

THREE-DIMENSIONAL HYDROSTRATIGRAPHIC CHARACTERIZATION OF
THE CLAIBORNE AQUIFER IN SOUTHWEST GEORGIA, USA

by

AMY LAUBENSTEIN

(Under the Direction of Adam Milewski)

ABSTRACT

Drought conditions in southwest Georgia can detrimentally impact agricultural communities and their available water supply. Source-switching to deeper aquifers in drought events can provide an alternative water resource, however, uncertainty exists in the geology and hydrogeology of these aquifer systems. In this study, a three-dimensional hydrostratigraphic model was constructed by collecting pre-existing wells in southwest Georgia. This model was similar to two-dimensional hydrostratigraphic correlations in previous studies, however, some changes were recognized in the areal extent of the Claiborne aquifer. Areas of thinning could also be depicted and provided insight into what sites could be more susceptible to leakage between aquifer systems. It is supported that the three-dimensional hydrostratigraphic model can be used in the characterization of wells to aid in the further development of understanding the geologic and hydrogeologic framework in southwest Georgia.

INDEX WORDS: Southwest Georgia, USA, hydrostratigraphy, water resources,
three-dimensional model

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DEDICATION

My greatest achievements in life have been provided by the patience and support offered by my mom, Jennifer, and my dad, Bryan.

This achievement honors my grandfather, Kirk Hardenburg, who passed the week I started this program. Thank you for the lessons you have taught me, the voice you gave me, and the memories we have made. Thank you for always believing in me, and I hope I continue to make you proud as you watch over me.

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CHAPTER 1

INTRODUCTION

1.1 Importance

Southwest Georgia is home to one of the largest producing agricultural landscapes in the United States. Drought events threaten Georgia's increasing agricultural demands and population growth. As a concern for depleting source water availability impacted by drought, geological and hydrogeological characterization of southwest Georgia is crucial for understanding alternative water resource availability across the region.

1.2 Agriculture and Water Resource Demands in Southwest Georgia

In Georgia, the most advanced agricultural demands are in the southwest region of the state (Williams et al., 2017). The growth in the use of irrigation equipment, especially in southwest Georgia, increased 2000% in total acres irrigated from 1976 to 2013 (Williams et al., 2017). Georgia is the nation's leading producer of broilers and peanuts (Prillaman, 2024). The growing seasons in Georgia span from March to October, which influences the nearly yearly demand of water resources (Painter, 2019).

The Georgia Water Stewardship Act of 2010 stated farmers' rights to water withdrawal permits, which is how farmers can access surface water and groundwater withdrawal (Georgia Water Stewardship Act, 2010). However, these agricultural water withdrawal permits were suspended in 2012 following the drought conditions in the state (Truszczynski et al., 2023). Agricultural water permits are now being accepted on April

1, 2025, after 13 years of their suspension (*Gov. Kemp, 2024*). It is common for irrigation systems in southwest Georgia to be fulfilled through surface water and the Upper Floridan aquifer for groundwater; however, in the overall regular use of these resources, water levels can be decreased significantly (*Sutton et al., 2021*).

Southwest Georgia's water resources used in irrigation schemes become even more limited in drought events. Climate vulnerability also becomes a concern in this region (*Williams et al., 2017*). Four groundwater aquifers are used: the upper Cretaceous, the Clayton, the Claiborne, and the Upper Floridan aquifers (*Chumbley & Scroggs, 2024*). Data collected over a nearly 40-year period exhibited significant declines in water levels from the Upper Floridan aquifer and deeper-lying aquifers in Georgia's Coastal Plain that are most likely associated with the high demands in agriculture and irrigation practices (*Sutton et al., 2021*). The Upper Floridan aquifer is the principal source of groundwater used in southwest Georgia and is one of the most productive aquifers in the nation (*Jones & Torak, 2006*). Irrigation pumpage is one of the leading withdrawals in groundwater and can decrease aquifer storage, water levels, and recharge to the Upper Floridan aquifer (*Jones & Torak, 2006; Mitra et al., 2019; Singh et al., 2016; Sutton et al., 2021; Williams et al., 2017*). The demands in irrigation schemes, coupled with poor practices in water withdrawal, will continue to deplete the used water resources, given the connectivity between the surface water and the Upper Floridan aquifer in this region (*Mitra et al., 2019*). Droughts also have a major influence on the accessibility of these water resources during extreme conditions, with an estimated drought frequency of 15-20 percent based on a time scale of 116 years (*Ford & Lobsier, 2013*).

1.2.1 Drought Conditions

Drought events have drastically affected water availability in southwest Georgia. With five major drought events over 35 years in Georgia, these prolonged events decrease the water supply due to a lack of precipitation, thus decreasing water levels (Gordon et al., 2012; Knaack et al., 2012; Painter, 2019).

1.2.2 The Claiborne Aquifer

The Claiborne Aquifer is the second deepest-lying aquifer in southwest Georgia. Its demand as a water resource in southwest Georgia has been predicted to increase for most southwest counties by 2060 (Georgia Water Planning, 2023). However, the exact hydrogeological nature of the Claiborne aquifer is unclear, and limitations exist in understanding its productivity for source-switching during prolonged drought events.

1.3 GA-FIT Drought SWAP

The Georgia Flow Incentive Trust, or GA-FIT, in partnership with the Georgia Water Planning and Policy Center at Albany State University, facilitates the Drought Source Water Alternatives Program, or Drought SWAP, to allow the accessibility for deeper-lying aquifers to be the source of irrigation use during drought events in southwest Georgia. This program, funded through the American Rescue Plan Act, has allowed \$49.8 million to be invested toward the construction of monitoring and production wells that will source deeper groundwater in southwest Georgia that aim to preserve the water supply in surface water, specifically from the Flint River, and the Upper Floridan aquifer (Georgia Water Planning and Policy Center, 2022).

1.4 Objectives

This research aimed to characterize the geology and hydrogeology in southwest Georgia, which will impact the observation and visualization of hydrostratigraphic trends. The overlying objectives of this research are outlined below:

1. Assemble and process existing data on the geology and hydrogeology of the region.
2. Characterize the geology and hydrogeology of southwest Georgia through the construction of a three-dimensional model of pre-existing data sources to characterize the hydrogeologic framework.
3. Evaluate connectivity between aquifer systems and identify suitable locations for drilling deeper aquifer wells.

These objectives were achieved through the three-dimensional gridding of approximately 80 wells across a 33-county study area in southwest Georgia to create a hydrostratigraphic block model of the Upper Floridan and Claiborne aquifer systems. Multiple studies combined well data from various sources to create models that characterized groundwater flow, hydrostratigraphic variability, and water level trends in southwest Georgia (Jones & Torak, 2006; Williams & Dixon, 2015; Williams & Kuniansky, 2015; Gordon & Gonthier, 2017; Gordon & Painter, 2018). Three sources of well data, two from publications and the other being the GA-FIT wells, were used in modeling efforts that were extensive in resources, such as drillers, cuttings, lithology, and geophysical logs (Herrick, 1961; Williams & Dixon, 2015). The well data allowed the

construction of a gridded three-dimensional surface through radial basis function interpolation. Each surface that was created in Surfer was examined to understand the hydrostratigraphic framework of southwest Georgia through elevation contours and classed post maps, isopach maps, strike and dip profiles, and observations of outcropping or thinning of units across the landscape.

1.5 Impact

Given the complexity of aquifer systems and the advancements in well drilling, the hydrogeologic characterization of the aquifer system in southwest Georgia is crucial to distinguishing the aquifers' lateral extents and in terms of productivity as an adequate water source. This characterization aims to improve the understanding of hydraulic connectivity given the thinning, or outcropping, of confining units that separate the aquifer systems. The discontinuity of lithological units and interconnectivity of aquifer systems could highlight potential risks and regional scarcity from over-pumping or pumping during extreme droughts for wells in southwest Georgia (Jones & Torak, 2006). This is critical for future use in the growth of irrigation practices to utilize deeper aquifer wells that will not detrimentally impact the existing supplies already in use.

1.6 Chapters Outline

Chapter 2 provides an overview of the literature and discusses the geology, physiography, lithostratigraphy, hydrostratigraphy, and climatic and anthropogenic effects that are characteristic of the southwest Georgia region. Chapter Three delves into the methodology and additional steps to ensure the quality of observations. Chapter Four

reports the results of the three-dimensional model structure and the profiles and validation through two-dimensional correlation software. Chapter Five discusses the general strike and dip profiles in the extent of the study area, as well as evaluates model efficiency through previous studies that investigate the subsurface geology of southwest Georgia. This chapter also discusses any limitations and future work to be done in the model. Chapter Six summarizes the research objectives achieved from this project.

CHAPTER 2

LITERATURE REVIEW

2.1 Geologic History and Physiographic/Geographic Setting

Georgia has five geographic regions (Clarke & Zisa, 1976). Southwest Georgia is located within the Coastal Plain. In Georgia, the Coastal Plain is bounded by the Piedmont province's crystalline rocks to the north (Cooke, 1943). In the southwest portion of the state's Coastal Plain, three physiographic areas are present: the Fall Line Hills, the Dougherty Plain, and the Tifton Highlands (Fig. 1, Veatch & Stephenson, 1911; Owen, 1964).

The Fall Line Hills begin south of the Fall Line and make up the northern portion of the Coastal Plain in Georgia, which has a ridge-and-valley-type landscape. Adjacent to the south of the Fall Line Hills in southwest Georgia is the Dougherty Plain, where the terrain smooths into lowlands and a karstic landscape (Torak et al., 1996). The Dougherty Plain meets Florida and Alabama near Lake Seminole and extends toward the northeast to Crisp County (Torak et al., 1996). This area is a flat, low-lying, "subsoil" and "mantled" karst plain with a dense number of sinkholes given the proximity of the limestone material in this region (Beck & Arden, 1984). Subsoil indicates the process of a cover of debris that was formed and mantled indicates the transport of such sediments (Beck & Arden, 1984). This region and its surface waters are connected to the principal groundwater source in southwest Georgia, the Upper Floridan aquifer, and the dissolution

of its limestone composition causes some surface waters to become trapped underground (Beck & Arden, 1984; Hicks et al., 1987). The Chattahoochee and Flint Rivers are also linked to the drainage of the Dougherty Plain (Hayes et al., 1983). The Tifton Uplands is located adjacent to the east extent of the Dougherty Plain in southwest Georgia and continues into northern Florida (Torak et al., 1996). The Apalachicola–Chattahoochee–Flint (ACF) River Basin exists along the edge of the Tifton Uplands that meets with the Dougherty Plain (Torak et al., 1996).

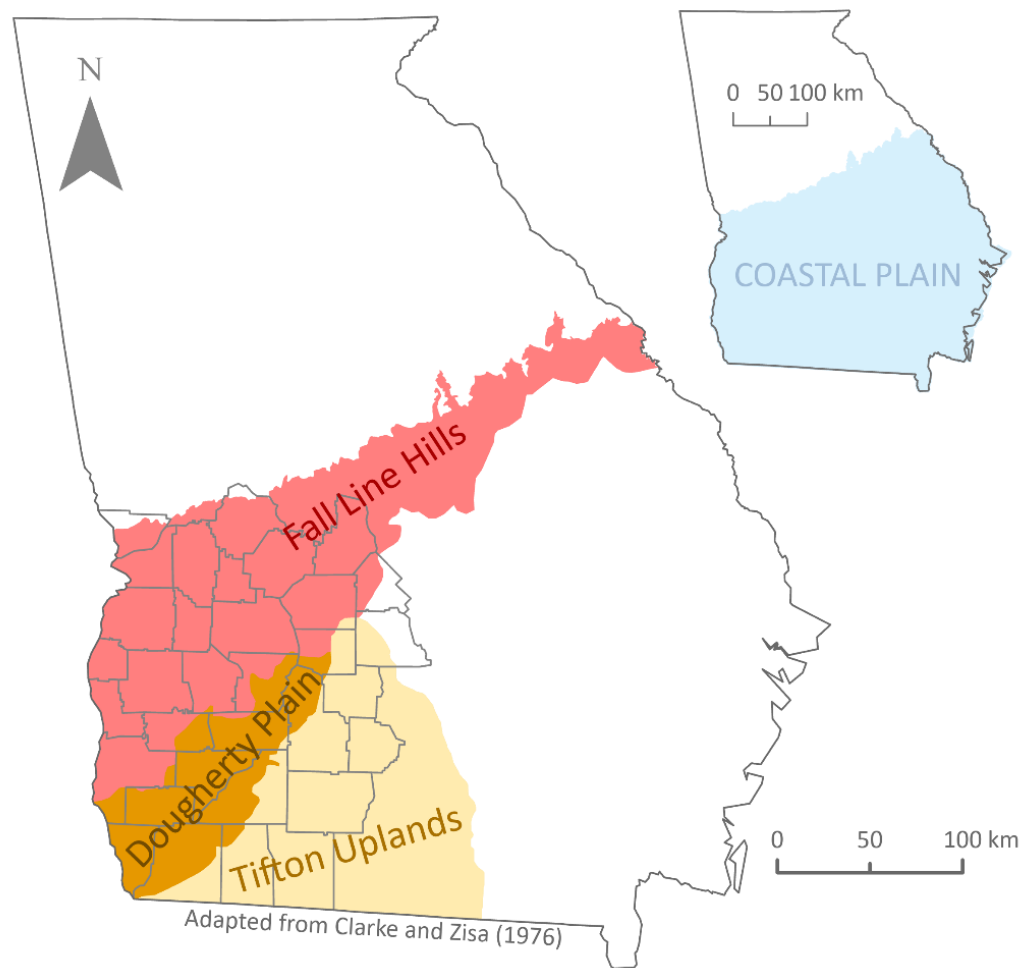


Figure 1. Geography and General Physiography of Southwest Georgia, USA (Esri Inc., adapted from EPA; Clark & Zisa, 1976).

The Gulf Trough is also an influential geologic feature in southwest Georgia geology, existing in a northeastward trending landscape that begins in Decatur County and continues into Effingham County (Huddleston, 1993). This linear feature could indicate a marine channel, specifically a marine strait in high sea level conditions (Popenoe et al., 1987; Huddleston, 1993). The Gulf Trough, studied through the analysis of seismic and stratigraphic data, is a facies boundary of deeper water to shallower water environments, formed during the middle and late Eocene and early Oligocene (Popenoe et al., 1987). With the overall quality of the Gulf Trough, there exist considerable amounts of total dissolved solids, especially in the concentration of sulfate (Chumbley & Scroggs, 2024).

2.1.1 Apalachicola–Chattahoochee–Flint River Basin

The Apalachicola, Chattahoochee, and Flint Rivers (ACF) create a shared river basin network in western Georgia, as well as in parts of Western Alabama and Northwestern Florida, and are often discussed extensively in water planning and policy due to their shared resources among states (Fig. 2, Tonsmeire et al., 2015). The ACF basin covers an area of 19,265 square miles, 90 percent of which is within Georgia and Alabama (Torak & Painter, 2006). The Apalachicola River Basin, which is south of Lake Seminole in northern Florida, makes up 18 percent of the ACF basin. The Chattahoochee River comprises 38 percent of the ACF basin and has 14 dams along its extent (Tonsmeire et al., 2015). The Flint River Basin, which makes up 42 percent of the ACF basin is solely present in Georgia. This basin starts near Atlanta, Georgia, and flows southward into Lake Seminole near Bainbridge, Georgia, with only two dam reservoirs

(Tonsmeire et al., 2015). This river basin contains most counties in the southwest Georgia region. Although the ACF is the major network in this study, seven counties to the east are also a part of the Ocmulgee, Ochlocknee, and Suwanee River Basins.

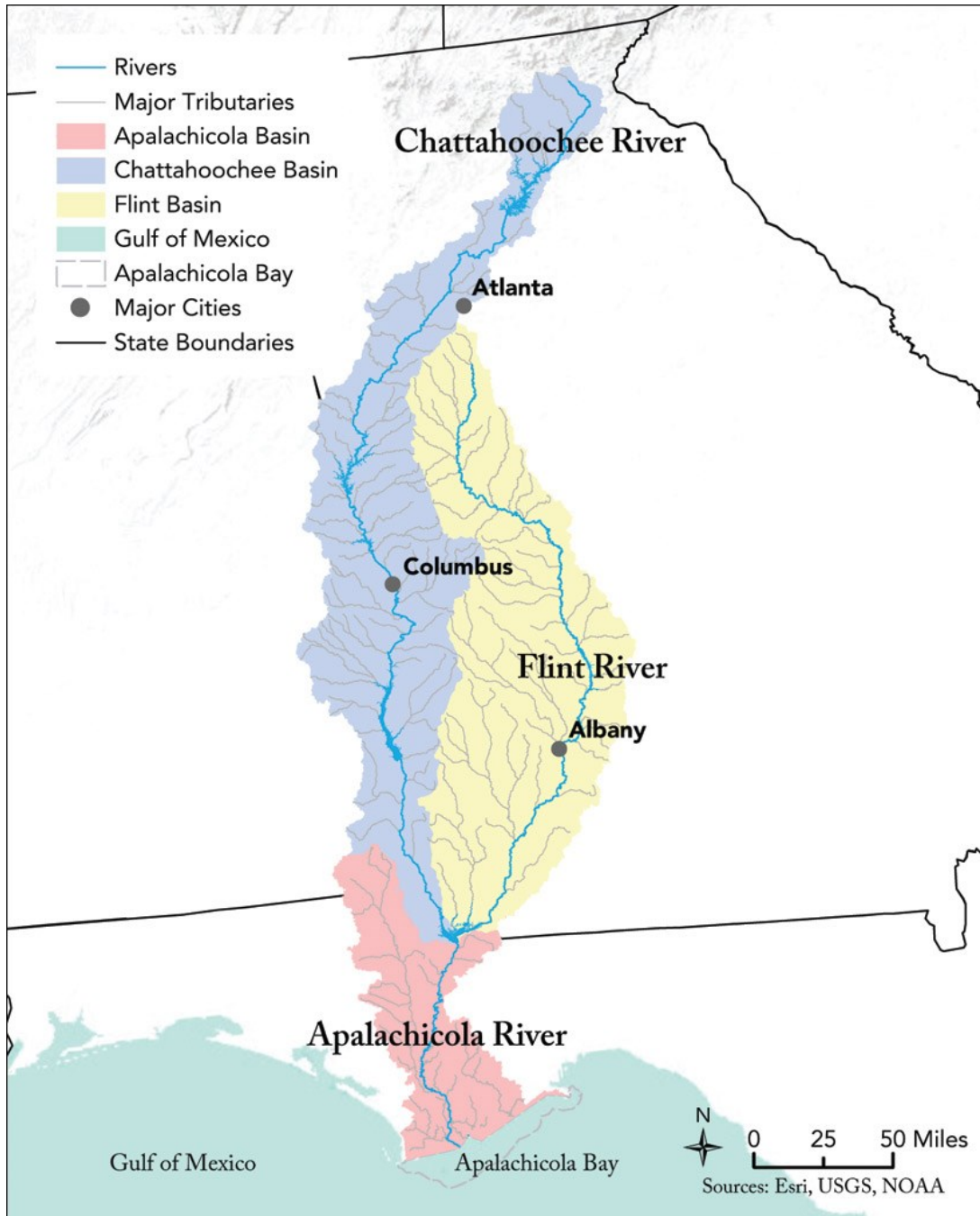
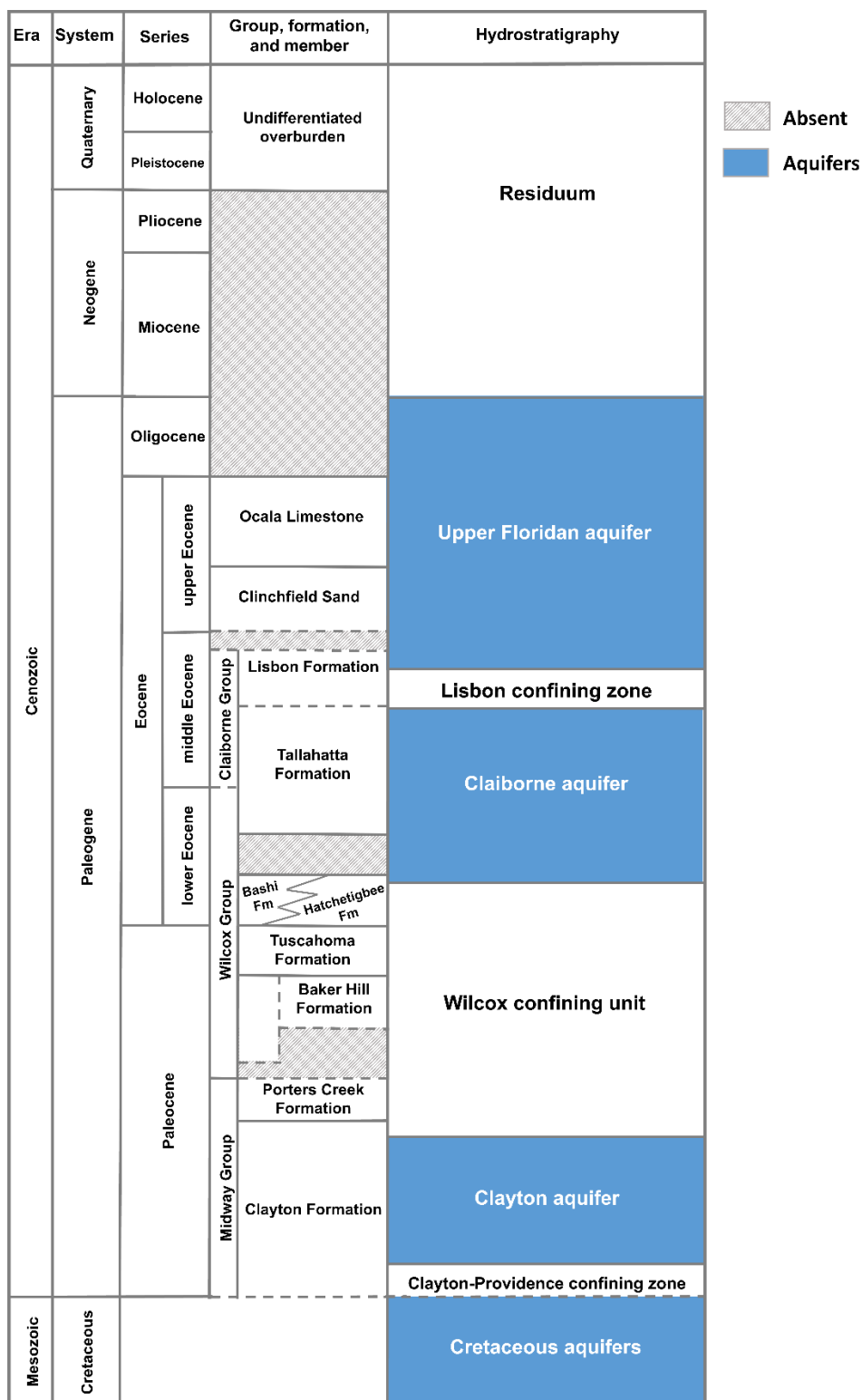


Figure 2. Apalachicola–Chattahoochee–Flint River Basin (created by Jonathan Skaggs/River Basin Center)

2.2 Lithostratigraphy

Lithostratigraphy is the study of stratigraphic units that follow the Law of Superposition, characterized by stratigraphic position and characteristics in lithology (NACSN, 2021). The significance of lithostratigraphy for this study is to familiarize what materials separate the aquifers in this region, and the lithostratigraphic formations that characterize an aquifer system. For example, the Claiborne aquifer mostly comprises the sandy portions of the lower Lisbon Formation and the Tallahatta Formation.

The stratigraphic formations of southwest Georgia are Cretaceous to Recent. The deepest rocks of the Coastal Plain, referred to as basement rock, are the crystalline rocks of the Piedmont, which range from Proterozoic to Jurassic. The basement rock consists of an array of diorites, gneisses, schist, and quartzite (Cooke, 1943; Eargle, 1955; Herrick & Vorhis, 1963). The sediments of the southwestern Coastal Plain in Georgia dip and thicken southward and southeastward (Chumbley & Scroggs, 2024). Units pertinent to this research and considered in further analysis that are present within southwestern Georgia are described in further detail below (Fig. 3).



Adapted from Gordon and Gonthier 2017

Figure 3. Generalized stratigraphy and hydrostratigraphy of southwest Georgia, USA (adapted from Gordon and Gonthier, 2017).

2.2.1 Cretaceous Formations

The Cretaceous formations are the Tuscaloosa Formation, Eutaw Formation, Blufftown Formation, Cusseta Sand, Ripley Formation, and Providence Sand. The earliest sediments of the southwestern Coastal Plain are known to be from the Upper Cretaceous, characterized by the Tuscaloosa Formation (Cooke, 1943; Herrick & Vorhis, 1963). The unique hydrogeology of these Cretaceous formations is important in characterizing Cretaceous aquifer wells and their hydraulic properties in southwest Georgia.

2.2.2 Clayton Formation

Overlying the Cretaceous Eutaw Formation is the Clayton Formation. Geographically, this formation has siliclastic, carbonate, and transition areal extents (Clarke et al., 1984). The siliclastic area is composed of medium to coarse sand, with layers of clay, sand, and sandy limestone (Clarke et al., 1984). The carbonate areas have three different units within the Clayton Formation, mainly limestone, and this is the most extensive of the three areas across southwest Georgia (Clarke et al., 1984). With the transition between the siliclastic and carbonate areas, the Clayton Formation consists of well-sorted sand, silt, and clay, with layers of clayey fossiliferous limestone (Clarke et al., 1984).

