

Section 10

Sub-Regional Transient Cretaceous Aquifer Model Development and Calibration

In order to better represent the Cretaceous Aquifer in the Coastal Plain of Georgia, a sub-regional transient Cretaceous Aquifer groundwater flow model was developed from the calibrated regional Georgia EPD groundwater model in accordance with the procedures discussed in Section 7. This section provides a more detailed description of the sub-regional Cretaceous Aquifer model development and calibration.

10.1 Sub-Regional Transient Cretaceous Aquifer Model Development

10.1.1 Model Domain and Grid Refinement

Figure 10-1 displays the sub-regional transient Cretaceous Aquifer model domain and grid system. As shown on Figure 10-1, the model horizontal domain spans a distance of approximately 82 miles in the north-south direction and approximately 160 miles in the east-west direction, encompassing approximately 13,120 square miles. The sub-regional model covers the majority of the Cretaceous Aquifer in southeast and south-central Georgia.

The entire sub-regional Cretaceous Aquifer model area was discretized into cells using a uniform grid system with dimensions of 2,000 feet by 2,000 feet. The model domain was divided horizontally into a grid of 216 rows and 423 columns. A total of 91,368 grid blocks or cells were used to cover the Cretaceous Aquifer within southeast and south-central Georgia. The model origin relative to the North American Datum of 1983 (NAD83) State of Georgia West Zone Planar Coordinate System is:

- X: 2,429,172 feet;
- Y: 589,643 feet; and
- Rotation Angle: 26 degrees.

10.1.2 Model Stratigraphy

As with the Georgia EPD regional model, the sub-regional Cretaceous Aquifer model vertical extent encompasses almost the entire thickness of the Coastal Plain Aquifer System. It is vertically discretized into seven layers to represent all the aquifers in the Coastal Plain of Georgia. The model layers are as follows:

- Layer 1 - Surficial Aquifer/Brunswick Aquifers (specified head boundary that supplies water to the underlying active aquifers);
- Layer 2 - Upper Floridan Aquifer;

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

The confining units between these aquifers are represented as leakance (i.e., vertical hydraulic conductivity divided by the confining unit thickness) between the model layers.

A three-dimensional isometric representation of the sub-regional groundwater model stratigraphy is displayed on **Figure 10-2**. North-south and east-west cross sections of the model are presented on **Figures 10-3** and **10-4**, respectively.

10.1.3 Sub-Regional Model in Transient Conditions

The sub-regional transient Cretaceous Aquifer groundwater flow model was developed from the calibrated steady-state regional Georgia EPD model to represent an average rainfall year, a high rainfall year, and a low rainfall year using a monthly stress period interval. As discussed in Section 2.1, annual rainfall quantities in 2004, 2005, and 2006 represent an average rainfall year, a high rainfall year, and a low rainfall year, respectively. The sub-regional model for this project was constructed and calibrated to represent the range of hydrologic conditions that occurred in this three-year period. Thirty-six monthly stress periods were used in the model to represent the period from January 2004 through December 2006.

10.1.4 Model Modifications

In order to construct the transient sub-regional Cretaceous Aquifer groundwater model from the calibrated Georgia EPD steady-state regional model, the following model packages were modified:

- Water levels in the River Package were changed from a single long-term average elevation to monthly average surface water elevations observed at 28 staff gauge stations in the major rivers for the period 2004 through 2006.
- Groundwater levels in the General Head Boundary Package, used to represent the lateral edge boundary elevations along the west, south, and east model boundaries in Layer 2 through Layer 7, were changed from a single long-term average elevation to monthly values based on observed groundwater levels at monitor wells for the period 2004 through 2006. The north model boundary was designated as a no flow boundary along the Fall Line.

- The Recharge Package was changed from a single long-term average value to monthly values based on monthly NOAA rainfall data for 2004, 2005, and 2006. A detailed description of the procedures used to estimate the monthly recharge values was presented in Section 7.3. The variations in the net recharge within the sub-regional Cretaceous Aquifer model area are also presented in Section 10.6.
- The Time-Variant Specific Head Package for the Surficial Aquifer was used to represent monthly values based on observed groundwater levels at monitor well locations and surface water levels at staff gauge stations in the major rivers for the period 2004 through 2006.
- Initial storage coefficients of the aquifers were assigned in the model based on the USGS CPCAS model (Faye and Mayer, 1996). During model calibration, this parameter was varied to produce a good match to observed heads.
- Initial heads along the boundaries of the sub-regional model were specified using data from the regional model and monitor well time series data near the boundary of the sub-regional model (see Section 7.3 – General Head Boundary for more details).

10.1.5 Aquifer Characteristics

The sub-regional Cretaceous Aquifer model was constructed using the same hydrologic and hydrogeologic properties and boundary types for the aquifer systems used in the regional model. The layer data, including the horizontal hydraulic conductivities, transmissivity, leakance, and top and bottom elevations of each aquifer layer, were interpolated from the regional model into the sub-regional models. These parameters were further calibrated to the transient conditions occurring in 2004 through 2006.

10.2 Comparison of the Sub-Regional Cretaceous Aquifer Model to Georgia EPD Regional Model

To verify that the sub-regional Cretaceous Aquifer model's hydrologic and hydrogeologic properties and boundary conditions were selected and modified properly from the regional Georgia EPD model, the model was run using the same steady-state conditions as the regional Georgia EPD model. The groundwater elevations from the sub-regional model were then compared to the simulated groundwater elevations using the regional model.

The simulated steady-state groundwater elevation contours for Layers 2 through 7 (existing conditions) from the sub-regional model were overlain on the groundwater elevation contours from the regional model (**Figures 10-5 through 10-10**). As shown on these figures, a comparison of the groundwater elevation contours indicates that the sub-regional Cretaceous Aquifer model provides results that are similar to the regional Georgia EPD model for the Coastal Plain Aquifer System in Georgia.

In addition, a scattergram was used to compare the sub-regional model to the regional model by contrasting the groundwater elevations at 137 monitor well locations (**Figure 10-11**). If a perfect correlation between the two models existed, all of the points would fall on the 45-degree line shown on the figure. The closeness of the plotted points to the 45-degree line indicates that the simulated groundwater elevations using the sub-regional model are very similar to the simulated groundwater elevations using the regional Georgia EPD model. Therefore, the sub-regional Cretaceous Aquifer model reasonably represents the calibrated regional Georgia EPD model's hydrologic and hydrogeologic properties and boundary conditions.

10.3 Available Groundwater and Surface Water Level Data

10.3.1 Measured Groundwater Levels

According to the USGS NWIS database, there are 17 existing monitor wells installed in different aquifers of the Coastal Plain Aquifer System within the sub-regional Cretaceous Aquifer model domain. These 17 wells are a subset of the monitoring wells in the regional model (320 wells), as described in Section 6.4.1. The locations of these monitor wells in the sub-regional Cretaceous Aquifer model are shown on **Figure 10-12**, and the locations of monitor wells in each aquifer are shown on **Figures Q-1 through Q-4** in **Appendix Q**. The distribution of monitor wells by aquifer used for the sub-regional model calibration is as follows:

- 4 monitor wells in the Upper Floridan Aquifer (Layer 2);
- 2 monitor wells in the Claiborne/Gordon/Lower Floridan Aquifers (Layer 3);
- 5 monitor wells in the Clayton-Dublin Aquifers (Layer 4);
- 0 monitor well in the Providence Sand-Peedee-Dublin Aquifers (Cretaceous Aquifer System) (Layer 5);
- 6 monitor wells in the Eutaw-Midville Aquifer (Cretaceous Aquifer System) (Layer 6); and
- 0 monitor wells in the Upper Atkinson-Upper Tuscaloosa Aquifer (Cretaceous Aquifer System) (Layer 7).

Groundwater elevation data are available for these monitor wells for the period between January 2004 and December 2006 (**Table R-1** in **Appendix R**). As shown, a total of 596 measured groundwater levels at 17 monitor well locations, from January 2004 through December 2006, were used for the sub-regional Cretaceous Aquifer model calibration. During this time period, groundwater levels at Cretaceous Aquifer monitor well locations varied from approximately 101 feet NGVD, recorded at 32Y033

in Burke County in July 2004, to approximately 281 feet NGVD, recorded at 15Q016 in Crisp County in April 2005.

10.3.2 Surface Water Levels

From the USGS NWIS database, observed surface water levels at 28 gauging stations (Figure 5-15) located in rivers and tributaries were obtained for the period between January 2004 and December 2006. These data were used for the model river stage elevations of the model River Package.

10.4 Well Pumping Rates

Georgia EPD records show that pumping data in the Cretaceous Aquifer model domain for the existing permitted wells between January 2004 and December 2006 are only available for the major public water supply and industrial users. There are no pumping data available for most of the agricultural users. As discussed in Sections 5.4.6 and 7.3, for users without pumping records, the average pumping rates for each permitted user's wells were estimated based on Georgia EPD reports, allocations, well capacities, and USGS publications by Fanning (2003) and Fanning and Trent (2009). For the transient model, each permitted agricultural well pumping rate was redistributed based on the growing season (i.e., March through October) and the non-growing season (i.e., November through February) in different rainfall conditions/years (Fanning et al., 2001; Hook and Harrison, 2005; Hook and Harrison, 2007).

Well pumping rates in the model Well Package were updated for major public water supply and industrial users and estimated agricultural user well pumping rates on a monthly basis for both the growing and non-growing seasons. **Figure 10-13** shows monthly pumping rates used in the sub-regional Cretaceous Aquifer model. Pumping shown on this figure is from all aquifers within the sub-regional model domain.

10.5 Sub-Regional Transient Cretaceous Aquifer Groundwater Flow Model Calibration Results

The ASTM document "*Standard Guide for Comparing Ground-Water Flow Model Simulations to Site-Specific Information*" provides industry-accepted guidance for calibration. Many of the calibration metrics recommended in this guide were used to present the sub-regional groundwater model calibration results. CDM followed this guide to present groundwater calibration results, including comparison of simulated and measured groundwater levels (residuals), standard deviation of residuals, as well as several other calibration metrics. Root Mean Squared Error (RMSE), a metric used to evaluate calibration, is not included in this ASTM standard.

10.5.1 Groundwater Levels

Comparisons between the observed and model-computed groundwater elevations at monitor well locations in different aquifers within the sub-regional Cretaceous Aquifer model domain are presented as follows:

- **Figure 10-14** presents comparisons between the observed and model-computed groundwater elevations at a selected monitor well in the Upper Floridan Aquifer (Layer 2);
- **Figures 10-15** displays comparisons between the observed and model-computed groundwater elevations at a selected monitor well in the Claiborne/Gordon/Lower Floridan Aquifers (Layer 3);
- **Figures 10-16 through 10-19** illustrate comparisons between the observed and model-computed groundwater elevations at selected monitor wells in the Clayton-Dublin Aquifers (Layer 4);
- **Figures 10-20 and 10-25, Tables 10-1 through 10-4** show comparisons between the observed and model-computed groundwater elevations at selected monitor wells in the Eutaw-Midville Aquifer (Layer 6); and
- Comparisons between the observed and model-computed groundwater elevations for all 17 monitor wells are presented in **Tables S-1 through S-17** in **Appendix S**. The correlation between the observed and model-computed groundwater elevations are shown on **Figures S-1 through S-17** in Appendix S.

Scattergrams comparing observed and model-computed groundwater elevations are one method for evaluating the calibration of groundwater models. A comparison between the observed and model-computed groundwater elevations across all model layers is depicted on **Figure 10-26** using a scattergram for the 17 monitor wells. A layer-by-layer comparison between the observed and model-computed groundwater elevations for the 17 monitor wells in Layer 2 through Layer 4, and Layer 6 are presented in the form of a scattergram displayed on **Figure S-18 through S-21** in Appendix S, respectively. Scattergrams were not developed for Layers 5 and 7 because there are no existing monitor wells in these aquifer units. The corresponding statistical analysis, such as groundwater level residuals, standard deviation of residuals, and RMSE of residuals, are also presented on these figures. The sub-regional Cretaceous Aquifer model calibration statistics for all aquifer layers and each individual layer are summarized in **Table 10-5**. As shown in these figures and tables, there is a very strong correlation between the observed and model-computed groundwater elevations across all model layers.

Table 10-1 Calibration Results for Monitor Well 18T001

Stress Period (month)	Month- Year	Time (day)	Model Layer	Observed Head (ft NGVD)	Computed Head (feet NGVD)	Residual (feet)
1	Jan-04	31	6	260.49	259.95	-0.54
2	Feb-04	60	6	260.82	260.33	-0.50
3	Mar-04	91	6	260.89	260.70	-0.19
4	Apr-04	121	6	260.71	260.76	0.05
5	May-04	152	6	260.34	260.32	-0.02
6	Jun-04	182	6	259.76	260.00	0.24
7	Jul-04	213	6	259.55	259.79	0.23
8	Aug-04	244	6	259.04	259.60	0.56
9	Sep-04	274	6	259.30	259.81	0.51
10	Oct-04	305	6	259.47	260.39	0.92
11	Nov-04	335	6	259.62	260.88	1.26
12	Dec-04	366	6	259.88	261.25	1.37
13	Jan-05	397	6	260.03	261.47	1.44
14	Feb-05	425	6	260.30	261.60	1.30
15	Mar-05	456	6	260.68	261.71	1.03
16	Apr-05	486	6	260.83	261.64	0.81
17	May-05	517	6	260.55	261.11	0.56
18	Jun-05	547	6	260.33	260.64	0.31
19	Jul-05	578	6	260.32	260.37	0.06
20	Aug-05	609	6	259.95	260.28	0.33
21	Sep-05	639	6	259.57	260.45	0.89
22	Oct-05	670	6	259.17	260.65	1.48
23	Nov-05	700	6	259.14	260.90	1.75
24	Dec-05	731	6	259.60	261.10	1.50
25	Jan-06	762	6	260.09	261.24	1.14
26	Feb-06	790	6	260.44	261.33	0.89
27	Mar-06	821	6	260.63	261.34	0.71
28	Apr-06	851	6	260.47	261.05	0.58
29	May-06	882	6	260.05	260.31	0.26
30	Jun-06	912	6	259.26	259.54	0.28
31	Jul-06	943	6	258.24	259.04	0.80
32	Aug-06	974	6	257.53	258.76	1.23
33	Sep-06	1004	6	257.36	258.67	1.31
34	Oct-06	1035	6	257.25	258.96	1.70
35	Nov-06	1065	6	257.52	259.29	1.77
36	Dec-06	1096	6	257.95	259.56	1.61
Average of Residuals						0.77
Standard Deviation of Residuals						0.64
Root Mean Squared Error						0.99

Table 10-2 Calibration Results for Monitor Well 24V001

Stress Period (month)	Month-Year	Time (day)	Model Layer	Observed Head (ft NGVD)	Computed Head (feet NGVD)	Residual (feet)
1	Jan-04	31	6	211.88	210.57	-1.31
2	Feb-04	60	6	212.32	210.85	-1.47
3	Mar-04	91	6	212.53	211.15	-1.38
4	Apr-04	121	6	212.41	211.29	-1.12
5	May-04	152	6	212.02	211.18	-0.84
6	Jun-04	182	6	211.53	211.06	-0.47
7	Jul-04	213	6	210.72	210.95	0.23
8	Aug-04	244	6	209.82	210.85	1.03
9	Sep-04	274	6	209.71	210.96	1.25
10	Oct-04	305	6	209.78	211.26	1.48
11	Nov-04	335	6	209.80	211.64	1.84
12	Dec-04	366	6	210.06	212.06	2.00
13	Jan-05	397	6	210.53	212.41	1.88
14	Feb-05	425	6	210.99	212.71	1.72
15	Mar-05	456	6	211.45	212.99	1.54
16	Apr-05	486	6	211.87	213.11	1.24
17	May-05	517	6	212.00	212.93	0.93
18	Jun-05	547	6	212.11	212.75	0.64
19	Jul-05	578	6	212.05	212.54	0.49
20	Aug-05	609	6	211.94	212.47	0.53
21	Sep-05	639	6	211.47	212.54	1.07
22	Oct-05	670	6	211.06	212.73	1.67
23	Nov-05	700	6	210.87	213.00	2.13
24	Dec-05	731	6	211.08	213.29	2.21
25	Jan-06	762	6	211.38	213.55	2.17
26	Feb-06	790	6	211.57	213.74	2.17
27	Mar-06	821	6	211.76	213.90	2.14
28	Apr-06	851	6	211.85	213.90	2.05
29	May-06	882	6	211.84	213.62	1.78
30	Jun-06	912	6	211.40	213.24	1.84
31	Jul-06	943	6	210.44	212.91	2.47
32	Aug-06	974	6	209.57	212.75	3.18
33	Sep-06	1004	6	209.06	212.61	3.55
34	Oct-06	1035	6	208.67	212.74	4.07
35	Nov-06	1065	6	208.62	212.94	4.32
36	Dec-06	1096	6	208.79	213.19	4.40
Average of Residuals						1.43
Standard Deviation of Residuals						1.52
Root Mean Squared Error						2.07

Table 10-3 Calibration Results for Monitor Well 28X001

Stress Period (month)	Month-Year	Time (day)	Model Layer	Observed Head (ft NGVD)	Computed Head (feet NGVD)	Residual (feet)
1	Jan-04	31	6	203.60	201.18	-2.42
2	Feb-04	60	6	204.15	201.06	-3.09
3	Mar-04	91	6	204.39	201.13	-3.26
4	Apr-04	121	6	204.58	201.11	-3.47
5	May-04	152	6	204.54	200.83	-3.71
6	Jun-04	182	6	204.16	200.49	-3.67
7	Jul-04	213	6	203.36	200.09	-3.27
8	Aug-04	244	6	201.83	199.71	-2.12
9	Sep-04	274	6	200.68	199.53	-1.15
10	Oct-04	305	6	200.15	199.59	-0.56
11	Nov-04	335	6	200.04	199.81	-0.23
12	Dec-04	366	6	200.25	200.12	-0.13
13	Jan-05	397	6		200.48	
14	Feb-05	425	6	201.45	200.80	-0.65
15	Mar-05	456	6	201.89	201.12	-0.77
16	Apr-05	486	6	202.46	201.31	-1.15
17	May-05	517	6	202.78	201.22	-1.56
18	Jun-05	547	6	203.07	201.01	-2.06
19	Jul-05	578	6	202.95	200.75	-2.20
20	Aug-05	609	6	202.76	200.52	-2.24
21	Sep-05	639	6	202.26	200.45	-1.81
22	Oct-05	670	6	202.17	200.55	-1.62
23	Nov-05	700	6	201.99	200.77	-1.22
24	Dec-05	731	6	202.19	201.08	-1.11
25	Jan-06	762	6	202.59	201.42	-1.17
26	Feb-06	790	6	202.93	201.71	-1.22
27	Mar-06	821	6	203.34	201.98	-1.36
28	Apr-06	851	6	203.70	202.10	-1.60
29	May-06	882	6	203.86	201.94	-1.92
30	Jun-06	912	6	203.81	201.58	-2.23
31	Jul-06	943	6	203.32	201.17	-2.15
32	Aug-06	974	6	202.24	200.82	-1.42
33	Sep-06	1004	6	200.88	200.59	-0.29
34	Oct-06	1035	6	199.90	200.59	0.69
35	Nov-06	1065	6	199.58	200.77	1.19
36	Dec-06	1096	6	199.63	201.07	1.44
Average of Residuals						-1.53
Standard Deviation of Residuals						1.27
Root Mean Squared Error						1.97

Table 10-4 Calibration Results for Monitor Well 29AA09

Stress Period (month)	Month-Year	Time (day)	Model Layer	Observed Head (ft NGVD)	Computed Head (feet NGVD)	Residual (feet)
1	Jan-04	31	6	173.05	173.63	0.58
2	Feb-04	60	6	173.17	174.05	0.88
3	Mar-04	91	6	173.15	173.98	0.83
4	Apr-04	121	6	172.90	173.32	0.42
5	May-04	152	6	172.54	172.43	-0.11
6	Jun-04	182	6	172.31	172.19	-0.12
7	Jul-04	213	6	172.19	171.75	-0.44
8	Aug-04	244	6	171.90	171.53	-0.37
9	Sep-04	274	6	171.99	172.28	0.29
10	Oct-04	305	6	171.89	172.55	0.66
11	Nov-04	335	6	171.76	172.73	0.97
12	Dec-04	366	6	171.68	172.89	1.21
13	Jan-05	397	6	171.57	172.81	1.24
14	Feb-05	425	6	171.61	172.93	1.32
15	Mar-05	456	6	171.86	173.25	1.39
16	Apr-05	486	6	172.23	172.89	0.66
17	May-05	517	6	172.15	172.40	0.25
18	Jun-05	547	6	172.35	172.22	-0.13
19	Jul-05	578	6	172.57	173.70	1.13
20	Aug-05	609	6	172.95	173.88	0.93
21	Sep-05	639	6	172.79	173.83	1.04
22	Oct-05	670	6	172.89	174.06	1.17
23	Nov-05	700	6	172.76	174.39	1.63
24	Dec-05	731	6	172.78	174.32	1.54
25	Jan-06	762	6	172.93	174.44	1.51
26	Feb-06	790	6	172.99	174.74	1.75
27	Mar-06	821	6	173.09	175.15	2.06
28	Apr-06	851	6	173.15	174.67	1.52
29	May-06	882	6	172.96	173.74	0.78
30	Jun-06	912	6	172.74	173.68	0.94
31	Jul-06	943	6	172.53	173.20	0.67
32	Aug-06	974	6	172.31	172.98	0.67
33	Sep-06	1004	6	172.18	173.36	1.18
34	Oct-06	1035	6	171.92	173.40	1.48
35	Nov-06	1065	6	171.83	173.76	1.93
36	Dec-06	1096	6	171.81	174.24	2.43
Average of Residuals						0.94
Standard Deviation of Residuals						0.68
Root Mean Squared Error						1.16

Table 10-5 Cretaceous Aquifer Sub-Regional Model Calibration Statistics

Calibration Statistic	Value/Unit				
	Model Layer ¹				
	Overall ²	2	3	4	6
No. of Monitor Wells	17	4	2	5	6
Average of Residuals (ft) ³	0.39	0.39	3.02	-0.89	0.64
Standard Deviation of Residuals (ft)	3.90	6.40	4.05	2.31	1.57
Root Mean Square Error of Residuals (ft)	3.92	6.39	5.03	2.47	1.69
Observed Head Difference Across Layers at MWs (ft)	180 (101 to 281)	172 (109 to 281)	137 (101 to 238)	119 (152 to 271)	89 (172 to 261)
Average of Residuals/Head Difference Across Layers at MW (%)	0.22	0.23	1.68	0.75	0.72
Standard Deviation of Residuals/ Head Difference Across Layers at MW (%)	2.16	3.71	2.25	1.95	1.76

¹Notes:

Model Layer 1 - Surficial/Brunswick Aquifer

Model Layer 2 - Upper Floridan Aquifer

Model Layer 3 - Claiborne/Gordon/Lower Floridan Aquifers

Model Layer 4 - Clayton-Dublin Aquifers

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

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

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

²Head difference across all model layers (vertically and spatially)

³Residuals are defined as model-computed minus observed groundwater elevations.

MWs means monitor wells.

As shown in Table 10-5, the average residual (model-computed minus observed) for all layers and 596 observed groundwater levels at 17 monitor well locations is about 0.39 feet. The standard deviation and RMSE of residuals are approximately 3.90 and 3.92 feet, respectively. The ratio of the average of residuals to the head difference across the model is approximately 0.22 percent. The ratio of the standard deviation of residuals to the head difference across the model is approximately 2.16 percent. The average of residuals for Layers 2 through 6 ranges from approximately 0.39 feet in Layer 2 to 3.02 feet in Layer 3. The standard deviation of residuals for Layers 2 through 6 ranges from approximately 1.57 feet in Layer 6 to 6.40 feet in Layer 2. The RMSE of residuals for Layers 2 through 6 ranges from approximately 1.69 feet in Layer 6 to 6.39 feet in Layer 2.

