

Section 2

Geology and Hydrogeology

This section describes the hydrogeologic setting of the areas being modeled. This description includes the prevailing climatological conditions, physiography, topography and drainage, regional geologic and hydrogeologic conditions, and groundwater conditions that support the development of the groundwater flow model.

2.1 Climatological Conditions

2.1.1 Rainfall

To support the development of the regional and sub-regional groundwater flow models, daily rainfall data for the period from 1948 through 2008 were obtained from the National Oceanic and Atmospheric Administration (NOAA) for the Coastal Plain of Georgia. As summarized in **Table 2-1**, a total of 48 rainfall stations (31 in Georgia, 8 in Florida, 4 in Alabama, and 5 in South Carolina) were selected for further evaluation based on data completeness and representative location. The locations of these stations along with average annual rainfall for each station's respective period of record are shown on **Figure 2-1**.

As shown in Table 2-1, the average annual rainfall in the Coastal Plain within Georgia is approximately 49 inches. Figure 2-1 shows that the lowest annual rainfall (i.e., less than 50 inches) within the Coastal Plain of Georgia occurs in the central-eastern Georgia, while the highest annual rainfall (i.e., greater than 50 inches) within the Study Area occurs in Alabama, southwestern Georgia, Florida, and coastal portions of Georgia. The historical monthly rainfall for the Study Area is shown on **Figure 2-2**. Rainfall is unevenly distributed, with approximately 59 percent of the annual rainfall occurring during the wet season summer months of June through August and the winter/early spring months of January through March.

Table 2-1 Historical Annual Rainfalls in the Study Area

State	Period of Record Rainfall Volumes (in)			
	Station Count	Average	Maximum Average	Minimum Average
Georgia	31	48.96	54.95	45.90
Florida	8	53.17	61.33	47.28
Alabama	4	53.56	56.01	50.12
South Carolina	5	48.30	50.21	45.60
Study Area	48	49.98	61.33	45.60

Rainfall data from the last 15 years (1994 through 2008) were evaluated for each of the 48 selected rainfall stations in the Study Area to determine a recent consecutive three-year time period that represented a combination of a low rainfall year, average rainfall year, and high rainfall year for use in model calibration. **Table 2-2** summarizes the annual rainfall for each selected station between 1994 and 2008. The historical average annual rainfall for each selected station is further provided in Table 2-2. The annual rainfall within the Study Area between 1994 and 2008 is shown on **Figure 2-3**.

As shown in Table 2-2, annual rainfall amounts in 2004, 2005, and 2006 within the Study Area were approximately 51.5, 56.0, and 39.2 inches, respectively. Therefore, annual rainfall totals in 2004, 2005, and 2006 represent an average rainfall year, a high rainfall year, and a low rainfall year, respectively.

Figures 2-4 through 2-6 show the monthly variability in rainfall for selected stations in the Georgia Coastal Plain for 2004, 2005, and 2006, respectively, along with long-term monthly averages. Generally consistent with historical trends, the maximum rainfall during this time period occurred in winter/early spring and mid-summer, while the minimum rainfall during this time period occurred in the fall and late spring.

2.1.2 Evaporation

According to Kohler et al., (1969), the mean annual lake evaporation for the Coastal Plain of Georgia varies from approximately 42 to 46 inches, with an average of 44 inches. The difference between rainfall and lake evaporation within the Coastal Plain of Georgia is approximately 6 inches/year. The average monthly lake evaporation based on historical data (Farnsworth and Thompson, 1982) at eight NOAA pan evaporation stations in Georgia is shown on **Figure 2-7**. The locations of the eight evaporation stations in Georgia are illustrated on Figure 2-1. A pan evaporation coefficient of 0.75 was used to calculate monthly lake evaporation. The maximum lake evaporation (i.e., 5.4 inches) usually occurs in the mid-summer months of June and July, while the minimum lake evaporation (i.e., 1.8 inches) usually occurs in the winter months of December and January.

Based on Plate 9 of USGS PP1403-C (Bush and Johnston, 1988), the mean annual evapotranspiration (ET) for areas overlying the Floridan Aquifer System within the Georgia Coastal Plain area ranges from approximately 31 to 40 inches, with an average of approximately 35 inches/year (**Figure 2-8**).

2.1.3 Direct Runoff

Based on Plate 8 of USGS PP1403-C (Bush and Johnston, 1988), the mean annual average runoff in surface water basins within the Georgia Coastal Plain area varies from approximately 8 to 26 inches, with an average of approximately 14 inches/year (**Figure 2-9**). Variability in direct runoff can be attributed to rainfall, topography and the proximity of the water table to the land surface. Runoff, along with ET and rainfall data from this publication, was used to calculate net recharge within the

Table 2-2 Summary of Annual Rainfall Volumes for Selected Rainfall Stations in Study Area

Station ID	Station Name	State	Year															POR Avg.*	POR STD.*
			1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008		
140	ALBANY 3 SE	GA	70.65	45.63	48.35	64.38	58.78	34.38	41.33	34.22	41.23	55.71	55.38	56.27	44.26	46.84	47.84	50.29	8.86
211	ALMA BACON CO AP	GA	57.69	37.01	44.99	57.02	51.14	34.29	45.06	31.13	45.86	55.77	46.57	49.60	41.23	39.92	44.37	47.17	8.11
311	APPLING 2 NW	GA	54.14	42.49	45.49	56.60	52.55	32.33	35.66	37.56	41.51	49.09	39.95	45.39	40.27	39.98	45.00	47.01	7.65
406	ASHBURN 3 ENE	GA	57.99	34.34	47.64	58.90	57.83	36.18	46.94	43.04	50.28	49.49	52.11	48.01	39.29	37.69	35.56	47.71	6.85
586	BAINBRIDGE INTL PAPER	GA	73.68	53.74	57.47	62.50	57.62	22.21	44.26	45.77	48.88	52.52	49.61	75.14	29.02	19.76	54.75	54.95	11.24
1463	CAIRO 3NW	GA	76.66	45.35	54.50	60.65	50.78	35.27	40.46	53.53	48.13	47.23	43.22	57.99	38.56	38.00	34.77	50.93	11.34
2153	COLQUITT 2 W	GA	65.43	47.53	53.98	68.10	65.68	44.45	34.49	36.44	68.32	58.73	46.79	63.70	46.60	38.94	57.60	52.27	9.49
2166	COLUMBUS METRO AP	GA	49.29	44.82	43.72	50.92	32.78	26.39	35.59	37.97	44.08	56.42	48.99	62.51	38.84	37.84	50.76	48.59	9.41
2450	CUTHBERT	GA	78.62	50.92	50.38	57.73	61.78	36.13	42.55	42.78	50.67	56.94	55.30	62.65	49.84	39.60	53.47	51.63	10.4
2839	DUBLIN	GA	57.06	47.40	45.31	57.53	35.55	32.77	32.73	40.08	43.73	54.41	48.48	49.42	33.81	37.03	37.54	46.26	8.18
2966	EASTMAN 1 W	GA	62.72	43.82	42.71	56.96	49.77	43.24	40.55	42.25	48.45	51.22	51.77	51.64	34.76	41.88	34.91	46.35	7.03
3460	FOLKSTON 3 SW	GA	68.45	42.11	42.52	50.20	43.26	30.96	31.38	36.30	45.85	56.08	62.82	63.20	35.42	50.33	49.30	50.82	9.12
3754	GLENNVILLE	GA	64.91	49.06	37.27	53.88	52.24	38.62	28.45	26.77	17.46	59.37	51.02	43.62	37.33	41.67	43.77	47.57	8.86
4429	HOMERVILLE 5 N	GA	75.67	48.25	53.29	74.12	45.82	30.78	47.00	37.62	48.52	62.40	57.24	58.42	32.61	43.15	45.52	54.40	9.95
4676	JESUP 8 S	GA	61.95	49.12	36.26	52.88	42.46	40.15	38.36	31.57	44.51	56.09	55.42	61.69	36.34	41.03	46.14	49.90	8.63
4728	JULIETTE	GA	62.81	45.39	48.80	49.28	51.76	34.76	33.81	40.35	43.05	51.42	43.54	57.92	34.55	43.18	49.00	48.37	8.5
5811	METTER	GA	46.23	20.75	8.85	M	M	M	M	M	M	0.77	M	M	21.85	35.88	43.41	48.10	7.82
5979	MONTEZUMA	GA	60.87	40.09	46.77	65.61	47.18	38.51	36.21	38.69	38.71	52.05	49.04	54.02	38.38	36.19	45.92	45.90	8.4
6087	MOULTRIE 2 ESE	GA	73.27	45.95	37.01	55.87	53.17	34.61	45.52	43.54	50.34	51.66	57.73	52.43	37.77	36.86	53.40	49.78	10.11
7201	PRESTON	GA	61.09	44.72	54.54	59.21	65.35	37.64	41.56	49.21	44.57	52.24	54.38	54.79	46.69	41.78	56.44	49.33	8.12
7777	SANDERSVILLE	GA	61.51	46.90	36.72	46.11	58.93	45.70	17.64	8.94	45.64	54.27	44.35	57.83	34.82	40.89	41.60	46.79	8.06
7808	SAPELO IS	GA	55.79	45.43	48.82	54.55	46.15	44.42	33.82	39.75	56.23	50.52	28.96	61.48	44.00	38.69	44.75	51.11	8.87
7847	SAVANNAH INTL AP	GA	69.44	51.11	36.16	50.66	49.47	48.78	37.44	31.64	47.42	47.71	37.18	46.03	34.45	49.94	47.29	48.17	9.7
8064	SILOAM 3 N	GA	53.08	48.23	48.91	51.57	48.32	36.45	29.29	39.37	45.85	53.90	46.39	44.65	37.46	29.60	44.04	47.31	7.75
8517	SYLVANIA 2 SSE	GA	62.53	52.09	35.27	62.05	51.23	33.00	30.59	38.04	39.31	61.01	39.76	37.11	29.03	39.46	18.02	47.41	10.7
8661	THOMASTON 2 S	GA	65.28	37.98	47.55	47.26	M	15.04	36.49	39.51	46.65	55.93	50.37	59.68	28.43	39.30	35.31	49.72	7.55
8703	TIFTON	GA	59.64	33.13	38.92	48.46	44.03	28.01	44.68	42.64	51.78	51.44	35.45	59.59	37.03	40.46	44.25	47.09	8.42
8974	VALDOSTA 2 S	GA	M	M	M	M	M	M	M	M	M	33.63	56.84	57.57	48.74	35.52	39.24	50.59	10.09
9141	WARRENTON	GA	57.56	46.35	38.31	57.36	55.58	37.33	38.92	40.98	45.13	54.04	43.05	48.90	37.92	41.21	48.12	47.48	8.72
9186	WAYCROSS 4 NE	GA	53.29	52.26	49.10	53.61	48.92	45.27	44.03	37.60	44.98	60.09	60.05	55.89	38.34	45.92	53.18	48.91	9.07
9194	WAYNESBORO 2 S	GA	66.23	58.56	39.76	56.68	54.35	38.47	38.98	18.59	47.57	56.12	48.59	53.46	38.95	34.91	50.69	45.98	9.18
211	APALACHICOLA AP	FL	77.18	53.08	79.08	57.85	54.86	42.61	47.90	53.87	67.54	72.08	45.51	51.28	45.95	29.57	40.73	56.11	12.97
2944	FERNANDINA BEACH	FL	53.41	73.21	53.16	59.72	48.93	32.77	41.61	36.86	55.60	42.46	53.84	59.14	35.03	40.77	42.76	49.27	9.72
5099	LIVE OAK	FL	65.87	33.24	54.70	62.32	71.29	38.95	41.06	42.45	45.57	60.27	59.09	58.88	38.98	34.26	43.74	52.36	11.48
5275	MADISON	FL	37.75	45.78	53.70	45.78	57.41	51.24	40.98	39.39	40.29	61.01	54.58	19.57	37.89	34.55	55.13	50.90	10.98
5377	MARIANNA 7 NE	FL	M	M	M	M	M	M	M	1.70	54.16	51.46	48.38	65.94	39.99	24.91	61.56	52.97	18.35
5539	MAYO	FL	66.52	45.59	67.83	58.04	69.19	37.93	42.66	40.44	54.95	59.28	61.43	56.68	44.34	46.59	53.06	55.17	10.75
8758	TALLAHASSEE WSO AP	FL	85.40	52.40	56.72	64.25	58.83	50.07	44.51	63.45	56.08	65.30	56.83	68.28	49.34	44.47	60.37	61.33	13.00
6828	PANACEA 1 S	FL	M	M	M	M	M	M	M	31.49	55.53	69.55	59.01	66.05	34.67	24.68	50.04	47.28	15.61
1178	BRUNDIDGE	AL	44.81	62.59	59.82	62.47	69.01	47.27	37.33	54.86	49.42	75.07	56.61	62.77	40.12	51.97	53.1	53.34	9.34
3761	HEADLAND	AL	69.69	54.41	69.37	56.18	64.48	37.59	26.31	49.81	45.31	60.16	52.51	61.51	45.47	48.05	51.43	54.78	10.27
5172	MATHEWS	AL	50.92	67.48	40.37	41.03	M	10.36	38.32	53.66	48.80	59.50	50.29	57.63	36.77	38.94	48.04	50.12	9.49
6129	OPELIKA	AL	M	52.06	54.98	62.10	46.21	48.94	36.21	28.73	28.44	47.92	52.02	33.98	32.91	41.39	48.03	56.01	9.21
506	BATESBURG	SC	59.71	59.17	42.45	54.72	50.94	39.56	43.18	33.34	44.03	61.87	48.94	45.95	44.23	28.95	41.03	47.34	8.51
559	BEAUFORT WWTP	SC	61.13	48.67	30.99	45.02	43.67	24.82	3.40	M	9.50	50.42	39.75	59.83	20.52	M	M	48.39	9.64
2730	EDISTO ISLAND	SC	58.07	44.23	42.14	59.17	44.68	46.95	30.48	25.50	58.35	43.47	M	9.67	15.67	37.30	51.8	49.98	7.98
8219	SPRINGFIELD	SC	49.81	52.66	37.67	56.52	50.48	39.78	41.32	43.06	39.04	53.35	44.02	41.07	36.46	35.35	51.91	45.60	9.37
8922	WALTERBORO 1 SW	SC	3.97	M	2.83	M	M	24.06	40.34	38.16	54.73	50.84	34.53	24.37	31.13	35.51	47.32	50.21	10.42
Total Model Area			62.51	48.68	49.72	57.26	54.30	39.73	39.77	40.82	48.17	56.42	51.49	56.04	39.19	40.19	47.00		
Total GA Stations			62.95	46.15	46.13	57.14	52.45	37.68	40.26	39.81	46.92	54.72	50.48	55.02	38.84	40.40	47.00		
Total Complete Records			39	39	34	37	35	30	29	37	40	36	33	35	38	39	32		
Wet			79%	13%	9%	46%	34%	0%	0%	0%	5%	31%	6%	54%	0%	0%	0%		
Dry			0%	10%	12%	0	3%	53%	45%	46%	3%	0%	3%	0%	58%	56%	13%		
Average			21%	77%	79%	54%	63%	47%	55%	54%	93%	69%	91%	46%	42%	44%	88%		

*Excludes incomplete records.

Bold Text = Missing Data

M = Missing Data

outcrop areas for the Upper Floridan, Claiborne, Clayton and the Cretaceous Aquifers in the development of the groundwater models, as further discussed in Section 5. Although the ET and runoff estimates from this publication state that they are for the areas overlying the Upper Floridan Aquifer, the basin boundaries for which these values were derived extend to the Fall Line and therefore include direct recharge (outcrop) areas of the Claiborne, Clayton, and Cretaceous Aquifers.

2.1.4 Aquifer Recharge

As stated in the previous section, recharge to the Upper Floridan Aquifer outcrop areas were calculated for the Coastal Plain Aquifer System model using NOAA rainfall data for Georgia and evapotranspiration and runoff data from the USGS Professional Paper 1403-C titled *Ground-Water Hydraulics, Regional Flow, and Groundwater Development of the Floridan Aquifer System in Florida and Parts of Georgia, South Carolina and Alabama* (Bush, 1988). A map of predevelopment recharge for areas overlying the Floridan Aquifer System is presented on **Figure 2-10**. Predevelopment recharge is anticipated to be slightly higher than recharge used in the model due to a reduction in infiltration associated with urbanization.

According to USGS Professional Paper 1410-C (Barker and Pernik, 1994) titled *Regional Hydrology and Simulation of Deep Ground-Water Flow in the Southeastern Coastal Plain Aquifer System in Mississippi, Alabama, Georgia, and South Carolina* the amount of recharge to an aquifer is limited by the amount of infiltration, which in turn is limited by the difference between precipitation and overland flow (ignoring the effects of surface storage and evaporation). Infiltration and overland flow are inversely related. The ratio of infiltration to overland flow decreases as the rate of precipitation exceeds the infiltration capacity of the soil.

From this USGS study, the areal distribution of recharge to the regional ground-water flow regime of the Southeastern Coastal Plain (inclusive of the clastic portions of the Coastal Plain Aquifer system) was analyzed by model simulation. An area wide, long-term rate of recharge to the local ground-water regime was calculated for the water budget from what is known about precipitation, total runoff, evapotranspiration, and base flow. Although these estimates of recharge are not based on direct observation of infiltration or recharge, they were consistent with the pattern of recharge potential. **Figure 2-11** illustrates the relative potential for recharge to result from the infiltration of precipitation in the outcrop area of the Southeastern Coastal Plain Aquifer System. Because recharge is a direct residual of infiltration, the regional patterns reflected by this map were used to estimate the recharge rates for input to the Southeastern Coastal Plain Aquifer System simulation model of the aquifer system. Figure 2-11 shows three broad categories of recharge potential, which were inferred from the (1) outcrop lithology from Renken (1996), (2) soil types from the U. S. Department of Agriculture Soil Conservation Service (1967), and (3) baseflow distribution from Stricker (1983), Aucott and others (1986), and Faye and Mayer (1990).

Because the regional model of the Southeastern Coastal Plain Aquifer System only simulated deep flow regime, the input recharge was less than the total recharge to the

entire aquifer system (Barker, 1986). Simulated recharge to the deep flow regime averaged 0.6 in/yr, which was less than one-tenth the estimated total recharge of 7 in/yr (**Figure 2-12**). The difference between the two is equal to the groundwater discharge to relatively shallow surface drainages, which was not simulated with the coarse grids of the regional model. As was previously explained, the deep flow regime is the predominantly confined, less dynamic part of the flow system – including all of the subcrop area and all of the outcrop areas that discharges to the major streams. Conceptually, simulated recharge equals precipitation minus the sum of evapotranspiration and all runoff that is not simulated.

Because the model was limited to simulating the baseflow of only major streams, the input recharge represents only the water that discharges either to these streams or from downgradient parts of the deep, confined flow regime. The original understanding of the deep flow regime was largely conceptual; the definition of recharge to this regime was, likewise, conceptual. The rates of input recharge were fashioned initially from the map of infiltration potential (Fig. 2-11) and were refined later through trial-and-error simulation. The calibrated distribution of recharge from the groundwater flow model of the Southeastern Coastal Plain Aquifer System (Faye and Mayer, 1996) is shown on **Figure 2-13**. Simulated recharge averaged about 0.6 in/yr over the nearly 46,500 mi² of actively simulated outcrop area.

2.2 Physiography

There are five physiographic provinces within the states of Georgia, eastern Alabama, western South Carolina, and northern Florida (Miller, 1990) as shown on **Figure 2-14**. From northwest to southeast, including all the provinces in the state of Georgia, the following physiographic provinces are encountered:

- Appalachian Plateau;
- Valley and Ridge provinces;
- Blue Ridge province;
- Piedmont province; and
- Coastal Plain province.

These physiographic provinces are based on landforms, geologic structures, type of rocks, and the ages of the rocks. **Figure 2-15** presents a cross-section of the five physiographic provinces from northwestern Alabama to southeastern Georgia. The majority of the Coastal Plain of Georgia (57,450 square miles, or 86 percent of the total area) lies within the Coastal Plain province, while the remainder lies in the Piedmont Blue Ridge and Valley and Ridge provinces (9,430 square miles, or 14 percent of the total area).

