Synopsis Report Groundwater Availability Assessment

Georgia's
State Water Plan

Georgia Environmental
Protection Division

Review Draft
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Contents

Note: The Georgia Environmental Protection Division acknowledges the efforts of CDM in development of the analysis and models summarized here and in preparation of this document.

Tables

Figures

Summary of Sustainable Yield Results in Prioritized Aquifers

This synopsis document presents the results of an assessment of the availability of groundwater resources in select prioritized aquifers of Georgia. The assessment work was completed to support the development of Regional Water Development and Conservation Plans (Regional Plans) as called for by the Georgia Comprehensive State-wide Water Management Plan (Water Plan). This section presents a summary of the results of the modeling effort. Subsequent sections of this synopsis provide background information and more detail on the assessments of individual aquifers. A report was also produced providing more detailed information on each modeling effort, including model development, calibration, and sustainable yield analysis.

Figure S-1 presents the location of aquifers in the State of Georgia prioritized for determination of sustainable yield (see Section 2.1 for definition of Sustainable Yield):

- Upper Floridan aquifer in the Dougherty Plain;
- Upper Floridan aquifer in south-central Georgia;
- Upper Floridan aquifer in south-central Georgia and the eastern Coastal Plain of Georgia;
- Cretaceous aquifer between Macon, Georgia and Augusta, Georgia;
- Claiborne aquifer
- Paleozoic rock aquifers in the Northwestern Georgia Valley and Ridge System; and
- Crystalline Rock aquifers in the Piedmont and Blue Ridge Provinces (water budgets only).

Sustainable yield modeling for the Upper Floridan aquifer in the Dougherty Plain of southwestern Georgia was performed using the existing U.S. Geological Survey (USGS) numerical model of the Dougherty Plain Upper Floridan aquifer. Sustainable yield modeling for other prioritized aquifers in the Coastal Plain of Georgia (the Upper Floridan aquifer in south-central Georgia and the eastern Coastal Plain of Georgia, the Cretaceous aquifer, and the Claiborne aquifer) was performed using a regional numerical model that included all of the aquifers. Sustainable yield modeling for the Paleozoic rock aquifer was performed using a numerical model of a study basin in northwestern Georgia. Sustainable yield of the crystalline rock aquifer was determined using water budgets developed for basins in the Piedmont and Blue Ridge provinces of Georgia.

Sustainable yields were determined using numerical model simulations with various combinations of withdrawals from existing wells and, where applicable, from hypothetical new wells. Results of the simulations therefore indicated a range of

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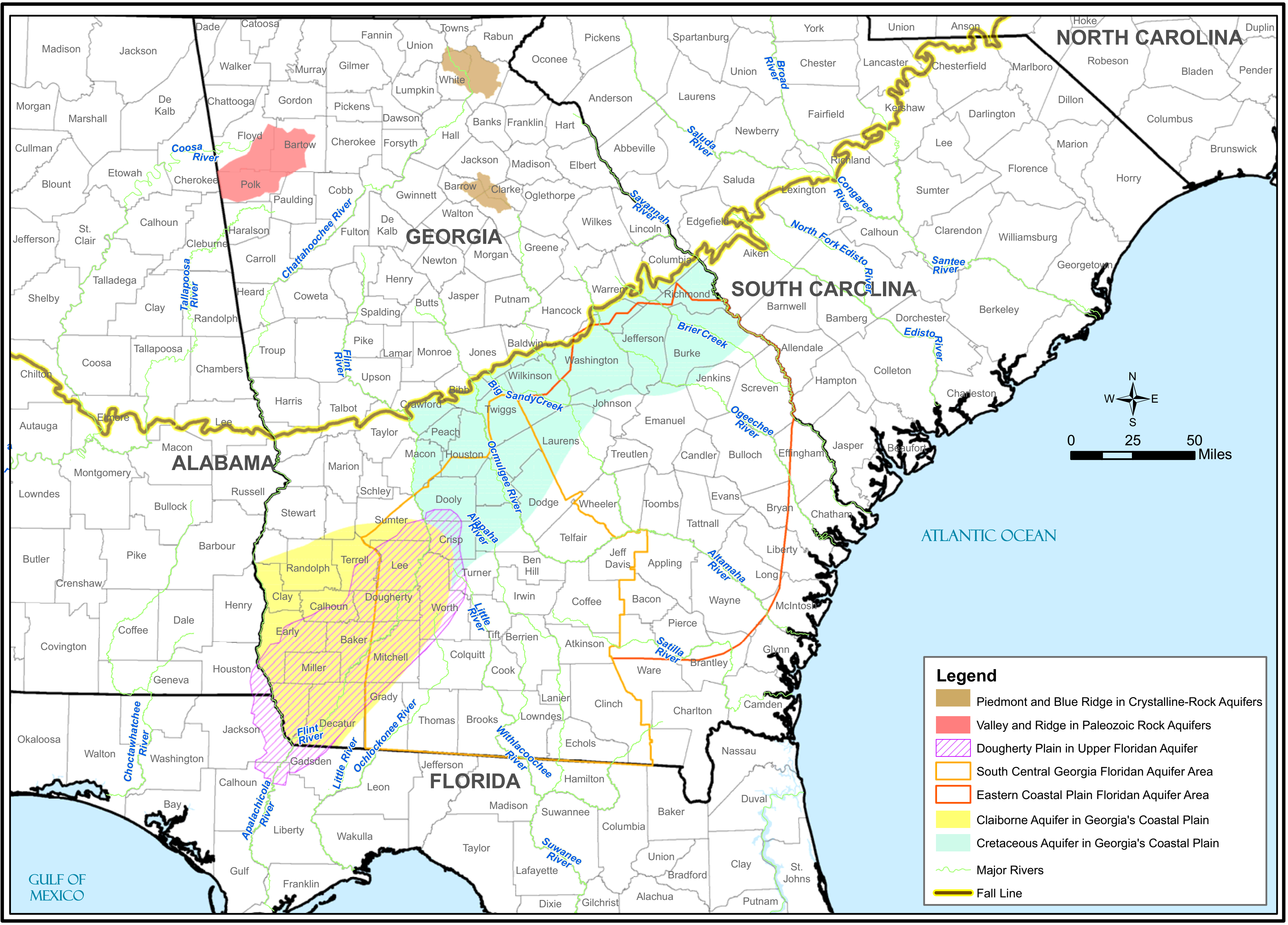

Figure S-1
Location of the High Prioritized Aquifers Selected for Study

sustainable yield for each prioritized aquifer. **Table S-1** presents the ranges of sustainable yields of Coastal Plain and Paleozoic rock aquifers that were modeled numerically. **Table S-2** presents the range of sustainable yields of the crystalline rock aquifer. Sustainable yields in Table S-2 are presented for the entire basin and are normalized for the area of the basin.

The regional Coastal Plain model included estimated current withdrawals from the portions of aquifers in Alabama, Florida, and South Carolina that were within the regional model boundary. Sustainable yield simulations did not include increased withdrawals from the portions of aquifers in Alabama, Florida, and South Carolina. Withdrawals were increased only within the prioritized aquifers in Georgia to determine sustainable yield ranges.

Baseline withdrawals were determined for some of the prioritized aquifers and are presented in Tables S-1 and S-2. Baseline withdrawals were estimated on actual current withdrawals, not permitted capacities. Municipal and industrial withdrawals were obtained from data reported to Georgia EPD by permittees. Unpermitted domestic and commercial withdrawals (estimated by the USGS to have been about 12 percent of total state-wide groundwater use during 2005) were estimated from USGS data and county records. Agricultural withdrawals were estimated using a combination of USGS and Georgia EPD data.

Sustainable yields for prioritized aquifers in the regional Coastal Plain model were determined by zooming into the aquifer areas within the regional model boundary. The modeling indicated that increasing withdrawals from one prioritized aquifer would increase recharge from other aquifers. Therefore, the total range of sustainable yield with simultaneous withdrawals from all prioritized aquifers was less than the total range of sustainable yield with only individual aquifer withdrawals. Table S-1 presents the totals of sustainable yields of prioritized aquifers with withdrawals modeled individually and simultaneously.

In addition to the above estimated ranges of sustainable yield, a number of other observations can be drawn from this groundwater resources assessment:

- There are relatively large quantities of additional groundwater available above existing withdrawals before the sustainable yields of prioritized aquifers in the regional Coastal Plain model are reached (based on the selected sustainable yield criteria of allowable groundwater drawdown from current conditions of 30 feet or less and streamflow reductions from current conditions of 40 percent or less).

- There are smaller amounts of additional groundwater available from the Paleozoic-rock aquifer in the northwestern Georgia study basin and from the crystalline-rock aquifer in the Piedmont and Blue Ridge.

- A combination of increasing withdrawals from existing and hypothetical new wells results in the highest range of sustainable yield in the Upper Floridan aquifer and the Claiborne aquifer.

Table S-1
Sustainable Yield Estimates Using Numerical Models

Aquifer	Modeled Sustainable Yield (mgd)		Baseline Groundwater Withdrawal (mgd)
	Minimum	Maximum	
Upper Floridan Aquifer in Dougherty Plain[(1)]	237	328	157
Upper Floridan Aquifer in South-Central Georgia	622	836	329
Upper Floridan Aquifer in South-Central Georgia & Eastern Coastal Plain	868	982	475
Claiborne Aquifer	100	250	67
Cretaceous Aquifer	198	201	124
South-Central Georgia & Eastern Coastal Plain Upper Floridan & Claiborne & Cretaceous Aquifer Withdrawing Separately	1,166	1,433	667
South-Central Georgia & Eastern Coastal Plain Upper Floridan & Claiborne & Cretaceous Aquifer Withdrawing Together	1,066	1,229	667
Paleozoic-Rock Aquifer in Northwestern Georgia Valley and Ridge	27	70	15

(1) October 1999 Baseline Withdrawal

Table S-2
Sustainable Yield Estimates Using Water Budget Models

Aquifer	Current Groundwater Consumption (mgd)	Basin Sustainable Yield[1] (mgd)		Area Normalized Sustainable Yield[1] (mgd/mi^2)	
		Minimum	Maximum	Minimum	Maximum
Crystalline Rock Aquifer in Piedmont	1.2	1.6	7.9	0.010	0.049
Crystalline Rock Aquifer in Blue Ridge	2.4	19.9	99.5	0.063	0.316

[1] Based on Mid-level (50%) Steamflow Reduction Category. See Section 3.2 for Details.

- Increasing withdrawals from existing wells in the Cretaceous aquifer results in the highest range of sustainable yield for this aquifer. The addition of hypothetical new wells does not increase the range of sustainable yield of this aquifer.

- Because the total range of sustainable yield of prioritized aquifers in the regional Coastal Plain model with simultaneous withdrawals from all prioritized aquifers would be less than the total range with individual aquifer withdrawals, the selection of which aquifers will be utilized for future water supply should be evaluated when planning for use of the sustainable yield from an individual aquifer.

- As withdrawals are increased, groundwater will initially come from storage until steady state conditions are reached at a new equilibrium of recharge, withdrawals, and natural discharges. Sources of recharge can include leakage from other aquifers and geologic units, recharge from surface waters, and rainfall. Transient modeling indicated that it may take up to 40 years of withdrawals within the ranges of sustainable yields for aquifers to reach new equilibriums.

Section 1
Background

1.1 Purpose of Study

This groundwater modeling project was designed to accomplish the following:

- Compiling and reviewing available data on Georgia's groundwater resources;
- Prioritizing aquifers and aquifer units (presented in Section 1.2);
- Developing calibrated groundwater flow models and other assessment tools for estimating the sustainable yields in these prioritized units. A calibrated model involves varying model input parameters to match field conditions, such as available hydrogeologic data and groundwater monitoring well data; and
- Providing a range of aquifer sustainable yield estimates for the prioritized aquifers.

This synopsis provides a brief overview of the tools and methods applied, and presents a range sustainable yield estimates for the aquifers prioritized for analysis in this phase of the planning process.

1.2 Prioritized Aquifers in Georgia

A comprehensive accounting of the sustainable yield of all of the aquifers in Georgia would have been extraordinarily expensive and time consuming. Therefore, Georgia EPD prioritized aquifers for which a method for determining sustainable yields would be developed, and for which a range of sustainable yield estimates would be provided. Aquifers were prioritized based on the following criteria:

- Functional characteristics of the aquifer;
- Existing evidence of adverse effects due to withdrawals from the aquifer;
- Forecasts suggesting significant increases in demands placed on the aquifer; and
- Acceptability of impacts due to increased groundwater withdrawals.

Figure S-1 presents the locations of aquifers prioritized for the determination of sustainable yield ranges. The aquifers include an example of each aquifer type found in Georgia. Estimates of ranges of sustainable yield were made for portions of the Upper Floridan aquifer, the Cretaceous aquifer, and the Claiborne aquifer in the Coastal Plain of Georgia using calibrated numerical models; in the Paleozoic-rock aquifers in northwestern Georgia using a qualitatively calibrated numerical model; and in the crystalline-rock aquifers of the Piedmont and Blue Ridge physiographic provinces using water budgets.

Section 2
Sustainable Yield Approach

2.1 Sustainable Yield Criteria

There have been many definitions over the years of "sustainable, safe, or perennial yield" of an aquifer system. A reasonable and well accepted definition of sustainability that seems to encompass most ideas was proposed in 1998 by a Task Force of the American Society of Civil Engineers (ASCE, 1998). Their definition of sustainability is as follows:

"Sustainable water resource systems are those designed and managed to fully contribute to the objectives of society, now and in the future, while maintaining their ecological, environmental, and hydrological integrity."

For this phase of water resources planning, the focus on unwanted results and metrics of unwanted results was on broader scale potential impacts resulting from the withdrawal of groundwater. Impacts were primarily assessed on an annual basis, with consideration for drought years. Only the limits of aquifer yield were explored, with no comparison to projected water needs. An initial set of metrics to constrain withdrawals to ranges of sustainable yields were developed based on broad scientific principles and practical guidelines. These criteria included those that have been applied in comparable circumstances elsewhere and were tested for their applicability in Georgia. It is expected that these criteria will serve as guidelines to be addressed in greater detail and possibly adjusted as the regional plans are developed and stakeholder input is solicited.

The overarching concept to be evaluated is whether an increase in recharge, removal of water stored in the system through larger groundwater withdrawals, or a decrease in discharge causes unwanted results. The following metrics are applied, with variations developed appropriate to each of the aquifers being studied and to the level of detail provided by the models used to assess sustainable yield:

- Drawdowns of groundwater levels in the pumped aquifer do not exceed 30 feet between pumping wells;
- Recharge from surface water sources were constrained to 40 percent of baseflow in order to maintain opportunities for surface water use (modified to 10 percent of baseflow in the Paleozoic rock aquifer and 40 percent of streamflow in the crystalline rock aquifer);
- Reduction in aquifer storage does not go beyond a new base level;
- Groundwater levels are not lowered below the top of a confined aquifer; and

- The ability of the aquifer to recover to baseline groundwater levels between periods of higher pumping during droughts is not exceeded.

2.1.1 Loss of Confined Head/Pressure (Drop of Water Levels Between Pumping Wells)

A practical limit to avoid impacts to nearby wells is to restrict withdrawals such that groundwater level drawdown in the pumped aquifer does not exceed 30 feet below levels representative of current conditions between pumping wells. Limiting drawdown between pumping wells to 30 feet could minimize effects of increased withdrawals on other wells. It would also decrease the potential for creating sinkholes in carbonate aquifers at or near the ground surface. Application of this metric would require a definition of where 30 feet of drawdown is measured and locations of new wells would need to consider where 30 feet of drawdown could occur. Assumptions associated with the use of this metric are presented separately for each of the modeled aquifers.

2.1.2 Changing an Aquifer from Confined to Unconfined Conditions

Pumping was restricted in all areas to avoid drawing the water table down from overlying aquifers and/or confining units such that portions of the confined aquifer become unconfined (i.e., the potentiometric surface drops below the top surface of the aquifer). Changing an aquifer from confined to unconfined conditions would decrease the transmissivity of an aquifer and thereby decrease well yields from the aquifer.

2.1.3 Minimize Impacts to Streamflow

Lowering of the groundwater table usually results in a reduction in water flowing from springs and in-stream baseflow (streamflow that is totally dependent on groundwater discharge). Metrics were selected to constrain recharge from surface water sources in order to maintain opportunities for surface water use. It should be noted that baseflows used to constrain surface water recharge to groundwater were baseflows generated by the model and not baseflows determined from stream hydrographs.

At this level of water resources planning, there is a need for a sufficiently simple method that can make use of readily available streamflow statistics. One practical method is the Tennant Method (Tennant, 1976), which relies on percentages of mean annual flow in order to recommend seasonally adjusted in-stream flows. The method has become popular because it is an easy to apply standard that can be used with limited and readily available data and is therefore practical for the level planning being completed for the Water Plan. Because this is a groundwater assessment, the Tennant Method was modified to focus the assessment on the period of lowest annual baseflow as well as the lowest annual streamflow. A modified Tennant Method is applied for most of these groundwater assessments in order to provide initial guidance on limits to groundwater withdrawals. As applicable, modifications to the Tennant Method are presented separately for each of the modeled aquifers.

2.2 Sustainability Measures by Modeling Approach

During this phase of the water resources planning process, the modeling approach used to estimate the sustainable yield of an aquifer depended on the availability of data and the level of detail required to answer basic questions about the potential impacts of withdrawals on aquifers and groundwater use. Three modeling approaches were piloted, ranging from a simple water budget to the development of fully calibrated numerical models with transient simulation capabilities. Each approach provides a different level of information, and thus a different approach to providing initial estimates of the sustainable yield of the aquifer in question. The exact metrics used to make a preliminary assessment of sustainability varied according to the modeling approach and are presented in the following sections. In all cases, the models were run until one of the sustainable yield metrics was reached and then that level of withdrawals was determined to be part of the range of sustainable yield.

Section 3

Piedmont and Blue Ridge Provinces: Streamflow-Based Water Budgets

3.1 Modeling Approach

A water budget approach was selected as the most appropriate mechanism to provide a planning level assessment of groundwater resource sustainability in basins of the Piedmont and Blue Ridge physiographic provinces of Georgia. The selected basins for the water budgets were:

- The Middle Oconee River Lower Basin, which covers 163 square miles in portions of Clarke, Oconee, Barrow, and Jackson counties of the Piedmont; and
- The Chattahoochee River-Chickamauga Creek and Soque River basins, which cover 315 square miles in portions of Habersham, Towns, Union, and White counties of the Blue Ridge.

The location of the Piedmont and Blue Ridge Watersheds are shown in **Figure S-2**.

A water budget is an accounting of water movement within the hydrologic cycle, both natural and artificial. Water budgets can be completed at a basin or subbasin level, although each approach may have unique limitations based on the quantity and quality of data available to provide an assessment of the system. Water budgets serve as useful tools for a number of reasons. In the context of assessing groundwater resource sustainability, the process of collecting, compiling and analyzing the data necessary to develop water budgets is useful for:

- Estimating groundwater withdrawal rates and recharge.
- Identifying the relationship between streamflow and baseflow.
- Identifying the areas served by domestic wells and onsite wastewater systems.
- Developing an understanding of the potential impacts that sanitary sewers have on groundwater recharge.
- Developing an understanding of the movement and use of water within a drainage basin.
- Developing a concise means of comparing drainage basins with each other in terms of water consumption, baseflow, and runoff.
- Identifying drainage basins that have a relatively high level of water consumption.
- Comparing the natural versus man-made components of the hydrologic cycle.

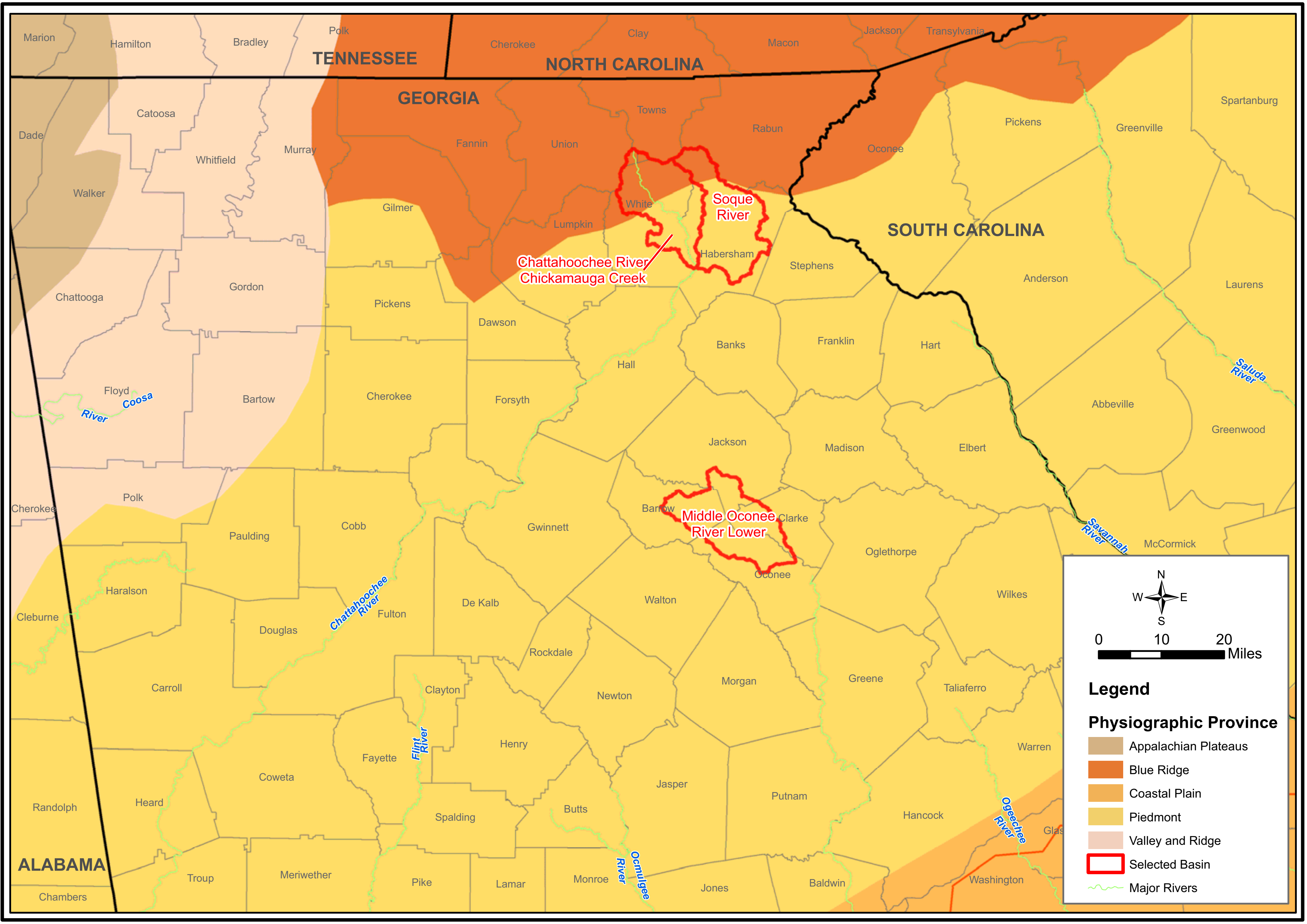

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Figure S-2
Piedmont and Blue Ridge Model Areas

- Identifying subbasins where large exports or imports of water are occurring.
- Identifying where management decisions will result in the most impact and allowing the resource managers and planners to focus management efforts on the most pressing issues.
- Providing a basis to assess sustainability of the water resource.

