

Section 9

Sub-Regional Transient Claiborne Aquifer Model Development and Calibration

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

9.1 Sub-Regional Transient Claiborne Aquifer Model Development

9.1.1 Model Domain and Grid Refinement

Figure 9-1 displays the sub-regional transient Claiborne Aquifer model domain and grid system. As shown on Figure 9-1, the model horizontal domain spans a distance of approximately 110 miles in the north-south direction and approximately 100 miles in the east-west direction, encompassing an area of approximately 11,000 square miles. The sub-regional model covers the entire extent of the Claiborne Aquifer within Georgia.

The entire sub-regional Claiborne 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 290 rows and 265 columns. A total of 76,850 grid blocks or cells were used to cover the Claiborne Aquifer in the Coastal Plain of Georgia. The model origin relative to the North American Datum of 1983 (NAD83) State of Georgia West Zone Planar Coordinate System is:

- X: 2,112,640 feet;
- Y: 147,408 feet; and
- Rotation Angle: 26 degrees.

9.1.2 Model Stratigraphy

As with the Georgia EPD regional model, the sub-regional Claiborne Aquifer model vertical extent encompasses the entire thickness of the Coastal Plain Aquifer System. It is vertically discretized into seven layers to represent all of 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 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 9-2**. North-south and east-west cross sections of the model are presented on **Figures 9-3** and **9-4**, respectively.

9.1.3 Transient Sub-Regional Model

The sub-regional transient Claiborne 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 the monthly stress period interval. As discussed in Section 2.1, annual rainfalls 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.

9.1.4 Model Modifications

In order to construct the transient sub-regional Claiborne Aquifer groundwater model from the calibrated Georgia EPD steady-state regional model, several model packages were modified as follows:

- The River Package was 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.
- The General Head Boundary Package, used to represent the lateral edge boundaries along the north, east, south, and west model boundaries in Layer 2 through Layer 7, was 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 rainfall data 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 net recharge within the sub-regional Claiborne Aquifer model area are also presented in Section 9.6.

- 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).

9.1.5 Aquifer Characteristics

The sub-regional Claiborne Aquifer model was constructed using the same hydrologic and hydrogeologic properties and boundary types for the aquifer systems represented 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.

9.2 Comparison of the Sub-Regional Claiborne Aquifer to the Regional Georgia EPD Model

To verify that the sub-regional Claiborne 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 conditions as the regional Georgia EPD model. The groundwater elevations from the sub-regional model were then compared to the 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 9-5 through 9-10**). As shown on these figures, a comparison of the groundwater elevation contours indicates that the sub-regional Claiborne 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 63 monitor well locations

(**Figure 9-11**). 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 Claiborne Aquifer model reasonably represents the calibrated regional Georgia EPD model's hydrologic and hydrogeologic properties and boundary conditions.

9.3 Available Groundwater and Surface Water Level Data

9.3.1 Measured Groundwater Levels

According to the USGS NWIS database, there are 63 existing monitor wells installed in different aquifers of the Coastal Plain within the sub-regional Claiborne Aquifer model domain. These 63 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 Claiborne Aquifer model are shown on **Figure 9-12**, and the locations of monitor wells in each aquifer are shown on **Figures M-1 through M-4** in **Appendix M**. The distribution of monitor wells by aquifer used for sub-regional model calibration is as follows:

- 39 monitor wells in the Upper Floridan Aquifer (Layer 2);
- 12 monitor wells in the Claiborne/Gordon Aquifers (Layer 3);
- 11 monitor wells in the Clayton-Dublin Aquifers (Layer 4);
- 1 monitor well in the Providence Sand-Peedee-Dublin Aquifers (Cretaceous Aquifer System) (Layer 5);
- 0 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 N-1** in **Appendix N**). As shown, a total of 2,036 measured groundwater levels at 63 monitor well locations, from January 2004 through December 2006, were used for the groundwater model calibration. During this time period, groundwater levels at the Claiborne Aquifer monitor well locations ranged from approximately 52 feet NGVD, recorded at 12L020 in Dougherty County in September 2004, to approximately 303 feet NGVD, recorded at 11P015 in Lee County in August 2005.

9.3.2 Surface Water Levels

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

9.4 Well Pumping Rates

Georgia EPD records show that pumping data from the Claiborne 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 9-13** shows monthly pumping rates used in the Claiborne Aquifer model. Pumping rates shown on this figure are from all aquifers within the sub-regional model domain.

9.5 Sub-Regional Transient Claiborne 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.

9.5.1 Groundwater Levels

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

- **Figures 9-14 through 9-17** present the comparisons between the observed and the model-computed groundwater elevations at selected monitor wells in the Upper Floridan Aquifer (Layer 2);
- **Figures 9-18 through 9-21** and **Tables 9-1 through 9-4** present the comparisons between the observed and the model-computed groundwater elevations at selected monitor wells in the Claiborne Aquifer (Layer 3);
- **Figures 9-22 through 9-24** illustrate the comparisons between the observed and the model-computed groundwater elevations at selected monitor wells in the Clayton Aquifer (Layer 4); and
- **Figure 9-25** shows the comparisons between the observed and model-computed groundwater elevations at a selected monitor well in the Providence Sand-Peedee-Dublin Aquifers (Layer 5).
- Comparisons between the observed and the model-computed groundwater elevations at the 63 monitor wells are presented in **Tables O-1 through O-63** in **Appendix O**. The correlations between the observed and the model-computed groundwater elevations are shown on **Figures O-1 through O-63** in Appendix O.

Scattergrams comparing the observed and the model-computed groundwater elevations are one method for evaluating the calibration of groundwater models. A comparison between the observed and the model-computed groundwater elevations across all model layers is depicted on **Figure 9-26** using a scattergram for the 63 monitor wells. A layer-by-layer comparison between the observed and model-computed groundwater elevations for the 63 monitor wells in Layer 2 through Layer 5 are presented in the form of a scattergram displayed on **Figure O-64 through O-67** in Appendix O, respectively. A scattergram was not developed for Layers 6 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 Claiborne Aquifer model calibration statistics for all aquifer layers and each individual layer are summarized in **Table 9-5**. 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 9-1 Calibration Results for Monitor Well 06K010

Stress Period (month)	Month- Year	Time (day)	Model Layer	Observed Head (ft NGVD)	Computed Head (feet NGVD)	Residual (feet)
1	Jan-04	31	3	234.52	234.30	0.22
2	Feb-04	60	3	234.89	234.28	0.61
3	Mar-04	91	3	234.93	234.16	0.77
4	Apr-04	121	3	234.83	234.10	0.73
5	May-04	152	3	234.76	234.07	0.70
6	Jun-04	182	3	234.19	234.12	0.07
7	Jul-04	213	3	234.43	234.10	0.33
8	Aug-04	244	3	234.31	234.09	0.23
9	Sep-04	274	3	234.40	234.23	0.17
10	Oct-04	305	3	234.33	234.19	0.14
11	Nov-04	335	3	234.19	234.24	-0.05
12	Dec-04	366	3	234.20	234.21	-0.01
13	Jan-05	397	3	234.37	234.18	0.19
14	Feb-05	425	3	234.61	234.16	0.45
15	Mar-05	456	3	234.73	234.22	0.51
16	Apr-05	486	3	235.37	234.29	1.08
17	May-05	517	3	235.41	234.27	1.13
18	Jun-05	547	3	235.56	234.32	1.24
19	Jul-05	578	3	235.64	234.36	1.28
20	Aug-05	609	3	235.76	234.38	1.37
21	Sep-05	639	3	235.48	234.32	1.16
22	Oct-05	670	3	235.35	234.25	1.10
23	Nov-05	700	3	0.00	234.26	-234.26
24	Dec-05	731	3	0.00	234.26	-234.26
25	Jan-06	762	3	0.00	234.25	-234.25
26	Feb-06	790	3	235.14	234.25	0.90
27	Mar-06	821	3	235.21	234.17	1.04
28	Apr-06	851	3	235.06	234.13	0.93
29	May-06	882	3	235.10	234.13	0.98
30	Jun-06	912	3	234.67	234.07	0.60
31	Jul-06	943	3	234.22	234.03	0.20
32	Aug-06	974	3	233.78	234.01	-0.23
33	Sep-06	1004	3	233.40	233.98	-0.58
34	Oct-06	1035	3	233.01	233.97	-0.96
35	Nov-06	1065	3	233.05	233.95	-0.91
36	Dec-06	1096	3	0.00	233.95	-233.95
Average of Residuals						-25.59
Standard Deviation of Residuals						74.79
Root Mean Squared Error						78.06

Table 9-2 Calibration Results for Monitor Well 12M001

Stress Period (month)	Month-Year	Time (day)	Model Layer	Observed Head (ft NGVD)	Computed Head (feet NGVD)	Residual (feet)
1	Jan-04	31	3	136.30	136.97	0.67
2	Feb-04	60	3	142.46	140.51	-1.95
3	Mar-04	91	3	127.64	135.66	8.01
4	Apr-04	121	3	121.66	124.08	2.42
5	May-04	152	3	114.16	117.02	2.86
6	Jun-04	182	3	117.17	121.84	4.67
7	Jul-04	213	3	121.66	119.71	-1.95
8	Aug-04	244	3	117.64	119.02	1.38
9	Sep-04	274	3	119.18	124.19	5.02
10	Oct-04	305	3	120.78	124.64	3.86
11	Nov-04	335	3	121.43	126.74	5.32
12	Dec-04	366	3	131.02	133.31	2.30
13	Jan-05	397	3	135.37	135.36	-0.01
14	Feb-05	425	3	140.91	135.81	-5.10
15	Mar-05	456	3	134.96	132.61	-2.34
16	Apr-05	486	3	130.84	127.63	-3.21
17	May-05	517	3	121.66	120.50	-1.16
18	Jun-05	547	3	124.50	121.61	-2.90
19	Jul-05	578	3	126.97	122.07	-4.90
20	Aug-05	609	3	128.08	122.32	-5.76
21	Sep-05	639	3	112.76	109.55	-3.21
22	Oct-05	670	3	109.78	108.84	-0.93
23	Nov-05	700	3	108.56	109.74	1.18
24	Dec-05	731	3	117.20	120.91	3.71
25	Jan-06	762	3	119.14	125.26	6.12
26	Feb-06	790	3	123.55	127.83	4.28
27	Mar-06	821	3	118.88	125.11	6.23
28	Apr-06	851	3	115.01	111.31	-3.70
29	May-06	882	3	107.81	108.69	0.88
30	Jun-06	912	3	94.11	106.80	12.69
31	Jul-06	943	3	91.50	105.45	13.95
32	Aug-06	974	3	91.36	104.89	13.53
33	Sep-06	1004	3	92.77	104.66	11.89
34	Oct-06	1035	3	98.95	105.06	6.11
35	Nov-06	1065	3	107.26	105.69	-1.56
36	Dec-06	1096	3		106.75	
Average of Residuals						2.24
Standard Deviation of Residuals						5.35
Root Mean Squared Error						5.73

Table 9-3 Calibration Results for Monitor Well 11J011

Stress Period (month)	Month- Year	Time (day)	Model Layer	Observed Head (ft NGVD)	Computed Head (feet NGVD)	Residual (feet)
1	Jan-04	31	3	124.81	124.74	-0.07
2	Feb-04	60	3	124.87	126.94	2.06
3	Mar-04	91	3	125.14	126.11	0.98
4	Apr-04	121	3	124.75	125.12	0.37
5	May-04	152	3	124.02	124.55	0.53
6	Jun-04	182	3	122.85	124.28	1.43
7	Jul-04	213	3	122.32	123.97	1.65
8	Aug-04	244	3	121.82	123.54	1.72
9	Sep-04	274	3		125.55	
10	Oct-04	305	3	122.58	125.11	2.54
11	Nov-04	335	3	122.96	124.99	2.04
12	Dec-04	366	3	123.35	125.05	1.71
13	Jan-05	397	3	123.42	124.93	1.51
14	Feb-05	425	3	123.64	125.46	1.82
15	Mar-05	456	3	124.16	126.49	2.33
16	Apr-05	486	3	127.35	128.95	1.60
17	May-05	517	3	128.82	126.32	-2.50
18	Jun-05	547	3	129.14	126.38	-2.77
19	Jul-05	578	3	129.63	127.98	-1.65
20	Aug-05	609	3	130.15	126.39	-3.75
21	Sep-05	639	3	129.73	124.86	-4.86
22	Oct-05	670	3	127.50	124.14	-3.36
23	Nov-05	700	3	126.79	123.90	-2.90
24	Dec-05	731	3	125.69	124.42	-1.27
25	Jan-06	762	3	125.82	125.05	-0.77
26	Feb-06	790	3	126.52	125.19	-1.33
27	Mar-06	821	3	127.18	125.56	-1.62
28	Apr-06	851	3	126.72	124.71	-2.01
29	May-06	882	3	125.57	124.03	-1.54
30	Jun-06	912	3	123.71	122.97	-0.74
31	Jul-06	943	3	122.04	122.35	0.31
32	Aug-06	974	3	121.12	122.28	1.16
33	Sep-06	1004	3	120.59	122.26	1.67
34	Oct-06	1035	3	120.04	122.15	2.11
35	Nov-06	1065	3	120.03	122.77	2.74
36	Dec-06	1096	3	120.01	122.79	2.78
Average of Residuals						0.05
Standard Deviation of Residuals						2.11
Root Mean Squared Error						2.08

Table 9-4 Calibration Results for Monitor Well 13M005

Stress Period (month)	Month-Year	Time (day)	Model Layer	Observed Head (ft NGVD)	Computed Head (feet NGVD)	Residual (feet)
1	Jan-04	31	3	226.87	222.55	-4.32
2	Feb-04	60	3	227.62	225.13	-2.50
3	Mar-04	91	3	228.11	226.33	-1.78
4	Apr-04	121	3	224.50	220.79	-3.70
5	May-04	152	3	223.49	222.37	-1.12
6	Jun-04	182	3	222.50	224.24	1.74
7	Jul-04	213	3	220.84	221.83	1.00
8	Aug-04	244	3	218.14	221.01	2.87
9	Sep-04	274	3	223.57	228.37	4.80
10	Oct-04	305	3	225.87	229.85	3.98
11	Nov-04	335	3	227.07	229.62	2.55
12	Dec-04	366	3	228.62	230.36	1.75
13	Jan-05	397	3	229.63	230.60	0.96
14	Feb-05	425	3	230.35	230.70	0.35
15	Mar-05	456	3	230.99	231.02	0.03
16	Apr-05	486	3	232.19	232.31	0.11
17	May-05	517	3	231.08	229.67	-1.42
18	Jun-05	547	3	230.15	229.50	-0.65
19	Jul-05	578	3	230.02	229.60	-0.41
20	Aug-05	609	3	228.03	227.93	-0.11
21	Sep-05	639	3		226.03	
22	Oct-05	670	3	226.92	229.27	2.35
23	Nov-05	700	3	226.74	228.86	2.12
24	Dec-05	731	3	227.32	229.47	2.16
25	Jan-06	762	3	228.66	230.96	2.30
26	Feb-06	790	3	229.65	231.31	1.66
27	Mar-06	821	3	230.24	231.00	0.75
28	Apr-06	851	3	228.69	228.04	-0.66
29	May-06	882	3	225.40	224.09	-1.31
30	Jun-06	912	3	216.99	214.61	-2.38
31	Jul-06	943	3	209.95	210.29	0.34
32	Aug-06	974	3	210.84	217.19	6.36
33	Sep-06	1004	3	213.22	222.37	9.15
34	Oct-06	1035	3	215.51	224.52	9.01
35	Nov-06	1065	3	217.36	225.19	7.83
36	Dec-06	1096	3	218.45	224.53	6.07
Average of Residuals						1.43
Standard Deviation of Residuals						3.30
Root Mean Squared Error						3.55

Table 9-5 Claiborne Aquifer Sub-Regional Model Calibration Statistics

Calibration Statistics	Value/Unit				
	Model Layer ¹				
	Overall ²	2	3	4	5
No. of Monitor Wells	63	39	12	11	1
Average of Residuals (ft) ³	0.28	-0.50	1.46	1.74	2.05
Standard Deviation of Residuals (ft)	4.82	4.01	4.66	6.91	2.07
Root Mean Square Error of Residuals (ft)	4.83	4.04	4.88	7.12	2.89
Observed Head Difference Across Layers at MWs (ft)	251 (52 to 303)	222 (59 to 281)	211 (92 to 303)	228 (52 to 280)	21 (67 to 88)
Average of Residuals/Head Difference Across Layers at MW (%)	0.11	0.22	0.69	0.76	9.56
Standard Deviation of Residuals/Head Difference Across Layers at MW (%)	1.92	1.81	2.21	3.04	9.64

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 Aquifer

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 9-5, the average residual (model-computed minus observed) for all layers and 2,036 observed groundwater levels at 63 monitor well locations is about 0.28 feet. The standard deviation and RMSE of residuals are approximately 4.82 and 4.83 feet, respectively. The ratio of the average of residuals to the head difference across the model is approximately 0.11 percent. The ratio of the standard deviation of residuals to the head difference across the model is approximately 1.92 percent. The average of residuals for Layers 2 through 5 ranges from approximately -0.50 feet in Layer 2 to 2.05 feet in Layer 5. The standard deviation of residuals for Layers 2 through 5 ranges from approximately 2.07 feet in Layer 5 to 6.91 feet in Layer 4. The RMSE of residuals for Layers 2 through 5 ranges from approximately 2.89 feet in Layer 5 to 7.12 feet in Layer 4.

According to the model calibration criteria established for this project, the sub-regional Claiborne 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 9-5, the groundwater levels at monitor well locations varied from about 52 to 303 feet

NGVD, representing a difference of 251 feet across the entire model area (both spatially and vertically). Thus, the criterion for mean residual was about 0.11 percent of the head difference and the criterion for the standard deviation was about 1.92 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.

9.5.2 Groundwater Flow Patterns

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

- 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 9-27 through 9-32**, 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 9-33 through 9-38**, 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 O-68 through O-73** in Appendix O, 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 O-74 through O-79** in Appendix O, respectively.

As shown on these figures, the predominant groundwater flow direction in all of the aquifers within the project area occurs from the outcrop areas south of the Fall Line toward the south to the Gulf of Mexico. 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 O-69 to those on Figure 9-28 indicate that there is little, if any differences between wet and dry years, even in the recharge areas.

The figures demonstrate that groundwater flows in the Upper Floridan Aquifer (Layer 2) and Claiborne/Gordon/Lower Floridan Aquifers (Layer 3) are significantly influenced by the Gulf Trough. The calibrated sub-regional Claiborne Aquifer groundwater model clearly represents this hydrogeologic feature.

9.5.3 Vertical Head Differences Between Aquifers

As shown on Figures 9-27 through 9-32 and 9-33 through 9-38, there are vertical head differences between each layer (i.e., Layers 2 through 7) within the sub-regional Claiborne 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 9-6 and **Figure 9-39** summarize the model-computed and observed groundwater levels in 26 monitor well clusters installed in different aquifers at 11 locations (**Figure 9-40**). As shown in Table 9-6 and on Figure 9-39, the average vertical head differences between aquifers vary as follows:

- From approximately -6 feet (upward gradient) to 50 feet (downward gradient) with an average downward gradient of about 19 feet from the Upper Floridan Aquifer to the Claiborne Aquifer in the model domain;
- From approximately 18 feet (downward gradient) to 94 feet (downward gradient) with an average downward gradient of about 49 feet between the Claiborne and Clayton Aquifers;
- At monitor well cluster 12L029/12L021, there was a downward gradient from the Upper Floridan Aquifer to the Providence Sand-Peedee-Dublin Aquifers of approximately 78 feet; and
- At monitor well clusters 13L012/ 13L013 and 13L049/ 13L002, there was a downward gradient from the Upper Floridan Aquifer to the Clayton Aquifer of approximately 61 and 74 feet, respectively.
- The average of vertical head difference residuals is 1.08 feet and the standard deviation of vertical head difference residuals is 3.27 feet.

As shown on Figure 9-39, the average residual of vertical groundwater head difference (model-computed minus observed) for all layers is about 1.08 feet. Overall standard deviation and RMSE of residuals are approximately 3.27 feet and 3.39 feet, respectively. Some of the well clusters are in close proximity to groundwater withdrawals (wells) that could affect the vertical components of hydraulic gradient.