According to the model calibration criteria established for this project, the sub-regional Cretaceous Aquifer groundwater flow model calibration met the average of residuals and the standard deviation of residuals criteria. These two criteria should be related to the head difference across the simulated Study Area. As shown in Table 10-5, the groundwater levels varied from about 101 to 281 feet NGVD, representing a

difference of approximately 180 feet across the entire model area (both spatially and vertically). Thus, the criterion for mean residual was about 0.22 percent of the head difference and the criterion for the standard deviation was about 2.16 percent. Modeling efforts in similar settings have used criteria in the range of 5 percent or more with success; therefore, the criteria stated above are seen as relatively strict, and this model can be considered to be well-calibrated.

10.5.2 Groundwater Flow Patterns

Using the calibrated sub-regional transient Cretaceous Aquifer groundwater model, CDM performed a series of groundwater flow model simulations to represent groundwater levels in the growing and the non-growing seasons for an average rainfall year, a high rainfall year, and a low rainfall year. The simulations performed are described below (some of the figures are in this section of the report and some are in Appendix S):

- Simulated June 2006 to represent a growing season in a low rainfall year. The groundwater elevation contours for the Upper Floridan Aquifer (Layer 2) through the Upper Atkinson-Upper Tuscaloosa Aquifer (Layer 7) are presented on **Figures 10-27 through 10-32**, respectively.
- Simulated December 2006 to represent a non-growing season in a low rainfall year. The groundwater elevation contours for the Upper Floridan Aquifer (Layer 2) through the Upper Atkinson-Upper Tuscaloosa Aquifer (Layer 7) are presented on **Figures 10-33 through 10-38**, respectively.
- Simulated June 2004 to represent a growing season in an average rainfall year. The groundwater elevation contours for the Upper Floridan Aquifer (Layer 2) through the Upper Atkinson-Upper Tuscaloosa Aquifer (Layer 7) are presented on **Figures S-22 through S-27**, respectively.
- Simulated June 2005 to represent a growing season in a high rainfall year. The groundwater elevation contours for the Upper Floridan Aquifer (Layer 2) through the Upper Atkinson-Upper Tuscaloosa Aquifer (Layer 7) are presented on **Figures S-28 through S-33**, respectively.

As shown on these figures, the predominant groundwater flow direction in all of the aquifers within the model domain occurs from the outcrop areas south of the Fall Line toward the southeast to the Atlantic Ocean. This flow pattern is consistent with regional groundwater flow patterns in the Coastal Plain of Georgia (Figures 2-24 through 2-28). Comparison of the contours on Figure S-24 to those on Figure 10-29 indicate that there is little, if any differences between wet and dry years, even in the recharge areas.

10.5.3 Vertical Head Differences between Aquifers

As shown on Figures 10-27 through 10-32 and Figures 10-33 through 10-38, there were vertical head differences between each layer (i.e., Layers 2 through 7) within the sub-

regional Cretaceous Aquifer model domain. Significant vertical head differences generally indicate, consistent with available hydrogeologic data, the presence of a confining or semi-confining layer between each aquifer unit.

Table 10-6 and **Figure 10-39** summarize model-computed and observed groundwater levels in five monitor well clusters installed in different aquifers at two locations (**Figure 10-40**). As shown in Table 10-6 and on Figure 10-39, the average vertical head differences between aquifers vary as follows:

- From approximately -37 feet (upward gradient) to 25 (downward gradient) with an average upward gradient of about -6 feet from the Claiborne/Gordon/Lower Floridan Aquifers to the Clayton-Dublin Aquifers.
- At monitor well cluster 32Y033/32Y030, an upward gradient from the Gordon Aquifer to the Eutaw-Midville Aquifer was approximately -65 feet.

Table 10-6 Comparison Between Observed and Simulated Vertical Head Differences in Sub-Regional Cretaceous Aquifer Model

MW Cluster	Aquifer	USGS Well ID	Model Layer	Average Groundwater Elevation (ft NGVD) (2004 - 2006)		Residual (ft)
				Measured	Computed	
1	Claiborne/Gordon/Lower Floridan	14P015	3	228.3	233.0	4.8
	Clayton-Dublin	14P014	4	207.1	208.0	0.9
	Δ Head	-	-	21.2	25.0	-
2	Clayton-Gordon	32Y033	3	113.4	114.5	1.1
	Clayton-Dublin	32Y031	4	153.7	152.1	-1.6
	Eutaw-Midville	32Y030	6	177.0	179.4	2.3
	Δ Head	-	-	-63.6	-64.8	-
Average of Residuals						1.5
Standard Deviation of Residuals						2.3
Root Mean Square Error of Residuals						2.6

As shown on Figure 10-39, the average residual of vertical groundwater head difference (model-computed minus observed) for all layers is about 1.50 feet. Overall standard deviation and RMSE of residuals are approximately 2.31 feet and 2.56 feet, respectively.

Based on the model simulation results, the vertical head differences criterion was met.

10.6 Revised Hydrogeologic and Hydrologic Properties

As discussed in Section 10.1.4, the initial hydrologic and hydrogeologic properties in the sub-regional Cretaceous Aquifer model were imported from the calibrated regional Georgia EPD model. During the transient model calibration, spatial changes

in the hydraulic conductivity, transmissivity, leakance, and storage coefficient of the aquifers were made. Modifications to these parameters are shown on **Figures T-1** through **T-19** in **Appendix T** for Layers 2 through 7, respectively. Variations of hydrogeologic properties within the sub-regional model area can also be found in the MODFLOW output file. There are very small differences in the hydrogeologic properties between the regional model and the subregional Cretaceous Aquifer model.

The average net recharge used in the calibrated sub-regional Cretaceous Aquifer model is shown on **Figure T-20**. There are no published values of monthly recharge. The average recharge values used in the outcrop areas of the regional model are consistent with literature and estimates from streamflow data. The procedures used estimate monthly recharge values are described in Section 7.3. Variations in the net recharge within the sub-regional model area can also be found in the MODFLOW output file. Rather than show the recharge distribution for each month of the 36 month simulation period, the spatial recharge distribution is presented for three months that represent the range of changes from the steady-state model values. **Figures 10-41** through **10-43** present the net recharge distributions for May 2004 (the beginning of the growing season in an average rainfall year), June 2005 (a high rainfall month in a high rainfall year), and April 2006 (a low rainfall month at the beginning of the growing season in a low rainfall year), respectively.

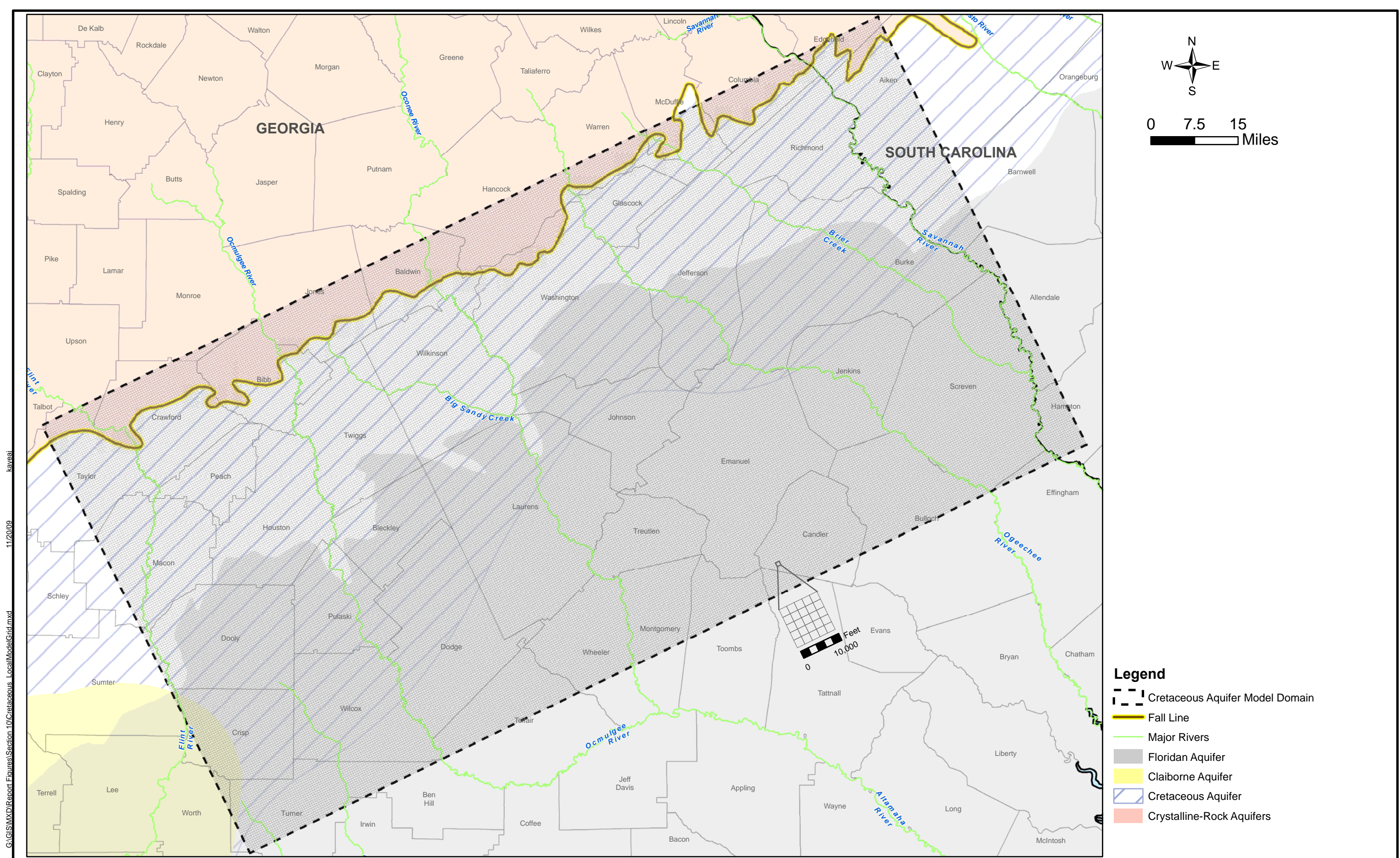
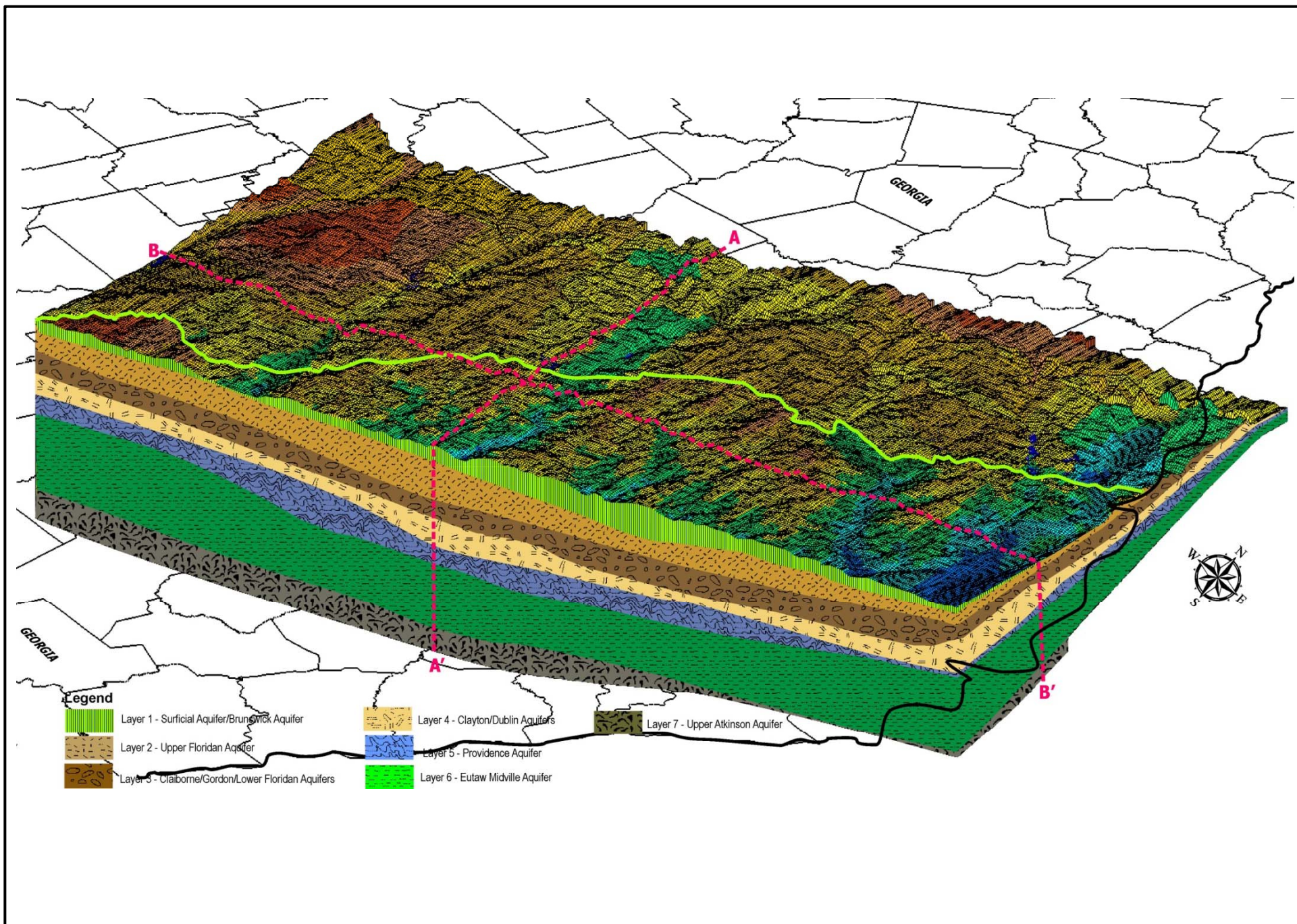
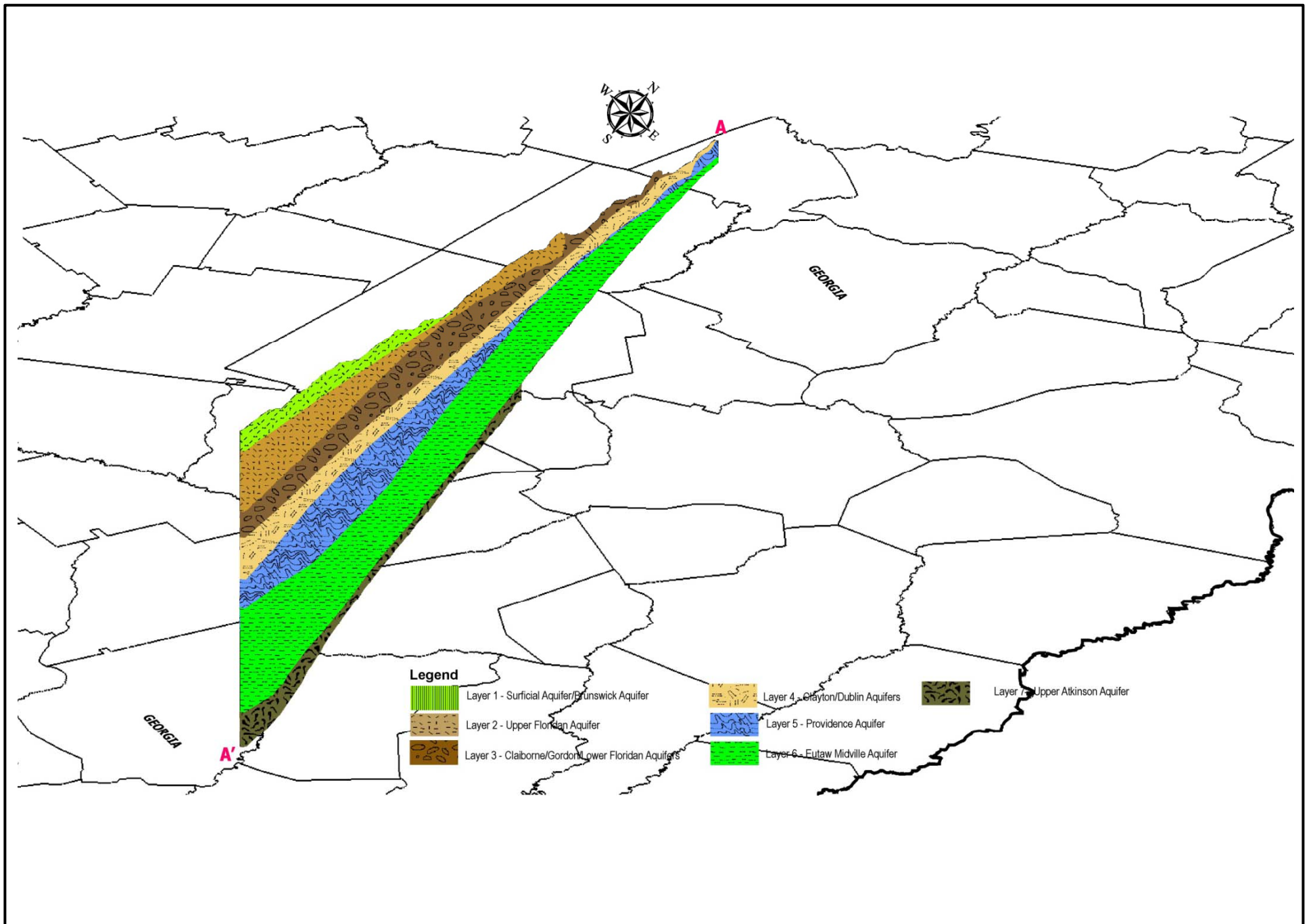


Figure 10-1
Sub-Regional Transient Cretaceous Aquifer Model and Model Grid System





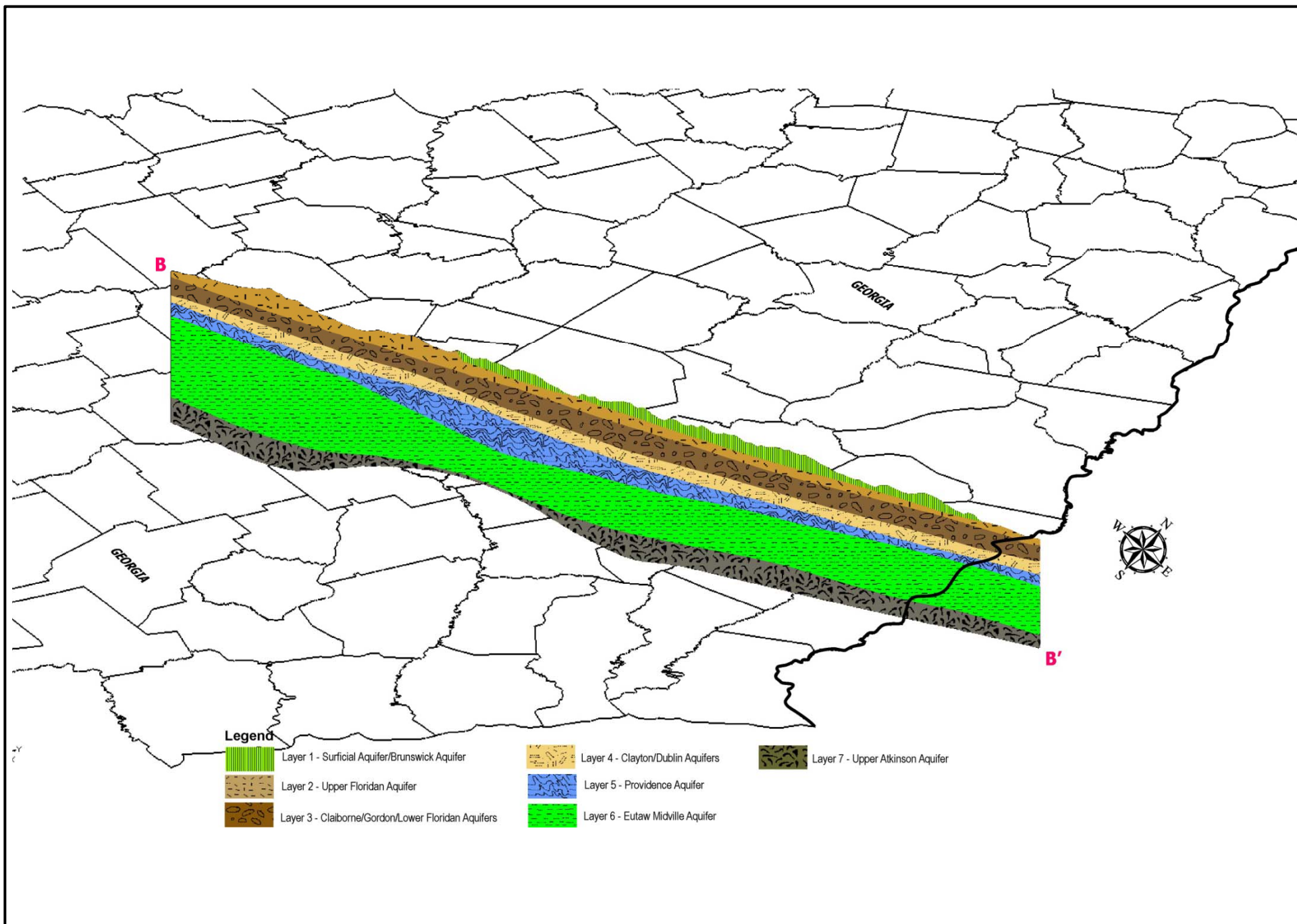
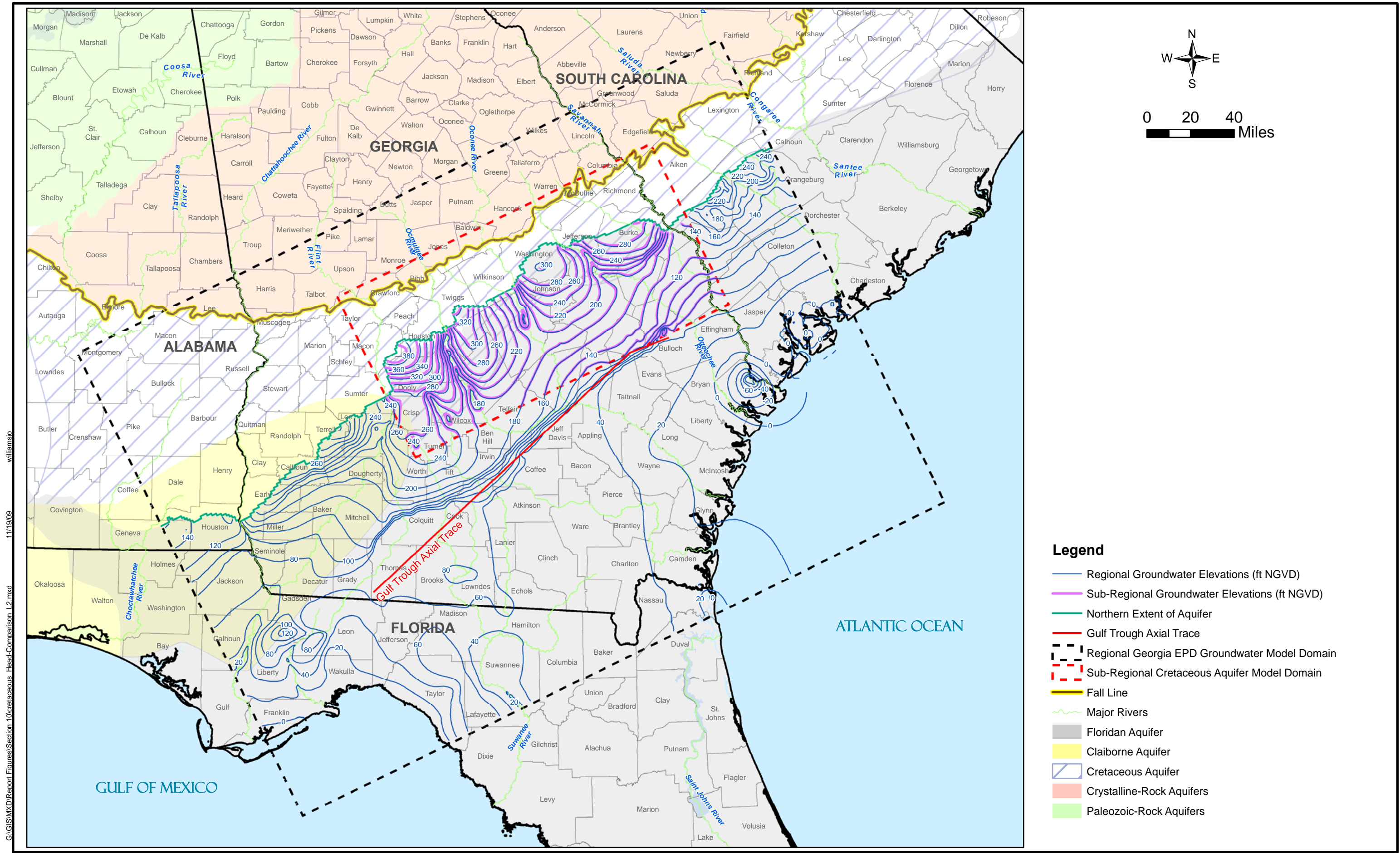
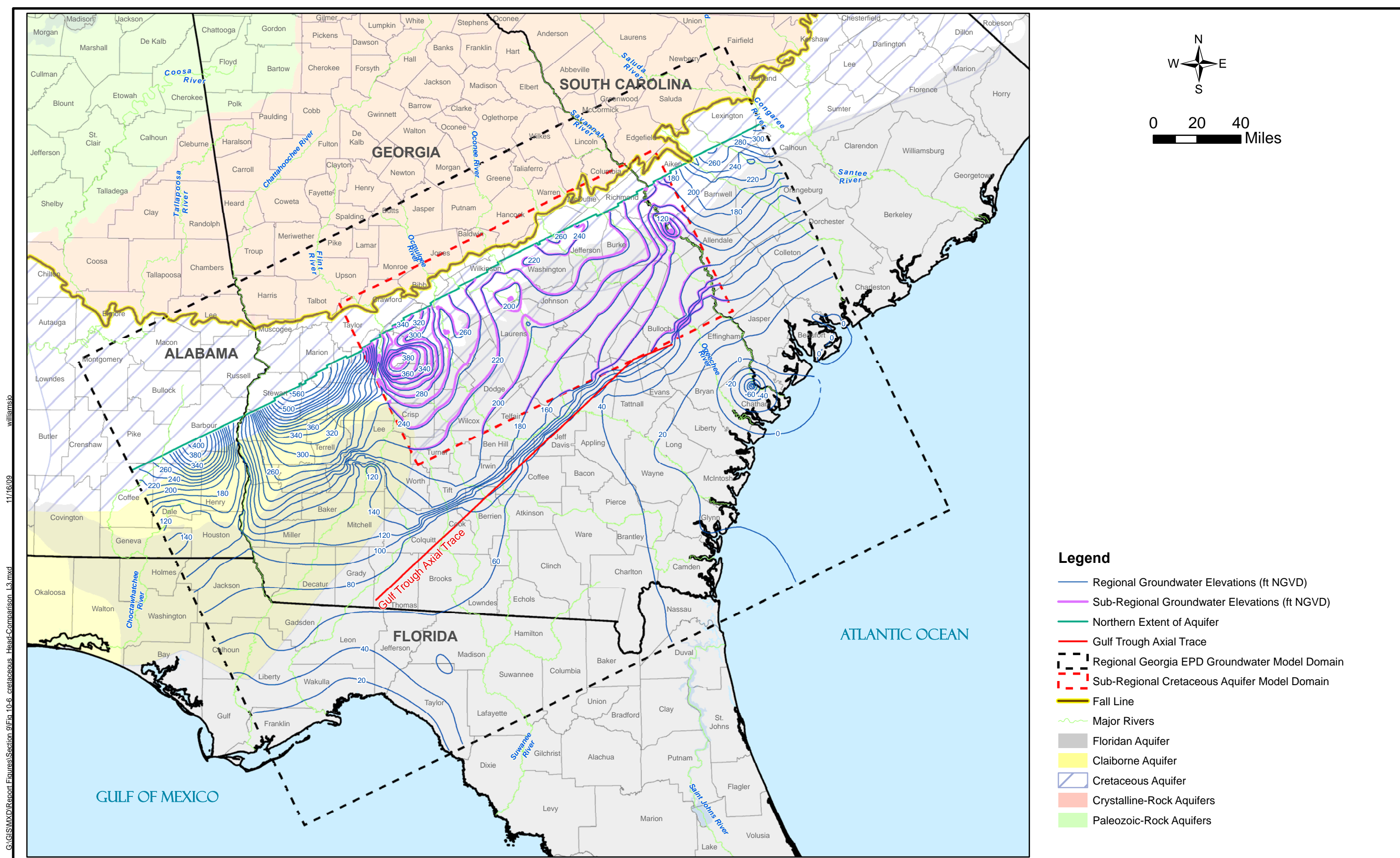