The full water budget accounts for both the natural and artificial movement of water within the hydrologic cycle. The equation used in the assessment generally reflects water "in" to the system:

- Average precipitation;
- Wastewater and industrial discharge to groundwater systems;
- Estimated domestic recharge from onsite wastewater treatment systems (i.e., septic systems); and
- Discharge to streams.

and water "out" of the system:

- Evapotranspiration;
- Runoff component of precipitation;
- Surface water withdrawal from streams/creeks;
- Groundwater withdrawal from public water supply systems, industrial, commercial and agricultural wells;
- Estimated withdrawal from domestic wells; and
- Median baseflow of streams.

The components of the water budget equation which specifically relate to groundwater can be rearranged to develop an estimate of net groundwater consumption. Net groundwater consumption can thereby be defined as the estimated withdrawal from all groundwater wells (public water supply systems, industrial, commercial, domestic, and agricultural wells) minus the groundwater recharge from wastewater treatment plants, onsite treatment systems and other sources including industrial discharges to groundwater. By comparing net groundwater consumption to the sustainable yield criteria discussed in Section 2 of this Synopsis, estimates of net groundwater availability can be developed.

For shallow, water table aquifers in direct connection with surface water, water budgets can be constructed using existing data on rainfall, streamflow, aquifer and surface water withdrawals, and aquifer and surface water discharges. These water budgets are usually created on an annual basis due to limited information on the withdrawals, and they rely on stream baseflow estimates to approximate the recharge of the groundwater system. An underlying assumption of this method is that the surface watershed and the groundwater basin cover the same area, making them appropriate for unconfined, surficial aquifers.

Water budgets offer no ability to estimate impacts due to the locations of groundwater withdrawals, nor do they account for possible "lag time" between withdrawals and impacts to streams. Because the water budget focuses on streamflow as the primary estimator of recharge and groundwater availability, the most practical method is to apply a variant of the Tennant Method to make an initial estimate of sustainable yield.

3.2 Estimated Range of Sustainable Yield

In the Piedmont and Blue Ridge area, the modified Tennant Method was used to develop values for sustainable yield. Tennant suggests several categories of streamflow reduction, and these are modified here into minimum, mid-level, and maximum allowable streamflow reduction categories and are subtracted from the mean monthly flow during the most severe stress period of the year (September).

Because of the limited ability of the Crystalline-Rock aquifers in the Piedmont and Blue Ridge areas to provide water, an even more stringent or conservative estimate of sustainable yield is also provided as the lower end of the range of sustainable yield. In this case, the streamflow reduction targets are further reduced, allowing only 20% of the difference between the mean September flow and the Tennant reduction category thresholds to calculate groundwater availability. The Tennant Method was further modified to provide an indication of sustainable yield considering only the baseflow component of streamflow. In this way, an attempt is made to provide an upper limit to groundwater withdrawals that will leave sufficient water in the stream during the period of lowest flows to support opportunities for surface water withdrawals.

The increase of impermeable cover within a basin would result in a decrease in recharge to groundwater and a subsequent decrease in stream base flow. The water budgets developed for the Water Plan did not consider decreased stream base flows resulting from future increases in impermeable cover. Because of the way stream base flow was used as a metric in the water budgets to determine sustainable yields, increases in impermeable cover and subsequent decreases in stream base flows would result in lower sustainable yields.

Daily streamflow data from the period 1989 – 2008 for the Middle Oconee River (Piedmont) and Chattahoochee River (Blue Ridge) were used to calculate the mean annual streamflow and baseflow and a range of streamflow and baseflow reduction amounts (40% to 60%) were evaluated. The 50% mid-level streamflow was chosen as the criterion to estimate the net amount of groundwater available for use in both basins. Using the 40% streamflow reduction amount (60% of flow remains in the stream) in the Piedmont basin resulted in a situation in which current consumption already exceeded the sustainable yield. This was not considered reasonable given the negative net groundwater consumption in the basin. Therefore a mid-level reduction of 50% was used in both the Piedmont and Blue Ridge basins.

30Q2 (driest monthly flow with a recurrence interval of 2 years) and 7Q10 (driest weekly flow with a recurrence interval of 10 years) values were also developed for comparative purposes only. The resulting values are shown in **Table S-3** for total streamflow. The values shown under the label "Tennant Method Thresholds" are simply the mean annual streamflow multiplied by the appropriate reduction factors. The threshold values are given in several different units (cubic feet per second, inches per year, million gallons per day, and million gallons per square mile) to provide appropriate units for a variety of applications. The values in the columns labeled "Net Amount Available for Use" show the net amount of groundwater consumption that could occur on an average annual basis so that mean monthly streamflow does not drop below the minimum flow reduction category during the month of September.

In Table S-3, the Net Amount Available for Use in the Piedmont has a lower range of 0 million gallons per day (mgd), meaning that based on the most conservative or minimum allowable streamflow reduction estimate, the watershed is currently consuming levels equal to or greater than the sustainable yield. If less conservative criteria are applied, then additional groundwater is available.

Table S-3 also presents a more restrictive use of the Tennant Method similar to an approach applied in the New Jersey Highlands to estimate sustainable yield. In this case, the Tennant Method streamflow reduction categories are further reduced, allowing only 20% of the difference between the mean September flow and the Tennant threshold to calculate groundwater availability.

Table S-4 compares the net groundwater consumption values derived from the water budgets to the groundwater sustainability measures calculated via the modified Tennant Method using the mid-level (50%) streamflow reduction category.

- Column "a" is taken from the estimates found in Table S-3. In the Piedmont, the water budget was completed for the Middle Oconee River Lower Basin, which is only a portion (roughly 41%) of the larger drainage basin for which Tennant Thresholds and the net amount available for use were calculated in Table S-3. Therefore, the values were normalized to reflect the smaller basin size. In the upper part of the table, the estimate uses the streamflow reduction percentage value from the modified Tennant Method. In the lower part of the table, the estimate uses the more restrictive estimate of sustainable yield based on only 20% of the value provided in the upper part of the table. The intent is to provide a range of sustainable yield estimates for consideration by the Regional Councils.
- Column "b" shows current groundwater use.

Table S-3
Groundwater Sustainability Measures for Study Basins in the Piedmont and Blue Ridge

Basin	Basin Area Upstream of Station[1] (sq. miles)	Units	Tennant Method Thresholds					Net Amount Available For Use		Measures of Low Flow	
			Mean Annual Flow (Q_{MA})	Minimum Streamflow Reduction Category ($0.6 \times Q_{MA}$)	Mid-level Streamflow Reduction Category ($0.5 \times Q_{MA}$)	Maximum Streamflow Reduction Category ($0.4 \times Q_{MA}$)	Mean Sept. Flow	Based on Mean Sept. Flow Minus Tennant Threshold[2]	Based on Mean Sept. Flow Minus Tennant Threshold X 20%[3]	7Q10	30Q2
Piedmont											
Oconee River (by Athens)	398	*cfs*	488	293	244	195	274	**0 to 79**	**0 to 15.8**	20	119
USGS Station No. 2217500		*in/yr*	16.6	10.0	8.3	6.7	9.3	**0 to 2.7**	**0 to 0.5**	0.7	4.1
		mgd	315	189	158	126	177	**0 to 50.9**	**0 to 10.2**	12.6	77
		mgd/mi^2	0.8	0.5	0.4	0.3	0.4	**0 to 0.13**	**0 to 0.03**	0.03	0.2
Blue Ridge											
Chattahoochee River (by Cornelia)	315	*cfs*	740	444	370	296	524	**80 to 228**	**16.0 to 45.6**	132	298
USGS Station No. 2331600		*in/yr*	31.9	19.1	15.9	12.8	22.6	**3.4 to 9.8**	**0.7 to 2.0**	5.7	12.8
		mgd	478	287	239	191	339	**51.7 to 147.4**	**10.3 to 29.5**	85.3	193
		mgd/mi^2	1.5	0.9	0.8	0.6	1.1	**0.16 to 0.47**	**0.03 to 0.1**	0.27	0.6

[1] In the Piedmont, the study basin was not at the headwaters of the basin, therefore the flows (in cfs and mgd) do not match the flows shown in Table S-4. Table S-4 uses 40.95% of the flows shown here to account for the basin size.

[2] The net amount available for use (range) was calculated by subtracting the range of Streamflow Categories from the Mean September Flow.

[3] The net amount available for use (range) was calculated by subtracting the Streamflow Categories from the Mean September Flow, then multiplying by 0.20.

Table S-4
Comparison of Groundwater Sustainability Measures to Net Groundwater Consumption Using Tennant Thresholds

Basin	Units	(a) Net Amount Available for Use Based on Mean Sept. Flow Minus Tennant Threshold[1]	(b)	(c)	(d) [c/a X 100]	(e) [a - c]
			Dry Year Conditions			
			Groundwater Use	Net Groundwater Consumption	Net Groundwater Consumption as a Percentage of Amount Available	Net Groundwater Available
Piedmont[2]						
Middle Oconee River Lower Basin	*cfs*	**12.3**	1.86	-0.74	0%	13.0
(163 sq. miles)	*in/yr*	**1.0**	0.16	-0.06		1.08
	mgd	**7.9**	1.20	-0.48		8.4
	mgd/mi^2	**0.049**	0.007	-0.003		0.052
Blue Ridge						
Chattahoochee River-Chickamauga	*cfs*	**154**	3.71	1.28	0.9%	152.7
Creek and Soque River Basin	*in/yr*	**6.6**	0.16	0.06		6.58
(315 sq. miles)	*mgd*	**99.5**	2.40	0.83		98.7
	mgd/mi^2	**0.316**	0.008	0.003		0.313

Basin	Units	(a) Net Amount Available for Use Based on Mean Sept. Flow Minus Tennant Threshold X 20%[1]	(b)	(c)	(d) [c/a X 100]	(e) [a - c]
			Dry Year Conditions			
			Groundwater Use	Net Groundwater Consumption	Net Groundwater Consumption as a Percentage of Amount Available	Net Groundwater Available
Piedmont[2]						
Middle Oconee River Lower Basin	*cfs*	**2.5**	1.86	-0.74	0%	3.2
(163 sq. miles)	*in/yr*	**0.20**	0.16	-0.06		0.26
	mgd	**1.6**	1.20	-0.48		2.1
	mgd/mi^2	**0.010**	0.007	-0.003		0.013
Blue Ridge						
Chattahoochee River-Chickamauga	*cfs*	**30.8**	3.71	1.28	4.5%	29.5
Creek and Soque River Basin	*in/yr*	**1.33**	0.16	0.06		1.27
(315 sq. miles)	*mgd*	**19.9**	2.40	0.83		19.1
	mgd/mi^2	**0.063**	0.008	0.003		0.061

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[1] Based on Mid-level (50%) Streamflow Reduction Category.

[2] The Middle Oconee River Lower basin is 163 square miles, and is 40.95% of the larger 398 square mile basin upstream of the USGS Station where flow records were available (see Table S-3). The flows shown in column a (in *cfs* and *mgd*) were adjusted to reflect the smaller basin size (40.95% of total basin values), and therefore, do not match the flows shown in Table S-3; however, the normalized flows (in *in/yr* and *mgd/mi*^{2}) are identical.

- Column "c" shows net groundwater consumption (accounting for water used but returned to the groundwater or stream).
- Column "d" gives the percentage of water available currently being consumed (if negative, it is shown as 0%).
- Column "e" provides an estimate of the amount of water available for future consumption.

As previously noted, net groundwater consumption in the Piedmont basin was negative, meaning that more water is estimated to be returning though onsite wastewater treatment systems than is leaving through wells. Using the mid-level (50%) streamflow reduction category presented in the upper part of Table S-4, the net amount of groundwater available is estimated to be 7.9 mgd, which is over 6 times the amount currently being used in the watershed. If the more restrictive method is used (lower part of Table S-4), the net amount of groundwater available is estimated to be 1.6 mgd, which is 33% more than the amount currently being used in the watershed. If only the baseflow component is considered and the mid-level (50%) Tennant Threshold is calculated using baseflow, the net amount of groundwater available is estimated to be 0.8 mgd, which is 0.5 mgd below the amount currently being used in the watershed.

Net groundwater consumption in the Blue Ridge basin is positive, meaning that water is being consumed within the watershed. Using the least restrictive measure described above and presented in the upper part of the table, the net amount of groundwater available is estimated to be 99.5 mgd, which is over 41 times the amount currently being used in the watershed. If the more restrictive method is used (lower part of Table S-4), the net amount of groundwater available is estimated to be 19.9 mgd, which is over 8 times the amount currently being used in the watershed. If only the baseflow component is considered and the mid-level (50%) Tennant Threshold is calculated using baseflow, the net amount of groundwater available is estimated to be 55.6 mgd, which is over 23 times the amount currently being used in the watershed.

The water budgets show that more groundwater is available from the crystalline rock aquifer than is currently being withdrawn. It might be difficult to find sufficient water-bearing fractures in the crystalline rock aquifer to develop the full range of sustainable yield, however. Therefore, it is recommended that the lower-end of the sustainable yield range be used for planning purposes.

Section 4
Northwestern Georgia: Numerical Groundwater Flow Model

4.1 Modeling Approach

A numerical model of confined and unconfined Paleozoic rock aquifers in northwestern Georgia was developing using existing, available data on water levels and aquifer heads (the elevation to which water will rise in a well), aquifer properties, the spatial extents and folding of the aquifers, confining units, and the thickness of each stratigraphic unit (geologic subdivisions in the rocks), as well as estimates of average annual withdrawals and stream baseflow. The model was checked against available groundwater head data and streamflows in a qualitative manner, but there was generally insufficient data to develop a quantitatively calibrated model.

Model simulation results were compared against streamflow data and regional water level elevation data to determine whether simulated results were generally representative of observed field conditions. Transient (time variable) and steady state (equilibrium) simulations were conducted during model development and for the sustainable yield analysis. The area modeled covered several watersheds within the Valley and Ridge physiographic province in Floyd, Polk, Bartow and Paulding counties where the largest spatial extent of Knox Group outcrops. The study area is shown in **Figure S-3**.

A transient model simulation based on 2007 data was conducted to represent drought year conditions. Drought year conditions were used to assess sustainable yield. The model was used to help assess the sustainability of proposed or hypothesized groundwater withdrawals by simulating streamflow and drawdown impacts of the withdrawals and comparing to selected sustainability metrics as described in Section 2 and below.

4.2 Estimated Range of Sustainable Yield

For the northwestern Georgia model, the following sustainable yield criteria were used to estimate an upper and lower bound for sustainable yield of the Paleozoic rock aquifer in the study basin:

- Restrict the reduction in total streamflow and spring flow due to additional withdrawals to 10 percent of mean annual discharge. An upper bound yield can be estimated by limiting the drought year baseflow reduction to 10 percent of mean annual baseflow (higher withdrawals are possible because a greater decline in streamflow is allowed). A lower bound yield can be estimated by limiting the drought year baseflow reduction to 10 percent of drought year mean annual baseflow (lower withdrawals are possible because a smaller decline in streamflow is allowed). The allowable percentage reduction of 10 percent was set

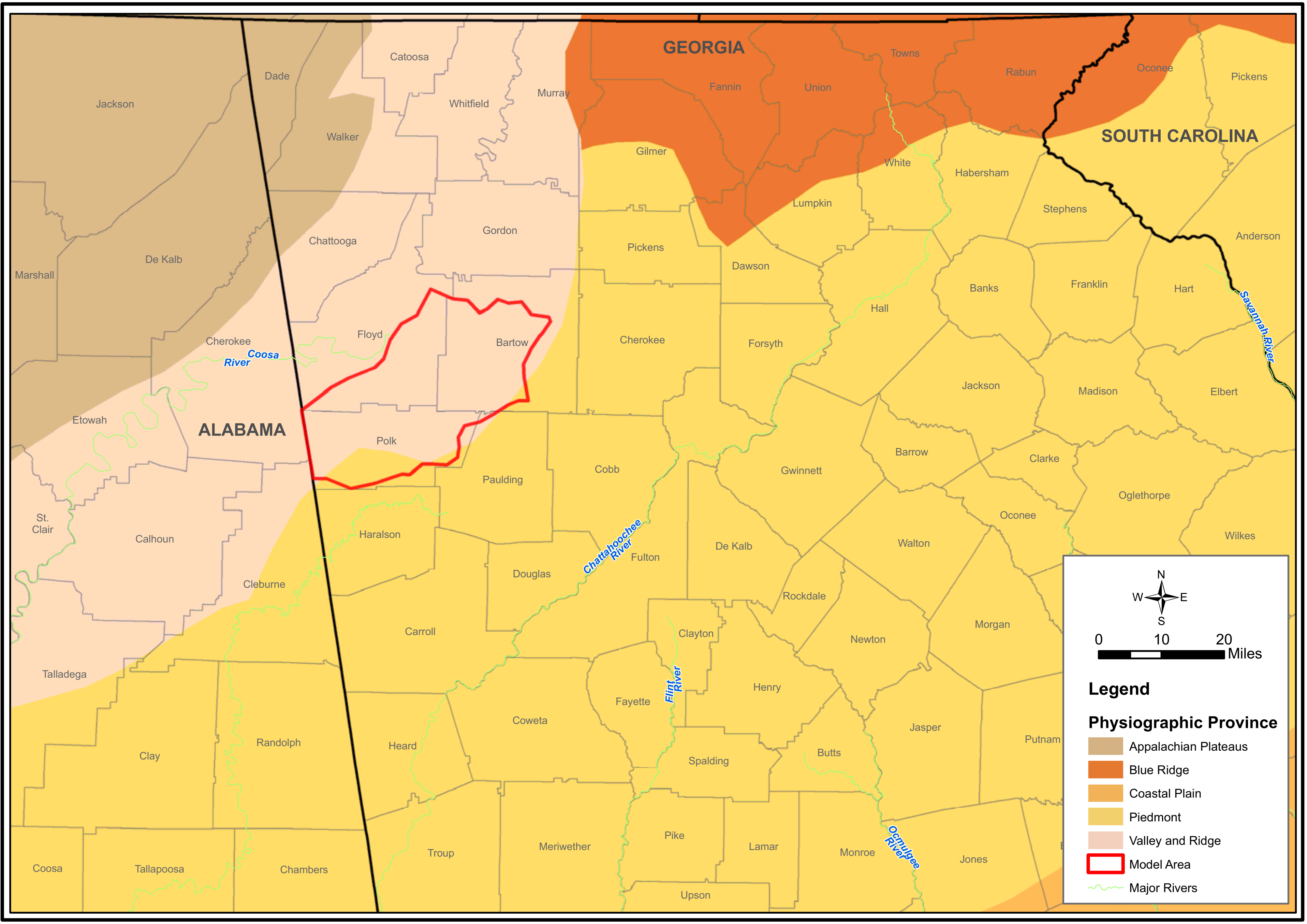

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Figure S-3
Northwestern Georgia Model Area

conservatively low because allowing a higher percentage would not have maintained opportunities for surface water use, and because the accuracy of the qualitatively calibrated model is not known.

- Restrict the reduction in total streamflow in any single stream and single spring due to additional withdrawals above current conditions to 15 percent of mean annual discharge under a drought year scenario.
- Restrict water table declines due to additional withdrawals above current conditions within the model area to less than 30 feet between pumping wells.
- Avoid drawing the water table down to within 10 feet of the top of a confined aquifer to avoid creating unconfined aquifer conditions.

A baseline no pumping simulation was completed for comparison with the simulations of hypothetical withdrawals. This was selected for the basis of comparison for the sustainable yield analysis because the number of existing pumping locations within the model area was generally small. Furthermore, the existing wells were not uniformly distributed and tended to be clustered near streams and rivers. Hypothetical groundwater withdrawals were simulated from uniformly distributed wells that were added to the model. The simulated withdrawals were divided evenly among the hypothetical wells and were held constant over time.

Figures S-4 and S-5 show hydrographs of simulated stream baseflow for the pumping and no-pumping conditions over a period of one year for the entire study area. According to the first sustainability metric, the drought year baseflow with pumping (solid red line) should not fall below the no-pumping baseflow (solid blue line) by more that 10 percent of mean annual baseflow (dashed blue line). This is further described below for each hydrograph.

Figure S-4 shows the results of the one year drought condition transient simulation for pumping at the upper limit of sustainable yield, estimated to be 70 mgd. There are three lines on the upper graph:

- Simulated stream baseflow during a drought year without groundwater withdrawals (solid blue line). Dry-year stream baseflow was simulated with no groundwater withdrawals and plotted as cubic feet per second (CFS) versus the day of the year.
- Drought year streamflow reduced by 10% of mean annual baseflow for a normal year of precipitation (dashed blue line). Simulated dry-year baseflow minus 10% of simulated average year baseflow was plotted as CFS versus the day of the year.
- Simulated stream baseflow with 70 mgd of pumping from the aquifer system (solid red line). Baseflow with groundwater withdrawals was simulated to fall within the envelope to determine the sustainable yield for an average year.

