic Units, and Georgia EPD Coastal Plain Model Layers

Erathem	System	Series	SE Alabama / SW Georgia / NE Florida Panhandle		Central Georgia to North Florida		East Georgia/West South Carolina		Model Layer
			Geologic Formations	Hydrogeologic Formations	Geologic Formations	Hydrogeologic Formations	Geologic Formations	Hydrogeologic Formations	
Cenozoic	Quaternary	Post Miocene	Alluvium Deposits / *	Surficial Aquifer	Undifferentiated, Terrace and Alluvium Deposits	Surficial Aquifer	Undifferentiated, Terrace and Alluvium Deposits	Surficial Aquifer / Brunswick Aquifer & Confining Unit	1
	Tertiary	Miocene	Alum Bluff / *	Upper Confining Unit	Hawthorn Group	Upper Confining Unit	Hawthorn Group	Brunswick Aquifer	
		Oligocene	Suwannee Limestone and Residuum	Upper Floridan Aquifer	Suwannee Limestone	Upper Floridan Aquifer	Suwannee Limestone	Upper Floridan Aquifer and equivalents	2
		Eocene	Ocala Limestone and Residuum		Ocala Limestone		Ocala Limestone / Barnwell Formation		
			Lisbon Formation		Lisbon Confining Unit		Avon Park / Lisbon Formation		
		Paleocene	Tallahatta Formation	Claiborne Aquifer	Tallahatta Formation / Oldsmar Formation	Gordon / Lower Floridan Aquifers	Oldsmar Formation	Lower Floridan Aquifer	3
			Tuscahoma Formation	Tuscahoma Confining Unit	Cedar Keys Formation / Tuscahoma Formation	Tuscahoma Confining Unit	Tuscahoma / Fishburne Formations	Tuscahoma - Fishburne Confining Unit	3**
			Clayton Formation	Clayton - Ellenton Aquifer	Clayton Formation	Clayton - Ellenton Aquifer / Dublin Aquifer	Peedee Formation	Dublin Aquifer	4
			Providence Sand	Providence Sand - Peedee Confining Unit	Providence Sand	Providence Sand - Peedee Confining Unit	Providence Sand	Providence Sand - Peedee Confining Unit	4**
	Ripley Formation	Providence Sand - Peedee Aquifer	Providence Sand - Peedee / Dublin Aquifer	Providence Sand - Peedee / Dublin Aquifer		5			
Mesozoic	Cretaceous	Cusseta Sand / Blufftown Formation	Ripley Black Creek Confining Unit	Cusseta Sand	Ripley Black Creek Confining Unit	Cusseta Sand	Ripley Black Creek Confining Unit	5**	
		Eutaw Formation	Eutaw-Midville Aquifer	Blufftown Formation / Eutaw Formation	Eutaw-Midville Aquifer	Blufftown Formation / Eutaw Formation	Ripley Black Creek Confining Unit	6	
			Eutaw Cape Fear Confining Unit	Eutaw / Cape Fear Formation	Eutaw Cape Fear Confining Unit	Cape Fear Formation	Eutaw-Midville Aquifer	6	
			Upper Atkinson - Upper Tuscaloosa Aquifer		Upper Atkinson - Upper Tuscaloosa Aquifer		Eutaw Cape Fear Confining Unit	6**	
		Tuscaloosa Formation	Middle Atkinson Confining Unit	Atkinson Formation	Middle Atkinson Confining Unit	Atkinson Formation	Upper Atkinson - Upper Tuscaloosa Aquifer	7	
		Atkinson Formation/Tuscaloosa	Lower Atkinson - Lower Tuscaloosa Aquifer		Lower Atkinson - Lower Tuscaloosa Aquifer		Middle Atkinson Confining Unit	Not included in model	
			Mitchell Confining Unit		Mitchell Confining Unit				

Notes:
* Does not exist in all portions of the geographic areas listed above
**Confining units were represented in the model by Leakance (vertical hydraulic conductivity divided by the thickness of the confining unit)

For the Georgia Coastal Plain groundwater modeling, the Groundwater Modeling System (GMS) was selected software was selected as the primary graphical user interface due to their flexibility and graphics capabilities (pre-and post-processing). Groundwater Vistas MODFLOW software was also used for some pre- and post-processing.

As discussed in Section 3 of this report, there are seven groundwater flow models that either encompass or cover a portion of the Study Area. For this project, CDM started with the existing USGS model of the Coastal Plain Clastic Aquifer System (CPCAS) (Faye and Mayer, 1996). This model was modified, updated, and calibrated under steady-state conditions to match long-term groundwater levels observed in monitor wells located in the Coastal Plain of Georgia (refer to Section 5.4 for details). Although not included in the original scope of work for this project, a regional groundwater flow model was considered to be invaluable in establishing reasonable boundary conditions for sub-regional (focused) models. This regional model can also serve as a sound technical tool for the State to make high level water management decisions for the groundwater resources in this region.

5.3 USGS Coastal Plain Clastic Aquifer System Model

As discussed in Section 3.2, the existing USGS CPCAS groundwater flow model (Faye and Mayer, 1996) covers most of the Coastal Plain area in southern Georgia (**Figure 5-1**). The USGS model represents a distance of approximately 200 miles in the north-south direction and 328 miles in the east-west direction, encompassing an area of approximately 65,600 square miles. The entire USGS model area was discretized into cells using a uniform grid system (i.e., a grid system with uniform grid spacing). The model area was divided into 50 rows and 82 columns, with a grid spacing of 4 miles in both north-south and east-west directions.

The extent of the USGS model encompassed the clastic deposits portion of the Coastal Plain Aquifer System in Georgia, and was vertically discretized into six layers to represent the different aquifer systems. The model layers were as follows:

- Layer 1 - Upper Floridan Aquifer-Barnwell Aquifer (specified head boundary that supplies water to the underlying active aquifers);
- Layer 2 - Claiborne/Tallahatta-Gordon/Lower Floridan Aquifers;
- Layer 3 - Clayton-Ellenton/Dublin Aquifers;
- Layer 4 - Providence Sand-Peedee/Dublin Aquifers;
- Layer 5 - Eutaw-Midville Aquifer; and
- Layer 6 - Upper Atkinson-Upper Tuscaloosa Aquifers.

The average aquifer hydraulic parameters used in the USGS model are summarized in **Table 5-2**. As shown in this table, average transmissivity varies from about 1,890 to 11,380 square feet per day (ft²/day). The model used leakance rather than explicit layers to representing the confining units. The average vertical leakance between the aquifers varies from approximately 6.0×10^{-6} to 4.2×10^{-5} per day (day⁻¹). Average storage coefficient in the aquifers varies from approximately 7.0×10^{-4} to 1.4×10^{-3} .

Table 5-2 Aquifer Parameters Used in USGS Coastal Plain Clastic Aquifer Groundwater Model

Transmissivity (ft ² /day)			Leakance (day ⁻¹)			Storage Coefficient		
Min	Max	Avg.	Min	Max	Avg.	Min	Max	Avg.
Layer 1-Upper Floridan-Barnwell Aquifers*								
-	-	-	4.32E-07	8.64E-04	3.20E-05	-	-	-
Layer 2-Claiborne-Tallahatta-Gordon-Lower Floridan Aquifers								
71	82,184	11,379	1.73E-08	8.55E-04	4.20E-05	5.20E-04	8.20E-03	1.23E-03
Layer 3-Clayton-Ellenton/Dublin Aquifers								
254	5,011	1,740	1.12E-07	1.32E-04	1.10E-05	5.30E-04	5.30E-03	1.43E-03
Layer 4-Cretaceous Aquifer (Providence Sand-Peedee-Dublin Aquifers)								
255	11,029	3,602	1.73E-08	1.30E-04	1.60E-05	5.40E-04	5.40E-03	6.99E-04
Layer 5-Cretaceous Aquifer (Eutaw-Midville Aquifers)								
506	35,078	10,859	8.64E-09	1.38E-04	6.00E-06	5.50E-04	5.50E-03	9.17E-04
Layer 6-Cretaceous Aquifer (Upper Atkinson-Upper Tuscaloosa Aquifers)								
251	4,009	1,891	-	-	-	5.60E-04	5.60E-03	7.37E-04

Note:

Layer 1 (Upper Floridan–Barnwell Aquifers) was represented as a constant head boundary in the model.

The CPCAS model was constructed using an early version of the USGS MODFLOW code. The top and bottom elevations, thicknesses, and hydraulic conductivities of the aquifers were not used in the model. Instead, transmissivity, which is a term that combines thickness of the aquifer multiplied by the hydraulic conductivity, was used to define the aquifer characteristics. The model was calibrated in a steady-state condition (a long-term average) and a transient condition (the period from 1978 through 1982) to match simulated groundwater levels to observed groundwater levels in 763 data points) and in 291 monitor wells, respectively. The overall root mean squared errors (a measure of the dispersion of the data around the average) of the steady-state and transient model calibration were about 20.5 feet and 28.2 feet, respectively.

A detailed description of the model development and calibration procedures is presented in the USGS Professional Paper 1410-F entitled “*Simulation of Ground-Water Flow in Southeastern Coastal Plain Clastic Aquifers in Georgia and Adjacent Parts of Alabama and South Carolina*” (Faye and Mayer, 1996).

5.4 Georgia EPD Coastal Plain Regional Groundwater Model Development

To better represent the hydrogeologic conditions within the project area, CDM modified and updated the USGS CPCAS model by incorporating available hydrogeologic data from existing regional groundwater models in or adjacent to the project areas. Several steps were taken to develop the regional groundwater flow model from the CPCAS model and other models. The specific steps are detailed below:

- Expanded the southern boundary of the CPCAS model domain to cover all Georgia counties within the Coastal Plain area;
- Added the surficial aquifer (the topmost layer in the model) as a constant head boundary;
- Changed the Upper Floridan Aquifer from constant head to active aquifer flow cells;
- Refined the model grid system from a coarse spacing (4 miles by 4 miles) to a finer grid mesh (1 mile by 1 mile);
- Activated model cells to cover the entire Coastal Plain Aquifer System in Georgia and portions of north-central Florida, western South Carolina, and eastern Alabama;
- Incorporated the hydrogeologic properties from the existing regional groundwater models in the region and available publications;
- Used the MODFLOW River Package to represent the major rivers in the outcrop areas in the model domain;
- Used the MODFLOW Recharge Package to represent the long-term average rainfall recharge where the surficial aquifer does not exist and in the outcrop areas; and
- Updated the pumping well data to more current pumping locations and rates using data provided by GaEPD the Florida water management districts, South Carolina, and Alabama. A detailed description of the procedures used to estimate the pumping rates is discussed in the Section 5.4.6 of this report.

Several data sources were used for the GaEPD Coastal Plain Aquifer model development, as follows:

- Hydrogeologic data from the CPCAS groundwater flow model (Faye And Mayer, 1996);

- Hydrogeologic data from the Coastal Georgia groundwater flow model (Payne et al., 2005);
- Hydrogeologic data from the Northeast Florida groundwater flow model (Birdie et al., 2008);
- Hydrogeologic data from the North Florida groundwater model (Schneider et al., 2008);
- Hydrogeologic data from the Tallahassee, Florida groundwater flow model (Davis and Katz, 2007);
- USGS and Georgia Geological Survey (GGS) publications;
- Hydrogeologic/hydrologic data provided by Georgia EPD;
- USGS river stage and daily discharge data;
- Rainfall, evapotranspiration and runoff data from the USGS Regional Aquifer Simulation and Analysis Study for the Floridan Aquifer System (Bush and Johnston, 1988) were used to calculate areal recharge where the surficial aquifer does not exist and in the outcrop areas;
- USGS digital elevation model data; and
- Pumping well data from Georgia EPD, the Florida water management districts, South Carolina, and Alabama.

5.4.1 Model Domain and Grid Design

As shown on Figure 5-1, the existing CPCAS model domain covers an area of approximately 65,600 square miles, but only approximately 33,000 square miles of active cells (modeled areas). The model area was discretized into orthogonal cells with uniform grid spacing. The model area was divided into 50 rows and 82 columns, with a square grid spacing of 4 miles in both the north-south and east-west directions. The model origin for the CPCAS model (which occurs in the southwestern corner of the model) relative to the North American Datum of 1983 (NAD83) State of Georgia West Zone Planar Coordinate System is:

- X: 2,072,347 feet;
- Y: -107,226 feet; and
- Rotation Angle: 26 degrees.

The model grid uses the Cartesian Coordinate System of numbering rows and columns with the origin (X=0, Y=0) referenced in space to the State of Georgia State Plane Coordinate System. The model rotation angle refers to the alignment of the y-

axis relative to true north. A rotation angle of 26 degrees aligns the direction of grid perpendicular to the direction of predominant groundwater flow in the Coastal Plain aquifers. Aligning the grid in this manner minimizes the numerical error associated with solution of the governing groundwater flow equation in MODFLOW (USEPA, 1993). To include all the Georgia counties within the Coastal Plain area, the southern boundary of the CPCAS model domain was extended approximately 50 miles south. The modified (CDM) regional model domain covers an area of approximately 77,400 square miles and includes Georgia and portions of north-central Florida, western South Carolina, and eastern Alabama. The entire modified model area was discretized into cells using a uniform grid. The model area was divided into 236 rows and 328 columns, with a grid spacing of 1 mile in both north-south and east-west directions (**Figure 5-2**). The modified (GaEPD Coastal Plain) model origin (which also occurs in the southwestern corner of the model) relative to NAD83 State of Georgia West Zone Planar Coordinate System is:

- X: 2,155,672 feet;
- Y: -278,069 feet; and
- Rotation Angle: 26 degrees.

Comparison of the CPCAS model domain (Figure 5-1) with the modified model domain (Figure 5-2) shows that the modified model not only covers a larger area, but also has a higher degree of resolution than the existing USGS CPCAS model. In accordance with good modeling practices for finite-difference groundwater flow models (Anderson and Woessner, 1992; USEPA, 1993), the model grid was aligned so that groundwater flow would occur perpendicularly to the grid cells. A model grid rotation of 26 degrees accomplishes this goal.

5.4.2 Model Stratigraphy

To simulate groundwater flow and the changes in groundwater levels due to pumping, recharge and discharge in the Upper Floridan Aquifer, an additional model layer was added to represent the surficial aquifer system, and the Upper Floridan Aquifer-Barnwell Aquifer was made an active layer. The surficial aquifer, which exchanges water with the Upper Floridan Aquifer across the upper confining unit, was modeled as a constant head boundary condition where present. In areas where the surficial aquifer is not present, recharge was specified to the highest active layer in the model. The confining units between the aquifers are represented as leakance (i.e., vertical hydraulic conductivity divided by the confining unit thickness) between the model layers. This process and details of specifying recharge and boundary conditions (constant head, general head, etc) will be described in the subsections below. The translation between the hydrogeologic units and the seven model layers (six active and one constant head) in the modified regional model are summarized in **Table 5-3**.