Figure 10-4
East-West Cross Sections Through Cretaceous Aquifer in Georgia



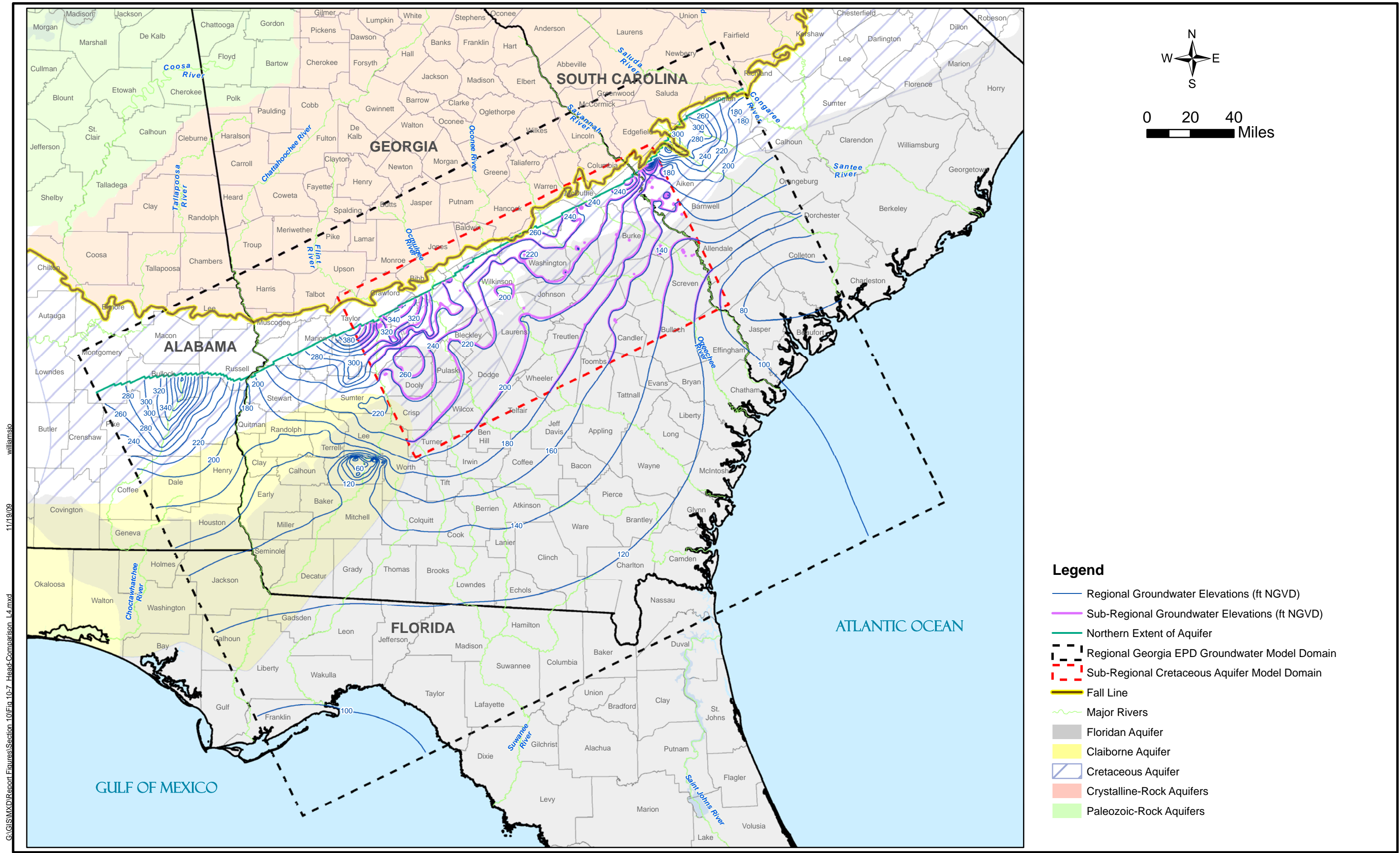
G:\GISMXD\Report Figures\Section 10\cretaceous Head-Comparison L2.mxd 11/19/09 williamsio

CDM **Figure 10-5**
Comparison of Groundwater Elevations in Upper Floridan Aquifer (Layer 2)
Using Regional Georgia EPD Model and Sub-Regional Cretaceous Aquifer Model



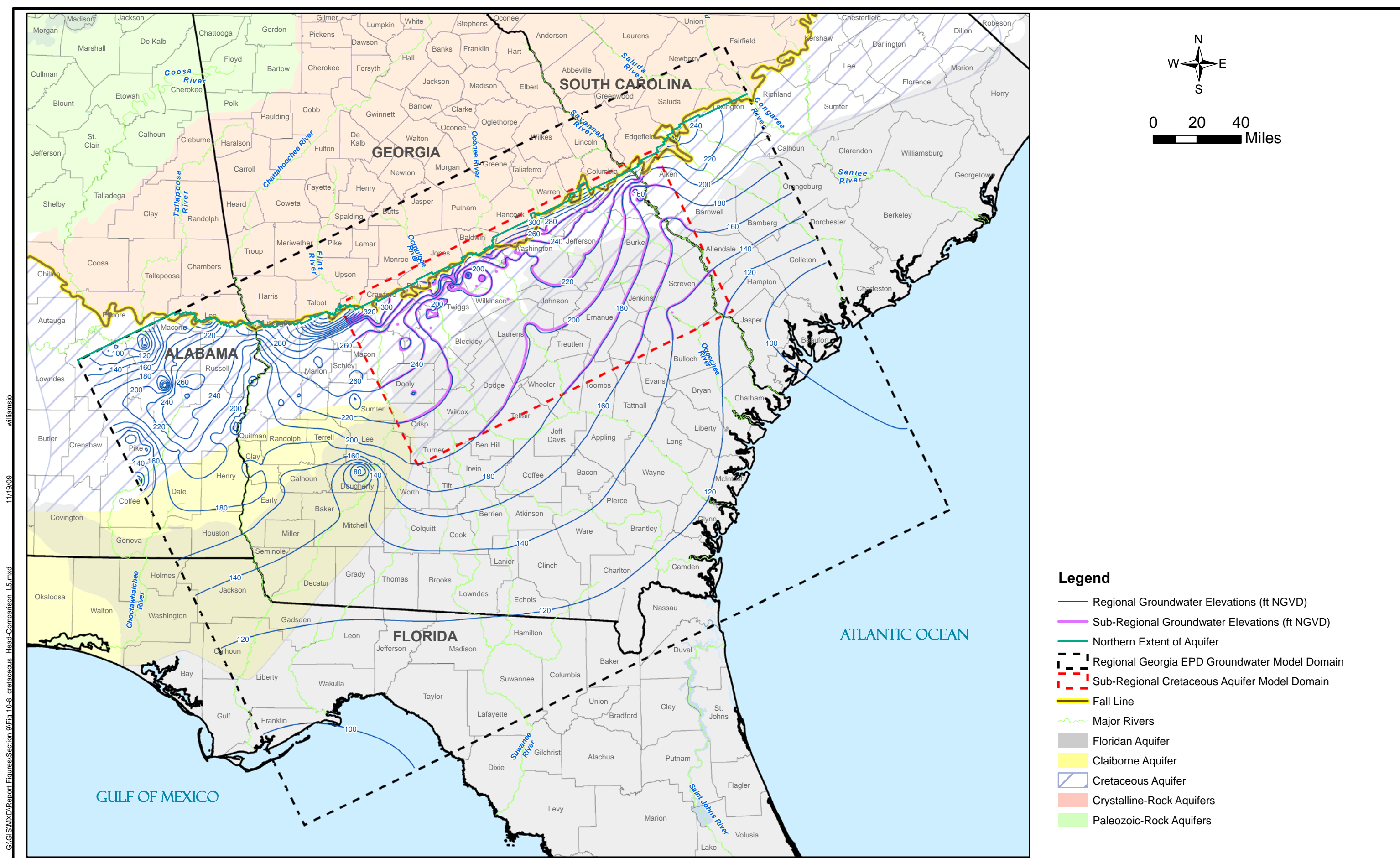
G:\GISMXD\Report Figures\Section 9\Fig 10-6_cretaceous_head-comparison_L3.mxd 11/16/09 williamsb

CDM **Figure 10-6**
Comparison of Groundwater Elevations in Claiborne/Gordon/Lower Floridan Aquifers (Layer 3)
Using Regional Georgia EPD Model and Sub-Regional Cretaceous Aquifer Model



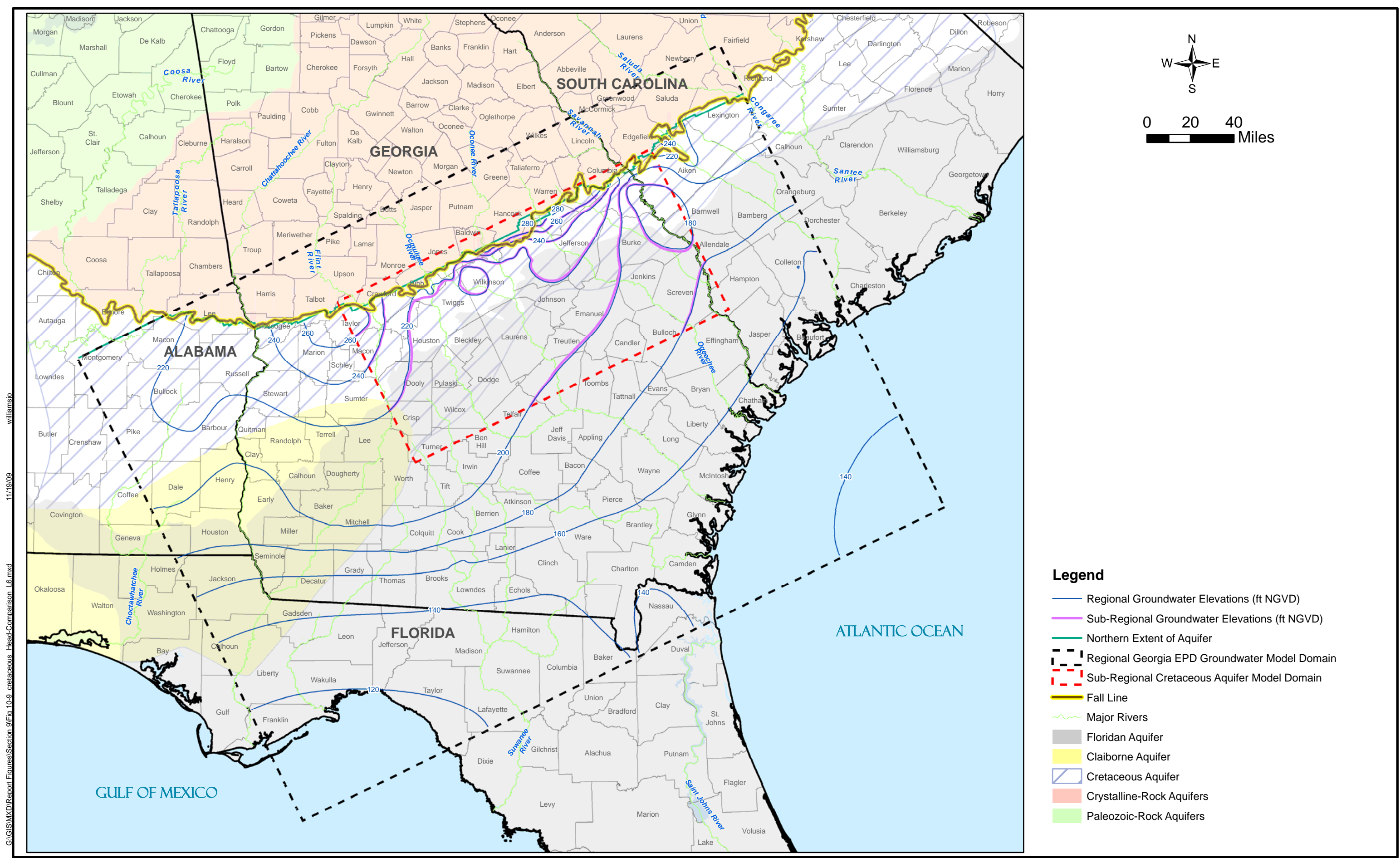
G:\GISMXD\Report Figures\Section 10\Fig 10-7 Head-Comparison_L4.mxd 11/19/09 williamsio

CDM **Figure 10-7**
Comparison of Groundwater Elevations in Clayton-Dublin Aquifers (Layer 4)
Using Regional Georgia EPD Model and Sub-Regional Cretaceous Aquifer Model



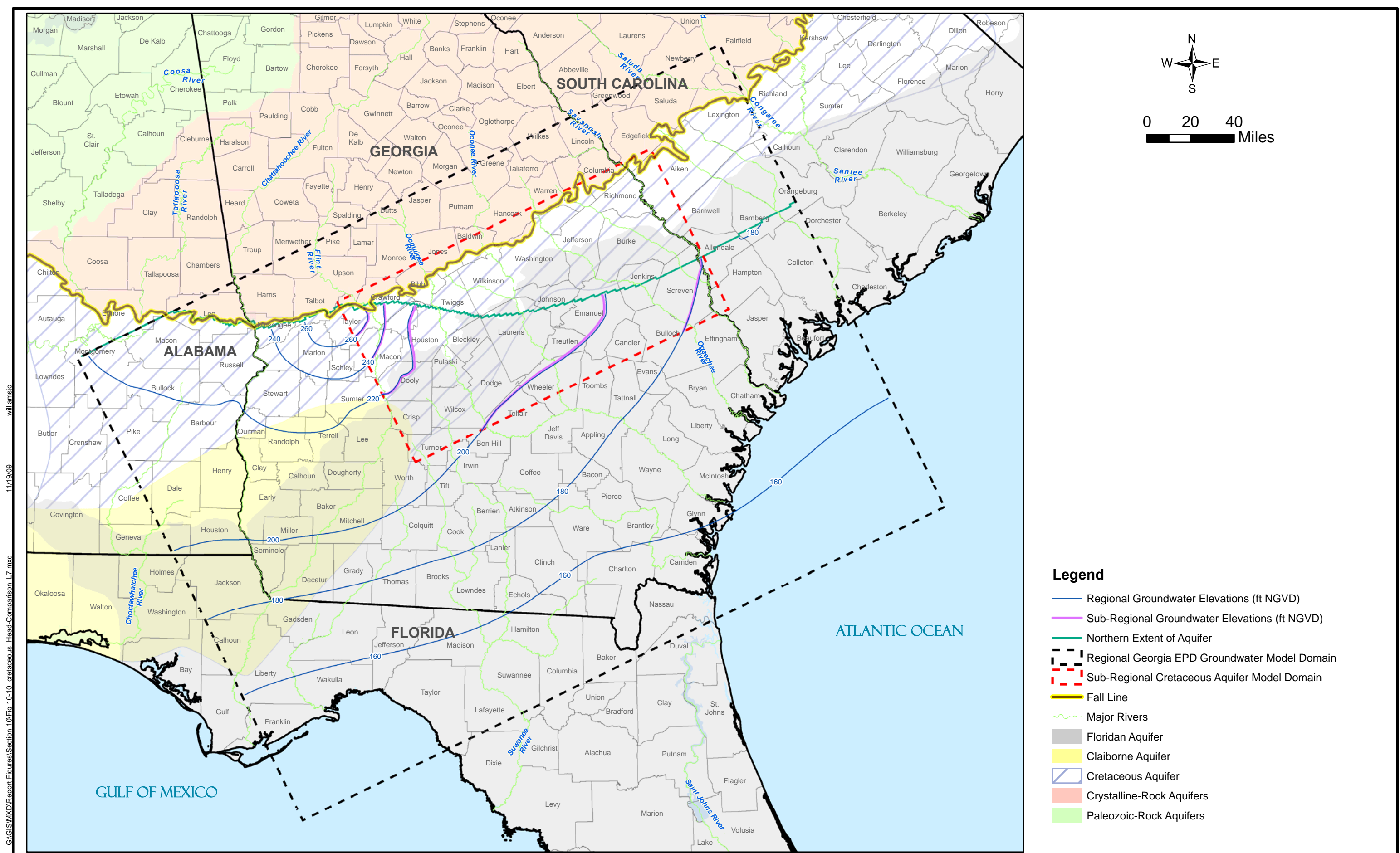
G:\GISMXD\Report Figures\Section 9\Fig 10-8_cretaceous_Head-Comparison_L5.mxd 11/19/09 williamsio

CDM **Figure 10-8**
Comparison of Groundwater Elevations in Providence Sand-Peedee-Dublin Aquifers (Layer 5)
Using Regional Georgia EPD Model and Sub-Regional Cretaceous Aquifer Model



G:\GISMXD\Report Figures\Section 9\Fig 10-9_cretaceous_Head-Comparison_L6.mxd 11/19/09 williamsio

CDM **Figure 10-9**
Comparison of Groundwater Elevations in Eutaw-Midville Aquifer (Layer 6)
Using Regional Georgia EPD Model and Sub-Regional Cretaceous Aquifer Model



G:\GISMXD\Report Figures\Section 10\Fig 10-10_cretaceous_head-comparison_L7.mxd 11/19/09 williamsjo

CDM **Figure 10-10**
Comparison of Groundwater Elevations in Upper Atkinson-Upper Tuscaloosa Aquifers (Layer 7)
Using Regional Georgia EPD Model and Sub-Regional Cretaceous Aquifer Model