2.2.3 Wilcox Group

The Wilcox Group is subdivided into the Porters Creek Formation, the Nanfalia and Baker Hill Formations, the Tuscaloosa Formation, and the Bashi and Hatchetigbee

Formations (Clarke et al., 1984). The Porters Creek Formation overlies the Clayton Formation. At the boundary of these formations, the underlying limestone of the Clayton Formation has potential for dissolution, causing residual clays and the heavy-bedded clays that make up the Porters Creek Formation (Gibson, 1982a)

The Baker Hill Formation is of light gray kaolinitic clays and cross-bedded sands, which are thought to be deposited in estuarine or fluvial environments (Gibson, 1982a). This formation outcrops in the Chattahoochee River (Gibson, 1982a). The Nanfalia Formation, which was previously grouped with the Baker Hill Formation, can be separated by its shelly glauconitic sands and occurs more downdip (Gibson, 1982a). Overlying the Baker Hill Formation is the Tuscaloosa Formation, where the base is shelly glauconitic sand with clays, which can weather to red shades (Gibson, 1982a). Up-dip, the Hatchetigbee Formation is composed of very fine to fine-grained sand, with interlaminated very fine sand, silt, and clay. (Gibson, 1982a; Long, 1989) As it grades down-dip towards the south, it is also characterized in age as the Bashi Formation, with fossiliferous and glauconitic sands (Gibson, 1982b).

For purposes of this study, the Wilcox Group will be referred to as a group rather than by formations; however, it is important to note that some areas of the Wilcox Group had been denoted by a thick interval of clay in a well log, with some wells that displayed more interlayered beds of sands that still made it part of an impermeable unit to describe the hydrostratigraphy of southwest Georgia.

2.2.4 Tallahatta Formation

The lower to middle Eocene Tallahatta Formation is composed of limestones, silty sands, and clay, usually ranging from dark gray to gray tones (Gordon & Gonthier, 2017). Limestone, often fossiliferous, and sand comprise the top bound of the unit will exhibit low gamma-ray readings (Gordon & Gonthier, 2017). Few calcareous fossils are to distinguish the exact age of this formation. However, the Tallahatta Formation is most likely early Eocene in age, which is shown by coarse siliclastic, noncalcareous sediments deposited in a fluvial to shallow marine environment (Bybell & Gibson, 1985).

2.2.5 Lisbon Formation

Also referred to as the McBean Formation, the middle Eocene Lisbon Formation acts as a confining unit in southwest Georgia. The up-dip portion, near Lee County, is composed of dense, sandy limestone that is fossiliferous and glauconitic, with interbedded sands and clay lenses, estimated to be about ten feet thick (Hicks et al., 1981; Hicks et al., 1987). Down-dip, it is composed of dolomitic limestone with thin beds of sand, and in Dougherty County, it thickens to 100 feet (Hicks et al., 1981; Hicks et al., 1987). The presence of clays and gray, or green, soft limestone is prominent at the uppermost extent of the unit, with featured high gamma rays (Gordon & Gonthier, 2017).

2.2.6 Ocala Formation

The late Eocene Ocala Formation is mainly composed of limestone, which aligns with low gamma readings (Williams & Kuniandy, 2015; Gordon & Gonthier, 2017). The top of the unit is distinguished by soft coquina sediments with micritic limestone

mud (Williams & Kuniansky, 2015). The base has been conflictingly described in studies as hard tan limestone or soft fossiliferous limestone that has been dolomitized in some locations and can contain glauconite (Williams & Kuniansky, 2015; Gordon & Gonthier, 2017).

2.2.7 Undifferentiated Sediments and Surficial Deposits

Above the Ocala Formation, the surficial deposits, specifically in the Dougherty Plain, are Quaternary deposits that are a mixture of sand and clay weathered from the Ocala limestone (Hayes et al., 1983). These deposits thicken to west Florida and coarsen westward (Williams & Kuniansky, 2015).

2.3 Hydrostratigraphy

Hydrostratigraphy is the study of stratigraphic units, which can also be referred to as hydrogeologic units, that are characterized by their water-bearing properties (Tóth, 1978). The hydrogeologic units that are most widely used for the three-dimensional hydrostratigraphic correlation are aquifers and confining units. An aquifer is based on the ability to transmit and store water beneath the surface (Maliva, 2016). Aquifers are heterogeneous, which means that the areal extents vary in a geologic formation and range from being confined, unconfined, or semi-confined (Maliva, 2016). Southwest Georgia has four major aquifer systems, and from deep to shallow: the Cretaceous aquifer, the Clayton aquifer, the Claiborne aquifer, and the Upper Floridan aquifer (Fig. 3; Clarke & McConnell, 1987). The separation of these aquifers is provided by a confining, or semi-confining, unit, which acts as a barrier between aquifer systems and given its low

hydraulic conductivity, given its relatively impermeable material (Maliva, 2016). The confining units in southwest Georgia, from deep to shallow, are the Clayton-Providence, the Wilcox, and the Lisbon.

2.3.1 Cretaceous aquifer system

This aquifer system is composed of sand and gravel and has a soft sodium bicarbonate type (Clarke & McConnell, 1987). In the up-dip area of southwest Georgia, Cretaceous aquifers would be more easily accessible to drill into, given their depth below the surface. The Cretaceous aquifers are the Blufftown aquifer, the Cusseta aquifer, and the Providence aquifer (Clarke et al., 1983; Clarke et al., 1984; Long 1989). Toward the east downdip in the Coastal Plain, these aquifers merge, and the Providence aquifer may meet with the overlying formations that characterize the Clayton aquifer in up-dip and down-dip areas with the underlying formations that compose the Cusseta aquifer (Clarke et al., 1984; Clarke et al., 1985).

2.3.2 Clayton-Providence Confining Unit

The Providence Sand's upper portion and the Clayton Formation's lower portion comprise what has been previously described as a confining unit. However, this unit is not prominent in the siliclastic areas of southwest Georgia and may cause the Clayton and Providence aquifers to be displayed as one aquifer system (Clarke et al., 1984).

2.3.3 Clayton Aquifer

The Clayton Aquifer is the middle limestone unit of the Clayton Formation (Chumbley & Scroggs, 2024). This aquifer is composed of limestone and calcareous sands and could leak from the Providence aquifer (Clarke & McConnell, 1987; Chumbley & Scroggs, 2024). In previous monitoring of pH levels in shallow and deep wells, the up-dip areas near the outcrop region were relatively acidic, and the down-dip areas were more basic (Chumbley & Scroggs, 2024). The Clayton and Providence aquifers combine in siliclastic areas near the east of the Ocmulgee River. However, in carbonate areas, they remain as separate systems (Clarke et al., 1984; Chumbley & Scroggs, 2024).

2.3.4 Wilcox Confining Unit

The Wilcox confining unit is represented by the Wilcox Group. The silty clay composition of the Wilcox confining unit has high gamma and low resistivity (Gordon & Gonthier, 2017). The Wilcox unit has been studied in groundwater flow modeling and had hydraulic properties that indicated the interconnection of the Clayton and Claiborne aquifer systems in Mitchell County (Gordon & Gonthier, 2017).

2.3.5 Claiborne Aquifer

The Claiborne aquifer is represented by the sandy portions of the base of the Lisbon Formation and the Tallahatta Formation, denoted in geophysical logs as having low gamma and high resistivity (Gordon & Gonthier, 2017). The aquifer outcropped towards the surface in a trending line near the Fall Line Hills through Dawson, Georgia,

and Americus, Georgia, extending from north Early County to west Dooly County (Beck et al., 1985; Chumbley & Scroggs, 2024). This aquifer is composed of fine to coarse sands and limestone. This can often be the entire extent of the Tallahatta and include the upper extent of the Lisbon.

The Claiborne aquifer has a gentle dipping direction toward the southeast and thickens into a limestone-dominant material downdip (Beck et al., 1985). The upper extent of the aquifer ranged from 200 feet above NAVD 88 in Terrell County to 402 feet below NAVD 88 in Decatur County (Gordon & Gonthier, 2017). In 2023, shallow wells in the up-dip region of the Claiborne aquifer were acidic, and some that were deeper were most likely influenced by limestone or sandy limestone (Chumbley & Scroggs, 2024). The aquifer is recharged primarily from the outcrop region, with also a possibility that leakage could occur from overlying strata downdip, but this has been previously stated as a rare or unlikely occurrence (Beck et al., 1985). Later studies suggest that preferential flow from irrigation and precipitation could contribute to aquifer recharge given its rapid response to both but stated that more data was needed to support this mechanism (Bosch & Hicks, 1993). This was later challenged by two 72-hour pumping tests conducted in 2015 and 2016 in Early and Mitchell counties, which showed no interconnection between the Upper Floridan, Claiborne, or Clayton aquifers in Mitchell County, but was displayed in the Claiborne aquifer in Early County, which was most likely connected to underlying strata (Gordon & Gonthier, 2017).

2.3.6 Lisbon Confining Unit

The Lisbon confining unit, composed within the middle Eocene Claiborne Group, is composed of dense limestone and clay of the Lisbon Formation, the materials that make it an impermeable unit (Beck et al., 1985; Gordon & Gonthier, 2017). This is displayed by high gamma values with the clay material, and low resistivity (Gordon & Gonthier, 2017).

2.3.7 Upper Floridan Aquifer

As the primary groundwater resource used by the population of Georgia, the Upper Floridan aquifer is composed of limestone, dolomite, and calcareous sands (Clarke & McConnell, 1987; Chumbley & Scroggs, 2024). Leakage into the Upper Floridan Aquifer was recorded from 1900 to 1980, where downward leakage increased by 27% (Faye & Mayer, 1997). This aquifer is recharged by infiltration, leakage, and direct connectivity to surface waters (Williams & Kuniansky, 2015). This aquifer outcrops within the Dougherty Plain and continues to meet the surface in adjacent areas to the northeast (Chumbley & Scroggs, 2024). Changes in groundwater flow are also present, with flows that travel southwestward in the Dougherty Plain and southeastward across the remaining extent of the Coastal Plain (Chumbley & Scroggs, 2024). The Upper Floridan aquifer drains into the Chattahoochee and Flint Rivers (Torak & McDowell, 1996).

2.3.8 Residuum and Surficial Aquifer System

The Upper Floridan aquifer is bounded by surficial residuum or unconsolidated materials. The residuum is a semi-confining to confining unit above the Upper Floridan

aquifer system, varying in thickness across the study region (Torak et al., 1996; Williams & Kuniansky, 2015). Composed of siliclastic or carbonate rocks, the residuum formed from the dissolution and weathering of rocks that resulted from the limestone material of the Upper Floridan aquifer (Williams & Kuniansky, 2015).

Although the geological history of relative sediment types and general lateral extents of the formations are described by previous publications, the systems that affect the deposition of sediments are highly complex. Tectonic subsidence, eustatic sea level changes, sedimentation rates, and changes in water depth all vary to impact the deposition and erosion of sediments over time (Holland, 2025). There are also lateral and vertical changes in facies that occur and are not tabular for the entire Coastal Plain of Georgia. Deeper water facies, which are typically clay dominant, will pinch out landward and up-dip of depositional processes, and shallow water facies, which are typically sand dominant, will pinch out seaward and downdip of depositional processes. This complexity in the stratigraphic units makes it more difficult to sufficiently define changes in systems across southwest Georgia and the composition of its aquifer systems.

2.4 Climatic and Anthropogenic Effects on Water Resources in Southwest Georgia

2.4.1 Groundwater Use

The Upper Floridan aquifer is a significant source of groundwater use in Georgia. In 2015, the Upper Floridan aquifer in Georgia contributed 68% of groundwater use, with 57% going towards agricultural needs and irrigation (Painter, 2019). From 2013 to 2023, the number of wells used for irrigation in Georgia increased by 5 percent (NASS, 2025). In data compiled from 2010 to 2020, thermoelectric power, crop irrigation, and public

supply contributed to withdrawals greater than 0.1 to 10 million gallons per day in southwest Georgia (Stets et al., 2025). From water use data collected from 1985 to 2015, the Lower Flint–Ochlocknee water planning region, which makes up most of the study area in southwest Georgia, had declining water use trends in domestic and commercial, industry and mining, and thermoelectric power (Painter, 2019). In contrast, livestock and aquaculture had increased over 5 times its original amount, and irrigation had a substantial 90 percent increase from its use in 1985 (Painter, 2019). Landsat satellite imaging data also depicted this increase, investigated by a study that used data from 1976 to 2013, displayed a 4,500 percent increase in center-pivot systems, which cover a circular area and are the leading irrigation equipment in Georgia’s irrigation schemes. (Williams et al., 2017; Porter & Perry, 2022).

2.4.2 Drought Events

In addition to potential malpractices in water use, southwest Georgia is subject to climate vulnerability, a term used for the frequency of extreme weather events such as floods and droughts, studied in decadal trends from 1975 to 2012 (K.C. et al., 2015). From 1980 to 2015, five major drought events have impacted Georgia (Painter, 2019). From December 2010 to 2012, Georgia experienced drought conditions that severely impacted the hydrologic and water quality conditions of surficial aquifers and of the Upper Floridan Aquifer, leaving seven surficial aquifer wells dry and 140 wells out of the 355 wells monitored below mean water levels at a record low (Gordon et al., 2012). During these dry seasons, pumping from wells is how farmers fulfill the needs of irrigation since many surficial waters are dried out (Fig.4, Gordon et al., 2012). As a

result of the severity of the 2012 drought that heavily impacted Georgia, suspensions were placed on water agricultural permits to protect local surface water, such as the Lower Flint and Chattahoochee River basins, and groundwater, specifically from the Upper Floridan aquifer (Truszczynski et al., 2023).

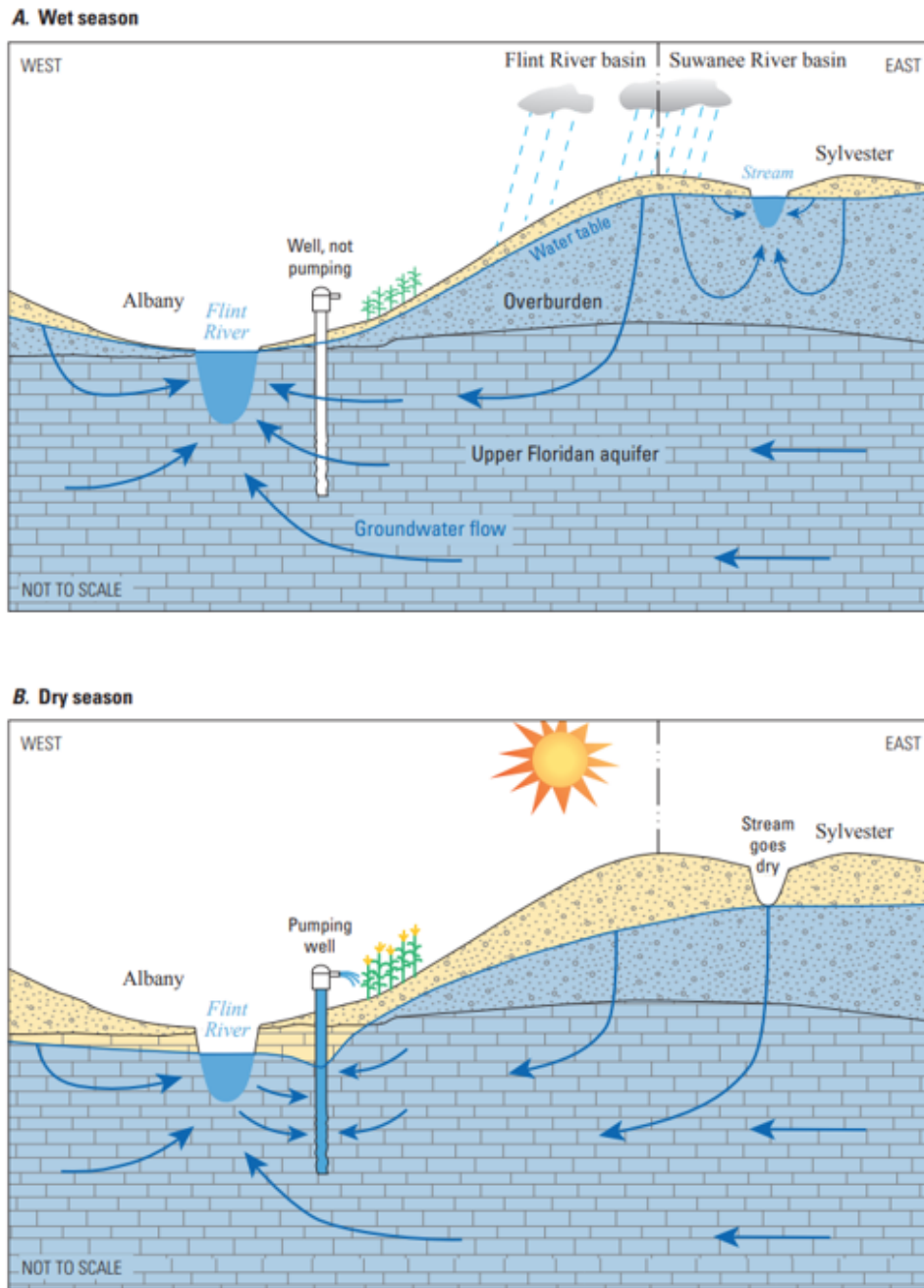


Figure 4. Wet and dry seasons with interconnection in the Upper Floridan Aquifer in southwest Georgia. (Image provided by Gordon et al., 2012)

2.4.4 Population Growth

In the severity of these agricultural demands, Georgia's population is also predicted to increase by nearly 15% from 2020 to 2040 (National Population Projections, 2024). This population increase, along with all other pertaining factors, makes it necessary to understand the hydrogeological characteristics of the aquifer systems in southwest Georgia. With the Upper Floridan aquifer being the principal aquifer of the Georgia Coastal Plain, other options must be assessed to sustain the demands of agricultural production, public supply, and other hydropower uses. It was even stated that a framework of utilizing only one aquifer for all uses would be limited in longevity, and a multi-aquifer design would be the most effective for maintaining the water resources of all aquifers in southwest Georgia (McFadden & Perriello, 1983).

2.4.5 Source-Switching

A study on the cost-effectiveness of source switching in southwest Georgia stated that funds should be allocated towards counties with the highest probability of well failure for drilling, which was represented in Randolph County (Mullen & Niu, 2023). The lowest probability of well failure was in Decatur County, and it was recommended that research funds be allocated toward understanding the hydrogeology of the Claiborne aquifer for that county (Mullen & Niu, 2023).

CHAPTER 3

METHODS

3.1 Study Site

The study area includes 33 counties in southwest Georgia (Fig. 5). The study area was expanded past the bounds of the GA-FIT Drought SWAP Project area counties to observe potential outcropping and discontinuation of the Claiborne Aquifer through historical well data.

For deeper-lying aquifer systems beneath the Upper Floridan aquifer, the lithological and geophysical data decreased in sufficient characterization in the extent of southwest Georgia. The Georgia Geologic Survey, US Geological Survey, Georgia Environmental Protection Division, and other sources were all used to search for wells for hydrostratigraphic modeling (Williams & Dixon, 2015; Herrick, 1961; Gordon & Gonthier, 2017). Historical well data includes any wells drilled in the study site counties. They were more likely to be considered in further analysis if they contained additional geological data, such as geophysical logs, specifically gamma ray and resistivity, cuttings or core descriptions.

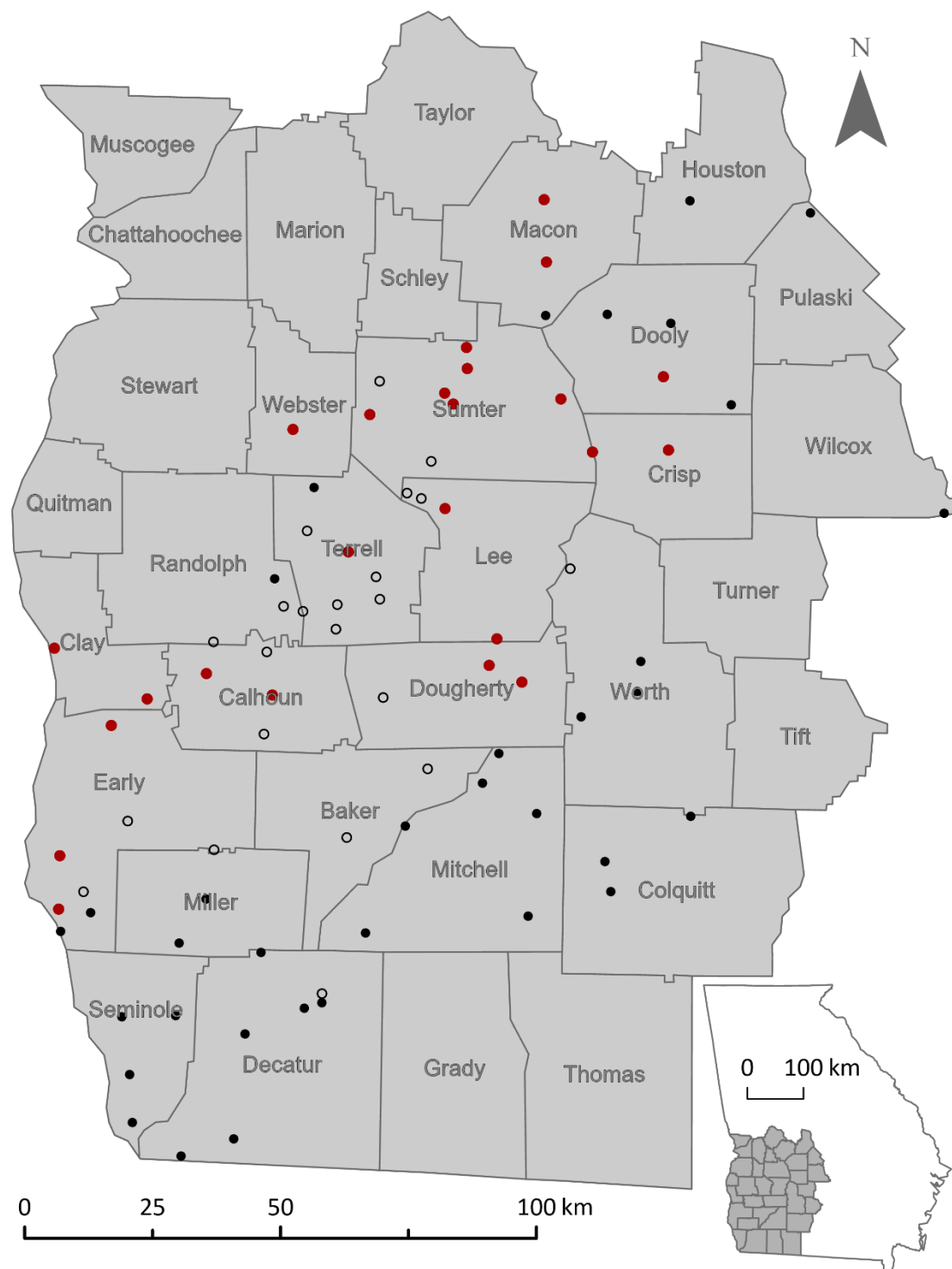


Figure 5. Study site with well locations in southwest Georgia, USA. Red dots indicate Herrick (1961) wells, black dots indicate Williams and Dixon (2015) wells, and black open dots indicate GA-FIT wells.

3.2 Data Collection

Geophysical, lithological, water-bearing properties, well cuttings descriptions, and hydrostratigraphic formations were used to further understand the hydrogeology and geology of southwest Georgia for three-dimensional modeling (Herrick, 1961; Williams & Dixon, 2015; Georgia Water Planning and Policy Center 2022). In the sources used, GA-FIT and Herrick (1961) were the first input into the study area, and counties with limited to no data were provided by Williams and Dixon (2015). Additional information on existing wells planned to be used in modeling efforts was available in other databases that could be used for analysis (Williams et al., 2016; Williams & Dixon, 2015; Williams & Dixon, 2015; Herrick, 1961; Gordon & Gonthier, 2017).

The GA-FIT and Herrick (1961) wells were initially stated by thicknesses of lithological descriptions, starting from a depth below sea level, or a set depth below zero (Herrick, 1961). Hydrostratigraphy was not described in these sources. Thus, interpretation was based on available descriptions and provided logs. Additional wells from another source were added to the model to fill counties with limited to no data (Williams & Dixon, 2015). A file of all wells and their depth to the top of each hydrostratigraphic unit was created for three-dimensional model construction (see Appendix A).

3.2.1 *GA-FIT*

The GA-FIT Drought SWAP facilitated the drilling of Claiborne- and Cretaceous-aquifer monitoring and production wells, provided through the funding from the Georgia Governor's Office of Planning and Budget obtained through the American Recovery Act.

The Georgia Water and Planning Center at Albany State University facilitated the program's objectives, and funds were extended to members and scientists in participating academic institutions, state departments, and private companies. For all monitoring and production wells, mud rotary drilling was performed by the Golden Triangle Resource Conservation and Development Council (Golden Triangle RC&D) located in Albany, Georgia. The well cuttings were collected from the 13 monitoring wells at 10-foot increments (Table 1). These cuttings were described by Geospatial & Hydrologic Services (GHS) using standard practices in soil classification. Geophysical logging was conducted by the Georgia Environmental Protection Division (GAEPD) and included gamma ray, spontaneous potential, caliper, and resistivity logs.

GA-FIT wells, labeled by Claiborne (CA) and Cretaceous (CT) for monitoring wells and SW for production wells, were evaluated by the geophysical and drilling logs that provided an indication of hydrostratigraphic units and their depth extents. GA-FIT wells were a depth-based measurement, so all values originally started with the topmost surficial unit at a value of zero, which would be used in a below-altitude measurement. Twenty-two GA-FIT wells were included in the final output of the three-dimensional surfaces.

Table 1. GA-FIT monitoring wells and general site information.

GA-FIT Monitoring Well	County	Longitude (WGS 84)	Latitude (WGS84)	Elevation (m) NAD 88	Depth of borehole for 8" casing (ft)
CT 1	RANDOLPH	-84.718597	31.624272	99.493	550
CT 2	SUMTER	-84.377432	32.084534	160.265	250
CT 3	TERRELL	-84.526452	31.820570	123.787	450
CT 4	MARION	-84.541039	32.167535	55.894	340
CT 5	CALHOUN	-84.613885	31.462294	67.276	N/A
CA 1	EARLY	-84.892811	31.307691	64.026	200
CA 4	BAKER	-84.443097	31.280452	48.442	370
CA 5	BAKER	-84.277177	31.401728	50.199	320
CA 6	WORTH	-83.983442	31.754286	74.829	280
CA 7	EARLY	-84.982585	31.182599	55.894	320
CA 8	EARLY	-84.715222	31.257984	58.174	310
CA 10	DECATUR	-84.492957	31.005234	40.530	660
CA 11	DOUGHERTY	-84.368829	31.527250	61.470	560

3.2.2 Herrick (1961)

The USGS Bulletin 70 (B70) had lithologic descriptions available from well samples, formation names, and potential water-bearing zones based on the lithology of the oil and permitting wells, denoted by the prefix GGS (Herrick, 1961). All available data was useful in determining the extent of aquifer systems. For most wells, the same thickness of the Claiborne was maintained in what was labeled as the Tallahatta Formation. The same thickness values were also used for the Upper Floridan aquifer, labeled by the Ocala Formation. Slight revisions of thickness were made if a lithologic unit descriptor did not fit into the description of an aquifer. For example, a thick unit of dense clay at the top, or the base, of the Tallahatta Formation. The clay unit would be placed in the subsequent confining unit's thickness. In scenarios where the distinctions of thin clay bed units in a formation, such as the Tallahtatta Formation, this was included in

the extent of the aquifer since it is common for this aquifer to vary in sands, clay, and limestone materials. It was also important to observe zones of potential interconnectivity and outcropping.