Table 5-3 Summary of Hydrogeologic Units and Model Layer in the Georgia EPD Regional Groundwater Model

SE Alabama/ SW Georgia/ NE Florida Panhandle	Central Georgia to North Florida	East Georgia/ West South Carolina	Model Layer
Hydrogeologic Unit			
Surficial Aquifer	Surficial Aquifer	Surficial Aquifer/Brunswick Aquifer Confining Unit/ Brunswick Aquifer	1*
Upper Floridan Aquifer	Upper Floridan Aquifer	Upper Floridan-Barnwell Aquifers	2
Claiborne Aquifer	Claiborne Aquifer/ Gordon Aquifer	Lower Floridan Aquifer	3
Clayton-Dublin Aquifers	Clayton- Dublin Aquifers	Dublin Aquifer	4
Providence Sand- Peedee Aquifers	Providence Sand - Peedee-Dublin Aquifers	Providence Sand - Peedee-Dublin Aquifers	5**
Eutaw-Midville Aquifer	Eutaw-Midville Aquifer	Eutaw-Midville Aquifer	6**
Upper Atkinson-Upper Tuscaloosa Aquifers	Upper Atkinson-Upper Tuscaloosa Aquifers	Upper Atkinson-Upper Tuscaloosa Aquifers	7**

Note:

*Layer 1 (surficial aquifer) was represented as a constant head boundary in the model.

**The Providence Sand- Peedee-Dublin Aquifers, Eutaw-Midville and Upper Atkinson-Upper Tuscaloosa aquifers make up the Cretaceous Aquifer System. The bottom of the model corresponds to the top of the Middle Atkinson confining unit, which is a no flow boundary. Also, the Lower Atkinson-Lower Tuscaloosa Aquifer, which the lowest member of the Cretaceous Aquifer System, is not included in the model since there is no pumping from this aquifer and water quality is poor.

The thickness and top and bottom elevations of each hydrogeologic unit and corresponding modified model layer were determined from data in the following available publications:

- *Hydrogeologic Framework of the Floridan Aquifer System in Florida and in Parts of Georgia, Alabama, and South Carolina*, USGS Professional Paper 1403-B, Plates 26, 28, 29, 31, 32 and 33;
- *Simulation of Ground-Water Flow in Southeastern Coastal Plain Clastic Aquifers in Georgia and Adjacent Parts of Alabama and South Carolina*, USGS Professional Paper 1410-F, Figures 6, 9, 10 and 11;
- *Structure-Contour Map of the Top of the Cretaceous Aquifer System*, USGS Hydrogeologic Atlas HA-10, Sheet 33;
- Aquifers A₂, A₃, and A₂C₂A₃, USGS Hydrogeologic Atlas HA-3 Sheet 3;
- *Hydrogeology of the Clayton and Ellenton Aquifers in South-West Georgia*, Georgia Geological Survey Information Circular-55, Figures 4 through 6; and
- *Hydrogeology of the Gordon Aquifer System of East-Central Georgia*, Georgia Geological Survey, Information Circular 75, Figures 5 through 10.

A three-dimensional isometric representation of the groundwater model stratigraphy is displayed on **Figure 5-3**. Individual model layers (from the surficial aquifer to the Upper Atkinson-Upper Tuscaloosa Aquifers) are shown on **Figures A-1 through A-7** in **Appendix A**. Model cross-section locations are also shown on **Figure 5-4**. North-south and east-west cross sections through the modified model are shown on **Figures 5-4 and 5-5**, respectively. A comparison of the model stratigraphy (**Figure 5-4** and **Figures A-1 through A-7**) to the observed stratigraphy shown on **Figures 2-16, 2-17, and 2-18** demonstrates that the modified model stratigraphy reasonably represents the Coastal Plain Aquifer System in Georgia.

5.4.3 Boundary Conditions

The three types of boundary conditions typically used in numerical groundwater flow models are as follows:

- Constant head boundary (Dirichlet boundary);
- Specified flow boundary (Neumann boundary); and
- Head-dependent (Cauchy boundary).

All three boundary conditions are used in the modified model. The regional model boundary conditions are shown on **Figure 5-6**.

5.4.3.1 Constant Head Boundaries

Constant head boundaries (Dirichlet conditions) are used when the groundwater head is known and is constant at a given location for a given time interval. For steady-state models, the constant or specified head does not vary. For transient models, the constant head elevations can change from stress period to stress period. In the modified regional model, the Atlantic Ocean and the Gulf of Mexico were specified as constant heads. The surficial aquifer system (where present) and portions of the Upper Floridan Aquifer (the Atlantic Ocean and the Gulf of Mexico along the model lateral edges) were specified as a constant head.

The constant heads assigned for the surficial aquifer system were generated based on the following data:

- The simulated groundwater levels from the existing calibrated groundwater models:
 - USGS Coastal Georgia groundwater flow model (Payne et al., 2005), and
 - USGS Tallahassee groundwater flow model (Davis and Katz, 2007);
- Groundwater elevation data at 34 monitor well locations;
- River stage data in the major rivers; and

- Digital elevation model (2008) for land surface elevations with linear regression used in Georgia (Peck and Payne, 2003).

5.4.3.2 Specified Flow Boundaries

Specified flow boundaries (Neumann conditions) are used when the flow across a given area is known. A no flow boundary is a specified flow boundary where the flow is zero. A no flow boundary was assigned to the lateral edge boundaries of the model in all model layers. Since the Coastal Plain Aquifer System originates at the Fall Line this is a clear no flow boundary. From published groundwater elevation contour maps, groundwater flow is parallel to the eastern and western model boundaries and therefore these are no flow boundaries. The southern boundary of the model was made a no flow boundary since it is sufficiently far from Georgia to not affect groundwater flow with the Coastal Plain Aquifer system in Georgia.

Recharge (e.g., rainfall minus ET minus direct runoff) and well pumping are specified flow boundaries used in the model (see Section 5.4.8 for more details).

5.4.3.3 Head-Dependent Boundaries

Head-dependent boundaries (Cauchy conditions) are used when the flow across a boundary is calculated given a boundary head value. It is also called a mixed boundary because it relates boundary heads to boundary flows. In MODFLOW, the flow is proportional to the head differential across the boundary and a conductance term. The conductance term is related to hydraulic conductivity of the boundary material and the distance from the closest active cell.

There are several types of head-dependent boundary conditions. Typical head-dependent boundaries are General Head Boundaries (typically perimeter boundaries), Rivers or flowing water features that can act as either a source or a sink for groundwater, and Drains which act only as a sink for groundwater. In the regional steady-state model, the MODFLOW River Package was used to represent the major rivers and their tributaries. In all of the project models, the River Package was used to represent the major rivers and their tributaries where a given aquifer outcropped. The River Package was not used in model layer 1 (Surficial-Brunswick Aquifer) since this layer was modeled as a constant head boundary.

5.4.4 Aquifer Characteristics

Initial hydrogeologic properties for the aquifers of the modified regional model were imported from the following existing groundwater models and available data sources as initial values for each aquifer:

- The hydrogeologic properties for the majority of the model were obtained from the USGS CPCAS groundwater flow model (Faye and Mayer, 1996).
- The hydrogeologic properties for the eastern coastal area of the model were obtained from the USGS Coastal Georgia groundwater flow model (Payne et al., 2005).

- Hydrogeologic data inputs for the southern expansion area of the model were obtained from the following models and sources:
 - SJRWMD Northeast Florida groundwater flow model (Birdie et al., 2008);
 - SJRWMD North Florida groundwater flow model (Schneider et al., 2008);
 - USGS Tallahassee groundwater flow model (Davis and Katz, 2007); and
 - Data provided by Georgia EPD.

These hydrogeologic properties served as initial values that were adjusted during steady-state model calibration.

MODFLOW has four aquifer condition options that can be specified for each model layer as follows:

- Option 1: Strictly unconfined aquifer (the groundwater level is constantly maintained below the top of the aquifer);
- Option 2: Unconfined/confined (mixed) aquifer;
 - Transmissivity varies with saturated thickness and hydraulic conductivity is specified;
 - Storage is represented as specific yield if the aquifer goes unconfined, while storage coefficient is used if the aquifer stays confined.
- Option 3: Unconfined/confined (mixed) aquifer; and
 - Transmissivity is constant (i.e., does not vary with saturated thickness);
 - Storage is represented as specific yield if the aquifer goes unconfined, while storage coefficient is used if the aquifer stays confined.
- Option 4: Strictly confined aquifer (the groundwater level is constantly maintained above the top of the aquifer).

Table 5-4 summarizes the aquifer condition options specified for each layer in the modified regional model as well as the top and bottom elevations and hydrogeologic parameters representative of each layer. For each model layer, **Figures B-1 through B-7** in **Appendix B** shows the range of top elevations, while **Figures B-8 through B-14** in **Appendix B** show the range of thicknesses. The bottom elevations of model layer 7 are summarized on **Figure B-15** in **Appendix B**. The top and bottom elevations and thicknesses of the hydrogeologic units shown on **Figures 5-4 and 5-5** along with **Figures A-1 through A-7** were used to construct the model.

Table 5-4 Hydrogeologic Parameters Used in the Georgia EPD Regional Groundwater Model

Model Layer	Aquifer Name	Aquifer Condition	Parameter					Average Thickness	Average Elevation (feet NGVD)	
			Name	Units	Avg.	Max	Min	feet	Top	Bottom
1	Surficial-Brunswick	Strictly Unconfined Option 1	Leakance	day ⁻¹	1.8E-04	1.7E-02	1.0E-08	-	-	-
2	Upper Floridan	Unconfined/confined (mixed) Option 2	K _h	feet/day	840	15,000	2	661	-62	-723
			Leakance	day ⁻¹	8.8E-05	4.0E-03	4.9E-07			
3	Claiborne-Gordon-Lower Floridan	Unconfined/confined (mixed) Option 3	Transmissivity	ft ² /day	13,471	82,184	71	415	-596	-1,011
			Leakance	day ⁻¹	2.1E-05	2.1E-03	1.4E-08			
4	Clayton-Dublin	Strictly confined – Option 4	Transmissivity	ft ² /day	1,840	5,011	254	451	-932	-1,384
			Leakance	day ⁻¹	5.0E-06	1.3E-04	1.0E-08			
5	Providence Sand-Peedee-Dublin	Strictly confined – Option 4	Transmissivity	ft ² /day	2,406	11,029	255	363	-1,278	-1,644
			Leakance	day ⁻¹	1.0E-05	6.2E-04	1.7E-08			
6	Eutaw-Midville	Strictly confined – Option 4	Transmissivity	ft ² /day	7,387	35,078	506	605	-1,644	-2,249
			Leakance	day ⁻¹	2.5E-06	1.4E-04	8.6E-09			
7	Upper Atkinson-Upper Tuscaloosa	Strictly confined – Option 3	Transmissivity	ft ² /day	1,450	4,009	302	294	-2,478	-2,772

K_h = horizontal hydraulic conductivity

5.4.4.1 Transmissivity

Transmissivity is a hydraulic property that is a measure of the ability of an aquifer to transmit groundwater in the direction parallel to the base of the aquifer throughout its entire saturated thickness. From Equation 5-1, transmissivity is defined as the product of the hydraulic conductivity and the saturated thickness.

$$T = (K_h)(b) \quad \text{(Equation 5-1)}$$

Where: T is transmissivity of the aquifer in squared feet per day,
K_h is the horizontal hydraulic conductivity of the aquifer in feet per day, and
b is saturated thickness in feet.

As shown in Table 5-4, there is a range of transmissivity values used in the model since T varied spatially within each aquifer.

From this summary, these aquifers range from moderate to highly permeable. The aquifer transmissivity values used in the GaEPD Coastal Plain Aquifer Model are very similar to the values used in the USGS Coastal Plain Clastic Aquifer Groundwater Model (see Table 5-2). Aquifer transmissivities were adjusted during model calibration.

5.4.4.2 Hydraulic Conductivity

Horizontal hydraulic conductivity was specified for the Upper Floridan Aquifer (Layer 2) since this was the only layer represented by MODFLOW aquifer condition option 2. As shown in Table 5-4, there is a range of horizontal hydraulic conductivity in Layer 2 (Upper Floridan Aquifer) since this parameter varies spatially from 2 to 15,000 ft/day with an average value of approximately 840 ft/day. The hydraulic conductivity of the Upper Floridan aquifer was adjusted during model calibration.

5.4.4.3 Leakance

From Equation 5-2, leakance is defined as vertical hydraulic conductivity divided by the saturated thickness.

$$L = (K_v)/(b) \quad \text{(Equation 5-2)}$$

Where: L is leakance in day⁻¹,
K_v is the vertical hydraulic conductivity of the confining unit in feet/day, and
b is saturated thickness of the confining unit in feet.

As shown in Table 5-4, there is a range of confining unit leakance values used in the model since K_v, or b, or both varied spatially within each aquifer. Leakance of the confining units was adjusted during model calibration.

The leakance values range from very high to very low. This range of values demonstrates the variability in leakance over this wide geographic area. The confining unit leakance values used in the GaEPD Coastal Plain Aquifer Model are

very similar to the values used in the USGS Coastal Plain Clastic Aquifer Groundwater Model (see Table 5-2).

5.4.5 Land Surface Elevations

Based on the USGS database, a digital elevation model (2008) for the southeastern United States with 30 by 30 meter resolution was obtained for the project, as shown on **Figure 5-7**. The topographic elevations within the Georgia Coastal Plain portion of the modified regional model ranged from a low of approximately 0 feet NGVD near the Atlantic Ocean to a high of approximately 755 feet NGVD in Marion County, south of the Fall Line.

5.4.6 Well Locations and Pumping Rates

In order to calibrate the regional groundwater flow model, the model well file was updated to represent current conditions. Several sources of data were used to update the well file as noted below.

5.4.6.1 Pumping Locations

Existing permitted well locations and pumping rates within the Georgia Coastal Plain area were provided by Georgia EPD. The location of municipal, industrial and agricultural wells within the Coastal Plain of Georgia were included in EPD databases. Major municipal and industrial wells with a pumping capacity of greater than 100,000 gallons per day were included in two databases. EPD does not issue water use permits for withdrawals under 100,000 gpd. Agricultural well locations were included in a third database. The databases consisted of a GIS shapefile with pumping well locations (X, Y coordinates) by permit ID and a spreadsheet with total monthly water use by permit ID for the period 1994 through 2008. These database files did not contain total depth or open hole/screen interval for each well, only an aquifer designation. Best professional judgment was used to assign a model layer to each specified aquifer in order to represent the actual pumping withdrawals by well.

Existing permitted well locations and pumping rates in the Upper Floridan Aquifer and Lower Floridan Aquifer in coastal Georgia were available from GaEPD for 10 of the 24 coastal counties. For the remaining 14 coastal counties well locations in the Upper and Lower Floridan Aquifers were obtained from the USGS Georgia Coastal model (Fanning and Trent, 2009);

Well locations and pumping rates for the modeled areas located in Alabama and South Carolina were provided by the Alabama Office of Water Resources and the South Carolina Department of Health and Environmental Control for the time periods 1993 through 2008 and 2000 through 2008, respectively.