The Appalachian Plateau extends from New York to Alabama including a relatively small portion in northwestern Georgia. The deposits from this Plateau province form the western boundary of the Appalachian Mountains. Dade County and parts of Chattooga and Walker Counties in northwestern Georgia are in the Appalachian Plateau. These deposits consist of sedimentary rocks from the Paleozoic era. The Valley and Ridge province comprises most of the northwestern area of Georgia and consist of Paleozoic-rock aquifers. The Blue Ridge province is located in northeast Georgia and comprises the highest mountain range in that State. This mountain range forms a drainage divide known as the Eastern Continental Divide, separating rivers flowing to the Gulf of Mexico from rivers flowing to the Atlantic Ocean. The Blue Ridge province includes the crystalline-rock aquifers.

The Piedmont province forms the foothills of the Appalachian Mountains. The Valley and Ridge and Blue Ridge provinces are bounded to the south by the Piedmont. This province includes the crystalline-rock aquifers, and it is underlain by igneous and metamorphic rocks from the Precambrian period and the Paleozoic era. The southern part of the Piedmont province, which extends west to east from Alabama, Georgia, South Carolina, and North Carolina, also delineates the boundary called the Fall Line. The Fall Line is a geological boundary between the crystalline rocks from the Piedmont province and the sedimentary rocks from the Coastal Plain province.

The Coastal Plain province is located south of the Fall Line, and is sometimes divided into the Upper Coastal Plain and the Lower Coastal Plain. The Upper Coastal Plain covers the central and southern portions of Georgia and the Lower Coastal Plain covers coastal and southeast Georgia and Florida. The seven major aquifer systems discussed in Section 1 were combined into the following aquifer layers for the regional Coastal Plain model:

- Surficial Aquifer-Brunswick Aquifers;
- Upper Floridan Aquifer;
- Claiborne-Gordon-Lower Floridan Aquifers;
- Clayton-Dublin Aquifers; and
- Cretaceous Aquifer System (Cressler, 1999).

The surficial aquifer system is present to some extent in each of the physiographic provinces of Georgia. It is generally unconfined, except for the coastal area of the Coastal Plain province, where at least two semi-confined aquifers have been identified (Peck et al., 2009).

2.3 Topography and Drainage

Georgia has a very diverse topography and surface water drainage system, which changes from north to south. The north of the State is mountainous, the central is

characterized by rolling hills, and the south is the Coastal Plain with fairly flat topography. The Blue Ridge Mountains terminate in northern Georgia, with the highest point in the State (Brasstown Bald) at 4,784 feet above mean sea level. The Blue Ridge Mountains have a sloping transition into the Piedmont region that ends in a ridge of sand hills running across the state from Augusta to Columbus. On the Florida border, there is a low lying area known as the Okefenokee Swamp, a very large peat-filled wetland. The Coastal Plain ends in marshlands along the Atlantic Ocean. Off-shore are the Sea Islands, called the Golden Isles of Georgia. Based on the digital elevation model (DEM) (2008), the land surface elevations within the Georgia Coastal Plain range from approximately 0 feet National Geodetic Vertical Datum (NGVD) in off-shores areas near the Atlantic Ocean to approximately 755 feet NGVD in Marion County, south of the Fall Line.

Rivers in Georgia play an important role in relation to groundwater because they both contribute to and receive from the hydrologic budget. Groundwater flows in the recharge areas are controlled largely by topography and stream-aquifer relations. Precipitation recharges the Upper Floridan, Claiborne, Clayton, and the Providence aquifers in their outcrop areas in the Upper Coastal Plain. Groundwater flows south-southeast down-gradient through the aquifers, which become confined. Pre-development conditions in west-southwestern Georgia, in areas where the Chattahoochee and Flint rivers cut through outcropping aquifers, had an upward component of groundwater flow which provided baseflow to the rivers. However, due to pumpage, groundwater gradients have reversed in some down dip areas (Gorday et al., 1997). Definition of the surface water drainage basins and analysis of the streamflow data was needed to perform baseflow separation analyses for groundwater-surface water interaction, which was a groundwater model calibration metric. The use of these data for baseflow separation analysis is presented in Section 6.3.3.

2.4 Regional Geology

The geology of Georgia is comprised of five distinct geologic regions (Figure 2-14). They are the Appalachian Plateau, the Valley and Ridge, the Blue Ridge, the Piedmont, and the Coastal Plain.

2.4.1 The Appalachian Plateau

The Appalachian Plateau consists of sedimentary rocks of the Paleozoic era. Fossils found on these rocks are from shallow marine environments and were deposited during the Cambrian and Pennsylvanian periods. The Appalachian Plateau was formed by uplift during the mountain building that formed the Appalachians. The plateau is interrupted by valleys where limestone and shale deposits are exposed along the crests of giant folds in the Alabama area. These deposits are the oldest of the plateau, from the Cambrian and Devonian periods, while the youngest deposits of the plateau are encountered in the flat bottoms of the giant folds, from the Mississippian and Pennsylvanian periods.

2.4.2 The Valley and Ridge

The Valley and Ridge province consists of Paleozoic sedimentary rocks that have been folded and faulted to form the long northeast-southwest-trending valleys and ridges that give the region its name. The faults are all thrust faults at which sheets of limestone, sandstone, and shale have been pushed northwestward on top of each other.

2.4.3 The Blue Ridge

The Blue Ridge province consists of metamorphic rocks, many of which are metamorphosed equivalents of Paleozoic sedimentary rocks. Others are metamorphosed igneous rocks. The Blue Ridge region forms the southern Appalachians.

2.4.4 The Piedmont

The Piedmont province consists of generally higher grade metamorphic and igneous rocks. It is the weathering of the Piedmont where Georgia gets its common red color soils. These soils consist of aluminosilicate clay minerals, iron oxides, quartz, feldspar, mica and other minerals which result from the severe weathering of feldspar-rich igneous and metamorphic rocks.

2.4.5 The Coastal Plain

This section presents the geology of the Coastal Plain in Georgia, which will be used to develop the groundwater flow models. Details on how these geologic units are represented in the project groundwater models are presented in Section 5.1. The Coastal Plain province consists of Cretaceous and Cenozoic sedimentary rocks and sediments. It is separated from the Piedmont by a boundary termed the Fall Line. The Fall Line is the Mesozoic extent of the Atlantic Ocean. The Fall Line crosses through the center of the State from Augusta in the east and on to Columbus in the west and marks the place where rivers flowing off the Piedmont and onto the Coastal Plain have prominent waterfalls and rapids (hence the term Fall Line). Technically, this line runs from Georgia to New York, forming the boundary between the hard, crystalline rocks of the Piedmont and Blue Ridge and the softer, more erodible strata of the Coastal Plain. The Coastal Plain strata dip toward the southeast, and thus they are younger nearer the coast. At least near the Fall Line, they are ultimately underlain by igneous and metamorphic rocks like those of the Piedmont. The sedimentary rocks of the Coastal Plain consist partly of sediment eroded from the Piedmont and partly of limestone generated by marine organisms and processes at sea.

The Coastal Plain rocks form a thick wedge of unconsolidated to poorly consolidated, dominantly clastic strata that dip gently coastward from a feather-edge near the Fall Line. They are typically non-marine to marginal marine at their northernmost extent, and they grade to deeper marine deposits as they extend into the deep subsurface (Renken, 1996).

There are several major structural features within the Study Area of the Coastal Plain which include Georgia Southwest and Southeast Embayments, the Gulf Trough, the Beaufort Arch, the peninsular arch, and the Ocala uplift (Renken, 1996). These structural features have had a major effect on the thickness and type of sediment deposited in the Study Area.

The Southeast Georgia Embayment is a shallow, east-to-northeast-plunging syncline that subsided at a moderate rate from the Late Cretaceous until the late Cenozoic. The thickness of Coastal Plain deposits is greatest in the vicinity of the Southeast Georgia Embayment (Clarke et al., 2004; Miller, 1986).

The Southwest Georgia Embayment is also referred to as the Apalachicola Embayment, and is a southwest-plunging syncline containing a thick sequence of predominantly clastic material (Miller, 1986). The northern end of the Embayment narrows and extends into the Gulf Trough in southern Georgia (Scott et al., 2001 and Scott, 2001). It widens and deepens as it extends into the modern Gulf of Mexico (Scott et al., 2001 and Scott, 2001). This feature is believed to be the middle Mesozoic to middle Cenozoic depositional basin of the Apalachicola River (Schmidt, 1984). Carbonate deposition occurred westward from the Florida platform into the embayment. The region has continued to subside, and the downwarping of sediments are observed, as well as the thickening of Upper Floridan Aquifer units consisting of Ocala, Suwannee, and St. Marks limestones.

The Gulf Trough is a significant sediment-filled depression or "trough," located in southern Georgia, which trends diagonally in a northeastward direction for approximately 200 miles (Figure 2-14). It consists of a zone of relatively thick accumulations of Miocene and younger aged deposits consisting of fine-grained clastic sediments and argillaceous (containing appreciable amounts of clay) carbonates, in which permeability and thickness of the Coastal Plain deposits decrease. The origin of the Gulf Trough is not fully understood. One hypothesis is that the Gulf Trough is a series of grabens formed by tectonic forces (Miller, 1986). Another theory is that it may have been a strait, formed mainly by the erosion of sediments and non-deposition by strong ocean currents, similar to the Straits of Florida located between the mainland and the Great Bahama Bank (Patterson and Herrick, 1971). Recent off-shore seismic and drill core analysis work indicates a continuation of the Gulf Trough trend through South Carolina and North Carolina. Analysis of stratigraphy indicates a zone of non-deposition and facies boundaries (deep and shallow marine) indicating that the Gulf trough was a current-swept marine strait that was active in the high sea levels of the middle and late Eocene and the early Oligocene. Also, the geologic history during this time does not involve tectonism (deforming of the earth's crust) or major epeirogeny (vertical or tilting of the earth's crust), but it clearly involves eustasy (sea level change) (Popenoe et al., 1987).

Regardless of its origin, the Gulf Trough impedes groundwater flow because of the juxtaposition of rocks of higher permeability updip and downdip of the trough, with

those of lower permeability within the trough. The structural effect can be seen on potentiometric surface maps of the aquifer system (Clarke et al., 2004; Krause and Randolph, 1989; Miller, 1986).

A smaller structural feature is also evident and has an impact on the geology and hydrogeology of the Study Area. For example, the Gilbertown-Pickens-Pollard fault system in Alabama locally forms the updip limit of the Floridan Aquifer System. The Beaufort Arch is a structural feature that is centered near Hilton Head Island and trends parallel to the coast. It interrupts the regional southward dip of the sediments in that area. The Coastal Plain deposits thin and are present at shallower depths than in the vicinity of the Southeast Georgia Embayment (Clarke et al., 2004).

The Peninsular Arch is a northwest-trending feature that was continually positive from Jurassic until Late Cretaceous time (Miller, 1986). Its location is depicted on Figure 2-14 and occurs in north Florida and south-central Georgia. It may have also been sporadically positive during the Cenozoic age. The effect of this feature has been to control sedimentation in north central Florida, and it has been proposed to be a result of compressional tectonics (Miller, 1986).

The Ocala Uplift is another northwest-trending uplift paralleling the Peninsular Arch to the west and its location is depicted on Figure 2-14. The Ocala Uplift only affects sediments of middle Eocene and younger. It is thought to be a buildup of Eocene carbonate sediments, or more likely, a compaction of Eocene material after deposition (Miller, 1986).

The generalized geology of the Coastal Plain of Georgia consists of the 15 geologic units of the Coastal Plain sediments that are listed below (Faye and Mayer, 1996; Gorday et al., 1997; Huddleston, 1988; McFadden and Perriello, 1983; Meyer, 1989; Miller, 1986; Payne et al., 2005; Randazzo, 1997; Renken, 1996; Scott, 1988) in descending order:

- Undifferentiated, alluvium, terrace, and shallow marine deposits of Holocene, Pleistocene, and Pliocene age;
- Alum Bluff and Hawthorn Group of Miocene age;
- Suwannee Limestone of Oligocene age;
- Ocala Limestone and Barnwell Formation of late Eocene age;
- Lisbon, Avon Park, and McBean Formations of middle Eocene age;
- Tallahatta, Oldsmar, and Fishburne Formations of middle to early Eocene age;
- Tusahoma and Cedar Keys Formations of early Eocene and late Paleocene age;
- Clayton Formation of early Paleocene age;

- Providence and Peedee Formation of Upper Cretaceous age;
- Ripley Formation of Upper Cretaceous age;
- Blufftown and Black Creek Formations of Upper Cretaceous age;
- Eutaw Formation of Upper Cretaceous age;
- Atkinson Formation of Upper Cretaceous age;
- Tuscaloosa Formation of Upper Cretaceous age; and
- Undifferentiated deposits of Lower Cretaceous age.

Within the Coastal Plain of Georgia, a generalized chronostratigraphic column and map showing the generalized geology are shown in **Table 2-3** and **Figure 2-16**, respectively. Each of these geologic units is briefly described in **Table 2-4**.

2.5 Regional Hydrogeology

This section presents the hydrogeology of the Coastal Plain in Georgia, which is used to develop the conceptual model of groundwater flow. Details on how these hydrogeologic units are represented in the project groundwater models are presented in Section 5.1. The vertical and horizontal boundaries of regional hydrogeologic, time, and rock stratigraphic units do not correlate everywhere. The rock units that make up the regional aquifers in the Coastal Plain of Georgia were deposited in alluvial or transitional to marginal marine environments. Therefore, the hydraulic connection of stratigraphically equivalent rocks changes from place to place. Age equivalent rock strata may be a productive aquifer in one area but act as a confining unit in another (Renken, 1996). The hydrogeologic units used to describe the aquifer framework encompass several formations or parts of formations and, therefore, cross time stratigraphic boundaries.

The aquifers within the Coastal Plain of Georgia are summarized as the following: the Surficial-Brunswick Aquifers, Upper Floridan Aquifer, Claiborne-Gordon-Lower Floridan Aquifers, Clayton-Dublin Aquifers, and the Cretaceous Aquifer System, which includes the Providence Sand-Peedee-Dublin Aquifers, Eutaw-Midville Aquifer, and the Upper Atkinson-Upper Tuscaloosa Aquifers. Because of its stratigraphic position crossing the Cretaceous and Paleocene geologic series, the Dublin hydrologic unit was included in both the Clayton-Dublin and Cretaceous Aquifer System layers (Clarke, Brooks, and Faye, 1985). The Floridan Aquifer is composed of the Upper and Lower Floridan Aquifers in southeast Georgia and in the peninsula of Florida. Where it exists, the surficial aquifer system is separated from the Upper Floridan Aquifer by the clayey Miocene deposits of the Hawthorn Group in the central and eastern part of the Coastal Plain of Georgia and by Alum Bluff in the central and southwest area of the Florida Panhandle.

Table 2-3 Chronostratigraphy of the Geologic and Hydrogeologic Units of the Study Area

Erathem	System	Series	SE Alabama / SW Georgia / NE Florida Panhandle		Central Georgia to North Florida		East Georgia/West South Carolina	
			Geologic Formations	Hydrogeologic Formations	Geologic Formations	Hydrogeologic Formations	Geologic Formations	Hydrogeologic Formations
Cenozoic	Quaternary	Post Miocene	Alluvium Deposits / *	Surficial Aquifer	Undifferentiated, Terrace and Alluvium Deposits	Surficial Aquifer	Undifferentiated, Terrace and Alluvium Deposits	Surficial Aquifer / Brunswick Aquifer & Confining Unit
	Tertiary	Miocene	Alum Bluff / *	Upper Confining Unit	Hawthorn Group	Upper Confining Unit	Hawthorn Group	Brunswick Aquifer
		Oligocene	Suwannee Limestone and Residuum	Upper Floridan Aquifer	Suwannee Limestone	Upper Floridan Aquifer	Suwannee Limestone	Upper Floridan Aquifer and equivalents
		Eocene	Ocala Limestone and Residuum		Ocala Limestone		Ocala Limestone / Barnwell Formation	
			Lisbon Formation		Lisbon Confining Unit		Avon Park / Lisbon Formation	
		Paleocene	Tallahatta Formation	Claiborne Aquifer	Tallahatta Formation / Oldsmar Formation	Tallahatta - Gordon / Lower Floridan Aquifers	Oldsmar Formation	Lower Floridan Aquifer
			Tuscahoma Formation	Tuscahoma Confining Unit	Cedar Keys Formation / Tuscahoma Formation	Tuscahoma Confining Unit	Tuscahoma / Fishburne Formations	Tuscahoma - Fishburne Confining Unit
			Clayton Formation	Clayton - Ellenton Aquifer	Clayton Formation	Clayton - Ellenton Aquifer / Dublin Aquifer	Peedee Formation	Dublin Aquifer
		Mesozoic	Cretaceous	Providence Sand	Providence Sand - Peedee Confining Unit	Providence Sand	Providence Sand - Peedee Confining Unit	Providence Sand
	Ripley Formation			Providence Sand - Peedee Aquifer	Providence Sand - Peedee / Dublin Aquifer		Providence Sand - Peedee / Dublin Aquifer	
Cusseta Sand / Blufftown Formation	Ripley Black Creek Confining Unit			Cusseta Sand	Ripley Black Creek Confining Unit	Cusseta Sand	Ripley Black Creek Confining Unit	
Eutaw Formation	Eutaw-Midville Aquifer			Blufftown Formation / Eutaw Formation	Eutaw-Midville Aquifer	Blufftown Formation / Eutaw Formation	Ripley Black Creek Confining Unit	
	Eutaw Cape Fear Confining Unit			Eutaw / Cape Fear Formation	Eutaw Cape Fear Confining Unit	Cape Fear Formation	Eutaw-Midville Aquifer	
	Upper Atkinson - Upper Tuscaloosa Aquifer				Upper Atkinson - Upper Tuscaloosa Aquifer		Eutaw Cape Fear Confining Unit	
Tuscaloosa Formation	Middle Atkinson Confining Unit			Atkinson Formation	Middle Atkinson Confining Unit	Atkinson Formation	Upper Atkinson - Upper Tuscaloosa Aquifer	
Atkinson Formation/Tuscaloosa	Lower Atkinson - Lower Tuscaloosa Aquifer				Lower Atkinson - Lower Tuscaloosa Aquifer		Middle Atkinson Confining Unit	
	Mitchell Confining Unit				Mitchell Confining Unit			

Notes:
* Does not exist in all portions of the geographic areas listed above

Table 2-4 Geologic Unit Descriptions

Formation	Composition	Location	Notes
Undifferentiated Alluvium, Terrace, and Shallow Marine Deposits	Unconsolidated soils, predominantly sand, clayey sands, and sandy clay	Primarily in the southeastern part of the state	Where present, these deposits make up the surficial aquifer.
Alum Bluff Formation	Clays, sands, shell beds, and occasional carbonate beds (Huddleston, 1988). Mica is a common constituent and glauconite and phosphate occur sporadically. These sediments generally have low permeabilities and are part of the upper confining unit.	South-central Georgia and Florida. West of the Apalachicola River, the Hawthorne Group is replaced by the Alum Bluff Group.	Includes the Chipola Formation, Oak Grove Sand, Shoal River Formation, Choctawhatchee Formation, and the Jackson Bluff Formation (Huddleston, 1988; Braunstein et al., 1988).
Hawthorn Group	Complex, highly variable package of interbedded and intermixed siliciclastic, carbonate, and phosphatic sediments (Scott, 1988; Huddleston, 1988). Comprises the upper confining unit overlying the Floridan Aquifer for most of the Coastal Plain of Georgia. It consists of deposits of the Miocene, mostly of clay, silt, and sand beds containing phosphate. It is considered a low-permeability unit due to the fines. Within this unit, there are permeable lenses of sands, limestone, and dolomite that are part of the surficial aquifer in southeast Georgia and the peninsula of Florida (Miller, 1986; Meyer, 1989; Scott, 1988).	The Hawthorn Group Formation primarily occurs in the southeastern portion of the state.	For descriptive purposes, all the component formations are not recognized in this generalized summary. Figure 2-17 shows the extent and thickness of the upper (Miocene) confining deposits.
Suwannee Limestone	Cream to tan highly vuggy limestone. It is part of the Tertiary sequence that contains the Floridan Aquifer System.	Primarily occurs in the southern portion of the state. In southwest Georgia, the Suwannee outcrops as a weathered residuum providing semi-confinement to the Floridan in that area. Thicknesses up to 100 feet have been reported in the Tifton, Georgia area.	The Suwannee overlies the Ocala Limestone, and its lithologic similarities with the Ocala make it difficult to determine thicknesses (Hicks et al., 1987)
Ocala Limestone	Typically a white, generally, soft, friable, porous limestone. The Ocala is one of the most permeable rock units in the Floridan Aquifer System (Miller, 1986)	The Ocala Limestone of Late Eocene age overlies the Lisbon Formation, where present, and the Avon Park Formation in the Coastal Plain of Georgia. It primarily occurs in the southern portion of the state. In eastern Georgia and southwestern South Carolina, it grades laterally into more clastic sediments of the Barnwell Formation.	Approximate thicknesses range from 50 feet (updip) to 475 feet (downdip) (Gorday et al., 1997).

