Synopsis Report - Groundwater Availability Assessment Updates

Georgia's State Water Plan

Georgia Environmental Protection Division

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Contents

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

Introduction

This synopsis report provides updated information that was prepared and presented to the Regional Water Planning Councils (Councils) for their consideration during the 5-year regional water plan review and revision process. The updated information included in this report supplements the estimated sustainable yield ranges prepared in 2010 for the following prioritized aquifers in Georgia:

- 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 and Augusta;
- Claiborne aquifer in the Coastal Plain of Georgia;
- Paleozoic rock aquifers in the Northwestern Georgia Valley and Ridge System; and
- Crystalline Rock aquifers in the Piedmont and Blue Ridge Provinces.

These analyses were previously summarized in the *Synopsis Report – Groundwater Availability Assessment* (EPD, March 2010) [1], were presented to the Councils during the previous planning cycle, and informed the preparation of the 2011 Regional Water Plans.

In 2012, an analysis of the estimated sustainable yield ranges for the Clayton aquifer was also completed. Due to a marked decline in aquifer levels observed in the 1980s, the Clayton Aquifer has been under a moratorium for new withdrawals since that time. The 2012 sustainable yield analysis indicates that, under the modeling assumptions used in that analysis, overall yield is small compared to other aquifers. The current demand centers are

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[1] The *Synopsis Report – Groundwater Availability Assessment* (EPD, March 2010) is available at this website: http://www.georgiawaterplanning.org/pages/resource_assessments/ground_water_availability.php. Estimated sustainable yield ranges for the first five of the prioritized aquifers were calculated using steady-state simulation modeling. Estimates for the Upper Floridan aquifer in south-central Georgia; the Upper Floridan aquifer in south-central Georgia and the eastern Coastal Plain of Georgia; the Cretaceous aquifer between Macon and Augusta; and the Claiborne aquifer in the Coastal Plain of Georgia were completed with steady-state models developed under contract to EPD for this purpose. Due to the high degree of interconnection between the surface and groundwater in the Dougherty Plain, the modeling for the Upper Floridan aquifer in the Dougherty Plain was conducted using a model previously developed by USGS. Sustainable yield estimates for the Paleozoic rock aquifers in the Northwestern Georgia Valley and Ridge System were based on a numerical groundwater flow model. For the Crystalline Rock aquifers in the Piedmont and Blue Ridge Provinces, estimated ranges were based on water budgets only.

where the declines in aquifer levels have been observed and where the criterion that limits sustainable yield first becomes evident in the modeling, which means that the analysis does not indicate water availability in these areas. The limited amount of additional water that may be available from the Clayton aquifer is generally south of the current demand centers (Randolph, Terrell, Lee, Dougherty counties), in an area where the Claiborne is expected to be available. Hence, the moratorium on the Clayton remains in place.

Between 2014 and early 2017, additional groundwater assessments were conducted in response to recommendations made by several Regional Water Planning Councils in the 2011 Regional Water Plans. These analyses are summarized below, with detailed descriptions and results presented in the attached Appendices.

Appendix A, Altamaha Water Planning Region: Capacity of the Floridan Aquifer to Replace Agricultural Surface Water Withdrawals in the Canoochee River Basin

- The 2010 modeling to assess surface water availability[2] indicated potential gaps in stream flow at the Claxton node on the Canoochee River. The watershed for this node lies in both the Altamaha and the Coastal Georgia Water Planning Regions. One management practice identified by Councils to address the potential gaps is to replacing surface water withdrawals with groundwater withdrawals in the watershed upstream of the node. As there are no permitted municipal or industrial surface water withdrawals in this watershed, an inventory of the locations and amounts of permitted farm surface water withdrawals was conducted. The Georgia Regional Coastal Plain model was then used to evaluate whether the estimated sustainable yield of the Floridan aquifer could support additional groundwater withdrawals in order to offset the existing nearby surface water withdrawals in portions of the Canoochee River Basin.

Appendix B, Coastal Georgia Water Planning Region: Capacity of the Floridan and Cretaceous Aquifers to Replace Agricultural Surface Water Withdrawals in the Ogeechee River Basin

- The 2010 modeling to assess surface water availability[3] indicated potential gaps in stream flow at the Eden and Kings Ferry nodes on the Ogeechee River. The watershed for these nodes lies in the Altamaha, Coastal Georgia, Savannah-Upper Ogeechee, and Upper Oconee Water Planning Regions. Similar to the watershed above the Claxton node, there are no permitted municipal or industrial surface water

[2] The surface water availability results are in the *Synopsis Report – Surface Water Availability Assessment* (EPD, March 2010), available at: http://www.georgiawaterplanning.org/pages/resource_assessments/surface_water_availability.php

[3] See http://www.georgiawaterplanning.org/pages/resource_assessments/surface_water_availability.php

withdrawals in watershed upstream of the Eden or Kings Ferry nodes. An inventory of the locations and amounts of permitted farm surface water withdrawals was conducted. The Georgia Regional Coastal Plain model, which is a steady-state model, was used to evaluate whether the estimated sustainable yield of the Floridan and Cretaceous aquifers can support additional groundwater withdrawals in order to offset the existing nearby surface water withdrawals in portions of the Ogeechee River Basin.

Appendix C, Middle Ocmulgee Water Planning Region: Recommendations for Monitoring Cretaceous Aquifer Groundwater Withdrawal Impacts

- An analysis was conducted in response to the Council's identified need for a monitoring plan for areas in the Middle Ocmulgee basin relying on the Cretaceous aquifer (Houston, Peach, Crawford, Bibb, Twiggs and Pulaski counties). The sub-regional steady-state model of the Cretaceous aquifer between Macon and Augusta was used to simulate groundwater withdrawals from the Cretaceous aquifer within the Council area and to identify areas within the study area that may potentially be adversely impacted by increased pumping from the Cretaceous Aquifer. Further, the analysis included identifying parameters for monitoring and tracking groundwater withdrawal impacts. Recommendations for long-term monitoring to track the impacts of groundwater withdrawals on overall aquifer sustainable yield in the Cretaceous aquifer were also made.

Appendix D, Upper Flint Water Planning Region: Sustainable Yield of the Cretaceous Aquifer System in the Upper Flint River Basin

- A Southwest Georgia Sub-Regional Model was used to estimate the sustainable yield of the Cretaceous aquifer in the Upper Flint Water Planning Region. The steady-state model was used to evaluate the impact of increased groundwater withdrawals from the Cretaceous aquifer in the area where the Upper Flint region overlies the aquifer. Response of the aquifer to increased pumping was compared with specific indicators of potential local or regional impacts. Indicators of impact include limiting use of neighboring wells (drawdown) and reducing groundwater contributions to stream baseflow. Sustainable yield estimates were determined by simulating withdrawals from existing wells and, where applicable, simulating hypothetical new wells until a threshold of one of these potential impacts was reached.

Appendix E, Claiborne Aquifer Specific Capacity and Transmissivity Analysis (Final Report submitted to the Georgia Environmental Finance Authority)

- The 2011 Regional Water Plans for the Upper Flint and Lower Flint-Ochlockonee regions found that analysis of the Claiborne aquifer demonstrated the need for caution in management of withdrawals from the aquifer and the need for more specific analysis, based on the location of withdrawals, directed at preventing future adverse impacts. In addition, the Councils in this basin recommended replacing surface water withdrawals with groundwater, where site-specific analysis indicates this is practical and will not harm resources, in order to help address potential gaps in surface water availability.

These findings led the State of Georgia to invest in field measurements of Claiborne aquifer characteristics in areas of Southwest Georgia where data were lacking. One set of field measurements of aquifer characteristics was conducted by the U.S. Geologic Survey under contract to the Georgia Environmental Protection Division.[4] Six additional test wells in the Claiborne were completed under contract to the Georgia Environmental Finance Authority. Data from those wells, USGS, and EPD files were analyzed by CDM Smith, with results presented in Appendix E.

Based on these recent site-specific data on Claiborne aquifer characteristics, further analysis of aquifer response is planned using a transient model. A transient model developed in 2015-2016 will have to be re-calibrated using the more recent data. This model will provide a platform for analysis of time-varying response to additional demand on the Claiborne aquifer.

[4] Gordon, D.W., and Gonthier, Gerard, 2017, Hydrology of the Claiborne aquifer and interconnection with the Upper Floridan aquifer in southwest Georgia: U.S. Geological Survey Scientific Investigations Report 2017–5017, 49 p., https://doi.org/10.3133/sir20175017.

APPENDIX A

Task 1

Altamaha Water Planning Region: Capacity of the Floridan Aquifer to Replace Agricultural Surface Water Withdrawals in the Canoochee River Basin

Prepared for:
Georgia Department of Natural Resources
Environmental Protection Division

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ARCADIS Design & Consultancy for natural and built assets

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Altamaha Water Planning Region: Capacity of the Floridan Aquifer to Replace Agricultural Surface Water Withdrawals in the Canoochee River Basin

1. Introduction

CDM Smith prepared this report in support of the Georgia Comprehensive State-wide Water Plan. The report describes and documents results of groundwater model simulations of additional Floridan aquifer groundwater withdrawals in the Canoochee River watershed. The purpose of the additional groundwater withdrawals is to replace surface water withdrawals in areas where the previous resource analysis identified potential shortfalls in surface water availability.

1.1 Background

In February 2008, the Georgia General Assembly adopted the Georgia Comprehensive State-wide Water Plan (State Water Plan) dated January 8, 2008. The State Water Plan established a regional water resources management planning process, which was initiated in March 2009. Groundwater and surface water resource assessment modeling was conducted to evaluate water availability and potential shortfalls (or gaps) for current and future (2050) water supply demands. Summaries of groundwater and surface water resource assessments are presented in Regional Water Plan documents developed for the various water planning regions.

The Altamaha Regional Water Planning Council (Altamaha Council) is one of 11 planning regions established throughout the state. The Georgia Environmental Protection Division (EPD) develops water use forecasts that are used by the Councils to identify water management practices to address regional water supply needs. The Altamaha Council has expressed concern about the streamflow shortfall (or "gap") identified at the Claxton planning node on the Canoochee River. Planning nodes are locations with long-term stream gages where the surface water resource assessment for current and future conditions was performed. According to the surface water resource assessment summarized in the Altamaha Regional Water Plan, the average shortfall under current and forecasted 2050 agricultural demands is approximately 5 cubic feet per second (cfs) (3.2 million gallons per day [MGD]) and 11 cfs (7.1 MGD), respectively (CDM, 2011b). One strategy for increasing streamflow in the Canoochee River would be to reduce existing agricultural surface water withdrawals in the Canoochee River drainage basin and replace them with groundwater withdrawals.

The Georgia EPD is in the process of revising current and future agricultural water demand projections, and an updated surface water resource assessment and gap analysis will be completed once these projections are made available. For the purpose of this study, however, the streamflow gaps presented in the Altamaha Regional Water Plan (CDM, 2011b) serve as the basis for evaluation.

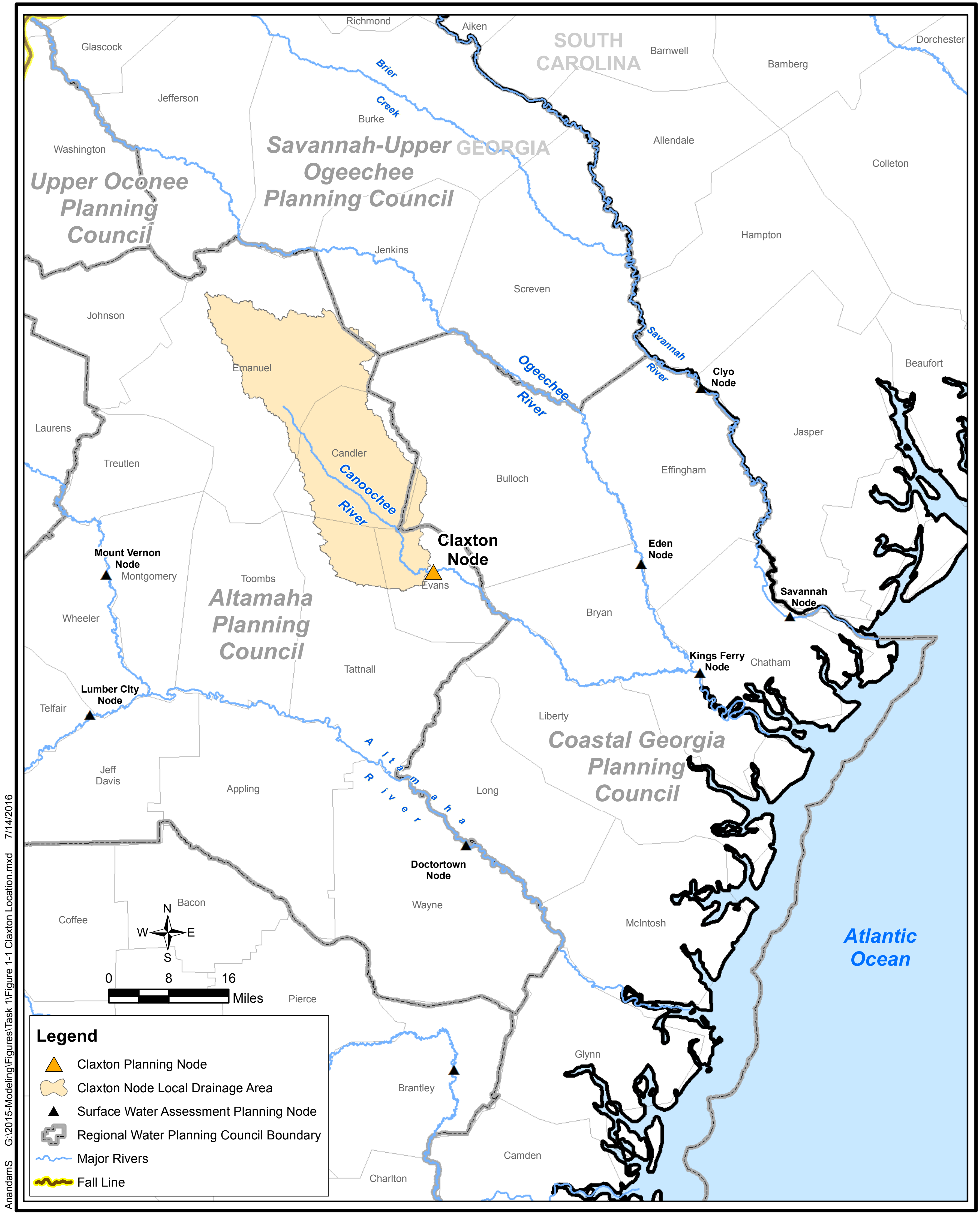
The Claxton planning node is located in Evans County, Georgia. The Canoochee River drainage basin upstream of the Claxton node includes parts of Evans, Candler, Emanuel, Tattnall, and Bullock Counties. **Figure 1-1** shows the locations of the Claxton node, the Canoochee River, and the Canoochee River drainage basin upstream of the Claxton node.

1.2 Approach

This report explores the possibility of reducing surface water shortfalls by using groundwater in place of surface water. Because there are no known municipal, industrial or domestic self-supply surface water demands in this watershed area, the analysis presented in this report focuses specifically on the use of groundwater in place of surface water to meet agricultural water demands. A groundwater modeling analysis was conducted to evaluate the potential impacts of increasing groundwater withdrawals from the Floridan aquifer upstream of the Claxton node. CDM Smith completed the following tasks for this study:

- Mapped and reviewed the inventory of agricultural parcels and associated locational coordinates and acreage in the Canoochee River drainage basin upstream of the Claxton planning node with permitted surface water, groundwater, and mixed ("well-to-pond") withdrawals.
- Developed surface water replacement scenarios in which new groundwater withdrawals were assigned to the Floridan aquifer at irrigated parcel locations (parcel centroid) and groundwater withdrawal rates were based on parcel area and monthly irrigation requirements.
- Applied the Regional Coastal Plain Model developed for the State Water Plan to simulate baseline pumping conditions and scenarios with increased Floridan aquifer groundwater pumping to replace existing surface water withdrawals.
- Compared simulated steady-state Floridan aquifer water levels for baseline and surface water replacement scenarios to determine if sustainable yield criteria previously defined for the State Water Plan would be locally exceeded due to the increased groundwater pumping. Similarly, simulated groundwater discharges to surface water were reviewed to determine if sustainable yield criteria previously defined for the State Water Plan would be exceeded due to the increased groundwater pumping.
- Compared the additional groundwater withdrawal that could potentially be achieved with the surface water shortfall at the Claxton planning node to evaluate whether substituting groundwater for surface water agricultural use should be considered further in water resources management planning.

The steady-state Regional Coastal Plain Model was applied for this study (CDM, 2011a). The model represents long-term average conditions and does not incorporate monthly or seasonal variations in groundwater stresses including pumping and recharge. Although a time-varying response to pumping changes cannot be simulated in a steady-state model, it is appropriate for the analysis of average groundwater impacts due to changes in groundwater pumping. A range



CDM Smith

Figure 1-1
Location of Canoochee River Claxton Planning Node

of groundwater pumping rates was simulated to evaluate the range of potential Floridan aquifer water-level drawdown that may occur due to additional groundwater withdrawals.

1.3 Report Organization

The remainder of this report is organized as follows:

- Section 2 provides an overview of the State Water Plan groundwater resource assessments and the groundwater models developed and applied for that study.
- Section 3 presents a summary of the irrigated acreage data and assumptions used to estimate agricultural water use.
- Section 4 presents the results of model simulations of Floridan aquifer impacts as a result of substituting groundwater withdrawals for existing surface water irrigation. Simulations were also conducted to assess the capacity of the Floridan aquifer to support increased pumping without exceeding established State Water Plan sustainable yield criteria.
- Section 5 provides a brief discussion of the streamflow shortfall (or "gap") computed for the Claxton node and the potential reduction of the shortfall that may be achieved by substituting groundwater withdrawals for existing surface water withdrawals.
- Section 6 presents a summary of the study.
- Section 7 provides a list of references used in this study.

2. Overview of State Plan Groundwater Resource Assessments

2.1 Assessment Approach and Criteria

In 2009 and 2010, the availability of groundwater resources in select prioritized aquifers of Georgia was evaluated. The assessment was completed to support the Regional Water Development and Conservation Plans as part of the State Water Plan. The prioritized aquifers included the Floridan aquifer in south-central Georgia and the eastern Coastal Plain of Georgia, which underlies the Canoochee River drainage basin. Other prioritized aquifers included the Claiborne, Clayton, and Cretaceous aquifer systems.

Numerical steady state groundwater flow models were developed for the State Water Plan to support the groundwater availability assessments. The results of groundwater flow model simulations with increased pumping in the prioritized aquifers were compared with baseline simulations representing existing conditions to estimate local impacts of the increased pumping. The simulated changes in water-level elevations and groundwater baseflow to streams were compared with sustainable yield criteria developed for the State Water Plan study.

Formulation of the sustainable yield criteria for the groundwater resource assessments is presented in Section 11 of the document titled *Groundwater Flow Modeling of the Coastal Plain Aquifer System of Georgia* (CDM, 2011a). For the purposes of the groundwater resource assessments, sustainable yield was defined as the maximum amount of groundwater withdrawal that could occur from defined extraction points within each aquifer without violating sustainable yield metrics. The following metrics were applied, with some variations depending on the prioritized aquifer being studied and the level of detail provided by the respective models used to assess sustainable yield:

- Drawdowns of groundwater levels in the pumped aquifer do not exceed 30 feet between pumping wells;
- Pumping was limited to levels that would not decrease mean annual stream baseflow by more than 40 percent;
- 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.

The primary metrics that applied to the sustainable yield analysis for the Floridan aquifer were the first two listed above which pertain to drawdown and impacts to baseflow. In the Claxton node area, the surficial aquifer is active, overlying the Floridan aquifer, such that there is generally little interaction between the Floridan aquifer and surface water. For the analysis presented in this report, the primary metric for evaluating groundwater withdrawals impacts is simulated drawdown.

The sustainable yield of the Floridan aquifer in south-central Georgia and the eastern Coastal Plain of Georgia was found to be sufficient to meet groundwater demands projected through the year 2050 (CDM, 2011a) exclusive of the additional groundwater withdrawals being evaluated in this study. Furthermore, withdrawals from the Floridan aquifer in the Claxton node area are not restricted by the Coastal Georgia Water & Wastewater Plan for Managing Salt Water Intrusion (Georgia EPD, 2006). Hence, increased withdrawals from the Floridan aquifer in this area may be considered for offsetting reduced surface water withdrawals. The Floridan aquifer underneath the Canoochee River basin can be subdivided into an upper-permeable carbonate zone and a deeper lower-permeable zone. From here on, the term "Floridan" aquifer in this report refers to the upper-permeable zone.

2.2 Georgia Regional Coastal Plain Groundwater Model

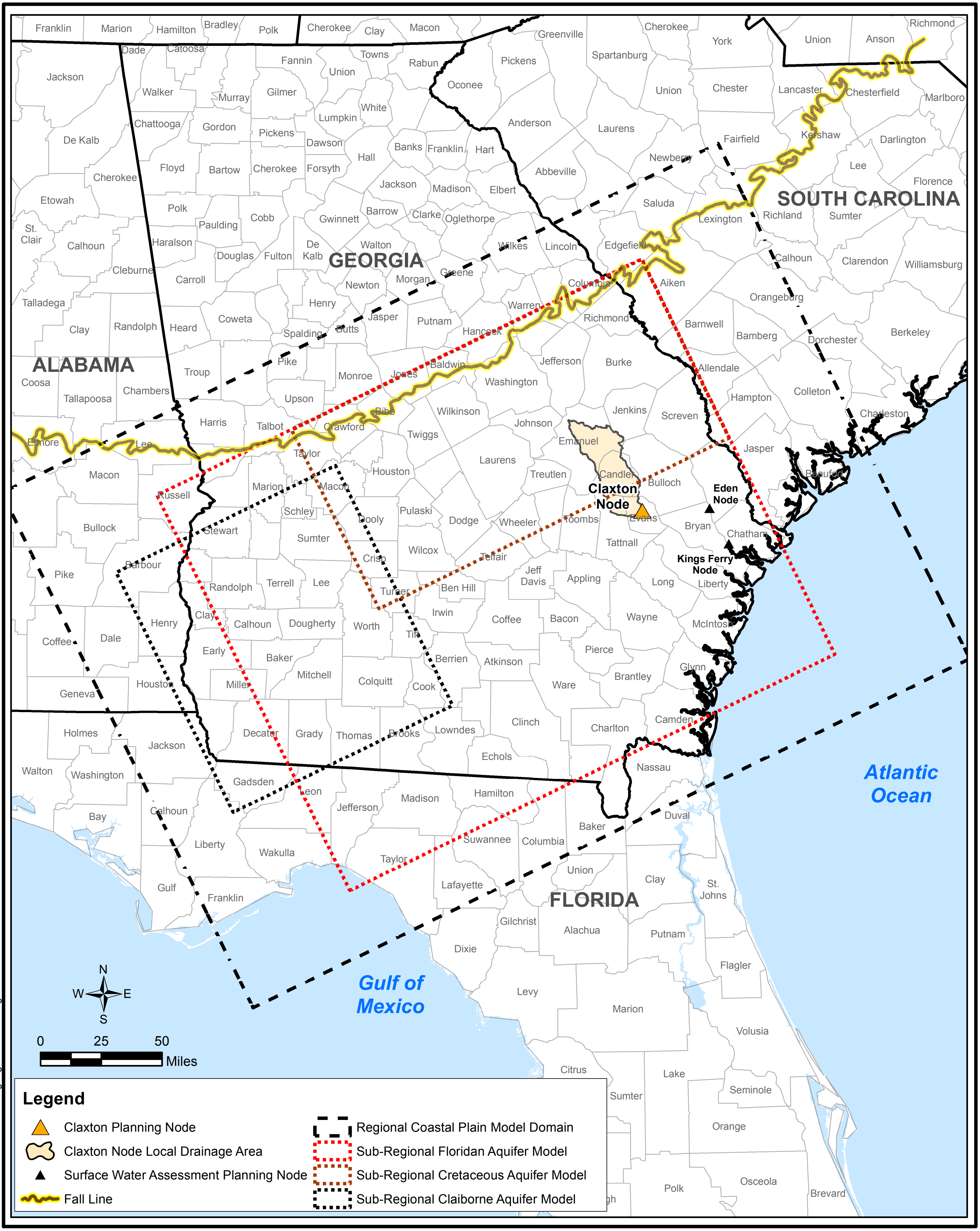
The Georgia Regional Coastal Plain Model (domain shown on **Figure 2-1**) was developed in 2009-2010 to support the State Water Plan sustainable yield assessments (CDM, 2011a). For this purpose, an existing regional United States Geological Survey (USGS) Coastal Plain Clastic Aquifer System Model was modified and updated, including expanding the model domain, refining the computational grid, and incorporating available local data in and near the prioritized study areas.

Vertically, the model includes the entire Georgia Coastal Plain aquifer sequence down to the Cretaceous aquifer system. Prioritized aquifers for the assessment included the Floridan, Claiborne, Clayton, and Cretaceous aquifer systems. The regional model was calibrated using available hydrogeologic data and observed groundwater elevations at monitoring wells under steady-state conditions. Regional model simulations have been conducted in steady-state mode only.

The regional model was revised in 2012 to incorporate new data on agricultural groundwater withdrawals and an expanded representation of river-groundwater interaction (i.e., the number of river nodes was increased to include smaller tributary streams that were not previously represented). The agricultural, municipal, and industrial steady-state pumping in the 2012 revised regional model represents annual average groundwater withdrawals for the year 2010. The regional model with revised pumping and river representation was recalibrated in steady-state mode. The recalibration included modifications to model hydraulic properties and boundary conditions (CDM Smith, 2012a).

2.3 Sub-Regional Models

Sub-regional models were initially developed for the Floridan aquifer in south-central Georgia and the eastern Coastal Plain of Georgia, the Claiborne aquifer, and the Cretaceous aquifer between Macon and Augusta (Figure 2-1). The sub-regional models were used to develop sustainable yield estimates for the corresponding aquifers. Generally speaking, with the exception of model grid spacing and model domain limits, the sub-regional and regional models are consistent in terms of model layering, aquifer properties, and other model input parameter values. The initial Floridan, Claiborne, and Cretaceous sub-regional models were calibrated in transient as well as steady-state mode.



anandams G:\2015-Modeling\Figures\Task 1\Figure 2-1 Model Domains.mxd 4/20/2016

Figure 2-1
Georgia State-wide Water Plan Groundwater Models

The sub-regional models for the Cretaceous aquifer and the Claiborne aquifer, as well as the regional model, were recalibrated in 2012 to incorporate new data on agricultural groundwater withdrawals and an expanded representation of river-groundwater interaction (CDM Smith, 2012a). At that time, CDM Smith also developed and calibrated a sub-regional model for the Clayton aquifer based on the updated regional model (CDM Smith, 2012b). The agricultural, municipal, and industrial steady-state pumping in the 2012 sub-regional models represents annual average groundwater withdrawals for the year 2010. The revised Cretaceous and Claiborne sub-regional models were recalibrated and applied in steady-state mode. The Clayton sub-regional model also was calibrated and applied in steady-state mode.

The sub-regional model of the Floridan aquifer in south-central Georgia and the eastern Coastal Plain of Georgia includes the Canoochee River drainage basin study area. However, that model has not been updated or recalibrated and, as a result, the hydraulic property assignments and boundary conditions are not consistent with the updated regional model and the other sub-regional models. For this reason, the Georgia Regional Coastal Plain Model, and not the Floridan sub-regional model, was used to assess the potential impacts of increased groundwater pumping from the Floridan aquifer in the Canoochee River basin.

2.4 Regional Coastal Plain Model Framework

2.4.1 Modeling Code

The Regional Coastal Plain Model used for this study was built using the MODFLOW three-dimensional finite-difference groundwater modeling code developed by the USGS (McDonald and Harbaugh, 1988). It is publicly available and widely used and accepted.

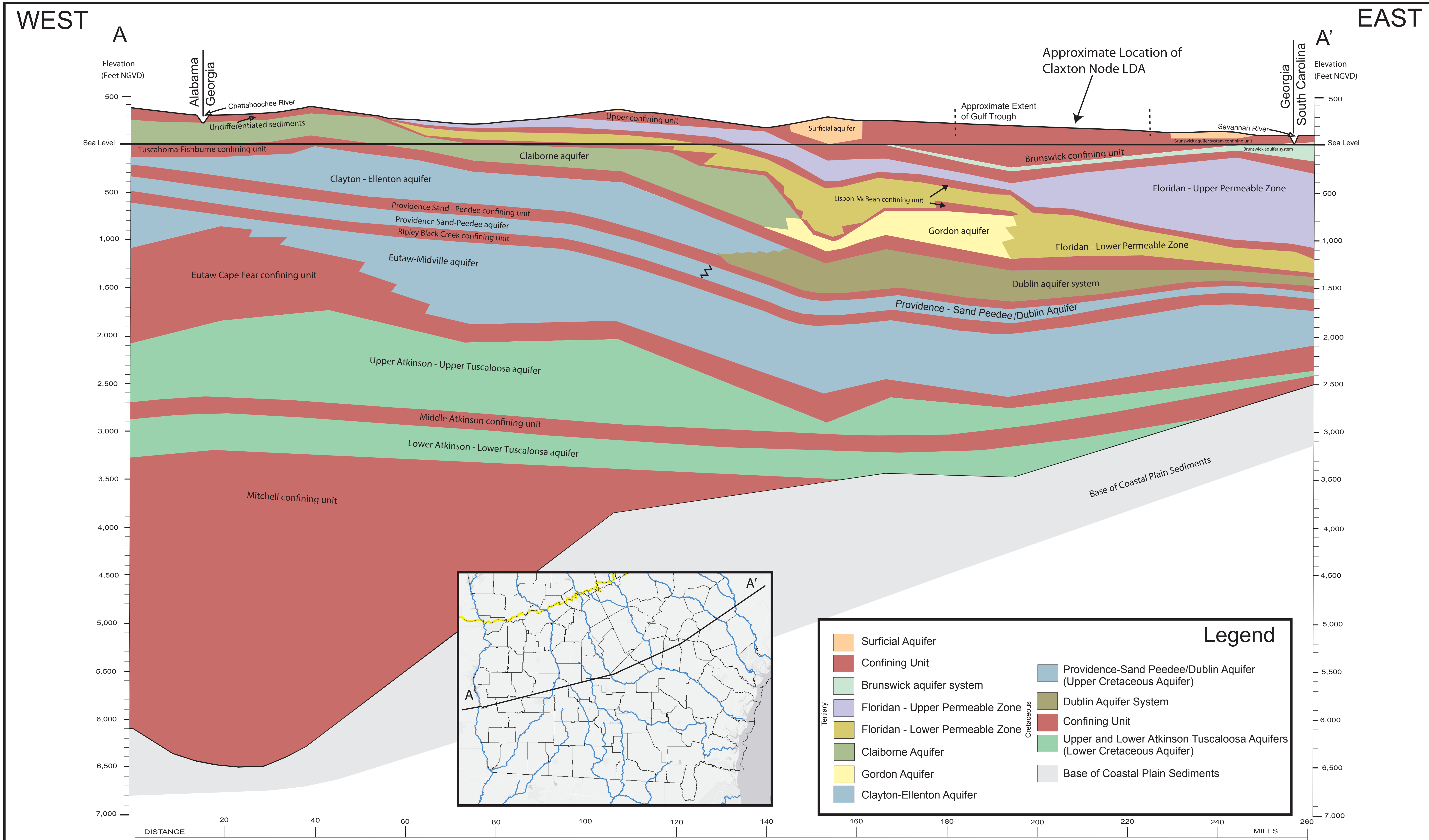
2.4.2 Model Domain and Grid

The regional groundwater flow model domain is shown on Figure 2-1. The model domain includes the entire Coastal Plain area within the state of Georgia. The northwestern limit of the Coastal Plain aquifer system is the contact with the metamorphic/igneous rocks of Precambrian and Paleozoic age at the Fall Line, which marks the updip extent of the Coastal Plain sediments. The domains of the State Water Plan sub-regional models, as well as the Canoochee River drainage basin, are also shown on Figure 2-1 for reference.

The regional model domain is subdivided into a uniform computational grid with 236 rows and 328 columns. Each grid cell is 1 square mile. The grid is rotated 26 degrees to be aligned with the general northwest-to-southeast groundwater flow direction across the Coastal Plain aquifer system. While this is a regional-scale model, the grid discretization is sufficient for this study to identify potential areas of excessive drawdown due to increased groundwater pumping.

2.4.3 Model Layering

Figure 2-2 presents a hydrostratigraphic cross section showing the hydrogeologic units, including aquifers and confining units, in the study area.



Source Modified from Renken, 1996; Miller, 1990 and Miller, 1986

Figure 2-2
East - West Hydrostratigraphic Cross Section Through the Study Area

The regional model (as well as the sub-regional models) contains seven layers numbered from top to bottom representing different aquifer systems within the Coastal Plain. In the Claxton node vicinity, the model layers are:

- Layer 1 – Surficial/Brunswick Aquifers
- Layer 2 – Floridan Aquifer Upper Permeable Zone (formerly designated as Upper Floridan Aquifer)
- Layer 3 – Claiborne/Floridan Aquifer Lower Permeable Zone (formerly designated as Lower Floridan Aquifer)/Gordon Aquifer
- Layer 4 – Clayton and Cretaceous Dublin Aquifers (in Task 1 study area, model layer 4 is the Dublin Aquifer)
- Layer 5 – Providence Sand-Peedee-Dublin Cretaceous Aquifers (in Task 1 study area, model layer 5 is the Providence Sand Aquifer)
- Layer 6 – Eutaw-Midville Aquifer (Cretaceous)
- Layer 7 – Upper Atkinson-Upper Tuscaloosa Cretaceous Aquifer (in Task 1 study area, model layer 7 is the Upper Atkinson Aquifer)

2.4.4 Rivers

The interaction between groundwater and surface water (i.e., rivers) is generally represented in the top active layer in the model. Thus, where an aquifer outcrops, the layer representing that aquifer will be the top active model layer and groundwater-surface water interaction will be actively simulated here. The exception is in model layer 1 (surficial aquifer system or Brunswick aquifer system) where rivers are not explicitly represented since a constant head boundary is applied to all active model cells in layer 1. In the Canoochee River basin study area, model layer 1 is active and overlies the Floridan aquifer. Any impact on stream baseflow due to increased pumping from the Floridan aquifer can be explicitly accounted for in the updip (north) area where the Floridan aquifer outcrops and is in direct contact with the rivers. Any impact on streamflow within the study area where the Floridan aquifer is overlain by the surficial/Brunswick aquifer system can be approximated by comparing the layer 1 water budget with added Floridan pumping to the base case layer 1 water budget.

2.4.5 Groundwater Withdrawals in Claxton Node Local Drainage Area

The Claxton node local drainage area (LDA) or drainage basin includes the area upstream that contributes to Canoochee River flow at the Claxton node. Withdrawals from the Floridan aquifer within the Claxton node LDA included in the regional groundwater model total approximately 3.6 MGD, with about 3.0 MGD withdrawn for agricultural irrigation and about 0.6 MGD withdrawn for public water supply. The Regional Coastal Plain Model represents annual average groundwater withdrawals for the year 2010.

3. Agricultural Irrigation Demand Estimates for the Claxton Node Local Drainage Area

Irrigated acreage within the Claxton node LDA and estimated irrigation water depths were used to approximate the agricultural surface water demand for parcels currently irrigated with surface water. These computed demands were then used to develop input to the groundwater model simulations described in Section 4.

3.1 Irrigated Acreage

CDM Smith mapped and reviewed a Georgia EPD inventory ("Ogeechee.7z" transmitted to CDM Smith in January 2016) of agricultural parcels in the Canoochee River watershed upstream of the Claxton planning node. The agricultural parcels are grouped into the following categories:

1. Parcels that use only surface water for irrigation
2. Parcels that use only groundwater for irrigation
3. Parcels that are served by both surface water and groundwater

Table 3-1 summarizes the number of parcels and irrigated acreage for each category within the Claxton node LDA. The spatial distribution of these parcels is shown on **Figure 3-1**.

Table 3-1. Irrigated Area Upstream of Claxton Node

Irrigated Parcels	Number of Parcels	Irrigated Area (acres)
Parcels supplied by surface water only	214	6,080
Parcels supplied by groundwater only	110	4,460
Parcels supplied by both surface water and groundwater	124	3,910
Total	**448**	**14,450**

Parcels that are served by both surface water and groundwater also include users that withdraw groundwater for storage in on-site ponds before using it for irrigation. Because the purpose of this task is to replace direct surface water withdrawals with groundwater, surface-water-only users were selected and irrigation demands were calculated for these parcels only.

3.2 Irrigation Depth

The irrigation demand was estimated using parcel areas and irrigation depths developed by Dr. James Hook et al. (2005). Monthly irrigation depths have been estimated for dry, normal, and wet rainfall years for different regions within Georgia based on climate and crop water needs. For the Claxton node area, irrigation depths for the Coastal Zone were used.

Monthly mean irrigation depths for the Georgia Coastal Zone are presented in **Table 3-2**.

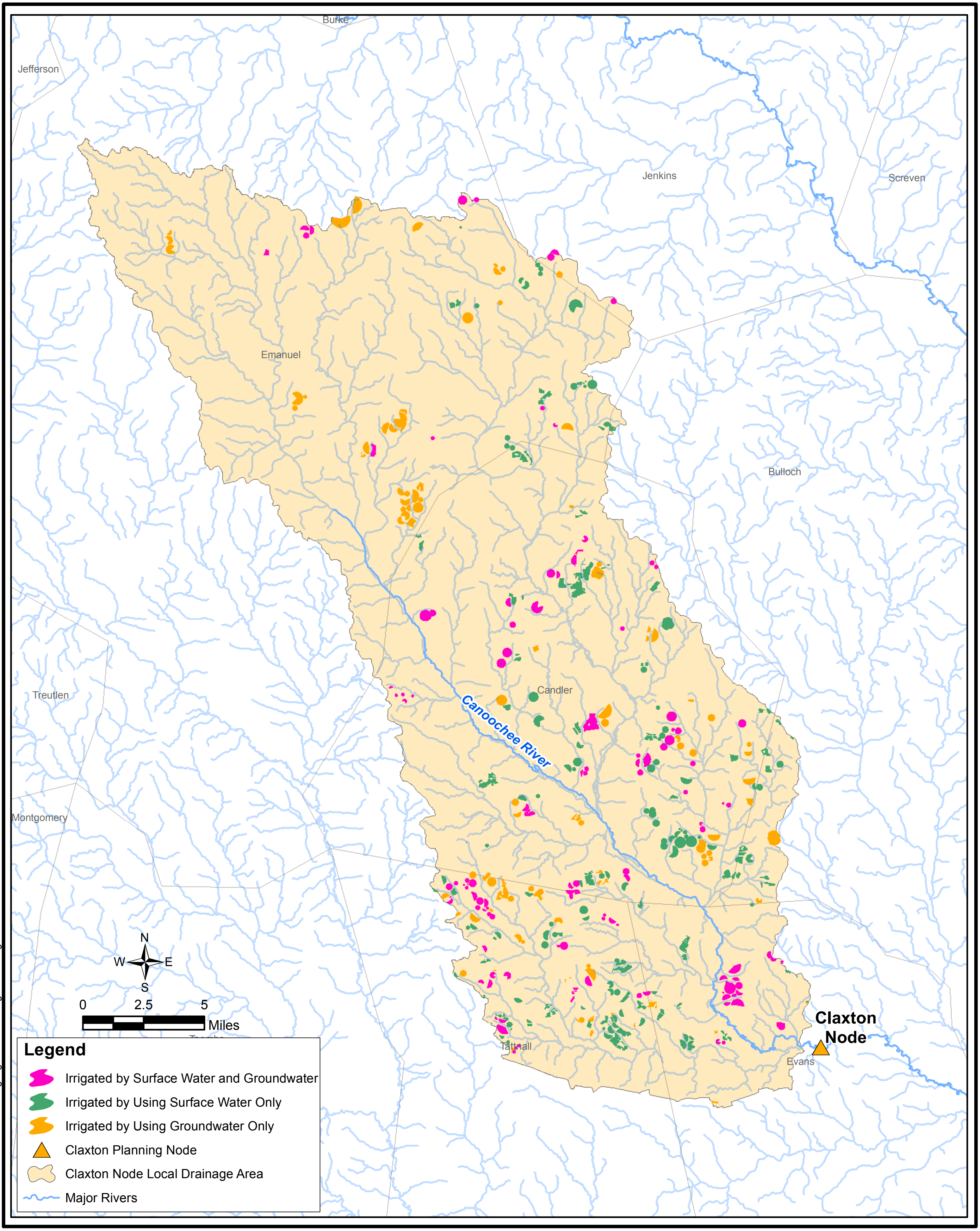


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Figure 3-1
Irrigated Area in Canoochee River Basin Upstream of Claxton Planning Node

Table 3-2. Mean Irrigation Depth for Crops Using Groundwater in Coastal Zone

Month	Mean Irrigation Depth (inches/month)			
	Dry	Normal	Wet	High-Demand and Low-Demand Average for Normal Conditions
January	0.28	0.20	0.09	
February	0.17	0.13	0.07	
March	0.39	0.18	0.06	
April	0.73	0.54	0.13	
May	1.88	1.30	0.34	
June	2.04	1.33	0.49	
July	3.04	1.54	0.41	
August	1.96	1.37	0.40	1.39 (High Demand: May – August)
September	1.15	0.72	0.40	
October	0.86	0.51	0.20	
November	0.49	0.27	0.11	
December	0.46	0.25	0.12	0.35 (Low Demand: September – April)
Total (inches/year)	**13.45**	**8.34**	**2.82**	

The average irrigation depth for high-demand periods (May through August) in a normal rainfall year is approximately 1.39 inches/month (orange shading). The average irrigation depth for low-demand periods (September through April) in a normal rainfall year is approximately 0.35 inches/month (green shading).

3.3 Irrigation Demand

Based on irrigated area and mean irrigation depths, irrigation demands were calculated individually for each parcel for high-demand and low-demand periods.

The average irrigation demand for parcels irrigated by surface water only is presented in **Table 3-3**. The estimated irrigation demand for high-demand and low-demand periods is approximately 7.44 MGD and 1.90 MGD, respectively.

Table 3-3. Calculated Irrigation Demand of Surface-Water-Only Parcels – Claxton Node LDA

	Number of Parcels	Total Irrigated Area (acres)	Mean Irrigation Depth (inches/month)		Total Irrigation Demand (MGD)	
			(May – August)	(September – April)	(May – August)	(September – April)
Surface-Water-Only Parcels that Will Be Replaced by Groundwater	214	6,080	1.39	0.35	7.44	1.90

In the groundwater model simulations described in the next section, the irrigation demand at each parcel was simulated as a Floridan aquifer groundwater withdrawal at the parcel centroid location.

4. Simulation Results Showing Impact of Increased Groundwater Pumping to Replace Agricultural Surface Water Withdrawals

The steady-state Regional Coastal Plain Model was used to evaluate the incremental Floridan aquifer water-level drawdown that may result from additional Floridan groundwater withdrawals used to offset reduced surface water withdrawals. A range in pumping rates was simulated to evaluate the potential range of water-level drawdown that may result from the additional groundwater withdrawals. Simulated drawdowns for the scenarios presented below were reviewed with respect to Upper Floridan Aquifer sustainable yield results presented in the document titled *Groundwater Flow Modeling of the Coastal Plain Aquifer System of Georgia* (CDM, 2011a). The following scenarios were simulated, and are described in greater detail in Sections 4.2 – 4.5 below:

- Additional Floridan aquifer withdrawals comparable to the surface water irrigation demand during high-demand periods (total additional withdrawal of 7.44 MGD)
- Modified version of the first scenario, which does not include groundwater withdrawals in areas of low transmissivity in the Claxton node LDA (total additional withdrawal of 3.65 MGD)
- Additional Floridan aquifer withdrawals in excess of surface water irrigation demand during high-demand periods (total additional withdrawal of 10.51 MGD)
- Additional Floridan aquifer withdrawals comparable to the surface water irrigation demand during low-demand periods (total additional withdrawal of 0.93 MGD)

The Regional Coastal Plain Model is a steady-state model and, as such, represents long-term average conditions. By applying groundwater withdrawals comparable to the surface water irrigation demands for the high-demand period (May through August) in a steady-state model, a conservatively high estimate of potential drawdown is produced because the water demand during this period is greater than the average monthly demand for a normal year (approximately 0.7 inches/month). In practice, high demands of this magnitude occur only during a few months of the year, and the aquifer conditions are not expected to reach steady-state during that relatively short time period. Thus, the simulated steady-state drawdown associated with the additional high-demand period groundwater withdrawal represents an upper end of the range of potential drawdowns that may result with the addition of new groundwater withdrawals to offset the decreased agricultural surface water withdrawals. In this case, the steady-state model presents a conservative estimate of the potential drawdown associated with the increased groundwater withdrawal. The simulated steady-state drawdown associated with low-demand groundwater withdrawal represents a lower end of the range of potential drawdowns that may result with the addition of new groundwater withdrawals. The steady-state model in this case may not provide a conservative estimate of drawdown for all low-demand months, since in some months, the additional withdrawals are greater than the low-demand period average.

To estimate whether the additional groundwater withdrawals presented in this report might contribute to excessive drawdowns if implemented in addition to sustainable yield pumping rates, simulated drawdowns for each scenario were reviewed with respect to Upper Floridan Aquifer sustainable yield simulation drawdowns for the low end of the estimated sustainable yield (393 MGD additional pumping over existing 465 MGD groundwater withdrawal). Simulated drawdowns for the low end sustainable yield simulation are shown for the Claxton node vicinity in **Figure 4-1**. Simulated drawdowns in excess of the 30-foot sustainable yield metric occur east and west of the Claxton node LDA. Within the Claxton node LDA, simulated drawdowns for the low end sustainable yield simulation range approximately from 3 to 21 feet.

For each groundwater withdrawal scenario, the simulated Floridan aquifer drawdown in the vicinity of Hilton Head, South Carolina was also reviewed to evaluate whether the increased pumping in the Claxton node LDA might potentially lower Floridan aquifer heads near Hilton Head where salt water intrusion is a concern,

4.1 Baseline Conditions for Drawdown Calculations

Simulated Floridan aquifer heads in the steady-state Regional Coastal Plain Model were used to define the baseline conditions for this analysis. Groundwater pumping in this baseline simulation is consistent with reported 2010 groundwater withdrawals. Contours of simulated Floridan aquifer heads (model layer 2) in the baseline simulation are shown on **Figure 4-2**.

Within the Claxton node LDA, simulated groundwater elevations in the Floridan aquifer range from approximately 30 feet National Geodetic Vertical Datum (NGVD) to more than 220 feet NGVD. The cone of depression resulting from Floridan aquifer pumping by the City of Savannah is evident southeast of the Claxton node LDA, as depicted on Figure 4-2.

The steep simulated hydraulic gradient evident in southeastern Candler County reflects the influence of the Gulf Trough, a low-transmissivity geologic feature that cuts across southern Georgia. The Gulf Trough is a significant sediment-filled depression or "trough," which trends diagonally in a northeastward direction for approximately 200 miles (Patterson and Herrick, 1971; Popenoe et al., 1987). It consists of a zone of relatively thick accumulations of Miocene and more recent deposits consisting of fine-grained clastic sediments and argillaceous (containing appreciable amounts of clay) carbonates, in which permeability and thickness of the Coastal Plain deposits decrease. The Gulf Trough impedes groundwater flow because of the juxtaposition of rocks of higher permeability in the updip and downdip areas of the trough, with those of lower permeability within the trough. The structural effect can be seen in the baseline simulation results (Figure 4-1) and published potentiometric surface maps of the aquifer system (Clarke et al., 2004; Krause and Randolph, 1989; Miller, 1986). The transmissivity values obtained from Aquifer Performance Tests (APTs) of wells that fall within the Gulf trough are orders of magnitude lower than those measured at wells located outside the Gulf Trough (Clarke et al., 2004).

The delineation of the Gulf Trough in the Regional Coastal Plain Model, shown on Figure 4-2, was based on published regional reports and model calibration. The transmissivity of the Floridan aquifer is relatively higher south of the Gulf Trough compared to the aquifer north of the Gulf Trough, and the presence of this feature affects the simulated impact from the additional

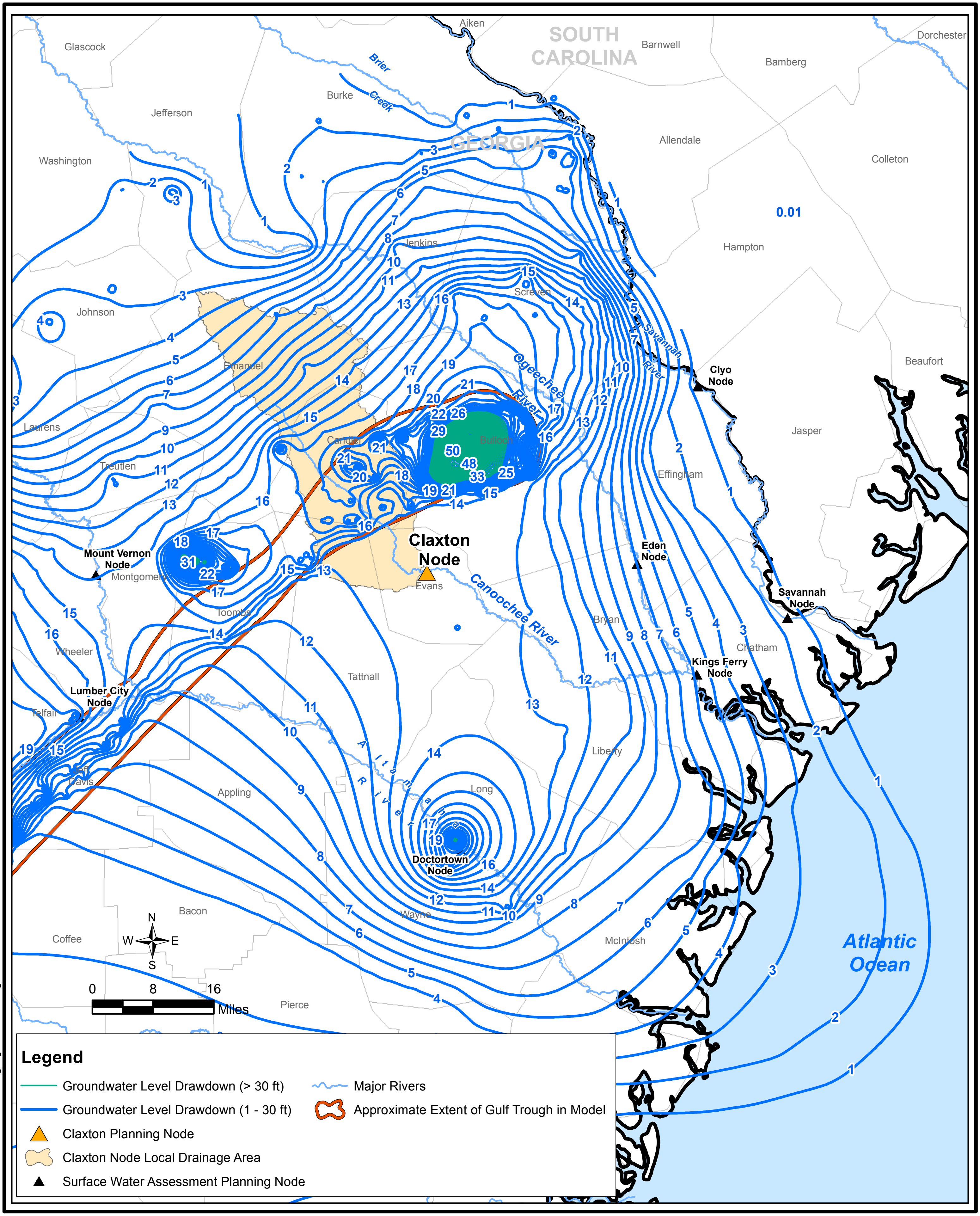

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Figure 4-1
Simulated Groundwater Level Drawdown in Upper Floridan Aquifer (Layer 2) Due to Increasing Existing Well Pumping in Floridan Aquifer in South Central Georgia and Eastern Coastal Plain (ΔQ= 393 MGD) Using Sub-Regional Upper Floridan Aquifer Model (CDM, 2011a)

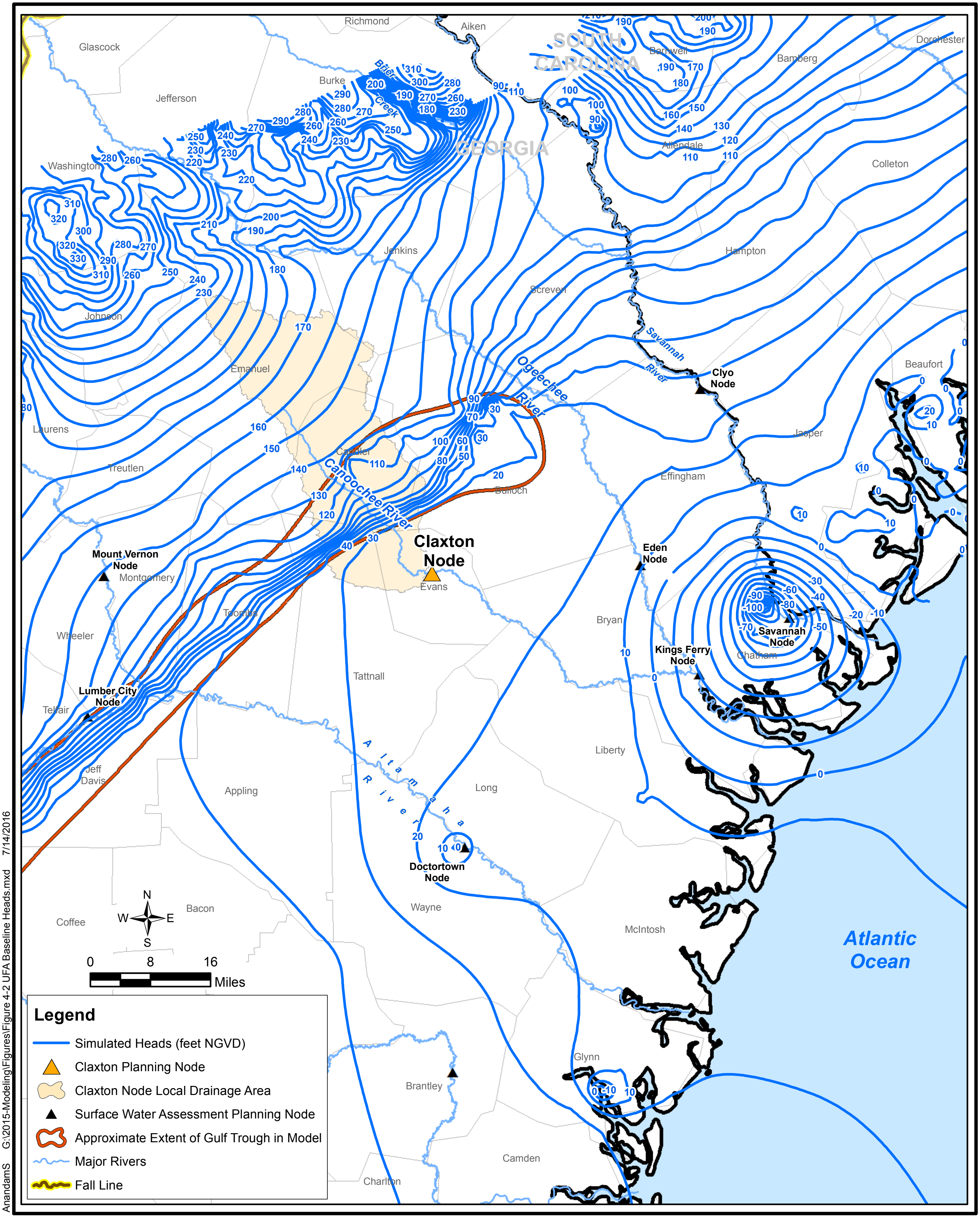

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Figure 4-2
Simulated Baseline (Existing Calibration) Floridan Aquifer Heads
Regional Coastal Plain Model

groundwater withdrawals introduced to replace the decreased surface water irrigation withdrawals.

4.2 Simulated Floridan Aquifer Drawdown with Additional High-Demand Agricultural Pumping

Additional groundwater withdrawals equivalent to the irrigation demand currently supplied by surface water sources were applied to the Floridan aquifer (model layer 2) in a steady-state simulation. The additional groundwater withdrawals represent the quantity of water currently supplied by surface water during high-irrigation-demand months (estimated total additional withdrawal of 7.44 MGD). The incremental water-level drawdown associated with the additional pumping was calculated by subtracting simulated Floridan aquifer heads with additional pumping from simulated baseline condition Floridan heads. Simulated drawdown contour maps were used to evaluate the impacts of introducing additional groundwater withdrawals to the Floridan aquifer.

The simulated Floridan aquifer drawdown for this scenario is shown on **Figure 4-3**. Simulated drawdown in an area of Candler County east of the Canoochee River exceeds the 30-feet drawdown metric for sustainable yield. The additional groundwater withdrawals in this scenario could not be implemented in addition to sustainable yield pumping rates. The simulated drawdowns are influenced by the presence of the low-transmissivity zone representing Gulf Trough sediments in the model.

The simulated Floridan aquifer drawdown beneath Hilton Head Island is less than 0.01 feet; therefore, the pumping presented in this scenario is not likely to contribute to additional salt water intrusion in the Floridan aquifer beneath Hilton Head Island.

4.3 Simulated Floridan Aquifer Drawdown with No Additional Groundwater Pumping in Gulf Trough Area, High-Demand Agricultural Pumping

Because of the low transmissivity associated with the Gulf Trough area within the Floridan aquifer, it may not be economically advantageous to install and operate groundwater wells there. If agricultural parcels served by surface water withdrawals within the Gulf Trough area are excluded from the modeling analysis, the maximum simulated drawdown in the Floridan aquifer is reduced to approximately 10 feet within the Claxton node LDA (**Figure 4-4**). Excluding the parcels in the Gulf Trough area reduces the amount of the irrigation demand that is diverted from surface water to groundwater from a total of 7.44 MGD to 3.65 MGD based on high-irrigation-demand months and from a total of 1.90 MGD to 0.93 MGD based on low-irrigation-demand months. These modified demands were calculated by eliminating the parcels that lie within the Gulf Trough and their area as shown in **Table 4-1**.

Because the simulated drawdown for this pumping scenario is approximately 10 feet or less, it may be possible to implement the pumping in this scenario in addition to sustainable yield pumping rates, with only minor incremental increases in drawdown. In locations where the simulated drawdown in the sustainable yield simulation presented in Figure 4-1 is approximately 30 feet, the simulated drawdown for this scenario (3.65 MGD) is less than 2 feet.

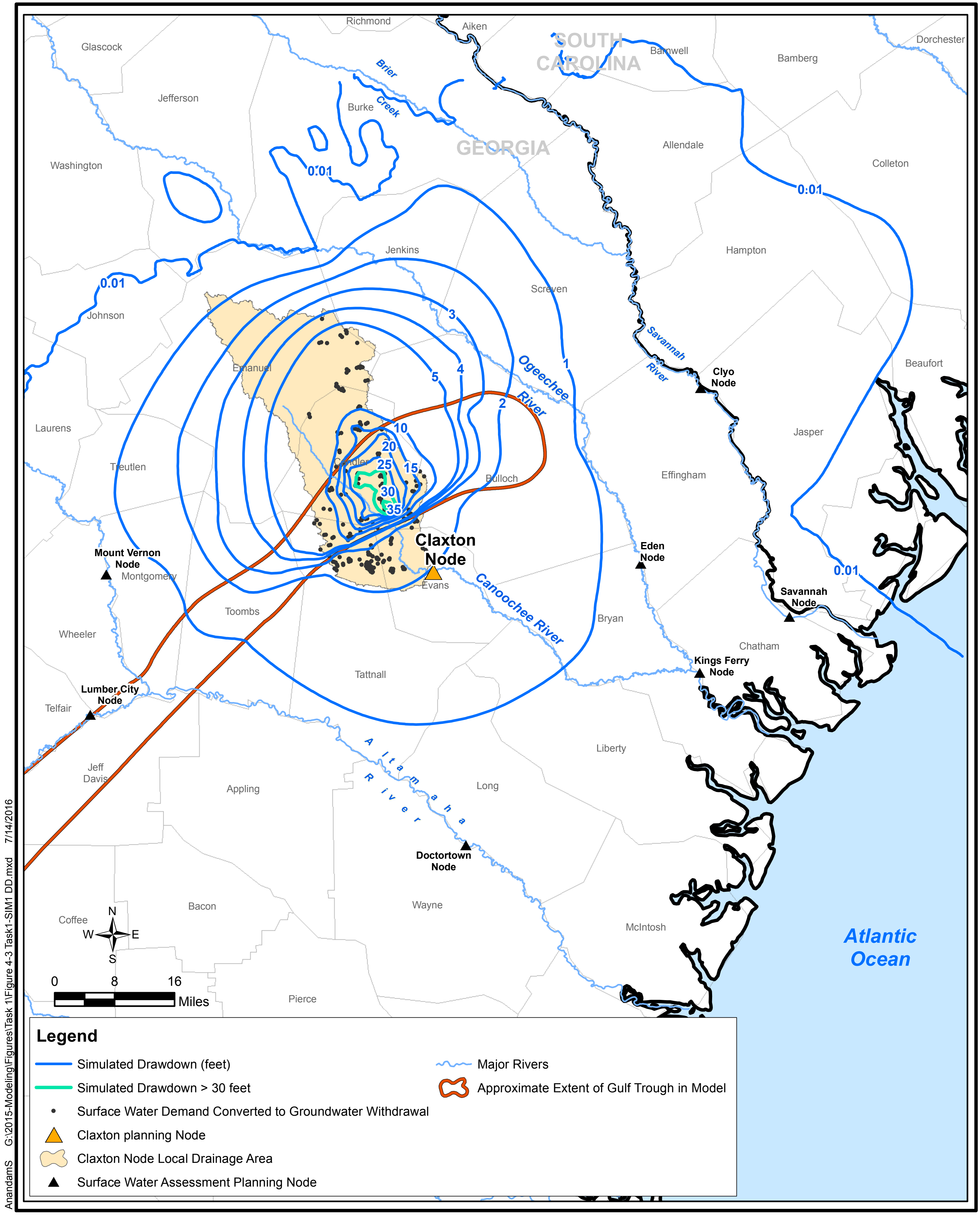

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Figure 4-3
Simulated Drawdown in Floridan Aquifer Heads
Additional Groundwater Withdrawal: 7.44 MGD

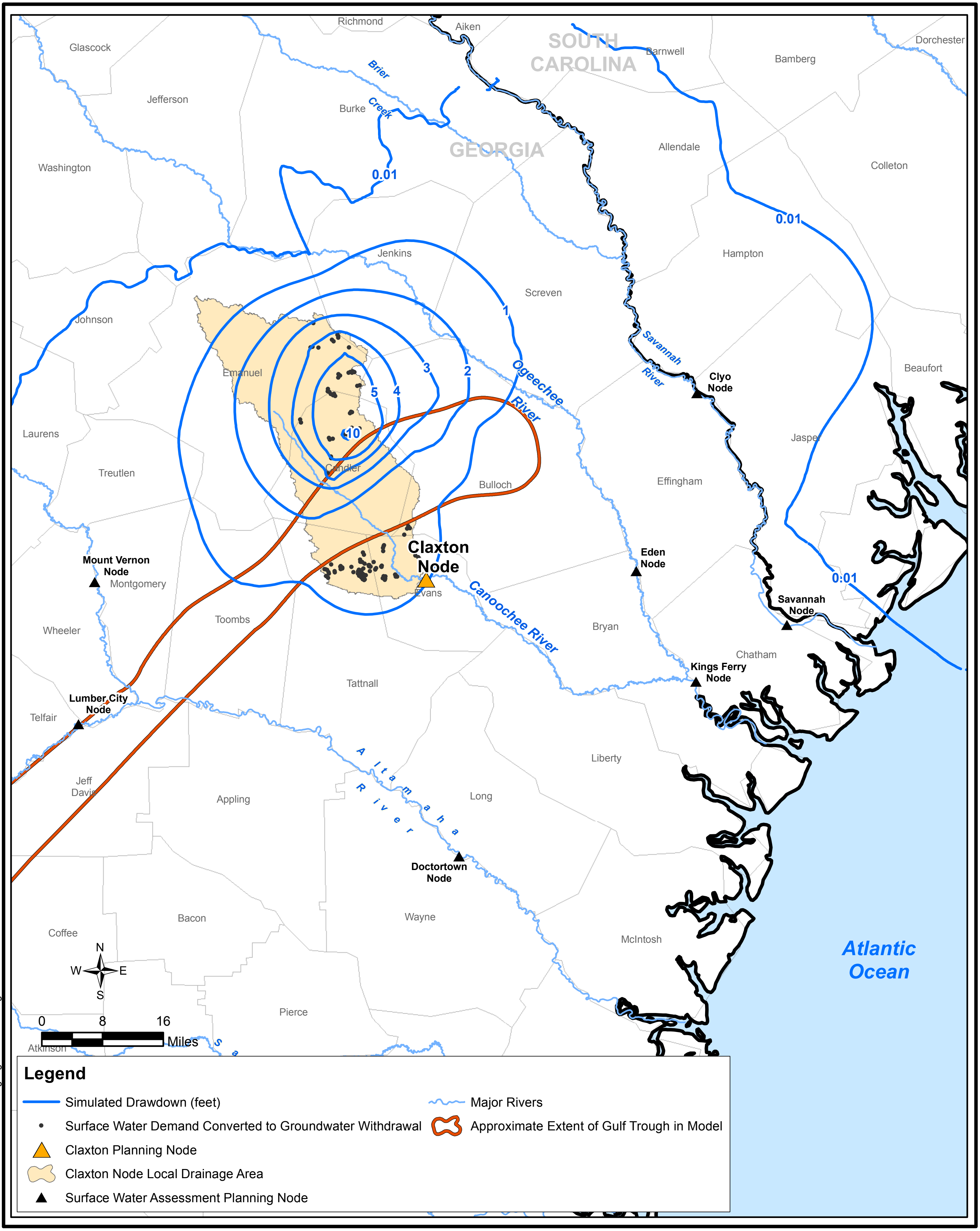

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Figure 4-4
Simulated Drawdown in Floridan Aquifer Heads
Additional Groundwater Withdrawal: 3.65 MGD (No Withdrawals in Gulf Trough Area)

In this scenario (Figure 4-4), the simulated Floridan aquifer drawdown beneath Hilton Head Island is less than 0.01 feet; therefore, the additional groundwater withdrawals are not likely to contribute to additional salt water intrusion in the Floridan aquifer beneath Hilton Head Island.

Table 4-1. Calculated Irrigation Demand of Surface-Water-Only Parcels That Will Be Replaced by Groundwater (Excluding Gulf Trough Area)

	Number of Parcels	Total Irrigated Area (acres)	Mean Irrigation Depth (inches/month)		Total Additional Groundwater Demand (MGD)	
			(May – August)	(September – April)	(May – August)	(September – April)
Surface-Water-Only Parcels that Will Be Replaced by Groundwater	121	2,980	1.39	0.35	3.65	0.93

4.4 Increased Floridan Aquifer Groundwater Withdrawals Without Exceeding Sustainable Yield Criteria

Groundwater model simulations were performed to evaluate the additional amount of Floridan aquifer groundwater withdrawal that could be achieved without exceeding the sustainable yield criterion of 30 feet of drawdown established by the State Water Plan groundwater resource assessments (CDM, 2011a). These simulations were performed by applying incremental multiplication factors until the maximum simulated drawdown was approximately 30 feet. Additional groundwater withdrawals were not assigned within the Gulf Trough area.

The simulations suggest that Floridan aquifer groundwater withdrawals within the Claxton node LDA can be increased to approximately 10.51 MGD without violating the sustainable yield criteria (**Figure 4-5**).

The simulated drawdown in an area of Candler County east of the Canoochee River is approximately 30 feet. The additional groundwater withdrawals in this scenario could not be implemented in addition to sustainable yield pumping rates without violating the 30-feet drawdown criterion. As with the other scenarios, the simulated Floridan aquifer drawdown beneath Hilton Head Island is less than 0.01 feet; therefore, the pumping presented in this scenario is not likely to contribute to additional salt water intrusion in the Floridan aquifer beneath Hilton Head Island.

4.5 Simulated Floridan Aquifer Drawdown, Low-Demand Agricultural Pumping

Model simulations were performed of additional groundwater withdrawals representing quantities of water currently supplied by surface water during low-irrigation-demand months (0.93 MGD). Groundwater withdrawals were not assigned for locations of agricultural parcels within the Gulf Trough area. The simulated drawdown in the Floridan aquifer for this simulation is approximately 3 feet (**Figure 4-6**). The area of greatest simulated drawdown occurs north of the Gulf Trough area.

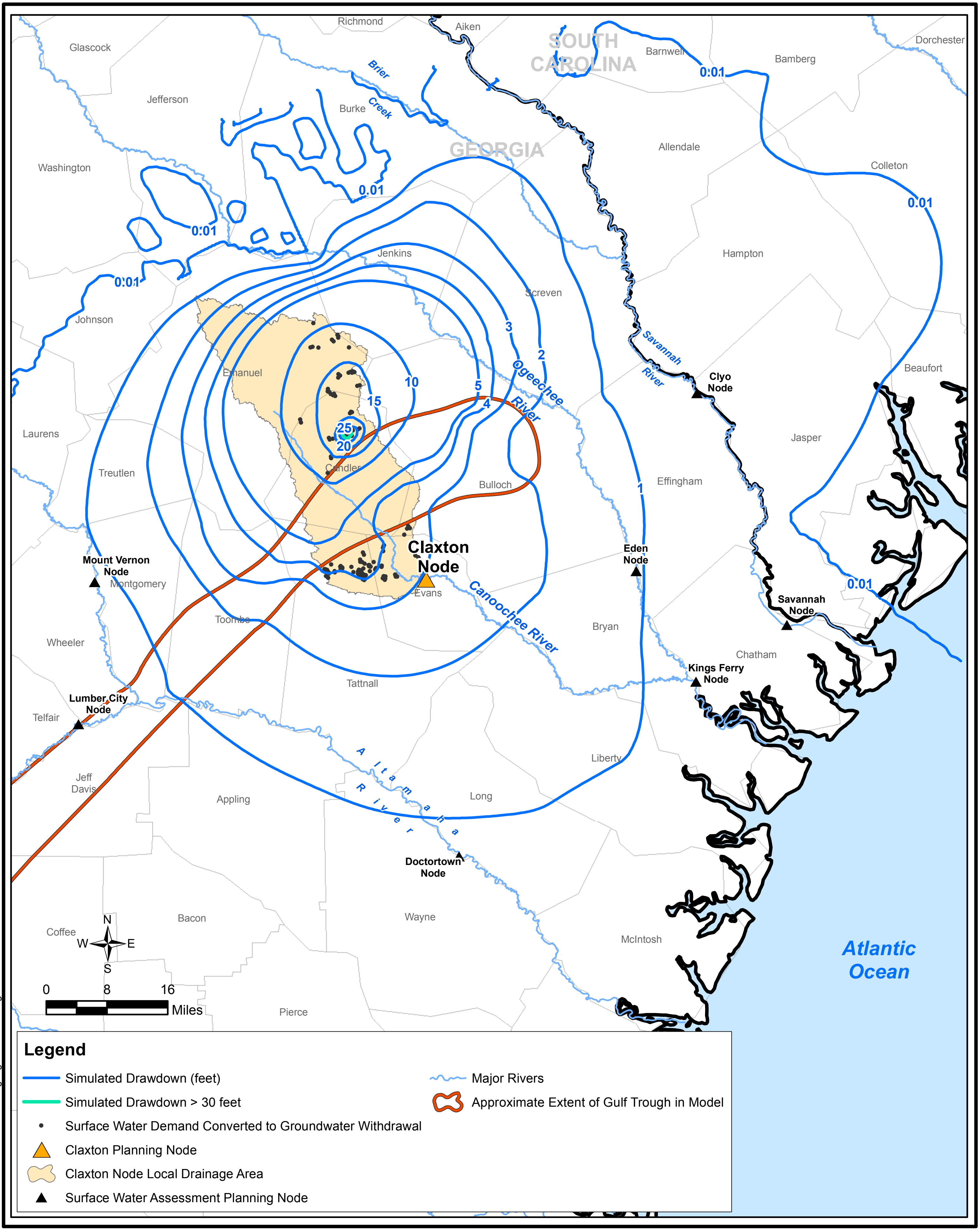

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Figure 4-5
Simulated Drawdown in Floridan Aquifer Heads
Additional Groundwater Withdrawal: 10.51 MGD (No Withdrawals in Gulf Trough Area)

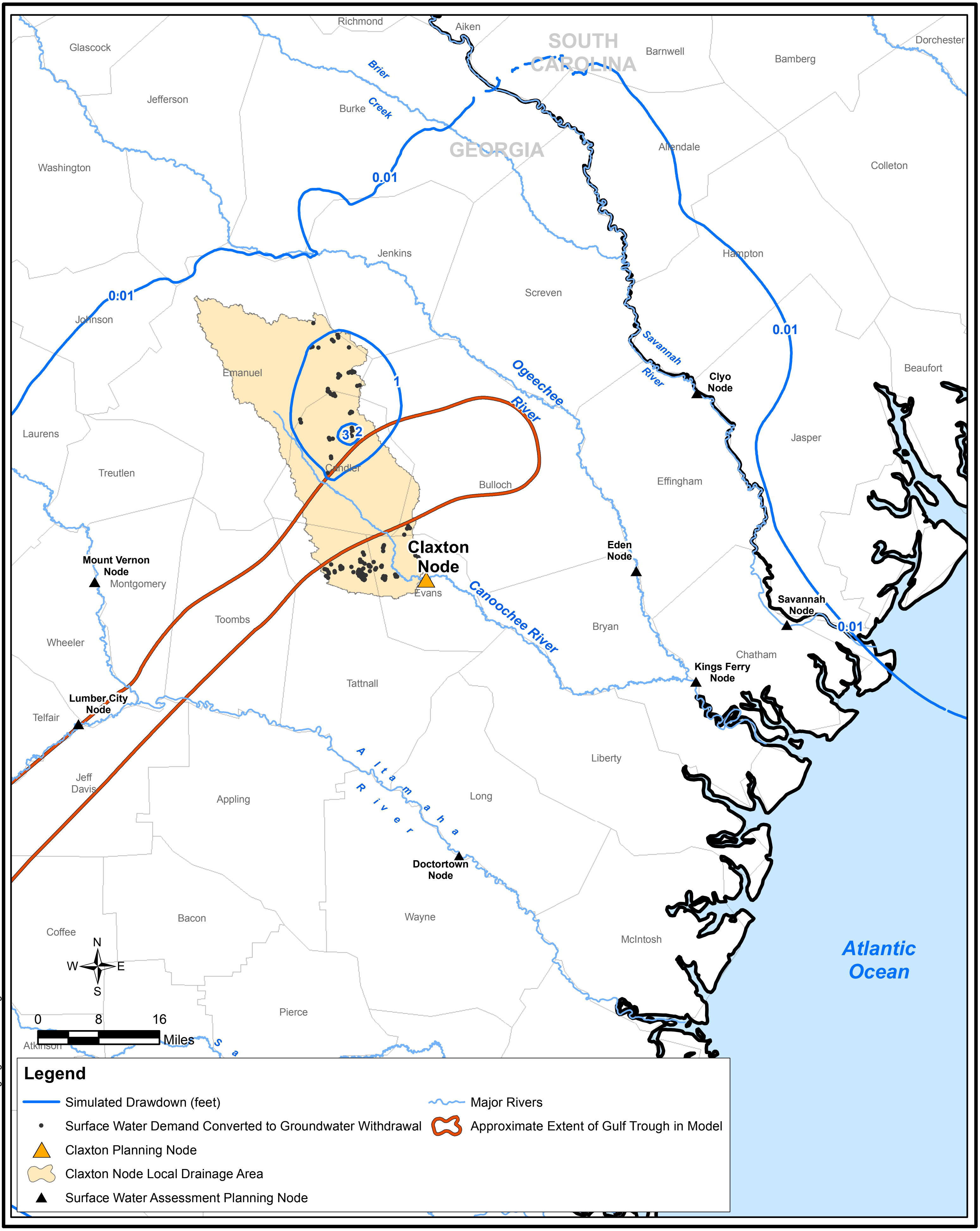

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Figure 4-6
Simulated Drawdown in Floridan Aquifer Heads
Additional Groundwater Withdrawal: 0.93 MGD (No Withdrawals in Gulf Trough Area)

Because the simulated drawdown for this pumping scenario is less than 3 feet, it may be possible to implement the pumping in this scenario in addition to sustainable yield pumping rates, with only minor incremental increases in drawdown. In locations where the simulated drawdown in the sustainable yield simulation presented in Figure 4-1 is approximately 30 feet, the simulated drawdown for this scenario (3.65 MGD) is less than 1 foot.

The simulated Floridan aquifer drawdown beneath Hilton Head Island is less than 0.01 feet; therefore, the additional groundwater withdrawals are not likely to contribute to additional salt water intrusion in the Floridan aquifer beneath Hilton Head Island.

4.6 Simulated Impact on Stream Baseflow

The baseline groundwater simulation was compared to the simulation in which groundwater withdrawals at existing locations were increased to 10.51 MGD (Section 4.4) to evaluate the potential impact of the additional withdrawals on groundwater baseflow to streams.

Within the Claxton node LDA, the Floridan aquifer is not in direct contact with streams or rivers, and the surficial aquifer is active and overlies the Floridan aquifer. Therefore, the potential impact on streamflow was inferred by comparing the increases in downward leakage from the constant head cells representing the Surficial/Brunswick aquifers comprising model layer 1. The increased leakage from the surficial aquifer induced by additional pumping in different simulations is less than 2 percent of the baseline volume. Such a small increase in vertical leakage from the surficial aquifer will have minimal impact on the baseflow of the streams that are in direct contact with the surficial aquifer.

The impact to streamflow due to increased pumping from the Floridan aquifer in the updip area in the north (where the Floridan aquifer outcrops) was estimated by comparing the baseflow reductions in different simulations to the baseflow in the baseline simulation. The baseflow reductions (when compared to the baseline model) due to additional pumping in different simulations are less than 1 percent.

5. Potential Impact on the Streamflow Shortfall at the Claxton Node

As previously noted, agricultural demand projections are currently being revised, and an updated surface water resource assessment and gap analysis will be completed once the revised projections are available. In addition to updated water demands, the gap analysis will be revised using new United States Army Corps of Engineers (USACE) Hydrologic Engineering Center Reservoir System Simulation (HEC-ResSim) surface water models developed for the Canoochee and other river basins statewide, with capabilities for analysis of geo-referenced river and reservoir networks and management of associated time-series data.

For the purpose of this study, the streamflow gaps presented in the Altamaha Regional Water Plan (CDM, 2011b) served as the basis for analysis. The average streamflow shortfall under current and forecasted 2050 agricultural demands is approximately 5 cfs (3.2 MGD) and 11 cfs (7.1 MGD), respectively (CDM, 2011b).

Groundwater model simulation results suggest that groundwater pumping at existing surface water irrigation parcels located outside the Gulf Trough area could be increased by a total rate of 10.51 MGD without exceeding the 30-feet drawdown criterion established for sustainable yield by the State Water Plan groundwater resource assessments.

6. Summary

CDM Smith prepared this report to summarize the groundwater modeling analysis performed in support of the State Water Plan. The modeling analysis consisted of simulating the impact of additional Floridan aquifer groundwater withdrawals in the Canoochee River watershed to replace agricultural surface water withdrawals in the Claxton planning node LDA for which surface water resource analysis identified potential shortfalls of approximately 3.2 MGD and 7.1 MGD under current and forecasted 2050 demands, respectively (CDM, 2011b).

The steady-state Regional Coastal Plain Model (CDM, 2011a) developed for the State Water Plan groundwater resource assessments was applied to evaluate the incremental Floridan aquifer water-level drawdown that may result from additional Floridan groundwater withdrawals to supply the agricultural irrigation demand currently supplied by surface water. Simulated Floridan aquifer heads in the regional model representative of 2010 conditions were used to define baseline conditions for this evaluation. A range of additional Floridan aquifer withdrawals were simulated to evaluate the potential range of water-level drawdown that may result. **Table 6-1** summarizes the simulated groundwater withdrawal scenarios and the corresponding maximum simulated drawdown.

Table 6-1. Simulated Groundwater Withdrawal Scenarios

Scenario	Additional Groundwater Pumping (MGD)	Maximum Simulated Drawdown (Feet)
Additional Groundwater Withdrawals to Replace Surface Water Demand – High-Demand Average	7.44	35
Additional Groundwater Withdrawals to Replace Surface Water Demand – High-Demand Average (Excluding Parcels in Gulf Trough)	3.65	10
Additional Groundwater Withdrawals to Replace Surface Water Demand – Increased Pumping (Excluding Parcels in Gulf Trough)	10.51	30
Additional Groundwater Withdrawals to Replace Surface Water Demand – Low-Demand Average (Excluding Parcels in Gulf Trough)	0.93	3

The simulation results indicate that replacing all of the existing surface water withdrawals within the Claxton node LDA with groundwater withdrawals corresponding to high-demand irrigation rates (representative of average May through August demands) could result in locally lowered groundwater levels more than 30 feet below the baseline conditions. This would exceed the sustainable yield criterion defined in the State Water Plan groundwater resource assessments of a 30-foot maximum drawdown between wells.

The simulated drawdown was highest in the Gulf Trough area where model transmissivity in the Floridan aquifer is very low. Since this low-transmissivity area may not be economically conducive to groundwater development, additional simulations were conducted in which groundwater substitution fluxes were excluded from the Gulf Trough area.

Results from these additional simulations suggest that groundwater pumping at existing surface water irrigation locations outside the Gulf Trough area could be increased to a total withdrawal of 10.51 MGD without exceeding the 30-feet drawdown criterion. For all of the simulated groundwater withdrawal scenarios, the simulated reduction in groundwater discharge to rivers was small (less than 2 percent).

The results of this study can inform the development of future management practices by Planning Councils. Additional groundwater withdrawals can contribute to reduction of current or future gaps, in conjunction with drought contingency planning, demand management practices, and other surface water management measures.

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APPENDIX B

Task 2

Coastal Georgia Water Planning Region: Capacity of the Floridan and Cretaceous Aquifers to Replace Agricultural Surface Water Withdrawals in the Ogeechee River Basin

Prepared for:
Georgia Department of Natural Resources
Environmental Protection Division

August 2016

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Task 2

Coastal Georgia Water Planning Region: Capacity of the Floridan and Cretaceous Aquifers to Replace Agricultural Surface Water Withdrawals in the Ogeechee River Basin

1. Introduction

CDM Smith prepared this report in support of the Georgia Comprehensive State-wide Water Plan. The report describes groundwater model simulation analysis of additional Floridan and Cretaceous aquifer groundwater withdrawals in the Ogeechee River watershed. The purpose of the additional groundwater withdrawals is to replace surface water withdrawals in areas where the previous resource analysis identified potential shortfalls in surface water availability.

