

# Section 7

## Regional to Sub-Regional Groundwater Flow Model Development Process

### 7.1 Regional Groundwater Flow Model

Although the regional steady-state groundwater flow model was not originally anticipated when this project was scoped, it was developed and used to evaluate the model extent and provide lateral edge boundary conditions for detailed sub-regional groundwater flow modeling. This methodology is a fairly common, accepted industry practice. This section describes how the regional model was used in developing the sub-regional models.

### 7.2 Transient Sub-Regional Groundwater Flow Models

According to the scope of work, CDM was tasked with developing and calibrating transient numerical groundwater flow models for four project areas in prioritized aquifers within the Coastal Plain aquifer of Georgia, as follows:

- The Upper Floridan Aquifer in south-central Georgia;
- The Upper Floridan Aquifer in the eastern Coastal Plain;
- The entire extent of the Claiborne Aquifer in southwestern Georgia; and
- The Cretaceous Aquifer between Augusta and Macon, Georgia.

Although there are four project areas, three transient sub-regional models were developed and calibrated for this project. The Claiborne and Cretaceous Aquifer models were developed as stand-alone models, and the Upper Floridan Aquifer model was developed to cover two project areas (south-central Georgia and eastern Coastal Plain). These areas are immediately adjacent to one another, and pumping from one area will impact the other. The extent of the three sub-regional models is shown on **Figure 7-1**. In the Upper Floridan Aquifer, however, the sustainable yield assessment simulations for the south-central Georgia area were conducted separately from the sustainable yield simulations for the eastern Coastal Plain area, and then simulations were conducted for the Upper Floridan Aquifer in both south-central Georgia and the eastern coastal plain to assess the impact of pumping in the adjacent area on the sustainable yield estimates.

Several preliminary simulations were performed using the Georgia EPD regional groundwater flow model to evaluate groundwater level drawdown due to pumping in south-central Georgia and the eastern Coastal Plain and to help determine the horizontal extent of the Upper Floridan Aquifer Subregional Model. **Figures 7-2 and 7-3** display the groundwater level drawdown in the Upper Floridan Aquifer that results from increasing the Upper Floridan Aquifer well pumping by approximately five times the current pumping in south-central Georgia and the eastern Coastal Plain,

respectively. The groundwater level drawdown in other Coastal Plain aquifers due to increasing the Upper Floridan Aquifer well pumping in south-central Georgia and the eastern Coastal Plain are presented on **Figures H-1 through H-10 in Appendix H**. As shown on these figures, increasing pumping from one area has a drawdown impact on the other. For the test runs, pumping increases of 1,200 and 524 mgd were simulated in south-central Georgia and the eastern Coastal Plain, respectively. These pumping rates were anticipated to be greater than the sustainable yields for the Upper Floridan Aquifer in these areas.

For the Cretaceous Aquifer sub-regional model, the eastern boundary of the model extends just past the Georgia-South Carolina state line, and the western model boundary extends to the Flint River. The northern boundary of this model extends into the crystalline rock aquifers of the Piedmont at the northern extent of the Cretaceous Aquifer System and extends approximately 83 miles to the south. For the Claiborne Aquifer sub-regional model, the extent of the model includes all of the Claiborne Aquifer in Georgia, southeastern Alabama and north Florida. Along the western, southern and eastern lateral edges of Layers 2 through 7 for all three sub-regional models, a General Head Boundary condition was used to assist with drawdown that may occur at the edges of these models during performance of the sustainable yield simulations of increased pumping in these prioritized aquifers. The northern lateral edge boundary of layers 2 through 7 for all three sub-regional models, a no flow boundary was used to represent the termination of these aquifers near the Fall Line.

Based on data collected by the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center for the period 1948 through 2008, the average annual rainfall in the Coastal Plain of Georgia is approximately 49 inches (see Section 2.1). The recorded annual rainfall in 2004, 2005, and 2006 was approximately 51.5, 56.0, and 39.2 inches, respectively. Therefore, annual rainfalls in 2004, 2005, and 2006 represent an average rainfall year, a high rainfall year, and a low rainfall year, respectively. Three sub-regional groundwater flow models for this project were constructed and calibrated to represent the range of hydrologic conditions that occurred in this three-year period.

### 7.3 Process for Sub-Regional Groundwater Flow Model Development

In order to construct transient sub-regional groundwater models from the calibrated Georgia EPD steady-state regional model, several items related to model construction and inputs were changed. The specific items are presented below.

- **Sub-Regional Model Layers:** Each sub-regional model included the same seven model layers as those in the regional model for representation of all aquifers in the Coastal Plain of Georgia (i.e., from the Surficial Aquifer to the Upper Atkinson Aquifer).