Herrick (1961) wells selected in the study area counties totaled 24 wells and reached at least the Claiborne Group or displayed outcropping of deeper-lying units. If the author deemed some of the samples from the wells as producing non-satisfactory results, those wells were excluded from the model building (Herrick, 1961).

3.2.3 Williams & Dixon (2015)

The Williams and Dixon (2015) report, published by USGS, had its hydrostratigraphic units predefined by shapefiles and a geodatabase in ArcGIS Pro (Williams & Dixon, 2015). These hydrostratigraphic units were collected from a compilation of other various historic wells sourced through several institutions and publications (Williams & Dixon, 2015). The wells that were selected had prefix descriptions that described the purpose of each. Georgia Geological Survey oil and gas permitting wells (GGS, DP), state wells (GA), and USGS identification were all prefixes present in Williams and Dixon (2015) wells. For software integration, layers defined by the shapefiles were exported to display a “depth to the top of the unit” of the hydrostratigraphic layer (Fig. 6). The units provided in feet were then converted to meters to match the format used in the database input into Surfer software. The wells within the desired counties were classified according to the depth of at least the Claiborne aquifer. The wells chosen for modeling efforts were based on areas where the B70 and

GA-FIT wells did not have adequate data, accounting for 30 wells included into the final output of three-dimensional surfaces.

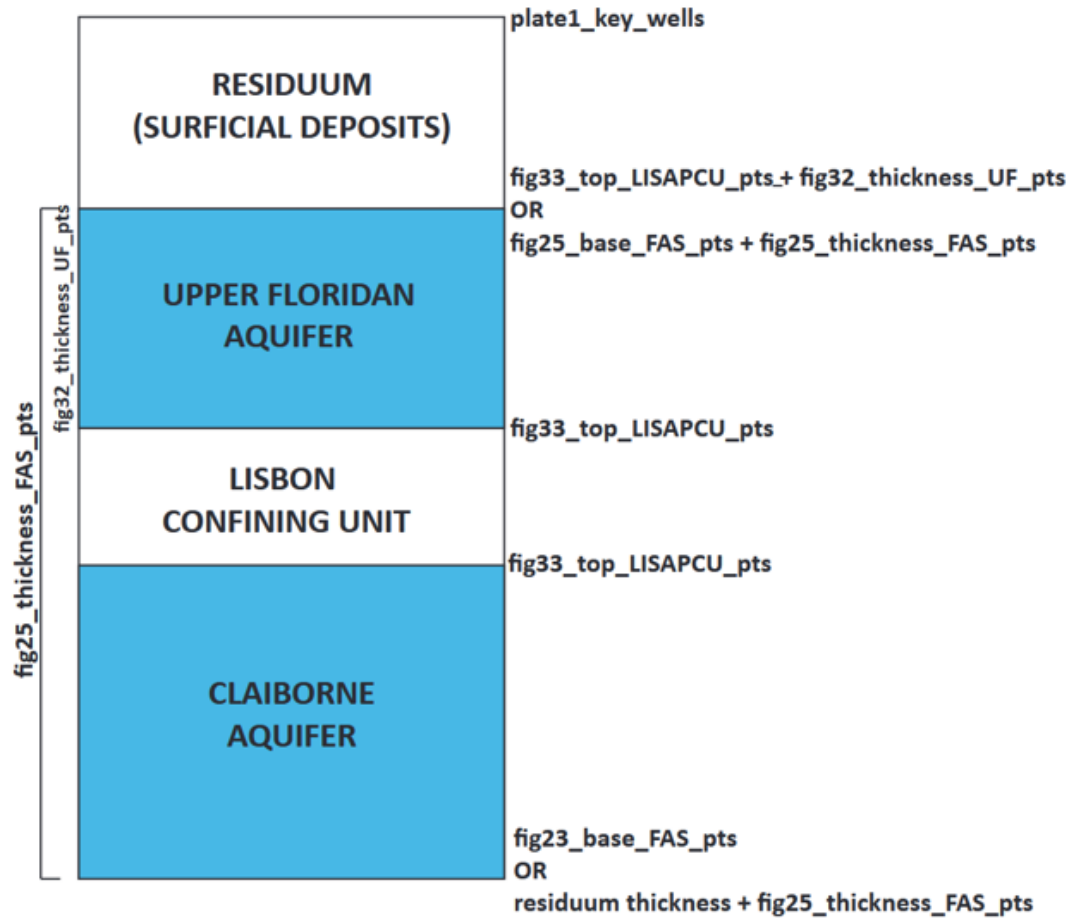


Figure 6. Shapefiles used in the calculation of the top bound of hydrostratigraphic surfaces provided by Williams and Dixon (2015).

3.2.4 Digital Elevation Model Retrieval

A Digital Elevation Model (DEM) was used to export each well point's elevation values from the three used sources. The DEM used to source the elevations was retrieved from the National Map (US Geological Survey, 2023). The selected elevation data was in a spatial resolution of a one-third arc second, or approximately ten meters. This elevation layer used a geographic coordinate system of North American Datum 1983 (NAD 83),

and its elevation values were referenced to the North American Vertical Datum of 1988 (NAVD 88). Sixteen DEM files were mosaiced to cover the extent of the study area for elevation calculation.

GA-FIT wells were in the World Geodetic System 1984 (WGS 84) and converted to North American Datum (NAD 83) to fit the same geographic coordinate system for Willaims and Dixon (2015) and Herrick (1961). Willaims and Dixon (2015) provided shapefiles that were used from the NAD 83 coordinate system. Multiple shapefiles were used to calculate depth values based on the altitudes of their existing shapefiles of elevations and thicknesses of units (Fig. 6). These calculated depth values were then subtracted from the DEM altitude to have the hydrostratigraphic unit top as a depth below the NAVD88 altitude.

3.3 Pre-Processing of Three-Dimensional Surfaces

Surfer, a program by Golden Software, was used to depict wells from GA-FIT and historic wells in three-dimensional visualization (Golden Software, 2025). The three data sources were combined into one database for input to create the three-dimensional model. For some wells used in modeling, values of hydrostratigraphic unit tops that had no thickness at a specific site were placed at a small value, 0.3 meters greater than the underlying hydrostratigraphic unit. This allowed the surfaces to be constructed from the same number of data points across the study area, and the limited thickness values allowed overall interpretation of general outcropping and pinching out of hydrostratigraphic units.

3.3.1 Projected Coordinate System Conversion

For data entry into Surfer software, the X, Y, and Z values in the data file must be in the same linear units to correctly grid a surface layer. This was done by inputting the latitude (Y) and longitude (X) values in decimal degrees from the geographic coordinate system North American Datum 1983 (NAD83) in Surfer and processing a projection in Surfer software for State Plane System GA West of 1983 FIPS 1002 (meters) to get values in linear units (Golden Software, 2021).

3.3.2 Test of Data and Gridding Methods

In Surfer, a three-dimensional model is produced from the overlay of several three-dimensional surface layers. A gridding method was used to create three-dimensional surface layers for the model, which used the interpolation and extrapolation of data points from the selected well sites. There are 12 gridding methods offered in Surfer software. The Claiborne aquifer top surface was compared in the 12 gridding methods to test realistic contours, lowest residual sum, and most calculated residuals (Fig. 7).

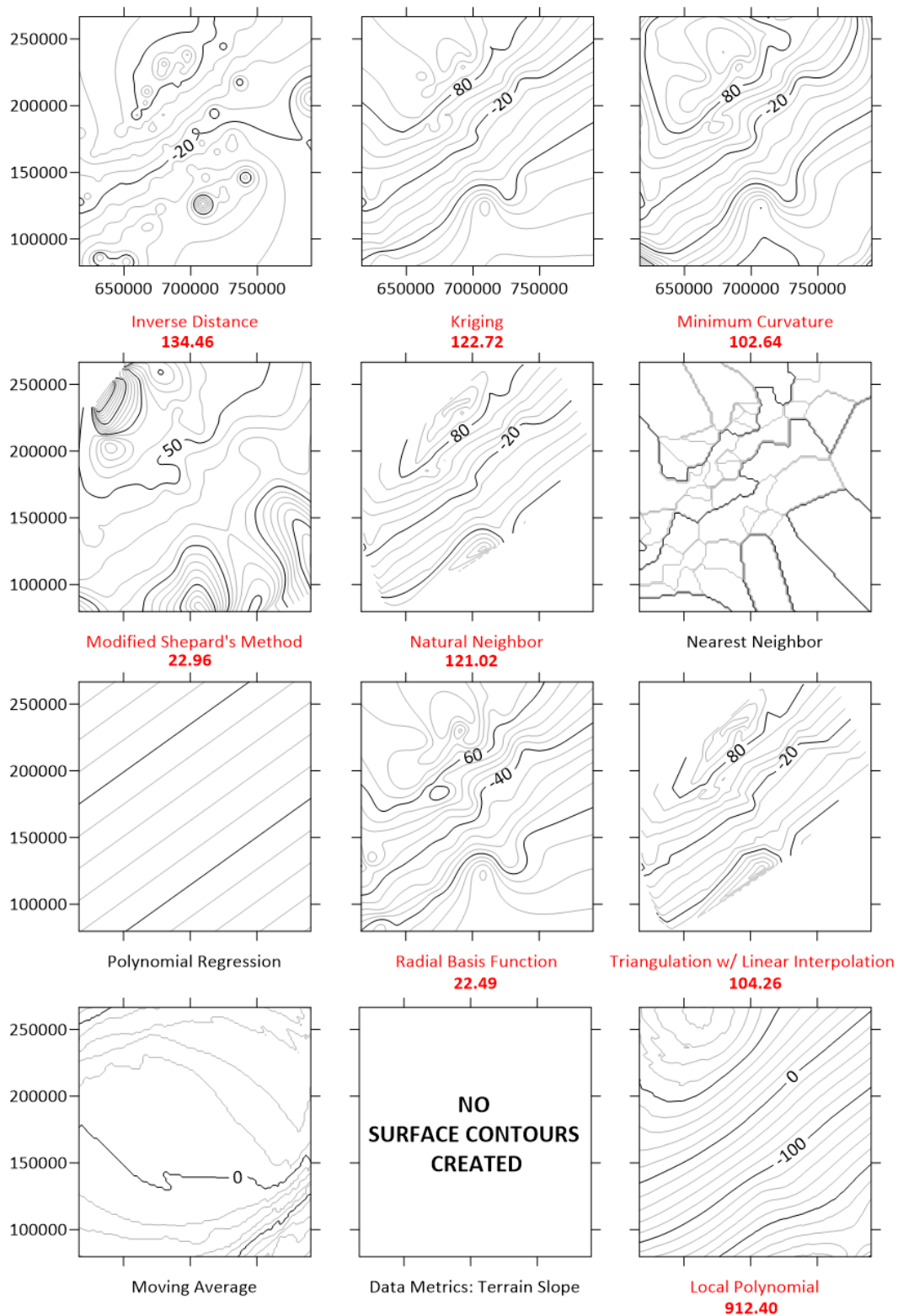


Figure 7. Gridding methods simulated the Claiborne aquifer hydrostratigraphic top layer in Surfer software (Golden Software, 2025). Those displayed in red were tested further for calculated residual sums, displayed in bold beneath the gridding method.

A test of the residual sums of the gridding methods that resembled realistic structural contours was compared. The method with the lowest residual sum and the most calculated values would be used for the three-dimensional model. The contour maps were created using a script in the Surfer's Scriptor application (Golden Software, 2019b). The residuals were taken from each of the realistic contour maps. The calculation of residual sums provided in Surfer software is:

$$\Sigma Z_{res} = \Sigma (|Z_{dat} - Z_{grd}|) \quad (Equation 1)$$

Where:

Z_{res} = the residual value

Z_{dat} = the elevation value in the data file

Z_{grd} = the elevation value of the surface at the XY coordinate from the grid file

The gridding method with realistic contours, the lowest value of residual sums, and the most calculated residual sums of the Claiborne surface layer were determined to be the Radial Basis Function. Although this was not visually the smoothest contour surface out of other gridding methods, the residual sums were significantly lower than the other methods (see Appendix B).

The Radial Basis Function is an exact interpolator, or when a data point coincides with the center of a grid node (Golden Software, 2019a). The Radial Basis Function, much like Kriging, creates a smooth appearance and can be flexible in handling fewer data points as opposed to other gridding methods (Golden Software, 2019a). Basis kernel function and R^2 were the two parameters that could be specified by the user when using

the Radial Basis Function. The preferred and default basis kernel function for the surface creation was multiquadric, which can produce the smoothness of a surface of each 3D surface layer, and was calculated based on the following equation (Golden Software, 2024):

$$B(h) = \sqrt{h^2 + R^2} \quad (\text{Equation 2})$$

Where:

h = anisotropy, or the relative distance from point to node

R^2 = the shaping factor.

The R^2 value, or the shaping factor, provided the ability for the smoothing of the three-dimensional surface using Radial Basis Function and was included in Surfer software by the following equation:

$$R^2 = \frac{(\text{length of diagonal of the data extent})^2}{(25 * \text{number of data points})} \quad (\text{Equation 3})$$

The R^2 value was set at the default value of 30,000,000 for all layers. The default for Surfer software was that “No Search” is performed on the data, given that there are less than 250 data points, and all need to be used for surface layer modeling.

The surface layer of the hydrostratigraphic units was tested on their quality based on the original data. In the gridding process of creating a three-dimensional surface layer, interpolation errors resulted, which are calculated as the difference between the interpolated and the observed values in a cross-validation test. Cross-validation reports

also tested other statistical methods that compute the fitness of data to the gridding output (see Appendix C). These were tested on all layers included in the 3D model, and any values above a 50 percent interpolated error were discarded from the dataset before the final model construction.

Six wells were discarded based on their values above 50 percent interpolated error: GGS559, GGS109, GGS3536, 09G015, 10G314, and GA-WX2. This resulted in 76 wells used in the final three-dimensional surfaces and model output (Fig. 8). The error for (Row 8 well) was 52%. This point was still included in the analysis; given the importance of including the GA-FIT wells in the model, and given the small percentage above 50, it was still considered in model interpretation. In the output grid geometry, the minimum and maximum bounds for the XY values were set to include all counties. Thus, there would be extrapolated sections of the map that contain no data points (Table 2). The grid geometry for the three-dimensional surface display was chosen based on the extent of the 33 counties within the study area. Grid nodes were set to create equal spacing across the surface layers created.

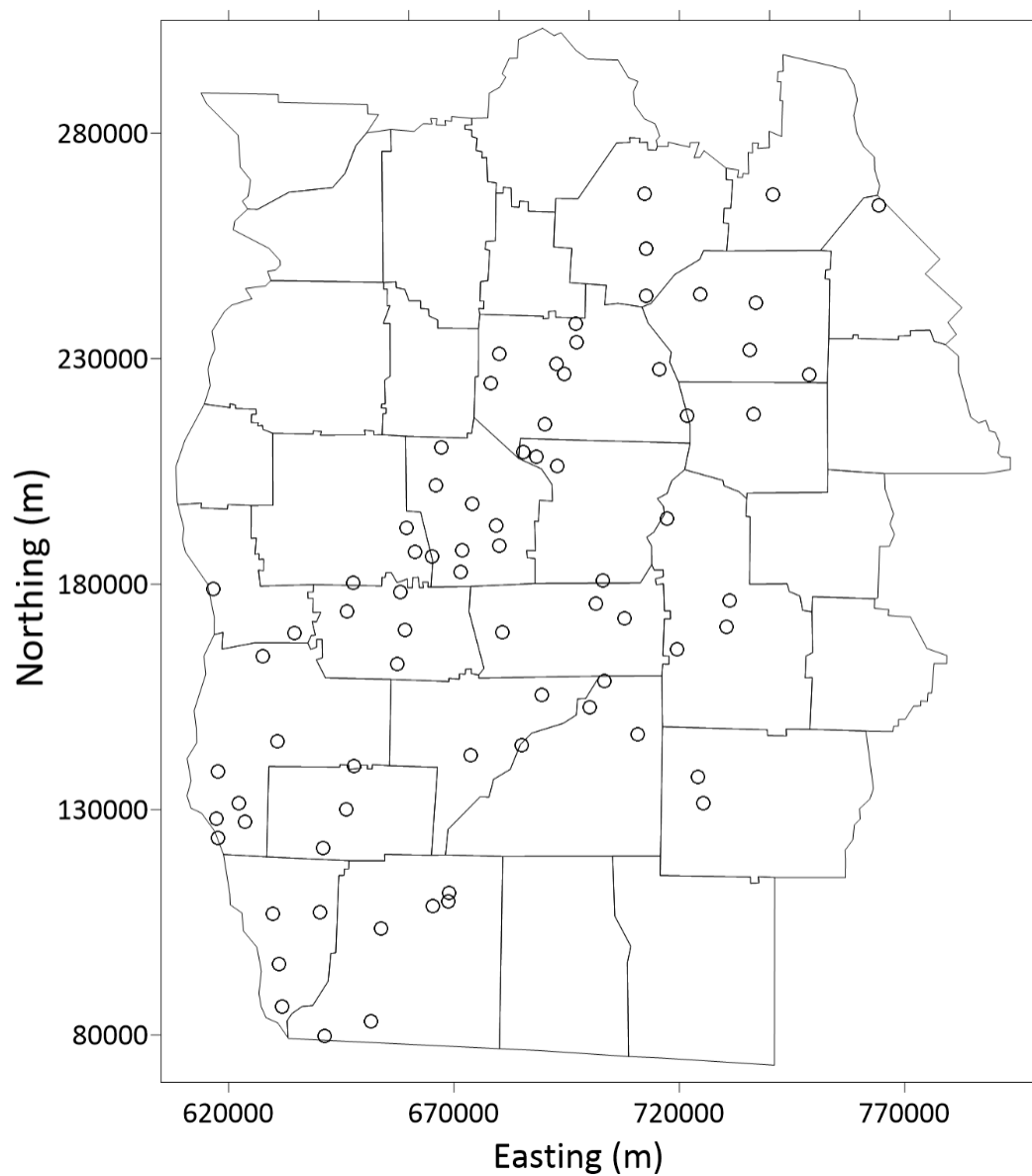


Figure 8. Map of 76 well sites in 33-county study area after grid data processing and datum conversion in Surfer software.

Table 2. Minimum and maximum bounds of the three-dimensional surfaces in the output of the grid geometry. Values are in the State Plane System GA West of 1983 FIPS 1002 (meters).

Minimum X	605,000
Maximum X	800,000
Minimum Y	69,500
Maximum Y	305,000

3.4 Three-Dimensional Surface Creation and Modeling

The surfaces of the residuum, the Upper Floridan aquifer, the Lisbon confining unit, the Claiborne aquifer, and the Wilcox confining unit were modeled using the Radial Basis Function. The Clayton and Cretaceous aquifers and the Cretaceous Confining unit were not modeled due to a significant lack of data.

Surfer software was used for the three-dimensional surface layers to visualize trends in elevation, thickness, and outcropping regions. Isopach maps were produced from the 3D gridded surfaces of each top layer. An isopach map showed the stratigraphic thickness of the residuum, Upper Floridan aquifer, Lisbon confining unit, and the Claiborne aquifer. Classed post maps were created to assess data trends in the elevation of surfaces, and elevation contour maps were also depicted.

After the three-dimensional surfaces were modeled in Surfer and overlaid to produce a three-dimensional hydrostratigraphic model, areas of outcropping, thinning, or abrupt changes were further assessed through ten relative strike and dip profiles (Fig. 9). If two or more wells are in the same proximal location of the concerned zones,

lithological and geophysical logs were used to note if the site depicted an unsuitable area for drilling or a potential modeling error caused when delineating between hydrostratigraphic units.

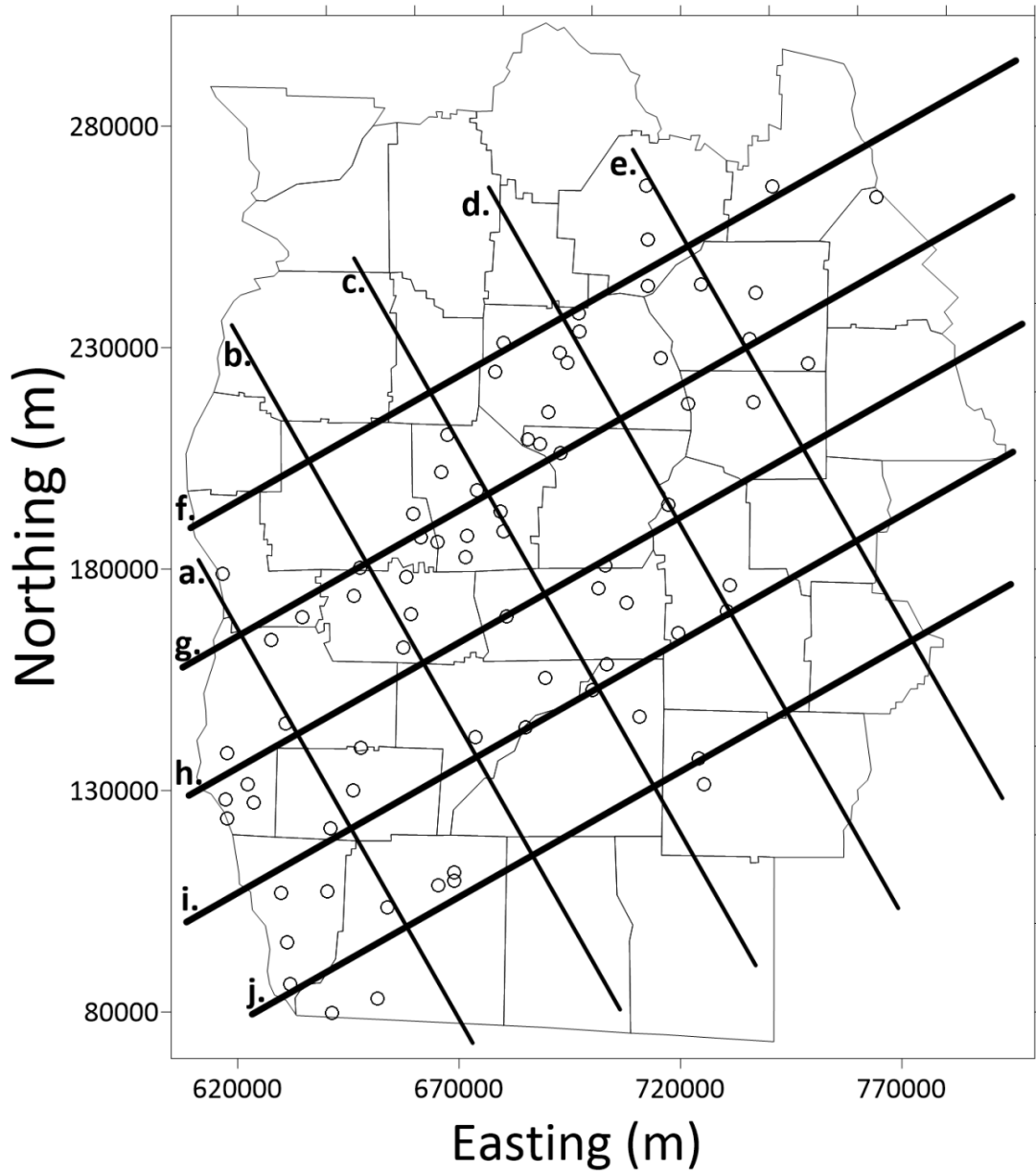


Figure 9. Transect lines for general strike and dip profiles from the three-dimensional model.

3.5 Model Validation

The three-dimensional model was compared with pre-existing publications that discuss the areal extents of aquifer systems, thickness values, and stratigraphic correlations across the southwest Georgia landscape (Gordon & Painter, 2018; Gordon & Gonthier, 2017; Williams & Kuniansky, 2015; Davis et al., 1983).

WellCAD MultiWell module software was used to create two-dimensional stratigraphic correlations to depict areas that required further investigation in modeling efforts (ALT, 2024). The locations of denoted zones of potential interconnectivity or outcropping from the profiles created in Surfer were modeled in WellCAD through the correlation of two or more wells in the resulting areas of concern from Surfer modeling.

Each well was displayed, if well data permitted, with lithostratigraphy and color, water-bearing zones, and any geophysical logs (SP, resistivity, and conductivity logs), if applicable, that aided in understanding sediment changes and aquifer capability.

Hydrostratigraphic units and wells were the same as those defined in Surfer. The Ocala Formation was assumed to be the full extent to define the Upper Floridan aquifer, and the Tallahatta Formation was assumed mostly to be the full extent of the Claiborne aquifer for model simplicity. Assumptions of formations that coincided with aquifers and confining units follow methodologies based on previous studies and the well descriptions of formations (Herrick, 1961; Williams et al., 2016).

To test the efficiency of the Radial Basis Function that was used to construct the three-dimensional surfaces, a sensitivity analysis of the shaping factor was tested. This test was to further evaluate the default shaping factor value (30,000,000) and if it was efficient to mitigate the impacts of bullseye-like contours or the overprediction of

smoothing efforts. This was performed by creating new three-dimensional surfaces with one and two orders of magnitude higher and lower than the default shape factor of the three-dimensional model. The isopach maps of the Upper Floridan and Claiborne aquifers were used for this comparison between shape factor variability, which had displayed depressions in the mapped surface in bullseye-like contours.