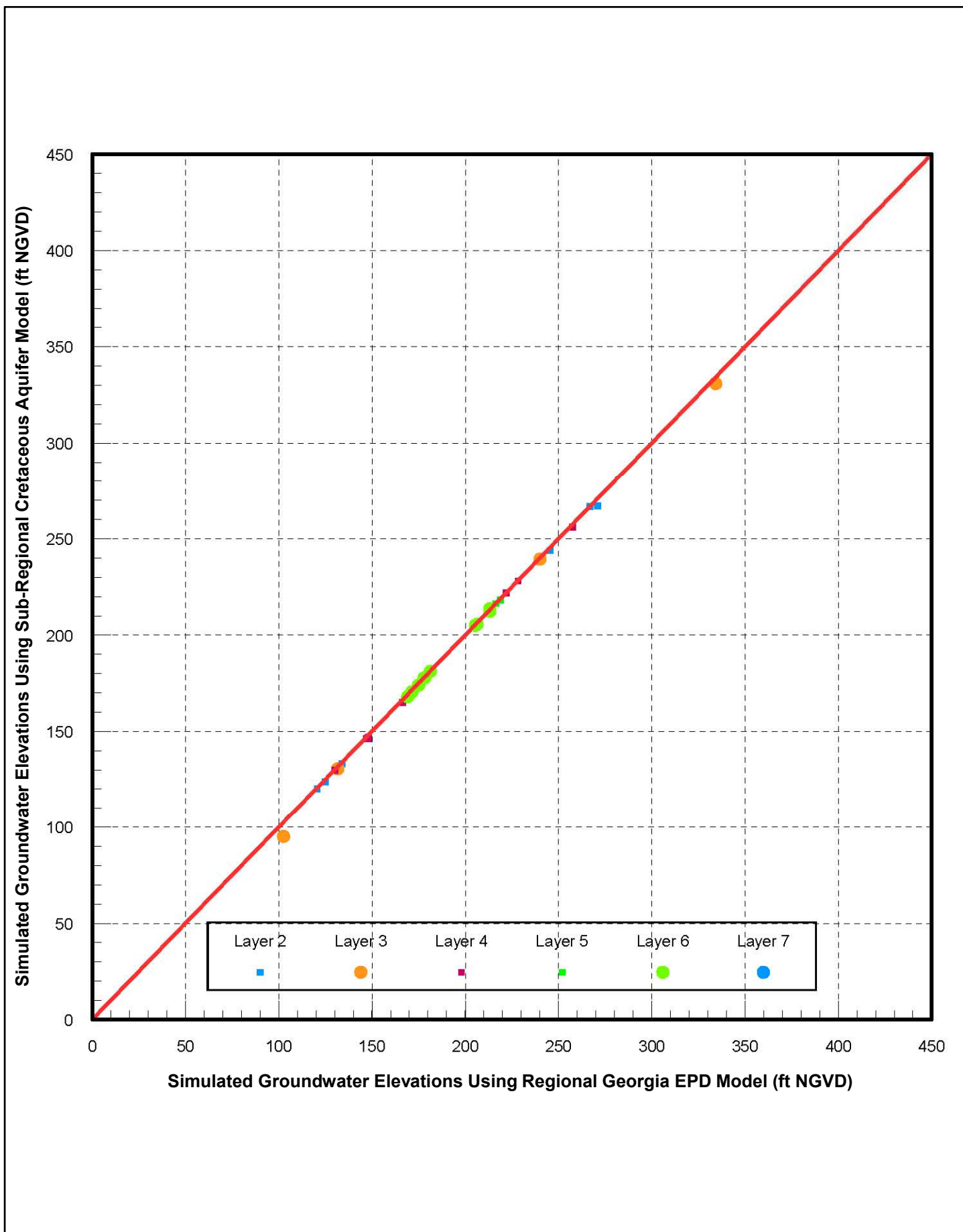
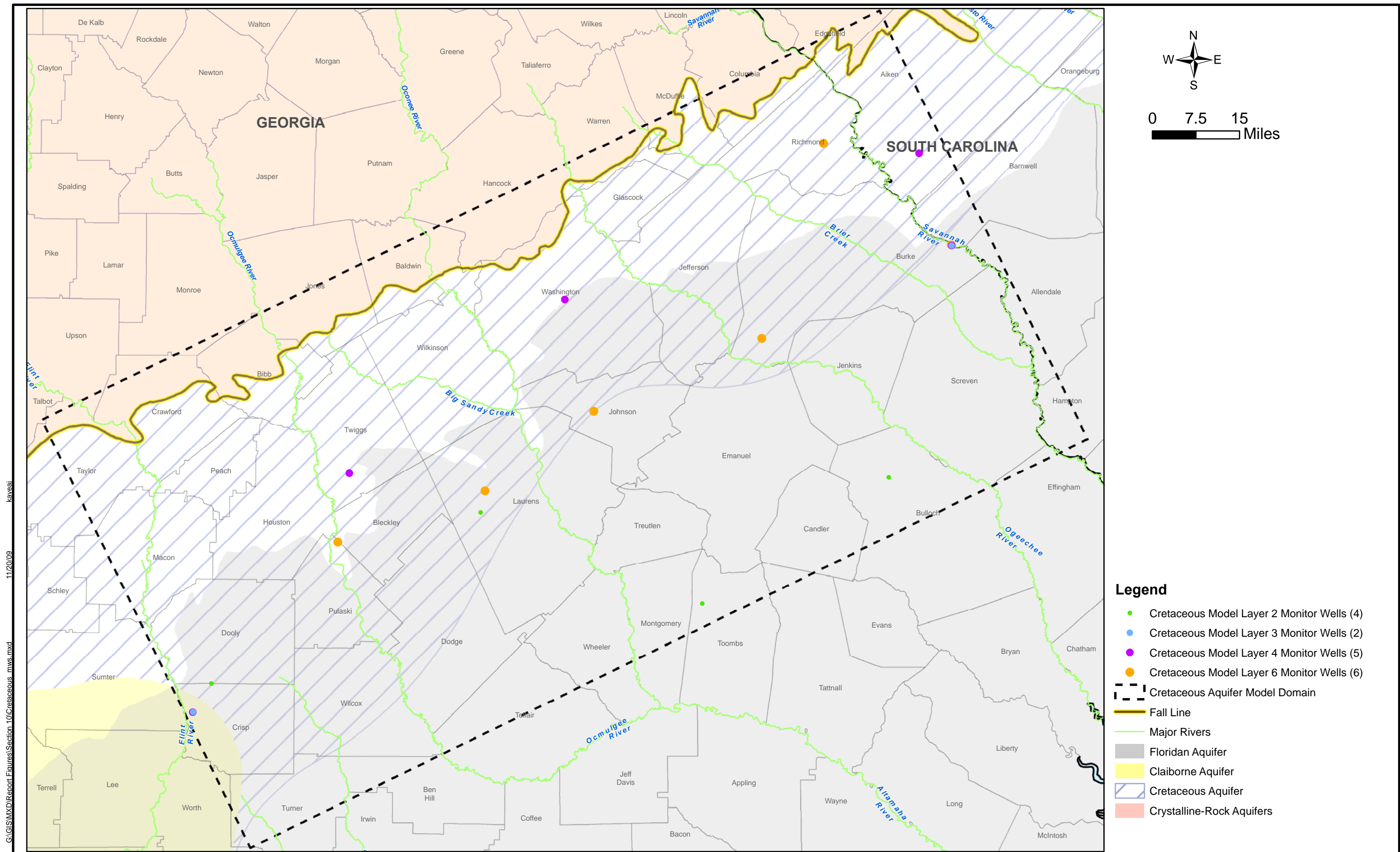


Figure 10-11
Scattergram Comparison of Regional Georgia EPD Groundwater Flow Model
Versus Sub-Regional Cretaceous Aquifer Groundwater Flow Model



G:\GIS\MXD\Report Figures\Section 10\Cretaceous mws.mxd
11/20/09
kaveai

CDM

Figure 10-12
Monitor Well Locations
In Sub-Regional Cretaceous Aquifer Groundwater Flow Model Domain

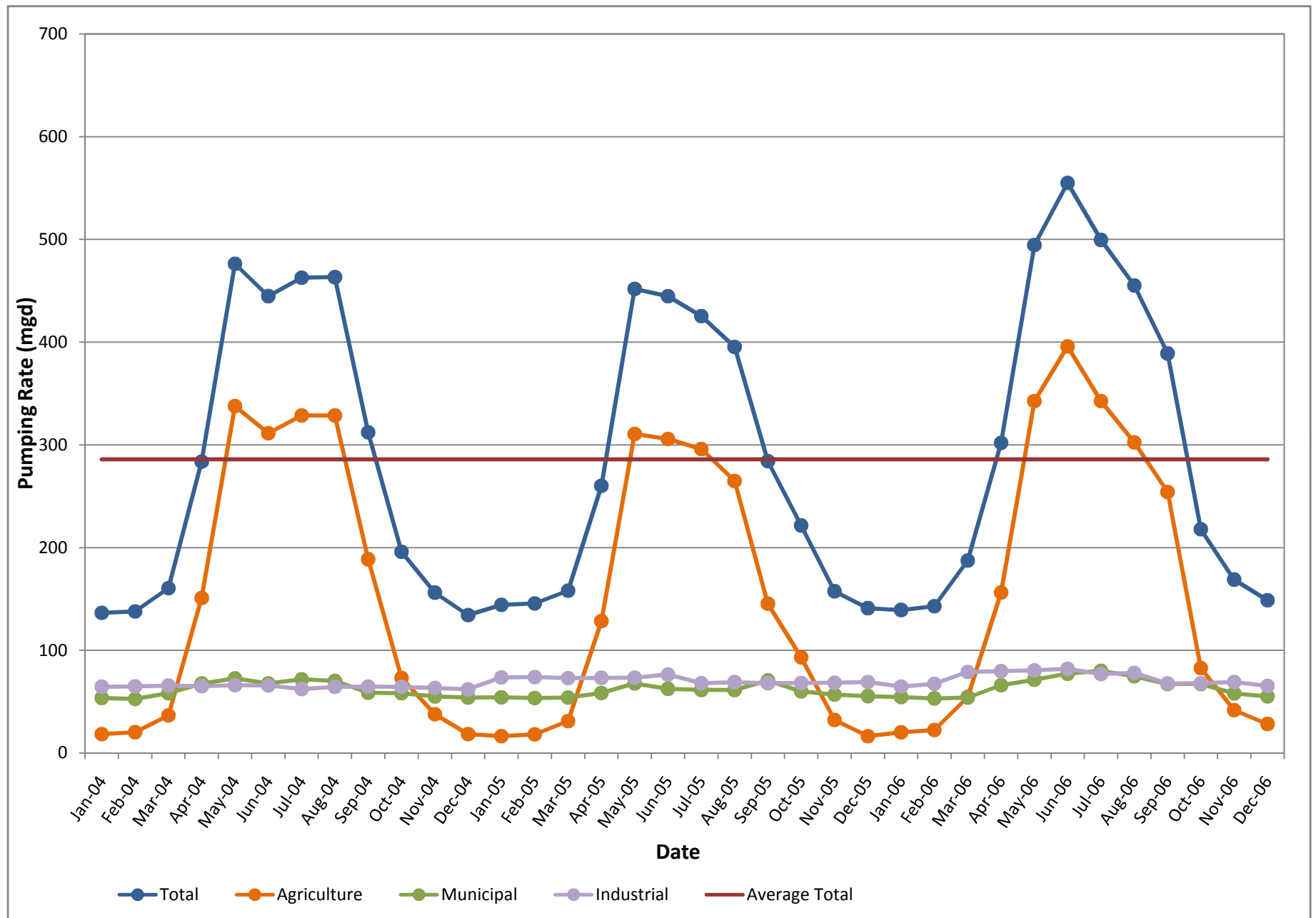


Figure 10-13
Permitted User Well Pumping Rates in Georgia
Used in Sub-Regional Cretaceous Model

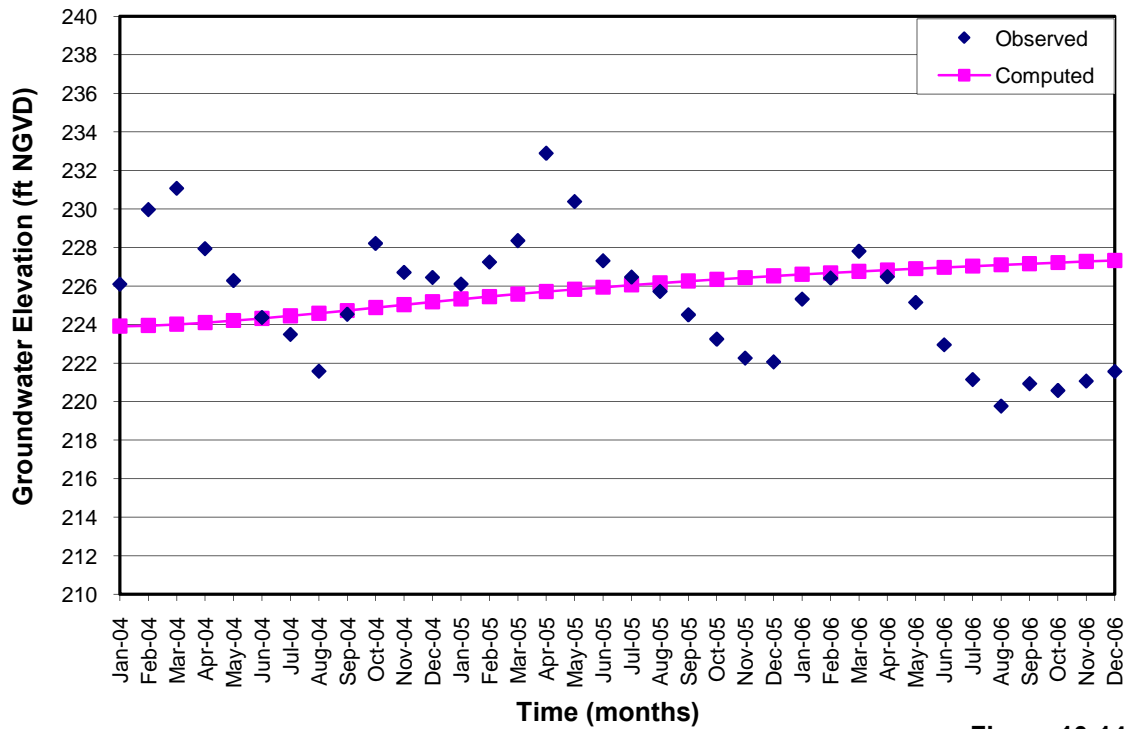


Figure 10-14

Comparison of Measured versus Simulated Groundwater Levels at 21T001 (Layer 2)

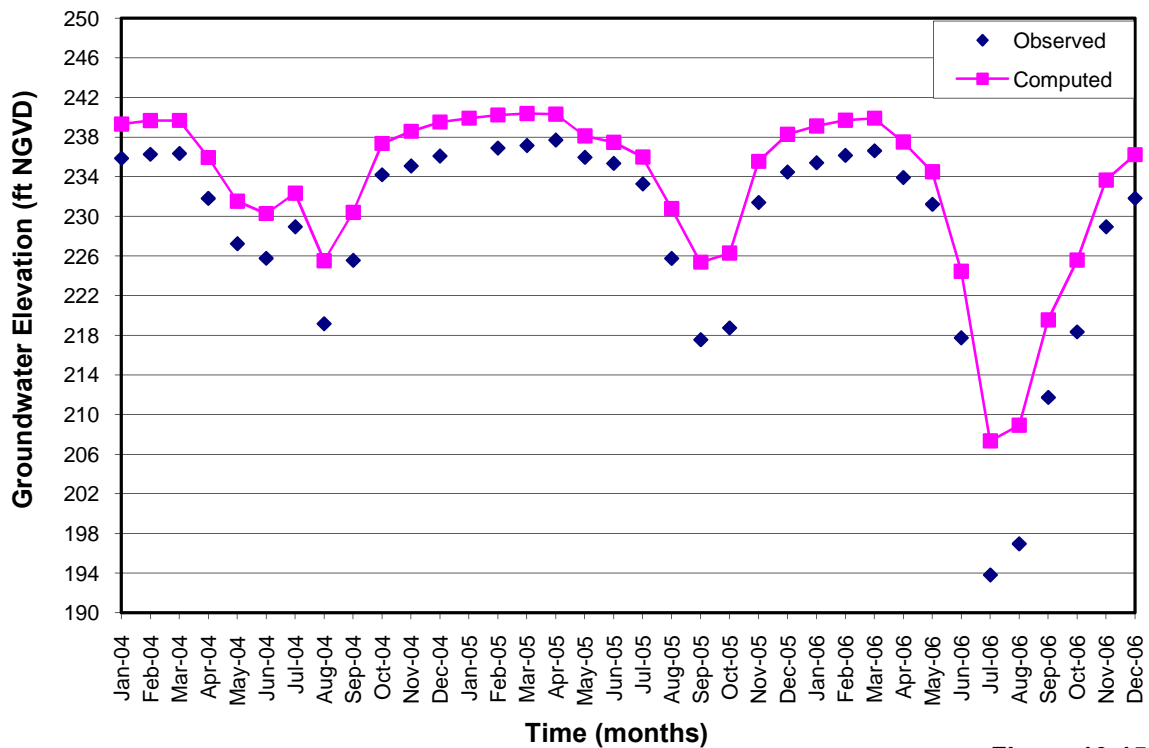


Figure 10-15

Comparison of Measured versus Simulated Groundwater Levels at 14P015 (Layer 3)

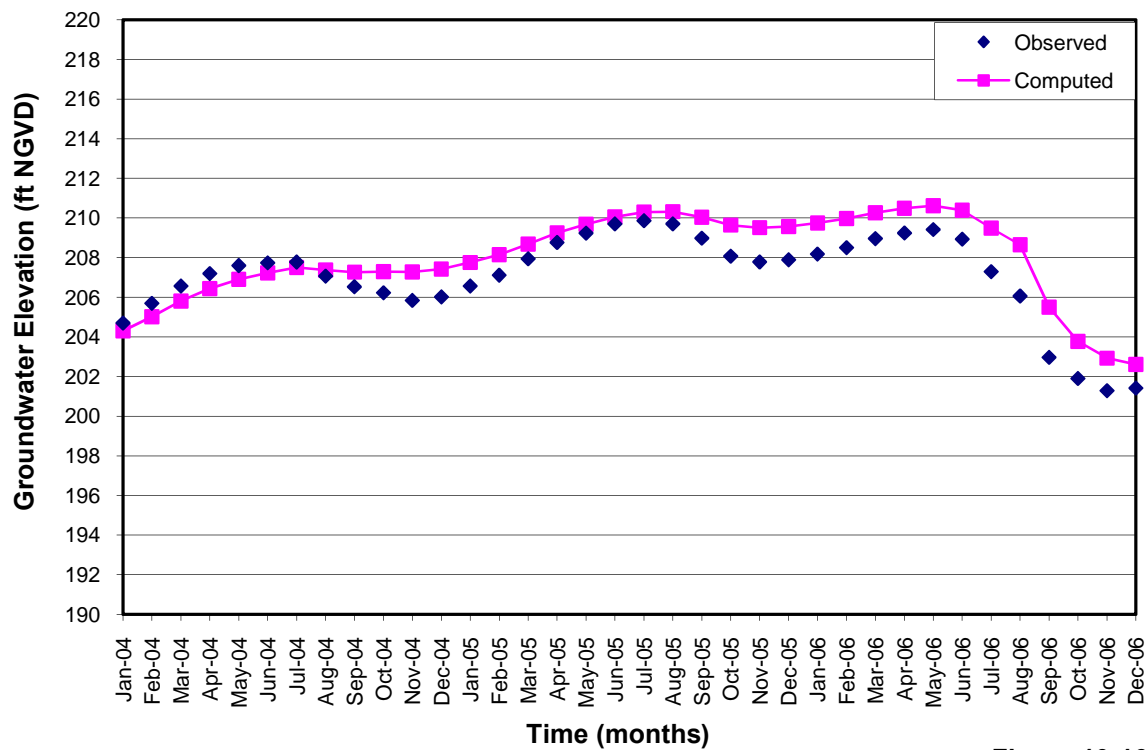


Figure 10-16

Comparison of Measured versus Simulated Groundwater Levels at 14P014 (Layer 4)

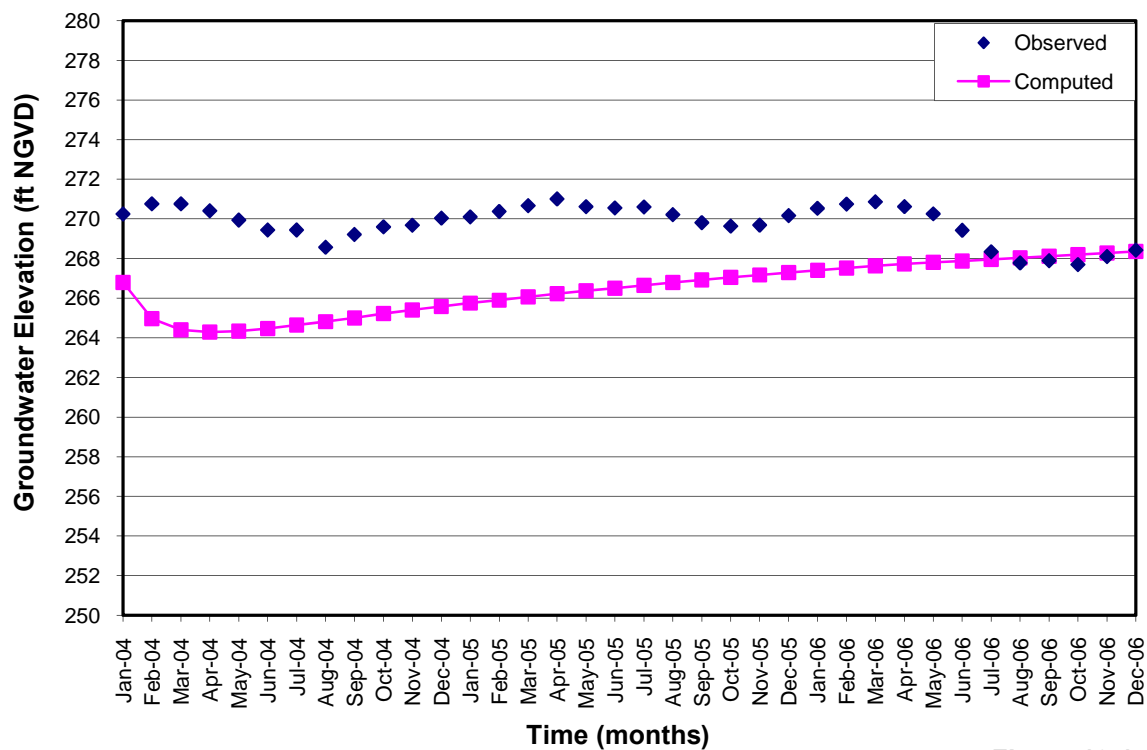


Figure 10-17

Comparison of Measured versus Simulated Groundwater Levels at 18U001 (Layer 4)