- Sub-Regional Model Grid System: The sub-regional model discretization was refined from a uniform grid spacing of 1 mile by 1 mile used in the regional model to a uniform grid spacing of 2,000 feet by 2,000 feet for each sub-regional model.
- Transient Conditions: Temporal discretization (i.e., stress periods) of the sub-regional model was modified from steady-state conditions in the regional model to monthly transient conditions to represent the hydrology and pumping in an average rainfall year, a high rainfall year, and a low rainfall year.
- Hydrogeologic Properties: The sub-regional models were constructed using the same hydrologic and hydrogeologic properties of the aquifer systems used in the regional model. The layer data, including the horizontal hydraulic conductivities, transmissivity, leakance, and top and bottom elevations of each aquifer layer, were interpolated from the regional model into the smaller grids of the sub-regional models. These parameters were further calibrated in transient conditions.
- General Head Boundary for the Sub-Regional Models: Groundwater elevations from the regional model were assigned to the western, southern and eastern sub-regional model boundary for each aquifer layer, except Layer 1 (Surficial Aquifer). A General Head boundary condition was used under transient conditions to represent variation of groundwater levels at the lateral edges of the sub-regional models based on monitor well data. As stated above, the northern lateral edge boundary of layers 2 through 7 for all three sub-regional models, a no flow boundary was used to represent the termination of these aquifers near the Fall Line (consistent with the regional model).
- Well Pumping: According to Georgia EPD records, pumping data for the existing permitted wells are only available for the major public water supply and industrial users. There are no pumping data available for most of the agricultural users.
  - Two data sources were provided by Georgia EPD for the municipal and industrial major water users with a permitted pumping rate > 0.1 mgd, since this is the threshold requiring a permit from Georgia EPD. These 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. Agricultural well locations were included in the third database. These database files did not contain total screen depth listed or 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.
  - As discussed in Section 5.4.6, for users without pumping records, the average pumping rates for each permitted user's wells were estimated based on Georgia EPD reports, allocations, well capacities, and USGS publications by

Fanning (2003) and Fanning and Trent (2009). For the transient model simulations, each permitted agricultural well pumping rate was redistributed based on growing season (i.e., March through October) and non-growing season (i.e., November through February) for different rainfall years (Fanning et al., 2001; Hook and Harrison, 2005; Hook and Harrison, 2007).

- **River Package:** Monthly average surface water elevations at 97 staff gauging stations in the rivers were used in the model River Package to represent surface water elevations in an average rainfall year, a high rainfall year, and a low rainfall year.
- **Aquifer Recharge:** Monthly recharge (e.g., rainfall minus ET minus direct runoff) was assigned to the transient model to represent the monthly rainfall in an average rainfall year (2004), a high rainfall year (2005), and a low rainfall year (2006). The monthly recharge rates were estimated based on the long-term average monthly rainfall and the monthly rainfall in an average rainfall year (2004), a high rainfall year (2005), and a low rainfall year (2006). A detailed description of the procedures used for monthly aquifer recharge estimation in the outcrop areas for this study is summarized, as follows:
  - **Step 1** Calculate the long-term average monthly rainfall ( $RF_{avg\_m}$ ) based on the NOAA rainfall data for the Study Area.
  - **Step 2** Calculate the monthly rainfall ( $RF_m$ ) for 2004, 2005 and 2006 based on the NOAA rainfall data.
  - **Step 3** Based on the long-term average monthly rainfall (Step 1) and the monthly rainfall for 2004, 2005 and 2006 (Step 2), calculate the monthly rainfall ratios of  $RF_m/RF_{avg\_m}$  for each model cell ( $R_{rf}$ ).
  - **Step 4** Based on the monthly rainfall ratio (Step 3) and the long-term average recharge rate ( $R_{avg}$ ) discussed in Section 5.4.8 and Section 6.6, determine monthly recharge rates for 2004, 2005 and 2006 for each model cell of the sub-regional groundwater models. The formula ( $R_{month} = R_{avg} \times R_{rf}$ ) was used to estimate the monthly recharge value.
- **Groundwater Levels in the Surficial Aquifer:** The MODFLOW Time-Variant Specific Head Package was applied to represent the variation in groundwater levels in the Surficial Aquifer. The Time-Variant Specific Heads were based on the monthly groundwater levels measured at the monitor wells in the Surficial Aquifer.

After construction of the sub-regional models, all three models were recalibrated in transient conditions to match observed groundwater levels at monitor well locations. The transient conditions consisted of 36 monthly stress periods (January 2004 through December 2006) to represent an average rainfall year (2004), a high average rainfall year (2005), and a low rainfall year (2006).