CHAPTER 4

RESULTS

4.1 Data Entry and 3D Surface Characteristics

After the errors were removed and model construction was assessed, 76 wells were used in the extent of southwest Georgia within the bounding box of the data. Of the 33 counties in the study area, 22 counties contained well sites (Fig. 8). The concentration of data in the output geometry was in an elliptic shape that extended from the southwest to the northeast of the modeled boundary limits at a length of 2.4×10^5 meters. The width, from northwest to southeast, was 1.2×10^5 meters.

In the overall three-dimensional display of the model, the grid geometry of the furthest extents was displayed (Fig. 10). On the west edge of the profile, the residuum had a trough-like depression and overlapping of surfaces towards the north. Overall trends in elevation, provided from contour maps and classed post maps, and trends in thickness, provided from isopach maps, were displayed.

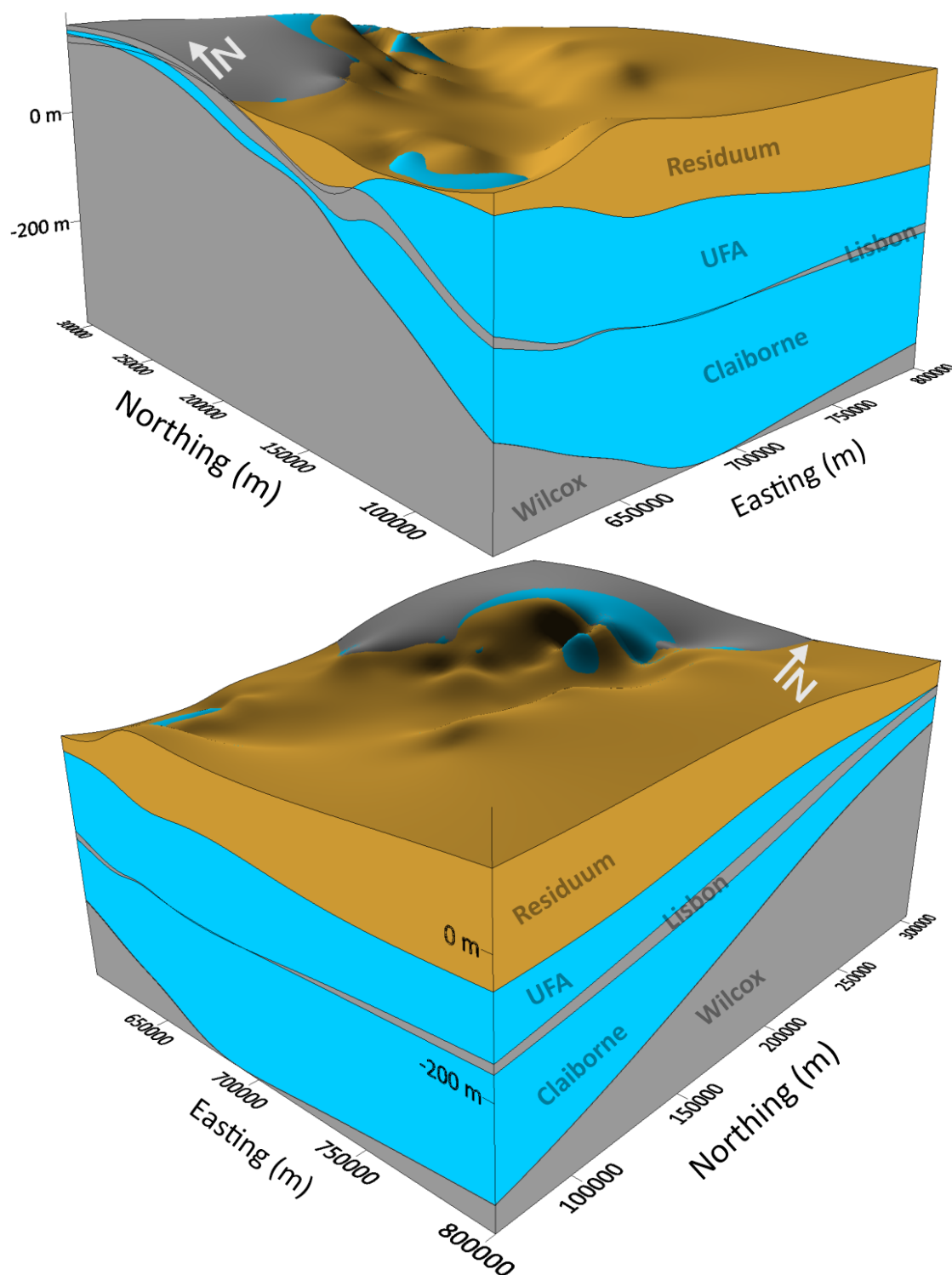


Figure 10. Display of three-dimensional hydrostratigraphic model.

4.1.1 Elevation

Contour maps were set at -250 to 250 meters on a 10-meter contour interval with the same color scale gradients for each surface (Fig. 11). Wilcox was greatly deeper in elevation in the southern portion of the model compared with the other surfaces mapped. Thus, the contours displayed at -450 meters for the Wilcox confining unit were placed in the same color shade as a value at -250 meters, labelled in deep blue. The legend for the color scale only color, down to a depth of -250 meters in a deep blue color. It is important to note that this deep blue color is used for depths greater than -250 meters, specifically for the Wilcox gridded surface. Each contour map of the elevation of the hydrostratigraphic surfaces displayed a decreasing trend in elevation from the northwest to the south and southwest portions of the area mapped. The residuum did not appear to have dark shades, or deep elevation values. The Upper Floridan aquifer had its greatest depth at -50 meters in the southwestern portion of the contour map. The aquifer's surface displayed mostly high elevations, or were positive in the datum, for most of the mapped area. The Lisbon confining unit and the Claiborne aquifer had similar contours and overall trends in elevation. The Wilcox confining unit had more closely packed contour lines that displayed a steep gradient of the unit top toward the southern portion of the map.

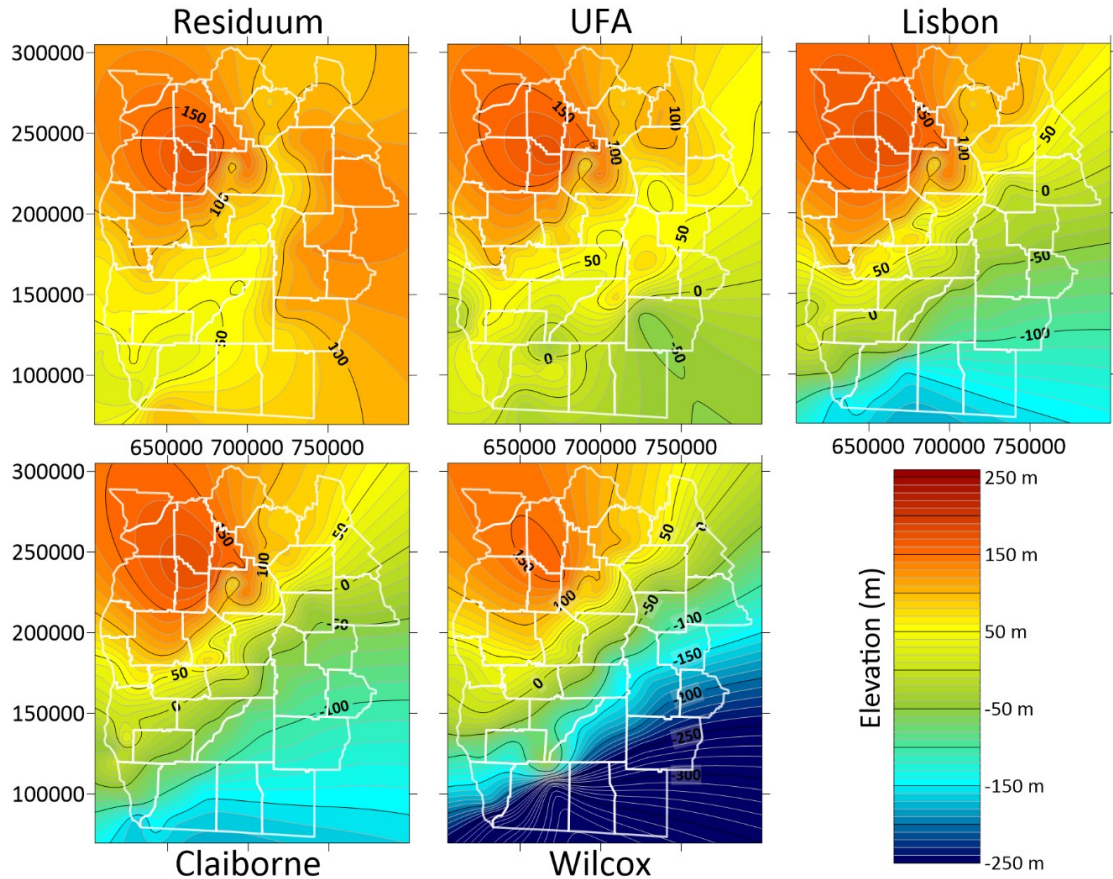


Figure 11. Hydrostratigraphic top layer elevations of the three-dimensional surfaces in Surfer software.

Elevation trends were also displayed by classed post maps, which set values to a classification of symbols that could be visualized over the map's extent. Classed post maps of the elevations of each gridded surface were set to 50-meter intervals with defined colored shapes that depicted overall trends in each surface layer (Fig. 12). The overall trend of surfaces was displayed by decreasing elevation from the northwest to the southeast portion of the study area. The residuum, or surface elevation, had no clear trend across the mapped area in the elevation data. The Lisbon confining unit, the Claiborne aquifer, and the Wilcox confining unit displayed trends of the elevation gradient most efficiently that traveled from northwest to southeast across the study area.

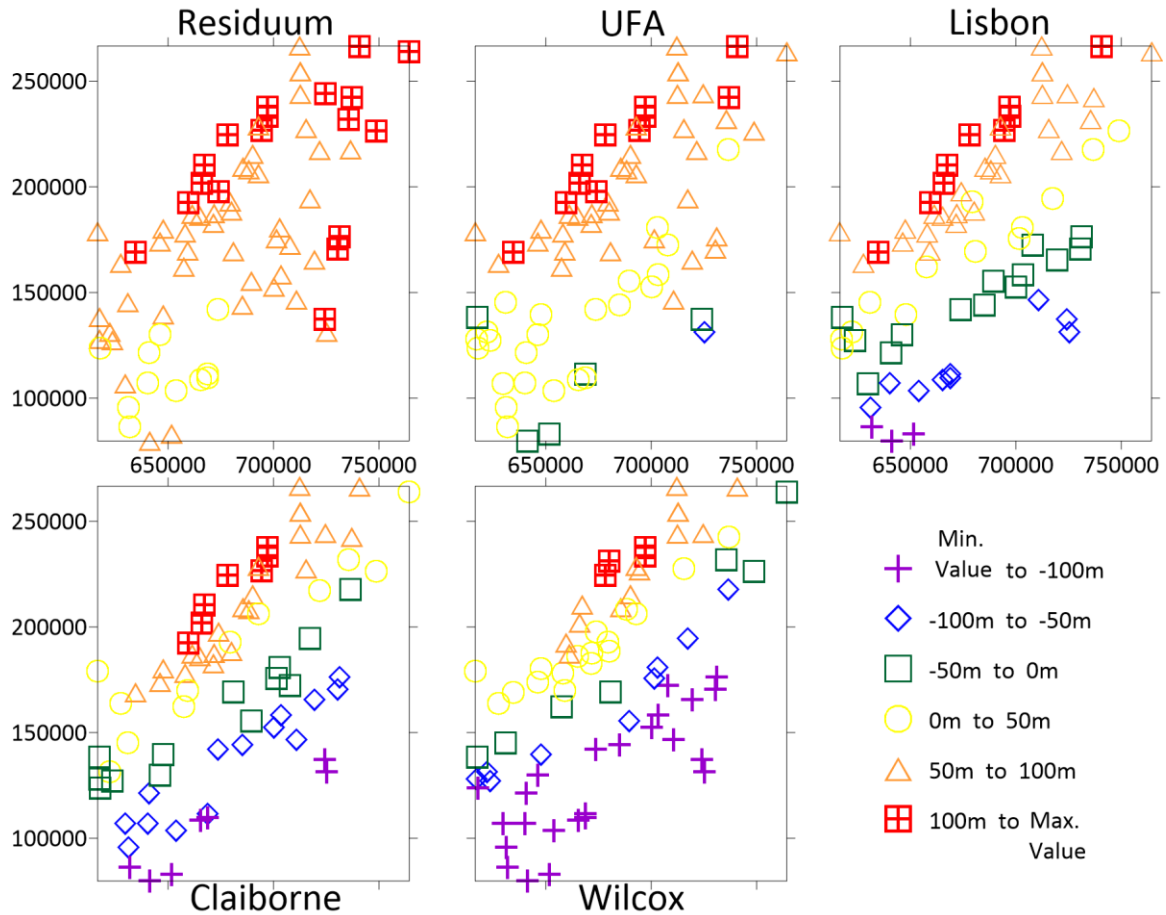


Figure 12. Classed post map of elevation of the data entry for the three-dimensional model.

4.1.2 Thickness and Zones of Outcropping

Thicknesses were calculated for the hydrostratigraphic units created from the three-dimensional surfaces, which were mapped using isopach maps of the residuum, Upper Floridan aquifer, Lisbon confining unit, and Claiborne aquifer (Fig. 13).

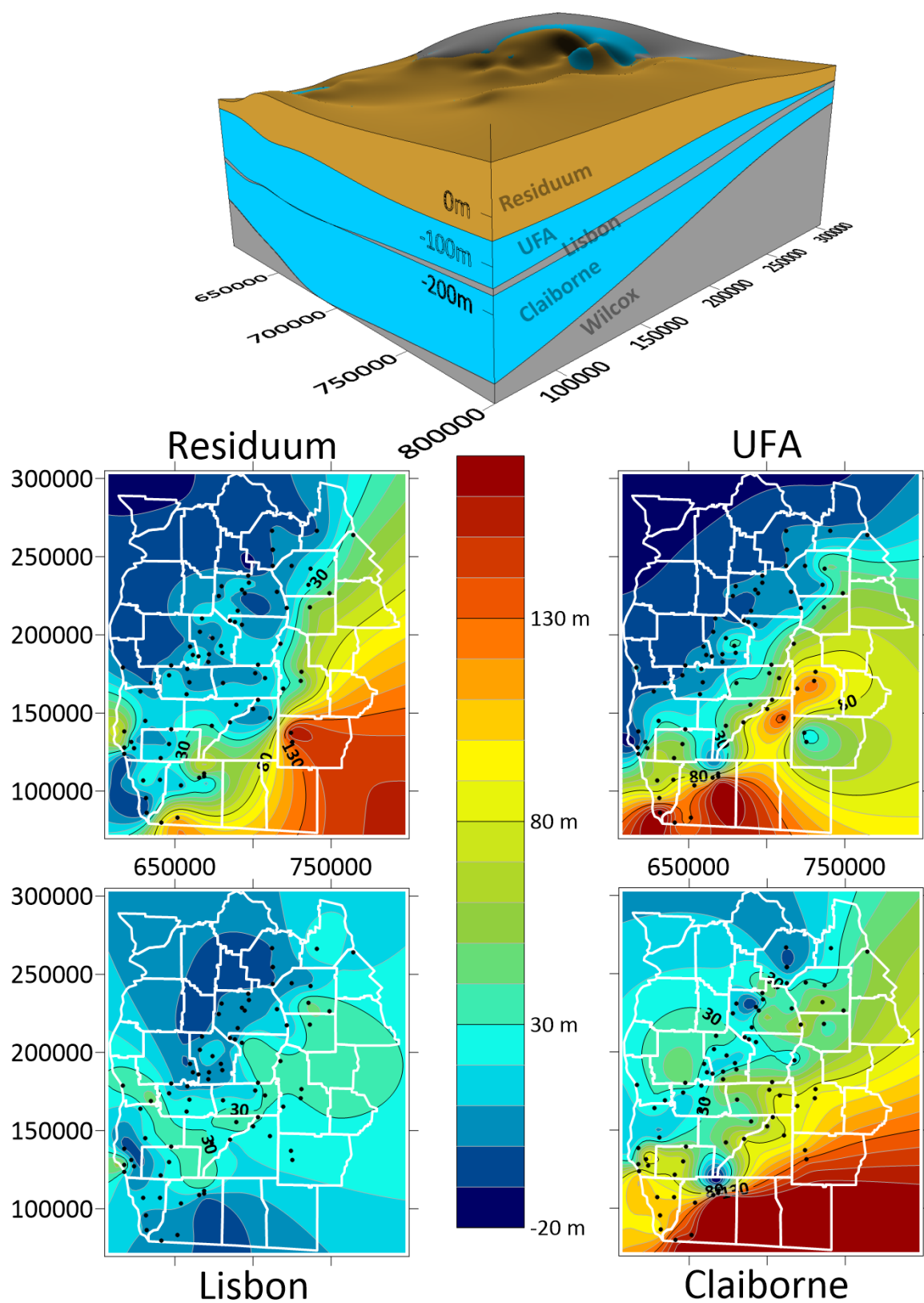


Figure 13. Isopach maps of the modeled hydrostratigraphic unit thickness.

Residuum followed a trend of increasing thickness from northwest to southeast of the mapped area and had the largest thickness value toward the southeast at a 140-meter thickness in Colquitt and Thomas counties. The northwest portion of the map displayed outcropping in a trend from south Clay County to west Houston County. These zero-meter thickness values resulted from the underlying Upper Floridan aquifer that also outcropped in this region (Fig. 14).

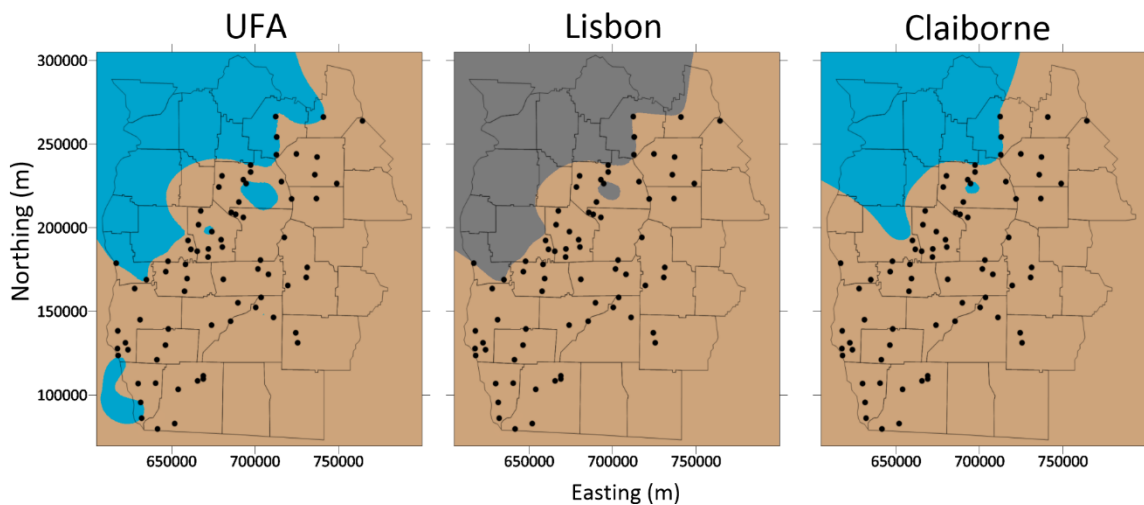


Figure 14. Outcropped regions of the Upper Floridan Aquifer (UFA), the Lisbon confining unit, and the Claiborne aquifer. Blue and gray are the outcropped regions of the underlying hydrostratigraphic surfaces, and the tan brown is the residuum.

The Upper Floridan aquifer followed a trend of increasing thickness from the northwest to the south. The Upper Floridan aquifer had a similar trend to residuum in the thickness contours, with the northwest and west portions of the gridded area mostly displayed by zero-meter values or negative values in thickness. The extent of these negative thickness value regions was much greater than the residuum, which extended into the south of Early County and trended to the east of Houston County. The largest

thickness value was to the southeast in Seminole, Decatur, and Grady counties, at 145 meters.

The Lisbon unit's thickness had no clear trend across the mapped area, with values below zero meters in the north and southwest portions of Webster and Schley counties and surrounding counties. This was displayed in Decatur and Grady counties in the south as well. The largest values of thickness on the map were in the center of the mapped area and at 30 meters in thickness. These large thickness values were prevalent in Clay, east Early, east Miller, Baker, Dougherty, Lee, north Worth, Tift, Turner, Crisp, Wilcox, and Dooly counties.

The Claiborne aquifer increased in thickness to the southeast and had the highest thickness at 160 meters, which spanned from southwest Decatur County to south Colquitt County. A bullseye point of zero thickness values was displayed north of the GA-FIT well CA10 where Decatur, Miller, Baker, and Mitchell counties' boundaries met. South of this bullseye contour area, a rapid increase in thickness occurred. The thickness contours displayed on this map were as steep as those displayed in the Upper Floridan aquifer towards the south portion of the isopach map. The Lisbon confining unit was thinnest to the south of the gridded surface layers, and the Upper Floridan and Claiborne aquifers were within their thickest extent of over 100 meters. The areas where the Lisbon confining unit is thinnest were investigated further through profile mapping.

4.2 Profile Displays

The profiles were displayed with elevations in meters along the y-axis and distances of the transect lines displayed in meters along the x-axis. Five profiles were

constructed in the general downdip direction of hydrostratigraphic units, and five profiles were constructed for the strike based on the downdip profiles (Fig. 15-16). Each profile displayed the residuum or surficial deposits in gold brown, the Upper Floridan and Claiborne aquifers in blue, and the Lisbon and Wilcox confining units in dark gray.

4.2.1 Dip Profiles

The dip profiles were not constructed to the north and northwest bounds of the gridded surfaces. This was chosen based on including the visualization of units outcropping in the north to preserve the display further downdip for observation and analysis (Fig. 15).

In the dip direction across the study area, toward the south, the thickness of the aquifer systems increased. The Lisbon confining unit was drastically thinner in this region, which appeared less than 5 meters thick. Outcropping in the five dip profiles was displayed. Outcropping occurred in a trend from southwest Early County to Houston County. Zones of thinning of the Lisbon confining unit were displayed from dip profiles 1, 2, and 3, as they extended into the southeast of the study area, which was limited in well data.

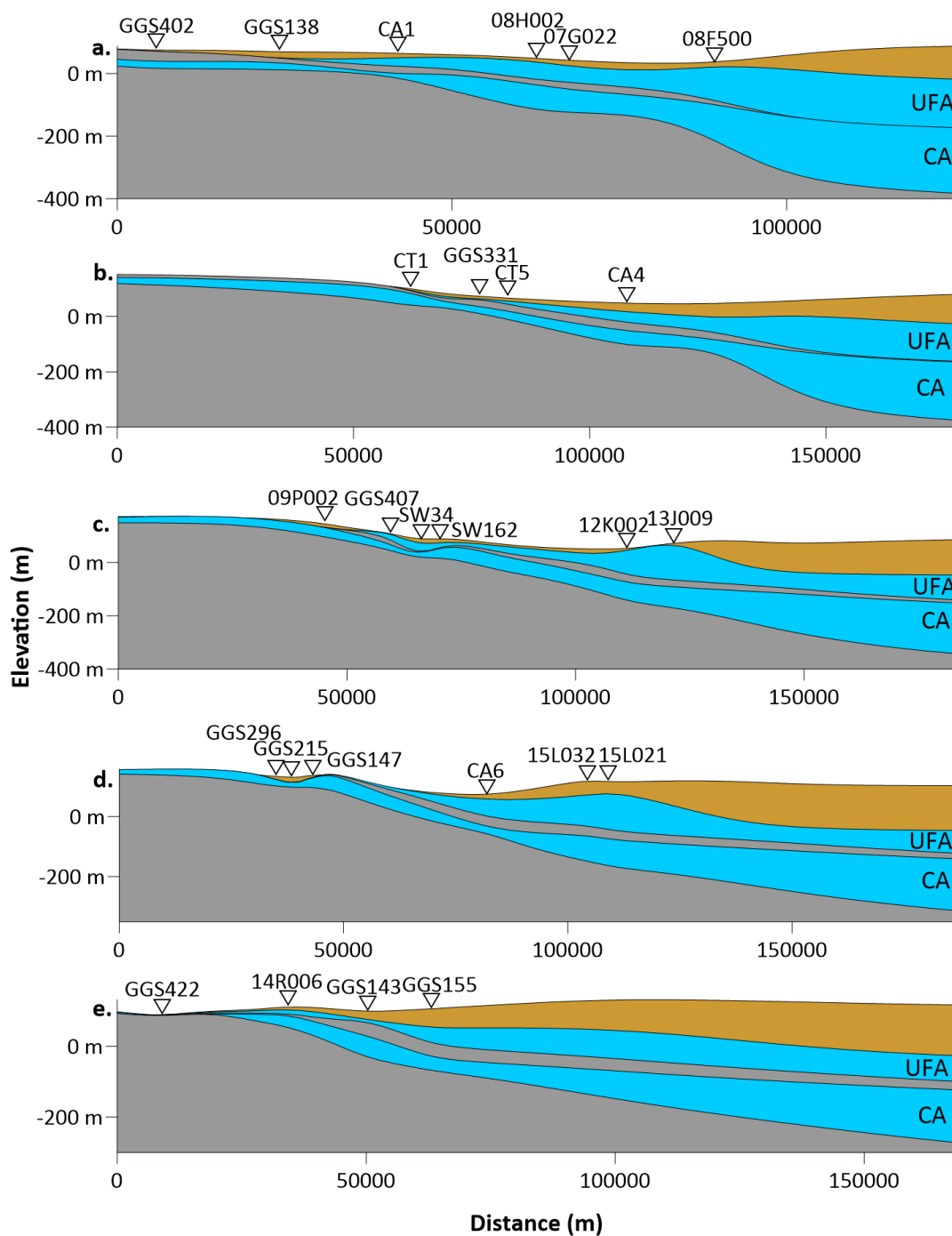


Figure 15. Dip profiles of the three-dimensional hydrostratigraphic model, transects from Figure 9. Transect lines for general strike and dip profiles from the three-dimensional model. Blue represents aquifers Upper Floridan Aquifer (UFA) and Claiborne Aquifer (CA). Gray represents confining units Lisbon and Wilcox, and residuum is in gold brown.