Figure S-4

Total Simulated Baseflow Within Model Domain For No Pumping and 70 MGD Pumping Scenarios

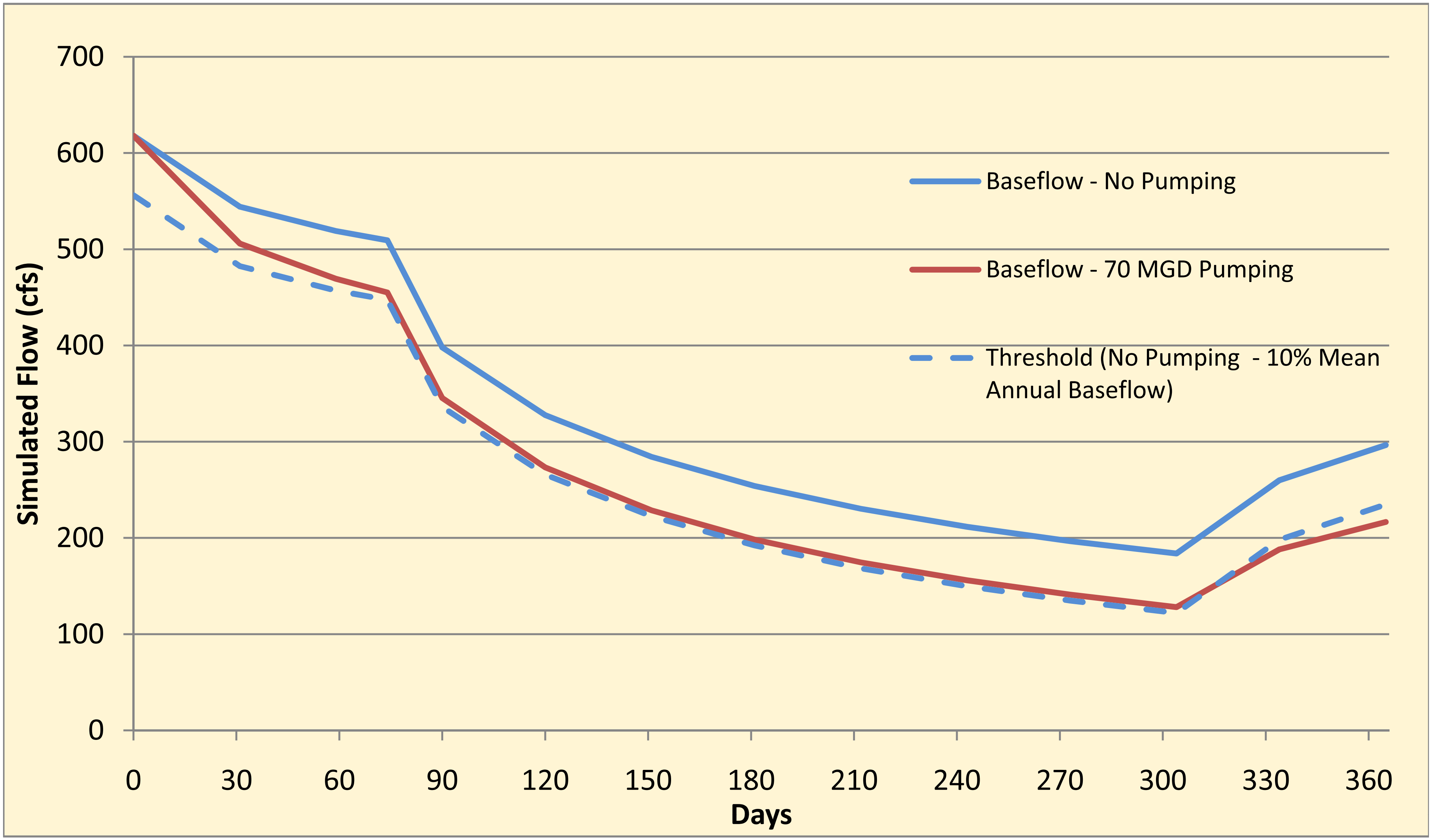

Figure S-5

Total Simulated Baseflow Within Model Domain For No Pumping and 27 MGD Pumping Scenarios

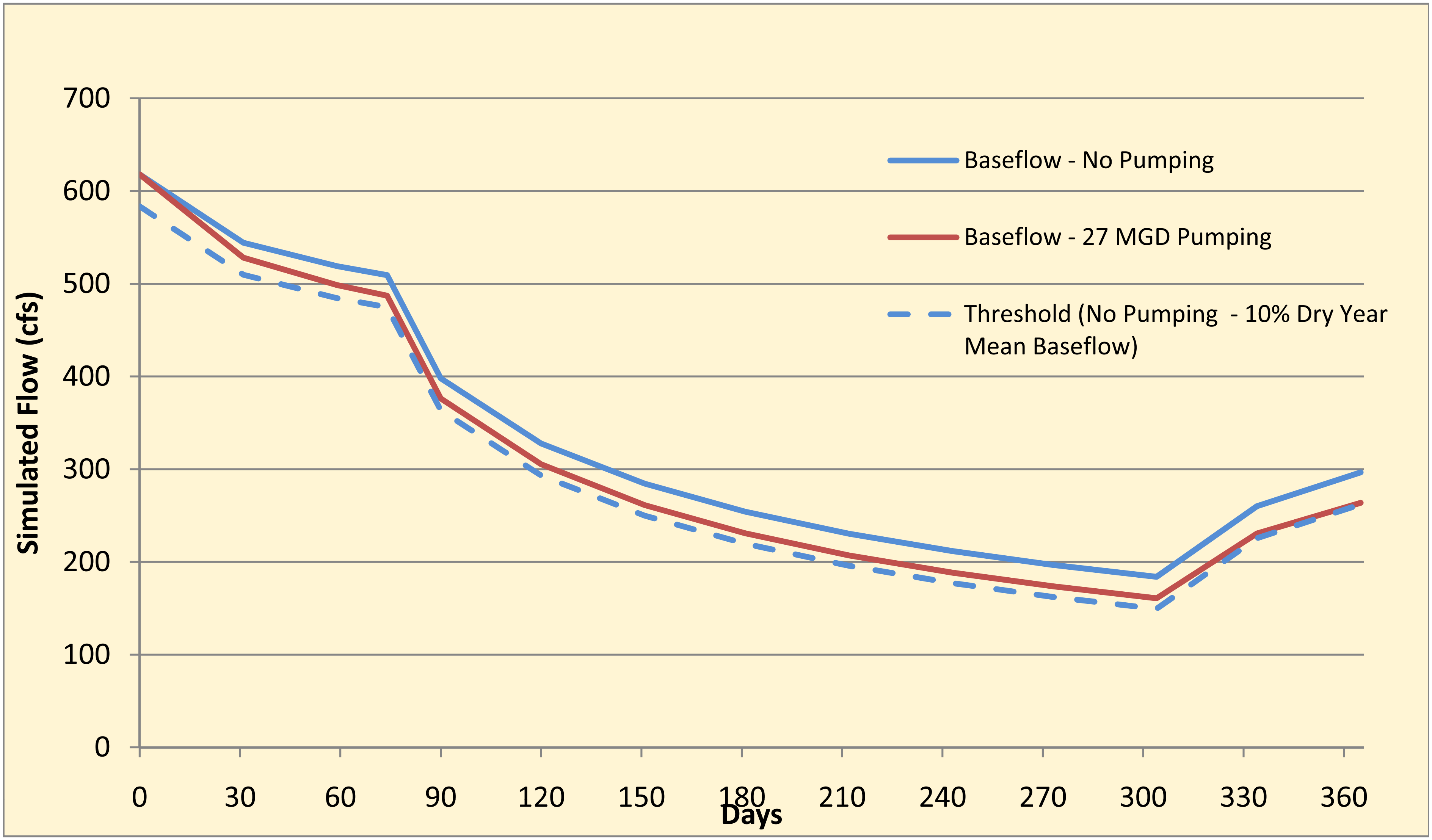

Figure S-5 shows the results of the one year dry condition transient simulation for pumping at the lower limit of sustainable yield, estimated to be 27 mgd. There are three lines on the lower graph:

- Simulated stream baseflow during a drought year without groundwater withdrawals (solid blue line). Dry-year stream baseflow was simulated with no groundwater withdrawals and plotted as cubic feet per second (CFS) versus the day of the year.
- More conservative – drought year streamflow reduced by 10% of mean annual baseflow for a drought year of precipitation (dashed blue line). Simulated dry-year baseflow minus 10% of simulated dry-year baseflow was plotted as CFS versus the day of the year.
- Simulated stream baseflow with 27 mgd of pumping from the aquifer system (solid red line). Baseflow with groundwater withdrawals was simulated to fall within the envelope to determine the sustainable yield for a dry year.

The fact that the simulated baseflow under pumping conditions (the red lines) approaches the upper and lower bounds of the allowable reduction in streamflow (the dashed blue lines) in the two graphs suggest that, based on the sustainable criteria selected, the range of sustainable yield falls somewhere between 27 mgd and 70 mgd. There is less baseflow and less groundwater recharge from surface water during a dry year than an average year, leading to the lower range of the sustainable yield.

Two other criteria must also be met to remain below the sustainable yield threshold:

- Drought year baseflow for any individual spring or stream should not be reduced by more than 15 percent of mean annual baseflow. Even at the maximum end of the range of sustainable yield (70 mgd), all of the simulated individual sub-watershed baseflows (used to represent spring flows in the model) declined by less than 15%.
- The water table decline (drawdown) due to withdrawals should not exceed 30 feet except in the immediate vicinity of a pumping well. Simulated areas of water table decline greater than 30 feet due to the evenly distributed 70 MGD withdrawals were negligible, so this metric did not affect the sustainable yield assessment.

In all cases during the northwest Georgia model runs, the streamflow sustainable yield metric was the only one encountered by the simulations.

In summary, model results indicate a range of sustainable yield of 27 to 70 MGD for the model domain. As indicated by the range, assessments of sustainable yield depend very significantly on the criteria selected. Sustainable yield will also depend on other factors, particularly the actual location and timing of withdrawals.

Section 5
Georgia Coastal Plain: Regional and Sub-Regional Calibrated Groundwater Flow Models

Where sufficient hydrogeologic data existed, a calibrated three-dimensional groundwater flow model of the aquifer system was developed. A calibrated model increases the confidence level of the sustainable yield estimate. Additionally, transient flow capabilities would allow for the ability to change the magnitude and direction of flow with time. With transient capabilities, the model can be used to assess the timing of withdrawals as well as the spatial distribution of withdrawals. Numerical flow models were developed for the Claiborne, Cretaceous, and Upper Floridan aquifers in the Coastal Plain aquifer system in Georgia.

5.1 Dougherty Plain Modeling Approach

In order to provide a basis for estimating the sustainable yield in Upper Floridan aquifer in the Dougherty Plain area, an existing United States Geological Survey (USGS) Modular Finite Element (MODFE) model of the Upper Floridan aquifer in this area was used with no modifications. The model domain, along with Georgia, Alabama, and Florida counties is shown by the dashed purple area in Figure S-1. The Dougherty Plain area is located at the southwestern corner of Georgia and the model extends slightly into Alabama and Florida. The model covers an area of approximately 4,700 square miles. Two versions of the model were furnished by the USGS: a transient model and a steady state model. The steady state model was chosen for this analysis because it was determined to be sufficient for sustainable yield evaluations.

The model was calibrated to conditions in October 1999, during which time the model area was experiencing a drought. Because it was the month of lowest stream baseflow, it was therefore a month of greatest constraint on the sustainable yield. Groundwater withdrawals during months other than October, particularly those during the agricultural irrigation season, would be higher than the October 1999 baseline and may in fact exceed the sustainable yield during the time of withdrawal.

During a review of the model documentation and the execution of several preliminary test simulations, it was apparent that the critical sustainability metric in the Dougherty Plain area was the potential impact to base flows of the river system. Because there is a significant degree of connection between the Upper Floridan aquifer and the rivers in this part of Georgia, excessive drawdown of the aquifer does not appear to be a major concern because the rivers would recharge the aquifer under increased withdrawal scenarios.

There are a number of river systems within the model domain. **Figure S-6** shows the model domain with the associated tributary basins or hydrologic unit. Each hydrologic unit is identified by a unique hydrologic unit code (HUC).

To assess sustainable yield, drought condition withdrawals were incrementally increased in a specific hydrologic unit while keeping the withdrawals in the remaining hydrologic units at the original rate. The withdrawal rate multiplier was increased until a streamflow reduction metric was triggered. This process was repeated for each hydrologic unit until unique multipliers were determined for each hydrologic unit. Once all of these multipliers were determined, a series of simulations followed in which the groundwater withdrawals were increased in all hydrologic units by their unique multiplier. Due to the cumulative effect of withdrawals on streamflow, it became necessary to lower the withdrawal multipliers until the streamflow reduction metric was no longer violated. This then, represented an estimate of the sustainable yield of the Upper Floridan aquifer in the Dougherty Plain.

5.2 Dougherty Plain Sustainable Yield Ranges

Table S-5 shows the multipliers when the groundwater withdrawal increases are simulated concurrently. There are several river reaches in HUC 03130004, including the Chattahoochee River, Sawhatchee, Kirkland, and Bryans. While it appears to be technically possible to have a significant increase in the groundwater withdrawal from the Chattahoochee River basin, this hydrologic unit straddles both the Alabama and Florida state lines. Significant increases in groundwater withdrawals would cause impacts in these adjacent states. Therefore, Table S-5 shows a sustainable yield range that both includes and does not include additional withdrawals from this hydrologic unit code.

The table lists the October 1999 baseline withdrawals and the revised withdrawals providing a sustainable yield estimate. These cumulative increases in groundwater withdrawals result in an overall increase in the withdrawal of between 80 mgd and 171 mgd over October 1999 baseline for the study area.

There are two hydrologic unit groups (03130009 – Ichawaynochaway Creek, and 03130008 – Lower Flint River, with minor portions of the upper and lower Ochlocknee River) in which approximately 70 percent of the potential increase in groundwater withdrawals originates. Thus, there is a significant amount of water available, but this available water tends to be centrally located in the basin.

As discussed previously, the most significant metric was the reduction in baseflow to the rivers; however, there is also a drawdown effect. To ensure that there were no violations, the drawdown was calculated. Due to the lack of a significant confining unit above the Upper Floridan aquifer, the drawdown due to increased withdrawals is less than 5 feet and does not approach the 30 foot drawdown metric. In this case, streamflow reduction controls the estimate of sustainable yield. **Figure S-7** shows the river reach that violated the baseflow metric used to determine sustainable yield when simulating the increased withdrawals concurrently.

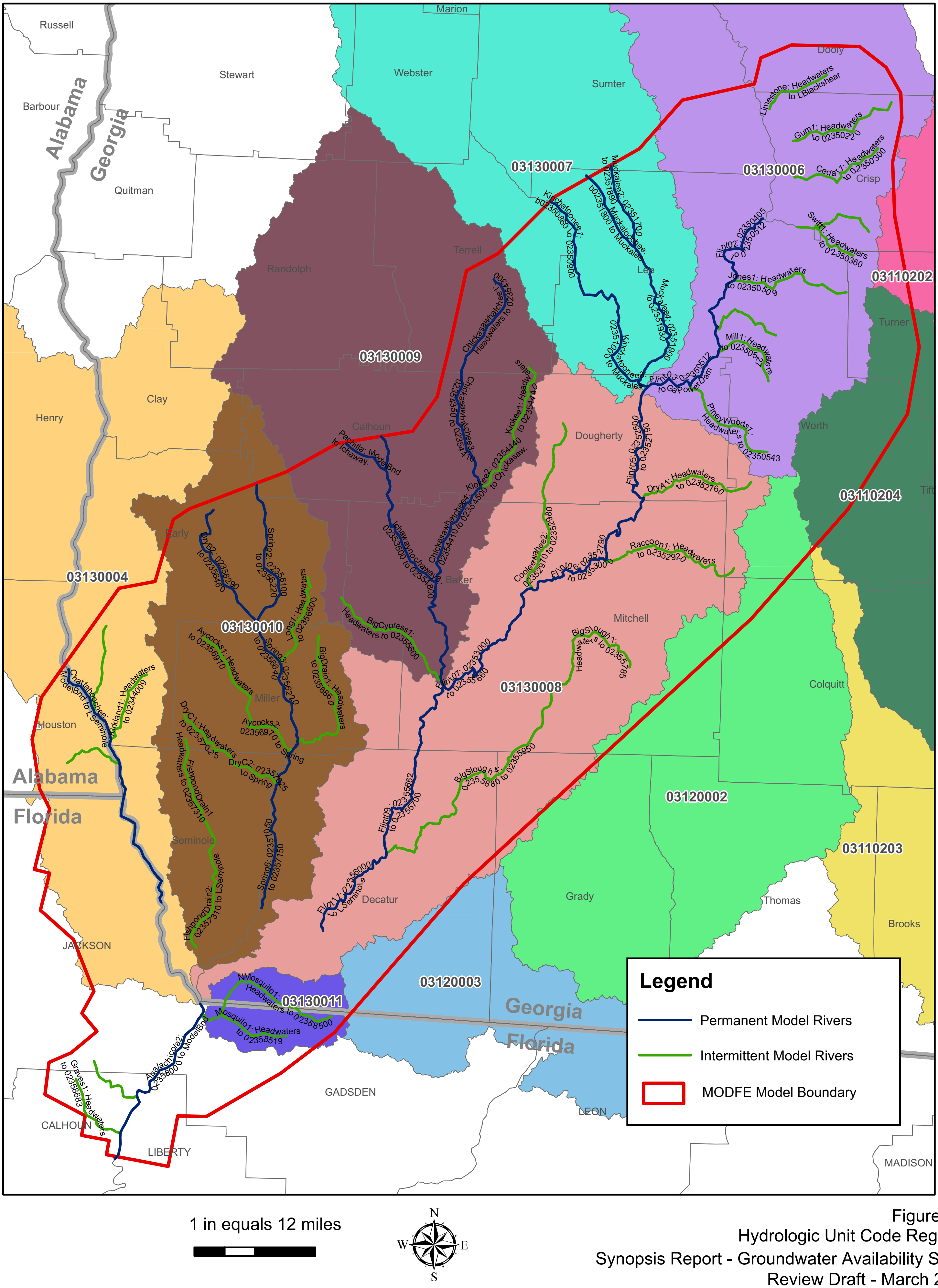

Figure S-6
Hydrologic Unit Code Regions

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Table S-5

Dougherty Plain Concurrent Groundwater Withdrawal Increase Factors

HUC	Baseline October 1999 Withdrawals (mgd)	Revised Withdrawals without HUC 03130004		Revised Withdrawals with HUC 03130004	
		Multiplier	Withdrawal (mgd)	Multiplier	Withdrawal (mgd)
03130007	3.97	1.73	6.88	1.73	6.88
03130006 03110202 03110204	11.39	1.87	21.34	1.87	21.34
03130009	9.86	4.22	41.62	4.22	41.62
03130010	39.91	1.21	48.33	1.21	48.33
03130008 03120002 03120003	77.64	1.33	102.95	1.33	102.95
03130004	11.21	1.00	11.21	9.17	102.80
03130011	2.99	1.51	4.53	1.51	4.53
Totals	**157**		**237**		**328**

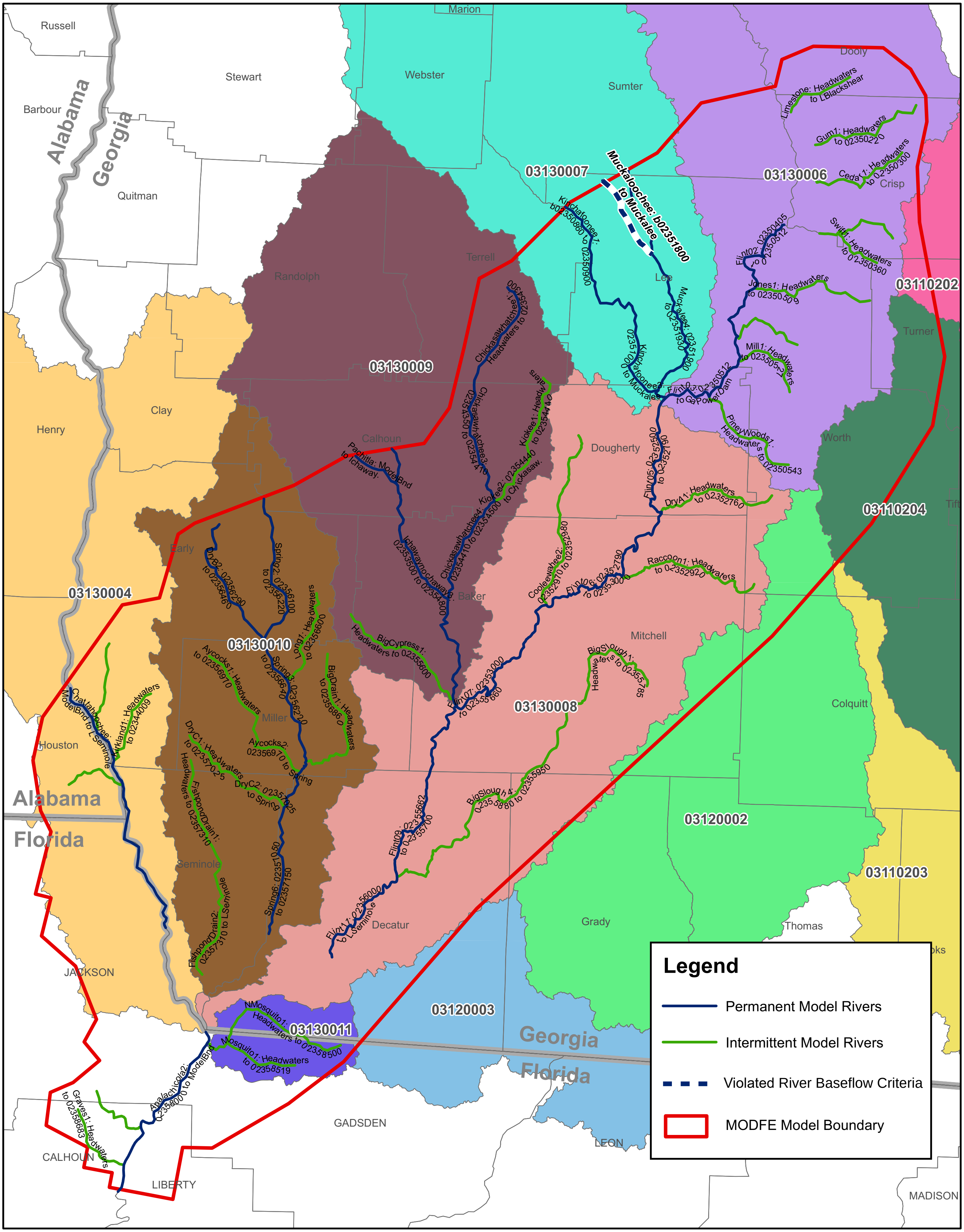

Figure S-7
Cumulative Violations
MODFE Model
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In order to further examine the range of sustainable yield, an additional simulation was performed using March 2001 data. March 2001 was the month that had the highest river stages within the time range of the U.S.G.S transient model. Completing sustainable yield runs using March 2001 data, therefore, allowing a comparison of sustainable yield during times of low and high stream baseflow.

The original steady state model input parameters were replaced with those parameters that represented the March 2001 period in the transient model. Specifically, river stages, groundwater withdrawals, and recharge/leakage values were replaced with March 2001 information. The sustainable yield simulations were then rerun with March 2001 baseline withdrawals. Similar to the original simulation, there were two general scenarios considered, pumping increases allowed in HUC 03130004, which causes some drawdown in Alabama and Florida, and pumping increases not allowed in HUC 03130004. These scenarios resulted in an overall sustainable yield range of 262 to 347 mgd, slightly higher than the October 1999 results of 237 to 328 mgd.

5.3 Coastal Plain Modeling Approach

Sustainable yields were determined for four prioritized Coastal Plain aquifers:

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

The approach used to model the prioritized Coastal Plain aquifers was as follows:

- An existing regional USGS Coastal Plain Clastic aquifer System model was modified and updated by incorporating available data and the existing groundwater models in or adjacent to the project areas to better represent the hydrogeologic conditions within the project area.
- A regional groundwater flow model was developed and calibrated to observed groundwater elevations at monitor well locations. It was also calibrated using available hydrogeologic data, groundwater monitoring well data, and existing models under steady-state conditions to establish boundary conditions (elevations) for the sub-regional models.
- Three sub-regional groundwater flow models for the prioritized aquifers were developed by zooming into portions of the calibrated regional groundwater model.
- Models of the prioritized aquifers were calibrated to observed groundwater elevations at monitor well locations under transient conditions that represented average, high, and low rainfall years. 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). The benchmark condition was that heads should have achieved at least 90 percent of their pre-drought levels within four years.

- The calibrated model of each prioritized aquifer was used to simulate increased groundwater withdrawals from the aquifer to determine the range of sustainable yield for the individual aquifer.
- The calibrated regional model was used to simulate increased groundwater withdrawals from all prioritized aquifers to determine the total range of sustainable yield for simultaneous increased withdrawals from all of the prioritized aquifers.

The extents of the regional and prioritized aquifer models are shown on **Figure S-8**.

The general sustainable yield metrics presented in Section 2 were further refined to be used for the Georgia Coastal Plain numerical models. To estimate a range of sustainable yields using a calibrated numerical model, withdrawals were increased over baseline withdrawals and the aquifers were allowed to fully adjust to the new groundwater withdrawal regime. In other words, aquifers were allowed to reach a new equilibrium at the higher withdrawals. Equilibrium was seen once the pattern of annual variation in aquifer heads had stabilized. Model results for the time of year when heads were at their lowest (usually in August or September) were compared to the set of selected sustainable yield metrics.

Even if it is assumed that the sustainable yield is properly assessed and that the 30-foot groundwater level drawdown metric at system equilibrium for the driest month is the determining metric, this still does not mean a single sustainable yield number can be calculated. The sustainable rate of aquifer withdrawal is sensitive to the location and density of withdrawals. Withdrawals in a small area may result in a 30-foot drawdown whereas the same withdrawals dispersed over a larger area will have a lesser drawdown result. This means that sustainable yield must be assessed as a range, and that the ultimate sustainable yield within that range will depend on the pattern and density of withdrawals.