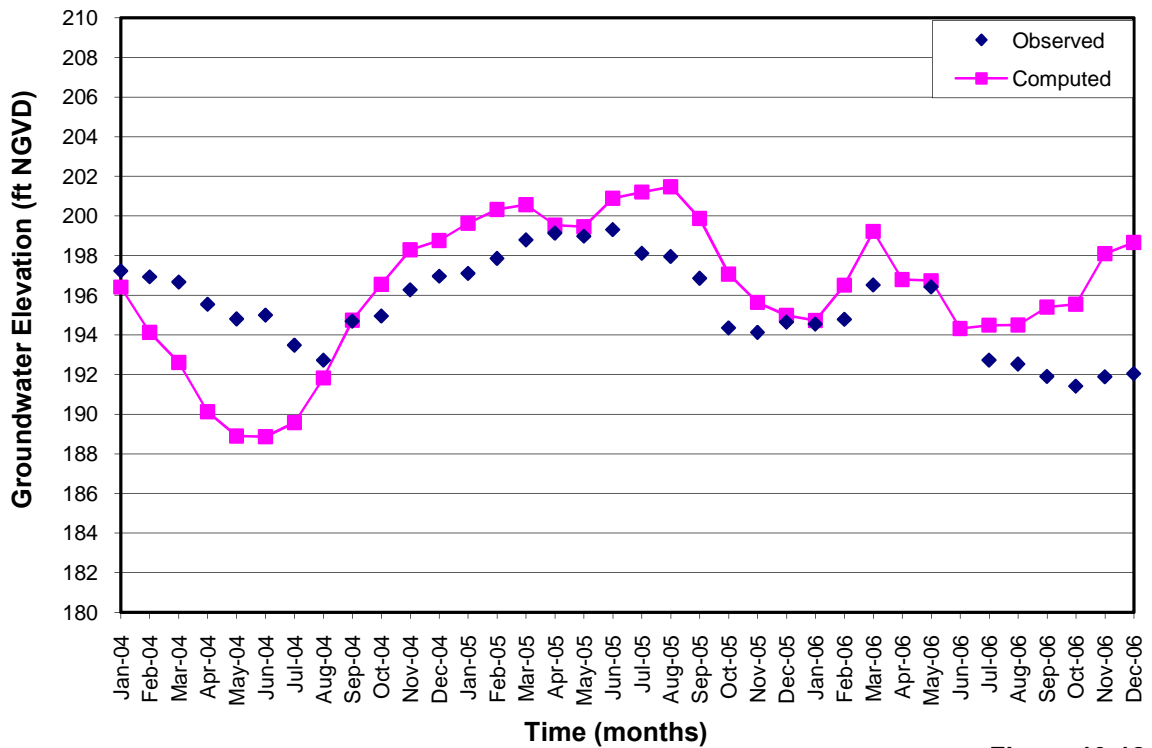


Figure 10-18

Comparison of Measured versus Simulated Groundwater Levels at 23X027 (Layer 4)

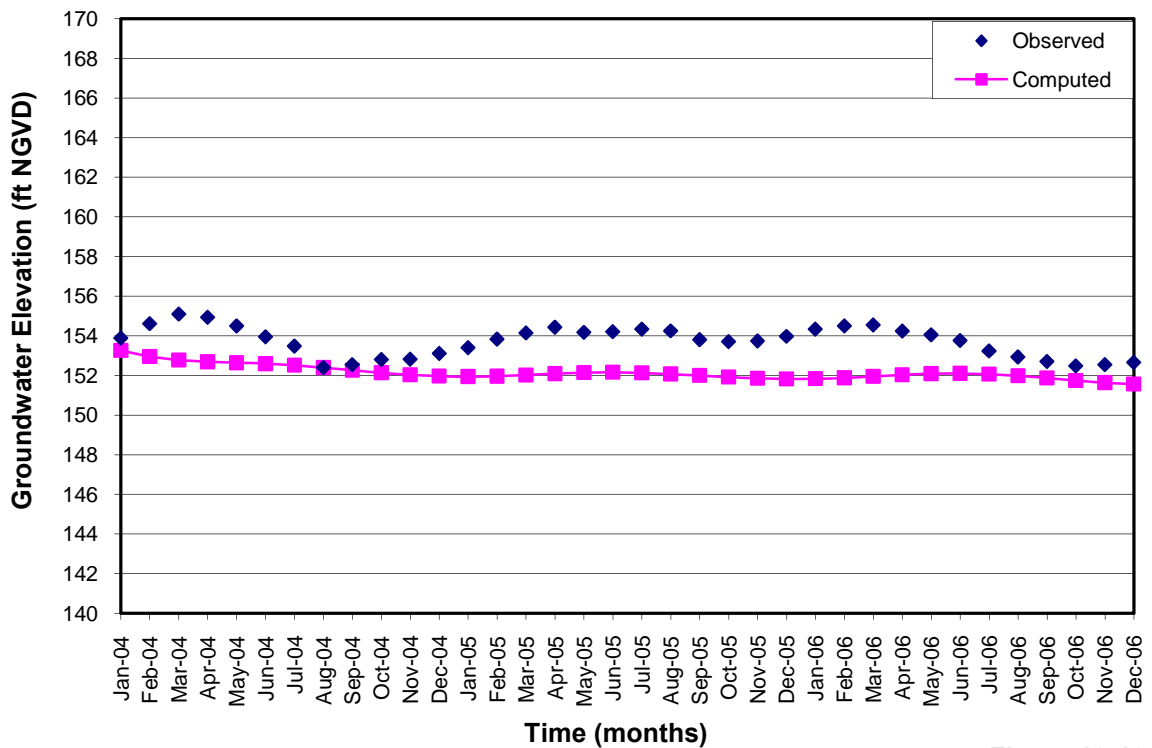


Figure 10-19

Comparison of Measured versus Simulated Groundwater Levels at 32Y031 (Layer 4)

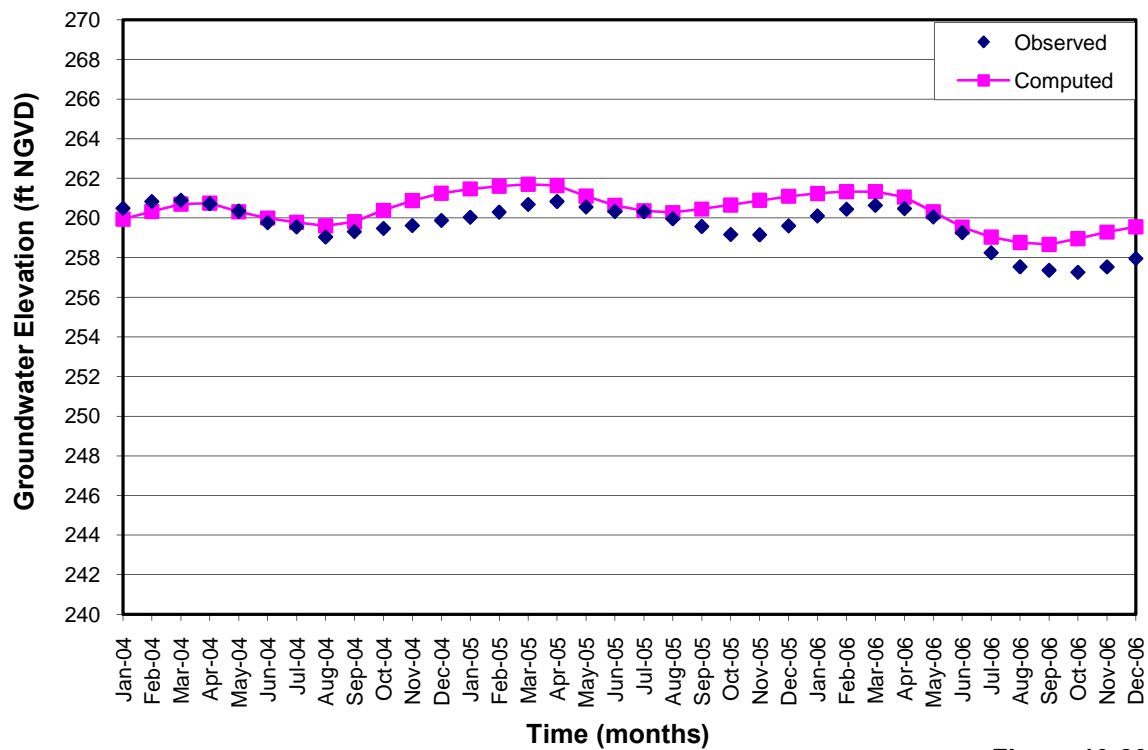


Figure 10-20

Comparison of Measured versus Simulated Groundwater Levels at 18T001 (Layer 6)

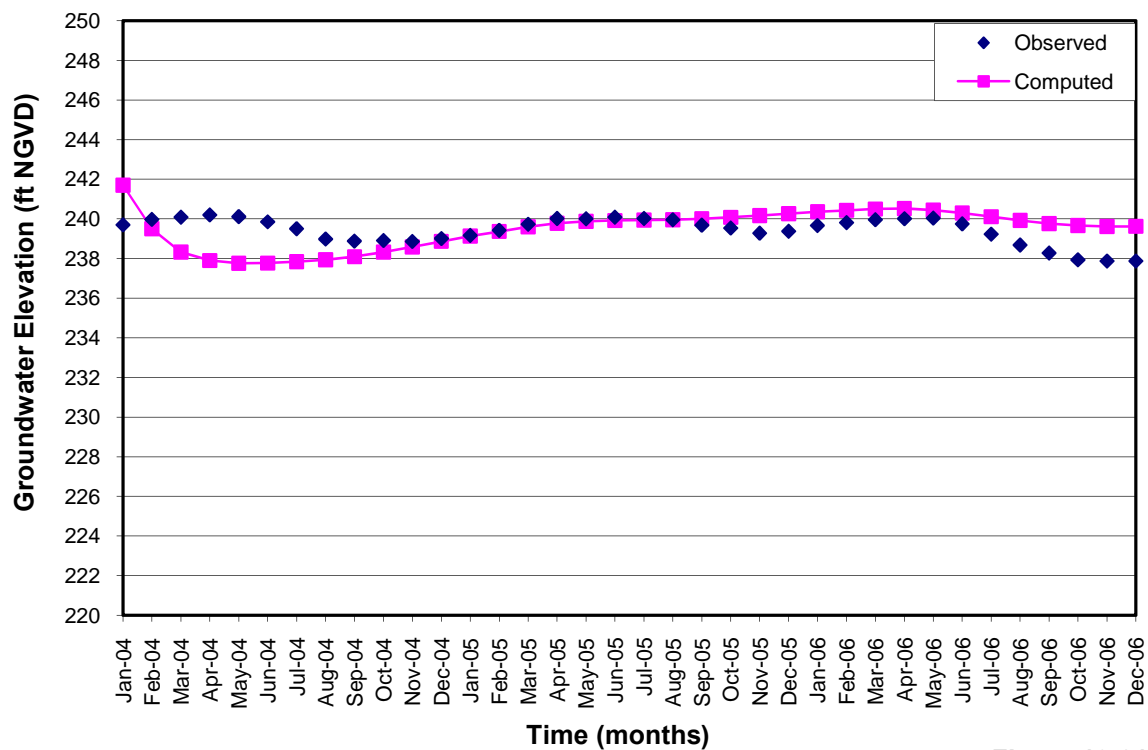


Figure 10-21

Comparison of Measured versus Simulated Groundwater Levels at 21U004 (Layer 6)

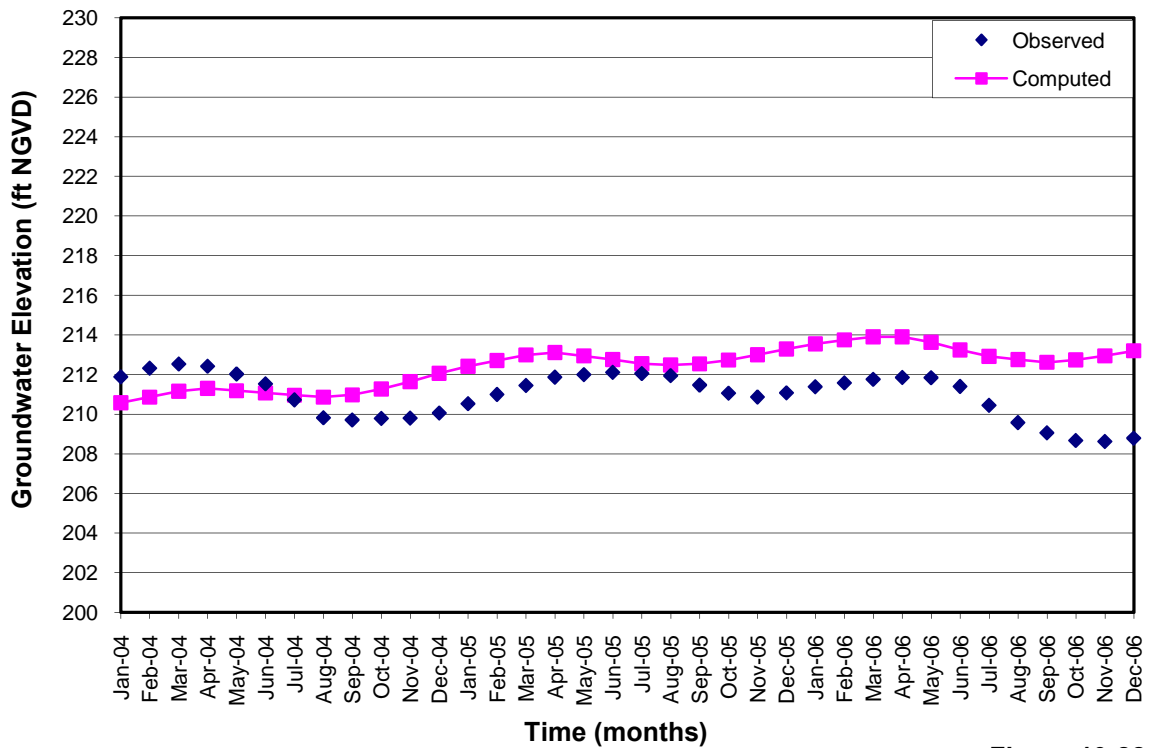


Figure 10-22

Comparison of Measured versus Simulated Groundwater Levels at 24V001 (Layer 6)

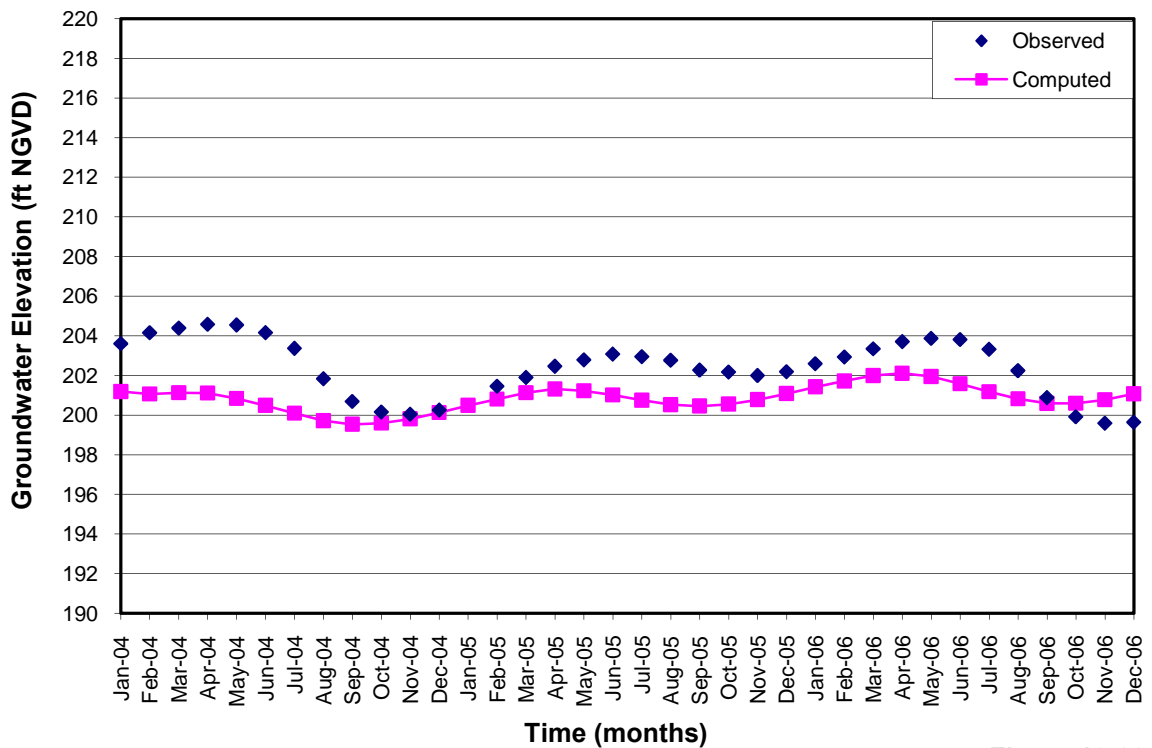


Figure 10-23

Comparison of Measured versus Simulated Groundwater Levels at 28X001 (Layer 6)

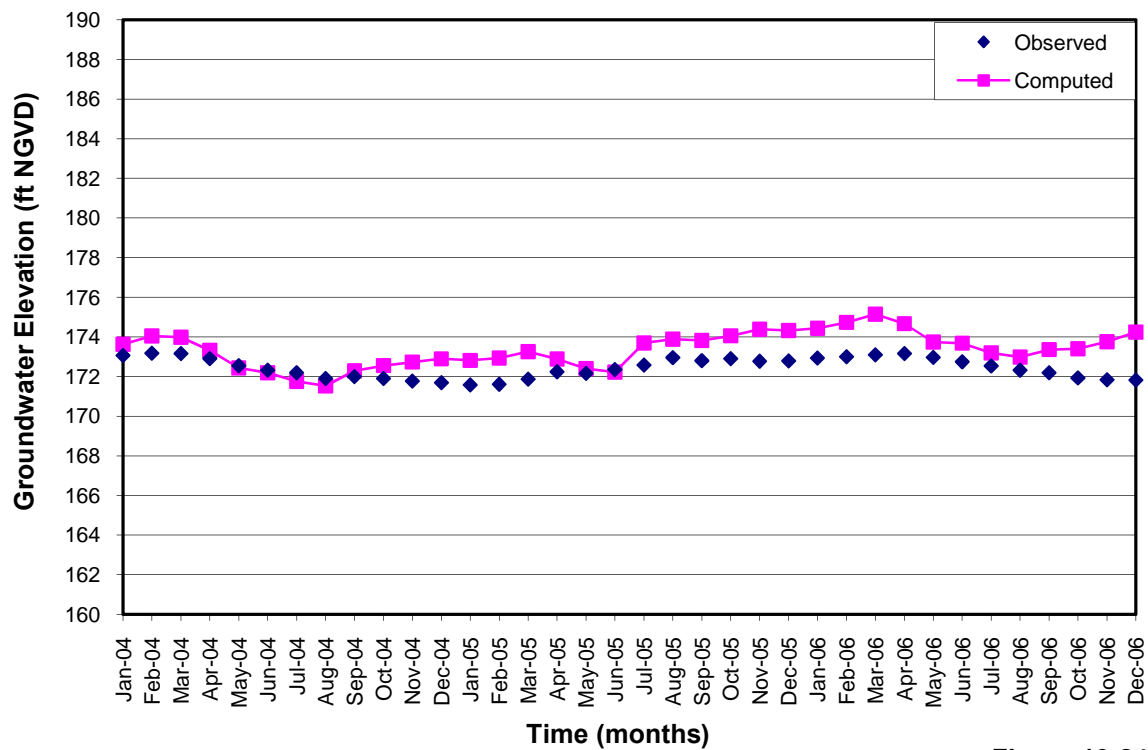


Figure 10-24

Comparison of Measured versus Simulated Groundwater Levels at 29AA09 (Layer 6)

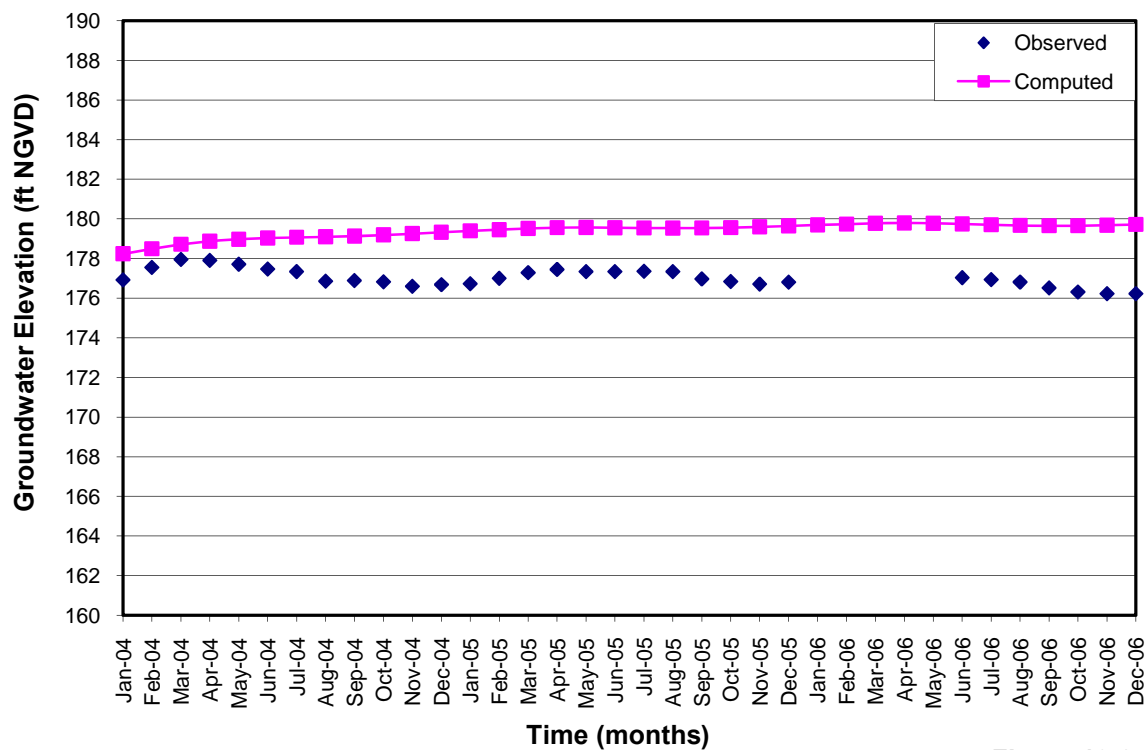


Figure 10-25

Comparison of Measured versus Simulated Groundwater Levels at 32Y030 (Layer 6)

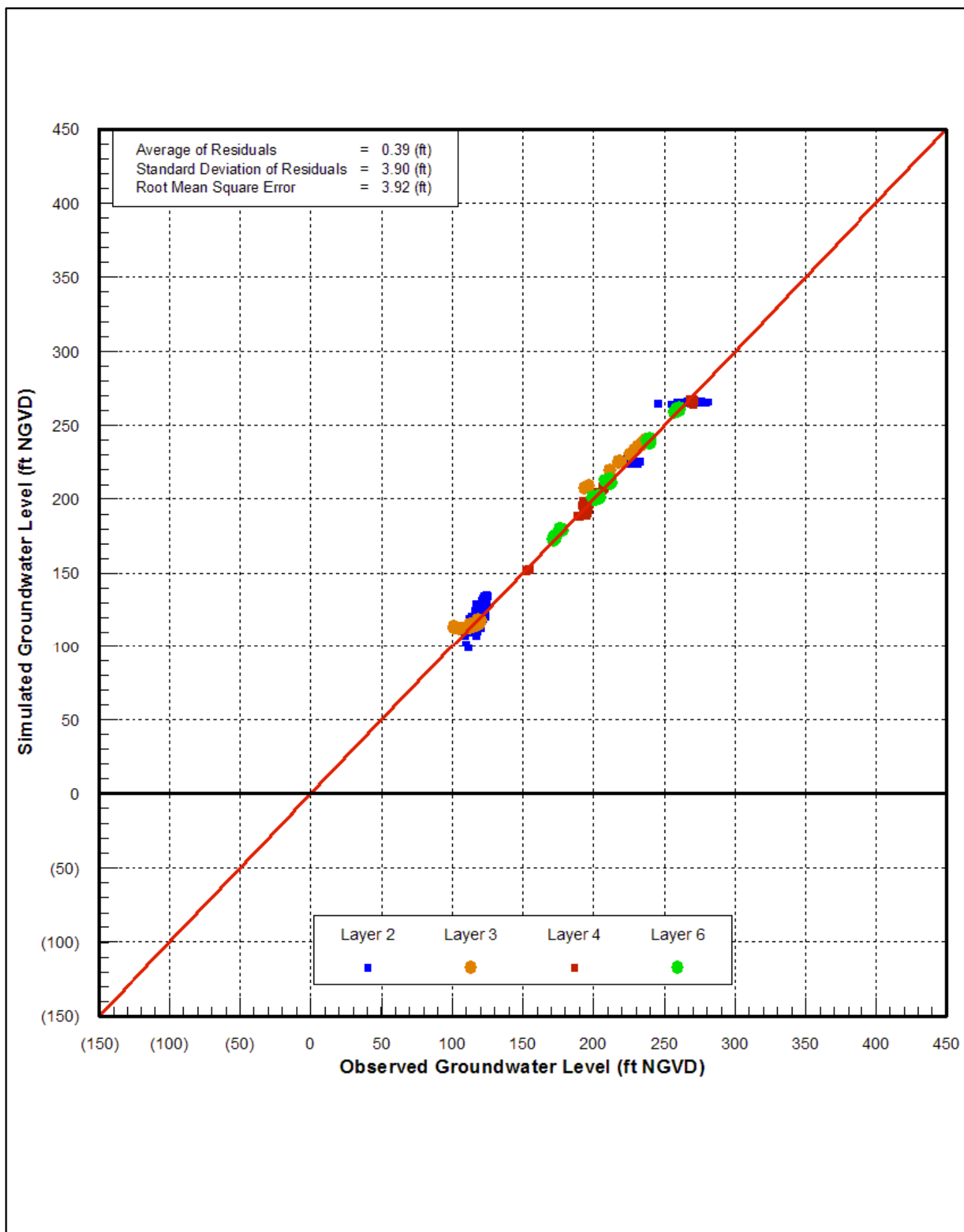


Figure 10-26
Scattergram Comparison of Observed and Simulated Groundwater Elevations
For Sub-Regional Cretaceous Aquifer Groundwater Flow Model Calibration