Dip Profile 1

Profile 1 was created along a 12.5×10^1 kilometer transect line in the southwestern portion of the mapped area, which traveled from southwest Clay County to southeast Decatur County (Fig. 15a). Six wells closest to the transect line are displayed in the profile. However, more wells were present in the relative area of the transect line. The thickness of the Claiborne aquifer increased from 20 meters to 150 meters in the most downdip portion of the profile. The Upper Floridan aquifer followed a similar trend. It displayed an outcrop near well GGS138 in northern Early County. The Upper Floridan aquifer thickened down-dip of GGS138 and increased to a thickness of 130 meters at 08F500. The Lisbon began in the profile at a value of approximately 30 meters, decreased to ten meters near 08F500, and continued to thin toward the end of the transect line.

Dip Profile 2

Profile 2 was a transect line that traveled 17.8×10^1 kilometers just northeast of the profile 1 transect line, which started in northwest Stewart County and ended in southeast Grady County (Fig. 15b). The data near the transect line was less dense compared with profile 1. The four wells depicted along the profile were toward the center, three in Calhoun County and one in Baker County. These four wells accounted for 4.62×10^4 meters along the transect. The transect line had a similar data display to profile 1. Compared with profile 1, the Upper Floridan aquifer outcropped in the same trend to the northeast, near well CT1 in south Randolph County, thickened to 130 meters toward the end of the transect.

In the northwestern portion of the transect line, the Lisbon confining unit acted as the surficial unit, and the Claiborne aquifer was located approximately 10 meters below the surface. The Claiborne aquifer started at a thickness of 30 meters and rose to approximately 40 meters at CT1. The Claiborne aquifer thickened to 55 meters at the last well on the profile, CA4, and increased to approximately 190 meters at the downdip portion of the transect line. The thickness of the Lisbon confining unit was constant at 10 to 15 meters; however, it decreased to a thickness of 5 to 10 meters in an area that exceeded well data points.

Dip Profile 3

Profile 3 was 18.4×10^1 kilometers along the transect line, which started in south Chattahoochee County and traveled to southeast Thomas County (Fig. 15c). Six wells were used to display the profile. In this profile, the residuum was thin towards the northwest and thickened to the southeast, where the transect line continued past well 13J009. Toward the start of the transect line, near well 09P002, the Lisbon confining unit and the Upper Floridan aquifer outcropped. The Upper Floridan thickened downdip to 130 meters at 13J009 and decreased in thickness to 30 meters at GGS170. The Lisbon confining unit was thick at GGS407, at 15 to 20 meters, but thinning occurred between SW34 and SW162 in a range of less than five meters. The Lisbon confining unit thickened to 25 to 35 meters down-dip. The Claiborne aquifer increased from a range of 20 to 40 meters near 09P002, GGS407, and the SW wells to 75-80 meters at 12K002 and 13J009 and continued to thicken to 130 meters at the end of the transect.

Dip Profile 4

Profile 4, at 18.7×10^1 kilometers, traveled through north Macon County to just beyond south Colquitt County (Fig. 15d). Data in the region is like that of profile 3 and was dense in data toward the northwest end of the transect line, with six wells depicted along the profile. Near the beginning of the transect line, at GGS147, the residuum, the Upper Floridan aquifer, the Lisbon confining unit, and the Claiborne aquifer all appeared to outcrop. The outcropping of units occurred within 1×10^3 meters. The Wilcox confining unit also appeared to reach the surface past the extent of well data in the northeast portion of the mapped area. The slope of the hydrostratigraphic units was similar to that of profile 3, as well as the respective thickness values. The residuum thickened to approximately 130 meters as the profile traveled down-dip. The Upper Floridan aquifer also increased in thickness down-dip, reaching 55 meters at CA6 to 110 to 115 meters at 15L032 and 15L021. It decreased to 55 meters, beyond the wells on the profile and was consistent at this thickness for the rest of the transect line. The Lisbon confining unit was also thicker in this profile compared with profiles 1, 2, and 3, at its thickest point at approximately 75 meters around GGS3536, after it decreased in thickness in an area of no well data points. The Claiborne aquifer was 30 meters at CA6 and 85 meters at 15L032 and 15L021 and continued to increase in thickness down-dip.

Dip Profile 5

Profile 5 was 1.69×10^5 kilometers and was the northeast transect line that analyzed the dip direction of units (fig 15e.). This area was sparse in data, and all wells were concentrated in the northern portion of the transect. Four wells were depicted along

profile 5. Profile 5 had a gentler slope to the outcropping than what had occurred in Profiles 3 and 4 for the residuum, Upper Floridan aquifer, Lisbon confining unit, and Claiborne aquifer. This outcrop occurred within 800 meters of all four units that outcropped south of GGS422.

The residuum increased from 20 meters to 14R006 to 40 meters and continued to increase toward the end of the transect to approximately 135 meters. The Upper Floridan aquifer increased from ten meters to 14R006 to 40 to 45 meters at GGS155. Downdip, the Lisbon confining unit, was similar in thickness to profile 4, at approximately 35 meters at the last well in the transect, GGS155. The Claiborne aquifer was thicker in this profile when compared with the other dip profiles, ranging from 30 to 55 meters in the up-dip, and continued to increase in thickness downdip past the well points provided on the transect line.

4.2.2 Strike Profiles

In the strike direction across the study area, in a trend southeastward with each profile, the relative smoothness of the surface increased, and displayed not as drastic transitions in the hydrostratigraphic units as compared with the profiles in the north. Zones of thinning in the Lisbon confining unit were displayed in profiles 1, 2, 3, and 5 (Fig. 16).

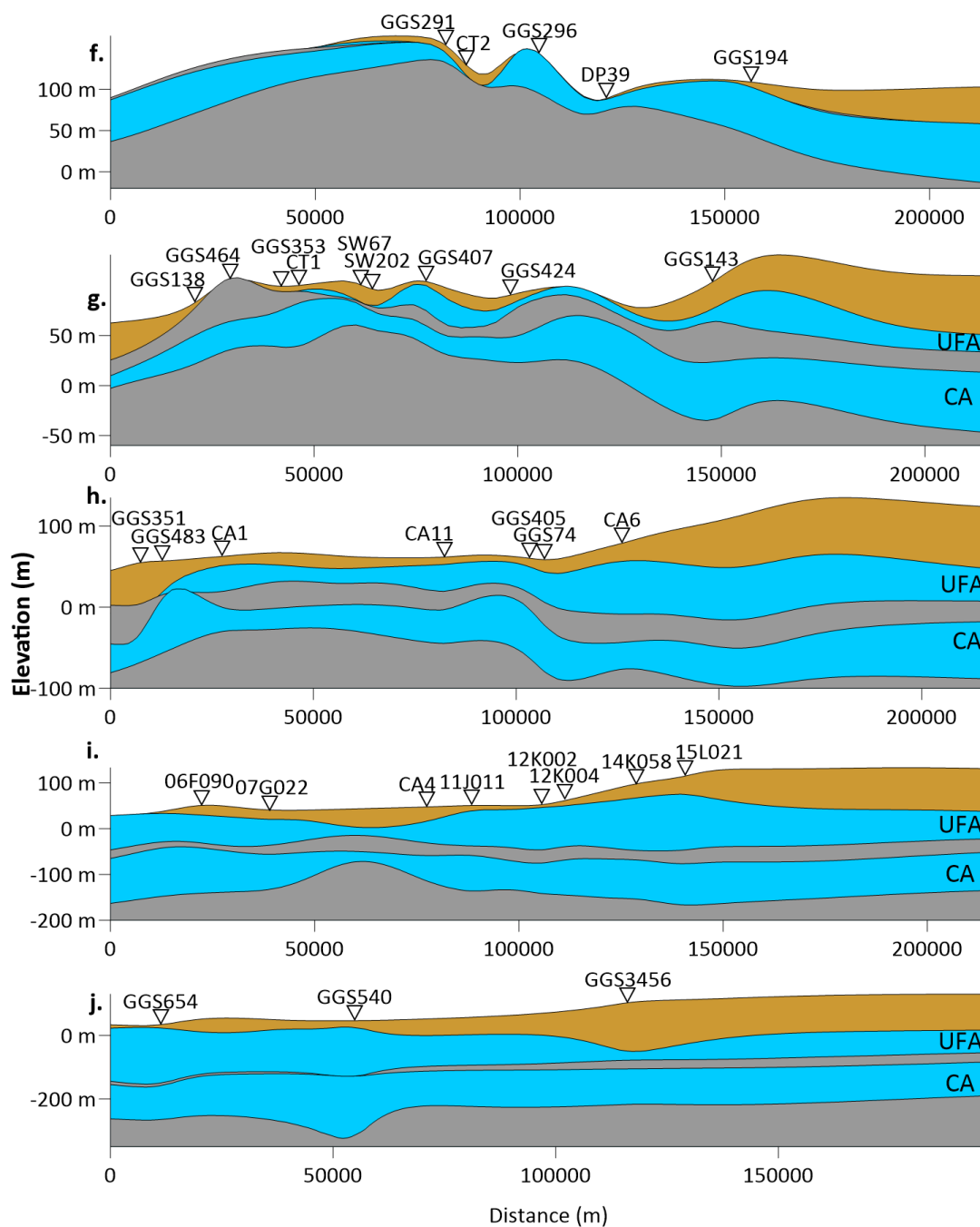


Figure 16. Strike profiles of the three-dimensional hydrostratigraphic model, transect lines displayed in Figure 9. Blue represents aquifers Upper Floridan Aquifer (UFA) and Claiborne Aquifer (CA). Gray represents confining units Lisbon and Wilcox, and residuum is in gold brown.

Strike Profile 1

Profile 1 is the uppermost transect line used in the direction of the study area (Fig. 16f). This transect, from north Clay County to beyond east Houston County, was 21.4×10^1 meters long. The density of data is displayed toward the center of the transect line in Sumter, Macon, and Houston counties. The display of hydrostratigraphic units in this profile contrasted heavily with the other strike profiles. The Upper Floridan and Lisbon aquifers had minimal thickness and potentially nonexistent across some portions of the profile. Two significant increases in the surface elevation of the units occurred near GGS291 and GGS296.

Strike Profile 2

Profile 2 was displayed in a densely packed area of well data (Fig. 16g). The transect line was 21.5×10^1 kilometers in length, from north Early County to beyond east Pulaski County. The nine closest wells to the line were used to describe the profile variations. Compared with profile 1, the hydrostratigraphic units were still sporadic compared with the other profiles to the south. The residuum varied from being outcropped to a thickness of 15 meters sporadically across the transect and increased in thickness at the end of the transect line.

The Upper Floridan aquifer had outcropped in several areas along strike profile 2. It outcropped near GGS464, CT1, and GGS424. The greatest thickness for the Upper Floridan aquifer on this transect line was 20 meters at GGS407 and toward the northeast side of the transect beyond GGS143. The Lisbon Aquifer had thinned and had loss in thickness completely between CT1 and SW202. The thickness displayed near the western

side of the transect line was denoted on the isopach maps as a peak in values near 30 meters, and toward the northeast end of the transect, the Lisbon aquifer had a thickness of 35 meters near GGS143. The Claiborne aquifer had a constant thickness across the landscape, from around 25 to 35 meters; however, it appeared the thickest at the drastic rise in elevation of the hydrostratigraphic units, at a thickness of 45 meters. There appeared to be a connection between the Upper Floridan and Claiborne aquifers between CT1 and 09M004.

Strike Profile 3

Profile 3 was 21.6×10^1 kilometers from southwest Early County to northeast Wilcox County (Fig. 16h). This line was less dense in surrounding data compared with profile 2, and well points covered the western portion of the transect line. In the southwestern portion of the profile, near GGS351, residuum was at a thickness of 30 meters and thinned to a range of 10 to 15 meters across most of the transect line. The residuum thickness changed to a range of 45 to 50 meters toward the northeastern portion of the transect, west of CA6.

The Upper Floridan aquifer had no thickness at the farthest southwest depicted well on the transect, but rather than being outcropped, it appeared below the 30-meter residuum layer near GGS483. The Upper Floridan aquifer had a constant thickness of 10 to 15 meters. It increased to 55 meters at the northeastern portion of the transect line, similar in thickness to the overlying residuum in this profile area. The Lisbon confining unit had one significant pinching area near GGS483 and increased in thickness to 25 meters between CA1 and CA11. Some thinning of the Lisbon confining unit occurred

near CA11 and GGS405, at a thickness value of 25 meters. The Claiborne aquifer began in the transect at 55 meters and had a rapid increase in thickness to 80 meters near the pinching of the Lisbon confining unit near GGS483. The Claiborne aquifer decreased in thickness to 30 meters near CA6 and continued in profile to a range of 45 to 60 meters.

Strike Profile 4

Profile 4 appeared to have smoother transitions between units compared with strike profiles 1 and 2 (Fig. 16i). Profile 4 was 21.5×10^1 kilometers long, from northwest Seminole County to east Turner County. The data along this transect was prominent throughout the transect line, displayed on the profile by eight wells. This profile had more dense data near the transect than profiles 1 and 3, but it was not as dense in surrounding data as in profile 2. In this profile, an outcrop of the residuum layer appeared in the southwest. Compared with profile 3, the residuum was similar in thickness across this profile. It began at 06F090 at 15 meters and increased between 07G022 and CA4 to 15 meters at 11J011. The residuum continued to thicken to five meters and increased beyond 14K058.

The Upper Floridan aquifer was approximately 60 meters thick at the beginning of the transect line, which decreased between 07G022 and CA4. The Upper Floridan aquifer increased toward the center of the profile, from 40 meters to 120 meters, and decreased past available well data. The Lisbon confining unit began on the profile at its thinnest extent at approximately ten meters and remained at a constant range of 20 to 30 meters for the rest of the transect line. The Claiborne aquifer began at 100 meters thickness at 06F090 and decreased to 80 meters at 07G022. This was the same location

where the Upper Floridan aquifer followed the same thinning trend and increased to a value of 55 meters. The Claiborne aquifer thickened to approximately 85 meters and was constant at a provided thickness.

Strike Profile 5

Profile 5 was 19.7×10^1 kilometers long, from south Seminole County to east Tift County (Fig. 16j). Profile 5 displayed three wells that were concentrated in the southwest portion. The residuum increased across the transect line from five meters to 155 meters. The Upper Floridan aquifer was 160 meters at GGS654, decreased across the profile to a minimum thickness of 30 meters at GGS3456, and increased to a constant thickness for the rest of the profile. The Lisbon confining unit was thin at the beginning of the profile, from around five to ten meters, and increased to 25 meters at GGS3456 and remained constant for the rest of the profile. The Claiborne aquifer was 80 meters thick at GGS654, which increased to a maximum thickness of 130 meters and remained at a constant 110 meters for the rest of the profile.

A check was performed in WellCAD to observe this change in thickness, and the transition from GGS540 to CA10 was the cause of the drastic change. If the removal of one of the selected wells were chosen, the surface would appear much more of a gradational transition in thickness to 13J009. A point of concern within this profile is at GGS540, where the aquifers increased to their thickest extents, and the Lisbon confining unit became its thinnest.

4.3 WellCAD Validation

The MultiWell Module through WellCAD software was used on profiles that exhibited areas of concern. The areas of concern were denoted by the thinning of the Lisbon confining unit, abrupt changes in thickness of hydrostratigraphic units, or hydrostratigraphic units that overlap, pinch out, or outcrop beneath the surface. WellCAD did not have the ability to go beyond the bounds of the wells in the correlations.

For dip profiles 3 and 4, the WellCAD MultiWell module was used to create a hydrostratigraphic two-dimensional correlation that could depict the areas of concern presented in the 3D model.

Dip profile 3 was modeled from 09P002 to 13J009 from the thinning of the Lisbon confining unit between SW34 and SW162 (Fig. 17). The WellCAD model showed that between these wells, SW 34 to SW162 correlated the Lisbon confining unit to be thinner and graded upwards and tapered downslope to 12K002 whilst having the unit thickened.

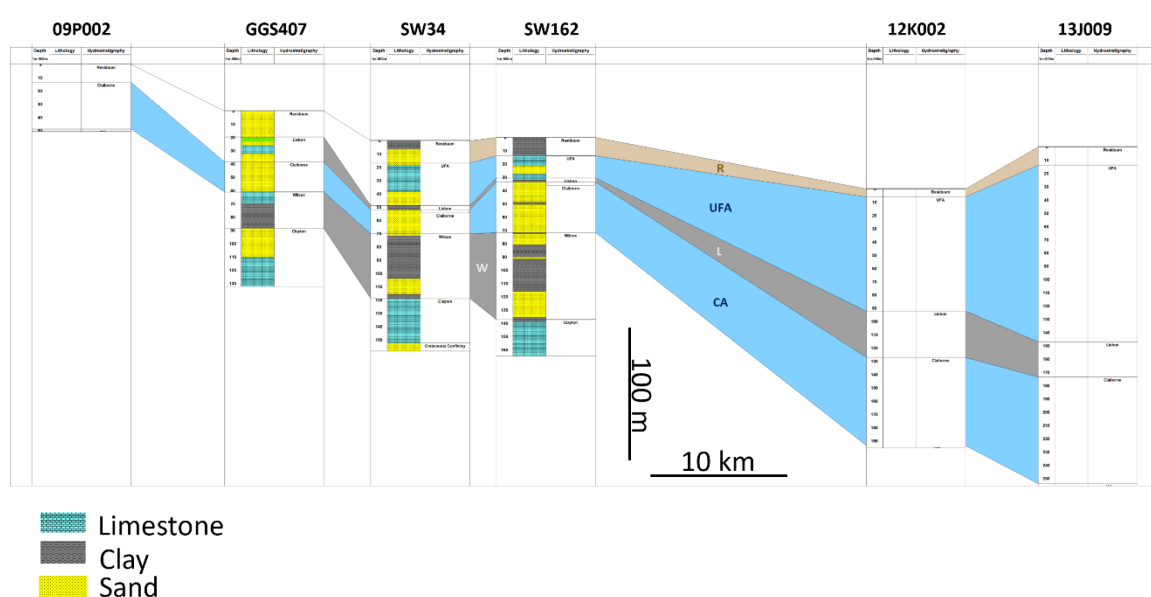


Figure 17. Dip profile 3 in WellCAD hydrostratigraphic correlation.



Strike profiles 1, 2, 3, and 5 were also modeled in the WellCAD MultiWell module. In strike profile 1, the elevation variability from GGS291 to GGS194 was drastic compared with the other strike profiles. In Surfer, the profile displayed the units of residuum, the Claiborne aquifer, and the Wilcox confining unit. The residuum appeared to disappear between GGS296 and DP 39. In WellCAD, the loss of the residuum in profile appeared to be a result of the elevation mapped from GGS296 to DP39, where the elevation of DP39 was much lower than GGS296 (Fig. 19). In WellCAD, the Claiborne aquifer was present in all wells in the profile except for DP39, which was from residuum to the contact with the Wilcox confining unit. The Upper Floridan aquifer and Lisbon confining unit were not represented in the profile until GGS194.

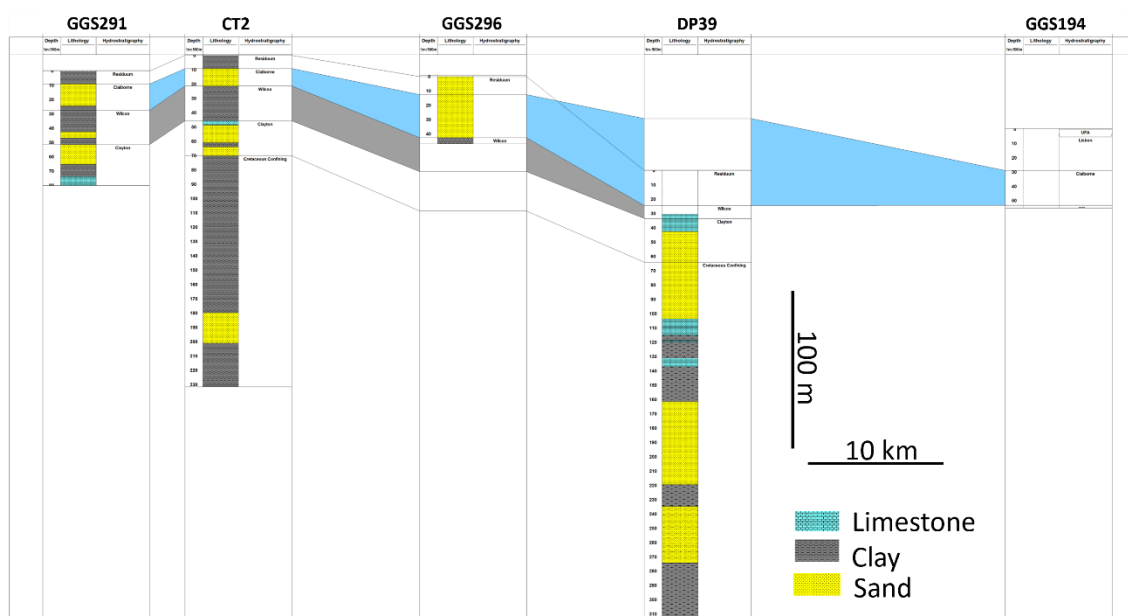


Figure 19. Strike profile 1 in WellCAD hydrostratigraphic correlation.

Strike profile 2, with its wavy appearance of hydrostratigraphic units, was also placed in WellCAD across the full extent of the profile mapped in Surfer (Fig. 20). The

thinning of the Lisbon confining unit contributed to the characterization of SW67 and SW202. The thickest extent of the Lisbon confining unit was at GGS464 and did not characterize residuum in the top extent of the borehole.

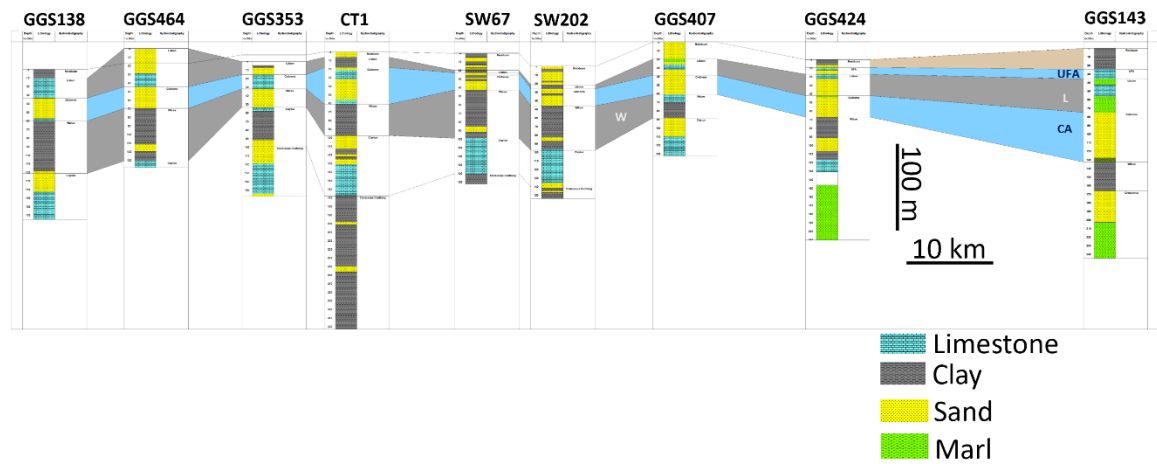


Figure 20. Strike profile 2 in WellCAD hydrostratigraphic correlation.

Strike profile 3 had been mapped in WellCAD from GGS351 to CA1, given the Claiborne aquifer that appeared to thicken into the extent of the Upper Floridan aquifer at GGS483 (Fig. 21). It also appeared that the Upper Floridan aquifer pinched out beneath the layer of residuum. In WellCAD, if the CA7 is included in the correlation, this is situated just directly next to GGS483, from the opposite side of the transect line. Similar to strike profile 1, CA7 was much lower in elevation compared with GGS483, and CA7 had the characterization of the Upper Floridan aquifer, whereas GGS483 did not. The CA7 also characterized the Lisbon confining unit as much thinner than the Claiborne aquifer. The WellCAD stratigraphic correlation does not show the Claiborne aquifer going into the Upper Floridan aquifer like the 3D model profile displayed.

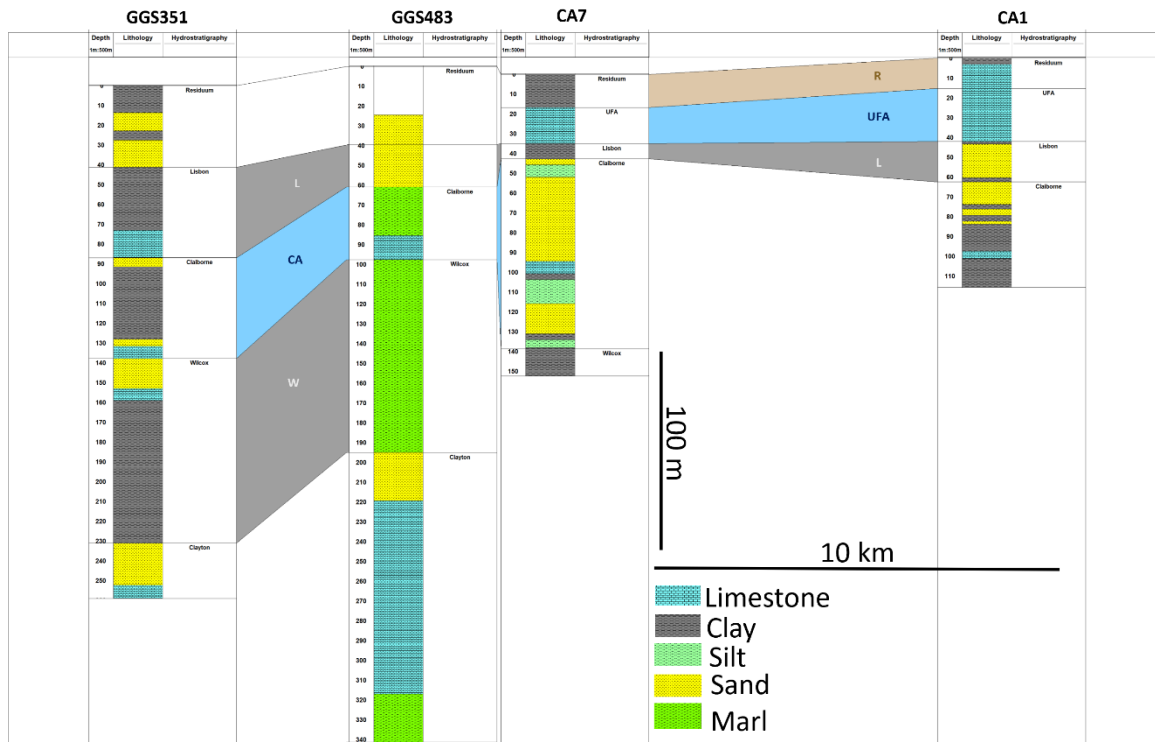


Figure 21. Strike profile 3 in WellCAD hydrostratigraphic model.