In the Coastal Plain, there are multiple aquifers underlying the region. Withdrawals in one aquifer often cause groundwater level drawdown in underlying and overlying aquifers. If withdrawals are allowed to increase in each of the aquifers within the sustainable yield of that individual aquifer, the cumulative effect of simultaneous withdrawals from multiple aquifers could result in drawdowns of more than 30 feet more than 40 percent recharge from streamflow.

The regional model was run simultaneously increasing withdrawals from all prioritized aquifers with withdrawals reduced until the metrics for drawdown and recharge from streamflow were met across the multiple aquifers. This analysis resulted in estimates of sustainable yield for increasing withdrawals in multiple aquifers simultaneously.

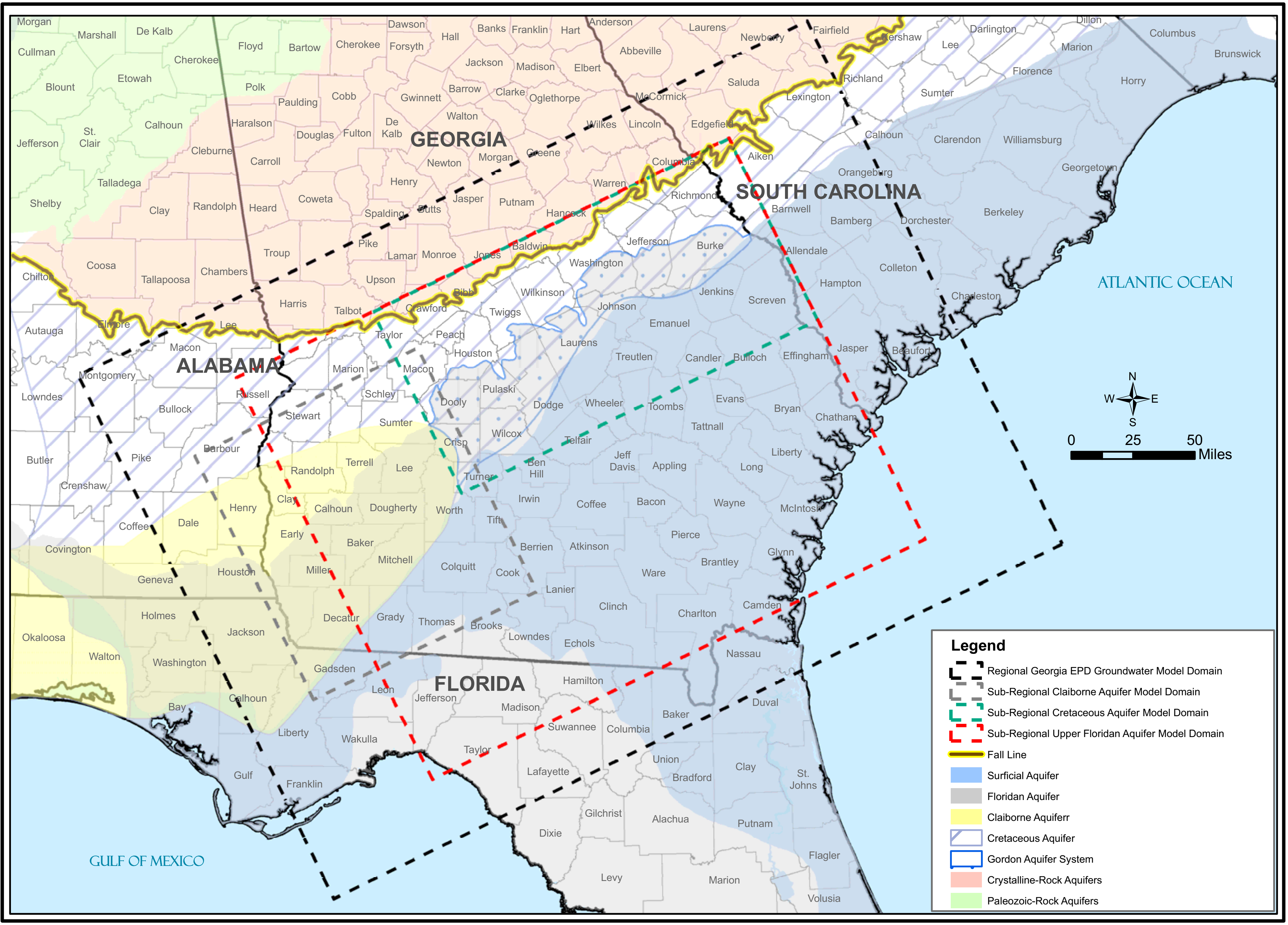

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Figure S-8
Regional and Sub-Regional Model Domains

5.4 Sustainable Yield of South-Central Georgia and Eastern Coastal Plain Upper Floridan Aquifer, Claiborne Aquifer, and Cretaceous Aquifer

The sustainable yield in the Upper Floridan aquifer in south-central Georgia and the eastern Coastal Plain were evaluated together. First, the sustainable yield of south-central Georgia was evaluated by itself by increasing withdrawals from existing and hypothetical new wells. Withdrawals from the Upper Floridan aquifer in the eastern coastal plain were held at baseline levels. Then, withdrawals were increased in the existing wells in the eastern Coastal Plain along with increasing withdrawals from existing and hypothetical new wells in south-central Georgia. Unlike in south-central Georgia, new wells were not considered in the Upper Floridan aquifer in the eastern Coastal Plain when simulated withdrawals were increased because existing withdrawals are low and there is widespread spatial coverage of existing wells. Two scenarios were evaluated for withdrawal increases: one included all wells increasing uniformly, and the other increased withdrawals only in areas where there are relatively little withdrawals currently.

Table S-6 provides a summary of the results of sustainable yield modeling of the individual prioritized aquifers. The table provides a range of increases in withdrawals over current rates of withdrawals for each individual prioritized aquifer, assuming that the other prioritized aquifers do not increase withdrawals above their current levels. Section 5.5 provides the range of increases in withdrawals over current rates of withdrawals for each individual prioritized aquifer, assuming that all of the other prioritized aquifers simultaneously increase withdrawals above their current levels to their sustainable yield rates.

5.4.1 Upper Floridan Aquifer in South-Central Georgia

As shown in Table S-6, the estimated baseline withdrawal rate from the Upper Floridan aquifer in south-central Georgia was approximately 329 mgd. Uniformly increased withdrawals from the existing wells in the Upper Floridan aquifer in south-central Georgia represented the low end of the range of sustainable yield, whereas non-uniformly increased withdrawals from the existing wells and hypothetical new wells in the south-central Georgia Upper Floridan aquifer represents the high end of the range of sustainable yield.

If withdrawals are uniformly increased from existing wells in the Upper Floridan aquifer in south-central Georgia, the withdrawals can be increased from a baseline of 329 mgd to 622 mgd. This pumping scenario results in localized exceedance of the 30-foot groundwater level drawdown metric and a corresponding baseflow reduction of approximately 23 percent.

If withdrawals are non-uniformly increased (that is, only in areas where there are relatively little withdrawals currently), total withdrawals could be increased further in south-central Georgia toward 836 mgd, an upper bound for the range of sustainable yield. **Figure S-9** presents the range of sustainable yield for the Upper

Table S-6

Summary of Sustainable Yield Estimates for Withdrawals from Individual Prioritized Aquifers in the Coastal Plain of Georgia

Aquifer	Baseline Groundwater Withdrawal	Sustainable Yield of Individual Aquifer	
	(mgd)	(mgd)	
South-Central Georgia Upper Floridan Aquifer	329	Min Max	622 836
South-Central Georgia & Eastern Coastal Plain Upper Floridan Aquifer[1]	475	Min Max	868 982
Claiborne Aquifer	67	Min Max	100 250
Cretaceous Aquifer	124	Min Max	198 201
Total for the Prioritized Aquifers	**667**	**Min** **Max**	**1,166** **1,433**

[1] The increased withdrawals from the Upper Floridan Aquifer for the eastern coastal plain were evaluated in combination with the south-central area of Georgia.

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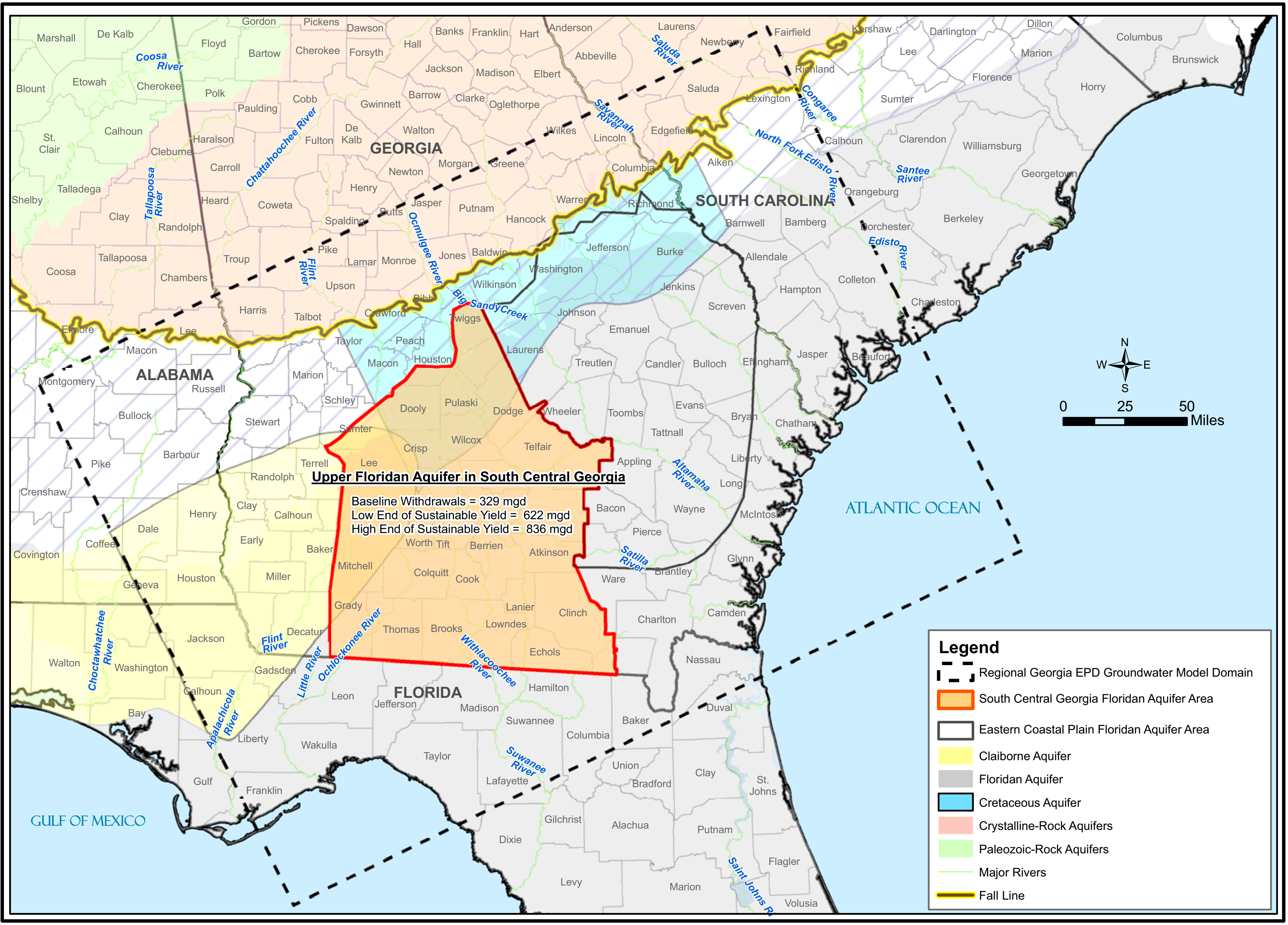

Figure S-9
Groundwater Modeling for Upper Floridan Aquifer Sustainable Yield Assessment in South Central Georgia

Floridan aquifer in south-central Georgia. The results presented in this figure assume that withdrawals in the aquifer are increased while holding withdrawals in the other aquifers at existing estimated rates. **Figures S-10a and S-10b** are groundwater level drawdown maps, showing where the drawdown metric of 30 feet was exceeded for the minimum and maximum sustainable yield, respectively.

5.4.2 Upper Floridan Aquifer in South-Central and Eastern Coastal Plain Georgia

Table S-6 provides sustainable yield estimates for withdrawal increases in south-central Georgia and Eastern Coastal Plain Georgia occurring simultaneously. Estimated baselines withdrawals in both areas were approximately 475 mgd. If withdrawals are uniformly increased from existing wells in the Upper Floridan aquifer in south-central Georgia and the eastern Coastal Plain, the withdrawals could be increased from a baseline of 475 mgd to 868 mgd. This withdrawal scenario resulted in a localized exceedance of the 30-foot groundwater level drawdown metric and a corresponding baseflow reduction of approximately 23 percent.

If withdrawals are non-uniformly increased from existing wells in south-central Georgia and the eastern Coastal Plain, total withdrawals could be increased further toward 982 mgd, an upper bound for the range of sustainable yield. Note that there is already a wide distribution of existing pumping wells in this area. Therefore, the addition of new wells within this combined area did not result in the maximum estimate of increased sustainable yield over the estimate of increased sustainable yield for south-central Georgia by itself. **Figure S-11** presents the range of sustainable yields for the Upper Floridan aquifer in south-central Georgia and the eastern Coastal Plain of Georgia. The results presented in this figure assume that withdrawals in the aquifer are increased while holding withdrawals in the other aquifers at existing estimated rates. **Figures S-12a and S-12b** are groundwater level drawdown maps, showing where the drawdown metric of 30 feet was exceeded for the minimum and maximum sustainable yield, respectively.

5.4.3 Claiborne Aquifer

The results of the groundwater modeling for the Claiborne aquifer sustainable yield assessment are also summarized in Table S-6. The estimated baseline withdrawal rate from the Claiborne aquifer in Georgia is approximately 67 mgd. If withdrawals are uniformly increased from the existing wells in the Claiborne aquifer, the withdrawals can be increased from a baseline of 67 mgd to 100 mgd. This pumping scenario results in an exceedance of the 30-foot groundwater level drawdown metric and a corresponding baseflow reduction of approximately 6 percent. If withdrawals are non-uniformly increased from the existing wells, total pumping withdrawals can be increased to 250 mgd. **Figure S-13** presents the range of sustainable yield for the Claiborne aquifer. The results presented in this figure assume that withdrawals in the aquifer are increased while holding withdrawals in the other aquifers at existing estimated rates. **Figures S-14a and S-14b** are groundwater level drawdown maps,

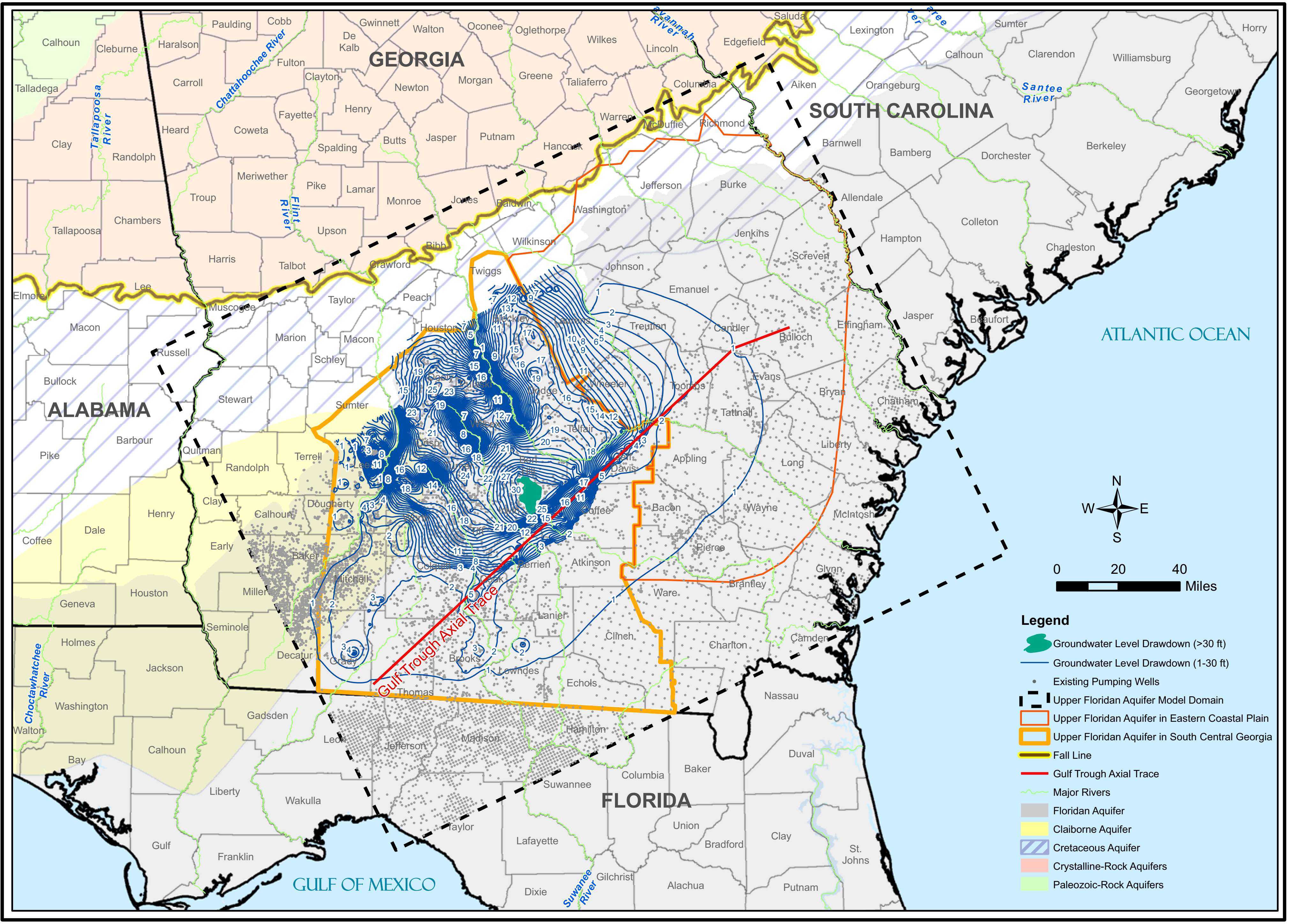

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Figure S-10a
Simulated Groundwater Level Drawdown in Upper Floridan Aquifer (Layer 2)
Due to Increasing Existing Well Pumping in Upper Floridan Aquifer in South Central Georgia (ΔQ= 293 mgd)
Using Sub-Regional Upper Floridan Aquifer Model

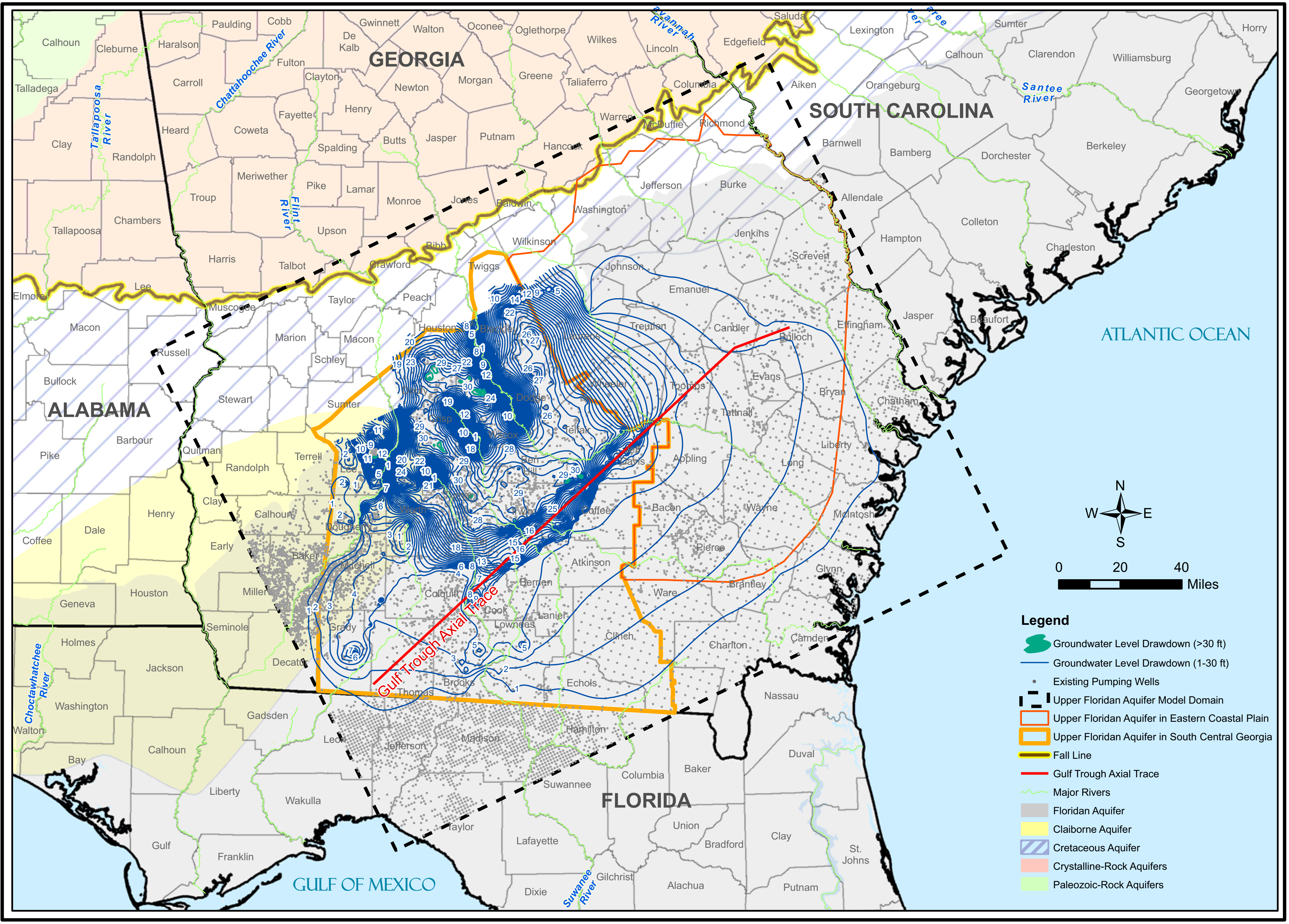

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Figure S-10b
Simulated Groundwater Level Drawdown in Upper Floridan Aquifer (Layer 2)
Due to Increasing Existing Well Pumping in Upper Floridan Aquifer in South Central Georgia (ΔQ= 507 mgd)
Using Sub-Regional Upper Floridan Aquifer Model