Existing permitted well locations and pumping rates for the modeled area located in northern Florida were provided by the Northwest Florida Water Management District (NFWFMD), Suwannee River Water Management District (SRWMD), and St. Johns River Water Management District (SJRWMD) for the period 1996 through 2008 for the

model domain located within their respective jurisdictions. Data provided by the SRWMD were in the form of model input data from the *Groundwater Flow Model of North Florida and South-Central Georgia* (Schneider, et al., 2008).

A total of 16,366 municipal, industrial and agricultural pumping wells were identified within the regional model domain. The distribution of pumping wells by model layer is given below:

- 12,904 wells located in Upper Floridan Aquifer (Layer 2);
- 2,094 wells located in Claiborne/Gordon/Lower Floridan aquifers (Layer 3);
- 535 wells located in Clayton-Dublin Aquifer (Layer 4);
- 492 wells located in Providence Sand-Peedee-Dublin Aquifer (Layer 5);
- 339 wells in Eutaw-Midville Aquifer (Layer 6); and
- 2 wells in Upper Atkinson-Upper Tuscaloosa Aquifer (Layer 7).

Table 5-5 and **Figures 5-8** through **5-13** present the well locations by aquifer unit (Layers 2 through 7) based on the data sources that cover the regional model domain. A total of 16,366 pumping wells with a total pumping rate of approximately 1,617 mgd were used in the regional groundwater model. The estimated total pumping rate represents an estimate of actual pumping in Georgia, Florida, South Carolina and Alabama, as distinct from permitted pumping capacity. In Georgia, the permitted pumping rate is often higher than the amount actually pumped. The well locations in the Upper and Lower Floridan Aquifers in 14 of the coastal counties shown on Figures 5-6, 5-8 and 5-9 were taken from the USGS Georgia Coastal model (Fanning and Trent, 2009). The well locations shown are not exact locations and were determined by the USGS by taking county by county pumping data and distributing the pumping over a series of wells placed on a 1 mile by 1 mile grid system.

The well locations in the different aquifers, categorized by water use type, are presented in Table 5-5 and on **Figures C-1** through **C-6** in **Appendix C**. The total water use from these pumping wells for the states located in the regional groundwater flow model domain (i.e., Georgia, Florida, South Carolina, and Alabama) is summarized in **Table 5-6**. A total of approximately 1,617 mgd is being pumped from the groundwater throughout the model area, with the majority of flows originating from agricultural uses in Georgia and public supply for the remaining states.

Table 5-5 Pumping Well Distribution by Data Source and Water Use Type for the Georgia EPD Regional Groundwater Model Area

Data Source	Number of Wells					
	Model Layer ¹					
	2	3	4	5	6	7
Georgia EPD	7,962	1,157	292	371	334	0
USGS Coastal Model	890	783	0	0	0	0
Alabama Office of Water Resources	49	120	16	116	0	0
South Carolina Department of Health & Environmental Control	523	6	227	5	5	2
NWFWMD (Florida)	546	7	0	0	0	0
SRWMD (Florida)	2,815	0	0	0	0	0
SJRWMD (Florida)	119	21	0	0	0	0
Total	12,904	2,094	535	492	339	2
Water Use Type	Number of Wells					
	Model Layer ¹					
	2	3	4	5	6	7
Public Water Supply	516	106	183	269	5	0
Commercial/Industrial	101	20	107	176	10	0
Agricultural ²	8,300	1,164	239	47	324	0
Other	163	0	6	0	0	2
Undetermined	3,824	804	0	0	0	0
Total	12,904	2,094	535	492	339	2

¹Notes:

Model Layer 2 - Upper Floridan Aquifer

Model Layer 3 - Claiborne/Gordon/Lower Floridan Aquifers

Model Layer 4 – Clayton-Dublin Aquifers

Model Layer 5 - Providence Sand-Peedee-Dublin Aquifer (Cretaceous Aquifer System)

Model Layer 6 - Eutaw-Midville Aquifer (Cretaceous Aquifer System)

Model Layer 7 - Upper Atkinson-Upper Tuscaloosa Aquifer (Cretaceous Aquifer System)

²Estimated from USGS data and data from the University of Georgia College of Agriculture and Environmental Sciences (Hook and Harrison, 2007).

Table 5-6 Historical Water Use Pumping Distribution for the Georgia EPD Regional Coastal Plain Aquifer System Groundwater Model Area

State	Water Use Category (mgd)				
	Public Water Supply	Commercial/Industrial	Agriculture ¹	Other ^{2,3,4,5}	Total
Georgia	299 (26%)	179 (15%)	689 (59%)	NA	1,167
Florida	104 (36%)	57 (20%)	72 (25%)	54 (19%)	287
Alabama	50 (73%)	4 (6%)	14 (21%)	NA	68
South Carolina	36 (38%)	15 (16%)	28 (29%)	16 (17%)	95
Total					1,617

NA indicates not applicable,

Numbers in parentheses represent percent of total water use for each water use type.

¹Estimated from USGS data and data from the University of Georgia College of Agriculture and Environmental Sciences (Hook and Harrison, 2007).

²Includes the following water uses for the NFWFMD: aquaculture (0.09 mgd), heat pump supply (0.34 mgd), other outside use (0.002 mgd), power production (0.31 mgd) and water-based recreation (0.15 mgd).

³Includes the following water uses for the SRWMD: domestic (14.44 mgd), aquaculture (0.003 mgd), mining (35.75 mgd), and thermoelectric (2.37 mgd).

⁴Includes the following water uses for the SJRWMD: recreation area (0.01 mgd) and urban landscape irrigation (0.12 mgd).

⁵Includes the following water uses for South Carolina: aquaculture (0.40 mgd), golf course use (4.95 mgd), mining (4.68 mgd), and thermopower (6.07 mgd).

5.4.6.2 Well Pumping Rates

Existing well pumping rates for municipal and industrial wells within the Georgia Coastal Plain were provided by Georgia EPD. The EPD well pumping data was also compared to USGS 2000 and 2005 water use data for Georgia 2000 and 2005. The USGS data was provided on a county by county basis by use and source.

There are no pumping data available from EPD for most of the agricultural users. USGS water use data included estimated county by county agricultural use data by source (surface water and groundwater). In order to estimate the agricultural user well pumping rates for the steady-state regional groundwater flow model and the transient sub-regional groundwater flow models, CDM reviewed and evaluated available publications and databases of Georgia agricultural withdrawals.

Average agricultural well pumping rates for the steady-state regional groundwater model (representing the average conditions) were estimated based on USGS water use data by Georgia county for 2000 and 2005 (Fanning, 2003 and Fanning and Trent, 2009), and Georgia EPD GIS data on agricultural well capacities. Hook and Harrison's studies (2005 and 2007), as well as the Fanning et al. study (2001), were used to approximate the seasonal variation in estimated total agricultural withdrawals for the transient sub-regional groundwater models.

A detailed description of the agricultural well pumping rate estimation procedures used for this study is presented below:

Average Agricultural Well Pumping Rates for the Steady-State Regional Groundwater Model

- **Step 1** - Calculate Georgia agricultural user withdrawals by county (Q_{ag}) for 2000 and 2005 based on the USGS publications by Fanning (2003) and Fanning and Trent (2009). According to the NOAA data (see Section 2), annual rainfall amounts in 2000 and 2005 within the Study Area were approximately 39.8 and 56.0 inches, respectively (average annual rainfall is about 49.0 inches). Therefore, annual rainfall totals in 2000 and 2005 represent a low rainfall year and a high rainfall year, respectively.
- **Step 2** - Based on the Georgia EPD GIS data, determine the agricultural well permitted capacities for each county (Q_{cap}).
- **Step 3** - Based on agricultural user withdrawals (Step 1) by county and well capacities (Step 2), calculate the ratio of Q_{ag}/Q_{cap} for each county (R_{co}).
- **Step 4** - Based on the ratio (Step 3) and permitted well capacity (Step 2- Georgia EPD GIS data), determine individual agricultural well pumping rates ($Q_{wellactual}$) in 2000 and 2005 for all of the Georgia counties in the regional groundwater model domain. The formula ($Q_{wellactual} = Q_{cap} \times R_{co}$) was used for this purpose.
- **Step 5** - Calculate the average agricultural well pumping rate (Q_{well_avg}) for each agricultural well based on individual agricultural well pumping rates in 2000 (low rainfall year) and 2005 (high rainfall year) (Step 4). The formula $Q_{well_avg} = (Q_{wellactual@2000} + Q_{wellactual@2005})/2$ was used to estimate the average agricultural withdrawals.

Monthly Agricultural Well Pumping Rates for the Transient Sub-Regional Groundwater Models

- **Step 6** - Based on Hook and Harrison's studies (2005 and 2007) as well as Fanning et. al. study (2001), determine/distribute the monthly agricultural well pumping rates for each agricultural use well in an average rainfall year (Step 5), a high rainfall year (Step 4) and a low rainfall year (Step 4) for the three-monthly transient sub-regional groundwater flow models for the Upper Floridan, Claiborne and Cretaceous Aquifers. The monthly agricultural withdrawals represent the seasonal variation of the agricultural water use (e.g., growing season and non-growing season).
- **Step 7** - After completing the estimation of the agricultural well pumping rates, the MODFLOW Well Packages were prepared based on low rainfall year and high rainfall year individual agricultural well pumping rates determined in Step 4. Each well was assigned into the groundwater model through the MODFLOW Well Package. The MODFLOW Well Package is designed to simulate wells, which withdraw water from the aquifer (or add water into the aquifer) at a specified rate during a given time period.

For users without pumping records, the pumping rates were estimated based on Georgia EPD reports, allocations, well capacities and USGS publications by Fanning (2003) and Fanning and Trent (2009). Percentages of total annual allocations for each permitted user were assigned to the corresponding aquifer wells based on well types, source locations, and pumping capacities. The total average pumping rate from all the existing permitted user wells within the Coastal Plain Aquifer of Georgia was approximately 1,167 mgd, which is consistent with published data in an average rainfall year presented in Table 4-3 (Fanning and Trent, 2009).

5.4.7 River Package

The MODFLOW River Package was used to represent the major rivers and streams in the outcrop areas of the Coastal Plain. Input data for the River package consist of the river bottom elevation, the river stage, the river bed sediment thickness, and the hydraulic conductivity of these sediments.

The river bottom elevation was estimated from available topographic data near each river or stream. River stage data were obtained from the USGS National Water Information System (NWIS) database. The river bottom sediment thickness was estimated to be one foot thick, and the associated hydraulic conductivity of the sediments was estimated to be approximately one foot per day. The river bed hydraulic conductivity values were adjusted slightly during model calibration. The locations of the River cells within the regional model domain are shown on **Figure 5-14**. From Figure 5-14, only major rivers and streams that are not directly connected to the surficial aquifer system are represented in the model since the surficial aquifer is modeled as a constant head boundary. As a result, fewer than half of the major river reaches are represented in the model and these river reaches are connected to lower hydrogeologic units in areas where they outcrop.

A total of 97 staff gauges are located within the model area (**Figure 5-15**). Average surface water elevations in the rivers are presented in **Table 5-7**. As shown in Table 5-7, surface water elevations in the rivers vary from approximately 4 feet NGVD in Chatham County in the coastal area to 334 feet NGVD in Upson County near the Fall Line within the model domain.

5.4.8 Aquifer Recharge

The Recharge Package in MODFLOW is designed to simulate spatially distributed recharge to the groundwater system. Recharge occurs as a result of rainfall that percolates into the aquifers. As discussed in Section 2.1, recharge (e.g., rainfall minus ET minus direct runoff) within the model domain ranges from approximately one to six inches/year. Recharge was applied to the uppermost active layer (i.e., cells that are not constant head) primarily in the outcrop area south of the Fall Line.

Table 5-7 Summary of Selected Major River Stage Stations

Station ID	Staff Gauge Station	State Plane GA West (ft)		Data Recorded Period		Average Stage (ft NGVD)	Max Stage (ft NGVD)	Min Stage (ft NGVD)
		X	Y	Begin Date	End Date			
02225000	ALTAMAHA RIVER NEAR BAXLEY	2,859,018	709,895	10/1/1999	3/22/2009	66.8	82.1	61.9
02353000	FLINT RIVER AT NEWTON	2,242,799	475,363	4/11/1938	3/22/2009	118.0	146.6	113.0
02353500	ICHAWAYNOCHAWAY CREEK AT MILFORD	2,178,093	503,108	10/1/1998	3/22/2009	151.9	164.9	149.8
02223000	OCONEE RIVER AT MILLEDGEVILLE	2,587,880	1,125,072	10/2/1986	3/22/2009	240.2	266.6	230.9
02213000	OCMULGEE RIVER AT MACON	2,464,312	1,032,927	10/1/1992	3/22/2009	278.2	296.6	274.2
02213500	TOBESOFKEE CREEK NEAR MACON	2,422,037	1,021,922	10/1/2000	3/22/2009	312.2	323.4	311.3
02228000	SATILLA RIVER AT ATKINSON	3,015,340	451,579	10/1/1997	3/22/2009	21.4	34.0	17.0
02353400	PACHITLA CREEK NEAR EDISON	2,136,433	565,922	3/24/1988	3/22/2009	216.2	223.1	213.3
02198980	SAVANNAH RIVER AT FORT PULASKI	3,308,037	755,032	10/10/1987	12/4/2005	4.0	28.1	-1.7
02356000	FLINT RIVER AT BAINBRIDGE	2,166,965	331,692	10/1/1936	3/22/2009	75.0	97.0	60.0
02357000	SPRING CREEK NEAR IRON CITY	2,117,552	378,588	10/1/1998	3/22/2009	89.8	103.6	85.3
02349900	TURKEY CREEK AT BYROMVILLE	2,378,383	798,654	10/1/2000	3/22/2009	291.5	297.9	290.4

Table 5-7 Summary of Selected Major River Stage Stations (Continuation)

Station ID	Staff Gauge Station	State Plane GA West (ft)		Data Recorded Period		Average Stage (ft NGVD)	Max Stage (ft NGVD)	Min Stage (ft NGVD)
02352500	FLINT RIVER AT ALBANY	2,303,589	579,794	10/1/1971	3/22/2009	155.6	186.6	151.5
02317500	ALAPAHA RIVER AT STATENVILLE	2,652,763	257,783	10/1/1997	3/22/2009	81.4	106.2	77.3
02202500	OGEECHEE RIVER NEAR EDEN	3,147,582	807,925	10/1/1988	3/22/2009	22.6	33.0	17.4
02203000	CANOOCHEE RIVER NEAR CLAXTON	3,001,322	802,076	10/1/2000	3/22/2009	83.7	96.0	81.4
02223056	OCONEE RIVER AT AVANT MINE	2,633,967	1,071,040	11/4/1992	3/22/2009	208.5	223.4	204.2
02318700	OKAPILCO CREEK AT GA 33	2,486,215	300,746	10/1/1999	3/22/2009	115.5	125.8	111.3
02341505	CHATTAHOOCHEE RIVER AT US 280	2,040,993	893,219	10/31/1986	3/22/2009	190.2	222.3	185.0
02350512	FLINT RIVER AT GA 32	2,342,615	627,414	10/1/1987	3/22/2009	191.2	225.6	187.8
02351890	MUCKALEE CREEK AT GA 195	2,305,042	645,976	10/1/1997	3/22/2009	225.3	236.7	221.9
02226160	ALTAMAHA RIVER NEAR EVERETT CITY	3,095,510	528,282	2/22/2008	3/22/2009	7.1	12.3	4.3
02223382	OCONEE RIVER NEAR DUBLIN	2,674,291	982,332	11/4/1992	10/2/1996	169.4	184.6	163.2
02223500	OCONEE RIVER AT DUBLIN	2,688,533	927,815	10/15/1986	3/22/2009	154.7	180.2	149.5