## **7.4 Calibration Criteria and Metrics for Transient Sub-Regional Groundwater Flow Models**

The calibration criteria for the transient sub-regional groundwater flow models are similar to those used for the steady-state regional model discussed in Section 6.2, as follows:

- The average of residuals (the difference between observed and model computed) in groundwater elevations in all stress periods shall be less than 10 feet across all model layers;
- The standard deviation of residuals or Root Mean Squared Error (RMSE) in groundwater elevations shall be less than 20 feet across all model layers; and
- Computed vertical head differences between the Upper Floridan Aquifer (Layer 2) and deeper aquifers at monitor well clusters shall be within 25 percent of significant observed head differences.

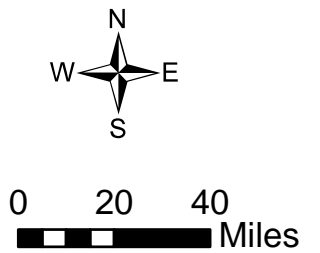
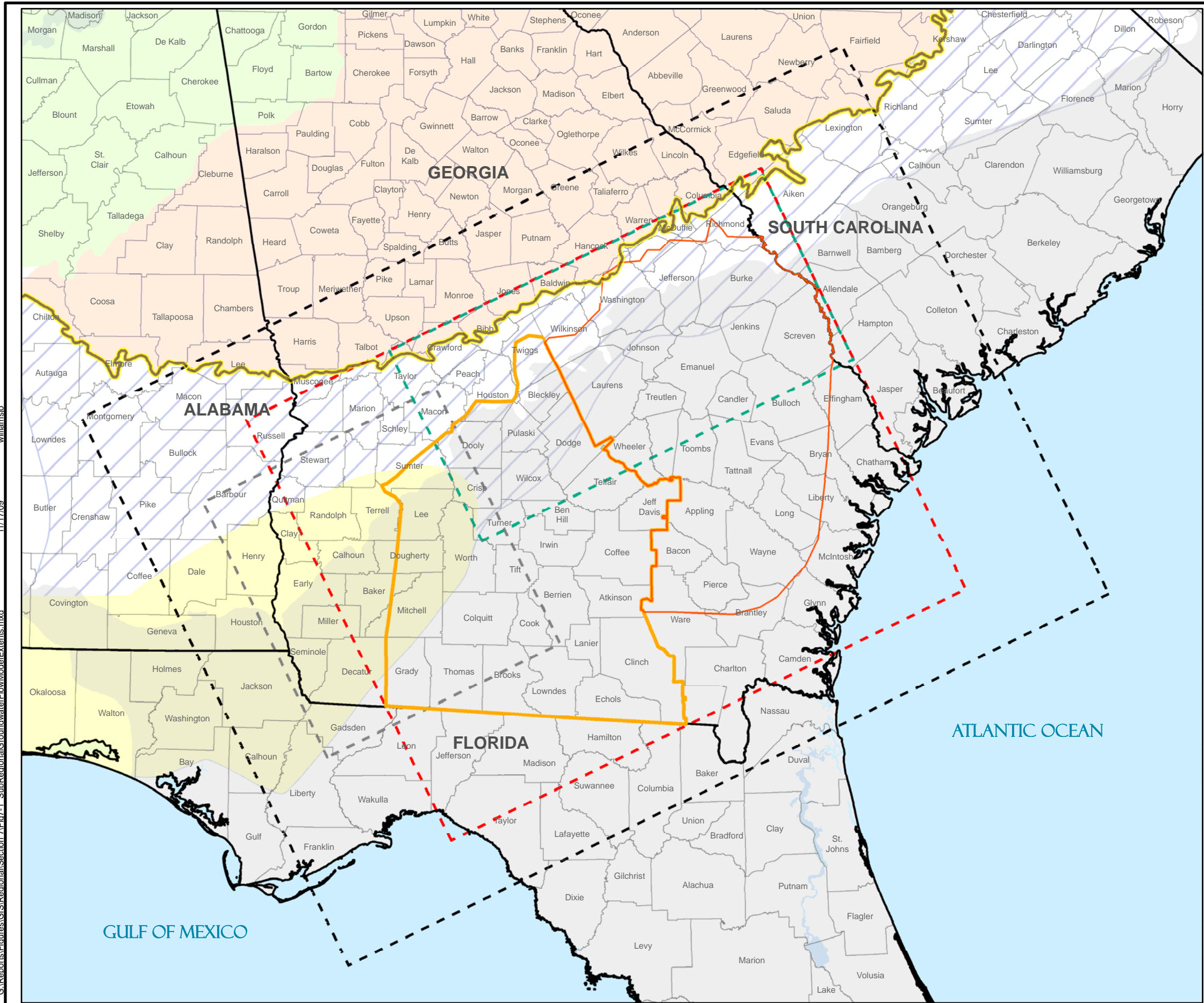
In addition to these numerical criteria, the following subjective criteria were also considered:

- The model needs to match the observed flow patterns both laterally and vertically; and
- There should be limited to no spatial bias in residuals (i.e., differences between measured and simulated heads).