G:\Reports\GWM\ModelingResults\Cretaceous\Cretaceous23-Calibration\GW-EL\SP_30\WMD\9.3\Fig10-27_Layer2_SP30_TModel-27_GW-EL.mxd 11/19/09 nelsonm

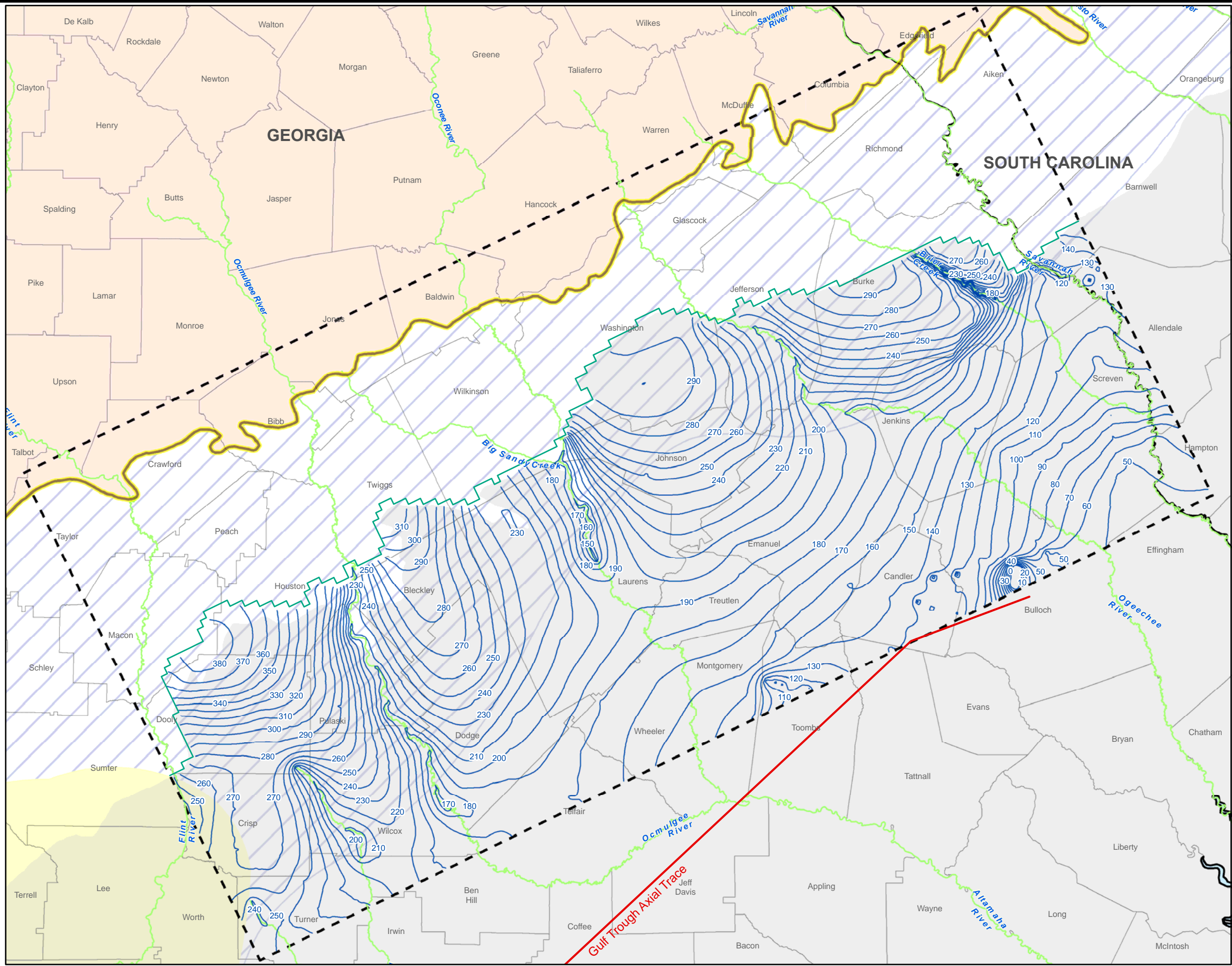
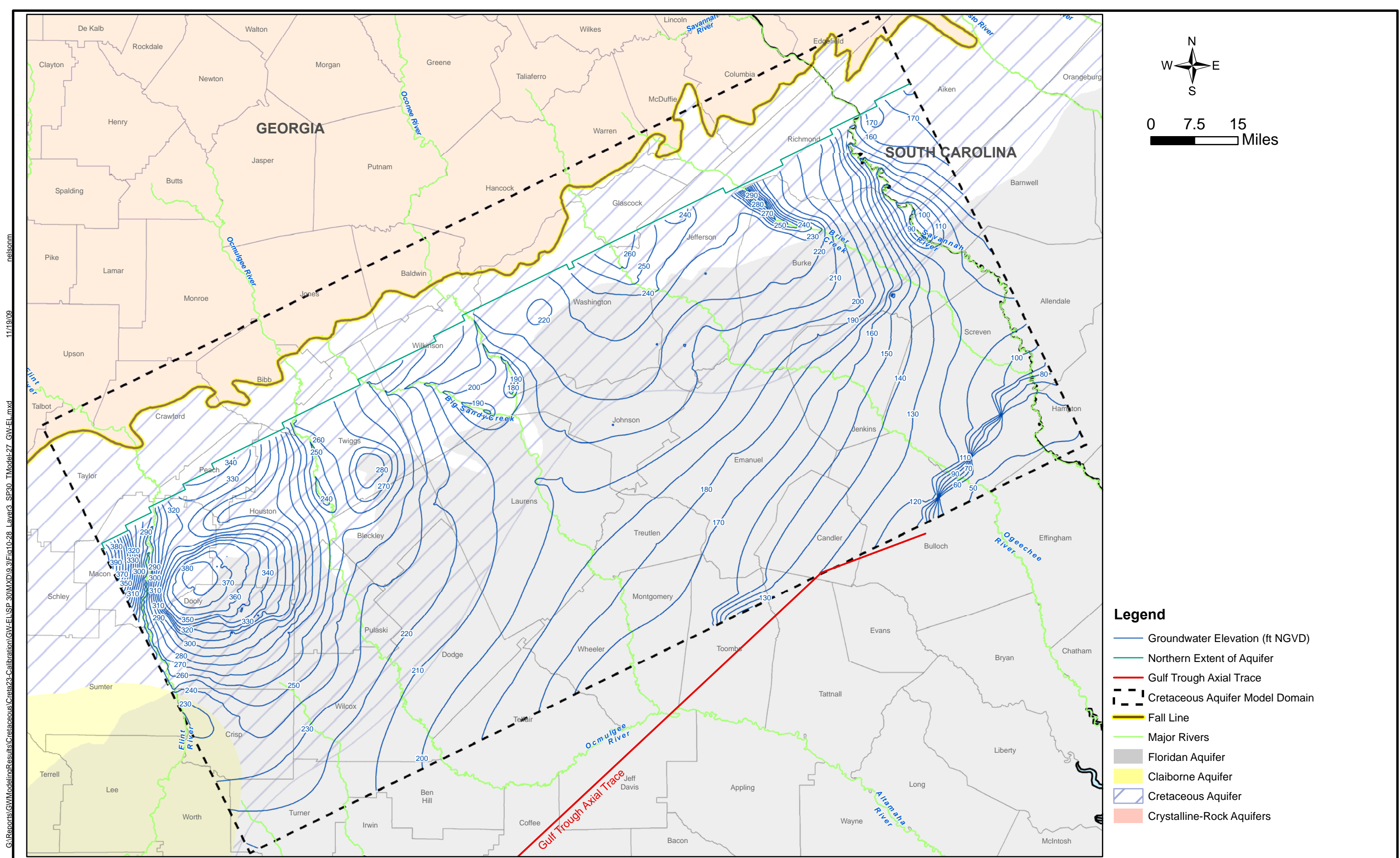


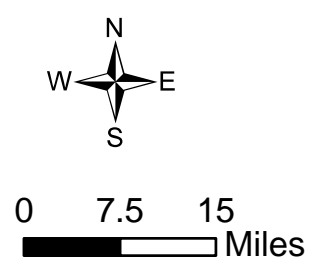
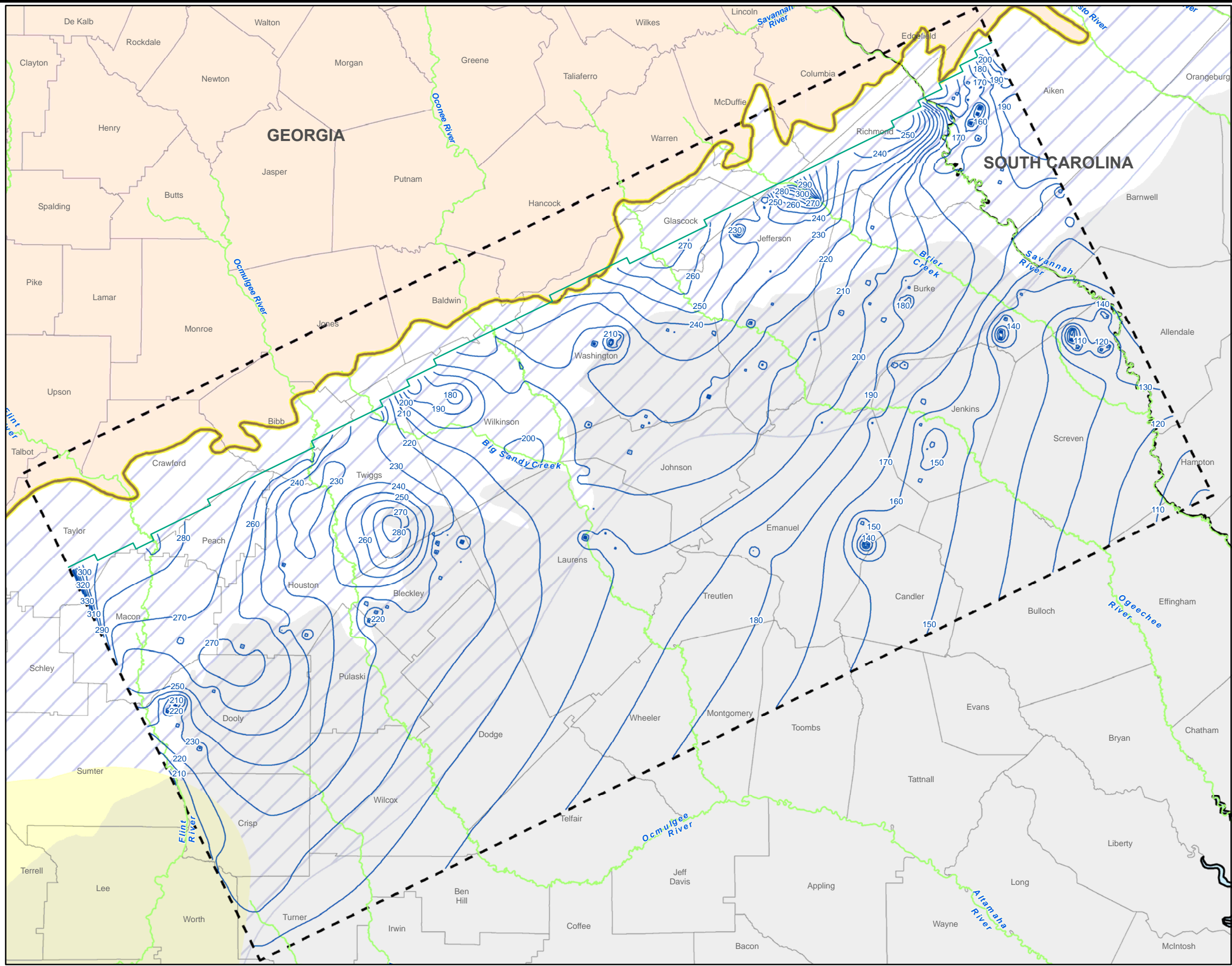
Figure 10-27
Simulated Groundwater Elevations in Upper Floridan Aquifer (Layer 2)
in Sub-Regional Cretaceous Aquifer Groundwater Flow Model Domain in June 2006



G:\Reports\GWM\ModelingResults\Cretaceous\Crate23-Calibration\GW-EL\SP_30\WMD\9.3\Fig10-28_Layer3_SP30_TModel-27_GW-EL.mxd 11/19/09 nelsonm

CDM **Figure 10-28**
Simulated Groundwater Elevations in Claiborne/Gordon/Lower Floridan Aquifers (Layer 3)
in Sub-Regional Cretaceous Aquifer Groundwater Flow Model Domain in June 2006

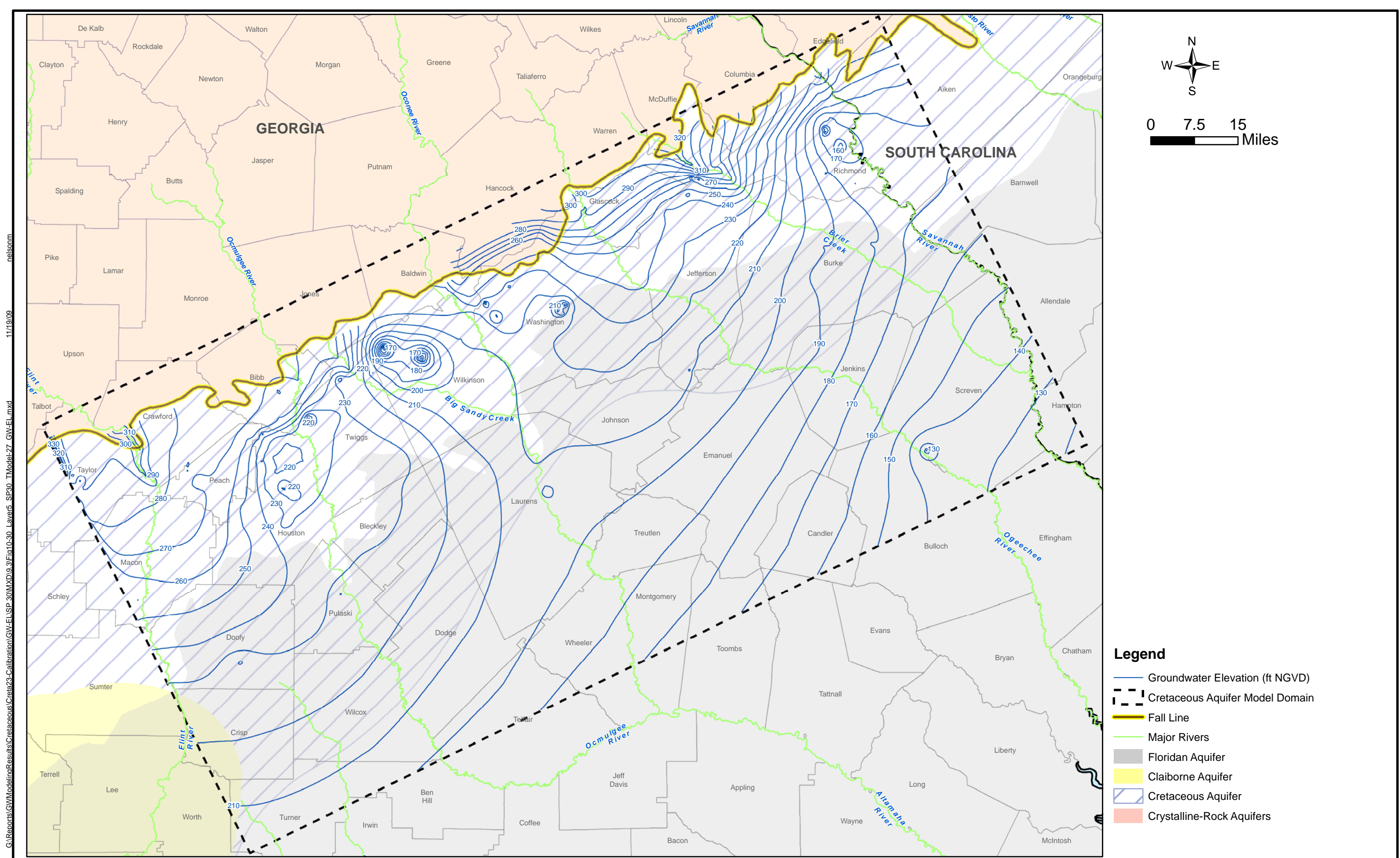
G:\Reports\GWM\ModelingResults\Cretaceous\Cretaceous23-Calibration\GW-EL\SP_30\WMD\9.3\Fig10-29_Layer4_SP30_TModel-27_GW-EL.mxd 11/19/09 nelsonm



- Legend**
- Groundwater Elevation (ft NGVD)
 - Northern Extent of Aquifer
 - Cretaceous Aquifer Model Domain
 - Fall Line
 - Major Rivers
 - Floridan Aquifer
 - Claiborne Aquifer
 - Cretaceous Aquifer
 - Crystalline-Rock Aquifers



Figure 10-29
Simulated Groundwater Elevations in Clayton-Dublin Aquifers (Layer 4)
in Sub-Regional Cretaceous Aquifer Groundwater Flow Model Domain in June 2006



G:\Reports\GWM\modellingResults\Cretaceous\Cretaceous23-Calibration\GW-EL\SP_30\MXD\9.3\Fig10-30_Layer5_SP30_TModel-27_GW-EL.mxd 11/19/09 nelsonm

CDM

Figure 10-30
Simulated Groundwater Elevations in Providence Sand-Peedee-Dublin Aquifers (Layer 5)
in Sub-Regional Cretaceous Aquifer Groundwater Flow Model Domain in June 2006

G:\Reports\GWM\ModelingResults\Cretaceous\Cretaceous23-Calibration\GW-EL\SP_30\WXYD9.3\Fig10-31_Layer6_SP30_TModel-27_GW-EL.mxd 11/19/09 nelsonm

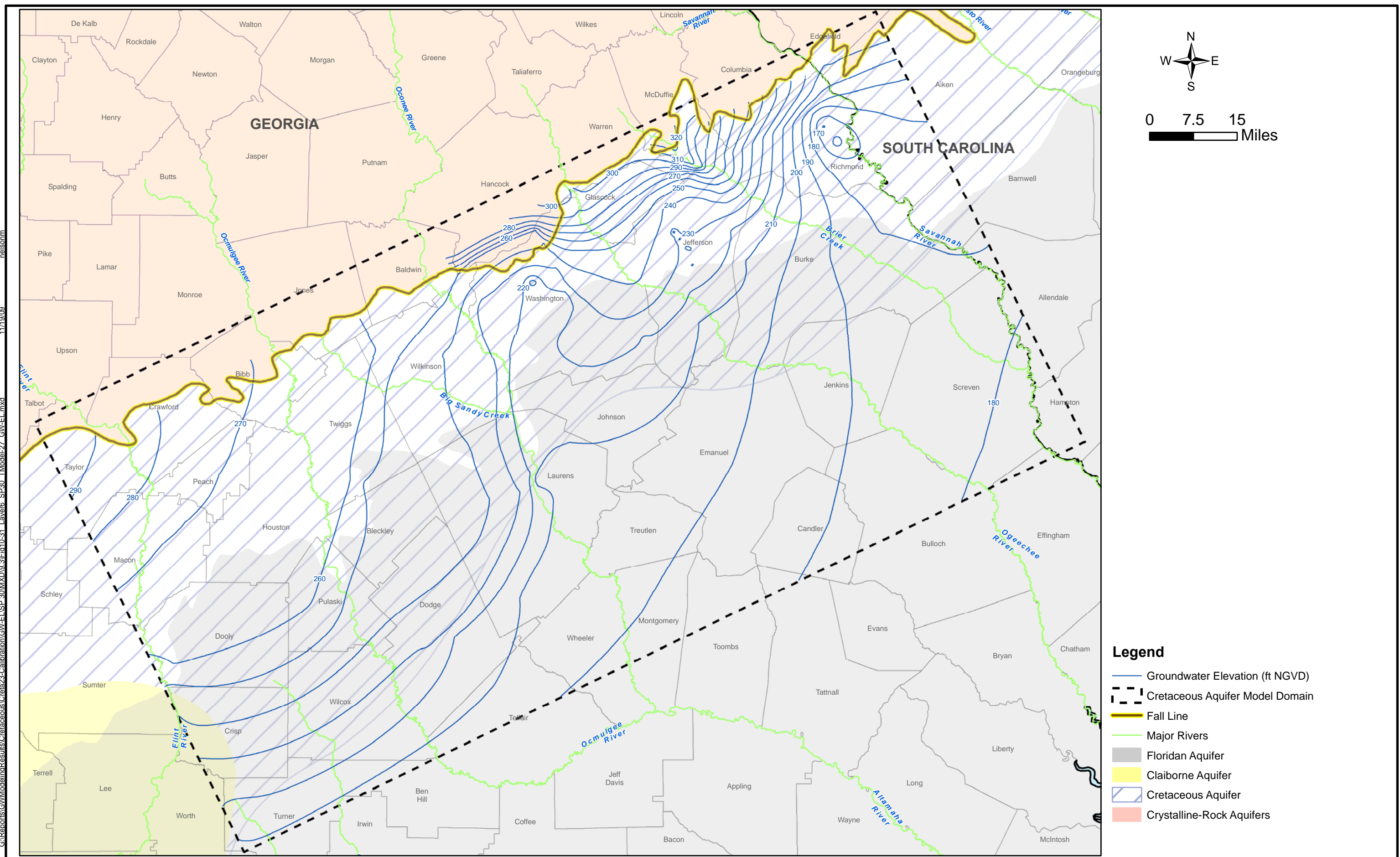
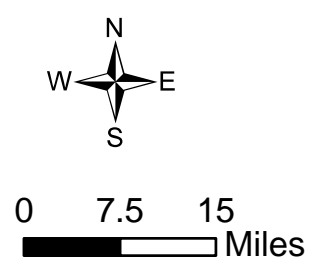
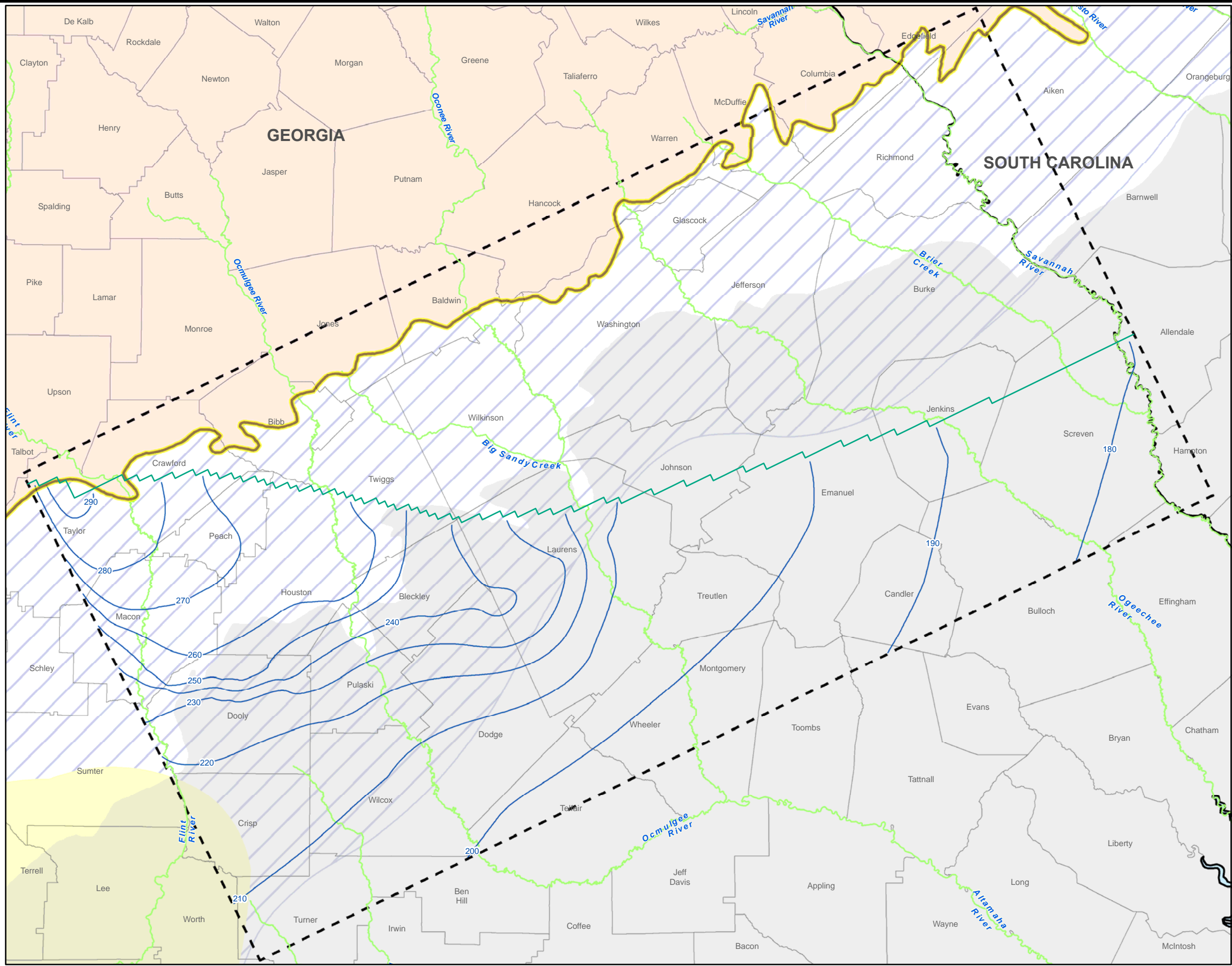