Table 5-7 Summary of Selected Major River Stage Stations (Continuation)

Station ID	Staff Gauge Station	State Plane GA West (ft)		Data Recorded Period		Average Stage (ft NGVD)	Max Stage (ft NGVD)	Min Stage (ft NGVD)
02349500	FLINT RIVER AT MONTEZUMA	2,334,519	835,862	10/1/1971	2/29/2004	260.3	281.5	255.7
02356980	AYCOCKS CREEK NEAR BOYKIN	2,118,161	395,559	3/4/1993	12/14/1995	6.6	12.5	3.6
02341566	CHATTAHOOCHEE R (ALA ST DOCK AUX) COLUMBUS	2,049,595	886,180	10/1/1990	9/30/2002	189.5	215.1	184.4
02227500	LITTLE SATILLA RIVER NEAR OFFERMAN	2,955,193	534,093	10/1/2000	3/22/2009	62.5	71.3	59.1
02198000	BRIER CREEK AT MILLHAVEN	3,068,383	1,076,169	10/1/1992	9/30/2008	99.4	109.4	95.3
02350080	LIME CREEK NEAR COBB	2,349,348	739,785	3/12/1993	3/22/2009	260.1	267.1	257.6
02225500	OHOOPEE RIVER NEAR REIDSVILLE	2,912,725	761,593	10/1/2000	3/22/2009	78.4	94.4	74.2
02215500	OCMULGEE RIVER AT LUMBER CITY	2,759,755	700,899	10/1/1989	3/22/2009	91.6	105.4	86.9
02216180	TURNPIKE CREEK NEAR MCRAE	2,682,478	726,505	10/1/2000	3/22/2009	176.1	183.2	174.2
02339500	CHATTAHOOCHEE RIVER AT WEST POINT	1,984,835	1,051,275	10/1/1932	3/22/2009	556.3	575.7	553.2
02347500	FLINT RIVER NEAR CULLODEN	2,276,337	989,853	9/1/2000	3/22/2009	337.9	364.8	334.9
02226180	BRUNSWICK R AT VILLAGE PIER AT ST SIMMONS ISLAND	3,163,295	422,910	11/18/1998	3/22/2009	0.2	4.1	-6.1

Table 5-7 Summary of Selected Major River Stage Stations (Continuation)

Station ID	Staff Gauge Station	State Plane GA West (ft)		Data Recorded Period		Average Stage (ft NGVD)	Max Stage (ft NGVD)	Min Stage (ft NGVD)
02196999	SAVANNAH RV ABOVE NEW SAVANNAH BLUFF LOCK & DAM	2,975,723	1,234,194	10/1/1989	3/22/2009	115.7	430.7	108.9
02198840	SAVANNAH RIVER (I-95) NR PORT WENTWORTH	3,229,064	826,200	6/17/1987	9/30/2005	27.0	30.7	24.6
02226500	SATILLA RIVER NEAR WAYCROSS	2,872,276	455,064	10/1/2000	3/22/2009	73.5	84.3	69.9
02201000	WILLIAMSON SWAMP CREEK AT DAVISBORO	2,773,972	1,085,847	10/1/1992	3/22/2009	266.7	274.5	265.1
02226000	ALTAMAHA RIVER AT DOCTORTOWN	3,024,315	609,515	4/1/1991	3/22/2009	31.4	40.0	25.4
02350600	KINCHAFOONEE CREEK AT PRESTON	2,178,339	746,723	10/1/1986	3/22/2009	340.6	347.7	338.1
02223248	OCONEE RIVER NEAR OCONEE	2,668,266	1,015,922	11/4/1992	3/22/2009	177.6	196.9	172.3
02354500	CHICKASAWHATCHEE CREEK AT ELMODEL, GA	2,197,996	491,325	7/28/1995	3/22/2009	139.0	154.3	137.3
02354800	ICHAWAYNOCHAWAY CREEK NEAR ELMODEL, GA	2,194,987	470,722	4/15/1995	3/22/2009	145.4	162.4	142.8
02355350	ICHAWAYNOCHAWAY CREEK BELOW NEWTON, GA	2,201,504	442,918	4/15/1995	3/22/2009	102.8	131.8	100.1
02316000	ALAPAHA RIVER NEAR ALAPAHA, GA	2,600,606	504,826	9/4/2002	3/22/2009	213.1	225.0	208.8
02318500	WITHLACOOCHEE RIVER AT US 84, NEAR QUITMAN, GA	2,520,469	289,127	10/2/1993	3/22/2009	89.5	113.8	85.8

Table 5-7 Summary of Selected Major River Stage Stations (Continuation)

Station ID	Staff Gauge Station	State Plane GA West (ft)		Data Recorded Period		Average Stage (ft NGVD)	Max Stage (ft NGVD)	Min Stage (ft NGVD)
21973269	SAVANNAH RIVER NEAR WAYNESBORO, GA	3,034,823	1,154,237	1/22/2005	3/22/2009	78.9	89.3	75.7
02198100	BEAVERDAM CREEK NEAR SARDIS, GA	3,018,013	1,076,580	10/1/2000	3/22/2009	188.4	193.6	187.6
02201230	OGEECHEE RIVER AT MIDVILLE, GA	2,890,026	1,029,181	2/27/2003	9/30/2008	172.4	178.4	168.3
02210500	OCMULGEE RIVER NEAR JACKSON, GA	2,396,921	1,203,391	3/12/1987	3/22/2009	424.0	437.9	423.0
02353265	ICHAWAYNOCHAWAY CREEK AT GA 37, NEAR MORGAN, GA	2,166,937	555,588	5/31/2001	3/22/2009	182.7	190.7	180.2
02354410	CHICKASAWHATCHEE CREEK NEAR LEARY, GA	2,214,344	546,953	8/4/2001	3/22/2009	178.5	182.3	176.0
02354475	SPRING CREEK NEAR LEARY, GA	2,208,422	533,126	10/1/2005	3/22/2009	172.1	173.4	170.0
02195520	SAVANNAH RIVER NEAR EVANS, GA	2,918,892	1,313,076	7/7/2005	3/22/2009	274.8	279.2	272.7
02314495	SUWANNEE RIVER ABOVE FARGO, GA	2,808,066	261,008	10/1/1999	3/22/2009	98.9	112.0	93.7
02318000	LITTLE RIVER NEAR ADEL, GA	2,491,472	420,806	10/19/2000	3/22/2009	194.4	208.4	191.3
02198690	EBENEZER CREEK AT SPRINGFIELD, GA	3,182,645	872,349	10/1/2000	3/22/2009	24.7	34.3	22.9
02329342	LITTLE ATTAPULGUS CREEK AT ATTAPULGUS, GA	2,192,822	267,654	10/1/1999	9/30/2008	167.2	172.9	166.4

Table 5-7 Summary of Selected Major River Stage Stations (Continuation)

Station ID	Staff Gauge Station	State Plane GA West (ft)		Data Recorded Period		Average Stage (ft NGVD)	Max Stage (ft NGVD)	Min Stage (ft NGVD)
02343801	CHATTAHOOCHEE RIVER NEAR COLUMBIA, AL	2,001,767	459,267	9/18/1998	3/22/2009	79.3	111.4	75.5
02343940	SAWHATCHEE CREEK AT CEDAR SPRINGS, GA	2,022,350	430,538	1/19/2002	3/22/2009	102.3	108.4	100.6
02354440	KIOKEE CREEK NEAR PRETORIA, GA	2,234,168	546,911	6/20/2001	4/2/2005	178.0	181.5	175.5
02357150	SPRING CREEK NEAR REYNOLDSVILLE, GA	2,113,926	329,269	10/29/2004	3/22/2009	77.2	82.8	75.6
02197598	BRUSHY CREEK AT CAMPGROUND ROAD, NEAR WRENS, GA	2,857,232	1,161,861	6/15/2005	3/22/2009	311.4	315.3	310.9
02218300	OCONEE RIVER NEAR PENFIELD, GA	2,561,490	1,354,744	10/1/2000	3/22/2009	437.3	451.8	434.4
23177483	WITHLACOOCHEE RIVER AT MCMILLAN RD, NEAR BEMISS, GA	2,578,129	347,612	10/1/1993	3/22/2009	129.7	147.0	125.9
02349605	FLINT RIVER AT GA 26, NEAR MONTEZUMA, GA	2,334,607	834,044	10/1/2002	3/22/2009	259.3	277.5	255.6
02350900	KINCHAFOONEE CREEK AT PINWOOD ROAD, NR DAWSON, GA	2,269,649	641,742	10/1/2000	3/22/2009	216.3	231.2	213.7
02355662	FLINT RIVER AT RIVERVIEW PLANTATION, NR HOPEFUL, GA	2,198,472	414,940	5/8/2002	3/22/2009	69.5	98.7	64.9
02196835	BUTLER CREEK BELOW 7TH AVENUE, AT FT. GORDON, GA	2,922,154	1,256,962	3/28/2001	3/22/2009	262.2	264.9	261.4
02197020	SPIRIT CREEK AT US 1, NEAR AUGUSTA, GA	2,915,629	1,233,119	3/27/2001	3/22/2009	232.7	234.2	232.0

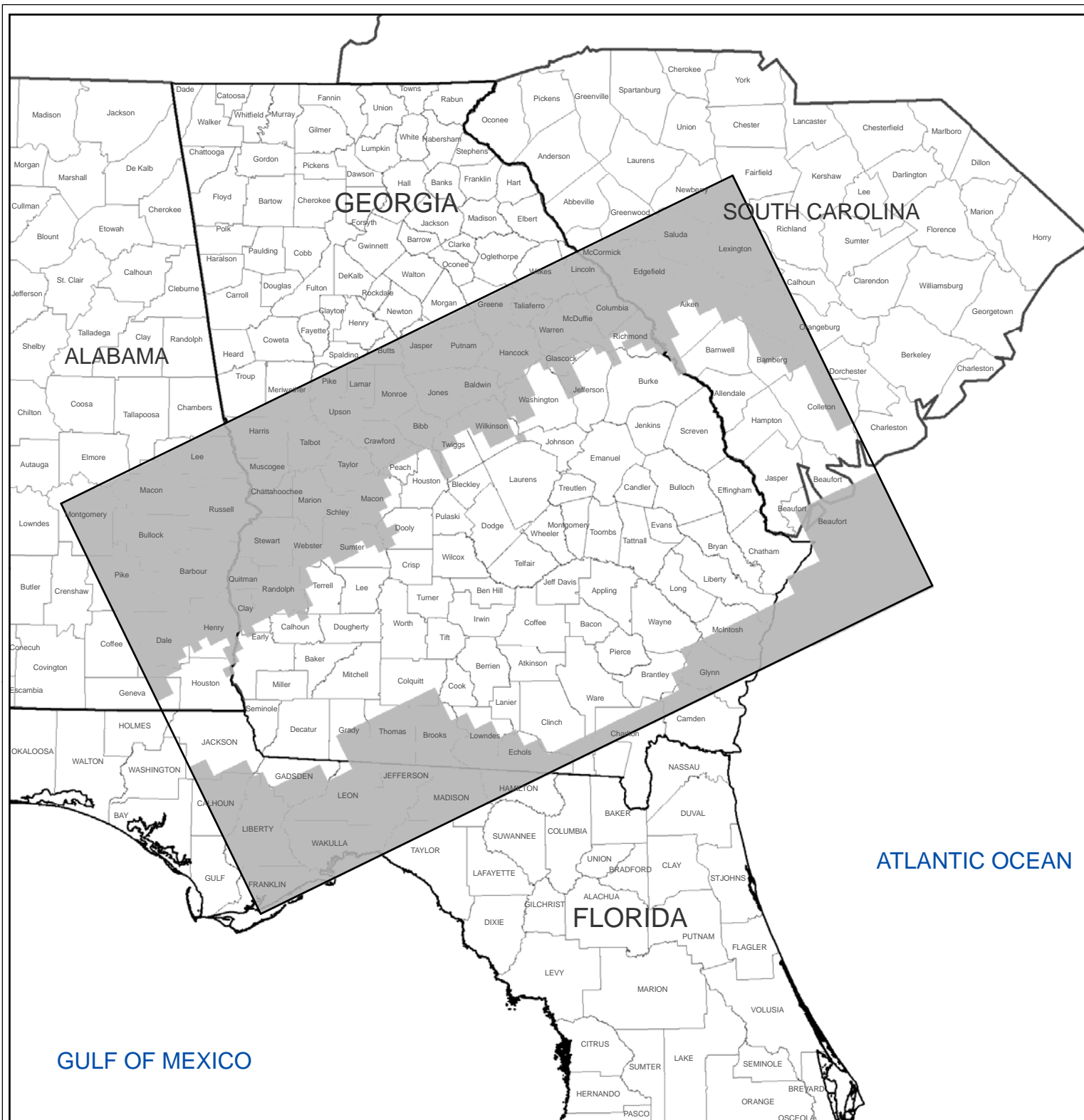
Table 5-7 Summary of Selected Major River Stage Stations (Continuation)