Strike profile 5 highlighted the thinning of the Lisbon confining unit between GGS654 and GGS540 and thickened to GGS3456 at a constant thickness for the rest of the profile (Fig. 22). Other wells were not listed in the profile in Surfer but also contributed to what was in the profile. Wells GGS191 and CA10 in eastern Decatur, near GGS540, caused such influence. The WellCAD stratigraphic correlation was displayed from the three wells, which included GGS191 and CA10. The transition from GGS540 to CA10 displayed a sharp change in the Lisbon confining unit's elevation while the same thickness was maintained. Based on all the wells, the Lisbon confining unit ranged from five to six meters from GGS654 to CA10.

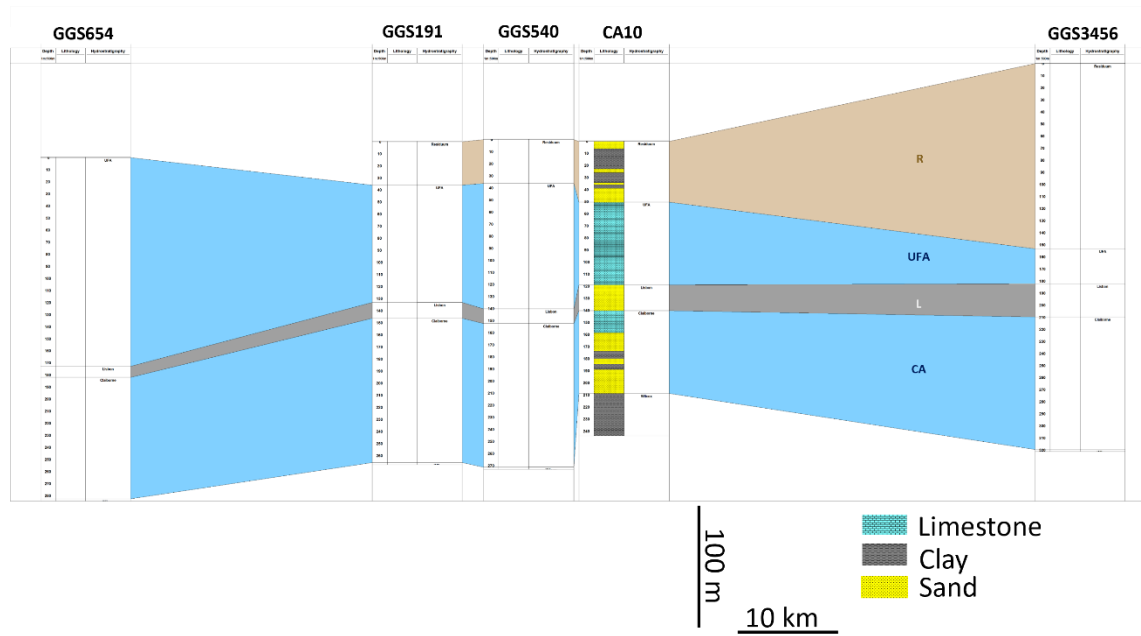


Figure 22. Strike profile 5 in WellCAD hydrostratigraphic correlation.

4.4 Sensitivity Analysis

The Upper Floridan and Claiborne aquifers' thicknesses were displayed by orders of magnitude that varied from the default shape factor value that tested the effects of surface smoothing (Fig. 23-24). Each isopach map was set to the same color ramp, from 20 to 160 meters, which was the same color scale as the original isopach maps. Areas in the study area that displayed white color were a result of the values exceeding the color scale used. These white areas were present in both the Upper Floridan and Claiborne aquifer isopach maps of one and two orders of magnitude higher than the default shape factor value of 3×10^7 .

Upper Floridan Aquifer

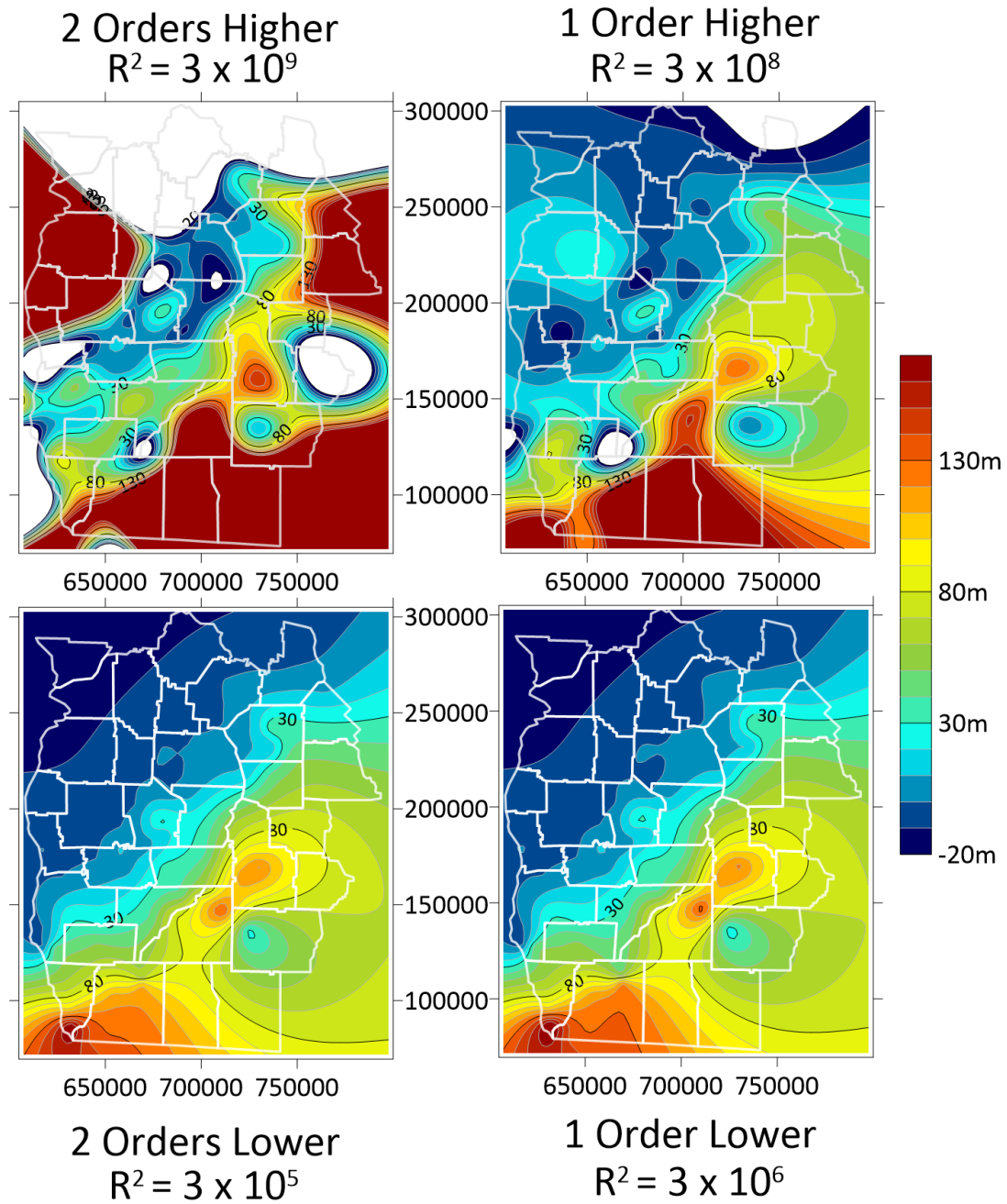


Figure 23. Isopach maps of the Upper Floridan aquifer's thickness displayed through varying shape factor values.

Claiborne Aquifer

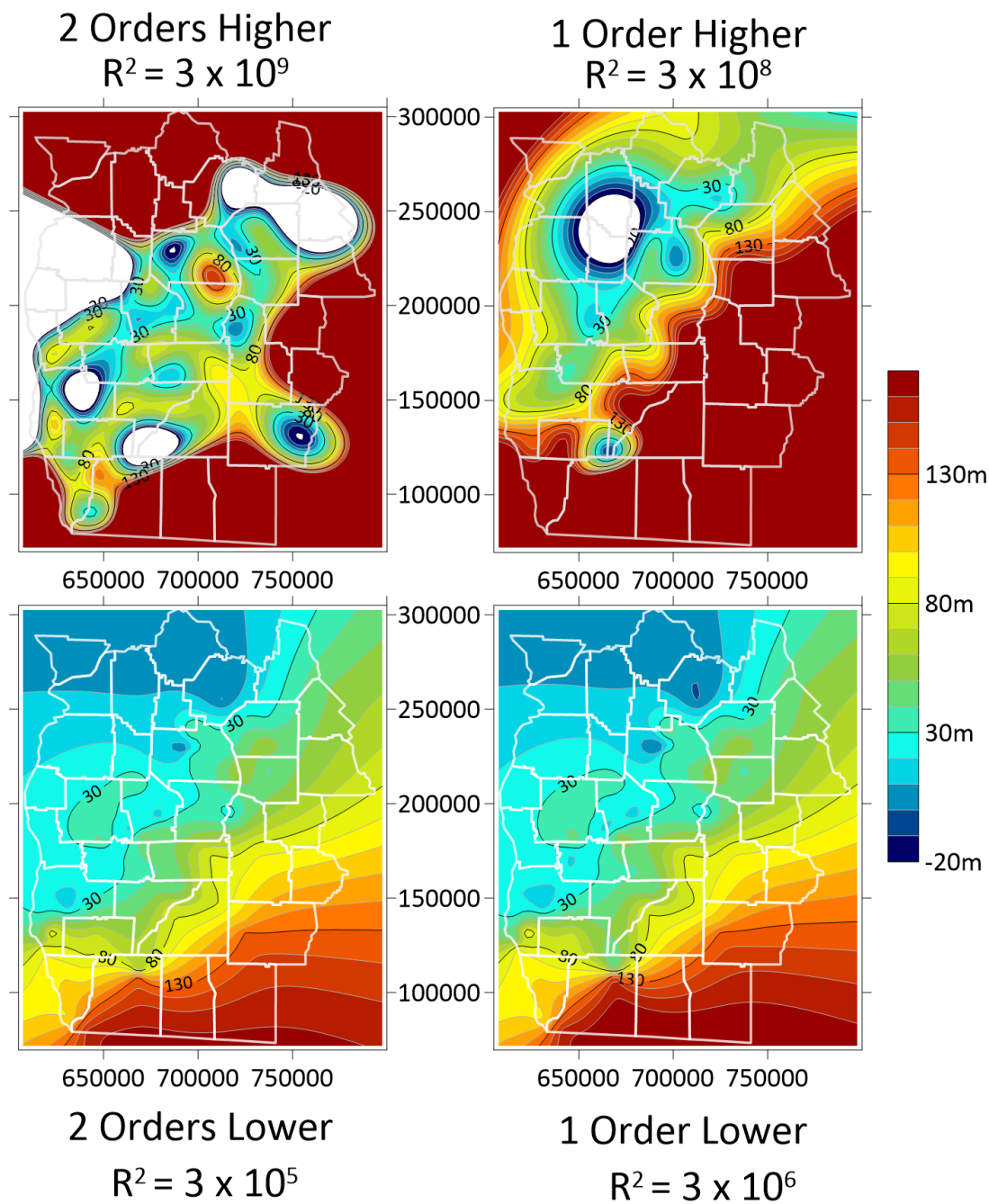


Figure 24. Isopach maps of the Claiborne aquifer's thickness displayed through varying shape factor values.

4.4.1 Upper Floridan Aquifer Sensitivity Analysis

In one order of magnitude higher than the default shape factor value used in the model, thickness contour lines were steeper toward the south portion of the mapped area, which exceeded values past 160 meters (Fig. 23). Bullseye-like contours from the original Upper Floridan aquifer surface increased in size, and new bullseye-like contours also were concentrated throughout other areas of the surface. In two orders of magnitude higher than the default shape factor value used in the model, thickness contour lines were more densely packed than the original display of the Upper Floridan isopach map and one order of magnitude higher. The bullseye-like contours also increased in density across the study area. The areas of the map that had limited well data had the thickness of the aquifer increased beyond 160 meters.

In one order of magnitude lower than the default shape factor value used in the model, bullseye-like contours seen in the original isopach map decreased in areal extent. The higher thickness values to the south of the mapped area also decreased, and the thickness contour lines were less densely packed to one another. In two orders of magnitude lower than the default shape factor value used in the model, the bullseye-like contours decreased in size even further. However, the overall display of thickness contours was relatively constant throughout one order and two orders of magnitude lower isopach maps.

4.4.2 Claiborne Aquifer Sensitivity Analysis

In one order of magnitude higher than the default shape factor value used in the model, the contour lines were extremely densely packed throughout the entire extent of

the mapped area (Fig. 24). The bullseye-like contours that were present in the original isopach map were broadened in display within the one order of magnitude higher isopach map. This trend continued to increase into the two orders of magnitude higher isopach map, with more white areas that suggested increased thickness values past 160 meters. The bullseye-like contours were also greatly increased.

In one order of magnitude lower than the default shape factor value used in the model, the contour lines were similar; however, some of the bullseye-like contours were not depicted in the mapped area, specifically near north Decatur County. In two orders of magnitude lower than the default shape factor value used in the model, the bullseye-like contour in north Decatur County was only represented by tightly packed thickness contour lines. The display of the one order and two orders of magnitude lower isopach maps were similar in their overall trends. They displayed the most resemblance to the original Claiborne aquifer isopach maps.

CHAPTER 5

DISCUSSION

A hydrostratigraphic three-dimensional model using available well data was created to advance the visual display and establish a qualitative and quantitative representation of the subsurface geology of southwest Georgia.

This model displayed trends or areas that would influence the installation of deeper-lying wells for use in drought events in southwest Georgia. This model was characterized by ten profiles that covered the extent of the 33-county study area and provided information for hydrogeological characterization. Comparison of the three-dimensional model to existing correlations performed in other studies confirms that even with concentrated data in one portion of the areal extent and a different database of wells, a similar product is achieved to review the hydrostratigraphy of southwest Georgia.

5.1 Three-Dimensional Model Structure and Profiles

5.1.1 Observations of Overall Hydrostratigraphic Model

In the overall display of the three-dimensional model block diagram, a depression runs from the southwest of the map into the northeast. This is assumed to be related to topographic depressions, such as the Dougherty Plain displayed in the profile. The residuum's trough-like depression and overlapping with underlying unit boundaries that were depicted on the western boundary of the block model diagram could be related to

the extent of the Dougherty Plain as well, and the interconnection of surficial and Upper Floridan aquifer systems in the Dougherty Plain.

5.1.2 Outcropped Regions

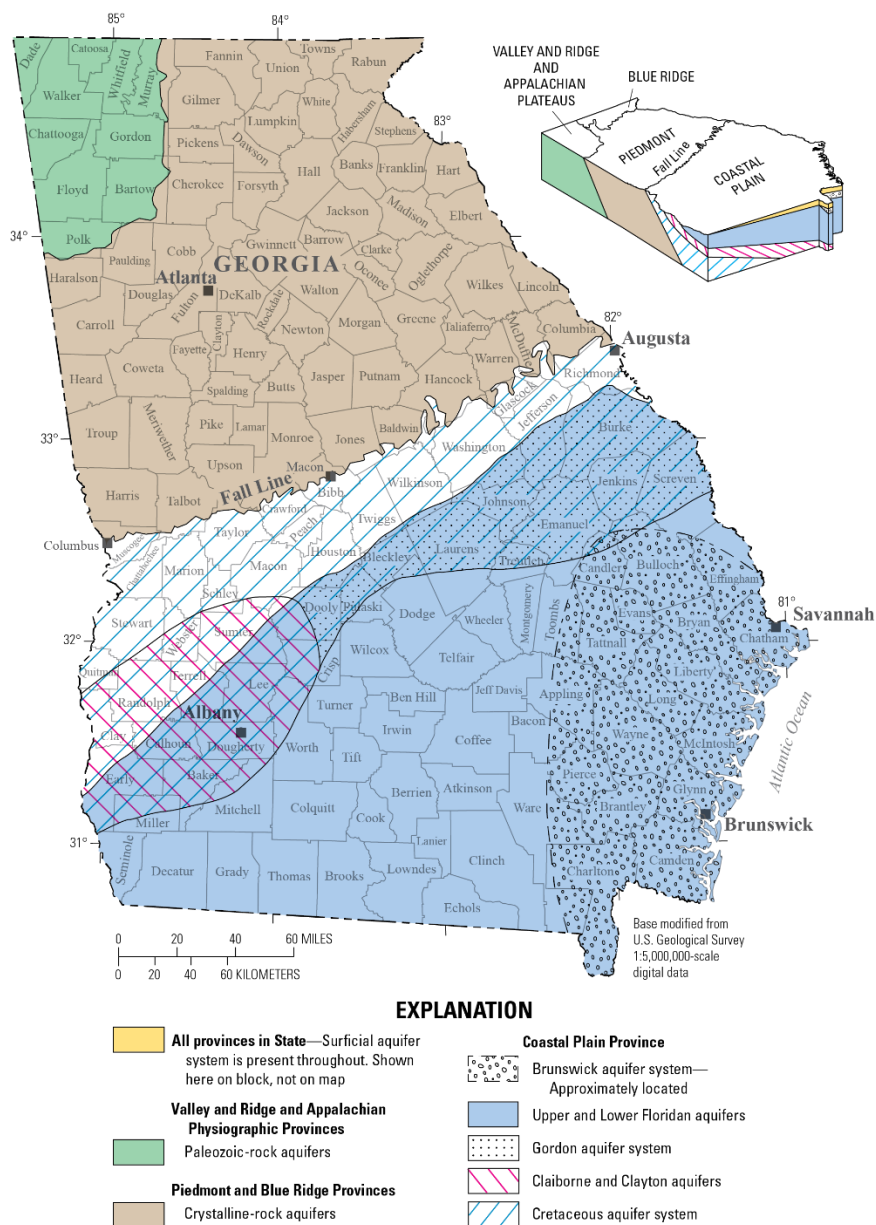
The areal extents of the hydrostratigraphic units can be determined through the three-dimensional model, provided through the two-dimensional and three-dimensional map displays of overlaid surfaces and the accompanying profiles. Isopach maps were used to observe outcropped regions; however, it was only assumed that the negative thickness values had the potential to be outcropped regions of the hydrostratigraphic units to the surface. The isopach maps were the last to be used to define outcrop extents, due to the further sensitivity analysis needed to test depressional areas.

The Upper Floridan aquifer outcropped, or was above the residuum surface layer, in a trend from south Clay County to southwest Houston County (Fig. 14). Two locations where the Upper Floridan aquifer overlaid the residuum were assumed to be the gridding method or well-site data. For example, the Upper Floridan aquifer could have been outcropped at a select well, but the potential for a layer of residuum above that was not included in the well description.

The Lisbon confining unit, which has often been paired in literature with the Claiborne aquifer, as the Claiborne group, had outcropped in a trend like the Upper Floridan aquifer, from south Clay County to north Houston County.

The Claiborne aquifer outcropped above the residuum near south Stewart County and trended to north Macon County. The Claiborne aquifer had a larger areal extent than referenced by previous publications (Gordon & Painter, 2018). The bound of the

Claiborne aquifer to the south, which did not account for the extrapolated area, was approximately in a trend from Decatur County to Colquitt County (Gordon & Painter, 2018; Beck et al., 1985). The outcrop of the Claiborne aquifer to the north was like the areal extent of the Gordon and Painter (2018) map. Previous publications displayed the Claiborne aquifer, which was subsequently grouped with the Clayton aquifer, and this did not cover as far south as the three-dimensional hydrostratigraphic model did (Fig. 25, Gordon and Painter 2018). However, from this model, the areal extent of the Claiborne aquifer appeared to be different than previous sources in the outcropped regions. More wells would need to be obtained beyond the areal extent of that original model scheme to test the true nature of that extent. However, other studies grouped units as the Floridan Aquifer System (FAS), which included the Upper Floridan aquifer, the Lisbon confining unit, the Claiborne aquifer, or sometimes labeled as the Lower Floridan aquifer, and the Wilcox confining unit (Fig. 26-27, Williams & Kuniansky, 2015). This up-dip extent was a more accurate display of the up-dip limit determined by the three-dimensional model. However, it was best displayed by the up-dip limit and did not consider the up-dip of the productivity of the aquifer system, which is displayed more south than the other areal extent (Williams and Kuniansky, 2015). Also, a correlation between Chumbley and Scroggs (2024), with the general recharge area revisualized by Davis et al., 1989. This general recharge area was aligned, with only slight differences in display to the three-dimensional model.



Areas of major aquifera in Georgia (modified from Clarke and Pierce, 1985).

Figure 25. Depiction of major aquifer systems in Georgia, USA (sourced from Gordon and Painter, 2018)

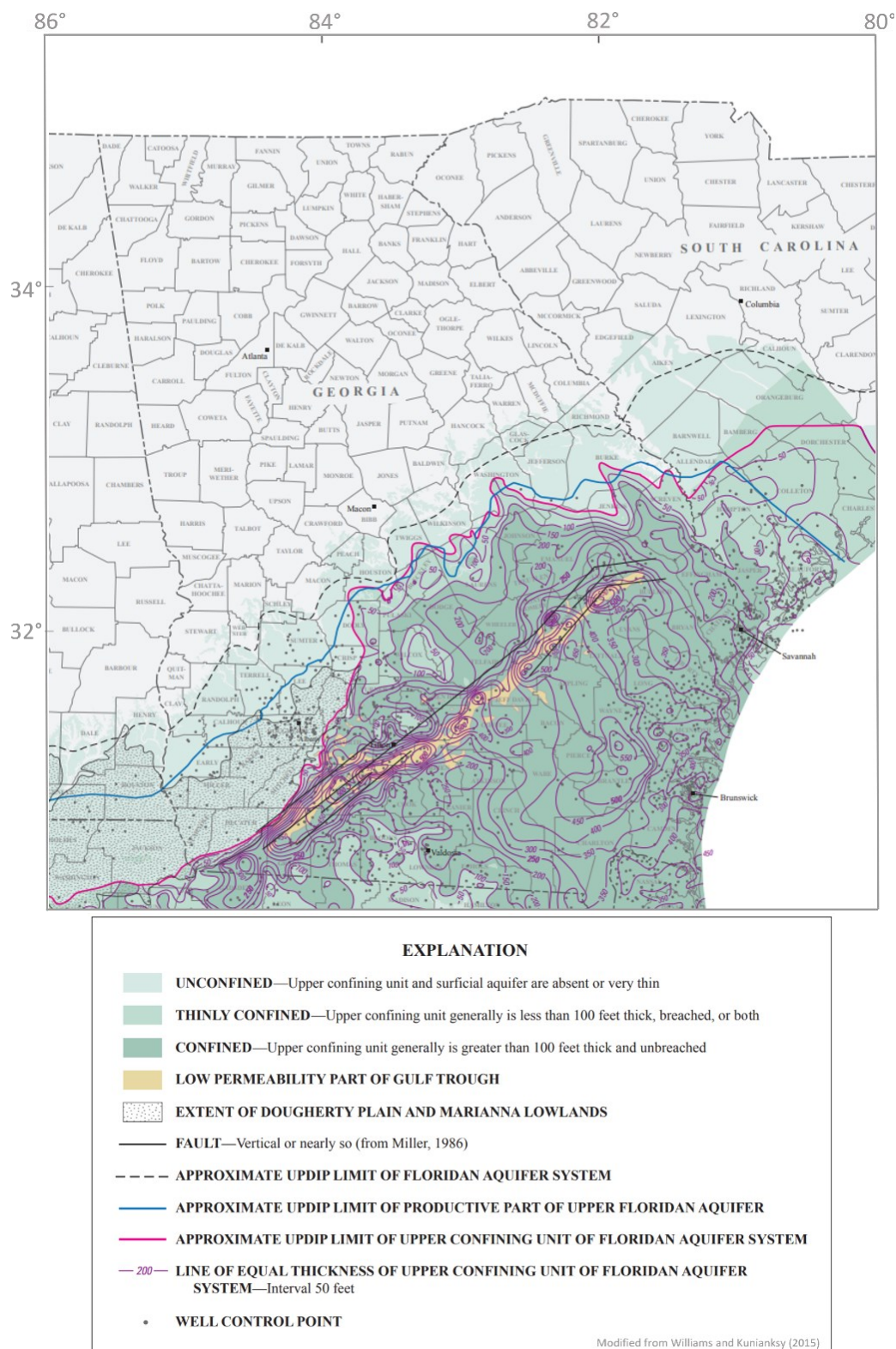


Figure 26. Areal updip extents of the Upper Floridan Aquifer (UFA) (adapted from Williams & Kuniansky, 2015).