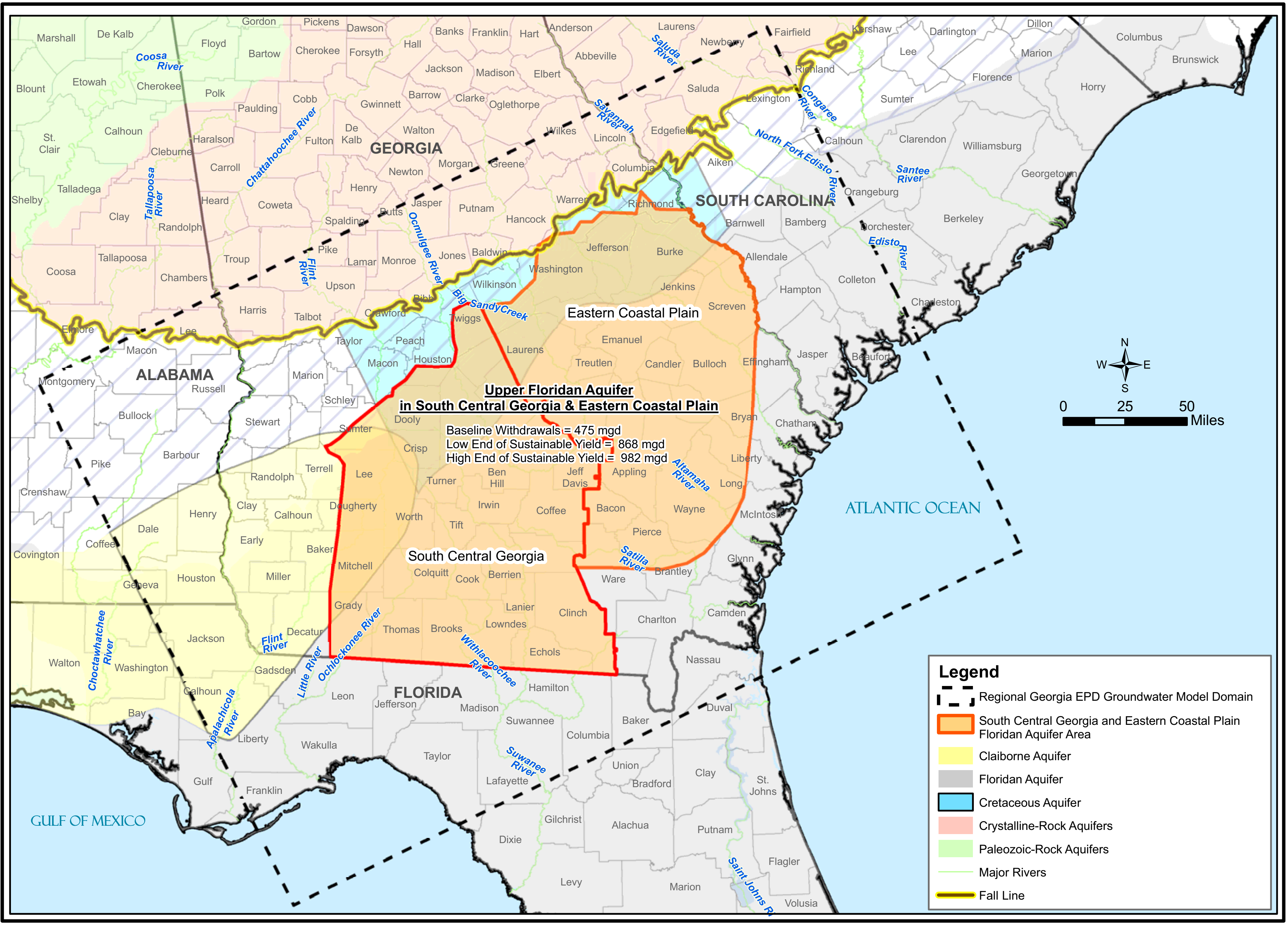

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Figure S-11
Groundwater Modeling for Upper Floridan Aquifer Sustainable Yield Assessment in South Central Georgia and Eastern Coastal Plain

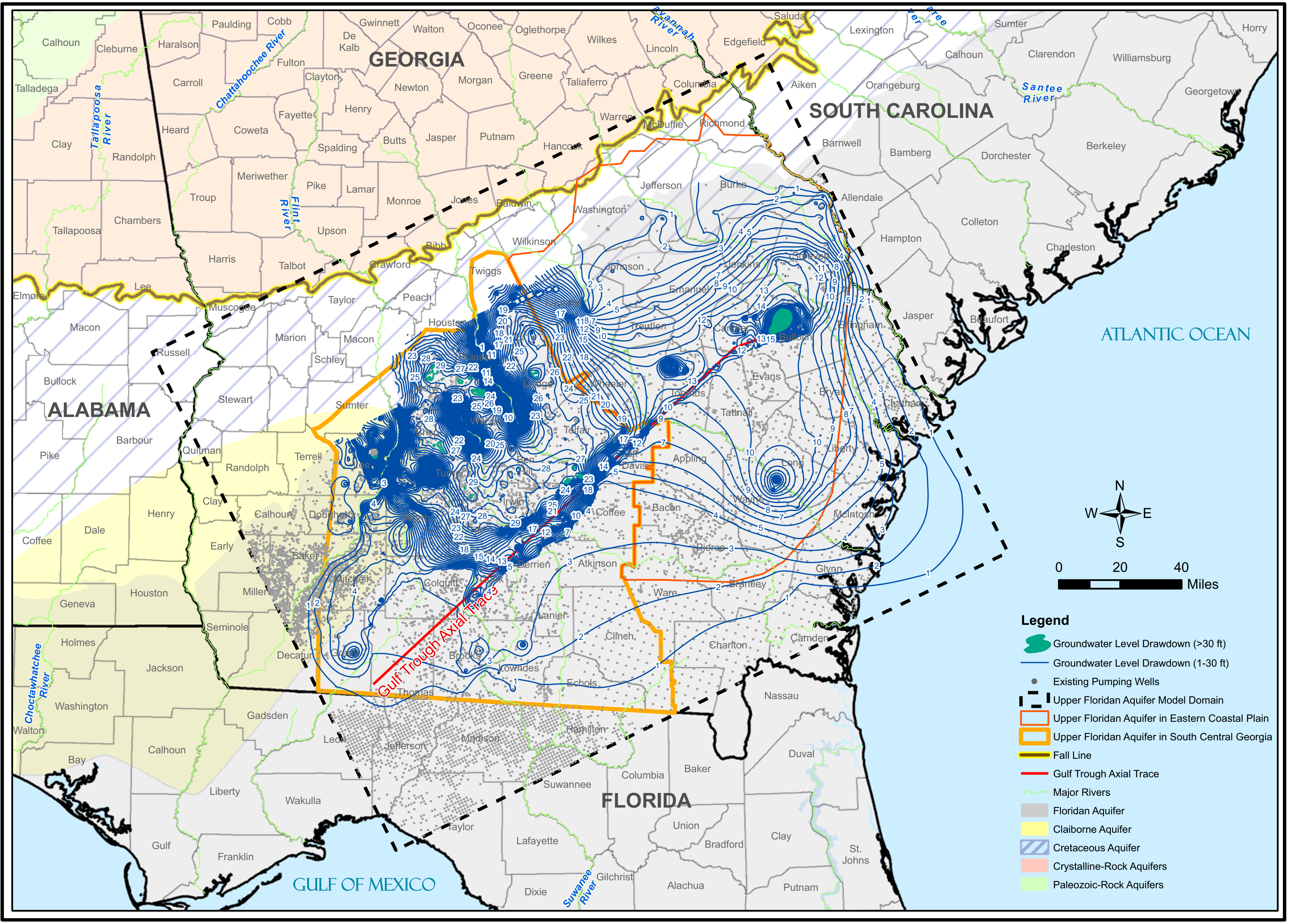

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Figure S-12a
Simulated Groundwater Level Drawdown in Upper Floridan Aquifer (Layer 2)
Increasing Existing Well Pumping in UF Aquifer in South Central GA and Eastern Coastal Plain (ΔQ= 507 mgd)
Using Sub-Regional Upper Floridan Aquifer Model

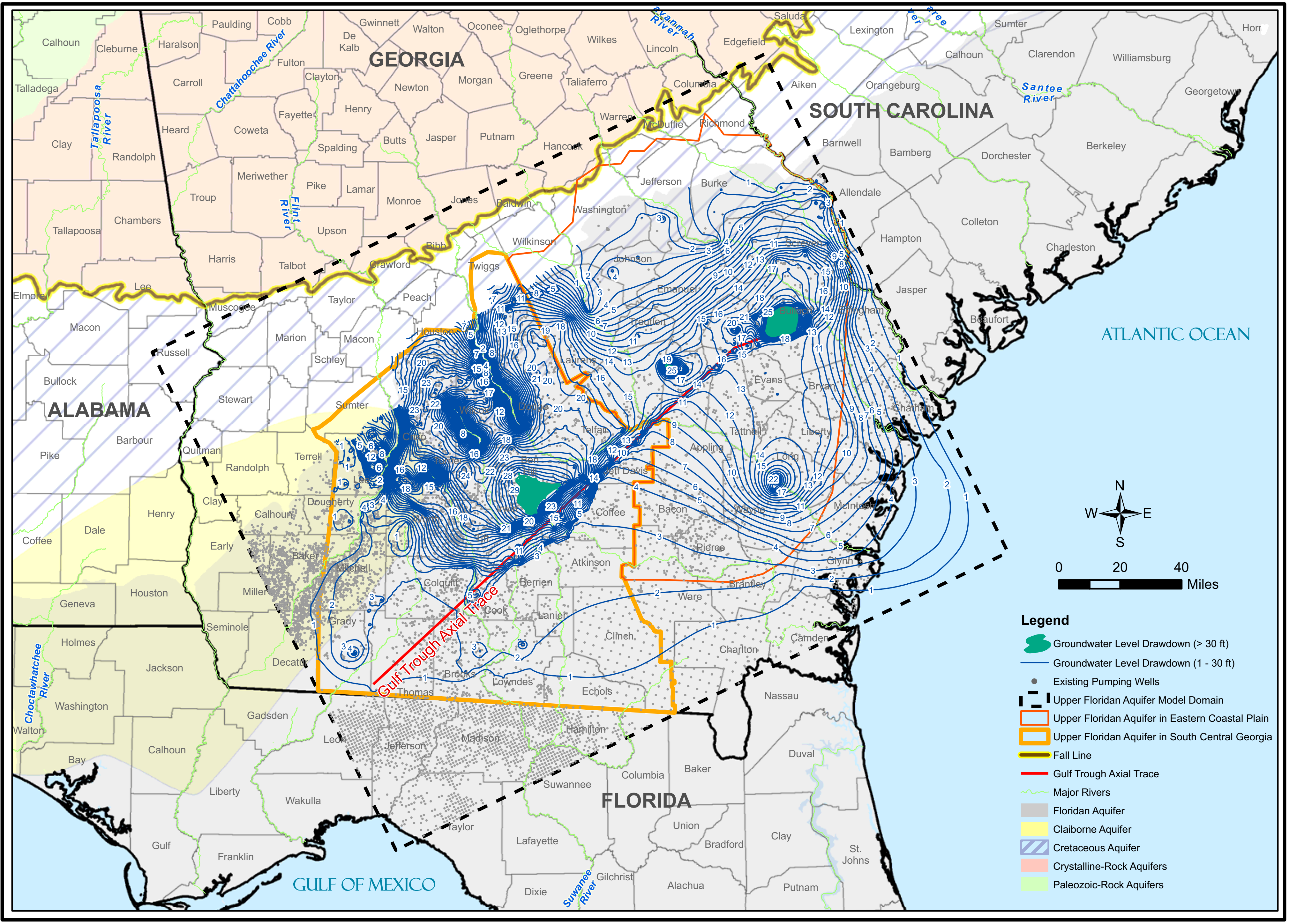

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Figure S-12b
Simulated Groundwater Level Drawdown in Upper Floridan Aquifer (Layer 2)
Due to Increasing Existing Well Pumping in UF Aquifer in South Central GA and Eastern Coastal Plain (ΔQ= 393 mgd)
Using Sub-Regional Upper Floridan Aquifer Model

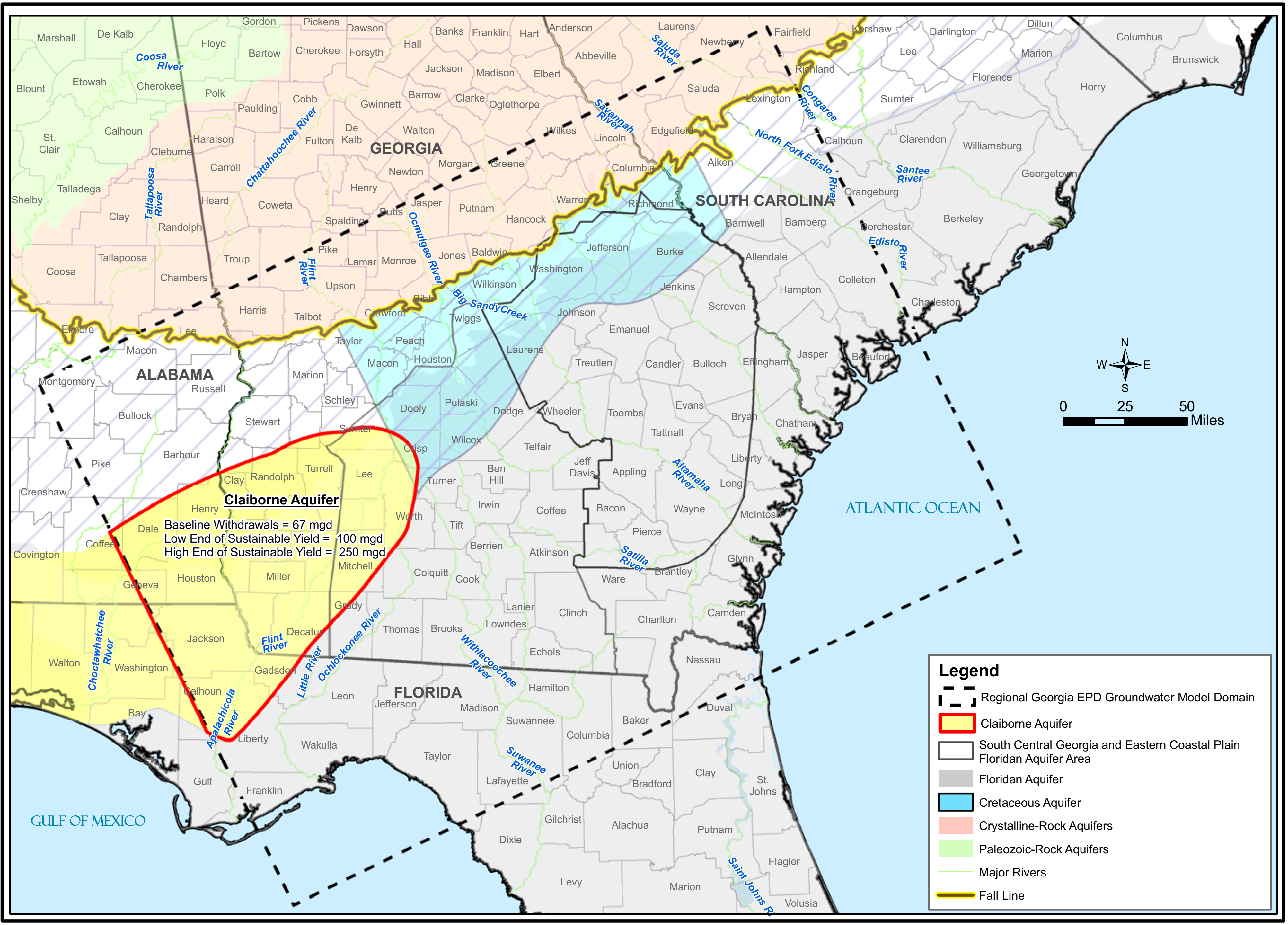

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Figure S-13
Groundwater Modeling for Claiborne Aquifer Sustainable Yield Assessment

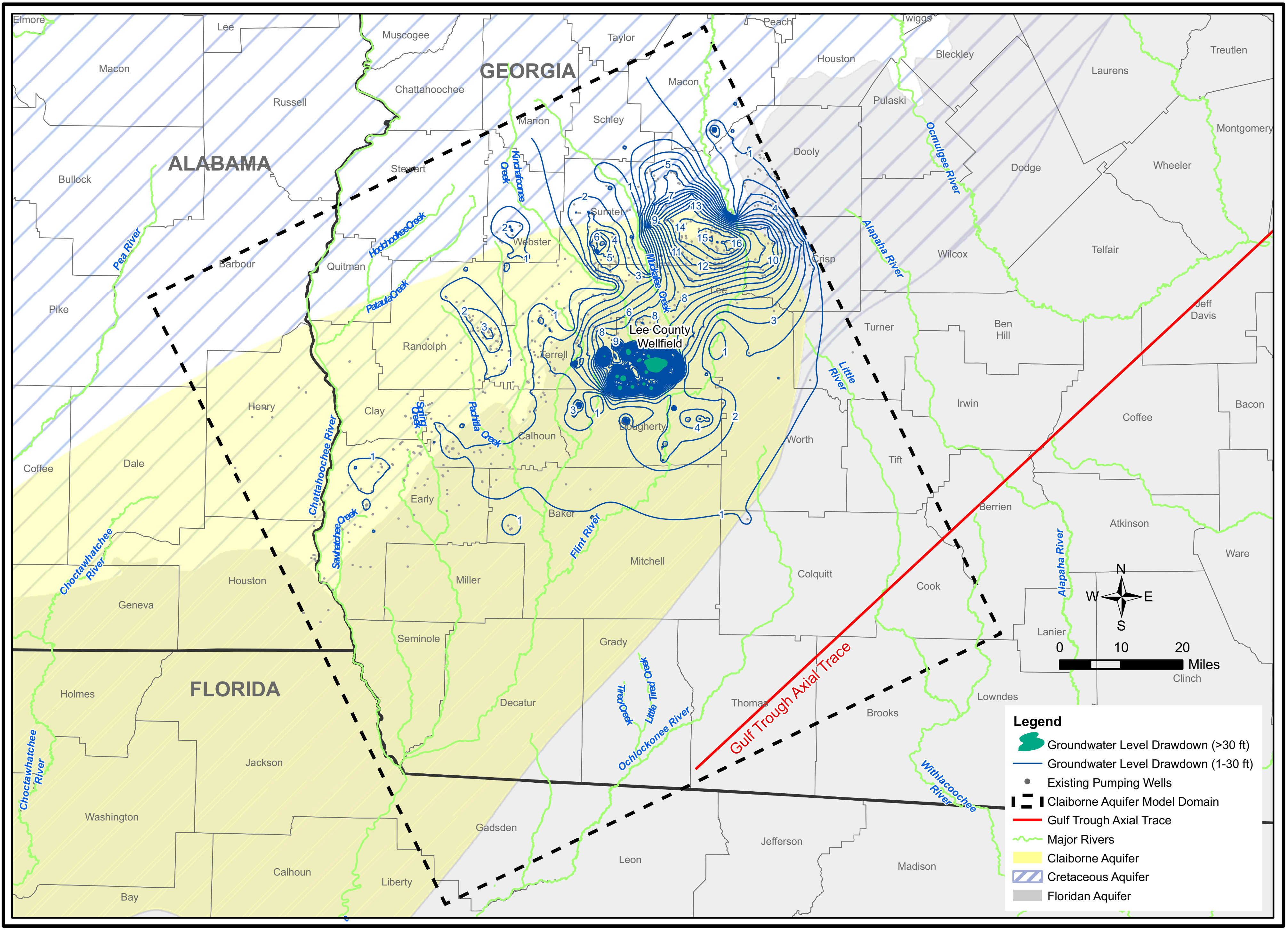

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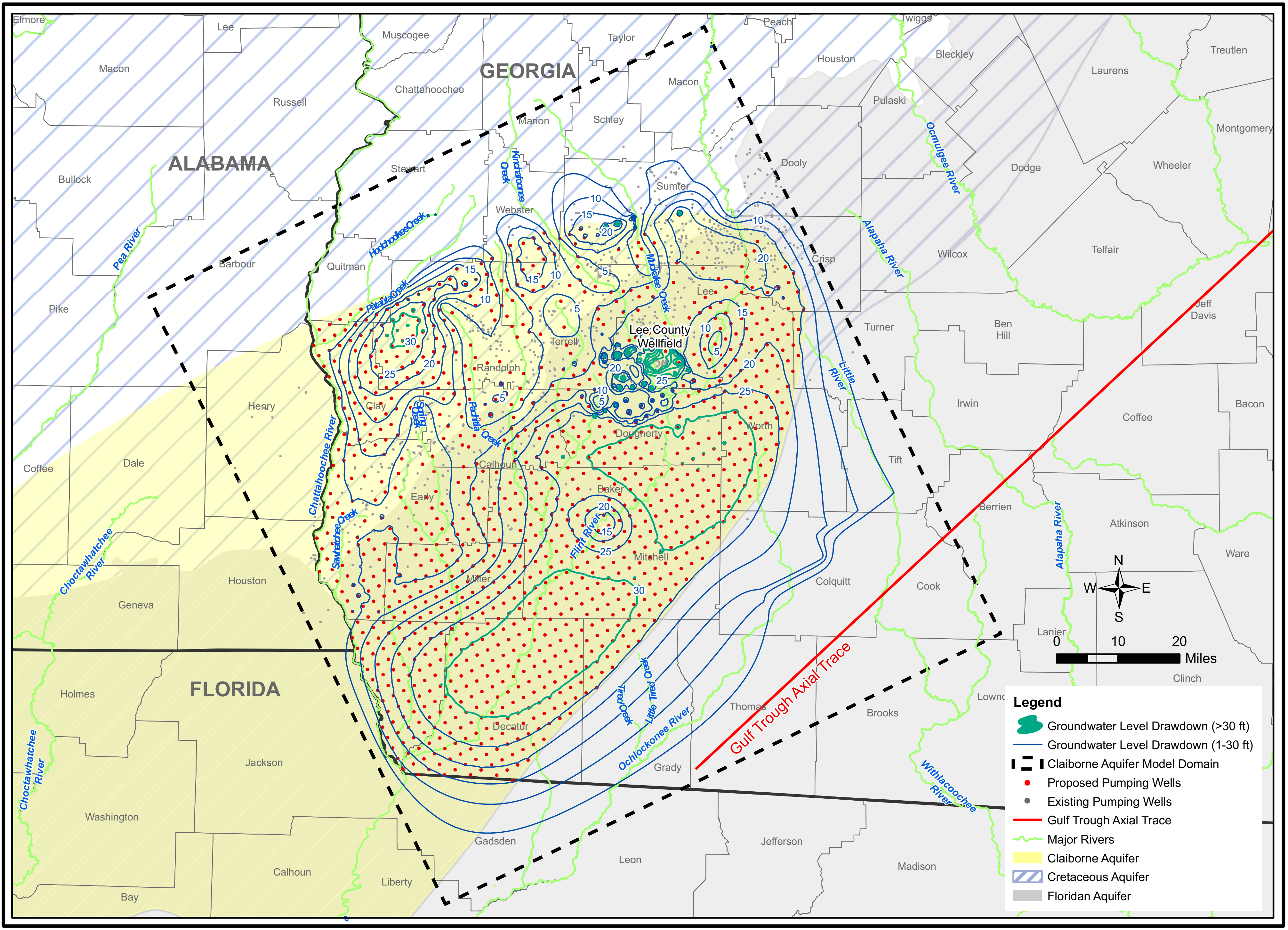
Figure S-14a
Simulated Groundwater Level Drawdown in Claiborne Aquifer (Layer 3)
Due to Increasing Existing Well Pumping in Claiborne Aquifer (ΔQ= 33 mgd)
Using Sub-Regional Claiborne Aquifer Model



G:\Reports\GWModelingResults\Claiborne\Case4\GW-DD\8.5x11\MXD\Fig 14-27 claiborne_L3-DD-Case4-ew-dQ-183mgd-SIM2-1B_8.5x11.mxd

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Figure S-14b
Simulated Groundwater Level Drawdown in Claiborne Aquifer (Layer 3)
Due to Increasing Existing and Additional Well Pumping in Claiborne Aquifer (ΔQ= 183 mgd)
Using Sub-Regional Claiborne Aquifer Model

showing where the drawdown metric of 30 feet was exceeded for the minimum and maximum sustainable yield, respectively.