Station ID	Staff Gauge Station	State Plane GA West (ft)		Data Recorded Period		Average Stage (ft NGVD)	Max Stage (ft NGVD)	Min Stage (ft NGVD)
02215100	TUCSAWHATCHEE CREEK NEAR HAWKINSVILLE, GA	2,502,188	815,156	10/1/2000	3/22/2009	212.8	224.4	211.2
02343225	PATAULA CREEK NEAR GEORGETOWN, GA	2,045,884	662,323	5/22/2008	3/22/2009	213.0	219.7	211.5
02344872	FLINT RIVER BELOW BIG BRANCH, NEAR MOLENA, GA	2,186,213	1,108,525	7/1/2004	3/22/2009	655.7	681.0	652.9
02349605	FLINT RIVER AT GA 26, NEAR MONTEZUMA, GA	2,334,607	834,044	10/1/2002	3/22/2009	259.3	277.5	255.6
02350900	KINCHAFOONEE CREEK AT PINEWOOD ROAD, NR DAWSON, GA	2,269,649	641,742	10/1/2000	3/22/2009	216.3	231.2	213.7
02355662	FLINT RIVER AT RIVERVIEW PLANTATION, NR HOPEFUL, GA	2,198,472	414,940	5/8/2002	3/22/2009	69.5	98.7	64.9
02202040	OGEECHEE RIVER AT ROCKY FORD RD, NR ROCKY FORD, GA	3,012,566	971,375	9/27/2002	3/22/2009	110.8	119.1	107.6
02327500	OCHLOCKONEE RIVER NEAR THOMASVILLE, GA	2,334,610	318,509	10/12/2000	3/22/2009	138.8	153.7	134.4
02351500	MUCKALEE CREEK NEAR AMERICUS, GA	2,268,280	757,641	5/31/2001	3/22/2009	323.8	331.1	321.6
02358000	APALACHICOLA RIVER AT CHATTAHOOCHEE FLA	2,078,970	255,614	10/1/1928	3/22/2009	16.9	76.5	-2.8
02359170	APALACHICOLA RIVER NR SUMATRA, FLA.	2,027,776	-17,417	5/11/1950	3/22/2009	5.2	15.3	1.1
02315500	SUWANNEE RIVER AT WHITE SPRINGS, FLA.	2,747,271	121,311	6/1/1906	3/22/2009	24.1	85.4	1.1

Table 5-7 Summary of Selected Major River Stage Stations (Continuation)

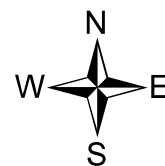
Station ID	Staff Gauge Station	State Plane GA West (ft)		Data Recorded Period		Average Stage (ft NGVD)	Max Stage (ft NGVD)	Min Stage (ft NGVD)
02319500	SUWANNEE RIVER AT ELLAVILLE, FLA	2,610,267	141,265	2/1/1927	3/22/2009	33.9	68.0	28.5
02319800	SUWANNEE RIVER AT DOWLING PARK, FLORIDA	2,586,152	90,243	10/3/1996	3/22/2009	26.1	54.0	21.1
02320000	SUWANNEE RIVER AT LURAVILLE, FLA.	2,611,261	37,716	2/3/1927	3/22/2009	14.5	47.0	1.4
02320500	SUWANNEE RIVER AT BRANFORD, FLA.	2,688,958	-13,960	7/9/1931	3/22/2009	13.8	38.8	6.7
02168504	SALUDA RIVER BELOW LK MURRAY DAM NR COLUMBIA, SC	3,192,409	1,486,564	10/1/1988	3/22/2009	174.1	185.9	171.0
02173500	NORTH FORK EDISTO RIVER AT ORANGEBURG, SC	3,300,880	1,283,054	10/28/1982	8/30/1983	153.0	158.9	148.6
02174000	EDISTO RIVER NEAR BRANCHVILLE, SC	3,326,524	1,172,008	8/3/1986	9/30/1996	84.6	90.9	80.3
02361000	CHOCTAWHATCHEE RIVER NEAR NEWTON, AL.	1,845,835	491,371	10/1/1971	3/22/2009	143.4	177.4	140.0
02361500	CHOCTAWHATCHEE RIVER NEAR BELLWOOD AL	1,790,564	425,331	12/7/2000	3/22/2009	5.9	16.3	2.8
02363000	PEA RIVER NEAR ARITON AL	1,793,324	583,775	10/1/1987	3/22/2009	249.9	270.4	248.3
02364000	PEA RIVER AT ELBA, AL.	1,704,987	519,182	10/1/1971	3/22/2009	166.1	202.5	159.2
02173000	SOUTH FORK EDISTO RIVER NEAR DENMARK, S.C.	3,222,550	1,247,715	8/13/1931	2/23/2009	163.2	166.8	159.6
02175000	EDISTO RIVER NR GIVHANS, SC	3,453,879	1,122,114	1/4/1939	3/18/2009	26.1	36.3	21.1

Figure 5-16 shows the distribution of recharge applied to the model in the outcrop areas. From Figure 5-16, recharge within the outcrop area of Georgia ranges from 0.1 to 6.0 inches per year. This range of recharge estimates is consistent with the range of recharge estimates from the USGS for the Upper Floridan Aquifer (0 to 15 inches/year from Figure 2-10) and the Claiborne, Clayton, and Cretaceous Aquifers (0 to 5 inches/year from Figure 2-13) in the outcrop areas.



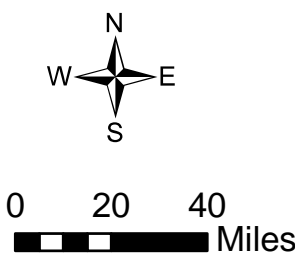
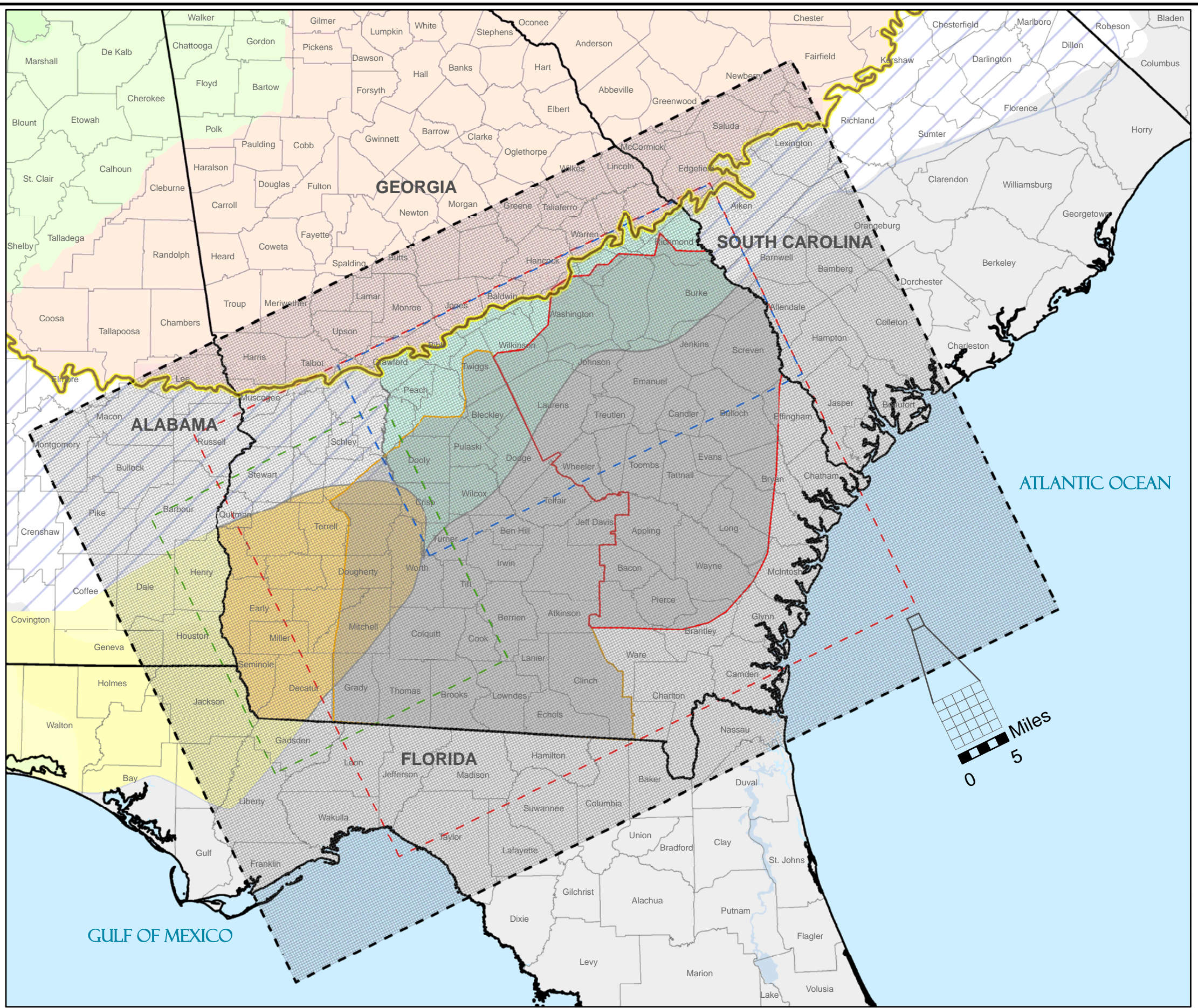
Legend

- Active Model Cells
- Inactive Model Cells

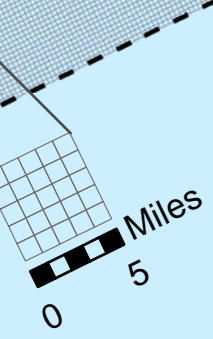


0 30 60 Miles

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- Legend**
- Regional Coastal Plain Model Domain
 - Sub-Regional Claiborne Aquifer Model Domain
 - Sub-Regional Cretaceous Aquifer Model Domain
 - Sub-Regional Upper Floridan Aquifer Model Domain
 - Eastern Coastal Plain Floridan Aquifer Area
 - South Central Georgia Floridan Aquifer Area
 - Claiborne Aquifer in Georgia
 - Cretaceous Aquifer in Georgia
 - Floridan Aquifer
 - Claiborne Aquifer
 - Cretaceous Aquifer
 - Crystalline-Rock Aquifers
 - Paleozoic-Rock Aquifers
 - Fall Line



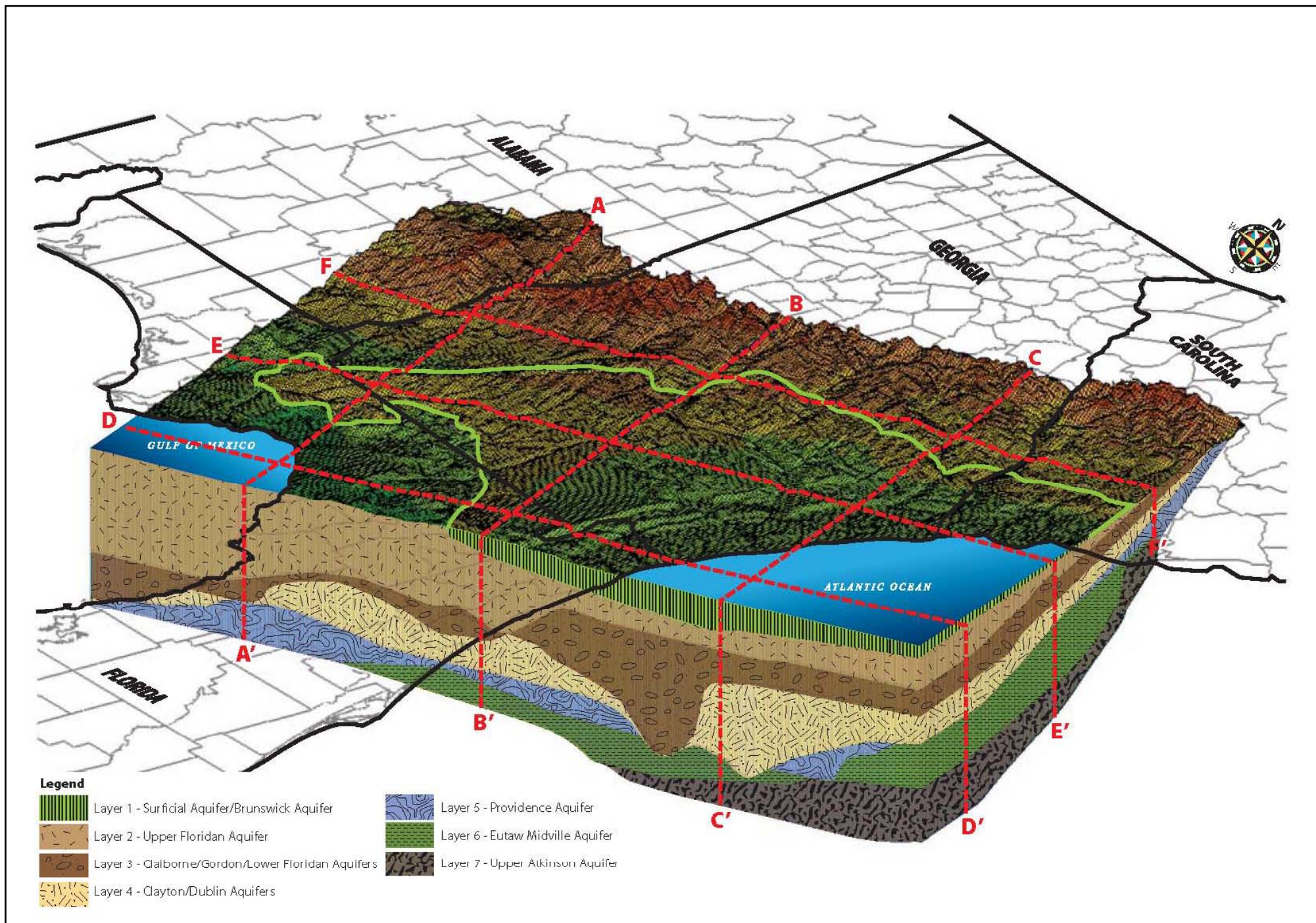
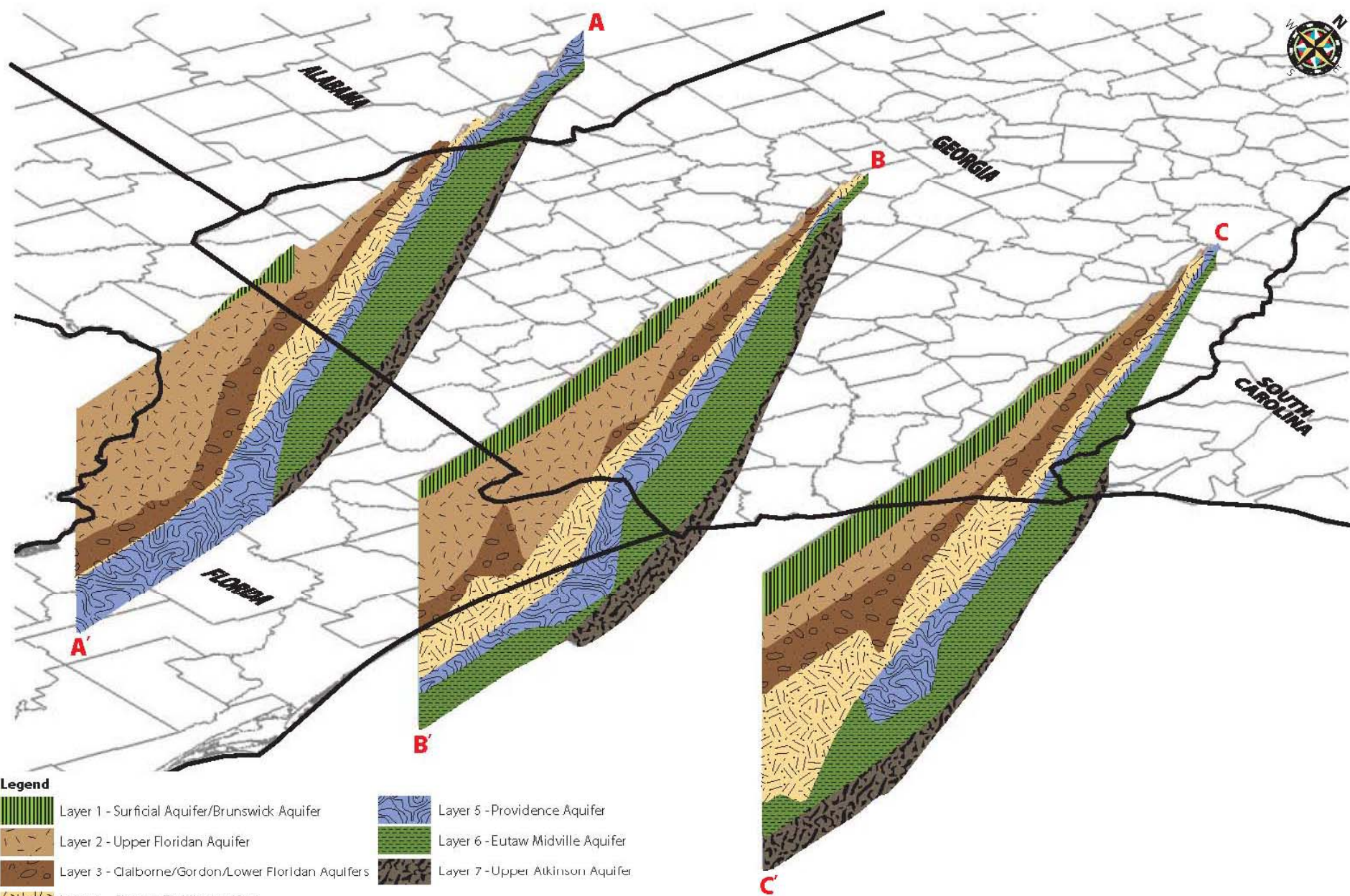