Figure 10-31
Simulated Groundwater Elevations in Eutaw-Midville Aquifer (Layer 6)
in Sub-Regional Cretaceous Aquifer Groundwater Flow Model Domain in June 2006

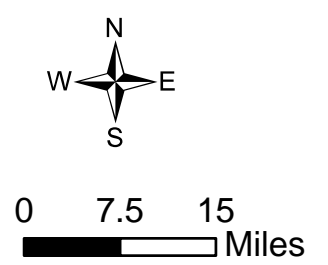
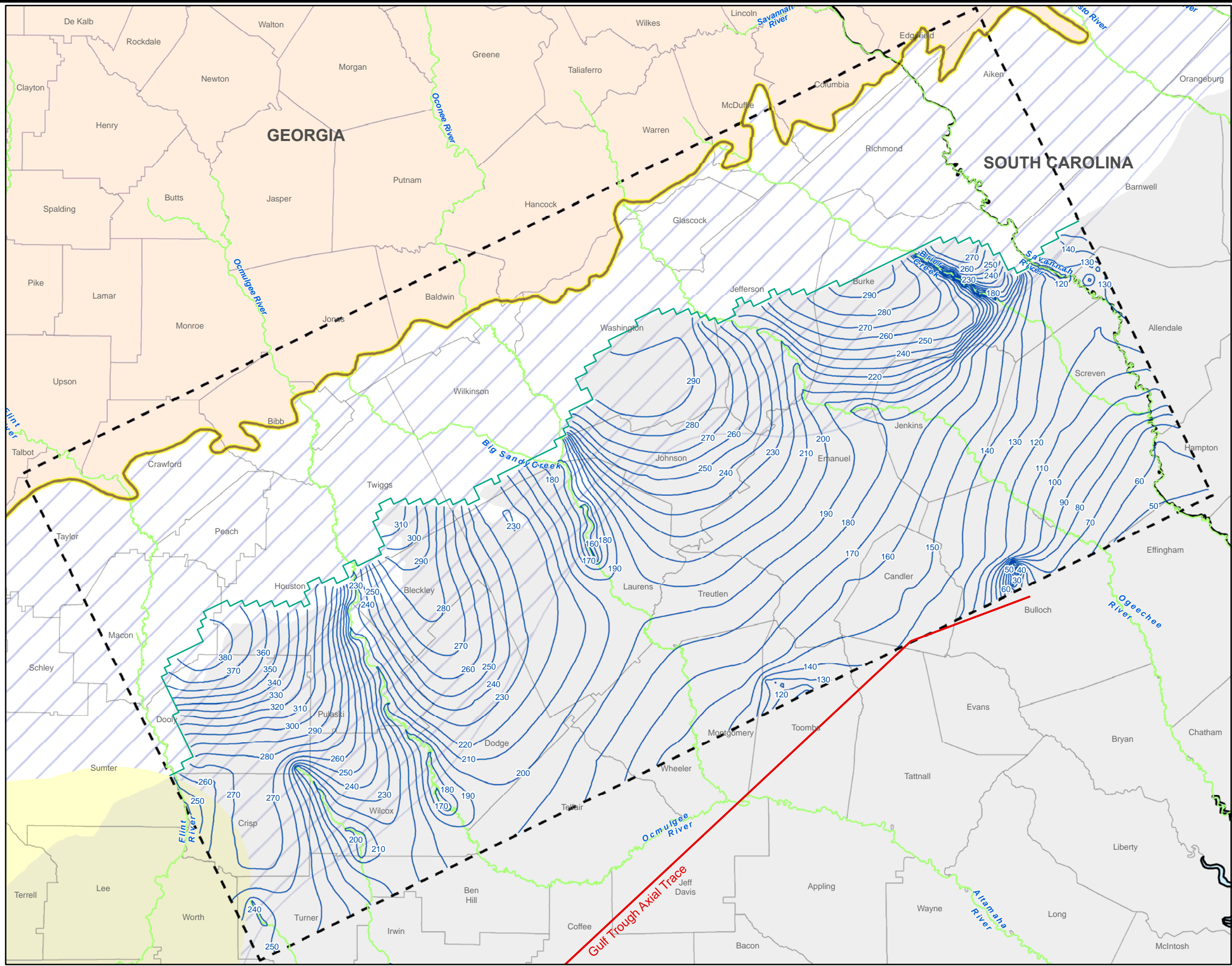
G:\Reports\GWM\ModelingResults\Cretaceous\Cretaceous23-Calibration\GW-EL\SP_30\WXYD9.3\Fig10-32_Layer7_SP30_TModel-27_GW-EL.mxd 11/19/09 nelsonm



- Legend**
- Groundwater Elevation (ft NGVD)
 - Northern Extent of Aquifer
 - Cretaceous Aquifer Model Domain
 - Fall Line
 - Major Rivers
 - Floridan Aquifer
 - Claiborne Aquifer
 - Cretaceous Aquifer
 - Crystalline-Rock Aquifers

CDM **Figure 10-32**
Simulated Groundwater Elevations in Upper Atkinson-Upper Tuscaloosa Aquifers (Layer 7)
in Sub-Regional Cretaceous Aquifer Groundwater Flow Model Domain in June 2006

G:\Reports\GWM\ModelingResults\Cretaceous\Cret23-Calibration\GW-EL\SP 36\WMD\9.3\Fig10-33_Layer2_SP36_TModel-27_GW-EL.mxd 11/19/09 nelsonm



- Legend**
- Groundwater Elevation (ft NGVD)
 - Northern Extent of Aquifer
 - Gulf Trough Axial Trace
 - Cretaceous Aquifer Model Domain
 - Fall Line
 - Major Rivers
 - Floridan Aquifer
 - Claiborne Aquifer
 - Cretaceous Aquifer
 - Crystalline-Rock Aquifers



Figure 10-33
Simulated Groundwater Elevations in Upper Floridan Aquifer (Layer 2)
in Sub-Regional Cretaceous Aquifer Groundwater Flow Model Domain in December 2006

G:\Reports\GWM\ModelingResults\Cretaceous\Crate23-Calibration\GW-EL\SP_36\WMD9.3\Fig10-34_Layer3_SP36_TModel-27_GW-EL.mxd 11/19/09 nelsonm

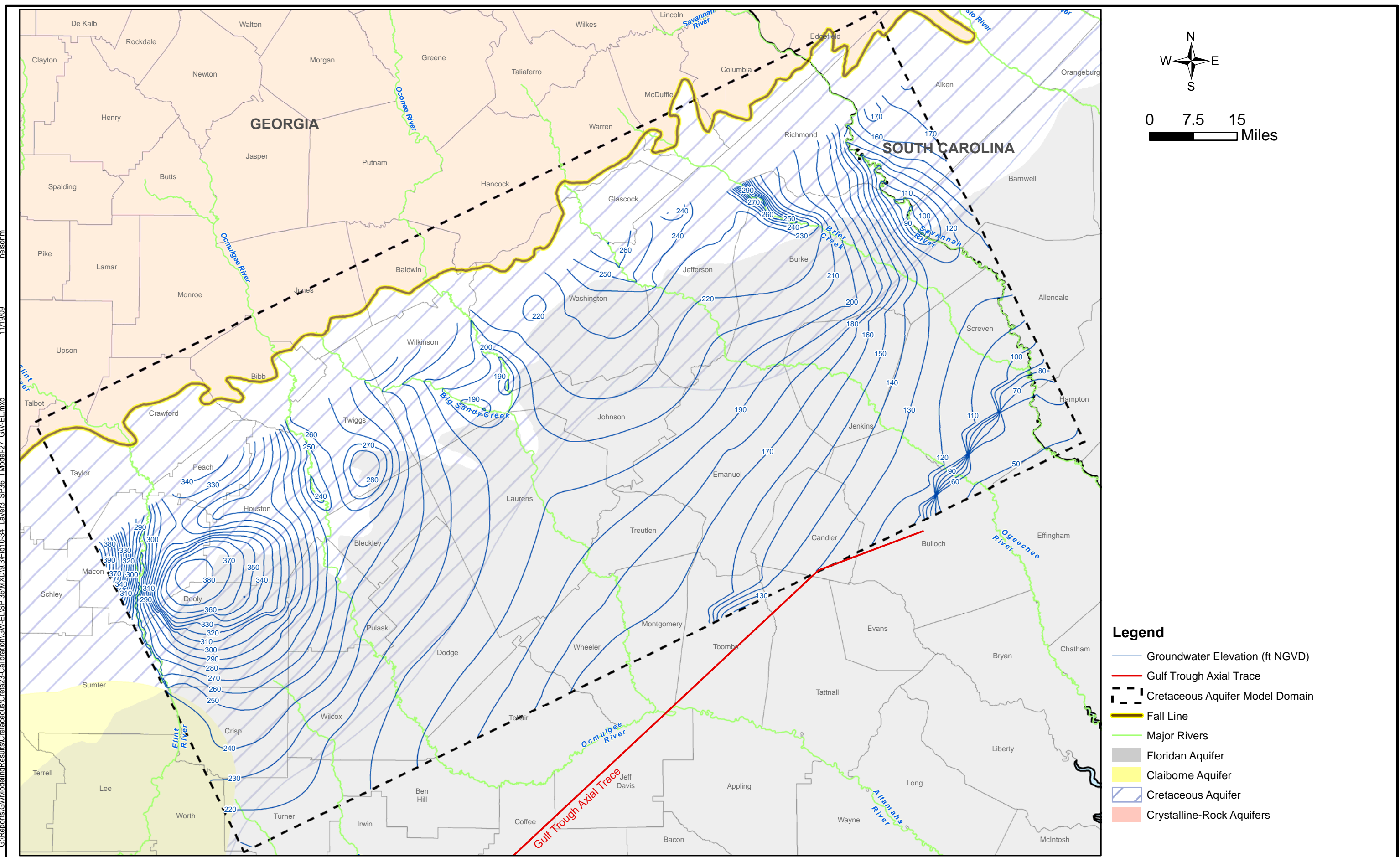
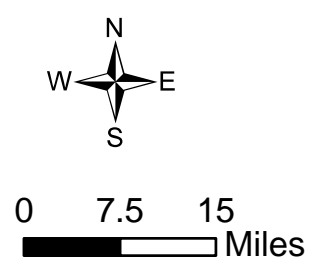
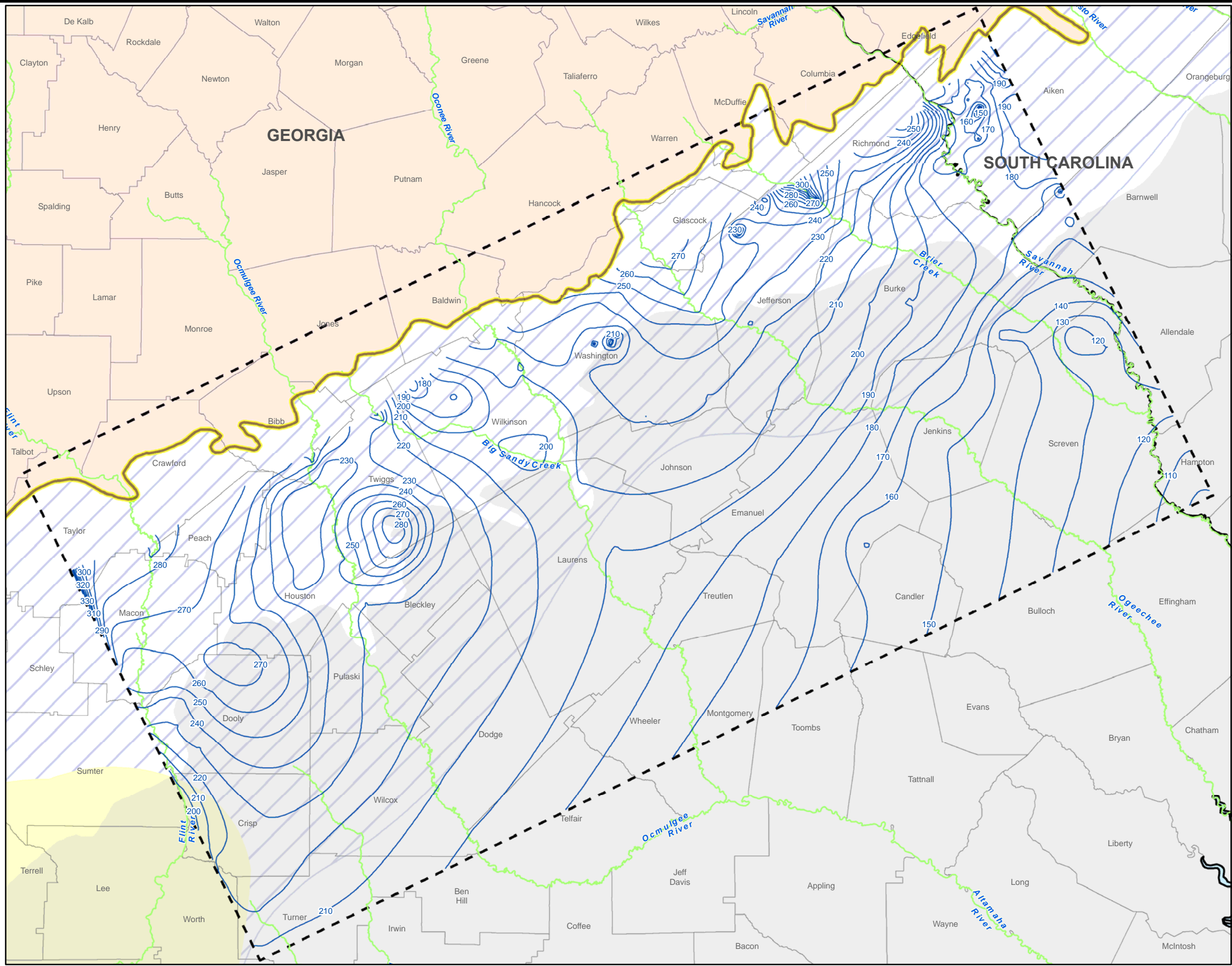


Figure 10-34
Simulated Groundwater Elevations in Claiborne/Gordon/Lower Floridan Aquifers (Layer 3)
in Sub-Regional Cretaceous Aquifer Groundwater Flow Model Domain in December 2006



G:\Reports\GWM\ModelingResults\Cretaceous\Cretaceous23-Calibration\GW-EL\SP 36\WYD9.3\Fig10-35_Layer4_SP36_TModel-27_GW-EL.mxd 11/19/09 nelsonm



- Legend**
- Groundwater Elevation (ft NGVD)
 - Cretaceous Aquifer Model Domain
 - Fall Line
 - Major Rivers
 - Floridan Aquifer
 - Claiborne Aquifer
 - Cretaceous Aquifer
 - Crystalline-Rock Aquifers



Figure 10-35
Simulated Groundwater Elevations in Clayton-Dublin Aquifers (Layer 4)
in Sub-Regional Cretaceous Aquifer Groundwater Flow Model Domain in December 2006

G:\Reports\GWM\ModelingResults\Cretaceous\Cretaceous23-Calibration\GW-EL\SP_36\MXD\9.3\Fig10-36_Layer5_SP36_TModel-27_GW-EL.mxd 11/19/09 nelsonm

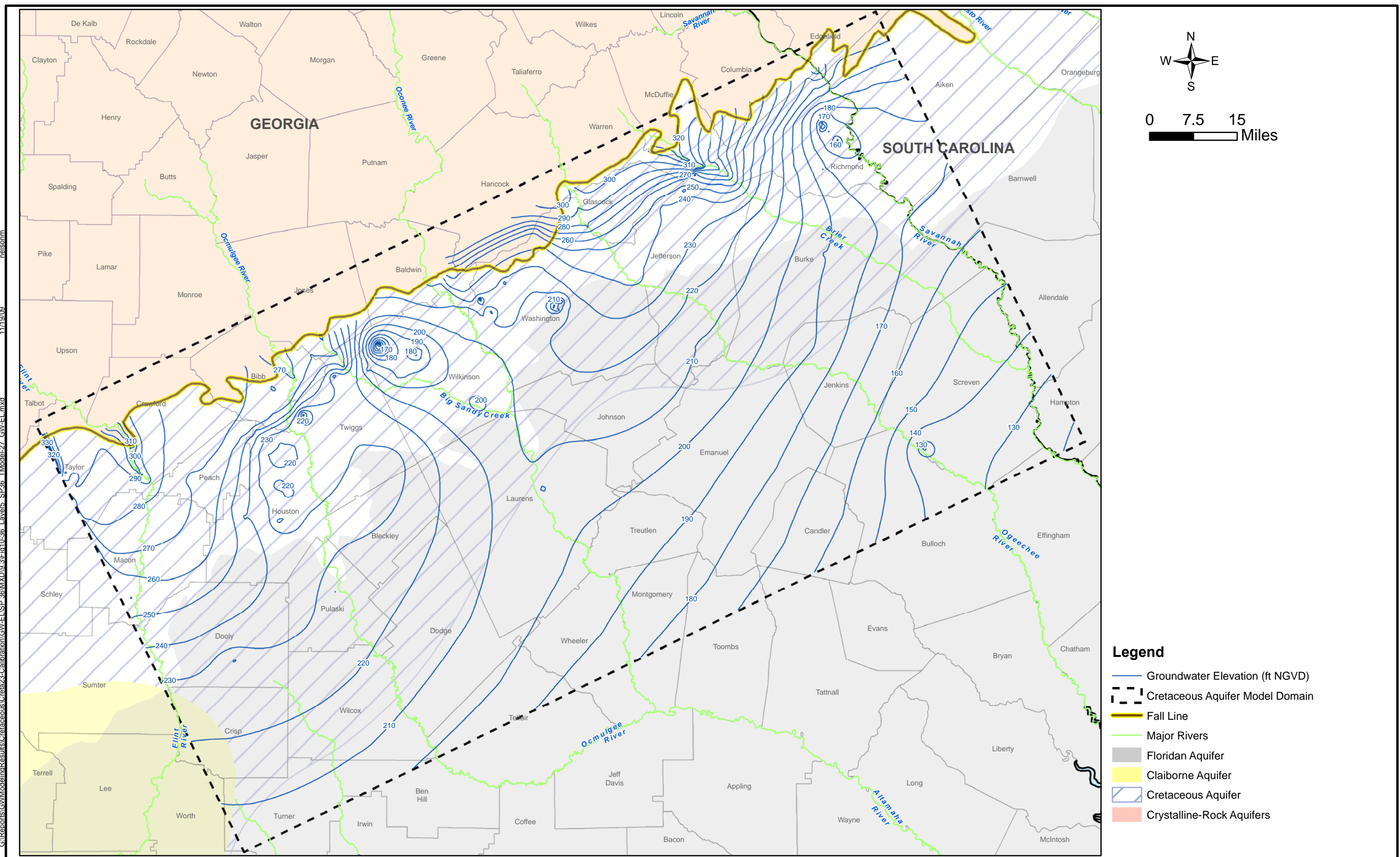
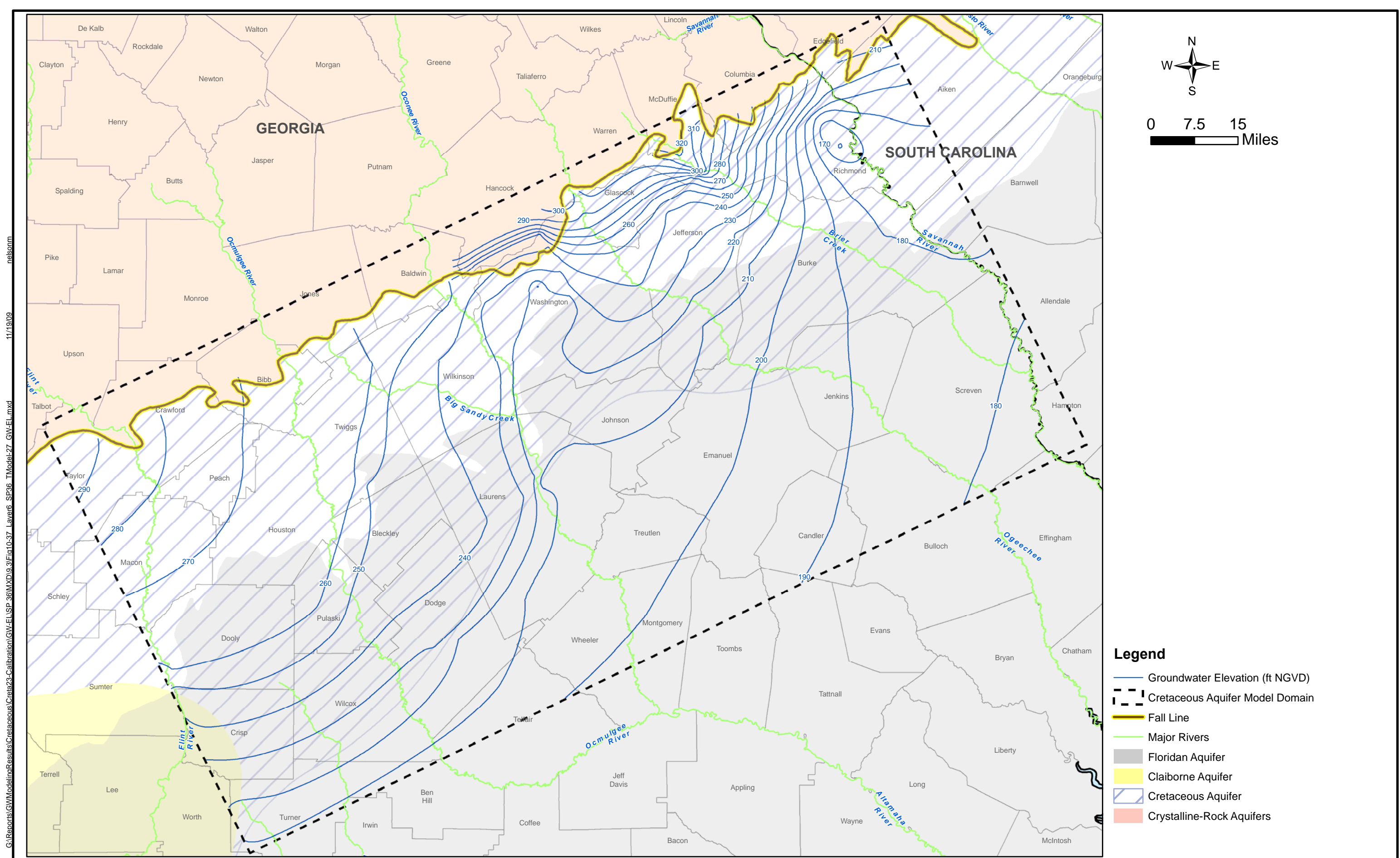