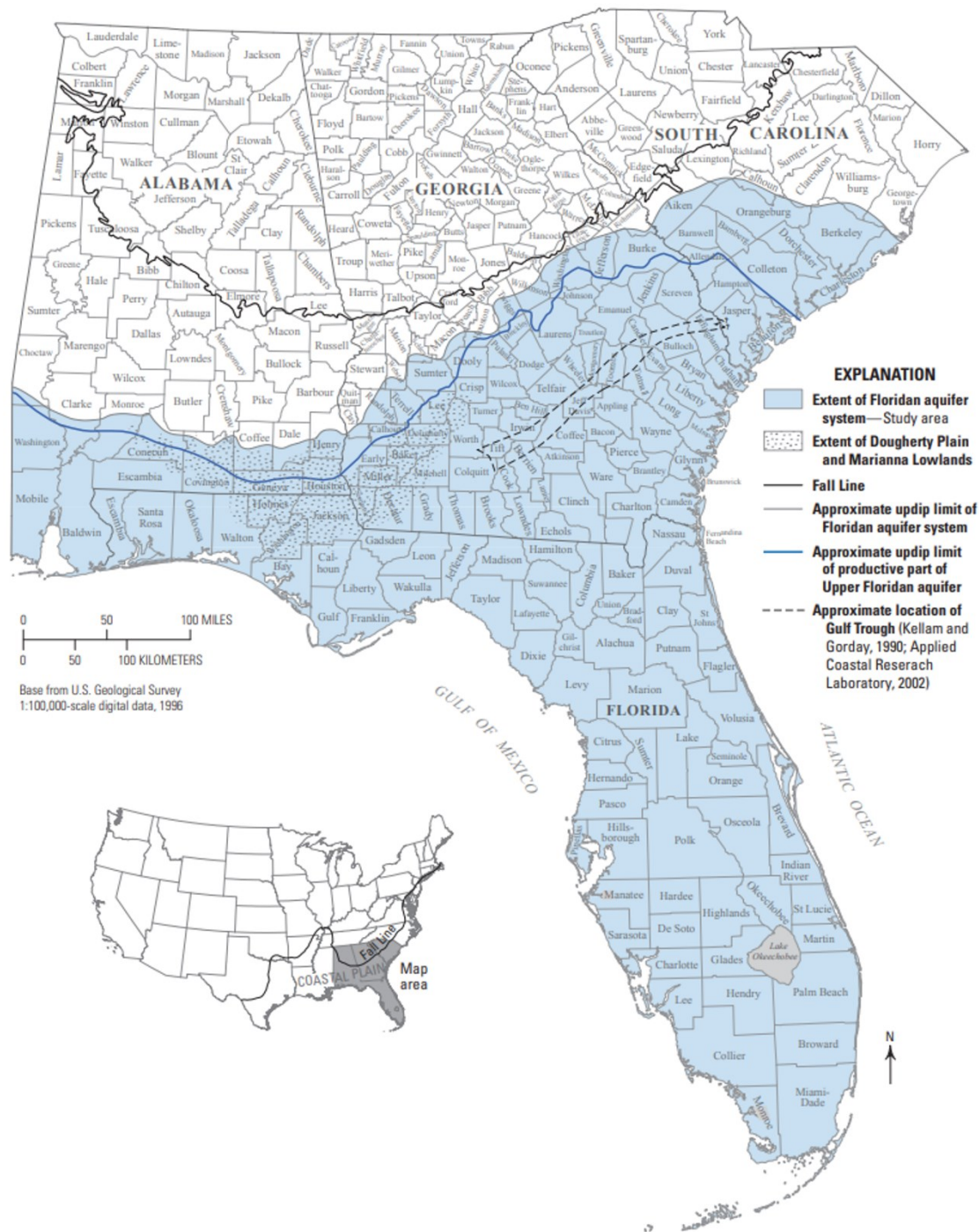


Figure 27. Floridan Aquifer System up-dip extents and other surficial features (sourced from Williams and Kuniansky, 2015).

5.1.3 Abrupt Changes in Profiles

From the thickness and elevation changes displayed in some of the profiles that had sporadic changes up-dip, thinning of the hydrostratigraphic units, or the outcropping of units to the surface, the WellCAD software was used for two-dimensional correlation of some of the general strike and dip profiles. From the WellCAD validation of the three-dimensional profiles, it was recognized that close-lying wells that differed in elevation of their surface layers caused the abrupt transitions in the surface layers displayed. To resolve this, a re-evaluation of the wells input into the three-dimensional surface layer would denote which well was better for the overall display, given the surrounding wells and their hydrostratigraphy that continued with a smoother profile. A downside to this would be the selection of one well that would be mitigated from the model, which was the correct display of the subsurface to cause this abrupt change. However, given that a lot of these abrupt changes were connected to the GA-FIT wells, the re-evaluation of these wells in the landscape needs to be reincorporated into the model, especially towards the outcropped region of the hydrostratigraphic units in the mapped region.

5.2 Comparative Analysis of Model Capabilities for Hydrostratigraphic Units

5.2.1 Gordon and Gonthier (2017)

Another publication that had available correlations of the hydrostratigraphy of southwest Georgia was by Gordon and Gonthier (2017). Their study assessed areas of hydraulic connectivity through pumping tests in southwest Georgia, specifically in Mitchell and Early counties (Gordon & Gonthier, 2017). Along with this study, Figure 7 of their report displayed two profiles across the southwest Georgia study region, with a

collection of well sites they had used (Fig. 28; Gordon & Gonthier, 2017). Profile A ran across a transect from east Early County to west Mitchell County. Profile B ran across a transect from north Seminole County to north Worth County. Compared with these profiles, Figure 24 was created to observe the three-dimensional hydrostratigraphic model capabilities with the general trend of transects and to observe that a similar result can be reached with different well inputs.

The result of the three-dimensional model along the profiles was distinctly similar, given by the trend in the Claiborne aquifer thickness changes that occurred from 12L403 to 14N016 in the B profile. The three-dimensional model had more curvature to its hydrostratigraphic layers, which was interpreted to result from the Radial Basis Function interpolation modeling of each surface. Only five wells overlapped in databases for the paper and the three-dimensional model: 11J011, GGS3001, GGS483, 12K002, and GGS540. However, 11J011 was the only well shown on the study's transect line, located only on the end of the A profile, near A'. This supported the three-dimensional hydrostratigraphic model's overall structure as a useful representation of hydrostratigraphy based on a much more extensive network of well sites that can be advanced through further well integration.

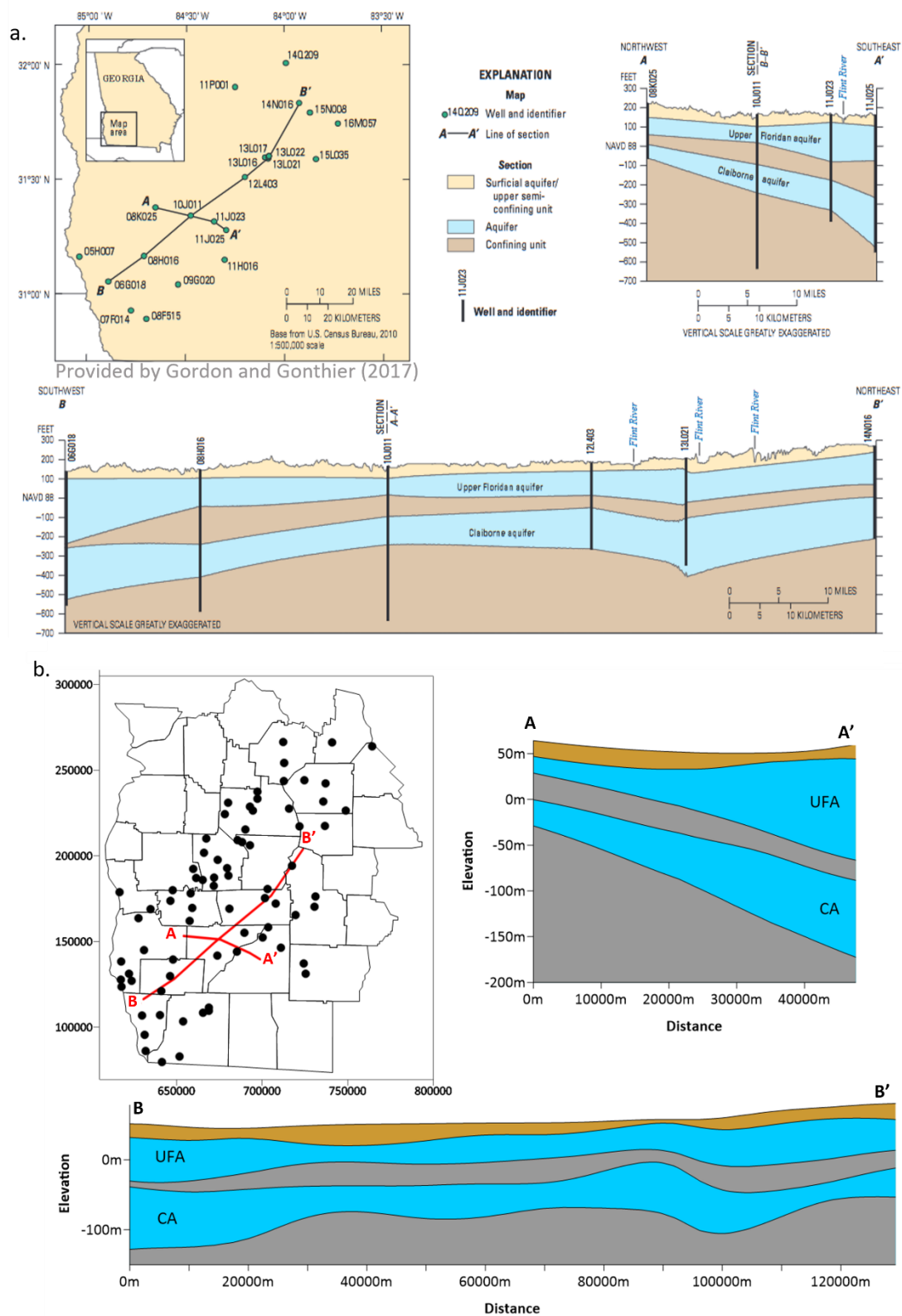


Figure 28. Comparison of the a.) Gordon and Gonthier (2017) profiles and b.) three-dimensional model profiles.

5.2.2 *Williams and Kuniansky (2015)*

In a companion report with the Williams and Dixon (2015) paper, a study examined the Floridan Aquifer System in the southeastern United States that created hydrostratigraphic correlations across the landscape (Williams & Kuniansky, 2015). This report consisted of three hydrogeological profiles that covered portions of southwest Georgia. In two of these plates, 9 and 10, the profiles were in a general dip direction of the hydrostratigraphic units, and the third plate was along the strike of the southernmost counties in the three-dimensional model study area.

In plate 9, the general dip profile in the extent of Georgia only, denoted as C to C', ran from Randolph County to Thomas County (Fig. 29 and 30). It was recreated in the general trend of the transect line in the three-dimensional model (Fig. 29). The transect line used was displayed by four wells in the study. The C profile displayed by the plate in Williams and Kuniansky (2015) fit the general display of what the three-dimensional model produced.

In plate 10, the general dip profile that was located east of plate 9 was denoted by D to D'. This profile traveled from south Macon County to Lowndes County and was recreated in the three-dimensional model of the transect length that was in the extent of Georgia, comprised of five wells (Fig. 29 and 31; Williams & Kuniansky, 2015). The display of hydrostratigraphic units recreated in the three-dimensional model was similar in trend with the two-dimensional correlation. Similar trends in the outcrop of units, dip direction, and unit thickness were displayed. The abrupt shift in thickness of the Upper Floridan aquifer between DP 39 and GGS108 in the study's correlation was depicted in the 3D model profile.

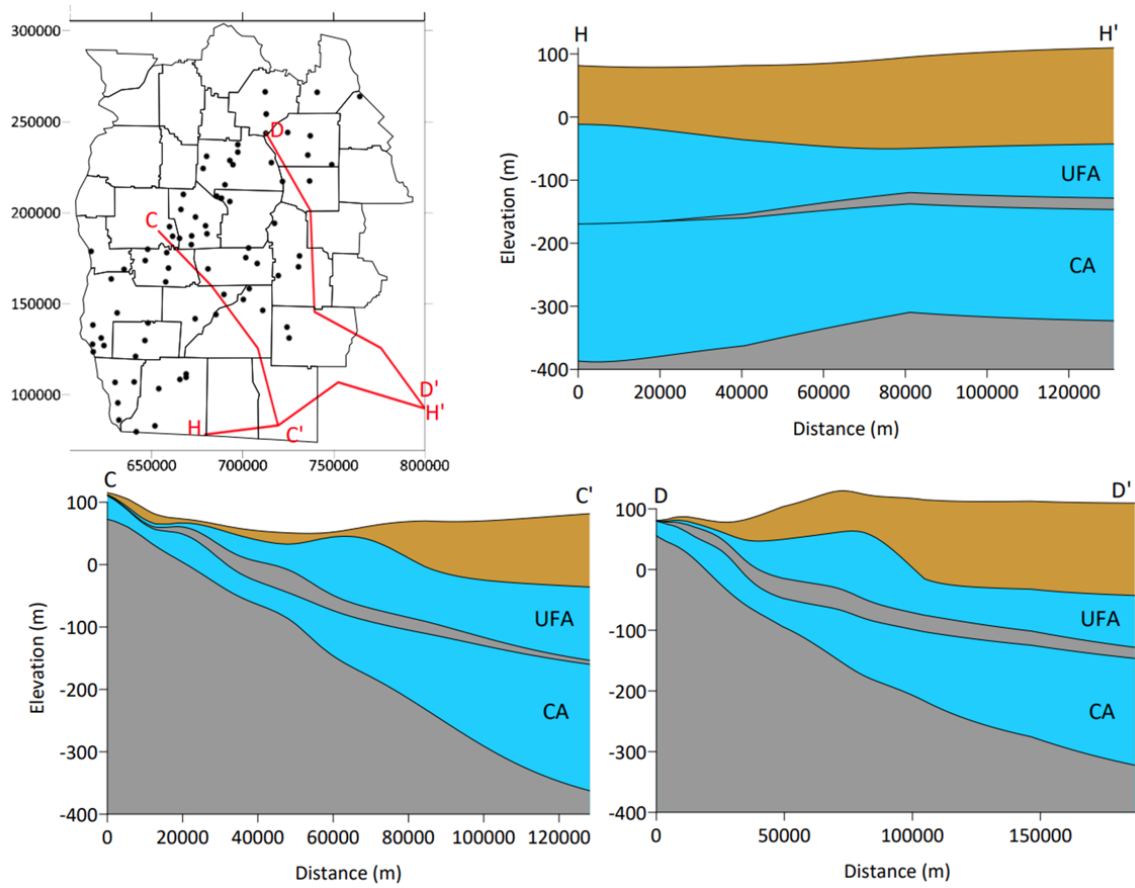


Figure 29. The three-dimensional model with Williams and Kuniansky (2015) profiles.

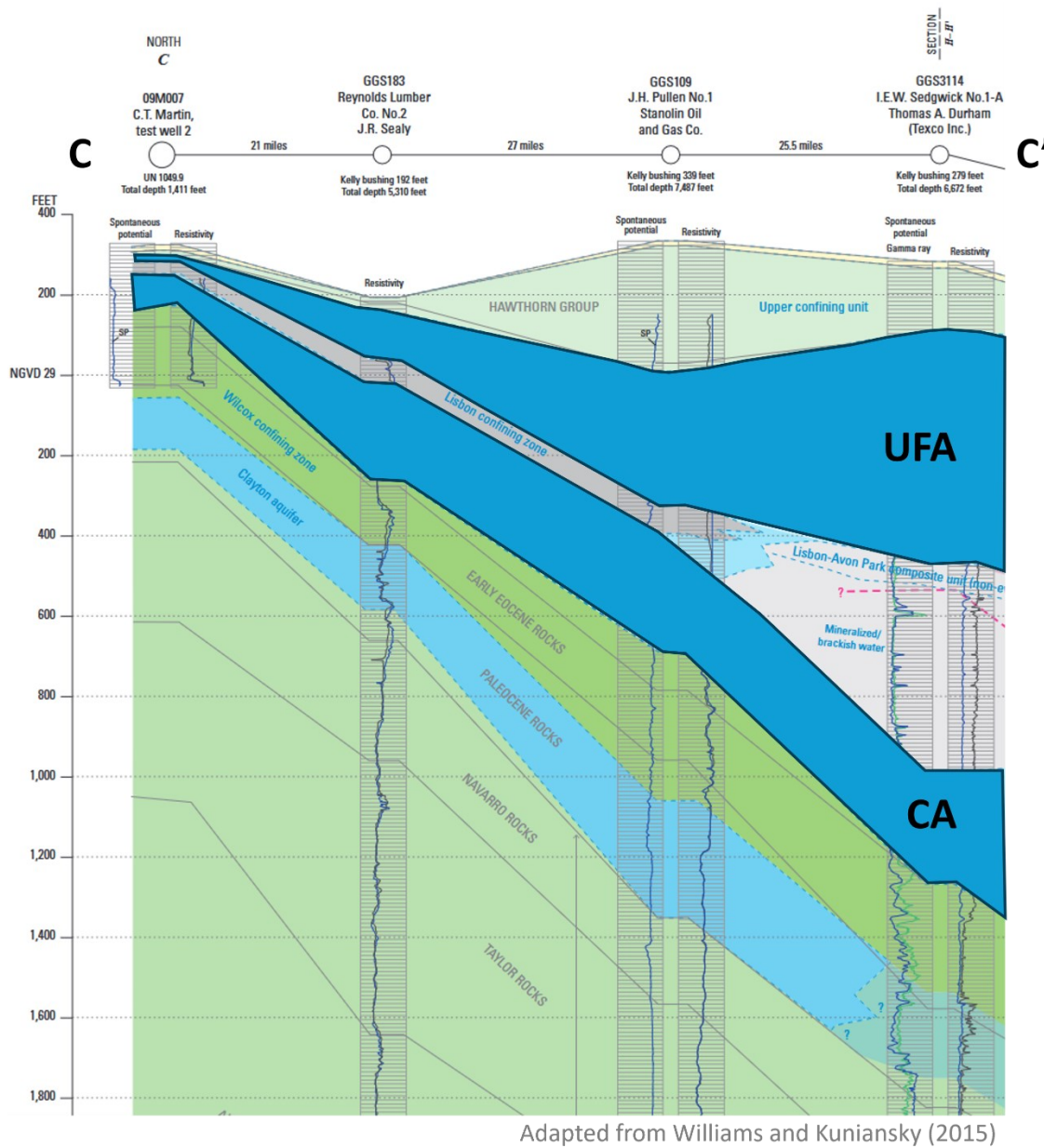


Figure 30. C to C' stratigraphic correlation mentioned in Figure 29 (adapted from Williams & Kuniansky, 2015).

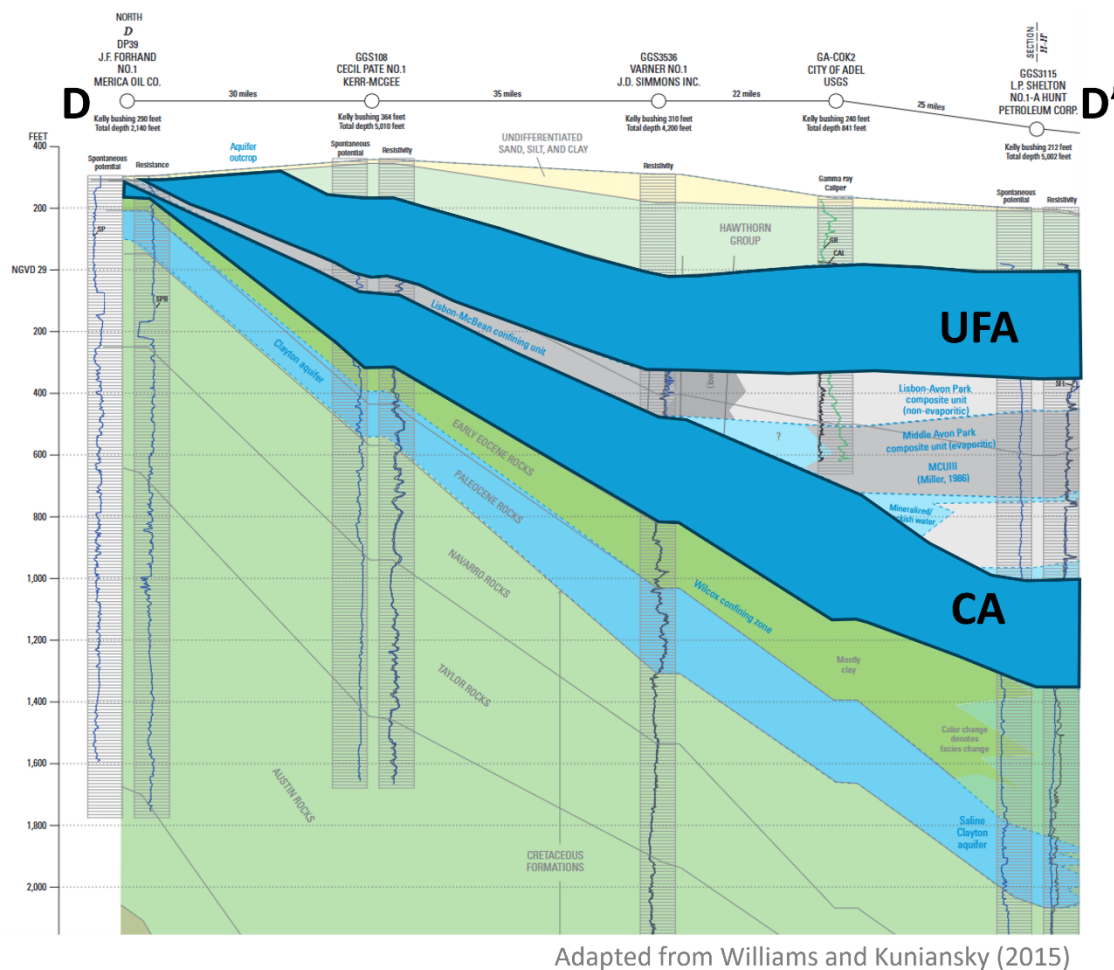
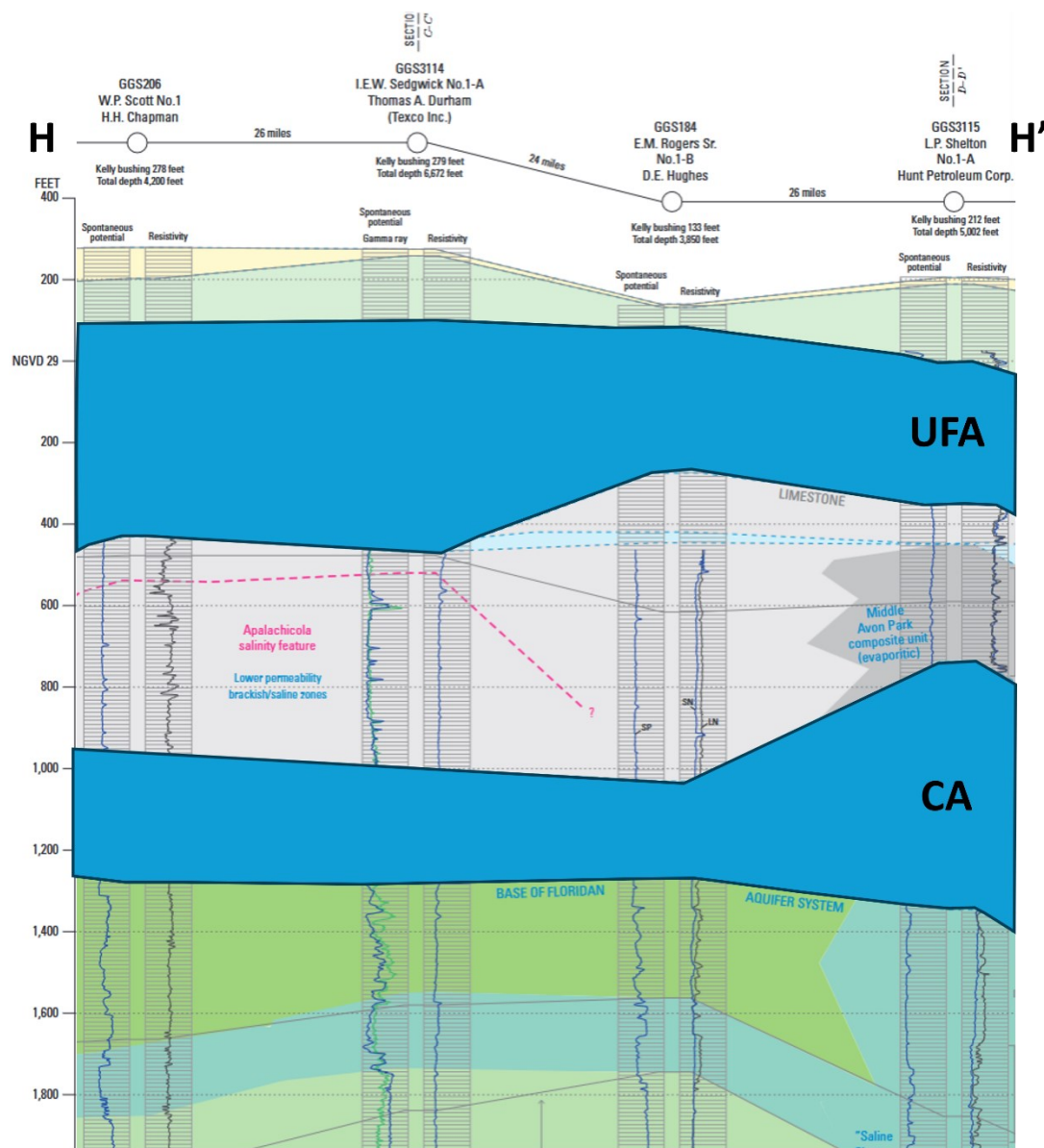


Figure 31. D to D' stratigraphic correlation depicted in Figure 29 (adapted from Williams & Kuniansky, 2015).



Adapted from Williams and Kuniansky (2015)

Figure 32. H to H' stratigraphic correlation depicted in Figure 29 (adapted from Williams & Kuniansky, 2015).

To test the extrapolation of the gridded surfaces, plate 14, referred to as the H to H' profile, was also recreated in the three-dimensional model in a general strike direction from Decatur County to Lowndes County, which was just within the gridded surface boundary (Fig. 29 and 32). The profile created from the three-dimensional model did not

display a well-distinguished relationship to the H profile. However, the hydrostratigraphic units discussed in the two-dimensional correlation were different than the terms used in the three-dimensional model. This assumed that given the semi-confining unit that was characterized in the profile by the paper, this was most likely not a representative display of the Lisbon confining unit, so the potential for this to be a portion of the Claiborne aquifer to match the three-dimensional model, and a Lisbon confining unit could be simulated through the break in the semi confining unit that occurred near GGS184 (Williams & Kuniansky, 2015).