Table 2-4 Geologic Unit Descriptions (Continuation)

Formation	Composition	Location	Notes
Barnwell Formation	Fine to coarse-grained, gray, yellow, pink, and red feldspar-rich sand and beds of light-gray to green, glauconitic, fossiliferous clay (Miller, 1986; Siple, 1967).	The Barnwell Formation occurs only in eastern Georgia and southwestern South Carolina.	Deposited simultaneously with the Ocala Limestone - the Barnwell in shallow water near shore, and the Ocala in deeper water.
Avon Park Formation	Thick sequence of fossiliferous limestone, dolomitic limestone, and dolostone. The lower portion of this unit has the lower permeable carbonates that comprise the middle semi-confining unit within the FAS.	Occurs in east-southeast Georgia and grades into the Lisbon Formation in the central portion of the State.	The Suwannee and Ocala Limestones and the upper part of the Avon Park Formation comprise the Upper Floridan Aquifer (Miller, 1986; Meyer, 1989).
Lisbon Formation	Updip consists of low permeability interbedded dark green to greenish gray, fossiliferous, calcareous, glauconitic sand, sandy clay, and clay that acts as a confining unit below the Upper Floridan Aquifer. Downdip, it grades into gray, greenish-gray, glauconitic clay with lenses of fine-grained, calcareous, glauconitic sand, and hard limestone (Miller, 1986).	The Lisbon Formation primarily occurs in the south-central portion of the state.	
McBean Formation	Fine-grained, loose to semi-consolidated, slightly fossiliferous sand of middle Eocene age. It grades downward and seaward into calcareous clay becoming a confining unit to the Tallahatta-Gordon Aquifer.	Occurs in northeast Georgia and South Carolina.	
Tallahatta Formation	In southwestern Georgia, the formation outcrops as fine to coarse-grained slightly fossiliferous sand interbedded with dark-brown, silty, micaceous, occasionally glauconitic limestone. Downdip, the Tallahatta grades into cream to light-gray, argillaceous, sandy limestone that in turn grades into the Avon Park Formation in central to south-central Georgia (Gorday et al., 1997; McFadden and Perriello, 1983; Miller, 1986).	Southwestern to south-central Georgia	More of marine in origin within the Coastal Plain Area.

Table 2-4 Geologic Unit Descriptions (Continuation)

Formation	Composition	Location	Notes
Oldsmar Formation	Off-white to light gray micritic limestone and vuggy dolostone. Evaporites are common in the lower parts of this formation. Westward and in south-central Georgia, the Oldsmar becomes increasingly argillaceous and interfingers with calcareous clastic rocks, and it grades to calcareous clay, then into glauconitic calcareous sand (McFadden and Perriello, 1983; Miller, 1986; Meyer, 1989).	The Oldsmar Formation occurs in east-southeast Georgia and grades into the Tallahatta Formation in the central portion of the state. The Oldsmar Formation underlies the entire Florida peninsula and the southeastern corner of Georgia.	
Cedar Keys Formation and equivalents	Dolostone, dolomitic limestone, and anhydrite. The Oldsmar and Cedar Keys Formations comprise the lower Floridan Aquifer (Miller, 1986; Meyer, 1989).	Southeastern and south-central Georgia and the Florida panhandle	
Tuscaloosa Formation	The lower unit is a transgressive unit containing mostly medium sands to gravel with abundant glauconite and clay laminae. The upper unit consists of very fine to fine, carbonaceous, clayey sands and clays of lagoonal origin (Gibson, 1982).	The Tuscaloosa Formation occurs in western Alabama to central-eastern Georgia in the Coastal Plain of Georgia. It provides the confining unit below the Claiborne Aquifer overlying the Clayton Aquifer.	Has an upper and lower unit.
Fishburne Formation	Nodular, glauconitic, and clayey limestone. The limestone typically is greenish gray to pale olive and shows little evidence of stratification. The apparent lack of bedding is probably due to bioturbation (stirring or mixing of sediment by organisms).	Localized to southeastern Georgia and southwestern South Carolina.	
Clayton Formation	Mostly fine to medium-grained glauconitic sand and clayey sand and smaller amounts of gray clay. The top of the Clayton contains a sandy hard limestone with significant effective porosity. It is thickest in western Georgia, where it constitutes a significant portion of the productive Clayton Aquifer.	Southwest-south-central Georgia and grades into the Dublin Aquifer in central portion of the state. The Clayton overlies the Upper Cretaceous deposits.	
Upper Cretaceous	Mostly coarse sand and gravels changing to silty, muddy sands and clays. The Late Cretaceous deposits formed in bays, lagoons, and estuaries along the Georgia coast. The Cretaceous aquifer system is composed of the Cretaceous deposits, which is confined above by the low permeability units of the Providence and Peedee Formations.	Deposits underlie the entire Coastal Plain of Georgia in the southern third of the state outcropping at or near the Fall Line.	From youngest to oldest, the Upper Cretaceous deposits consist of the following formations: Providence and Peedee Formation, Ripley Formation (includes Cusseta sand), Blufftown and Black Creek Formations, Eutaw-Cape Fear Formation, Atkinson Formation, and Tuscaloosa Formation.

The Upper Floridan Aquifer is separated from the Lower Floridan Aquifer by a semi-confining unit consisting of the lower, less permeable portion of the Avon Park Formation.

The generalized chronostratigraphy of the geologic and hydrogeologic units of the Coastal Plain of Georgia is shown in Table 2-3. North to South and East to West hydrostratigraphic cross-sections were developed to show the hydrogeologic units. The locations of the hydrostratigraphic cross-sections through the Coastal Plain of Georgia are shown on **Figure 2-18**. The east-west and north-south cross-sections are shown on **Figures 2-19** through **2-21**, respectively.

Figure 2-22 shows the extent and location of outcropping hydrogeologic deposits in the Coastal Plain of Georgia. These deposits are age equivalent sediments and rocks which comprise the various aquifers within the study area. Where these deposits outcrop are areas of primary recharge for their associated aquifers.

Groundwater flow is dynamic and is affected by topography, stream-aquifer relations, and the amount of confinement. As stated previously, precipitation recharges the Upper Floridan, Claiborne, Clayton, and Cretaceous Aquifers in their outcrop areas in the Upper Coastal Plain. Generally, groundwater flows south-southeast down-gradient through the aquifers, flowing through the down dipping strata, which become confined. Water that recharges an aquifer follows local, intermediate and regional flow paths having both horizontal and vertical flow components as shown on **Figure 2-23** (Heath, 1984). In the updip areas of the aquifers, the gradient is generally downward. In the downdip areas of the aquifers, the predevelopment gradient was generally upward.

Pumping in west-southwest Georgia has caused a reverse in flows and reduced baseflow to the major rivers. In southeast coastal Georgia, groundwater pumping has reduced the potentiometric head for the Upper Floridan Aquifer by as much as 60 to 130 feet, thereby inducing salt water intrusion (Clarke, 2003; Payne et al., 2005 & 2006; Randolph et al., 1991).

2.5.1 Surficial Aquifer System

The extent of the surficial aquifer in the Study Area is shown on Figure 2-22. The thickness of the surficial aquifer system is typically less than 50 feet for most of the Coastal Plain area where it exists. The surficial aquifer system is about 60 feet thick in southeastern Georgia and approximately 300 feet thick in the central eastern part of the Study Area. The surficial aquifer system generally thickens near the coast and consists mostly of beds of unconsolidated sand, shelly sand, and shell. In some places, clay beds are sufficiently thick and continuous to divide the system into two aquifers: an unconfined water table aquifer and a semi-confined portion. This aquifer system is comprised of deposits from Miocene to Holocene in age.

Groundwater in the surficial aquifer system is predominately under unconfined or water table conditions and the groundwater exists under atmospheric pressure. Some

thin clay beds create confined or semi-confined conditions within the system. Most of the water that enters the system moves quickly along short flow paths and discharges as baseflow to streams. In some places, water leaks upward from the underlying Floridan Aquifer System through the clayey confining unit (Hawthorn Group) separating the Floridan Aquifer and the surficial aquifer system. In locations where the hydraulic head of the Floridan is lower than the water table, leakage occurs in the opposite direction.

Transmissivity values of the surficial aquifer system range from 14 to 6,700 square feet per day (ft²/day) within the areas of unconfined conditions. In areas of confined conditions, transmissivity values have been reported to range from 150 to 6,000 ft²/day (Payne et al., 2005).

The surficial aquifer is not included as an active layer in the groundwater models developed to evaluate the ranges of sustainable yields for the coastal plain aquifer system, as described in Section 5.4.2 (Model Stratigraphy).

2.5.2 Brunswick Aquifer System

The surficial aquifer system and the Brunswick Aquifer System are typically separated by a confining unit of clay from the Coosawhatchie Formation (from the Hawthorn Group). The Brunswick Aquifer is encountered in the eastern side of the Coastal Plain of Georgia and is made up of Miocene age deposits. The Brunswick Aquifer System is comprised of an upper and lower unit separated by a clay unit of the Parachucla Formation (Clarke, 2003). The aquifer consists of poorly sorted, fine to coarse slightly phosphatic and dolomitic quartz sand and dense phosphatic limestone (Clarke et al., 1990; Leeth, 1999). In southeast Georgia, the aquifer has a high percent of clayey deposits. The thickness of the aquifer ranges from less than 100 to 200 feet. Groundwater within the Brunswick aquifer occurs primarily under semi-confined to confined conditions. Groundwater in semi-confined and confined aquifers occurs at pressures greater than atmospheric pressure due to upper confinement of the aquifer. Therefore, groundwater levels are typically referred to as a potentiometric surface since groundwater levels are typically above the top of the aquifer under confined conditions.

Transmissivity within this aquifer ranges from 15 to 4,700 ft²/day (Payne et al., 2005). The lower unit of the aquifer has higher transmissivity values than the upper unit. The Brunswick Aquifer is commonly utilized to offset pumpage from the Upper Floridan Aquifer. Groundwater levels in the lower unit of the Brunswick Aquifer typically respond to pumping from the Upper Floridan Aquifer.

The Brunswick Aquifer System is not included as an active layer in the groundwater models developed to evaluate the ranges of sustainable yields for the coastal plain aquifer system, as described in Section 5.4.2 (Model Stratigraphy).

2.5.3 Upper Confining Unit

The upper confining unit comprises the base of the surficial aquifer system, where it exists, and extends to the top of the Floridan Aquifer System. The upper confining unit is comprised of Miocene aged deposits, mostly of the Hawthorn Group for the central and eastern part of the Study Area, and the Alum Bluff Group in the central and southwest area of the Florida Panhandle. The deposits are composed of green clay, silt, micritic limestone and marl consisting of a highly variable lithology. The thickness of the upper confining unit within the Study Area ranges from 0 feet to 500 feet (Miller, 1986; Meyer, 1989; Scott, 1988). Figure 2-17 shows the extent of Miocene deposits providing confinement to the Floridan Aquifer System within the Study Area.

2.5.4 Floridan Aquifer System

The Floridan Aquifer System in the vicinity of the Study Area consists of a thick sequence of porous to dense limestone, dolomitic limestone, and dolostone. Where it contains freshwater, it is typically the principal source of water supply in the Study Area. The Floridan Aquifer System is composed of the Upper and Lower Floridan Aquifers. The Floridan Aquifer pinches out in northwest Georgia near the Fall Line where Cretaceous deposits outcrop, and it is thickest (>3,500 feet) in northeast Florida.

Variations in permeability within the Floridan Aquifer System result from a combination of original depositional conditions, diagenesis (the physical and chemical changes occurring in the sediments between the times of deposition and solidification), large-and small-scale structural features, and dissolution of carbonate rocks or evaporite deposits. Local permeability variations are accordingly more complex than the generalized regional description (Miller, 1986).

2.5.4.1 Upper Floridan Aquifer

The Upper Floridan Aquifer is separated from the Lower Floridan Aquifer by the semi-confining unit in the lower part of the Avon Park Formation. The Upper Floridan is highly permeable in most places and includes the Suwannee and Ocala Limestones, and the upper part of the Avon Park Formation.

Transmissivity values in the Upper Floridan Aquifer range from less than 10,000 ft²/day (in areas near the updip limit of the aquifer system) to greater than 1,000,000 ft²/day. In approximately half of the Study Area (central to northwest Georgia), the transmissivity values are less than or equal to 100,000 ft²/day. The south-central and southeast areas usually have transmissivity values greater than 100,000 ft²/day (Miller, 1990).

Groundwater within the Floridan Aquifer occurs primarily under confined conditions, except where the upper confining unit is missing. **Figure 2-24** shows a 1998 potentiometric surface map of the Upper Floridan Aquifer in the Study Area (Peck et al., 1999). As shown on Figure 2-24, the groundwater flow direction is generally from north (along the updip areas) to the southeast, except in the

southwestern side where the flow direction is towards south-southwest. The Valdosta groundwater high is a prominent feature along the Withlacoochee River in Brooks and Lowndes County. The effects of the Gulf Trough (trending northeast to southwest through the model of the Coastal Plain) can also be seen on Figure 2-24 where the potentiometric surface contours are very close together (indicating a steep hydraulic gradient) due to the lower permeability of the sediments within the Trough in the Upper Floridan in this area. There are two notable cones of depression in the potentiometric surface of the Upper Floridan Aquifer in Georgia; near the cities Savannah and Jesup, due to relatively large, concentrated withdrawals in these areas.

2.5.4.2 Lower Floridan Aquifer

The Lower Floridan Aquifer includes the lower part of the Avon Park Formation, the Oldsmar Limestone, and the upper part of the Cedar Keys Formation. Much of the Lower Floridan Aquifer contains highly mineralized water. The Lower Floridan Aquifer is not as spatially extensive as the Upper Floridan. The Lower Floridan Aquifer does not extend into north and western Georgia, where the age equivalent Claiborne and Tallahatta-Gordon aquifers exist. The Lower Floridan Aquifer primarily occurs in coastal Georgia and extreme southwestern Georgia near the Georgia-Florida state line. Given the locations of the Lower Floridan Aquifer in Georgia this aquifer does not outcrop.

2.5.5 Claiborne Aquifer

The Claiborne Aquifer exists predominately in the west side of the Coastal Plain of Georgia. It consists of saturated, permeable sand separated by less permeable sequences of fine sand, silt, and clay. The thickness of the sediments of the aquifer ranges from 50 to 290 feet. Transmissivity values of the Claiborne Aquifer range from approximately 3,000 to 4,000 ft²/day (Gorday et al., 1997; McFadden and Perriello, 1983).

The upper portion of this unit consists of fine to medium sands with interbedded limestone layers (Hicks et al., 1987). The Claiborne Aquifer lies within the upper Tallahatta and lower Lisbon Formations and is confined above by clay layers in the upper Lisbon Formation and confined below by clayey layers of the Tuscaloosa Formation. However, due to the moderate permeability (and corresponding leakance) of the upper Lisbon Formation between the Upper Floridan and Claiborne Aquifers drawdown in one of these aquifers affects water levels in the other (Gorday et al., 1997).

Groundwater within the Claiborne Aquifer occurs primarily under confined conditions, except in outcrops along streams and tributaries in a northeast trending band starting at Alabama-Georgia State Lines (Early and Clay Counties, Georgia) and extending to Macon and Dooly, Counties (McFadden and Perriello, 1983). The outcrop areas for the Claiborne Aquifer are shown on Figure 2-22. **Figure 2-25** shows a 1986 potentiometric surface map of the Claiborne Aquifer in southwest Georgia (Long, 1989a). As shown on Figure 2-25, the groundwater flow direction is generally

from north to the south. There is notable cone of depression in the potentiometric surface of the Claiborne Aquifer in Dougherty County, Georgia due to large pumping withdrawals in this area.

2.5.6 Gordon Aquifer

The Gordon Aquifer exists mostly within the central part of the Coastal Plain of Georgia. The thickness of these sediments ranges from 100 to 1,150 feet.

Transmissivity values range from approximately 70 to 75,800 ft²/day (Gorday et al., 1997; McFadden and Perriello, 1983). Groundwater within the Gordon Aquifer occurs primarily under confined conditions, except in outcrops along streams and tributaries in a northeast trending band starting in Houston County and extending to Richmond County at the Georgia-South Carolina State Line (Brooks, et al., 1985). The outcrop areas for the Gordon Aquifer are shown on Figure 2-22. **Figure 2-26** shows a 1981 potentiometric surface map of the Gordon Aquifer for central and eastern Georgia (Brooks et al., 1985). As shown on Figure 2-26, the groundwater flow direction in the Gordon Aquifer is generally from north to the south-southeast.

2.5.7 Clayton - Dublin Aquifers

The lowermost aquifer of Paleocene age is the Clayton Aquifer from the west to the central part of the Coastal Plain of Georgia. The Clayton Aquifer is composed mainly of limestone from the middle part of the Clayton Formation. Sand is the primary lithology in the upper and lower parts of the formation and is hydraulically connected with the limestone portions of this aquifer. The upper and lower contacts of the Clayton Formation are erosional in nature, causing thicknesses to vary over short distances. The thickness of the aquifer ranges from 50 to 350 feet, generally thickening to the southeast.

Transmissivity values within the Clayton Aquifer range from less than 1,000 to 13,000 ft²/day within the Coastal Plain of Georgia. The highest transmissivity values are encountered in west Georgia and east Alabama (Gorday et al., 1997; McFadden and Perriello, 1983).

Groundwater within the Clayton Aquifer occurs under confined conditions except in outcrops along streams and tributaries in a northeast trending band starting in Quitman County and extending to west-central Macon County (McFadden Perriello, 1983). The Dublin member of this Paleocene aquifer primarily occurs in south-central and coastal Georgia and does not outcrop. The Dublin aquifer crosses the Cretaceous-tertiary boundary, as shown in Table 2-3 and therefore, the Dublin aquifer is included with both the tertiary Clayton aquifer and the Cretaceous aquifer. The outcrop areas for the Clayton Aquifer are shown on Figure 2-22. **Figure 2-27** shows a 1986 potentiometric surface map of the Clayton Aquifer for southwest Georgia (Long, 1989b). As shown on Figure 2-27, the groundwater flow direction is generally from north to the south-southeast. There is a notable cone of depression in the potentiometric surface of the Clayton Aquifer in Dougherty County, Georgia due to large pumping withdrawals in this area.

The Dublin aquifer system consists of upper and lower hydrogeologic units. The upper portion is comprised of fine to coarse sand and limestone in the lower Ellenton unit (age equivalent to the Clayton Formation- Paleocene). The lower part consists of alternating layers of kaolinitic sand and clay of the Cretaceous Peedee-Providence unit (Clark et al., 1985). The transmissivity values of the Dublin aquifer system range from 2,200 to 35,000 ft²/day.

2.5.8 Cretaceous Aquifer System

The Cretaceous Aquifer System comprises sediments from the Cretaceous age consisting mostly of sand, clayey sand, sandstone, clay, chalk, shale, and marl. The Cretaceous Aquifer is separated from the Tertiary age (overlying) aquifers by the Providence Sand-Peedee confining unit. The upper Cretaceous Aquifer is separated from the lower Cretaceous Aquifer by the Eutaw-Cape Fear confining unit.

2.5.8.1 Upper Cretaceous Aquifer System

The Upper Cretaceous sediments within the Coastal Plain of Georgia consist of sand, clayey sand, clay, marl, and shale. In the southern part of the Coastal Plain of Georgia, the Upper Cretaceous sediments consist mostly of layers of chalk, clay, sandstone, and some limestone. The approximate thickness of the Upper Cretaceous sediments within the Coastal Plain of Georgia is 2,000 feet (Faye and Mayer, 1996). The upper Cretaceous Aquifer System comprises the Clayton Aquifer, Providence Sand-Peedee-Dublin Aquifer, and Eutaw-Midville Aquifer.