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

Table 9-6 Comparison Between Observed and Simulated Vertical Head Differences in Sub-Regional Claiborne Aquifer Model

MW Cluster	Aquifer	USGS ID	Model Layer	Average Groundwater Elevation, 2004-2006 (ft NGVD)		Residual (ft)
				Measured	Computed	
1	UFA	13L012	2	153.0	153.1	0.1
	Claiborne	13L011	3	128.8	127.8	-1.1
	Clayton	13L013	4	93.9	92.0	-1.9
	Δ Head	-	-	59.1	61.1	-
2	Claiborne	06K010	3	234.7	234.2	-0.5
	Clayton	06K009	4	136.8	139.7	3.0
	□ Head	-	-	97.9	94.5	-
3	Claiborne	11L001	3	198.5	196.4	-2.1
	Clayton	11L002	4	106.8	104.0	-2.9
	Δ Head	-	-	91.7	92.4	-
4	Claiborne	11P015	3	300.8	300.4	-0.4
	Clayton	11P014	4	246.8	246.7	0.0
	□ Head	-	-	54.1	53.7	-
5	Claiborne	12M001	3	118.4	120.6	2.2
	Clayton	12M002	4	92.6	102.3	9.7
	Δ Head	-	-	25.8	18.3	-
6	UFA ¹	12L029	2	155.9	157.8	2.0
	Claiborne	12L019	3	126.4	133.4	7.1
	Clayton	12L020	4	73.2	78.8	5.6
	Providence	12L021	5	77.7	79.8	2.1
	Δ Head	-	-	78.1	78.0	-
7	UFA ²	13L049	2	172.5	167.2	-5.3
	Claiborne ²	13L015	3	113.2	116.8	3.5
	Clayton ²	13L002	4	93.5	92.8	-0.8
	Δ Head	-	-	78.9	74.4	-
8	UFA	13M006	2	228.9	228.3	-0.6
	Claiborne	13M005	3	224.7	226.2	1.4
	□ Head	-	-	4.2	2.1	-
9	Claiborne	11K002	3	158.1	156.4	-1.7
	Clayton	11K005	4	110.2	111.5	1.3
	Δ Head	-	-	48.0	44.9	-
10	UFA	11J012	2	119.1	118.6	-0.5
	Claiborne	11J011	3	124.7	124.8	0.1
	□ Head	-	-	-5.6	-6.1	-
11	Claiborne	14P015	3	228.3	233.6	5.3
	Clayton	14P014	4	207.1	209.5	2.4
	Δ Head	-	-	21.2	24.1	-
Average of Residuals						1.1
Standard Deviation of Residuals						3.3
Root Mean Square Error of Residuals						3.4

Notes:

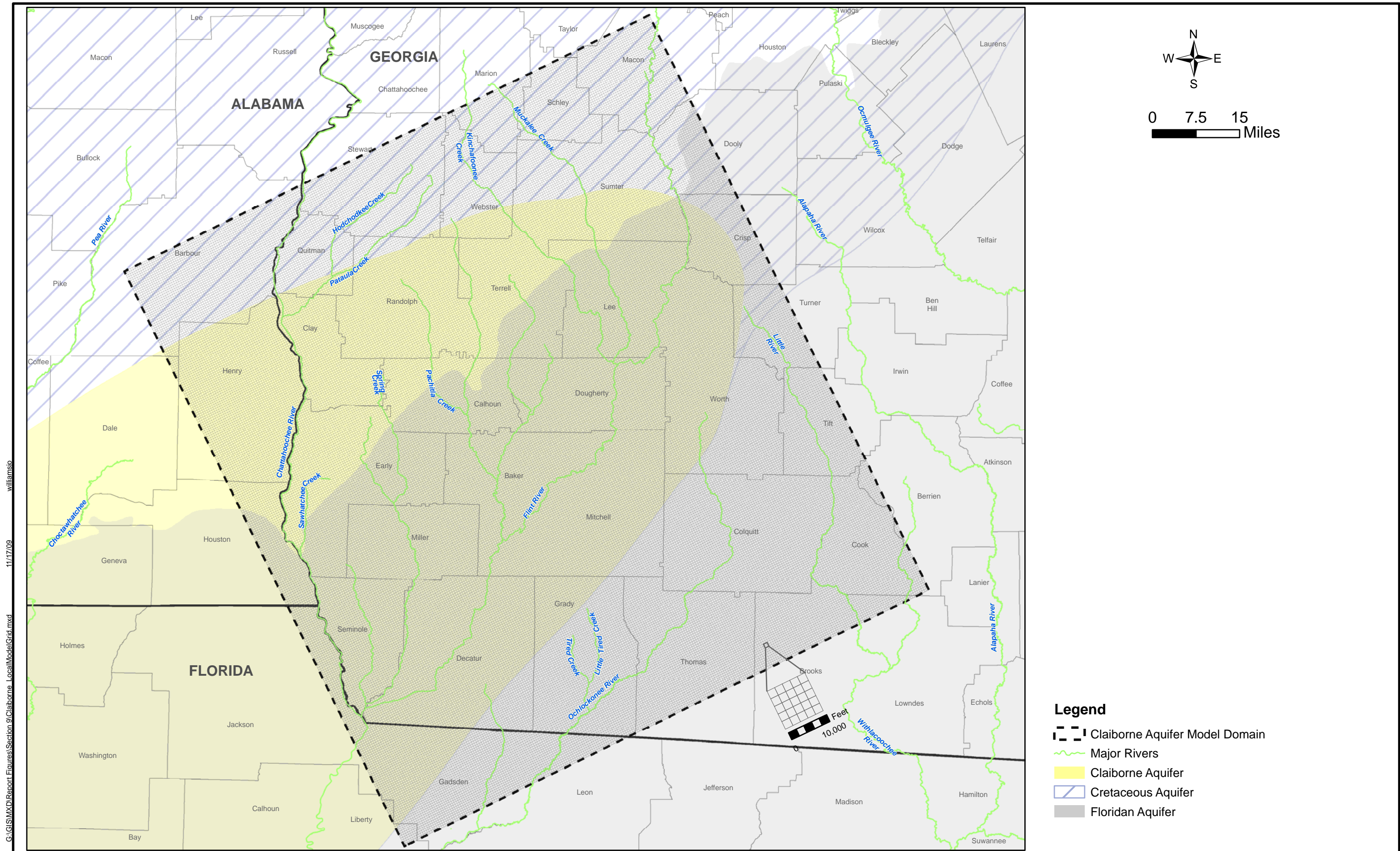
¹Monitor well is about 7,000 feet from cluster wells.

²Monitor wells are within about 3,000 feet radius.

9.6 Revised Hydrogeologic and Hydrologic Properties

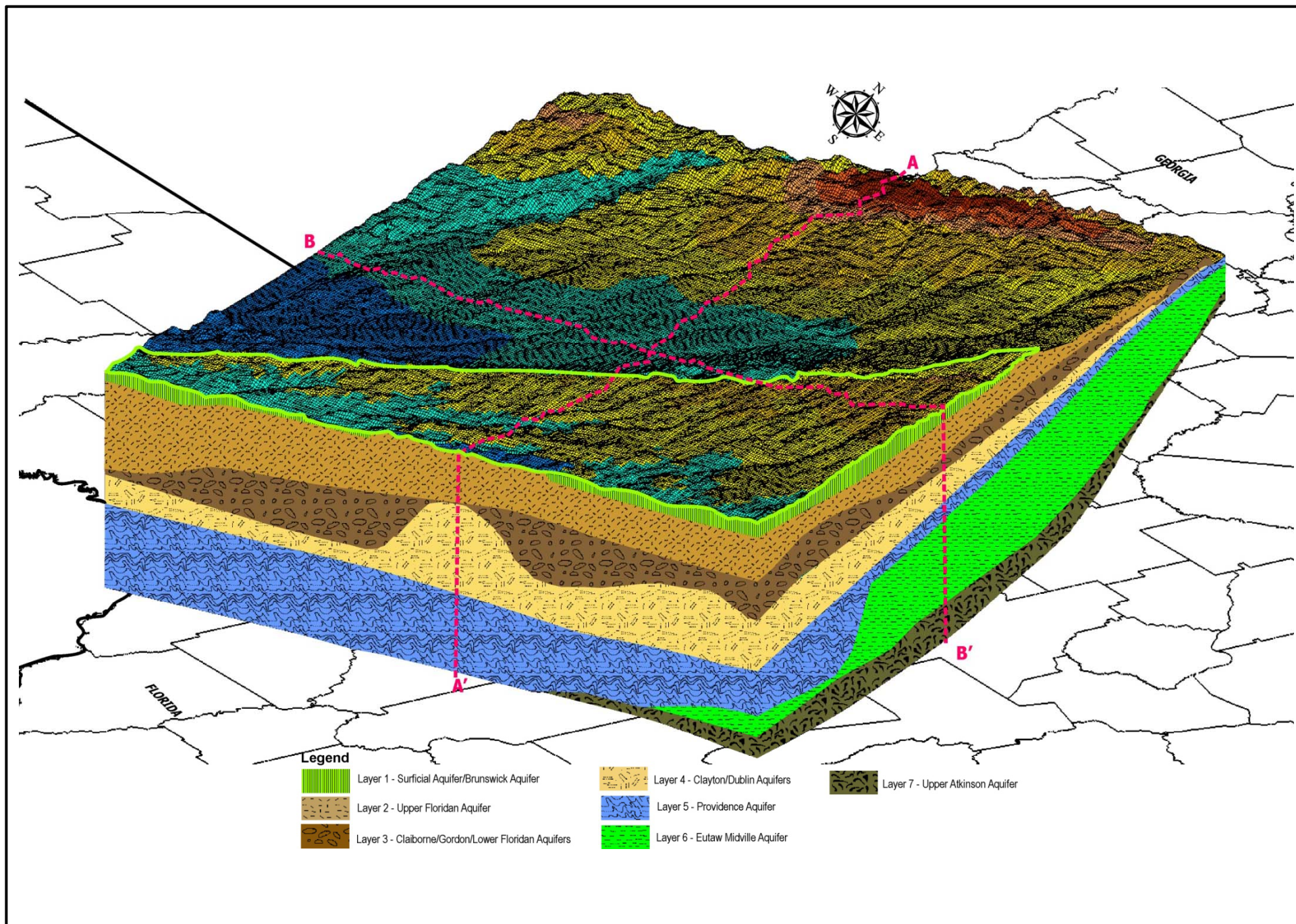
As discussed in Section 9.1.4, initial hydrologic and hydrogeologic properties in the sub-regional Claiborne Aquifer model were imported from the calibrated regional Georgia EPD model. During the transient model calibration, spatial changes in hydraulic conductivity, transmissivity, leakance and storage coefficient of the aquifers were made. Modifications to these parameters are shown on **Figures P-1 through P-19** in **Appendix P** for Layers 2 through 7, respectively. Variations in 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 Claiborne Aquifer model.

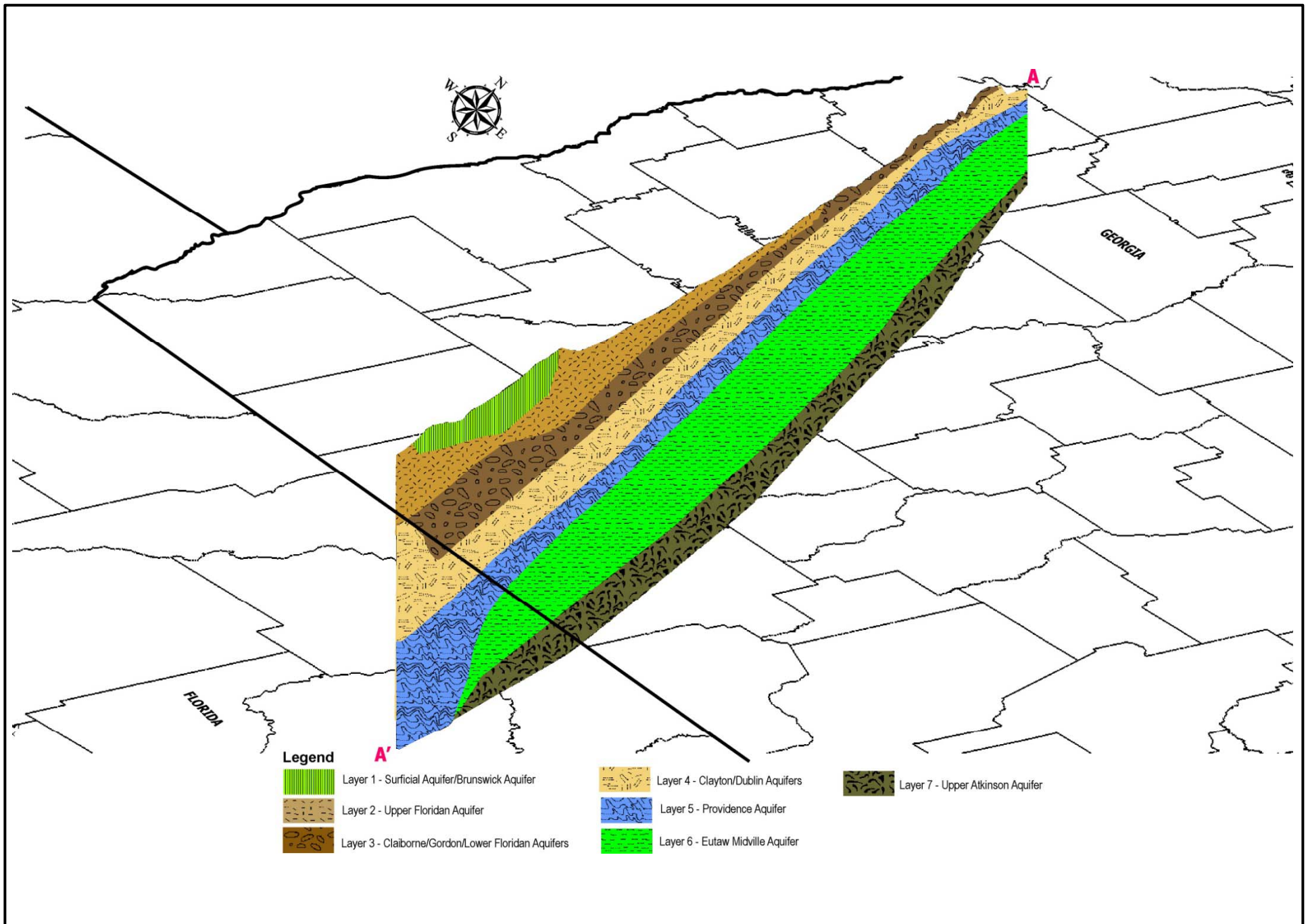
The average net recharge used in the calibrated sub-regional Claiborne Aquifer model is shown on **Figure P-20**. There are no published values of monthly recharge. The average recharge values used in the outcrop areas of the regional model are consistent with literature and estimates from streamflow data. The procedures used estimate monthly recharge values are described in Section 7.3. Variations in 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 9-41 through 9-43** 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.

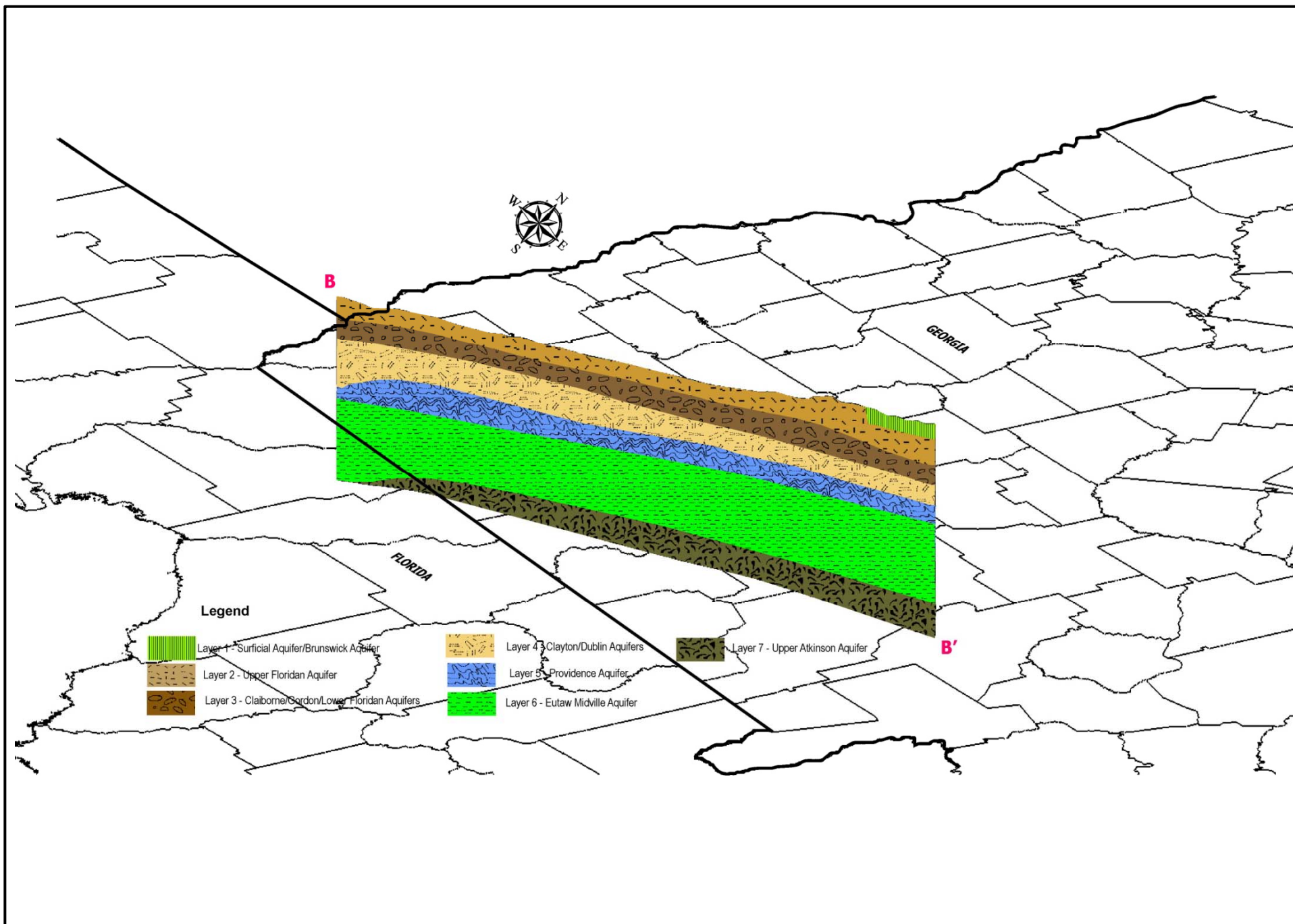


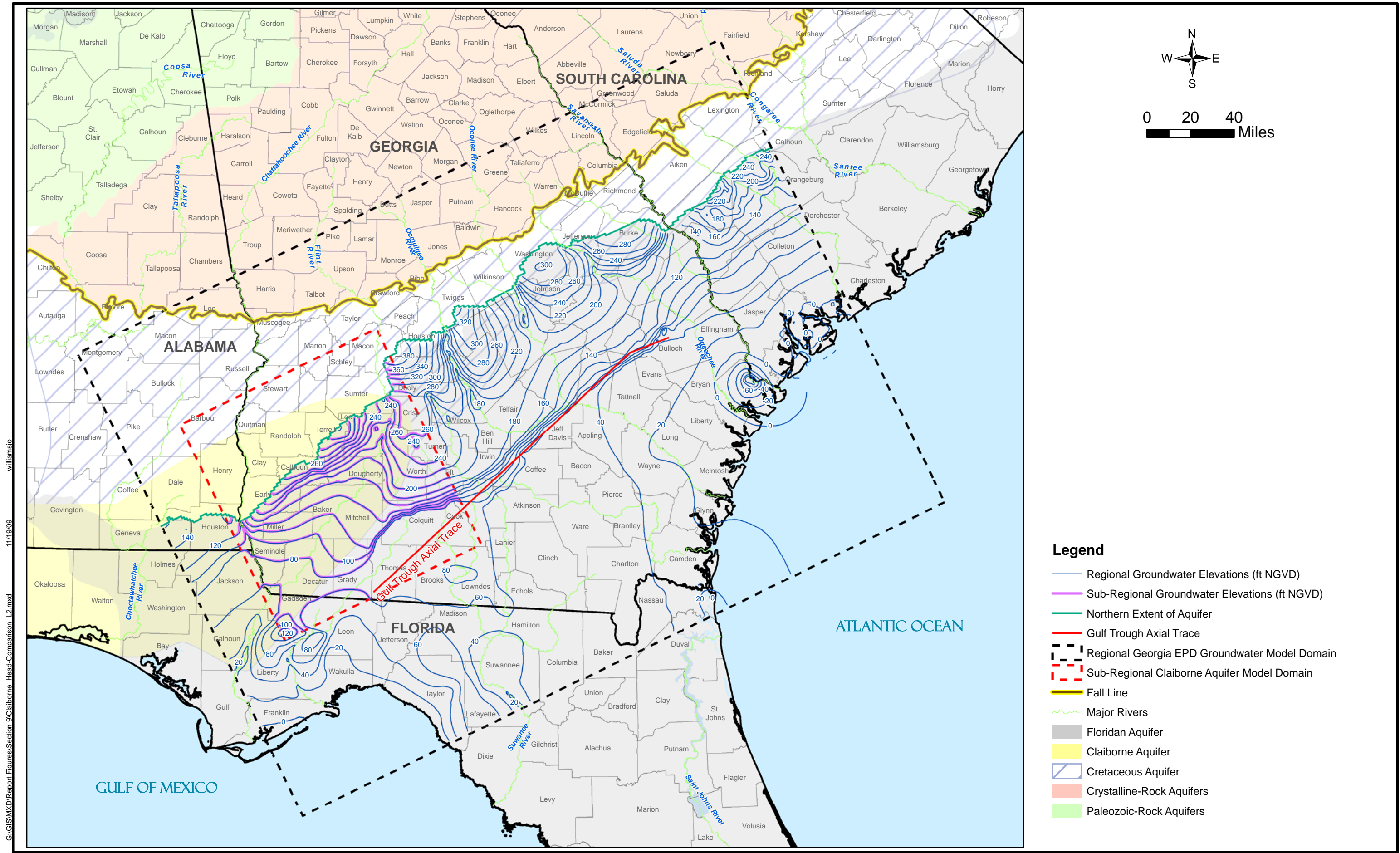
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CDM **Figure 9-1**
Sub-Regional Transient Claiborne Aquifer Model and Model Grid System