1.1 Background

In February 2008, the Georgia General Assembly adopted the Georgia Comprehensive State-wide Water Plan (State Water Plan) dated January 8, 2008. The State Water Plan established a regional water resources management planning process, which was initiated in March 2009. Groundwater and surface water resource assessment modeling was conducted to evaluate water availability and potential shortfalls (or gaps) for current and future (2050) water supply demands. Summaries of groundwater and surface water resource assessments are presented in Regional Water Plan documents developed for various water planning regions.

The Coastal Georgia Regional Water Planning Council (Coastal Georgia Planning Council) is one of 11 planning regions established throughout the state. The Georgia Environmental Protection Division (EPD) develops water use forecasts that are used by the Councils to identify water management practices to address regional water supply needs.

The Coastal Georgia Planning Council has expressed concern regarding the streamflow shortfall (or "gap") identified at the Eden and Kings Ferry planning nodes on the Ogeechee River. Planning nodes are locations with long-term stream gages where the surface water resources assessment for current and future conditions was performed. According to the surface water resource assessment summarized in the Coastal Regional Water Plan, the average shortfalls under current and forecasted 2050 demands are approximately 19 cubic feet per second (cfs) (12.3 million gallons per day [MGD]) and 31 cfs (20 MGD), respectively, at the Eden node and approximately 35 cfs (22.6 MGD) and 47 cfs (30.4 MGD) at the Kings Ferry node (CDM, 2011c). A strategy for increasing streamflow in the Ogeechee River would be to reduce existing agricultural surface water withdrawals in the Ogeechee River drainage basin and replace them with groundwater withdrawals.

The Georgia EPD is in the process of revising current and future agricultural water demand projections, and an updated surface water resource assessment and gap analysis will be completed once these projections are made available. For the purpose of this study, however, the streamflow gaps presented in the Altamaha Regional Water Plan (CDM, 2011b) serve as the basis for evaluation.

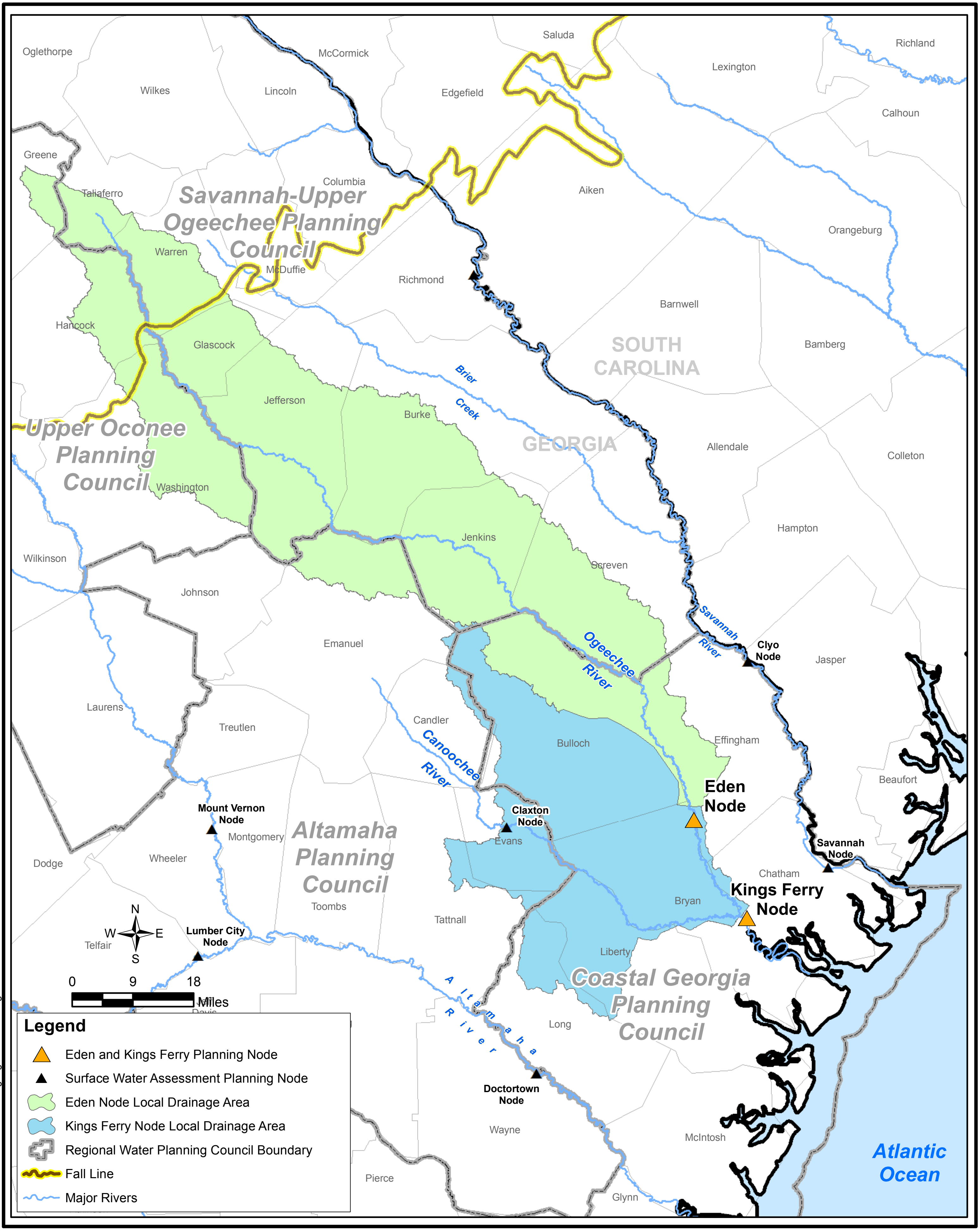
The Eden planning node is located in the Lower Ogeechee River drainage basin at the boundary between Bryan and Effingham Counties, Georgia. Upstream of the Eden gage, the Lower Ogeechee River drainage basin includes parts of Bryan, Effingham, Bulloch, Screven, Emanuel, and Jenkins Counties. The Upper Ogeechee River drainage basin includes portions of Jenkins, Burke, Jefferson, Glascock, Warren, Hancock, Taliaferro, and Greene Counties. The Kings Ferry planning node is downstream of the Eden node on the Ogeechee River and downstream of the Claxton node on the Canoochee River in Evans County, Georgia, which is located within the Altamaha planning region. The Kings Ferry planning node is located downstream of the confluence of the Ogeechee and Canoochee Rivers. **Figure 1-1** shows the locations of the Eden node, the Ogeechee River, and the Upper and Lower Ogeechee River drainage basins upstream of the Eden node.

The Eden node local drainage area (LDA) or drainage basin includes the area upstream of the Eden planning node that contributes to flows in the Ogeechee River at the Eden node. Figure 1-1 also shows the locations of the Claxton node, the Canoochee River and the Canoochee River drainage basin upstream of the Claxton node, and the Kings Ferry node and the local drainage area for the Kings Ferry node. The LDA of the Kings Ferry planning node includes that part of the drainage area upstream of the Kings Ferry node that is not tributary to either the Claxton or Eden nodes.

1.2 Approach

This report explores the possibility of reducing surface water shortfalls by using groundwater in place of surface water. Because there are no known municipal, industrial or domestic self-supply surface water demands in this watershed area, the analysis presented in this report focuses specifically on the use of groundwater in place of surface water to meet agricultural water demands. A groundwater modeling analysis was conducted to evaluate the potential impacts of increasing groundwater withdrawals within the Floridan and Cretaceous aquifers. This report is focused on the Eden and Kings Ferry planning nodes. A similar analysis was performed for the Claxton planning node and is documented under separate cover. CDM Smith completed the following tasks for this study:

- Mapped and reviewed the inventory of agricultural parcels and associated locational coordinates and acreage in the Ogeechee River drainage basin upstream of the Eden planning node with permitted surface water, groundwater, and mixed ("well-to-pond") withdrawals.
- Mapped and reviewed the inventory of agricultural parcels and associated locational coordinates and acreage in the Ogeechee and Canoochee River drainage basins upstream of the Kings Ferry planning node and downstream of the Eden and Claxton planning nodes with permitted surface water, groundwater, and mixed ("well-to-pond") withdrawals.
- Developed surface water replacement scenarios in which new groundwater withdrawals were assigned to the Floridan or Cretaceous aquifer at irrigated agricultural parcel locations (parcel centroid) currently served by surface water only. Groundwater



CDM Smith

Figure 1-1
Locations of Eden and Kings Ferry Nodes

withdrawal rates were based on parcel area and monthly irrigation requirements. The Floridan aquifer is the primary source of groundwater for irrigation in the Eden and Kings Ferry node drainage areas; however, in the upper reaches of the Eden node drainage area, in portions of Jefferson and Glascock counties, the Floridan aquifer does not exist and the Cretaceous aquifer serves as the primary groundwater source for irrigation.

- Applied the Regional Coastal Plain Model developed for the State Water Plan to simulate baseline pumping conditions and scenarios with increased Floridan and/or Cretaceous aquifer groundwater pumping to replace existing surface water withdrawals.
- Compared simulated steady-state Floridan and Cretaceous aquifer water levels for baseline and surface water replacement scenarios to determine if sustainable yield criteria previously defined for the State Water Plan would be locally violated due to the increased groundwater pumping. Changes in simulated groundwater discharges to surface water were also reviewed to determine if sustainable yield criteria previously defined for the State Water Plan would be exceeded due to the increased groundwater pumping.
- Compared the additional groundwater withdrawal that could potentially be achieved with the surface water shortfall at the Eden and Kings Ferry planning nodes to evaluate whether substituting groundwater for surface water agricultural use should be considered further in water resources management planning.

The steady-state Regional Coastal Plain Model was applied for this study (CDM, 2011a). The model represents long-term average conditions and does not incorporate monthly or seasonal variations in groundwater stresses such as pumping or recharge. Although a time-varying response to pumping changes cannot be simulated in a steady-state model, it is appropriate for the analysis of average groundwater impacts due to changes in groundwater pumping. A range of groundwater pumping rates was simulated to evaluate the range of potential Floridan aquifer water-level drawdown that may occur due to additional groundwater withdrawals.

1.3 Report Organization

The remainder of this report is organized as follows:

- Section 2 provides an overview of the State Water Plan groundwater resource assessment and the groundwater models developed and applied for that study.
- Section 3 presents a summary of the irrigated acreage data and assumptions used to estimate agricultural water use.
- Section 4 presents the results of model simulations of Floridan and Cretaceous aquifer impacts as a result of substituting groundwater withdrawals for existing surface water irrigation. Simulations were also conducted to assess the capacity of the Floridan and Cretaceous aquifers to support increased pumping without exceeding established State Water Plan sustainable yield criteria.
- Section 5 provides a brief discussion of the streamflow shortfall (or “gap”) computed for the Eden node and the Kings Ferry node and the potential reduction of the shortfall that

may be achieved by substituting groundwater withdrawals for existing surface water withdrawals.

- Section 6 presents a summary of the study.
- Section 7 provides a list of references used in this study.

2. Overview of State Plan Groundwater Resource Assessments

2.1 Assessment Approach and Criteria

In 2009 and 2010, the availability of groundwater resources in select prioritized aquifers of Georgia was evaluated. The assessment was completed to support Regional Water Development and Conservation Plans as part of the State Water Plan. The prioritized aquifers included the Floridan aquifer in south-central Georgia and the eastern Coastal Plain of Georgia, which underlies the Ogeechee River drainage basin. Other prioritized aquifers included the Claiborne, Clayton, and Cretaceous aquifer systems.

Numerical steady state groundwater flow models were developed for the State Water Plan to support the groundwater availability assessments. The results of groundwater flow model simulations with increased pumping in the prioritized aquifers were compared to baseline simulations representing existing conditions to estimate local impacts of the increased pumping. The estimated local impacts were then compared to sustainable yield criteria developed for the State Water Plan study.

Formulation of the sustainable yield criteria for the groundwater resource assessments is presented in Section 11 of the document titled *Groundwater Flow Modeling of the Coastal Plain Aquifer System of Georgia* (CDM, 2011a). For the purposes of the groundwater resource assessments, sustainable yield was defined as the maximum amount of groundwater withdrawal that could occur from defined extraction points within each aquifer without violating sustainable yield metrics. The following metrics were applied, with some variations depending on the prioritized aquifer being studied and the level of detail provided by the respective models used to assess sustainable yield:

- Drawdowns of groundwater levels in the pumped aquifer do not exceed 30 feet between pumping wells;
- Pumping was limited to levels that would not decrease mean annual stream baseflow by more than 40 percent;
- 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.

The primary metrics that applied to the sustainable yield analysis for the Floridan aquifer and Cretaceous aquifer system were the first two listed above which pertain to drawdown and impacts to baseflow. In the Kings Ferry node area, the surficial aquifer is active, overlying the Floridan aquifer, such that there is generally little interaction between the Floridan aquifer and surface water. The local drainage area for the Eden node extends to the north where the surficial aquifer is absent, and there is a hydraulic connection between the Floridan aquifer and surface water. The sustainable yield of the Floridan and Cretaceous aquifers in south-central Georgia and the eastern Coastal Plain of Georgia was found to be sufficient to meet groundwater demands projected through the year 2050 (CDM, 2011a). However, a portion of the Ogeechee River basin upstream of the Eden node is in the Coastal Permitting Plan Red Zone and withdrawals from the Floridan aquifer are restricted. A portion of the Ogeechee River basin upstream of the Eden node is also in the Coastal Permitting Plan Yellow Zone with Floridan aquifer withdrawal restrictions. Any increase in Floridan aquifer pumping in the Red and Yellow zones is considered to have a potential risk of impact on salt water intrusion.

2.2 Georgia Regional Coastal Plain Groundwater Model

The Georgia Regional Coastal Plain Model (domain shown on **Figure 2-1**) was developed in 2009-2010 to support the State Water Plan sustainable yield assessments (CDM, 2011a). For this purpose, an existing regional United States Geological Survey (USGS) Coastal Plain Clastic Aquifer System Model (Faye and Mayer, 1996) was modified and updated, including expanding the model domain, refining the computational grid, and incorporating available local data in and near the prioritized study areas. Vertically, the model includes the entire Georgia Coastal Plain aquifer sequence down to the Cretaceous aquifer system. Prioritized aquifers for the assessment included the Floridan, Claiborne, Clayton, and Cretaceous aquifer systems. The regional model was calibrated using available hydrogeologic data and observed groundwater elevations at monitoring wells under steady-state conditions. Regional model simulations have been conducted in steady-state mode only.

The regional model was revised in 2012 to incorporate new data on agricultural groundwater withdrawals and an expanded representation of river-groundwater interaction (i.e., the number of river nodes was increased to include smaller tributary streams than previously represented). The agricultural, municipal, and industrial steady-state pumping in the 2012 revised regional model represents annual average groundwater withdrawals for the year 2010. The regional model with revised pumping and river representation was recalibrated in steady-state mode. The recalibration included modifications to model hydraulic properties and boundary conditions (CDM Smith, 2012a).

2.3 Sub-Regional Models

Sub-regional models were initially developed for the Floridan aquifer in south-central Georgia and the eastern Coastal Plain of Georgia, the Claiborne aquifer, and the Cretaceous aquifer between Macon and Augusta (Figure 2-1). The sub-regional models were used to develop sustainable yield estimates for the corresponding aquifers. Generally speaking, with the exception of model grid spacing and model domain limits, the sub-regional and regional models are consistent in terms of model layering, aquifer properties, and other model input parameter values. The initial Floridan, Claiborne, and Cretaceous sub-regional models were calibrated in transient as well as steady-state mode.

The sub-regional models for the Cretaceous aquifer and the Claiborne aquifer, as well as the regional model, were revised and recalibrated in 2012 to incorporate new data on agricultural groundwater withdrawals and an expanded representation of river-groundwater interaction (CDM Smith, 2012a). At that time, CDM Smith also developed and calibrated a sub-regional model for the Clayton aquifer based on the updated regional model (CDM Smith, 2012b). The agricultural, municipal, and industrial steady-state pumping in the 2012 sub-regional models

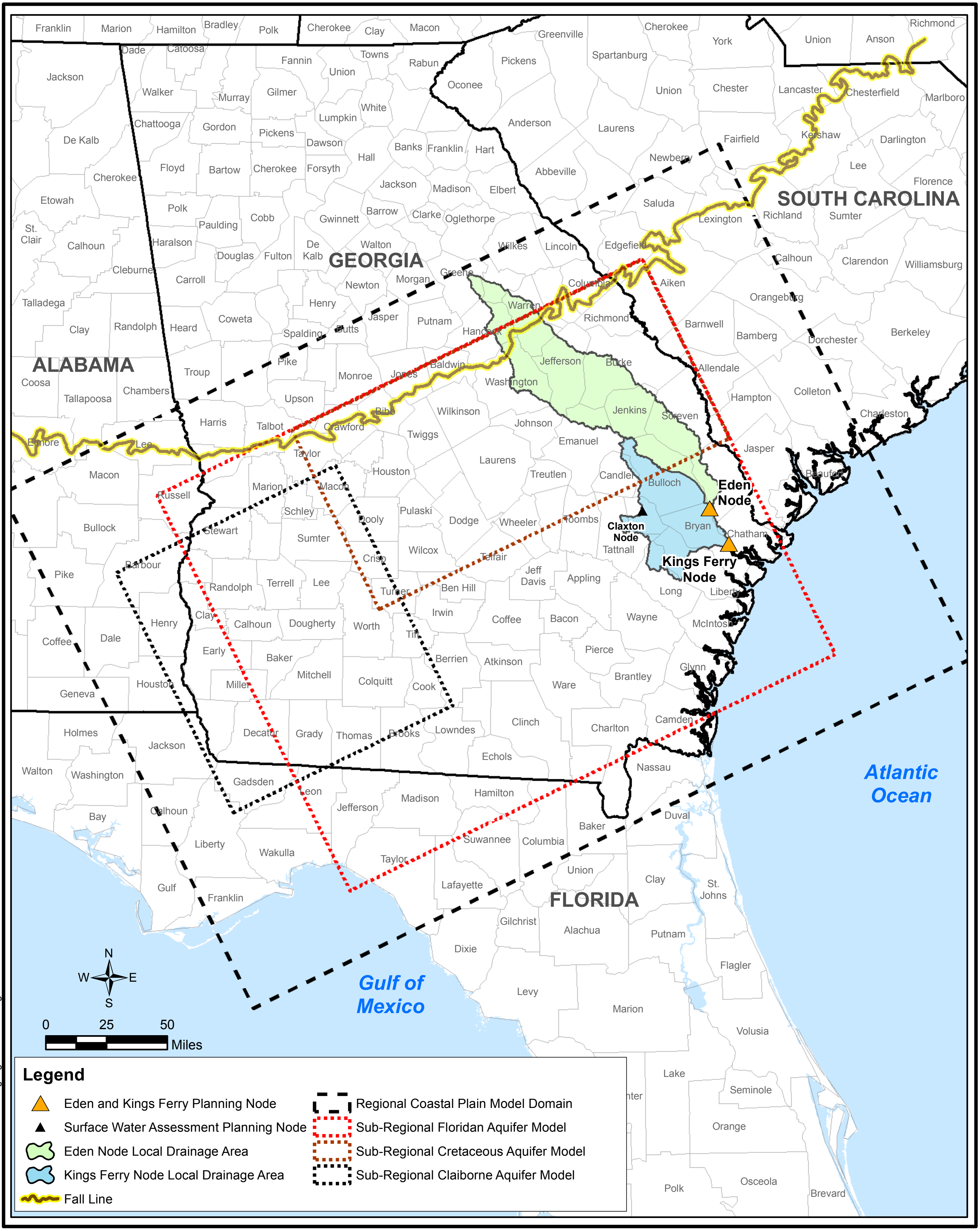


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Figure 2-1
Georgia State-wide Water Plan Groundwater Models

represents annual average groundwater withdrawals for the year 2010. The revised Cretaceous and Claiborne sub-regional models were recalibrated and applied in steady-state mode. The Clayton sub-regional model also was calibrated and applied in steady-state mode.

The sub-regional model of the Floridan aquifer in south-central Georgia and the eastern Coastal Plain of Georgia includes the Ogeechee River drainage basin study area. However, that model has not been updated or recalibrated and, as a result, the hydraulic property assignments and boundary conditions are not consistent with the updated regional model and the other sub-regional models. For this reason, the Regional Coastal Plain Model, and not the Floridan sub-regional model, was used to assess the potential impacts due to increased groundwater pumping from the Floridan and Cretaceous aquifers in the Ogeechee River basin.

2.4 Regional Coastal Plain Model Framework

2.4.1 Modeling Code

The Regional Georgia Coastal Plain Model used for this study was built using the MODFLOW three-dimensional finite-difference groundwater modeling code developed by the USGS (McDonald and Harbaugh, 1988). It is publicly available and widely used and accepted.

2.4.2 Model Domain and Grid

The regional groundwater flow model domain is shown on Figure 2-1. The model domain includes the entire Coastal Plain area within the State of Georgia. The northwestern limit of the Coastal Plain aquifer system is the contact with the metamorphic/igneous rocks of Precambrian and Paleozoic age at the Fall Line, which marks the updip extent of the Coastal Plain sediments. The domains of the sub-regional models, as well as the Ogeechee River drainage basin, are also shown on Figure 2-1 for reference.

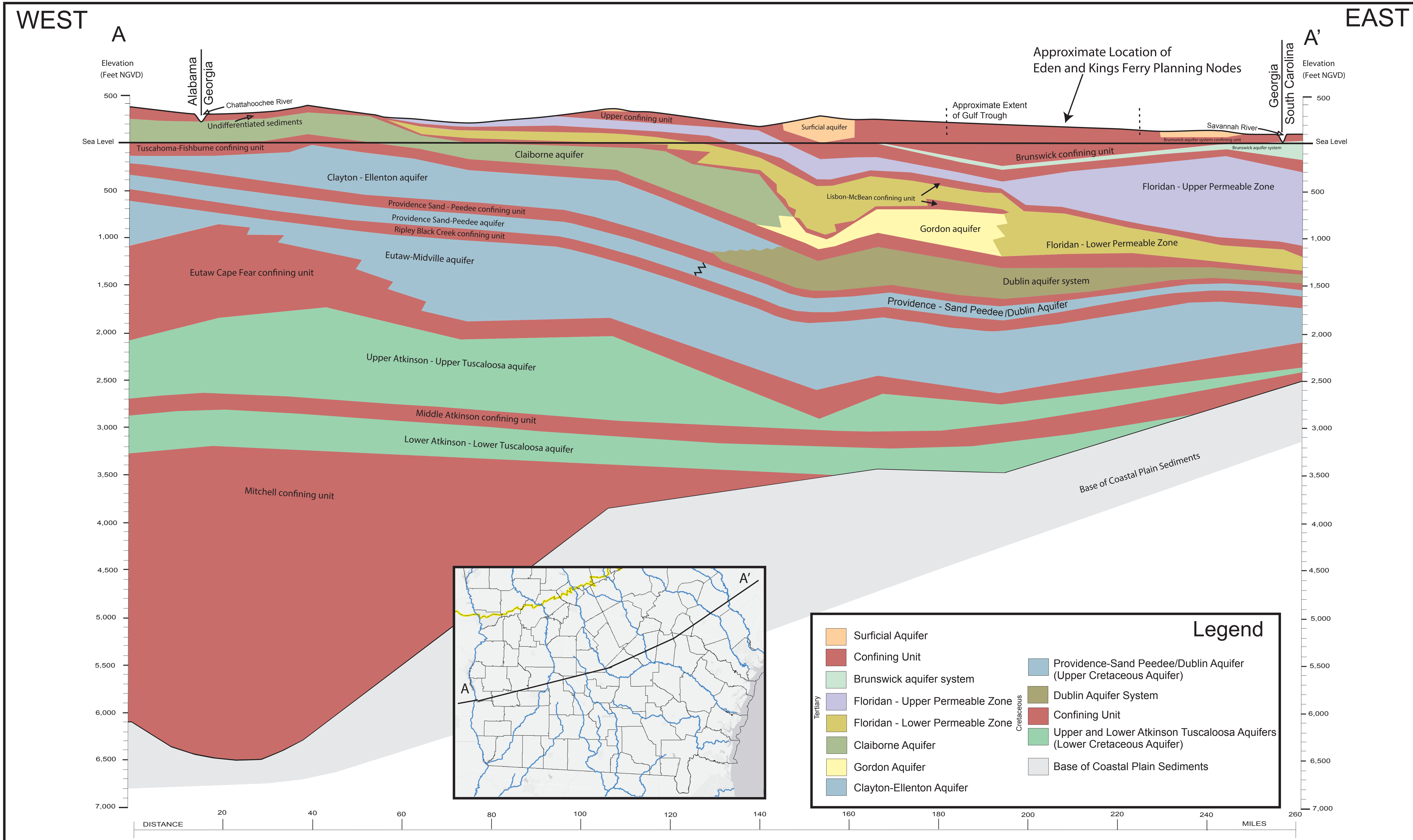
The regional model domain is subdivided into a uniform computational grid with 236 rows and 328 columns. Each grid cell is 1 square mile. The grid is rotated 26 degrees to be aligned with the general northwest-to-southeast groundwater flow direction across the Coastal Plain aquifer system. While this is a regional-scale model, the grid discretization is sufficient for this study to identify potential areas of excessive drawdown due to increased groundwater pumping.

2.4.3 Model Layering

Figure 2-2 presents a hydrostratigraphic cross section showing the hydrogeologic units, including aquifers and confining layers, in the study area.

The regional model (as well as the sub-regional models) contains seven layers numbered from top to bottom representing different aquifer systems within the Coastal Plain. In the Eden and Kings Ferry node vicinity, the model layers are:

- Layer 1 – Surficial/Brunswick Aquifers
- Layer 2 – Floridan Aquifer Upper Permeable Zone (formerly designated as Upper Floridan Aquifer)



Source Modified from Renken, 1996; Miller, 1990 and Miller, 1986

CDM Smith

Figure 2-2
East - West Hydrostratigraphic Cross Section Through the Study Area

- Layer 3 – Claiborne/Floridan Aquifer Lower Permeable Zone (formerly designated as Lower Floridan Aquifer)/Gordon Aquifer
- Layer 4 – Clayton and Cretaceous Dublin Aquifers (in Task 2 study area, model layer 4 is the Dublin Aquifer)
- Layer 5 – Providence Sand-Peedee-Dublin Cretaceous Aquifers (in Task 2 study area, model layer 5 is the Providence Sand Aquifer)
- Layer 6 – Eutaw-Midville Aquifer (Cretaceous)
- Layer 7 – Upper Atkinson-Upper Tuscaloosa Cretaceous Aquifer (in Task 2 study area, model layer 7 is the Upper Atkinson Aquifer)

From here on, the term "Floridan" aquifer in this report refers to the upper-permeable zone.

2.4.4 Rivers

The interaction between groundwater and surface water (i.e., rivers) is generally represented within the top active layer in the model. Thus, where an aquifer outcrops, the layer representing that aquifer will be the top active model layer and groundwater-surface water interaction will be actively simulated here. The exception is in model layer 1 (surficial aquifer system or Brunswick aquifer system) where rivers are not explicitly represented and a constant head boundary is applied to all active model cells in layer 1.

In the Canoochee River basin study area, model layer 1 is active and overlies the Floridan aquifer. Any impact on stream baseflow due to increased pumping from the Floridan aquifer can be explicitly accounted for in the updip (north) area where the Floridan aquifer and the Cretaceous aquifer outcrops and are in direct contact with the rivers. Any impact on streamflow within the study area where the Floridan and Cretaceous aquifers are overlain by the Surficial/Brunswick aquifer system can be approximated by comparing the layer 1 water budget with added Floridan pumping to the base case layer 1 water budget.

2.4.5 Groundwater Withdrawals in Eden and Kings Ferry Node Local Drainage Areas

The Eden node local drainage area (LDA) or drainage basin includes the area upstream of the Eden planning node that contributes to flows in the Ogeechee River at the Eden node. The Kings Ferry node LDA includes the area downstream of the Eden and Claxton nodes contributing to flows in the Ogeechee and Canoochee Rivers upstream of the Kings Ferry node. The Kings Ferry LDA does not include the LDAs of the Eden and Claxton nodes. Withdrawals from the Floridan aquifer within the Eden and Kings Ferry node LDAs included in the regional groundwater model – summarized in **Table 2-1** – total approximately 76.9 MGD for agricultural, industrial, and public water supply. The Regional Coastal Plain Model represents annual average groundwater withdrawals for the year 2010.

Table 2-1. Summary of Floridan and Cretaceous Groundwater Withdrawals in Eden and Kings Ferry LDAs in Regional Coastal Plain Model

Withdrawal Type	Eden LDA (MGD)	Kings Ferry LDA (MGD)
Municipal supply	6.0	2.1
Agricultural	44.4	16.9
Industrial	4.1	3.4
Total	**54.5**	**22.4**

3. Agricultural Irrigation Demand Estimates for the Eden and Kings Ferry Node Local Drainage Areas

Irrigated acreage within the Eden and Kings Ferry node LDAs and estimated irrigation water depth were used to approximate the agricultural surface water demand for parcels currently irrigated with surface water. These computed demands were used to develop input to the groundwater model simulations described in Section 4.

3.1 Irrigated Acreage

CDM Smith mapped and reviewed a Georgia EPD inventory ("Ogeechee.7z" transmitted to CDM Smith in January 2016) of agricultural parcels in the Ogeechee River watershed upstream of the Eden and Kings Ferry planning nodes. The agricultural parcels are grouped into the following categories:

1. Parcels that use only surface water for irrigation
2. Parcels that use only groundwater for irrigation
3. Parcels that are served by both surface water and groundwater

Table 3-1 summarizes the number of parcels and irrigated acreage for each category within the Eden node LDA. The spatial distribution of these parcels is shown on **Figure 3-1**.

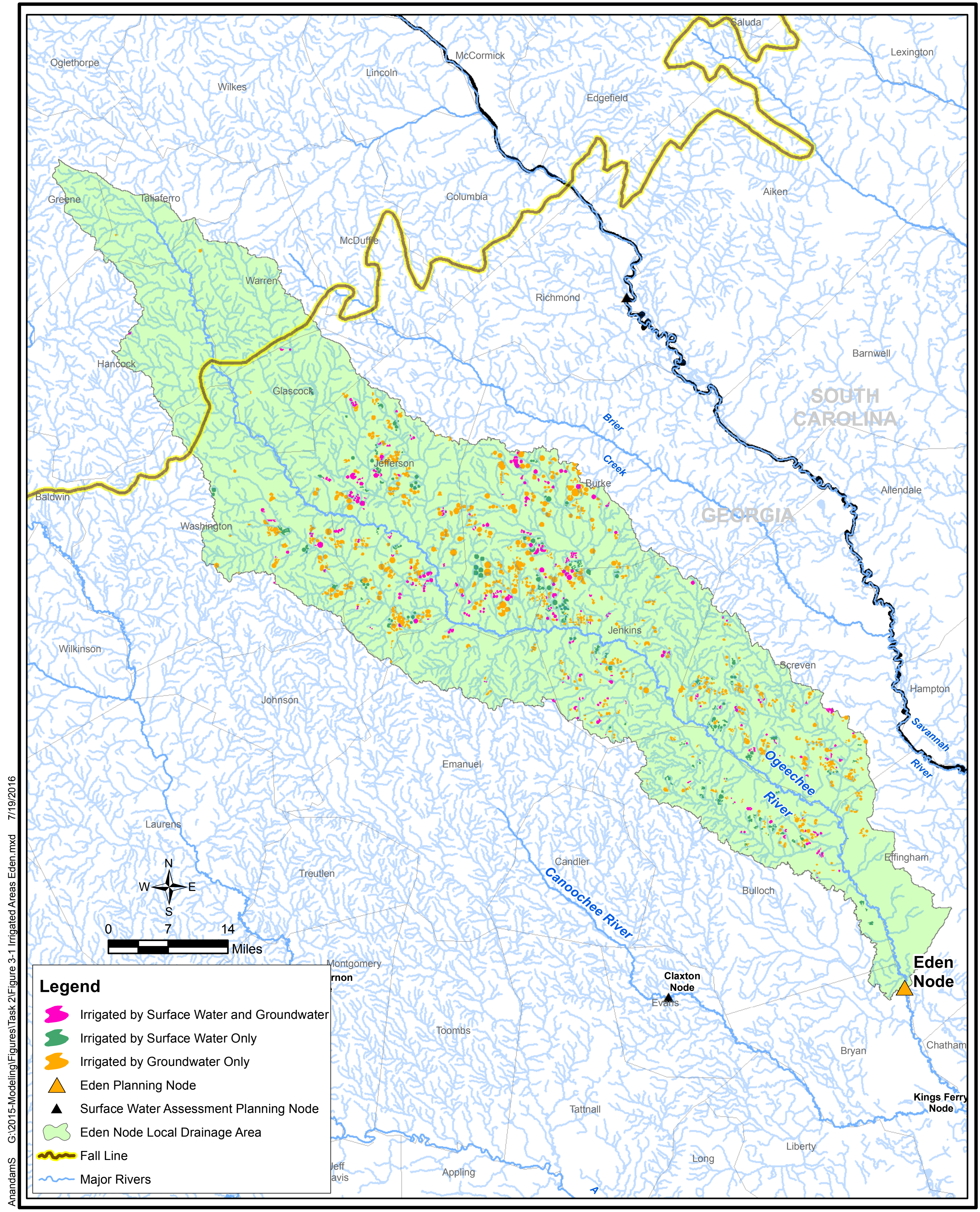
Table 3-1. Irrigated Area Upstream of Eden Node

Irrigated Parcels	No. of Parcels	Irrigated Area (acres)
Parcels supplied by surface water only	277	13,770
Parcels supplied by groundwater only	935	70,310
Parcels supplied by both surface water and groundwater	309	3,890
Total	**1,521**	**87,970**

Table 3-2 summarizes the number of parcels and irrigated acreage under each category for the Kings Ferry Node LDA and does not include parcels within the Claxton or Eden node LDAs. The spatial distribution of these parcels is shown on **Figure 3-2**.

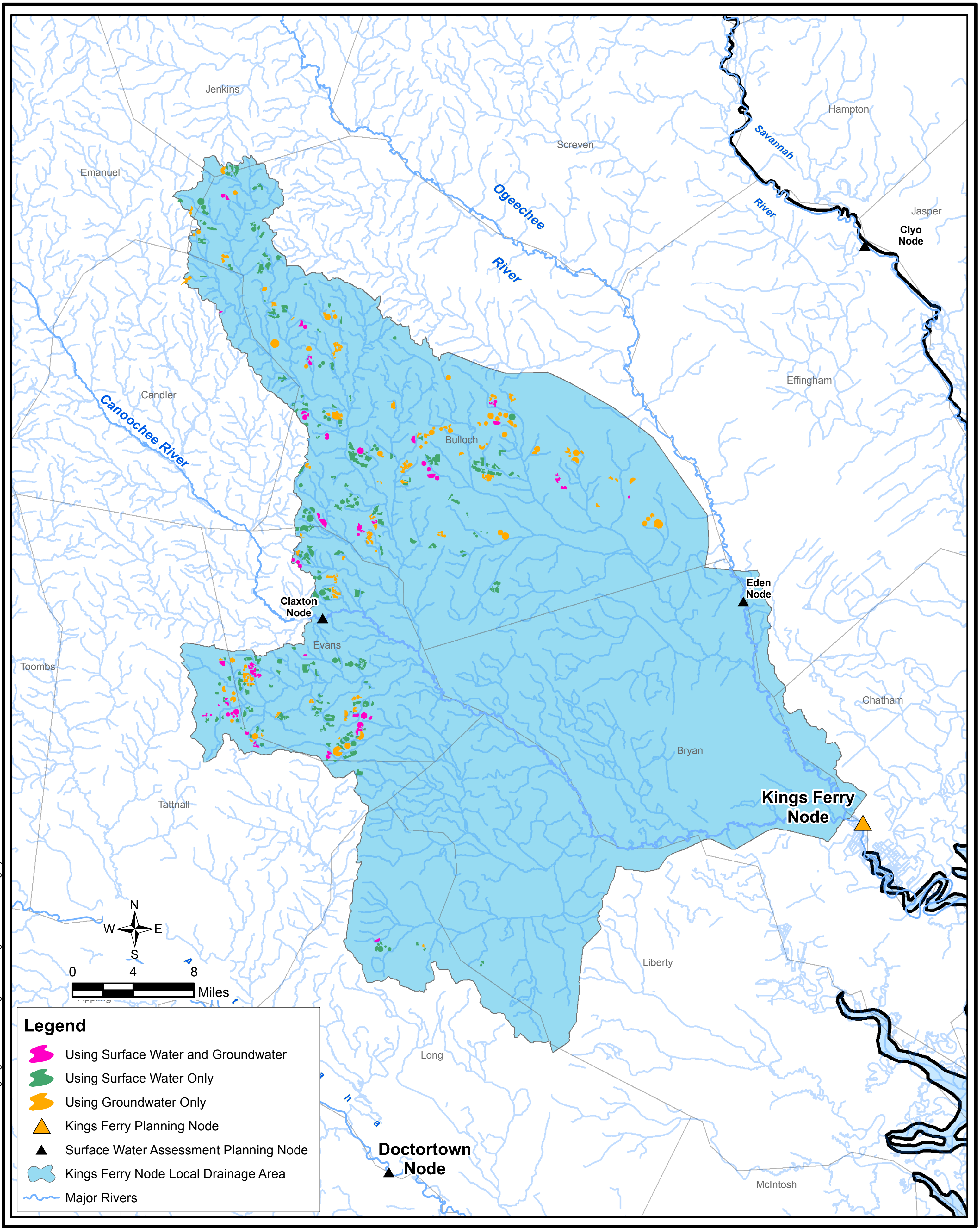
Table 3-2. Irrigated Area Upstream of Kings Ferry Node

Irrigated Parcels	No. of Parcels	Irrigated Area (acres)
Parcels supplied by surface water only	274	9,790
Parcels supplied by groundwater only	159	7,770
Parcels supplied by both surface water and groundwater	79	890
Total	**512**	**18,450**



CDM Smith

Figure 3-1
Irrigated Area in Ogeechee Basin Upstream of Eden Planning Node



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CDM Smith

Figure 3-2
Irrigated Area in Ogeechee Basin Upstream of Kings Ferry Planning Node

Parcels that are served by both surface water and groundwater also include users that withdraw groundwater for storage in on-site ponds before using it for irrigation. Because the purpose of this task is to replace direct surface water withdrawals with groundwater, surface-water-only users were selected and irrigation demands were calculated for these parcels only.

3.2 Irrigation Depth

Irrigation demand was estimated using parcel areas and irrigation depths developed by Dr. James Hook et al. (2005). Monthly irrigation depths have been estimated for dry, normal, and wet rainfall years for different regions within Georgia based on climate and crop water needs. For the Eden and Kings Ferry node areas, irrigation depths for the Coastal Zone were assumed.

Monthly mean irrigation depths for the Georgia Coastal Zone are presented in **Table 3-3**.

Table 3-3. Mean Irrigation Depth for Crops Using Groundwater in Coastal Zone

Month	Mean Irrigation Depth (inches/month)			
	Dry	Normal	Wet	High-Demand and Low-Demand Average for Normal Conditions
January	0.28	0.20	0.09	
February	0.17	0.13	0.07	
March	0.39	0.18	0.06	
April	0.73	0.54	0.13	
May	1.88	1.30	0.34	
June	2.04	1.33	0.49	
July	3.04	1.54	0.41	
August	1.96	1.37	0.40	1.39 (High Demand: May – August)
September	1.15	0.72	0.40	
October	0.86	0.51	0.20	
November	0.49	0.27	0.11	
December	0.46	0.25	0.12	0.35 (Low Demand: September – April)
Total (inches/year)	**13.45**	**8.34**	**2.82**	

The average irrigation depth for high-demand periods (May through August) in a normal rainfall year is approximately 1.39 inches/month (orange shading). The average irrigation depth for low-demand periods (September through April) in a normal rainfall year is approximately 0.35 inches/month (green shading). The average monthly irrigation depth during a normal rainfall year is approximately 0.7 inches/month (8.34 inches/12 months).

3.3 Irrigation Demand

Based on irrigated area and mean irrigation depths, irrigation demands were calculated individually for each parcel for high-demand and low-demand periods.

The Floridan aquifer is the primary source of groundwater for irrigation in the Eden and Kings Ferry node LDAs. However, in the upper reaches of the Eden node LDA, in portions of Jefferson and Glascock Counties, the Floridan aquifer does not exist and the Cretaceous aquifer serves as the primary groundwater source for irrigation.

The average water demand for parcels irrigated by surface water only within the Eden node LDA is presented in **Table 3-4**. The estimated agricultural irrigation demand for high-demand and low-demand periods upstream of the Eden gage is approximately 16.84 MGD and 4.30 MGD, respectively.

Table 3-4. Calculated Irrigation Demand of Surface-Water-Only Parcels – Eden Node

	Number of Parcels	Total Irrigated Area (acres)	Mean Irrigation Depth (inches/month)		Total Irrigation Demand (MGD)	
			(May – August)	(September – April)	(May – August)	(September – April)
Surface-Water-Only Parcels that Will Be Replaced by Groundwater from the Floridan Aquifer	242	12,030	1.39	0.35	14.71	3.76
Surface-Water-Only Parcels that Will Be Replaced by Groundwater from the Cretaceous Aquifer	35	1,740	1.39	0.35	2.13	0.54
Total	**277**	**13,770**	**1.39**	**0.35**	**16.84**	**4.30**

The average water demand for parcels irrigated by surface water only within the Kings Ferry node LDA is presented in **Table 3-5**. The estimated agricultural irrigation demand for high-demand and low-demand periods upstream of the Kings Ferry gage is approximately 11.97 MGD and 3.06 MGD, respectively.

Table 3-5. Calculated Irrigation Demand of Surface Water Only Parcels – Kings Ferry Node

	Number of Parcels	Total Irrigated Area (acres)	Mean Irrigation Depth (inches/month)		Total Irrigation Demand (MGD)	
			(May – August)	(September – April)	(May – August)	(September – April)
Surface-Water-Only Parcels that Will Be Replaced by Groundwater from Floridan Aquifer	274	9,790	1.39	0.35	11.97	3.06

In the groundwater model simulations described in the next section, the irrigation demand calculated for each parcel was simulated as a groundwater withdrawal at the parcel centroid location.

4. Simulation Results Showing Impact of Increased Groundwater Pumping to Replace Agricultural Surface Water Withdrawals

The steady-state Regional Coastal Plain Model was used to evaluate the incremental Floridan and Cretaceous aquifer water-level drawdown that may result from additional groundwater withdrawals from those aquifers used to offset reduced surface water withdrawals. Simulated drawdowns for the scenarios presented below were reviewed with respect to Upper Floridan Aquifer and Cretaceous Aquifer sustainable yield results presented in the document titled *Groundwater Flow Modeling of the Coastal Plain Aquifer System of Georgia* (CDM, 2011a). A range of pumping rates was simulated to evaluate the potential range of water-level drawdown that may result from the additional groundwater withdrawals. The following scenarios were simulated separately for the Eden LDA and the Kings Ferry LDA and are described in greater detail in Sections 4.2 – 4.5 below:

- Additional aquifer withdrawals to replace surface water irrigation demand during the high-demand period (average May through August demand)
- Modified version of the first scenario accounting for areas of low transmissivity in the Eden and Kings Ferry node LDAs
- Additional aquifer withdrawals in excess of surface water irrigation demand during the high-demand period
- Additional aquifer withdrawals to replace surface water irrigation demand during the low-demand period (average September through April demand)

To investigate the combined drawdown of replacing surface water use with groundwater use for agricultural irrigation in the Eden, Kings Ferry, and Claxton node LDAs combined, one additional simulation was performed, representing groundwater withdrawals from parcels in all three catchments during the high-demand period.

The Regional Coastal Plain Model is a steady-state model, and as such represents long-term average conditions. By applying the irrigation demands for the high-demand period (May through August) in a steady-state model, a conservatively high estimate of potential drawdown is produced, because the water demand during this period is greater than the average monthly demand for a normal year (approximately 0.7 inches per month). In practice, high demands of this magnitude occur only during a few months of the year, and the aquifer conditions are not expected to reach steady-state during that relatively short period of time. Thus, the simulated steady-state drawdown associated with the additional high-demand period of groundwater withdrawal represents an upper end of the range of potential drawdowns that may result with the addition of new groundwater withdrawals to offset agricultural surface water withdrawals. In this case, the steady-state model presents a conservative estimate of the potential drawdown associated with the increased groundwater withdrawal. The simulated steady-state drawdown associated with low-demand groundwater withdrawal represents a lower end of the range of potential drawdowns that may result with the addition of new groundwater withdrawals. The steady-state model in this case may not provide a conservative estimate of drawdown for all low-demand months, since in some months, the additional withdrawals may be greater than the low-demand period average.

To estimate whether the additional groundwater withdrawals presented in this report might contribute to excessive drawdowns if implemented in addition to sustainable yield pumping rates, simulated drawdowns for each scenario were reviewed with respect to Upper Floridan Aquifer and Cretaceous Aquifer sustainable yield simulation drawdowns for the low end of the estimated sustainable yield. For the Floridan aquifer the low end sustainable yield simulations included 393 MGD additional pumping over existing 465 MGD groundwater withdrawals. For the Cretaceous aquifer system, the low end sustainable yield simulations included 127 MGD additional pumping over existing 219 MGD groundwater withdrawals. Simulated drawdowns for the low end sustainable yield simulation are shown for the Eden node and Kings Ferry node vicinity in **Figure 4-1** and **Figure 4-2** for the Floridan aquifer and Cretaceous aquifer (model layer 5), respectively.

Simulated Floridan aquifer drawdowns in the Eden node LDA range from about 6 feet to more than 30 feet (northern portion of the Eden node LDA). Within the Kings Ferry node LDA, simulated Floridan aquifer drawdowns range from about 3 feet to 22 feet.

For each groundwater withdrawal scenario, the simulated Floridan aquifer drawdown in the vicinity of Hilton Head, South Carolina was also reviewed to evaluate whether the increased pumping in the Eden and Kings Ferry node LDAs might potentially lower Floridan aquifer heads near Hilton Head where salt water intrusion is a concern.

4.1 Baseline Conditions for Drawdown Calculations

Simulated 2010 Floridan and Cretaceous aquifer heads in the Regional Coastal Plain Model were used to define the baseline conditions for this analysis. Groundwater pumping in this simulation is consistent with reported 2010 groundwater withdrawals. Contours of simulated Floridan aquifer heads (model layer 2) in the baseline simulation are shown on **Figure 4-3**.

Within the Eden node LDA, the simulated groundwater elevations in the Floridan aquifer range from approximately 10 feet to more than 250 feet National Geodetic Vertical Datum (NGVD), while within the Kings Ferry node LDA, simulated Floridan aquifer head ranges from approximately -20 feet to 145 feet. The cone of depression resulting from Floridan aquifer pumping by the City of Savannah is evident southeast of the Eden node LDA and east of the Kings Ferry node LDA, as shown on Figure 4-3.

The steep simulated head gradient evident in central Bulloch County reflects the influence of the Gulf Trough, a low-transmissivity geologic feature located in southern Georgia. The Gulf Trough is a significant sediment-filled depression or "trough," which trends diagonally in a northeastward direction for approximately 200 miles (Patterson and Herrick, 1971; Popenoe et al., 1987). It consists of a zone of relatively thick accumulations of Miocene- and younger-aged deposits consisting of fine-grained clastic sediments and argillaceous (containing appreciable amounts of clay) carbonates, in which permeability and thickness of the Coastal Plain deposits decrease. The Gulf Trough impedes groundwater flow because of the juxtaposition of rocks of

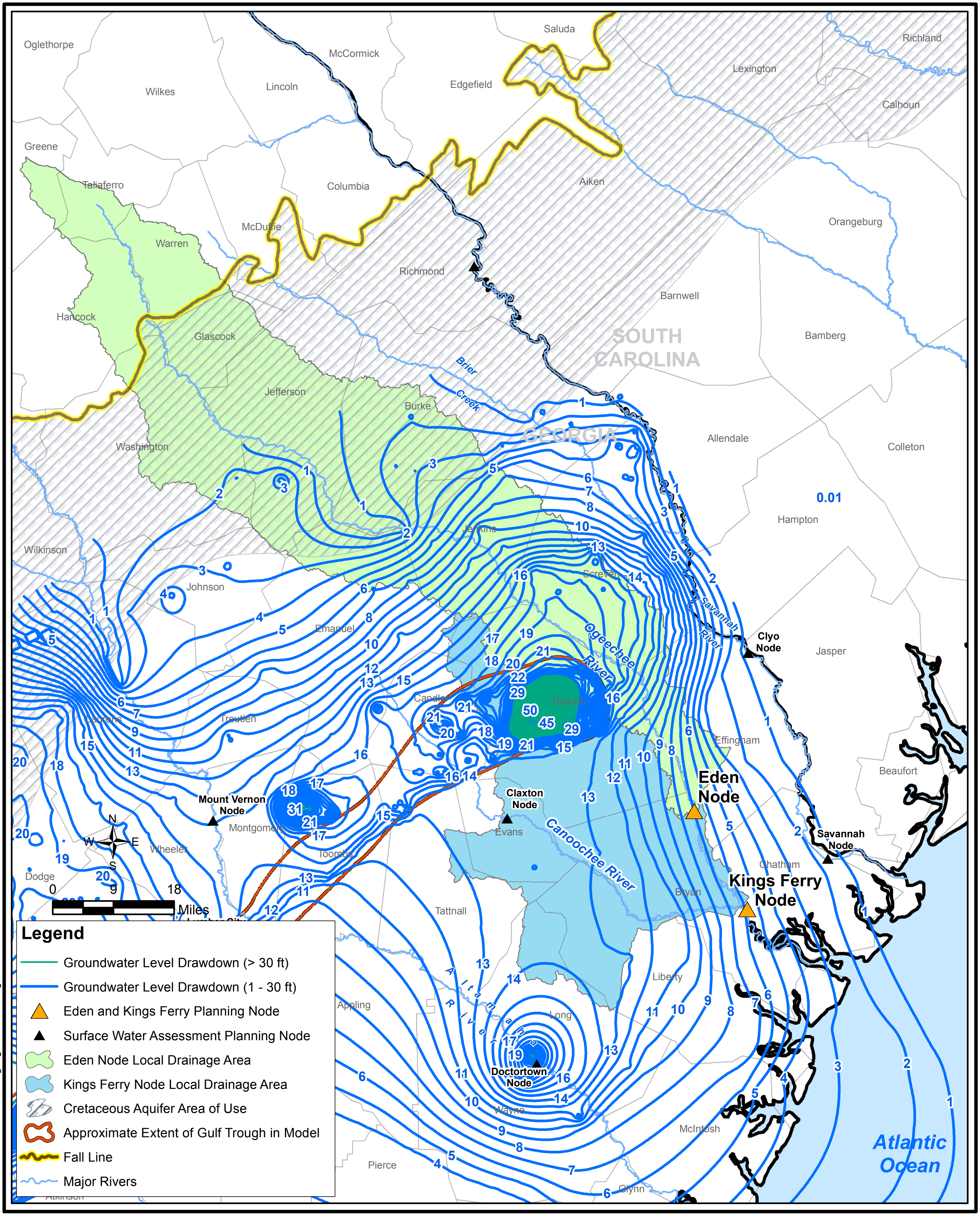

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Figure 4-1
Simulated Groundwater Level Drawdown in Upper Floridan Aquifer (Layer 2) Due to Increasing Existing Well Pumping in Floridan Aquifer in South Central Georgia and Eastern Coastal Plain (ΔQ= 393 MGD) Using Sub-Regional Upper Floridan Aquifer Model (CDM, 2011a)

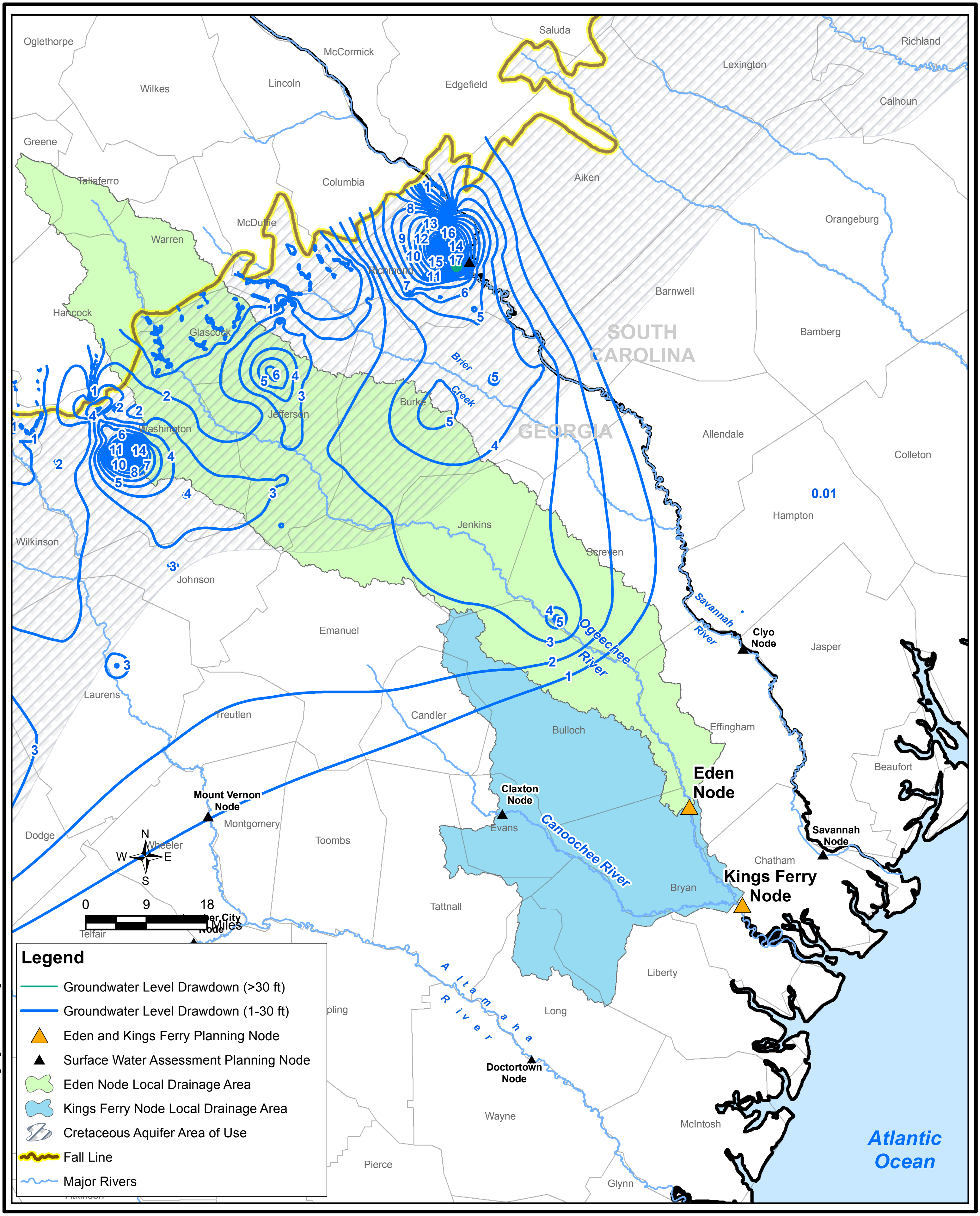

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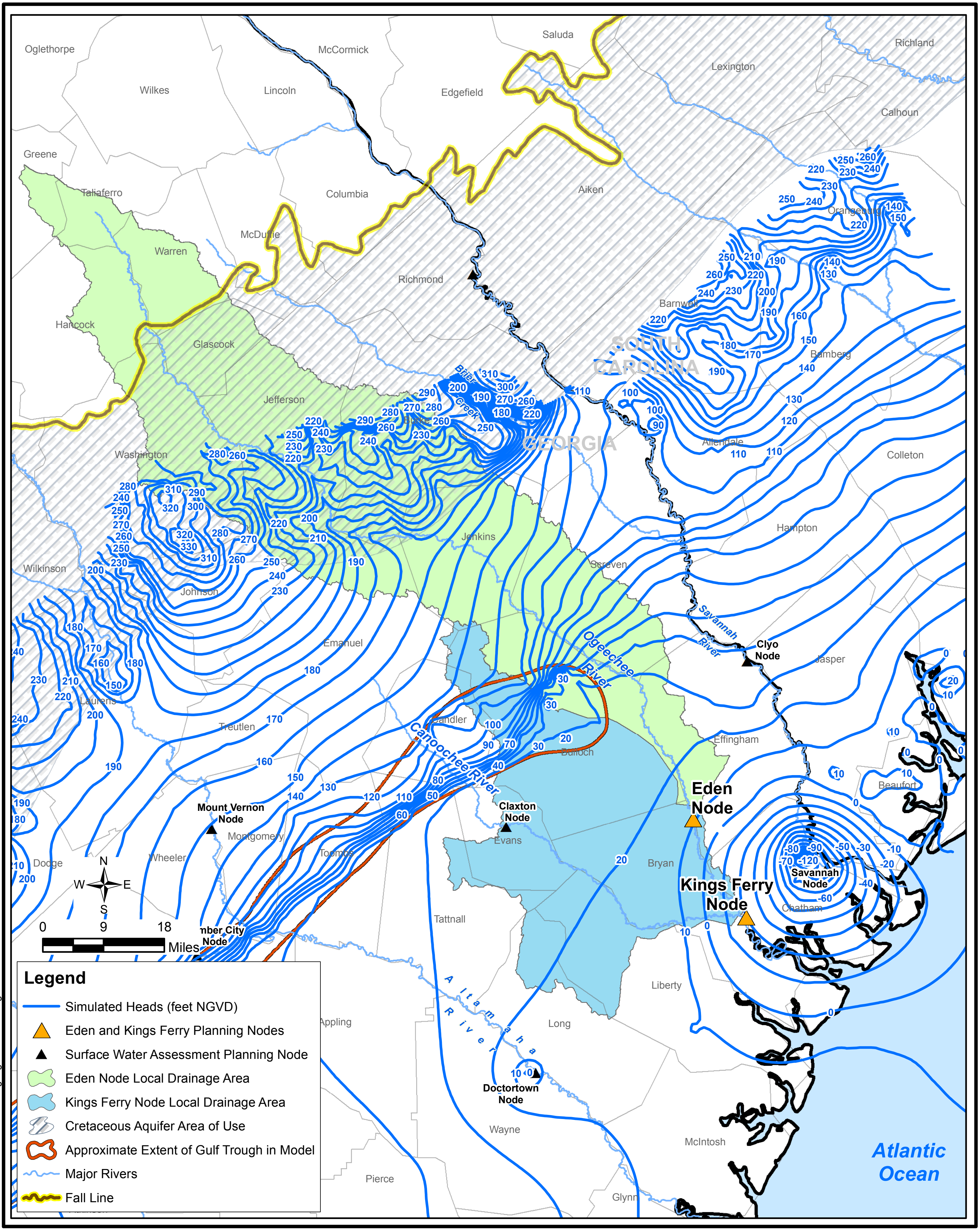
Figure 4-2
Simulated Groundwater Level Drawdown in Providence Aquifer (Layer 5) Due to Uniformly Increasing Existing Well Pumping in Cretaceous Aquifer (ΔQ= 127 mgd) Using Sub-Regional Cretaceous Aquifer Model (CDM Smith, 2012a)



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CDM Smith

Figure 4-3
Simulated Baseline (Existing Calibration) Floridan Aquifer Heads
Regional Coastal Plain Model

higher permeability in the updip and downdip areas of the trough, with those of lower permeability within the trough. The structural effect can be seen in the baseline simulation results (Figure 4-1) and published potentiometric surface maps of the aquifer system (Clarke et al., 2004; Krause and Randolph, 1989; Miller, 1986). The transmissivity values obtained from Aquifer Performance Tests (APTs) of wells that fall within the Gulf Trough are orders of magnitude lower than those measured at wells located outside the Gulf Trough (Clarke et al., 2004).

The delineation of the Gulf Trough in the Regional Coastal Plain Model, shown on Figure 4-1, was based on published regional reports and model calibration. The transmissivity of the Floridan aquifer in the model is relatively higher south of the Gulf Trough compared to the aquifer north of the Gulf Trough, and the presence of this feature affects the simulated impact from the additional groundwater withdrawals introduced to replace the decreased surface water irrigation withdrawals.

Simulated Cretaceous aquifer (model layer 5) head contours in the baseline simulation are shown on **Figure 4-4**. The simulated groundwater head elevations in the Cretaceous aquifer in the baseline regional model range from approximately 125 feet to more than 300 feet NGVD from the Kings Ferry node to the northwestern portion of the Eden node LDA near the Fall Line. The Gulf Trough does not extend into the Cretaceous aquifer.

4.2 Simulated Floridan Aquifer and Cretaceous Aquifer Drawdown with Additional High-Demand Agricultural Pumping

Additional groundwater withdrawals equivalent to the irrigation demand currently supplied by surface water sources were applied to the steady-state simulation. The additional groundwater withdrawals represent quantities of water currently supplied by surface water during the high-irrigation-demand period (average May through August demand). The incremental water-level drawdown was calculated by subtracting simulated Floridan aquifer and Cretaceous aquifer heads with additional pumping from simulated baseline condition heads. Simulated drawdown contour maps were used to evaluate the impacts of introducing additional groundwater withdrawals to the Floridan and Cretaceous aquifers. In this scenario, an additional 16.84 MGD of groundwater withdrawal was applied with approximately 14.71 MGD assigned to the Floridan aquifer and approximately 2.31 MGD assigned to the Cretaceous aquifer.

4.2.1 Eden Node

The simulated Floridan aquifer drawdown for the high-demand transfer scenario within the Eden Node LDA is shown on **Figures 4-5.** Simulated drawdown in the Floridan aquifer ranges from approximately 1 foot to 30 feet in the Eden Node LDA, (and exceeds the 30-feet sustainable yield criterion defined in the State Water Plan within a limited area of Bulloch County west of the Ogeechee River. The simulated drawdowns are influenced by the presence of the low-transmissivity zone representing Gulf Trough sediments in the model.

The simulated Cretaceous aquifer drawdown for the high-demand transfer scenario within the Eden Node LDA is shown on **Figures 4-6.** Simulated drawdown in the Cretaceous aquifer in Glascock County is on the order of 1 to 2 feet.

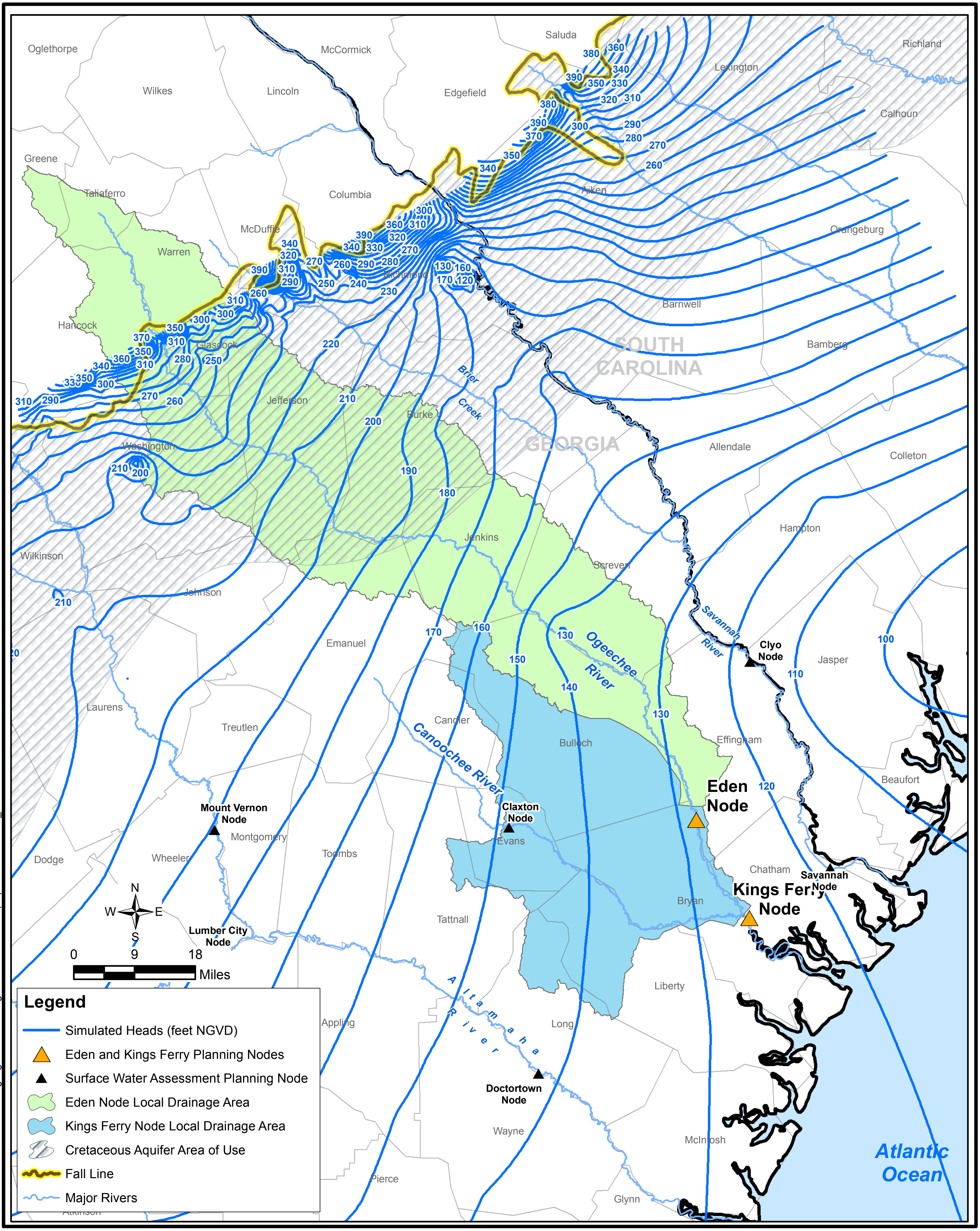

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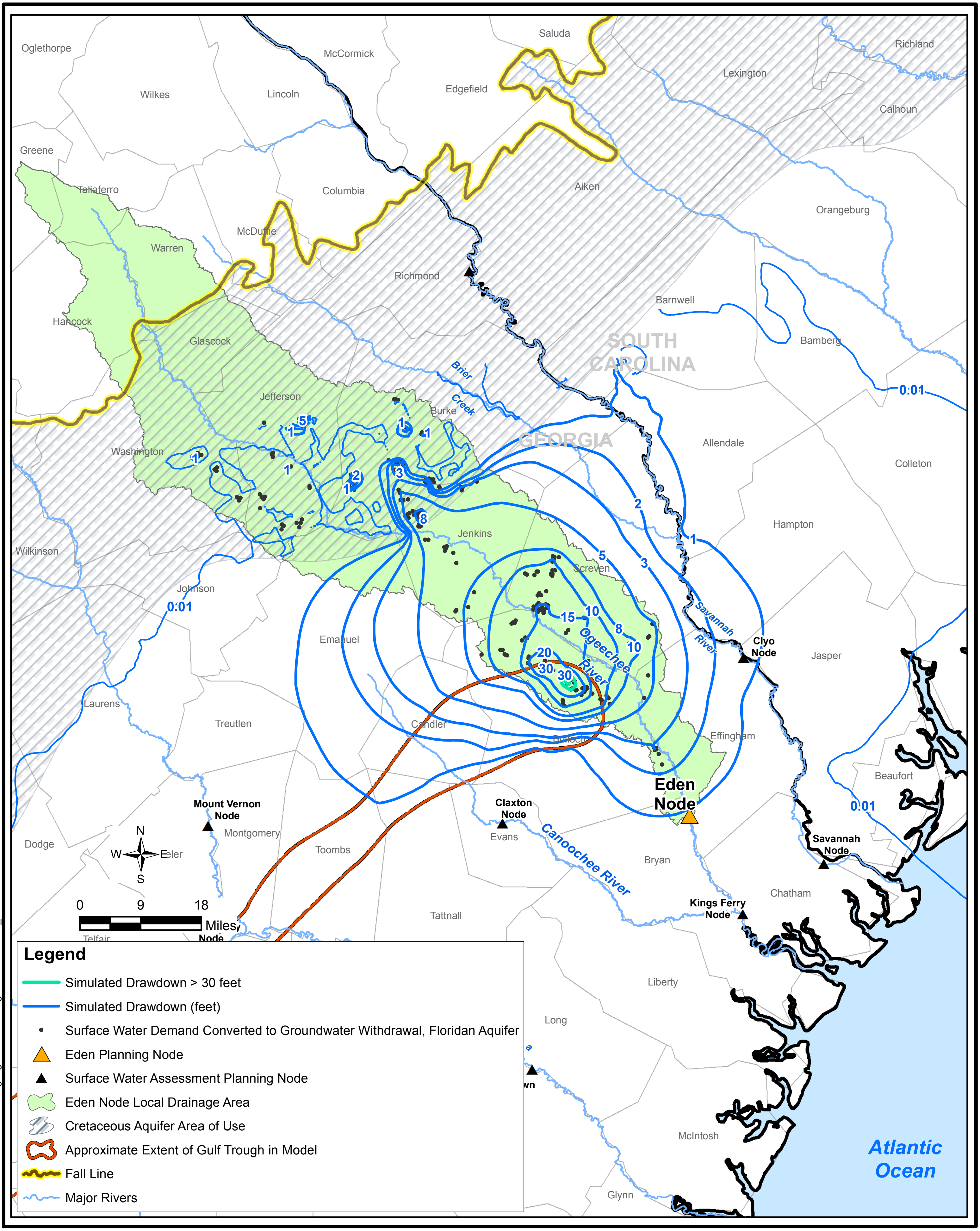
Figure 4-4
Simulated Baseline (Existing Calibration) Cretaceous Aquifer Heads (Layer 5)
Regional Coastal Plain Model



CDM Smith

Figure 4-5
Simulated Drawdown in Floridan Aquifer Heads, Eden Node LDA
Additional Groundwater Withdrawal: 14.71 MGD

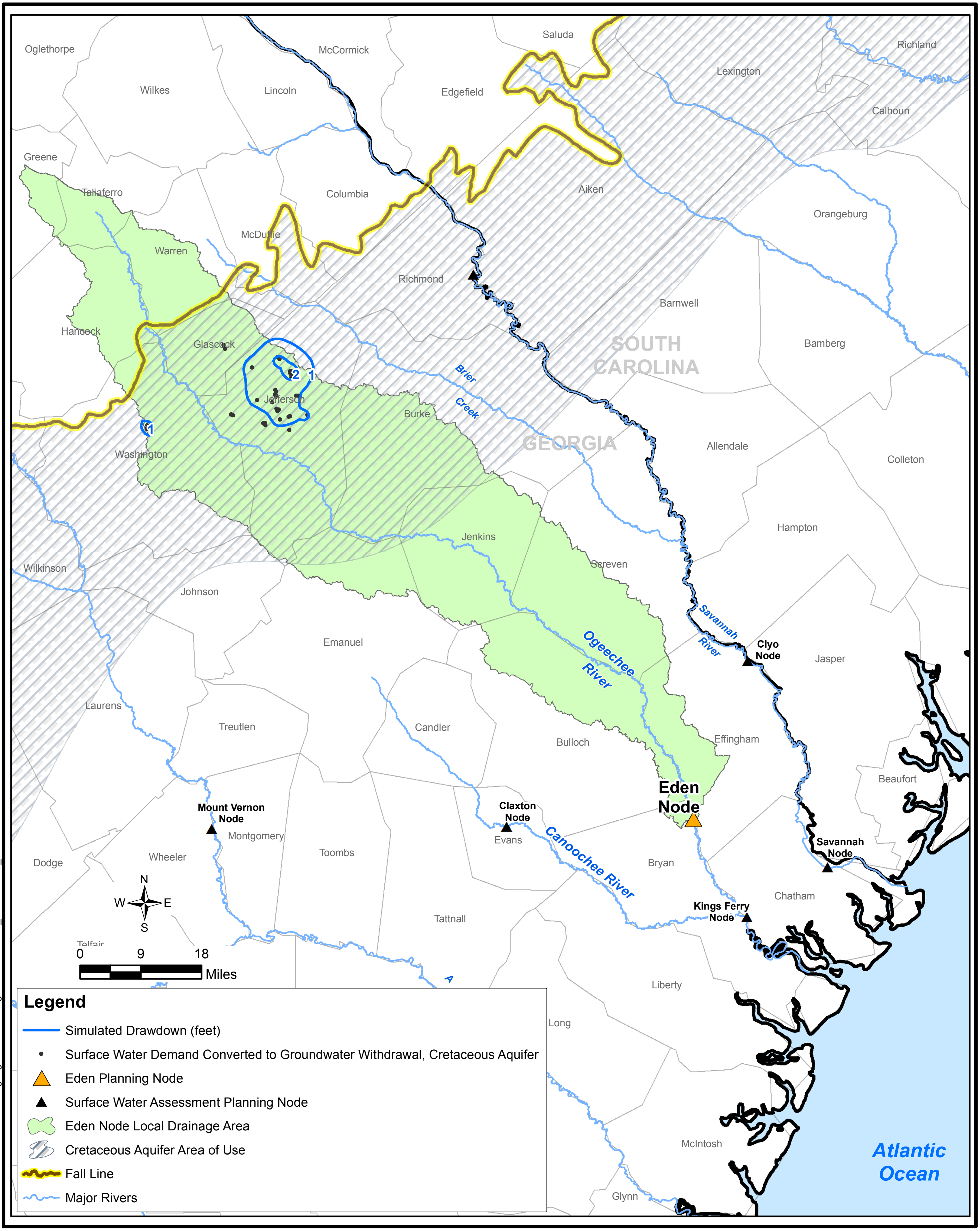


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Figure 4-6
Simulated Drawdown in Cretaceous Aquifer Heads, Eden Node LDA
Additional Groundwater Withdrawal: 2.13 MGD

The additional Floridan aquifer groundwater withdrawals in this scenario could not be implemented in addition to sustainable yield pumping rates, because the simulated drawdown in the scenario already exceeds the 30-feet sustainable yield drawdown criterion.

Because the simulated Cretaceous aquifer drawdown for this pumping scenario is approximately 2 feet or less, it may be possible to implement the Cretaceous aquifer pumping in this scenario in addition to sustainable yield pumping rates, with only minor incremental increases in drawdown.

In this scenario, the simulated Floridan aquifer drawdown beneath Hilton Head Island is less than 0.01 feet (Figure 4-5); therefore, the additional groundwater withdrawals are not likely to contribute to additional salt water intrusion in the Floridan aquifer beneath Hilton Head Island.

4.2.2 Kings Ferry Node

Within the Kings Ferry Node LDA, all additional groundwater pumping was applied to the Floridan aquifer. Simulated drawdown in the Floridan aquifer is generally 20 feet or less when 100 percent of the estimated agricultural surface water under high-demand conditions (11.97 MGD) was represented as groundwater withdrawals, as shown on **Figure 4-7**. Simulated drawdown in the Floridan aquifer in an area of western Bulloch County reaches 10 to 20 feet in the northern portion of the Kings Ferry LDA.

Adding the drawdowns shown on Figures 4-1 and 4-7 suggests that the combined pumping impact of this scenario and sustainable yield pumping rates may result in additional areas exceeding the 30-feet sustainable yield drawdown criterion. However, it may be possible to implement a portion of the additional Floridan aquifer groundwater withdrawals presented in this scenario in areas where sustainable yield simulation drawdowns are less than 30 feet.

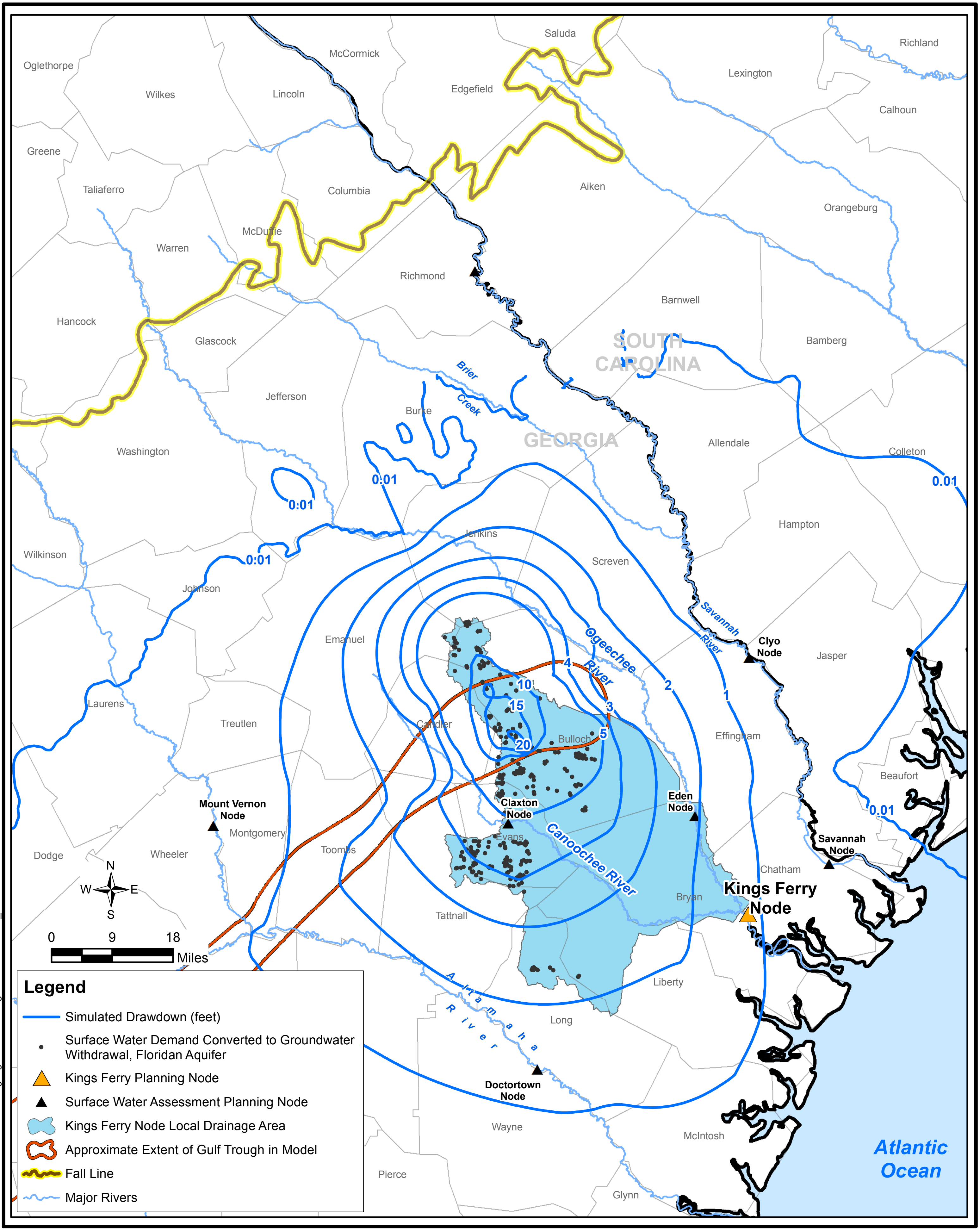
In this scenario, the simulated Floridan aquifer drawdown beneath Hilton Head Island is less than 0.01 feet; therefore, the additional groundwater withdrawals are not likely to contribute to additional salt water intrusion in the Floridan aquifer beneath Hilton Head Island.

4.3 Simulated Floridan Aquifer Drawdown with No Additional Groundwater Pumping in Gulf Trough Area, High-Demand Agricultural Pumping

Because of the low transmissivity associated with the Gulf Trough area within the Floridan aquifer, it may not be economically advantageous to install and operate groundwater wells there. Therefore, model simulations excluding additional groundwater withdrawals within the Gulf Trough area were performed to evaluate potential drawdown impacts.

4.3.1 Eden Node

Excluding the parcels in the Gulf Trough area reduces the simulated Floridan aquifer groundwater withdrawals from 14.71 MGD (Table 3-4) to 13.34 MGD (**Table 4-1**). If agricultural parcels served by surface water withdrawals within the Gulf Trough area are excluded from the modeling analysis, the simulated drawdown in the Floridan aquifer is reduced to approximately 10 feet or less within the Eden node LDA (**Figure 4-8**). Adding the drawdowns shown on Figures 4-1 and 4-8 suggests that the combined pumping impact of this scenario and sustainable yield pumping rates will likely not create any additional areas exceeding the 30-feet sustainable yield drawdown criterion; as such, the additional Floridan aquifer groundwater withdrawals



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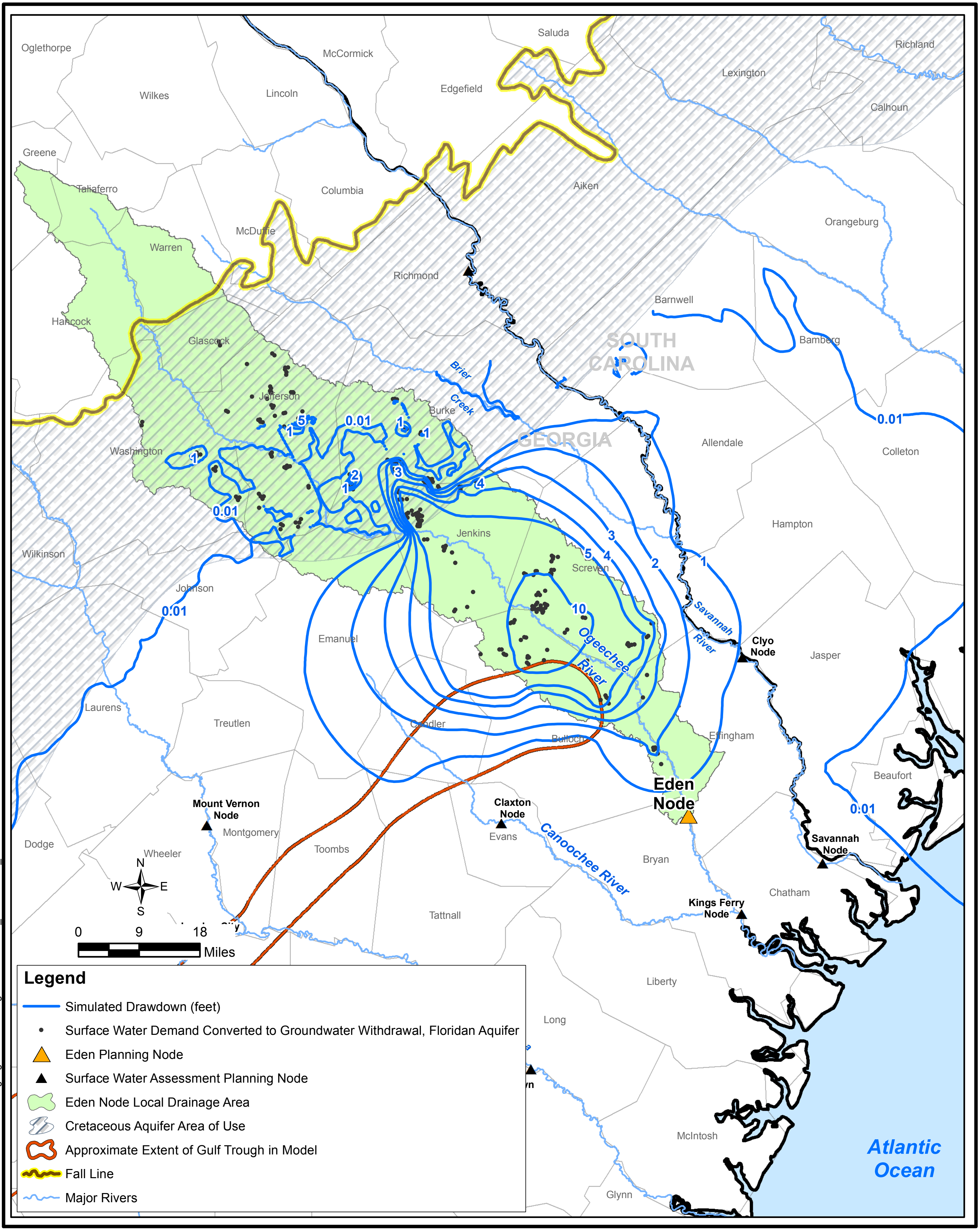
CDM Smith

Figure 4-7
Simulated Drawdown in Floridan Aquifer Heads, Kings Ferry Node LDA
Additional Groundwater Withdrawal: 11.97 MGD



CDM Smith

Figure 4-8
Simulated Drawdown in Floridan Aquifer Heads, Eden Node LDA
Additional Groundwater Withdrawal: 13.34 MGD (No Withdrawals in Gulf Trough Area)

presented in this scenario could potentially be implemented in addition to sustainable yield pumping rates.