2.5.8.1.1 Providence Sand-Peedee-Dublin Aquifers

A confining unit of clays and silts, part of the lower portion of the Clayton Formation and upper portion of the Providence Sand-Peedee confining deposits, separates the Clayton Aquifer from the Providence Sand-Peedee -Dublin Aquifers. In the western portion of the Coastal Plain of Georgia, the aquifer is referred to as the Providence Sand-Peedee Aquifers. In the east, this aquifer is considered the base of the Dublin Aquifer System. In the updip area of this aquifer, the confining unit is often missing. In the central to eastern portion of the Coastal Plain of Georgia, when the confining unit is missing, the aquifer is referred to as the Dublin-Midville Aquifer. The Providence-Peedee-Dublin Aquifers are confined below by silts and fine sands within the Perote Member of the Providence Sand and the Ripley Formation. The thickness of the aquifer ranges from approximately 100 to 400 feet.

Transmissivity values within the Providence Sand-Peedee-Dublin Aquifers range from less than 1,000 to 11,200 ft²/day within the Coastal Plain of Georgia. The highest transmissivity values have been measured north along central Georgia and northeast of the Coastal Plain of Georgia. In southwest Georgia, transmissivity values range from approximately 760 to 2,600 ft²/day (Gorday et al., 1997), whereas in south Georgia, transmissivity values range from 250 to 11,200 ft²/day (Faye and Mayer, 1996).

Groundwater within the Upper Cretaceous Aquifer occurs primarily under confined conditions, except where the Cretaceous is the uppermost aquifer in central Georgia just south of the Fall Line where the Cretaceous Aquifer outcrops (see Figure 2-23). **Figure 2-28** shows a 1980 potentiometric surface map of the Providence Sand-Peedee Aquifer in southwest Georgia (Clarke et al., 1983). As shown on Figure 2-28, the groundwater flow direction in the Providence Sand-Peedee Aquifer is generally from north to the south-southeast. There is notable cone of depression in the potentiometric surface of the Claiborne Aquifer in Dougherty County, Georgia due to large pumping withdrawals in this area.

2.5.8.1.2 Eutaw-Midville Aquifer

The Eutaw-Midville Aquifer underlies the Providence Sand-Peedee-Dublin Aquifers and has a sediment thickness ranging from approximately 240 to 480 feet (Faye and Mayer, 1996). Transmissivity in this aquifer ranges from less than 1,000 to 35,300 ft²/day (Faye and Mayer, 1996). The highest values have been measured in the north central area of Georgia and northeast portion of the Coastal Plain of Georgia.

2.5.8.2 Eutaw-Cape Fear Confining Unit

The Eutaw-Cape Fear confining unit separates the upper Cretaceous Aquifer from the lower Cretaceous Aquifer. This unit ranges in thickness from approximately 180 to 600 feet. Leakance values from the confining unit are on the order of 5.8×10^{-6} day⁻¹.

2.5.8.3 Lower Cretaceous Aquifer System

Sediments from the Lower Cretaceous Aquifer System consist mostly of coarse sand, sandstone, and clay. The thickness of these sediments exceeds approximately 3,000 feet in the areas of southwestern Georgia and adjacent areas of Alabama and Florida. In southern Georgia and Florida, the Lower Cretaceous Aquifer is not used for water supply due to the depth and mineralization of the aquifer. In the updip area closer to the Fall Line, the geologic units that make up the Lower Cretaceous Aquifer are used for water supply.

2.5.8.3.1 Upper Atkinson-Upper Tuscaloosa Aquifer

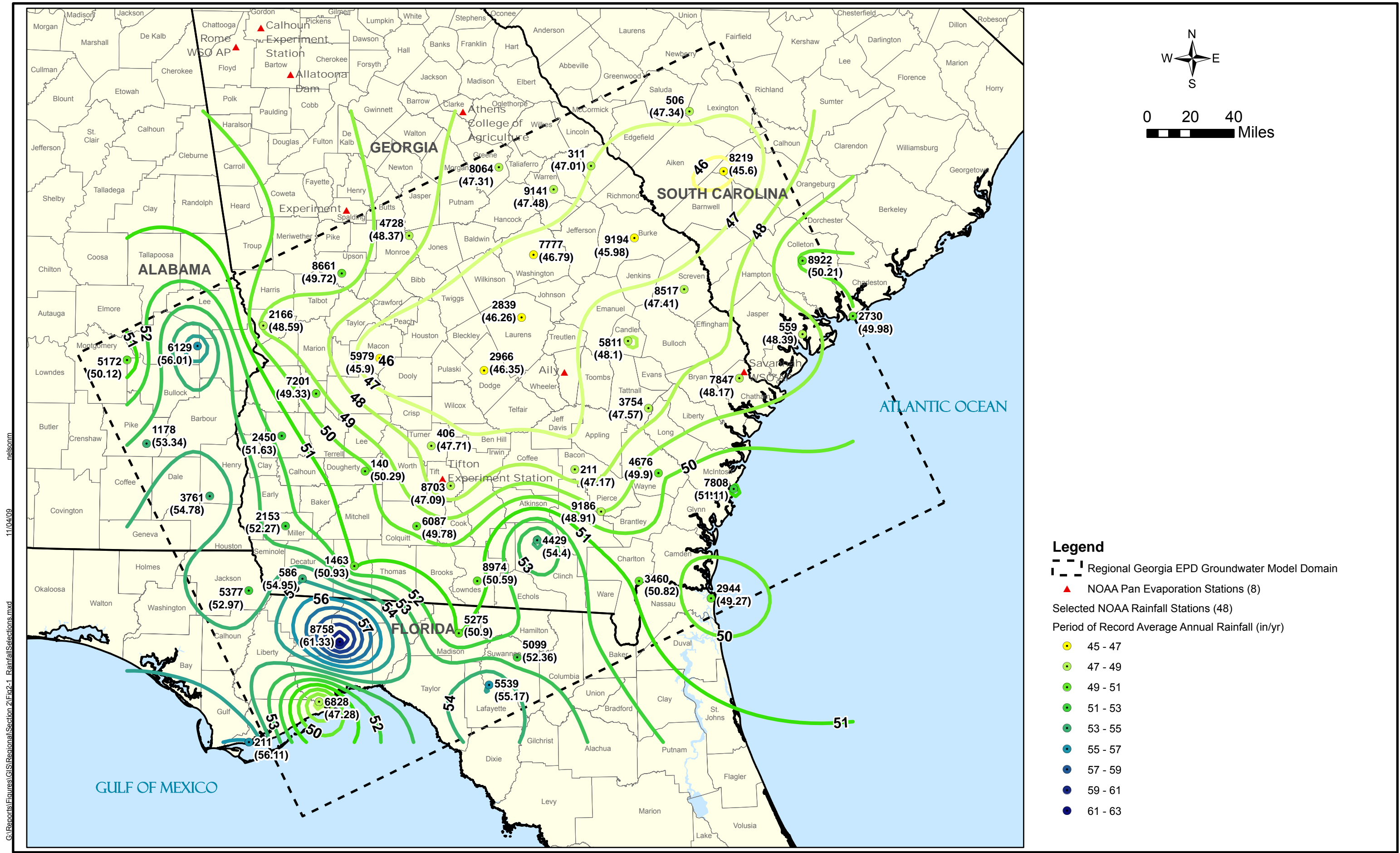
The Upper Atkinson-Upper Tuscaloosa Aquifer consists of coarse sand, sandstone, interbedded with clay and also with shale and mudstone within the Coastal Plain of Georgia. The aquifer thickness ranges from approximately 200 to 500 feet, while transmissivity values range from less than 1,000 to 4,000 ft²/day (Faye and Mayer, 1996).

2.5.8.3.2 Lower Atkinson - Lower Tuscaloosa Aquifer

The Lower Atkinson-Lower Tuscaloosa Aquifer is separated from the Upper Atkinson-Upper Tuscaloosa Aquifer by a confining unit. The thickness of this aquifer ranges from approximately 100 to 440 feet.

2.5.8.4 Mitchell Confining Unit

The Mitchell confining unit underlies the Lower Atkinson–Lower Tuscaloosa Aquifer in southwestern Georgia and forms the base of the Cretaceous Aquifer System and the Coastal Plain Aquifer System. Metamorphic and igneous rocks of primarily Paleozoic and Precambrian age underlie the Mitchell confining unit. In southeastern Georgia, the Mitchell confining unit is missing and the Lower Atkinson–Lower Tuscaloosa Aquifer are directly underlain by crystalline rocks.



nelson

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Figure 2-1
Locations of NOAA Selected Rainfall Stations and Pan Evaporation Stations

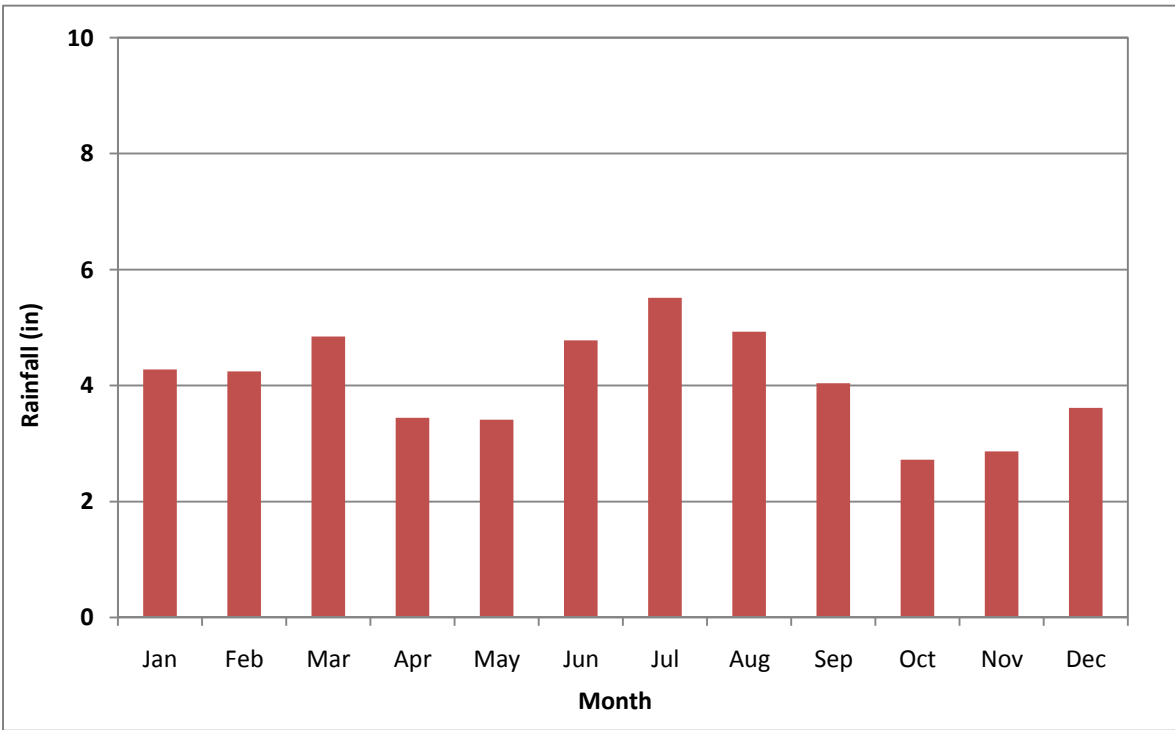


Figure 2-2
Historical Monthly Rainfall for the Study Area

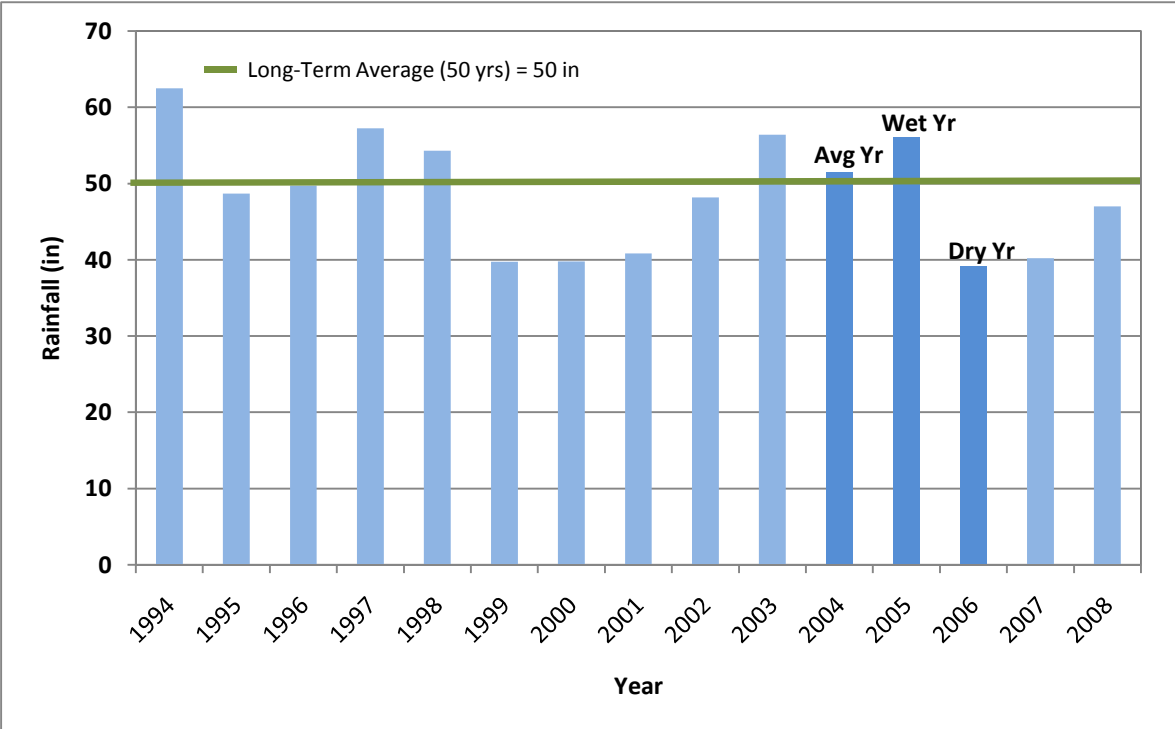


Figure 2-3
Annual Rainfall (1994-2008) for the Study Area

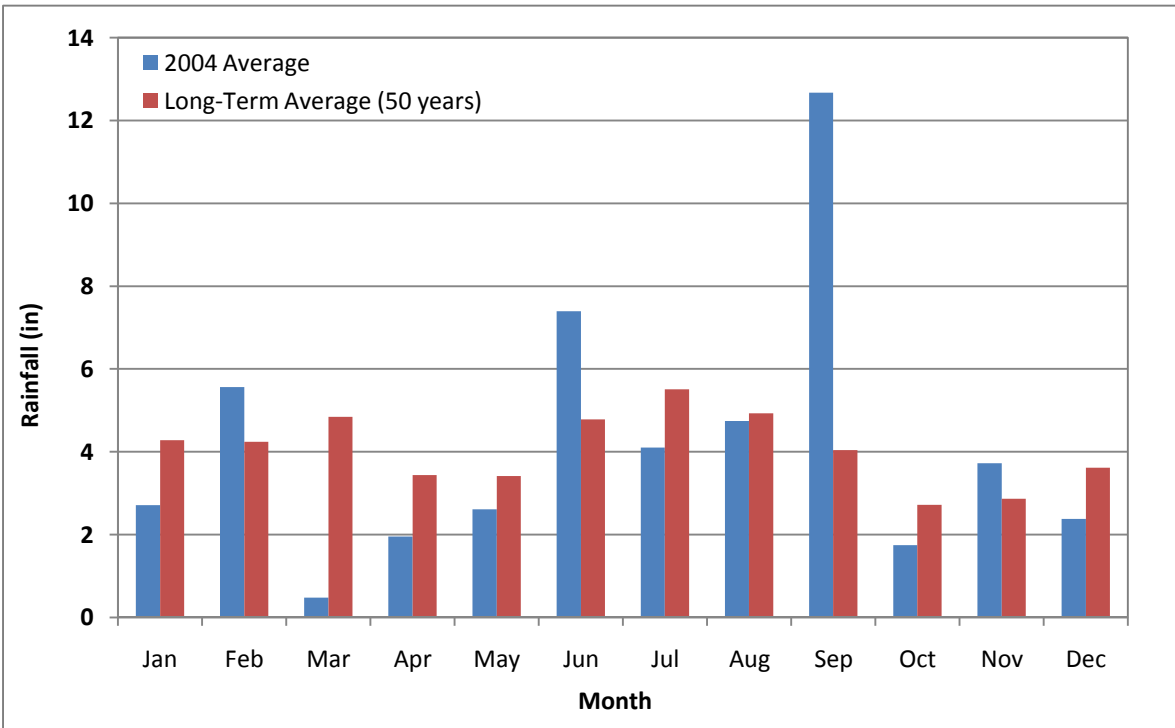


Figure 2-4
2004 Monthly Rainfall Distribution Recorded at Georgia's Rainfall Stations

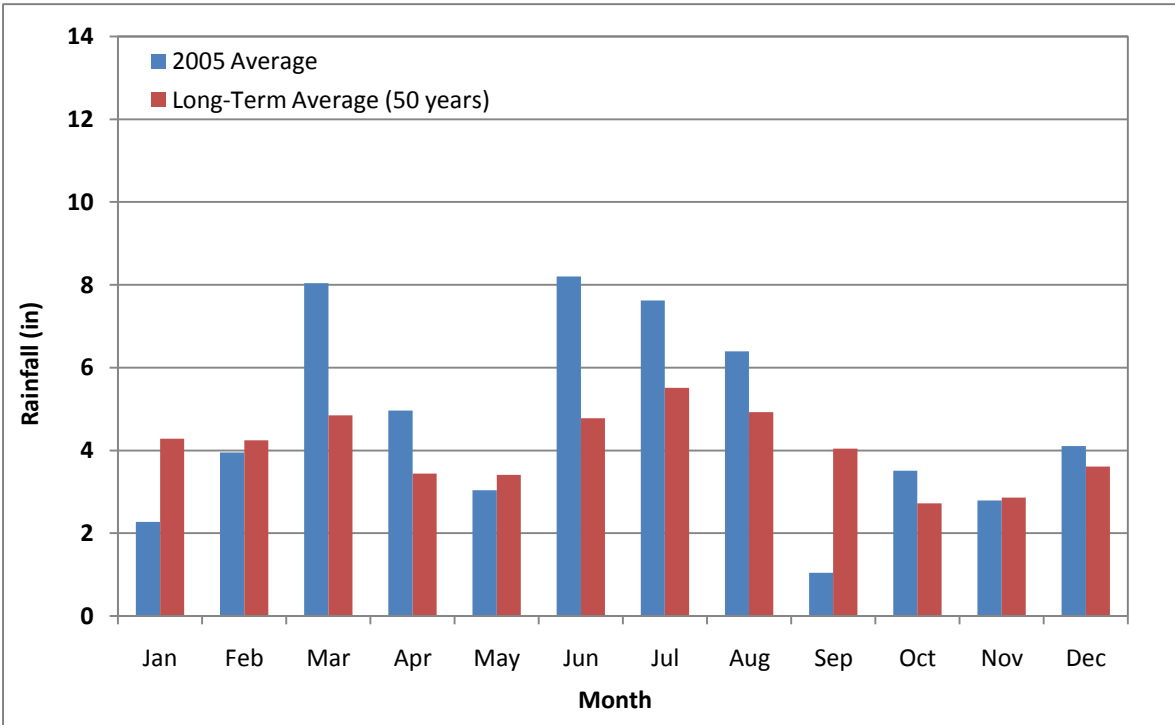


Figure 2-5
2005 Monthly Rainfall Distribution Recorded at Georgia's Rainfall Stations