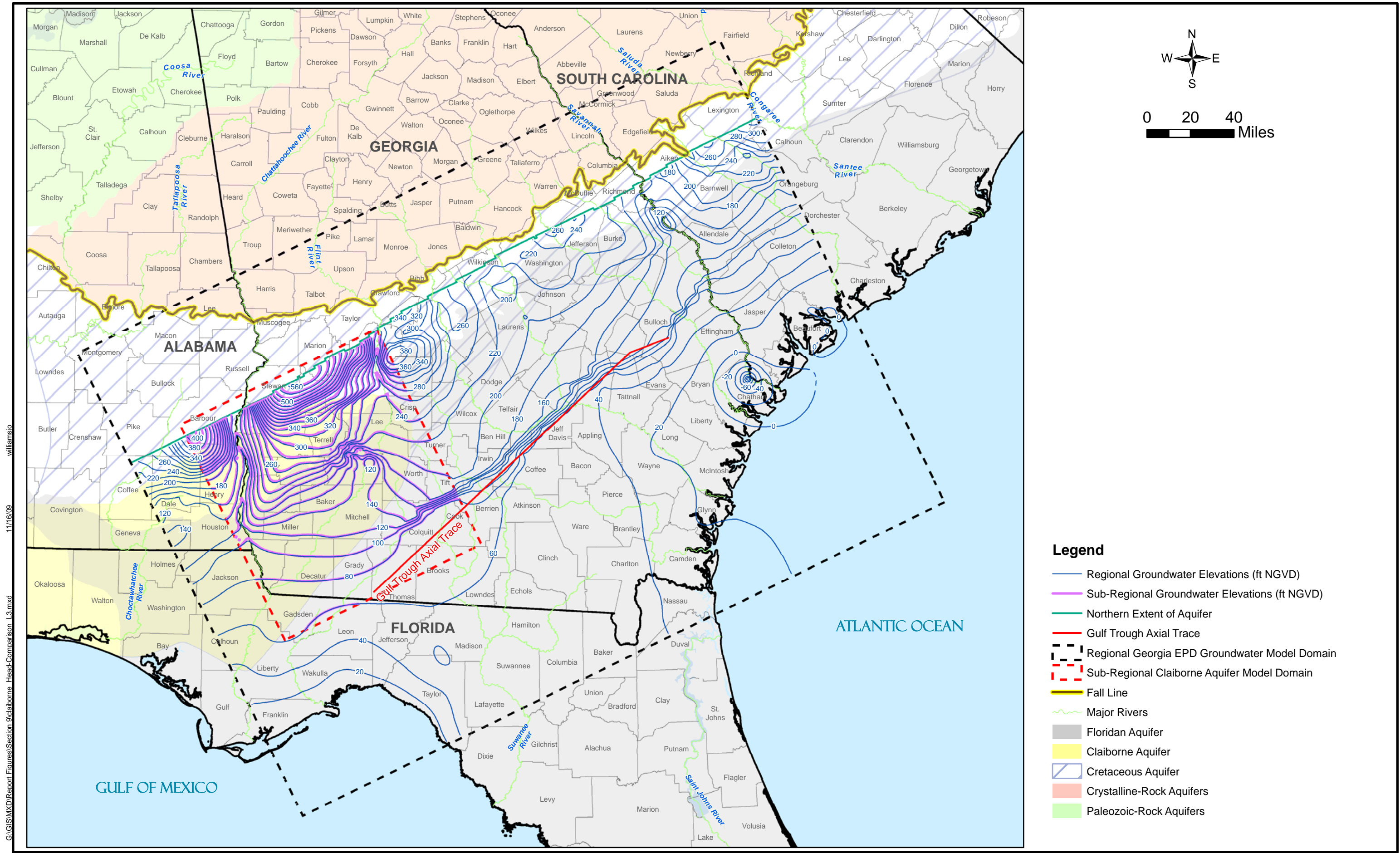




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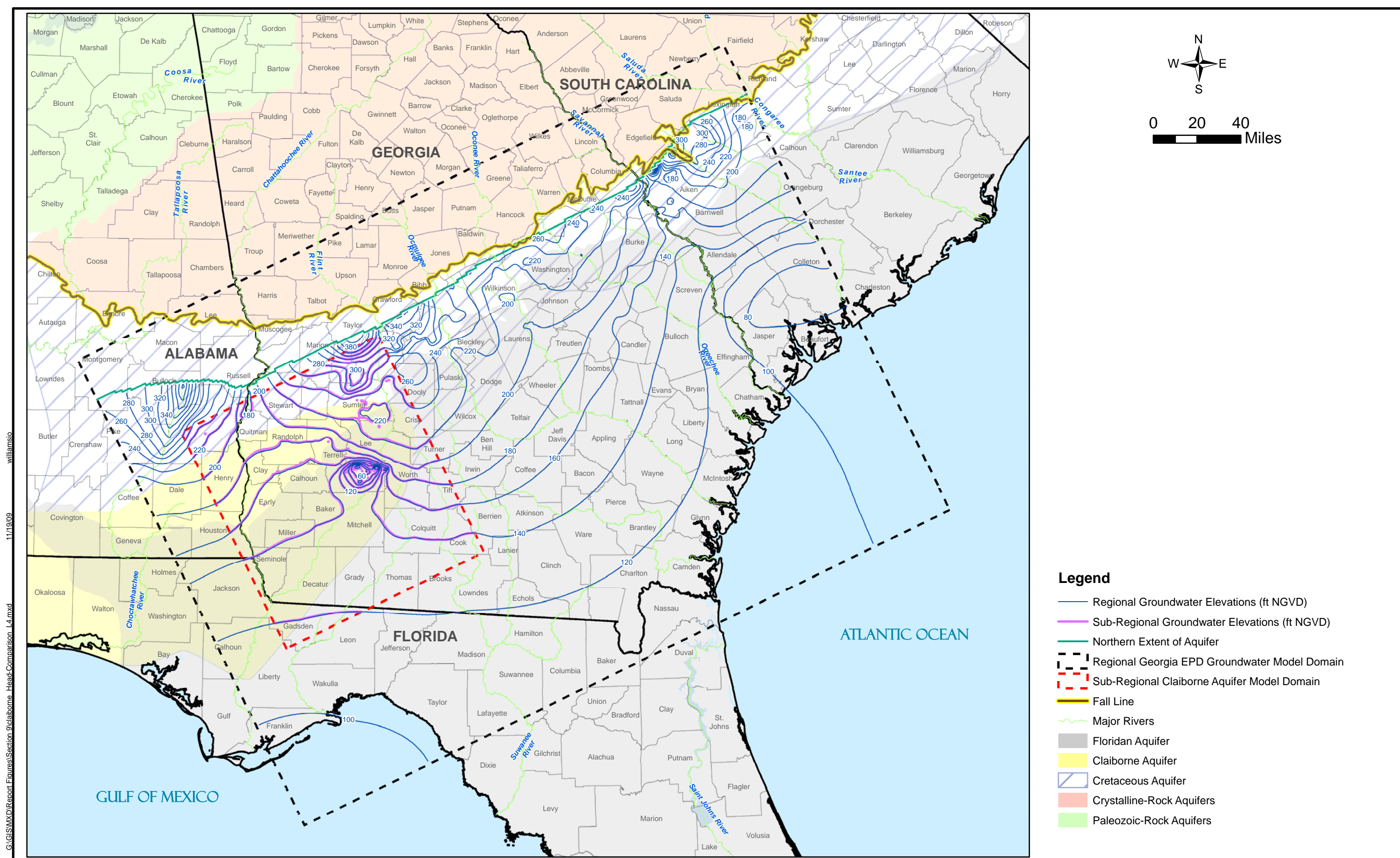
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Figure 9-5
Comparison of Groundwater Elevations in Upper Floridan Aquifer (Layer 2)
Using Regional Georgia EPD Model and Sub-Regional Claiborne Aquifer Model



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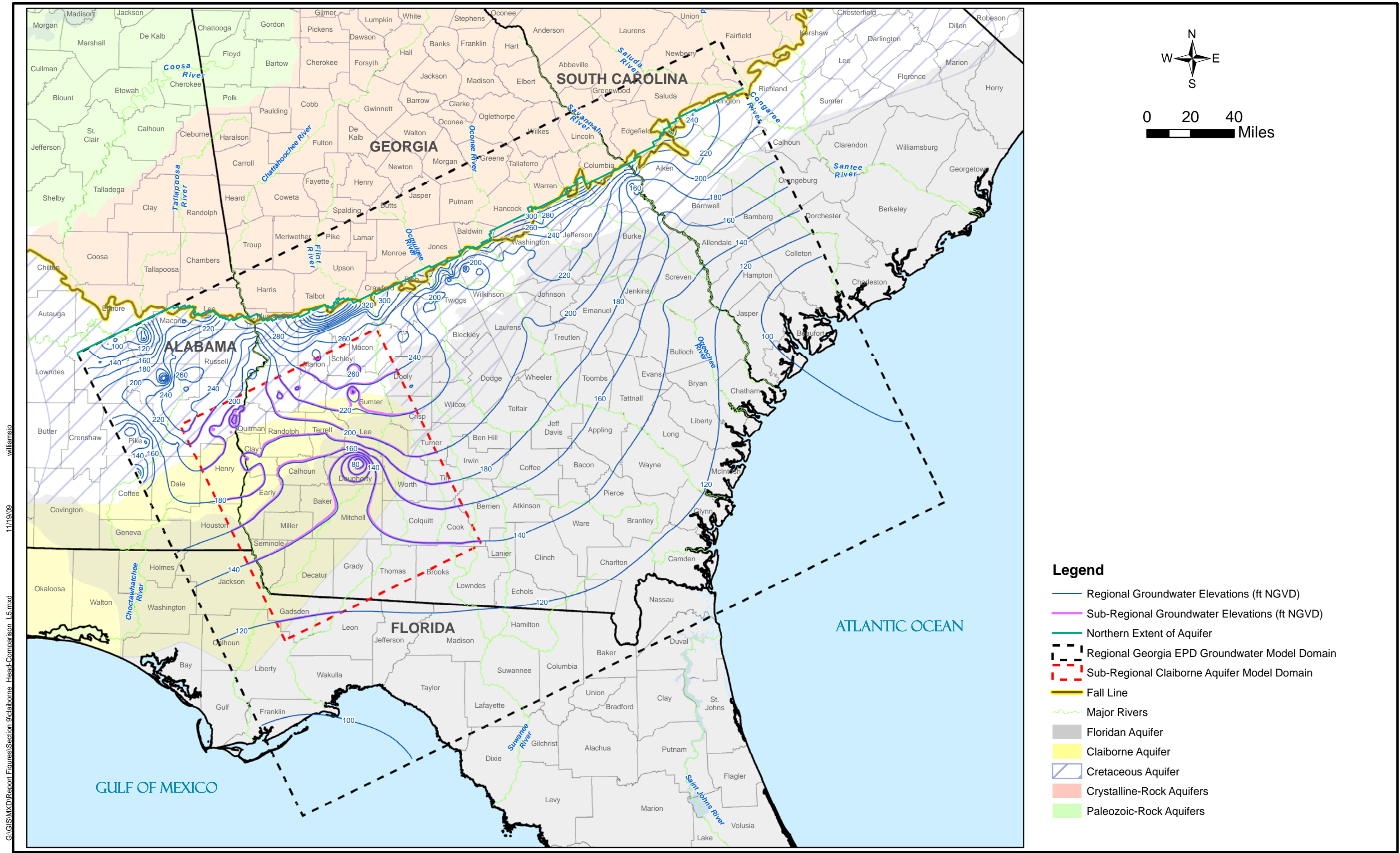
CDM **Figure 9-6**
Comparison of Groundwater Elevations in Claiborne/Gordon/Lower Floridan Aquifers (Layer 3)
Using Regional Georgia EPD Model and Sub-Regional Claiborne Aquifer Model



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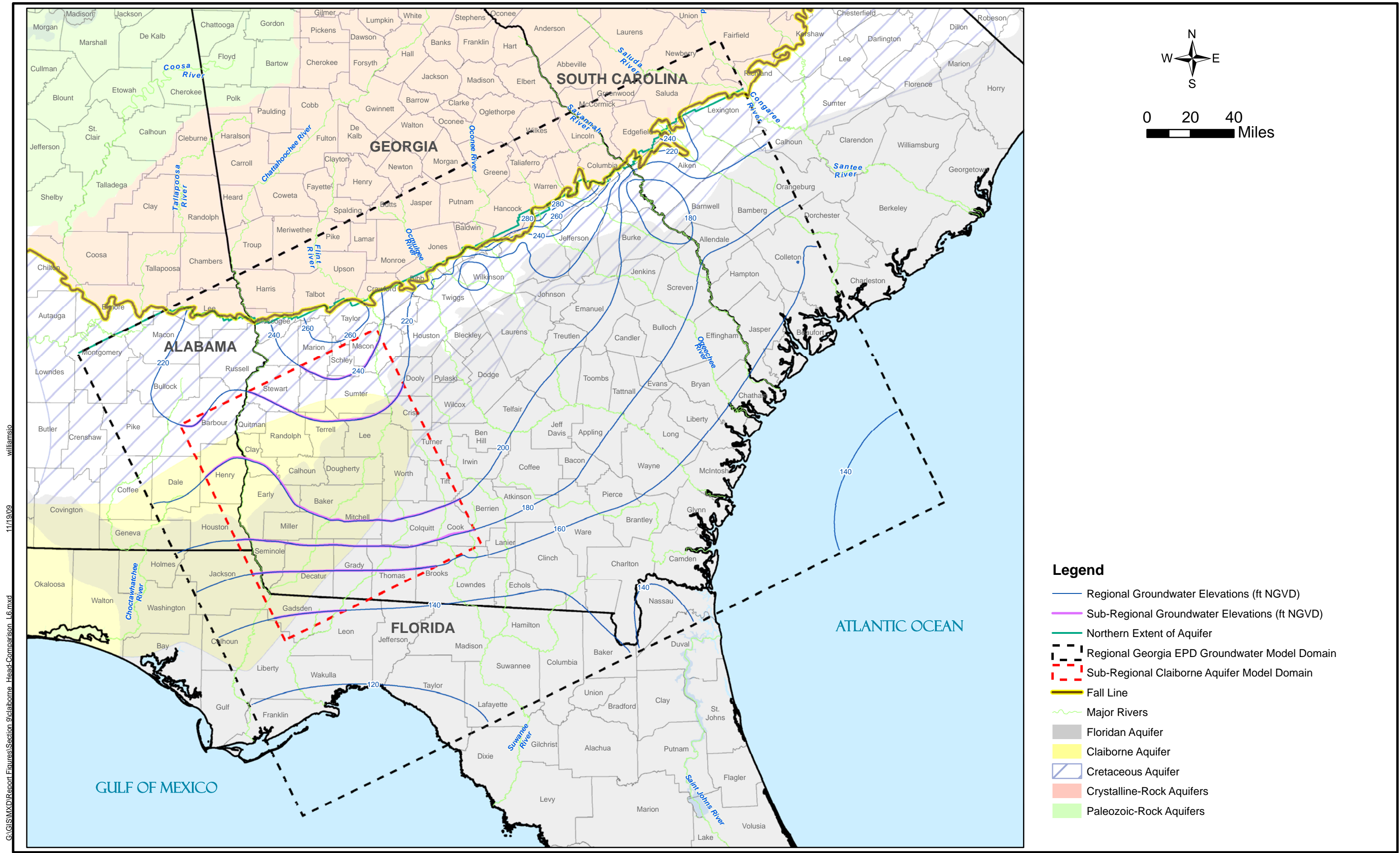
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Figure 9-7
Comparison of Groundwater Elevations in Clayton-Dublin Aquifers (Layer 4)
Using Regional Georgia EPD Model and Sub-Regional Claiborne Aquifer Model



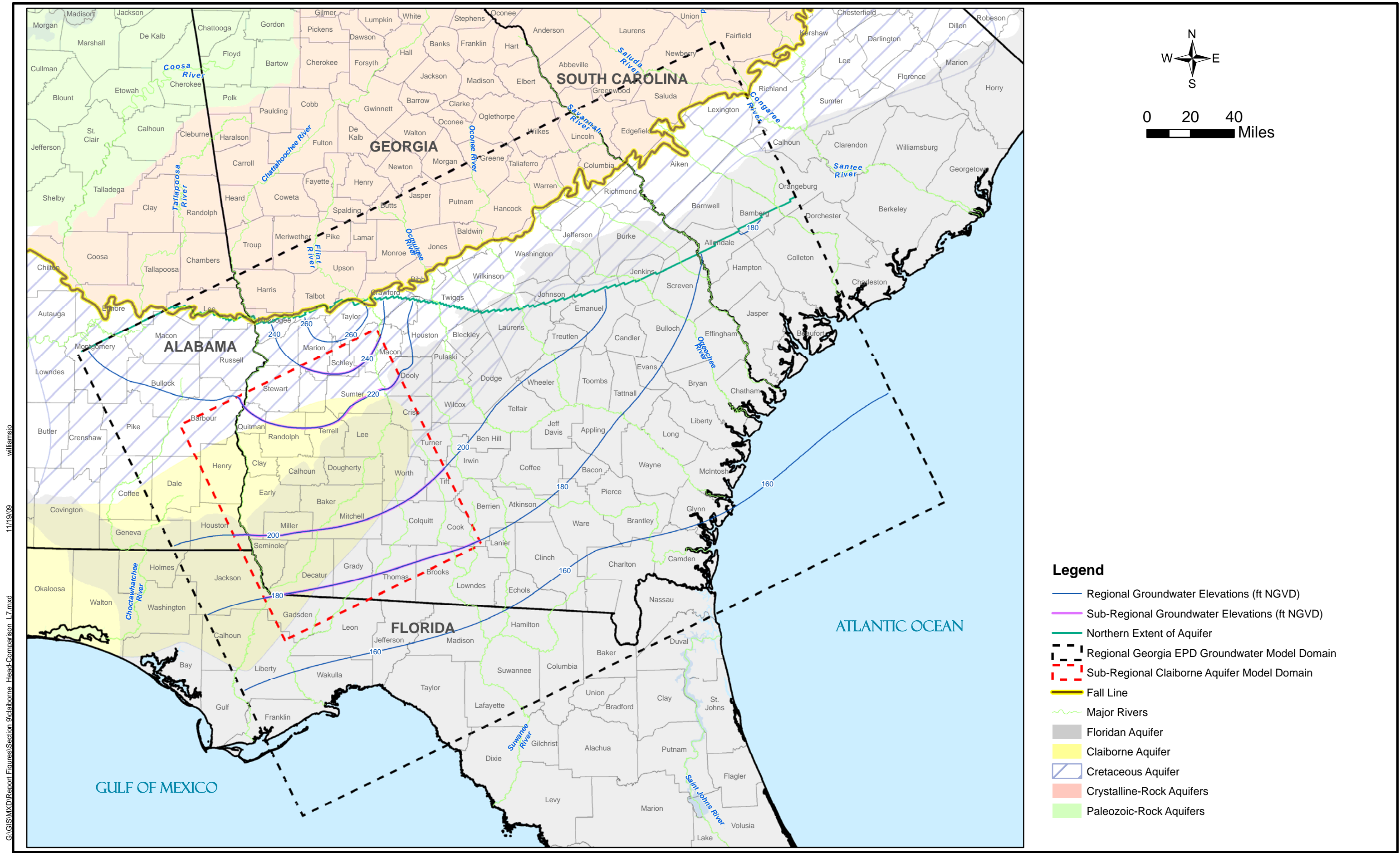
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CDM **Figure 9-8**
Comparison of Groundwater Elevations in Providence Sand-Peedee-Dublin Aquifers (Layer 5)
Using Regional Georgia EPD Model and Sub-Regional Claiborne Aquifer Model



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



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CDM **Figure 9-10**
Comparison of Groundwater Elevations in Upper Atkinson-Upper Tuscaloosa Aquifers (Layer 7)
Using Regional Georgia EPD Model and Sub-Regional Claiborne Aquifer Model