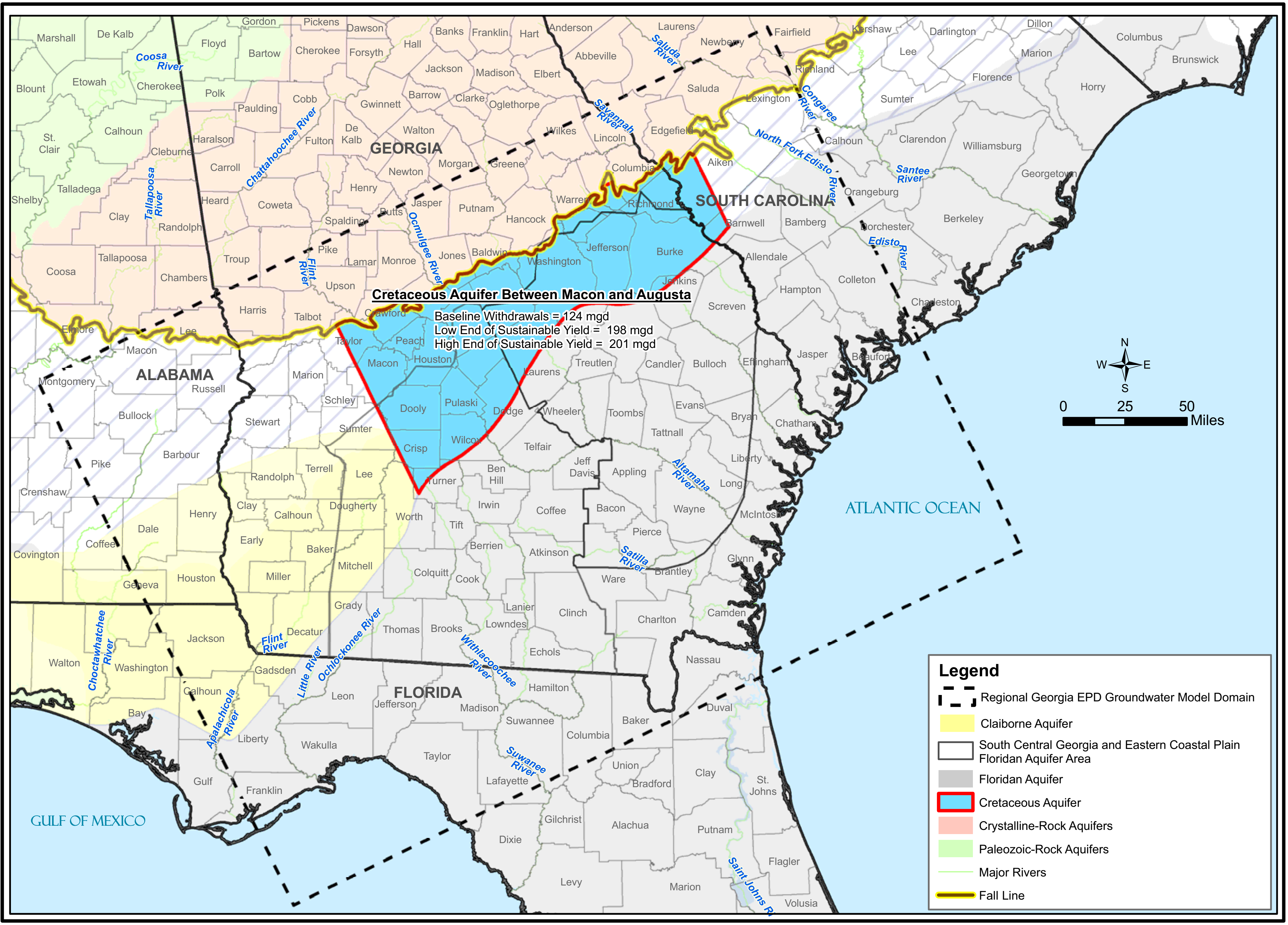
5.4.4 Cretaceous Aquifer

The results of the groundwater modeling for the Cretaceous aquifer sustainable yield assessment are presented in Table S-6. As shown in the table, the estimated baseline withdrawal rate from the Cretaceous aquifer is approximately 124 mgd, with 100 mgd pumped from the Providence aquifer and 24 mgd pumped from the Eutaw-Midville aquifer. If withdrawals are uniformly increased from the existing wells in the Cretaceous aquifer, the withdrawals can be increased from a baseline of 124 mgd to 198 mgd. This withdrawal scenario results in exceedance of the 30-foot groundwater level drawdown metric and a corresponding baseflow reduction of 39 percent. If withdrawals are non-uniformly increased from the existing wells, total withdrawals can be increased to 201 mgd. **Figure S-15** presents the range of sustainable yield for the Cretaceous aquifer between Macon and Augusta. The results presented in this figure assume that withdrawals in the aquifer are increased while holding withdrawals in the other aquifers at existing estimated rates. **Figures S-16a and S-16b** are groundwater level drawdown maps for the Providence aquifer, showing where the drawdown metric of 30 feet was exceeded for the minimum and maximum sustainable yield, respectively. **Figures S-17a and S-17b** are groundwater level drawdown maps for the Eutaw-Midville aquifer, showing where the drawdown metric of 30 feet was exceeded for the minimum and maximum sustainable yield, respectively.

5.5 Regional Model Combined Prioritized Aquifer Sustainable Yield Adjustment

Increased withdrawals occur at the same time in more than one Coastal Plain aquifer. Therefore, groundwater modeling simulations that increased withdrawals in all of the prioritized aquifers were completed to assess the potential impact of combined withdrawals on the overall range of sustainable yields.

Following the estimate of sustainable yield of each individual aquifer, the regional groundwater model was used to assess the potential impact of withdrawal increases in all the aquifers simultaneously. **Table S-7** shows the ranges of sustainable yields of individual prioritized aquifers with withdrawals increased in all prioritized aquifers simultaneously. Uniformly increasing withdrawals from the existing wells in all the prioritized aquifer represented the low end of the range of sustainable yields, whereas non-uniformly increasing withdrawals from the existing wells in each prioritized aquifer represents the high end of the range of sustainable yields. **Figure S-18** presents the results if withdrawals are increased in all of these prioritized aquifers. **Figures S-19a through S-19e** are groundwater level drawdown maps for each of the regional model layers, showing where the drawdown metric of 30 feet was exceeded for the minimum sustainable yield. **Figures S-20a through S-20e** provide the same information for the maximum sustainable yield.



Cretaceous Aquifer Between Macon and Augusta

Baseline Withdrawals = 124 mgd
Low End of Sustainable Yield = 198 mgd
High End of Sustainable Yield = 201 mgd

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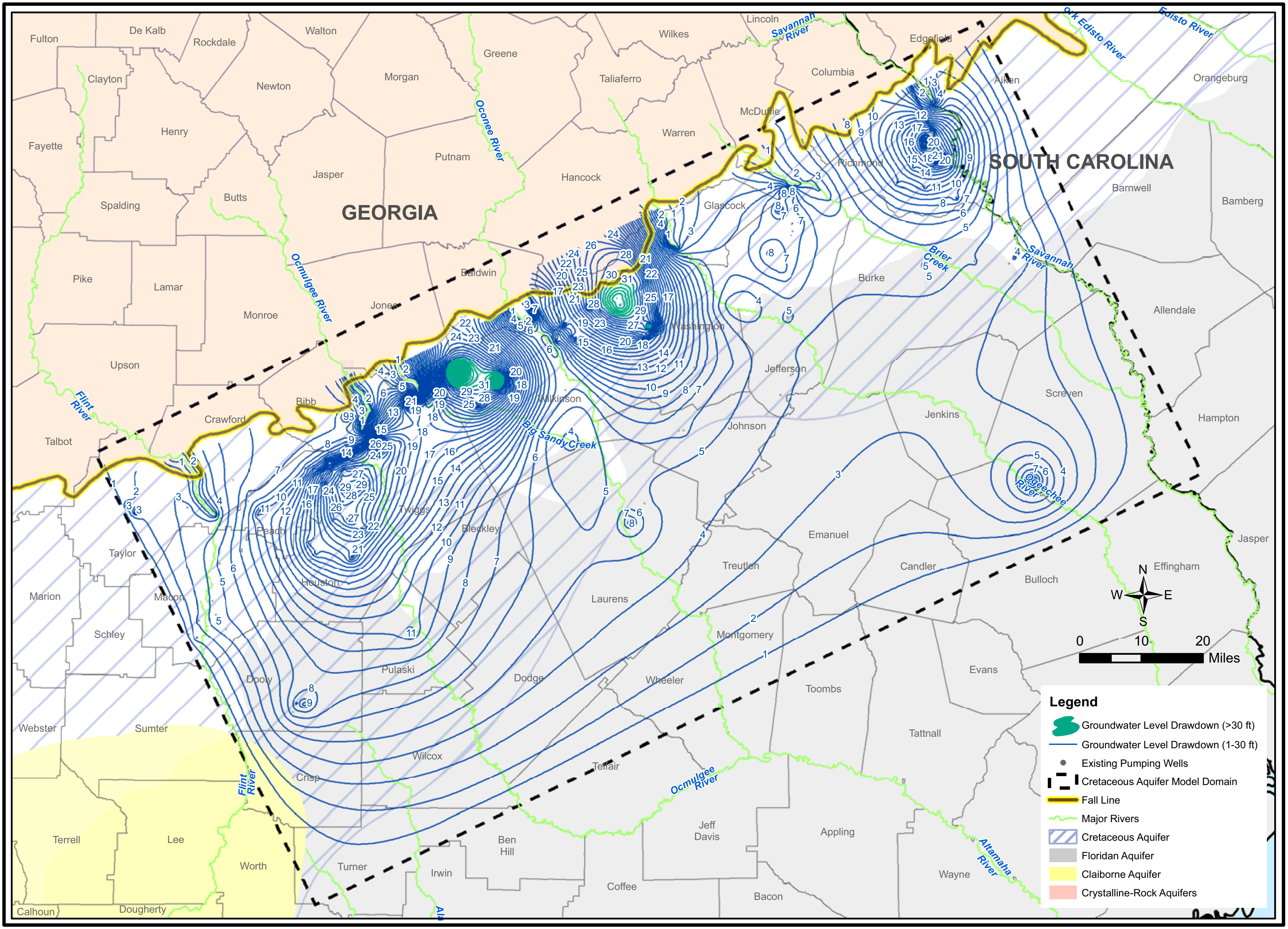
Figure S-15
Groundwater Modeling for Cretaceous Aquifer Sustainable Yield Assessment



G:\Reports\GWModelingResults\Cretaceous\Case1\dd\8.5x11MXD\Fig 15-17_cret_L5-SIM2-1C-ew-minQ-Case1-Local-dd_8.5x11.mxd

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Figure S-16a
Simulated Groundwater Level Drawdown in Providence Aquifer (Layer 5)
Due to Increasing Existing Well Pumping in Providence and Eutaw Midville Aquifer (ΔQ= 74 mgd)
Using Sub-Regional Cretaceous Aquifer Model

G:\Reports\GWModelingResults\Cretaceous\Case2\dd\8.5x11MXD\Fig 15-29_cret_L5-SIM2-2B-ew-minQ-Case2-Local-dd_8.5x11.mxd
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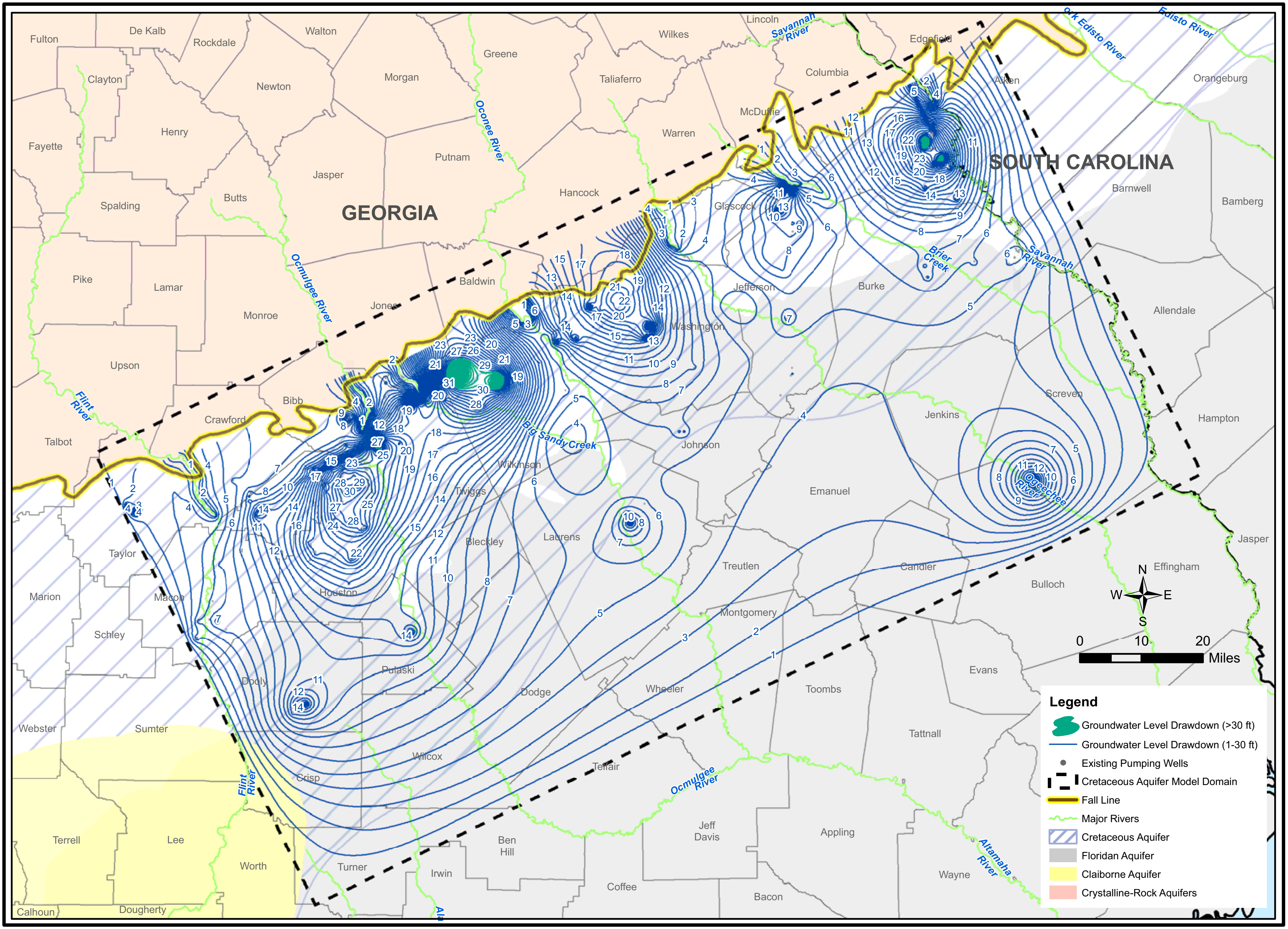

Figure S-16b
Simulated Groundwater Level Drawdown in Providence Aquifer (Layer 5)
Due to Increasing Existing Well Pumping in Providence and Eutaw Midville Aquifer (ΔQ= 78 mgd)
Using Sub-Regional Cretaceous Aquifer Model

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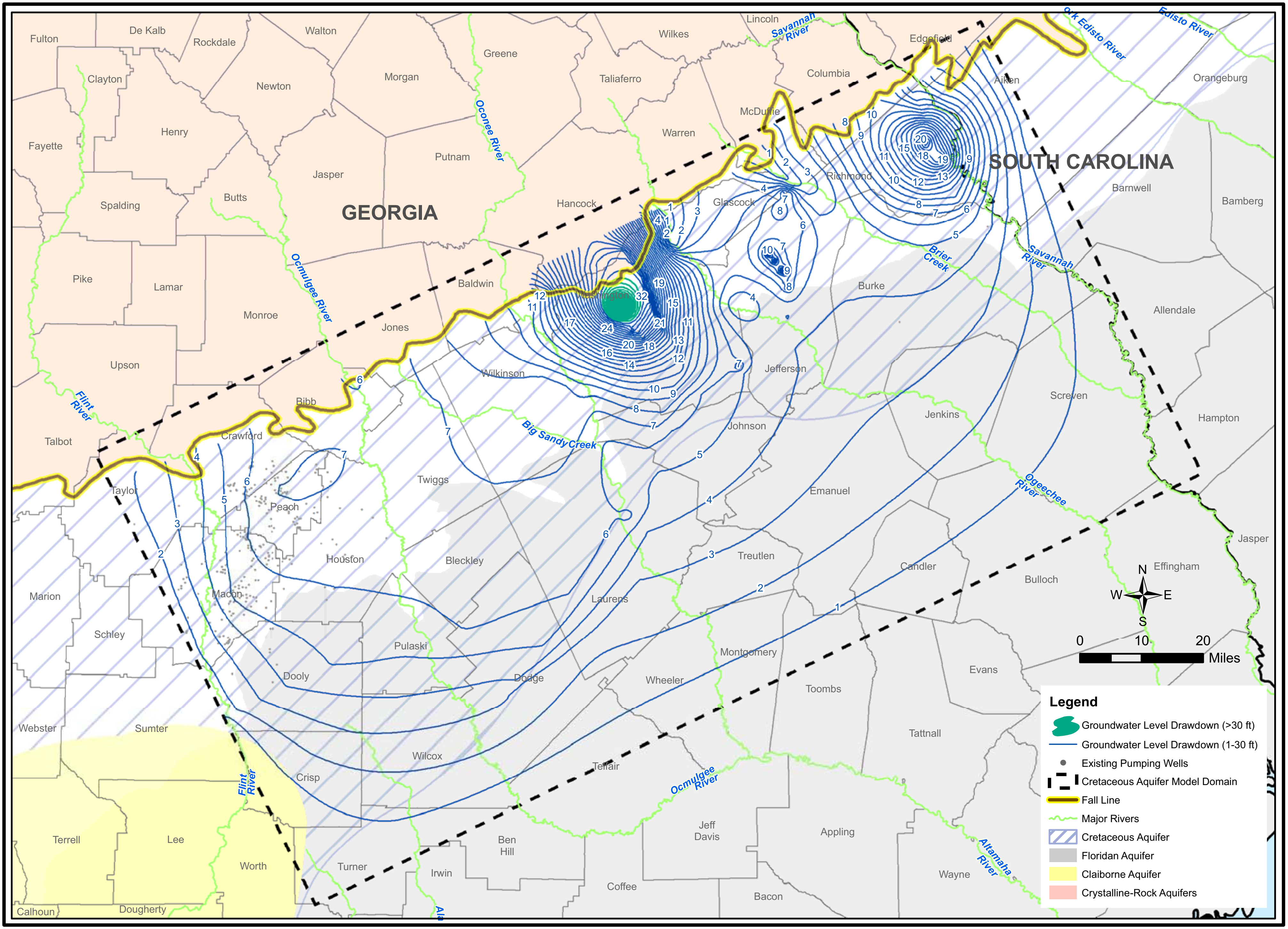

Figure S-17a
Simulated Groundwater Level Drawdown in Eutaw Midville Aquifer (Layer 6)
Due to Increasing Existing Well Pumping in Providence and Eutaw Midville Aquifer (ΔQ= 74 mgd)
Using Sub-Regional Cretaceous Aquifer Model

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G:\Reports\GWModelingResults\Cretaceous\Case2\dd\8.5x11MXD\Fig 15-30_cret_L6-SIM2-2B-ew-minQ-Case2-Local-dd_8.5x11.mxd

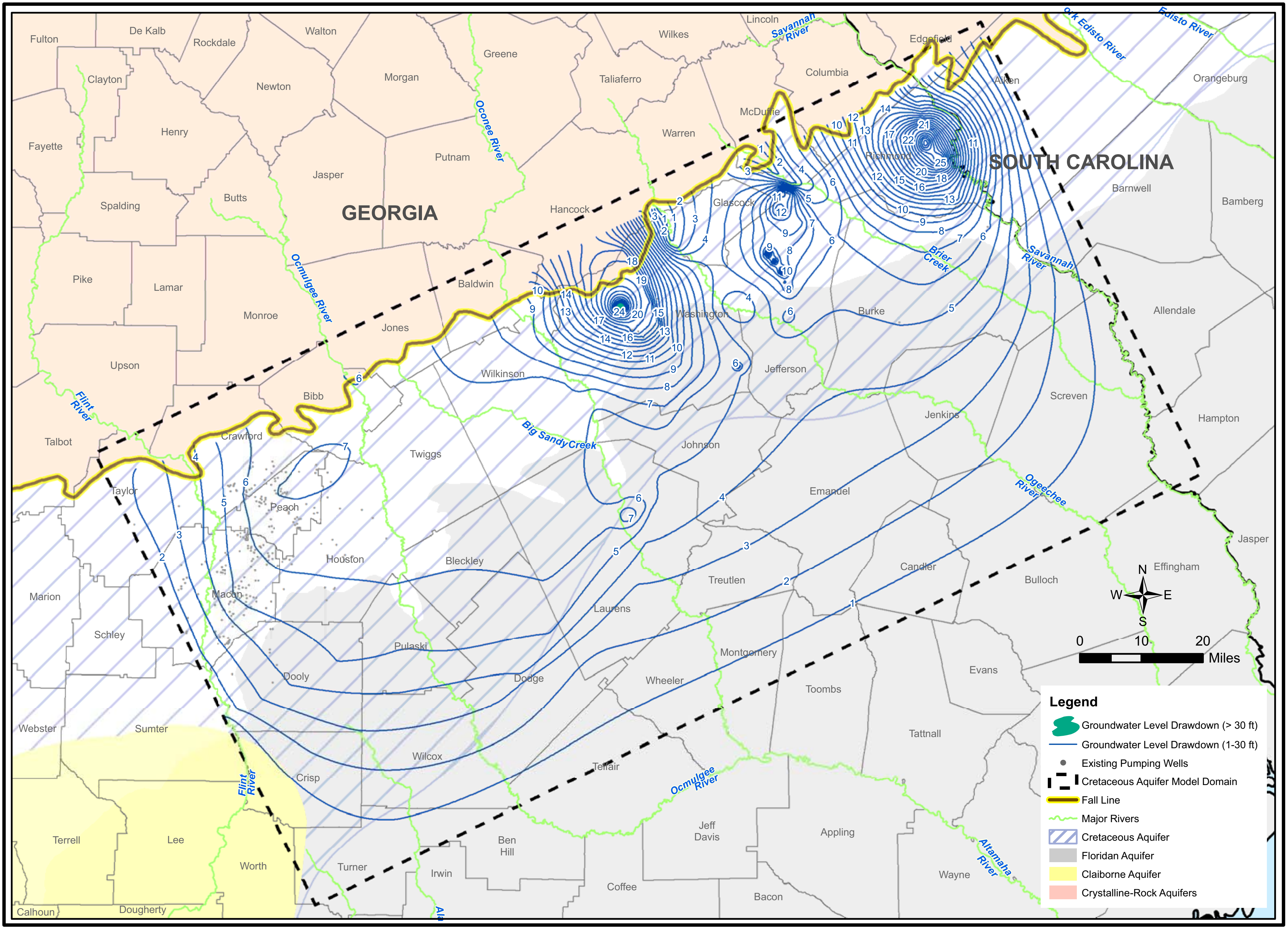

Figure S-17b
Simulated Groundwater Level Drawdown in Eutaw Midville Aquifer (Layer 6)
Due to Increasing Existing Well Pumping in Providence and Eutaw Midville Aquifer (ΔQ= 78 mgd)
Using Sub-Regional Cretaceous Aquifer Model

Table S-7

Summary of Sustainable Yield Estimates for Simultaneous Withdrawals from All of the Prioritized Aquifers in the Coastal Plain of Georgia

Aquifer	Baseline Groundwater Withdrawal	Simulated Groundwater Withdrawal Range from Prioritized Aquifers	
	(mgd)	(mgd)	
South-Central Georgia & Eastern Coastal Plain Upper Floridan Aquifer[1]	475	Min	768
		Max	859
Claiborne Aquifer	67	Min	100
		Max	183
Cretaceous Aquifer	124	Min	198
		Max	187
Total for the Prioritized Aquifers	**667**	**Min**	**1,066**
		Max	**1,229**

[1] The increased withdrawals from the Upper Floridan Aquifer for the eastern coastal plain were evaluated in combination with the south-central area of Georgia.