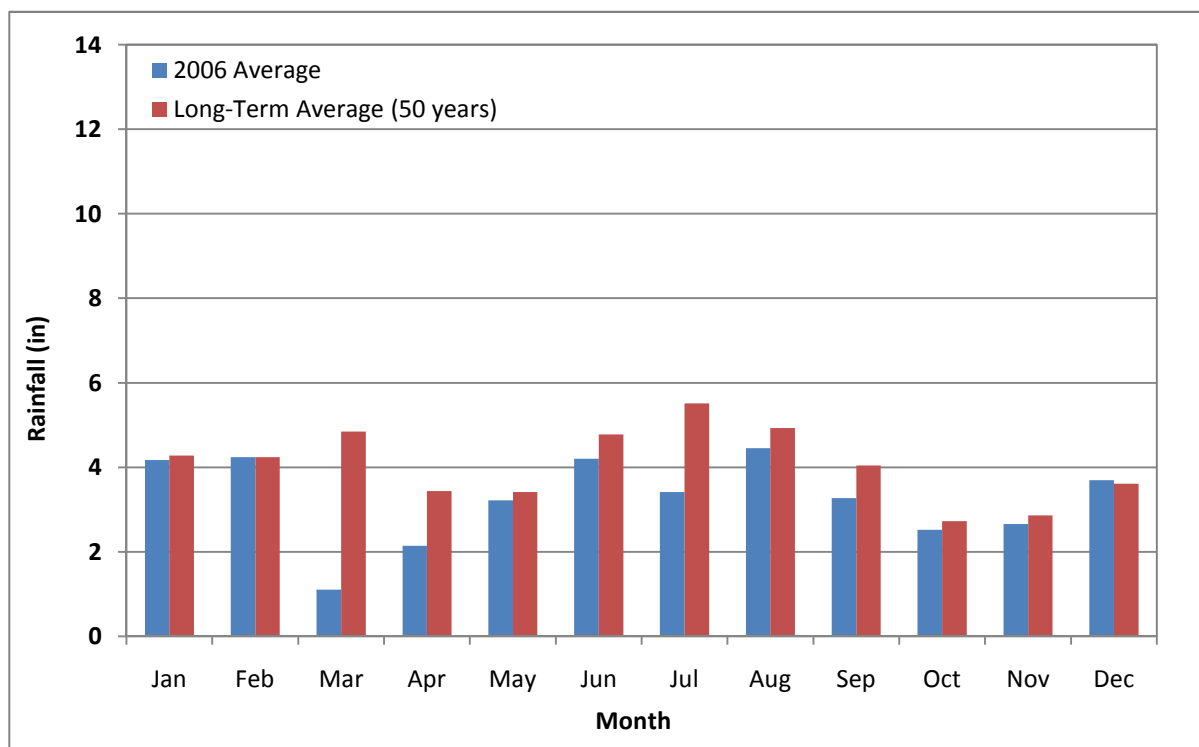


Figure 2-6
2006 Monthly Rainfall Distribution Recorded at Georgia's Rainfall Stations

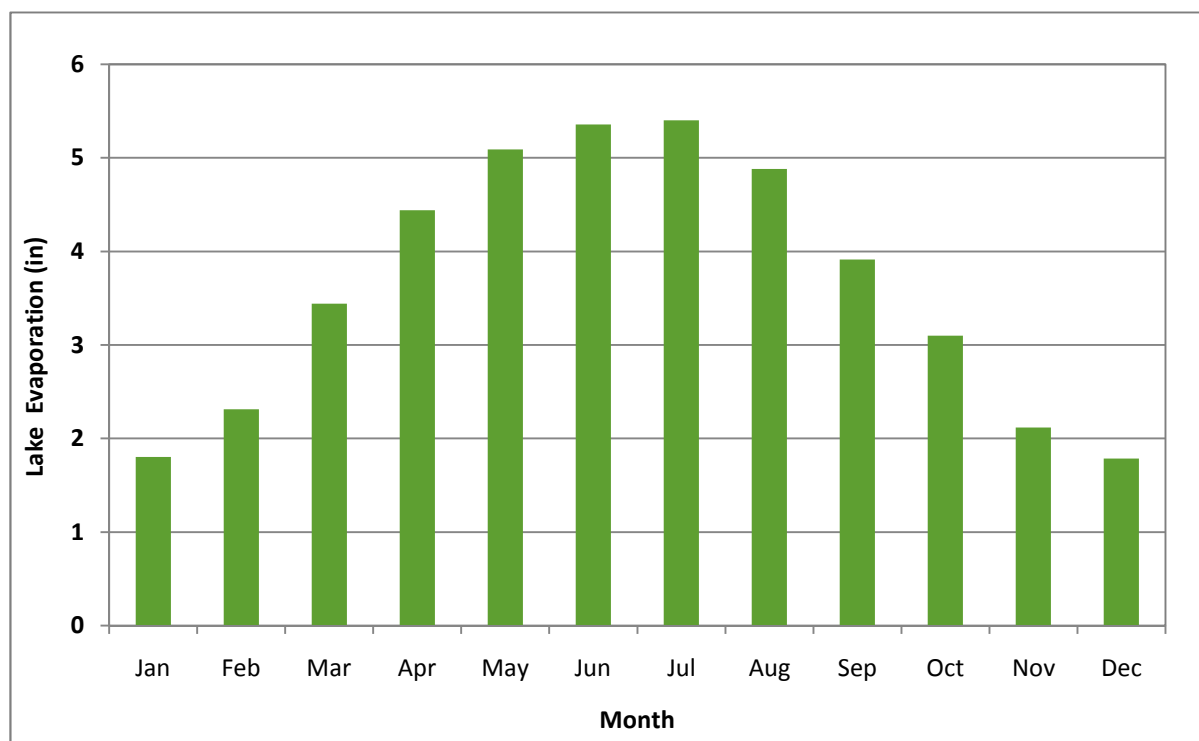


Figure 2-7
Monthly Lake Evaporation Distribution in Georgia

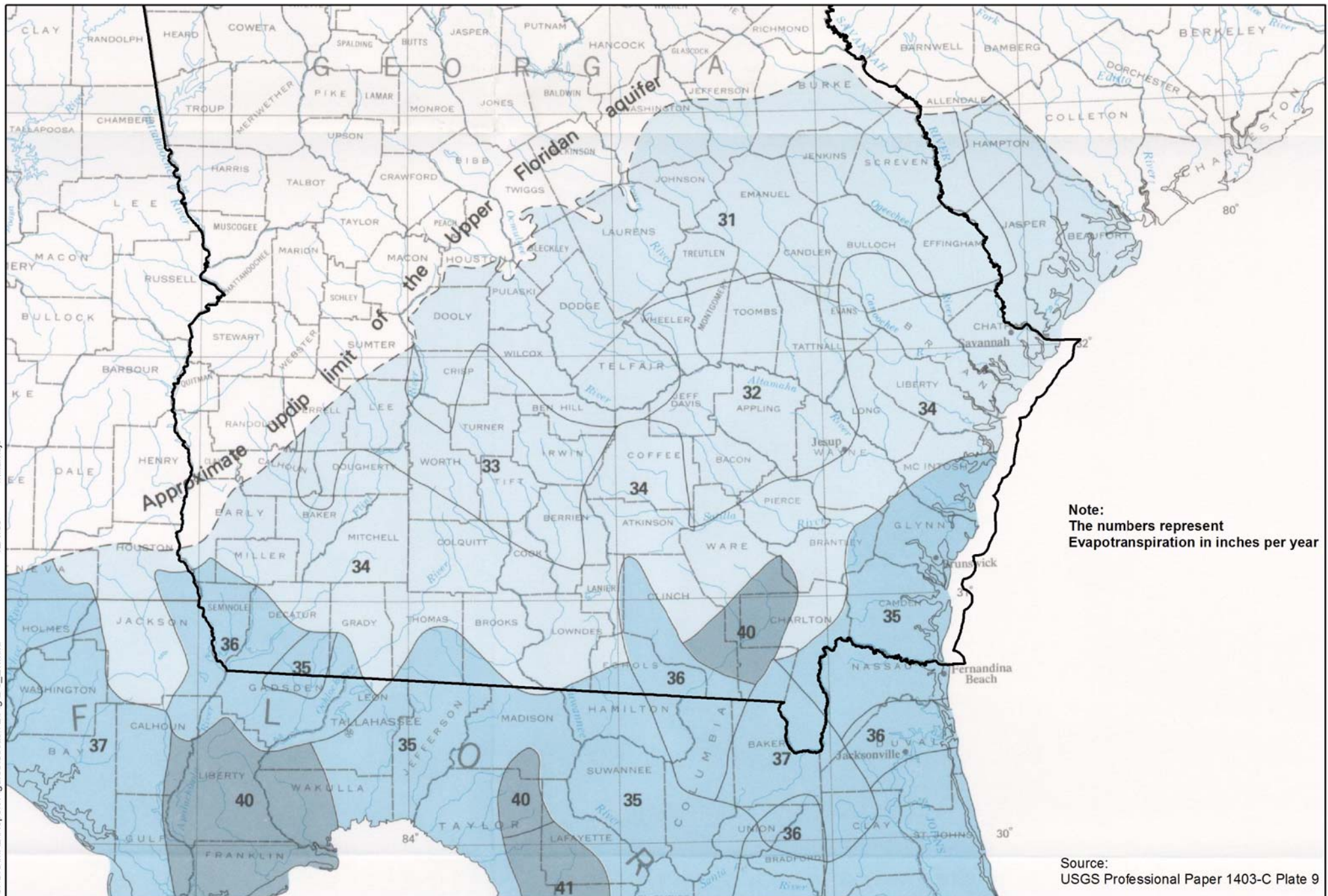


Figure 2-8
Estimated Evapotranspiration
From the Land Overlying the Upper Floridan Aquifer

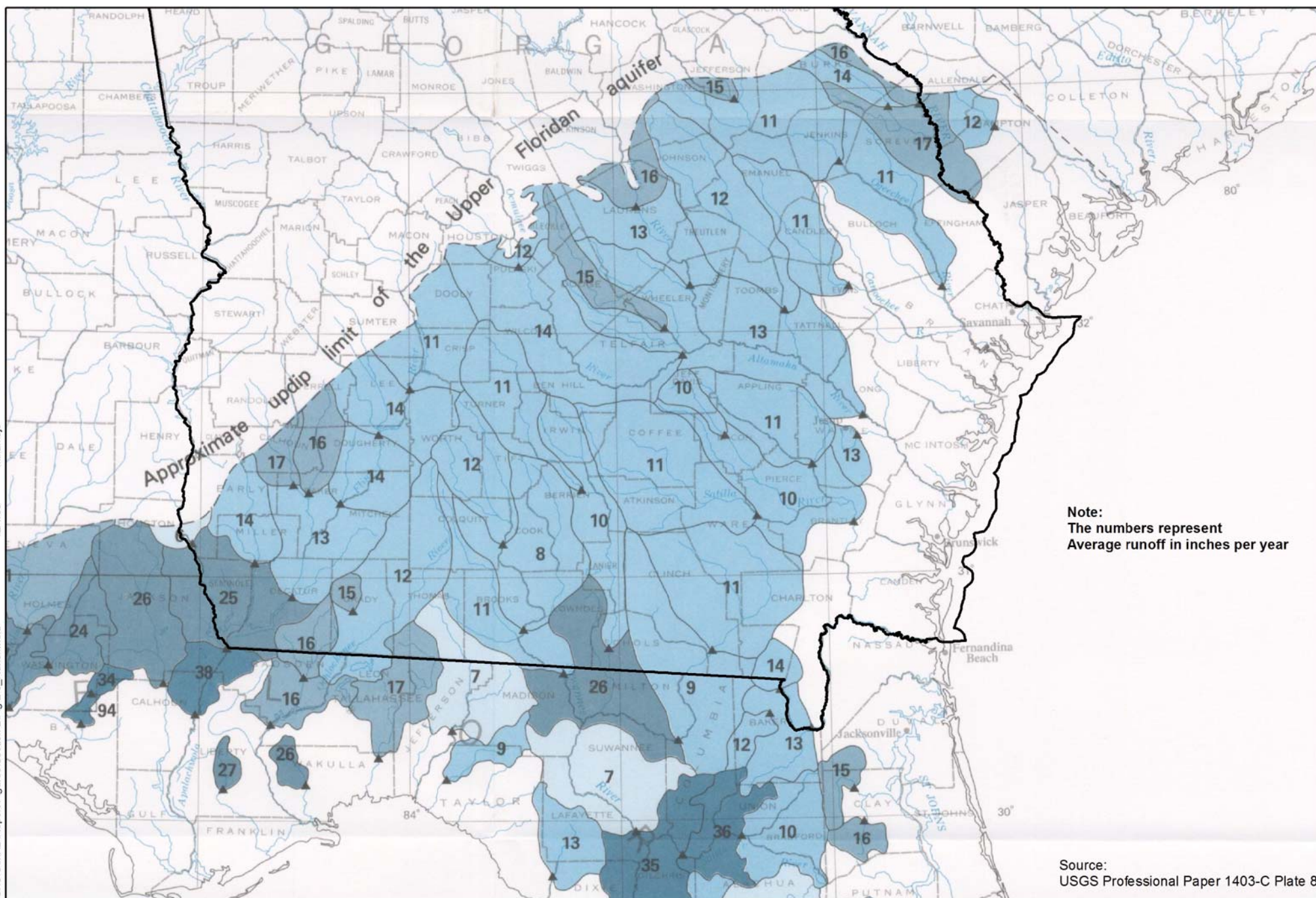
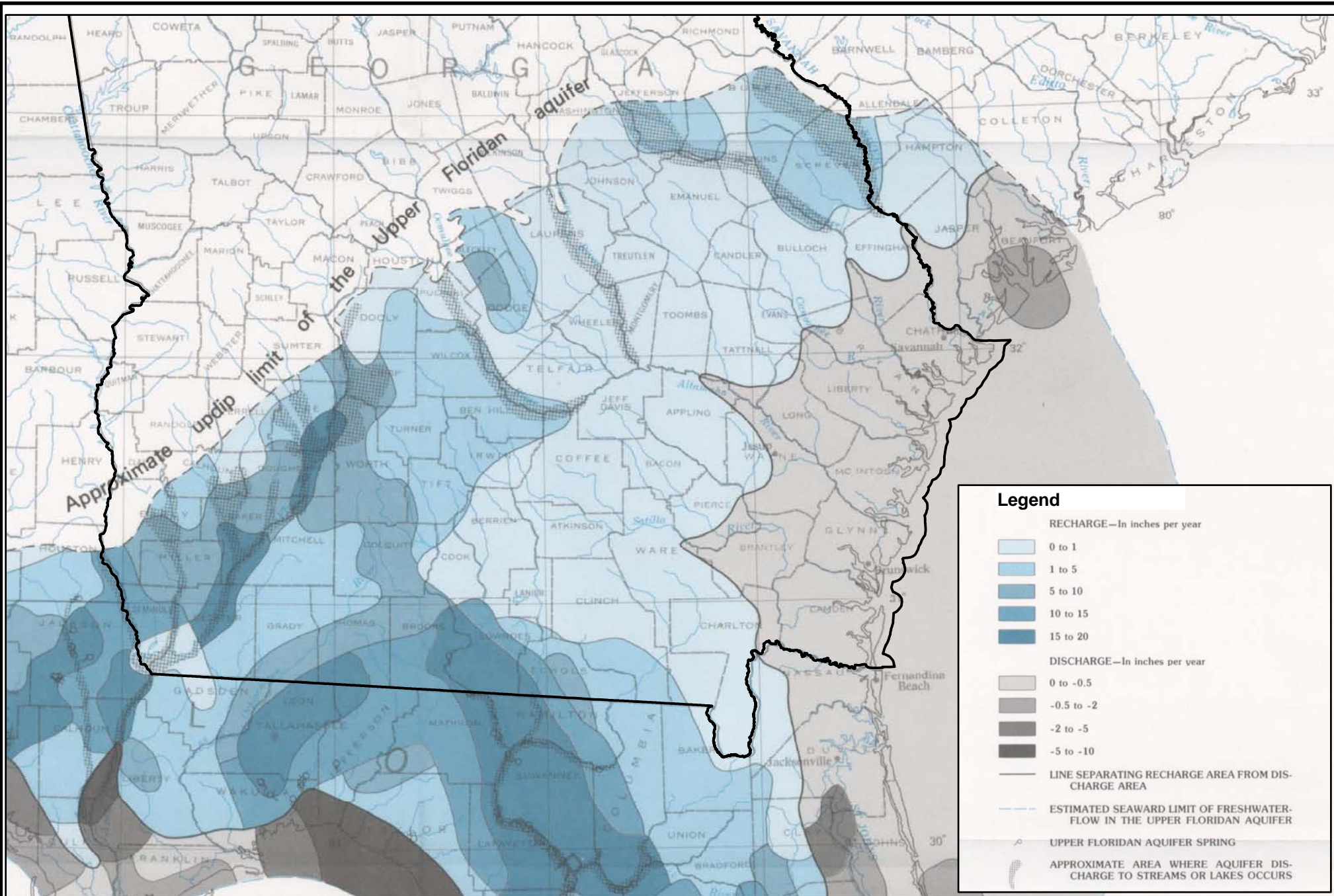


Figure 2-9
Average Runoff From Selected Surface Water Basins
Overlying the Upper Floridan Aquifer