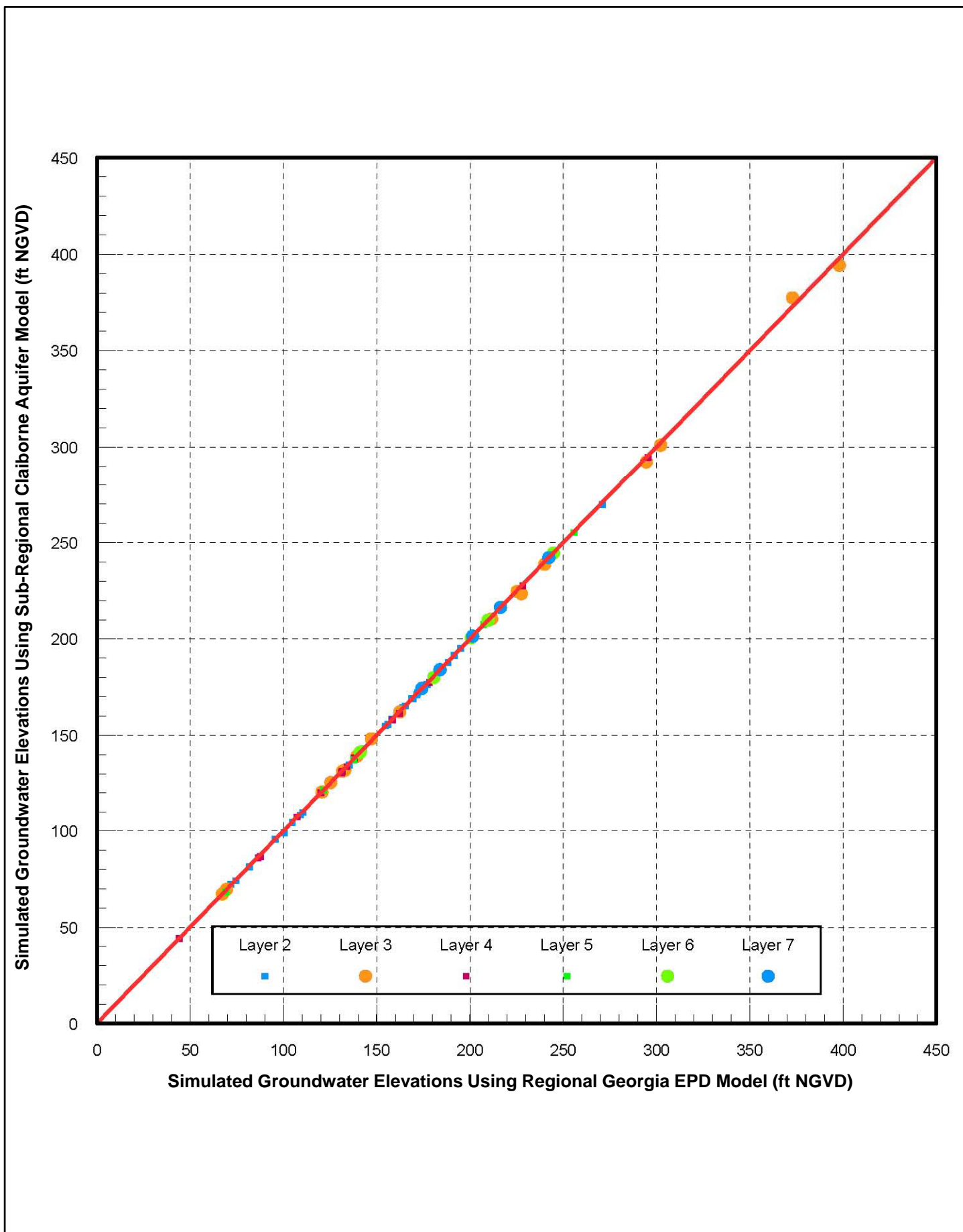


Figure 9-11
Scattergram Comparison of Regional Georgia EPD Groundwater Flow Model
Versus Sub-Regional Claiborne Aquifer Groundwater Flow Model

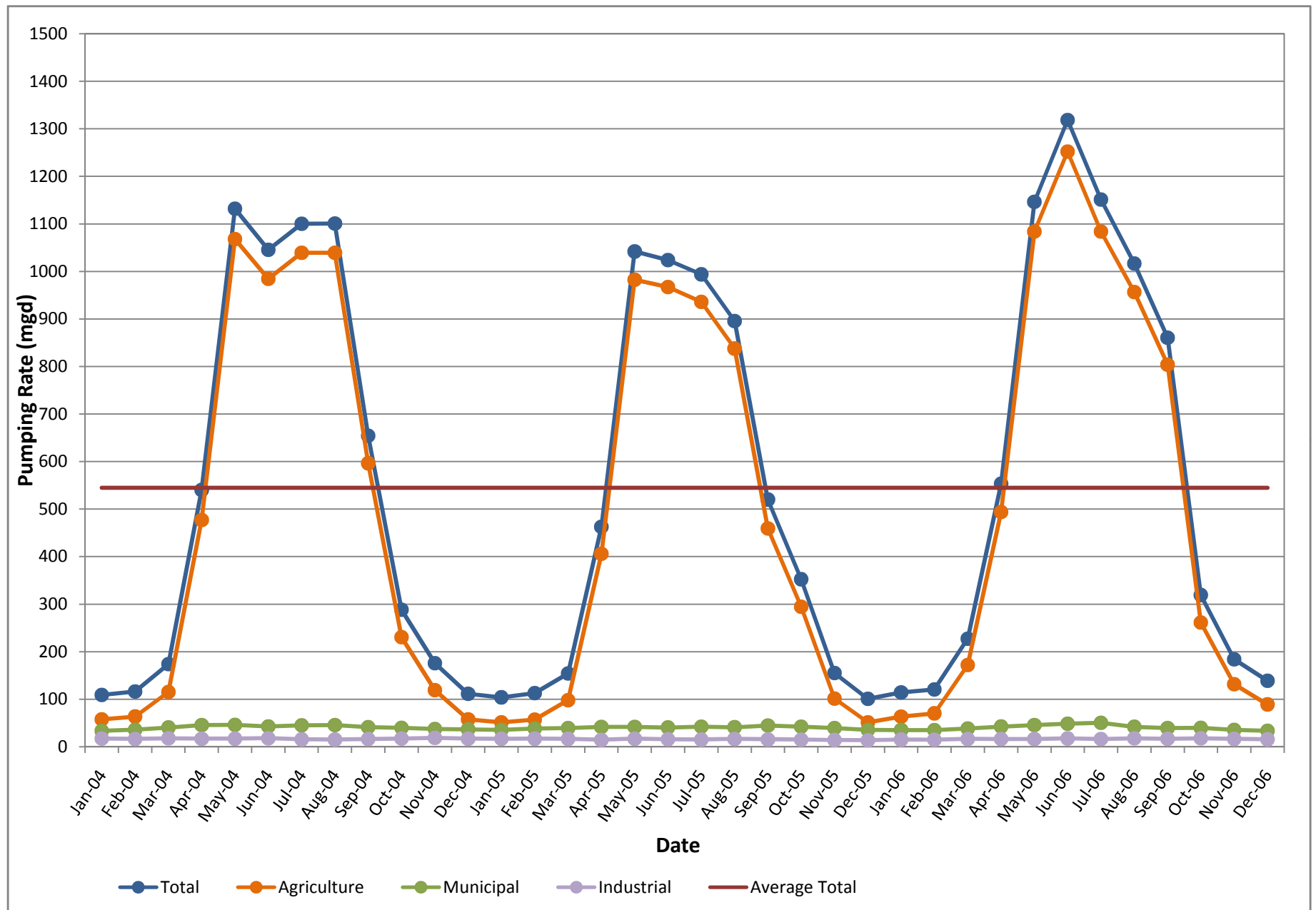


Figure 9-13
Permitted User Well Pumping Rates in Georgia
Used in Sub-Regional Claiborne Model

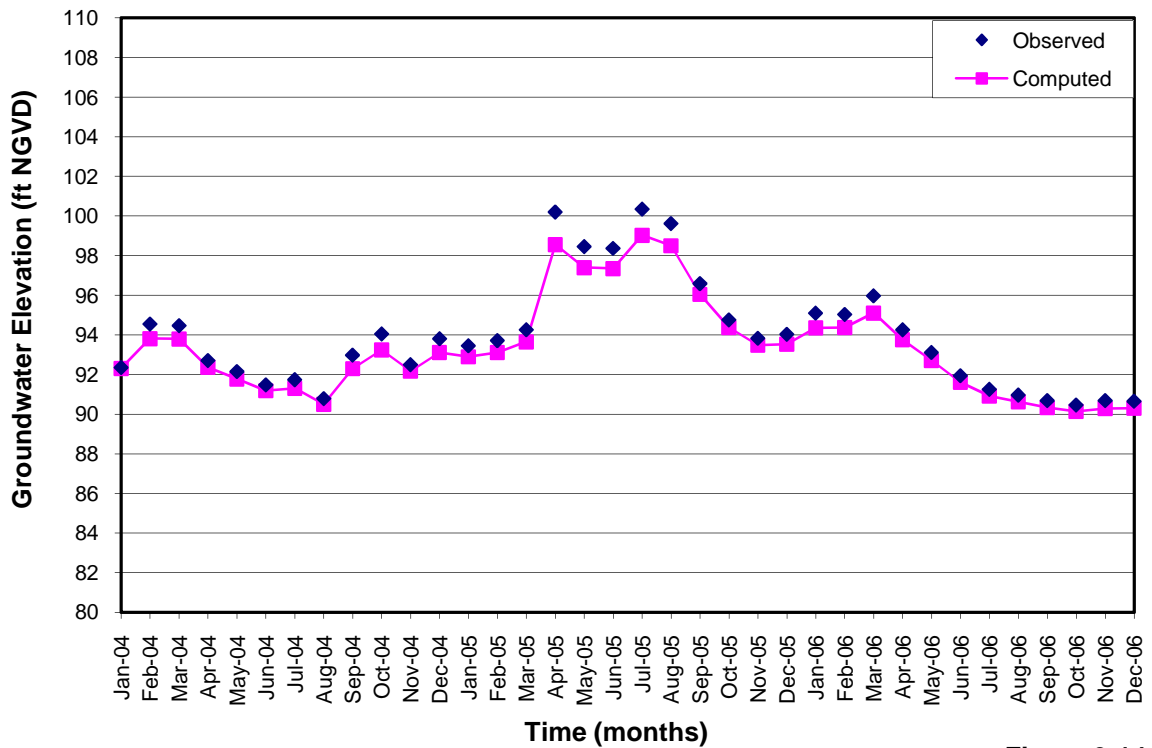


Figure 9-14

Comparison of Measured versus Simulated Groundwater Levels at 09G001 (Layer2)

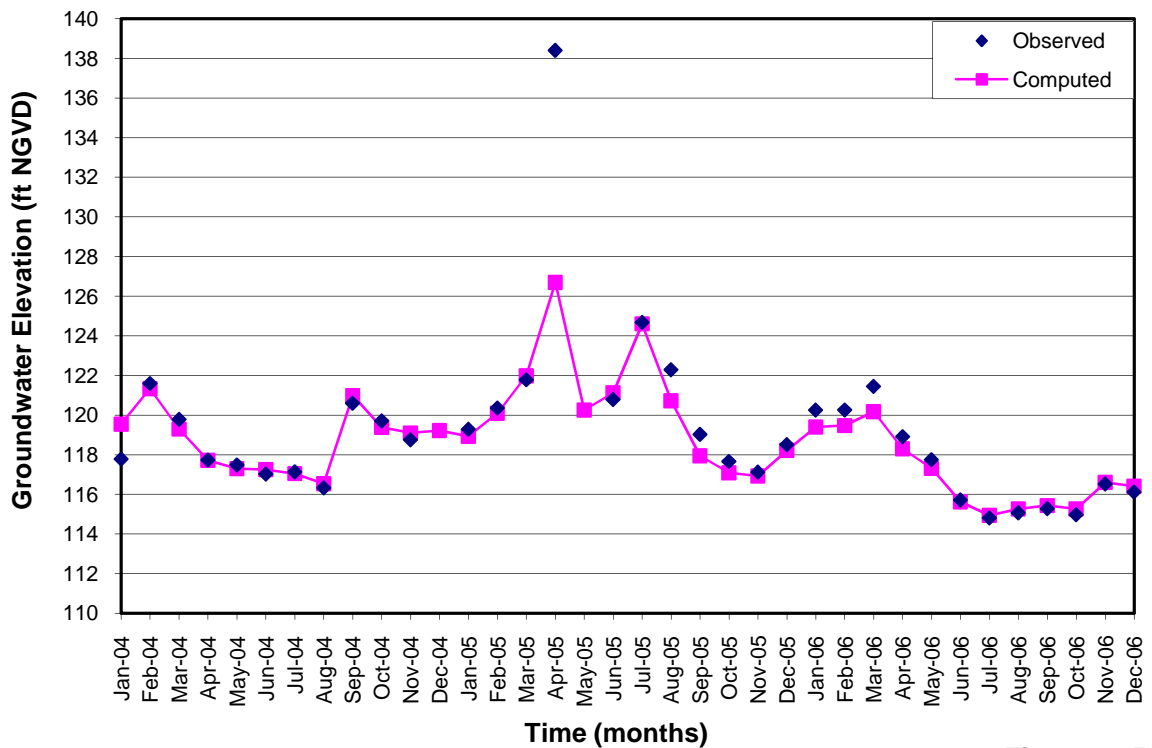


Figure 9-15

Comparison of Measured versus Simulated Groundwater Levels at 11J012 (Layer2)

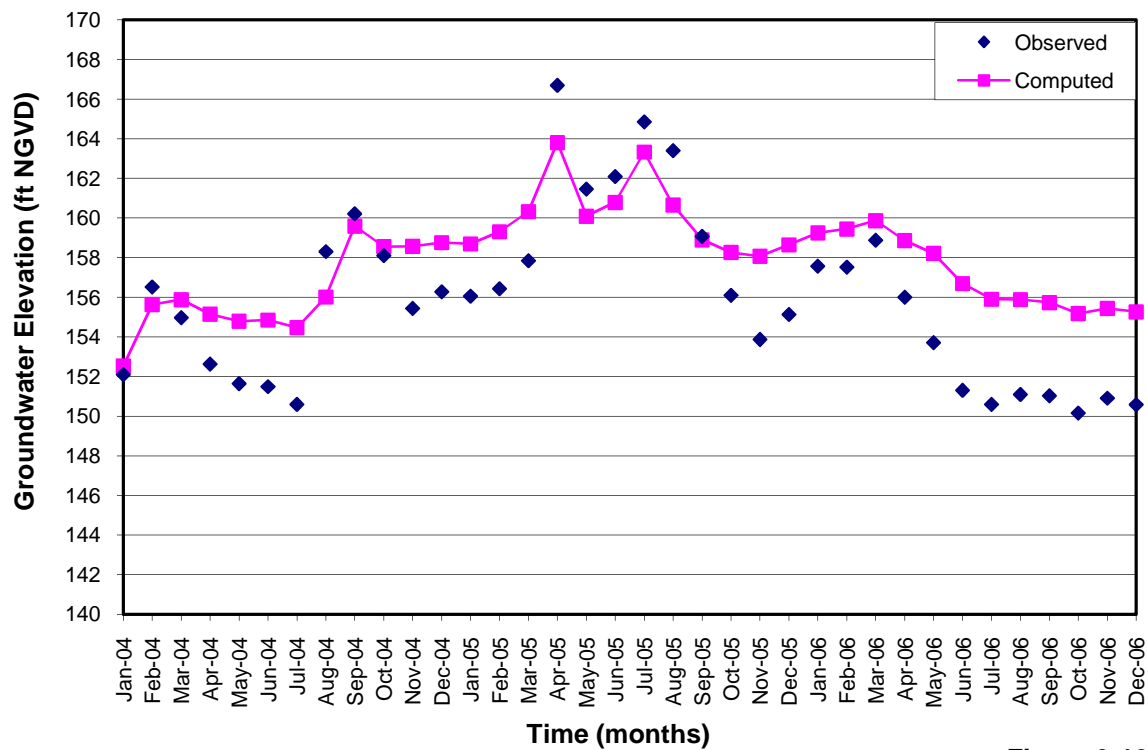


Figure 9-16
Comparison of Measured versus Simulated Groundwater Levels at 12L029 (Layer2)

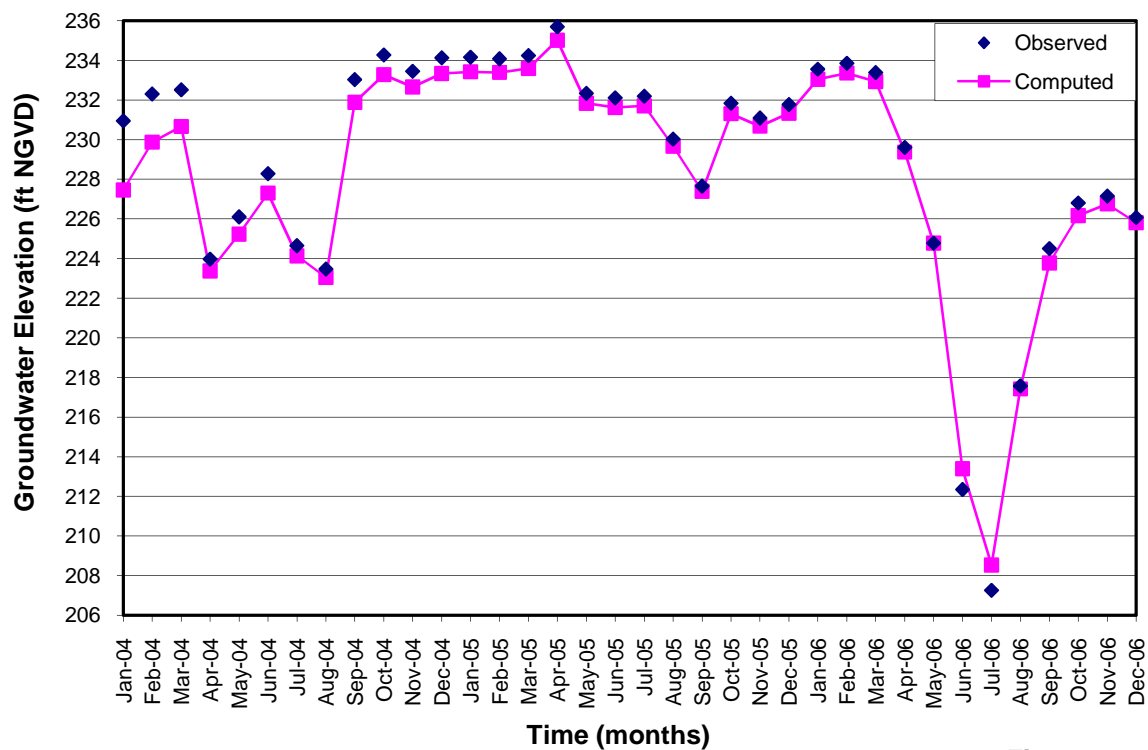


Figure 9-17
Comparison of Measured versus Simulated Groundwater Levels at 13M006 (Layer2)

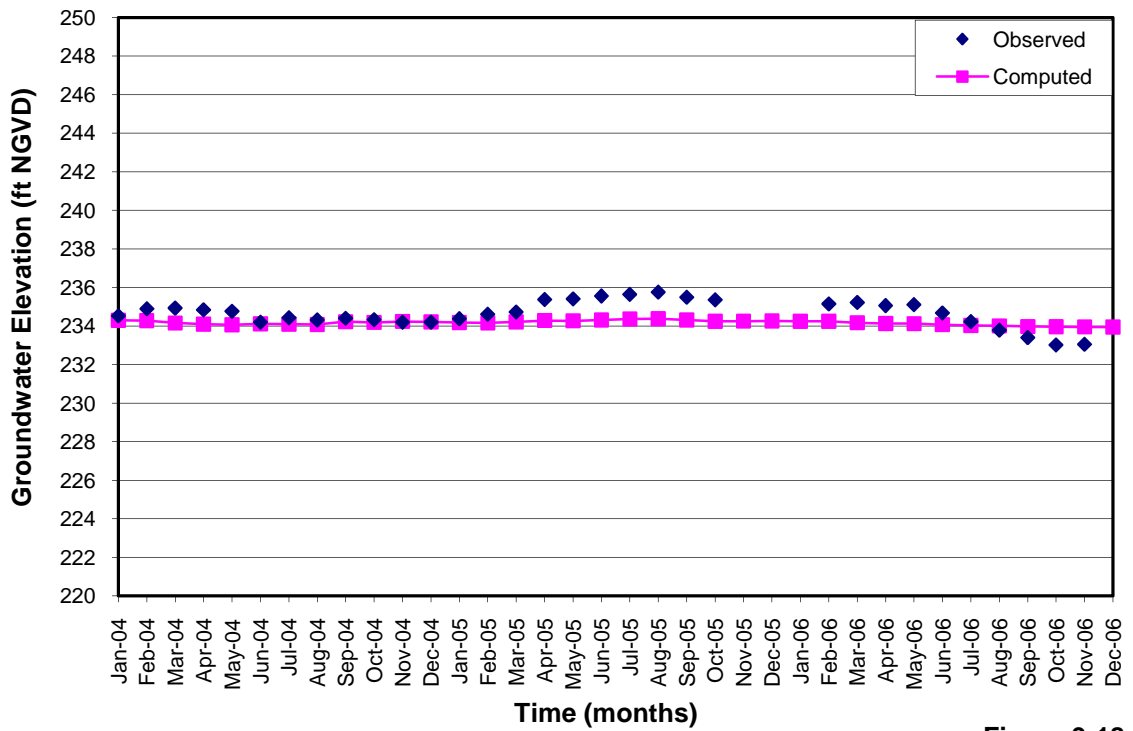


Figure 9-18
Comparison of Measured versus Simulated Groundwater Levels at 06K010 (Layer3)