Since Floridan aquifer pumping was reduced in this scenario, the simulated Floridan aquifer drawdown beneath Hilton Head Island remains less than 0.01 feet.

Table 4-1. Calculated Irrigation Demand of Surface-Water-Only Parcels Excluding Gulf Trough, Eden Node

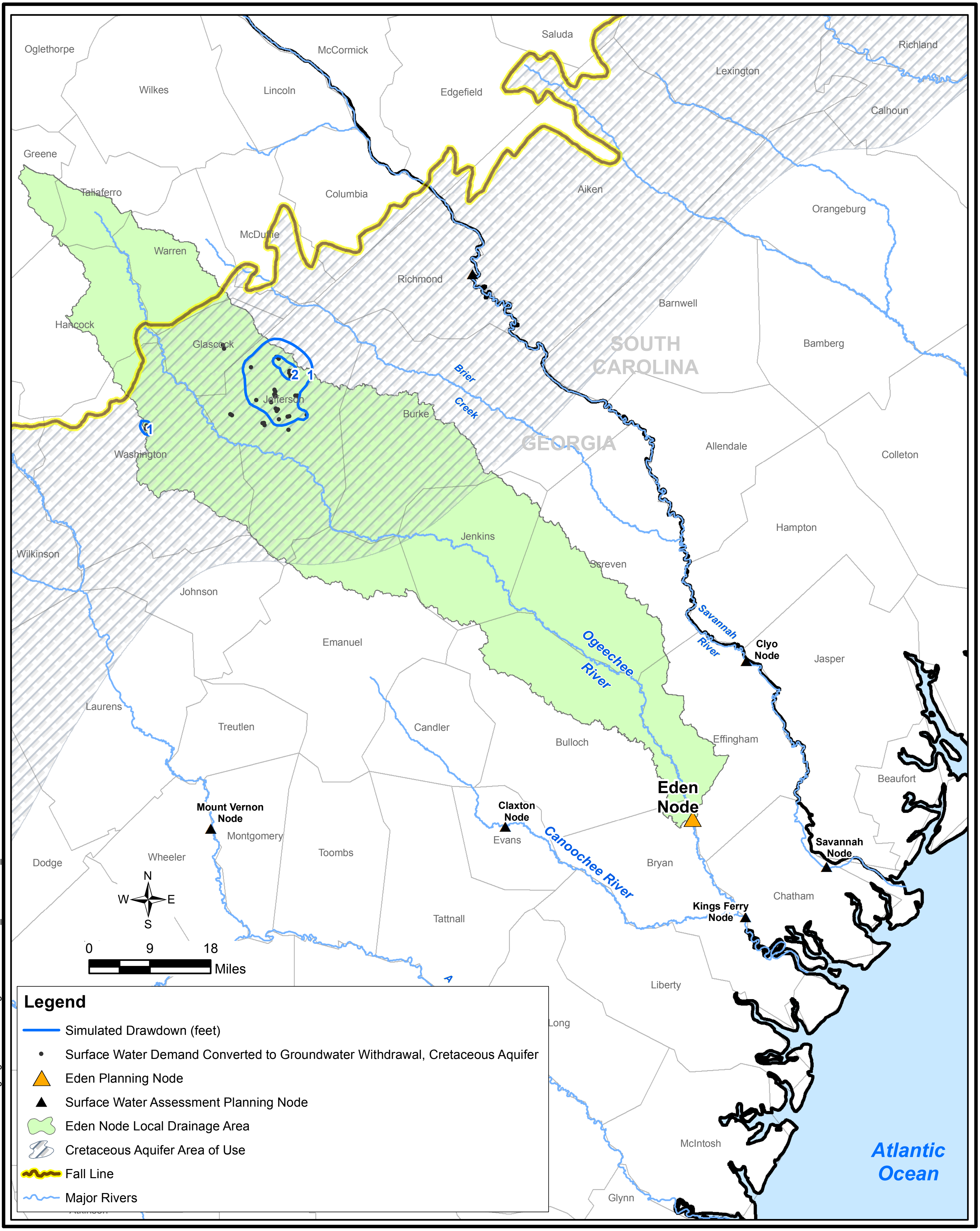
	Number of Parcels	Total Irrigated Area (acres)	Mean Irrigation Depth (inches/month)		Total Additional Groundwater Demand (MGD)	
			(May – August)	(September – April)	(May – August)	(September – April)
Surface-Water-Only Parcels that Will Be Replaced by Groundwater from Floridan Aquifer	207	10,910	1.39	0.35	13.34	3.41
Surface-Water-Only Parcels that Will Be Replaced by Groundwater from Cretaceous Aquifer	35	1,740	1.39	0.35	2.13	0.54
Total	**242**	**12,650**	**1.39**	**0.35**	**15.47**	**3.95**

Simulated withdrawals from the Cretaceous aquifer were not adjusted. -Simulated water level drawdown in the Cretaceous aquifer is approximately 1 to 2 feet for this simulation, as shown on **Figure 4-9**.

4.3.2 Kings Ferry Node

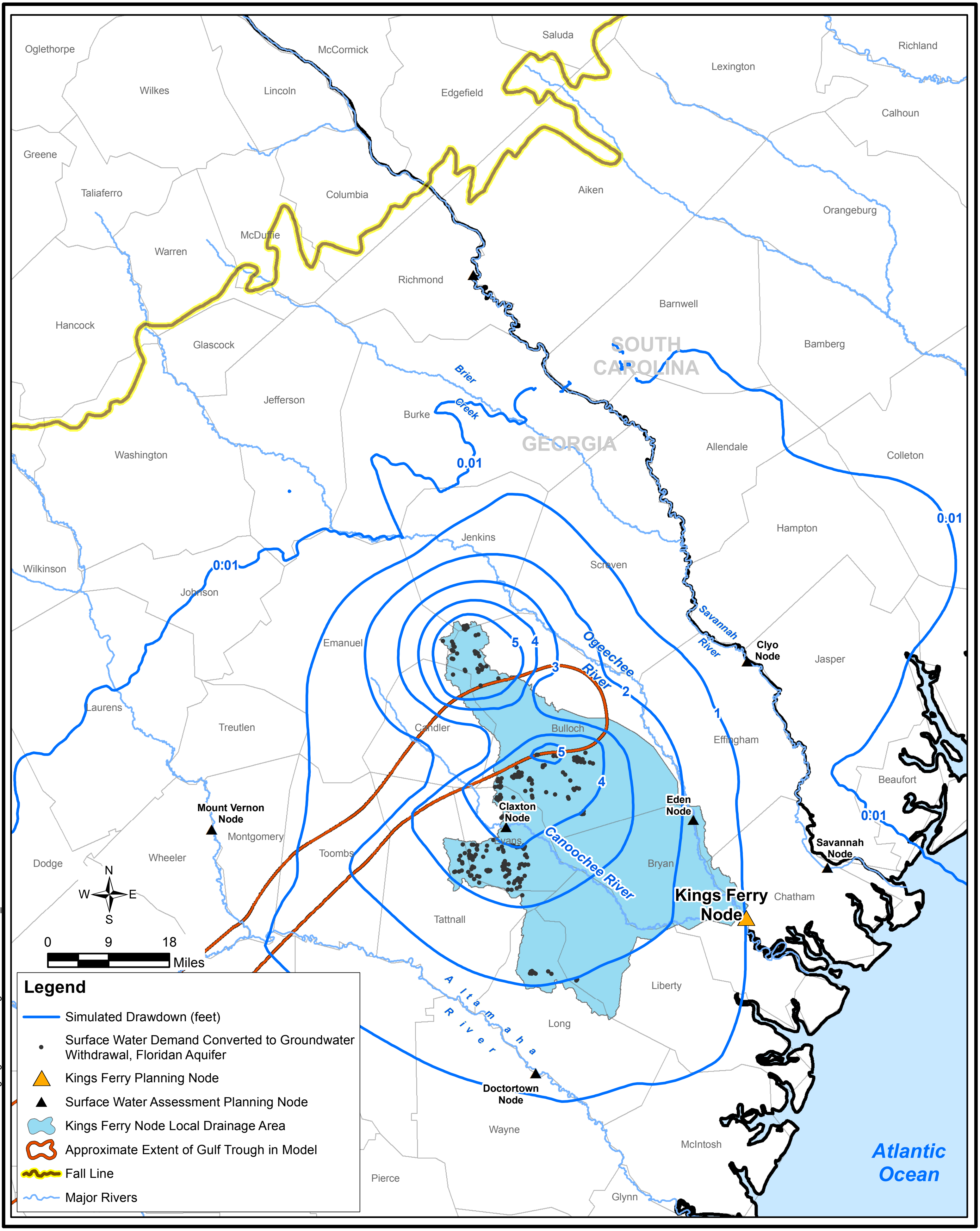
Excluding the parcels in the Gulf Trough area within the Kings Ferry node LDA reduces the simulated Floridan aquifer groundwater withdrawals from approximately 11.97 MGD (Table 3-5) to 9.73 MGD (**Table 4-2**). The simulated Floridan aquifer drawdown with this pumping reduction is approximately 5 feet or less (**Figure 4-10**).

Adding the drawdowns shown on Figures 4-1 and 4-10 suggests that the combined pumping impact of this scenario and sustainable yield pumping rates will likely not create any additional areas exceeding the 30-feet sustainable yield drawdown criterion; as such, the additional Floridan aquifer groundwater withdrawals presented in this scenario could potentially be implemented in addition to sustainable yield pumping rates. Also, since Floridan aquifer pumping was reduced in this scenario, the simulated Floridan aquifer drawdown beneath Hilton Head Island remains less than 0.01 feet.



CDM Smith

Figure 4-9
Simulated Drawdown in Cretaceous Aquifer Heads, Eden Node LDA
Additional Groundwater Withdrawal: 2.13 MGD (No Withdrawals in Gulf Trough Area)



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CDM Smith

Figure 4-10
Simulated Drawdown in Floridan Aquifer Heads, Kings Ferry Node LDA
Additional Groundwater Withdrawal: 9.73 MGD (No Withdrawals in Gulf Trough Area)

Table 4-2. Calculated Irrigation Demand of Surface-Water-Only Parcels Gulf Trough, Kings Ferry Node

	Number of Parcels	Total Irrigated Area (acres)	Mean Irrigation Depth (inches/month)		Total Additional Groundwater Demand (MGD)	
			(May – August)	(September – April)	(May – August)	(September – April)
Surface-Water-Only Parcels that Will Be Replaced by Groundwater from Floridan Aquifer	226	7,960	1.39	0.35	9.73	2.49

4.3.3 Eden, Claxton, and Kings Ferry Nodes Combined

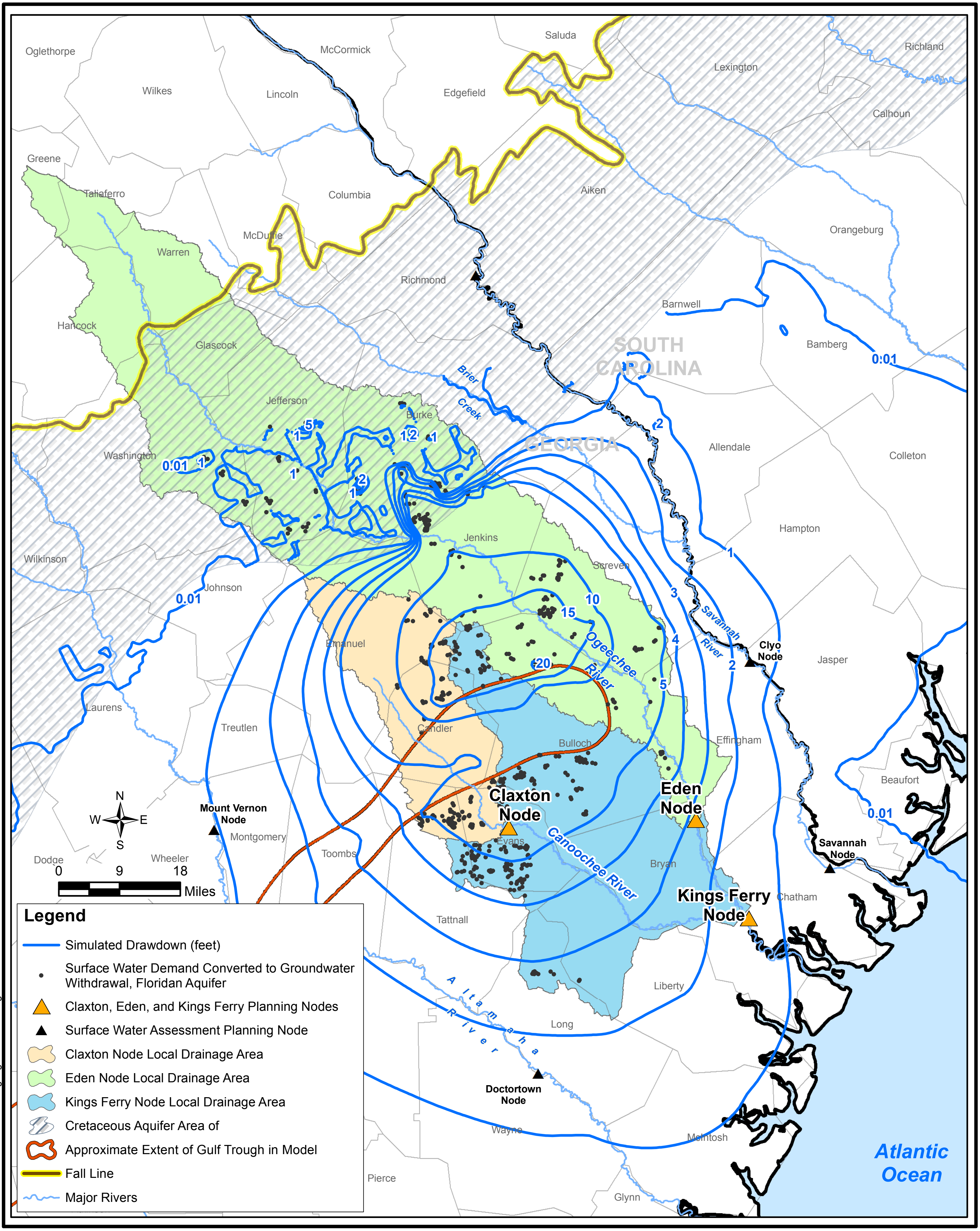
As is shown on Figure 1-1, the Kings Ferry planning node is downstream of the Eden node on the Ogeechee River and downstream of the Claxton node on the Canoochee River in Evans County, Georgia, which is located within the Altamaha planning region.

An additional simulation was performed to evaluate the combined drawdown in the Floridan and Cretaceous aquifers if all agricultural parcels served by surface water withdrawals within the Eden, Claxton, and Kings Ferry LDAs switched to groundwater use to meet their irrigation needs during the high-demand period. An analysis of the additional groundwater withdrawals to replace surface water withdrawals in the Claxton node LDA is documented under separate cover (CDM Smith, 2016). Groundwater withdrawals from agricultural parcels within the Gulf Trough area in the LDAs for all three planning nodes were excluded from the analysis. The total additional groundwater withdrawal from the Floridan and Cretaceous aquifers in this simulation is approximately 26.72 MGD and 2.13 MGD, respectively (**Table 4-3**).

Table 4-3. Calculated Irrigation Demand of Surface-Water-Only Parcels That Will Be Replaced by Groundwater (Excluding Gulf Trough), Eden, Claxton, and Kings Ferry Nodes Combined

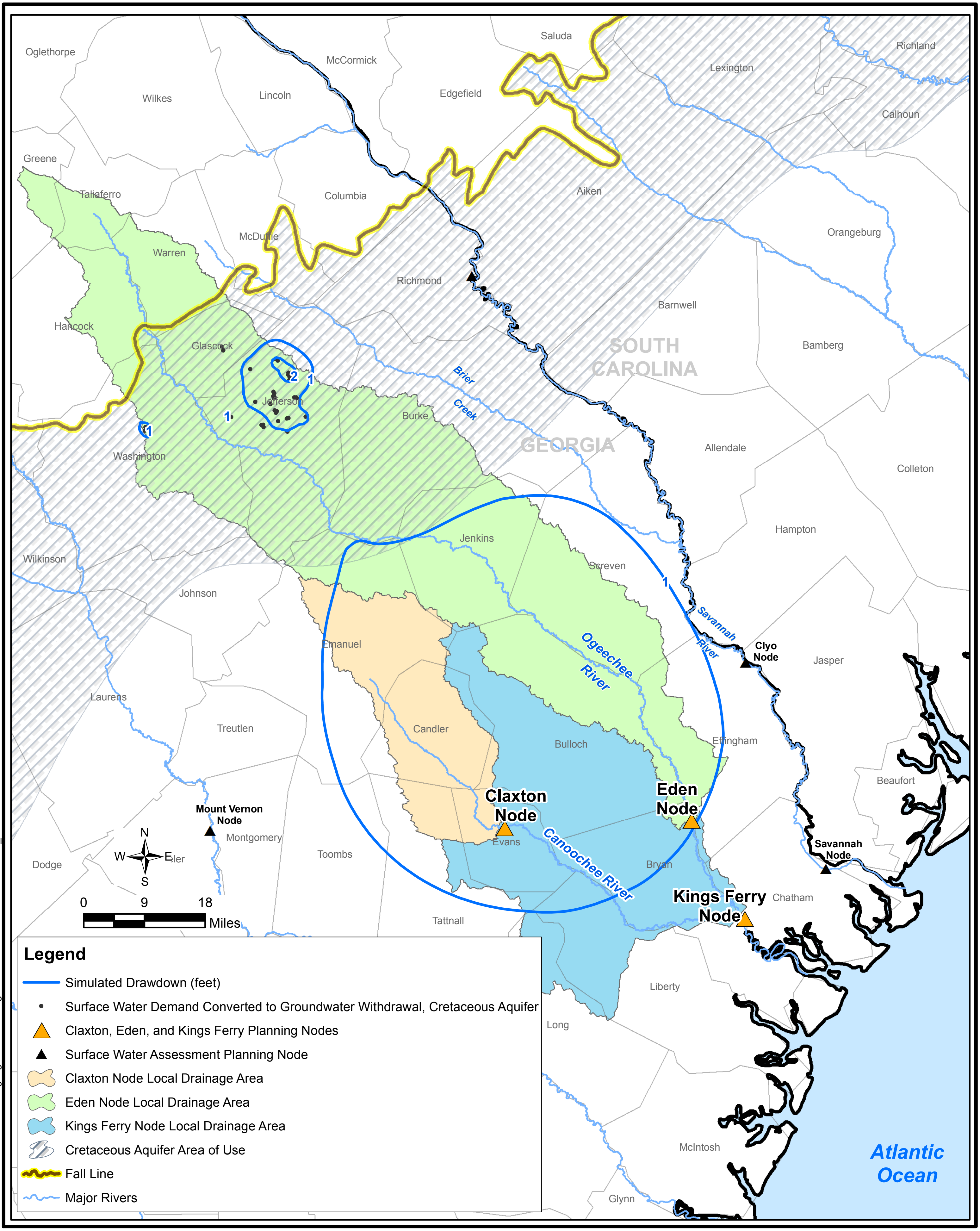
	LDA	Number of Parcels	Total Irrigated Area (acres)	Mean Irrigation Depth (inches/month)	Total Additional Groundwater Demand (MGD)
				(May – August)	(May – August)
Surface-Water-Only Parcels that Will Be Replaced by Groundwater from Floridan Aquifer	**Eden**	207	10,910	1.39	13.34
	Claxton	121	2,980	1.39	3.65
	Kings Ferry	226	7,960	1.39	9.73
Surface-Water-Only Parcels that Will Be Replaced by Groundwater from Cretaceous Aquifer	**Eden**	35	1,740	1.39	2.13
Total	**-**	**589**	**23,590**	**1.39**	**28.85**

Simulated groundwater drawdown contours for the Floridan and Cretaceous aquifers are shown on **Figures 4-11** and **4-12**, respectively. The maximum drawdown simulated in the Floridan aquifer is approximately 20 feet located in a small area within the Eden node LDA in Bulloch County west of the Ogeechee River and near the north (upgradient) side of the Gulf Trough. In the



CDM Smith

Figure 4-11
Simulated Drawdown in Floridan Aquifer Heads - Claxton, Eden, and Kings Ferry Node LDAs
Additional Groundwater Withdrawal: 26.72 MGD (No Withdrawals in Gulf Trough Area)



CDM Smith

Figure 4-12
Simulated Drawdown in Cretaceous Aquifer Heads - Claxton, Eden, and Kings Ferry Node LDAs
Additional Groundwater Withdrawal: 2.13 MGD (No Withdrawals in Gulf Trough Area)

Cretaceous aquifer, the combined effects of the additional agricultural groundwater withdrawals result in a maximum drawdown of approximately 1 to 2 feet, as shown on Figure 4-12. The additional Floridan aquifer groundwater withdrawals in this simulation result in approximately 1 foot of simulated drawdown in the Cretaceous aquifer over the Claxton and Kings Ferry node LDAs and the southern portion of the Eden node LDA, as shown on Figure 4-12. The simulated drawdown in the Floridan and Cretaceous aquifers resulting from this combined scenario does not exceed the sustainable yield drawdown criterion.

Adding the drawdowns shown on Figures 4-1 and 4-11 suggests that the combined pumping impact of this scenario and sustainable yield pumping rates may result in additional areas exceeding the 30-feet sustainable yield drawdown criterion. However, it may be possible to implement a portion of the additional Floridan aquifer groundwater withdrawals presented in this scenario in areas where sustainable yield simulation drawdowns are less than 30 feet. The simulated Floridan aquifer drawdown beneath Hilton Head Island is less than 0.01 feet in this scenario.

Generally speaking, the simulated Cretaceous aquifer pumping rates and resulting drawdowns are small, and could be implemented in addition to sustainable yield pumping rates.

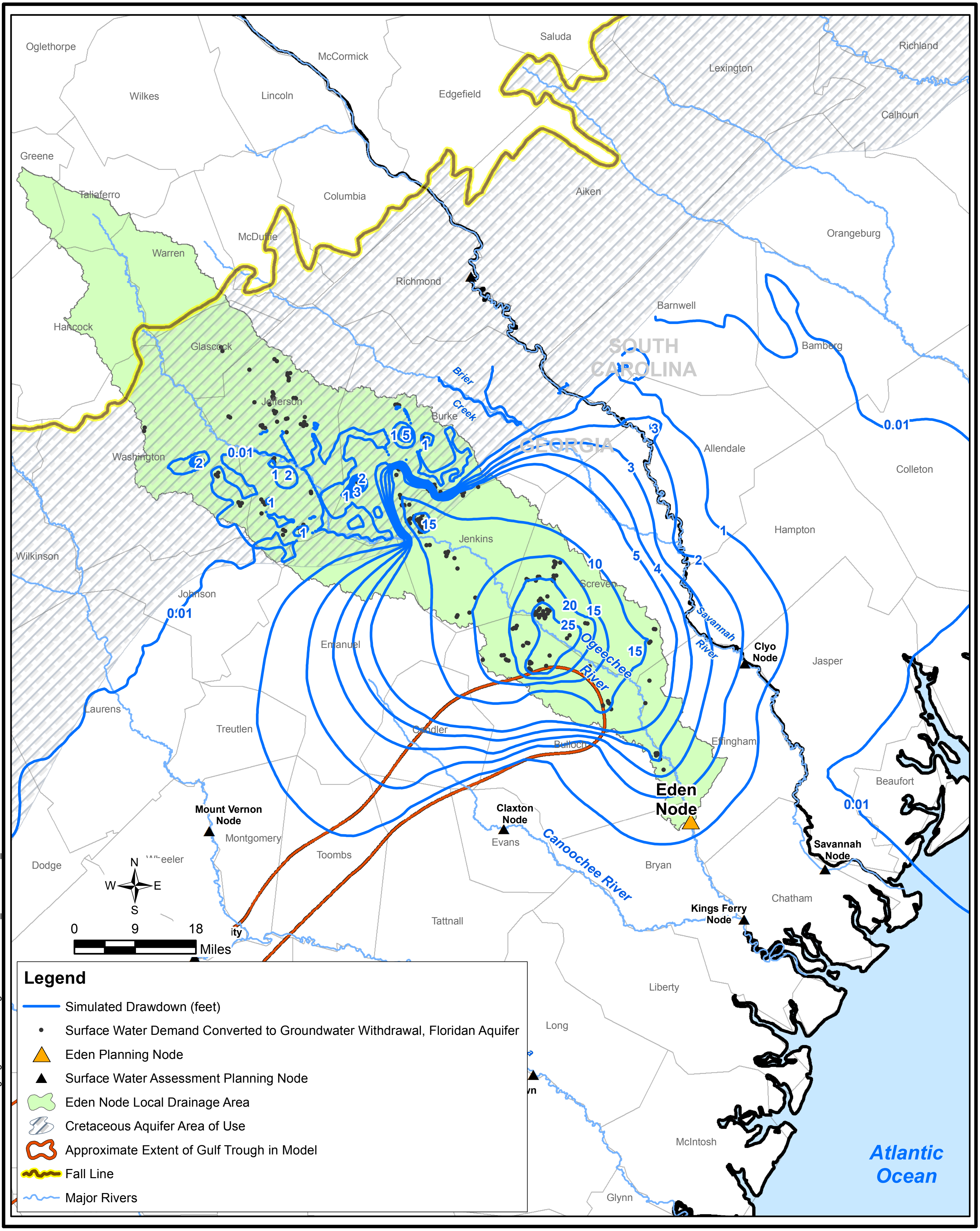
4.4 Increased Floridan Aquifer Groundwater Withdrawals Without Exceeding Sustainable Yield Criteria

Groundwater model simulations were performed to evaluate the additional amount of Floridan and Cretaceous aquifer groundwater withdrawal that could be achieved without exceeding the sustainable yield criterion of 30 feet of drawdown as established by the State Water Plan groundwater resource assessments (CDM, 2011a). These simulations were performed by applying incremental multiplication factors to withdrawals in both aquifers until the maximum simulated drawdown in either the Floridan or Cretaceous aquifer was approximately 30 feet. Additional groundwater withdrawals were not assigned within the Gulf Trough area.

Results of these simulations suggest that groundwater withdrawals within the Eden LDA can be increased by approximately 26.68 MGD from the Floridan aquifer and by approximately 4.26 MGD from the Cretaceous aquifer without violating the sustainable yield criteria (**Figures 4-13** and **4-14**). For the Kings Ferry LDA, the simulations suggest that the maximum groundwater withdrawal that can be supported from the Floridan aquifer is approximately 38.93 MGD (**Figure 4-15**).

The additional Floridan aquifer groundwater withdrawals presented in this scenario for both the Eden and Kings Ferry LDAs could not be implemented in addition to sustainable yield pumping rates, because the simulated drawdowns in the scenarios are generally at the 30-feet sustainable yield drawdown criterion. The additional Cretaceous aquifer groundwater withdrawals could be implemented in addition to sustainable yield pumping rates.

The simulated Floridan aquifer drawdown beneath Hilton Head Island is less than 0.01 feet in both the Eden node LDA and Kings Ferry node LDA scenarios.



CDM Smith

Figure 4-13
Simulated Drawdown in Floridan Aquifer Heads, Eden Node LDA
Additional Groundwater Withdrawal: 26.68 MGD (No Withdrawals in Gulf Trough Area)

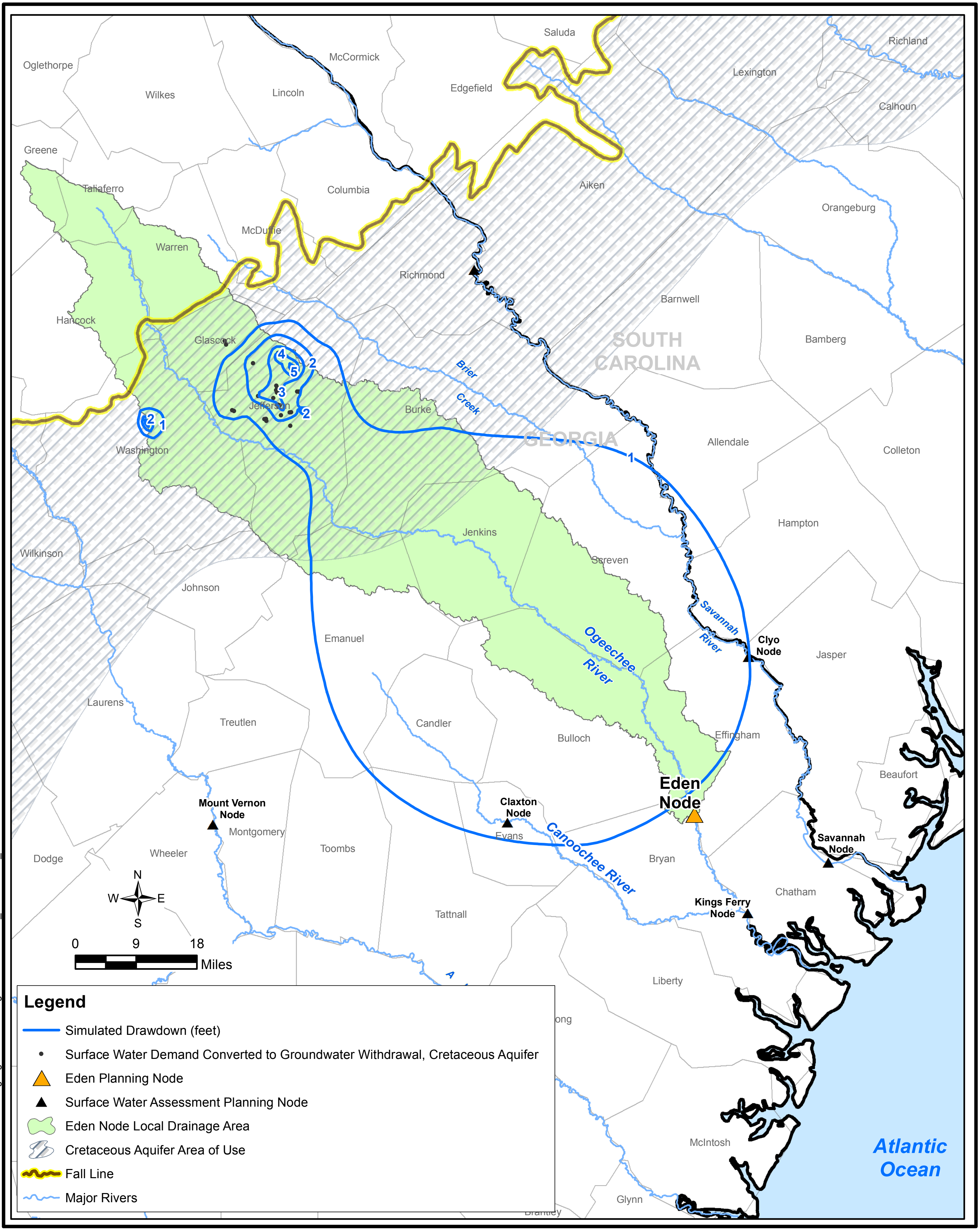


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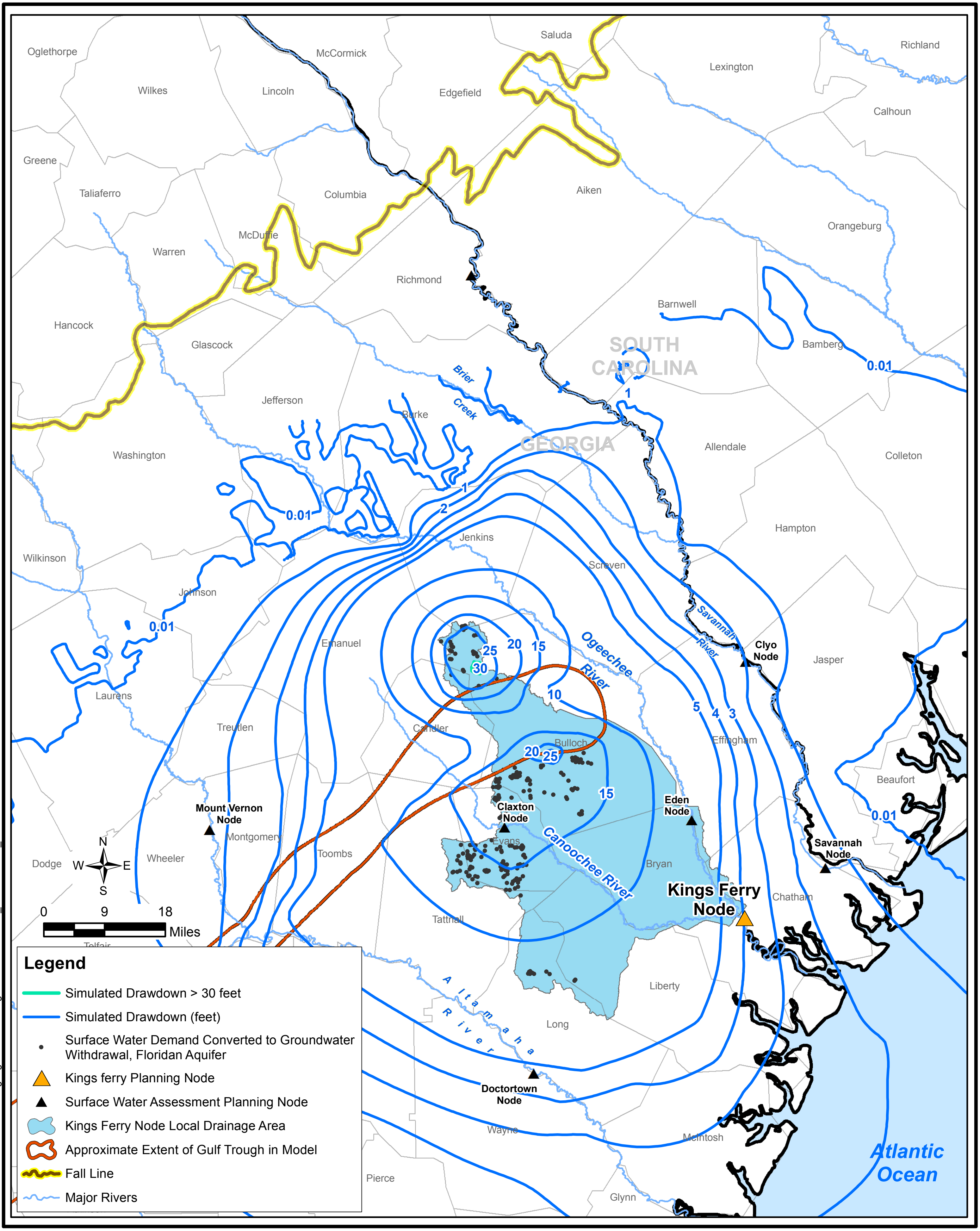
Figure 4-14
Simulated Drawdown in Cretaceous Aquifer Heads, Eden Node LDA
Additional Groundwater Withdrawal: 4.26 MGD (No Withdrawals in Gulf Trough Area)



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CDM Smith

Figure 4-15
Simulated Drawdown in Floridan Aquifer Heads, Kings Ferry Node LDA
Additional Groundwater Withdrawal: 38.93 MGD (No Withdrawals in Gulf Trough Area)

4.5 Simulated Floridan Aquifer Drawdown, Low-Demand Agricultural Pumping

Model simulations for both the Eden node LDA and the Kings Ferry node LDA were performed to represent the transfer of surface water withdrawals to groundwater withdrawals during the low-irrigation-demand period (September through April). For these scenarios, groundwater withdrawals were not assigned in locations of agricultural parcels within the Gulf Trough area.

Additional groundwater demands applied to the model for the Eden node LDA simulation were approximately 3.41 MGD from the Floridan aquifer and approximately 0.54 MGD from the Cretaceous aquifer. The simulated drawdown in the Floridan aquifer resulting from this additional pumping is approximately 3 feet (**Figure 4-16**). The area of greatest simulated drawdown in the Floridan aquifer occurs north of the Gulf Trough. Contours of simulated drawdown were not generated for the Cretaceous aquifer because the simulated drawdown was less than 1 foot.

In the Kings Ferry LDA, average irrigation demands during the low-demand period are approximately 2.49 MGD, and **Figure 4-17** shows the simulated drawdown in the Floridan aquifer resulting from application of this additional groundwater demand. During the low-demand months, simulated drawdown in the Kings Ferry LDA is less than 2 feet.

4.6 Simulated Impact on Stream Baseflow

Impact to streamflow due to increased pumping as a result of the transfer of surface water demands for agricultural irrigation to groundwater withdrawals is estimated by evaluating the simulated reduction in baseflow for the various groundwater pumping scenarios relative to the baseflow simulated under baseline conditions.

4.6.1 Eden Node Local Drainage Area

Within the Eden node LDA, the Floridan aquifer and the Cretaceous aquifer are in direct contact with the streams and rivers in the updip area (north) where the aquifers outcrop. In the southern portion of the Eden node LDA, the surficial aquifer is active and overlies the Floridan aquifer and Cretaceous aquifer.

The impact to streams due to increased pumping from the Floridan aquifer and the Cretaceous aquifer in the updip area is quantified by evaluating the reduction in simulated baseflow for the different simulations relative to baseline conditions. The results indicate that the reduction in simulated baseflow due to additional groundwater pumping is less than 1 percent under each scenario.

Impact on streamflow where the Floridan aquifer and Cretaceous aquifer are overlain by the surficial aquifer system was inferred by comparing the increases in downward leakage from the constant head cells representing the surficial aquifer in layer 1. The increased leakage from the surficial aquifer induced by additional pumping in different simulations was found to be less than 3 percent under all scenarios. Such a small increase in vertical leakage from the surficial aquifer will have minimal impact on the baseflow of the streams that are in direct contact with the surficial aquifer.

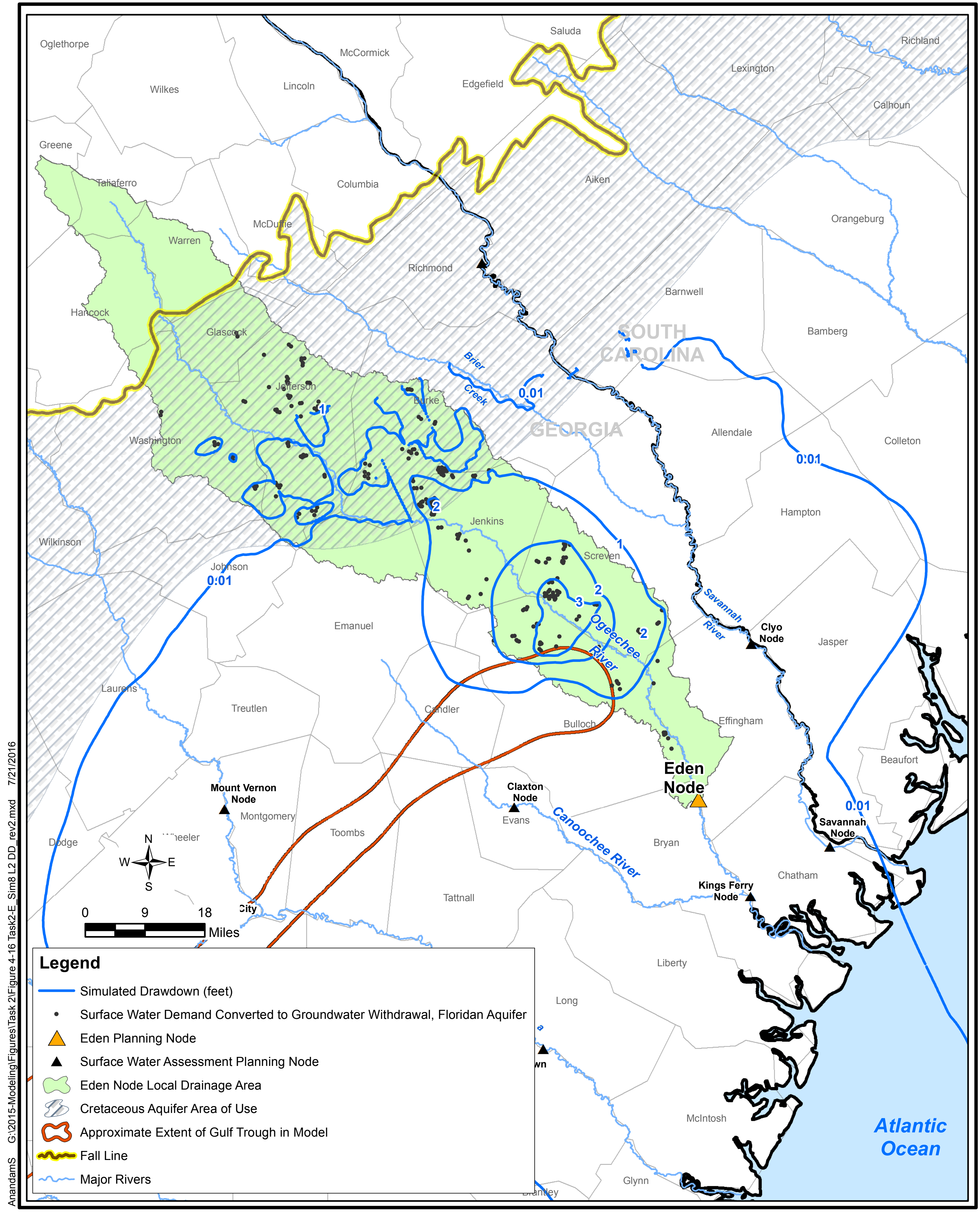

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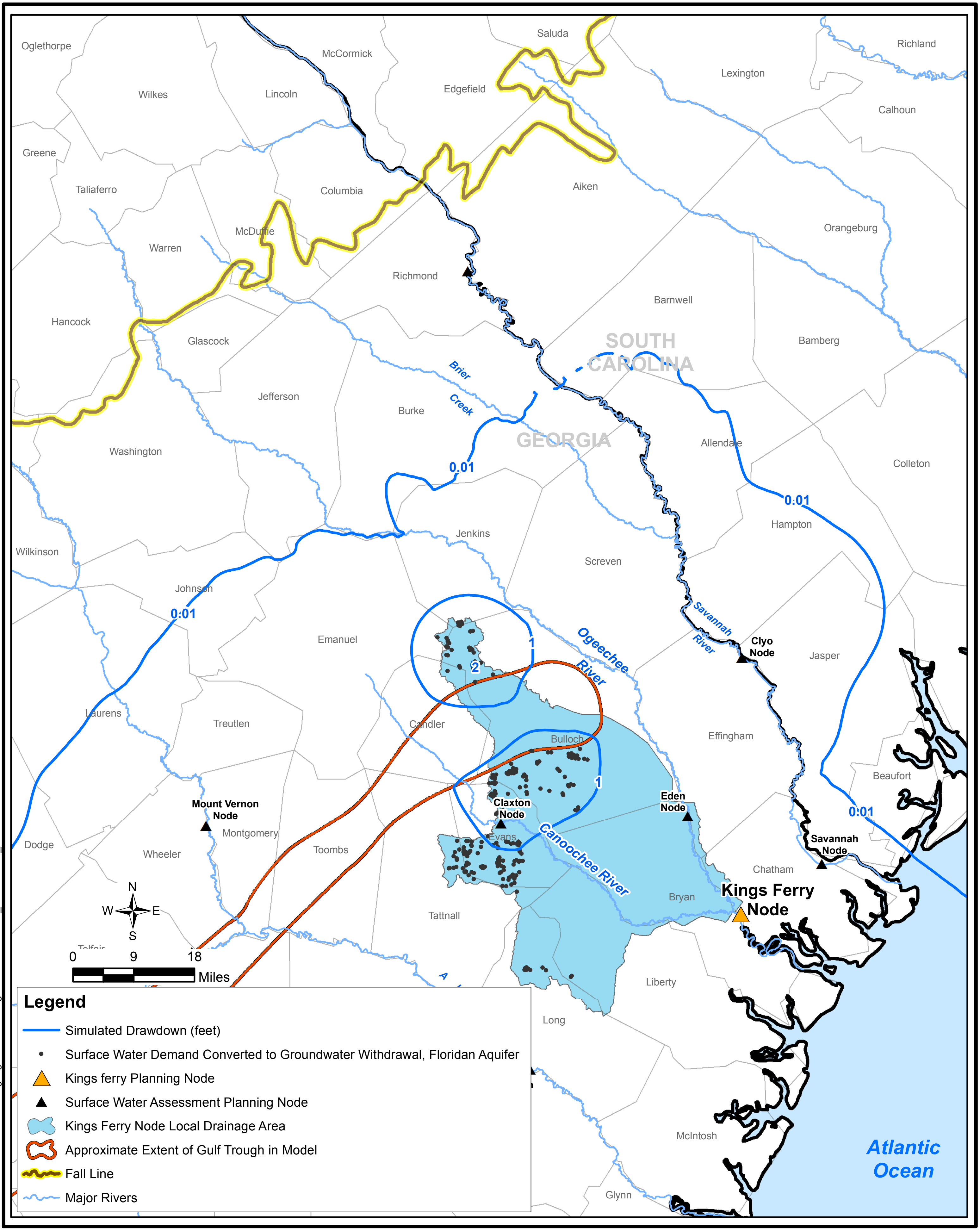
Figure 4-16
Simulated Drawdown in Floridan Aquifer Heads, Eden Node LDA
Additional Groundwater Withdrawal: 3.41 MGD (No Withdrawals in Gulf Trough Area)



CDM Smith

Figure 4-17
Simulated Drawdown in Floridan Aquifer Heads, Kings Ferry Node LDA
Additional Groundwater Withdrawal: 2.49 MGD (No Withdrawals in Gulf Trough Area)

4.6.2 Kings Ferry Node Local Drainage Area

Within the Kings Ferry node LDA, the surficial aquifer is active and overlies the Floridan aquifer. Therefore, the Floridan aquifer underneath the Kings Ferry node LDA is not in direct contact with the streams and rivers. As such, the impact on streamflow was inferred by comparing the increase in downward leakage from the surficial aquifer. The increased leakage from the surficial aquifer induced by additional pumping under each of the various scenarios described is less than 6 percent. This increase in vertical leakage from the surficial aquifer will have minimal impact on the baseflow of the streams that are in direct contact with the surficial aquifer.

The impact to streams due to the increased Floridan aquifer pumping in the updip area in the north (where the Floridan aquifer outcrops) was quantified by evaluating the reduction in simulated baseflow occurring under the various scenarios relative to baseline conditions. The results indicate that the reduction in simulated baseflow (relative to baseline conditions) due to additional groundwater pumping is less than 1 percent under each scenario.

5. Potential Impact on the Streamflow Shortfall at the Eden and Kings Ferry Nodes

As previously indicated, agricultural demand projections are currently being revised, and an updated surface water resource assessment and gap analysis will be completed once the revised projections are available. In addition to updated water demands, the gap analysis will be revised using new United States Army Corps of Engineers (USACE) Hydrologic Engineering Center Reservoir System Simulation (HEC-ResSim) surface water models developed for all of the major river basins in Georgia, with capabilities for analysis of geo-referenced river and reservoir networks and management of associated time-series data.

For the purpose of this study, the streamflow gaps presented in the Coastal Georgia Regional Water Plan (CDM, 2011c) served as the basis for analysis. The average surface water shortfall at the Eden node under current and forecasted 2050 demands is approximately 19 cfs (12.3 MGD) and 31 cfs (20 MGD), respectively, while current and forecasted surface water shortfalls at the Kings Ferry node are approximately 35 cfs (22.6 MGD) and 47 cfs (30.4 MGD), respectively (CDM, 2011c).

Groundwater model simulation results suggest that groundwater pumping at existing surface water irrigation parcels located outside the Gulf Trough area within the Eden node LDA could be increased by a total rate of approximately 26.7 MGD in the Floridan aquifer and approximately 4.3 MGD in the Cretaceous aquifer without exceeding the 30-feet drawdown criterion established for sustainable yield by the State Water Plan groundwater resource assessments. Groundwater modeling performed for the Kings Ferry node LDA suggests that an additional 38.9 MGD could be withdrawn from the Floridan aquifer without exceeding the sustainable yield drawdown criterion.

An additional simulation was performed to evaluate the combined impacts if groundwater withdrawals replace current surface water irrigation demands in the Eden, Claxton, and Kings Ferry node LDAs. The results of this simulation indicate that the maximum drawdown would not exceed approximately 20 feet if that approach were adopted within both the Coastal Georgia and the Altamaha Water Planning Regions. Groundwater withdrawals from agricultural parcels within the Gulf Trough area in the LDAs for all three planning nodes were excluded from the scenario.

6. Summary

CDM Smith prepared this report to summarize the groundwater modeling analysis performed in support of the State Water Plan. The modeling analysis consisted of simulating and evaluating the impact of additional Floridan and Cretaceous aquifer groundwater withdrawals in the Upper and Lower Ogeechee River watershed to replace agricultural surface water withdrawals in the Eden and Kings Ferry planning node LDAs where surface water resource analyses have identified a potential shortfall in surface water availability to meet current and future demands. The estimated shortfalls are approximately 12.3 MGD and 20 MGD under current and forecasted 2050 demands, respectively, at the Eden node and approximately 22.6 MGD and 30.4 MGD, respectively, at the Kings Ferry node (CDM, 2011c).

The steady-state Regional Coastal Plain Model developed for the State Water Plan groundwater resource assessments (CDM, 2011a) was applied to evaluate the incremental Floridan and Cretaceous aquifer water-level drawdown that may result from additional Floridan and Cretaceous aquifer groundwater withdrawals to supply the agricultural irrigation demand currently supplied by surface water. Simulated piezometric heads in the regional model representative of 2010 conditions in the Floridan and Cretaceous aquifers were used to define baseline conditions. For the Kings Ferry node analysis, all of the additional pumping was applied to the Floridan aquifer. For the Eden node analysis, most of the additional pumping was applied to the Floridan aquifer as well; however, a portion was applied to the Cretaceous aquifer in the northern part of the Eden node LDA. A range of pumping rates were simulated to evaluate the potential range of water-level drawdown that may result from the additional groundwater withdrawals. **Table 6-1** summarizes the simulated groundwater withdrawal scenarios and the corresponding maximum simulated drawdown. The simulated Floridan aquifer drawdown beneath Hilton Head Island is less than 0.01 feet in both the Eden node LDA and Kings Ferry node LDA scenarios.

Groundwater withdrawals simulated in scenarios where the incremental drawdown is less than 30 feet, could potentially be implemented in addition to sustainable yield pumping rates, but this should be assessed on a scenario by scenario basis.

Results from simulations corresponding to high-water-demand conditions indicate that replacing existing surface water agricultural withdrawals with groundwater withdrawals could result in locally lowered groundwater levels more than 30 feet below the baseline conditions, which would exceed the 30-feet sustainable yield criterion established by the State Water Plan groundwater resource assessments. This area of significant drawdown occurs in the Gulf Trough area where model transmissivity in the Floridan aquifer is significantly lower than the surrounding area. Because this low-transmissivity area may not be economically conducive to groundwater development, additional simulations were conducted that excluded groundwater substitution fluxes assigned in the Gulf Trough area. These simulation results suggest that groundwater pumping at parcels located outside the Gulf Trough area that currently rely on surface water for irrigation could be increased by approximately 26.68 MGD in the Eden LDA or by approximately 38.93 MGD in the Kings Ferry LDA without exceeding the previously defined 30-feet drawdown criterion. Additionally, modeling results indicate that, for all simulated groundwater withdrawal scenarios, the reduction in groundwater discharge/baseflow to streams and rivers is small (less than 6 percent) relative to the baseflow criterion established by the State Water Plan groundwater resource assessments (i.e., more than 40 percent simulated reduction in groundwater contributions to stream baseflow). Some of the scenarios presented could potentially be implemented in addition to sustainable yield pumping rates without expanding areas where drawdown may exceed the 30-feet sustainable yield criterion.

Table 6-1. Groundwater Withdrawal Scenario Simulation Summary

Scenario	Local Drainage Area	Additional Groundwater Pumping (MGD)		Maximum Simulated Drawdown (Feet)	
		Floridan aquifer	Cretaceous aquifer	Floridan aquifer	Cretaceous aquifer
Groundwater Withdrawals to Replace Surface Water Demand – High-Demand Average	**Eden**	14.71	2.13	40	2
	Kings Ferry	11.97	-	20	-
Groundwater Withdrawals to Replace Surface Water Demand – High-Demand Average (Excluding Parcels in Gulf Trough)	**Eden**	13.34	2.13	10	2
	Kings Ferry	9.73	-	5	-
	Eden, Claxton, Kings Ferry Combined	26.72	2.13	20	2
Groundwater Withdrawals to Replace Surface Water Demand – Increased Pumping (Excluding Parcels in Gulf Trough)	**Eden**	26.68	4.26	30	5
	Kings Ferry	38.93	-	30	-
Groundwater Withdrawals to Replace Surface Water Demand – Low-Demand Average	**Eden**	3.41	0.54	3	< 1
	Kings Ferry	2.49	-	2	-

The results of this study can inform the development of future management practices by Planning Councils. Additional groundwater withdrawals can contribute to reduction of current or future gaps, in conjunction with drought contingency planning, demand management practices, and other surface water management measures.

7. References

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APPENDIX C

Task 3

Middle Ocmulgee Water Planning Region: Recommendations for Monitoring Cretaceous Aquifer Groundwater Withdrawal Impacts

Prepared for:
Georgia Department of Natural Resources
Environmental Protection Division

CDM Smith

ARCADIS Design & Consultancy for natural and built assets

October 2016

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Task 3

Middle Ocmulgee Water Planning Region: Recommendations for Monitoring Cretaceous Aquifer Groundwater Withdrawal Impacts

1. Introduction

This report presents groundwater and surface water monitoring plan recommendations for areas in the Ocmulgee River watershed that primarily utilize the Cretaceous aquifer for groundwater supply. These recommendations were developed in response to concerns raised by the Middle Ocmulgee Water Planning Region during the development of its 2011 Regional Water Plan, regarding the potential impacts of increased local groundwater withdrawals. The Middle Ocmulgee Water Planning Region is shown on **Figure 1-1**.

1.1 Background

In February 2008, the Georgia General Assembly adopted the Georgia Comprehensive State-wide Water Plan (State Water Plan) dated January 8, 2008. The State Water Plan established a regional water resources management planning process, which was initiated in March 2009. Groundwater and surface water resource assessment modeling was conducted to evaluate water availability and potential shortfalls (or gaps) for current and future (2050) water supply demands. Summaries of groundwater and surface water resource assessments are presented in Regional Water Plan documents developed for the various water planning regions.

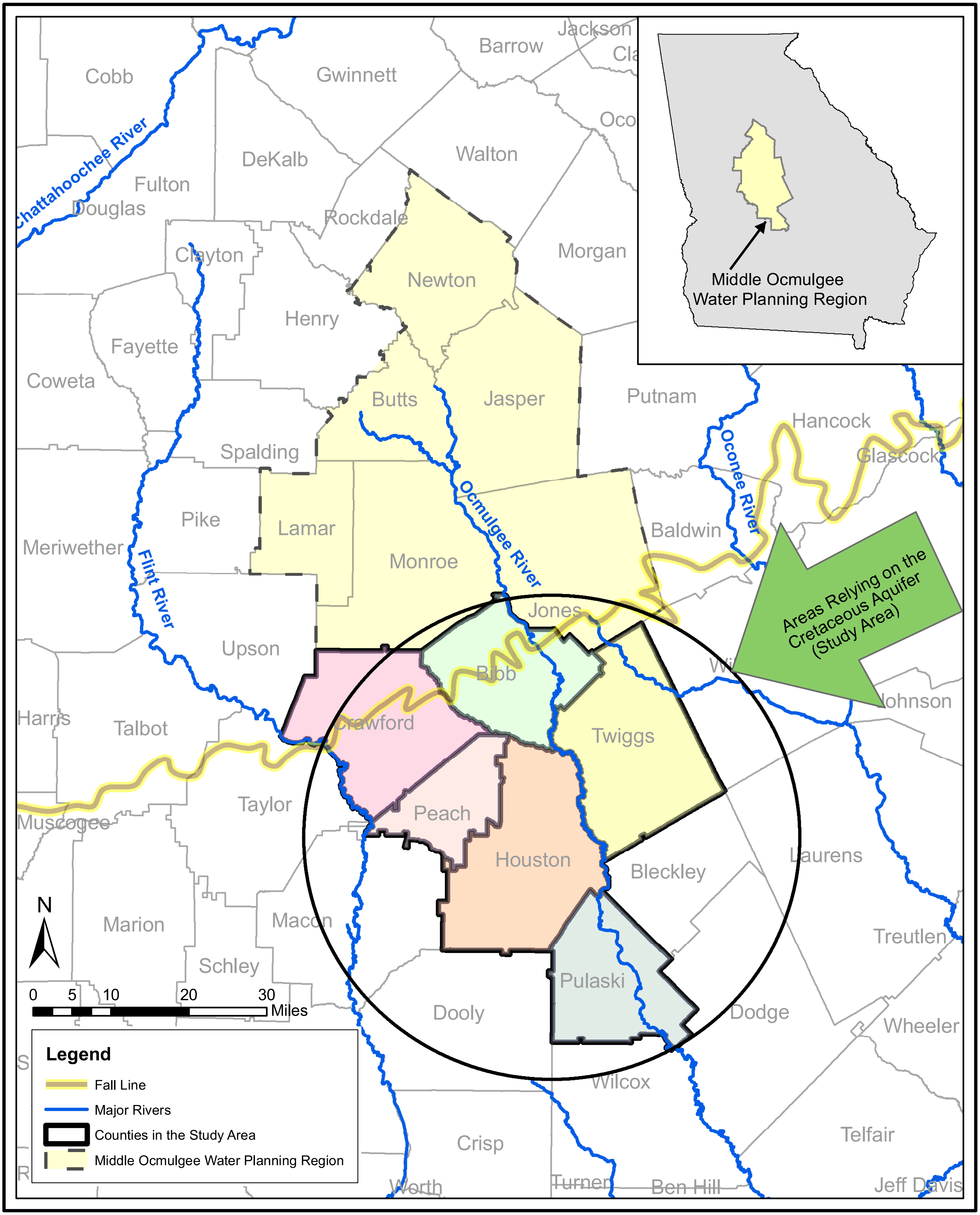
The Middle Ocmulgee Water Planning Region is one of 11 planning regions established throughout the state. The Middle Ocmulgee Water Planning Region is located in central Georgia in the vicinity of Macon. Within the planning region, the Cretaceous aquifer is utilized for water supply in Bibb, Crawford, Houston, Peach, Twiggs, and Pulaski Counties. These six counties are the focus of the information presented in this report, and are hereafter referred to as the "Study Area." Most of the area within these counties is located south of the Fall Line, which marks the updip extent of the Coastal Plain sediments.

The recommendations presented in this report were developed based on a review of existing groundwater and surface water data in the Study Area and the State Water Plan groundwater resource assessments.

1.2 Approach

CDM Smith completed the following tasks to support the development of monitoring recommendations:

- Reviewed groundwater flow model simulations of Cretaceous aquifer sustainable yield, which were developed for the Georgia State Water Plan groundwater resource assessment and are presented in the *Technical Memorandum on the Assessment of Sustainable Yield of the Claiborne and Cretaceous Aquifers, Georgia State-Wide Groundwater Resources Assessment* (CDM Smith, 2012a). Simulation results were reviewed to identify



CDM Smith

Figure 1-1
Middle Ocmulgee Water Planning Region and Areas Relying on the Cretaceous Aquifer For Water Supply

potential locations in the Study Area that may be adversely impacted by increased groundwater withdrawals.

- Reviewed available groundwater and surface water data for the Study Area compiled in the United States Geological Survey (USGS) National Water Information System (NWIS) database to evaluate availability and suitability of existing monitoring locations. Additionally, other sources of data that may be useful for monitoring groundwater conditions were considered.
- Developed general and specific recommendations for a long-term monitoring plan to guide future groundwater and surface water monitoring efforts in the Study Area.

1.3 Report Organization

The remainder of this report is organized as follows:

- Section 2 provides a summary of the State Water Plan groundwater resource assessment for the Study Area. Based on the groundwater resource assessment results, CDM Smith identified portions of the Study Area where groundwater, surface water, or wetlands resources may potentially be more sensitive to increased groundwater withdrawals from the Cretaceous aquifer.
- Section 3 presents groundwater and surface water monitoring locations and data currently available for the Study Area in the USGS NWIS database.
- Section 4 presents recommendations for developing a long-term monitoring plan for the Study Area.
- Section 5 presents a summary of the study.
- Section 6 provides a list of references used in this study.

2. Overview of State Water Plan Groundwater Resource Assessments

2.1 Assessment Approach and Criteria

In 2009 and 2010, the availability of groundwater resources in select prioritized aquifers of Georgia was evaluated. The assessment was completed to support the Regional Water Development and Conservation Plans as part of the State Water Plan. The prioritized aquifers included the Floridan aquifer in south-central Georgia and the eastern Coastal Plain of Georgia, which underlies the Canoochee River drainage basin. Other prioritized aquifers included the Claiborne, Clayton, and Cretaceous aquifer systems.

Numerical steady-state groundwater flow models were developed for the State Water Plan to support the groundwater resource assessments. The results of groundwater flow model simulations with increased pumping in the prioritized aquifers were compared with baseline simulations representing existing conditions to estimate local impacts of the increased pumping. The simulated changes in water-level elevations and groundwater baseflow to streams were compared with sustainable yield criteria developed for the State Water Plan study.

Formulation of the sustainable yield criteria for the groundwater resource assessments is presented in Section 11 of the document titled *Groundwater Flow Modeling of the Coastal Plain Aquifer System of Georgia* (CDM Smith, 2011a). A summary of the criteria is presented below.

For the purposes of the groundwater resource assessments, sustainable yield was defined as the maximum amount of groundwater withdrawal that could occur from defined extraction points within each aquifer without violating sustainable yield metrics. The following metrics were applied, with some variations depending on the prioritized aquifer being studied and the level of detail provided by the respective models used to assess sustainable yield:

- Drawdowns of groundwater levels in the pumped aquifer do not exceed 30 feet between pumping wells;
- Pumping was limited to levels that would not decrease mean annual stream baseflow by more than 40 percent;
- 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.

The primary metrics that applied to the sustainable yield analysis for the Cretaceous aquifer were the first two listed above which pertain to drawdown and impacts to baseflow.

2.2 Georgia Regional Coastal Plain Groundwater Model

The Georgia Regional Coastal Plain Model, shown on **Figure 2-1**, was developed in 2009-2010 to support the State Water Plan sustainable yield assessments (CDM Smith, 2011a). For this purpose, an existing regional United States Geological Survey (USGS) Coastal Plain Clastic Aquifer System Model was modified and updated, including expanding the model domain, refining the computational grid, and incorporating available local data in and near the prioritized study areas.

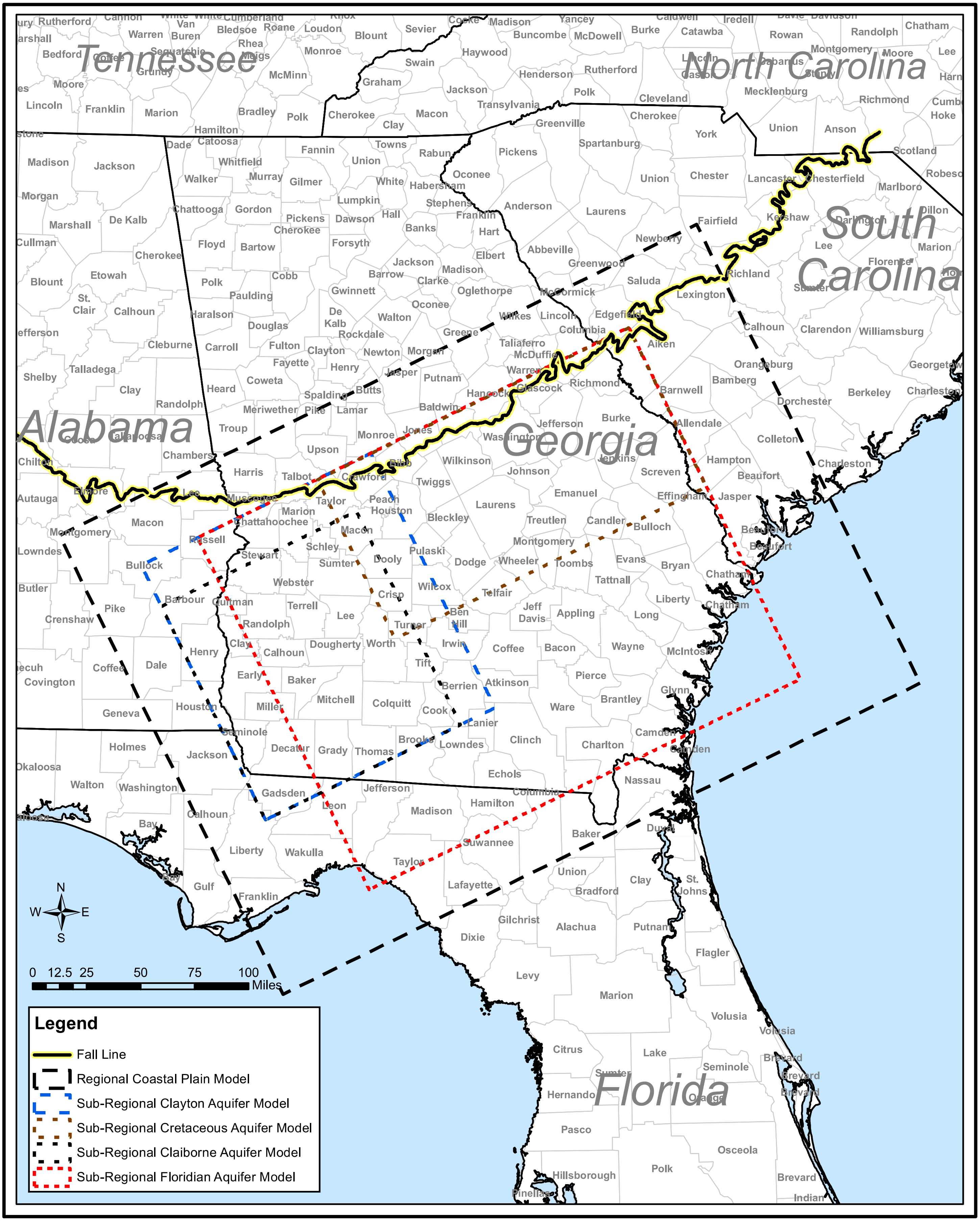
Vertically, the model includes the entire Georgia Coastal Plain aquifer sequence down to the Cretaceous aquifer system. Prioritized aquifers for the assessment included the Floridan, Claiborne, Clayton, and Cretaceous aquifer systems. The regional model was calibrated using available hydrogeologic data and observed groundwater elevations at monitoring wells under steady-state conditions. Regional model simulations have been conducted in steady-state mode only.

The regional model was revised in 2012 to incorporate new data on agricultural groundwater withdrawals and an expanded representation of river-groundwater interaction (i.e., the number of river nodes was increased to include smaller tributary streams that were not previously represented). The agricultural, municipal, and industrial steady-state pumping in the 2012 revised regional model represents annual average groundwater withdrawals for the year 2010. The regional model with revised pumping and river representation was recalibrated in steady-state mode. The recalibration included modifications to model hydraulic properties and boundary conditions (CDM Smith, 2012a).

2.3 Sub-Regional Models

Sub-regional models were initially developed for the Floridan aquifer in south-central Georgia and the eastern Coastal Plain of Georgia, the Claiborne aquifer, and the Cretaceous aquifer between Macon and Augusta (Figure 2-1). The sub-regional models were used to develop sustainable yield estimates for the corresponding aquifers. Generally speaking, with the exception of model grid spacing and model domain limits, the sub-regional and regional models are consistent in terms of model layering, aquifer properties, and other model input parameter values. The initial Floridan, Claiborne, and Cretaceous sub-regional models were calibrated in transient as well as steady-state mode.

The sub-regional models for the Cretaceous aquifer and the Claiborne aquifer, as well as the regional model, were revised and recalibrated in 2012 to incorporate new data on agricultural groundwater withdrawals and an expanded representation of river-groundwater interaction (CDM Smith, 2012a). At that time, CDM Smith also developed and calibrated a sub-regional model for the Clayton aquifer based on the updated regional model (CDM Smith, 2012b). The agricultural, municipal, and industrial steady-state pumping in the 2012 sub-regional models represents annual average groundwater withdrawals for the year 2010. The revised Cretaceous and Claiborne sub-regional models were recalibrated and applied in steady-state mode. The Clayton sub-regional model also was calibrated and applied in steady-state mode.



CDM Smith

Figure 2-1
Georgia State Water Plan Groundwater Models

2.4 Sub-Regional Cretaceous Model Framework and Pumping Assignments

The regional model, as well as the sub-regional models, contain seven layers numbered from top to bottom representing different aquifer systems within the Coastal Plain. In the Study Area vicinity, the model layers are:

- Layer 1 – Surficial/Brunswick Aquifers
- Layer 2 – Floridan Aquifer Upper Permeable Zone (formerly designated as Upper Floridan Aquifer)
- Layer 3 – Claiborne/Floridan Aquifer Lower Permeable Zone (formerly designated as Lower Floridan Aquifer)/Gordon Aquifer
- Layer 4 – Clayton and Cretaceous Dublin Aquifers (in the Study Area, model layer 4 represents the Dublin Aquifer)
- Layer 5 – Providence Sand-Peedee-Dublin Cretaceous Aquifers (in the Study Area, model layer 5 represents the Providence Sand Aquifer)
- Layer 6 – Eutaw-Midville Cretaceous Aquifer
- Layer 7 – Upper Atkinson-Upper Tuscaloosa Cretaceous Aquifer (in the Study area, model layer 7 represents the Upper Atkinson Aquifer)

In the baseline sub-regional Cretaceous model, 470 million gallons per day (mgd) of groundwater withdrawals are assigned model-wide to all aquifers. Of that amount, approximately 225 mgd is assigned to Cretaceous aquifer layers 4 (Dublin aquifer: 45 mgd), layer 5 (Providence Sand aquifer: 101 mgd), and layer 6 (Eutaw-Midville: 76 mgd). No pumping is assigned to layer 7 (Upper Atkinson). The Upper Atkinson aquifer is not used for water supply in the Study Area, and may potentially have adverse groundwater quality (Pollard and Vorhis, 1980).

In the (baseline) sub-regional Cretaceous aquifer model, simulated groundwater withdrawals from the six Study Area counties from all aquifers total 105 mgd. Of these withdrawals, 72 percent (or 76 mgd) is pumped from the Cretaceous aquifer (layer 4: 2 mgd, layer 5: 45 mgd, layer 6: 29 mgd).

Within the Study Area, more than 43 percent of the simulated pumping from the Cretaceous aquifer is used for agricultural purposes, and approximately 34 percent is used for public water supply. Industrial usage represents less than 23 percent of simulated groundwater withdrawals from the Cretaceous aquifer within the Study Area.

2.5 Results of Cretaceous Aquifer Sustainable Yield Simulations Within the Middle Ocmulgee Water Planning Region

For the State Water Plan groundwater resource assessments, the sustainable yield of the Cretaceous aquifer was investigated using various combinations of withdrawals from existing wells screened in layers 4 through 6 and, where applicable, from hypothetical new wells where existing wells were absent. The sustainable yield estimates developed for the Cretaceous aquifer thus represent a range of values, depending on the assumptions regarding the locations of future pumping increases that are applied in the simulations.

The 2012 low-end and high-end sustainable yield simulations completed for the State Water Plan have an additional 28 mgd (37 percent increase) and 37 mgd (49 percent increase) (or a total of 104 and 113 mgd), respectively, withdrawn from the Cretaceous aquifer within the Study Area.

The low end sustainable yield pumping, representing the minimum increase in groundwater withdrawals that could be accommodated without violating the sustainable yield criteria, is reached when simulated pumping increases are applied at existing groundwater withdrawal locations in the simulations. The high end sustainable yield pumping represents spatially dispersed groundwater withdrawals evenly distributed across the Cretaceous aquifer within the model area. The low-end sustainable yield simulation, which represents increases in pumping at existing pumping centers, is considered more realistic, as well as more conservative (from a drawdown perspective), than the high-end sustainable yield simulation with the additional pumping uniformly distributed. For that reason, review of available data and recommendations for monitoring are based on the results of the low-end sustainable yield simulation.

Observations within the Study Area based on the low-end sustainable yield simulations include:

- The maximum simulated drawdown in the Study Area is approximately 12 feet, as shown on **Figure 2-2**. The greatest simulated drawdown occurred in the Eutaw-Midville aquifer (layer 6). Figure 2-2 also shows USGS monitoring well locations, which are discussed in greater detail in Section3.
- The simulated groundwater baseflow in the Study Area is reduced by approximately 12 percent, compared with the baseline simulation.
- Based on a local zone budget analysis that focused on the area near the Fall Line, streamflow could be reduced where the Cretaceous aquifer is closest to ground surface and has the most potential to directly contribute to surface water baseflow. The model was not calibrated to the smaller streams; as a result, additional investigation and model calibration would be needed for a more detailed evaluation of pumping impacts on baseflow contribution to streams in this area.

The simulated drawdown in the Cretaceous aquifer in the Study Area under the low-end sustainable yield pumping rates is less than the 30-foot threshold used as a constraint in the Georgia State Water Plan sustainable yield analysis. Therefore, the simulations suggest that groundwater withdrawals from the Cretaceous aquifer in the Study Area could be increased more than those estimated by the groundwater resource assessments before the sustainable yield is reached locally.

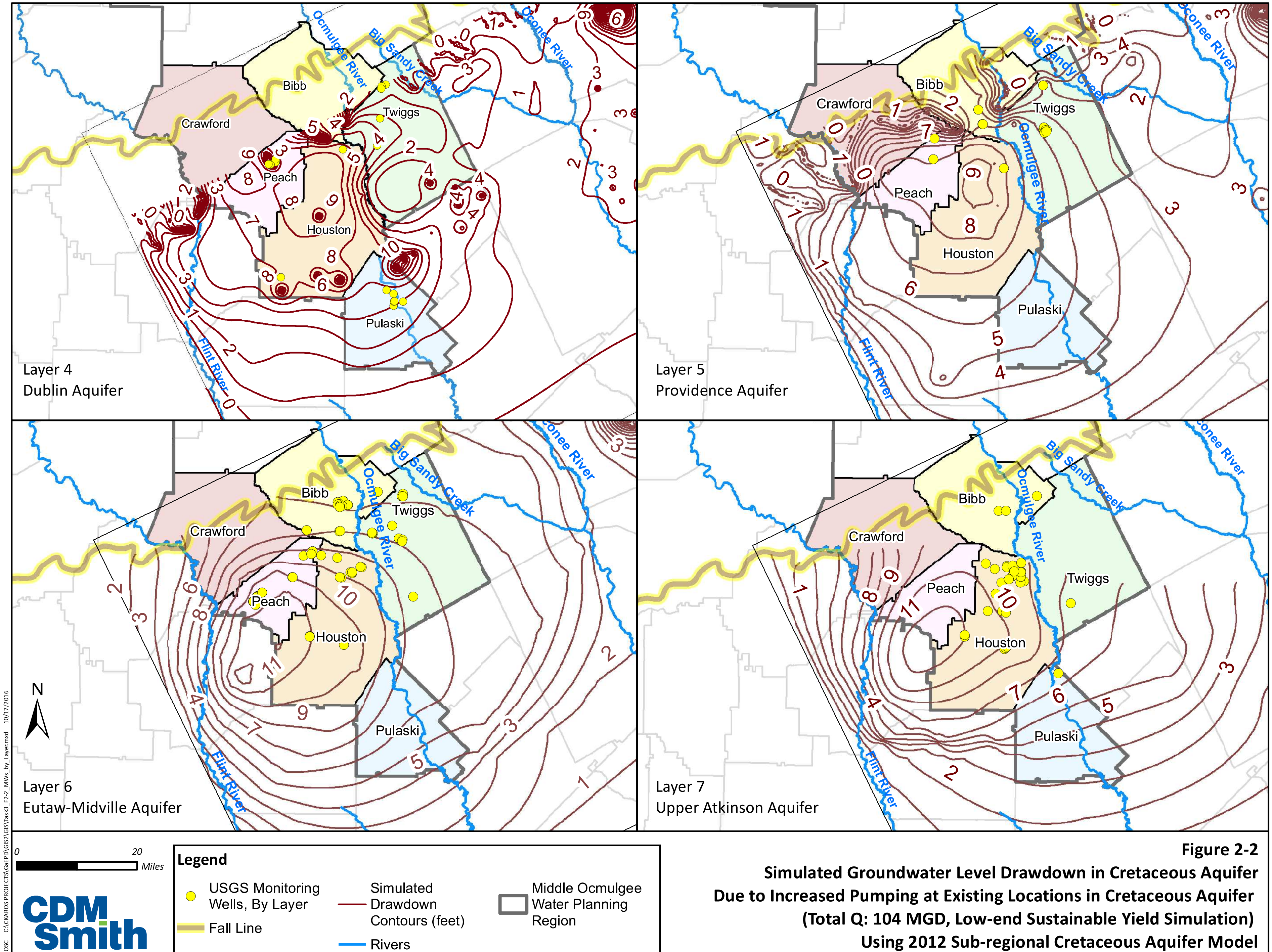


Figure 2-2
Simulated Groundwater Level Drawdown in Cretaceous Aquifer
Due to Increased Pumping at Existing Locations in Cretaceous Aquifer
(Total Q: 104 MGD, Low-end Sustainable Yield Simulation)
Using 2012 Sub-regional Cretaceous Aquifer Model

2.6 Areas Potentially Sensitive to Increased Cretaceous Aquifer Withdrawals

The Cretaceous aquifer sustainable yield simulation results provide insight on which locations within the Study Area may potentially be impacted adversely by pumping increases from the Cretaceous aquifer.

Portions of the Study Area potentially sensitive to increased Cretaceous aquifer withdrawals include:

1. *Peach and Houston Counties*

Figure 2-3 presents simulated layer 6 drawdown due to increased pumping in the low-end sustainable yield simulation. The locations of all Cretaceous aquifer groundwater withdrawal points in the model are also shown. The areas of greatest simulated groundwater drawdown are located in Peach County and Houston County, as well as in neighboring Macon and Dooly Counties. Should groundwater withdrawals in these counties increase, additional groundwater drawdown may occur. Macon and Dooly Counties are located outside of the Middle Ocmulgee Water Planning Region in the adjacent Upper Flint Water Planning Region.

Within the Study Area, the drawdown is greater in the Eutaw-Midville and Upper Atkinson aquifers (model layers 6 and 7) than in the shallower Cretaceous aquifers (layers 4 and 5) in the low-end sustainable yield simulation. The density of pumping well locations shown on Figure 2-3 indicates that pumping from the Cretaceous aquifer is also focused in Peach, Houston, Macon and Dooly counties.

2. *Ocmulgee River Tributaries and Wetland Areas*

The simulated groundwater contribution to streamflow (groundwater baseflow) in the Study Area is reduced by approximately 12 percent in the rivers and tributaries of the Study Area in the low-end sustainable yield simulation. While this is below the metric of 40 percent baseflow reduction used in the sustainable yield criteria of the Georgia State Water Plan, the steady-state model represents average hydrologic conditions. The potential effects of increased pumping under drought conditions were not assessed.

Some tributary streams and wetland areas, particularly in the northern portion of the Study Area near the Fall Line where the Cretaceous aquifer is most likely to be in direct contact with surface water, could potentially be impacted by increased Cretaceous aquifer withdrawals.

3. *Water quality in deeper pumping wells in the Cretaceous aquifer*

The Upper Atkinson aquifer, represented by model layer 7, is not currently pumped. However, the sustainable yield simulations suggest that, in the Study Area, groundwater elevations in the Upper Atkinson aquifer are likely to experience drawdown similar in magnitude to the Eutaw-Midville aquifer above it (layer 6). The sustainable yield simulations also suggest that in some areas, increases in groundwater withdrawals from the Cretaceous aquifer may generate an upward vertical gradient between layers 7 (Lower Atkinson) and 6 (Upper Atkinson). Particularly near pumping well locations, pumping wells screened in the Eutaw-Midville aquifer could possibly influence Upper Atkinson aquifer heads to draw groundwater vertically upward. If groundwater quality in the Upper Atkinson aquifer is poor in these locations, because of elevated

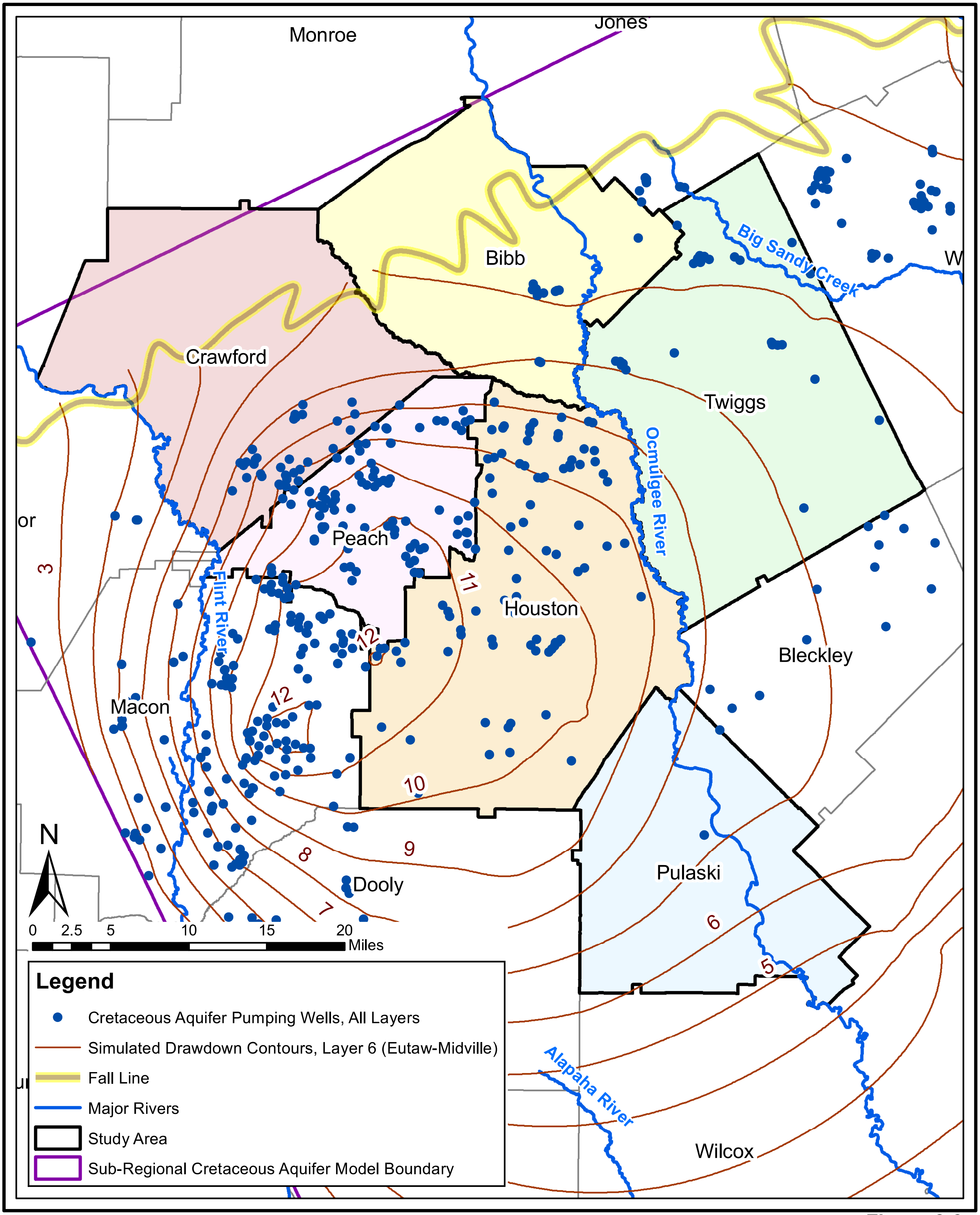


Figure 2-3
Cretaceous Aquifer Pumping Well Locations
Shown with Simulated Layer 6 Drawdown Contours
(Low-end Sustainable Yield Simulation)

CDM Smith

chloride concentrations (Pollard and Vorhis, 1980), there is a potential for degraded groundwater quality in the Eutaw-Midville aquifer, because of upwards groundwater flow from the underlying Upper Atkinson aquifer.