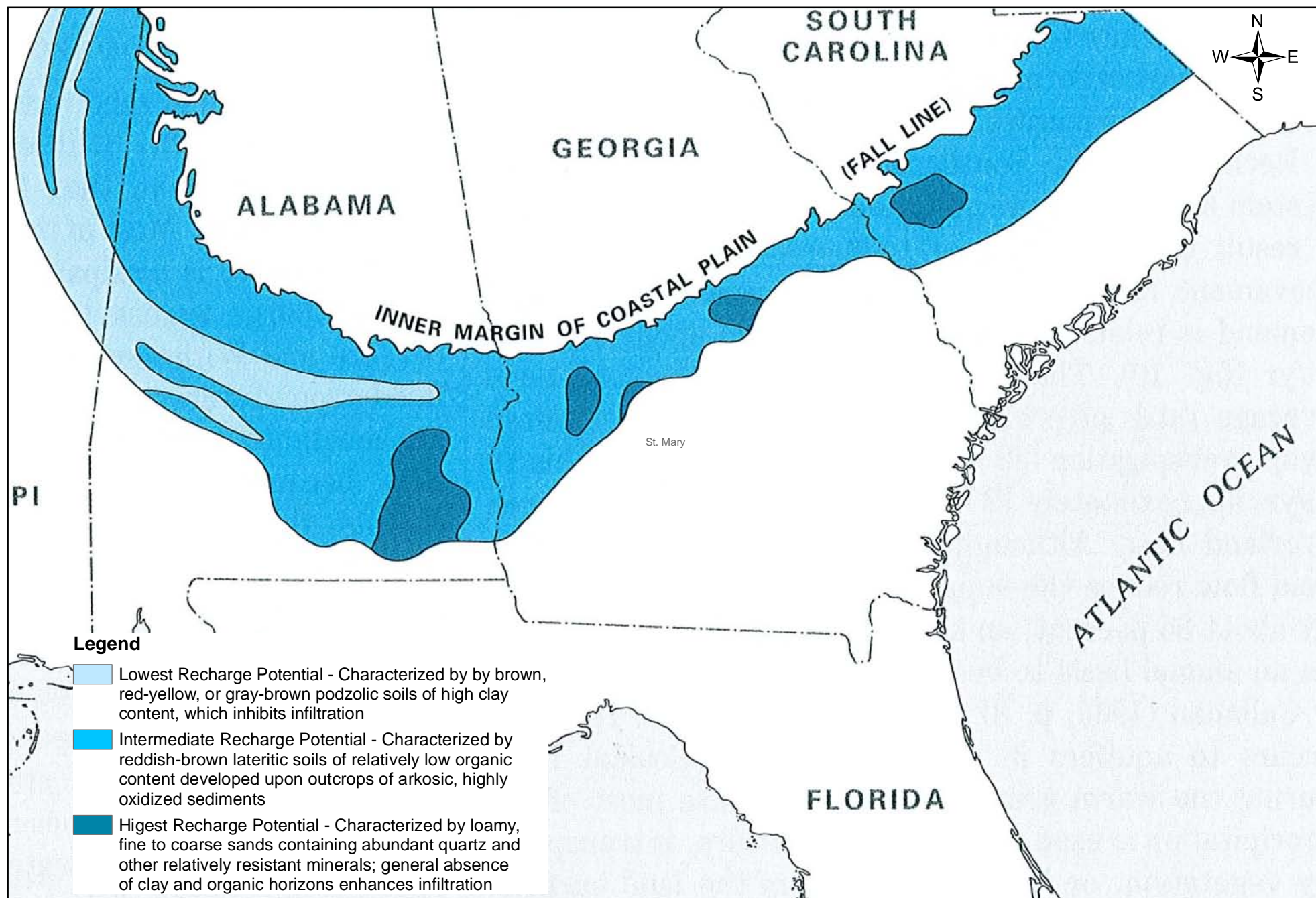
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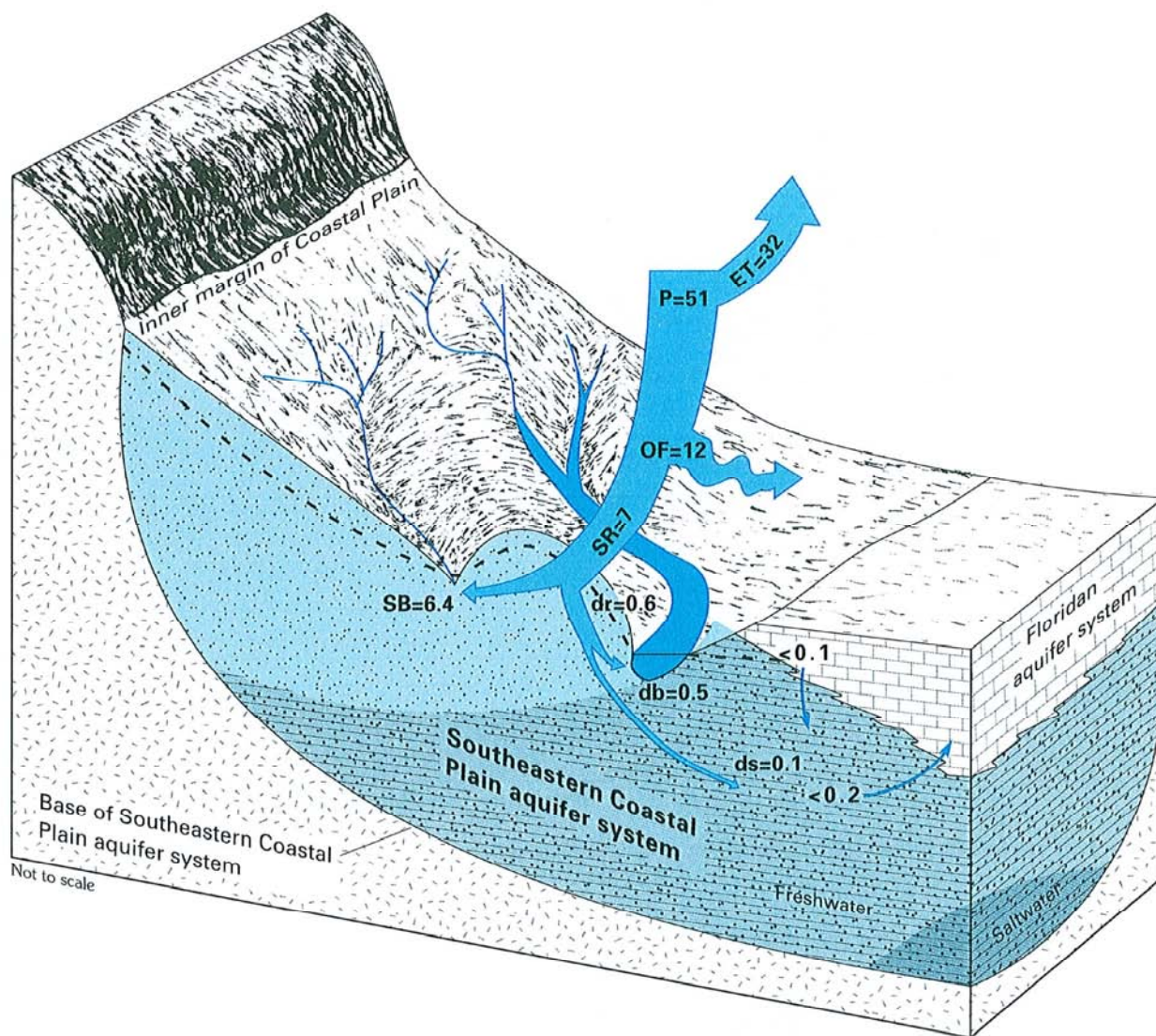


Source: Bush, P.W. and R.H. Johnston, 1988. Ground-Water Hydraulics, Regional Flow, and Groundwater Development of the Floridan Aquifer System in Florida and Parts of Georgia, South Carolina and Alabama. USGS, Professional Paper 1403-C Plate 11.

Figure 2-10
Estimated Predevelopment Recharge to and Discharge (As Diffuse Upward Leakage) From the Upper Floridan Aquifer

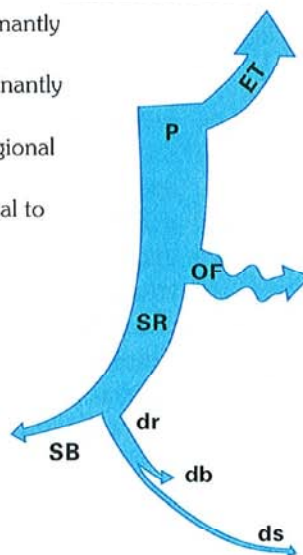


Source: Barker, R.A. and Pernik, M., 1994. Regional Hydrology and Simulation of Deep Ground-Water Flow in the Southeastern Coastal Plain Aquifer System in Mississippi, Alabama, Georgia, and South Carolina. USGS Professional Paper 1410-C.



Legend

- Aquifer in outcrop area—Under predominantly unconfined conditions
- Aquifer in subcrop area—Under predominantly confined conditions
- Major stream—Interacts primarily with regional flow system
- Small stream—Interacts primarily with local to intermediate flow system
- Hydraulic head



Schematic depiction of average annual water budget—Based on published data and results of steady-state simulation. Numbers are flow rates, in inches per year

P=Precipitation

ET=Evapotranspiration

OF=Overland flow

SR=Shallow (total) recharge—The percolation of precipitation below land surface that is lost neither to overland flow nor evapotranspiration

SB=Shallow base flow (to small streams)

dr=Deep recharge—Component of shallow (total) recharge that percolates below the hydraulic influence of small streams

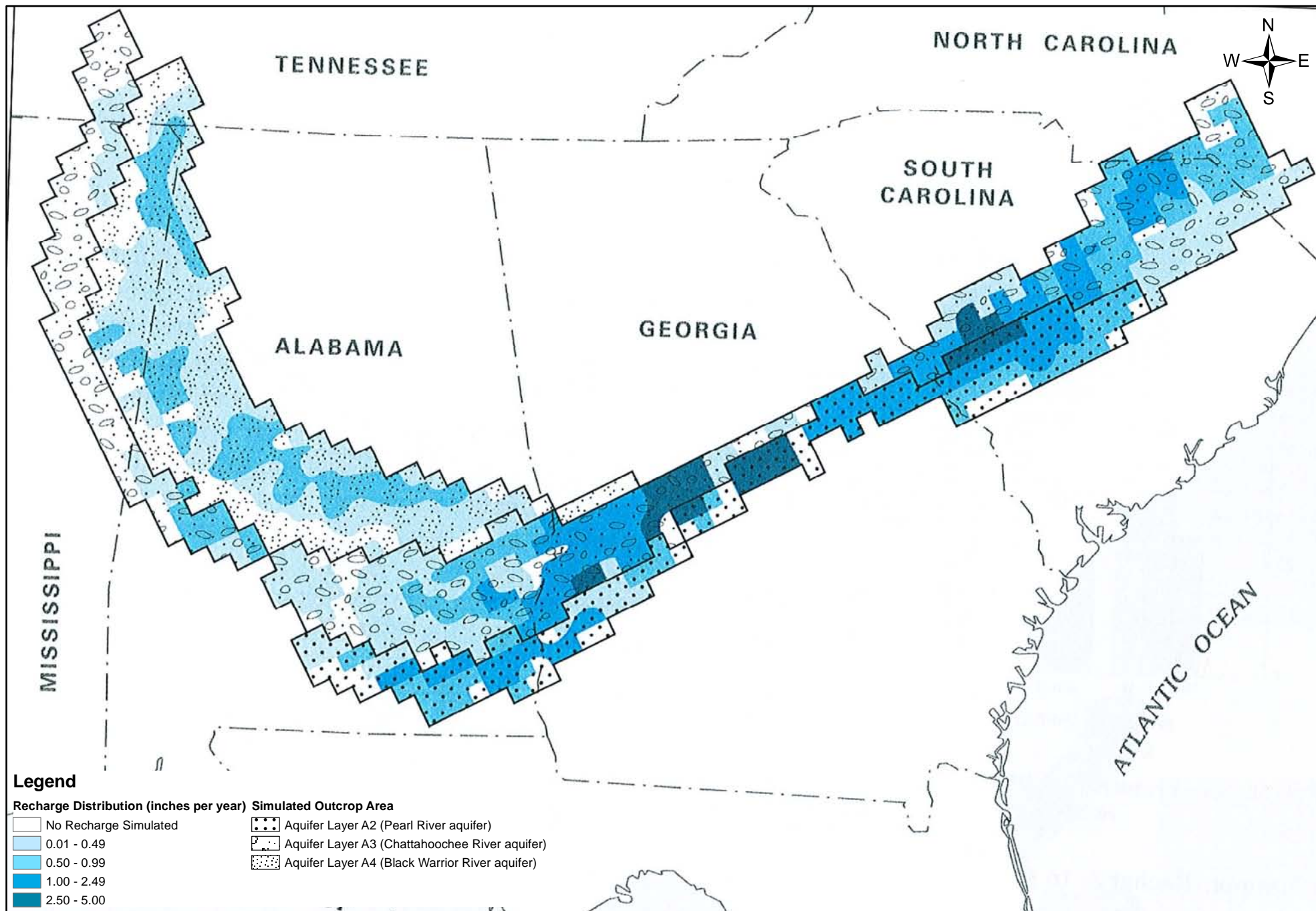
db=Deep base flow (to major streams)

ds=Deep seepage—Component of total recharge that percolates below level of major streams

Nonsimulated

Simulated

Source: Barker, R.A. and Pernik, M., 1994. Regional Hydrology and Simulation of Deep Ground-Water Flow in the Southeastern Coastal Plain Aquifer System in Mississippi, Alabama, Georgia, and South Carolina. USGS Professional Paper 1410-C.



Source: Barker, R.A. and Pernik, M., 1994. Regional Hydrology and Simulation of Deep Ground-Water Flow in the Southeastern Coastal Plain Aquifer System in Mississippi, Alabama, Georgia, and South Carolina. USGS Professional Paper 1410-C.

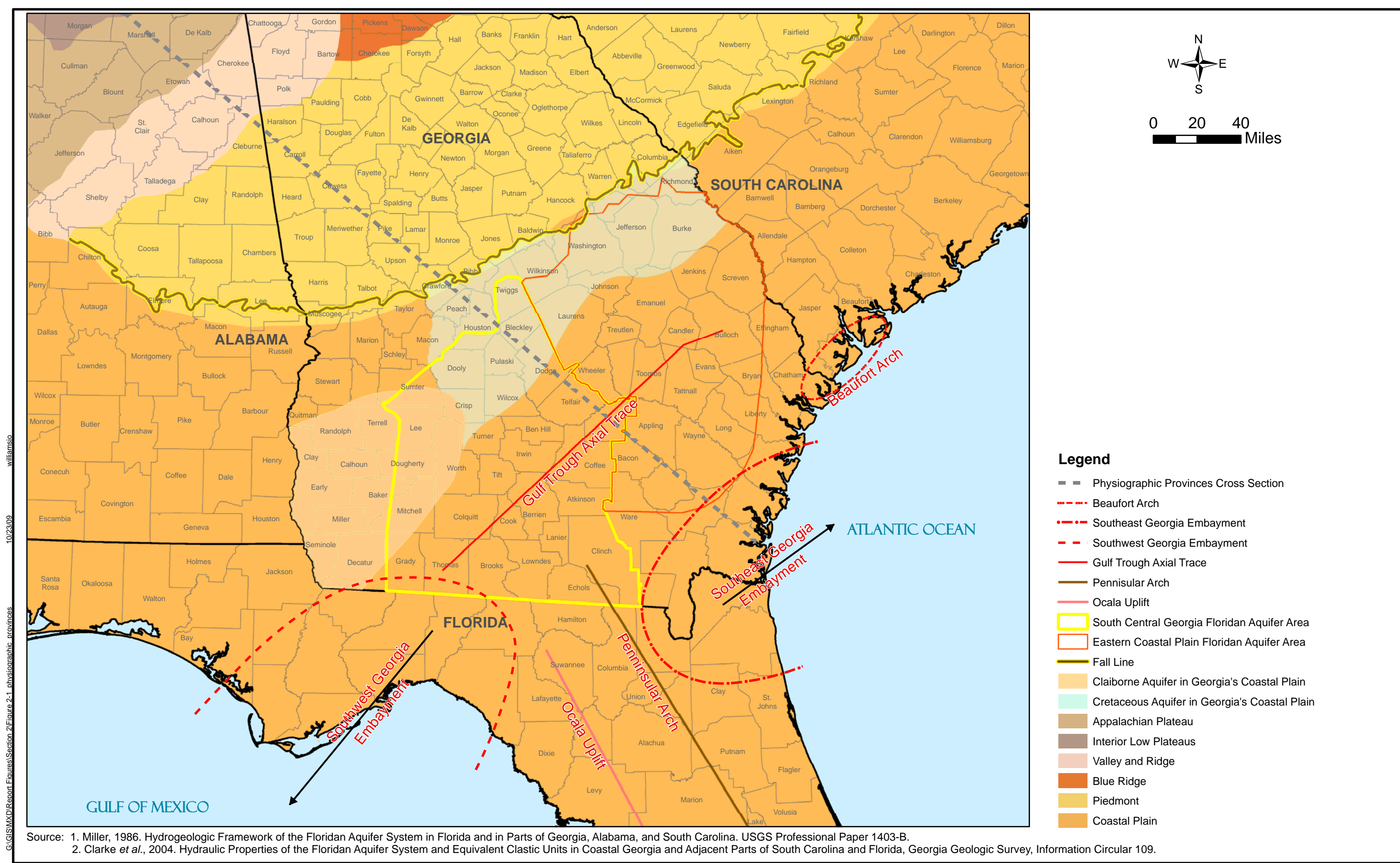
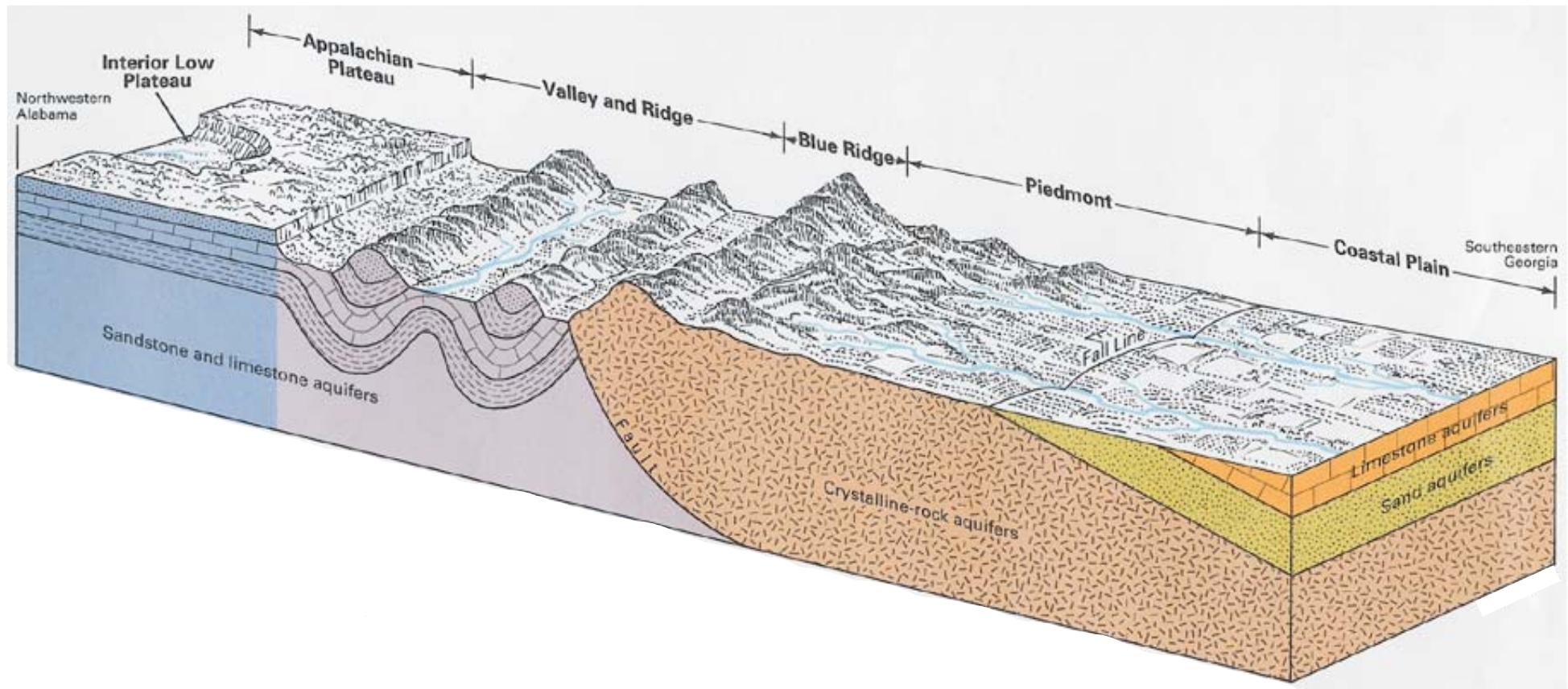


Figure 2-14
Physiographic Provinces in Georgia and Surrounding Areas



Source: USGS, Groundwater Atlas of United States, Alabama, Florida, Georgia, South Carolina, HA 730-G