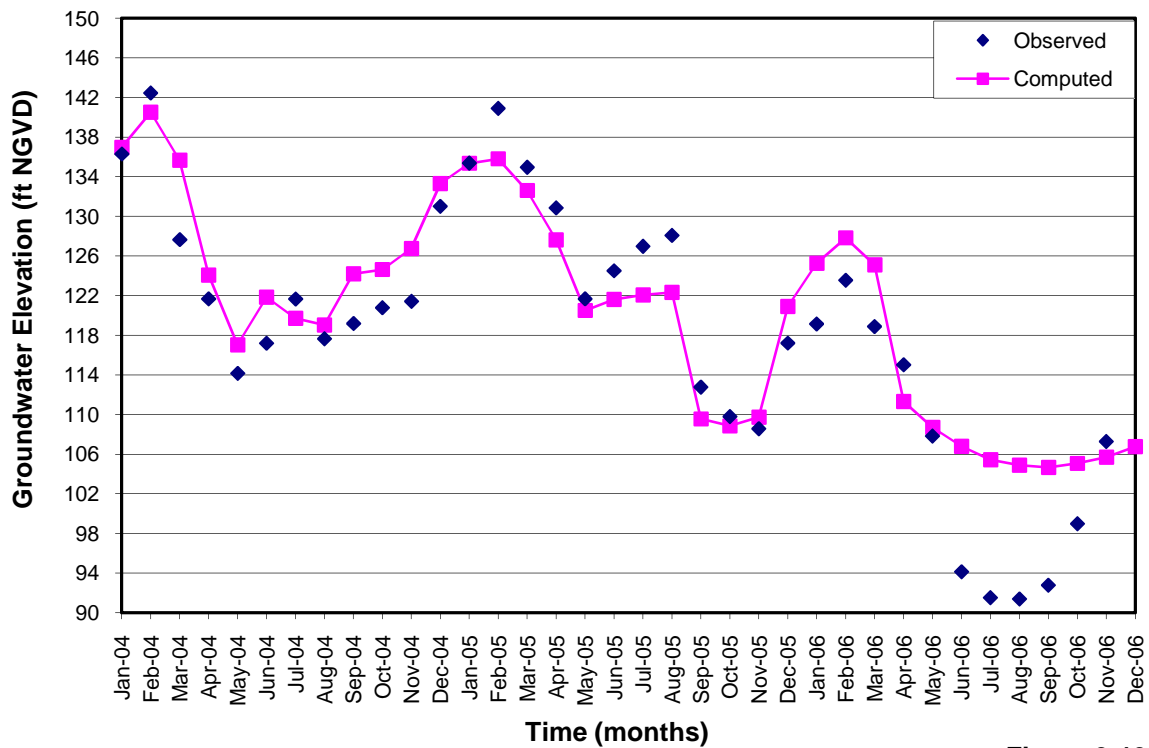


Figure 9-19
Comparison of Measured versus Simulated Groundwater Levels at 12M001 (Layer3)

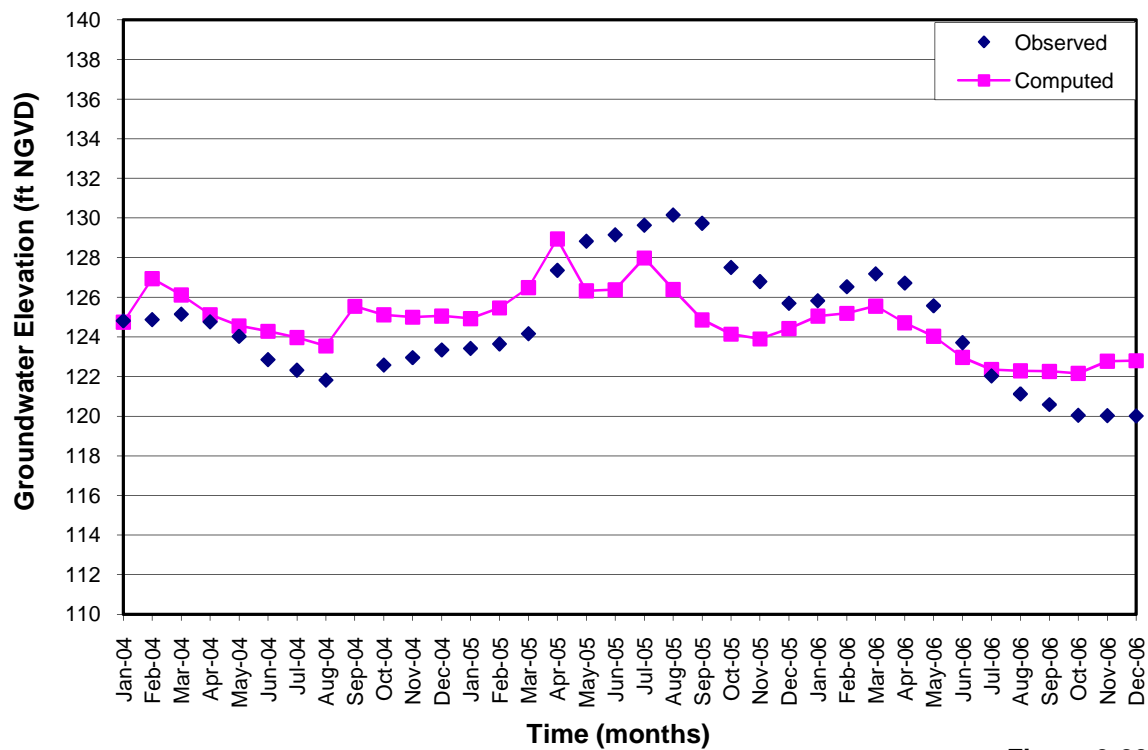


Figure 9-20
Comparison of Measured versus Simulated Groundwater Levels at 11J011 (Layer3)

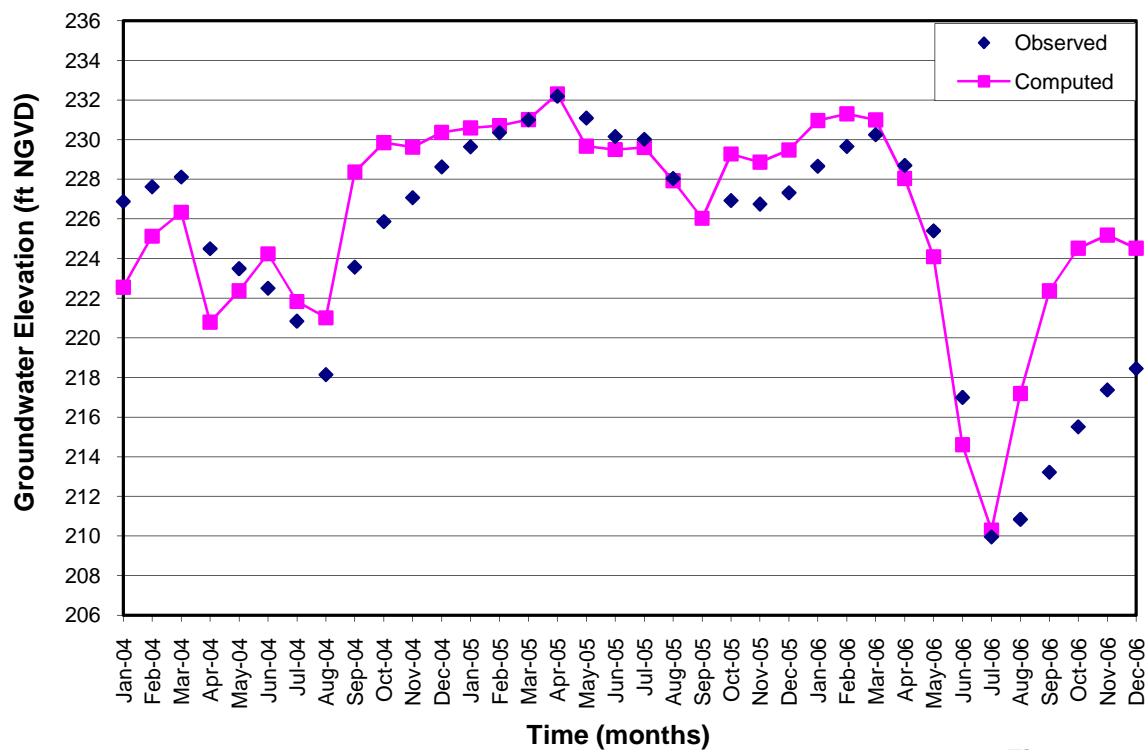


Figure 9-21
Comparison of Measured versus Simulated Groundwater Levels at 13M005 (Layer3)

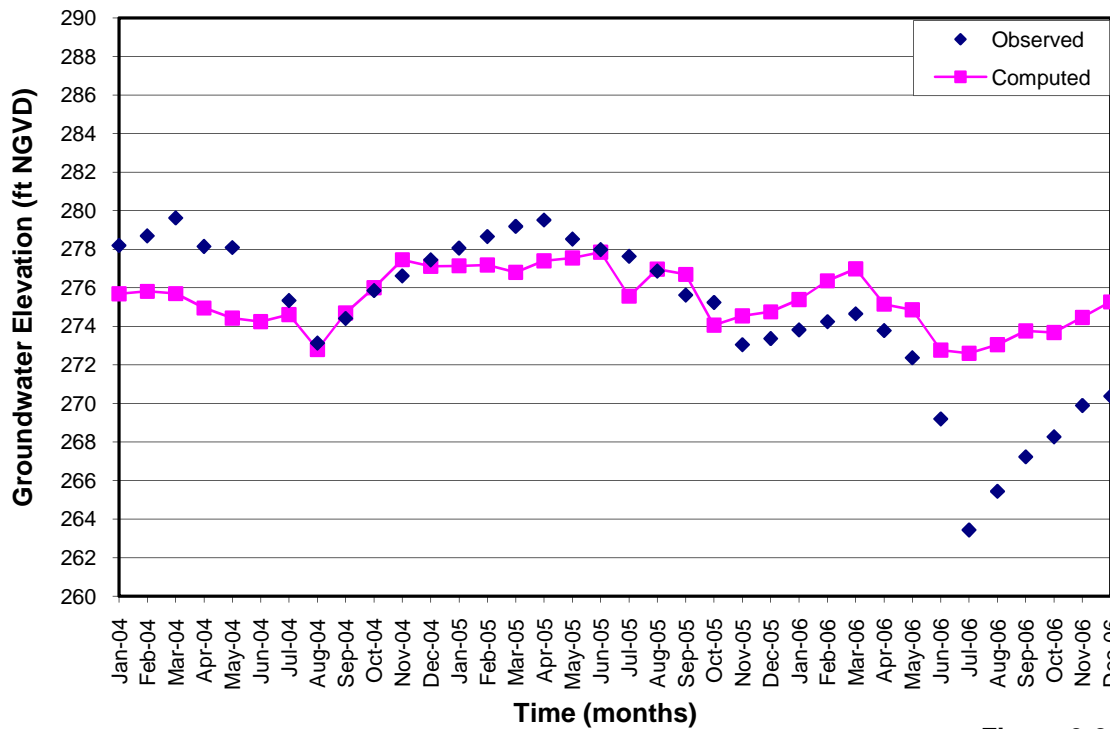


Figure 9-22

Comparison of Measured versus Simulated Groundwater Levels at 07N001 (Layer4)

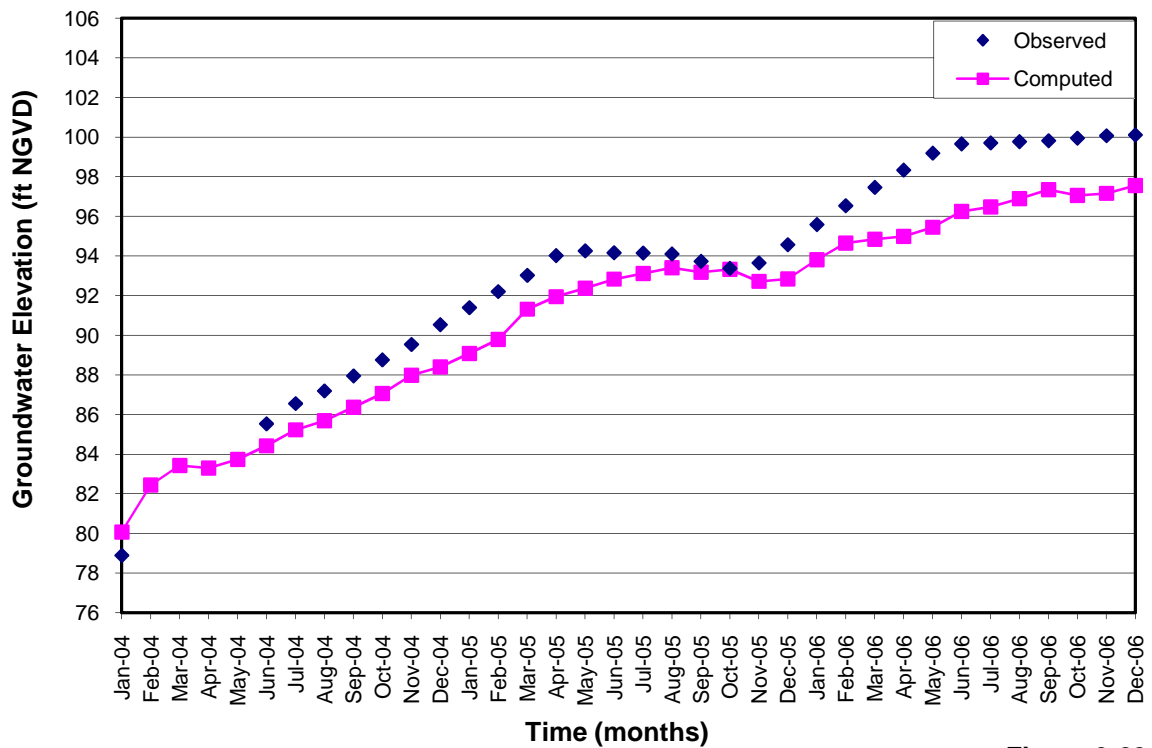


Figure 9-23

Comparison of Measured versus Simulated Groundwater Levels at 13L013 (Layer4)

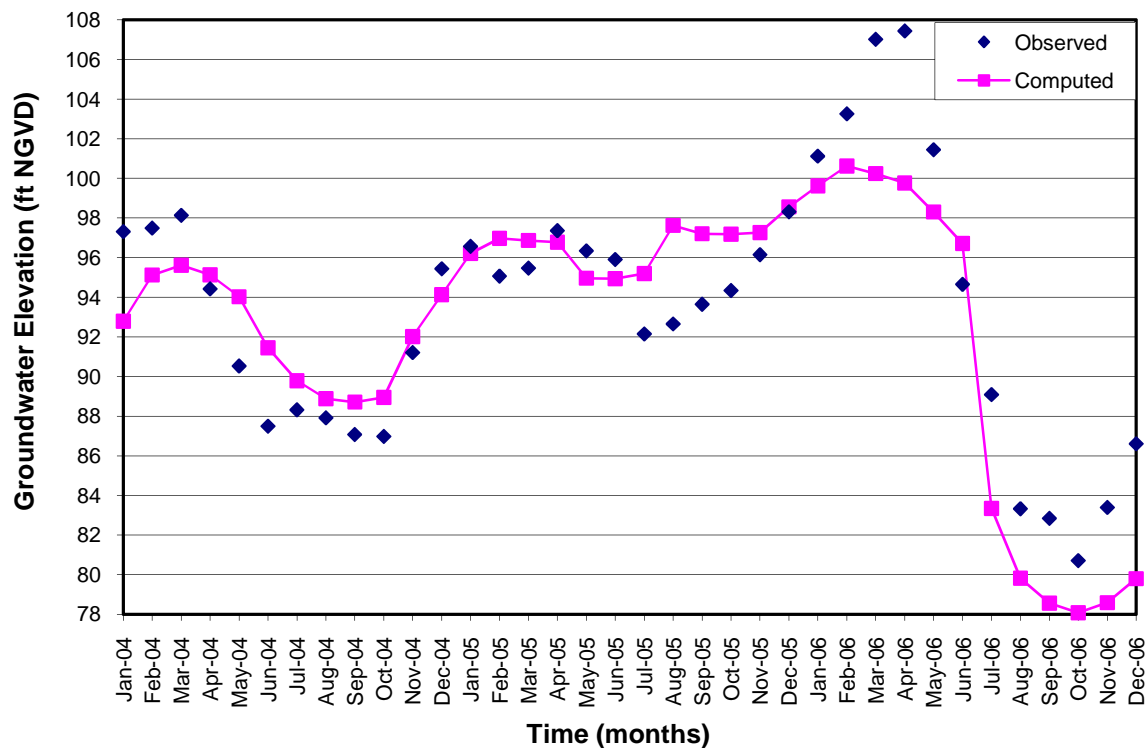


Figure 9-24
Comparison of Measured versus Simulated Groundwater Levels at 13L002 (Layer4)