The results of the sub-regional model calibrations are presented in Section 8 for the Upper Floridan Aquifer for south-central Georgia and the eastern coastal plain, in Section 9 for the Claiborne Aquifer, and in Section 10 for the Cretaceous Aquifer System.



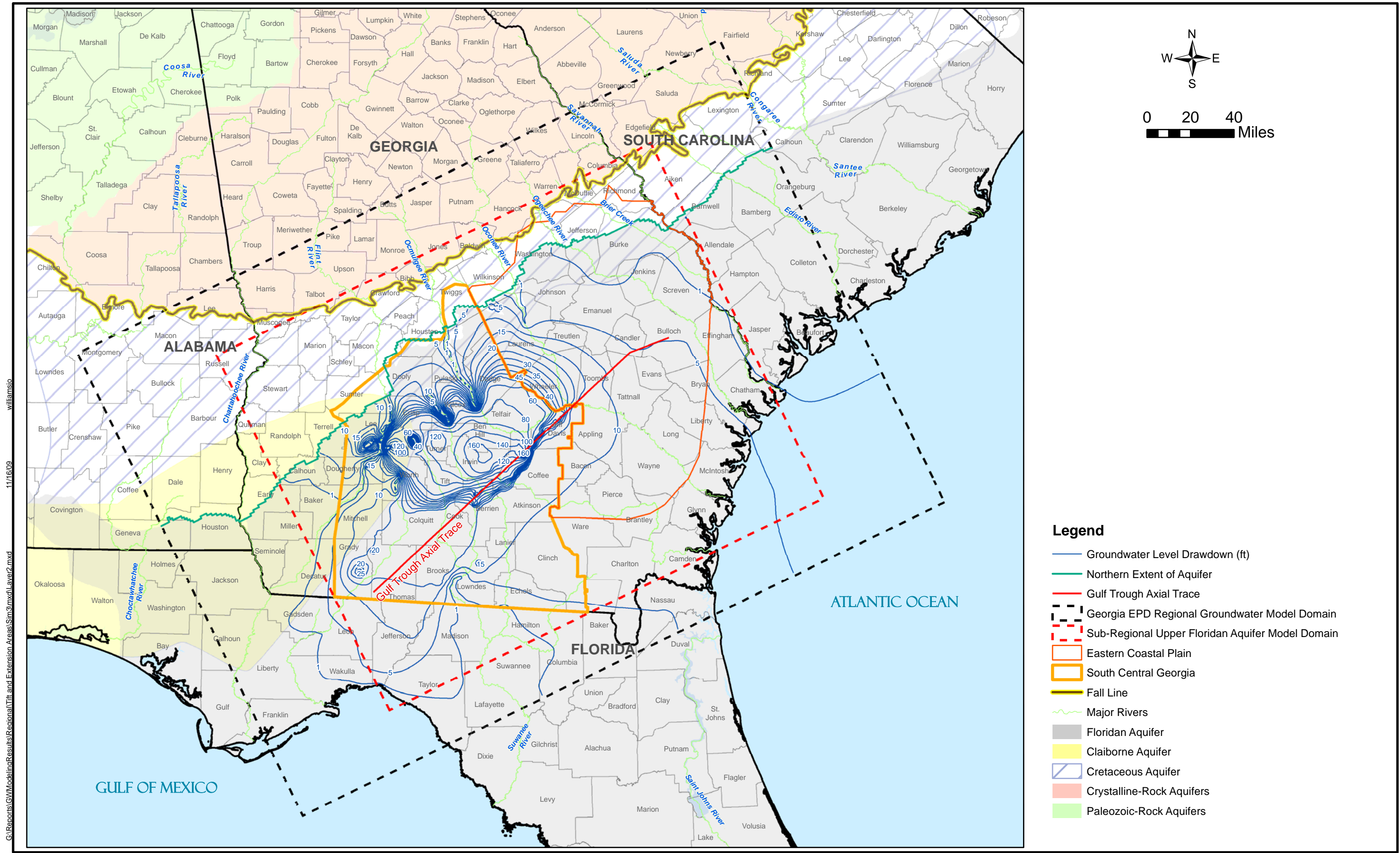
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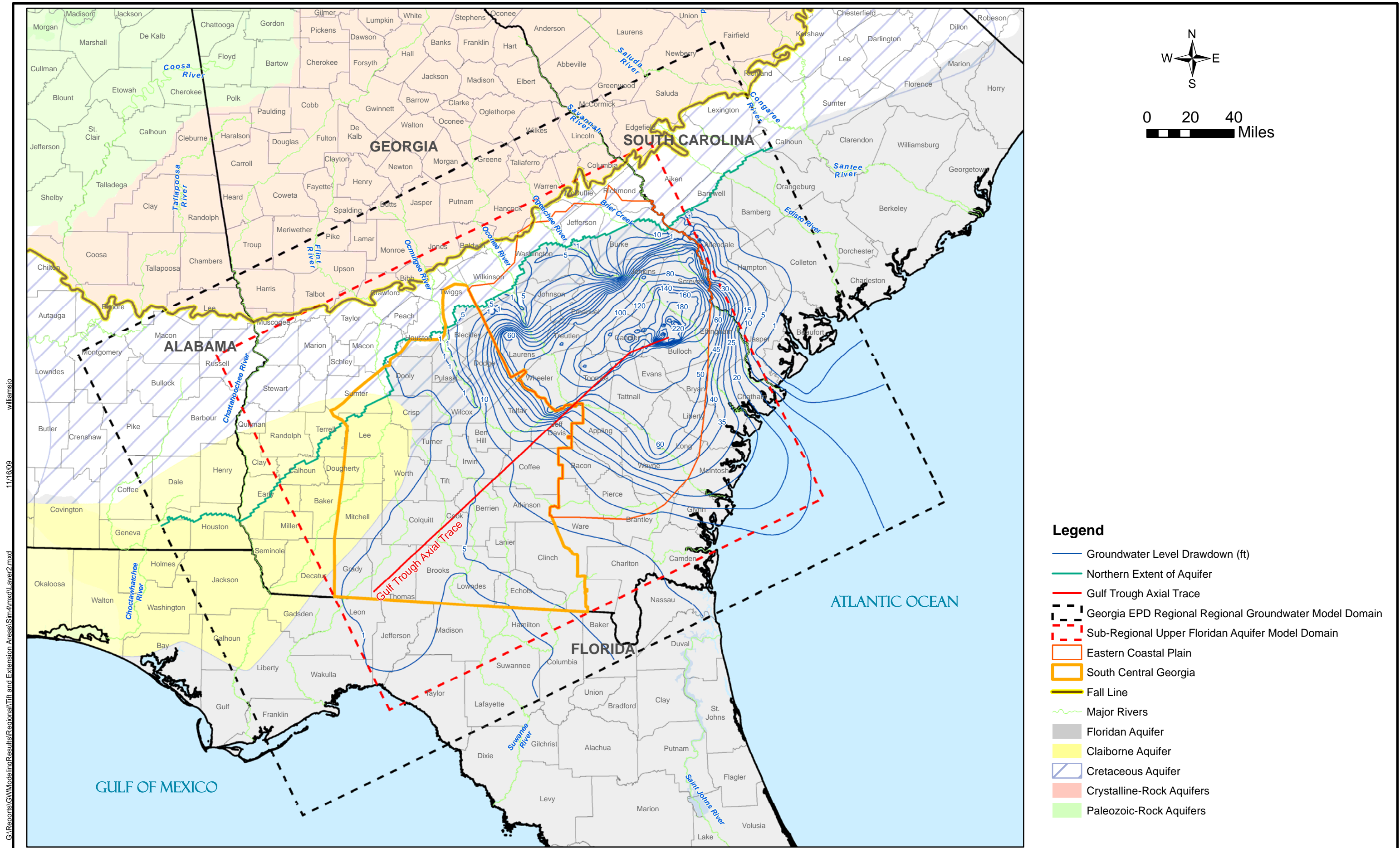
### Legend

- Regional Georgia EPD Groundwater 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
- Fall Line
- Floridan Aquifer
- Claiborne Aquifer
- Cretaceous Aquifer
- Crystalline-Rock Aquifers
- Paleozoic-Rock Aquifers









**Figure 7-3**  
**Simulated Groundwater Level Drawdown in Upper Floridan Aquifer (Layer 2)**  
**Due to Increasing Pumping in Eastern Coastal Plain Area ( $\Delta Q = 524$  mgd) Using Regional Georgia EPD Groundwater Model**