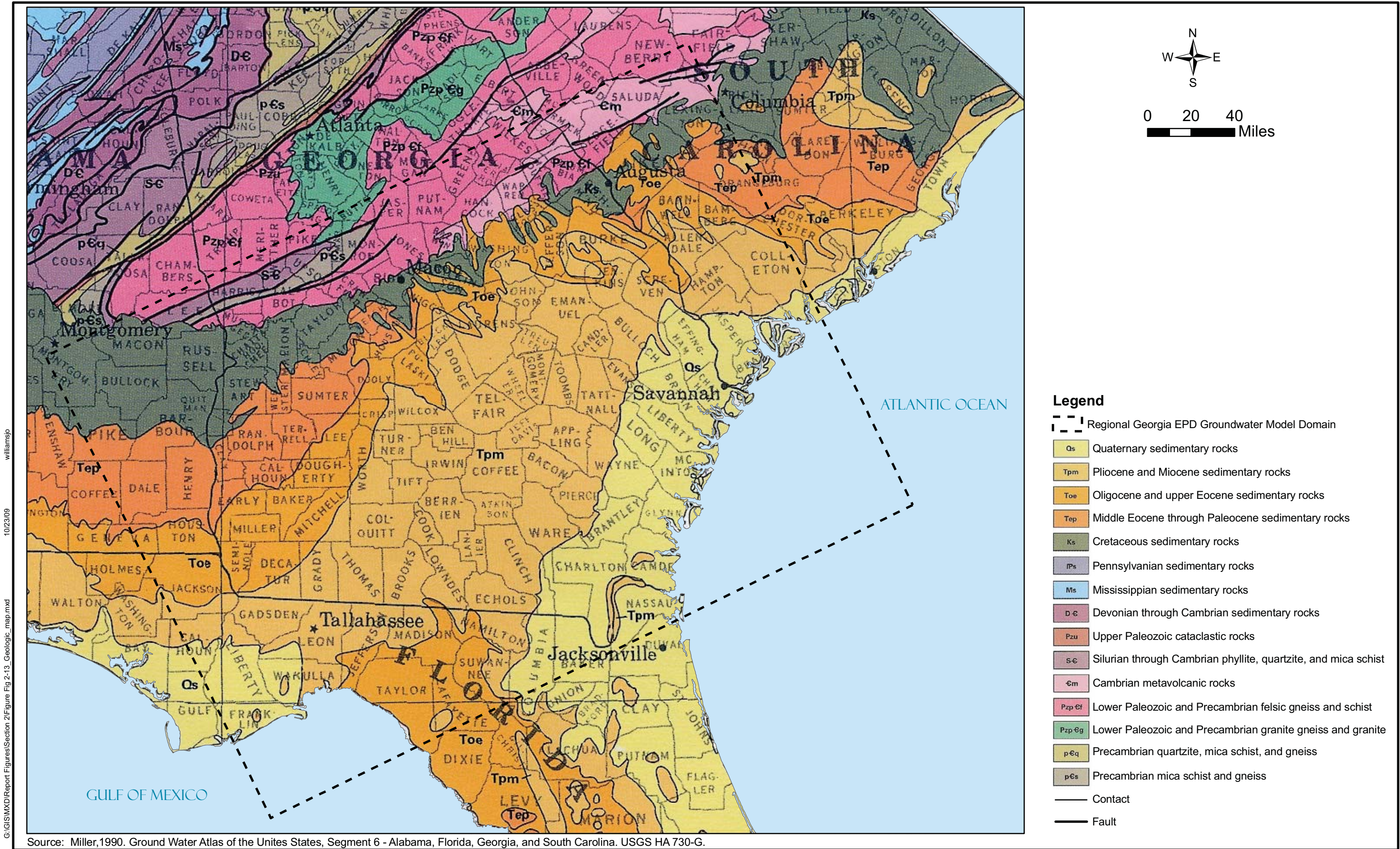
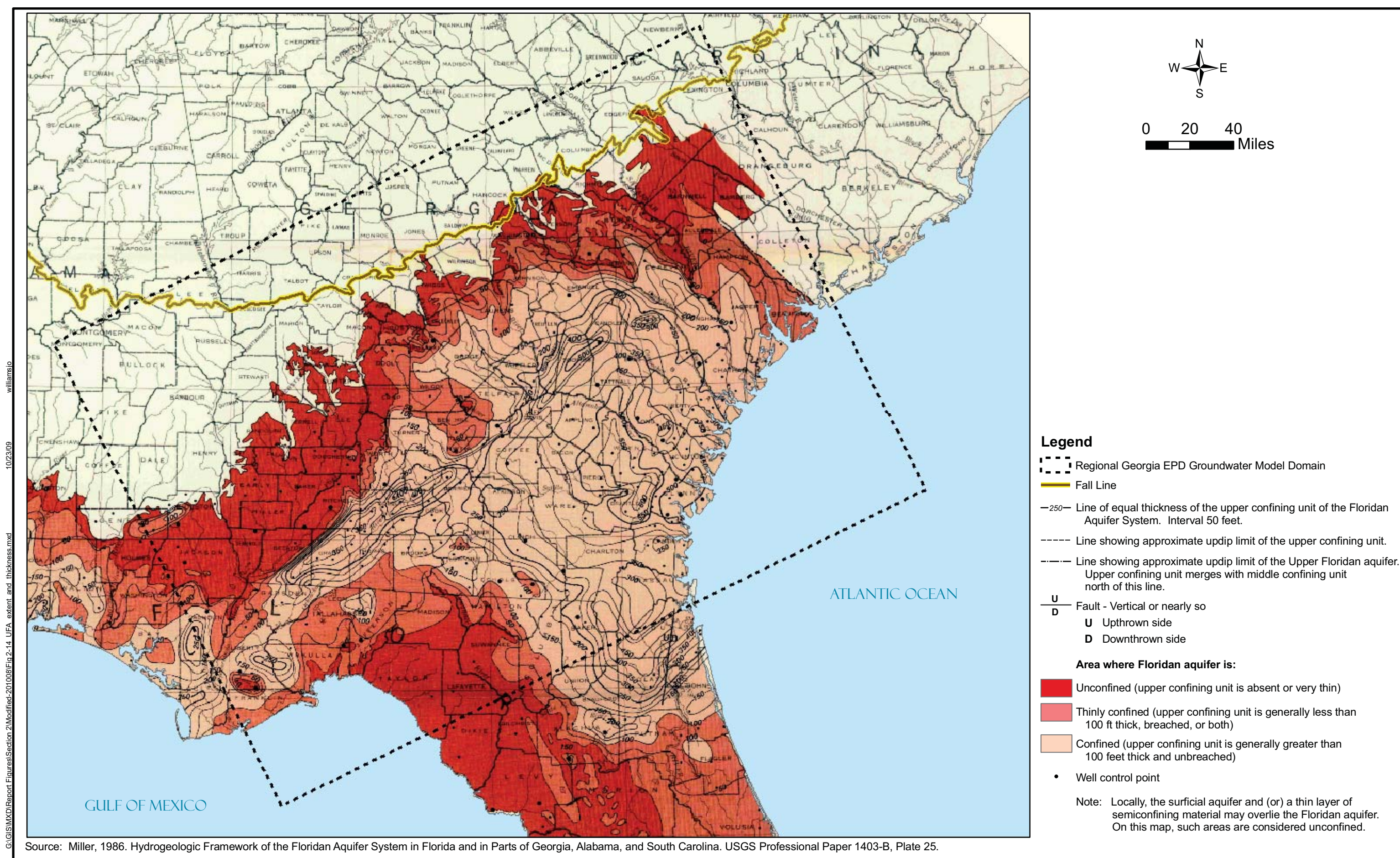
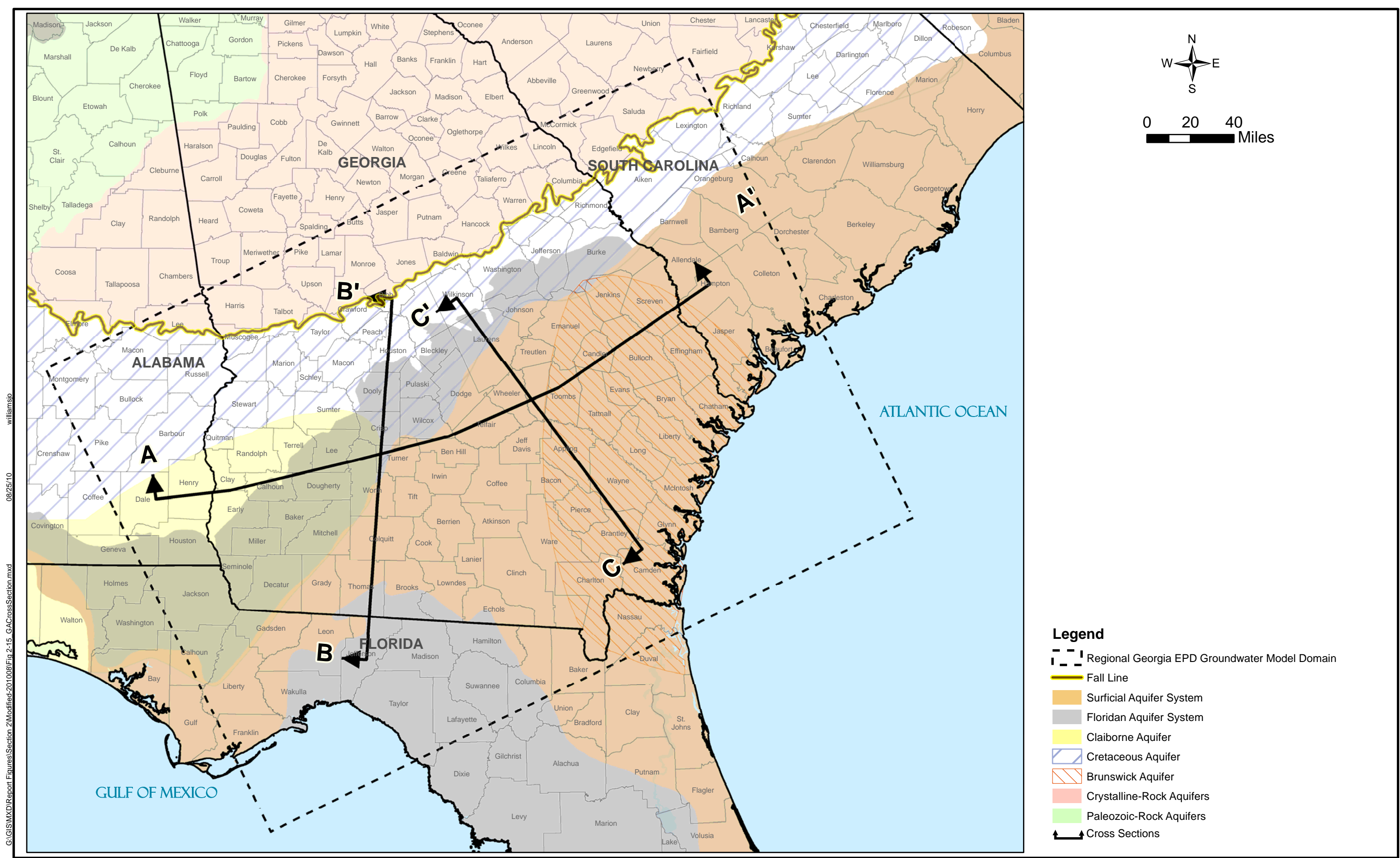


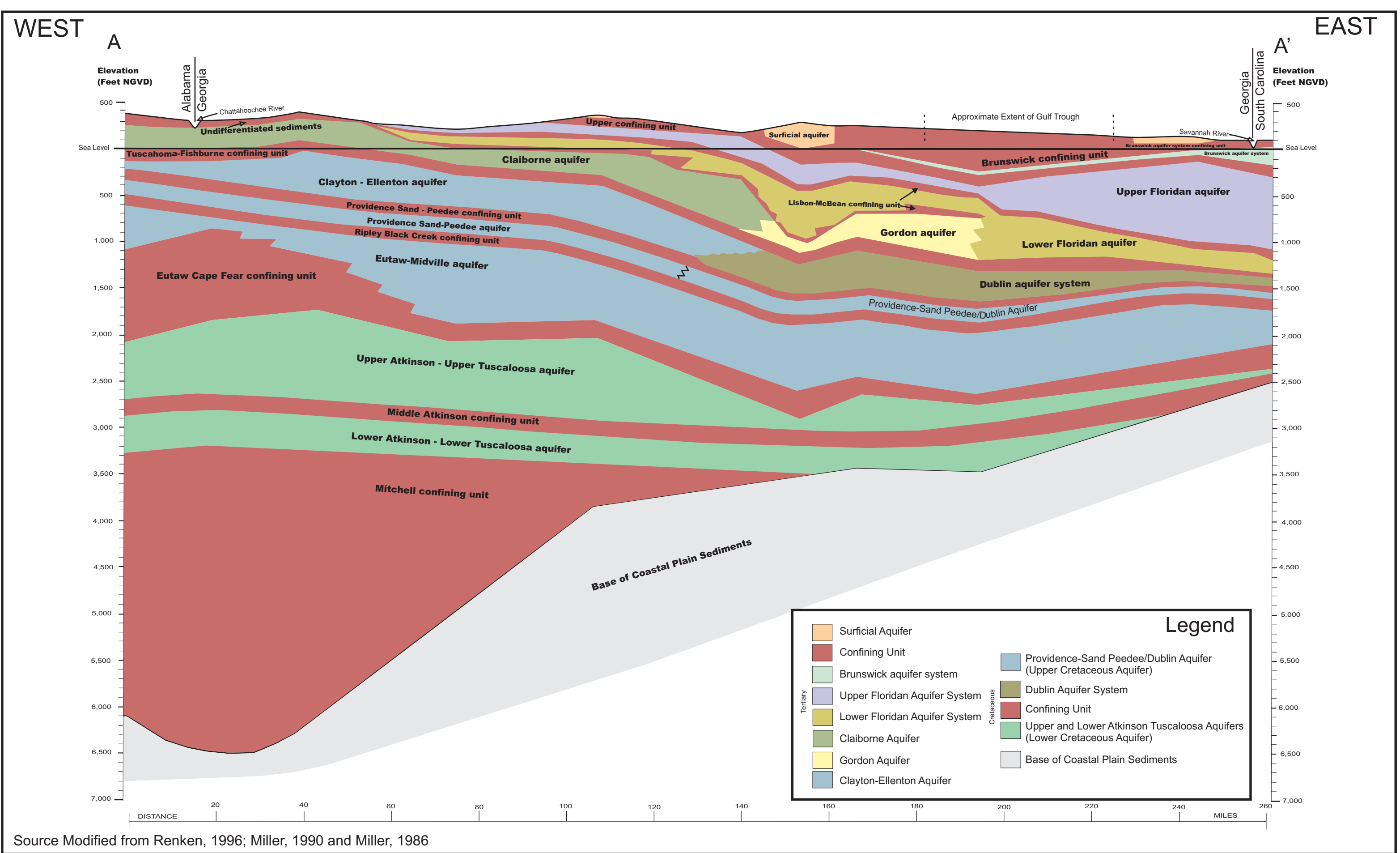
Figure 2-16
Generalized USGS Geologic Map Showing the Age and Extent of the Outcropping Unit

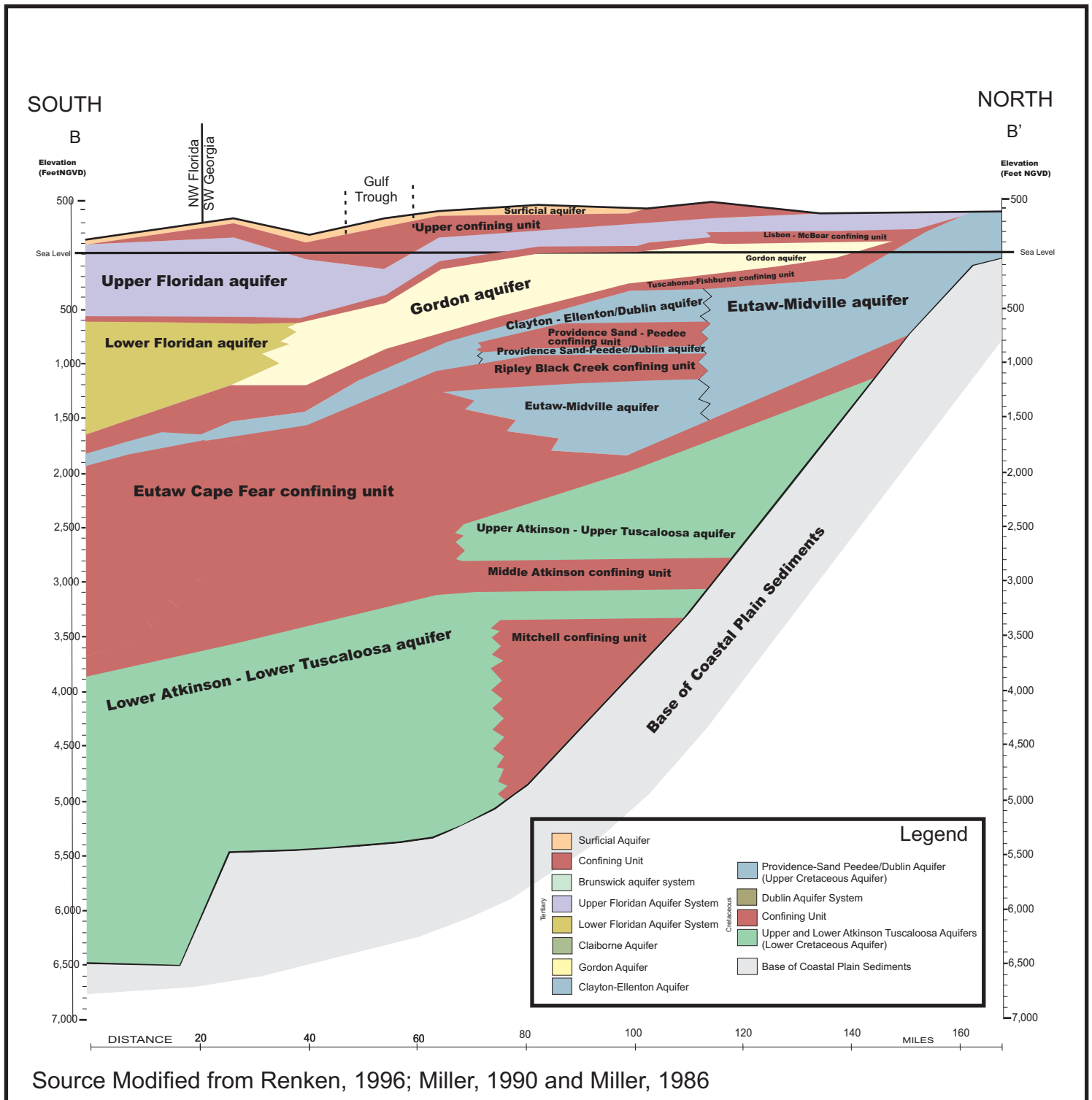


CDM **Figure 2-17**
Extent and Thickness of the Upper Confining Unit of the Floridan Aquifer System and Occurrence of Confined and Unconfined Conditions



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Figure 2-20
North-South Hydrostratigraphic Cross Section (B-B')
Through the Study Area

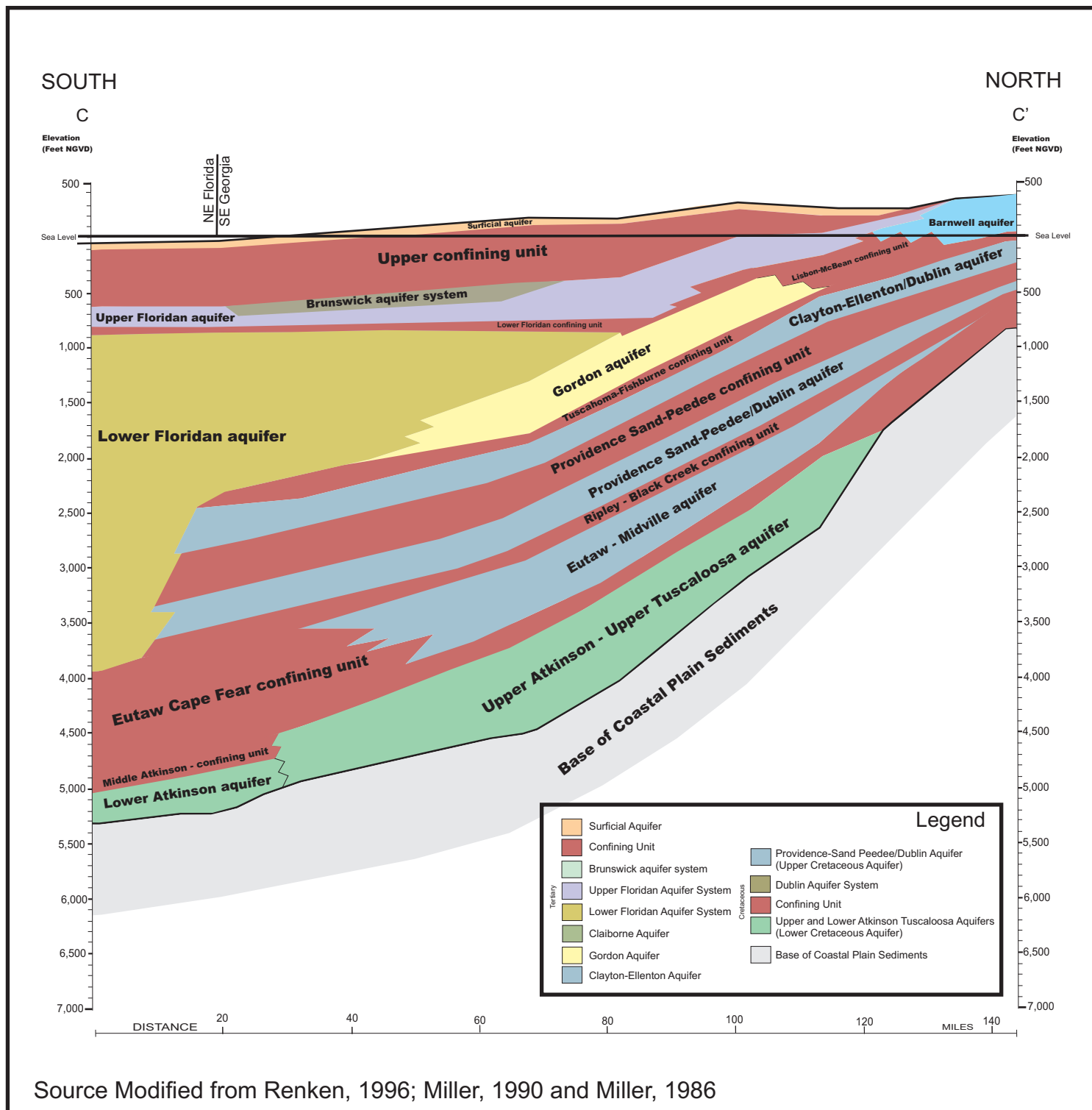


Figure 2-21
North-South Hydrostratigraphic Cross Section (C-C')
Through the Study Area