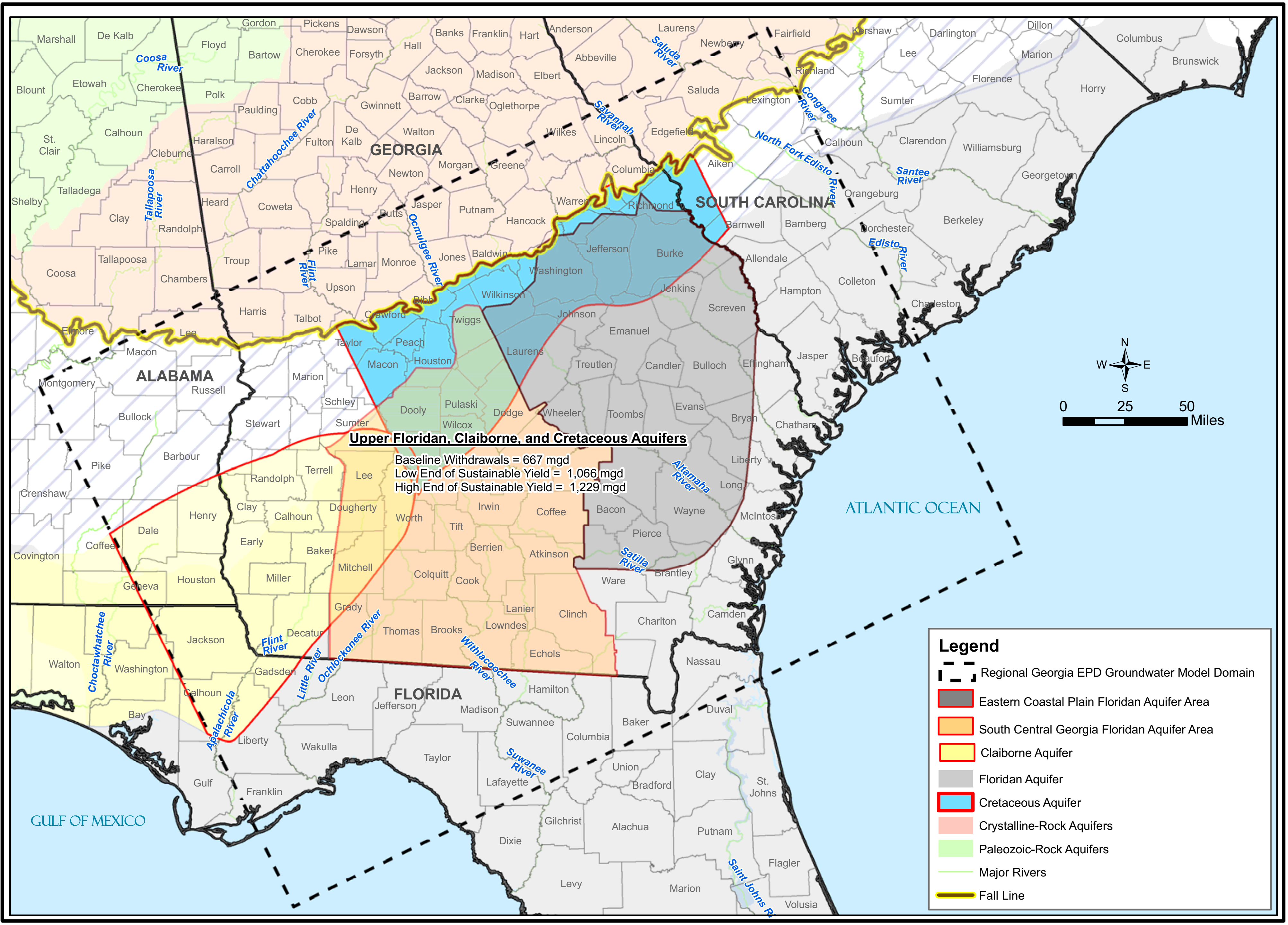

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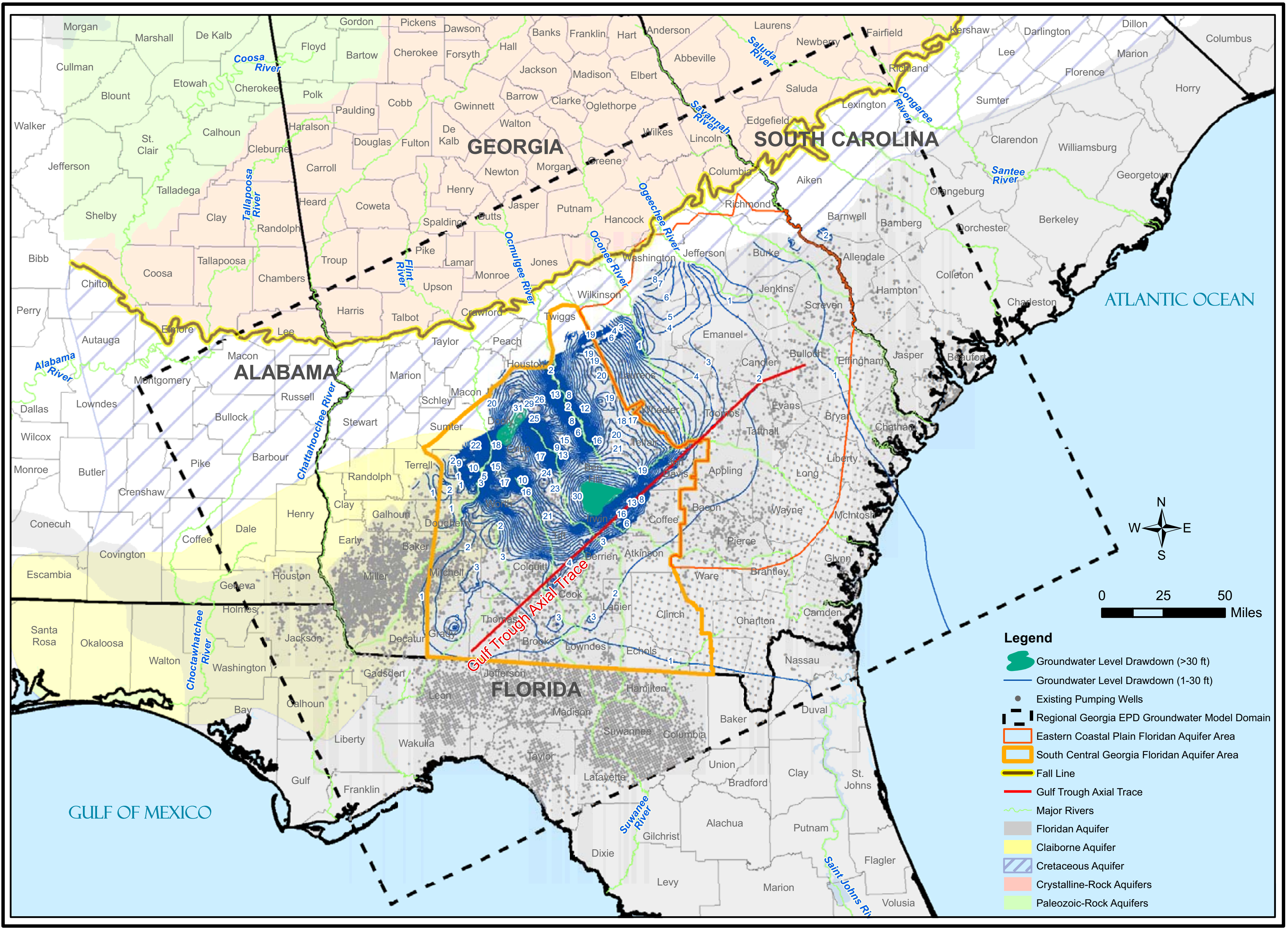
Figure S-18
Groundwater Modeling for Sustainable Yield Assessment of Upper Floridan in South Central Georgia and Eastern Coastal Plain, Claiborne Aquifer, and Cretaceous Aquifer



G:\Reports\GWModelingResults\Regional\Case1\GW-dd\8.5x11\MXD\Fig 16-13_L2-DD-Case1-ew-dQ-400mgd_regional_8.5x11.mxd 02/24/10 anandams

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Figure S-19a
Simulated Groundwater Level Drawdown in Upper Floridan Aquifer (Layer 2)
Due to Increasing Existing Well Pumping in Prioritized Aquifers (ΔQ= 400 mgd)
Using Regional Georgia EPD Groundwater Model

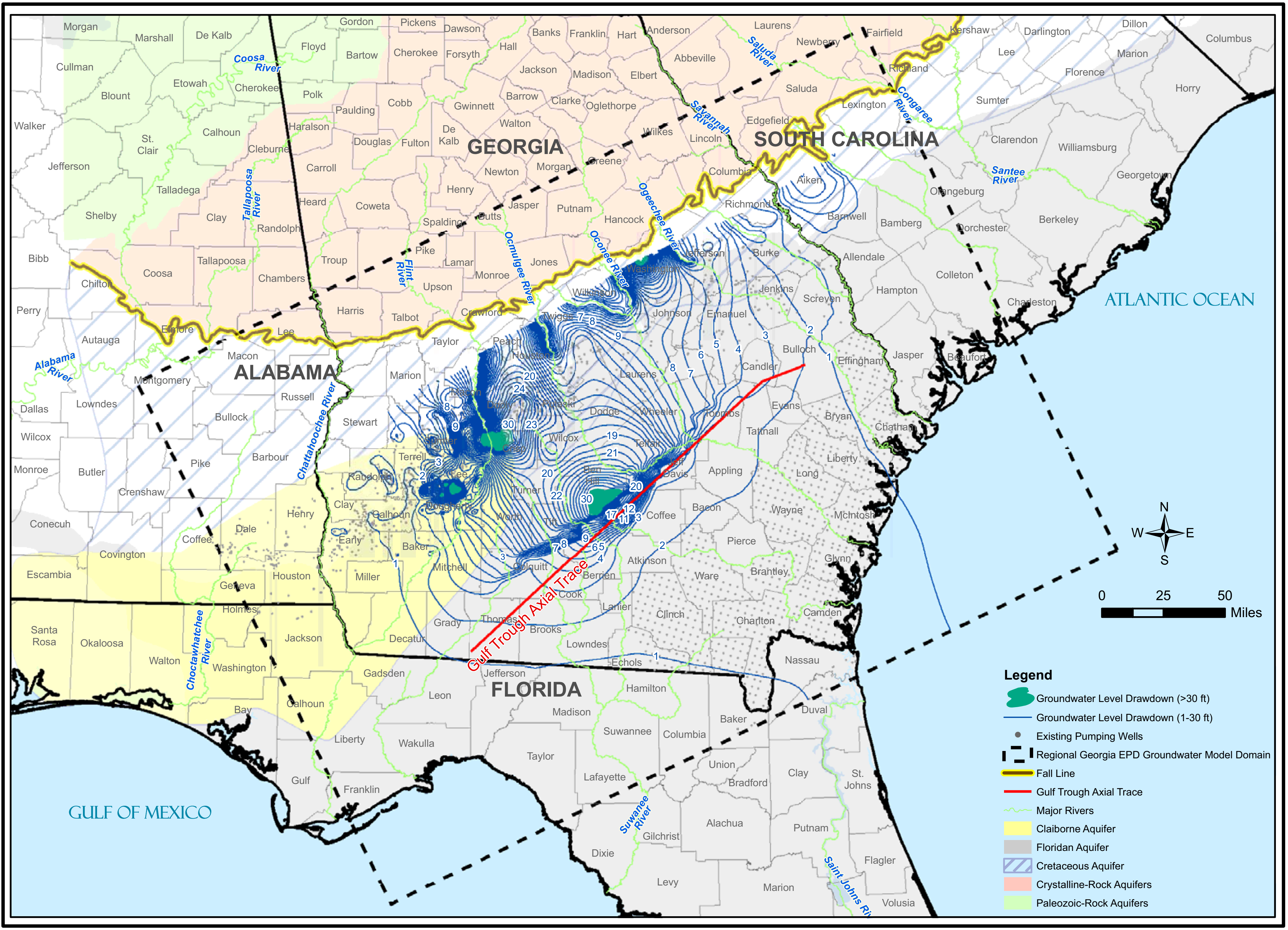

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Figure S-19b
Simulated Groundwater Level Drawdown in Claiborne/Gordon Aquifer (Layer 3)
Due to Increasing Existing Well Pumping in Prioritized Aquifers (ΔQ= 400 mgd)
Using Regional Georgia EPD Groundwater Model

G:\Reports\GWModelingResults\Regional\Case1\GW-dd\8.5x11MXD\Fig 16-15_L4-DD-Case1-ew-dQ-400mgd_regional_8.5x11.mxd 02/24/10 anandams

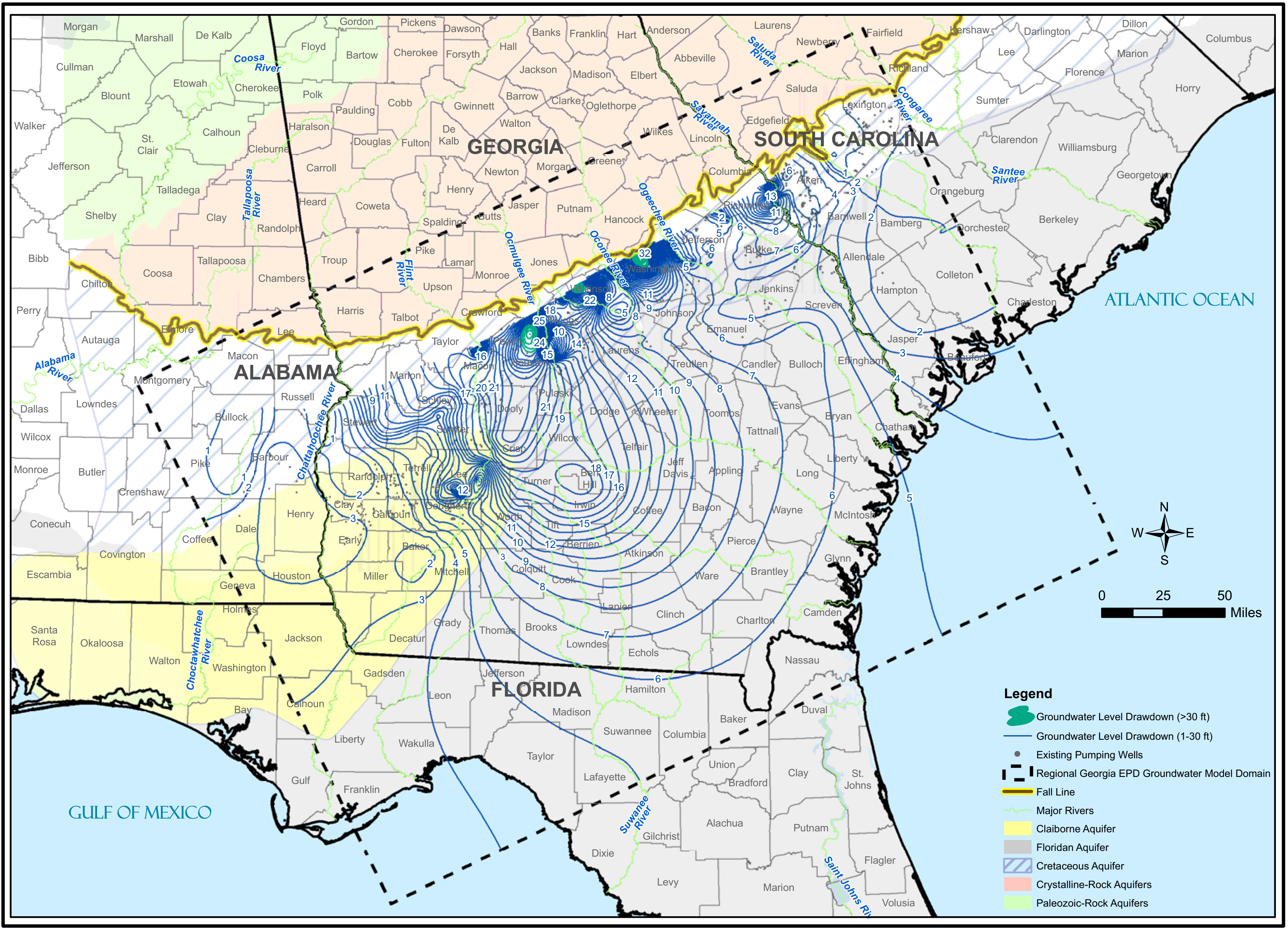

Figure S-19c
Simulated Groundwater Level Drawdown in Clayton/Dublin Aquifer (Layer 4)
Due to Increasing Existing Well Pumping in Prioritized Aquifers (ΔQ= 400 mgd)
Using Regional Georgia EPD Groundwater Model

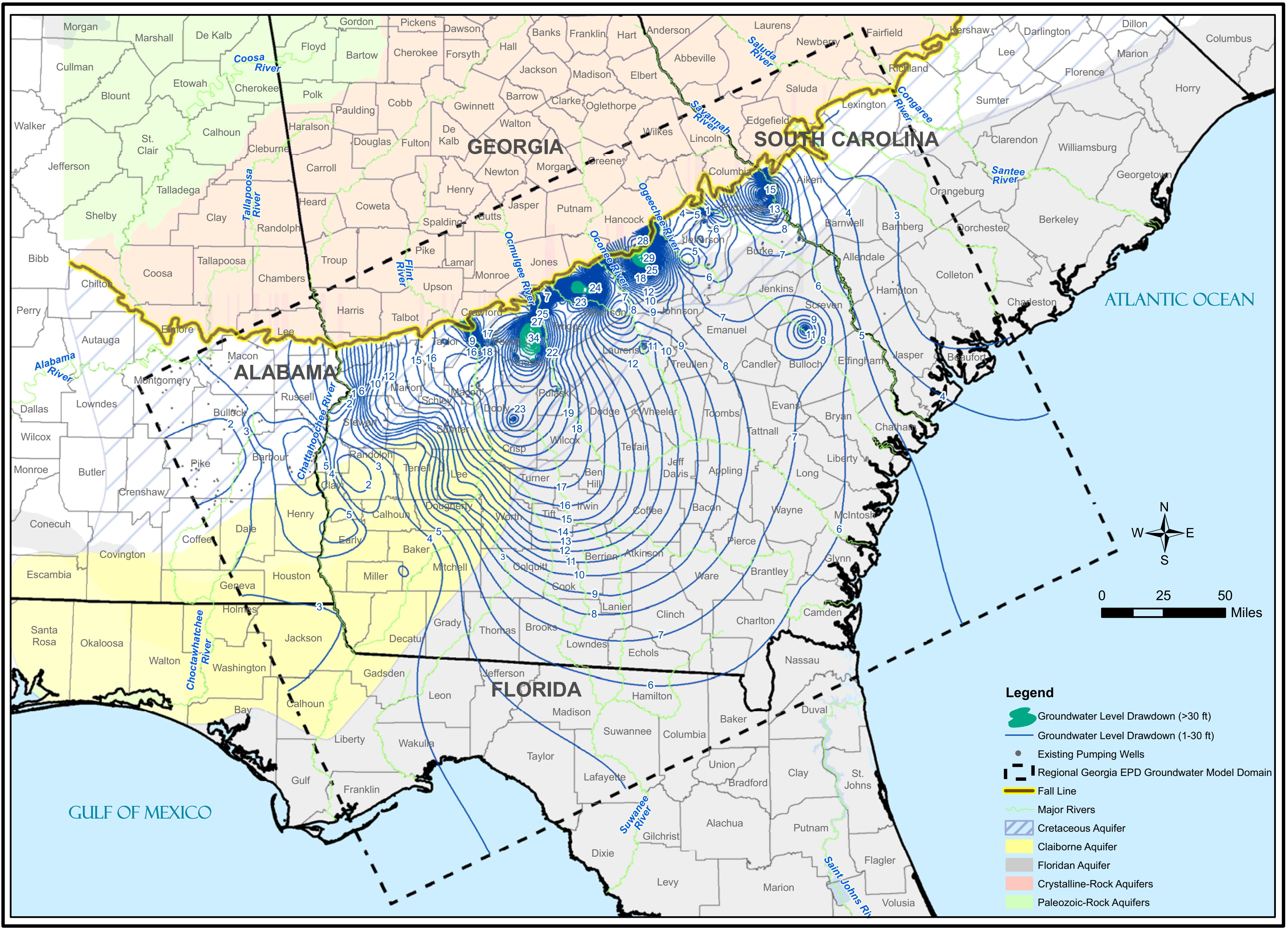

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Figure S-19d

Simulated Groundwater Level Drawdown in Providence Aquifer (Layer 5)
Due to Increasing Existing Well Pumping in Prioritized Aquifers (ΔQ= 400 mgd)
Using Regional Georgia EPD Groundwater Model

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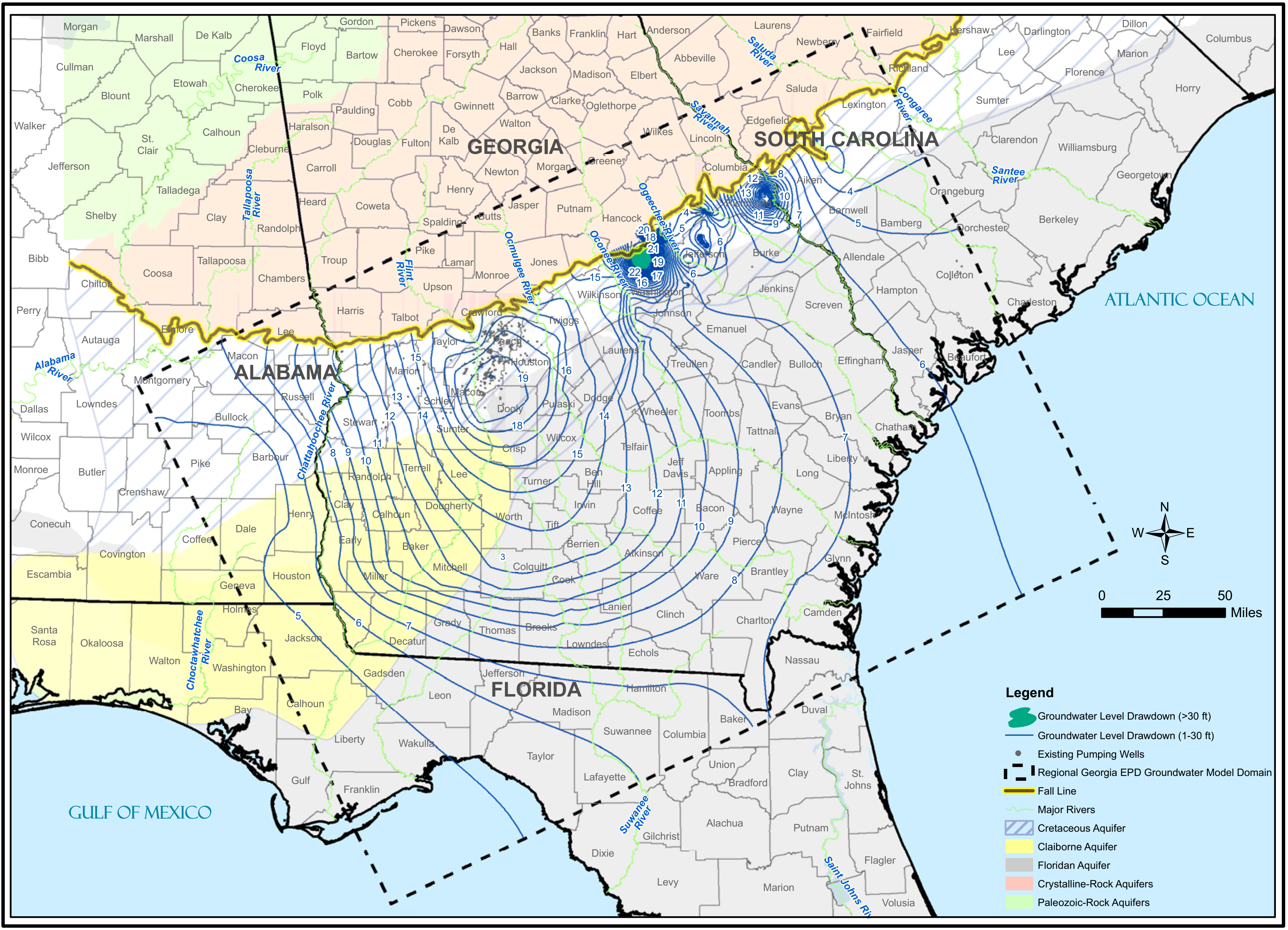