The three transects affirmed that the three-dimensional model is aligned with previous publications' display of the general trend of hydrostratigraphic units in their dip and thickness. Notably, this occurred in scenarios of different well sites included in the model. It is important to note that the datum used in the correlations of Williams and Kuniansky (2015) was the National Geodetic Vertical Datum of 1929 (NGVD29). The three-dimensional model was based on meter values from NAD 1983. Although the conversion of the vertical datums varies across the landscape, the difference between these would most likely not exceed a 0.2-meter difference (US Department of Commerce). Profiles C and D confirmed that the data displayed in the three-dimensional model produced similar results in thickness and hydrostratigraphic elevation trends.

5.2.3 Davis et al., 1989

The Georgia Geological Survey Hydrologic Atlas 18 (HA18) provided a significant recharge zone map of the principal aquifer systems in Georgia (Davis et al., 1989). Similarities in the overall recharge zone in HA18 with the three-dimensional

model outcrop zones compared with the three-dimensional model. The Claiborne aquifer's outcrop displayed from the three-dimensional model was more north in Clay, Sumter, and Houston counties when compared with the HA18 map. The three-dimensional model supported the outcrop zones of the aquifers were characteristic of the recharge zones map.

5.3 Sensitivity Analysis of Constructed Surfaces

A larger shape factor results in smoother surfaces and rounded hilltops (Golden Software, 2024). However, the sensitivity analysis test of hydrostratigraphic unit thicknesses of varied shape factor values did not display that same trend. The thickness contour intervals were densely packed, and bullseye-like contour errors increased.

Carlson and Foley (1991) recommended for future modeling to test multiple R^2 values and that a smaller R^2 value is more effective for multiquadric function-based interpolation modeling. It was also mentioned in Carlson and Foley (1991) that a simple display of contour or isopach maps does not indicate the full nature of the interpolation methodology used, so it is difficult to sufficiently determine which of the surfaces was the best fit. However, the depiction of less bullseye-contours that are suggestive of overprediction in the gridding method and contours that show more of a realistic contour display in the model's future uses.

5.4 Suitability for Drilling Projects

An area well suited for further drilling into deeper-lying aquifers depends on factors that could go beyond the scope of what a three-dimensional model's

characterization was comprised of. Factors that could be used to offer insight into prospective drill sites through the observations of the three-dimensional model include depth below the surface, the thickness of aquifers, separation of the confining unit, and performing further validation, material variability of hydrostratigraphic units of individual wells. A site that would exhibit high quality in drill-site suitability would be not too deep below the surface, which would influence the cost-effectiveness of drilling deeper aquifer wells, and where the confining unit between aquifers is thick, so the aquifer systems are separated. Seminole and Decatur Counties raised concern of well and aquifer efficiency given the depth below the land surface to the Claiborne aquifer and the thin structure of the Lisbon confining unit. Thus, areas of the thinning of the Lisbon confining unit posed a concern for future drilling projects, given the potential interconnectivity of the Claiborne and Upper Floridan aquifers. These areas of concern need to be further examined before the installation of wells. Areas of thinning of the Lisbon with relatively thick aquifer systems bounding it were in the furthest south counties of the southwest Georgia study area: Seminole, Decatur, and Grady counties.

CHAPTER 6

CONCLUSION

Droughts affect public and agricultural communities in southwest Georgia. If measures are not taken to mitigate the impacts of drought, the water resources in this region will face significant water level declines that could remain depleted. Recent programs have fostered drilling deeper aquifer wells to source water alternatives for farmers in drought events. The hydrogeological characterization of deep aquifer systems in southwest Georgia is a major component in understanding the quality and complexity of these deeper-lying aquifer systems as a water source and their production capabilities, which will be crucial to utilize in times of drought. Given climate vulnerability in southwest Georgia and the demands of a growing population and irrigated lands, this project is imperative to the future use of Georgia's water resources and protectivity of its aquatic ecosystems. Factors such as the cost of drilling and the availability of samples, funding, and workforce can impact the ability to research the hydrostratigraphy of southwest Georgia.

A three-dimensional hydrostratigraphic model was produced to depict the surface of hydrostratigraphic units of selected wells across a landscape and observe overall trends. A three-dimensional model removes the complexity of subsurface geology and refines well data to a conceptual display that can detect potential zones of the outcropping or "pinching out" of confining units. These confining units are valuable to mitigate the

simultaneous drawdown of aquifer systems that would suggest hydraulic connectivity based on their thickness and hydrologic properties.

This model was also able to depict the hydrostratigraphic surface layers over the entire extent of southwest Georgia and to depict the ability of the limits on data input into the three-dimensional model. This model offers a unique approach to the characterization of geology and hydrogeology that can be expanded with additional pre-existing wells. It is the first three-dimensional hydrostratigraphic display of southwest Georgia, with the potential to be enacted as a collective database of wells and an integration that will remain useful to the GA-FIT project.

6.1 Limitations and Future Work

Three-dimensional modeling is structured around well data, and three sources were used to test the interpolation efforts of hydrostratigraphic surfaces in southwest Georgia. Too many resources could cause issues in resolving hydrostratigraphic layers if all were interpreted under different schemes. Too few resources could cause limitations beyond the extent of data availability. The Radial Basis Function is one of the best gridding methods for data clumping across a map area. Thus, finding a balance of sources that constitute different areas, with some overlapping in the areal extent, would be ideal for model incorporation. Thus, further data integration into the model would be an additional check on the model's capabilities.

The hydrostratigraphic units in southwest Georgia were only modeled to the depth of the Wilcox confining unit in the display, given the scarcity of the used sources that were extensive into deeper aquifer systems. A further collection of sources that include

more data from deeper-lying aquifers should be incorporated to advance the three-dimensional model.

Sampling bias was performed when selecting the use of GA-FIT wells out of other studies that could have been chosen. The removal of GA-FIT wells could have caused abrupt changes in the display, given potential human error through the characterization of drillers and geophysical logs. The wells' materials and geophysical logs displayed other fits where markers for the surface tops could have been used with those wells instead. Also, for the classification of the lithology of the GA-FIT wells, the depth of the casing impacted the interpretation, given the loss of observing the relationship of geophysical log changes with driller log descriptions until a depth situated past the casing depth, which was placed in the middle of the aquifer, was characterized at depth. Another impact on lithologic and hydrostratigraphic characterization of the GA-FIT wells was the limitation of geophysical log readings, given that the monitoring wells were cased to the depth of the aquifer. Thus, geophysical readings shallower than that were not able to be interpreted with well-cutting descriptions.

The boreholes in the model with major peaks or disruptive changes from certain transects need to be further evaluated and potentially recharacterized to better fit the surrounding data in the three-dimensional model. This could be done by incorporating more wells into the model, given well scarcity, especially up-dip in the study area. Finding additional wells that are proximal to current wells could also be used in the model to provide justification for the characterization used. A test on varying inputs for different parameters that created the three-dimensional surfaces, such as the radial basis function method type and the shaping factor value, could also provide a synopsis for the

smoothing and overall display of each hydrostratigraphic surface. More incorporation of lithological changes and where the material of the hydrostratigraphic units change could influence hydraulic conductivity, which would be worthwhile to explore.

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APPENDIX A
SITE INFORMATION FOR SURFER INPUT

Well Number	County	Source	x 1983 gawest	y 1983 gawest	long NAD83 DD	lat NAD83 DD	Elevation m	Elevation ft	Residuum Top	UFA Top	Lisbon Top	CA Top	Wilcox Top
CA1	EARLY	GAFIT	630879.8665	145188.3427	-84.892811	31.307691	64.026	210.060	64.026	48.786	21.963	1.542	-15.222
CA4	BAKER	GAFIT	673679.87	141973.904	-84.443097	31.280452	48.442	158.930	48.442	19.486	-23.186	-52.142	-107.006
CA5	BAKER	GAFIT	689491.3252	155391.391	-84.277177	31.401728	50.198	164.690	50.198	31.910	-10.762	-48.862	-90.010
CA6	WORTH	GAFIT	717357.736	194488.3126	-83.983442	31.754286	74.828	245.500	74.828	58.064	0.152	-33.376	-59.284
CA7	EARLY	GAFIT	622231.7574	131379.4693	-84.982585	31.182599	55.894	183.380	55.894	37.606	20.842	13.222	-75.170
CA8	EARLY	GAFIT	647757.0137	139579.8832	-84.715222	31.257984	58.174	190.860	58.174	39.886	10.930	-21.074	-69.842
CA10	DECATUR	GAFIT	668842.6304	111475.7397	-84.492957	31.005234	40.530	132.970	40.530	-9.762	-78.342	-99.678	-168.258
CA11	DOUGHERTY	GAFIT	680801.5548	169320.0595	-84.368829	31.527250	61.470	201.670	61.470	52.326	18.798	-4.062	-45.210
CT1	RANDOLPH	GAFIT	647639.6919	180191.1881	-84.718597	31.624272	99.493	326.420	99.493	93.697	93.397	81.205	38.533
CT2	SUMTER	GAFIT	680104.4234	231109.0861	-84.377432	32.084534	160.265	525.810	160.265	151.721	151.421	151.121	138.929
CT3	TERRELL	GAFIT	665940.0289	201879.1316	-84.526452	31.820570	123.787	406.120	123.787	117.991	117.691	108.547	81.115
CT5	CALHOUN	GAFIT	657500.2217	162187.438	-84.613885	31.642294	67.276	220.720	67.276	55.084	42.892	18.508	-8.924
SW6	LEE	GAFIT	685469.3001	209261.1722	-84.320270	31.887567	96.345	316.090	96.345	81.405	81.105	78.057	50.625
SW172	LEE	GAFIT	688253.0887	208205.7464	-84.290830	31.878080	89.639	294.090	89.639	75.923	68.303	65.255	40.262
SW173	SUMTER	GAFIT	690190.0507	215460.4382	-84.270430	31.943530	99.411	326.150	99.411	87.519	87.219	84.171	56.739
SW162	TERRELL	GAFIT	680147.7878	188523.89	-84.376101	31.700450	90.741	297.710	90.741	77.025	60.261	57.213	19.113
SW34	TERRELL	GAFIT	679402.9994	192884.8201	-84.384050	31.739770	88.301	289.700	88.301	71.537	39.533	36.485	18.197
SW187	CALHOUN	GAFIT	658060.3771	178231.3525	-84.608672	31.607023	83.899	275.260	83.899	74.755	62.563	57.991	33.607
SW202	TERRELL	GAFIT	665125.9444	186153.2905	-84.534490	31.678710	82.506	270.690	82.506	61.470	61.170	56.598	36.786
SW67	RANDOLPH	GAFIT	661343.701	187136.8723	-84.574420	31.687460	97.849	321.030	97.849	78.337	78.037	74.989	55.177
SW197	TERRELL	GAFIT	671837.4693	187470.2861	-84.463741	31.690773	89.359	293.170	89.359	80.215	65.584	60.403	32.971
SW61	TERRELL	GAFIT	671561.7801	182671.0821	-84.466510	31.647480	83.420	273.690	83.420	77.324	72.752	69.704	17.888
GGG137	SUMTER	B70	715551.1534	227677.0594	-84.001980	32.053648	88.279	289.630	88.279	82.183	74.258	60.847	27.319
GGG138	EARLY	B70	627670.7587	163904.3274	-84.927882	31.476298	79.117	259.570	79.117	68.749	68.449	45.589	18.767
GGG143	DOOLY	B70	735563.6569	231953.6317	-83.789892	32.091766	103.704	340.240	103.704	79.320	68.042	29.028	-28.884
GGG145	MACON	B70	712701.0579	254404.6618	-84.031808	32.294736	97.269	319.120	98.469	98.169	97.869	97.569	97.269
GGG147	SUMTER	B70	694479.6993	226630.6737	-84.225121	32.044305	116.646	382.700	117.546	117.246	116.946	116.646	89.518
GGG155	CRISP	B70	736519.9933	217687.417	-83.780301	31.963070	94.944	311.500	94.944	45.262	3.504	-31.548	-69.648
GGG215	SUMTER	B70	697245.8921	233568.0815	-84.195850	32.106883	142.823	468.580	142.823	127.268	126.968	126.668	101.675
GGG261	DOUGHERTY	B70	707888.2421	172301.9887	-84.083578	31.554279	59.570	195.440	59.570	47.378	-13.582	-47.110	-128.187
GGG291	SUMTER	B70	678180.5451	224605.1411	-84.397665	32.025839	149.403	490.170	149.403	140.859	140.559	140.259	121.971
GGG296	SUMTER	B70	697076.1101	237680.5349	-84.197661	32.143973	145.471	477.270	146.371	146.071	145.771	145.471	102.799
GGG303	SUMTER	B70	721725.5732	217292.9167	-83.936827	31.959892	74.912	245.770	74.912	65.768	53.576	41.384	NA
GGG331	CALHOUN	B70	659135.0895	169813.1726	-84.596997	31.531134	72.392	237.510	72.392	65.077	62.029	37.340	8.384
GGG351	EARLY	B70	617370.7558	128005.6901	-85.033303	31.151837	50.155	164.550	50.155	9.307	9.007	-36.713	-87.614
GGG353	CALHOUN	B70	646244.4997	173979.1805	-84.732964	31.568180	88.388	289.990	88.388	73.448	73.148	56.384	35.048
GGG402	CLAY	B70	616565.5769	178932.5934	-85.046016	31.611085	78.337	257.010	78.937	78.637	78.337	44.809	20.425
GGG405	DOUGHERTY	B70	701480.0081	175599.9503	-84.151072	31.584052	58.010	190.320	58.010	51.914	12.290	-5.998	-77.321
GGG407	TERRELL	B70	673984.653	197745.768	-84.441365	31.783502	110.740	363.320	111.040	110.740	91.232	72.335	49.780
GGG408	MACON	B70	712701.0579	254404.6618	-84.031808	32.294736	97.269	319.120	98.469	98.169	97.869	97.569	97.269
GGG422	MACON	B70	712250.3121	266593.234	-84.036436	32.044665	88.904	291.680	90.104	89.804	89.504	89.204	88.904
GGG424	LEE	B70	692877.7817	206260.4681	-84.241933	31.860573	90.543	297.060	90.543	81.399	73.474	48.480	23.487
GGG464	CLAY	B70	634661.2114	169045.2388	-84.854657	31.523081	103.243	338.720	103.843	103.543	103.243	58.742	33.749
GGG483	EARLY	B70	617622.4946	138398.9414	-85.031515	31.245593	59.870	196.430	59.870	-0.490	-0.790	-1.090	-37.666
GGG504	SUMTER	B70	692800.4127	228774.2381	-84.242919	32.063628	99.040	324.930	99.040	87.448	87.148	86.848	83.800
GGG559	WEBSTER	B70	663198.6172	212677.4961	-84.556161	31.999047	139.237	456.810	139.237	130.093	108.757	90.469	73.705
GGG574	LEE	B70	703035.2646	180799.7004	-84.134669	31.630949	57.823	189.710	57.823	42.583	2.959	-25.997	-85.433
GGG109	MITCHELL	WK2015	709147.5708	126579.4556	-84.070733	31.141852	101.271	332.260	101.271	6.783	-93.801	-215.721	-422.985
DP39	MACON	WK2015	712579.2794	243918.0136	-84.033239	32.200161	79.809	261.840	80.709	80.409	80.109	79.809	55.425
GGG3536	COLQUITT	WK2015	740883.0927	146148.2991	-83.737119	31.317684	97.637	320.330	97.637	-32.208	-70.003	-146.203	-237.643
18T001	PULASKI	WK2015	764280.3974	263980.9566	-83.483513	32.379322	101.805	334.010	101.805	63.705	57.914	40.540	-6.704
06F090	SEMINOLE	WK2015	629756.9088	106924.5517	-84.901940	30.962500	50.138	164.500	50.138	24.230	-41.302	-54.103	-154.382
06H017	EARLY	WK2015	623647.8776	127311.3151	-84.967420	31.146000	58.458	191.790	58.458	40.170	-2.502	-9.817	-84.188
07D014	DECATUR	WK2015	641311.3936	79755.42538	-84.779440	30.718060	83.097	272.630	83.097	-3.466	-142.455	-145.503	-297.598
07F011	SEMINOLE	WK2015	640214.0201	107168.85	-84.792500	30.965280	35.332	115.920	35.332	18.873	-59.156	-72.567	-169.799
07G022	MILLER	WK2015	640904.5213	121357.977	-84.786100	31.093300	43.657	143.230	43.657	24.150	-32.543	-50.831	-128.555
08D093	DECATUR	WK2015	651622.5137	83059.71685	-84.671940	30.748330	87.215	286.140	87.215	-19.465	-149.005	-153.272	-307.806
08F500	DECATUR	WK2015	653835.96	103602.2258	-84.649750	30.933720	37.670	123.590	37.670	23.040	-87.298	-99.795	-216.228
08H002	MILLER	WK2015	646149.0707	129976.4375	-84.731590	31.171290	48.281	158.400	48.281	37.003	-12.984	-35.539	-108.996
09G015	DECATUR	WK2015	656910.8444	119519.0923	-84.618250	31.077410	44.875	147.230	44.875	34.207	-60.281	-72.168	-166.046
09M004	RANDOLPH	WK2015	659579.2179	192525.4385	-84.593254	31.736000	112.196	368.100	112.196	106.700	106.400	106.100	78.059
09P002	TERRELL	WK2015	667295.9932	210330.0034	-84.512413	31.896380	145.864	478.560	145.864	133.053	132.753	132.453	97.096
10G314	MITCHELL	WK2015	677386.3735	123339.0396	-84.403750	31.112440	42.148	138.280	42.148	22.336	-76.724	-91.964	-195.596
11J011	MITCHELL	WK2015	685121.8501	144200.7091	-84.322960	31.300740	50.680	166.270	50.680	39.098	-37.102	-57.828	-135.552
12K002	MITCHELL	WK2015	700194.0002	152596.7623	-84.164627	31.376568	52.051	170.770	52.051	45.955	-46.095	-75.051	-141.497
12K004	MITCHELL	WK2015	703415.3493	158417.9879	-84.130740	31.429070	56.901	186.680	56.901	40.137	-25.395	-56.180	-132.380
13J009	MITCHELL	WK2015	710786.4605	146608.1076	-84.053330	31.322500	83.695	274.590	83.695	69.979	-63.219	-89.737	-170.204
14K058	WORTH	WK2015	719484.1338	165548.8312	-83.961570	31.493320	95.631	313.750	95.631	67.894	-44.577	-65.913	-150.647
14R006	DOOLY	WK2015	724599.1557	244186.6484	-83.905739	32.202385	107.254	351.880	107.254	99.939	91.404	86.527	52.999
15L021	WORTH	WK2015	730474.5193	170503.3076	-83.845730	31.537680	115.325	378.360	115.325	75.701	-45.000	-75.480	-165.396
15L032	WORTH	WK2015	731159.6027	176368.1403	-83.838330	31.590560	124.889	409.740	124.889	70.025	-30.559	-64.392	-150.041
15R007	DOOLY	WK2015	737019.5688	242438.1558	-83.774063	32.186275	123.501	405.190	123.501	103.993	66.503	54.311	22.307
GA-WX2	WILCOX	WK2015	79										

APPENDIX B
RESIDUALS CALCULATION

	Inverse Distance		Minimum Curvature	Modified Shepard's Method	Natural Neighbor	Radial Basis Function	Triangulation with	
	to Power	Kriging					Linear Interpolation	Local Polynomial
0.426	1.046	0.691	0.486	0.771	0.289	0.686	6.364	
0.591	0.293	0.298	0.016	0.214	0.052	0.196	1.222	
1.180	0.316	0.388	0.048	0.315	0.011	0.025	3.446	
2.015	1.076	0.023	0.012	1.303	0.119	0.718	21.272	
2.815	4.295	1.024	1.018	3.972	0.645	3.837	23.564	
0.039	0.231	0.003	0.066	0.098	0.014	0.165	0.128	
1.862	1.891	1.390	0.546	3.089	0.202	2.888	9.524	
0.847	1.120	1.898	0.354	0.759	0.270	0.465	3.619	
3.462	1.546	0.806	0.176	1.794	0.220	1.374	13.303	
4.534	2.483	0.221	0.592	7.847	0.841	7.338	16.222	
3.202	0.075	0.669	0.041	0.044	0.090	1.666	13.672	
0.462	0.136	0.534	0.011	0.088	0.030	0.160	1.248	
3.430	0.404	2.000	0.262	0.437	0.106	0.415	0.092	
0.590	0.167	0.259	0.070	0.162	0.009	0.129	5.253	
0.549	0.163	0.142	0.013	0.086	0.106	0.097	1.416	
2.301	4.004	0.769	0.251	4.262	0.663	2.128	14.258	
1.850	3.098	1.808	0.541	3.941	0.423	3.774	17.058	
0.371	0.205	0.242	0.009	0.106	0.048	0.099	5.360	
2.143	3.741	1.536	1.344	4.665	0.889	4.502	4.916	
1.685	0.010	1.043	0.043	0.160	0.001	0.108	6.023	
0.428	0.658	0.456	0.063	0.108	0.046	0.104	5.894	
2.635	3.527	0.243	0.428	3.669	0.633	3.195	25.489	
0.253	1.054	0.939	0.576	0.837	0.406	0.021	2.621	
0.949	0.488	0.405	0.024	0.763	0.121	0.784	0.223	
0.298	0.060	0.843	0.018	0.172	0.066	0.541	0.920	
1.245	0.499	1.386	0.040	0.658	0.148	0.475	6.160	
4.141	5.677	1.337	1.369	6.672	0.792	6.184	18.118	
2.452	2.807	0.103	0.128	3.233	0.436	2.189	28.296	
2.970	0.977	2.717	0.754	1.813	0.059	2.746	19.292	
1.667	1.475	0.711	0.219	1.734	0.347	1.664	7.842	
4.478	1.861	0.369	0.505	3.056	0.480	2.864	16.225	
6.457	4.191	2.292	0.592	4.539	0.960	4.395	30.020	
0.226	2.233	0.446	0.087	2.586	0.336	2.000	15.697	
0.429	0.184	0.816	0.002	0.506	0.071	0.296	4.953	
5.684	7.703	4.236	1.648		1.732		23.414	
0.545	0.841	0.085	0.100	0.861	0.112	0.616	1.198	
0.350	0.792	5.323	0.002		0.055		15.714	
0.873	2.591	0.002	0.340	2.610	0.463	1.910	15.450	
1.964	0.131	4.064	0.533	0.267	0.195	0.276	0.911	
1.245	0.499	1.386	0.040	0.658	0.148	0.475	6.160	
0.372	0.890	6.061	0.067		0.111		22.785	
1.271	0.483	0.126	0.006	0.371	0.120	0.275	9.154	
2.023	1.022	1.509	0.099	1.604	0.214	1.179	6.399	
0.447	0.291	4.748	0.346		0.030		6.693	
4.049	7.775	7.576	2.605	9.328	1.072	7.485	19.326	
0.500	3.828	1.546	0.148		0.631		40.366	
2.462	2.511	5.029	0.406	2.017	0.373	1.447	12.008	
2.480	3.289	0.181	0.014	8.447	0.338	6.779	69.845	
0.082	1.354	0.351	0.197	1.704	0.292	1.635	11.876	
2.338	1.630	0.365	0.029		0.232		10.849	
0.005	0.094	0.257	0.023		0.014		1.662	
0.075	0.389	0.105	0.035	0.572	0.068	0.409	15.126	
0.298	0.523	0.710	1.054	0.204	0.159	0.371	9.872	
0.412	0.392	0.141	0.058		0.103		4.244	
1.113	0.111	1.014	0.016	0.061	0.019	0.004	8.125	
0.325	0.393	0.068	0.002	0.284	0.043	0.213	0.290	
2.827	0.799	0.036	0.037		0.126		0.374	
1.879	0.344	0.061	0.109	0.389	0.086	0.325	6.334	
0.157	0.314	0.407	0.192	0.571	0.073	0.377	3.821	
0.678	0.192	0.427	0.048	0.003	0.103	0.001	3.361	
5.288	2.450	0.533	0.088	2.926	0.460	2.383	22.686	
3.455	2.529	1.402	0.139	4.352	0.467	4.883	22.229	
1.074	0.547	0.907	0.005	0.879	0.077	0.839	5.433	
1.120	1.224	0.938	0.155	1.192	0.242	0.855	5.760	
2.955	1.060	0.063	0.204	1.863	0.211	1.984	6.853	
0.526	0.547	0.607	0.102	0.562	0.065	0.484	4.253	
1.977	1.219	0.415	0.150	1.647	0.247	1.357	6.001	
2.192	0.470	0.717	0.057	0.545	0.142	0.494	4.238	
0.997	1.237	0.347	0.195	1.230	0.250	0.901	15.960	
1.539	0.069	0.137	0.001	0.004	0.012	0.016	2.359	
1.282	0.861	0.490	0.066	0.752	0.186	0.522	4.129	
0.293	0.030	0.296	0.053	0.163	0.063	0.093	8.748	
0.735	0.524	0.192	0.013		0.046		0.662	
1.547	4.290	3.441	0.194		0.848		32.714	
1.645	0.041	0.570	0.156	0.226	0.011	0.162	4.343	
0.575	0.486	3.273	0.020		0.071		4.706	
0.021	3.175	0.135	0.462	7.737	0.654	5.437	16.508	
1.044	0.935	0.611	0.024	1.171	0.072	0.546	23.230	
1.682	3.687	5.883	1.762		0.625		7.865	
3.601	1.380	0.415	0.118	0.465	0.108	0.407	2.630	
0.456	0.729	0.738	0.084	0.892	0.102	0.889	6.447	
3.026	4.059	5.914	0.050		0.699		29.580	
Number of values	82	82	82	82	68	82	68	82
Sum	134.464	122.723	102.645	22.956	121.017	22.495	104.256	912.398

APPENDIX C

REPORTS FROM GRID SURFACES

This appendix includes the data statistics reports, cross-validation reports, and the grid data reports. Given the large number of data files, this will be available upon request.