Figure 10-36
Simulated Groundwater Elevations in Providence Sand-Peedee-Dublin Aquifers (Layer 5)
in Sub-Regional Cretaceous Aquifer Groundwater Flow Model Domain in December 2006

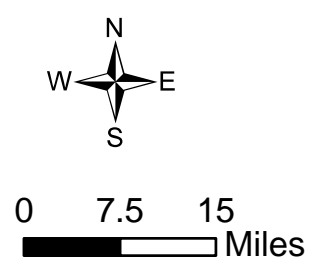
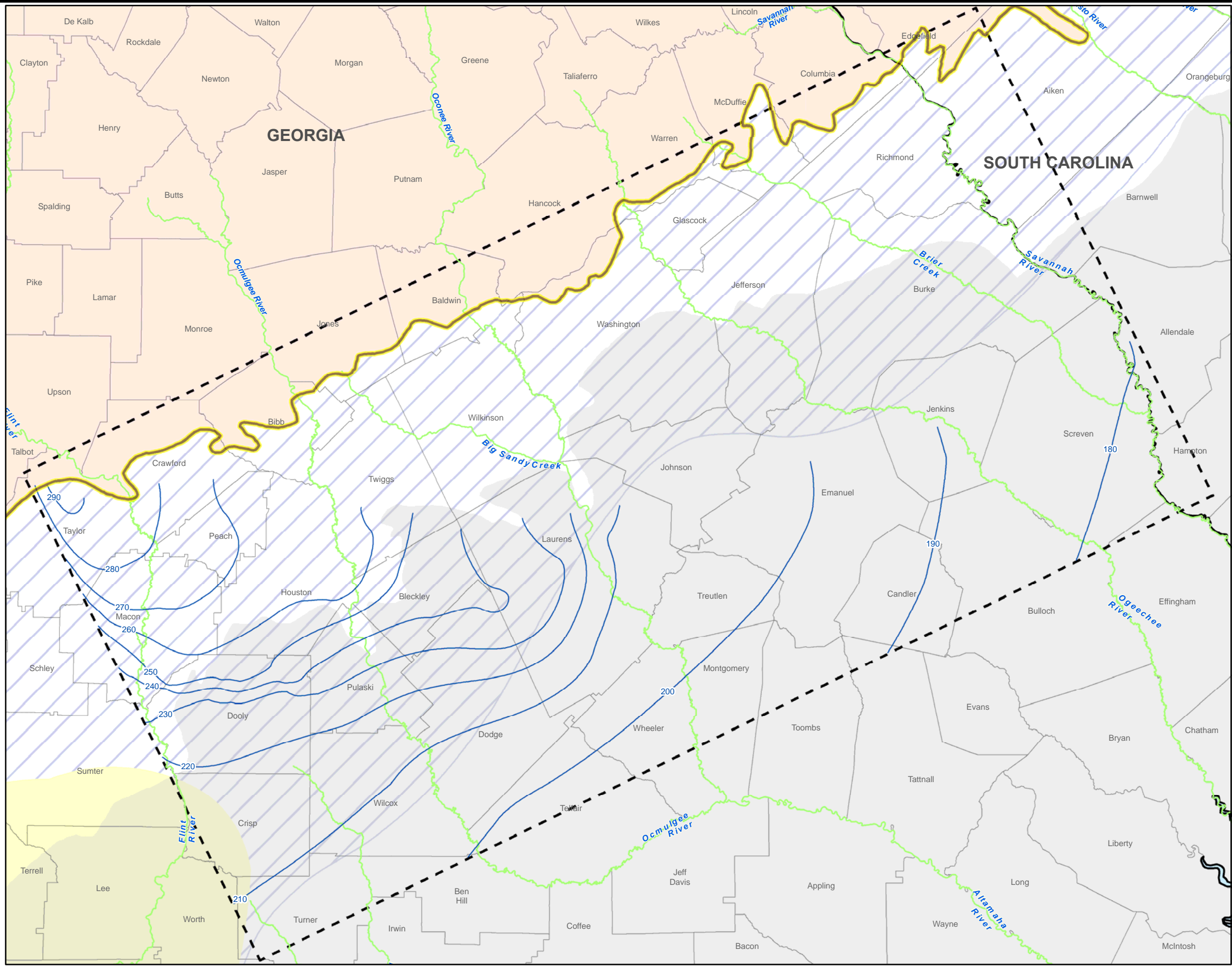


G:\Reports\GWM\ModelingResults\Cretaceous\Cretaceous23-Calibration\GW-EL\SP_36\WMD\9.3\Fig10-37_Layer6_SP36_TModel-27_GW-EL.mxd 11/19/09 nelsonm

CDM

Figure 10-37
Simulated Groundwater Elevations in Eutaw-Midville Aquifer (Layer 6)
in Sub-Regional Cretaceous Aquifer Groundwater Flow Model Domain in December 2006

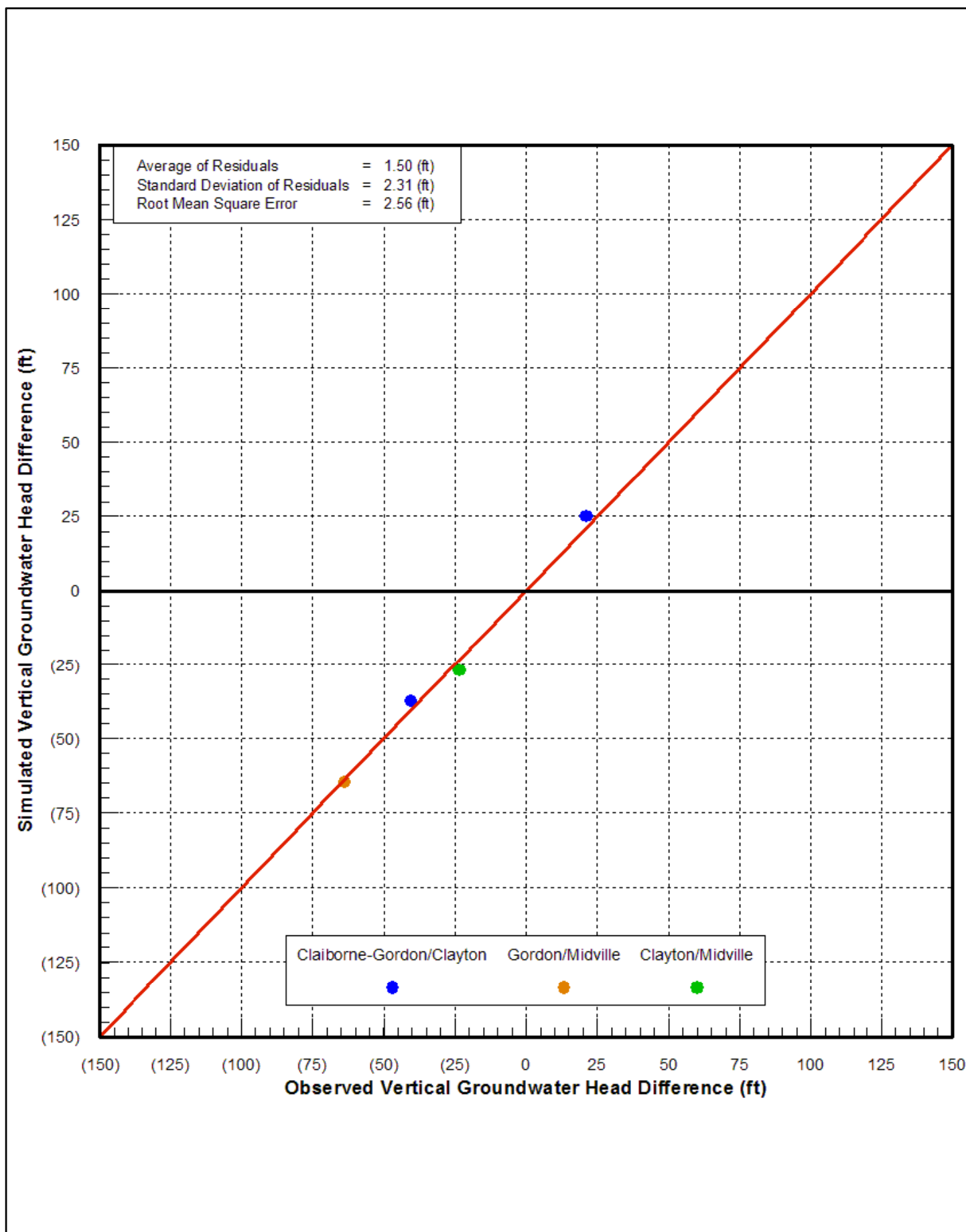
G:\Reports\GWM\ModelingResults\Cretaceous\Crate23-Calibration\GW-EL\SP_36\WYD9.3\Fig10-38_Layer7_SP36_TModel-27_GW-EL.mxd 11/19/09 nelsonm



- Legend**
- Groundwater Elevation (ft NGVD)
 - Cretaceous Aquifer Model Domain
 - Fall Line
 - Major Rivers
 - Floridan Aquifer
 - Claiborne Aquifer
 - Cretaceous Aquifer
 - Crystalline-Rock Aquifers



Figure 10-38
Simulated Groundwater Elevations in Upper Atkinson-Upper Tuscaloosa Aquifers (Layer 7)
in Sub-Regional Cretaceous Aquifer Groundwater Flow Model Domain in December 2006



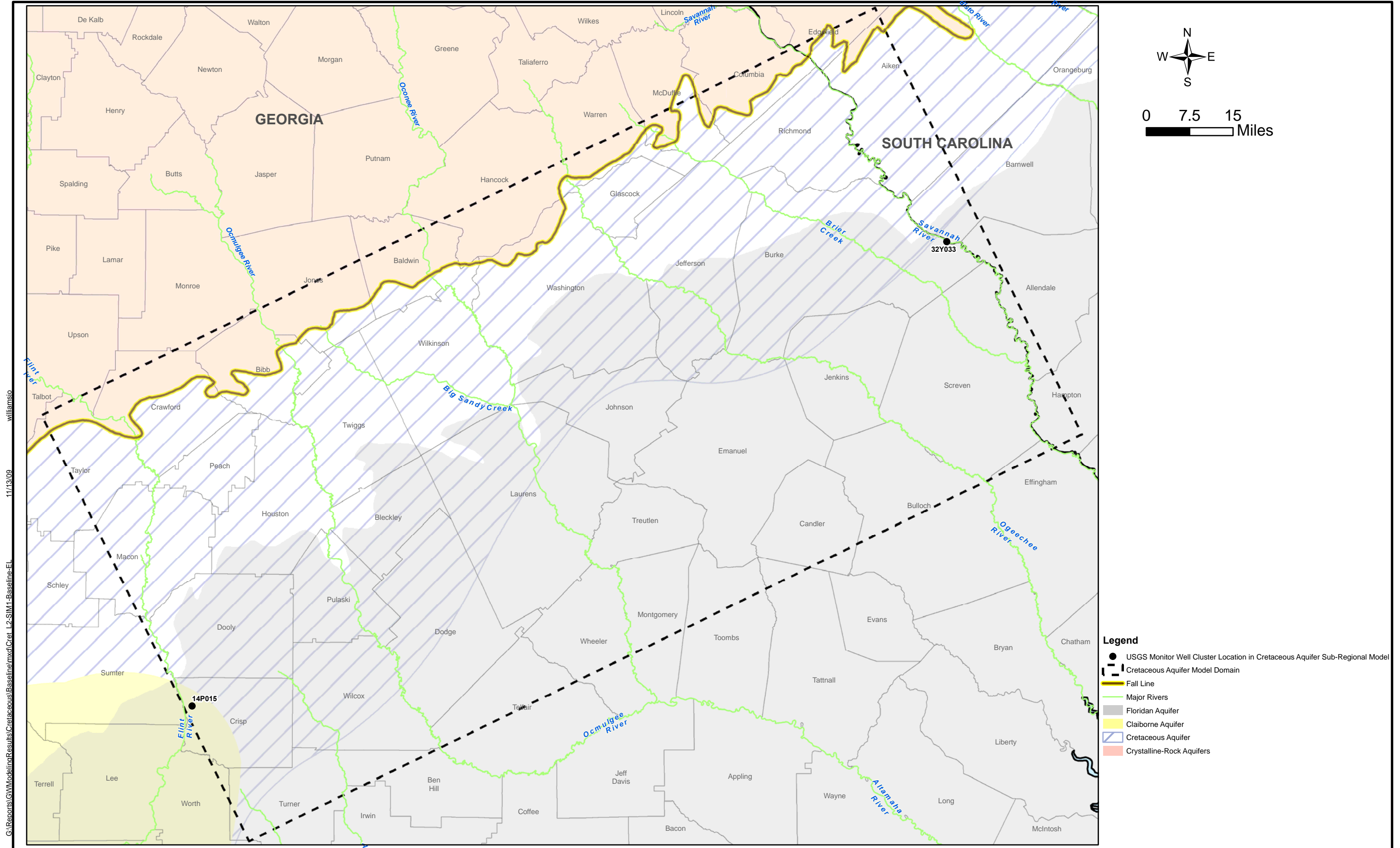
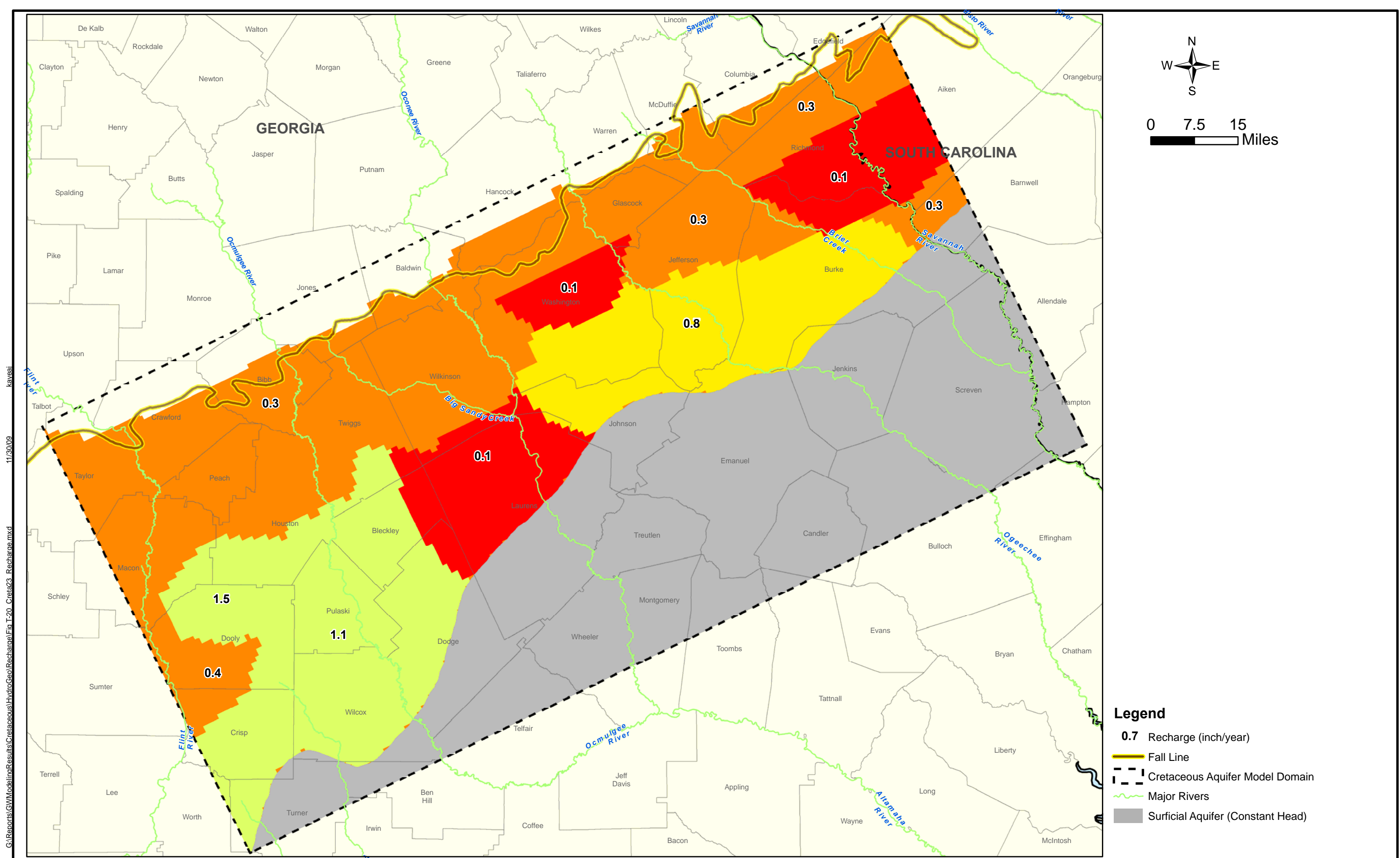


Figure 10-40
Monitor Well Cluster Locations in Cretaceous Aquifer Sub-Regional Groundwater Flow Model Domain



G:\Reports\GWM\GWMResults\Cretaceous\HydroGeo\Recharge\Fig 10-41_Crete23_Recharge.mxd 11/30/09 kayaj

CDM **Figure 10-41**
Net Recharge Distribution for May 2004 (beginning of the growing season in an average rainfall year) (SP5)
Used in Sub-Regional Cretaceous Aquifer Groundwater Model

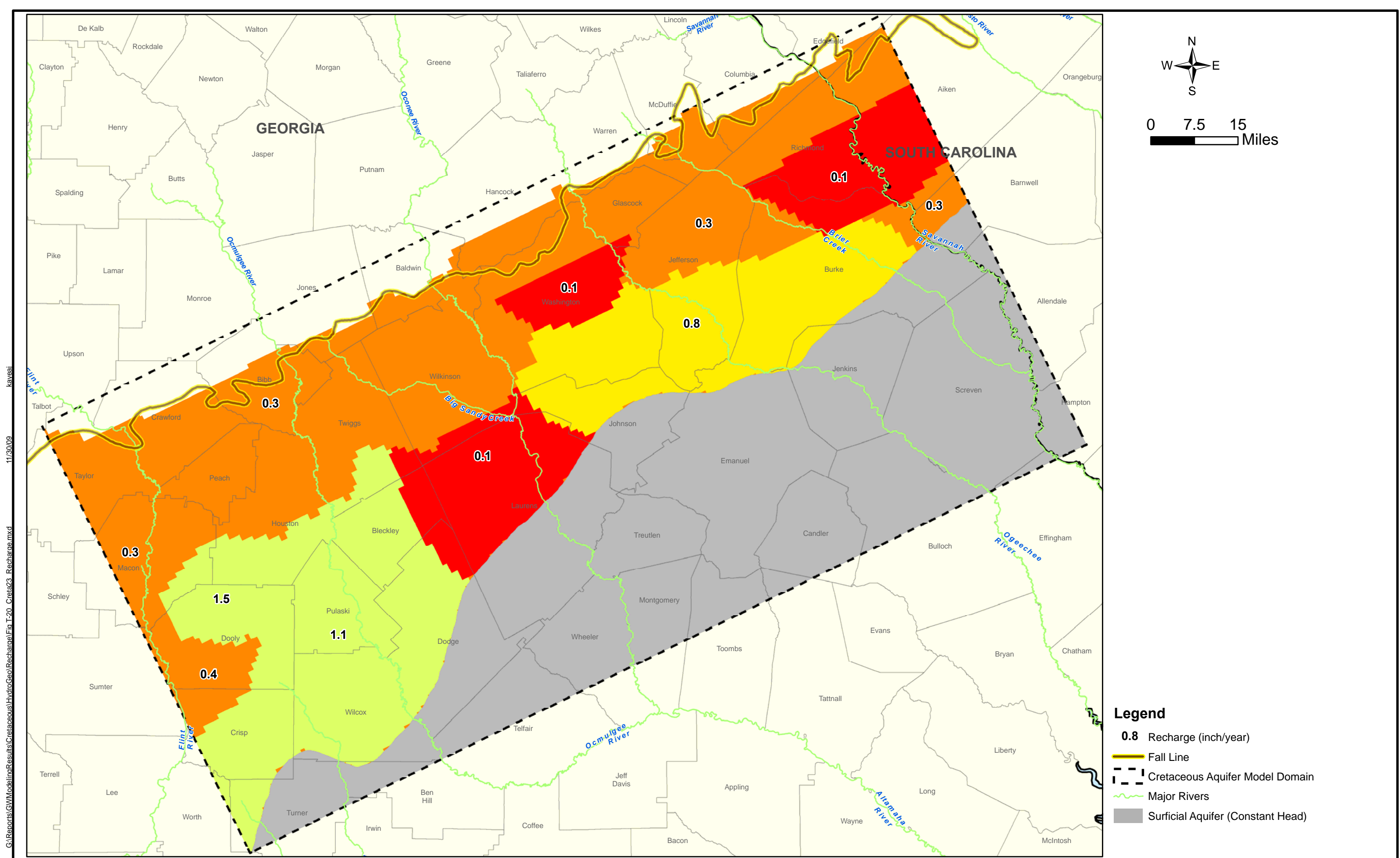


Figure 10-43
Net Recharge Distribution for April 2006 (a low rainfall month at the beginning of the growing season in a low rainfall year) (SP28)
Used in Sub-Regional Cretaceous Aquifer Groundwater Model