Figure 5-3
Three-Dimensional Regional Georgia EPD Groundwater Flow Model and Cross Section Locations



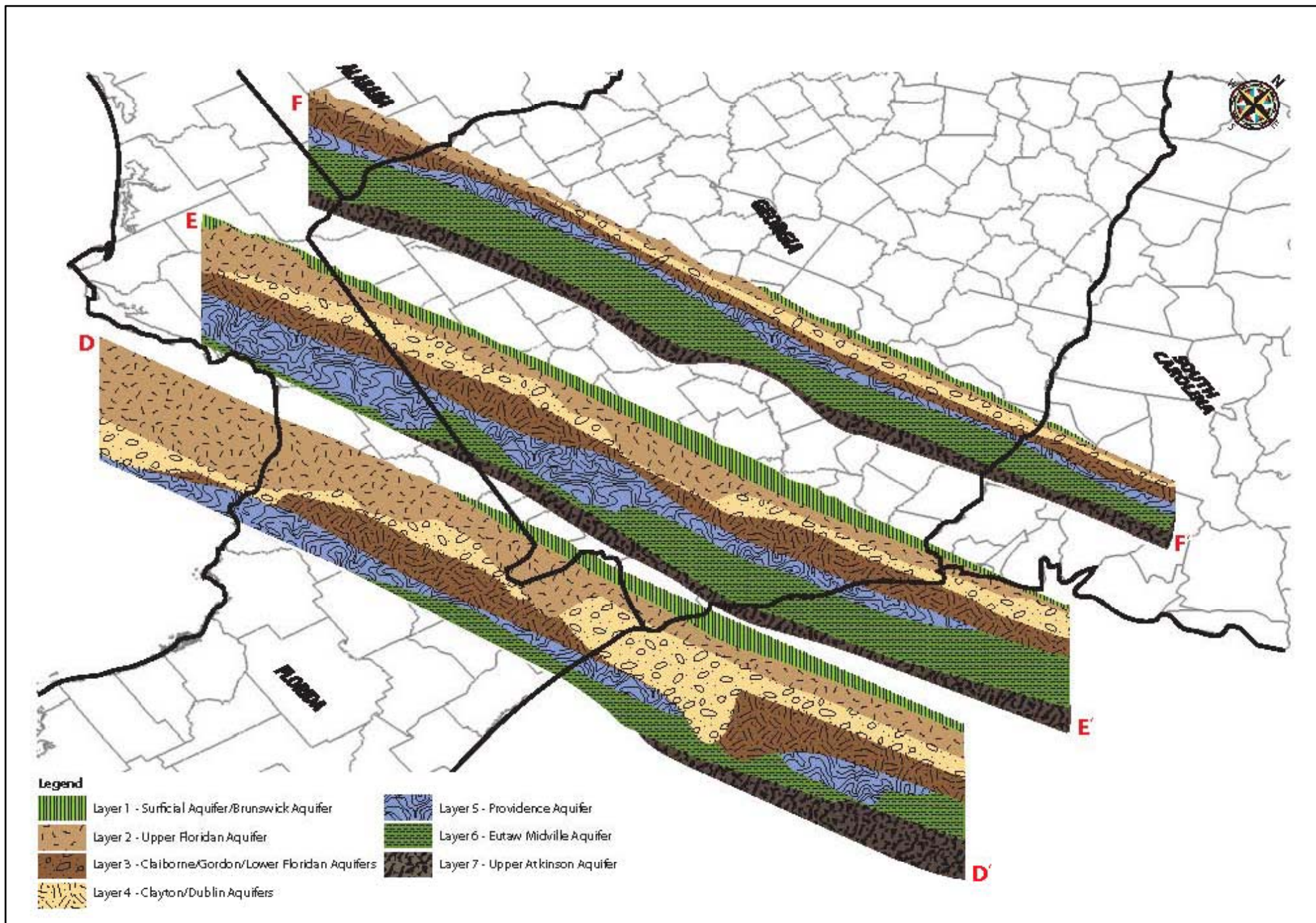
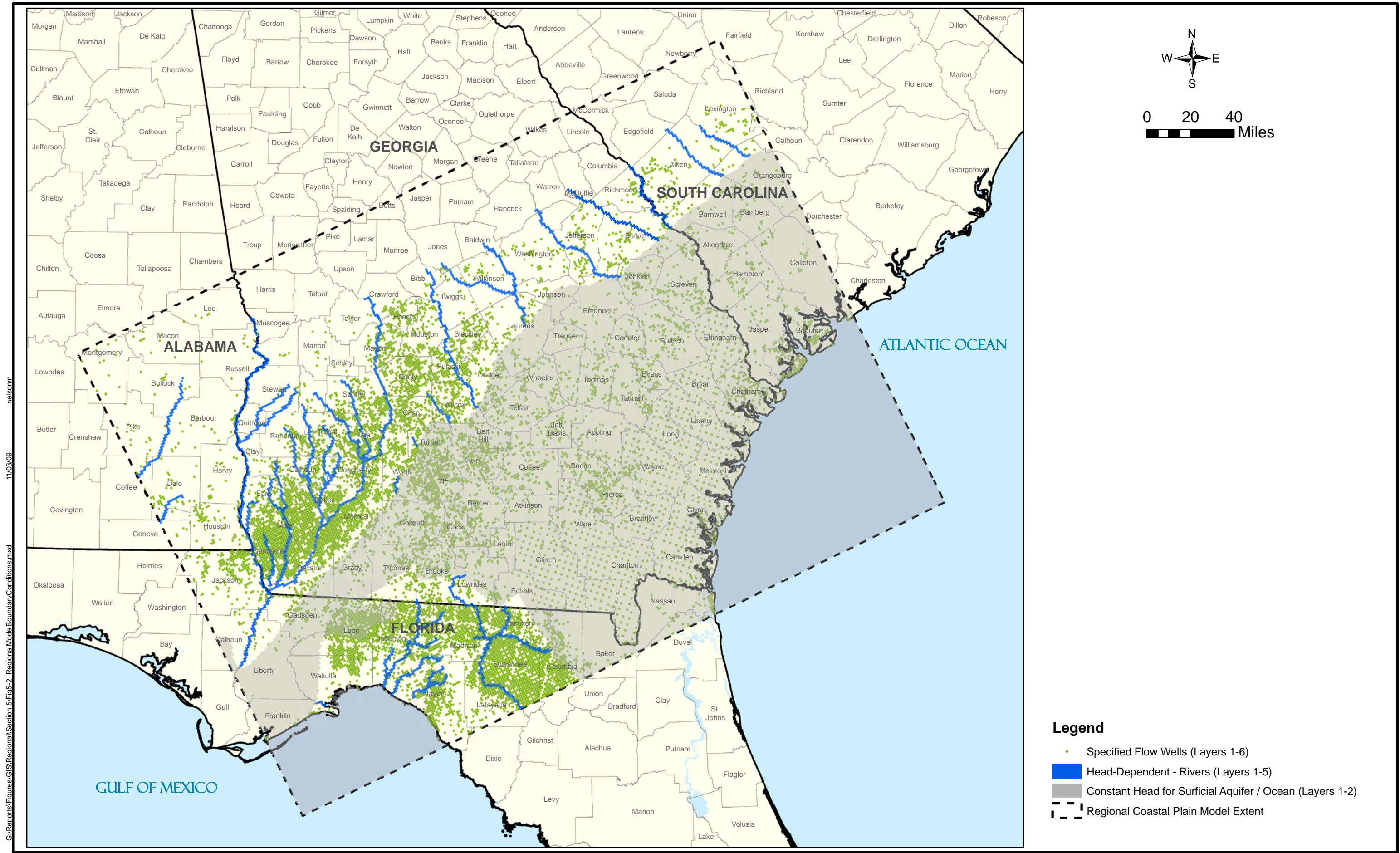
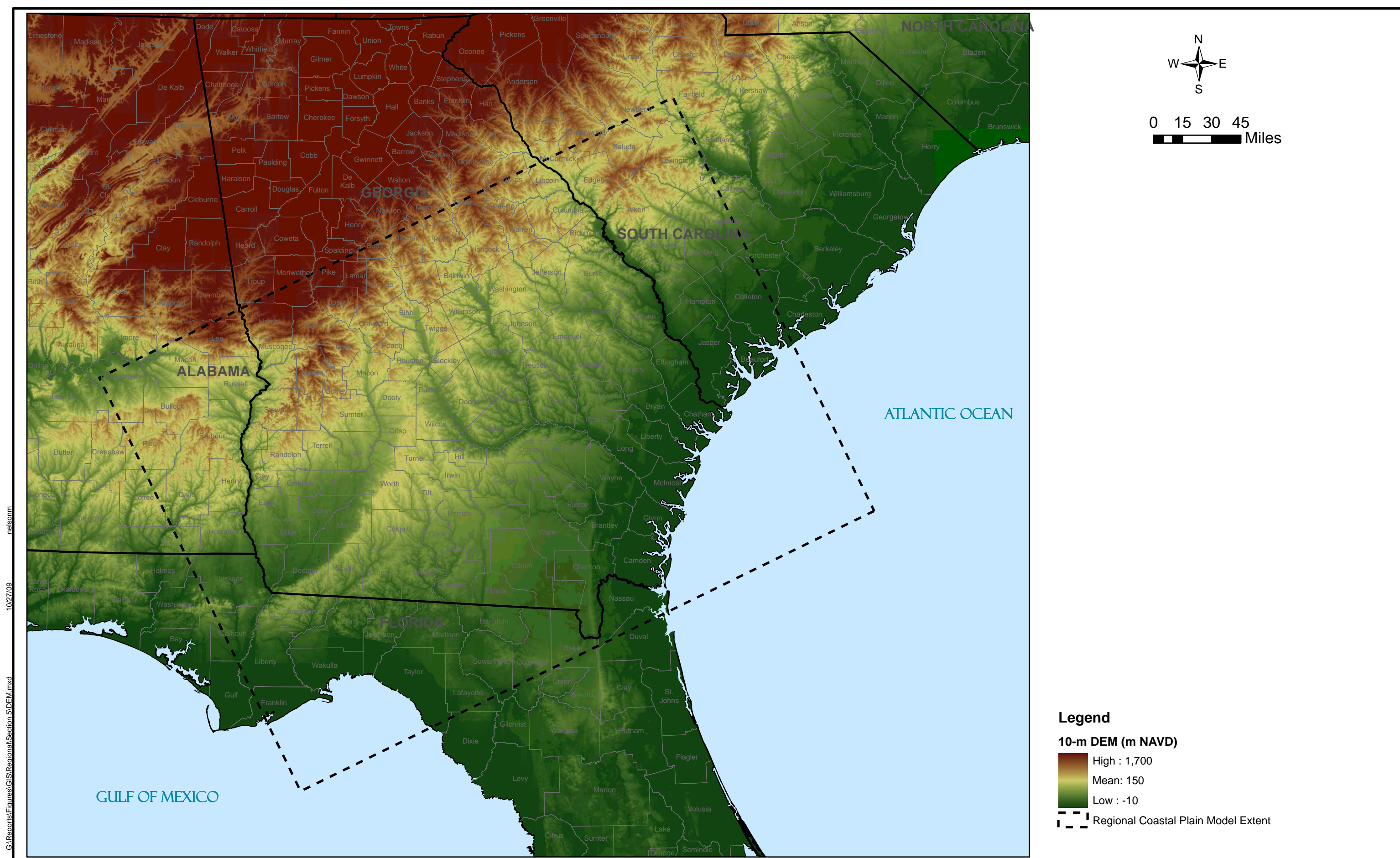