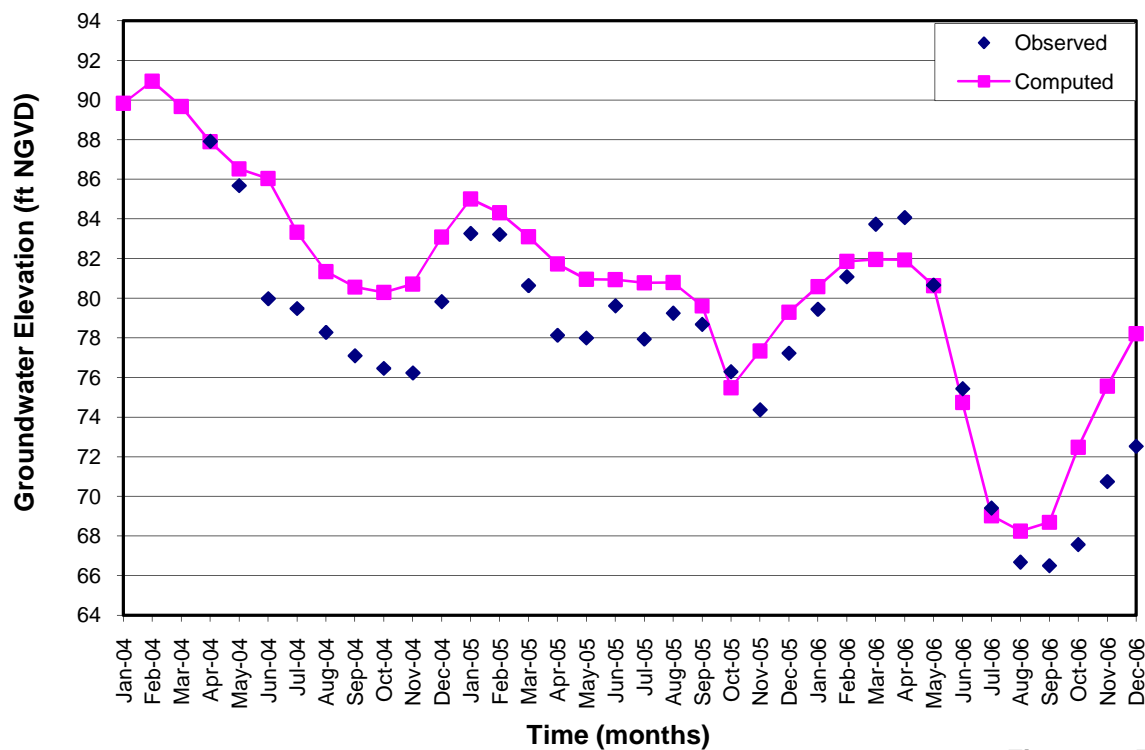
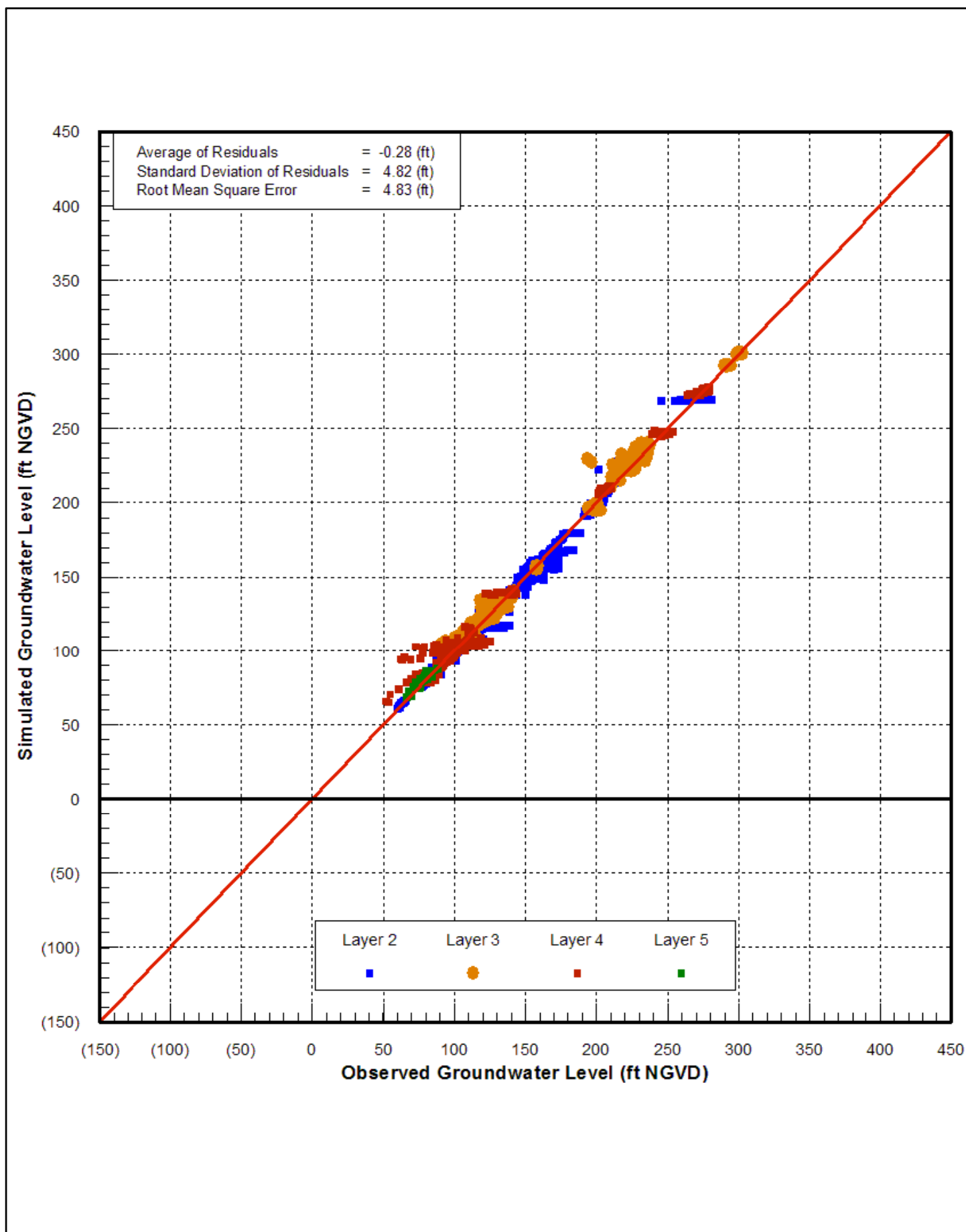
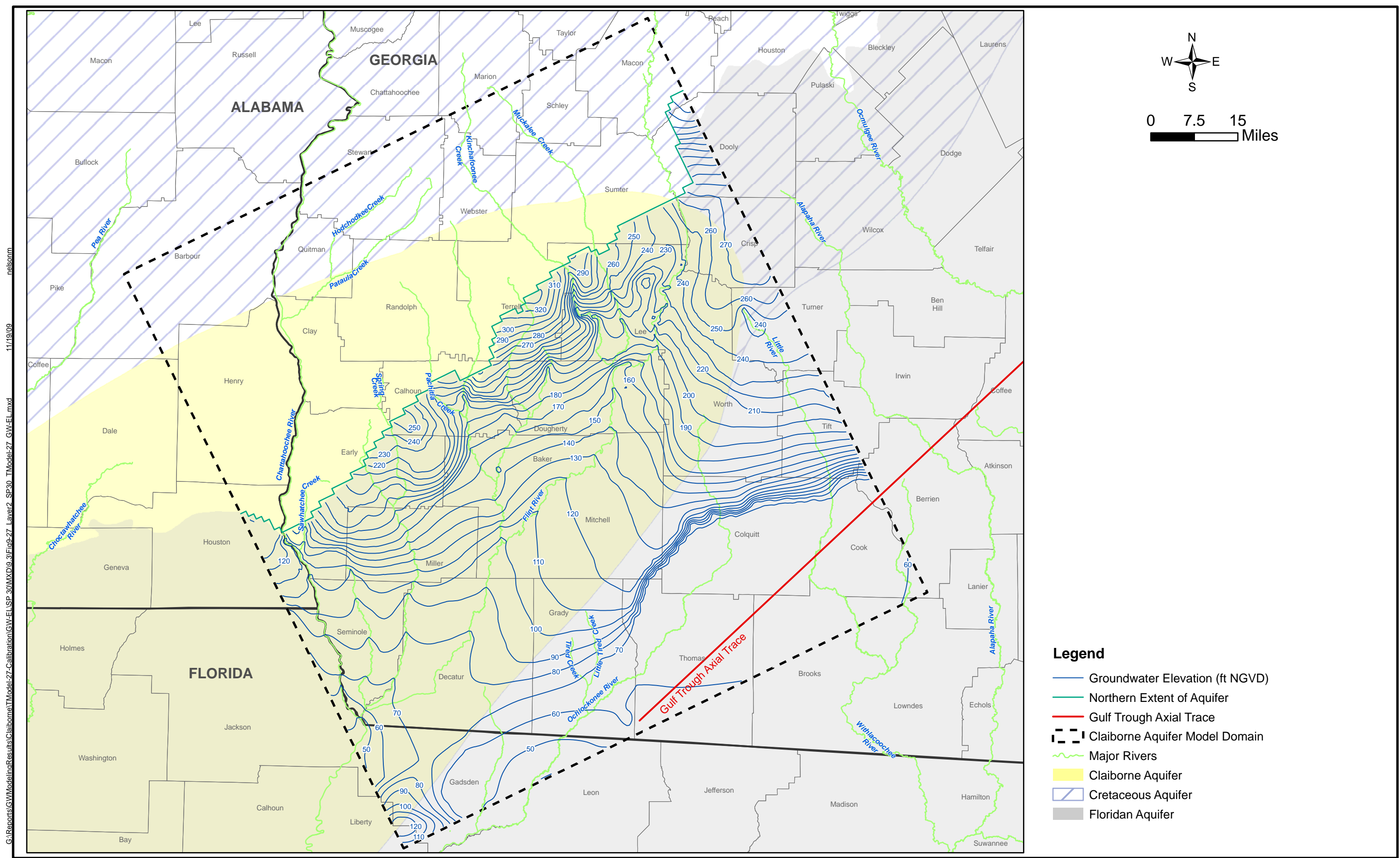


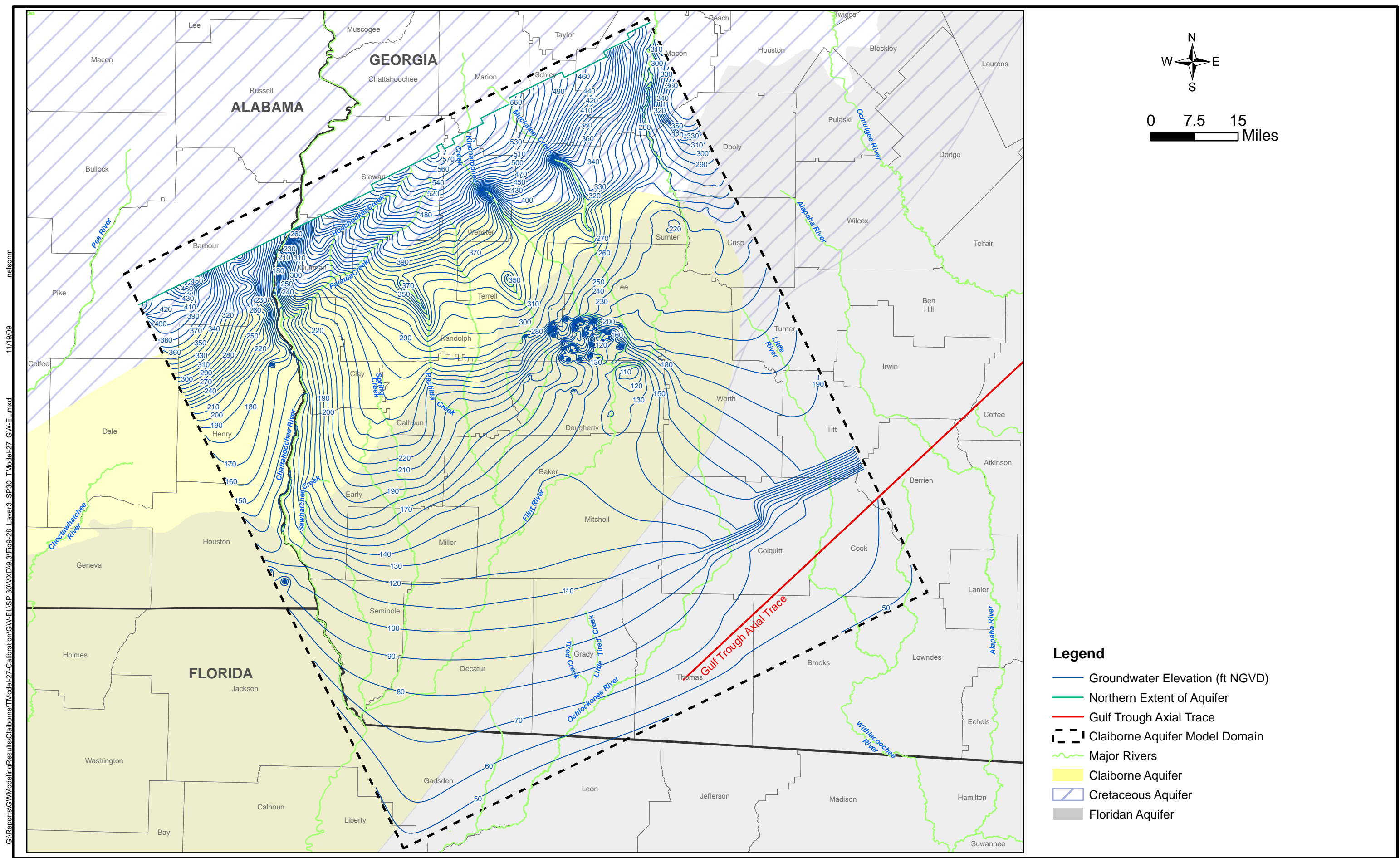
Figure 9-25
Comparison of Measured versus Simulated Groundwater Levels at 12L021 (Layer 5)





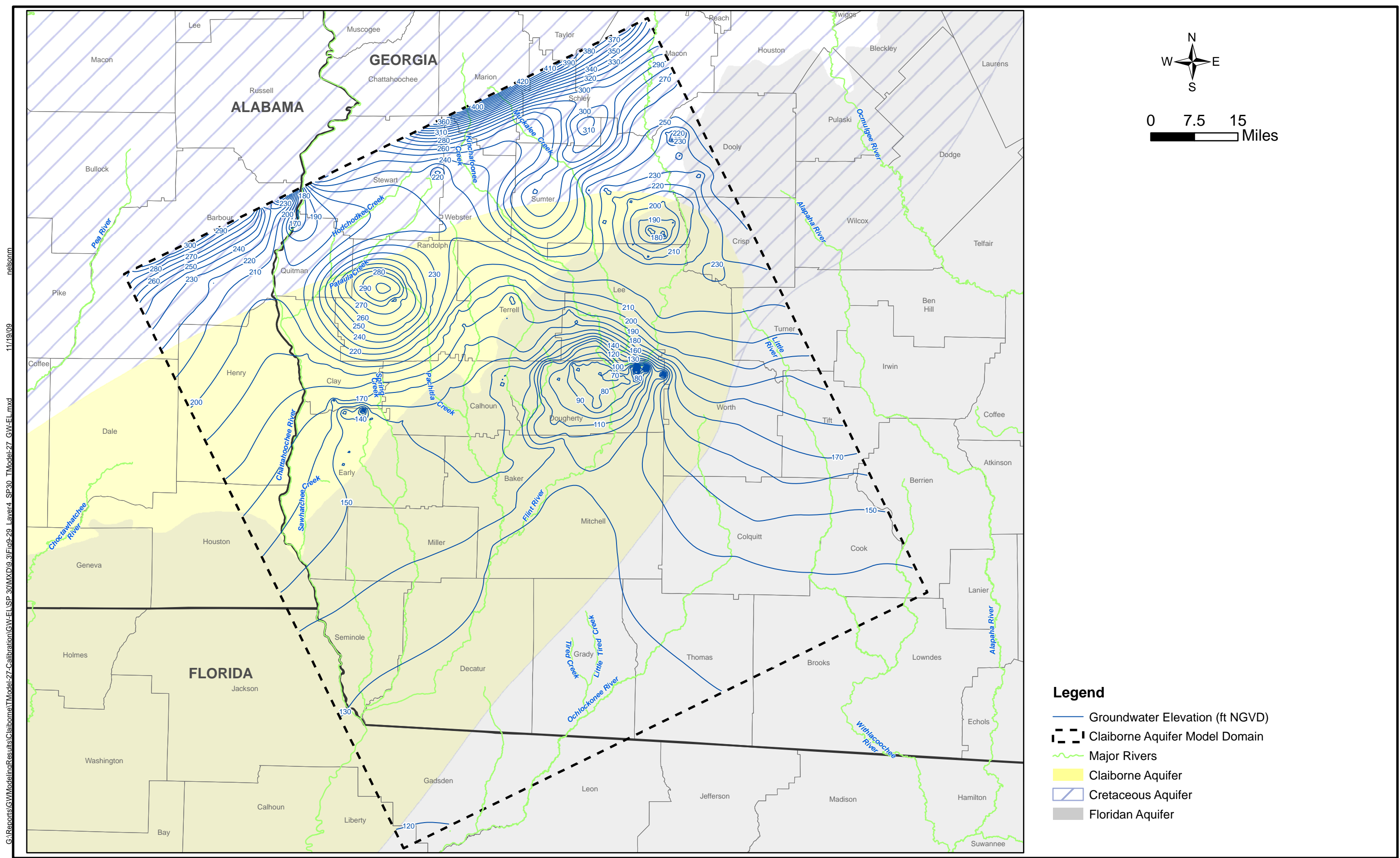
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CDM **Figure 9-27**
Simulated Groundwater Elevations in Upper Floridan Aquifer (Layer 2)
in Sub-Regional Claiborne Aquifer Groundwater Flow Model Domain in June 2006



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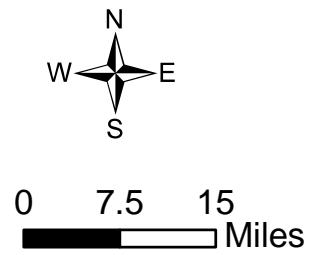
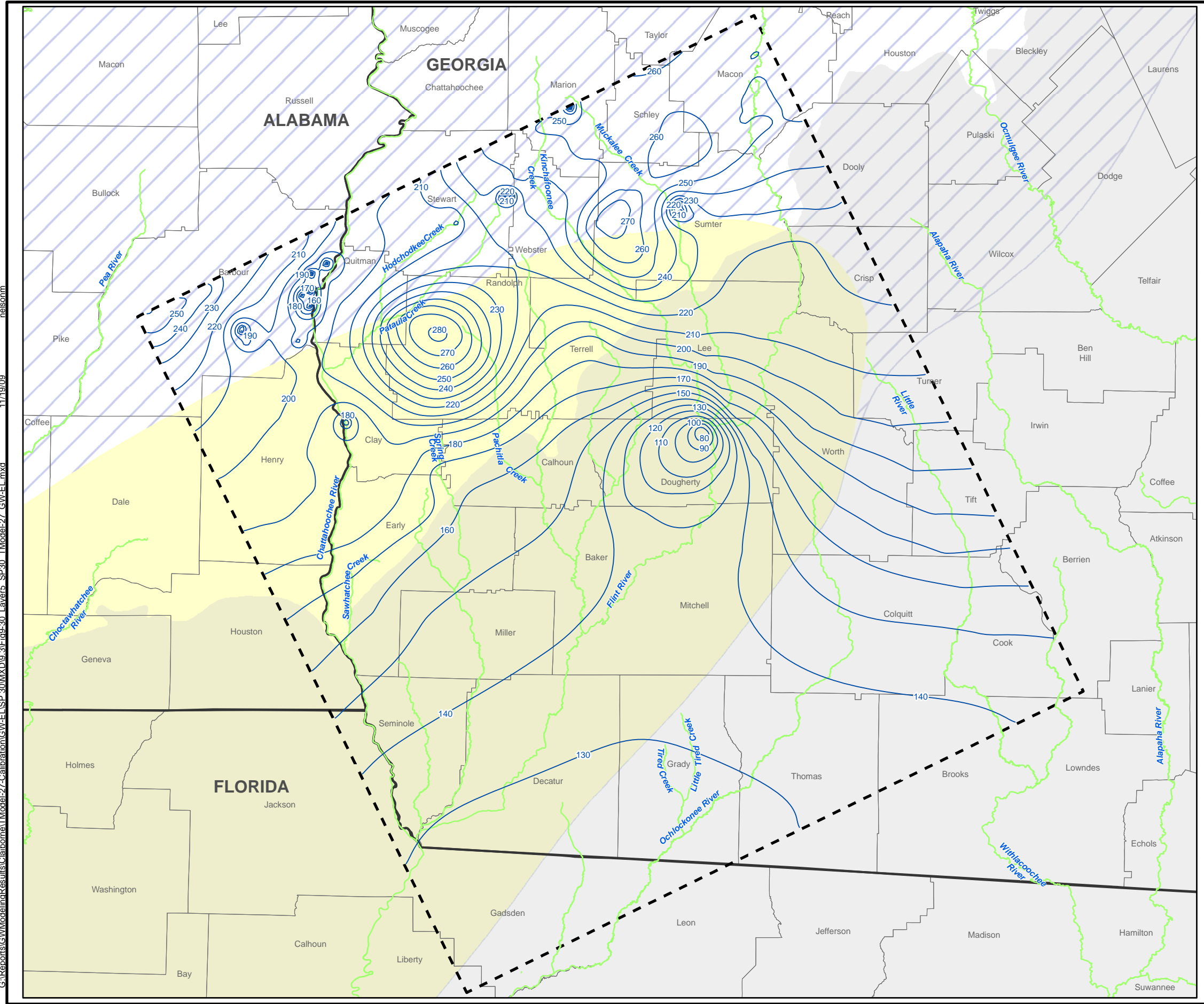
CDM **Figure 9-28**
Simulated Groundwater Elevations in Claiborne/Gordon/Lower Floridan Aquifers (Layer 3)
in Sub-Regional Claiborne Aquifer Groundwater Flow Model Domain in June 2006



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CDM **Figure 9-29**
Simulated Groundwater Elevations in Clayton-Dublin Aquifers (Layer 4)
in Sub-Regional Claiborne Aquifer Groundwater Flow Model Domain in June 2006

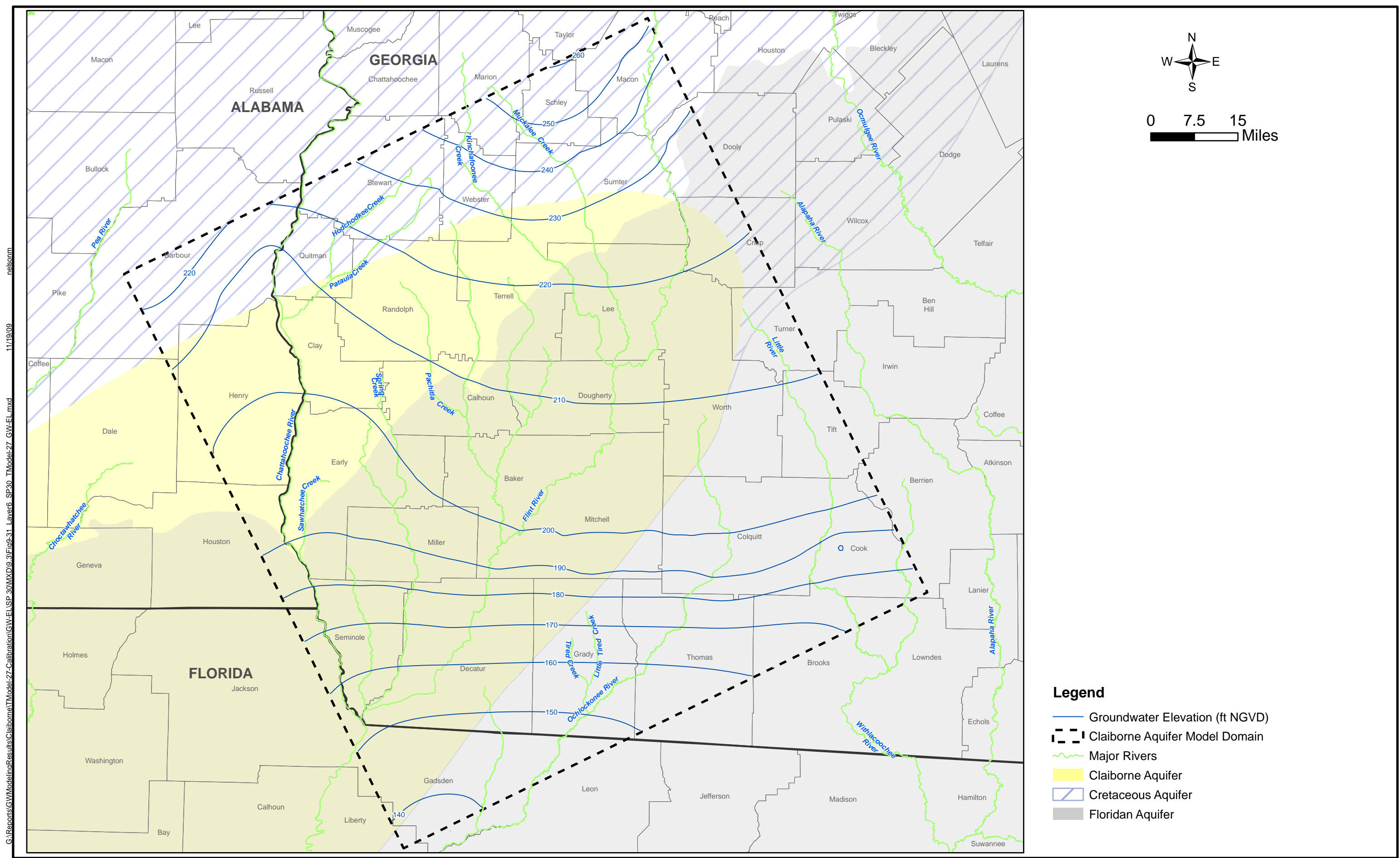
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Legend