3. Existing Monitoring Locations and Other Data

Existing monitoring locations may provide useful data for a long-term monitoring program. Information from the USGS NWIS database (http://waterdata.usgs.gov/nwis) was reviewed to identify groundwater and river monitoring locations and data records for the six counties of the Study Area. Data records retrieved from the USGS NWIS database include monitoring locations, stream flow data, and groundwater elevation data for the six counties.

Daily discharge measurements and monthly groundwater-level measurements are generally sufficient for monitoring long-term impacts of groundwater withdrawals. However, many of the entries in the USGS NWIS database contain infrequently collected individual measurements; these have comparatively little value in establishing long-term data trends. Well screen information is not included in the USGS NWIS database, but typically is available from USGS upon request.

3.1 Existing Groundwater Monitoring Locations and Available Water-Level Data

For the six counties in the Study Area, 288 of the monitoring wells in the USGS NWIS database are characterized as Cretaceous aquifer wells. The locations of these wells are shown on **Figure 3-1**. Based on USGS records, limited data (i.e., what few recorded data points are available were collected more than 25 years ago) are available for a majority of the wells (229). **Table 3-1** lists the 59 Cretaceous aquifer monitoring wells for which more recent data records (i.e., 1989 to the present) are available.

Only two monitoring wells in the Study Area screened in the Cretaceous aquifer have lengthy periods of water-level measurements in the USGS NWIS database:

- Well 18U001 in southern Twiggs County (616 feet deep, classified as a Dublin aquifer well). Period of record: July 1975 to present (daily measurements).
- Well 18T001 in northern Pulaski County (1,555 feet deep, classified as a Midville aquifer well). Period of record: June 1981 to present (daily measurements).

Cretaceous aquifer monitoring wells in the USGS NWIS database outside the Study Area, including in Macon and Dooly Counties, are not shown on Figure 3-1.

Sustainable yield simulations for the Cretaceous aquifer suggest that if most future pumping increases occur at existing pumping locations (i.e., the low end of the sustainable yield pumping scenario), the area where wells 18U001 and 18T001 are located (Figure 3-1) could potentially experience approximately 7 to 8 feet of drawdown as a result of increased groundwater withdrawals. Seasonal variations in pumping and groundwater recharge, or longer-term climate variations such as periods of drought, can also affect piezometric conditions in the Cretaceous aquifer. Future monitoring efforts should include collecting climate data as well as water-level and pumping histories to disaggregate the impacts of increased pumping from other factors.

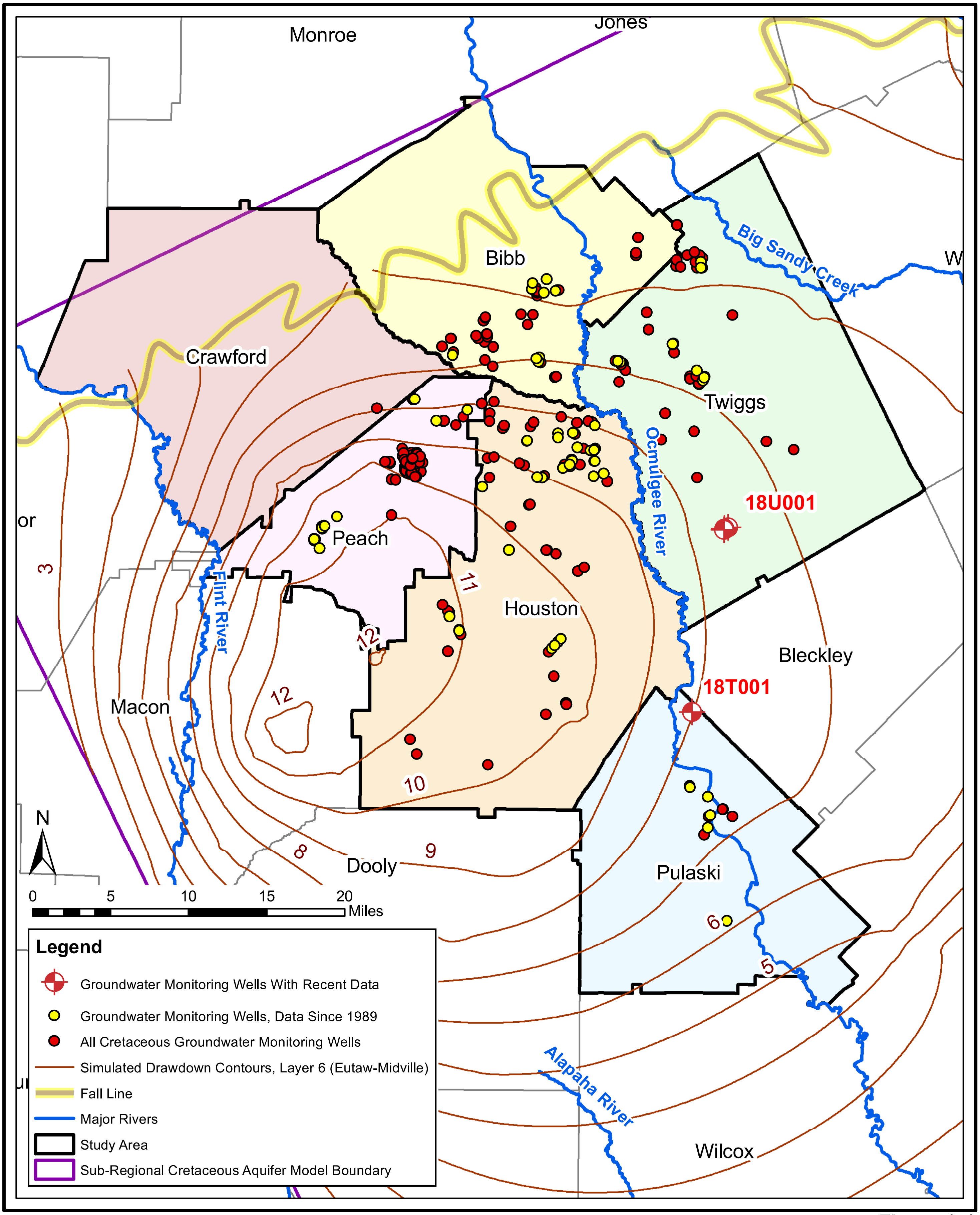


Figure 3-1
Cretaceous Aquifer Groundwater Monitoring Well Locations Shown with Simulated Layer 6 Drawdown Contours (Low-End Sustainable Yield Simulation)

Table 3-1. Study Area Cretaceous Aquifer Groundwater Monitoring Wells with Recent Data Records

Data as reported in the USGS NWIS database (http://waterdata.usgs.gov/nwis). Data count refers to the number of groundwater level data points in the database. Recent data records include at least some data points collected in 1989 or later.

USGS Site Number	Station	Latitude	Longitude	County	HUC	Aquifer Code	Well Depth (feet)	Hole Depth (feet)	Data Record Start	Data Record End	Data Count
323310083531201	14U001	32.55348	-83.8855	Peach	3070104	211MDVL	478	522	2/1/1962	11/6/1989	6
323230083535001	14U002	32.54098	-83.8974	Peach	3070104	211MDVL	500	512	12/1/1970	11/6/1989	6
323304083531301	14U004	32.55126	-83.8888	Peach	3070104	211MDVL	480	517	1/18/1954	11/6/1989	7
323223083533601	14U007	32.53293	-83.8913	Peach	3070104	211MDVL	NR	495	2/12/1975	11/6/1989	5
323344083521801	15U001	32.56209	-83.8719	Peach	3070104	211MDVL	NR	501	2/12/1975	11/6/1989	5
323904083454601	15V002	32.65126	-83.7627	Peach	3070103	211MDVL	NR	NR	2/12/1975	11/6/1989	5
324032083465301	15V003	32.67098	-83.7863	Peach	3070103	211MDVL	246	246	1/8/1960	11/6/1989	6
322619083381101	16T002	32.43876	-83.6363	Crawford	3070104	125DBMV	640	984	12/18/1967	10/22/1991	11
322628083380101	16T003	32.44154	-83.6335	Crawford	3070104	211MDVL	710	952	5/12/1969	11/7/1989	5
322652083373601	16T004	32.44765	-83.6266	Crawford	3070104	211MDVL	630	769	6/5/1973	11/7/1989	7
322721083441201	16T005	32.45571	-83.738	Crawford	3070104	125DBMV	465	504	6/25/1964	11/8/1989	6
322808083445701	16T006	32.46904	-83.7488	Crawford	3070104	125DBMV	650	678	7/13/1972	11/7/1989	5
322641083374801	16T009	32.44487	-83.6299	Crawford	3070104	211PVDC	625	922	7/23/1969	10/22/1991	11
323549083384801	16U001	32.59765	-83.6463	Crawford	3070104	211MDVL	422	460	11/27/1962	11/6/1989	8
323553083390601	16U002	32.5982	-83.6519	Crawford	3070104	211MDVL	430	494	8/13/1970	11/6/1989	6
323150083410001	16U011	32.5307	-83.6832	Crawford	3070104	125DBMV	625	625	8/11/1977	11/7/1989	4
323522083424501	16U013	32.58959	-83.7124	Crawford	3070104	211PVDC	95	95	6/26/1969	10/22/1991	9
324233083385701	16V001	32.7082	-83.6521	Bibb	3070103	125DBMV	368	375	8/1/1941	11/6/1989	5
324230083391101	16V002	32.70931	-83.6491	Bibb	3070103	125DBMV	220	509	5/12/1941	11/6/1989	12
324220083385701	16V018	32.7057	-83.6496	Bibb	3070103	125DBMV	240	261	3/13/1967	11/6/1989	9
323820083374501	16V019	32.63876	-83.6285	Crawford	3070104	125DBMV	440	503	2/8/1972	10/22/1991	17
323816083375001	16V020	32.63514	-83.6285	Crawford	3070104	125DBMV	435	616	7/16/1968	10/22/1991	9
323929083440601	16V022	32.66098	-83.7282	Peach	3070104	211MDVL	420	495	1/1/1956	11/6/1989	6
324315083423001	16V025	32.71209	-83.7444	Bibb	3070103	125DBMV	210	210	10/24/1980	11/6/1989	3
323755083394501	16V026	32.63209	-83.6624	Crawford	3070104	125DBMV	NR	NR	10/25/1984	10/22/1991	4

Table 3-1. Study Area Cretaceous Aquifer Groundwater Monitoring Wells with Recent Data Records (continued)

USGS Site Number	Station	Latitude	Longitude	County	HUC	Aquifer Code	Well Depth (feet)	Hole Depth (feet)	Data Record Start	Data Record End	Data Count
324656083382602	16W009	32.78236	-83.6405	Bibb	3070103	125DBMV	300	300	10/9/1989	10/9/1989	1
324642083392001	16W019	32.77875	-83.6557	Bibb	3070103	125DBMV	238	275	4/9/1964	11/6/1989	6
324611083383801	16W023	32.76986	-83.6435	Bibb	3070103	125DBMV	260	290	10/24/1966	11/6/1989	13
324623083392501	16W024	32.77292	-83.6568	Bibb	3070103	125DBMV	260	284	12/18/1964	11/6/1989	6
324616083374301	16W027	32.77125	-83.6305	Bibb	3070103	125DBMV	290	290	10/2/1979	11/6/1989	4
323624083365201	17U001	32.60792	-83.6157	Crawford	3070104	211MDVL	390	491	2/20/1960	11/6/1989	8
323604083344401	17U004	32.60126	-83.5788	Crawford	3070104	211MDVL	440	490	10/17/1958	11/7/1989	7
323554083352202	17U005	32.59848	-83.5893	Crawford	3070104	211MDVL	385	460	5/1/1956	11/7/1989	7
323719083351401	17U007	32.62264	-83.5932	Crawford	3070104	125DBMV	250	290	10/3/1941	10/22/1991	9
323652083364901	17U009	32.6132	-83.6135	Crawford	3070104	211MDVL	415	478	2/24/1961	11/6/1989	5
323634083365901	17U015	32.60959	-83.6163	Crawford	3070104	211MDVL	NR	NR	10/28/1982	11/6/1989	3
323622083372401	17U017	32.60626	-83.6232	Crawford	3070104	211MDVL	NR	NR	10/28/1982	11/6/1989	3
323645083351801	17U018	32.61264	-83.5882	Crawford	3070104	211MDVL	390	390	4/15/1971	11/7/1989	6
323722083352201	17U019	32.62292	-83.5891	Crawford	3070104	211MDVL	376	376	11/2/1976	11/7/1989	4
323820083364401	17V002	32.63903	-83.6124	Crawford	3070104	211MDVL	480	561	3/8/1977	11/6/1989	4
324312083300501	17V006	32.72153	-83.5018	Twiggs	3070103	125DBMV	310	342	10/1/1953	11/7/1989	4
323718083365101	17V012	32.6257	-83.6074	Crawford	3070104	211MDVL	311	367	7/24/1969	11/7/1989	4
324218083333501	17V019	32.70486	-83.5596	Twiggs	3070103	125DBMV	251	251	11/22/1972	11/8/1989	8
323851083353601	17V021	32.64598	-83.5877	Crawford	3070104	211MDVL	400	400	1/1/1958	11/7/1989	7
324220083334501	17V023	32.7057	-83.5624	Twiggs	3070103	125DBMV	400	530	6/14/1989	6/14/1989	1
321106083265401	18R003	32.18433	-83.4463	Pulaski	3070104	211PVDC	210	NR	11/18/1977	5/15/1998	8
321618083275701	18S003	32.271	-83.4666	Pulaski	3070104	211PVDC	470	473	10/29/1987	10/24/1990	3
321759083280001	18S010	32.29988	-83.4666	Pulaski	3070104	211PVDC	520	520	4/22/1981	10/23/1991	8
321656083275001	18S014	32.28238	-83.4638	Pulaski	3070104	211PVDC	450	450	10/29/1987	11/6/1989	2
321830083290901	18S020	32.30849	-83.4857	Pulaski	3070104	125DBLN	595	605	10/23/1991	10/23/1991	1
322245083290101	18T001	32.37932	-83.4835	Pulaski	3070104	211MDVL	1555	1555	6/23/1981	7/23/2015	182

Table 3-1. Study Area Cretaceous Aquifer Groundwater Monitoring Wells with Recent Data Records (continued)

USGS Site Number	Station	Latitude	Longitude	County	HUC	Aquifer Code	Well Depth (feet)	Hole Depth (feet)	Data Record Start	Data Record End	Data Count
323302083263401	18U001	32.5507	-83.4427	Twiggs	3070104	125DBLN	616	616	7/28/1975	7/23/2015	424
323300083263601	18U002	32.54848	-83.4468	Twiggs	3070104	211MDVL	1227	1560	12/9/1982	5/28/1998	99
323301083263601	18U003	32.54987	-83.4466	Twiggs	3070104	125DBLN	298	1545	7/29/1975	5/28/1998	152
324122083280401	18V005	32.68986	-83.4677	Twiggs	3070104	125DBMV	280	360	4/1/1968	11/7/1989	2
324116083281501	18V007	32.68709	-83.4691	Twiggs	3070104	125DBMV	225	345	3/1/1967	11/7/1989	5
324150083282901	18V010	32.69653	-83.4757	Twiggs	3070104	125DBMV	300	300	5/27/1976	11/7/1989	6
324750083281401	18W002	32.79764	-83.4705	Twiggs	3070103	125DBMV	395	552	3/18/1965	11/7/1989	18
324731083281401	18W013	32.79208	-83.4705	Twiggs	3070103	125DBMV	306	306	12/31/1944	11/7/1989	3

Notes:

Study Area is defined as Bibb, Crawford, Houston, Peach, Twiggs, and Pulaski Counties.

NR = No Record in the NWIS database

HUC = USGS Hydrologic Unit Code

USGS Aquifer Code Abbreviations:

DBLN = Dublin

DBMV = Dublin-Midville

PVDC = Providence

MDVL = Midville

Figure 3-2 shows the water level time history at wells 18U001 and 18T001. Water levels at these wells were relatively steady during the period from 1980 to 1995, ranging from approximately 278 to 281 feet at 18U001 and 275 to 278 feet at 18T001, and fluctuating on the order of 1 to 2 feet on a seasonal basis. Since 1995, however, water levels in both wells appear to have declined. Water-level elevations in well 18U001 (screened in the Dublin aquifer) have declined 6 feet from a high of approximately 281 feet in 1995 to approximately 275 feet in 2015. Water levels in well 18T001 (screened in the Eutaw-Midville aquifer) have declined approximately 8 feet, to approximately 269 feet in 2015. The low point for both wells (approximately 273 feet in 18U001 and 266 feet at 18T001) was observed in 2012; since that time, water levels appear to have increased slightly and stabilized somewhat. Seasonal water-level variations, with the lowest periods typically occurring in the late summer or autumn months, appear to be slightly more pronounced in recent years in both 18U001 and 18T001.

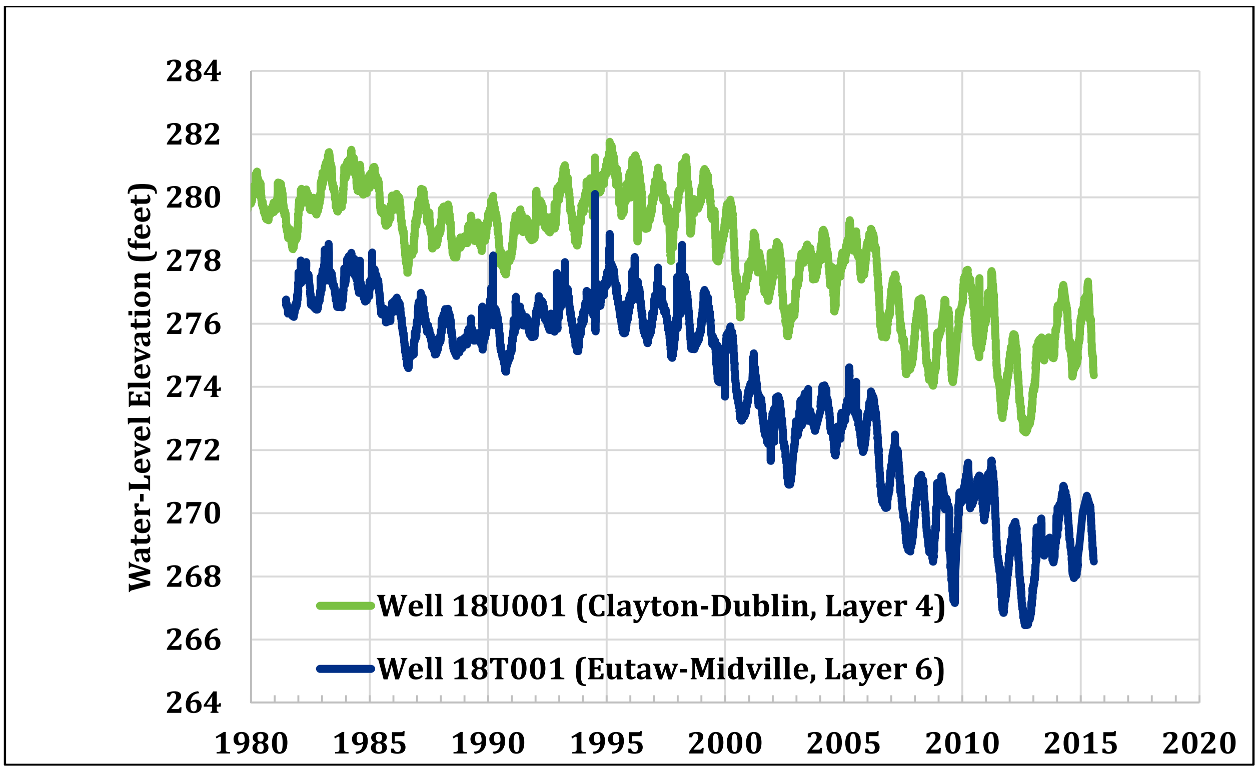


Figure 3-2
Groundwater-Level Elevations in Monitoring Wells 18U001 (Clayton-Dublin Aquifer) and 18T001 (Eutaw-Midville Aquifer)

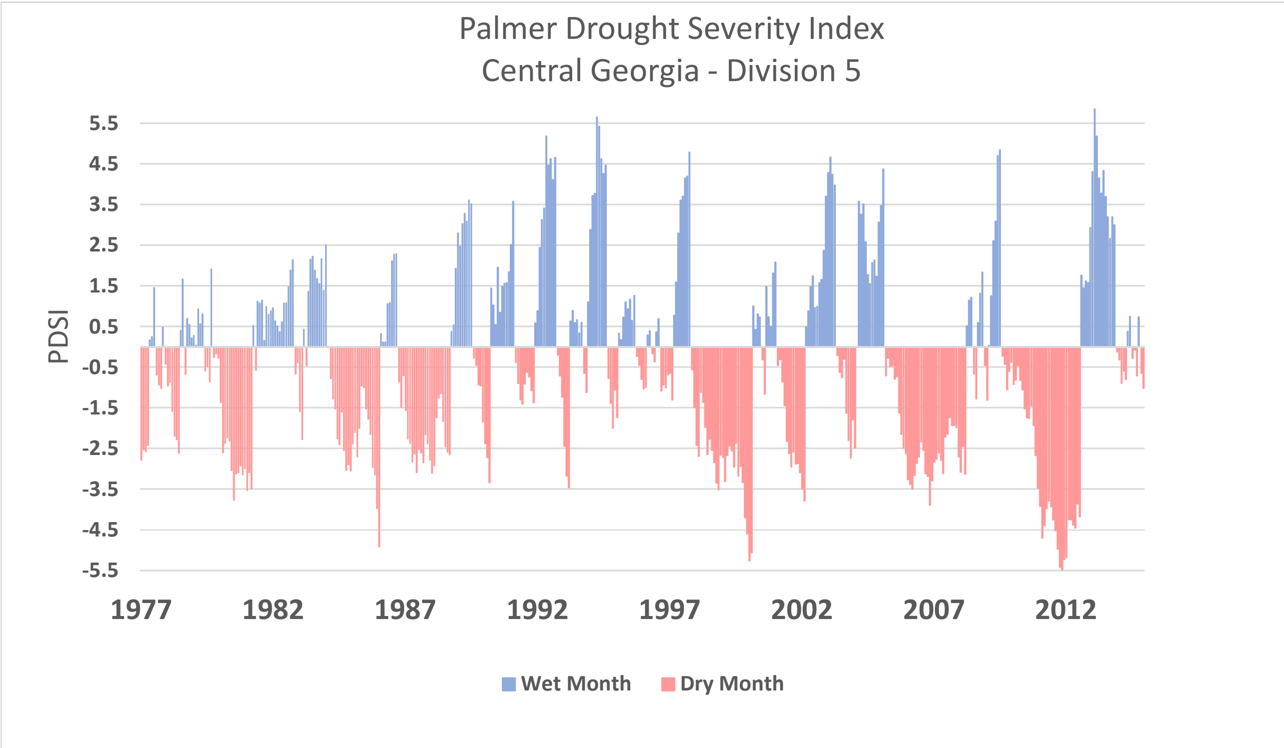
Over the past 35 years, water levels in well 18T001 typically have been between 2 and 8 feet lower than water levels in well 18U001, as shown on Figure 3-2, with that difference increasing in recent years compared to the elevation difference recorded in the 1980s.

To provide an example of how the data collected under the Middle Ocmulgee Water Planning Region's long-term monitoring plan may be analyzed to better understand climate and pumping impacts on aquifer water levels, the recent groundwater-level declines observed in wells 18U001 and 18T001 were reviewed, first to determine whether the water-level declines appear to correlate with recent climate conditions, and second to determine whether the water level decline may be related to recent patterns in pumping withdrawals. The water-level records for these two wells were compared to the Palmer Drought Severity Index (PDSI) and pumping records for the Study Area. The wells are not located adjacent to each other but appear to behave similarly; therefore, the similarity in the observed fluctuation in aquifer conditions that has occurred over the past few years in both wells indicates a likely response to a regional change in pumping or recharge patterns.

To compare water-level trends with climate variation, average monthly groundwater-level measurements for monitoring well 18U001 were posted next to monthly values for the PDSI (**Figure 3-3**). Positive PDSI values (blue) indicate wetter months, and negative PDSI values (red) indicate dry periods. The PDSI is calculated on a monthly basis, and a long-term archive of the monthly PDSI values for every climate division in the United States from 1895 through the present is maintained by the National Climatic Data Center (National Oceanographic and Atmospheric Administration [NOAA], 2016a). Groundwater-level trends in well 18U001 may be responding to climatological variations in wet and dry periods, with the recent decline likely attributable to at least three sustained dry periods since 1997. Annual precipitation in Macon, Georgia averaged approximately 1.6 inches below average from 1999 to 2014 (NOAA, 2016b). A relatively wet year, 2013, could be responsible for a modest water-level rebound in recent years from the lows observed in 2011 and 2012.

From 1985 to 2010, annual average pumping from the Cretaceous aquifer in the six counties in the Study Area varied from approximately 60 mgd to more than 80 mgd (Lawrence, 2015). The reported pumping rates were greatest in 2000 and 2005, approximately 10 to 15 percent higher than the average of the reported 1985 to 2010 pumping values. Since these years of somewhat increased pumping correspond with a period of generally falling water levels, increases in pumping may have also contributed to the observed trend in recent groundwater levels in Cretaceous monitoring wells 18T001 and 18U001.

Although less historical data are available for other Cretaceous aquifer wells, it may be worthwhile to consider these locations for inclusion in a monitoring program. Two other Cretaceous aquifer wells (18U002 and 18U003) are located adjacent to well 18U001. Their depths are 1,227 feet (Midville aquifer) and 298 feet (Dublin aquifer), respectively. Records of water-level measurements for these two wells were discontinued in 1998, and the current status of these wells is unknown. The remainder of the Cretaceous aquifer monitoring wells in the Study Area listed in the NWIS database have fewer than 20 data points. While data records for these wells are likely of limited use in establishing historical trends, it is possible that these wells may be of use in a future monitoring program, as discussed in Section 4.



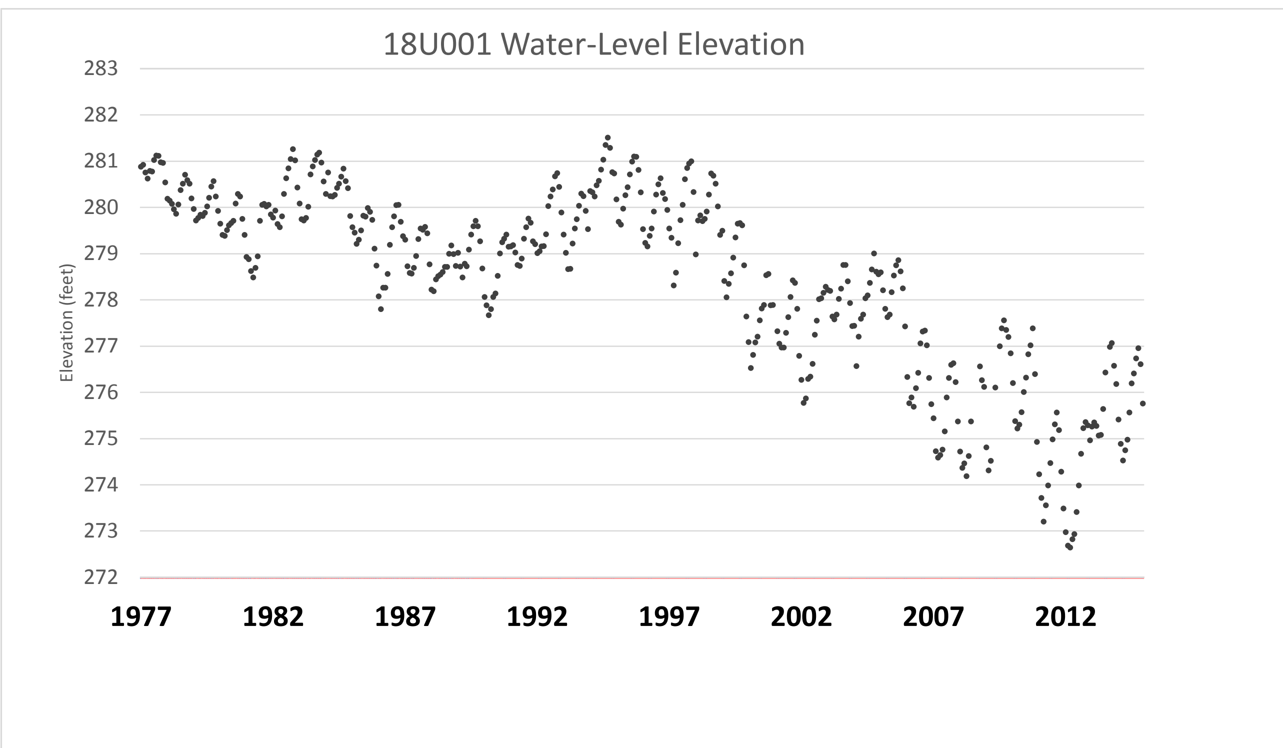


Figure 3-3
Palmer Drought Severity Index for Central Georgia and Groundwater-Level Elevations for Monitoring Well 18U001 (Clayton-Dublin Aquifer)

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3.2 Existing Surface Water Monitoring Locations and Available Discharge Data

Surface water gage locations (80 in total) within the Study Area listed in the USGS NWIS database are shown on **Figure 3-4**. Few lengthy records of stream discharge for the Study Area are available from the USGS NWIS database; however, eight of the gages (labeled on Figure 3-4 and listed in **Table 3-2**) have at least six years of daily discharge records available from the USGS NWIS database, most of which are for recent years.

Wetland areas identified in the 2011 National Land Cover Database (Homer et al., 2015) are also shown on Figure 3-4, mostly along the main stem river. Wetland areas and smaller tributaries may be more sensitive than other areas to reductions in groundwater levels that may result from increased groundwater withdrawals.

Table 3-2. Surface Water Gages in the Study Area with a Continuous Period of Record Exceeding Six Years

USGS Gage Number	Station Name	County	Average Daily Discharge (cubic feet per second)	Data Record Start	Data Record End
02213000	OCMULGEE RIVER AT MACON, GA	Bibb	2,860	1893	2015
02213500	TOBESOFKEE CREEK NEAR MACON, GA	Bibb	180	4/1/1937	2015
02213700	OCMULGEE RIVER NEAR WARNER ROBINS, GA	Bibb	1,600	11/16/1988	9/30/2006
02214075	ECHECONNEE CREEK AT HOUSTON RD, NEAR BYRON, GA	Peach	205	12/10/2009	2015
02214500	BIG INDIAN CREEK AT PERRY, GA	Houston	85	10/1/1943	7/31/1971
02214590	BIG INDIAN CREEK AT US 341, NEAR CLINCHFIELD, GA	Houston	130	12/10/2009	2015
02215000	OCMULGEE RIVER AT US 341, AT HAWKINSVILLE, GA	Pulaski	4,870	10/1/1928	10/4/2015
02215100	TUCSAWHATCHEE CREEK NEAR HAWKINSVILLE, GA	Pulaski	150	4/1/1986	2015

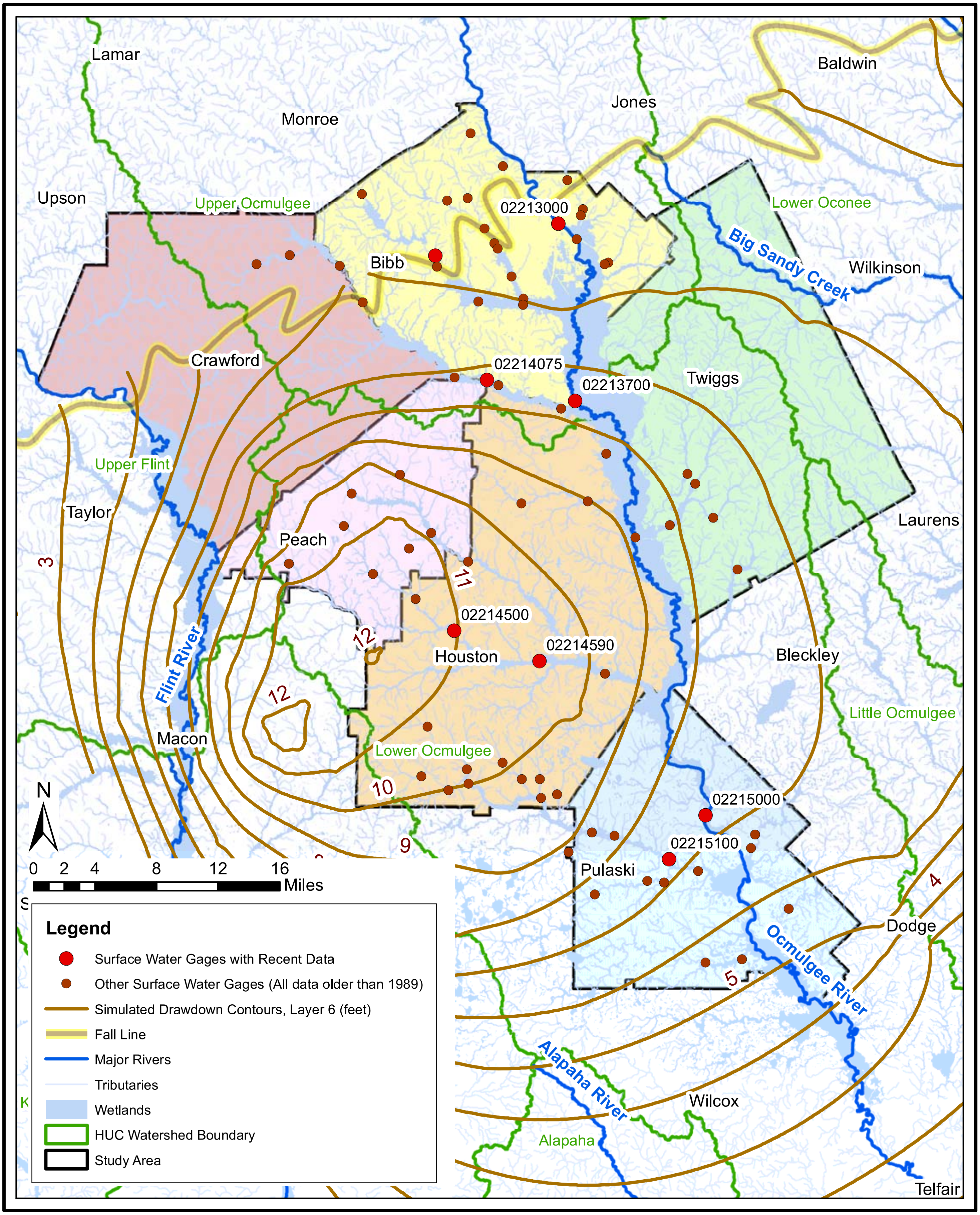

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Figure 3-4
USGS Stream Gage Locations in Study Area

3.3 Summary of Available Monitoring Locations

The following is a summary of existing monitoring locations compiled for use in evaluating existing conditions and that may potentially be useful for monitoring the impacts of increased groundwater withdrawals from the Cretaceous aquifer within the Study Area:

- 59 groundwater monitoring well locations screened in the Cretaceous aquifer. The number of wells listed by county is presented below. No wells were identified in Houston County:
  - Bibb County, 9 wells screened in the Dublin-Midville aquifer (aquifer code 125DBMV)
  - Crawford County, 25 wells: 8 wells screened in the Dublin-Midville aquifer (code 125DBMV), 15 wells screened in the Midville aquifer (aquifer code 211MDVL), and 2 wells screened in the Providence aquifer (aquifer code 211PVDC)
  - Peach County, 8 wells screened in the Midville aquifer (aquifer code 211MDVL)
  - Pulaski County, 6 wells: 4 wells screened in the Providence aquifer (aquifermcode 211PVDC), 1 well screened in the Midville aquifer (aquifer code 211MDVL), and 1 well screened in the Dublin aquifer (aquifer code 125DBLN)
  - Twiggs County, 11 wells: 8 wells screened in the Dublin-Midville aquifer (aquifer code 211DBMV), 2 wells screened in the Dublin aquifer (aquifer code 125DBLN), and 1 well screened in the Midville aquifer (aquifer code 211MDVL)
- 80 surface water gage locations:
  - Six surface water locations are monitored at least daily; daily discharge data may be downloaded from the USGS NWIS online database. Three of these locations are located on the main stem of the Ocmulgee River; the others are on the Tobesofkee, Echeconnee, Big Indian, and Tuscawhatchee Creeks, as described in Table 3-1.
  - Two additional surface water locations have been monitored extensively in the past. A gage on Big Indian Creek in Houston County was monitored daily from October 1943 to July 1971. Average discharge rates indicate this is a minor tributary. There is also a fourth gage on the main stem of the Ocmulgee River at US 341 at Hawkinsville in Pulaski County that has a robust daily data record from 1928 through the beginning of October 2015. It is unknown whether data collection will be continued at this gage.

In addition to the data available from the USGS NWIS database, the Georgia Environmental Protection Division (EPD) indicated that pumping records and static water-level measurements for supply wells may be available in a database of information reported by water purveyors on a monthly or annual basis. In general, there are inherent uncertainties associated with collecting static water-level measurements at active production wells (e.g., regarding whether the aquifer was allowed to sufficiently recover to true static conditions representative of the surrounding aquifer prior to measurement, and even which aquifer is represented by the measurement due to long well screens common at production wells or possible uncertainties in well construction records for older wells). Nevertheless, for some wells these data may prove to be of value in augmenting a monitoring program. The data should first be gathered and evaluated for its potential usefulness.

4. Recommendations for Long-Term Monitoring to Track Impacts of Groundwater Withdrawals from the Cretaceous Aquifer

Recommendations for a monitoring plan were developed based on a review of existing groundwater and surface water monitoring data for the Cretaceous aquifer in the Study Area and the State Water Plan groundwater resource assessments completed in 2012. Both low-end and high-end groundwater model sustainable yield simulations completed for the State Water Plan suggested that a reduction in groundwater elevations and groundwater baseflow to streams may occur with increased Cretaceous aquifer groundwater withdrawals, but that groundwater drawdowns and groundwater baseflow in the Study Area would not fall below the sustainable yield metrics.

A long-term monitoring plan will allow the Middle Ocmulgee Water Planning Region to evaluate the impacts of pumping increases from the Cretaceous aquifer. General monitoring plan components are presented below followed by specific recommendations for the Middle Ocmulgee Water Planning Region based on this study.

4.1 Typical Monitoring Plan Development Tasks

Monitoring plans, whether short-term or long-term, require that certain elements be considered or completed so that the data and information collected can meet the plan objectives. Recommended elements for a monitoring plan designed to assess the impacts of pumping withdrawals on groundwater and surface water resources may include the following:

1. *Clearly stated monitoring plan objectives that address important local concerns.* In addition to monitoring impacts to water levels, stream discharges, and water quality in the areas of greatest expected changes (i.e., the areas of concern as described in this report), the objectives for a monitoring plan may be linked to particular stakeholder concerns or sensitive ecological areas, such as wetlands known to contain rare, threatened, or endangered species. Monitoring plan objectives should be documented to guide development and implementation of the plan and assessment of the program.

2. *Metrics for assessing data collected and separating impacts due to groundwater withdrawals from normal climate variation in the data.* The long-term monitoring plan should establish *a priori* appropriate metrics and data collection intervals that allow for consistent data interpretation. The proposed use or purpose of any data compiled or collected as part of the monitoring program should be described. Justification for establishing the frequency of data collection should also be documented.

3. *A plan to continue to compile and track data currently being collected for other programs.* For example, data on groundwater withdrawals, static water-level measurements for production wells, and local precipitation data are currently collected by various entities. The monitoring plan should include documentation of the sources of useful data collected by others and identification of a means to obtain and analyze the data on a regular basis.

4. *A network of monitoring locations where data will be collected.* A large number of monitoring locations is not required; however, a sufficient number of locations to ensure proper coverage of groundwater conditions both laterally and vertically within the Cretaceous aquifer units should be selected for inclusion in the monitoring network to gather data to assess potential impacts where there are priority concerns. New locations may be phased in to fill data gaps as resources allow or priorities warrant.

5. *Sampling and analysis plan for data collection.* The sampling and analysis plan documents field protocols and intervals for measuring groundwater levels, performing surface water discharge measurements, and collecting water quality data (as may be necessary to meet the monitoring plan objectives). The sampling and analysis plan should include a health and safety plan for field personnel.

6. *A quality assurance program plan (QAPP).* The QAPP is a formal guide for reproducible data collection and implementation of the sampling and analysis plan over a period of many years. Documentation of data quality objectives is an essential component of the QAPP. In addition, standard operating procedures (SOPs) for field procedures and laboratory analysis (if required), which would typically include specifications for any equipment or instrumentation to be utilized for data collection, are also included in the QAPP. Many state agencies already have plans in place that either could be used as umbrella documents, or could potentially be amended to incorporate new monitoring programs.

7. *Data management plan.* A data management plan is necessary for organizing and storing the data once it has been collected.

8. *Assessment of baseline conditions.* Baseline conditions should be established for each of the monitoring well and surface water gage locations in the monitoring network at the beginning of the program to establish a basis for comparison with future data. Existing data should be compiled from available sources and supplemented with data from new monitoring locations. An assessment of baseline conditions may include stakeholder outreach to identify locations particularly vulnerable to the impacts of groundwater drawdown.

9. *Identification of resources and assignment of responsibilities.* Resources and responsibilities for implementation of the monitoring plan should be identified in the following areas:

    - Installing and instrumenting new locations for the monitoring network
    - Collecting and compiling readily available data, including pumping records, surface water withdrawal data, and online water-level and discharge data
    - Conducting the field program
    - Comprehensively assessing and evaluating data at pre-determined intervals
    - Providing oversight and review of the plan implementation, including reviews of the data collected, as described below.

10. *Plan to review and reevaluate.* A plan to review the data collected and to reevaluate the monitoring network should be developed. In addition to regular periodic reviews (e.g., annually), it may be appropriate to perform a review at other times, such as when major new groundwater withdrawals are planned or proposed, or when adverse impacts are observed or suspected. The plan for periodic review and evaluation would include specific criteria for triggering a more detailed, in-depth, or frequent review. At the time of review, priorities can be reassessed and the monitoring emphasis can be re-focused as needed to protect vulnerable ecological or water-supply resources. In addition, the frequency of data collection can be reevaluated and adjusted, if necessary.

Consultation with outside agencies such as USGS and other local, state, or federal agencies that may be potential sources of data or users of data collected under the program is recommended. Outside agencies may provide valuable information or guidance on the field program, so that data collected are acceptable for use by multiple agencies.

4.2 Recommendations for Monitoring in the Ocmulgee Watershed

The following activities should be performed prior to developing a long-term monitoring plan for the Ocmulgee watershed:

- Conduct stakeholder meetings and surveys to identify drivers and monitoring plan objectives
- Assess Cretaceous aquifer baseline conditions using existing information and monitoring locations
- Develop long-term monitoring plan

These activities are described below.

4.2.1 Conduct Stakeholder Meetings and Identify Monitoring Plan Focus and Objectives

Prior to finalizing monitoring objectives customized for the Study Area, it is necessary to confirm the locations of the resources most sensitive to the effects of lower water levels in the Cretaceous aquifer. The analysis presented in this document has helped to narrow the focus of additional investigation to the general areas that may be affected by increased drawdown, i.e., Peach and Houston Counties, assuming that increases in future groundwater withdrawals will primarily occur in the vicinity of existing pumping locations. However, the monitoring plan should also consider that seasonally dry periods or droughts could exacerbate the effects of pumping increases on sensitive target areas anywhere in the study area. Examples of resources that potentially could be impacted by increases in Cretaceous aquifer withdrawals include rare, endangered, and threatened species that are dependent on smaller tributaries; wetlands in the northern part of the Study Area where the Cretaceous aquifer may be in direct hydraulic contact with those resources; and shallow groundwater wells used for agricultural irrigation.

Specific users (or environmental resources) that may be the most sensitive to changes in groundwater levels within the Study Area were not identified or mapped as part of this study.

Additional investigation may be necessary to locate and map those resources most sensitive to lower groundwater levels within the Study Area. Some of these resources, such as Priority Conservation Areas and fish and wildlife resources, are identified in the Middle Ocmulgee Regional Water Plan (September, 2011). A stakeholder survey should be conducted to identify any other specific concerns (or locations of concern) associated with decreases in groundwater levels that have not already been identified.

4.2.2 Assess Baseline Conditions Based on Existing Information

Additional recommendations to establish baseline conditions within the Study Area include the following:

1. Recent static water-level data collected for supply wells may be compiled and analyzed to assess its potential usefulness in supplementing data collected for conventional monitoring wells.

2. A baseline assessment of existing water quality should be performed for at least a few deeper monitoring wells screened in the deeper intervals of the Eutaw-Midville aquifer, particularly near larger existing pumping centers drawing from similar intervals. Potential analytical parameters include major ions (sodium, calcium, magnesium, bicarbonate, sulfate and chloride), as well as other inorganic, and if needed, organic analytes. Selected analytes would be based on monitoring plan objectives and if appropriate stakeholder input. Installation of one or more Upper Atkinson wells in the area(s) where water quality concerns may exist may also be considered to provide selected monitoring well pairs that could be used to evaluate vertical hydraulic gradients. These wells could verify the hydraulic response to pumping that is inferred from the model simulations, and water quality from the well(s) could be used in the evaluation of potential water quality changes. Groundwater in the underlying Upper Atkinson aquifer is reportedly of poor quality, and the sustainable yield simulations suggest that pumping from the Eutaw-Midville aquifer has an influence on water levels in Upper Atkinson wells, in that layer 7 (Upper Atkinson aquifer) experiences similar drawdown as layer 6 (Eutaw-Midville aquifer) in the model simulations. It is unknown whether this influence is likely to be sufficient to induce significant upward migration of water from the Upper Atkinson aquifer; nevertheless, by characterizing current water quality in the lower Eutaw-Midville aquifer, any water quality changes in deeper zones could be identified.

3. Field visits should be conducted to gather or confirm information about the suitability of potential monitoring locations to include in the network of groundwater and surface water monitoring stations for the monitoring plan. Rehabilitation of existing monitoring wells and surface water gages, or installation of new wells and gages, should be considered to fill in data gaps. Details of evaluating the existing wells (examples include the use of video logging, downhole geophysics, etc.) should be outlined in the sampling and analysis plan. Preliminary lists of potentially suitable existing locations from the USGS NWIS database for groundwater and surface water stations are included as Tables 1 and 2.

4. The two Cretaceous groundwater monitoring wells, 18U001 and 18T001, should be included in the baseline evaluation as well as a long-term monitoring program. Water-level data are

readily available for download for these wells from the USGS NWIS website. Both wells provide a long record of historical data for analysis of water-level trends. Although less historical data are available for other locations, it may be worthwhile to consider other groundwater monitoring wells and surface water gage locations shown on Figures 3-1 and 3-4 for inclusion in the monitoring program.

5. The baseline evaluation should include a review of groundwater withdrawal data to evaluate the effect of pumping on groundwater elevations. Historical pumping data should be compiled from within the six counties, as well as from production wells located in Macon and Dooley Counties near the community of Perry, where future impacts from increased Cretaceous aquifer pumping withdrawals may be most pronounced.

4.2.3 Develop Long-Term Monitoring Plan

A long-term monitoring plan should be developed following the guidelines presented in Section 4.1, and based on the results of the stakeholder surveys and baseline evaluation described above.

Both the baseline assessment and the long-term monitoring plan should be coordinated with efforts and data collected by other local, state, or federal agencies, to the extent possible. The agencies may be able to provide additional information on the status of existing monitoring locations or potential new monitoring well locations in key areas, or they may gather pertinent pumping records, well construction data, or groundwater-level, surface water discharge, or water quality data not reflected in the USGS NWIS database. Furthermore, these agencies may be able to provide input on monitoring plan objectives and appropriate data quality objectives.

5. Summary

CDM Smith has developed groundwater and surface water monitoring plan recommendations for six counties in the Middle Ocmulgee Water Planning Region that primarily utilize groundwater from the Cretaceous aquifer for water supply. These recommendations were developed in response to concerns raised by the Middle Ocmulgee Water Planning Region regarding the potential impacts of increased groundwater withdrawals in the area. The area of focus for these recommendations includes Bibb, Crawford, Houston, Peach, Twiggs, and Pulaski Counties.

Monitoring plan recommendations were developed based on a review of existing groundwater and surface water data for the watershed and the State Water Plan groundwater resource assessments completed in 2012. General elements that should be considered in the development of a monitoring plan and specific recommendations for next steps for the Middle Ocmulgee Water Planning Region are presented. Recommended tasks that should be completed first include meeting with stakeholders in the planning council area, including other local, state, or federal agencies, to define the objectives of the monitoring program and then conducting a baseline data evaluation for the area that builds on the information presented in this report and incorporates other available existing data.

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APPENDIX D

Task 4

Upper Flint Water Planning Region: Sustainable Yield of the Cretaceous Aquifer System in the Upper Flint River Basin

Prepared for:
Georgia Department of Natural Resources
Environmental Protection Division

CDM Smith

ARCADIS Design & Consultancy for natural and built assets

May 8, 2017

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Task 4

Upper Flint Water Planning Region: Sustainable Yield of the Cretaceous Aquifer in the Upper Flint River Basin

1. Introduction

CDM Smith prepared this report in support of the Georgia Comprehensive State-wide Water Plan. The report describes groundwater model simulation analyses to estimate the sustainable yield of the Cretaceous aquifer in the Upper Flint River drainage basin. Sustainable yield is estimated as a range based on steady-state simulations of different levels of pumping and assessment of potential local or regional impacts.

1.1 Background

In February 2008, the Georgia General Assembly adopted the Georgia Comprehensive State-wide Water Plan (State Water Plan) dated January 8, 2008. The State Water Plan established a regional water resources management planning process, which was initiated in the Fall of 2008. As directed by the State Water Plan, groundwater and surface water resource assessment modeling was conducted to evaluate water availability and potential shortfalls (or gaps) for current and future (2050) water supply demands. The assessments were designed to help Regional Water Planning Councils identify areas where management actions may be needed to ensure that a region's resources can meet long-term demands for water supply. Summaries of groundwater and surface water resource assessments are presented in Regional Water Plan documents developed for different water planning regions.

The Upper Flint Regional Water Planning Council (Upper Flint Council) is one of 11 planning regions established throughout the state. The Upper Flint Council area includes Crisp, Dooley, Merriweather, Pike, Talbot, Taylor, Marion, Schley, Macon, Webster, Spalding, Upson, and Sumter Counties, and is shown on **Figure 1-1.** The Fall Line, which represents the northern extent of the Coastal Plain sediments is also shown on Figure 1-1. The Cretaceous aquifer is part of the Coastal Plain aquifer system in Georgia. This study focuses on the portion of the Upper Flint Council area south of the Fall Line, where the Cretaceous aquifer exists.

In 2009 and 2010, the availability of groundwater resources in select prioritized aquifers of Georgia was evaluated. The assessment was completed to support the Regional Water Development and Conservation Plans as part of the State Water Plan. The prioritized aquifers included the Floridan aquifer in south-central Georgia and the eastern Coastal Plain of Georgia, the Claiborne aquifer, the Clayton aquifer, and Cretaceous aquifer systems. In this earlier work, the Cretaceous aquifer study area covered the Cretaceous Aquifer between Macon and Augusta, Georgia. The Cretaceous aquifer in the Upper Flint River watershed was not included in the initial selection of prioritized aquifers. 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.

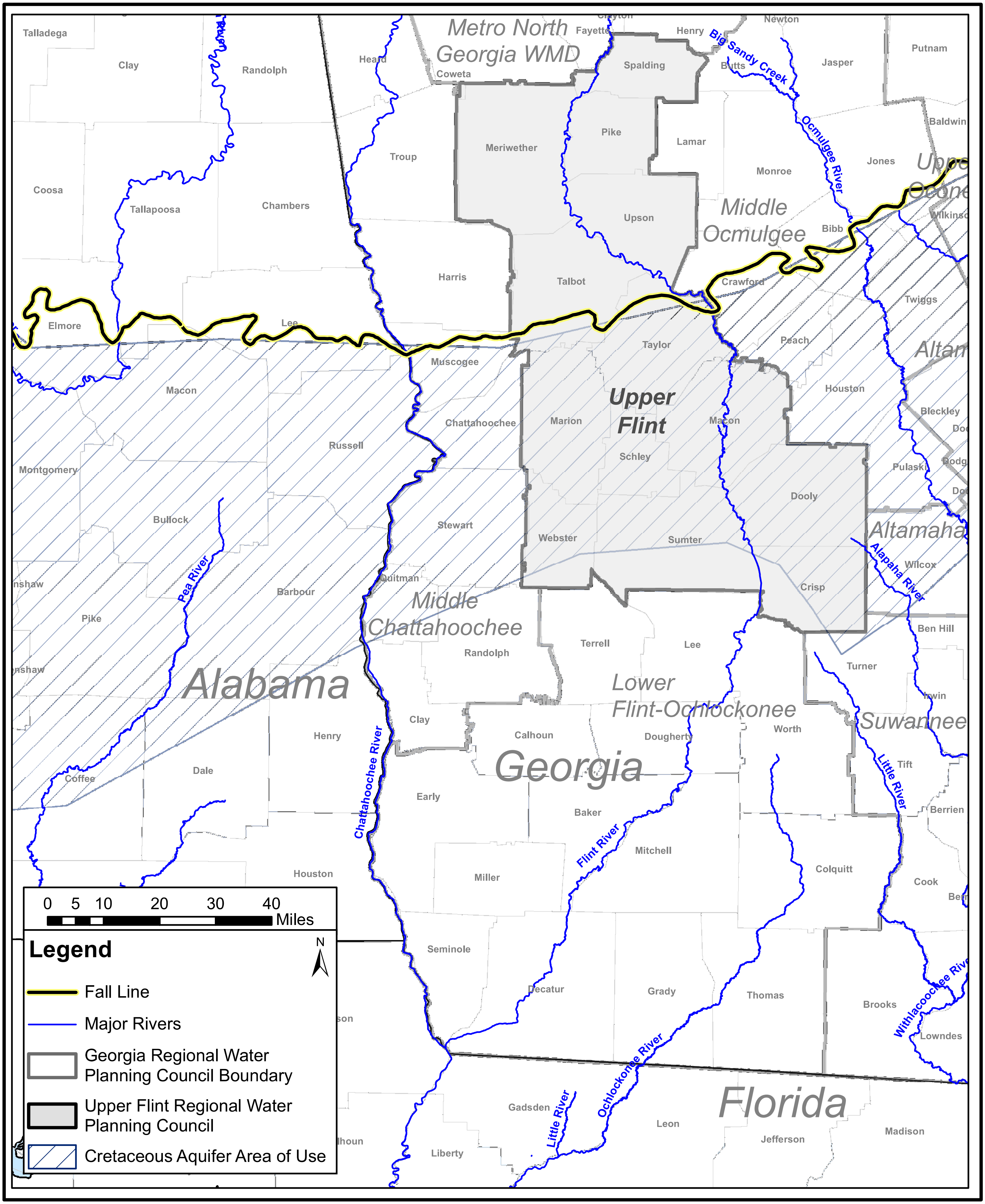

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Figure 1-1
Upper Flint Regional Water Planning Council Area

1.2 Approach

This report presents groundwater flow model simulations completed to estimate the sustainable yield of the Cretaceous aquifer in the Upper Flint Council area. CDM Smith completed the following tasks for this study:

- Reviewed the Regional Coastal Plain Model developed for the State Water Plan and associated sub-regional models for potential application to this study (CDM, 2011a; CDM Smith, 2012a, 2012b). The Southwest Georgia Sub-Regional Model (SW Georgia Model) was selected because the computational grid is somewhat finer than the regional model, and the model domain is appropriate for evaluating groundwater conditions in the Cretaceous aquifer in the Upper Flint Council Area. The SW Georgia Model was developed after the other State Water Plan sub-regional models, and as such was not available for groundwater resource assessments completed in 2009 – 2011.
- Applied the SW Georgia Model in steady-state mode to estimate Cretaceous aquifer sustainable yield in the Upper Flint Council area. This was done by first developing a baseline simulation, and then increasing simulated Cretaceous aquifer pumping in the Upper Flint Council area as high as possible without exceeding pre-established sustainable yield criteria. A range of sustainable yield values was developed based on different spatial distributions of the increased pumping assignments.

1.3 Report Organization

The remainder of this report is organized as follows:

- Section 2 provides an overview of the State Water Plan groundwater resource assessment and the groundwater models developed and applied for that study.
- Section 3 presents a summary description of the SW Georgia Model used for the sustainable yield analysis and presents the baseline simulation for the sustainable yield assessment, including a summary of the irrigated acreage data and assumptions used to estimate the agricultural groundwater use. Estimates of municipal and industrial pumping in the study area are also summarized.
- Section 4 presents the results of the Cretaceous aquifer sustainable yield model simulations.
- Section 5 presents a summary of the study.
- Section 6 provides a list of references used in this study.

2. Overview of State Water Plan Groundwater Resource Assessment

2.1 Assessment Approach and Criteria

In 2009 and 2010, the availability of groundwater resources in select prioritized aquifers of Georgia was evaluated. The assessment was completed to support the Regional Water Development and Conservation Plans as part of the State Water Plan. The prioritized aquifers included the Floridan aquifer in south-central Georgia and the eastern Coastal Plain of Georgia. Other prioritized aquifers included the Claiborne aquifer, Clayton aquifer, and the Cretaceous aquifer in southeast and south-central Georgia, between Macon and Augusta.

Numerical steady-state groundwater flow models were developed for the State Water Plan to support the groundwater availability assessments. The results of groundwater flow model simulations with increased pumping in the prioritized aquifers were compared with baseline simulations representing existing conditions to estimate local impacts of the increased pumping. The simulated changes in water-level elevations and groundwater baseflow to streams were compared with sustainable yield criteria developed for the State Water Plan study. The analysis was designed to aid Regional Water Planning Councils in identification of areas where management actions may be needed to ensure that a region's resources can meet long-term demands for water supply. Results do not necessarily identify levels of water use that will compromise the long-term viability of the resource.

Formulation of the sustainable yield criteria for the groundwater resource assessments is presented in Section 11 of the document titled *Groundwater Flow Modeling of the Coastal Plain Aquifer System of Georgia* (CDM, 2011a). A summary of the criteria is presented below.

For the purposes of the groundwater resource assessments, sustainable yield was defined as the maximum amount of groundwater withdrawal that could occur from defined extraction points within each aquifer without violating sustainable yield metrics (i.e., thresholds selected to indicate potential local or regional impacts to address in the regional planning process). The following metrics were applied, with some variations depending on the prioritized aquifer being studied and the level of detail provided by the respective models used to assess sustainable yield:

- Drawdowns of groundwater levels in the pumped aquifer do not exceed 30 feet between pumping wells;
- Pumping was limited to levels that would not decrease mean annual stream baseflow by more than 40 percent;
- 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.

The primary metrics that applied to the earlier sustainable yield analysis for the Cretaceous aquifer were the first two listed above which pertain to drawdown and impacts to baseflow. Using an analysis approach consistent with the earlier study, these two criteria were also used to guide the development of sustainable yield estimates for the Cretaceous aquifer in the Upper Flint Council area, as described in this report.

2.2 Georgia Regional Coastal Plain Groundwater Model

The Georgia Regional Coastal Plain Model (domain shown on **Figure 2-1**) was developed in 2009-2010 to support the State Water Plan sustainable yield assessments (CDM, 2011a). For this purpose, an existing regional United States Geological Survey (USGS) Coastal Plain Clastic Aquifer System Model was modified and updated, including expanding the model domain, refining the computational grid, and incorporating available local data in and near the prioritized study areas.

Vertically, the model includes the entire Georgia Coastal Plain aquifer sequence down to the Cretaceous aquifer system. Prioritized aquifers for the assessment included the Floridan, Claiborne, Clayton, and Cretaceous aquifer systems. The regional model was calibrated using available hydrogeologic data and observed groundwater elevations at monitoring wells under steady-state conditions. Regional model simulations have been conducted in steady-state mode only.

The regional model was revised in 2010-2011 to incorporate new data on agricultural groundwater withdrawals and an expanded representation of river-groundwater interaction (i.e., the number of river nodes was increased to include smaller tributary streams that were not previously represented). The agricultural, municipal, and industrial steady-state pumping in the 2010-2011 revised regional model represents annual average groundwater withdrawals for the year 2010. The regional model with revised pumping and river representation was recalibrated in steady-state mode. The recalibration included modifications to model hydraulic properties and boundary conditions (CDM Smith, 2012a).

2.3 Sub-Regional Models

Sub-regional models were initially developed for the Floridan aquifer in south-central Georgia and the eastern Coastal Plain of Georgia, the Claiborne aquifer, and the Cretaceous aquifer between Macon and Augusta (Figure 2-1). The sub-regional models were used to develop sustainable yield estimates for the corresponding aquifers. Except for model grid spacing and model domain limits, the sub-regional and regional models are generally consistent in terms of model layering, aquifer properties, and other model input parameter values. The initial Floridan, Claiborne, and Cretaceous sub-regional models were calibrated in transient as well as steady-state mode.

The sub-regional models for the Cretaceous aquifer and the Claiborne aquifer, as well as the regional model, were recalibrated in 2010-2011 to incorporate new data on agricultural groundwater withdrawals and an expanded representation of river-groundwater interaction (CDM Smith, 2012a). At that time, CDM Smith also developed and calibrated a sub-regional model for the Clayton aquifer based on the updated regional model (CDM Smith, 2012b). The agricultural, municipal, and industrial steady-state pumping in the 2010-2011 sub-regional

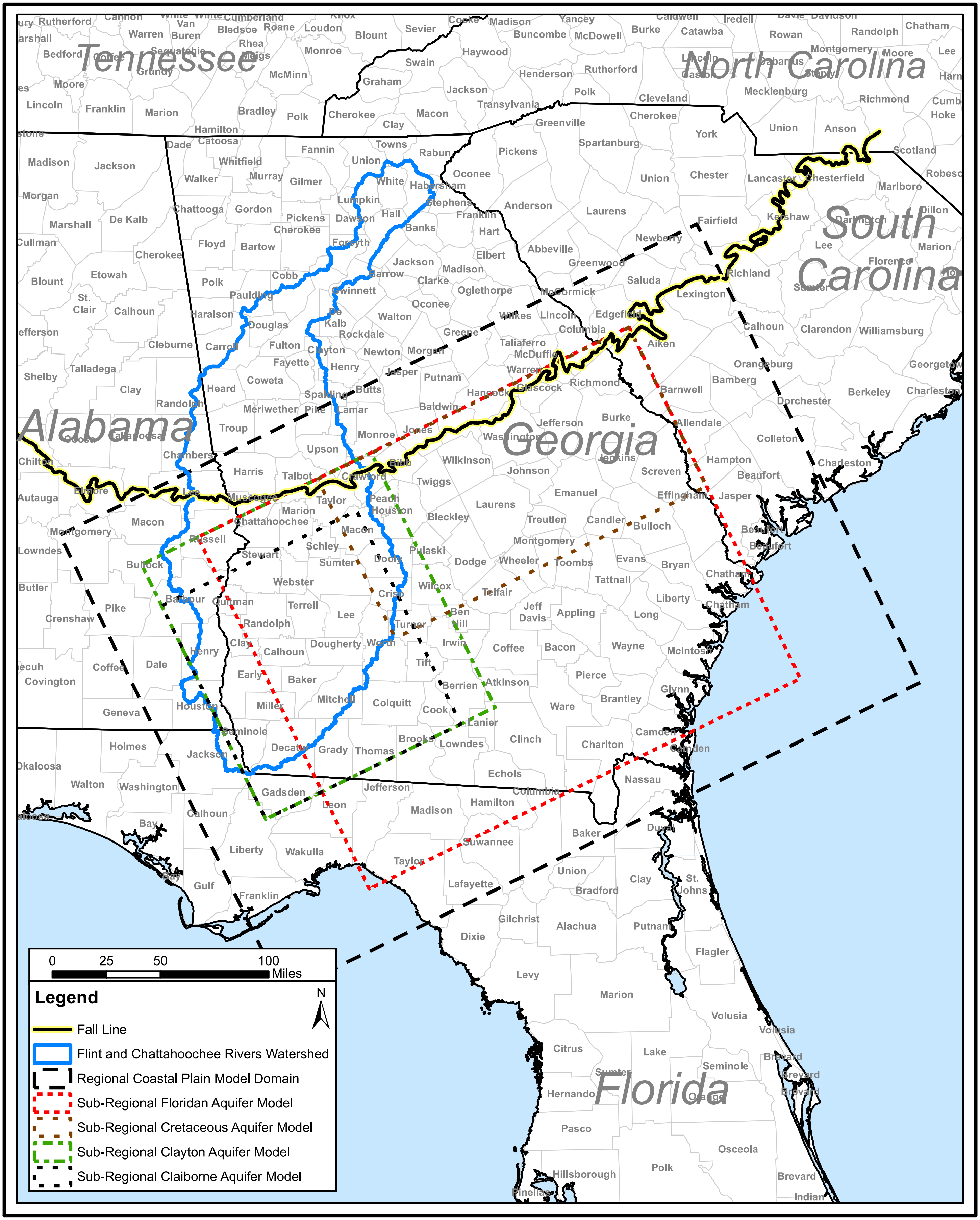


Figure 2-1
Georgia State-Wide Water Plan Groundwater Models

models represent annual average groundwater withdrawals for the year 2010. The revised Cretaceous and Claiborne sub-regional models were recalibrated and applied in steady-state mode. The Clayton sub-regional model also was calibrated and applied in steady-state mode.

3. Southwest Georgia Sub-Regional Model

After the groundwater resource assessments were completed for the State Water Plan, an additional sub-regional model was developed that encompasses the Flint River drainage basin within the Coastal Plain area of southwest Georgia. The Southwest (SW) Georgia Model was initially developed as a steady-state model with the same layering, hydraulic properties, recharge, and river representation as the updated/revised (2010 - 2011) regional and sub-regional models.

More recently, the SW Georgia Model was modified and updated. SW Georgia Model modifications, calibration results, and a summary of the model framework are presented in *Lower Flint-Ochlocknee Water Planning Region: Capacity of the Claiborne and Cretaceous Aquifers to Replace Agricultural Surface Water Withdrawals in the Lower Flint River Basin* (CDM Smith, 2017; manuscript in preparation).

3.1 Modeling Code

The SW Georgia Model was developed using MODFLOW 2000 (Harbaugh et al., 2000), a publicly available and widely used three-dimensional finite difference groundwater modeling code developed by USGS. The Regional Georgia Coastal Plain Model and the other associated sub-regional models were also developed using the MODFLOW code.

3.2 Model Domain and Grid

The model domain is shown on **Figure 3-1** and includes the entire Flint River drainage basin within the Georgia Coastal Plain area. The northern limit of the Coastal Plain aquifer system is the contact with the metamorphic/igneous rocks of Precambrian and Paleozoic age at the Fall Line, which marks the up-dip extent of the Coastal Plain sediments.

The SW Georgia Model domain is subdivided into a computational grid consisting of 445 rows and 264 columns with uniform grid cells of 2,000 feet by 2,000 feet, consistent with the other sub-regional models. Unlike the regional Georgia Coastal Plain Model and the other associated sub-regional models, the SW Georgia Model is oriented north-south and east-west with no rotation. This orientation better aligns with the Flint River drainage basin area. The model origin, relative to the North American Datum of 1983 (NAD83) State of Georgia West Zone Planar coordinate system is: X: 956,400 feet, Y: 162,300 feet.

3.3 Model Layering

Figure 3-2 presents a hydrostratigraphic (aquifers and confining layers) cross section of the study area. The SW Georgia Model, consistent with the other State Water Plan groundwater flow models, contains seven layers numbered from top to bottom representing different aquifer systems within the Coastal Plain. In the Flint River basin vicinity, the model layers are:

- Layer 1 – Surficial/Brunswick Aquifers. In the SW Georgia Model, where layer 1 is active it represents the Surficial aquifer.

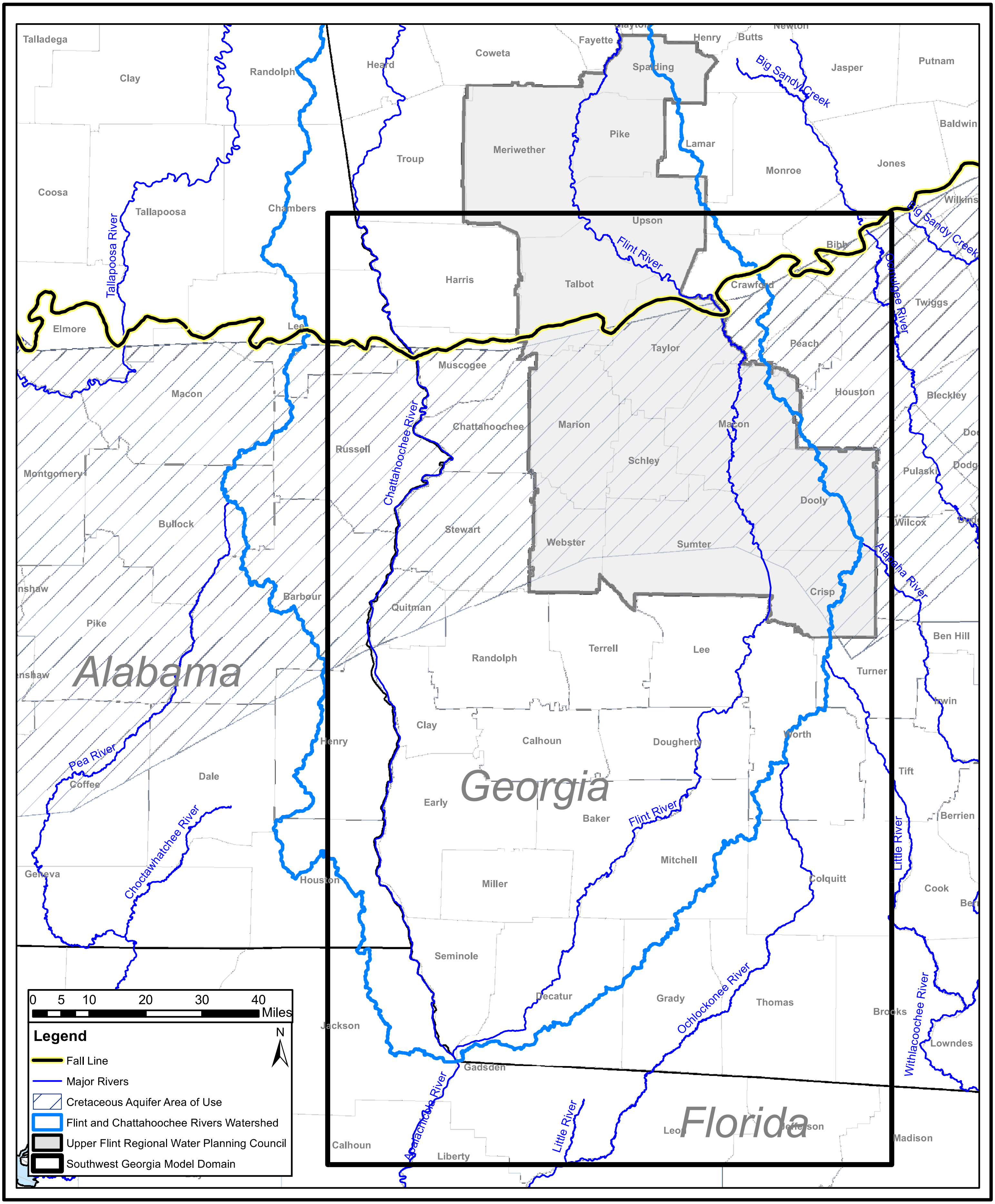
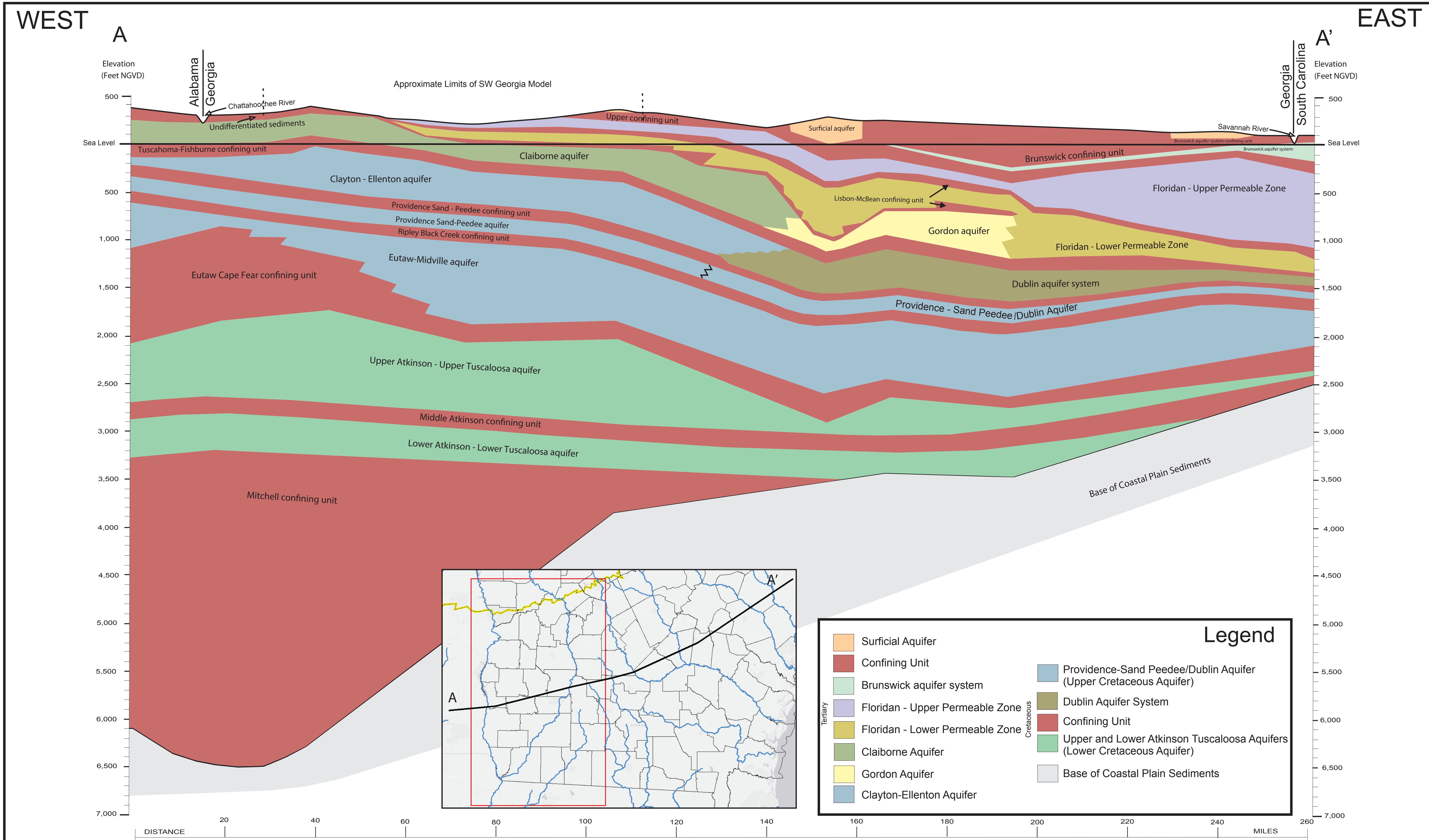


Figure 3-1
Southwest Georgia Model Domain



Source Modified from Renken, 1996; Miller, 1990 and Miller, 1986

CDM Smith

Figure 3-2
East - West Hydrostratigraphic Cross Section (A-A') Through the Study Area

- Layer 2 – Floridan Aquifer Upper Permeable Zone (designated in earlier documents as Upper Floridan Aquifer).
- Layer 3 – Claiborne/Floridan Aquifer Lower Permeable Zone (formerly designated as Lower Floridan Aquifer)/Gordon Aquifer. In the Upper Flint Council area, model layer 3 represents the Claiborne aquifer.
- Layer 4 – Clayton and Dublin (Cretaceous) Aquifers. In the Upper Flint Council area, model layer 4 represents the Clayton aquifer.
- Layer 5 – Providence Sand-Peedee-Dublin Aquifers (Cretaceous). In the Upper Flint Council area, model layer 5 is the Providence Sand Aquifer (Cretaceous).
- Layer 6 – Eutaw-Midville Aquifer (Cretaceous).
- Layer 7 – Upper Atkinson-Upper Tuscaloosa Aquifer (Cretaceous).

3.4 Perimeter Boundary Conditions

The following is a description of the perimeter boundary conditions applied in the transient SW Georgia model.

- A no-flow boundary condition is assigned everywhere to the bottom of the model (layer 7).
- A no-flow boundary condition is also applied at the Fall Line, which is the northern limit of the coastal plain aquifer system.
- A specified (constant) head boundary condition is assigned to model layer 1 (Surficial aquifer system) where layer 1 is active.
- Elsewhere, the top of the model in the outcrop areas is represented by a steady-state, model-simulated phreatic water-level surface.
- General head boundary (GHB) cells are assigned to the east, west and south perimeters of the model.

3.5 Baseline Simulation for Sustainable Yield Analysis

Simulated steady-state Cretaceous aquifer heads and simulated groundwater baseflow to rivers in the SW Georgia Model representative of recent groundwater pumping conditions were used to define the baseline conditions for the sustainable yield analysis. Groundwater pumping and model boundary condition assignments for the baseline simulation are described below.

3.5.1 Groundwater Withdrawals

Groundwater model assignments of withdrawal locations, depths, or aquifers and pumping rates within Georgia were developed based on agricultural irrigation metering data and Georgia Department of Natural Resources Environmental Protection Division (Georgia EPD, or EPD) databases.

For areas at the southern and western edges of the model domain that are outside of the state of Georgia, the pumping assignments were taken from the Regional Coastal Plain Model. The total pumping rate in the SW Georgia Model outside of Georgia (i.e. Florida and Alabama) is approximately 60 million gallons per day (MGD).

Agricultural Withdrawals

CDM Smith mapped and reviewed the EPD inventory of irrigated agricultural parcels in southwest Georgia (WettedAcres_2014_Deliverable_20160211.7z received March 25, 2016). The inventory indicates the water source(s) for each irrigated parcel, whether it is surface water, groundwater, or both surface water and groundwater. Parcels that are served by both surface water and groundwater are typically users that withdraw groundwater and store the water in on-site ponds before using it for irrigation. These ponds are also believed to receive surface run-off that contributes to the volume of water in the pond. Irrigated acreages for parcels within the SW Georgia Model domain are listed by water source in **Table 3-1.**

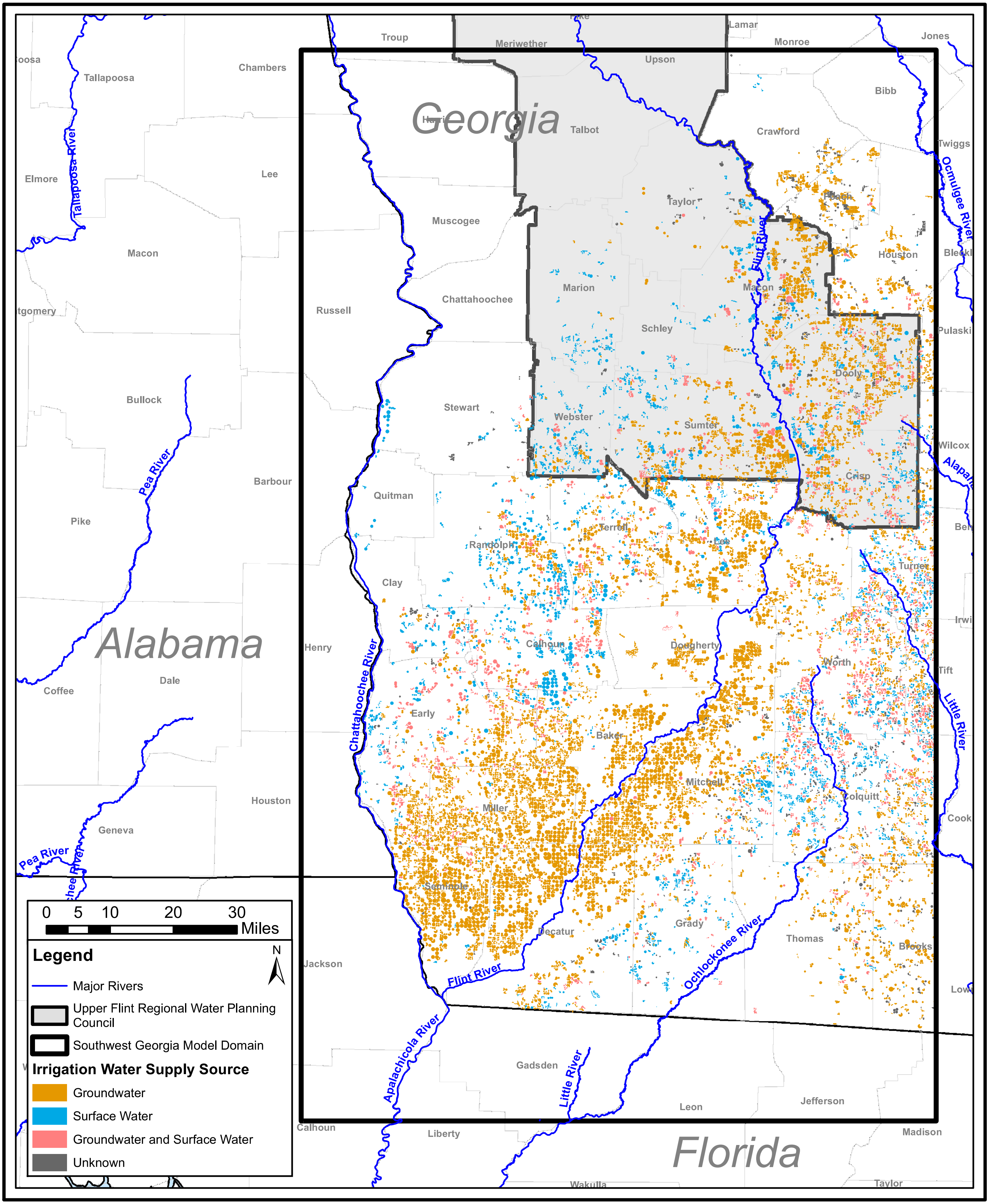
Table 3-1. Irrigated Area within the Southwest Georgia Model Domain

	Number of Parcels	Irrigated Area (acres)
Parcels Supplied by Groundwater Only	10,395	652,169
Parcels Supplied by both Surface Water and Groundwater	2,701	114,385
Parcels Supplied by Surface Water Only	4,156	168,615
Source of Irrigation Water Not Known	1,232	45,827
Total	18,484	980,996

The inventory also includes irrigated parcels where the source of irrigation water has not been determined. These parcels were not included in the development of groundwater withdrawal assignments for the baseline simulation, but are shown for reference on **Figure 3-3**. The total acreage under this category is less than five percent of total irrigated acreage within the SW Georgia Model domain.