Figure 5-5
East-West Cross Sections Through Coastal Plain Aquifer in Georgia



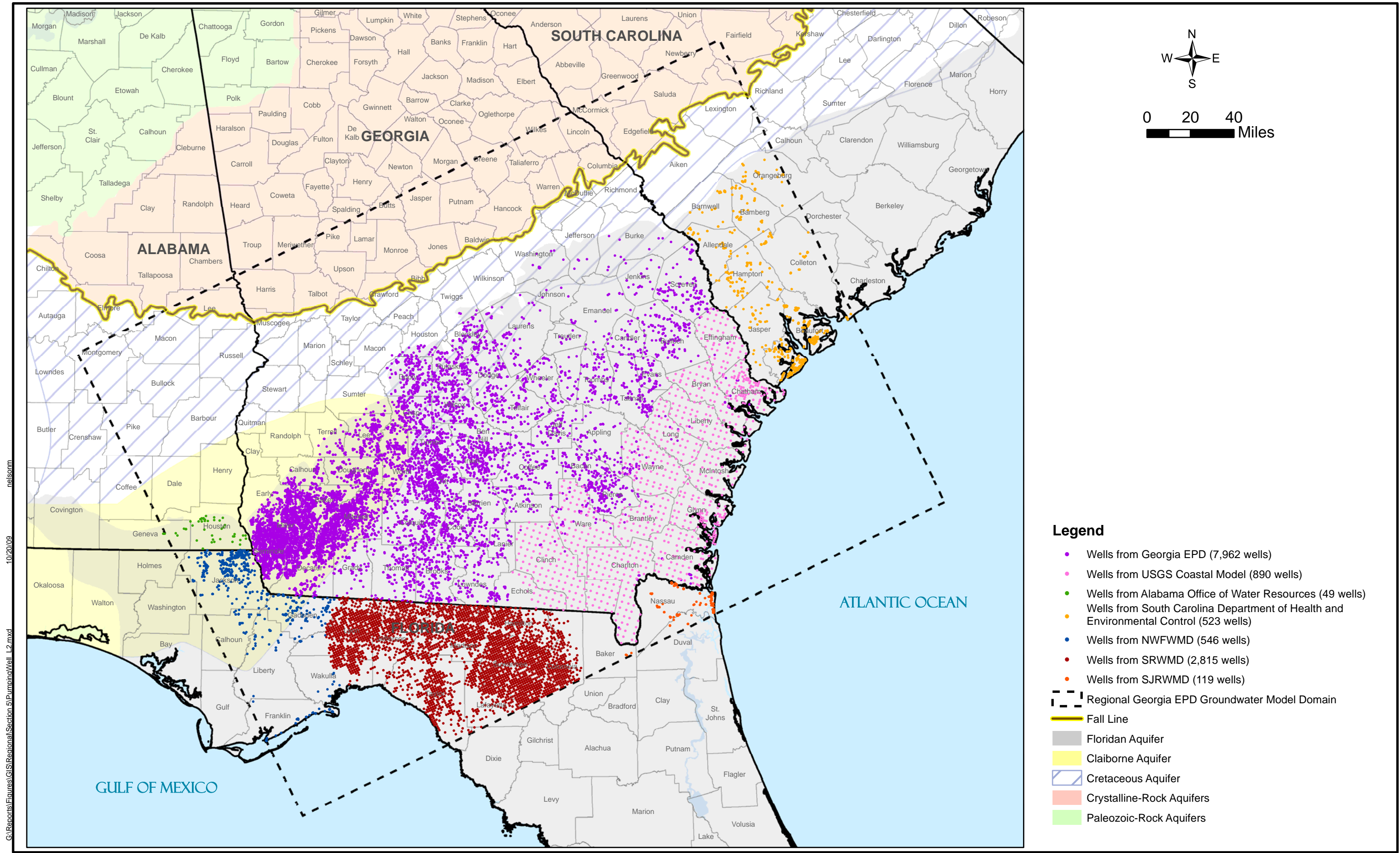
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CDM **Figure 5-6**
Regional Groundwater Flow Model Boundary Conditions



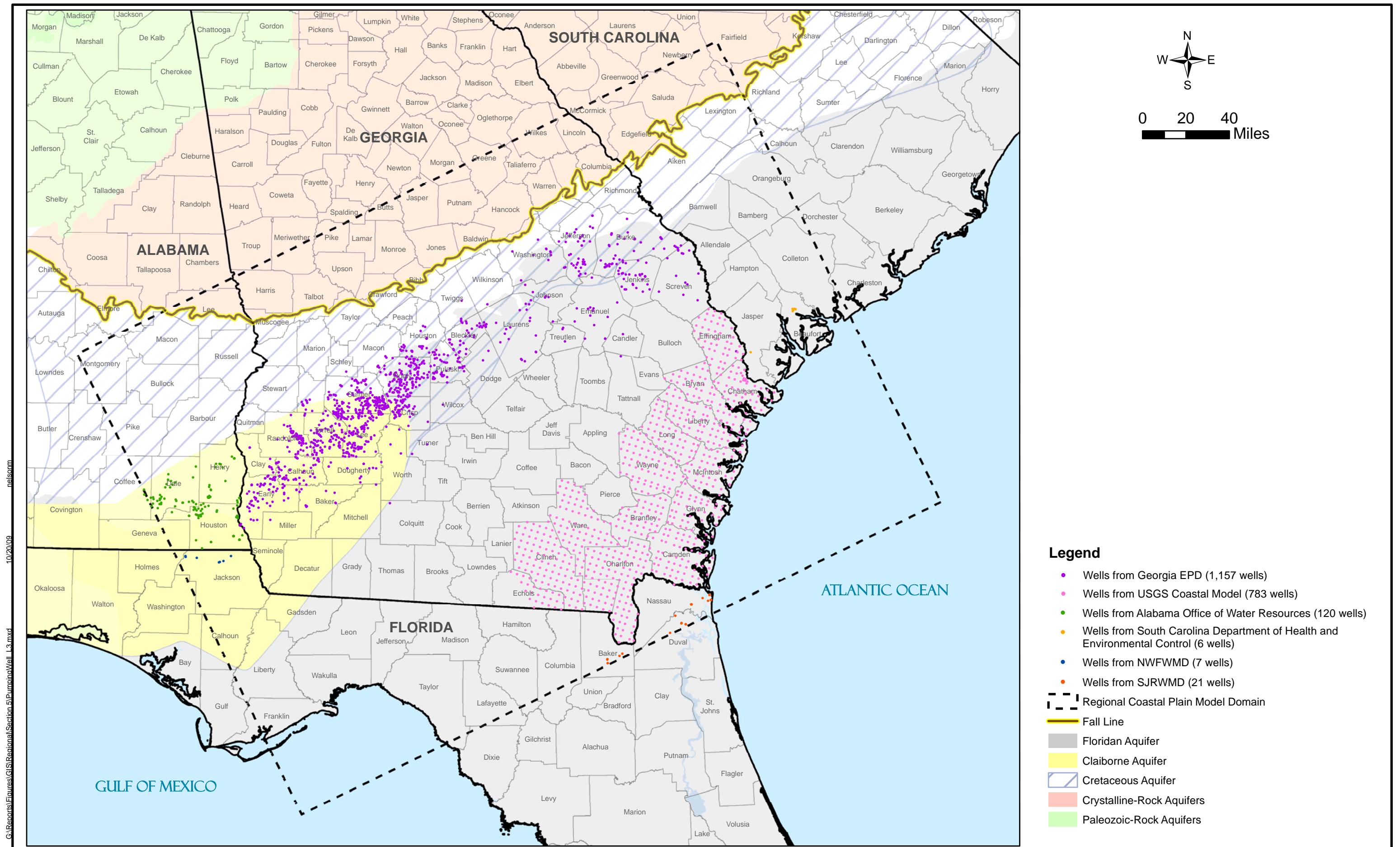
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CDM **Figure 5-7**
Digital Elevation Model (DEM) Map of the Southeastern United States



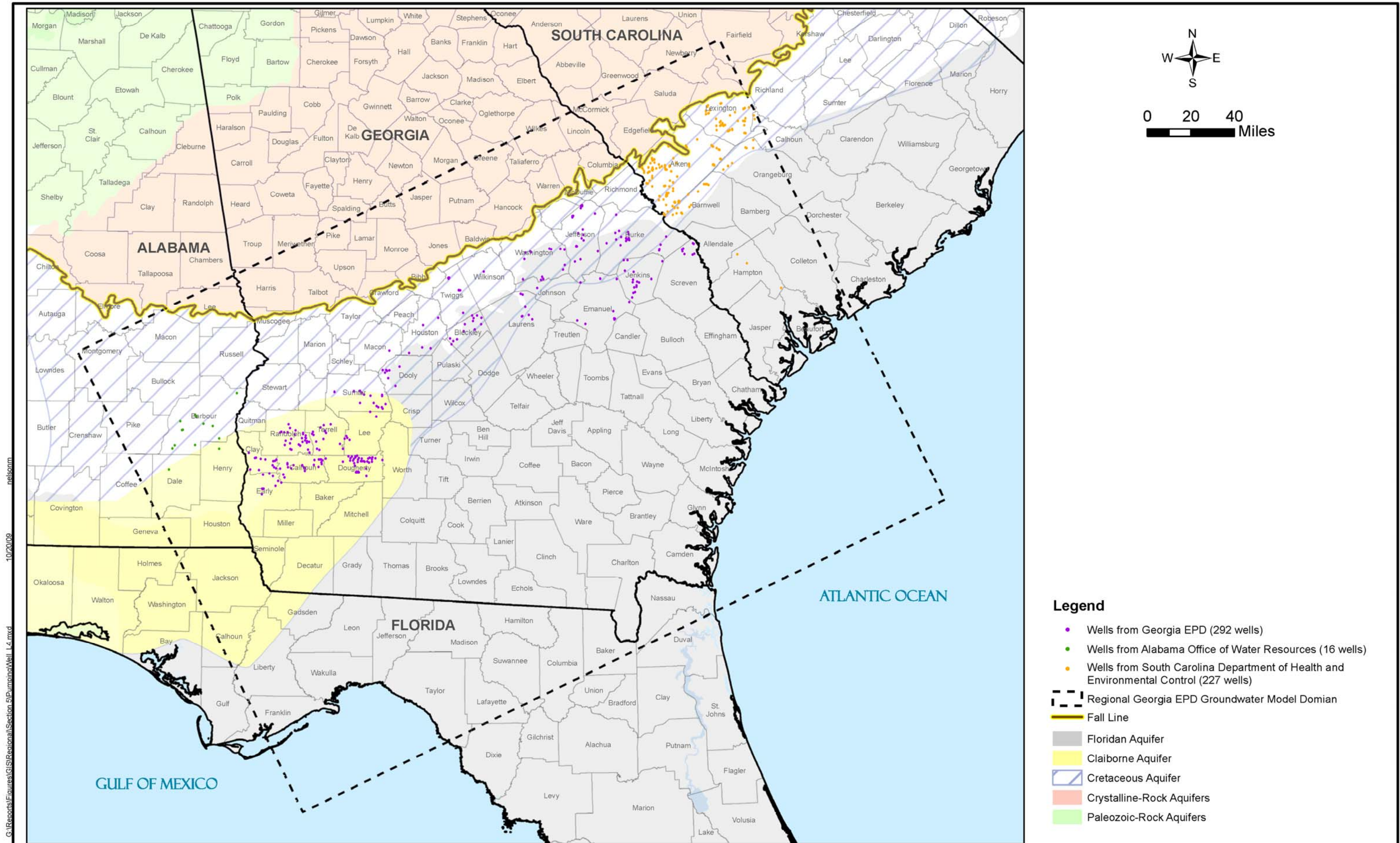
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Figure 5-8
Well Locations in Upper Floridan Aquifer (Layer 2)



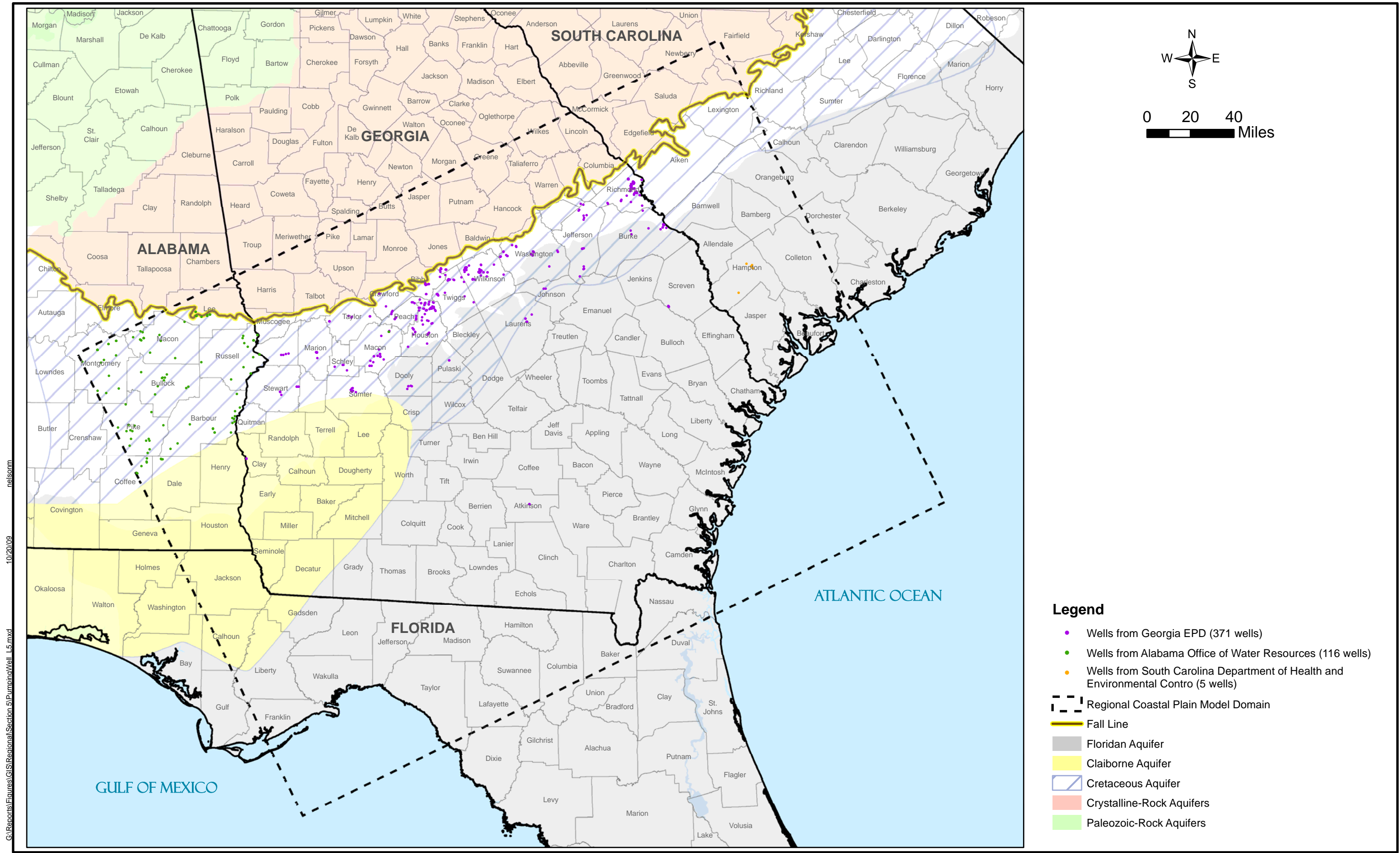
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CDM **Figure 5-9**
Well Locations in Claiborne/Gordon/Lower Floridan Aquifers (Layer 3)