- Groundwater Elevation (ft NGVD)
- Claiborne Aquifer Model Domain
- Major Rivers
- Claiborne Aquifer
- Cretaceous Aquifer
- Floridan Aquifer

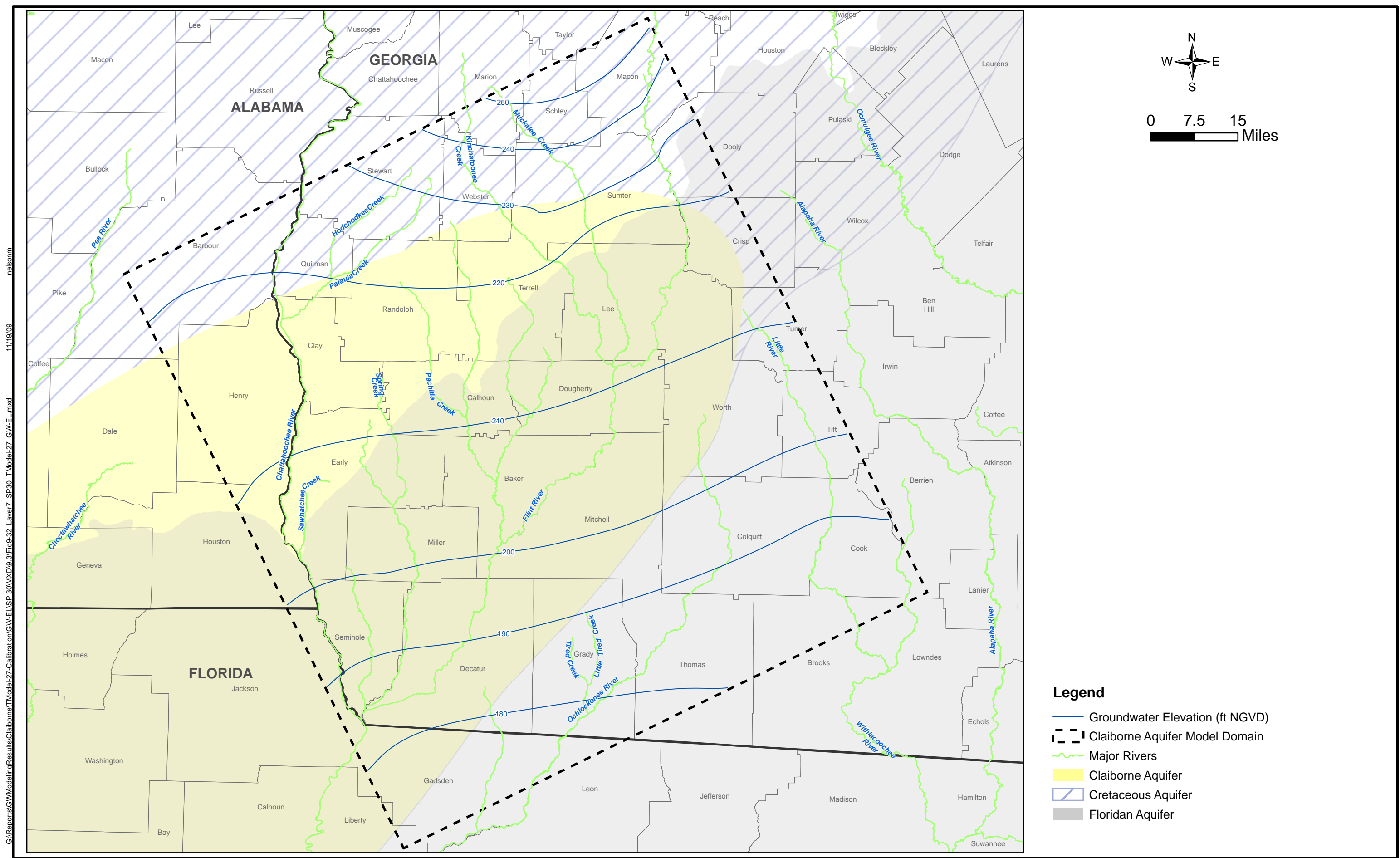
Figure 9-30
Simulated Groundwater Elevations in Providence Sand-Peedee-Dublin Aquifers (Layer 5)
in Sub-Regional Claiborne Aquifer Groundwater Flow Model Domain in June 2006



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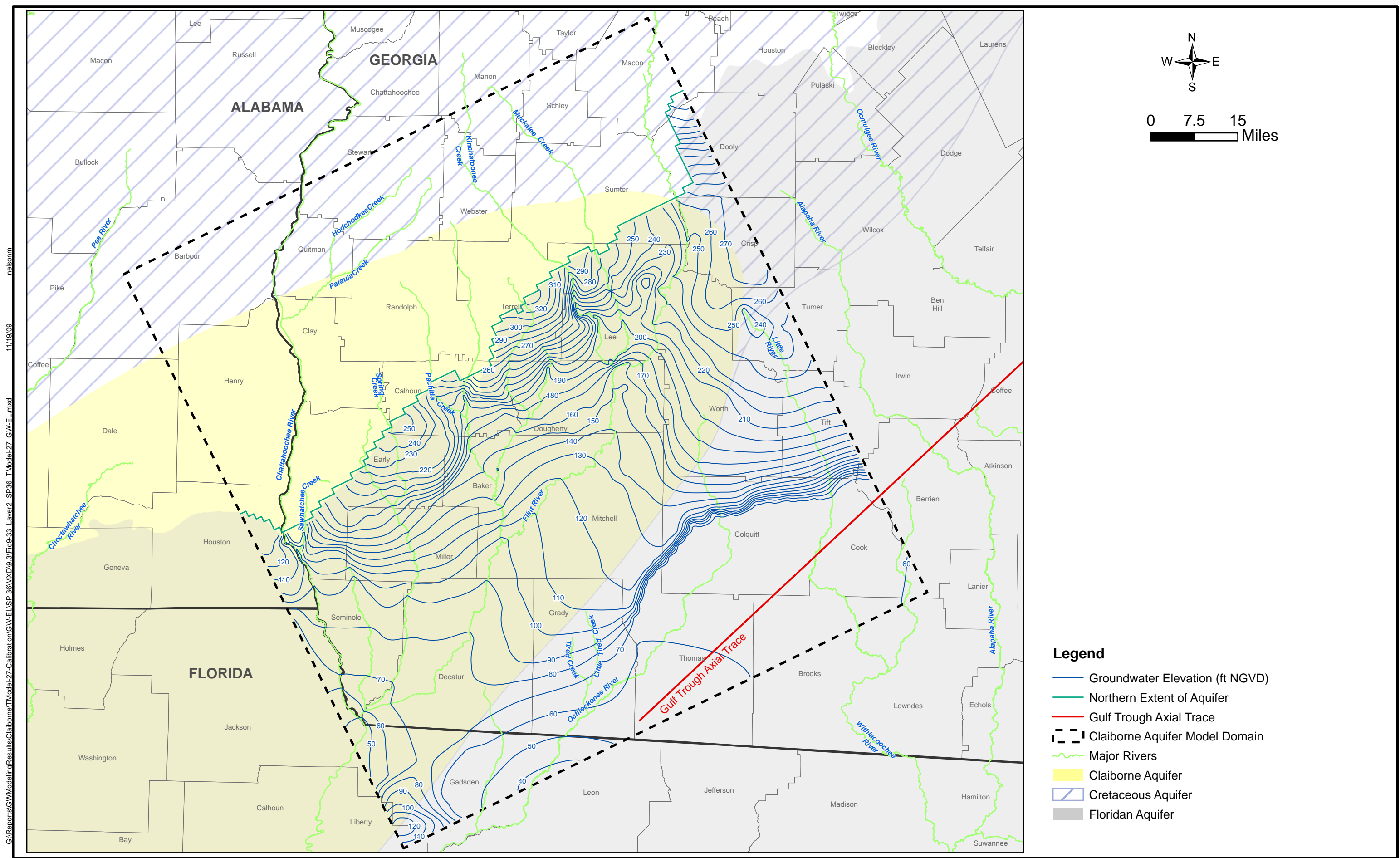
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Figure 9-31
Simulated Groundwater Elevations in Eutaw-Midville Aquifer (Layer 6)
in Sub-Regional Claiborne Aquifer Groundwater Flow Model Domain in June 2006



CDM

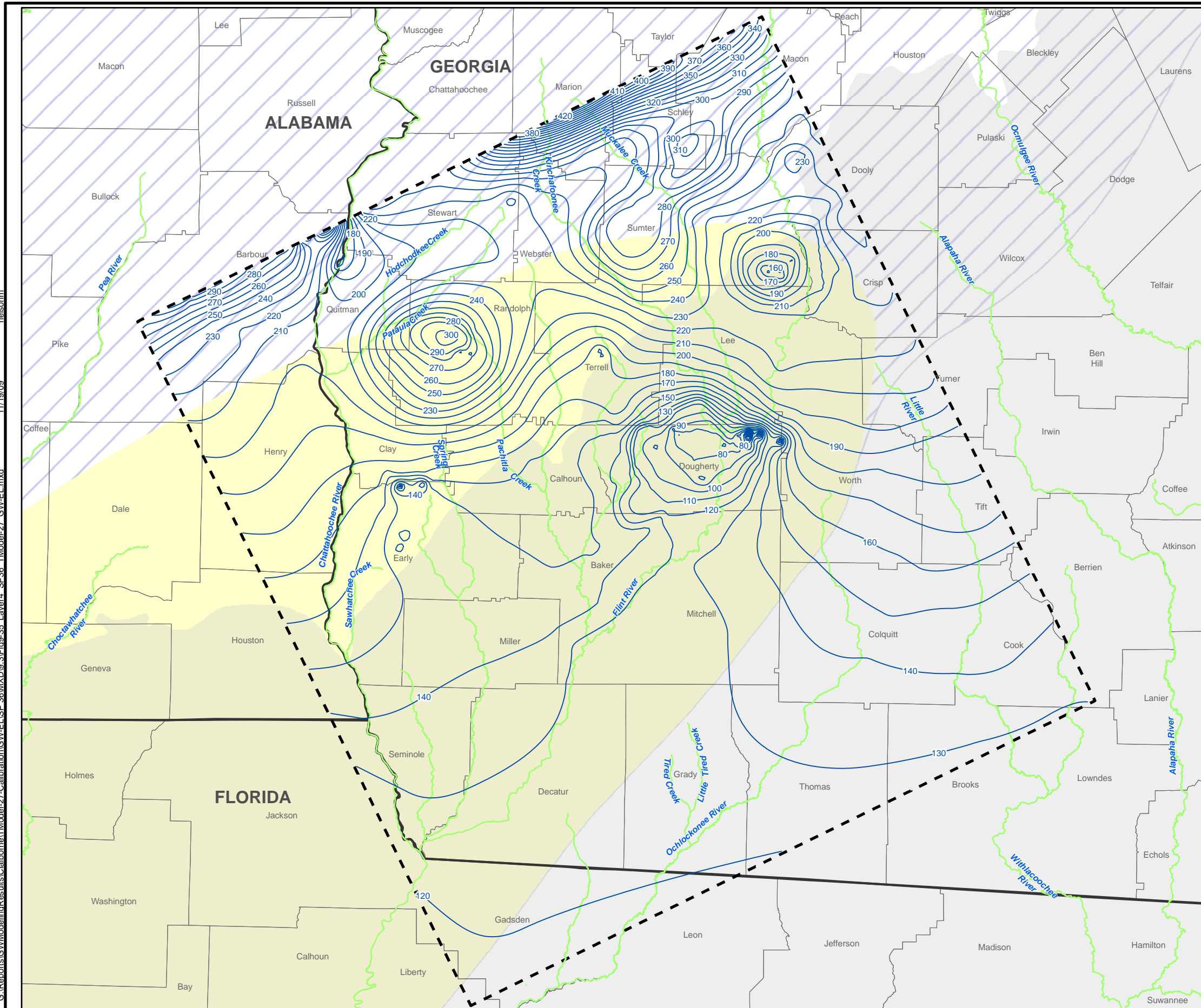
Figure 9-32
Simulated Groundwater Elevations in Upper Atkinson-Upper Tuscaloosa Aquifers (Layer 7)
in Sub-Regional Claiborne Aquifer Groundwater Flow Model Domain in June 2006



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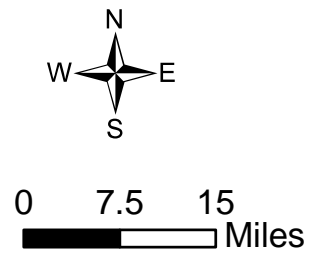
CDM **Figure 9-33**
Simulated Groundwater Elevations in Upper Floridan Aquifer (Layer 2)
in Sub-Regional Claiborne Aquifer Groundwater Flow Model Domain in December 2006

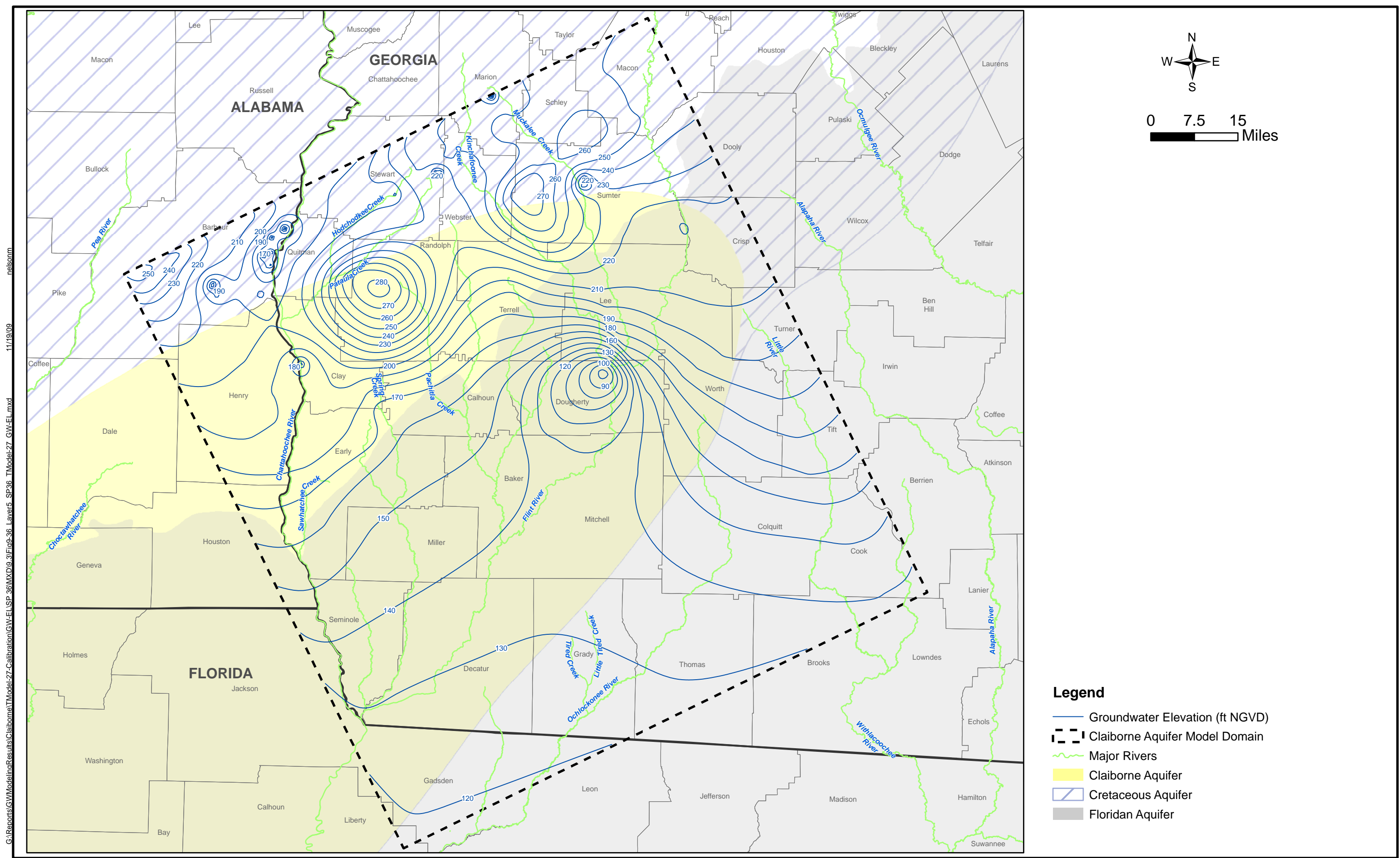
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Legend

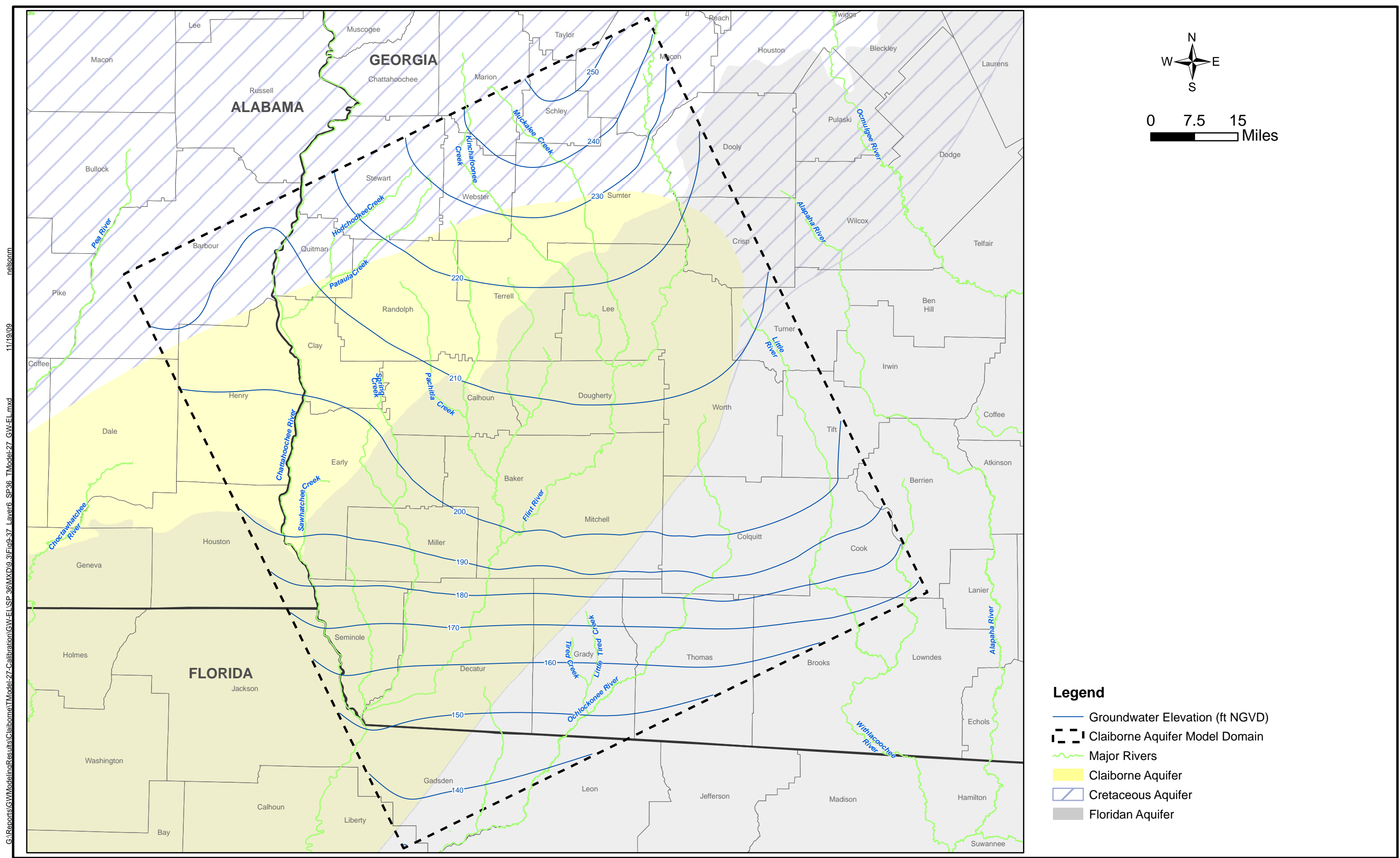
- Groundwater Elevation (ft NGVD)
- Claiborne Aquifer Model Domain
- Major Rivers
- Claiborne Aquifer
- Cretaceous Aquifer
- Floridan Aquifer