The agricultural groundwater withdrawals for known permit locations were assigned to model layers based on the identified aquifer listed in the inventory and/or model layer assignments in earlier models (Regional Coastal Plain Model and sub-regional Claiborne and Clayton Models). **Table 3-2** shows the total acreage, by source aquifer, of irrigated parcels within the model domain that are supplied by groundwater.

Since 2003, the Georgia Soil and Water Conservation Commission has installed more than 10,000 water meters on irrigation systems in Georgia to track agricultural water use on either an annual or monthly basis. Georgia EPD provided average annual irrigation depths for southwest Georgia, based on metered data, for 2007 – 2013. Over this period, which includes hydrologically dry, normal, and wet years, the metered annual irrigation depth averaged 11.76 inches, ranging from 8.76 inches in 2013 to 15.94 inches in 2011.



CDM Smith

Figure 3-3
Irrigated Parcel Locations in Georgia Within Southwest Georgia Model Domain

Table 3-2. Irrigated Acreage Utilizing Groundwater Within SW Georgia Model Domain

Source Aquifer	Model Layer	Irrigated Acreage – Groundwater Only	Irrigated Acreage – Groundwater/Surface Water
Floridan Aquifer Upper Permeable Zone	2	485,483	74,322
Claiborne	3	96,536	29,692
Clayton	4	14,330	3,163
Providence Aquifer (Cretaceous)	5	45,830	6,091
Eutaw-Midville Aquifer (Cretaceous)	6	4,646	534
Surficial or Unknown Aquifer	-	5,344	583
Total		652,169	114,385

The year 2010 can be viewed generally as a hydrologically average to dry year. The annual average irrigation depth for 2010 was 11.85 inches, close to the average of the 2007 – 2013 metered data. The 2010 annual irrigation depth was used to develop agricultural groundwater withdrawal assignments for the steady-state baseline simulation. Based on irrigated acreage and 2010 average irrigation depth, irrigation groundwater withdrawals were calculated individually for each parcel within the model domain and applied as a withdrawal flux at a location corresponding to the centroid of the parcel. Per EPD guidance, it was assumed that 70 percent of the irrigation demand from parcels listed as having groundwater and surface water sources is supplied by groundwater source. The remaining 30 percent of the demands is supplied by using surface water.

Most of the Cretaceous aquifer pumping is assigned to model layer 5 in the SW Georgia Model, the shallowest Cretaceous model layer. **Table 3-3** shows agricultural groundwater withdrawals by model layer assigned to the baseline simulation. By far, most of the groundwater-derived irrigation comes from the Floridan aquifer. Groundwater withdrawals from the Cretaceous aquifer comprise approximately eight percent of the total assigned groundwater agricultural withdrawals in the model. Information collected to date suggests that no agricultural groundwater withdrawal occurs from the deepest Cretaceous layer represented in the model (layer 7: Upper Atkinson – Upper Tuscaloosa Aquifer).

Table 3-3. Baseline Simulation Agricultural Groundwater Withdrawals Within SW Georgia Model Domain by Model Layer

Source Aquifer	Model Layer	Groundwater Irrigation Demand (MGD)
Floridan Aquifer Upper Permeable Zone	2	464
Claiborne Aquifer	3	99
Clayton Aquifer	4	16
Providence Aquifer (Cretaceous)	5	44
Eutaw-Midville Aquifer (Cretaceous)	6	4
Total:		627

Municipal and Industrial Demand

EPD provided monthly groundwater withdrawal rates from 2007 to 2015 for municipal and industrial (M&I) permits within the SW Georgia Model domain (GW_Withdrawals-m&i-southwest.xlsx, m&I-multi_wells-permits-for-locations.xlsx, GWUR 2008-2015.xlsx and albany-city-water-use.zip received between August 2015 and January 2016). Year 2010 pumping was assigned in the baseline simulation. Withdrawal locations consistent with previous regional and sub-regional models were used. Assigned pumping depths from the State Water Plan regional and sub-regional models were reviewed and adjusted based on screen and aquifer information supplied by EPD.

Table 3-4 shows average 2010 groundwater municipal and industrial demand by model layer assigned to the baseline simulation. Across all model layers, municipal and industrial groundwater withdrawals are generally much less than agricultural groundwater withdrawals. In the Cretaceous aquifer in the SW Georgia Model domain, however, municipal and industrial demand (43 MGD) is generally comparable to the agricultural demand (48 MGD) in the baseline simulation.

Table 3-4. Baseline Simulation Municipal and Industrial Groundwater Withdrawals Within SW Georgia Model Domain by Model Layer

Source Aquifer	Model Layer	Average 2010 Groundwater M&I Demand (MGD)
Floridan Aquifer Upper Permeable Zone	2	34
Claiborne Aquifer	3	20
Clayton Aquifer	4	7
Providence Aquifer (Cretaceous)	5	43
Eutaw-Midville Aquifer (Cretaceous)	6	0
Total:		104

3.5.2 Boundary Conditions

Average 2010 recharge, river stage, and general head boundary reference head assignments were assigned to the baseline simulation. A specified head boundary condition was assigned to model layer 1 (Surficial aquifer system) where layer 1 is active. These boundary condition assignments were developed SW Georgia Model updates presented in *Lower Flint-Ochlocknee Water Planning Region: Capacity of the Claiborne and Cretaceous Aquifers to Replace Agricultural Surface Water Withdrawals in the Lower Flint River Basin* (CDM Smith, 2017, manuscript in preparation).

3.5.3 Steady-State Baseline Simulation Results

Simulated baseline Cretaceous aquifer heads are presented on **Figure 3-4** (model layer 5 – Providence aquifer), **Figure 3-5** (model layer 6 – Eutaw-Midville aquifer), and **Figure 3-6** (model layer 7 –Upper Atkinson aquifer). Existing Cretaceous aquifer pumping locations in the model layer are also shown on Figure 3-4, Figure 3-5, and Figure 3-6. The sustainable yield simulations presented in Section 4 suggest that overlying Clayton aquifer heads may be influenced by increased pumping in the Cretaceous aquifer. Therefore, simulated Clayton aquifer heads (model layer 4) are also presented for reference, shown on **Figure 3-7**. Simulated baseline Clayton

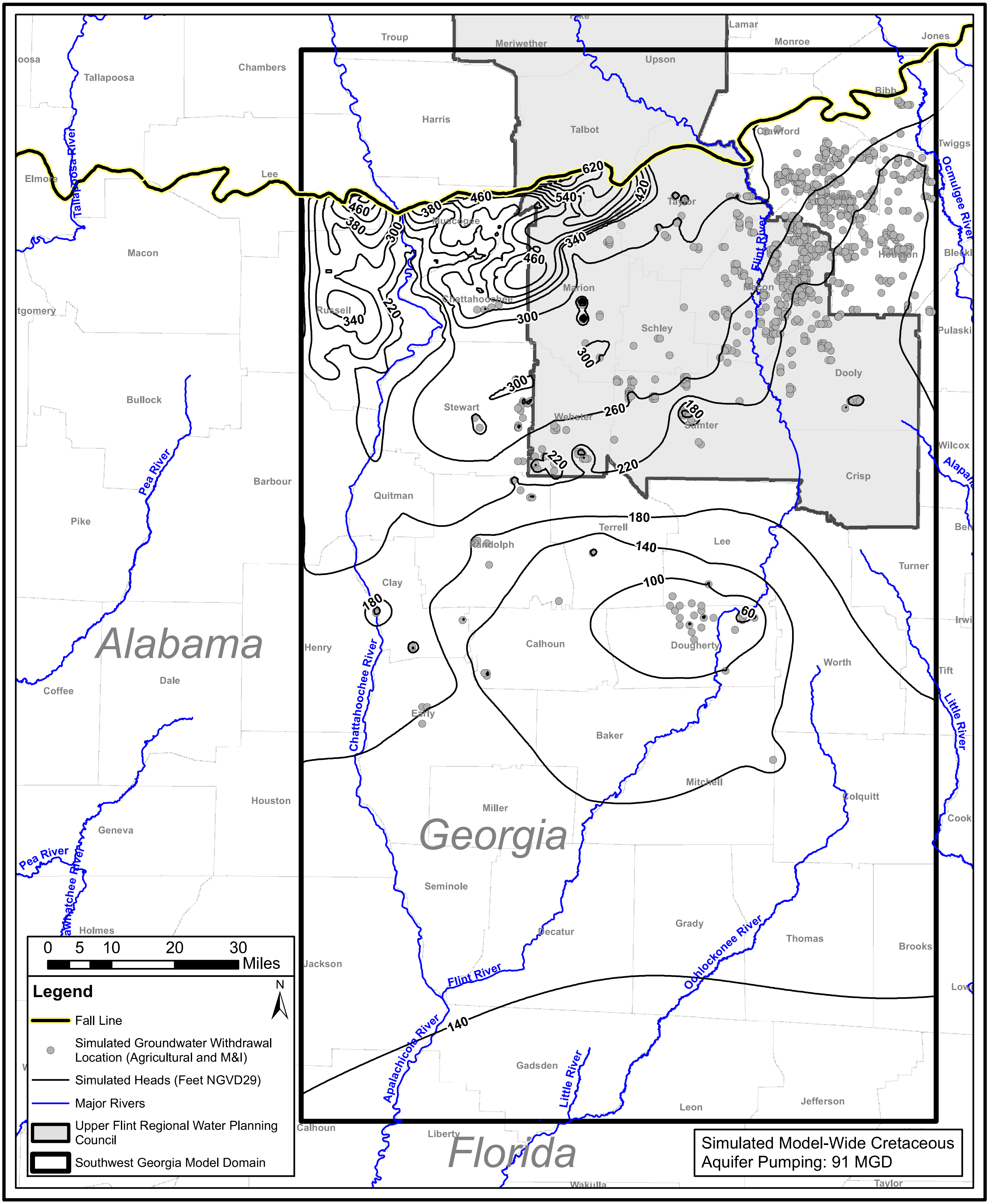


Figure 3-4
Simulated Cretaceous Aquifer Heads
Model Layer 5 (Providence Sand) - Baseline Simulation

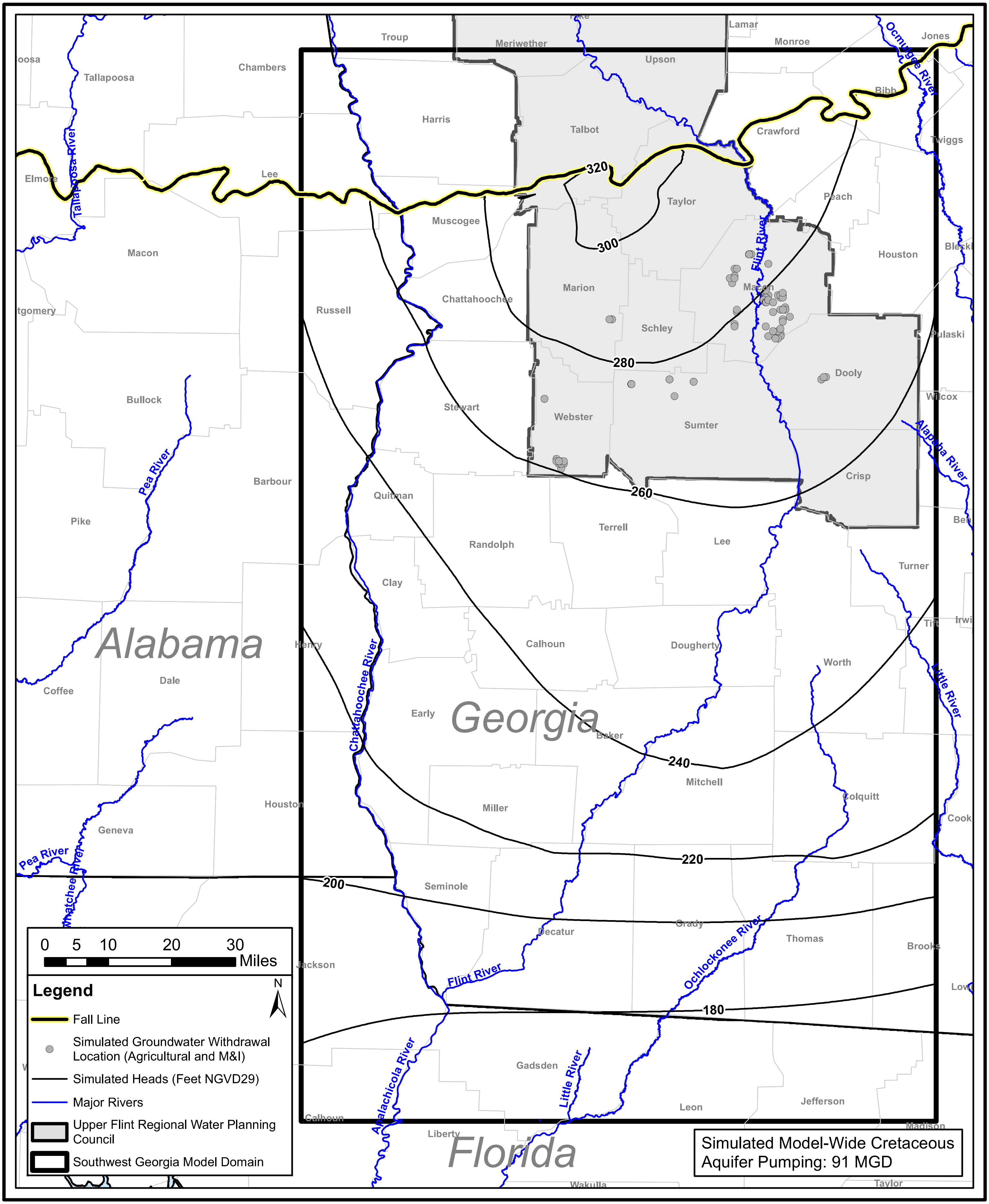


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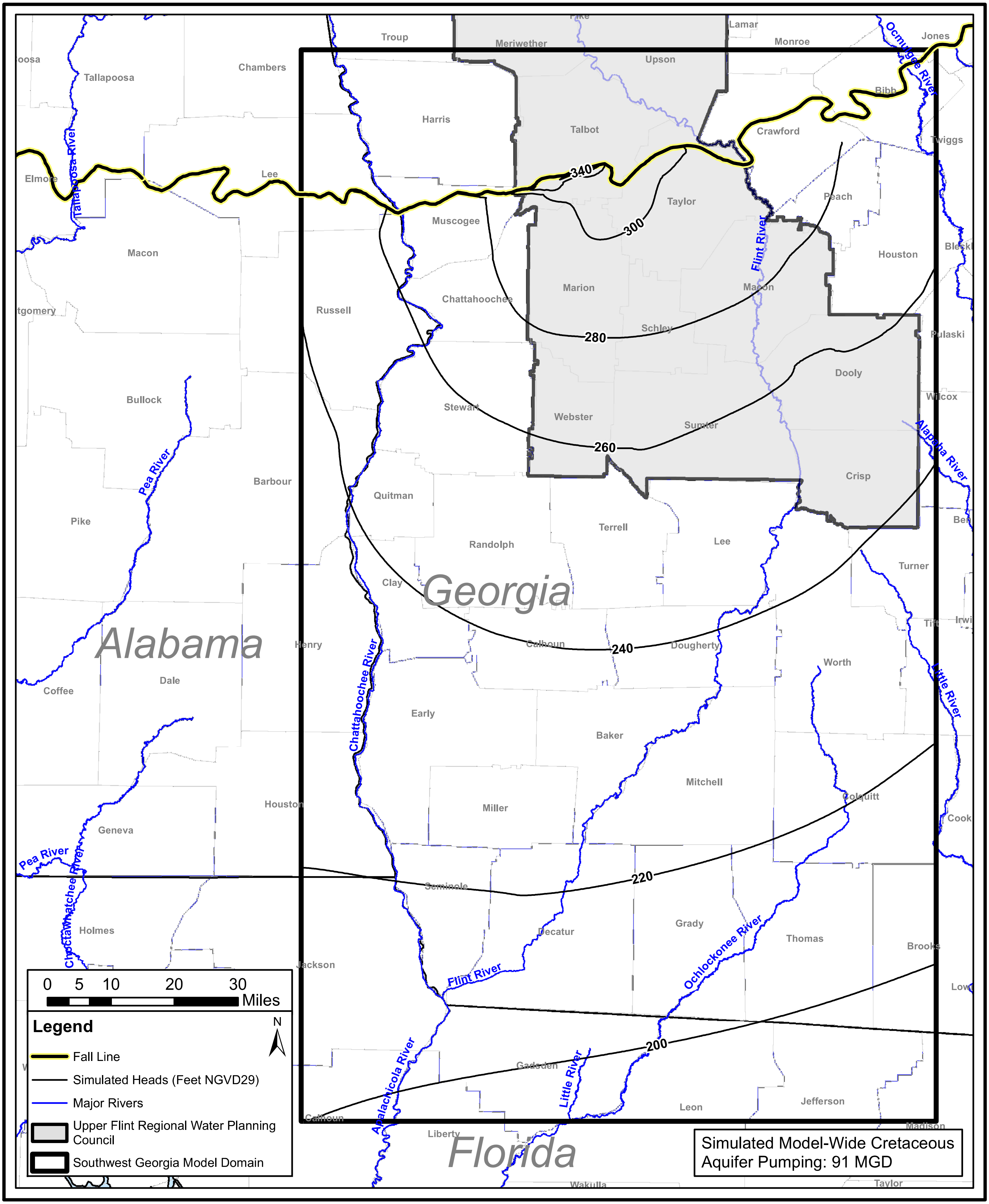
Figure 3-5
Simulated Cretaceous Aquifer Heads
Model Layer 6 (Eutaw-Midville) - Baseline Simulation



CDM Smith

Figure 3-6
Simulated Cretaceous Aquifer Heads
Model Layer 7 (Upper Atkinson - Upper Tuscaloosa) - Baseline Simulation

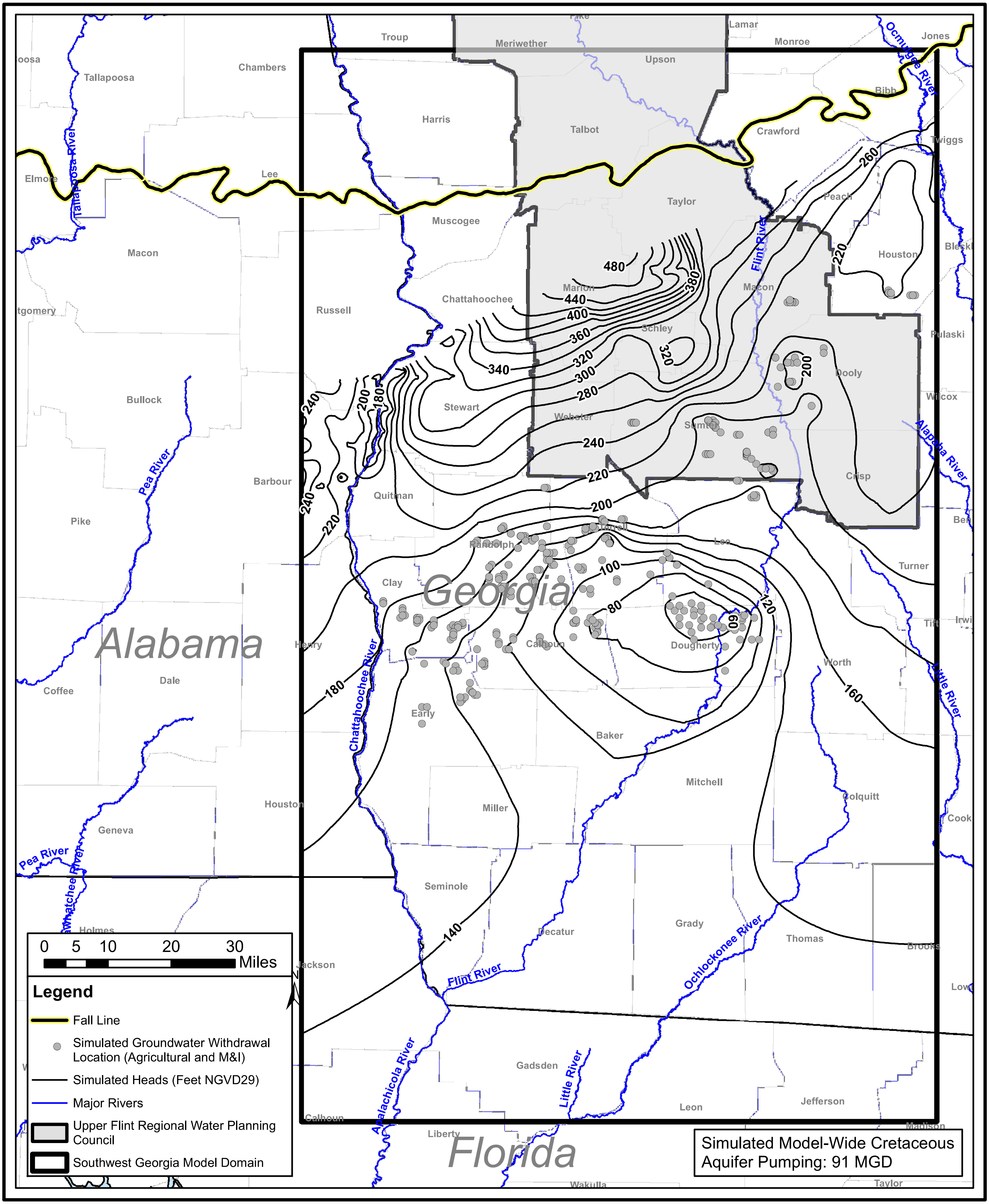


Figure 3-7
Simulated Clayton Aquifer Heads
Model Layer 4 - Baseline Simulation

aquifer head contours are shown for the limits of the Clayton aquifer as represented in the model. Within the SW Georgia Model, the Clayton Aquifer does not extend to the Fall Line.

In the baseline simulation, Cretaceous aquifer pumping model-wide and within the Upper Flint Council area is 91 MGD and 34 MGD, respectively. **Table 3-5** summarizes the baseline simulation water budget for the SW Georgia Model Cretaceous aquifer model layers (layers 5, 6, and 7).

Table 3-5. SW Georgia Model Simulated Water Budget for Cretaceous Aquifer Layers – Baseline Simulation

	Recharge (MGD)	Net Flux from Layers Above (MGD)	Well Flux (MGD)	General Head Boundary Flux (Model Perimeter) (MGD)	Constant Head Flux (Surficial Aquifer – Layer 1) (MGD)	River and Drain Flux (MGD)
Model-Wide (Cretaceous: Layers 5 to 7)	127	53	-91	-69	0	-19

Negative values indicate flux leaving simulated groundwater system.

4. Sustainable Yield Simulations

The sustainable yield of the Cretaceous aquifer within the Upper Flint Council area was estimated by incrementally increasing Cretaceous aquifer withdrawals within the Upper Flint Council area only, and comparing the simulated heads from the increased pumping scenario to the baseline simulation. The sustainable yield simulations were performed in steady-state mode.

The sustainable yield was defined as the maximum amount of groundwater withdrawal that could occur from defined extraction points within the Cretaceous aquifer without violating either of the following criteria:

- More than 30 feet of simulated groundwater level drawdown between pumping wells, from the baseline condition, and
- More than 40 percent simulated reduction of groundwater discharge to rivers and streams relative to the baseline simulation.

To bracket the likely range of sustainable yield, two different approaches to assigning the increased pumping were applied. To maintain consistency with earlier assessments of sustainable yield performed for the State Water Plan, an analysis approach similar to the earlier evaluations was followed. Details of the sustainable yield simulations are presented below.

4.1 Sustainable Yield Scenario 1: Simulations with Increased Pumping Assigned to Existing Pumping Locations

In Scenario 1, Cretaceous aquifer groundwater withdrawals (M&I, as well as agricultural) within the Upper Flint Council area that is within the Flint River watershed, were increased by a uniform factor until the maximum simulated drawdown was approximately equal to the sustainable yield drawdown limit of 30 feet. This scenario is applied to estimate the low end of the sustainable yield range because the pumping, and therefore the drawdown, is relatively concentrated spatially. A greater sustainable yield would be indicated if the simulated pumping is more widely distributed, as presented in Section 4.2. In Scenario 1, the limiting sustainable yield constraint was the 30-feet drawdown criterion. Potential reduction in groundwater discharge to rivers did not limit Scenario 1 groundwater withdrawals.

Using this approach, the low end of the sustainable yield was approximated by increasing the pumping in model layer 5 by a constant factor of approximately 1.1, and increasing the pumping in model layer 6 by a constant factor of approximately 5. A much higher pumping increase factor was applied to layer 6 because this layer has greater transmissivity and more spatially distributed pumping than layer 5. No pumping was assigned to model layer 7.

Pumping in all other aquifers and in the Cretaceous aquifer outside of the Upper Flint Council area was the same as in the baseline simulation, as were all other model inputs.

In the Scenario 1 simulation (low end of range of sustainable yield), Cretaceous aquifer pumping model-wide and within the Upper Flint Council area is 107 MGD and 50 MGD, respectively, 16 MGD greater than in the baseline simulation. Contours of simulated drawdown from the baseline simulation are shown on **Figure 4-1** (model layer 4 – Clayton aquifer), **Figure 4-2** (model layer 5 – Providence aquifer), **Figure 4-3** (model layer 6 – Eutaw-Midville aquifer), and **Figure 4-4** (model layer 7 – Upper Atkinson-Upper Tuscaloosa aquifer). Although there was no increase in pumping in layers 4 and 7, there was a simulated impact in these layers due to the pumping increases in layers 5 and 6. The maximum simulated drawdown of 30 feet was encountered in model layer 5 in an area of concentrated pumping in Marion County, and it results from a combination of pumping from model layers 5 and 6. In the Scenario 1 simulation, the maximum simulated drawdown in model layer 6 approximately 8 feet.

Table 4-1 lists the simulated Cretaceous aquifer pumping within the Upper Flint Council area for Scenario 1. The simulated reduction in groundwater discharge to rivers was approximately 1.5% percent, well below the sustainable yield criterion of a 40 percent reduction.

Table 4-1. Sustainable Yield Scenario 1 Simulated Cretaceous Aquifer Groundwater Withdrawals in Upper Flint Council Area

Model Layer	Upper Flint Council Area		
	Baseline (MGD)	Scenario 1 (MGD)	Simulated Increase in Groundwater Withdrawals (MGD)
Layer 5	-31	-34	3
Layer 6	-3	-16	13
Total 5 + 6	-34	-50	16

Negative values indicate flux leaving simulated groundwater system.

4.2 Sustainable Yield Scenario 2: Simulations with Increased Pumping Uniformly Distributed

The high end of the sustainable yield pumping range was estimated in Sustainable Yield Scenario 2, where additional Cretaceous aquifer pumping was simulated at uniformly spaced (10,000 feet) hypothetical wells in the Upper Flint Council area that is within the Flint River watershed. These wells were placed in model layers 5, 6 and 7. The simulated pumping locations for this sustainable yield scenario are shown on **Figure 4-5**. Scenario 2 includes pumping at existing M&I and agricultural well locations, as well as at the hypothetical locations shown in Figure 4-5.

The pumping rate at each individual pumping location shown in Figure 4-5 was assigned such that the simulated drawdown at each location was very close to 30 feet. Pumping was assigned to model layers 5, 6, and 7.

Pumping in all other aquifers and in Cretaceous aquifer pumping outside of the Upper Flint Council area was the same as in the baseline simulation. All other model inputs were the same as the baseline simulation.

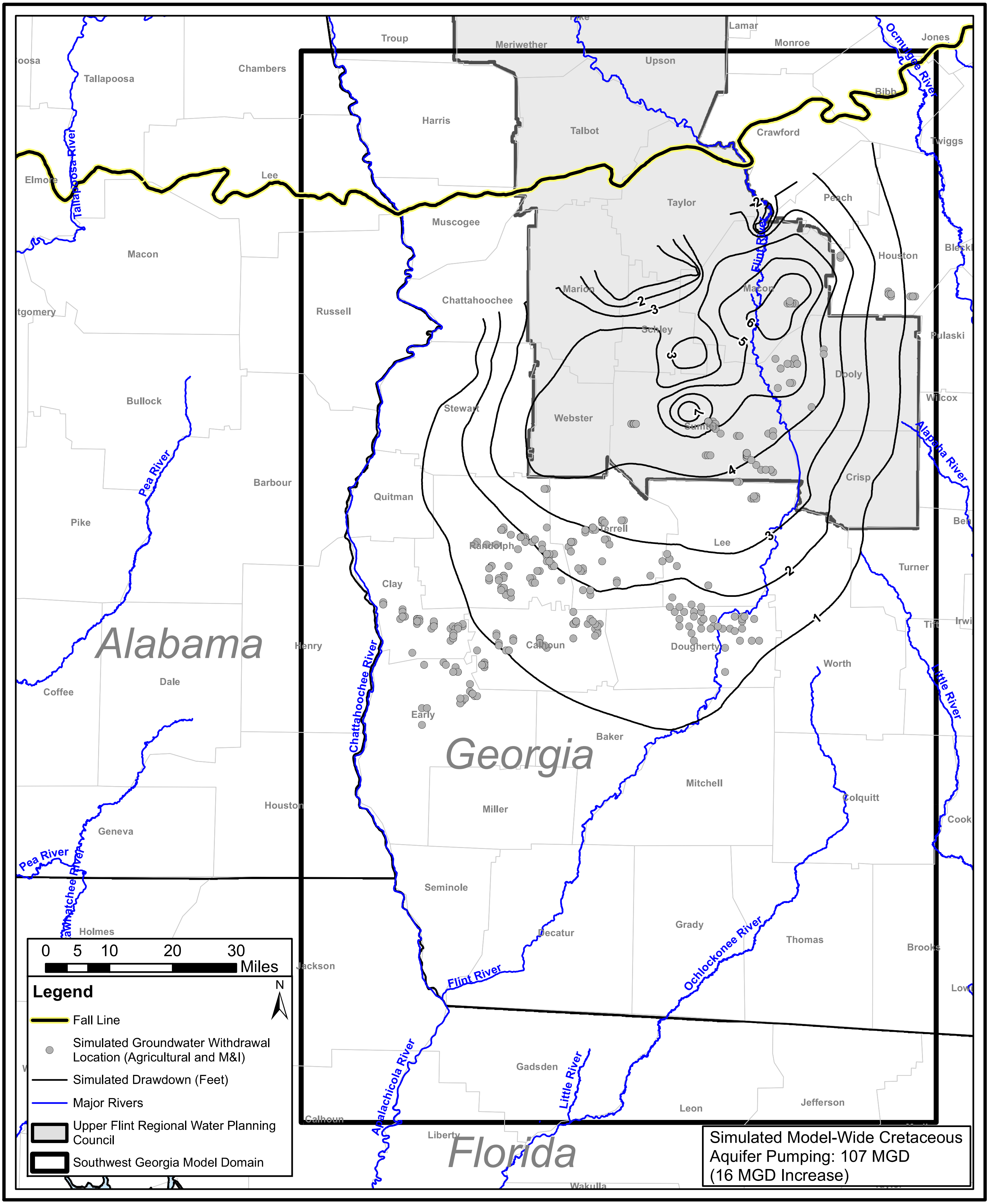
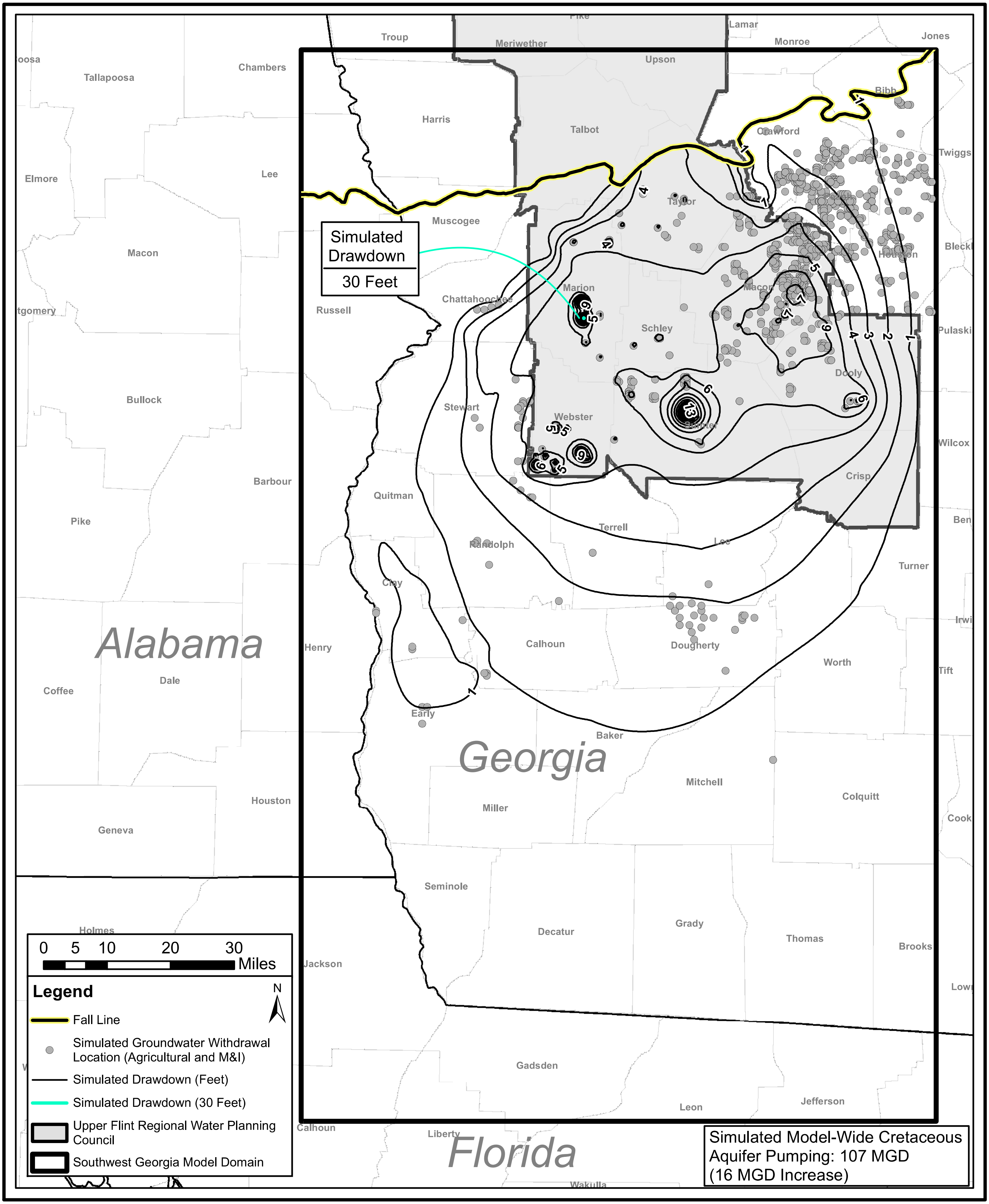
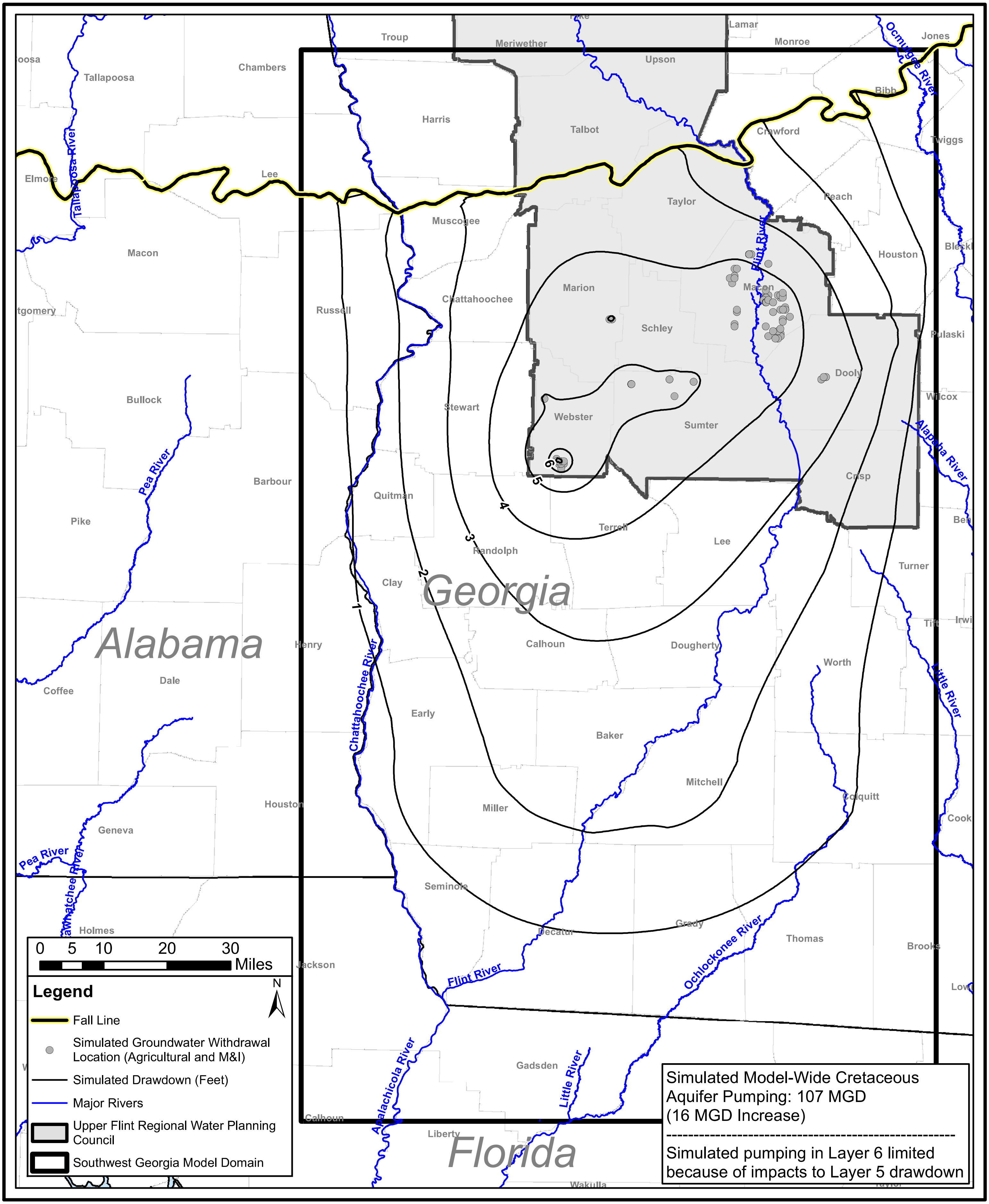


Figure 4-1
Simulated Clayton Aquifer Drawdown
Model Layer 4 - Scenario 1



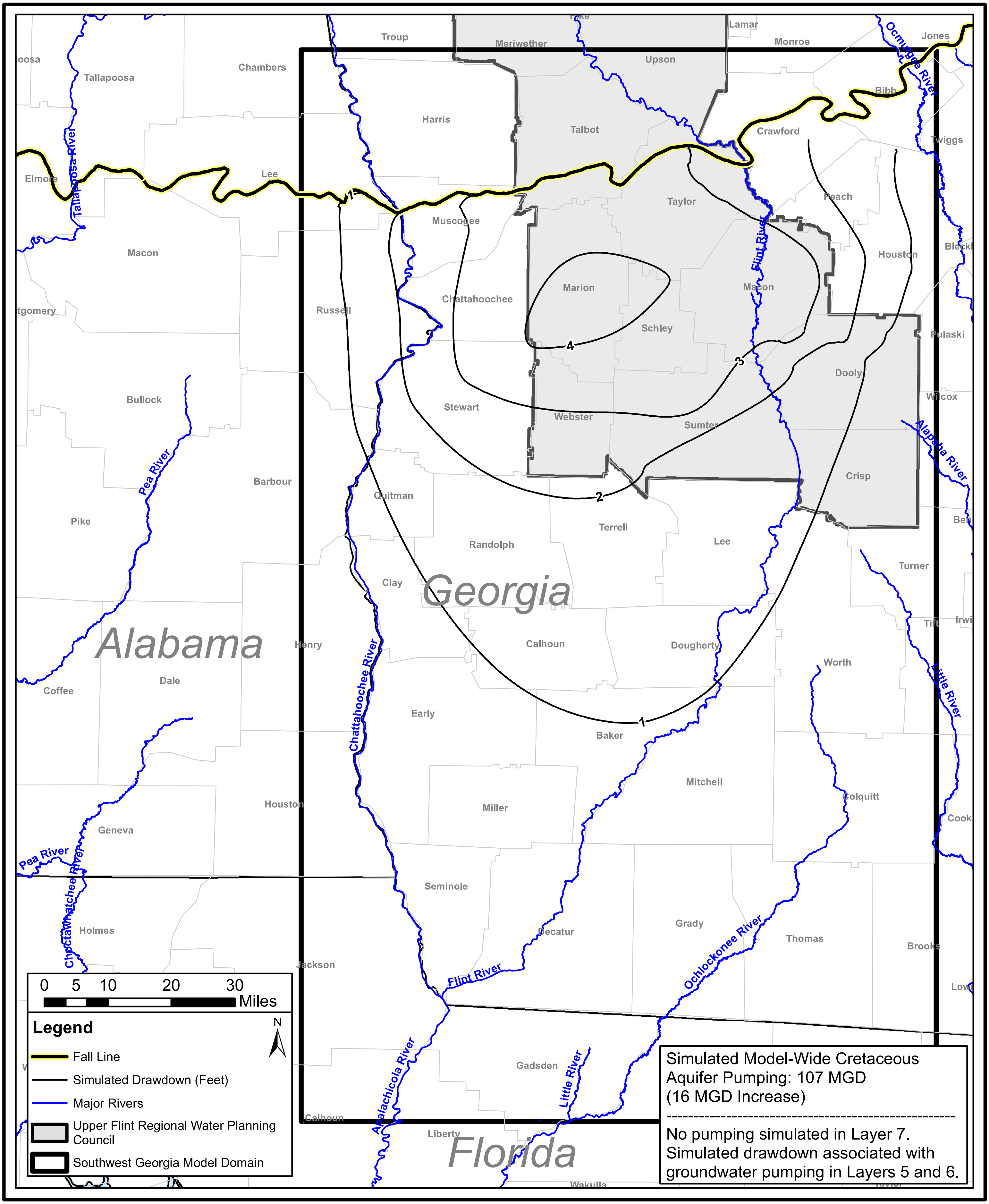
CDM Smith

Figure 4-2
Simulated Cretaceous Aquifer Drawdown
Model Layer 5 (Providence Sand) - Scenario 1



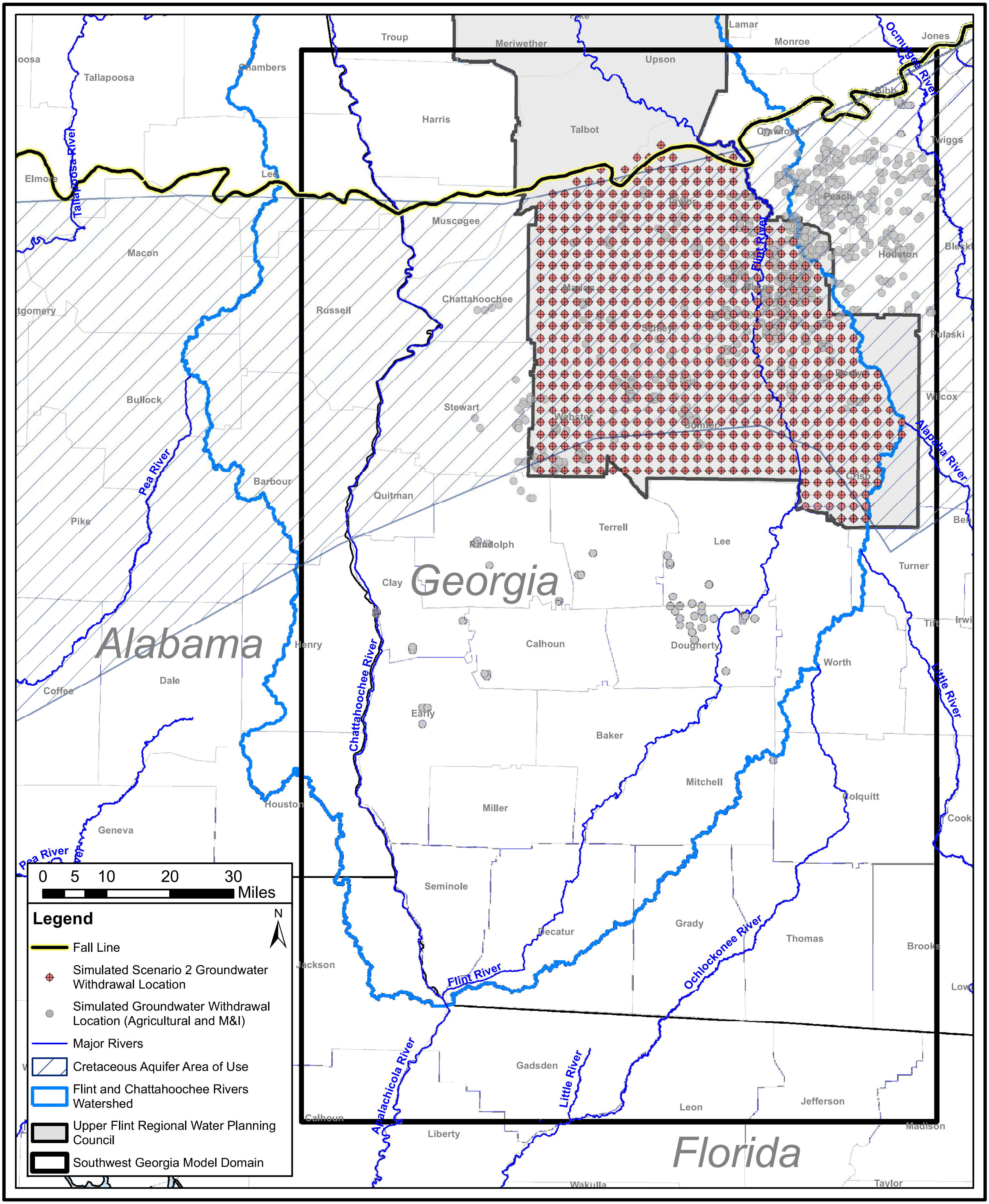
CDM Smith

Figure 4-3
Simulated Cretaceous Aquifer Drawdown
Model Layer 6 (Eutaw-Midville) - Scenario 1



CDM Smith

Figure 4-4
Simulated Cretaceous Aquifer Drawdown
Model Layer 7 (Upper Atkinson - Upper Tuscaloosa) - Scenario 1



CDM Smith

Figure 4-5
Simulated Additional Groundwater Withdrawal Locations
Model Layers 5, 6, 7 - Scenario 2

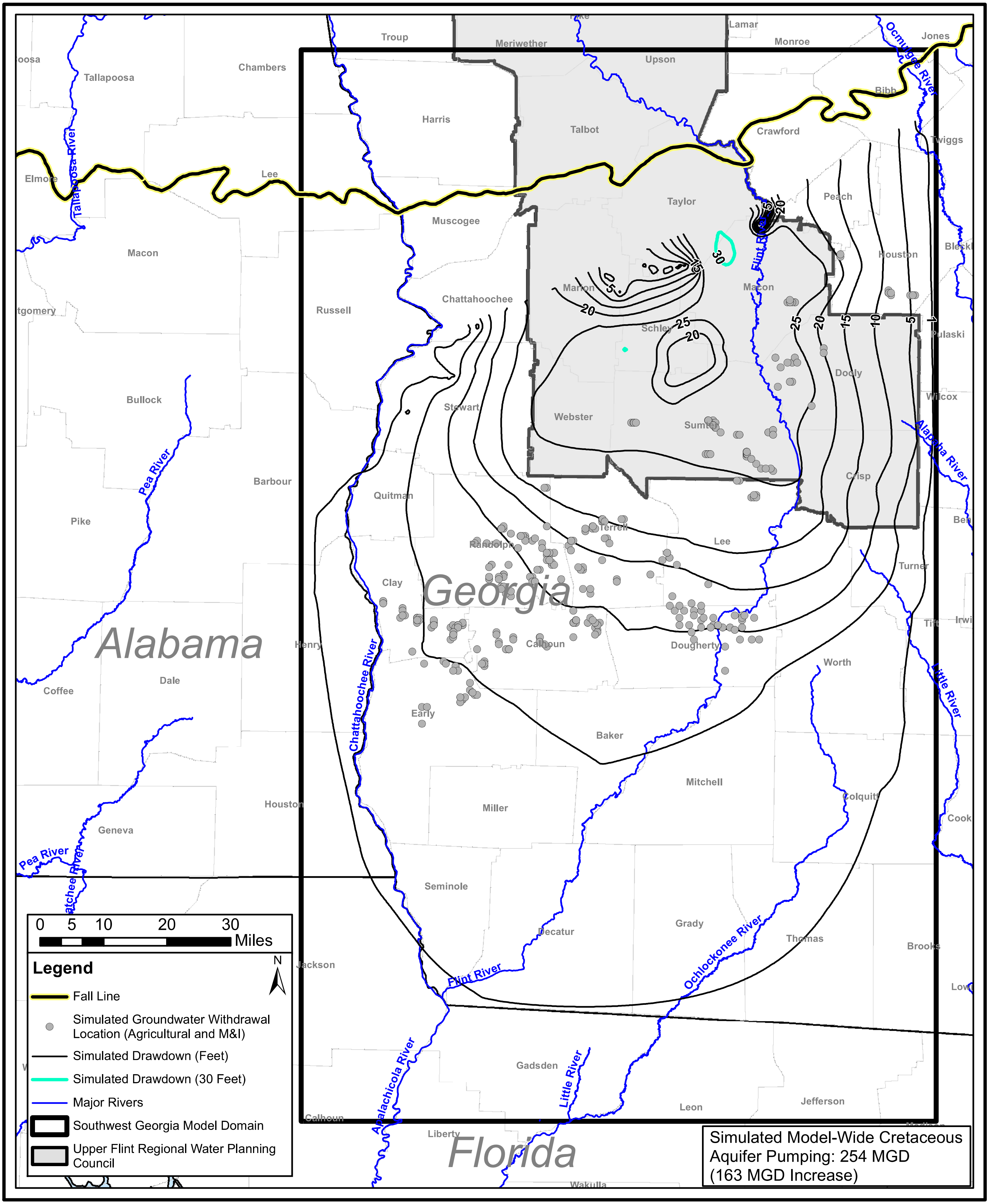
In the Scenario 2 simulation (high end of range of sustainable yield), Cretaceous aquifer pumping model-wide and within the Upper Flint Council area is 254 MGD and 197 MGD, respectively, which represents an additional withdrawal of approximately 163 MGD. Contours of simulated drawdown from the baseline simulation are presented on **Figure 4-6** (model layer 4 – Clayton aquifer), **Figure 4-7** (model layer 5 – Providence aquifer), **Figure 4-8** (model layer 6 – Eutaw-Midville aquifer), and **Figure 4-9** (model layer 7 – Upper Atkinson-Upper Tuscaloosa aquifer). Although there were no increases in pumping in layer 4 (Clayton aquifer), there was a simulated impact in this aquifer due to the pumping increases in model layers 5, 6 and 7. Simulated drawdown in model layer 4 did not exceed 30 feet. In model layers 5, 6 and 7, the simulated drawdown at the hypothetical well locations ranged from 28 to 30 feet, consistent with the design of the simulation. The simulated drawdown for Scenario 2 extends close to, or up to, the model boundary in model layers 4, 5, 6, and 7. Simulation tests suggest that if there is less groundwater inflow from areas adjacent to the model boundaries than computed by the model for the general head boundary conditions, drawdown impacts could be greater with the high volume of additional pumping represented in Scenario 2. The simulated reduction in groundwater discharge to rivers was approximately 17% percent, well below the sustainable yield criterion of a 40 percent reduction.

Table 4-2 lists the simulated Cretaceous aquifer pumping in the Upper Flint Council area for Scenario 2. Simulation results presented in Table 4-2 suggest that some groundwater withdrawal from model layer 7 is possible (4 MGD), although much less than from the overlying model layers 5 and 6 (197 MGD). When the overlying layers 5 and 6 are significantly utilized, there is a limited source of water to model layer 7. The water quality of groundwater at depth (model layer 7) may be poor because of elevated chlorides (Pollard and Vorhis, 1980). Because of potential water quality concerns, and simulation results suggesting limited contribution from model layer 7 (Upper Atkinson-Upper Tuscaloosa Cretaceous Aquifer), potential yield from this model layer was not included in the sustainable yield estimate for Scenario 2.

Table 4-2 Sustainable Yield Scenario 2 Simulated Cretaceous Aquifer Groundwater Withdrawals in Upper Flint Council Area

	Upper Flint Council Area		
	Baseline (MGD)	Scenario 2 (MGD)	Simulated Increase in Groundwater Withdrawals (MGD)
Layer 5	-31	-51	20
Layer 6	-3	-146	143
Total 5 + 6	-34	-197	163
Layer 7	0	-4	4

Negative values indicate flux leaving simulated groundwater system.



CDM Smith

Figure 4-6
Simulated Clayton Aquifer Drawdown
Model Layer 4 - Scenario 2

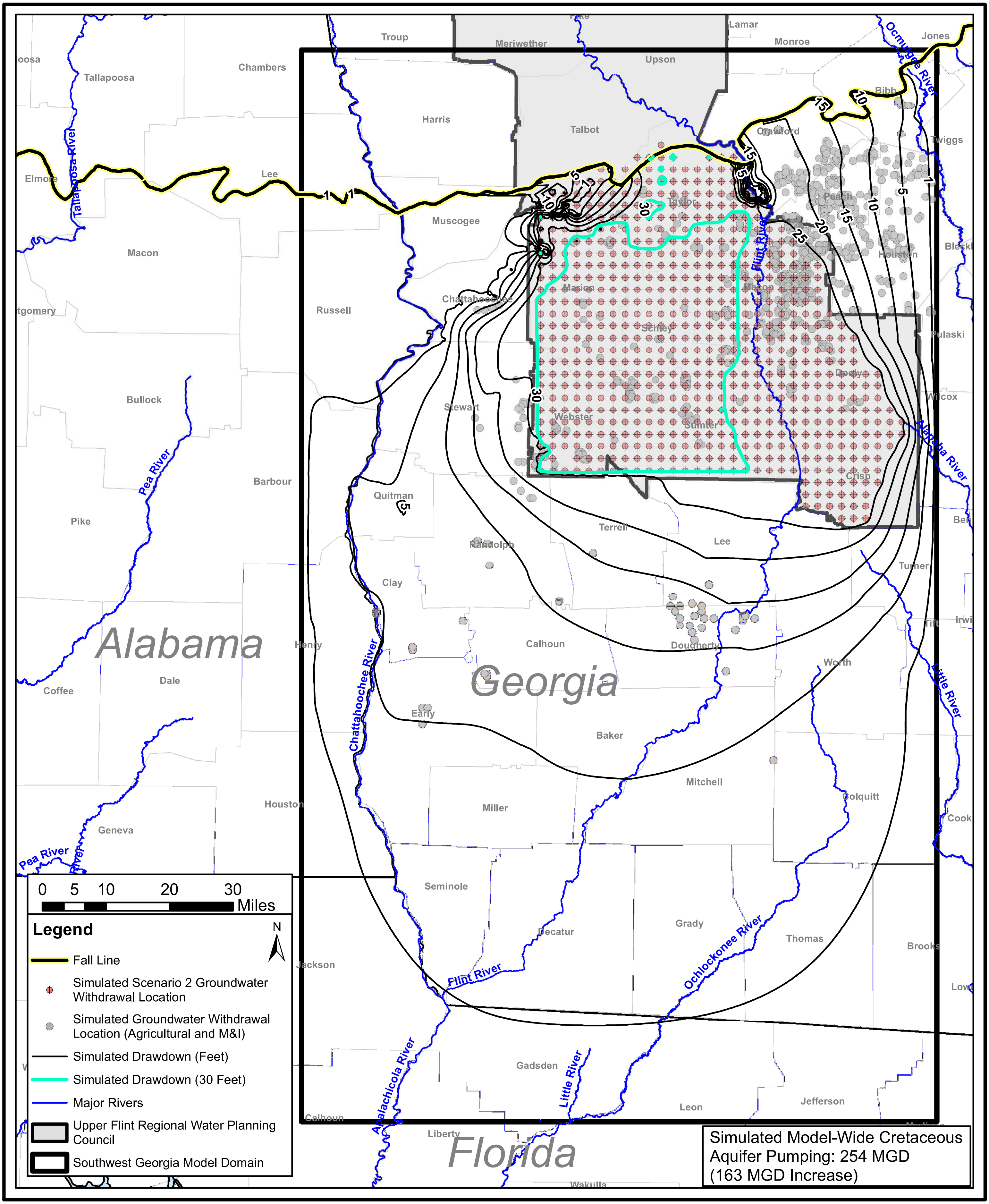
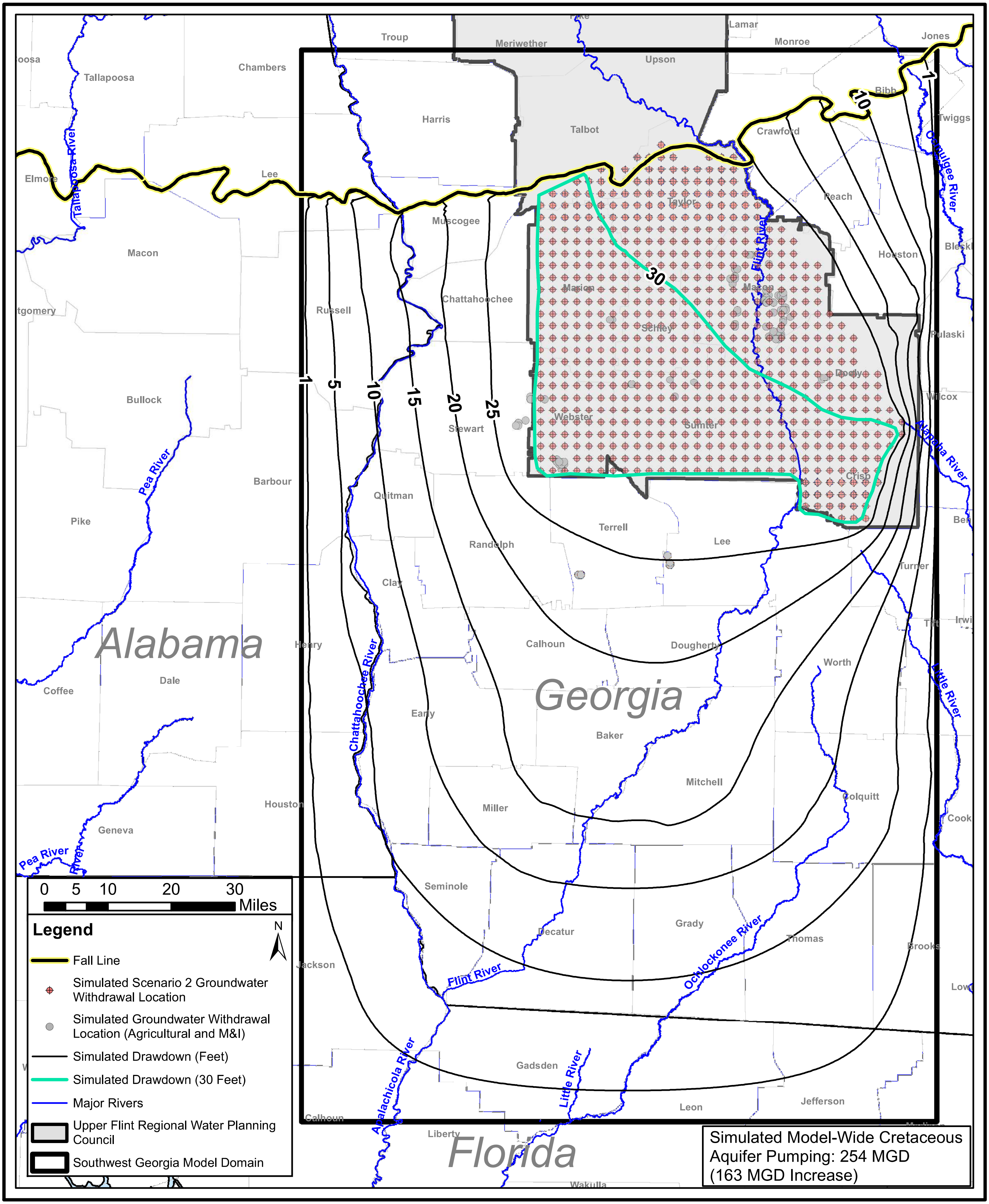


Figure 4-7
Simulated Cretaceous Aquifer Drawdown
Model Layer 5 (Providence Aquifer) - Scenario 2



CDM Smith

Figure 4-8
Simulated Cretaceous Aquifer Drawdown
Model Layer 6 (Eutaw-Midville) - Scenario 2

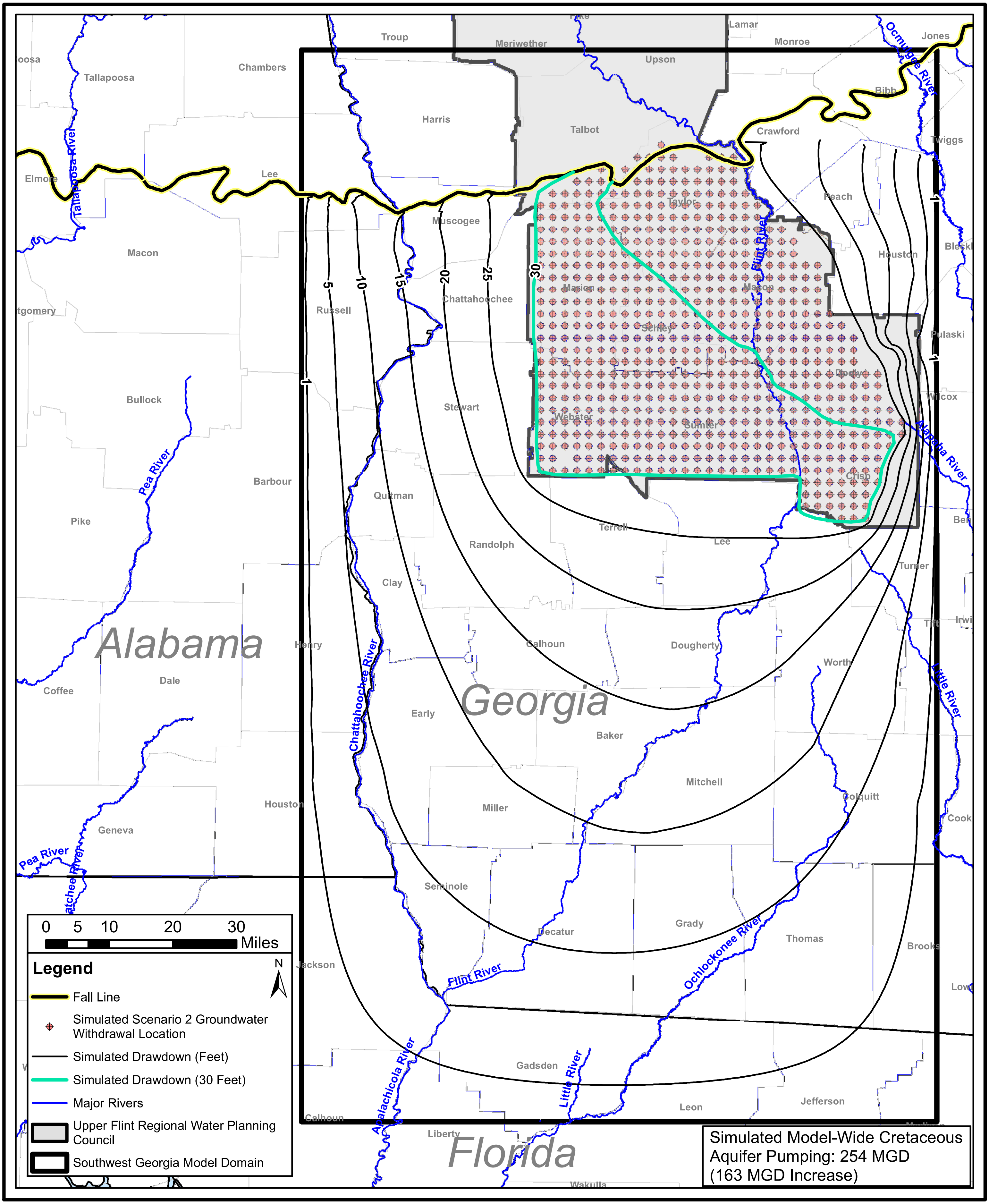


Figure 4-9
Simulated Cretaceous Aquifer Drawdown
Model Layer 7 (Upper Atkinson - Upper Tuscaloosa) - Scenario 2

5. Summary

CDM Smith prepared this report in support of the State Water Plan. The report describes groundwater model steady-state simulation analysis to estimate the sustainable yield of the Cretaceous aquifer in the Upper Flint Regional Water Planning Council (Upper Flint Council) Area.

Formulation of the sustainable yield criteria for earlier groundwater resource assessments is presented in Section 11 of the document titled *Groundwater Flow Modeling of the Coastal Plain Aquifer System of Georgia* (CDM, 2011a). These criteria were selected to indicate potential local or regional impacts to address in the regional planning process. For the sustainable yield evaluation of the Cretaceous Aquifer in the Upper Flint Council area, sustainable yield was defined as the maximum amount of groundwater withdrawal that could occur from defined extraction points within the Cretaceous aquifer without violating either of the following criteria:

- More than 30 feet of simulated groundwater level drawdown between pumping wells, from the baseline condition, and
- More than 40 percent simulated reduction of groundwater discharge to rivers and streams relative to the baseline simulation.

The sustainable yield simulations were completed using steady-state simulations of the SW Georgia Model. SW Georgia Model framework and calibration are presented under separate cover in *Lower Flint-Ochlocknee Water Planning Region: Capacity of the Claiborne and Cretaceous Aquifers to Replace Agricultural Surface Water Withdrawals in the Lower Flint River Basin* (CDM Smith, 2017; manuscript in preparation).

For the sustainable yield simulations, a baseline simulation of average 2010 steady-state groundwater conditions was developed. Average 2010 recharge, river stage, and general head boundary references were assigned to the baseline simulation. A specified head boundary condition was assigned to model layer 1 (Surficial aquifer system) where layer 1 is active. Agricultural groundwater withdrawals in the model were based on 2010 annual irrigation metering data and a recent Georgia EPD inventory of irrigated agricultural acreage. Municipal and industrial pumping assignments were consistent with reported 2010 values. In the baseline simulation, Cretaceous aquifer pumping model-wide and within the Upper Flint Council area is 91 MGD and 34 MGD, respectively.

Two scenarios were simulated to bracket a potential range of sustainable yield for the Cretaceous aquifer in the Upper Flint Planning Council area, consistent with the analysis approach used for sustainable yield assessments for earlier State Water Plan groundwater resource evaluations. In sustainable yield Scenario 1, designated as the low end of the sustainable yield range, groundwater withdrawals at existing groundwater withdrawal locations (agricultural, municipal and industrial) represented in the model were increased until sustainable yield criteria were exceeded.

In the Scenario 1 simulation (low end of range of sustainable yield), Cretaceous aquifer pumping model-wide and within the Upper Flint Water Planning Council area is 107 MGD and 50 MGD, respectively, which represents an additional withdrawal of approximately 16 MGD (**Figure 5-1**). Simulation results for this scenario indicated only small localized areas with simulated drawdowns between pumping wells close to 30 feet.

In sustainable yield Scenario 2, additional (beyond existing agricultural, municipal and industrial) groundwater withdrawals were assigned to uniformly spaced hypothetical wells until sustainable yield criteria were exceeded. The limited simulated contribution of the deepest model layer representing the Cretaceous aquifer (model layer 7), was not included in the sustainable yield estimate because of potential groundwater quality considerations and the relatively small amount of simulated groundwater contribution from this model layer in Scenario 2.

In the Scenario 2 simulation (high end of range of sustainable yield), Cretaceous aquifer pumping model-wide and within the Upper Flint Water Planning Council area is 254 MGD and 197 MGD, respectively, which represents an additional withdrawal of approximately 163 MGD (Figure 5-1).

Simulation results for Scenario 2 showed a relatively large area with simulated drawdowns between pumping wells close to 30 feet. Simulation tests suggest that if there is less groundwater inflow from areas adjacent to the model boundaries than computed by the model for the general head boundary conditions, drawdown impacts could be greater with the high volume of additional pumping represented in Scenario 2.

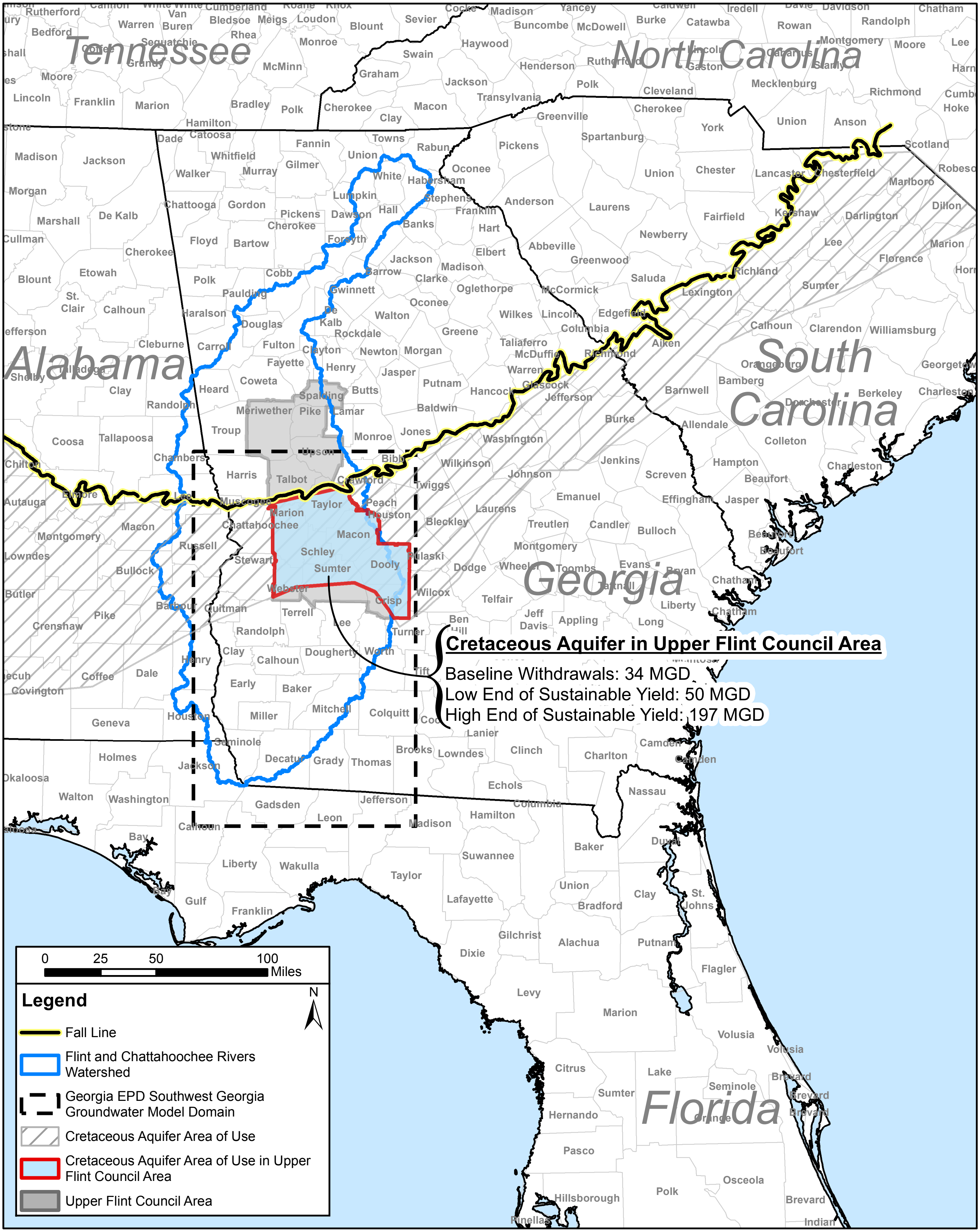


Figure 5-1
Summary of the Sustainable Yield Assessment for the Cretaceous Aquifer in the Upper Flint Council Area

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6. References

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APPENDIX E

Claiborne Aquifer Specific Capacity and Transmissivity Analysis

Georgia Environmental Finance Authority

March 13, 2017

CDM Smith

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Appendices

Section 1

Introduction

CDM Smith completed this study for the Georgia Environmental Finance Authority (GEFA) to compile and map Claiborne aquifer specific capacity values and estimated transmissivity in southwestern Georgia using data collected by GEFA, the Georgia Environmental Protection Department (GA EPD), and the United States Geologic Survey (USGS). Field measured specific capacity data were used to develop estimates of Claiborne aquifer transmissivity, and to develop maps of "normalized" specific capacity computed using a uniform set of well characteristics. Additionally, the estimated Claiborne aquifer transmissivity was compared with Claiborne aquifer property assignments in the groundwater flow models developed for the Georgia State Water Plan (State Water Plan).

The study area is located in southwest Georgia and includes the following counties: Dooly, Sumter, Crisp, Terrell, Lee, Worth, Calhoun, Dougherty, Early, Baker, Mitchell, Miller, Seminole, Decatur. The maps in this report present a spatial summary of Claiborne aquifer well yields (specific capacity) in the study area, and may be used as guidance in siting new Claiborne aquifer production wells.

The remaining report sections describe the analysis approach and results. Compilation and review of well information is presented in Section 2. Calculation and mapping of normalized specific capacity values for the Claiborne aquifer is described in Section 3. Comparisons between estimated aquifer transmissivity and State Water Plan model assignments are presented in Section 4. A summary of study results is provided in Section 5. References used in the study are listed in Section 6.

Section 2

Collection and Review of Claiborne Aquifer Well Data

2.1 Data Sources

The following data sources were used in this study:

- Top, bottom and thickness of the Claiborne aquifer: *Hydrogeologic Evaluation for Underground Injection Control in the Coastal Plain of Georgia* (Hydrologic Atlas (HA) 10; Arora, 1984).
- Claiborne aquifer well data compiled by GA EPD. The compiled well data were based on information presented in application and permit forms for production wells installed for agricultural use, or municipal and industrial (M & I) uses.
- GEFA Claiborne Aquifer Well Reports. CDM Smith reviewed well reports provided by GEFA for six new Claiborne aquifer wells installed in 2016.
- Reported specific capacity and well data presented in the USGS report *Hydrology of the Claiborne Aquifer and Its Interconnection with the Upper Floridan Aquifer in Southwest Georgia* (Gordon and Gonthier; publication pending).

Figure 2-1 shows the locations of the wells with data used in the study. The study included 40 agricultural supply wells, 11 M & I wells, 6 GEFA wells and 5 USGS-study wells (three of the USGS study wells are located very close to other study wells, and are not shown on Figure 2-1). Figure 2-1 also shows the location of Subarea 4 which is an area in the Apalachicola-Chattahoochee-Flint (ACF) river basin. GA EPD is currently not issuing any new or expanded permits for irrigation wells withdrawing groundwater from the Floridan aquifer in the lower Flint River basin, which is part of Subarea 4. Agricultural groundwater permits are available for other aquifers within Subarea 4, such as the Claiborne and Cretaceous aquifers.

2.2 Well Information Compiled for Analysis

The following information was compiled for the wells shown in Figure 2-1, and is summarized in **Table 2-1** and **Appendix A**:

- Locational coordinates (latitude-longitude)
- Well construction - depth, diameter, screened intervals
- Well testing specific capacity data – Pumping rate, pumping duration and drawdown in the well
- Reference elevation - land surface and/or top of casing

- Lithologic and geophysical logs, if available
- Measured water level data, if available

2.2.1 Well Information Provided by GAEPD

GA EPD provided data for 51 Claiborne aquifer wells within or close to Subarea 4; wells were selected from among existing wells based on the availability of complete lithologic logs and pump tests with specific capacity estimates. Wells in the southern portion of Subarea 4 are generally deeper, with the average well depth in Decatur, Seminole, Miller and Mitchell Counties exceeding 700 feet. Claiborne aquifer wells in the northern portion of Subarea 4 are not as deep; the average depth of the wells studied in Crisp, Dooly, Lee, Sumter and Terrell counties is 350 feet. Lithological logs for these wells were reviewed to estimate the top and bottom of the Claiborne aquifer and to determine whether the wells were screened entirely within the Claiborne aquifer.

GA EPD also provided information for "combination wells" that are screened in another aquifer in addition to the Claiborne aquifer. Data from these wells was not incorporated into the analysis because the specific capacity testing reflects a response from two aquifers.

2.2.2 Well Information Provided by GEFA

Between March and November 2016, GEFA drilled and tested six new wells screened in the Claiborne Aquifer. The wells are located in Seminole, Early, Calhoun (two sites), Baker, and Worth Counties. The wells are 6-inch test wells completed for the purpose of collecting data on Claiborne aquifer characteristics, and are not production wells. The installation and test reports for these wells, presented in **Appendix B,** include lithologic logs, step test data, 24-hour constant pumping rate and recovery test data, downhole electrical and natural gamma logs, and groundwater quality sampling results.

2.2.3 USGS Study

The USGS conducted a study in cooperation with the GA EPD to collect and compile hydrogeologic data from the Claiborne aquifer and its connection with the Upper Floridan aquifer. Data collected for this study include borehole geophysical logs, samples collected for water quality analyses, and two 72-hour aquifer pumping tests at new production wells installed in Mitchell and Early Counties. CDM Smith obtained specific capacity data that were compiled as part of the USGS study from the two new production wells and three other wells.

2.3 Claiborne Aquifer Thickness

The top, bottom and approximate thickness of the Claiborne aquifer in the study area, was estimated using information presented in the HA-10 (Arora, 1984), lithologic logs from the GEFA well reports, and USGS reporting. HA-10 contains elevation contours for the upper and lower limits of the Claiborne Aquifer over the northern portion of the study area, but does not include contours for Seminole, Decatur and Grady counties. The top and bottom of the Claiborne aquifer for wells in these counties was estimated from lithological logs. The depth to the Claiborne aquifer generally increases from north to south. In the study area, the Claiborne aquifer ranges in thickness from 50 to 320 feet, and is thinner in the northern portion of the study area.

Section 3

Normalized Specific Capacity Calculation and Mapping

3.1 Approach

The following steps were completed to process the field specific capacity data and to develop estimates of Claiborne aquifer transmissivity and normalized specific capacity:

- Transmissivity at each well was calculated from field specific capacity data.
- The computed transmissivity was used to calculate a normalized specific capacity using standard well and test parameters.
- The normalized specific capacity values were tabulated and mapped.

3.2 Transmissivity Calculation from Field Specific Capacity Data

Claiborne aquifer transmissivity at study area wells was calculated from field specific capacity measurements described in Section 2. Transmissivity values from specific capacity data were computed using an equation presented in many references including Walton (1970, page 315). The equation accounts for the diameter of the well, the duration of the specific capacity test and estimated aquifer storage parameters.

In general, transmissivity estimates developed from aquifer pumping test data that include drawdown measurements at nearby monitoring well(s) are more reliable; however, transmissivity estimates computed from specific capacity data are viewed as useful indicators of aquifer properties. In the analysis presented in this report, the calculated transmissivity is used as a basis for computing normalized specific capacity.

Transmissivity was calculated from field specific capacity data using the following equation (using consistent length and time units):

$$T = \frac{0.183Q}{s_w} \log \frac{2.25\,Tt}{r^2 S}$$

Where:

T = aquifer transmissivity

Q = constant discharge rate

s_w = drawdown in the well

t = time since start of pumping

r_w = well radius

S = storativity

For these calculations, the storativity (S) was assumed equal to the estimated aquifer thickness multiplied by 0.00005 ft^{-1}, which is an approximate estimate of the specific storativity (storativity divided by aquifer thickness) of the Claiborne aquifer from the State Water Plan models (CDM, 2011; CDM Smith 2012a). Calculated transmissivity values are somewhat sensitive to the assumed storativity value.

The above equation assumes that the pumping well screen fully spans the entire thickness of the aquifer. Where the pumping well screen only partially spans (or penetrates) the aquifer thickness, then the specific capacity (Q/s_w) is adjusted to account for partial penetration using an equation presented by Walton (1970, page 319).

$$\frac{Q}{s_w} = \frac{\frac{Q}{s_p}}{F_p}$$

Where:

Q/s_p = measured specific capacity for a partially penetrating well

$F_p = Kp\left(1 + 7\sqrt{\frac{r_w}{2K_p m}}\cos\frac{K_p \pi}{2}\right)$

K_p = ratio of screen length to aquifer saturated thickness

m = aquifer thickness

If multiple screen intervals were installed, the screen length for the calculation was defined as the length from the top of the shallowest screen to bottom of the lowest screen.

The computed transmissivities are listed in **Table 3-1**. Calculated transmissivity values range from approximately 91 ft^2/day to 13,349 ft^2/day, with higher transmissivity values typically noted in the northern portion of the study area. The USGS performed a similar estimate of transmissivity based on specific capacity data. The transmissivity presented in Table 3-1 for the USGS study wells was taken from *Hydrology of the Claiborne Aquifer and Interconnection with the Upper Floridan Aquifer in Southwest Georgia* (Gordon and Gonthier; publication pending).