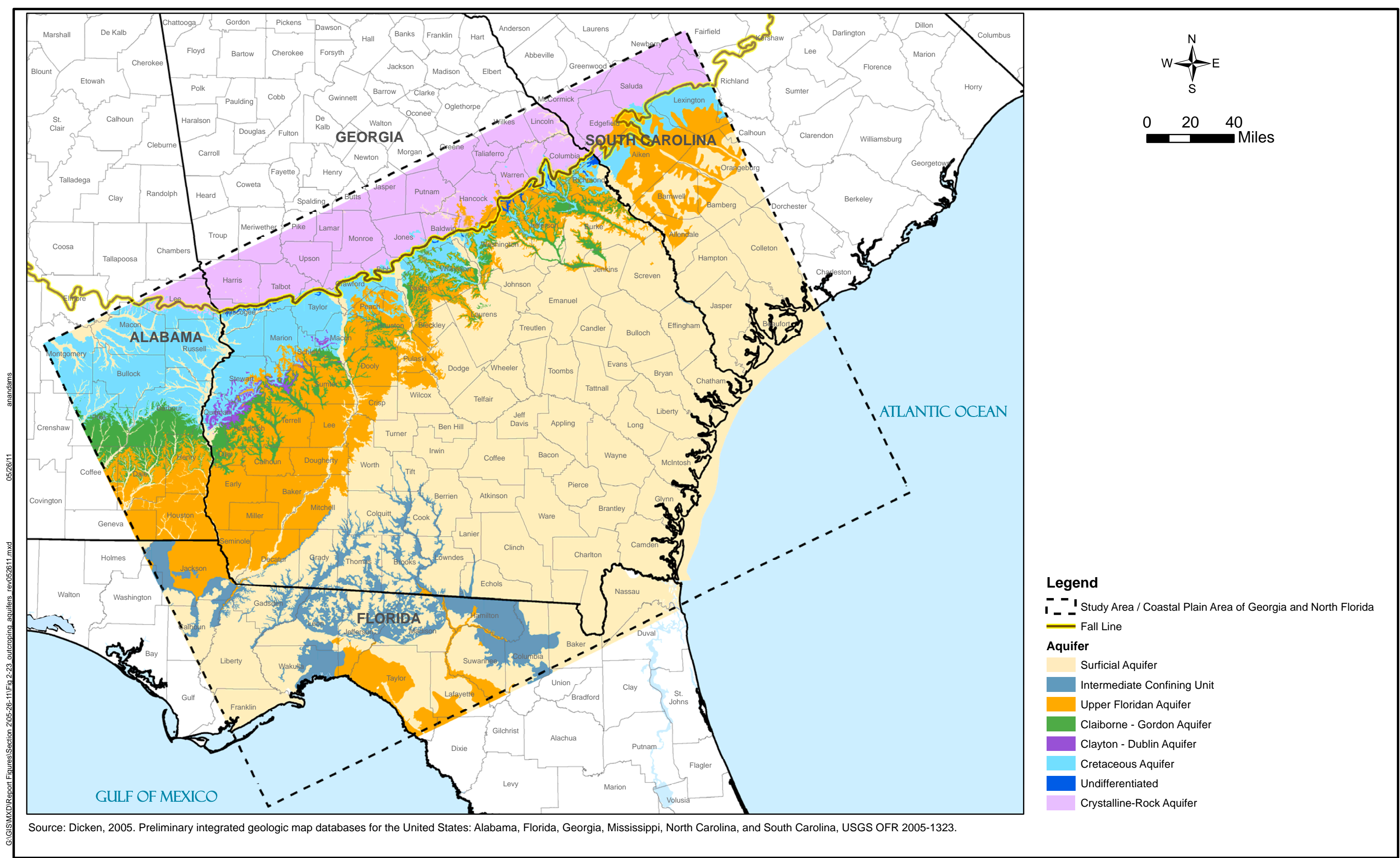
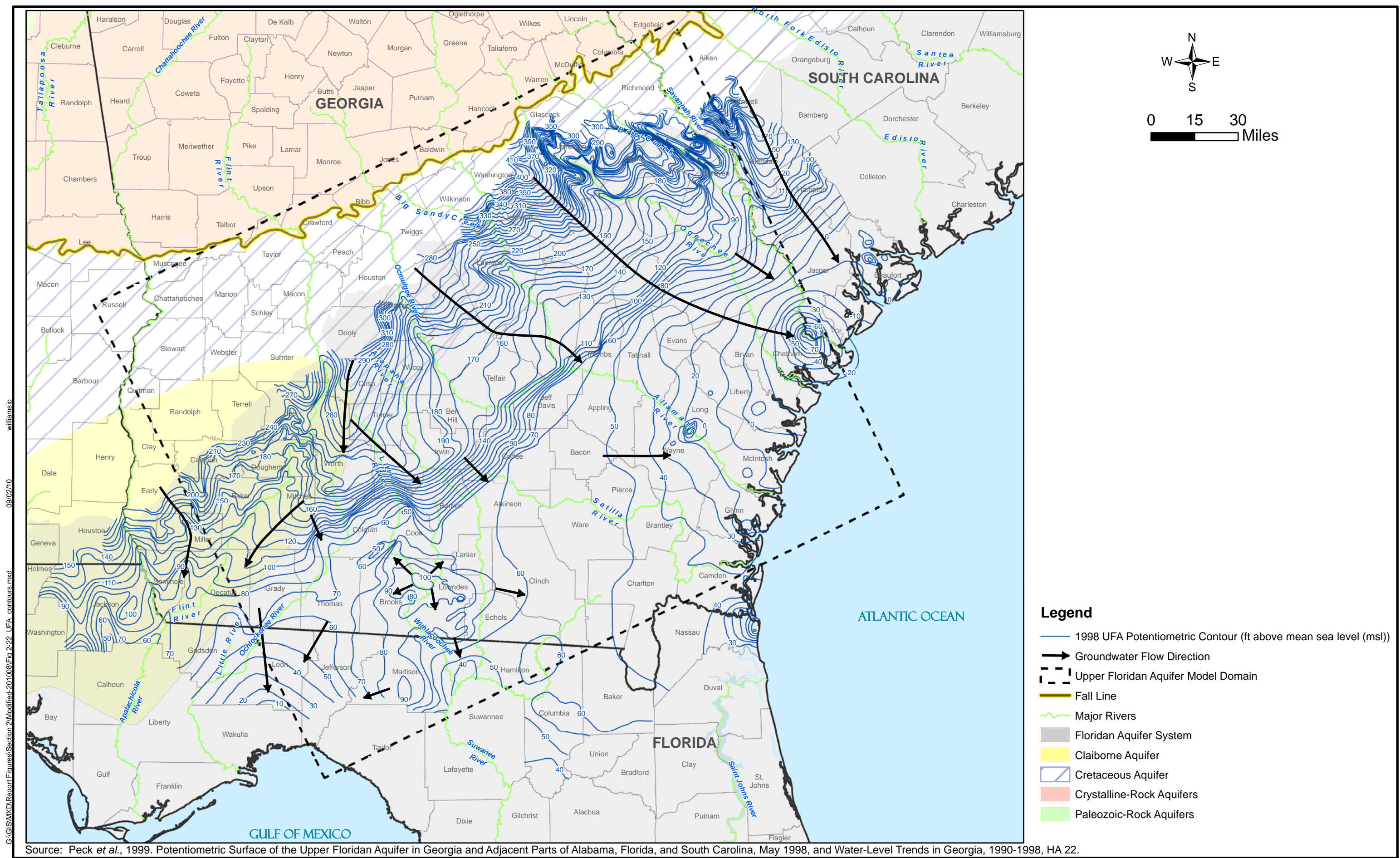
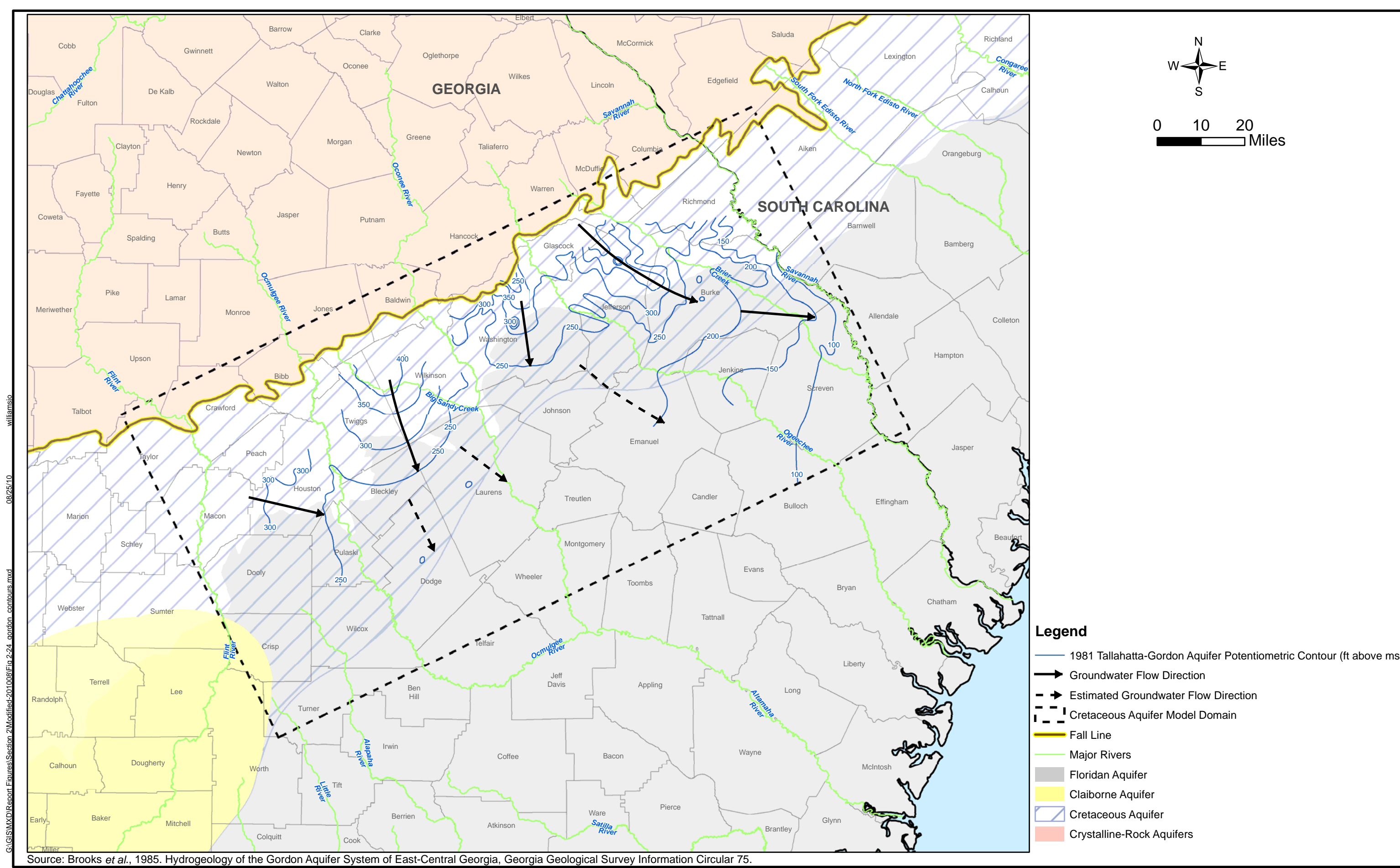


Figure 2-22
Aquifer Outcrop Areas

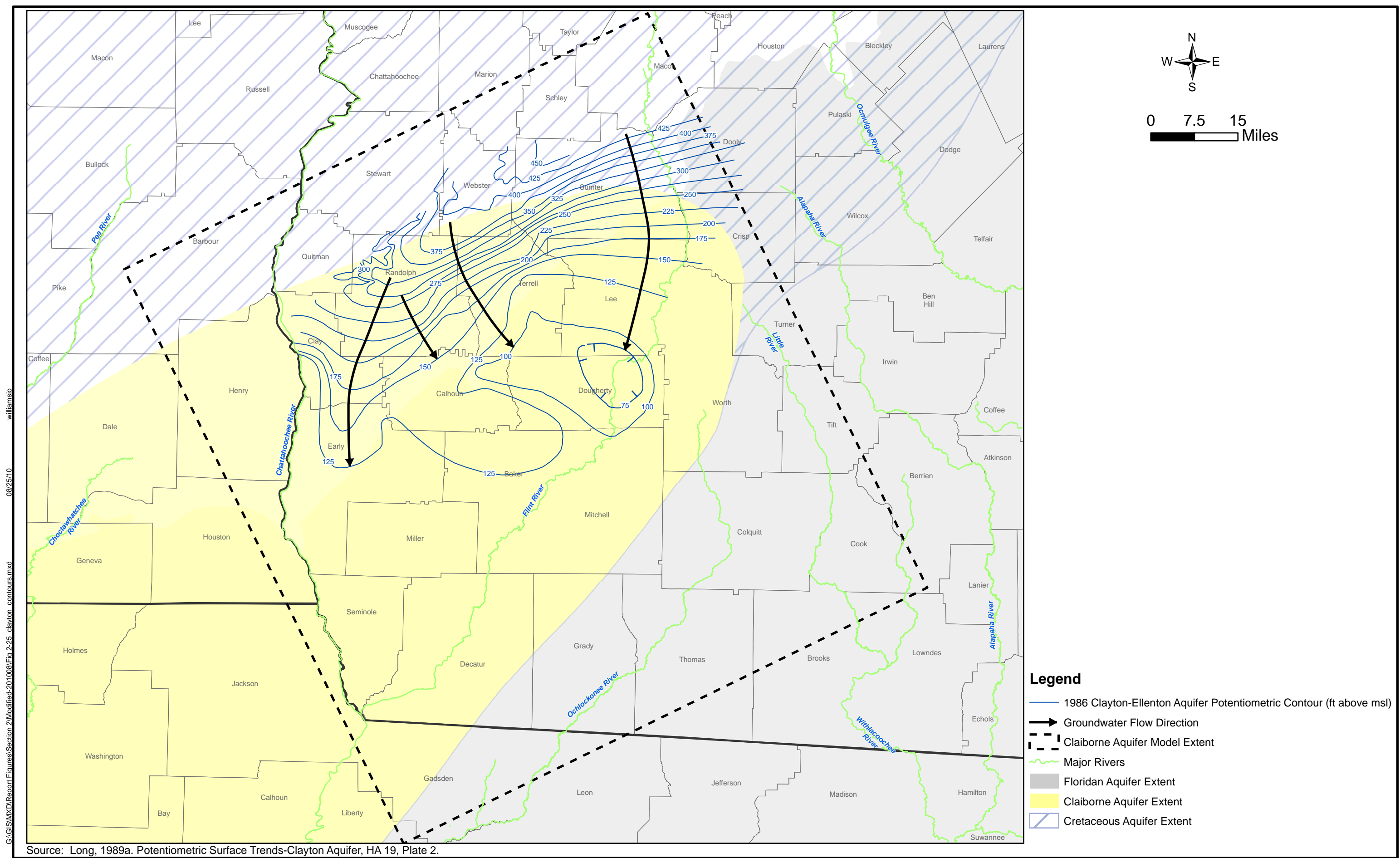


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Figure 2-24
Potentiometric Surface Map of the Upper Floridan Aquifer in the Study Area

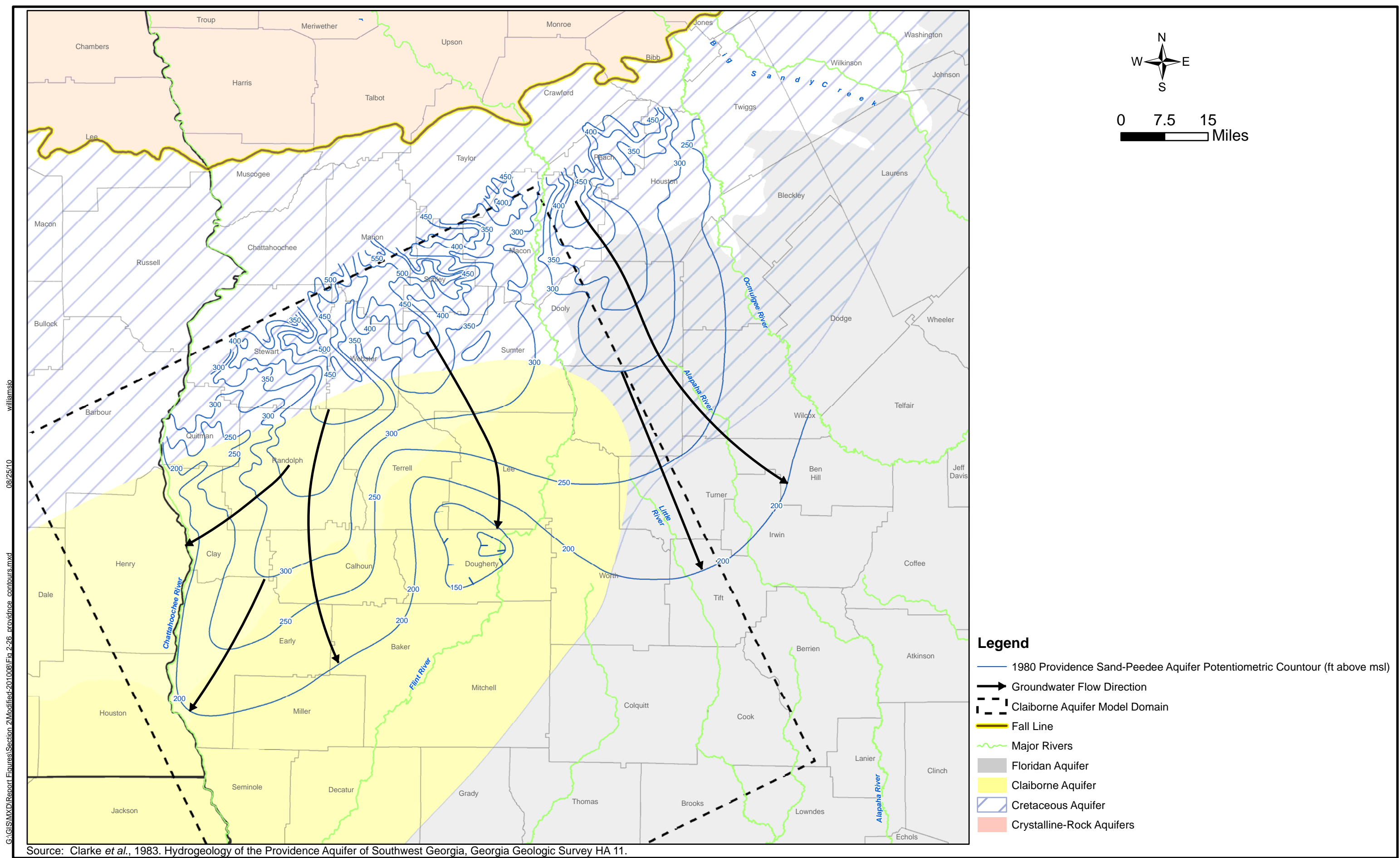


CDM **Figure 2-26**
Potentiometric Surface Map of the Gordon Aquifer in Central Georgia



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CDM **Figure 2-27**
Potentiometric Surface Map of the Clayton Aquifer in Southwest Georgia



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Source: Clarke *et al.*, 1983. Hydrogeology of the Providence Aquifer of Southwest Georgia, Georgia Geologic Survey HA 11.

CDM **Figure 2-28**
Potentiometric Surface Map of the Providence Sand-Peedee Aquifer in Southwest Georgia