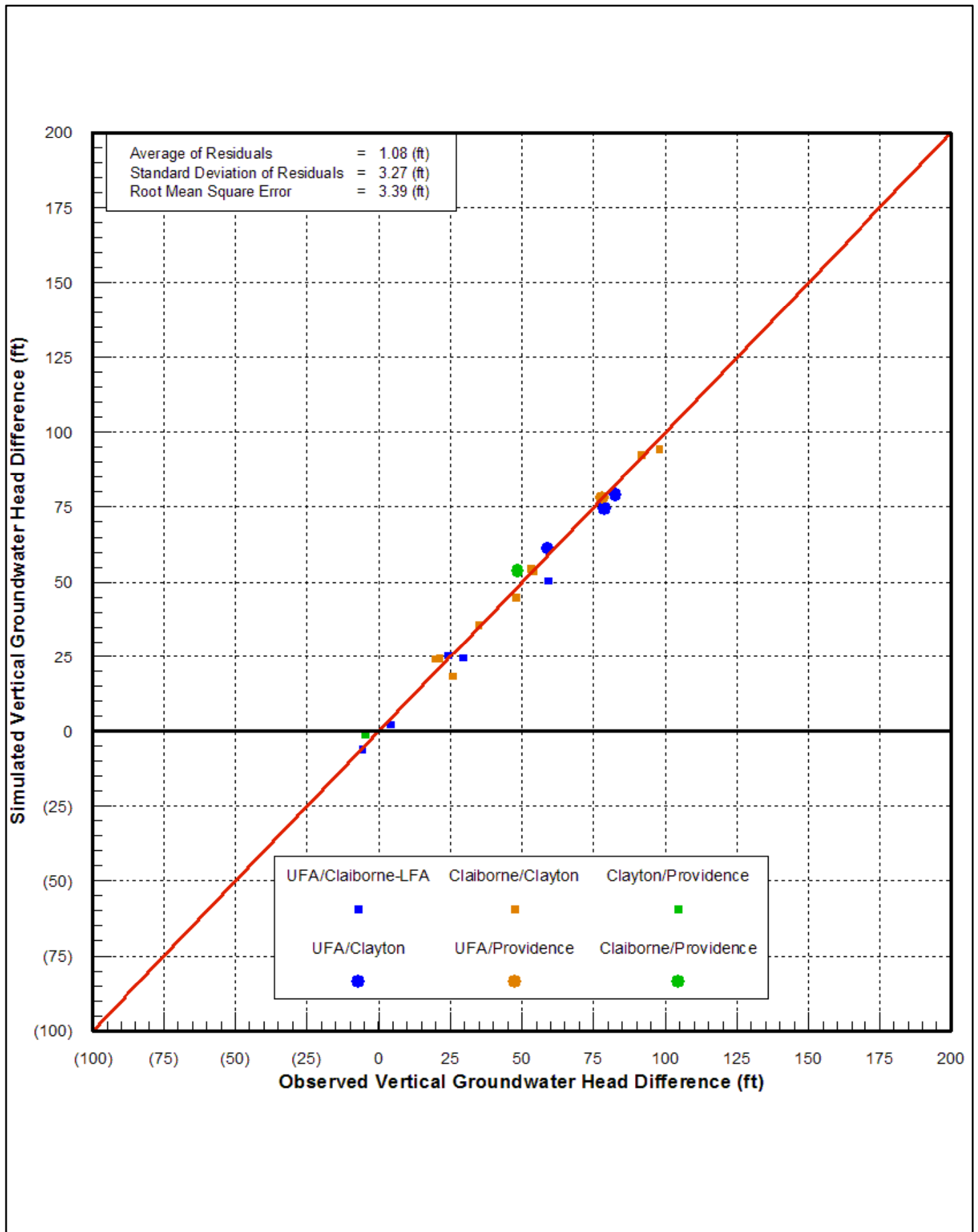
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CDM **Figure 9-36**
Simulated Groundwater Elevations in Providence Sand-Peedee-Dublin Aquifers (Layer 5)
in Sub-Regional Claiborne Aquifer Groundwater Flow Model Domain in December 2006



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CDM Figure 9-37
Simulated Groundwater Elevations in Eutaw-Midville Aquifer (Layer 6)
in Sub-Regional Claiborne Aquifer Groundwater Flow Model Domain in December 2006



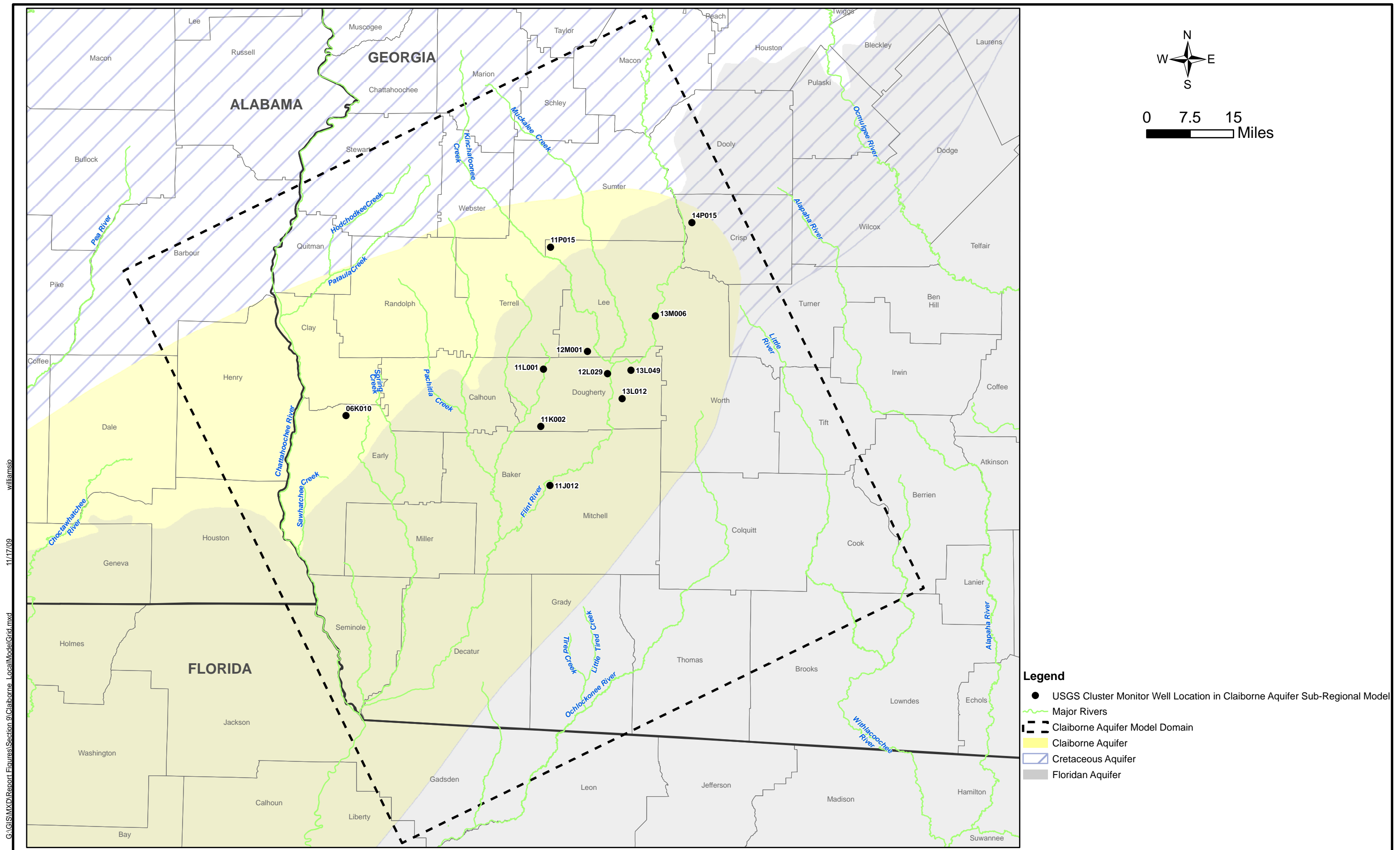


Figure 9-40

Cluster Monitor Well Locations in Claiborne Aquifer Sub-Regional Groundwater Flow Model Domain

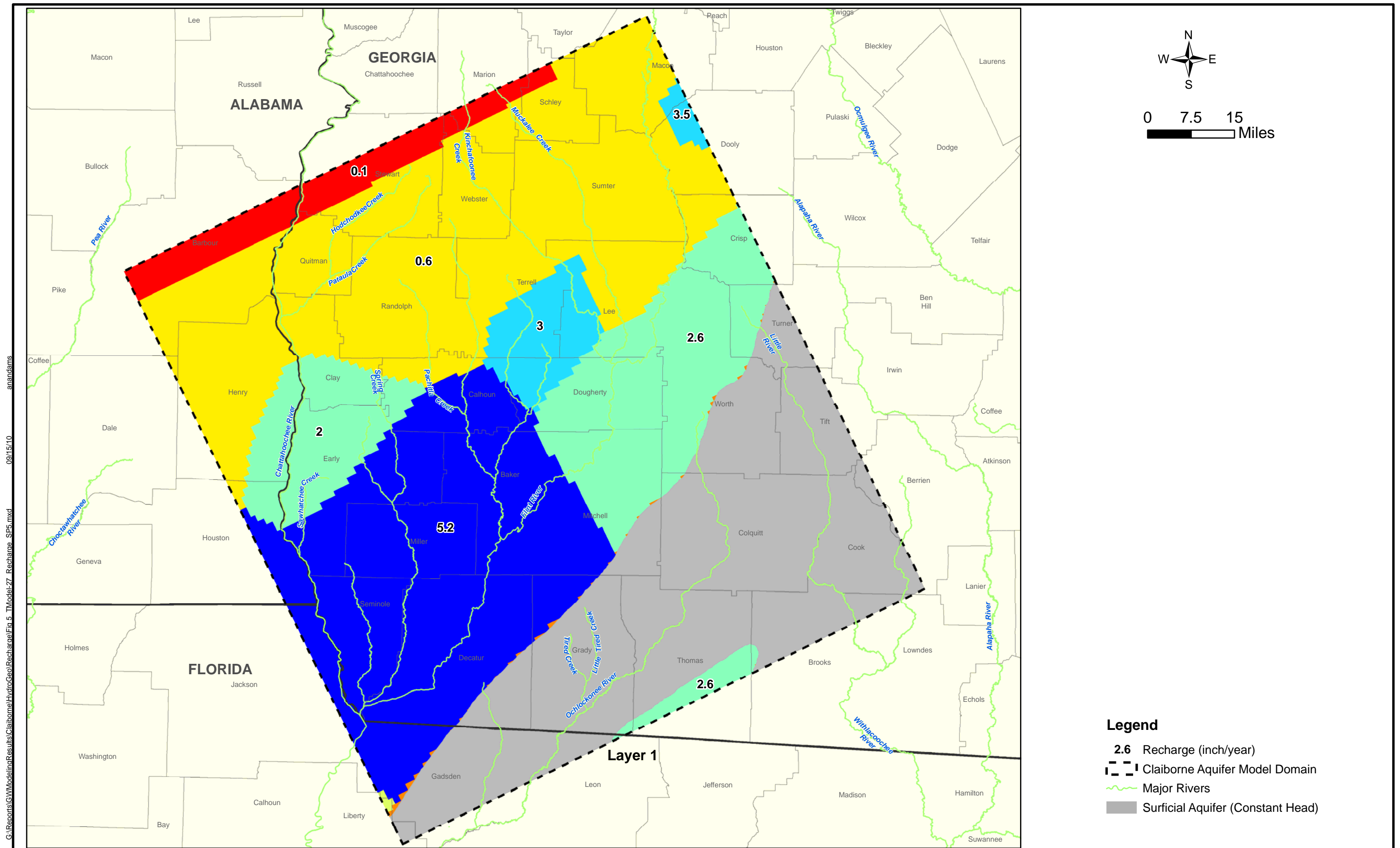
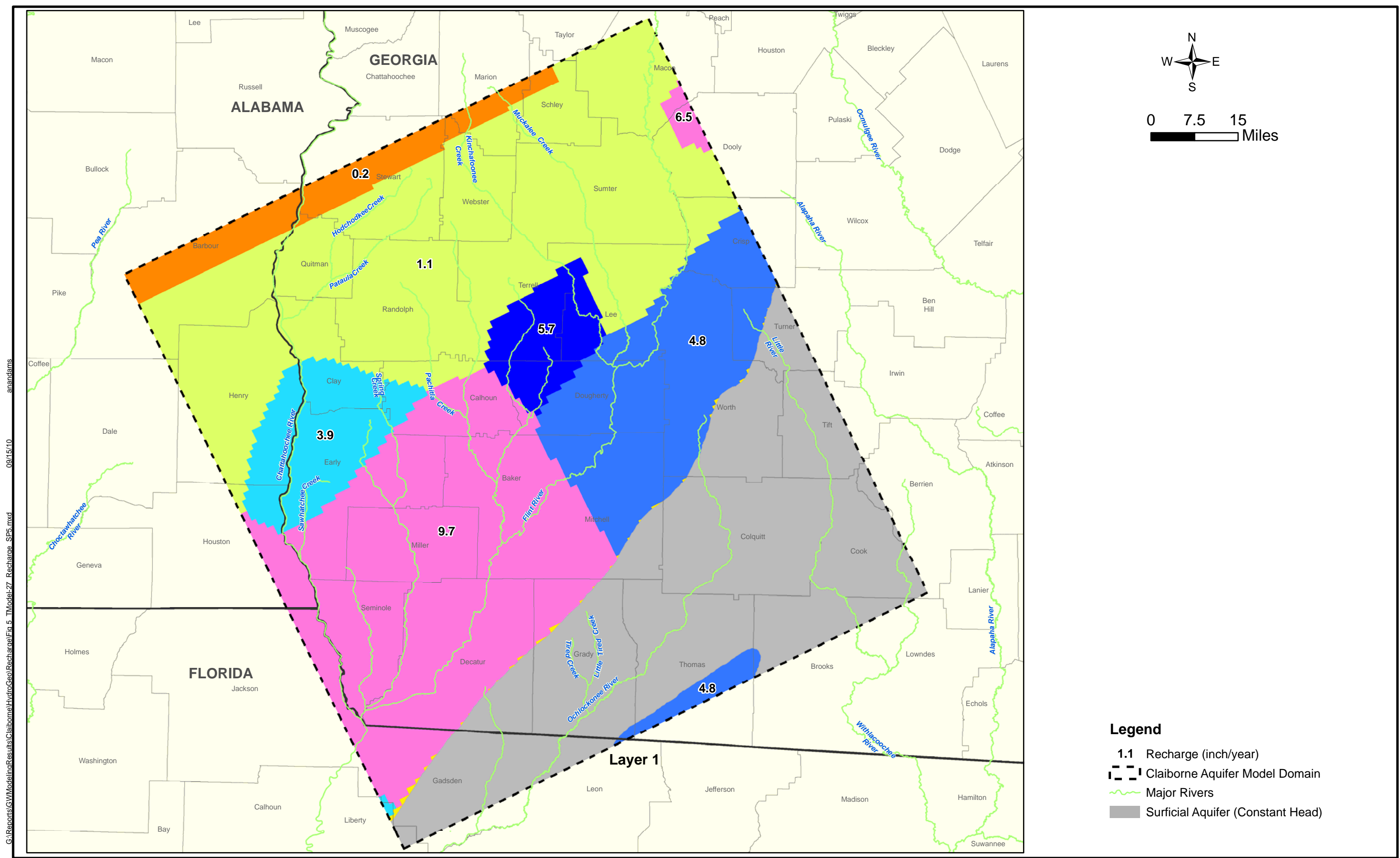


Figure 9-41

Net Recharge Distribution for May 2004 (beginning of the growing season in an average rainfall year) (SP5)
Used in Sub-Regional Claiborne Aquifer Groundwater Model



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CDM **Figure 9-42**
Net Recharge Distribution for June 2005 (a high rainfall month in a high rainfall year) (SP18)
Used in Sub-Regional Claiborne Aquifer Groundwater Model

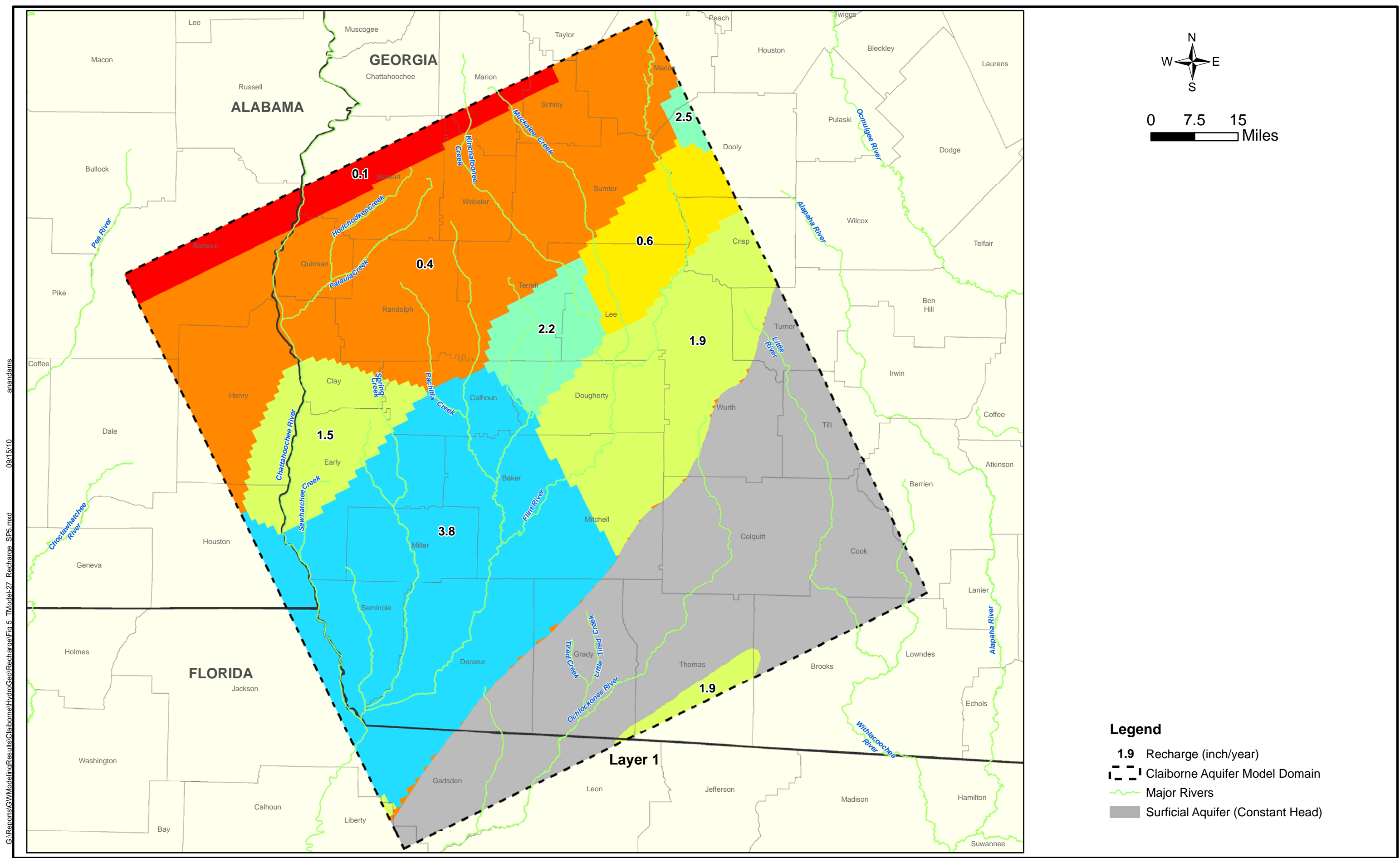


Figure 9-43

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 Claiborne Aquifer Groundwater Model