The transmissivity computations discussed above do not account for local entrance loss to the well which, depending on the withdrawal rate and well construction, can be significant. The drawdown measured in the well is assumed equal to the drawdown in the aquifer outside of the well. In many cases, the well loss may be a significant portion of the total drawdown measure in the well. As such, the aquifer transmissivity computed based on total drawdown in the well may underestimate actual aquifer transmissivity.

Data for estimating well loss are not available for this project. For the purpose of providing transmissivity estimates that account for the fact that some of the measured drawdown is likely due to local well loss, adjusted transmissivity values were also computed assuming that 20 percent of the measured well drawdown is local well loss, i.e., well efficiency is 80 percent. With the adjustment, calculated transmissivity values range from approximately 116 ft^2/day to 16,933 ft^2/day. This calculation was not performed for USGS study wells, because the method of transmissivity calculation was different from the approach described above. The comparison between the adjusted transmissivity values and Claiborne aquifer transmissivity estimates assigned in the Georgia State Plan models is discussed in section 4.

3.3 Normalized Specific Capacity Calculation

The calculated aquifer transmissivity was used to recompute a specific capacity value assuming a consistent well configuration and test duration at all locations. "Normalized" values of specific capacity were calculated to provide a consistent basis for evaluating specific capacity from one location to another. The same equations shown above were applied. The standard well details that were used in the "normalized" specific capacity calculation were selected based on review of the information compiled in Section 2 and consultation with GEFA and GA EPD.

The following standard well and test parameters were used to compute normalized specific capacity:

- Screen length – The estimated Claiborne thickness at the well was used (i.e., full penetration) if the thickness is less than or equal to 300 feet. Where the estimated aquifer thickness is greater than 300 feet, a maximum screen length of 300 feet was used.
- Diameter of borehole – 18 inches
- Duration of test – 24 hours

The normalized specific capacity values for the GEFA, agricultural and M&I wells are listed in Table 3-1. The difference between the field measured and normalized specific capacity is typically less than 15 percent. Field measured specific capacity values range from 0.49 to 48.45 gpm/foot of drawdown, and normalized specific capacity values range from 0.56 to 56.06 gpm/foot of drawdown.

Figure 3-1 presents the calculated normalized specific capacity at each well location. Contours developed from the normalized specific capacity values are presented in **Figure 3-2**. As with field measured specific capacity values, the normalized specific capacities are higher in the northern portion of the study area and lower in the south. Study area wells north of Dougherty County had an average normalized specific capacity of 22.8 gpm/foot of drawdown while wells south of Dougherty County had an average 6.6 gpm/foot of drawdown. Figures 3-1 and 3-2 show results from the USGS Newberry and Stripling well sites; the results for 06G018, 13L021 and 13L022 are listed in Table 3-1 but are not shown on the figures because they are co-located with other study wells and the analysis results are very similar to other study data.

As part of its study, the USGS developed contours of the Claiborne surface elevation (Gordon and Gonthier; publication pending). These contours are shown on Figure 3-1, and are presented to supplement the normalized specific capacity results. In addition to the specific capacity, the potential yield of a well is also governed by the amount of drawdown that may be allowed or acceptable at the pumping well. Pumping rates are generally restricted to keep the groundwater level at the pumping well from going below the top of the pumped aquifer. Because the Claiborne aquifer is deeper in the southern portion of the Study Area, greater pumping water level drawdowns may be acceptable than to the north where the top of the Claiborne aquifer is not as deep. As such, evaluation of potential well yield should take into account both the specific capacity and the amount of acceptable drawdown at the pumping location.

Section 4

Comparison of Calculated Claiborne Aquifer Transmissivity with Georgia State Water Plan Groundwater Model Input

Numerical groundwater flow models of Georgia Coastal Plain aquifers, including the Claiborne aquifer, were developed 2009 – 2010 for the State Water Plan groundwater resource evaluation. Since these numerical models were developed, additional wells have been installed in the Claiborne aquifer providing new information about Claiborne aquifer properties in the study area. The Southwest Georgia Sub-Regional Groundwater Model is one of the groundwater flow models that was developed for the State Water Plan groundwater resource assessment.

The assigned Claiborne aquifer transmissivity distribution in the State Water Plan Southwest Georgia Sub-Regional Groundwater Model was reviewed considering the Claiborne aquifer transmissivity values calculated from specific capacity data presented in this report. A summary of the State Water Plan groundwater flow models, and the comparison of calculated transmissivity from specific capacity data with the Claiborne aquifer model input is presented below.

4.1 Georgia State Water Plan Groundwater Assessments

In February 2008, the Georgia General Assembly adopted the Georgia Comprehensive State-wide Water Plan (State Water Plan) dated January 8, 2008. The State Water Plan established a regional water resources management planning process, which was initiated in shortly after Plan adoption. Groundwater and surface water resource assessment modeling was conducted to evaluate water availability and potential shortfalls (or gaps) for current and future (2050) water supply demands.

In 2009 and 2010, the availability of groundwater resources in select prioritized aquifers of Georgia was evaluated. The assessment was completed to support preparation of Regional Water Development and Conservation Plans following the framework established by the State Water Plan. The prioritized aquifers included the Floridan aquifer in south-central Georgia, the eastern Coastal Plain of Georgia, and the Dougherty Plain in Southwest Georgia. Other prioritized aquifers included the Claiborne, Clayton, and Cretaceous aquifer systems.

Numerical steady-state groundwater flow models were developed for the State Water Plan to support the groundwater resource assessments. In addition to a Regional Coastal Plain Model (CDM, 2011), sub-regional models were also developed to study the Upper Floridan aquifer system, the Claiborne aquifer, the Clayton aquifer, and the Cretaceous aquifer systems. The development, calibration and application of these models is presented in *Groundwater Flow Modeling of the Coastal Plain Aquifer System of Georgia* (CDM, 2011), *Technical Memorandum on the Assessment of the Sustainable Yield of the Claiborne and Cretaceous Aquifers, Georgia State-*

Wide Groundwater Resources Assessment (CDM Smith, 2012a), and *Technical Memorandum on the Assessment of the Sustainable Yield of the Clayton Aquifer, Georgia State-Wide Groundwater Resources Assessment (*CDM Smith, 2012b*)*.

Recently, the Southwest Georgia sub-regional model (SW Georgia Model), which was developed earlier as a preliminary model, was modified and updated for transient groundwater simulation analysis. The SW Georgia Model domain encompasses the Flint River drainage basin within the coastal plain area of southwest Georgia, including the study area for the analyses described in this report.

Model transmissivity values in all the State Water Plan groundwater flow models, including the SW Georgia Model, were originally based on the regional USGS Coastal Plain Clastic Aquifer System model (Faye and Mayer, 1996), and were adjusted during model calibration, if data were available to support adjusting model properties. In many locations and model layers, where calibration target data were not available, model transmissivity values are similar to those assigned in the regional USGS Coastal Plain Clastic Aquifer System model (Faye and Mayer, 1996).

The Southwest Georgia Model was calibrated in transient mode. Data from ten Claiborne aquifer wells were used as calibration targets for the model layer representing the Claiborne aquifer. The southernmost calibration well is located in central Mitchell County. Except for a few adjustments (reduction in Cretaceous aquifer transmissivity and reduction of localized high vertical leakance areas between model layers 3 and 4), the transmissivity values assigned to the transient SW Georgia Model were consistent with the latest regional and other sub-regional Georgia Coastal Plain models.

SW Georgia Model calibration results model-wide, and in the model layer representing the Claiborne aquifer, met calibration criteria established for the State Water Plan groundwater models (CDM, 2011). The simulated range and trend of Claiborne aquifer water level elevations was generally consistent with observed data, as were simulated groundwater elevations in other model layers.

4.2 Comparison Map

Transmissivity values at wells calculated from specific capacity data, and adjusted assuming an 80% well efficiency, are shown on **Figure 4-1**. Transmissivity values range from 116 ft^2/day to 16,933 ft^2/day, and follow a similar distribution as specific capacity values with higher transmissivity values generally calculated in the northern portion of the study area. Data for estimating well loss are not available for this project, and calculated transmissivities would be higher if the well efficiency is less than the assumed 80%.

Figure 4-1 also shows the SW Georgia Model transmissivity assignments for the model layer (3) representing the Claiborne aquifer, and the Claiborne aquifer wells used for model calibration.

Model transmissivity values are on average almost five times greater than transmissivity calculated from specific capacity data, and at some locations are more than 10 times greater than calculated transmissivity values. There are some locations where model assigned transmissivity values are similar or less than the transmissivity computed from specific capacity data.

Additional model testing would be required to evaluate the effect of a lower Claiborne aquifer transmissivity on model calibration and application.

Section 5

Summary

CDM Smith completed a study to compile and map Claiborne aquifer specific capacity values and estimated transmissivity in southwestern Georgia using data collected by GEFA, GA EPD, and the USGS. CDM Smith used field specific capacity data to develop estimates of Claiborne aquifer transmissivity, and to develop maps of "normalized" specific capacity, which was computed using a uniform set of well characteristics. The study included data from 40 agricultural supply wells, 11 M & I wells, 6 GEFA wells and 5 USGS-study wells. The maps in this report present a spatial summary of Claiborne aquifer well yields in the study area, and may be used as guidance in siting new Claiborne aquifer production wells.

In the study area, the Claiborne aquifer ranges in thickness from 50 to 320 feet, and is thinner in the northern portion of the study area. The depth to the Claiborne aquifer generally increases from north to south.

Claiborne aquifer transmissivity values, computed from field specific capacity data and adjusted to reflect an estimated 80 percent well efficiency, range from approximately 116 ft^2/day to 16,933 ft^2/day with higher transmissivity values computed at many well locations in the northern portion of the study area. Data for estimating well loss are not available for this project, and calculated transmissivities would be higher if the well efficiency is less than the assumed 80%.

The normalized specific capacity values, shown in maps presented in this report, are higher in the northern portion than in the southern portion of the study area. Computed normalized specific capacity values range from 0.56 to 56.06 gpm/foot of drawdown. Evaluation of potential well yield should take into account both the specific capacity and the amount of acceptable drawdown at the pumping location.

Claiborne aquifer transmissivity values, calculated from specific capacity data and assuming an 80% well efficiency, were compared with the assigned transmissivity distribution for the model layer representing the Claiborne aquifer in the State Water Plan SW Georgia Model. The SW Georgia Model was calibrated in transient mode using water level data from ten Claiborne aquifer wells. SW Georgia Model calibration results model-wide, and in the model layer representing the Claiborne aquifer, met calibration criteria established for the State Water Plan groundwater models (CDM, 2011). The simulated range and trend of Claiborne aquifer water level elevations were generally consistent with observed data, as were simulated groundwater elevations in other model layers.

Model transmissivity values are on average almost five times greater than transmissivity calculated from specific capacity data, and at some locations are more than 10 times greater than calculated transmissivity values. There are some locations where model assigned transmissivity values are similar or less than the transmissivity computed from specific capacity data.

Additional model testing would be required to evaluate the effect of a lower Claiborne aquifer transmissivity on model calibration and application.

Section 6

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Figures

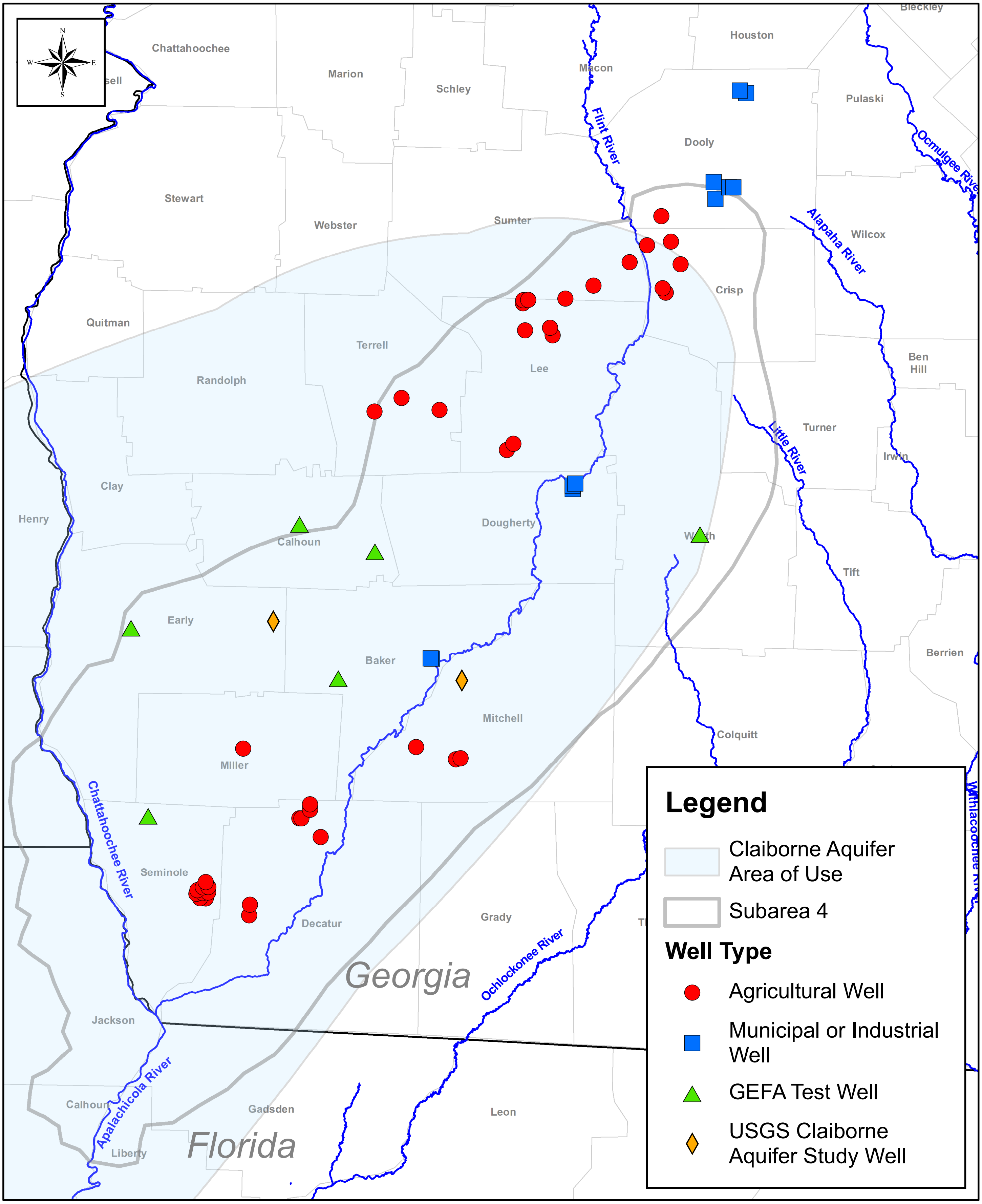

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Figure 2-1
Claiborne Aquifer Specific Capacity and Transmissivity Analysis
Claiborne Aquifer Well Locations in Subarea 4 Vicinity

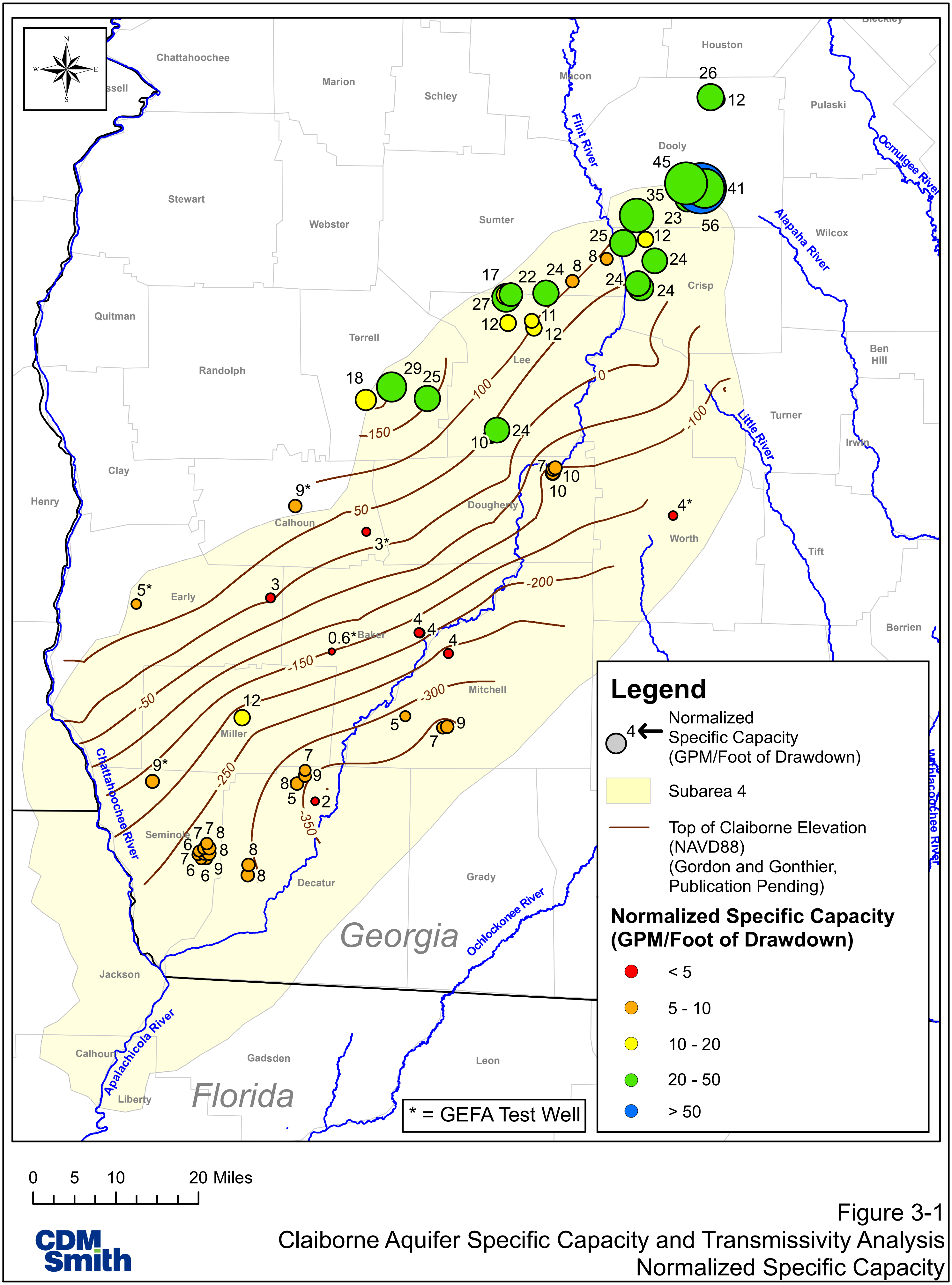

Figure 3-1
Claiborne Aquifer Specific Capacity and Transmissivity Analysis
Normalized Specific Capacity

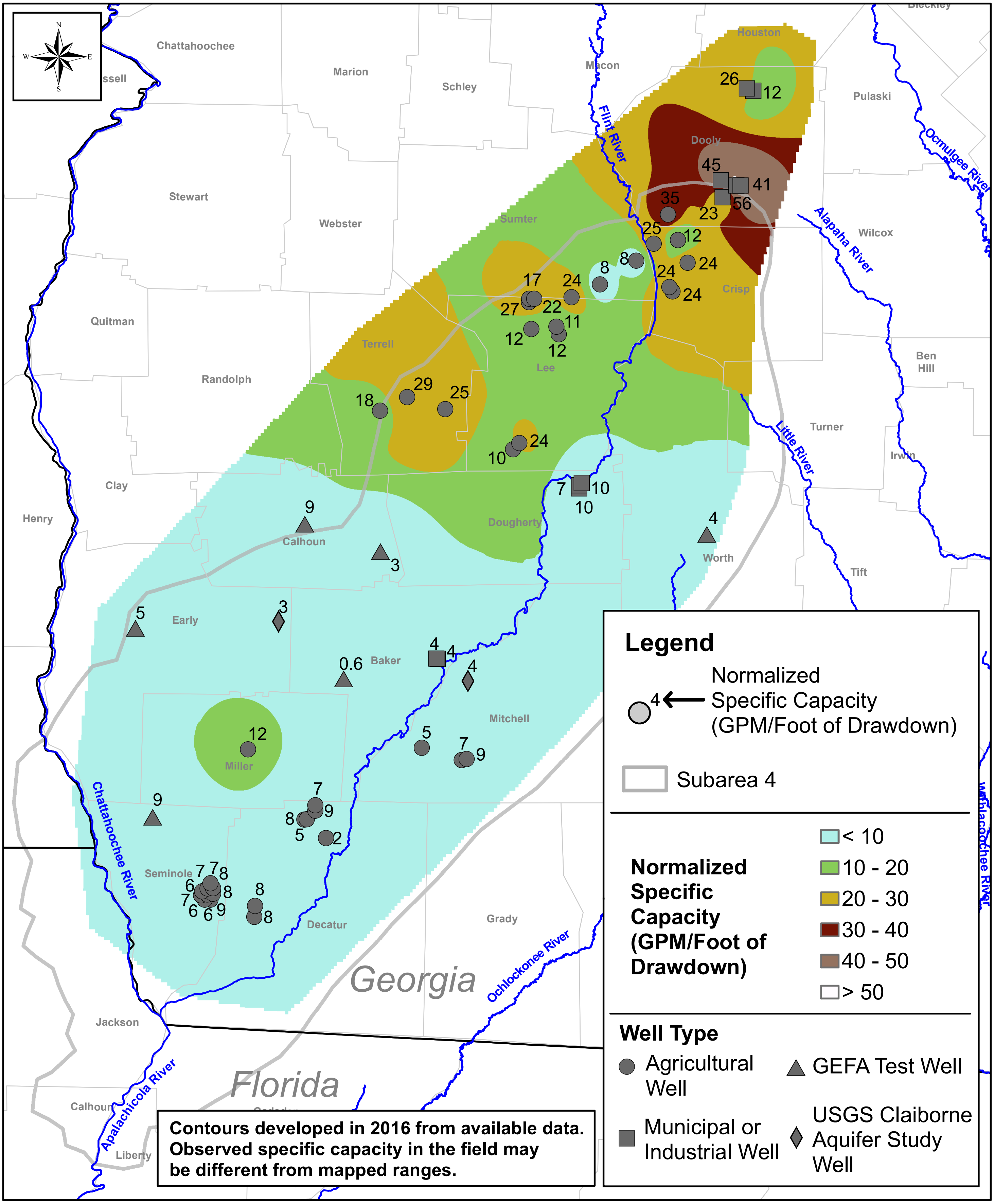

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Figure 3-2
Claiborne Aquifer Specific Capacity and Transmissivity Analysis
Normalized Specific Capacity Contours

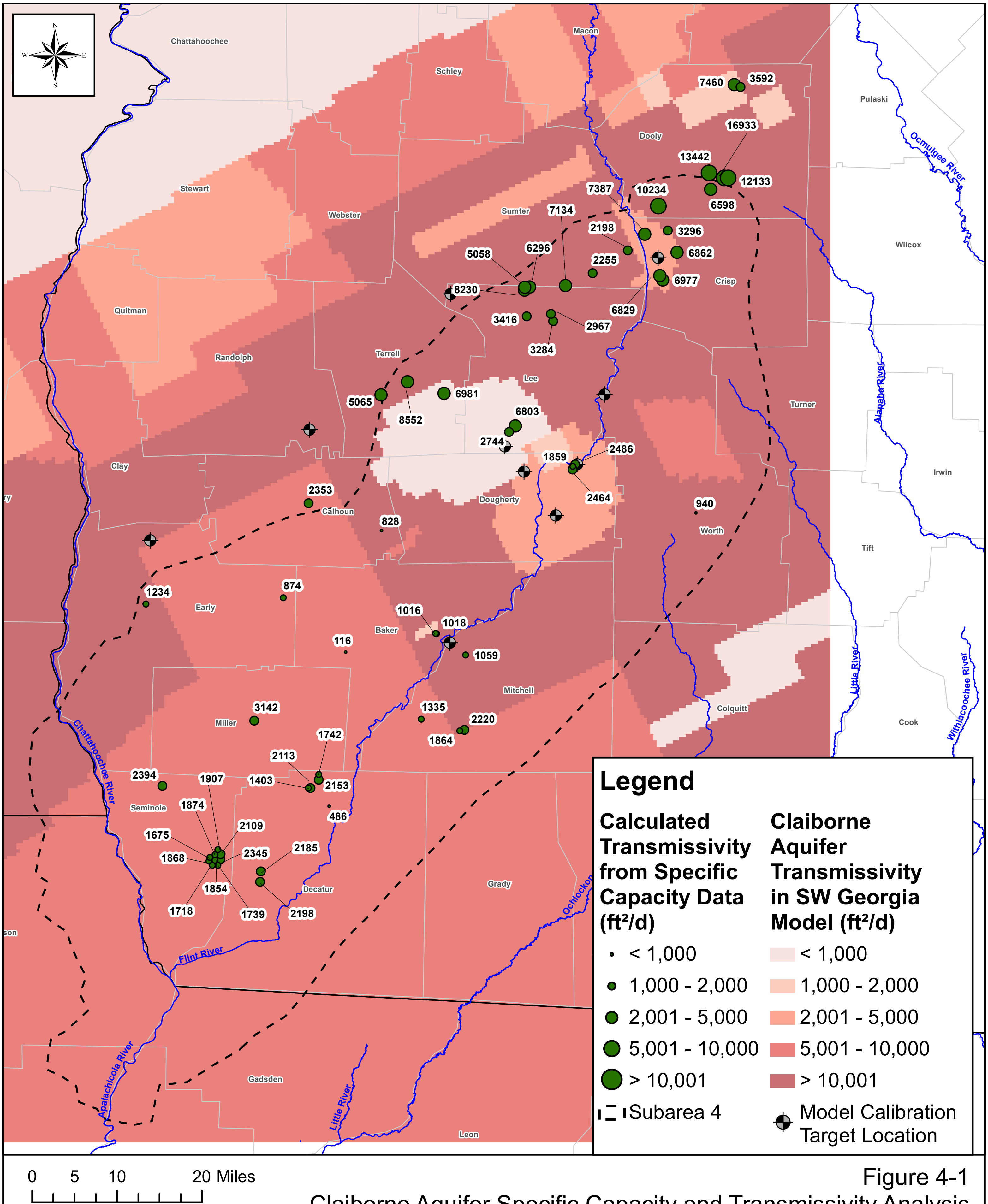

Figure 4-1
Claiborne Aquifer Specific Capacity and Transmissivity Analysis
Comparison of Estimated Transmissivity from Well Data with
Georgia State Water Plan Model Transmissivity Assignments

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Tables

Table 2-1
Well Construction and Testing Summary

Well ID	County	Land Surface Elevation (NAVD88 ft)	Total Depth (ft)	Well Screen Diameter (in)	Borehole Diameter Used For Calculations (in)	Claiborne Aquifer Thickness (ft)	Pump Test Rate (gpm)	Reported Drawdown (ft)	Test Duration (hr)
GEFA Claiborne Aquifer Study									
GEFA-Jones	Baker	180	540	6	7.9	180	100	206	24
GEFA-WMA	Calhoun	165	300	6	7.9	140	250	85	24
GEFA-Morgan-Calhoun	Calhoun	237	220	6	7.9	87	550	72	24
GEFA-Blakely	Early	225	270	6	7.9	120	300	71	24
GEFA-Donalsonville	Seminole	140	700	6	7.9	270	550	66	24
GEFA-Sylvester	Worth	359	1000	6	7.9	294	300	86	24
Agricultural and M&I Wells									
004-0001-03	Baker	169	560	6	16	191	450	111	24
004-0001-04	Baker	161	560	6	16	191	450	111	24
A96-040-0305	Crisp	277	300	12	23	188	1,200	60	24
A96-040-0304	Crisp	285	300	12	23	182	1,200	60	24
A00-040-0372	Crisp	275	320	10	21	177	1,000	50	24
A94-040-0295	Crisp	254	309	12	26	138	1,200	51	72
A02-040-0403	Crisp	310	320	12	12	158	1,200	140	24
G-10097	Decatur	120	800	12	12	260	2,000	225	8
G-10975	Decatur	114	800	10	14	300	2,000	228	12
G-10599	Decatur	147	684	8	12	217	600	305	24
A15-043-0744	Decatur	142	720	10	12	280	1,500	254	8
A15-043-0743	Decatur	143	680	12	16	280	2,000	244	24
A15-043-0742	Decatur	130	660	10	12	240	2,000	250	24
A15-043-0751	Decatur	118	700	10	12	260	2,000	303	24
A15-046-0550	Dooly	319	340	16	26	139	2,000	55	24
046-0002-03	Dooly	350	408	10	26	184	750	31	24
046-0002-04	Dooly	348	440	12	25	187	1,851	38	72
046-0002-05	Dooly	354	435	12	25	190	1,851	46	72

Table 2-1
Well Construction and Testing Summary

Well ID	County	Land Surface Elevation (NAVD88 ft)	Total Depth (ft)	Well Screen Diameter (in)	Borehole Diameter Used For Calculations (in)	Claiborne Aquifer Thickness (ft)	Pump Test Rate (gpm)	Reported Drawdown (ft)	Test Duration (hr)
046-0002-06	Dooly	350	400	12	12	171	780	17	8
046-0003-01	Dooly	380	315	11	24	156	503	59	8.5
047-0007-01	Dooly	432	390	16	26	152	2,900	98	8
047-0007-02	Dougherty	210	560	12	26	258	1,404	154	72
047-0007-03	Dougherty	204	550	12	26	257	1,370	195	72
047-0007-04	Dougherty	206	550	12	26	260	1,445	161	72
A01-088-0454	Lee	220	360	12	24	194	1,000	120	24
A02-088-0463	Lee	244	365	12	20	195	1,200	65	24
A97-088-0372	Lee	277	300	12	24	127	1,000	89	24
A09-088-0481	Lee	284	260	16	26	97	1,000	77	24
A15-088-0525	Lee	294	300	12	23	123	1,100	100	24
A00-088-0427	Lee	287	220	10	22	78	900	32	24
A01-088-0458	Lee	289	240	12	23	77	1,000	60	24
A08-088-0473	Lee	307	260	16	26	83	1,542	68	24
A00-088-0381	Lee	331	360	12	23	121	500	20	24
G-11215	Miller	150	560	12	16	186	2,000	160	10
G-11272	Mitchell	145	800	10	12	198	1,700	225	8
G-11271	Mitchell	140	800	10	14	198	2,000	220	8
G-10575	Mitchell	158	820	10	12	202	1,800	324	8
G-11088	Seminole	112	740	10	12	260	2,000	278	8
A15-125-0880	Seminole	121	740	10	12	260	2,000	281	8
G-11085	Seminole	100	760	10	12	320	2,000	259	8
A15-125-0877	Seminole	118	740	10	12	300	2,000	262	8
A15-125-0875	Seminole	116	720	10	12	300	2,000	212	8
G-11082	Seminole	112	720	10	12	280	2,000	289	8
A15-125-0878	Seminole	120	700	10	12	250	2,000	262	8

Table 2-1
Well Construction and Testing Summary

Well ID	County	Land Surface Elevation (NAVD88 ft)	Total Depth (ft)	Well Screen Diameter (in)	Borehole Diameter Used For Calculations (in)	Claiborne Aquifer Thickness (ft)	Pump Test Rate (gpm)	Reported Drawdown (ft)	Test Duration (hr)
G-11084	Seminole	111	700	10	12	220	2,000	235	8
A15-125-0876	Seminole	109	700	10	12	289	2,000	252	6
A01-129-0429	Sumter	314	330	12	24	136	1,000	130	24
A15-129-0516	Sumter	271	290	16	32	138	1,200	140	24
A11-135-0374	Terrell	322	190	10	18	165	500	34	8
G-08606	Terrell	314	320	10	18	194	420	19	24
A13-135-0391	Terrell	320	230	10	18	172	550	22	3
USGS Claiborne Aquifer Study									
13L021	Dougherty	203	560	12	12	309	1,500	155	24
13L022	Dougherty	206	550	12	12	260	1,660	193	24
USGS-Newberry	Early	224	310	8	8	70	292	98	24
USGS-Stripling	Mitchell	162	700	8	8	260	590	162	24
06G018	Seminole	140	700	6	6	268	550	66	24

Table 3-1
Calculated Transmissivity and Normalized Specific Capacity

Well ID	County	Field Specific Capacity (gpm/ft of drawdown)	Transmissvity (ft^2/day)	Adjusted Transmissivity Assuming 80% Well Efficiency (ft^2/day)	Normalized Specific Capacity (gpm/ft of drawdown)	Normalized Specific Capacity - Rounded For Mapping (gpm/ft of drawdown)
GEFA Claiborne Aquifer Study						
GEFA-Jones	Baker	0.49	91	116	0.56	1
GEFA-WMA	Calhoun	2.94	652	828	3.32	3
GEFA-Morgan-Calhoun	Calhoun	7.64	1,854	2,353	8.53	9
GEFA-Blakely	Early	4.23	972	1,234	4.75	5
GEFA-Donalsonville	Seminole	8.33	1,885	2,394	9.38	9
GEFA-Sylvester	Worth	3.49	739	940	3.96	4
Agricultural and M&I Wells						
004-0001-03	Baker	4.05	799	1,018	4.13	4
004-0001-04	Baker	4.05	798	1,016	4.13	4
A96-040-0305	Crisp	20.00	5,488	6,977	24.46	24
A96-040-0304	Crisp	20.00	5,372	6,829	23.92	24
A00-040-0372	Crisp	20.00	5,400	6,862	23.99	24
A94-040-0295	Crisp	23.53	5,820	7,387	25.30	25
A02-040-0403	Crisp	8.57	2,595	3,296	12.04	12
G-10097	Decatur	8.89	1,726	2,198	8.35	8
G-10975	Decatur	8.77	1,715	2,185	8.30	8
G-10599	Decatur	1.97	381	486	2.10	2
A15-043-0744	Decatur	5.91	1,100	1,403	5.32	5
A15-043-0743	Decatur	8.20	1,660	2,113	8.35	8
A15-043-0742	Decatur	8.00	1,693	2,153	8.50	9
A15-043-0751	Decatur	6.60	1,369	1,742	6.74	7
A15-046-0550	Dooly	36.36	8,053	10,234	34.60	35
046-0002-03	Dooly	24.19	5,189	6,598	23.18	23
046-0002-04	Dooly	48.45	13,349	16,933	56.06	56
046-0002-05	Dooly	40.24	9,560	12,133	41.42	41

Table 3-1
Calculated Transmissivity and Normalized Specific Capacity

Well ID	County	Field Specific Capacity (gpm/ft of drawdown)	Transmissvity (ft^2/day)	Adjusted Transmissivity Assuming 80% Well Efficiency (ft^2/day)	Normalized Specific Capacity (gpm/ft of drawdown)	Normalized Specific Capacity - Rounded For Mapping (gpm/ft of drawdown)
046-0002-06	Dooly	45.88	10,586	13,442	45.02	45
046-0003-01	Dooly	8.60	2,819	3,592	12.99	13
047-0007-01	Dooly	29.59	5,859	7,460	25.92	26
047-0007-02	Dougherty	9.12	1,937	2,464	9.51	10
047-0007-03	Dougherty	7.03	1,461	1,859	7.33	7
047-0007-04	Dougherty	8.98	1,955	2,486	9.60	10
A01-088-0454	Lee	8.33	2,155	2,744	10.28	10
A02-088-0463	Lee	18.46	5,353	6,803	23.96	24
A97-088-0372	Lee	11.24	2,582	3,284	11.80	12
A09-088-0481	Lee	12.99	2,684	3,416	12.32	12
A15-088-0525	Lee	11.00	2,333	2,967	10.71	11
A00-088-0427	Lee	28.13	6,482	8,230	27.40	27
A01-088-0458	Lee	16.67	3,982	5,058	17.08	17
A08-088-0473	Lee	22.68	4,953	6,296	21.56	22
A00-088-0381	Lee	25.00	5,616	7,134	24.26	24
G-11215	Miller	12.50	2,468	3,142	11.91	12
G-11272	Mitchell	7.56	1,463	1,864	7.39	7
G-11271	Mitchell	9.09	1,742	2,220	8.68	9
G-10575	Mitchell	5.56	1,047	1,335	5.43	5
G-11088	Seminole	7.19	1,364	1,739	6.49	6
A15-125-0880	Seminole	7.12	1,348	1,718	6.42	6
G-11085	Seminole	7.72	1,466	1,868	6.69	7
A15-125-0877	Seminole	7.63	1,455	1,854	6.88	7
A15-125-0875	Seminole	9.43	1,841	2,345	8.86	9
G-11082	Seminole	6.92	1,315	1,675	6.49	6
A15-125-0878	Seminole	7.63	1,471	1,874	7.46	7

Table 3-1
Calculated Transmissivity and Normalized Specific Capacity

Well ID	County	Field Specific Capacity (gpm/ft of drawdown)	Transmissvity (ft^2/day)	Adjusted Transmissivity Assuming 80% Well Efficiency (ft^2/day)	Normalized Specific Capacity (gpm/ft of drawdown)	Normalized Specific Capacity - Rounded For Mapping (gpm/ft of drawdown)
G-11084	Seminole	8.51	1,655	2,109	8.32	8
A15-125-0876	Seminole	7.94	1,496	1,907	7.58	8
A01-129-0429	Sumter	7.69	1,772	2,255	8.36	8
A15-129-0516	Sumter	8.57	1,726	2,198	8.16	8
A11-135-0374	Terrell	14.71	3,981	5,065	17.98	18
G-08606	Terrell	22.11	5,494	6,981	24.53	25
A13-135-0391	Terrell	25.00	6,716	8,552	29.35	29
USGS Claiborne Aquifer Study (1)						
13L021	Dougherty	9.66	4,000	--	--	--
13L022	Dougherty	8.60	2,300	--	--	--
USGS-Newberry	Early	2.99	798	--	--	3 (Field Specific Capacity)
USGS-Stripling	Mitchell	3.65	976	--	--	4 (Field Specific Capacity)
06G018	Seminole	8.33	2,228	--	--	--

Notes:

(1) Transmissivity presented as reported in *Hydrology of the Claiborne Aquifer and Interconnection with the Upper Floridan Aquifer in Southwest Georgia* (Gordon and Gonthier, publication pending).

Appendix A
Well Construction and Testing Details

CDM Smith

Appendix A
Well Construction and Testing Details

Well ID	GAEPD Permit ID	GAEPD Application ID	Well Use	Latitude	Longitude	County	Land Surface Elevation (NAVD88 ft)	Date Drilled	Total Depth (ft)	Well Screen Diameter (in)	Borehole Diameter Used For Calculations (in)	Depth to Top of Uppermost Screen Interval (ft)	Depth to Bottom of Lowest Screen Interval (ft)	Depth to Top of Claiborne based on HA10 or well logs (ft)	Claiborne Aquifer Thickness (ft)	Source of Claiborne Depth and Thickness	Static Depth to Water (ft)	Date Tested and of Static Depth to Water Measurement	Difference Between Depth to Top of Claiborne and Depth to Water (ft)	Pump Test Rate (gpm)	Reported Drawdown (ft)	Test Duration (hr)
GEFA-Jones	-	-	GEFA Claiborne Aquifer Study	31.2832	-84.5287	Baker	180	09/07/16	540	6	7.9	320	500	320	180	Drilling Log	40	09/14/16	280	100	206	24
GEFA-WMA	-	-	GEFA Claiborne Aquifer Study	31.4930	-84.4589	Calhoun	165	07/19/16	300	6	7.9	160	300	160	140	Drilling Log	3	07/25/16	157	250	85	24
GEFA-Morgan-Calhoun	-	-	GEFA Claiborne Aquifer Study	31.5376	-84.6044	Calhoun	237	06/08/16	220	6	7.9	120	220	126	87	Drilling Log	96	06/21/16	30	550	72	24
GEFA-Blakely	-	-	GEFA Claiborne Aquifer Study	31.3646	-84.9283	Early	225	05/11/16	270	6	7.9	150	270	150	120	Drilling Log	18	05/13/16	132	300	71	24
GEFA-Donalsonville	-	-	GEFA Claiborne Aquifer Study	31.0540	-84.8931	Seminole	140	03/30/16	700	6	7.9	400	700	400	270	Drilling Log	32	04/07/16	368	550	66	24
GEFA-Sylvester	-	-	GEFA Claiborne Aquifer Study	31.5214	-83.8315	Worth	359	11/03/16	1000	6	7.9	700	1000	700	294	Drilling Log	169	11/10/16	531	300	86	24
A96-040-0305	A96-040-0305	A96-040-0305	Agricultural	31.9209	-83.8964	Crisp	277	07/01/96	300	12	23	180	300	242	188	HA 10	45	07/01/96	197	1,200	60	24
A96-040-0304	A96-040-0304	A96-040-0304	Agricultural	31.9282	-83.9025	Crisp	285	08/01/96	300	12	23	180	300	242	182	HA 10	45	08/01/96	197	1,200	60	24
A00-040-0372	A00-040-0372	A00-040-0372	Agricultural	31.9679	-83.8675	Crisp	275	03/20/01	320	10	21	200	320	225	177	HA 10	30	04/02/01	195	1,000	50	24
A94-040-0295	A94-040-0295	A94-040-0295	Agricultural	31.9993	-83.9325	Crisp	254	08/14/94	309	12	26	189	309	145	138	HA 10	9	08/16/94	136	1,200	51	72
A02-040-0403	A02-040-0403	A02-040-0403	Agricultural	32.0054	-83.8860	Crisp	310	05/29/02	320	12	12	200	300	220	158	HA 10	40	05/29/02	180	1,200	140	24
G-10097	G-10097	G-10097	Agricultural	30.8905	-84.6981	Decatur	120	03/20/14	800	12	12	480	800	540	260	Drilling Log	30	03/31/14	510	2,000	225	8
G-10975	G-10975	G-10975	Agricultural	30.9082	-84.6967	Decatur	114	01/22/15	800	10	14	480	800	500	300	Drilling Log	32	02/17/15	468	2,000	228	12
G-10599	G-10599	G-10599	Agricultural	31.0205	-84.5617	Decatur	147	11/29/13	684	8	12	467	684	467	217	Drilling Log	55	No Data	412	600	305	24
A15-043-0744	A15-043-0744	G-10828	Agricultural	31.0512	-84.6030	Decatur	142	12/11/13	720	10	12	380	720	440	280	Drilling Log	56	12/18/13	384	1,500	254	8
A15-043-0743	A15-043-0743	G-10607	Agricultural	31.0513	-84.5989	Decatur	143	11/13/13	680	12	16	380	680	400	280	Drilling Log	36	11/18/13	364	2,000	244	24
A15-043-0742	A15-043-0742	G-10769	Agricultural	31.0656	-84.5823	Decatur	130	11/01/13	660	10	12	360	660	400	240	Drilling Log	40	11/05/13	360	2,000	250	24
A15-043-0751	A15-043-0751	G-10753	Agricultural	31.0746	-84.5824	Decatur	118	01/01/14	700	10	12	380	700	440	260	Drilling Log	17	01/08/14	423	2,000	303	24
A15-046-0550	A15-046-0550	G-10522	Agricultural	32.0475	-83.9049	Dooly	319	12/12/13	340	16	26	180	340	183	139	HA 10	55	12/19/13	128	2,000	55	24
A01-088-0454	A01-088-0454	A01-088-0454	Agricultural	31.6612	-84.2044	Lee	220	05/29/01	360	12	24	240	360	200	194	HA 10	40	06/06/01	160	1,000	120	24
A02-088-0463	A02-088-0463	A02-088-0463	Agricultural	31.6715	-84.1921	Lee	244	09/20/01	365	12	20	200	320	222	195	HA 10	60	11/20/01	162	1,200	65	24
A97-088-0372	A97-088-0372	A97-088-0372	Agricultural	31.8506	-84.1160	Lee	277	01/27/97	300	12	24	200	300	170	127	HA 10	68	01/27/97	102	1,000	89	24
A09-088-0481	A09-088-0481	G-06324	Agricultural	31.8591	-84.1693	Lee	284	07/24/08	260	16	26	120	260	144	97	HA 10	44	08/08/08	100	1,000	77	24
A15-088-0525	A15-088-0525	G-10265	Agricultural	31.8633	-84.1208	Lee	294	07/24/13	300	12	23	180	300	173	123	HA 10	45	8/5/2013	128	1,100	100	24
A00-088-0427	A00-088-0427	A00-088-0427	Agricultural	31.9037	-84.1733	Lee	287	03/09/07	220	10	22	120	220	106	78	HA 10	20	03/27/07	86	900	32	24
A01-088-0458	A01-088-0458	A01-088-0458	Agricultural	31.9089	-84.1729	Lee	289	07/18/00	240	12	23	180	240	105	77	HA 10	30	08/09/00	75	1,000	60	24
A08-088-0473	A08-088-0473	G-06183	Agricultural	31.9091	-84.1633	Lee	307	07/23/07	260	16	26	140	260	127	83	HA 10	32	07/31/07	95	1,542	68	24
A00-088-0381	A00-088-0381	A00-088-0381	Agricultural	31.9115	-84.0913	Lee	331	12/09/10	360	12	23	240	360	186	121	HA 10	60	12/15/10	126	500	20	24
G-11215	G-11215	G-11215	Agricultural	31.1663	-84.7113	Miller	150	04/01/15	560	12	16	300	560	322	186	HA 10	90	04/08/15	232	2,000	160	10
G-11272	G-11272	G-11272	Agricultural	31.1497	-84.3022	Mitchell	145	02/02/15	800	10	12	520	800	529	198	HA 10	90	02/19/15	439	1,700	225	8
G-11271	G-11271	G-11271	Agricultural	31.1514	-84.2931	Mitchell	140	01/30/15	800	10	14	520	800	527	198	HA 10	80	02/18/15	447	2,000	220	8
G-10575	G-10575	G-10575	Agricultural	31.1699	-84.3787	Mitchell	158	06/04/14	820	10	12	540	820	478	202	HA 10	46	06/10/14	432	1,800	324	8
G-11088	G-11088	G-11088	Agricultural	30.9183	-84.7820	Seminole	112	08/19/14	740	10	12	400	740	480	260	Drilling Log	32	08/26/14	448	2,000	278	8
A15-125-0880	A15-125-0880	G-11087	Agricultural	30.9184	-84.7929	Seminole	121	09/24/14	740	10	12	400	740	480	260	Drilling Log	24	10/22/14	456	2,000	281	8
G-11085	G-11085	G-11085	Agricultural	30.9257	-84.7997	Seminole	100	09/18/14	760	10	12	400	760	440	320	Drilling Log	16	10/16/14	424	2,000	259	8
A15-125-0877	A15-125-0877	G-10948	Agricultural	30.9270	-84.7878	Seminole	118	05/21/14	740	10	12	400	740	440	300	Drilling Log	18	05/29/14	422	2,000	262	8
A15-125-0875	A15-125-0875	G-11086	Agricultural	30.9282	-84.7772	Seminole	116	07/31/14	720	10	12	400	720	420	300	Drilling Log	28	08/12/14	392	2,000	212	8
G-11082	G-11082	G-11082	Agricultural	30.9319	-84.7978	Seminole	112	10/29/14	720	10	12	400	720	440	280	Drilling Log	21	11/06/14	419	2,000	289	8
A15-125-0878	A15-125-0878	G-11083	Agricultural	30.9367	-84.7876	Seminole	120	10/31/14	700	10	12	400	700	440	250	Drilling Log	18	11/07/14	422	2,000	262	8
G-11084	G-11084	G-11084	Agricultural	30.9373	-84.7768	Seminole	111	07/24/14	700	10	12	400	700	460	220	Drilling Log	35	08/03/14	425	2,000	235	8
A15-125-0876	A15-125-0876	G-11081	Agricultural	30.9453	-84.7819	Seminole	109	11/07/14	700	10	12	400	700	411	289	Drilling Log	28	11/14/14	383	2,000	252	6
A01-129-0429	A01-129-0429	A01-129-0429	Agricultural	31.9327	-84.0367	Sumter	314	02/22/01	330	12	24	230	330	183	136	HA 10	50	03/02/01	133	1,000	130	24
A15-129-0516	A15-129-0516	G-10799	Agricultural	31.9716	-83.9665	Sumter	271	12/09/13	290	16	32	170	290	160	138	HA 10	40	12/19/13	120	1,200	140	24
A11-135-0374	A11-135-0374	G-07157	Agricultural	31.7243	-84.4607	Terrell	322	01/08/10	190	10	18	90	190	59	165	HA 10	33	01/12/10	26	500	34	8
G-08606	G-08606	G-08606	Agricultural	31.7272	-84.3347	Terrell	314	05/24/13	320	10	18	160	320	110	194	HA 10	61	05/30/13	49	420	19	24
A13-135-0391	A13-135-0391	G-04447	Agricultural	31.7469	-84.4081	Terrell	320	05/10/10	230	10	18	130	230	66	172	HA 10	34	05/25/10	32	550	22	3
004-0001-03	004-0001	-	Municipal or Industrial	31.3161	-84.3487	Baker	169	12/01/95	560	6	16	350	555	384	191	HA 10	35	01/25/95	349	450	111	24
004-0001-04	004-0001	-	Municipal or Industrial	31.3166	-84.3509	Baker	161	12/01/95	560	6	16	335	545	375	191	HA 10	28	01/19/95	347	450	111	24
046-0002-03	046-0002	-	Municipal or Industrial	32.0756	-83.7995	Dooly	350	05/01/82	408	10	26	220	400	240	184	HA 10	64	05/01/82	176	750	31	24
046-0002-04	046-0002	-	Municipal or Industrial	32.0950	-83.7725	Dooly	348	01/20/94	440	12	25	280	425	238	187	HA 10	49	04/11/94	188	1,851	38	72
046-0002-05	046-0002	-	Municipal or Industrial	32.0950	-83.7644	Dooly	354	01/04/94	435	12	25	210	425	248	190	HA 10	46	03/23/94	202	1,851	46	72
046-0002-06	046-0002	-	Municipal or Industrial	32.1037	-83.8028	Dooly	350	03/03/47	400	12	12	210	390	214	171	HA 10	54	03/28/47	160	780	17	8
046-0003-01	046-0003	-	Municipal or Industrial	32.2506	-83.7389	Dooly	380	10/01/77	315	11	24	247	307	212	156	HA 10	60	11/04/77	152	503	59	8.5
047-0007-01	046-0007	-	Municipal or Industrial	32.2546	-83.7514	Dooly	432	07/10/14	390	16	26	210	390	250	152	HA 10	140	07/28/14	110	2,900	98	8
047-0007-02	047-0007	-	Municipal or Industrial	31.5967	-84.0775	Dougherty	210	01/11/79	560	12	26	300	550	281	258	HA 10	79	04/09/79	202	1,404	154	72
047-0007-03	047-0007	-	Municipal or Industrial	31.6021	-84.0773	Dougherty	204	12/04/78	550	12	26	290	540	271	257	HA 10	68	04/16/79	203	1,370	195	72
047-0007-04	047-0007	-	Municipal or Industrial	31.6056	-84.0723	Dougherty	206	12/22/78	550	12	26	300	540	273	260	HA 10	88	04/19/79	185	1,445	161	72
13L021	13L021	-	USGS Claiborne Aquifer Study	31.5966	-84.0777	Dougherty	203	No Data	560	12	No Data	300	550	281	309	USGS Study	No Data	No Data	--	1,500	155	24
13L022	13L022	-	USGS Claiborne Aquifer Study	31.6030	-84.0771	Dougherty	206	No Data	550	12	No Data	290	540	274	260	USGS Study	No Data	No Data	--	1,660	193	24
USGS-Newberry	08K026	-	USGS Claiborne Aquifer Study	31.3766	-84.6542	Early	222	2015	290	8	12	215	295	230	70	USGS Study	No Data	2015	--	292	98	24
USGS-Stripling	11J029	-	USGS Claiborne Aquifer Study	31.2798	-84.2907	Mitchell	162	2015	700	8	10	460	700	442	260	USGS Study	119	2015	323	590	162	24
06G018	06G018	-	USGS Claiborne Aquifer Study	31.0540	-84.8931	Seminole	161	No Data	700	6	No Data	400	700	340	268	USGS Study	No Data	No Data	--	550	66	24

HA 10: Arora, R., 1984. Hydrogeologic Evaluation for Underground Injection Control in the Coastal Plain of Georgia. Georgia Geological Survey Hydrologic Atlas (HA) 1(

USGS Study: Hydrology of the Claiborne Aquifer and Interconnection with the Upper Floridan Aquifer in Southwest Georgia (Gordon and Gonthier, publication pending

Appendix B
GEFA Well Reports

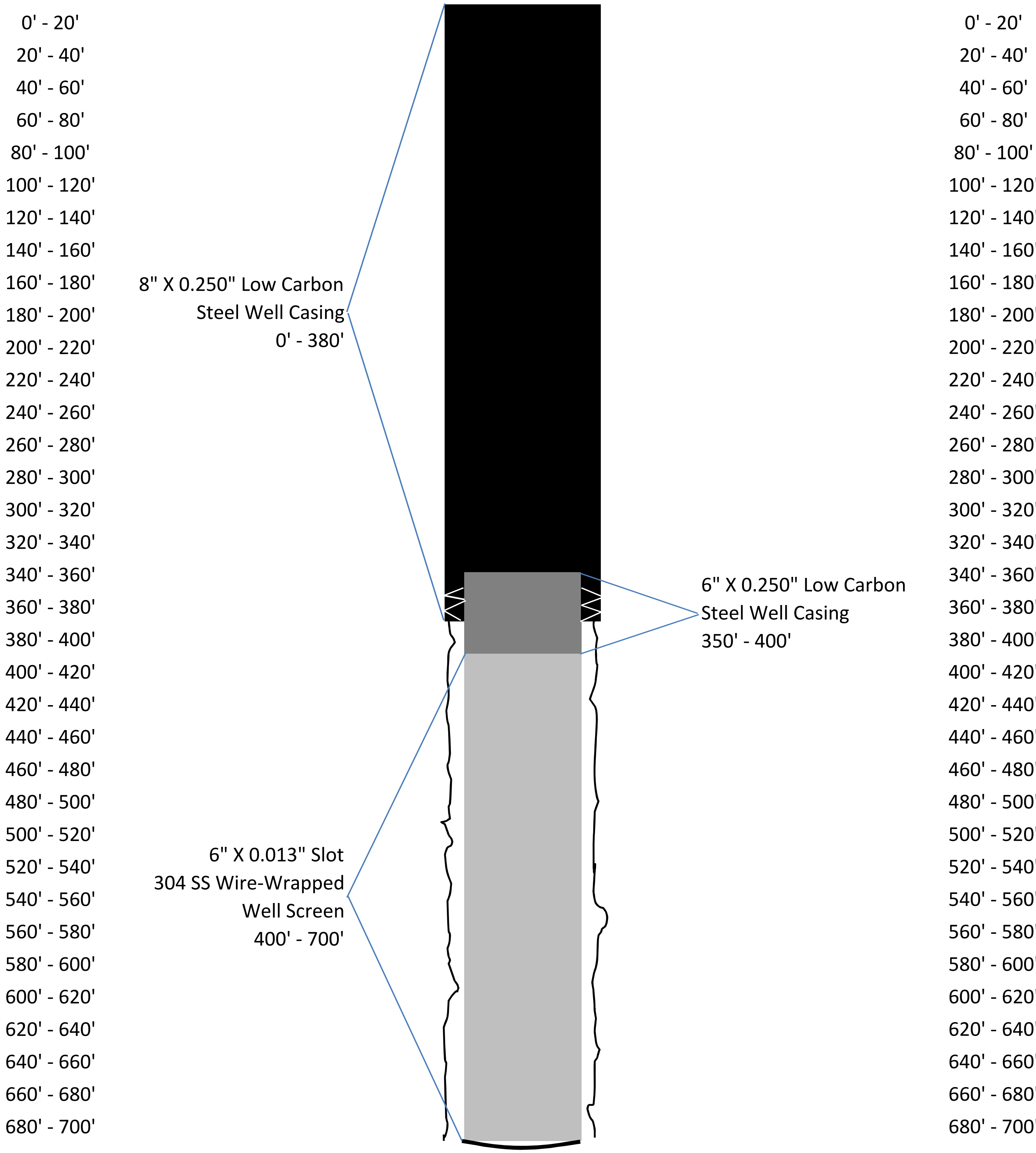
CDM Smith

Georgia Environmental Finance Authority
Claiborne Test Wells Project
Site: GDOT Facility
Location: Donalsonville, GA (Seminole County)
N 31.053960, W 84.893102

Well Drilling Information	
Total Depth of Well: 700' Below Land Surface	Drilling Method: Combination
Static Water Level: 32'	Date Drilled: March 30, 2016
Date Static Water Level Measured: April 6, 2016	Driller: Greg Grosch
Borehole Information	**Grouting**
Borehole Diameter: 9" From 0' to 380'	Type: High Yield Bentonite
Borehole Diameter: 7-7/8" From 380' to 700'	Interval: 0' to 380'
Casing Information	
Casing Material: Low Carbon Steel	
Casing Wall Thickness: 0.250"	
Casing Details: 8-5/8" Outside, 8-1/8" Inside From 0' to 380'	
Casing Details: 6-1/2" Outside, 6" Inside From 350' to 400'	
Well Screen Information	
Well Screen Material: Stainless Steel	
Well Screen Details: 6" X 0.013" Slot From 400' to 700'	
Test Pump Data	
Date Tested: April 7, 2016 - April 8, 2016	
Total Continuous Hours Tested: 24	
Did Water Level Stabilize: Yes	
Sustained Yield: 550 GPM	
Pumping Water Level: 98' at 24 Hours	
Drawdown: 66'	
Specific Capacity: 8.333 GPM/Ft. of Drawdown	
Time Until Recovery: 8 Hours	
Permanent Pump Data	
Pump Type: None	
Pump Diameter: None	
Discharge Size: None	
Motor HP: None	Motor RPM: None
Pump Capacity (GPM): None	Total Dynamic Head: None
Pump Setting Depth: None	
Pump Disinfected?: N/A	
Air Line Installed?: N/A	
Air Line Depth, If Installed: N/A	Air Line Diameter, If Installed: N/A
Chemigation Check Valve Installed?: N/A	

Attached: Geophysical Logs
Attached: Step Drawdown Test Results
Attached: 24 Hour Constant Rate Test Results
Attached: Water Quality Analysis

Georgia Environmental Finance Authority
Claiborne Test Wells Project
Site: GDOT Facility
Location: Donalsonville, GA (Seminole County)
N 31.053960, W 84.893102



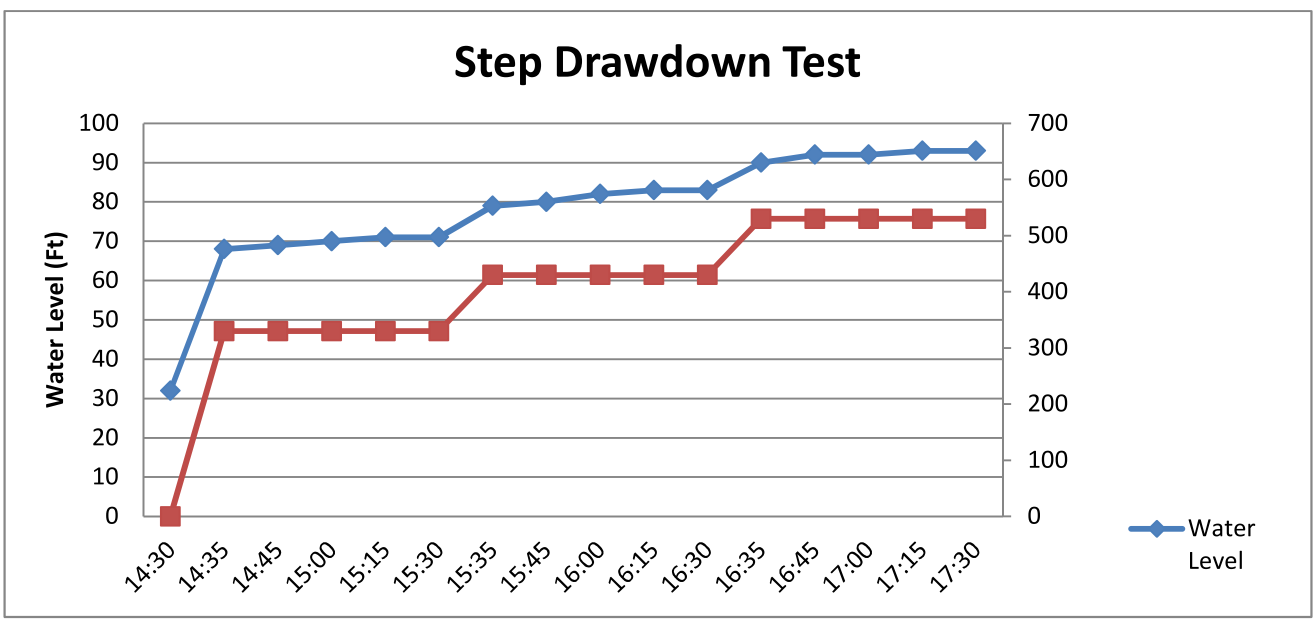
Lithologic Log

0' - 40'	Blueish - Grey Clay, Some Sandy
40' - 53'	Light Grey Fossiliferous Limestone
53' - 80'	White to Cream Fossiliferous Limestone
80' - 161'	White to Light Grey Limestone
161' - 204'	White Limestone with Very Small Very Fine Sand Streaks
204' - 293'	White Limestone
293' - 348'	Slightly Sandy White to Light Grey Limestone
348' - 378'	Light Grey Limestone
378' - 392'	Blueish - Grey Clay
392' - 400'	Blueish - Grey Clay with Sand and Shell Streaks
400' - 420'	Very Fine Sand with Trace Amounts of Shell; Small Clay Streaks
420' - 460'	Very Fine Sand
460' - 490'	Very Fine Sand; Some Clay
490' - 502'	Very Fine Sand
502' - 503'	Blueish - Grey Sandy Clay
503' - 538'	Very Fine Sand
538' - 552'	Blueish - Grey Sandy Clay
552' - 580'	Very Fine Sand; Some Clay
580' - 640'	Very Fine Black Speck Sand
640' - 668'	Very Fine Sand (50/50 Black/White)
668' - 672'	Blueish - Grey Clay
672' - 681'	Blueish - Grey Sandy Clay
681' - 700'	Blueish - Grey Clay

Location: Donalsonville, GA (Seminole County), N 31.053960, W 84.893102
Client: Georgia Environmental Finance Authority
Well ID: GEFA - Seminole
Test Date: 4/6/2016

Step Drawdown Test

Time	Water Level	Drawdown	GPM	Notes
14:30	32	0	0	Static
14:35	68	36	330	
14:45	69	37	330	
15:00	70	38	330	
15:15	71	39	330	
15:30	71	39	330	Increase
15:35	79	47	430	
15:45	80	48	430	
16:00	82	50	430	
16:15	83	51	430	
16:30	83	51	430	Increase
16:35	90	58	530	
16:45	92	60	530	
17:00	92	60	530	
17:15	93	61	530	
17:30	93	61	530	Pump Off

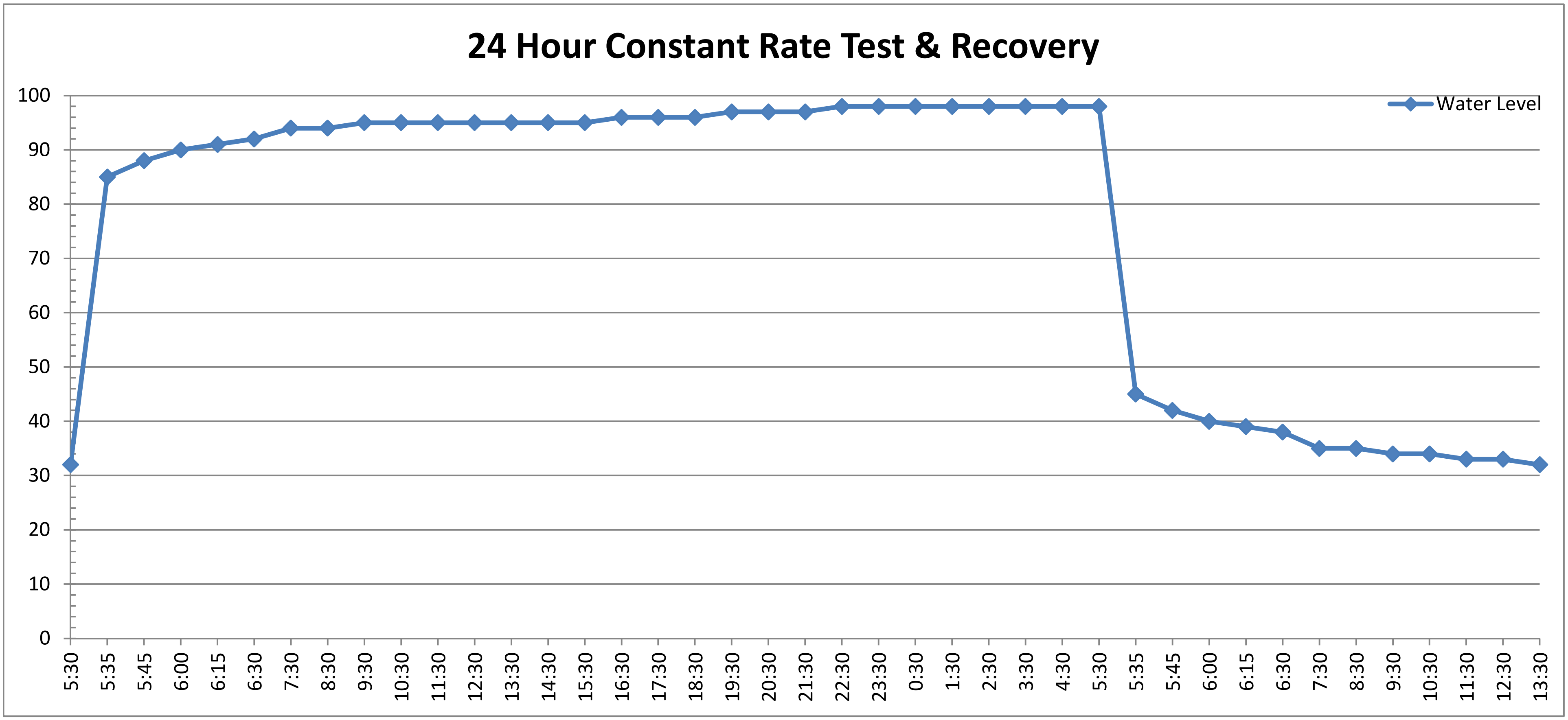


Georgia Environmental Finance Authority
Claiborne Test Wells Project
Site: GDOT Facility
Location: Donalsonville, GA (Seminole County)
N 31.053960, W 84.893102

24 Hour Constant Rate Testing & Recovery

Clock Time	Time Elapsed (Minutes)	Time Elapsed (Hours)	Water Level	GPM	Drawdown	Notes
5:30	0	0	32	0	0	Pump Started
5:35	5	0.083	85	550	53	
5:45	15	0.250	88	550	56	
6:00	30	0.500	90	550	58	
6:15	45	0.750	91	550	59	
6:30	60	1.000	92	550	60	
7:30	120	2.000	94	550	62	
8:30	180	3.000	94	550	62	
9:30	240	4.000	95	550	63	
10:30	300	5.000	95	550	63	
11:30	360	6.000	95	550	63	
12:30	420	7.000	95	550	63	
13:30	480	8.000	95	550	63	
14:30	540	9.000	95	550	63	
15:30	600	10.000	95	550	63	
16:30	660	11.000	96	550	64	
17:30	720	12.000	96	550	64	
18:30	780	13.000	96	550	64	
19:30	840	14.000	97	550	65	
20:30	900	15.000	97	550	65	
21:30	960	16.000	97	550	65	
22:30	1020	17.000	98	550	66	
23:30	1080	18.000	98	550	66	
0:30	1140	19.000	98	550	66	
1:30	1200	20.000	98	550	66	
2:30	1260	21.000	98	550	66	
3:30	1320	22.000	98	550	66	
4:30	1380	23.000	98	550	66	

5:30	1440	24.000	98	550	66	Pump Off
5:35	5	0.083	45	550	13	Recovery 5 Minutes
5:45	15	0.250	42	550	10	Recovery 15 Minutes
6:00	30	0.500	40	550	8	Recovery 30 Minutes
6:15	45	0.750	39	550	7	Recovery 45 Minutes
6:30	60	1.000	38	550	6	Recovery 1 Hour
7:30	120	2.000	35	550	3	Recovery 2 Hours
8:30	180	3.000	35	550	3	Recovery 3 Hours
9:30	240	4.000	34	550	2	Recovery 4 Hours
10:30	300	5.000	34	550	2	Recovery 5 Hours
11:30	360	6.000	33	550	1	Recovery 6 Hours
12:30	420	7.000	33	550	1	Recovery 7 Hours
13:30	480	8.000	32	550	0	Recovery 8 Hours



GIC Water Systems
Water Well Services

737 B Firetower Road
Dublin, Georgia 31021
(478) 274-9546 phone
(478) 275-0014 fax
gicws@nlamerica.com

GEFA - DONALSONVILLE

Electric Log W/ Natural Gamm

COMPANY	Grosch Drilling	OTHER SERVICES
WELL	GEFA-Donalsonville	
FIELD		
COUNTRY	USA	
STATE	Georgia	
COUNTY	Seminole	
LAT.:	31 3' 14"	
LONG.:	84 53' 36"	

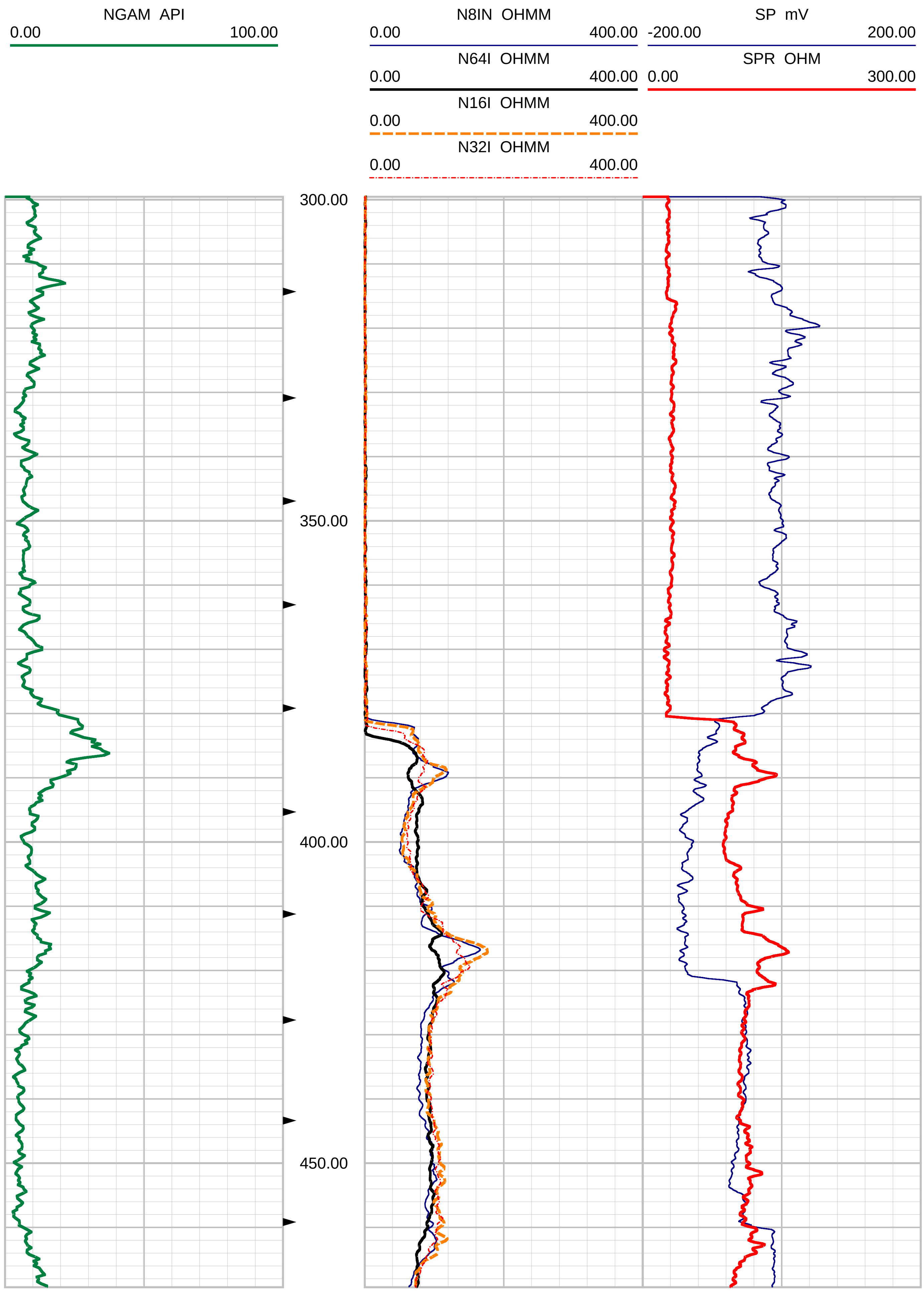
Perm. Datum	ground surf..	Elev	140 ft	KB	0.00
Log. Datum				DF	0.00
Drill Datum				GL	0.00

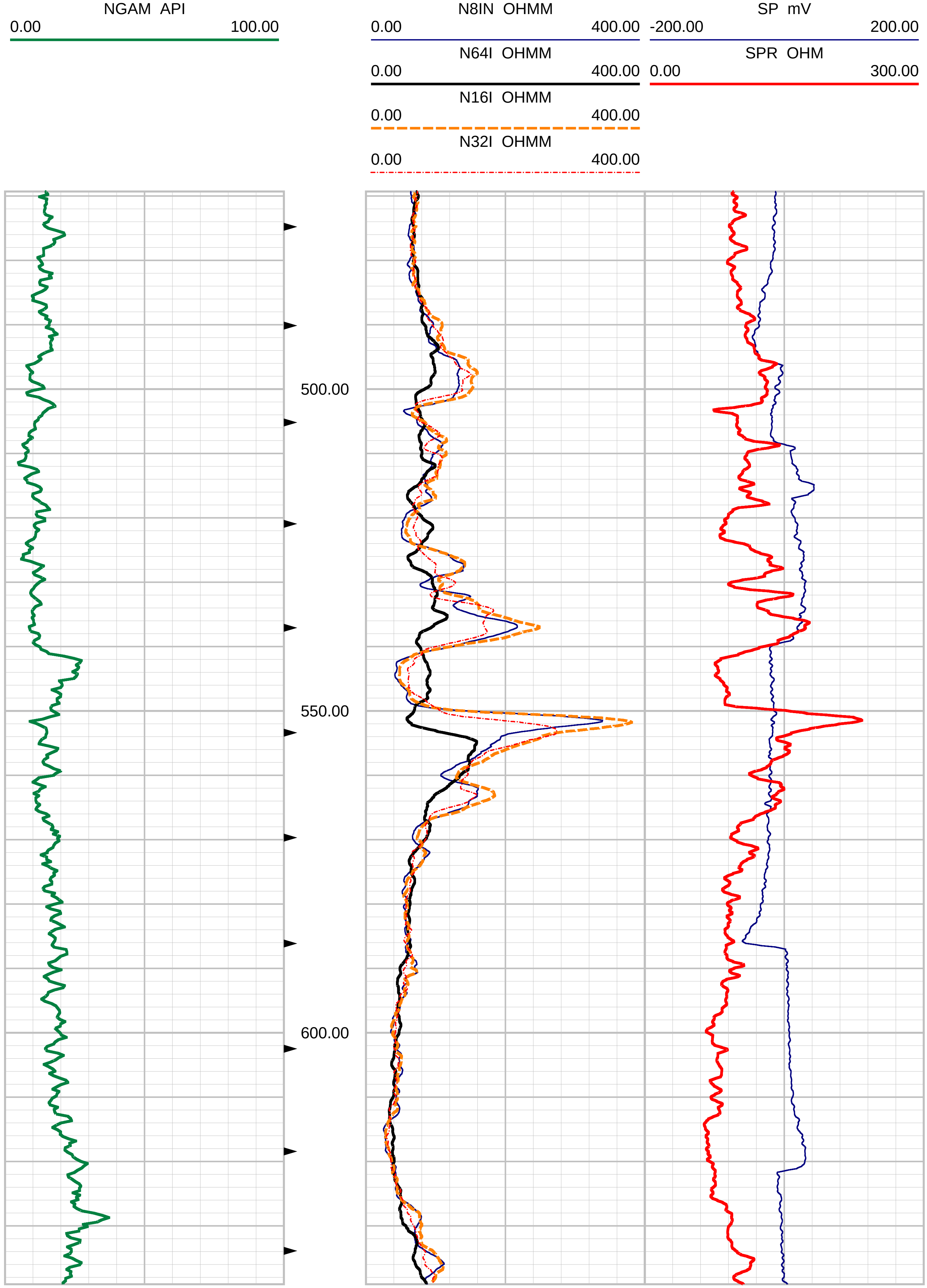
DATE	30 Mar 1	29 Mar 1	29 Mar 1
RUN#	0	0	0
TYPE OF LOG	ELMT6618		
DEPTH DRILLER	700.00	0.00	0.00
DEPTH LOGGER	700.00	0.00	0.00
LOG DEEPEST	700.00	0.00	0.00
LOG SHALLOW	0.00	0.00	0.00
FLUID IN HOLE	Water		
SALINITY			
DENSITY			
LEVEL	0		
MAX TEMP °C	0.00	0.00	0.00
RIG TIME	23:47		
RECORDED BY	S.Dixon, PG		
WITNESSED BY	S.Brantley		

RUN#	BIT RECORD			CASING RECORD			
	SIZE	FROM	TO	SIZE	WEIGHT	FROM	TO
0	6.00	380.00	700.00	8.00	0.00	0.00	380.00
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00

REMARKS (C:\Winlogger\Data\GEFA-Donalsonville.hed)

ELMT6618-8,16,32, and 64-Normal Resistivity, SPR, SP, Temp, and Nat..
Logging up
ROBERTSON GEOLOGGING TECHNOLOGY
Logging speed - 16ft/min


NGAM API
0.00
100.00
N8IN OHMM
0.00
400.00
N64I OHMM
0.00
400.00
N16I OHMM
0.00
400.00
N32I OHMM
0.00
400.00
SP mV
-200.00
200.00
SPR OHM
0.00
300.00
300.00
350.00
400.00
450.00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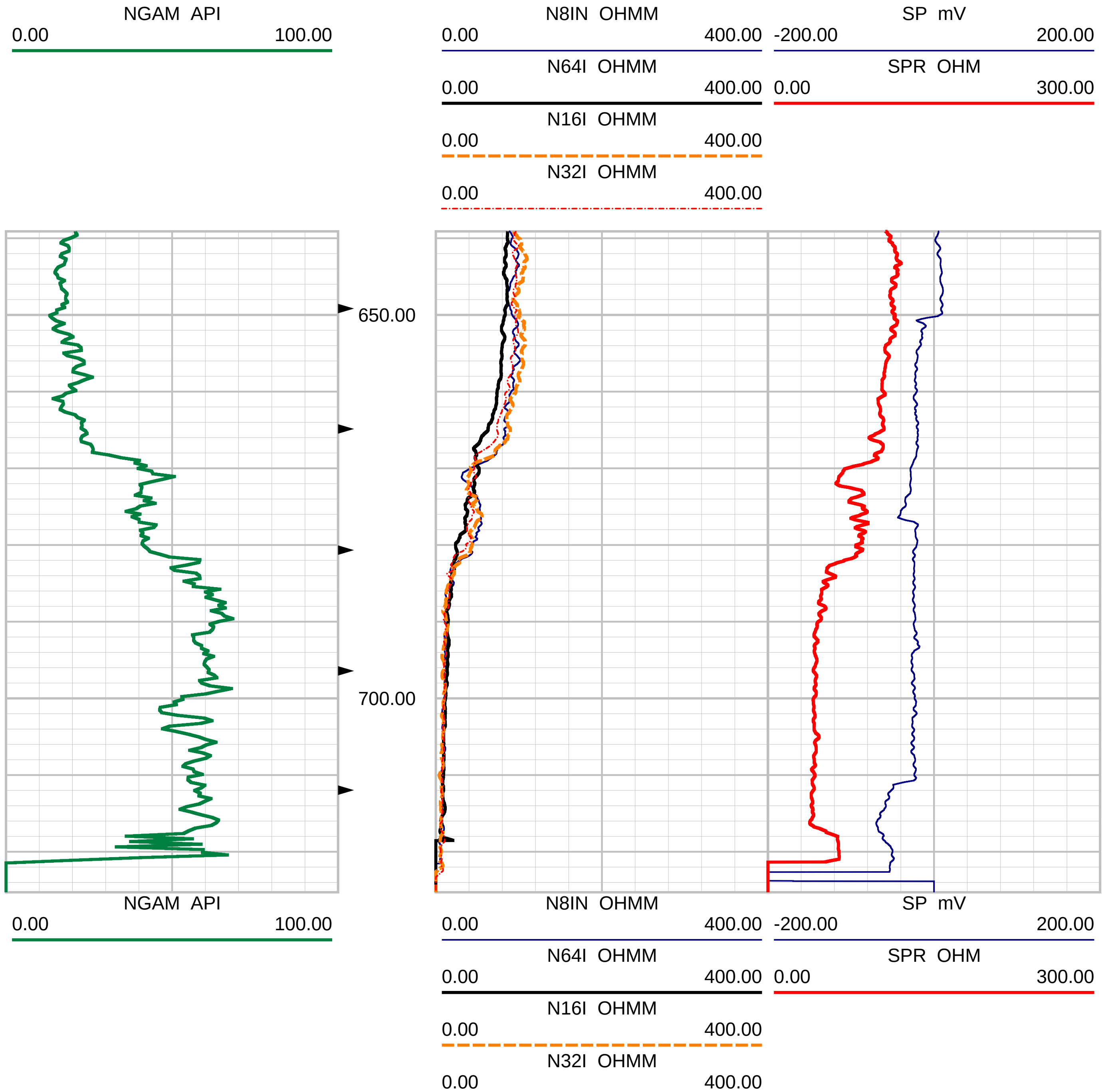
0.00
100.00
N8IN OHMM
0.00
400.00
N64I OHMM
0.00
400.00
N16I OHMM
0.00
400.00
N32I OHMM
0.00
400.00
SP mV
-200.00
200.00
SPR OHM
0.00
300.00
500.00
550.00
600.00



Depth: 299.00 ft   Date: 30 Mar 2016   Time: 00:35:35   File: "C:\Winlogger\DATA\GEFA-Donalsonville.LGX"

Water Analysis

Food Safety

Waters Agricultural Laboratories, Inc
P.O. Box 382 257 Newton Hwy
Camilla, Georgia 31730
Phone (229) 336-7216 FAX (229) 336-7967

GROSCH DRILLING

737 FIRETOWER ROAD
DUBLIN, GA 31021-

Received:	04/07/2016
Processed:	04/11/2016
Lab Number:	6506WT
Sample Number:	1
Grower:	GROSCH DRILLING