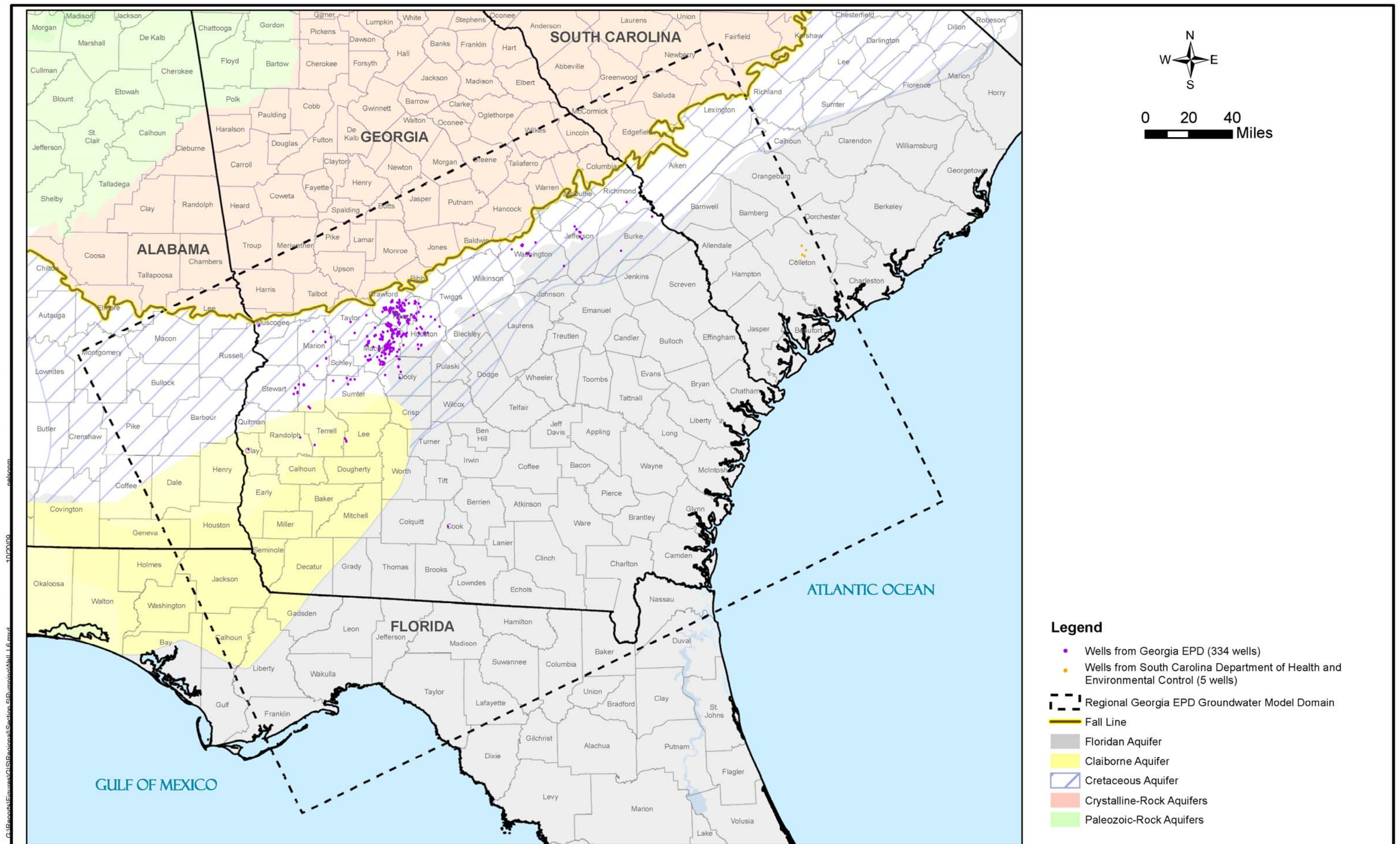
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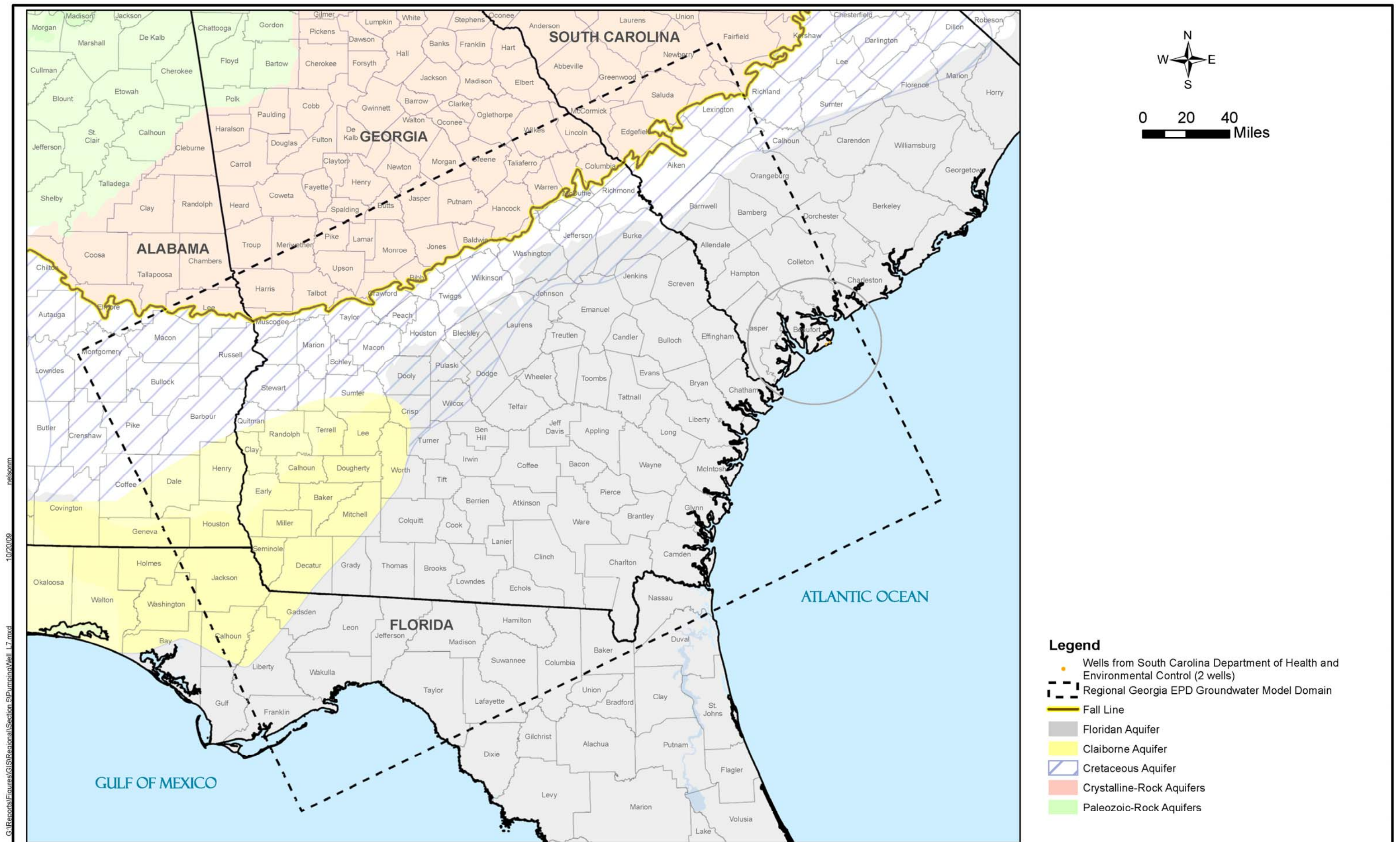
Figure 5-10
Well Locations in Clayton-Dublin Aquifers (Layer 4)



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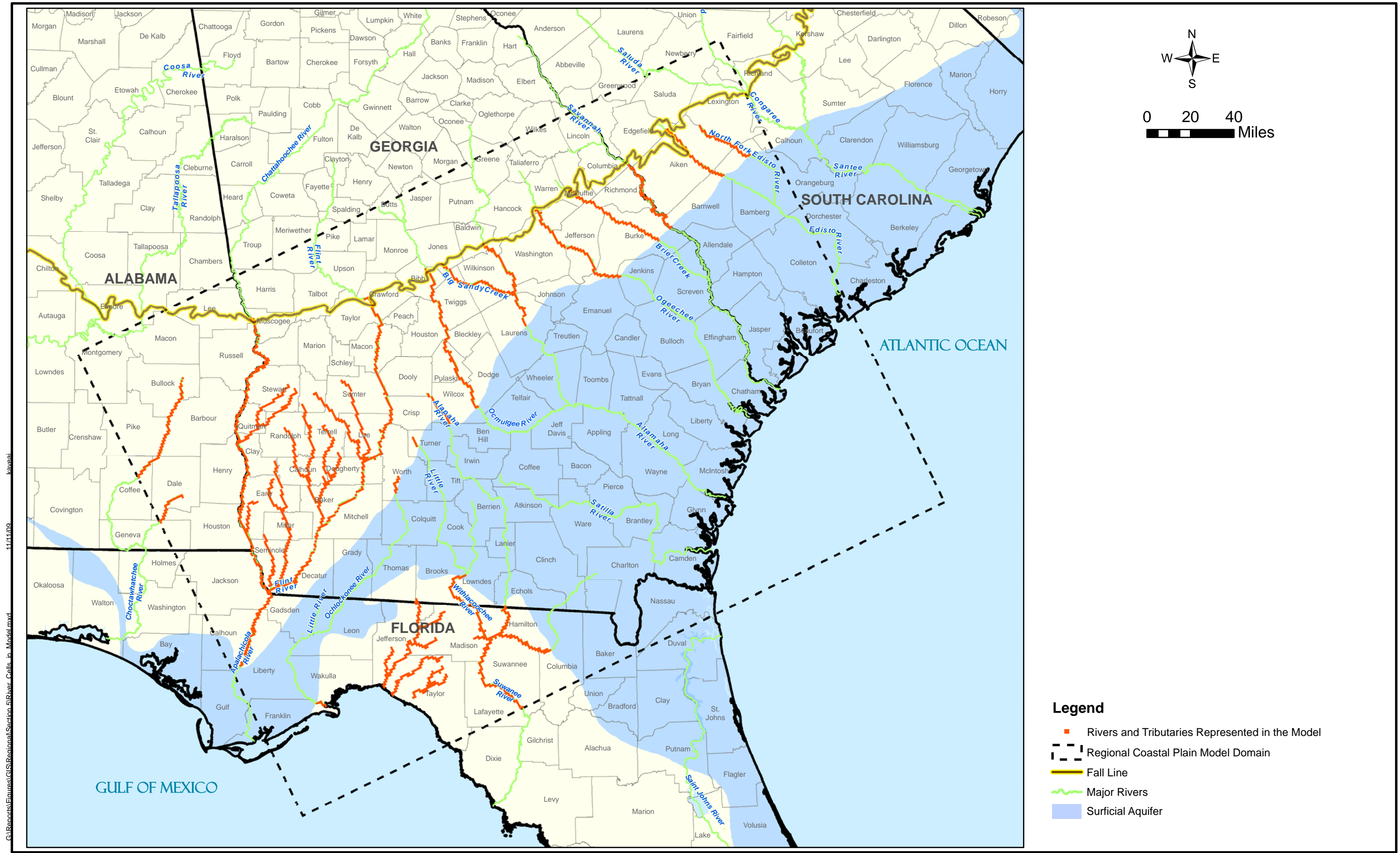
CDM **Figure 5-11**
Well Locations in the Providence Sand-Peedee-Dublin Aquifers (Layer 5)



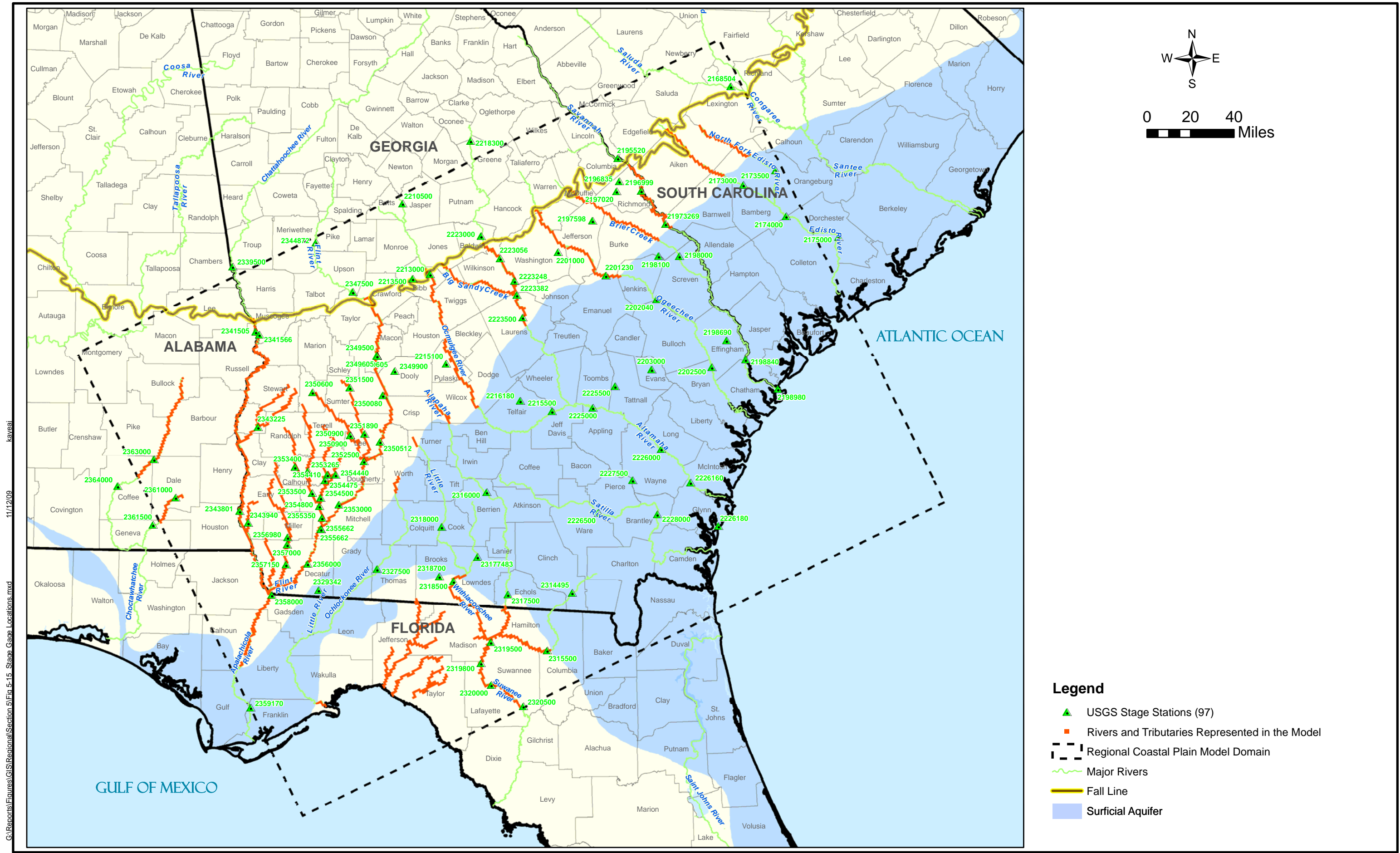


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Figure 5-13
Well Locations in Upper Atkinson-Upper Tuscaloosa Aquifers (Layer 7)



CDM **Figure 5-14**
Locations of River Cells in Regional Groundwater Flow Model



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CDM **Figure 5-15**
Locations of USGS Stage Stations in Regional Groundwater Flow Model