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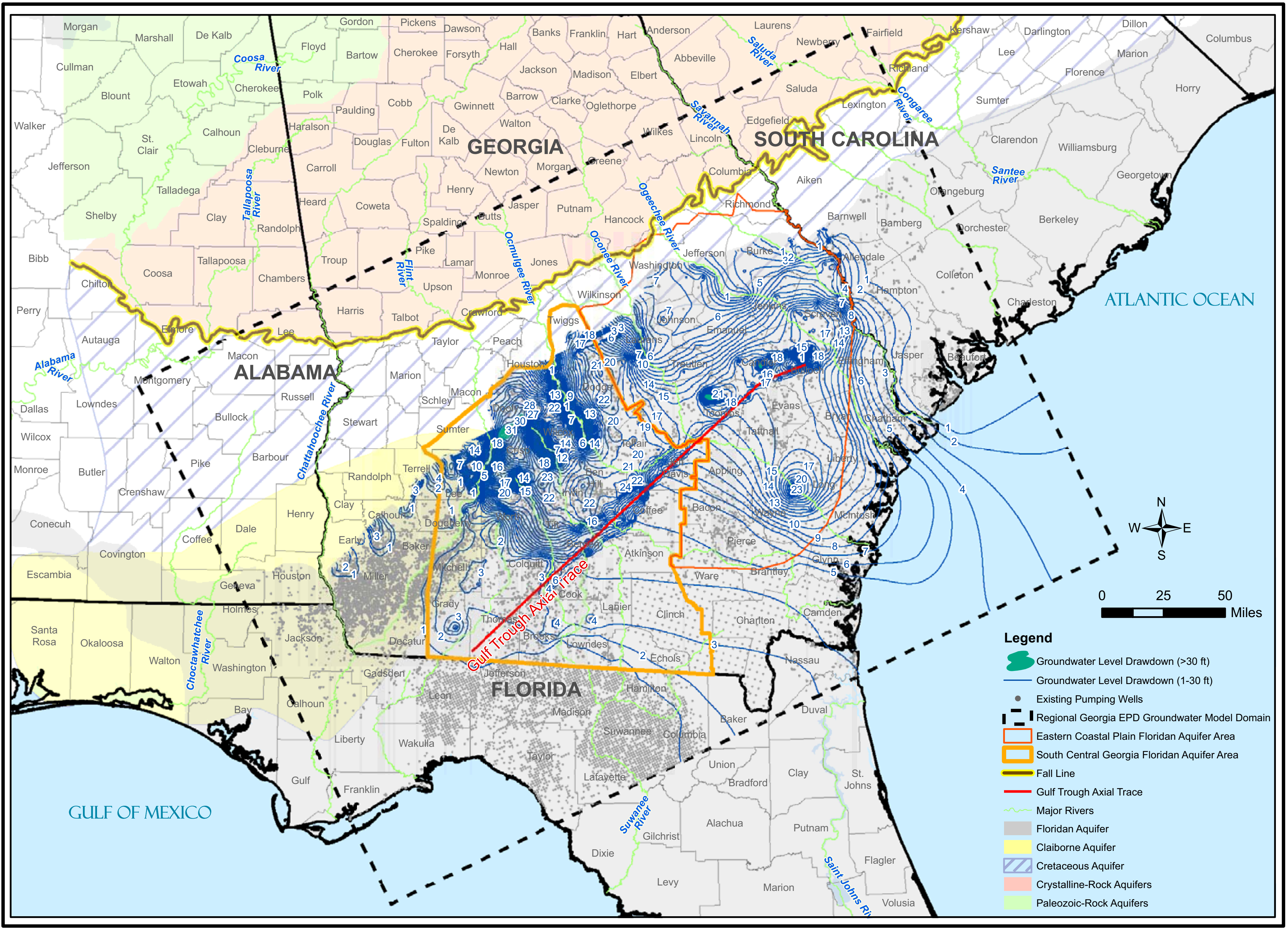
Figure S-19e
Simulated Groundwater Level Drawdown in Eutaw Midville Aquifer (Layer 6)
Due to Increasing Existing Well Pumping in Prioritized Aquifers (ΔQ= 400 mgd)
Using Regional Georgia EPD Groundwater Model



G:\Reports\GWModelingResults\Regional\Case2\GW-dd\8.5x11MXD\Fig 16-25_L2-DD-Case2-ew-dQ-563mgd_regional_8.5x11.mxd 02/24/10 anandams

Figure S-20a
Simulated Groundwater Level Drawdown in Upper Floridan Aquifer (Layer 2)
Due to Increasing Existing Well Pumping in Prioritized Aquifers (ΔQ= 563 mgd)
Using Regional Georgia EPD Groundwater Model

G:\Reports\GWModelingResults\Regional\Case2\GW-dd\8.5x11MXD\Fig 16-26_L3-DD-Case2-ew-dQ-563mgd_regional_8.5x11.mxd 02/24/10 anandams

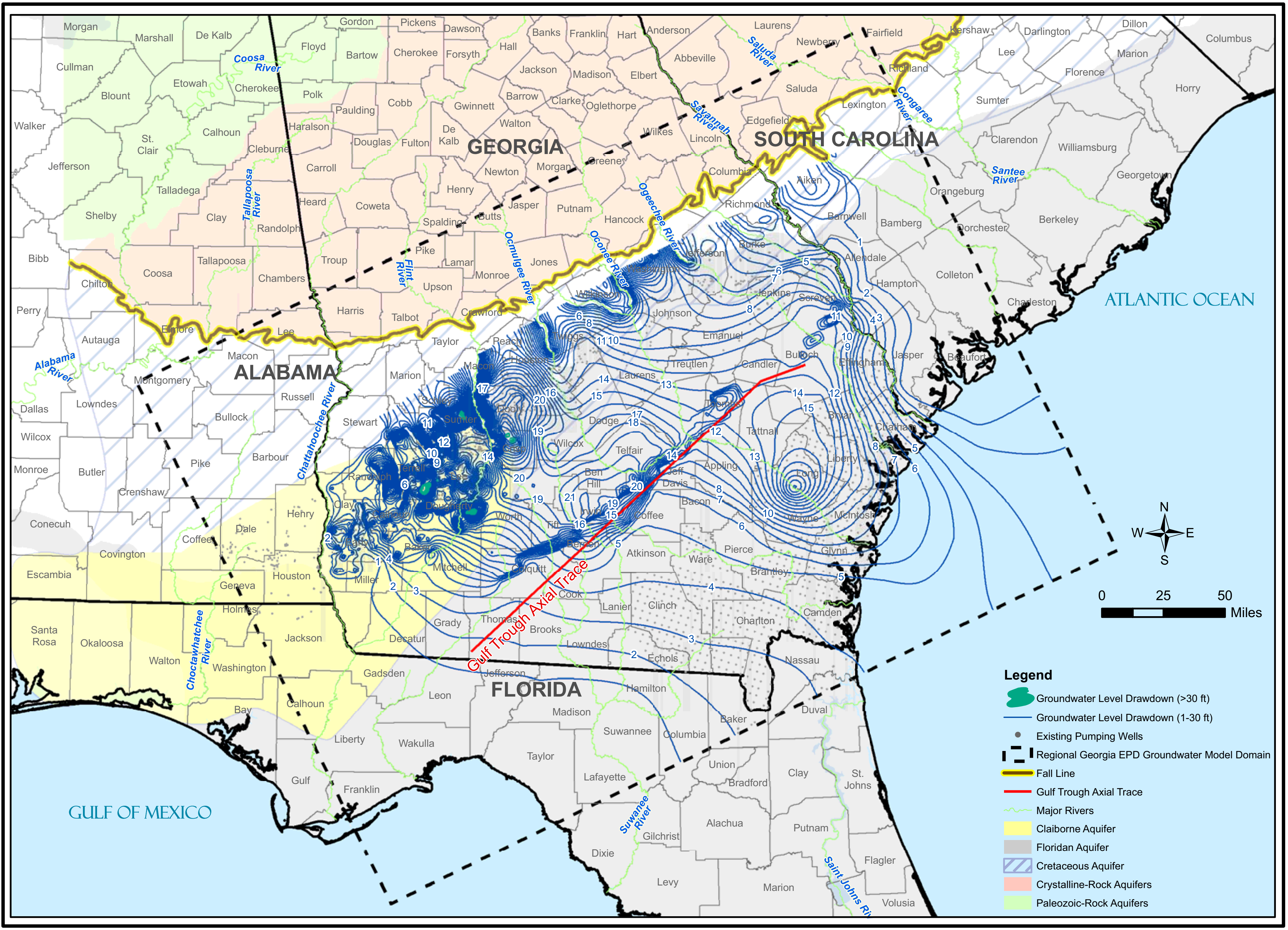


Figure S-20b
Simulated Groundwater Level Drawdown in Claiborne/Gordon Aquifer (Layer 3)
Due to Increasing Existing Well Pumping in Prioritized Aquifers (ΔQ= 563 mgd)
Using Regional Georgia EPD Groundwater Model

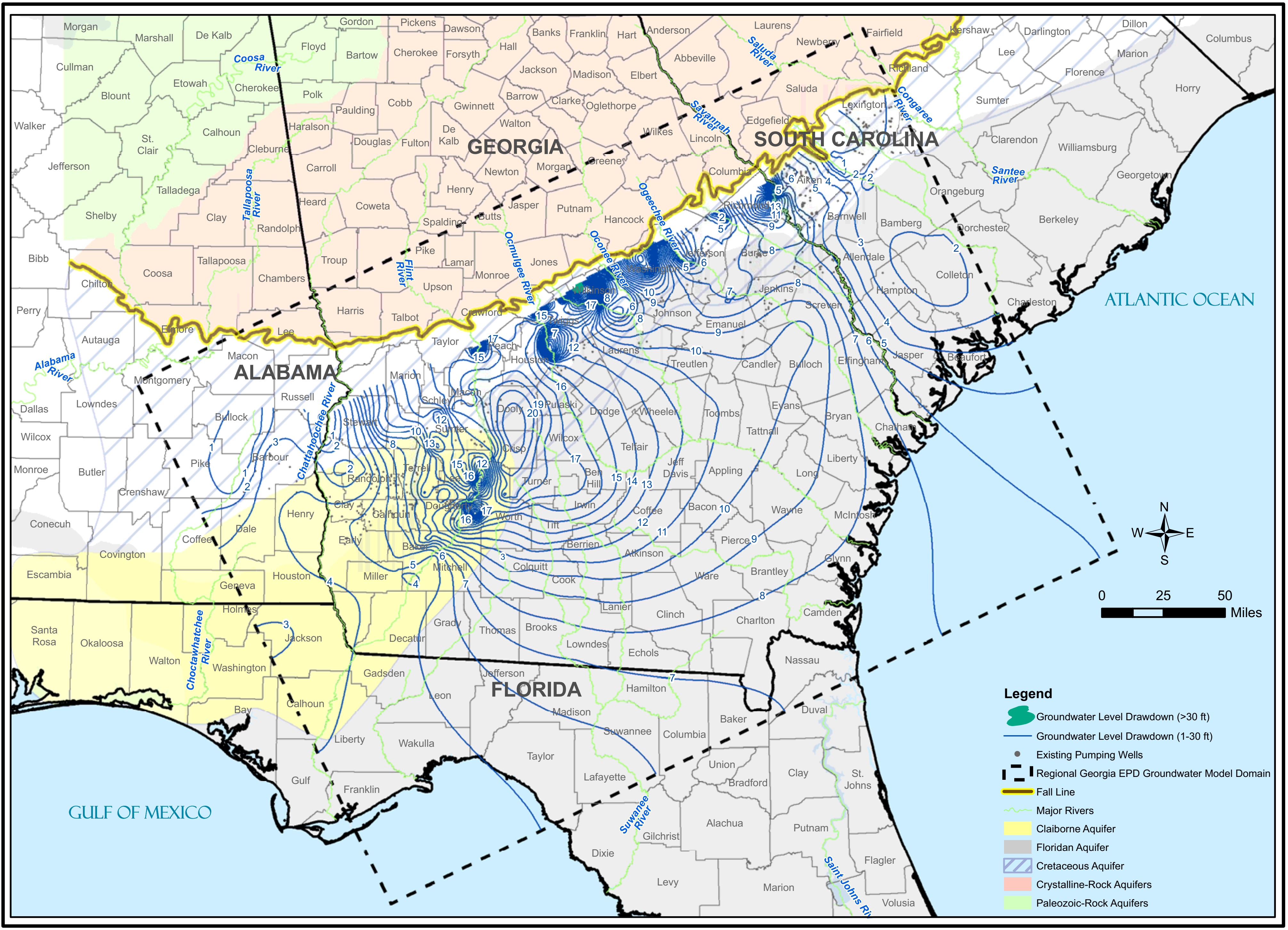


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Figure S-20c
Simulated Groundwater Level Drawdown in Clayton/Dublin Aquifer (Layer 4)
Due to Increasing Existing Well Pumping in Prioritized Aquifers (ΔQ= 563 mgd)
Using Regional Georgia EPD Groundwater Model

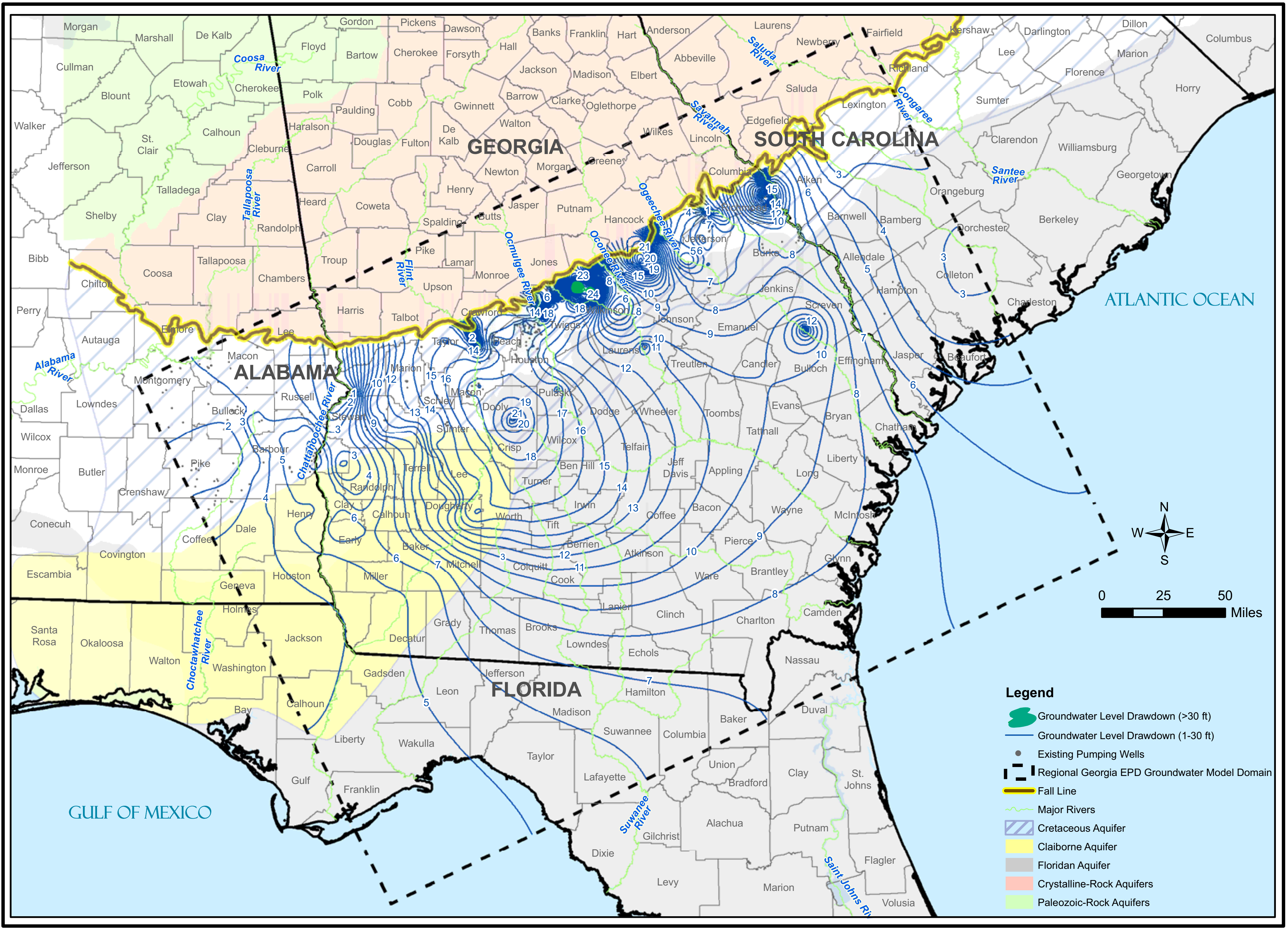

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Figure S-20d
Simulated Groundwater Level Drawdown in Providence Aquifer (Layer 5)
Due to Increasing Existing Well Pumping in Prioritized Aquifers (ΔQ= 563 mgd)
Using Regional Georgia EPD Groundwater Model

G:\Reports\GWModelingResults\Regional\Case2\GW-dd\8.5x11MXD\Fig 16-29_L6-DD-Case2-ew-dQ-563mgd_regional_8.5x11.mxd 02/24/10 anandams

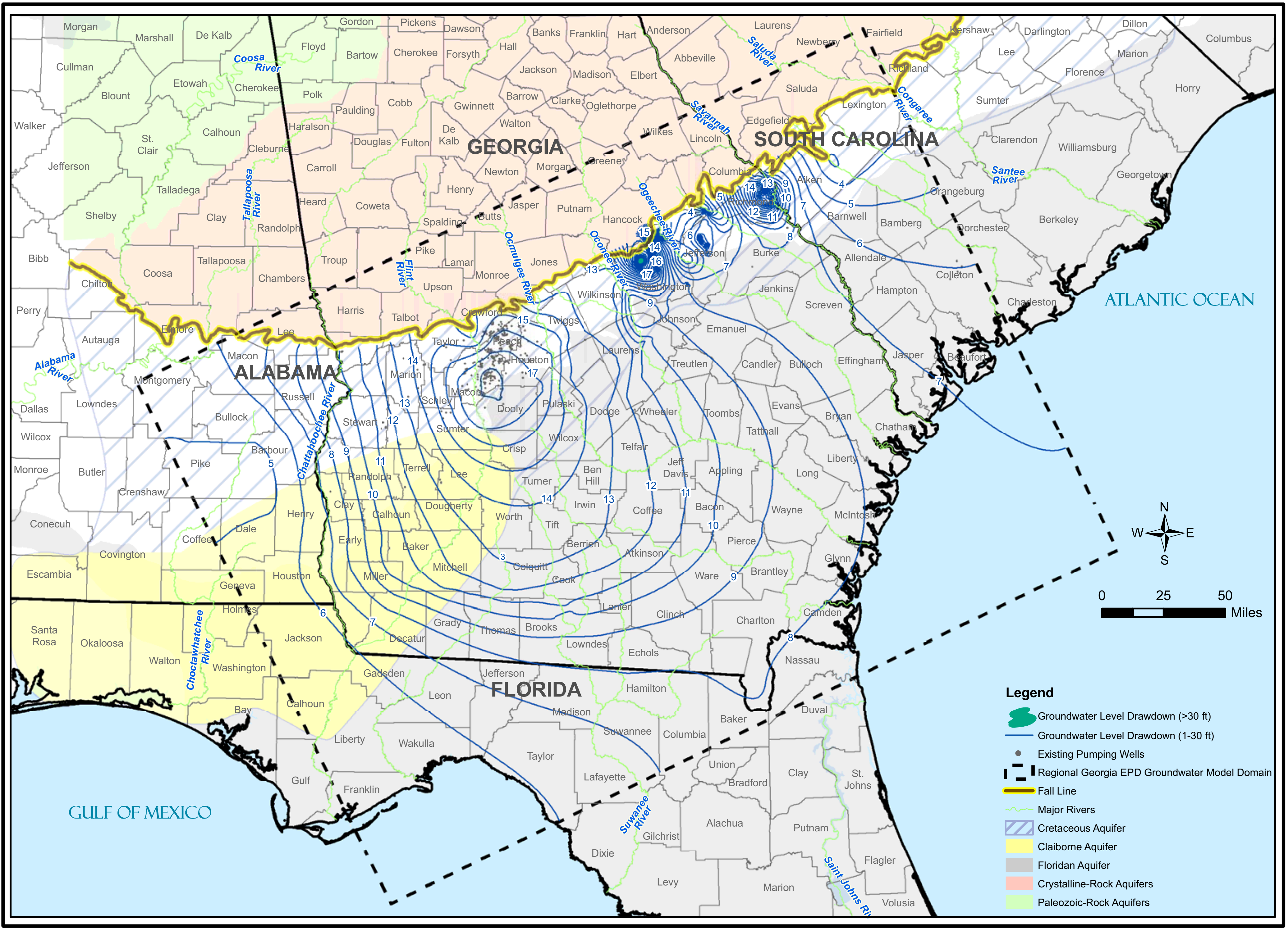

Figure S-20e
Simulated Groundwater Level Drawdown in Eutaw Midville Aquifer (Layer 6)
Due to Increasing Existing Well Pumping in Prioritized Aquifers (ΔQ= 563 mgd)
Using Regional Georgia EPD Groundwater Model

Table S-8 presents the total sustainable yield of individual prioritized aquifers with aquifer withdrawals modeled individually and simultaneously. The results of this analysis show that if withdrawals in each prioritized aquifer are increased simultaneously, the total sustainable yield of prioritized Coastal Plain aquifers is lower than individual aquifers. When withdrawals are increased simultaneously in each prioritized aquifer, there is hydraulic interference between well pumping on a larger scale that limits the aquifer yield before exceeding sustainable yield metrics.

Table S-8

Total Sustainable Yield of All Prioritized Coastal Plan Aquifers

Total of Sustainable Yields of Individual Prioritized Aquifers with Aquifer Withdrawals Modeled Individually	Min Max	1,166 mgd 1,433 mgd
Total of Sustainable Yields of Individual Prioritized Aquifers with Aquifer Withdrawals Modeled Simultaneously	Min Max	1,066 mgd 1,229 mgd