Results Reported In ppm Unless Otherwise Noted

Nitrate Nitrogen:	0.1	*L*				
			Carbonate:	0	*L*	
			BiCarbonate:	368.44	*H*	
Phosphorus:	0.02	*L*	pH:	8.2	*N*	
Potassium:	2.37	*L*	Conductivity:	0.326	*N*	*mmhos/cm*
Calcium:	27.93	*N*	Total Dissolved Solids:	208.64	*N*	
Magnesium:	12.39	*N*	Sodium Absorption Ratio (SAR):	0.99	*L*	
Sodium:	25.16	*L*				
Chloride:	7	*L*				
Sulfate:	6.14	*L*				
Boron:	0.03	*L*				
			Total Coliform:	3.1		mpn/100ml
			Generic eColi:	<1.0		mpn/100ml

Comments:

SM# 9223B

TOTAL SUSPENDED SOLIDS = 0.01 mg/L

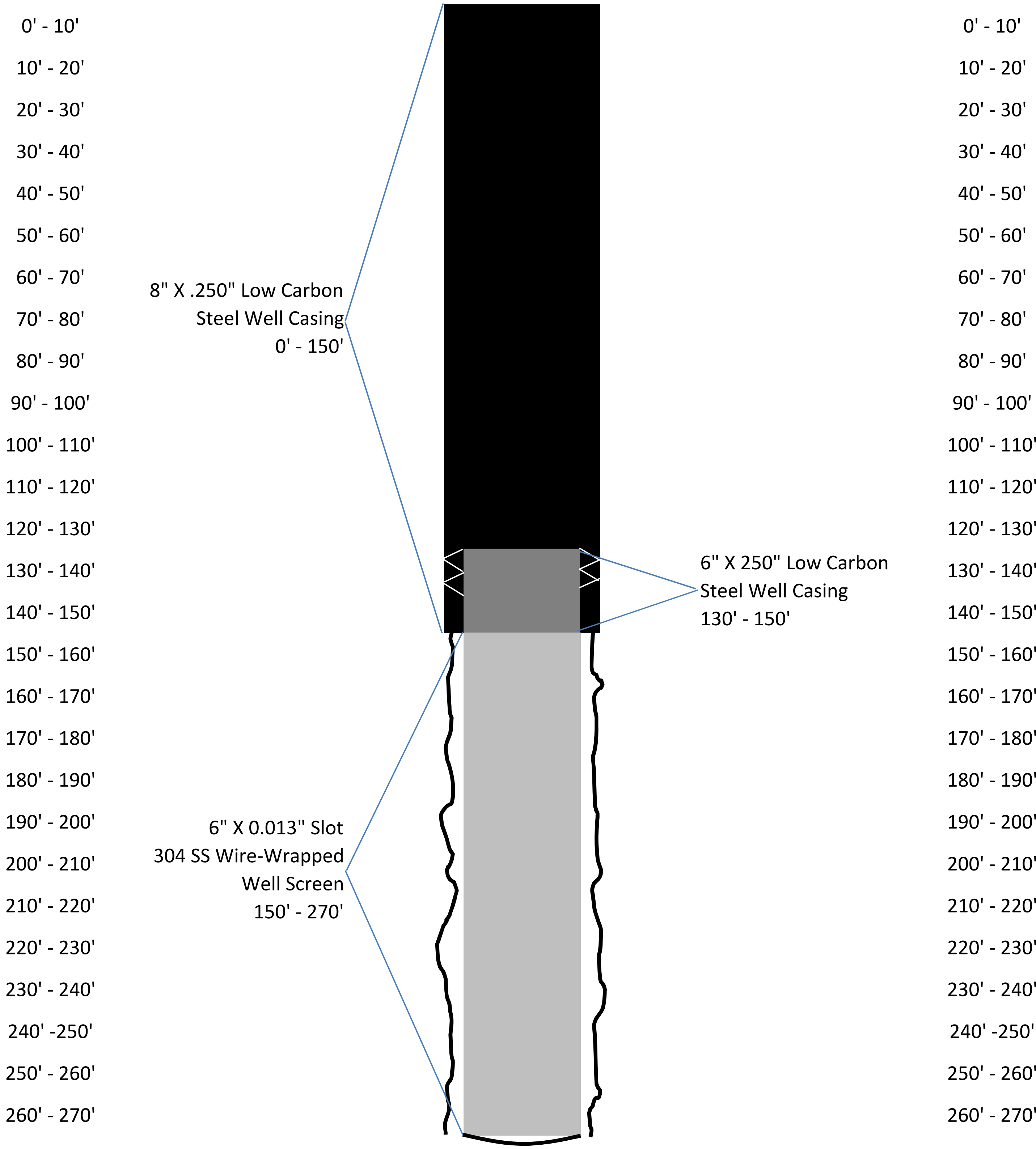
L = Low **N =Normal** **M = Moderate** **H = High** **VH = Very High**

Georgia Environmental Finance Authority
Claiborne Test Wells Project
Site: GDOT Facility
Location: Blakely, GA (Early County)
N 31.36455, W 84.92833

Well Drilling Information	
Total Depth of Well: 270' Below Land Surface	Drilling Method: Combination
Static Water Level: 18'	Date Drilled: May 5, 2016
Date Static Water Level Measured: May 11, 2016	Driller: Greg Grosch
Borehole Information	**Grouting**
Borehole Diameter: 9" From 0' to 150'	Type: High Yield Bentonite
Borehole Diameter: 7-7/8" From 150' to 270'	Interval: 0' to 150'
Casing Information	
Casing Material: Low Carbon Steel	
Casing Wall Thickness: 0.250"	
Casing Details: 8-5/8" Outside, 8-1/8" Inside From 0' to 150'	
Casing Details: 6-1/2" Outside, 6" Inside From 130' to 150'	
Well Screen Information	
Well Screen Material: Stainless Steel	
Well Screen Details: 6" X 0.013" Slot From 150' to 270'	
Test Pump Data	
Date Tested: May 12, 2016 - May 13, 2016	
Total Continuous Hours Tested: 24	
Did Water Level Stabilize: Yes	
Sustained Yield: 300 GPM	
Pumping Water Level: 89' at 24 Hours	
Drawdown: 71'	
Specific Capacity: 4.225 GPM/Ft. of Drawdown	
Time Until Recovery: 8 Hours	
Permanent Pump Data	
Pump Type: None	
Pump Diameter: None	
Discharge Size: None	
Motor HP: None	Motor RPM: None
Pump Capacity (GPM): None	Total Dynamic Head: None
Pump Setting Depth: None	
Pump Disinfected?: N/A	
Air Line Installed?: N/A	
Air Line Depth, If Installed: N/A	Air Line Diameter, If Installed: N/A
Chemigation Check Valve Installed?: N/A	

Attached: Geophysical Logs
Attached: Step Drawdown Test Results
Attached: 24 Hour Constant Rate Test Results
Attached: Water Quality Analysis

Georgia Environmental Finance Authority
Claiborne Test Wells Project
Site: GDOT Facility
Location: Blakely, GA (Early County)
N 31.36455, W 84.92833



Georgia Environmental Finance Authority
Claiborne Test Wells Project
Site: GDOT Facility
Location: Blakely, GA (Early County)
N 31.36455, W 84.92833

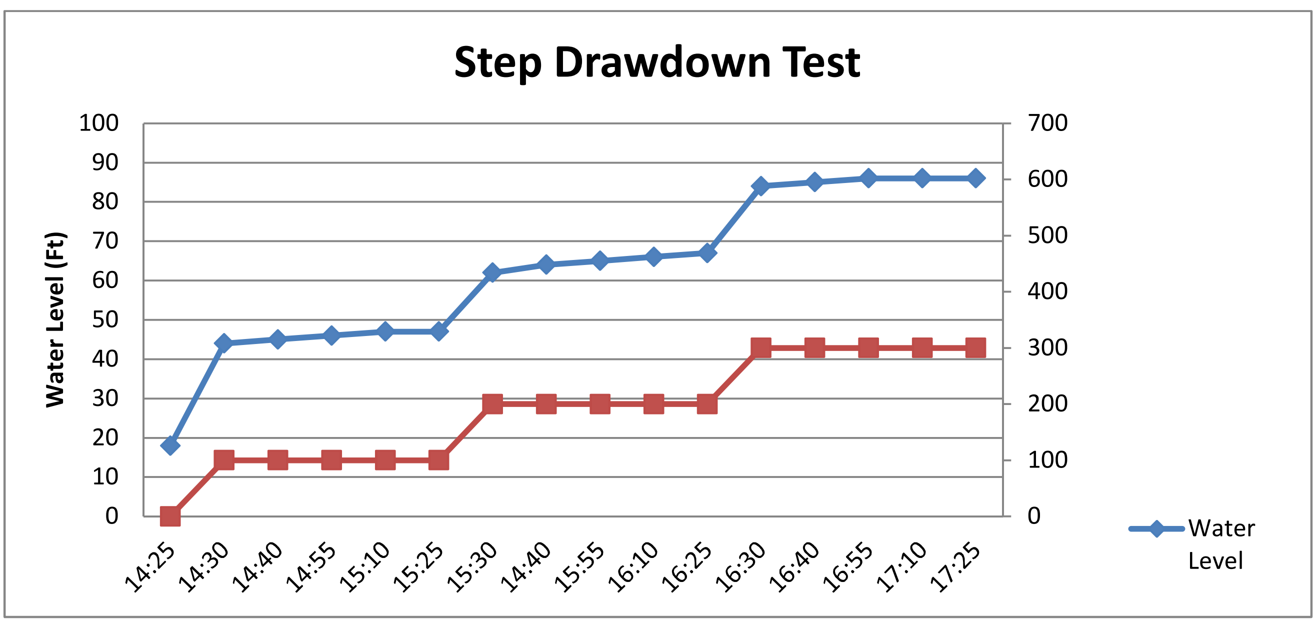
Lithologic Log

0' - 27'	Sticky Red, Yellow Clay
27' - 40'	Limestone; Sticky Yellow Clay with Sand Streaks
40' - 48'	Sticky Clay; Limestone
48' - 100'	Sticky White Clay with Limestone Streaks
100' - 108'	Limestone; Sticky White Clay
108' - 129'	Sticky Grey Clay with Limestone Streaks
129' - 140'	Hard Limestone with Clay Streaks
140' - 145'	Sandy Grey Clay with Fine Sand Streaks
145' - 146'	Hard Rock
146' - 160'	Sandy Grey Clay with Fine Sand Streaks
160' - 180'	Sandy Grey Clay with Small Fine Sand Streaks
180' - 200'	Sandy Grey Clay with Fine Sand Streaks
200' - 220'	Sandy Grey Clay with Very Fine Sand
220' - 240'	Very Fine Sand with a lot of Sandy Grey Clay Streaks
240' - 260'	Cemented Sand & Sandy Grey Clay with Very Fine Sand Layers
260' - 266'	Very Fine Sand with Sandy Clay Streaks
266' - 289'	Sticky Grey Clay
289' - 294'	Hard Rock
294' - 300'	Sticky Grey Clay
300' - 320'	Sticky Grey Clay with Small Rock Streaks
320' - 340'	Sticky Grey Clay (Some Sandy) with Small Rock Streaks
340' - 360'	Sticky Grey Clay (Some Sandy)
360' - 380'	Sticky Grey Clay (Some Sandy) with Small Rock Streaks
380' - 400'	Sticky Grey Clay (Some Sandy)

Location: Blakely, GA (Early County), N 31.36455, W 84.92833
Client: Georgia Environmental Finance Authority
Well ID: GEFA - Early
Test Date: 5/11/2016

Step Drawdown Test

Time	Water Level	Drawdown	GPM	Notes
14:25	18	0	0	Static
14:30	44	26	100	
14:40	45	27	100	
14:55	46	28	100	
15:10	47	29	100	
15:25	47	29	100	Increase
15:30	62	44	200	
14:40	64	46	200	
15:55	65	47	200	
16:10	66	48	200	
16:25	67	49	200	Increase
16:30	84	66	300	
16:40	85	67	300	
16:55	86	68	300	
17:10	86	68	300	
17:25	86	68	300	Pump Off

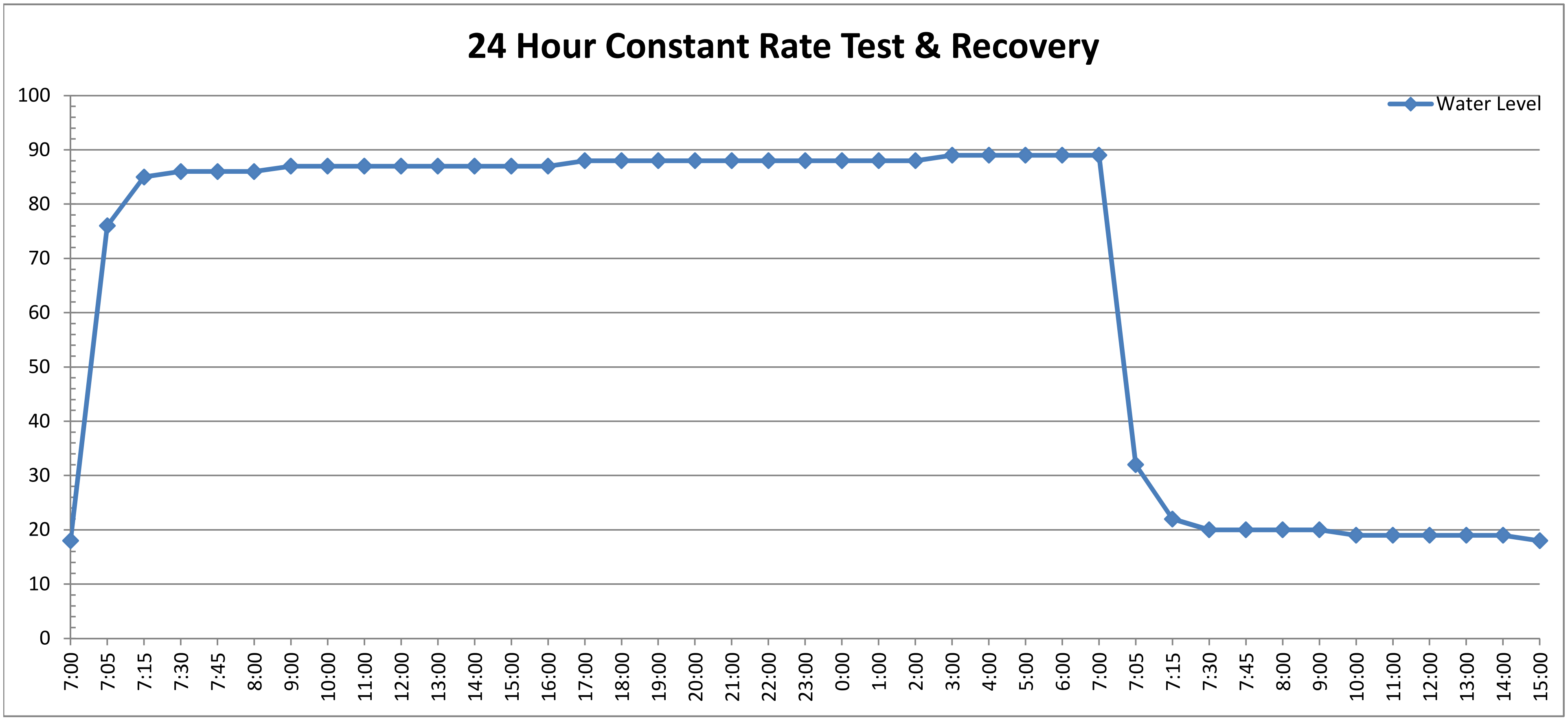


Georgia Environmental Finance Authority
Claiborne Test Wells Project
Site: GDOT Facility
Location: Blakely, GA (Early County)
N 31.36455, W 84.92833

24 Hour Constant Rate Testing & Recovery

Clock Time	Time Elapsed (Minutes)	Time Elapsed (Hours)	Water Level	GPM	Drawdown	Notes
7:00	0	0	18	0	0	Pump Started
7:05	5	0.083	76	300	58	
7:15	15	0.250	85	300	67	
7:30	30	0.500	86	300	68	
7:45	45	0.750	86	300	68	
8:00	60	1.000	86	300	68	
9:00	120	2.000	87	300	69	
10:00	180	3.000	87	300	69	
11:00	240	4.000	87	300	69	
12:00	300	5.000	87	300	69	
13:00	360	6.000	87	300	69	
14:00	420	7.000	87	300	69	
15:00	480	8.000	87	300	69	
16:00	540	9.000	87	300	69	
17:00	600	10.000	88	300	70	
18:00	660	11.000	88	300	70	
19:00	720	12.000	88	300	70	
20:00	780	13.000	88	300	70	
21:00	840	14.000	88	300	70	
22:00	900	15.000	88	300	70	
23:00	960	16.000	88	300	70	
0:00	1020	17.000	88	300	70	
1:00	1080	18.000	88	300	70	
2:00	1140	19.000	88	300	70	
3:00	1200	20.000	89	300	71	
4:00	1260	21.000	89	300	71	
5:00	1320	22.000	89	300	71	
6:00	1380	23.000	89	300	71	

7:00	1440	24.000	89	300	71	Pump Off
7:05	5	0.083	32	300	14	Recovery 5 Minutes
7:15	15	0.250	22	300	4	Recovery 15 Minutes
7:30	30	0.500	20	300	2	Recovery 30 Minutes
7:45	45	0.750	20	300	2	Recovery 45 Minutes
8:00	60	1.000	20	300	2	Recovery 1 Hour
9:00	120	2.000	20	300	2	Recovery 2 Hours
10:00	180	3.000	19	300	1	Recovery 3 Hours
11:00	240	4.000	19	300	1	Recovery 4 Hours
12:00	300	5.000	19	300	1	Recovery 5 Hours
13:00	360	6.000	19	300	1	Recovery 6 Hours
14:00	420	7.000	19	300	1	Recovery 7 Hours
15:00	480	8.000	18	300	0	Recovery 8 Hours



GIC Water Systems

Water Well Services

737 B Firetower Road
Dublin, Georgia 31021
(478) 274-9546 phone
(478) 275-0014 fax
gicws@nlamerica.com

GEFA - Blakely

Electric Log W/ Natural Gamm

COMPANY	Grosch Drilling	OTHER SERVICES
WELL	GEFA-Blakely	
FIELD		
COUNTRY	USA	
STATE	Georgia	
COUNTY	Early	
LAT.:	31.365	
LONG.:	-84.928	

Perm. Datum	ground surf..	Elev	~256 ft	KB	0.00
Log. Datum				DF	0.00
Drill Datum				GL	0.00

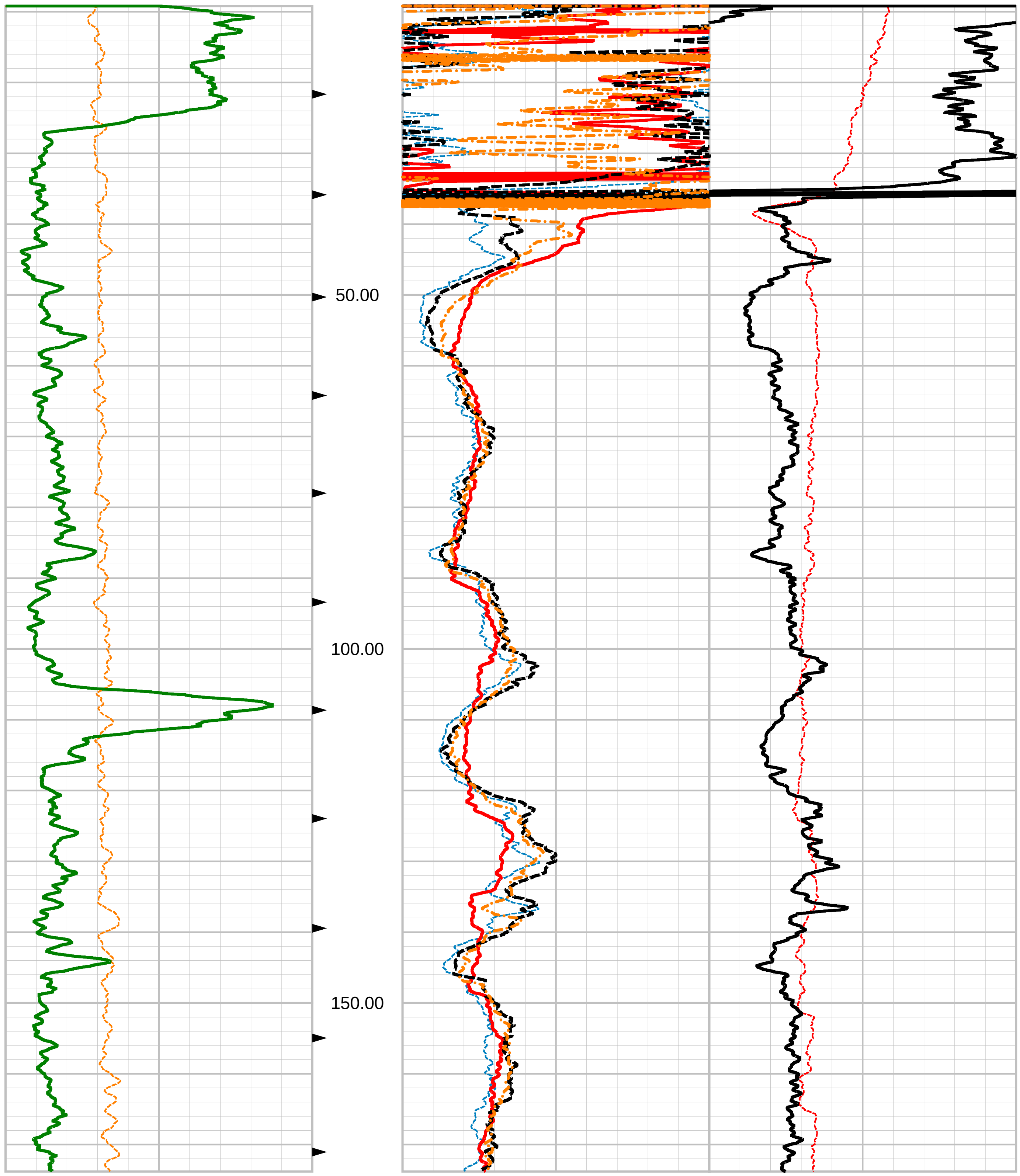
DATE	28 Apr 1	29 Mar 1	29 Mar 1
RUN#	0	0	0
TYPE OF LOG	ELMT6618		
DEPTH DRILLER	400.00	0.00	0.00
DEPTH LOGGER	400.00	0.00	0.00
LOG DEEPEST	400.00	0.00	0.00
LOG SHALLOW	0.00	0.00	0.00
FLUID IN HOLE	Water		
SALINITY			
DENSITY			
LEVEL	0		
MAX TEMP °C	0.00	0.00	0.00
RIG TIME	14:11		
RECORDED BY	S.Dixon, PG		
WITNESSED BY	S.Brantley		

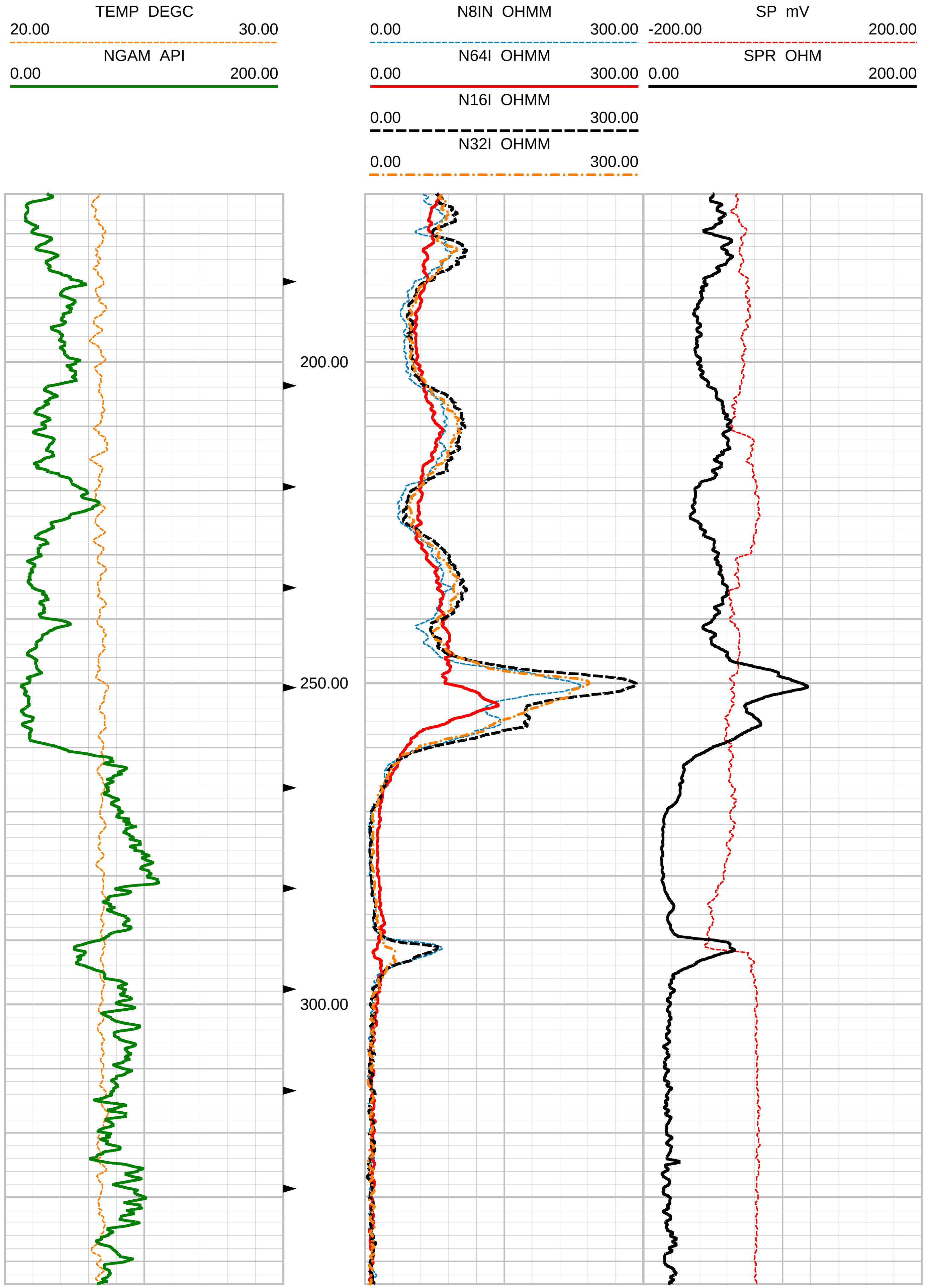
RUN#	BIT RECORD SIZE	BIT RECORD FROM	BIT RECORD TO	CASING RECORD SIZE	CASING RECORD WEIGHT	CASING RECORD FROM	CASING RECORD TO
0	5.13	0.00	400.00	0.00	0.00	0.00	0.00
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00

REMARKS (C:\Winlogger\Data\GEFA-Blakely.hed)

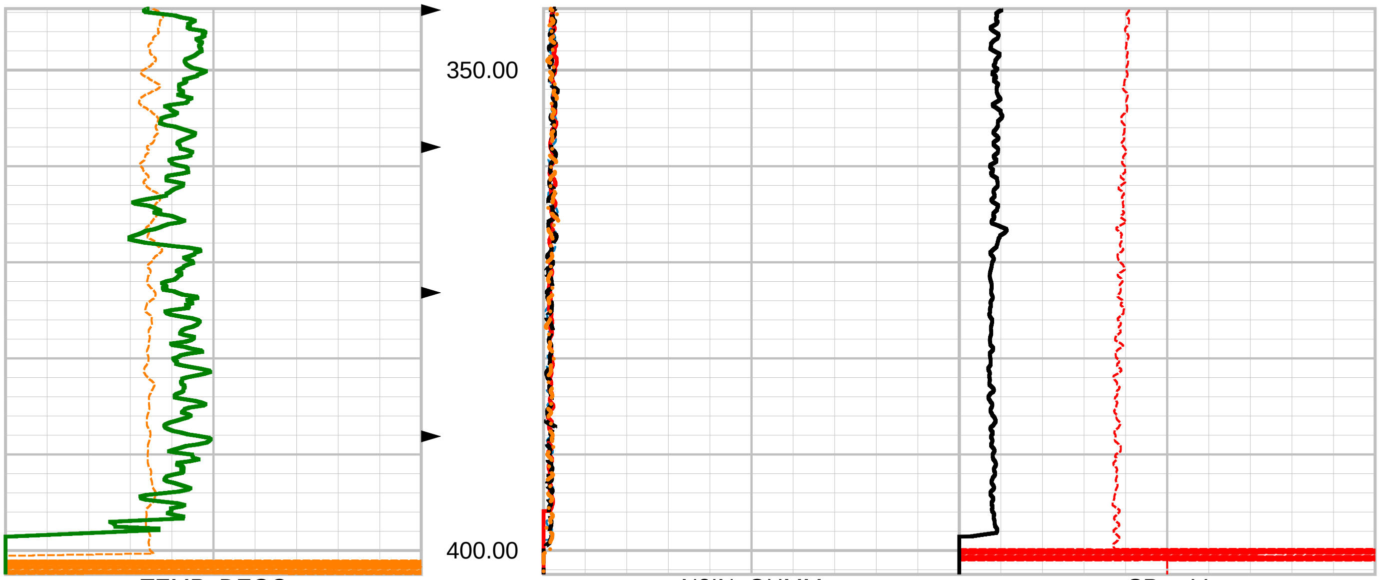
ELMT6618-8,16,32, and 64-Normal Resistivity, SPR, SP, Temp, and Nat..
ROBERTSON GEOLOGGING TECHNOLOGY
Logging up
Logging speed - 16ft/min

TEMP DEGC	N8IN OHMM	SP mV
20.00 — 30.00	0.00 — 300.00	-200.00 — 200.00
NGAM API	N64I OHMM	SPR OHM
0.00 — 200.00	0.00 — 300.00	0.00 — 200.00
	N16I OHMM	
	0.00 — 300.00	
	N32I OHMM	
	0.00 — 300.00	




TEMP DEGC
20.00 30.00
NGAM API
0.00 200.00
N8IN OHMM
0.00 300.00
N64I OHMM
0.00 300.00
N16I OHMM
0.00 300.00
N32I OHMM
0.00 300.00
SP mV
-200.00 200.00
SPR OHM
0.00 200.00
200.00
250.00
300.00

TEMP DEGC		N8IN OHMM		SP mV	
20.00	30.00	0.00	300.00	-200.00	200.00
NGAM API		N64I OHMM		SPR OHM	
0.00	200.00	0.00	300.00	0.00	200.00
		N16I OHMM			
		0.00	300.00		
		N32I OHMM			
		0.00	300.00		



TEMP DEGC		N8IN OHMM		SP mV	
20.00	30.00	0.00	300.00	-200.00	200.00
NGAM API		N64I OHMM		SPR OHM	
0.00	200.00	0.00	300.00	0.00	200.00
		N16I OHMM			
		0.00	300.00		
		N32I OHMM			
		0.00	300.00		

Depth: 9.00 ft Date: 28 Apr 2016 Time: 14:45:33 File: "C:\Winlogger\Data\GEFA-Blakely.LGX"

Water Analysis

Food Safety

Waters Agricultural Laboratories, Inc
P.O. Box 382 257 Newton Hwy
Camilla, Georgia 31730
Phone (229) 336-7216 FAX (229) 336-7967

GROSCH DRILLING

737 FIRETOWER ROAD
DUBLIN, GA 31021-

Received: 05/13/2016
Processed: 05/20/2016
Lab Number: 6898WT
Sample Number: 1
Grower: GROSCH IRRIGATION

Results Reported In ppm Unless Otherwise Noted

Nitrate Nitrogen:	**0.1** *L*				
		Carbonate:	**27** *H*		
		BiCarbonate:	**245.22** *H*		
Phosphorus:	**0.02** *L*	pH:	**8.2** *N*		
Potassium:	**2.75** *L*	Conductivity:	**0.299** *N*	*mmhos/cm*	
Calcium:	**40.95** *N*	Total Dissolved Solids:	**191.36** *N*		
Magnesium:	**11.46** *N*	Sodium Absorption Ratio (SAR):	**0.18** *L*		
Sodium:	**4.96** *L*				
Chloride:	**2** *L*				
Sulfate:	**7.07** *L*				
Boron:	**0.01** *L*				
		Total Coliform:	**>2419.6**	mpn/100ml	
		Generic eColi:	**<1.0**	mpn/100ml	

Comments:

TOTAL SUSPENDED SOLIDS = 0.12 PPM

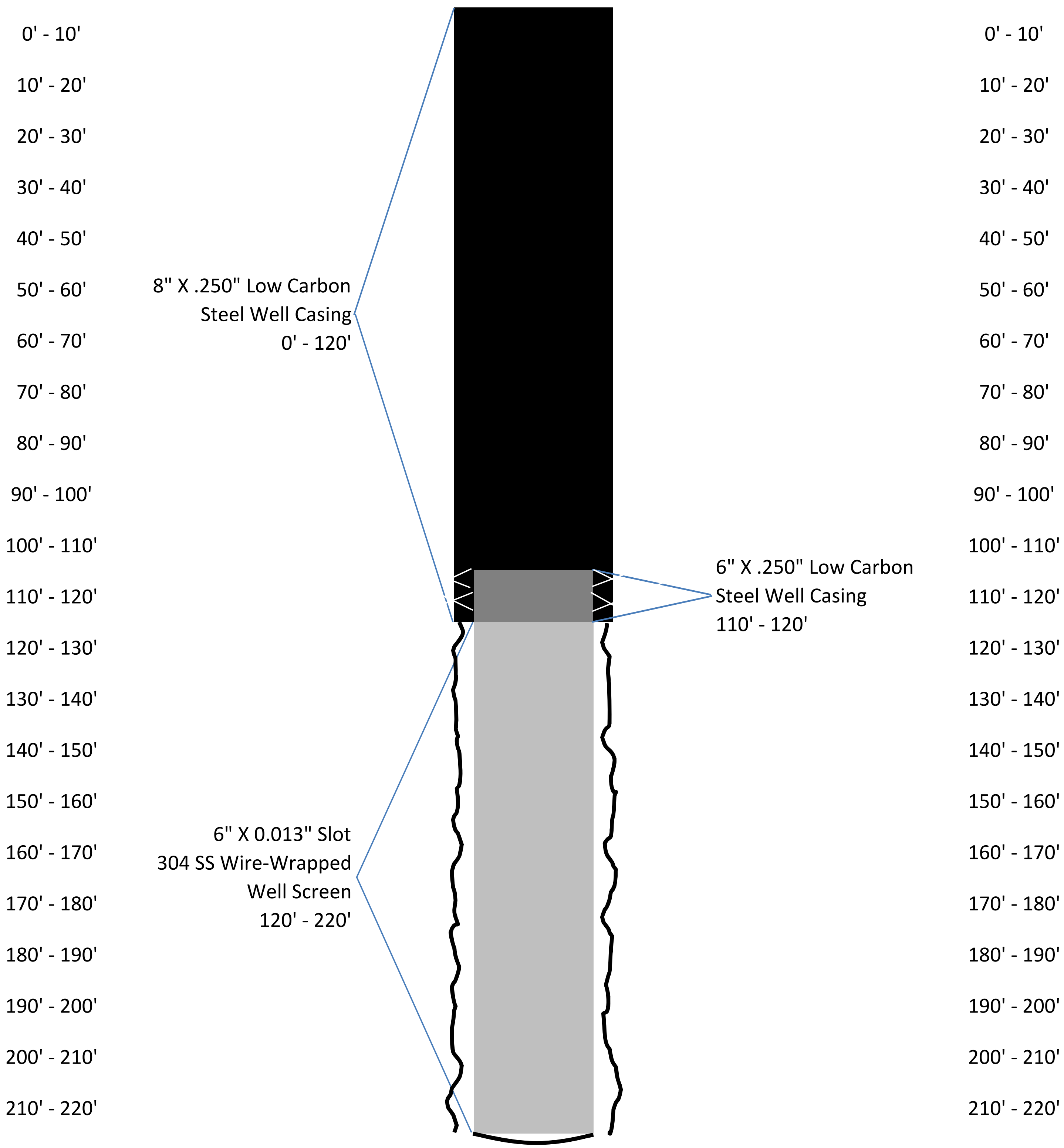
L = Low **N =Normal** **M = Moderate** **H = High** **VH = Very High**

Georgia Environmental Finance Authority
Claiborne Test Wells Project
Site: GDOT Facility
Location: Morgan, GA (Calhoun County)
N 31.53763, W 84.60444

Well Drilling Information	
Total Depth of Well: 220' Below Land Surface	Drilling Method: Combination
Static Water Level: 24'	Date Drilled: June 8, 2016
Date Static Water Level Measured: June 21, 2016	Driller: Greg Grosch
Borehole Information	**Grouting**
Borehole Diameter: 9" From 0' to 120'	Type: High Yield Bentonite
Borehole Diameter: 7-7/8" From 120' to 220'	Interval: 0' to 120'
Casing Information	
Casing Material: Low Carbon Steel	
Casing Wall Thickness: 0.250"	
Casing Details: 8-5/8" Outside, 8-1/8" Inside From 0' to 120'	
Casing Details: 6-1/2" Outside, 6" Inside From 110' to 120'	
Well Screen Information	
Well Screen Material: Stainless Steel	
Well Screen Details: 6" X 0.013" Slot From 120' to 220'	
Test Pump Data	
Date Tested: June 21, 2016 - June 22, 2016	
Total Continuous Hours Tested: 24	
Did Water Level Stabilize: Yes	
Sustained Yield: 550 GPM	
Pumping Water Level: 96	
Drawdown: 72	
Specific Capacity: 7.639 GPM/Ft	
Time Until Recovery: 13 Hours	
Permanent Pump Data	
Pump Type: None	
Pump Diameter: None	
Discharge Size: None	
Motor HP: None	Motor RPM: None
Pump Capacity (GPM): None	Total Dynamic Head: None
Pump Setting Depth: None	
Pump Disinfected?: N/A	
Air Line Installed?: N/A	
Air Line Depth, If Installed: N/A	Air Line Diameter, If Installed: N/A
Chemigation Check Valve Installed?: N/A	

Attached: Geophysical Logs
Attached: Step Drawdown Test Results
Attached: 24 Hour Constant Rate Test Results
Attached: Water Quality Analysis

Georgia Environmental Finance Authority
Claiborne Test Wells Project
Site: GDOT Facility
Location: Morgan, GA (Calhoun County)
N 31.53763, W 84.60444



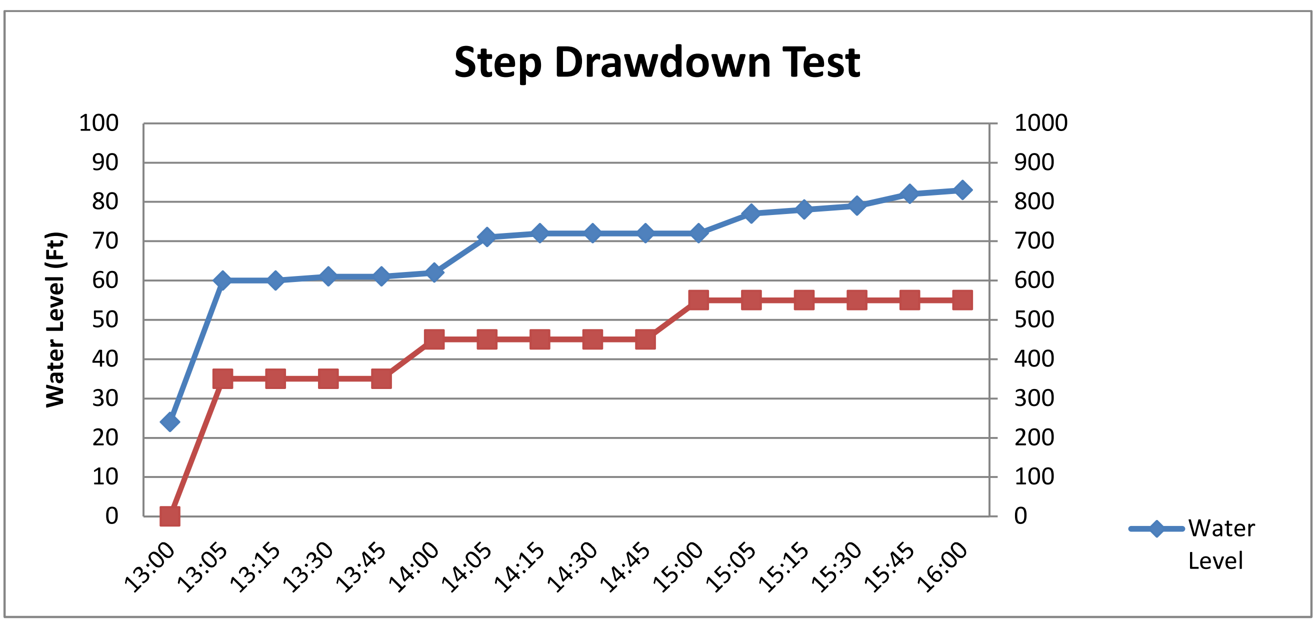
Lithologic Log

0' - 28'	Sticky Tan, Yellow, Grey Clay
28' - 49'	Limestone, Sticky White Clay
49' - 72'	Sticky Grey Clay, Limestone Streaks
72' - 80'	Limestone with Clay Streaks
80' - 120'	Limestone with Sticky Grey Clay Layers
120' - 126'	Limestone with Grey Clay Streaks
126' - 140'	Fine Sand, Sandy Grey Clay
140' - 156'	Fine Sand & Shell with Clay Streaks
156' - 157'	Hard Shellrock
157' - 160'	Fine Sand & Shell with Clay Streaks
160' - 200'	Very Fine Sand with Small Sandy Grey Clay Streaks
200' - 213'	Very Fine Sand with Sandy Clay Streaks
213' - 220'	Sandy Grey Clay with Small Sand Streaks
220' - 240'	Sandy Grey Clay with Small Fine Sand Streaks & Hard Rock Streaks
240' - 260'	Sandy Grey Clay (Sticky) with Small Fine Sand Streaks & Hard Rock Streaks
260' - 300'	Sticky Grey Clay with Hard Rock Streaks

Location: Morgan, GA (Calhoun County), N 31.53763, W 84.60444
Client: Georgia Environmental Finance Authority
Well ID: GEFA - Calhoun
Test Date: 6/15/2016

Step Drawdown Test

Time	Water Level	Drawdown	GPM	Notes
13:00	24	0	0	Static
13:05	60	36	350	
13:15	60	36	350	
13:30	61	37	350	
13:45	61	37	350	
14:00	62	38	450	Increase
14:05	71	47	450	
14:15	72	48	450	
14:30	72	48	450	
14:45	72	48	450	
15:00	72	48	550	Increase
15:05	77	53	550	
15:15	78	54	550	
15:30	79	55	550	
15:45	82	58	550	
16:00	83	59	550	Pump Off

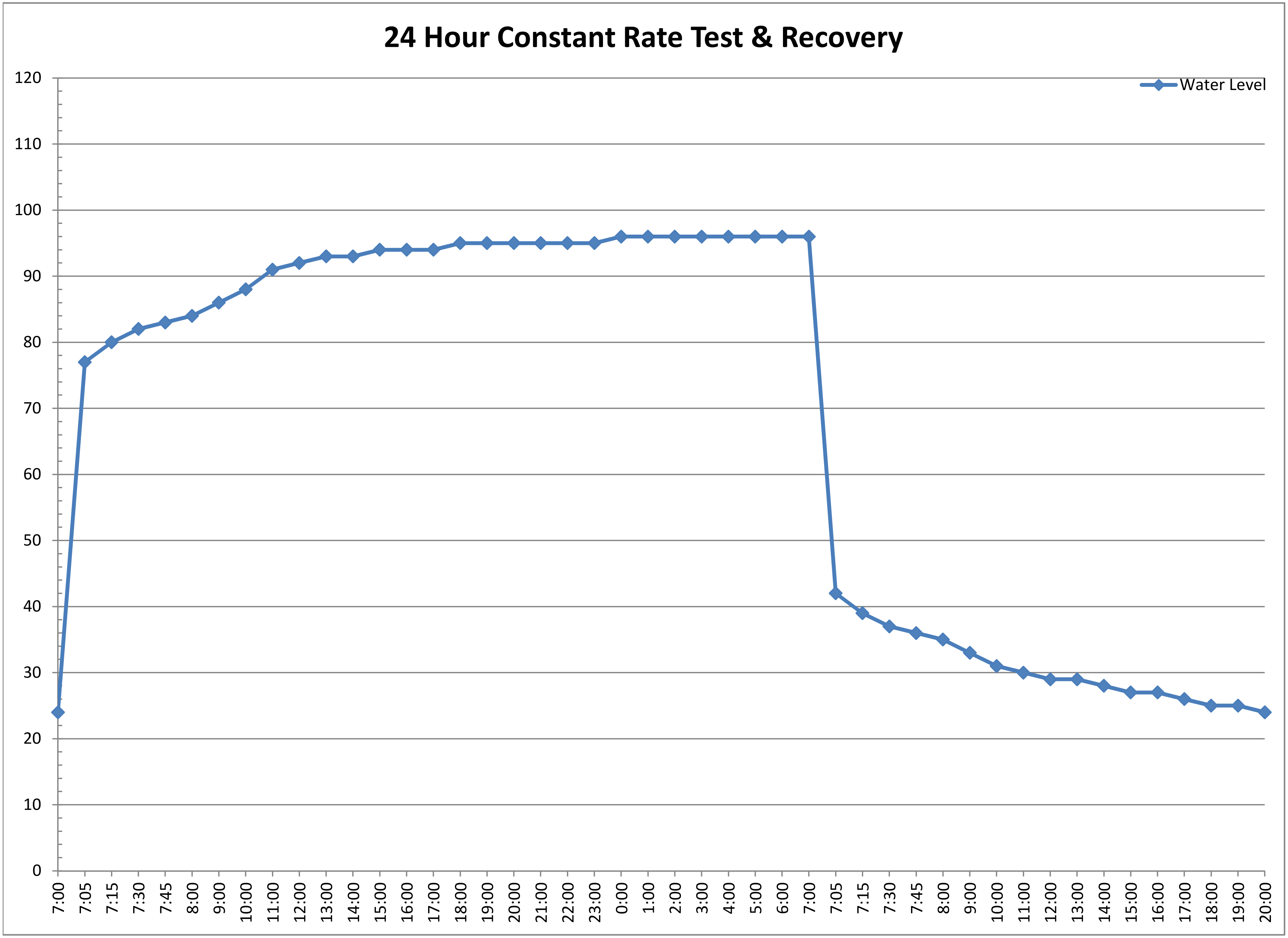


Georgia Environmental Finance Authority
Claiborne Test Wells Project
Site: GDOT Facility
Location: Morgan, GA (Calhoun County)
N 31.53763, W 84.60444

24 Hour Constant Rate Testing & Recovery

Clock Time	Time Elapsed (Minutes)	Time Elapsed (Hours)	Water Level	GPM	Drawdown	Notes
7:00	0	0	24	0	0	Pump Started
7:05	5	0.083	77	550	53	
7:15	15	0.250	80	550	56	
7:30	30	0.500	82	550	58	
7:45	45	0.750	83	550	59	
8:00	60	1.000	84	550	60	
9:00	120	2.000	86	550	62	
10:00	180	3.000	88	550	64	
11:00	240	4.000	91	550	67	
12:00	300	5.000	92	550	68	
13:00	360	6.000	93	550	69	
14:00	420	7.000	93	550	69	
15:00	480	8.000	94	550	70	
16:00	540	9.000	94	550	70	
17:00	600	10.000	94	550	70	
18:00	660	11.000	95	550	71	
19:00	720	12.000	95	550	71	
20:00	780	13.000	95	550	71	
21:00	840	14.000	95	550	71	
22:00	900	15.000	95	550	71	
23:00	960	16.000	95	550	71	
0:00	1020	17.000	96	550	72	
1:00	1080	18.000	96	550	72	
2:00	1140	19.000	96	550	72	
3:00	1200	20.000	96	550	72	
4:00	1260	21.000	96	550	72	
5:00	1320	22.000	96	550	72	
6:00	1380	23.000	96	550	72	

7:00	1440	24.000	96	550	72	Pump Off
7:05	5	0.083	42	0	18	Recovery 5 Minutes
7:15	15	0.250	39	0	15	Recovery 15 Minutes
7:30	30	0.500	37	0	13	Recovery 30 Minutes
7:45	45	0.750	36	0	12	Recovery 45 Minutes
8:00	60	1.000	35	0	11	Recovery 1 Hour
9:00	120	2.000	33	0	9	Recovery 2 Hours
10:00	180	3.000	31	0	7	Recovery 3 Hours
11:00	240	4.000	30	0	6	Recovery 4 Hours
12:00	300	5.000	29	0	5	Recovery 5 Hours
13:00	360	6.000	29	0	5	Recovery 6 Hours
14:00	420	7.000	28	0	4	Recovery 7 Hours
15:00	480	8.000	27	0	3	Recovery 8 Hours
16:00	540	9.000	27	0	3	Recovery 9 Hours
17:00	600	10.000	26	0	2	Recovery 10 Hours
18:00	600	11.000	25	0	1	Recovery 11 Hours
19:00	660	12.000	25	0	1	Recovery 12 Hours
20:00	720	13.000	24	0	0	Recovery 13 Hours


24 Hour Constant Rate Test & Recovery
Water Level
0
10
20
30
40
50
60
70
80
90
100
110
120
7:00
7:05
7:15
7:30
7:45
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
0:00
1:00
2:00
3:00
4:00
5:00
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7:05
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7:30
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14:00
15:00
16:00
17:00
18:00
19:00
20:00

GIC Water Systems
Water Well Services
737 B Firetower Road
Dublin, Georgia 31021
(478) 274-9546 phone
(478) 275-0014 fax
gicws@nlamerica.com

GEFA - Morgan

Electric Log W/ Natural Gamm

COMPANY	Grosch Drilling
WELL	GEFA-Morgan
FIELD	
COUNTRY	USA
STATE	Georgia
COUNTY	Calhoun
LAT.:	31.503763
LONG.:	-84.60444

OTHER SERVICES

Perm. Datum	ground surf..	Elev	~249 ft	KB	0.00
Log. Datum				DF	0.00
Drill Datum				GL	0.00

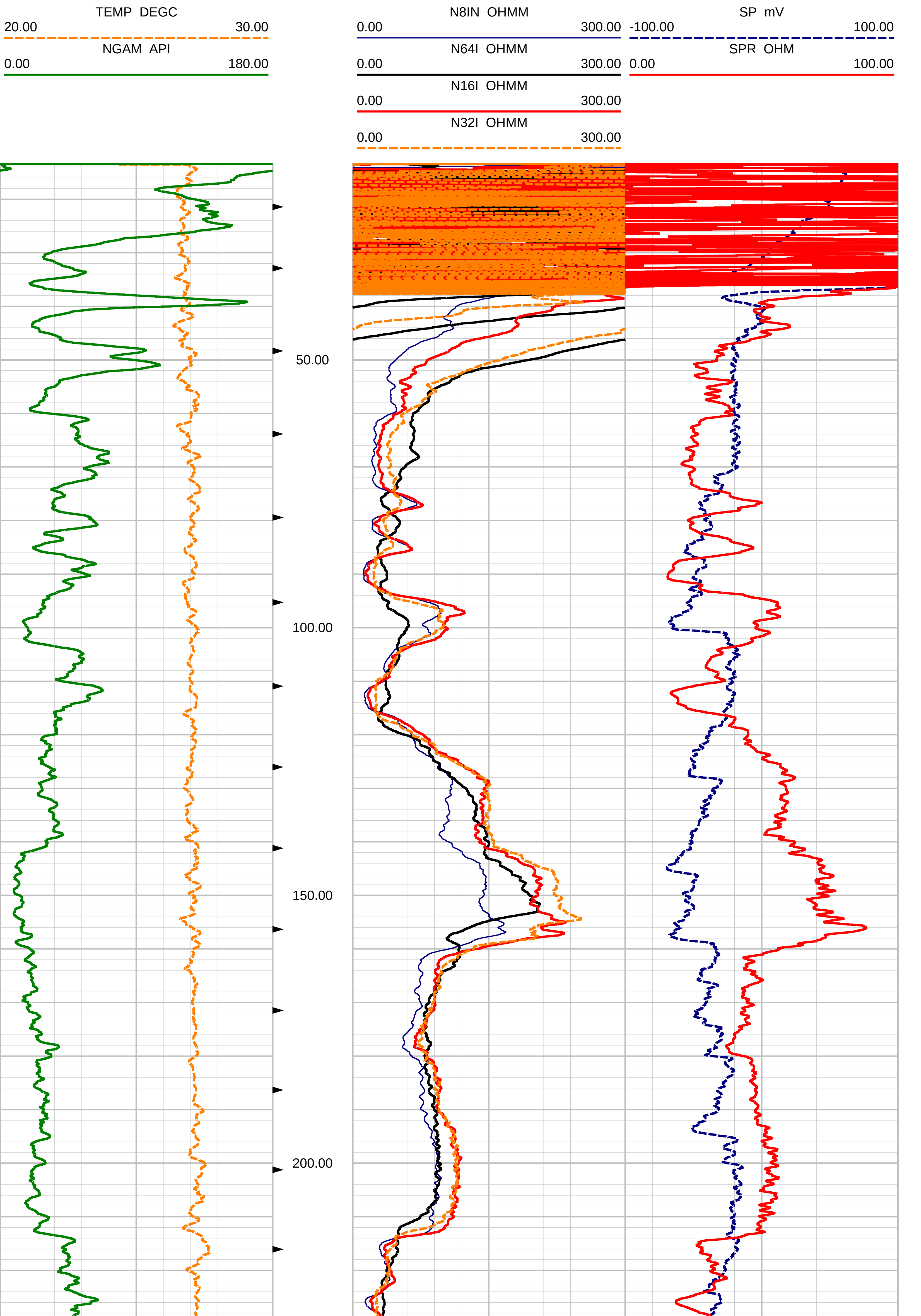
DATE	07 Jun 1		
RUN#	0	0	0
TYPE OF LOG	ELMT6618		
DEPTH DRILLER	300.00	0.00	0.00
DEPTH LOGGER	300.00	0.00	0.00
LOG DEEPEST	300.00	0.00	0.00
LOG SHALLOW	0.00	0.00	0.00
FLUID IN HOLE	Water		
SALINITY			
DENSITY			
LEVEL	0		
MAX TEMP °C	0.00	0.00	0.00
RIG TIME	13:11		
RECORDED BY	S.Dixon, PG		
WITNESSED BY	S.Brantley		

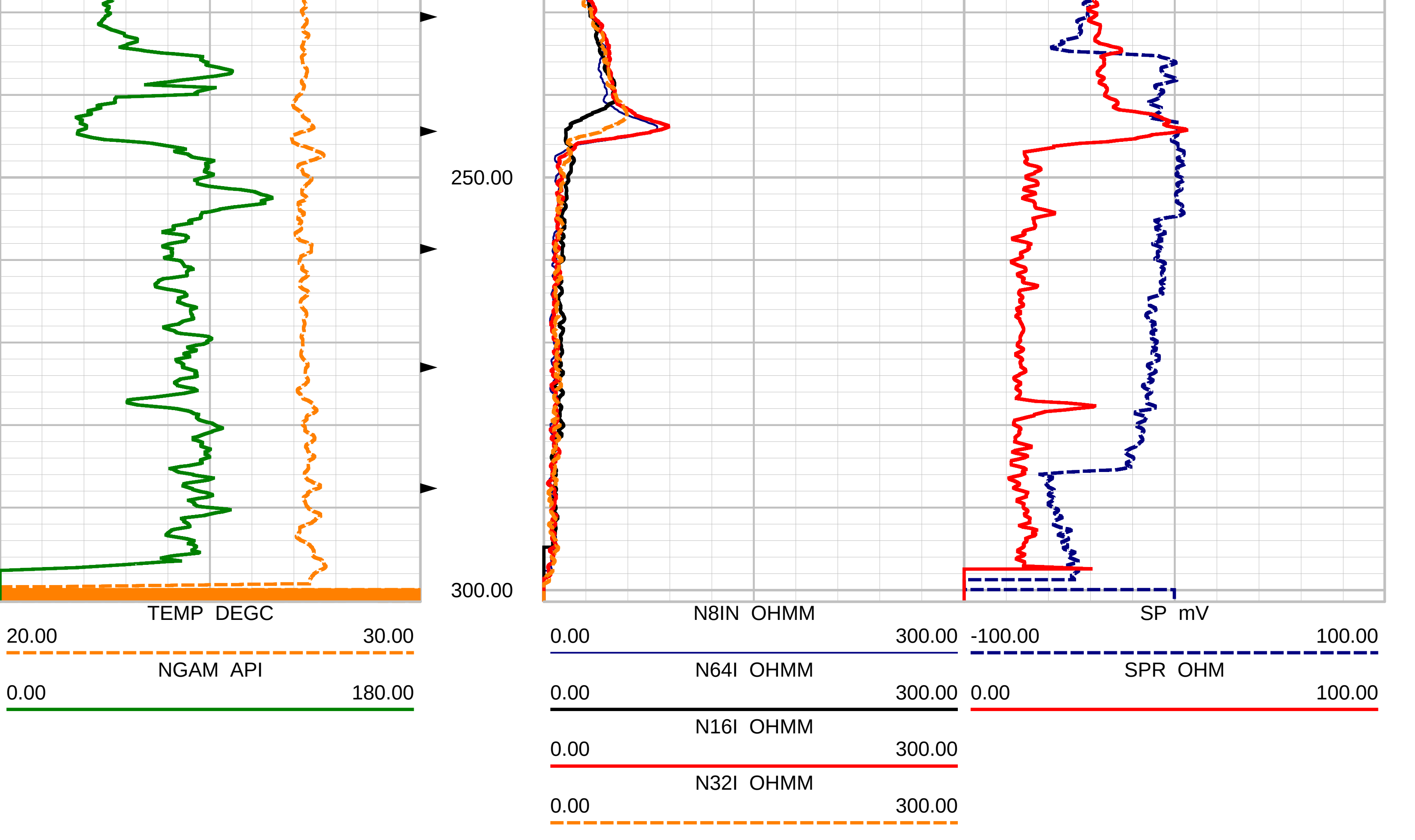
RUN#	BIT RECORD			CASING RECORD			
	SIZE	FROM	TO	SIZE	WEIGHT	FROM	TO
0	5.13	0.00	300.00	0.00	0.00	0.00	0.00
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00

ROBERTSON GEOLOGGING TECHNOLOGY

REMARKS (C:\Winlogger\Data\Morgan-GEFA.hed)

ELMT6618-8,16,32, and 64-Normal Resistivity, SPR, SP, Temp, and Natur..
Logging up
Logging speed - 16ft/min


TEMP DEGC
20.00
30.00
NGAM API
0.00
180.00
N8IN OHMM
0.00
300.00
N64I OHMM
0.00
300.00
N16I OHMM
0.00
300.00
N32I OHMM
0.00
300.00
SP mV
-100.00
100.00
SPR OHM
0.00
100.00
50.00
100.00
150.00
200.00



Depth: 13.00 ft Date: 07 Jun 2016 Time: 13:37:52 File: "C:\Winlogger\DATA\Morgan-GEFA.LGX"

Water Analysis

Food Safety

Waters Agricultural Laboratories, Inc
P.O. Box 382 257 Newton Hwy
Camilla, Georgia 31730
Phone (229) 336-7216 FAX (229) 336-7967

GROSCH DRILLING

737 FIRETOWER ROAD
DUBLIN, GA 31021-

Received: 06/22/2016
Processed: 06/27/2016
Lab Number: 7530WT
Sample Number: 1
Grower: GROSCH IRRIGATION

Results Reported In ppm Unless Otherwise Noted

Nitrate Nitrogen:	**0.1**	*L*		Carbonate:	**0**	*L*	
Phosphorus:	**0.01**	*L*		BiCarbonate:	**215.94**	*H*	
Potassium:	**1.22**	*L*		pH:	**7.9**	*N*	
Calcium:	**44.04**	*N*		Conductivity:	**0.224**	*N*	*mmhos/cm*
Magnesium:	**2.42**	*L*		Total Dissolved Solids:	**143.36**	*N*	
Sodium:	**3.02**	*L*		Sodium Absorption Ratio (SAR):	**0.12**	*L*	
Chloride:	**2**	*L*					
Sulfate:	**6.83**	*L*					
Boron:	**0.01**	*L*					
				Total Coliform:	**83.6**	mpn/100ml	
				Generic eColi:	**<1.0**	mpn/100ml	

Comments:

TOTAL SUSPENDED SOLIDS = 0.08
TOTAL SOLIDS = 0.10

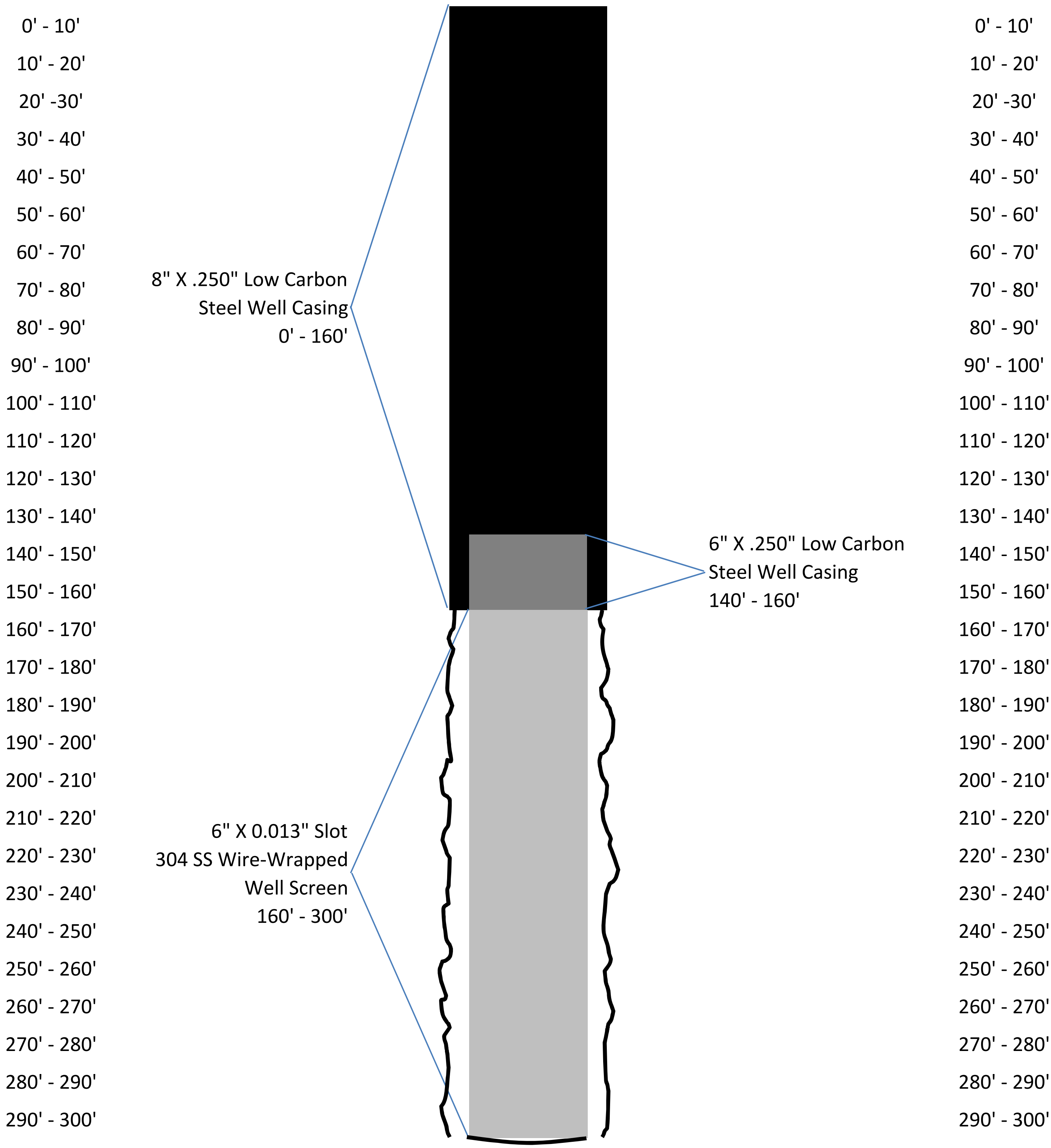
L = Low N =Normal M = Moderate H = High VH = Very High

Georgia Environmental Finance Authority
Claiborne Test Wells Project
Site: Chickasawhatchee WMA
Location: Calhoun County, GA
N 31.49302, W 84.45890

Well Drilling Information	
Total Depth of Well: 300' Below Land Surface	Drilling Method: Combination
Static Water Level: 3'	Date Drilled: July 19, 2016
Date Static Water Level Measured: July 22, 2016	Driller: Greg Grosch
Borehole Information	**Grouting**
Borehole Diameter: 9" From 0' to 160'	Type: High Yield Bentonite
Borehole Diameter: 7-7/8" From 160' to 300'	Interval: 0' to 160'
Casing Information	
Casing Material: Low Carbon Steel	
Casing Wall Thickness: 0.250"	
Casing Details: 8-5/8" Outside, 8-1/8" Inside From 0' to 160'	
Casing Details: 6-1/2" Outside, 6" Inside From 140' to 160'	
Well Screen Information	
Well Screen Material: Stainless Steel	
Well Screen Details: 6" X 0.013" Slot From 160' to 300'	
Test Pump Data	
Date Tested: July 25, 2016 - July 26, 2016	
Total Continuous Hours Tested: 24	
Did Water Level Stabilize: Yes	
Sustained Yield: 250 GPM	
Pumping Water Level: 88	
Drawdown: 85	
Specific Capacity: 2.941 GPM/Ft	
Time Until Recovery: 9 Hours	
Permanent Pump Data	
Pump Type: None	
Pump Diameter: None	
Discharge Size: None	
Motor HP: None	Motor RPM: None
Pump Capacity (GPM): None	Total Dynamic Head: None
Pump Setting Depth: None	
Pump Disinfected?: N/A	
Air Line Installed?: N/A	
Air Line Depth, If Installed: N/A	Air Line Diameter, If Installed: N/A
Chemigation Check Valve Installed?: N/A	

Attached: Geophysical Logs
Attached: Step Drawdown Test Results
Attached: 24 Hour Constant Rate Test Results
Attached: Water Quality Analysis

Georgia Environmental Finance Authority
Claiborne Test Wells Project
Site: Chickasawhatchee WMA
Location: Calhoun County, GA
N 31.49302, W 84.45890



Georgia Environmental Finance Authority
Claiborne Test Wells Project
Site: Chickasawhatchee WMA
Location: Calhoun County, GA
N 31.49302, W 84.45890

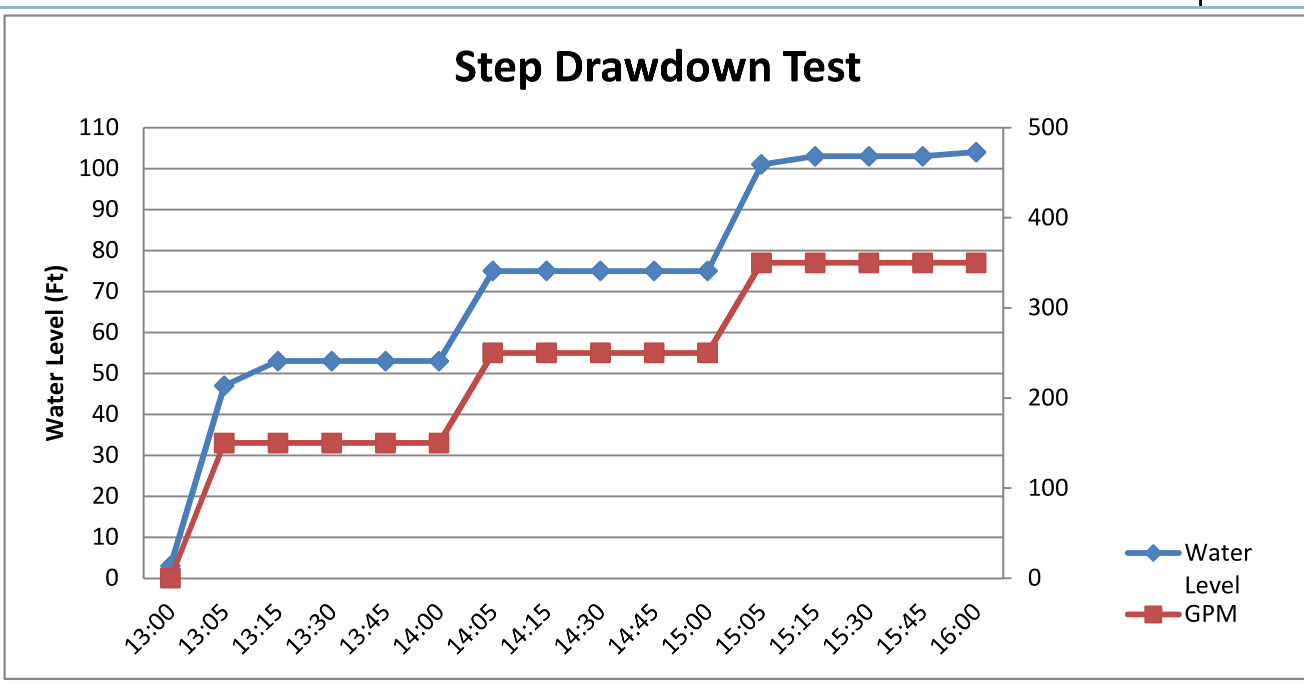
Lithologic Log

0' - 23'	Sticky Red, Yellow, White Clay
23' - 40'	Limestone & Sticky White Clay
40' - 60'	Limestone (Soft) with Clay Streaks
60' - 65'	Limestone
65' - 72'	Sticky Grey Clay with Limestone Streaks
72' - 154'	Limestone with Grey Clay Streaks
154' - 160'	Sticky Grey Clay with Limestone Streaks
160' - 172'	Sticky Grey Clay with Limestone and Sand Streaks
172' - 200'	Very Fine Sand with Limestone and Sticky Clay Streaks
200' - 220'	Very Fine Sand with Clay and Shellrock Streaks
220' - 240'	Very Fine Sand with Small Clay and Shellrock Streaks
240' -267'	Very Fine Sand with Clay Streaks
267' - 300'	Very Fine Sand and Shellrock with Clay Streaks
300' - 308'	Sandy Grey Clay with Sand and Shellrock Streaks
308' - 330'	Shellrock with Clay Streaks
330' - 340'	Sticky Grey Clay
340' - 360'	Sticky Grey Clay with Rock Streaks

Location: Chickasawhatchee WMA (Calhoun Co., GA) N 31.49302, W 84.45890
Client: Georgia Environmental Finance Authority
Well ID: GEFA - Chickasawhatchee
Test Date: 7/22/2016

Step Drawdown Test

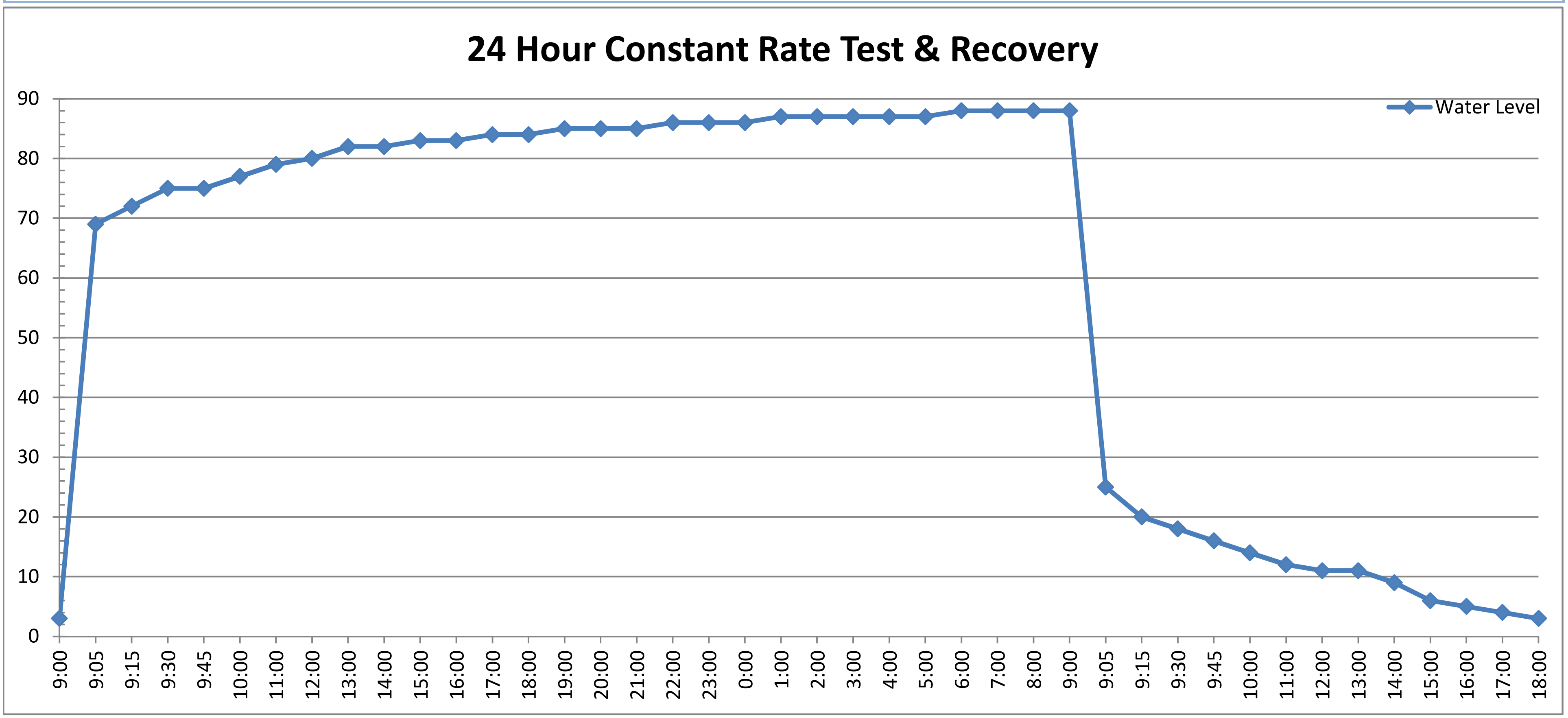
Time	Water Level	Drawdown	GPM	Notes
13:00	3	0	0	Static
13:05	47	44	150	
13:15	53	50	150	
13:30	53	50	150	
13:45	53	50	150	
14:00	53	50	150	Increase
14:05	75	72	250	
14:15	75	72	250	
14:30	75	72	250	
14:45	75	72	250	
15:00	75	72	250	Increase
15:05	101	98	350	
15:15	103	100	350	
15:30	103	100	350	
15:45	103	100	350	
16:00	104	101	350	Pump Off



24 Hour Constant Rate Testing & Recovery

Clock Time	Time Elapsed (Minutes)	Time Elapsed (Hours)	Water Level	GPM	Drawdown	Notes
9:00	0	0	3	0	0	Pump Started
9:05	5	0.083	69	250	66	
9:15	15	0.250	72	250	69	
9:30	30	0.500	75	250	72	
9:45	45	0.750	75	250	72	
10:00	60	1.000	77	250	74	
11:00	120	2.000	79	250	76	
12:00	180	3.000	80	250	77	
13:00	240	4.000	82	250	79	
14:00	300	5.000	82	250	79	
15:00	360	6.000	83	250	80	
16:00	420	7.000	83	250	80	
17:00	480	8.000	84	250	81	
18:00	540	9.000	84	250	81	
19:00	600	10.000	85	250	82	
20:00	660	11.000	85	250	82	
21:00	720	12.000	85	250	82	
22:00	780	13.000	86	250	83	
23:00	840	14.000	86	250	83	
0:00	900	15.000	86	250	83	
1:00	960	16.000	87	250	84	
2:00	1020	17.000	87	250	84	
3:00	1080	18.000	87	250	84	
4:00	1140	19.000	87	250	84	
5:00	1200	20.000	87	250	84	
6:00	1260	21.000	88	250	85	
7:00	1320	22.000	88	250	85	
8:00	1380	23.000	88	250	85	

9:00	1440	24.000	88	250	85	Pump Off
9:05	5	0.083	25	0	22	Recovery 5 Minutes
9:15	15	0.250	20	0	17	Recovery 15 Minutes
9:30	30	0.500	18	0	15	Recovery 30 Minutes
9:45	45	0.750	16	0	13	Recovery 45 Minutes
10:00	60	1.000	14	0	11	Recovery 1 Hour
11:00	120	2.000	12	0	9	Recovery 2 Hours
12:00	180	3.000	11	0	8	Recovery 3 Hours
13:00	240	4.000	11	0	8	Recovery 4 Hours
14:00	300	5.000	9	0	6	Recovery 5 Hours
15:00	360	6.000	6	0	3	Recovery 6 Hours
16:00	420	7.000	5	0	2	Recovery 7 Hours
17:00	480	8.000	4	0	1	Recovery 8 Hours
18:00	540	9.000	3	0	0	Recovery 9 Hours



GIC Water Systems
Water Well Services

737 B Firetower Road
Dublin, Georgia 31021
(478) 274-9546 phone
(478) 275-0014 fax
gicws@nlamerica.com

GEFA - CHICKASAWHATCHEE

Electric Log W/ Natural Gamm

COMPANY	Grosch Drilling	OTHER SERVICES
WELL	GEFA-CHICKASAWHATCHEE	
FIELD		
COUNTRY	USA	
STATE	Georgia	
COUNTY	Calhoun	
LAT.:	31.49302	
LONG.:	-84.45890	

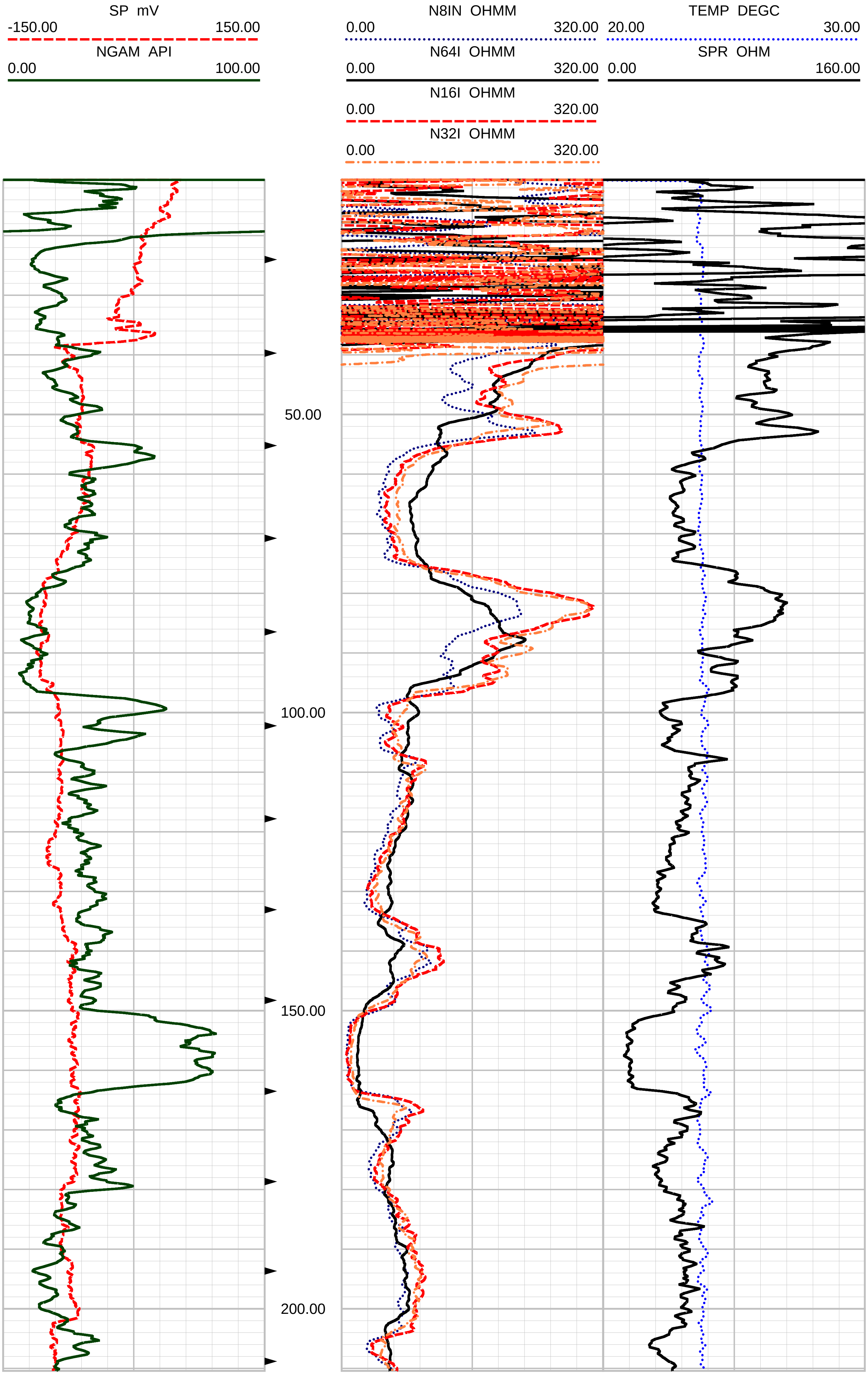
Perm. Datum	ground surface	Elev	~205 ft	KB	0.00
Log. Datum				DF	0.00
Drill Datum				GL	0.00

DATE	06 Jul 1	06 Jul 1	06 Jul 1
RUN#	0	0	0
TYPE OF LOG	ELMT6618		
DEPTH DRILLER	360.00	0.00	0.00
DEPTH LOGGER	360.00	0.00	0.00
LOG DEEPEST	360.00	0.00	0.00
LOG SHALLOW	0.00	0.00	0.00
FLUID IN HOLE	Water		
SALINITY			
DENSITY			
LEVEL	0		
MAX TEMP °C	0.00	0.00	0.00
RIG TIME	17:30		
RECORDED BY	S.Dixon, PG		
WITNESSED BY	S.Brantley		

RUN#	BIT RECORD SIZE	BIT RECORD FROM	BIT RECORD TO	CASING RECORD SIZE	CASING RECORD WEIGHT	CASING RECORD FROM	CASING RECORD TO
0	5.13	0.00	300.00	0.00	0.00	0.00	0.00
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00

REMARKS (C:\Winlogger\Data\GEFA-Chickasawhatchee-2.LGX.hed)

ELMT6618-8,16,32, and 64-Normal Resistivity, SPR, SP, Temp, and Natural Ga..
ROBERTSON GEOLOGGING TECHNOLOGY
Logging up
Logging speed - 16ft/min


SP mV
-150.00 150.00
NGAM API
0.00 100.00
N8IN OHMM
0.00 320.00
N64I OHMM
0.00 320.00
N16I OHMM
0.00 320.00
N32I OHMM
0.00 320.00
TEMP DEGC
20.00 30.00
SPR OHM
0.00 160.00
50.00
100.00
150.00
200.00

SP mV

-150.00 150.00

NGAM API

0.00 100.00

N8IN OHMM

0.00 320.00

N64I OHMM

0.00 320.00

N16I OHMM

0.00 320.00

N32I OHMM

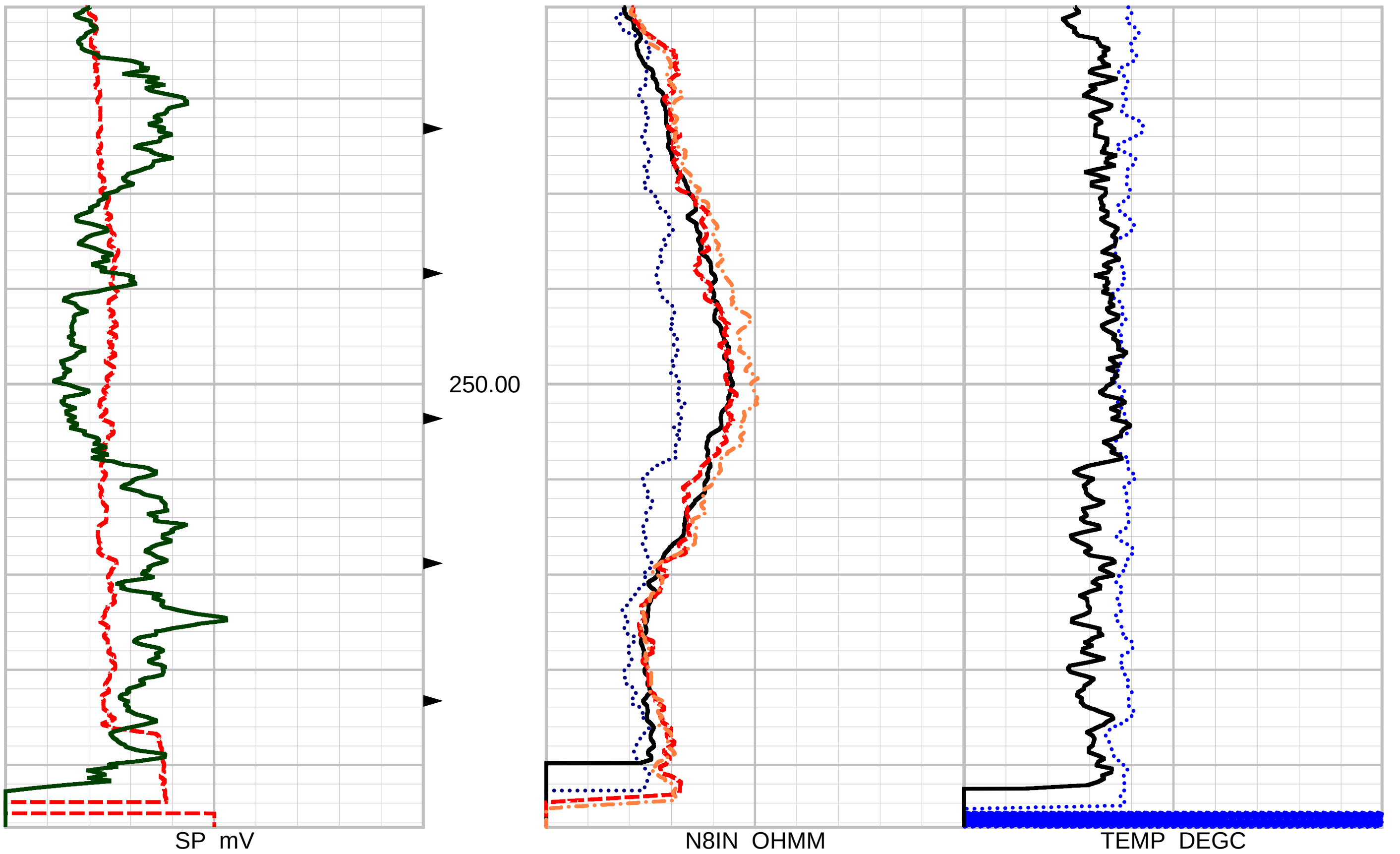
0.00 320.00

TEMP DEGC

20.00 30.00

SPR OHM

0.00 160.00



SP mV

-150.00 150.00

NGAM API

0.00 100.00

N8IN OHMM

0.00 320.00

N64I OHMM

0.00 320.00

N16I OHMM

0.00 320.00

N32I OHMM

0.00 320.00

TEMP DEGC

20.00 30.00

SPR OHM

0.00 160.00

Depth: 10.00 ft Date: 06 Jul 2016 Time: 18:25:37 File: "C:\Winlogger\Data\GEFA-Chickasawhatchee-2.LGX.LGX"

GIC Water Systems
Water Well Services

737 B Firetower Road
Dublin, Georgia 31021
(478) 274-9546 phone
(478) 275-0014 fax
gicws@nlamerica.com

GEFA - CHICKASAWHATCHEE

Electric Log W/ Natural Gamm

COMPANY	Grosch Drilling
WELL	GEFA-CHICKASAWHATCHEE
FIELD	
COUNTRY	USA
STATE	Georgia
COUNTY	Calhoun
LAT.:	31.49302
LONG.:	-84.45890

OTHER SERVICES

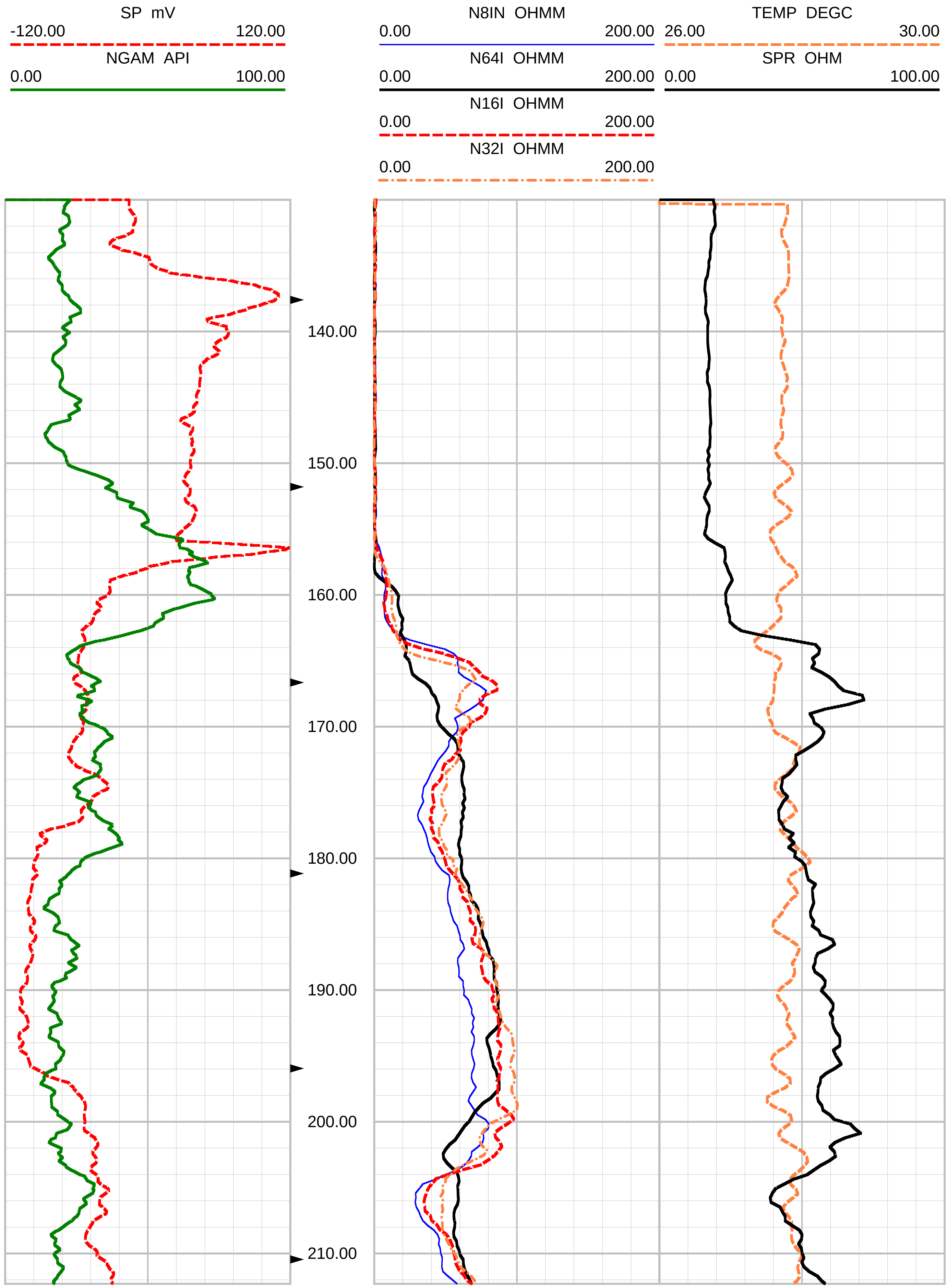
Perm. Datum	ground surf..	Elev	~205 ft	KB	0.00
Log. Datum				DF	0.00
Drill Datum				GL	0.00

DATE	19 Jul 1	06 Jul 1	06 Jul 1
RUN#	0	0	0
TYPE OF LOG	ELMT6618		
DEPTH DRILLER	320.00	0.00	0.00
DEPTH LOGGER	320.00	0.00	0.00
LOG DEEPEST	320.00	0.00	0.00
LOG SHALLOW	0.00	0.00	0.00
FLUID IN HOLE	Water		
SALINITY			
DENSITY			
LEVEL	0		
MAX TEMP °C	0.00	0.00	0.00
RIG TIME	14:40		
RECORDED BY	S.Dixon, PG		
WITNESSED BY	S.Brantley		

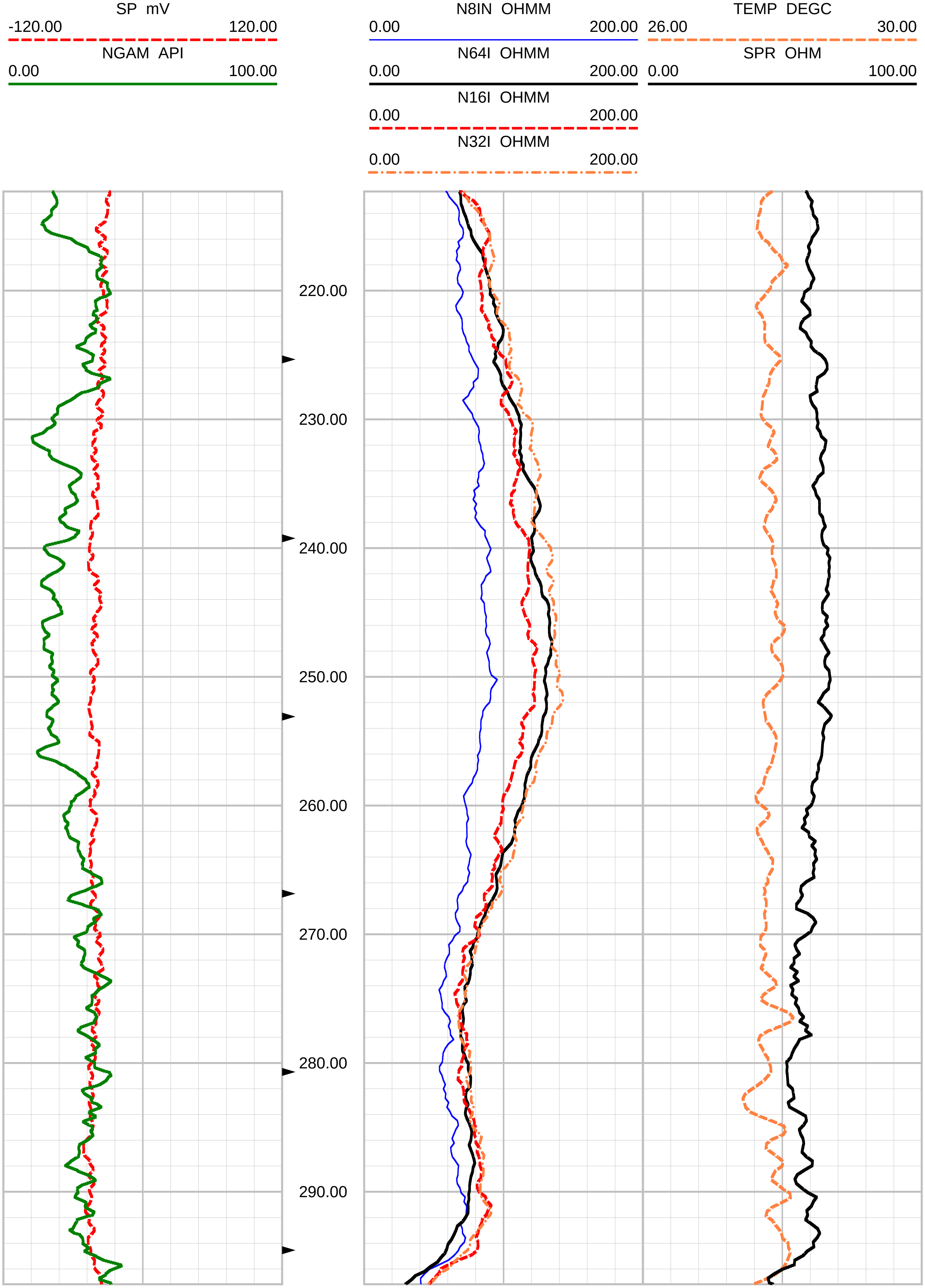
RUN#	BIT RECORD SIZE	FROM	TO	CASING RECORD SIZE	WEIGHT	FROM	TO
0	7.88	0.00	320.00	8.00	0.00	0.00	155.00
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00

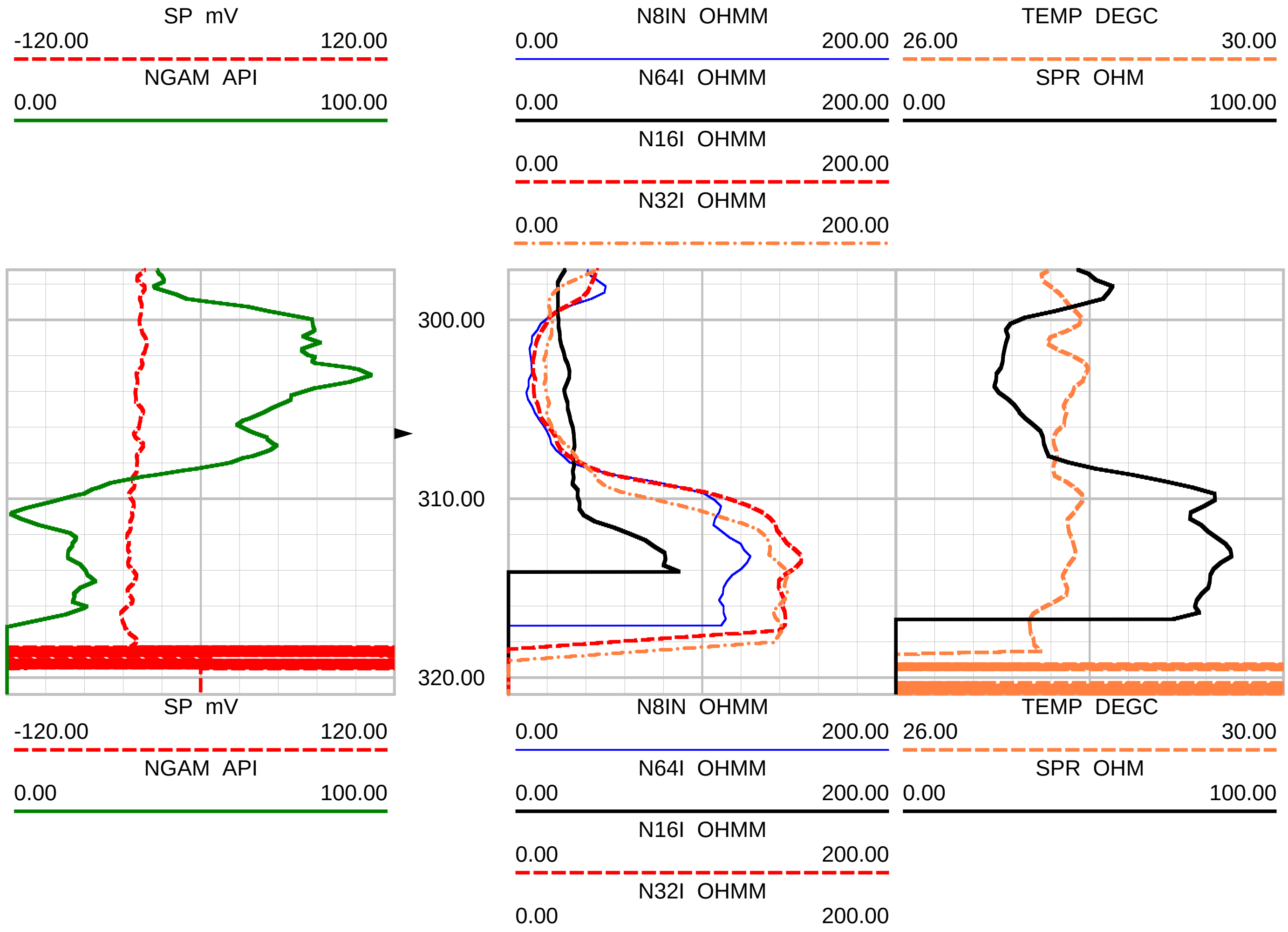
REMARKS (C:\Winlogger\Data\GEFA-Chickasawhatchee-7-19-16.LG..

ELMT6618-8,16,32, and 64-Normal Resistivity, SPR, SP, Temp, and Nat..
ROBERTSON GEOLOGGING TECHNOLOGY
Logging up
Logging speed - 16ft/min



SP mV
-120.00
120.00
NGAM API
0.00
100.00
N8IN OHMM
0.00
200.00
N64I OHMM
0.00
200.00
N16I OHMM
0.00
200.00
N32I OHMM
0.00
200.00
TEMP DEGC
26.00
30.00
SPR OHM
0.00
100.00
140.00
150.00
160.00
170.00
180.00
190.00
200.00
210.00


SP mV
-120.00
120.00
NGAM API
0.00
100.00
N8IN OHMM
0.00
200.00
N64I OHMM
0.00
200.00
N16I OHMM
0.00
200.00
N32I OHMM
0.00
200.00
TEMP DEGC
26.00
30.00
SPR OHM
0.00
100.00
220.00
230.00
240.00
250.00
260.00
270.00
280.00
290.00



Depth: 130.00 ft Date: 19 Jul 2016 Time: 15:03:18 File: "C:\Winlogger\Data\GEFA-Chickasawhatchee-7-19-16.LGX.LGX"

Water Analysis

Food Safety

Waters Agricultural Laboratories, Inc
P.O. Box 382   257 Newton Hwy
Camilla, Georgia 31730
Phone (229) 336-7216   FAX (229) 336-7967

GROSCH DRILLING

737 FIRETOWER ROAD
DUBLIN, GA 31021-

Received: 07/26/2016
Processed: 07/28/2016
Lab Number: 7726WT
Sample Number: WMA #2
Grower: GROSCH DRILLING

Results Reported In ppm Unless Otherwise Noted

Nitrate Nitrogen:	0.1	*L*					
			Carbonate:	38.4	*H*		
			BiCarbonate:	137.86	*M*		
Phosphorus:	0.01	*L*	pH:	8	*N*		
Potassium:	3.25	*L*	Conductivity:	0.299	*N*	*mmhos/cm*	
Calcium:	40.97	*N*	Total Dissolved Solids:	191.36	*N*		
Magnesium:	6.78	*L*	Sodium Absorption Ratio (SAR):	0.56	*L*		
Sodium:	14.69	*L*					
Chloride:	7	*L*					
Sulfate:	6.02	*L*					
Boron:	0.01	*L*					
			Total Coliform:	1.00	/ml		
			Generic eColi:	<1.0	/ml		
			Lead:	<0.015	*L*		

Comments:

TOTAL SUSPENDED SOLIDS - 0.002 PPM
TOTAL SOLIDS = 89.00 PPM

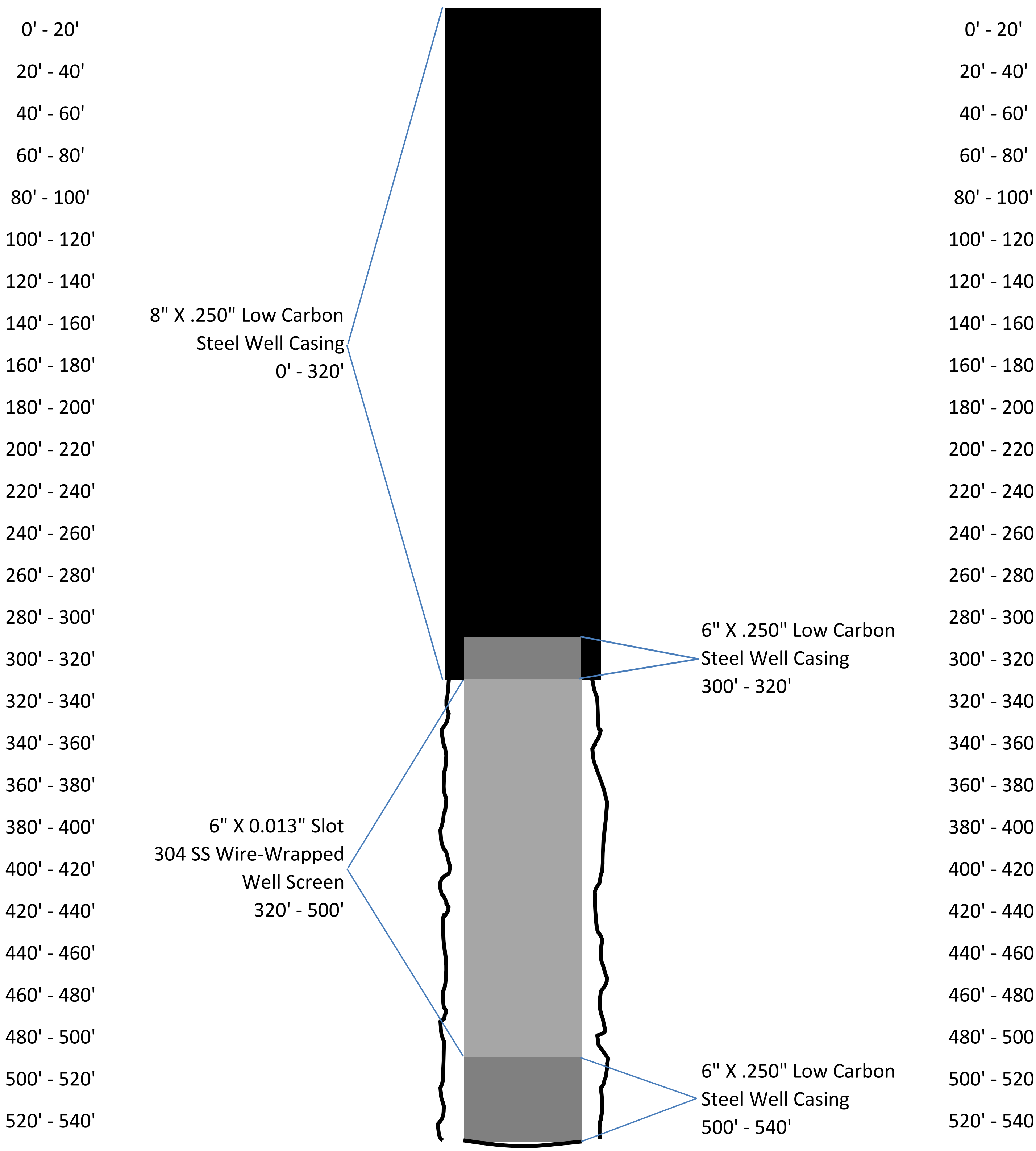
L = Low   **N =Normal**   **M = Moderate**   **H = High**   **VH = Very High**

Georgia Environmental Finance Authority
Claiborne Test Wells Project
Site: The Jones Center
Location: Baker County, GA
N 31.283153, W 84.528708

Well Drilling Information	
Total Depth of Well: 540' Below Land Surface	Drilling Method: Combination
Static Water Level: 40'	Date Drilled: September 7, 2016
Date Static Water Level Measured: September 15, 2016	Driller: Greg Grosch
Borehole Information	**Grouting**
Borehole Diameter: 9" From 0' to 320'	Type: High Yield Bentonite
Borehole Diameter: 7-7/8" From 320' to 540'	Interval: 0' to 320'
Casing Information	
Casing Material: Low Carbon Steel	
Casing Wall Thickness: 0.250"	
Casing Details: 8-5/8" Outside, 8-1/8" Inside From 0' to 320'	
Casing Details: 6-1/2" Outside, 6" Inside From 300' to 320'	
Casing Details: 6-1/2" Outside, 6" Inside From 500' to 540'	
Well Screen Information	
Well Screen Material: Stainless Steel	
Well Screen Details: 6" X 0.013" Slot From 320' to 500'	
Test Pump Data	
Date Tested: September 14, 2016 - September 15, 2016	
Total Continuous Hours Tested: 24	
Did Water Level Stabilize: Yes	
Sustained Yield: 100 GPM	
Pumping Water Level: 246	
Drawdown: 206	
Specific Capacity: 0.485 GPM/Ft	
Time Until Recovery: 9 Hours	
Permanent Pump Data	
Pump Type: None	
Pump Diameter: None	
Discharge Size: None	
Motor HP: None	Motor RPM: None
Pump Capacity (GPM): None	Total Dynamic Head: None
Pump Setting Depth: None	
Pump Disinfected?: N/A	
Air Line Installed?: N/A	
Air Line Depth, If Installed: N/A	Air Line Diameter, If Installed: N/A
Chemigation Check Valve Installed?: N/A	

Attached: Geophysical Logs
Attached: 24 Hour Constant Rate Test Results
Attached: Water Quality Analysis

Georgia Environmental Finance Authority
Claiborne Test Wells Project
Site: The Jones Center
Location: Baker County, GA
N 31.283153, W 84.528708



Georgia Environmental Finance Authority
Claiborne Test Wells Project
Site: The Jones Center
Location: Baker County, GA
N 31.283153, W 84.528708

Lithologic Log

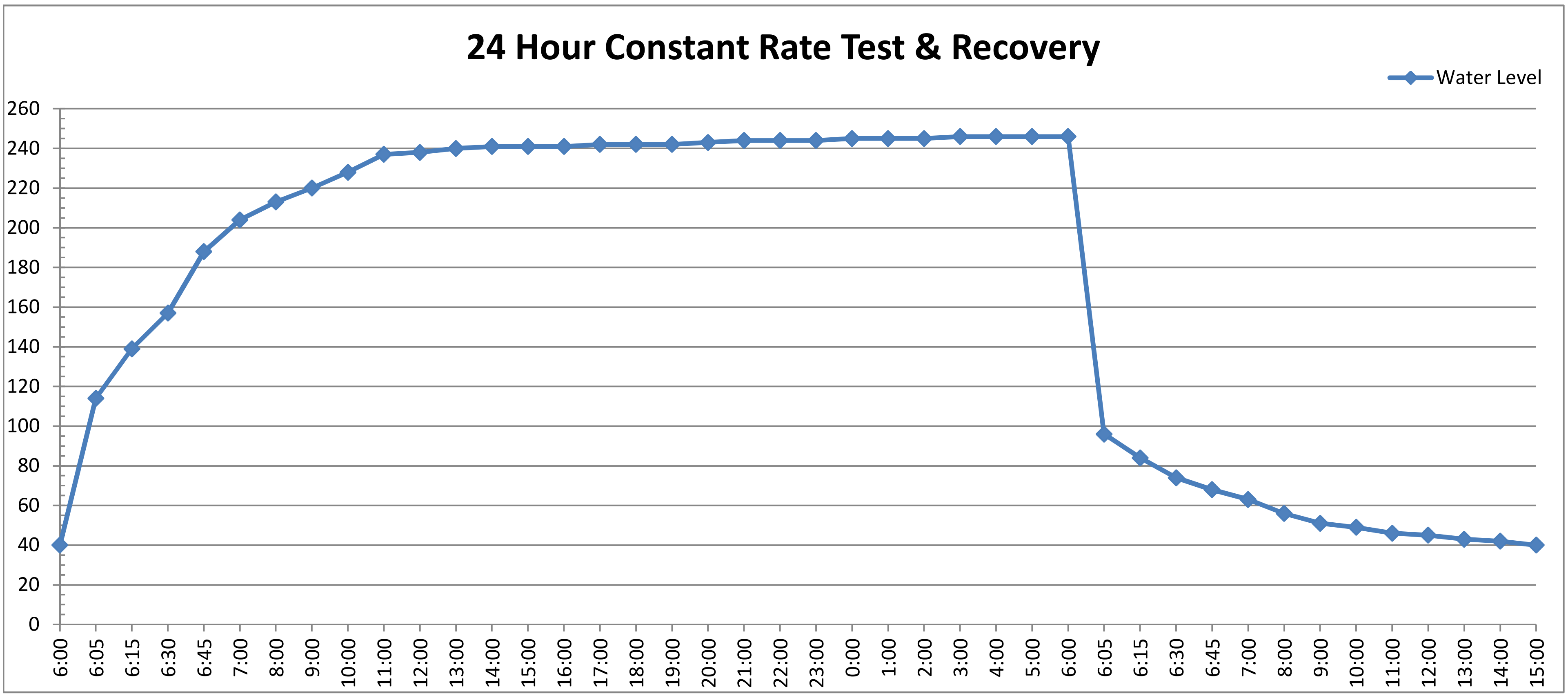
0' - 3'	Sand
3' - 15'	Clay
15' - 20'	Limestone
20' - 40'	Sandy Clay
40' - 60'	Clay with Sand Streaks
60' - 80'	Sandy Clay
80' - 120'	Limestone with Small Clay Layers
120' -195'	Limestone
195' - 220'	Green Limestone, Turning Dark Grey
220' - 250'	Dark Grey Limestone
250' - 280'	Light Grey Limestone with Shellrock
280' - 312'	Limestone with Clay Streaks
312' - 320'	Clay with Sand Streaks
320' - 360'	Clay with Sand & Rock Lenses
360' - 393'	Sand
393' - 394'	Hard Rock Lens
394' - 405'	Sand
405' - 407'	Clay Layer
407' - 420'	Sand with Rock Lenses
420' - 440'	Sand
440' - 460'	Shellrock
460' - 495'	Sand
495' - 540'	Clay

Georgia Environmental Finance Authority
Claiborne Test Wells Project
Site: The Jones Center
Location: Baker County, GA
N 31.283153, W 84.528708

24 Hour Constant Rate Testing & Recovery

Clock Time	Time Elapsed (Minutes)	Time Elapsed (Hours)	Water Level	GPM	Drawdown	Notes
6:00	0	0	40	0	0	Pump Started
6:05	5	0.083	114	100	74	
6:15	15	0.250	139	100	99	
6:30	30	0.500	157	100	117	
6:45	45	0.750	188	100	148	
7:00	60	1.000	204	100	164	
8:00	120	2.000	213	100	173	
9:00	180	3.000	220	100	180	
10:00	240	4.000	228	100	188	
11:00	300	5.000	237	100	197	
12:00	360	6.000	238	100	198	
13:00	420	7.000	240	100	200	
14:00	480	8.000	241	100	201	
15:00	540	9.000	241	100	201	
16:00	600	10.000	241	100	201	
17:00	660	11.000	242	100	202	
18:00	720	12.000	242	100	202	
19:00	780	13.000	242	100	202	
20:00	840	14.000	243	100	203	
21:00	900	15.000	244	100	204	
22:00	960	16.000	244	100	204	
23:00	1020	17.000	244	100	204	
0:00	1080	18.000	245	100	205	
1:00	1140	19.000	245	100	205	
2:00	1200	20.000	245	100	205	
3:00	1260	21.000	246	100	206	
4:00	1320	22.000	246	100	206	
5:00	1380	23.000	246	100	206	

6:00	1440	24.000	246	100	206	Pump Off
6:05	5	0.083	96	0	56	Recovery 5 Minutes
6:15	15	0.250	84	0	44	Recovery 15 Minutes
6:30	30	0.500	74	0	34	Recovery 30 Minutes
6:45	45	0.750	68	0	28	Recovery 45 Minutes
7:00	60	1.000	63	0	23	Recovery 1 Hour
8:00	120	2.000	56	0	16	Recovery 2 Hours
9:00	180	3.000	51	0	11	Recovery 3 Hours
10:00	240	4.000	49	0	9	Recovery 4 Hours
11:00	300	5.000	46	0	6	Recovery 5 Hours
12:00	360	6.000	45	0	5	Recovery 6 Hours
13:00	420	7.000	43	0	3	Recovery 7 Hours
14:00	480	8.000	42	0	2	Recovery 8 Hours
15:00	540	9.000	40	0	0	Recovery 9 Hours



GIC Water Systems
Water Well Services
737 B Firetower Road
Dublin, Georgia 31021
(478) 274-9546 phone
(478) 275-0014 fax
gicws@nlamerica.com

GEFA - JONES CENTER

Electric Log W/ Natural Gamm

COMPANY	Grosch Drilling
WELL	GEFA-JONES CENTER
FIELD	
COUNTRY	USA
STATE	Georgia
COUNTY	Baker
LAT.:	N31.283153
LONG.:	W84.528708

OTHER SERVICES

Perm. Datum	ground surface	Elev	~161 ft	KB	0.00
Log. Datum				DF	0.00
Drill Datum				GL	0.00

DATE	07 Sep 1		
RUN#	0	0	0
TYPE OF LOG	ELMT6618		
DEPTH DRILLER	540.00	0.00	0.00
DEPTH LOGGER	540.00	0.00	0.00
LOG DEEPEST	540.00	0.00	0.00
LOG SHALLOW	0.00	0.00	0.00
FLUID IN HOLE	DrillingFluid/Water		
SALINITY			
DENSITY			
LEVEL	0		
MAX TEMP °C	0.00	0.00	0.00
RIG TIME	16:50		
RECORDED BY	S.Dixon, PG		
WITNESSED BY	S.Brantley		

RUN#	BIT RECORD			CASING RECORD			
	SIZE	FROM	TO	SIZE	WEIGHT	FROM	TO
0	7.88	320.00	540.00	8.00	0.00	0.00	320.00
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00

REMARKS (C:\Winlogger\Data\GEFA-JonesCenter.hed)
ROBERTSON GEOLOGGING TECHNOLOGY
ELMT6618-8,16,32, and 64-Normal Resistivity, SPR, SP, Temp, and Natural Gamma
Logging up
Logging speed - 16ft/min

CALIBRATION CONSTANTS

N8IN

	CPS	JIG
VALUE 0	00000	00000
VALUE 1	00000	00000
VALUE 2	00000	00000
VALUE 3	00000	00000

N16I

	CPS	JIG
VALUE 0	00000	00000
VALUE 1	00000	00000
VALUE 2	00000	00000
VALUE 3	00000	00000

N32I

	CPS	JIG
VALUE 0	00000	00000
VALUE 1	00000	00000
VALUE 2	00000	00000
VALUE 3	00000	00000

N64I

	CPS	JIG
VALUE 0	00000	00000
VALUE 1	00000	00000
VALUE 2	00000	00000
VALUE 3	00000	00000

SP

	CPS	JIG
VALUE 0	00000	00000
VALUE 1	00000	00000
VALUE 2	00000	00000
VALUE 3	00000	00000

SPR

	CPS	JIG
VALUE 0	00000	00000
VALUE 1	00000	00000
VALUE 2	00000	00000
VALUE 3	00000	00000

TEMP

	CPS	JIG
VALUE 0	00000	00000
VALUE 1	00000	00000
VALUE 2	00000	00000
VALUE 3	00000	00000

NGAM

	CPS	JIG
VALUE 0	00000	00000
VALUE 1	00000	00000
VALUE 2	00000	00000
VALUE 3	00000	00000

N8IN

COEFFICIENT 0	0
COEFFICIENT 1	1
COEFFICIENT 2	0
COEFFICIENT 3	0

N16I

COEFFICIENT 0	0
COEFFICIENT 1	1
COEFFICIENT 2	0
COEFFICIENT 3	0

N32I

COEFFICIENT 0	0
COEFFICIENT 1	1
COEFFICIENT 2	0
COEFFICIENT 3	0

N64I

COEFFICIENT 0	0
COEFFICIENT 1	1
COEFFICIENT 2	0
COEFFICIENT 3	0

SP

COEFFICIENT 0	0
COEFFICIENT 1	1
COEFFICIENT 2	0
COEFFICIENT 3	0

SPR

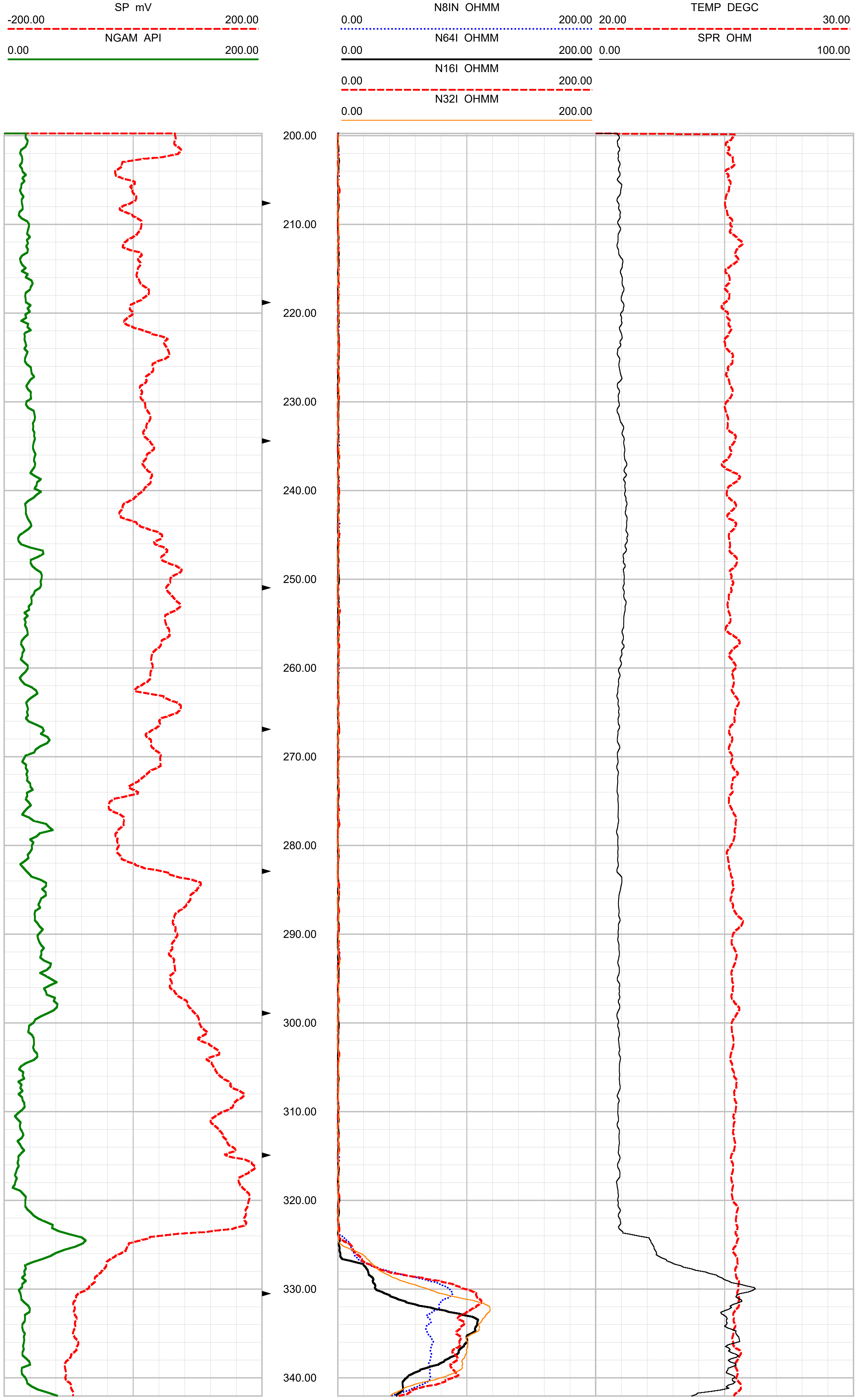
COEFFICIENT 0	0
COEFFICIENT 1	1
COEFFICIENT 2	0
COEFFICIENT 3	0

TEMP

COEFFICIENT 0	-8.63262
COEFFICIENT 1	0.00483858
COEFFICIENT 2	0
COEFFICIENT 3	0

NGAM

COEFFICIENT 0	0
COEFFICIENT 1	1.51
COEFFICIENT 2	0
COEFFICIENT 3	0


SP mV
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200.00
NGAM API
0.00
200.00
N8IN OHMM
0.00
200.00
N64I OHMM
0.00
200.00
N16I OHMM
0.00
200.00
N32I OHMM
0.00
200.00
TEMP DEGC
20.00
30.00
SPR OHM
0.00
100.00
200.00
210.00
220.00
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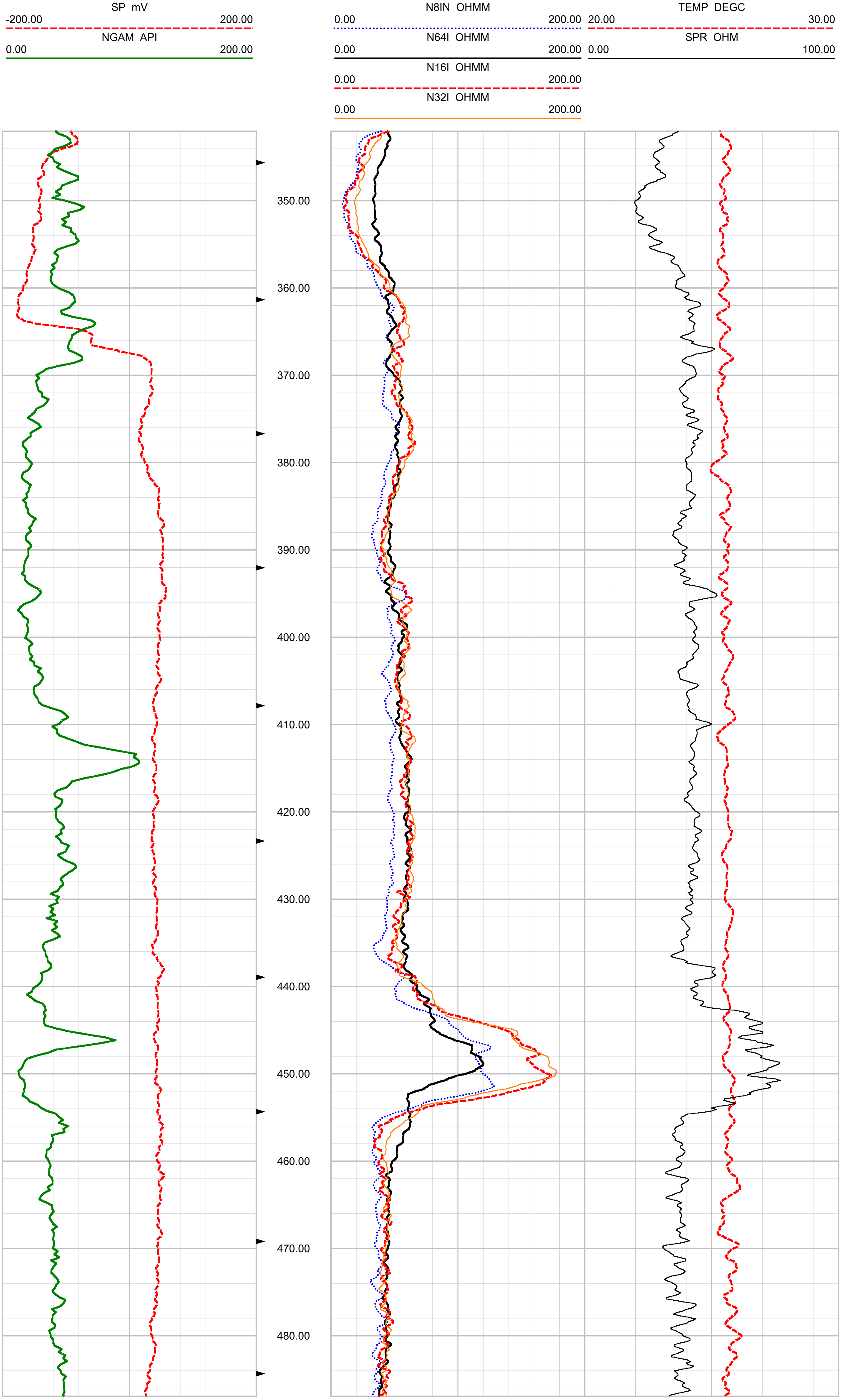
330.00
340.00


SP mV
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200.00
NGAM API
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N8IN OHMM
0.00
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N64I OHMM
0.00
200.00
N16I OHMM
0.00
200.00
N32I OHMM
0.00
200.00
TEMP DEGC
20.00
30.00
SPR OHM
0.00
100.00
350.00
360.00
370.00
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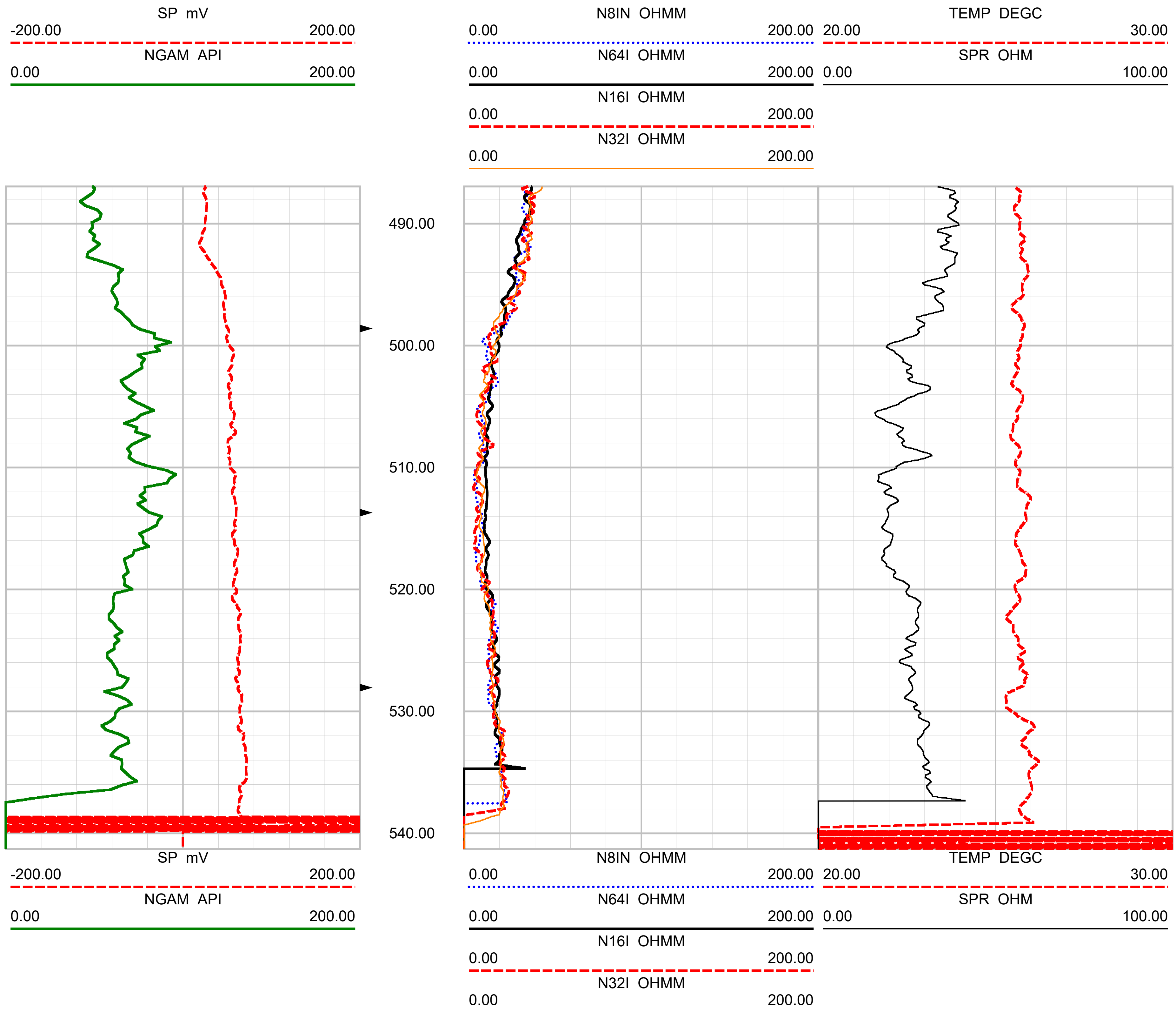
460.00
470.00
480.00



Depth: 199.00 ft Date: 07 Sep 2016 Time: 17:24:46 File: "C:\Winlogger\Data\GEFA-JonesCenter.LGX"

Water Analysis

Irrigation

Waters Agricultural Laboratories, Inc
P.O. Box 382 257 Newton Hwy
Camilla, Georgia 31730
Phone (229) 336-7216 FAX (229) 336-7967

GROSCH DRILLING

737 FIRETOWER ROAD
DUBLIN, GA 31021-

Received: 09/15/2016
Processed: 09/16/2016
Lab Number: 8068WT
Sample Number: 1
Grower: JONES CENTER

Results Reported In ppm Unless Otherwise Noted

			Iron:	0.02	*L*	
Nitrate Nitrogen:	0.1	*L*				
			Carbonate:	0	*L*	
			BiCarbonate:	219.6	*H*	
Phosphorus:	0.03	*L*	pH:	7.9	*N*	
Potassium:	3.46	*L*	Conductivity:	0.32	*N*	*mmhos/cm*
Calcium:	30.03	*N*	Total Dissolved Solids:	204.8	*N*	
Magnesium:	11.81	*N*	Sodium Absorption Ratio (SAR):	0.86	*L*	
Sodium:	22.17	*L*				
Chloride:	2	*L*				
Sulfate:	5.36	*L*				
Boron:	0.04	*L*				

Comments:

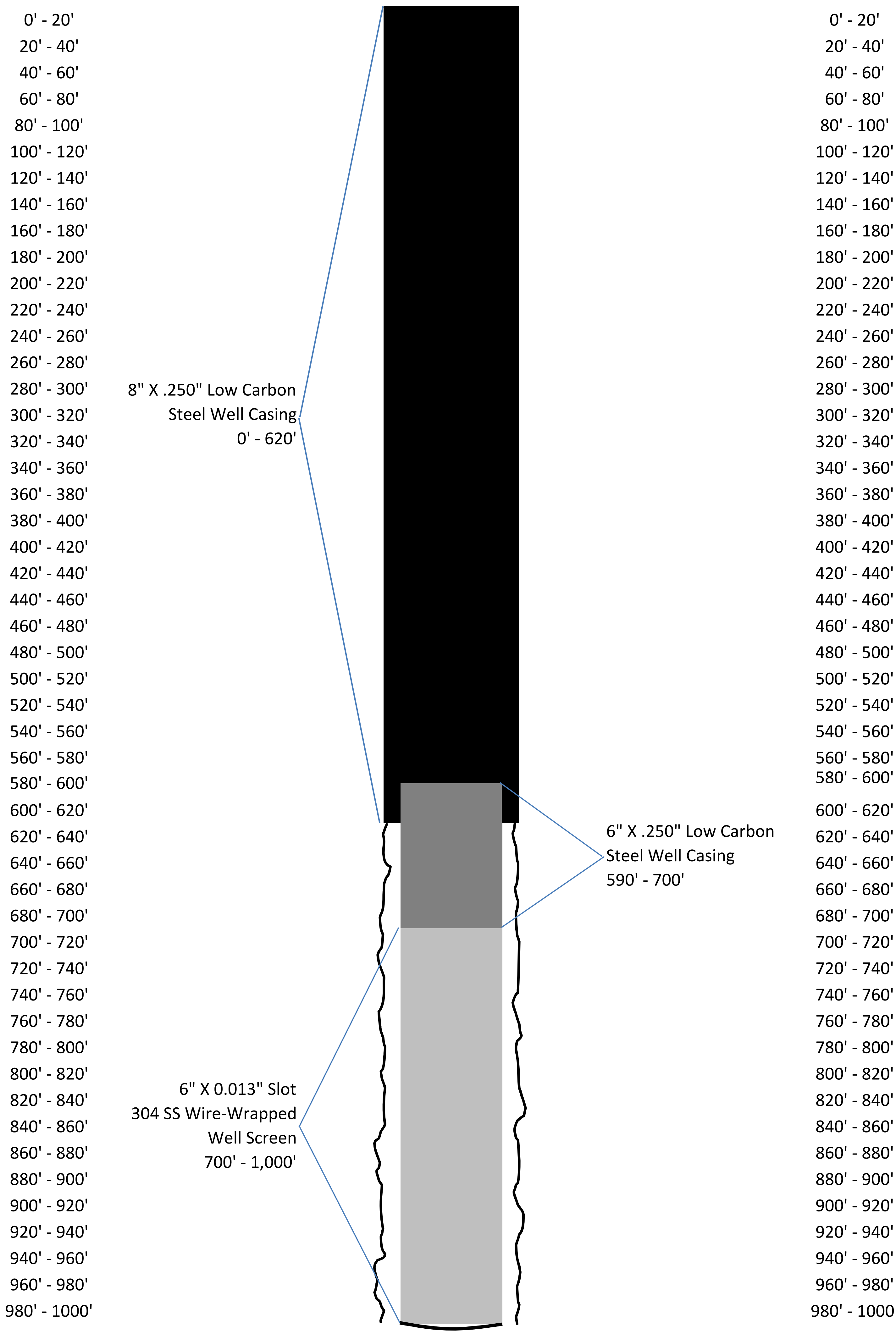
L = Low **N =Normal** **M = Moderate** **H = High** **VH = Very High**

Georgia Environmental Finance Authority
Claiborne Test Wells Project
Site: GDOT Facility
Location: Sylvester, GA (Worth County)
N 31.52140, W 83.83150

Well Drilling Information	
Total Depth of Well: 1,000' Below Land Surface	Drilling Method: Combination
Static Water Level: 169'	Date Drilled: November 3, 2016
Date Static Water Level Measured: November 9, 2016	Driller: Greg Grosch
Borehole Information	**Grouting**
Borehole Diameter: 9" From 0' to 620'	Type: High Yield Bentonite
Borehole Diameter: 7-7/8" From 620' to 1,000'	Interval: 0' to 620'
Casing Information	
Casing Material: Low Carbon Steel	
Casing Wall Thickness: 0.250"	
Casing Details: 8-5/8" Outside, 8-1/8" Inside From 0' to 620'	
Casing Details: 6-1/2" Outside, 6" Inside From 620' to 700'	
Well Screen Information	
Well Screen Material: Stainless Steel	
Well Screen Details: 6" X 0.013" Slot From 700' to 1,000'	
Test Pump Data	
Date Tested: November 10, 2016 - November 11, 2016	
Total Continuous Hours Tested: 24	
Did Water Level Stabilize: Yes	
Sustained Yield: 300 GPM	
Pumping Water Level: 255' at 24 Hours	
Drawdown: 86'	
Specific Capacity: 3.4884 GPM/Ft. of Drawdown	
Time Until Recovery: 9 Hours	
Permanent Pump Data	
Pump Type: None	
Pump Diameter: None	
Discharge Size: None	
Motor HP: None	Motor RPM: None
Pump Capacity (GPM): None	Total Dynamic Head: None
Pump Setting Depth: None	
Pump Disinfected?: N/A	
Air Line Installed?: N/A	
Air Line Depth, If Installed: N/A	Air Line Diameter, If Installed: N/A
Chemigation Check Valve Installed?: N/A	

Attached: Geophysical Logs
Attached: Step Drawdown Test Results
Attached: 24 Hour Constant Rate Test Results
Attached: Water Quality Analysis

Georgia Environmental Finance Authority
Claiborne Test Wells Project
Site: GDOT Facility
Location: Sylvester, GA (Worth County)
N 31.52140, W 84.83150



Georgia Environmental Finance Authority
Claiborne Test Wells Project
Site: GDOT Facility
Location: Sylvester, GA (Worth County)
N 31.52140, W 83.83150

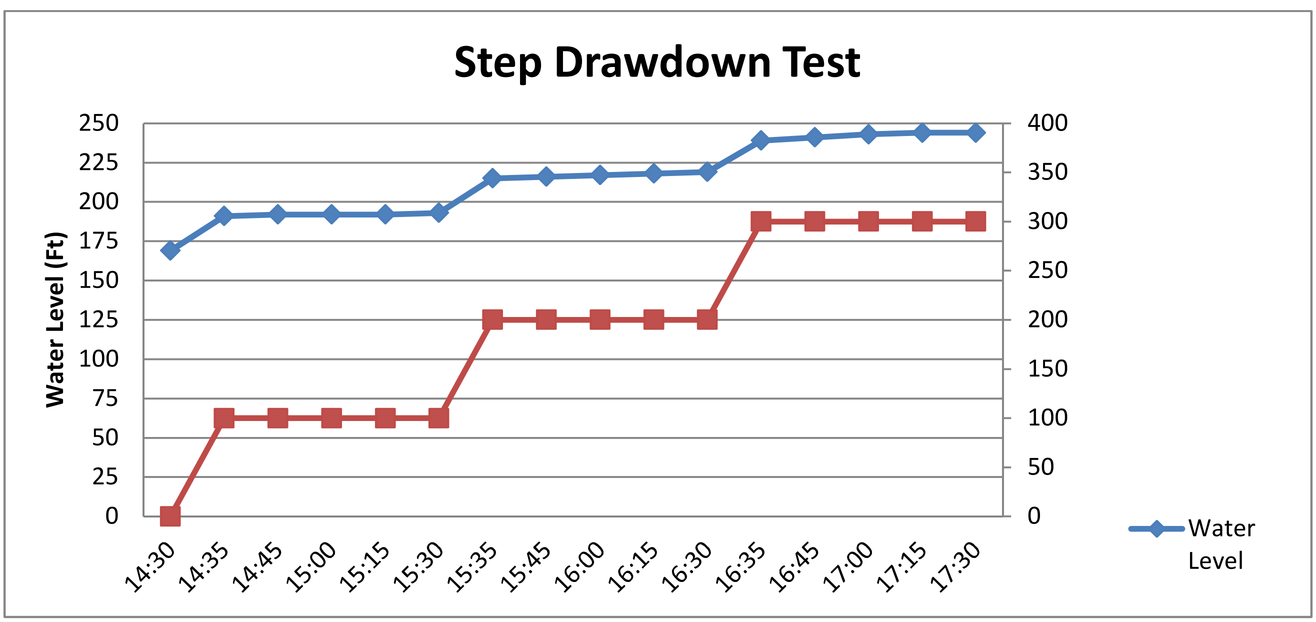
Lithologic Log

0' - 2'	Asphalt & Gravel
2' - 10'	Sand
10' - 130'	Clay
130' - 180'	White Limestone (Medium - Hard with some Soft Streaks)
180' - 230'	Soft White Limestone with some Hard Streaks
230' - 380'	Dark Grey Limestone
380' - 450'	Gummy Limestone
450' - 460'	Hard Limestone
460' - 480'	Hard Limeston with Soft Streaks
480' - 560'	Dark Tan Soft to Medium Limestone with Gummy Layers
560' - 610'	Green Limestone (Softer with Depth)
610' - 620'	Tan Limestone with Sand
620' - 627'	Fine Sand with Limestone
627' - 668'	Hard Limestone with White Clay and Fine Sand Streaks
668' - 685'	Soft Shellrock with Fine Sand Streaks
685' - 689'	Sandy Grey Clay
689' - 720'	Fine Sand & Shell with Clay Streaks
720' - 740'	Very Fine Sand & Shell with Sandy Grey Clay Layers
740' - 760'	Very Fine Sand & Shell with Hard Shellrock Layers & Sandy Clay Streaks
760' - 780'	Very Fine Sand with Hard Rock Layers & Sandy Clay Streaks
780' - 806'	Hard Shellrock with Very Fine Sand Layers & Small Clay Streaks
806' - 820'	Very Fine Sand with Clay Streaks
820' - 840'	Shellrock with Very Fine Sand & Sandy Clay Streaks
840' - 860'	Very Fine Sand with Hard Rock & Sandy Clay Streaks
860' - 960'	Very Fine Sand with Sandy Clay & Small Hard Rock Streaks
960' - 994'	Sandy Grey Clay with Very Fine Sand Layers & Small Rock Streaks
994' - 1000'	Sticky Grey Clay

Location: Sylvester, GA (Worth County), N 31.52140, W 83.83150
Client: Georgia Environmental Finance Authority
Well ID: GEFA - Worth
Test Date: 11/9/2016

Step Drawdown Test

Time	Water Level	Drawdown	GPM	Notes
14:30	169	0	0	Static
14:35	191	22	100	
14:45	192	23	100	
15:00	192	23	100	
15:15	192	23	100	
15:30	193	24	100	Increase
15:35	215	46	200	
15:45	216	47	200	
16:00	217	48	200	
16:15	218	49	200	
16:30	219	50	200	Increase
16:35	239	70	300	
16:45	241	72	300	
17:00	243	74	300	
17:15	244	75	300	
17:30	244	75	300	Pump Off

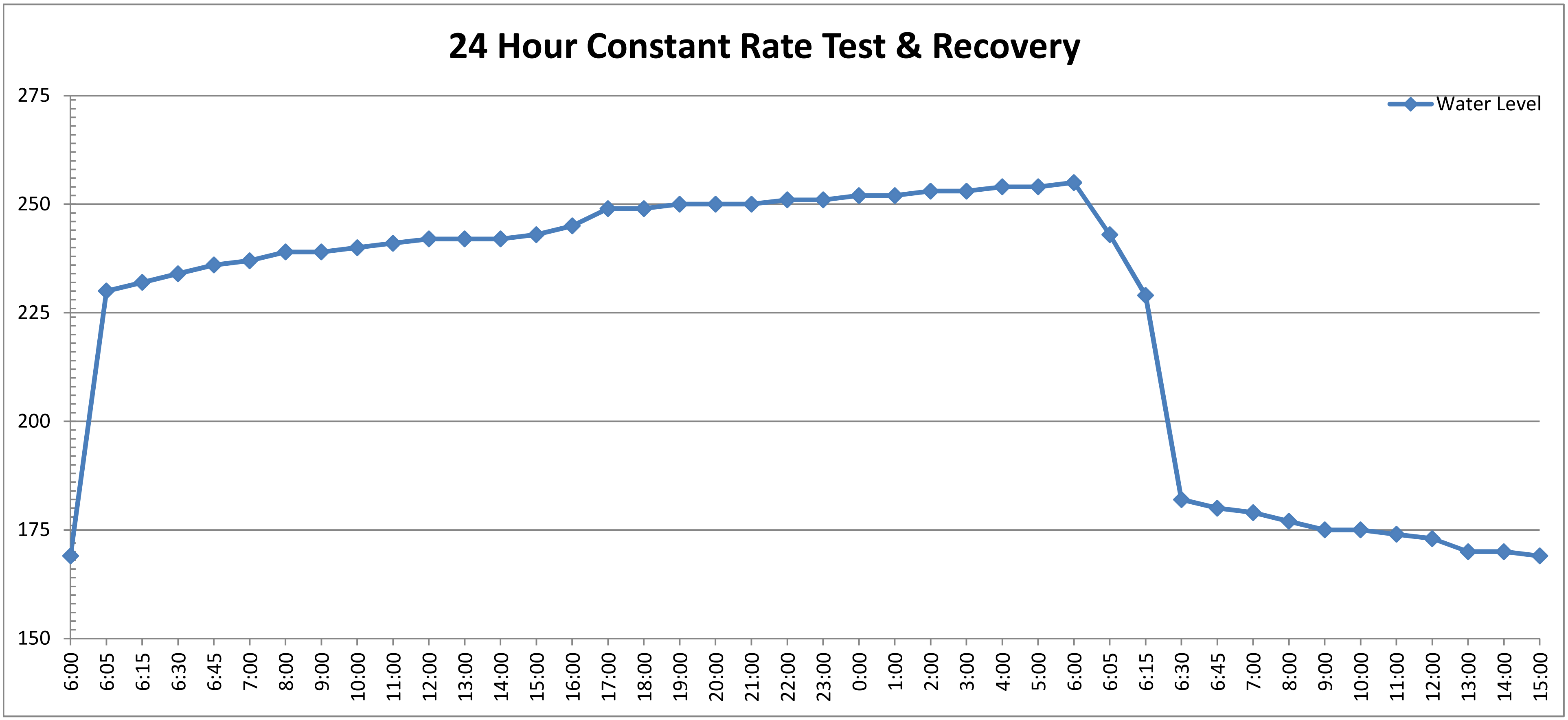


Georgia Environmental Finance Authority
Claiborne Test Wells Project
Site: GDOT Facility
Location: Sylvester, GA (Worth County)
N 31.52140, W 83.83150

24 Hour Constant Rate Testing & Recovery

Clock Time	Time Elapsed (Minutes)	Time Elapsed (Hours)	Water Level	GPM	Drawdown	Notes
6:00	0	0	169	0	0	Pump Started
6:05	5	0.083	230	300	61	
6:15	15	0.250	232	300	63	
6:30	30	0.500	234	300	65	
6:45	45	0.750	236	300	67	
7:00	60	1.000	237	300	68	
8:00	120	2.000	239	300	70	
9:00	180	3.000	239	300	70	
10:00	240	4.000	240	300	71	
11:00	300	5.000	241	300	72	
12:00	360	6.000	242	300	73	
13:00	420	7.000	242	300	73	
14:00	480	8.000	242	300	73	
15:00	540	9.000	243	300	74	
16:00	600	10.000	245	300	76	
17:00	660	11.000	249	300	80	
18:00	720	12.000	249	300	80	
19:00	780	13.000	250	300	81	
20:00	840	14.000	250	300	81	
21:00	900	15.000	250	300	81	
22:00	960	16.000	251	300	82	
23:00	1020	17.000	251	300	82	
0:00	1080	18.000	252	300	83	
1:00	1140	19.000	252	300	83	
2:00	1200	20.000	253	300	84	
3:00	1260	21.000	253	300	84	
4:00	1320	22.000	254	300	85	
5:00	1380	23.000	254	300	85	

6:00	1440	24.000	255	300	86	Pump Off
6:05	5	0.083	243	0	74	Recovery 5 Minutes
6:15	15	0.250	229	0	60	Recovery 15 Minutes
6:30	30	0.500	182	0	13	Recovery 30 Minutes
6:45	45	0.750	180	0	11	Recovery 45 Minutes
7:00	60	1.000	179	0	10	Recovery 1 Hour
8:00	120	2.000	177	0	8	Recovery 2 Hours
9:00	180	3.000	175	0	6	Recovery 3 Hours
10:00	240	4.000	175	0	6	Recovery 4 Hours
11:00	300	5.000	174	0	5	Recovery 5 Hours
12:00	360	6.000	173	0	4	Recovery 6 Hours
13:00	420	7.000	170	0	1	Recovery 7 Hours
14:00	480	8.000	170	0	1	Recovery 8 Hours
15:00	540	9.000	169	0	0	Recovery 9 Hours



GIC Water Systems
Water Well Services

737 B Firetower Road
Dublin, Georgia 31021
(478) 274-9546 phone
(478) 275-0014 fax
gicws@nlamerica.com

GEFA - Sylvester

Electric Log W/ Natural Gamm

COMPANY	Grosch Drilling	OTHER SERVICES
WELL	GEFA - Sylvester	
FIELD		
COUNTRY	USA	
STATE	Georgia	
COUNTY	Worth	
LAT.:	N31.52140	
LONG.:	W83.83150	

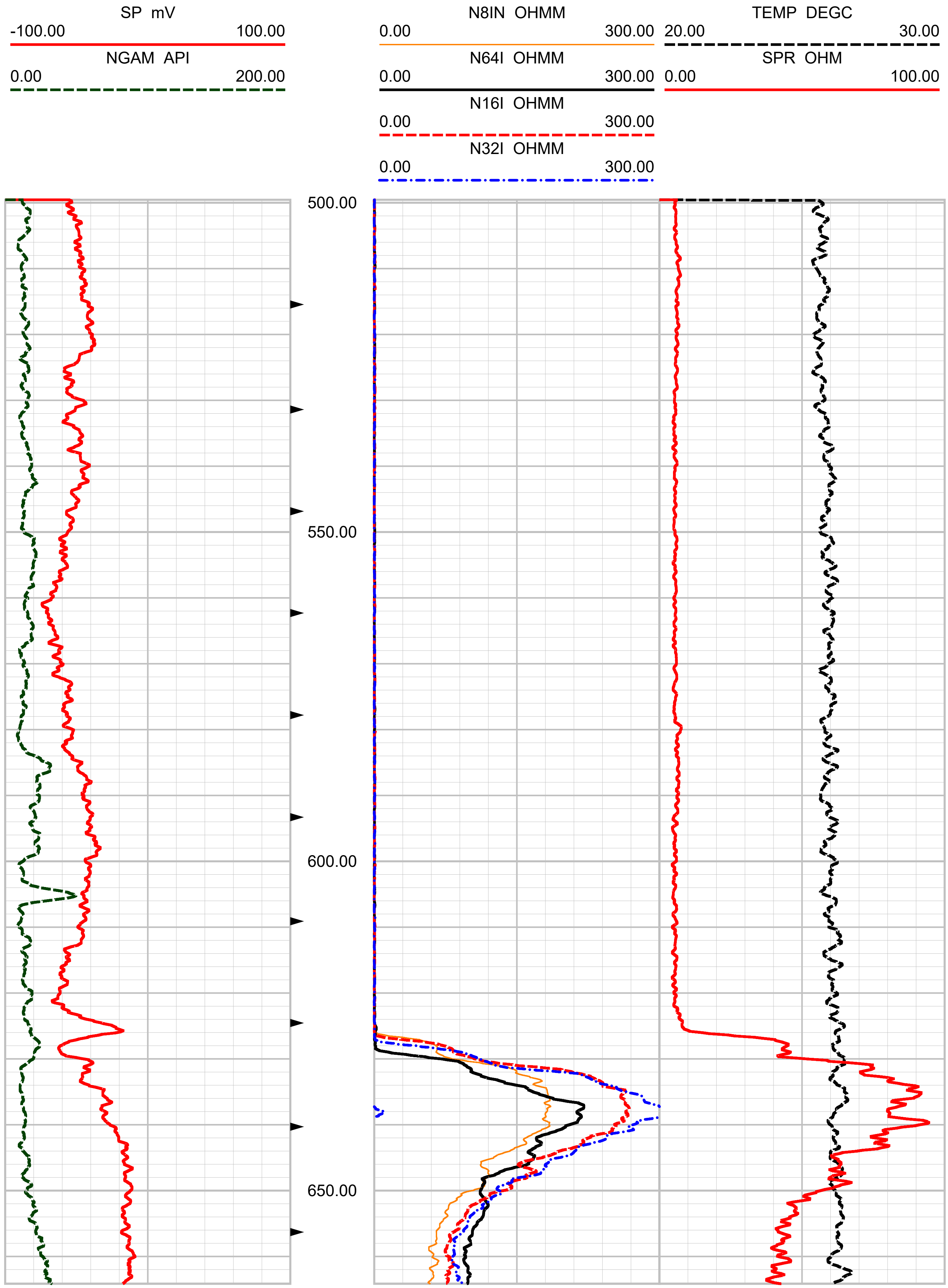
Perm. Datum	ground surf..	Elev	~386 ft	KB	0.00
Log. Datum				DF	0.00
Drill Datum				GL	0.00

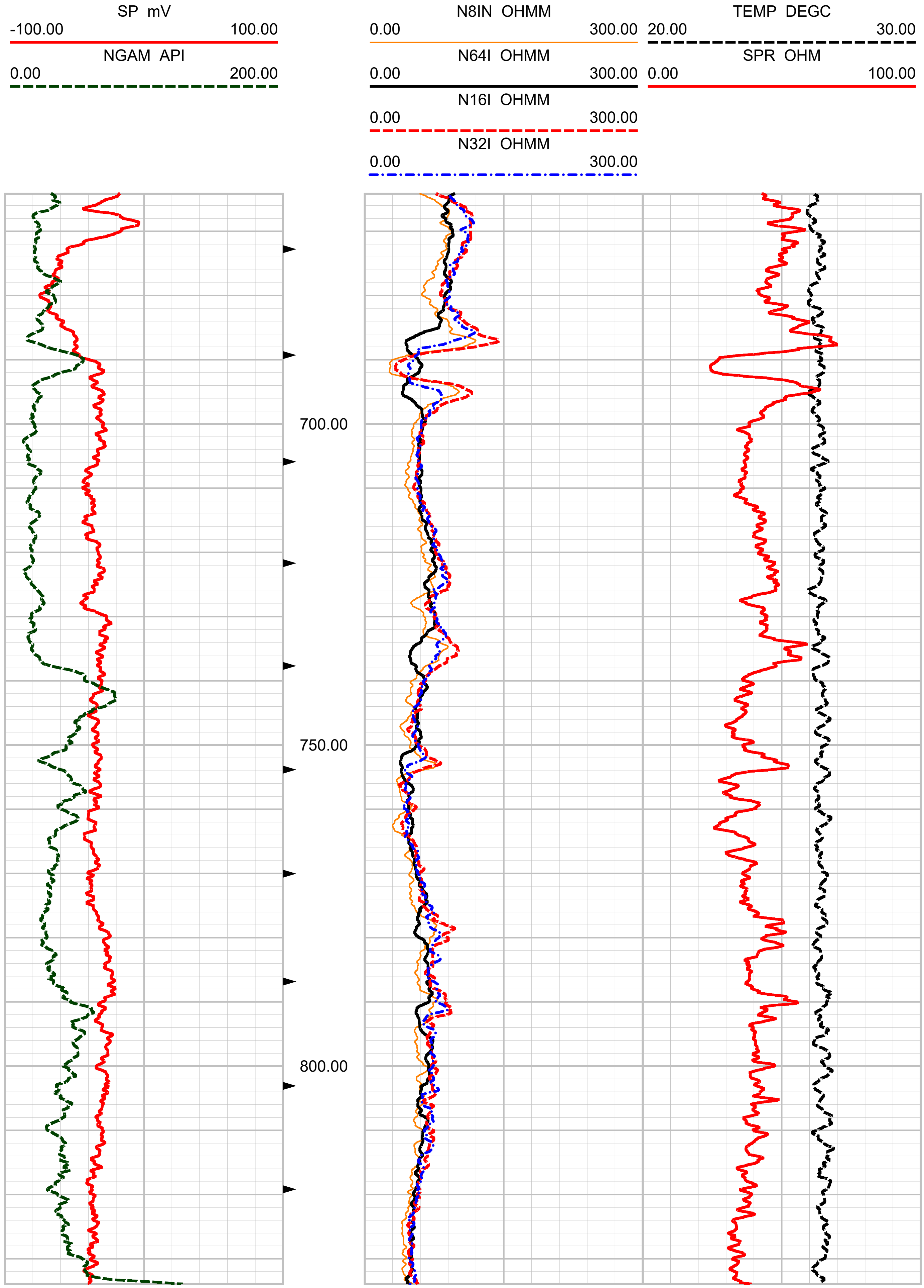
DATE	20 Oct 1	20 Oct 1	20 Oct 1
RUN#	0	0	0
TYPE OF LOG	ELMT6618		
DEPTH DRILLER	1000.00	0.00	0.00
DEPTH LOGGER	1000.00	0.00	0.00
LOG DEEPEST	1000.00	0.00	0.00
LOG SHALLOW	500.00	0.00	0.00
FLUID IN HOLE	DrillingFluid/Water		
SALINITY			
DENSITY			
LEVEL	0		
MAX TEMP °C	0.00	0.00	0.00
RIG TIME	03:18		
RECORDED BY	S.Dixon, PG		
WITNESSED BY	S.Brantley		

RUN#	BIT RECORD			CASING RECORD			
	SIZE	FROM	TO	SIZE	WEIGHT	FROM	TO
0	5.13	620.00	1000.00	6.00	0.00	0.00	620.00
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00

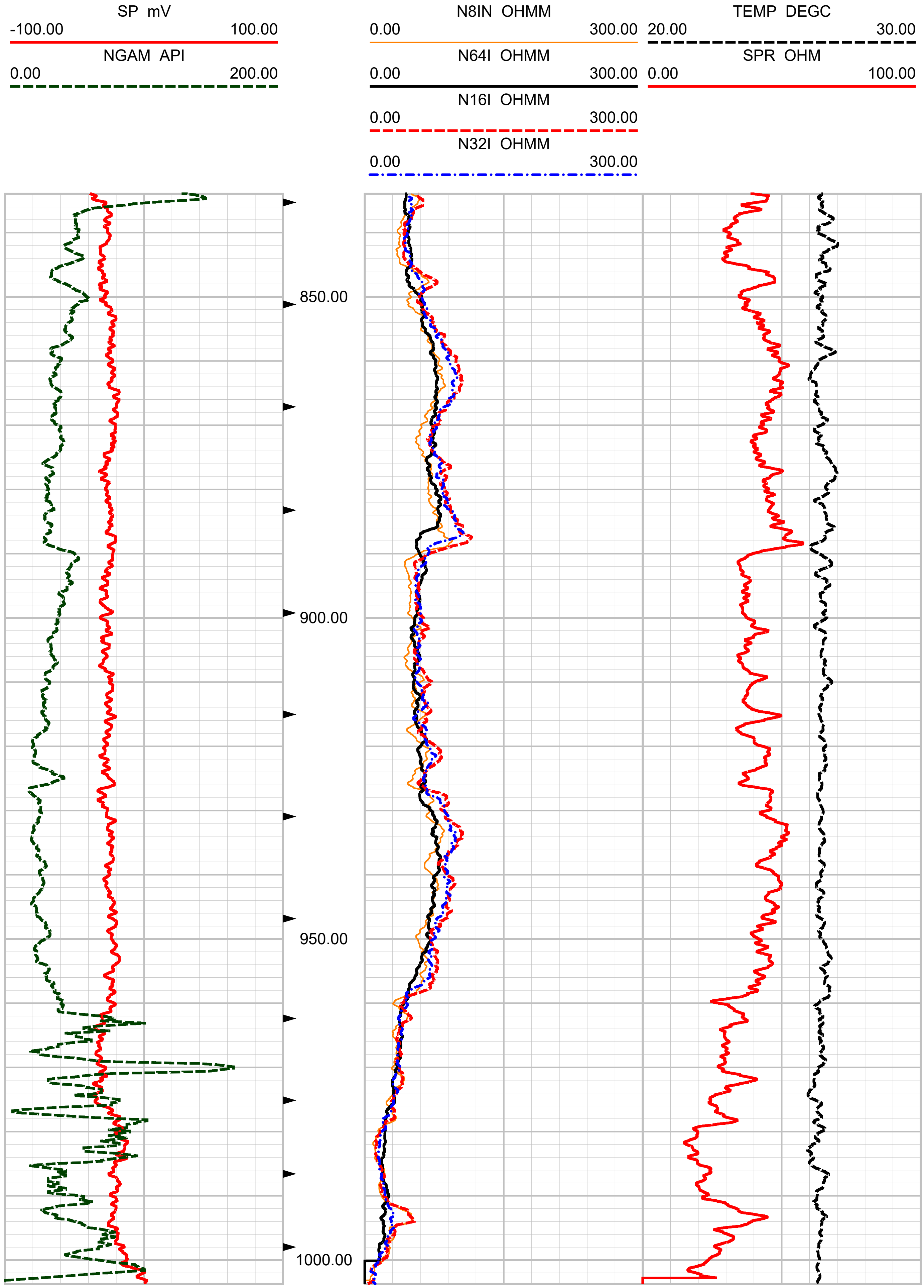
REMARKS (C:\Winlogger\Data\Sylvester-GEFA.hed)

ELMT6618-8,16,32, and 64-Normal Resistivity, SPR, SP, Temp, and Nat..
Logging up
ROBERTSON GEOLOGGING TECHNOLOGY
Logging speed - 16ft/min


SP mV
-100.00
100.00
NGAM API
0.00
200.00
N8IN OHMM
0.00
300.00
N64I OHMM
0.00
300.00
N16I OHMM
0.00
300.00
N32I OHMM
0.00
300.00
TEMP DEGC
20.00
30.00
SPR OHM
0.00
100.00
500.00
550.00
600.00
650.00



SP mV
-100.00
100.00
NGAM API
0.00
200.00
N8IN OHMM
0.00
300.00
N64I OHMM
0.00
300.00
N16I OHMM
0.00
300.00
N32I OHMM
0.00
300.00
TEMP DEGC
20.00
30.00
SPR OHM
0.00
100.00
700.00
750.00
800.00


SP mV
-100.00
100.00
NGAM API
0.00
200.00
N8IN OHMM
0.00
300.00
N64I OHMM
0.00
300.00
N16I OHMM
0.00
300.00
N32I OHMM
0.00
300.00
TEMP DEGC
20.00
30.00
SPR OHM
0.00
100.00
850.00
900.00
950.00
1000.00

SP mV		N8IN OHMM		TEMP DEGC	
-100.00	100.00	0.00	300.00	20.00	30.00
NGAM API		N64I OHMM		SPR OHM	
0.00	200.00	0.00	300.00	0.00	100.00
		N16I OHMM			
		0.00	300.00		
		N32I OHMM			
		0.00	300.00		

SP mV		N8IN OHMM		TEMP DEGC	
-100.00	100.00	0.00	300.00	20.00	30.00
NGAM API		N64I OHMM		SPR OHM	
0.00	200.00	0.00	300.00	0.00	100.00
		N16I OHMM			
		0.00	300.00		
		N32I OHMM			
		0.00	300.00		

Depth: 499.00 ft Date: 20 Oct 2016 Time: 04:16:19 File: "C:\Winlogger\DATA\Sylvester-GEFA.LGX"

Water Analysis

Food Safety

Waters Agricultural Laboratories, Inc
P.O. Box 382 257 Newton Hwy
Camilla, Georgia 31730
Phone (229) 336-7216 FAX (229) 336-7967

GROSCH DRILLING

737 FIRETOWER ROAD
DUBLIN, GA 31021-

Received: 11/11/2016
Processed: 11/15/2016
Lab Number: 1209WT
Sample Number: 1
Grower: GEFA SYLVESTER

Results Reported In ppm Unless Otherwise Noted

Nitrate Nitrogen:	0.1	*L*				
			Carbonate:	12	*N*	
			BiCarbonate:	186.66	*H*	
Phosphorus:	0.01	*L*	pH:	8.1	*N*	
Potassium:	3.77	*L*	Conductivity:	0.269	*N*	*mmhos/cm*
Calcium:	30.14	*N*	Total Dissolved Solids:	172.16	*N*	
Magnesium:	14.16	*N*	Sodium Absorption Ratio (SAR):	0.23	*L*	
Sodium:	6.25	*L*				
Chloride:	2	*L*				
Sulfate:	5.63	*L*				
Boron:	0.01	*L*				
			Total Coliform:	1553.1	mpn/100ml	
			Generic eColi:	<1.0	mpn/100ml	

Comments:

SM# 9223B

L = Low **N =Normal** **M = Moderate** **H = High** **VH = Very High**