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# NORTHEAST FLORIDA REGIONAL GROUNDWATER FLOW MODEL: MODEL REVISION AND EXPANSION

# NORTHEAST FLORIDA REGIONAL GROUNDWATER FLOW MODEL: MODEL REVISION AND EXPANSION

by

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# EXECUTIVE SUMMARY

The present modeling study was conducted in order to develop a technical tool for management of groundwater resources in northeast Florida. The area is experiencing steady population growth and demand for freshwater is expected to continue increasing in the future, requiring careful management of groundwater resources. The Floridan aquifer is the primary source of fresh groundwater in the area. The surficial aquifer overlying the Upper Floridan aquifer is not a major source of water, but is considered critical from an environmental perspective. A groundwater model was developed which simulates flow in both the Floridan and surficial aquifers. The primary goal of the present study was to utilize the model to estimate drawdown impacts on the Floridan and surficial aquifers in 2025. The St. Johns River Water Management District (District) can also utilize the model in the future for consumptive use permits (CUPs) and water resources planning purposes.

The present model is a revision and expansion of an existing model of northeast Florida, which was developed to simulate flow in the coastal regions of Clay, St. Johns, Duval, Nassau, and Camden counties. The present model is an expansion of the previous modeled area and encompasses 15 counties in northeast Florida and 4 counties in southeast Georgia. Additionally, the model was enhanced to simulate flow in the surficial aquifer. The revised model therefore enhances the District's ability to estimate drawdown impacts on the Floridan and surficial aquifers due to projected groundwater withdrawals in the larger northeast Florida and southeast Georgia area.

The model simulates flow in four aquifers separated by three semi-confining units, and underlain by a confining unit. The aquifer system includes the surficial aquifer system, the Upper Floridan aquifer, the Lower Floridan aquifer, and the Fernandina Permeable Zone. Since average drawdown impacts for 2025 are of interest, and since the Floridan aquifer equilibrates to pumping stresses in a short time frame, a steady state model was developed. Major groundwater uses, such as public supply, commercial/industrial, agricultural, golf course irrigation, recreational, and domestic self-supply, were accounted for in the modeling process.

The model was calibrated to observed water levels and interpreted potentiometric surfaces in the Upper Floridan and surficial aquifers in 1995. Additionally, the model was calibrated to spring flows measured in 1995. Since the Upper Floridan aquifer is the primary source of groundwater in the area, the focus of the study and model calibration was on accurately simulating flow in that aquifer. A satisfactory match was achieved between simulated and observed/interpreted water levels, and spring flows. The general groundwater flow trends, in terms of elevations and predominate directions of flow were reproduced by the model.

The calibrated model was utilized to simulate water levels for the year 2025. Withdrawals are projected to increase from 453 MGD in 1995 to 614 MGD in 2025. The simulation results indicate that in most of the study area, less than 2 feet of drawdown in the Upper Floridan aquifer is likely to occur. The largest drawdown is projected in Nassau County and is attributed to water use by Jefferson Smurfit, Rayonier, and Florida Public Utilities. Drawdowns in excess of 10 feet can be expected in the Fernandina Beach area of Nassau County. Most of Duval County is projected to experience drawdowns of between 2 to 10 feet in the Upper Floridan aquifer, primarily due to increased pumpage at JEA well sites. Localized drawdowns in excess of 10 feet can be expected in close proximity to the production wells, including municipal wells at Gainesville in Alachua County. Another area of relatively high drawdown coincides with projected 2025 pumpage in the Palm Coast area of Flagler County. Drawdowns in the Upper Floridan aquifer of up to 5 feet are expected in that area. Since most of the springs are in the southern portions of the study area, and away from major pumping centers, the cumulative spring flows in the study area are projected to decline in 2025 by less than 1 percent from 1995 levels.

Several areas were also found to experience a rise in water levels due to reduced groundwater pumpage. Noticeable rebound areas are in Camden and Nassau counties, and occurred due to the shutdown of the Durango Paper mill. Other minor rebounds are the outcome of reductions in projected water use at E.I. De Pont De Nemours Trail Ridge and the Georgia Pacific Palatka Plant.

Drawdown impacts in the surficial aquifer are generally less than 1/3 ft due to increased pumpage by the year 2025 being primarily in the Upper Floridan aquifer. Larger drawdowns (of up to 5 ft) were found to occur in the St Augustine and Palm Coast areas, where groundwater is withdrawn directly from the surficial aquifer and the intermediate aquifer in the Hawthorn Group.

# INTRODUCTION

The Floridan aquifer system is the primary source of freshwater in northeast Florida and southeast Georgia. The aquifer system consists of carbonate aquifers and intervening semi confining units. The surficial aquifer overlies the Floridan aquifer, consisting primarily of sand, clayey sand, shell, and thin limestone beds of the post-Miocene deposits (Clark et al. 1964). Steady population growth in the area has created increased demand for freshwater. This study is part of an ongoing program, led by the St. Johns River Water Management District (District), to address the need for a sound long-term water resources management policy in the area.
A computer model that simulates groundwater flow in the subsurface will be the primary tool utilized for managing water resources. Such models are most suited for simulating flow in complex, regional groundwater flow systems such as the Floridan and the overlying surficial aquifer systems. Regional groundwater models are most useful for predicting the response of the groundwater system to aquifer stresses, such as future withdrawals from wells. The model developed for this study is a numerical, finite-difference model, which simulates groundwater flow in northeast Florida and southeast Georgia (Figure 1). This model will be used as a tool to support the Water Supply Needs and Sources Assessment initiative of the District. Because the surficial aquifer provides for only a small percentage of total freshwater demand in the area, and due to lack of hydrogeologic data for the surficial aquifer, the emphasis of the study is on the Floridan aquifer system

## Study Objectives

The District developed a regional groundwater flow model of northeast Florida in 1997 (Durden, 1997, refer to Figure 1 for model area). The model encompassed four counties in northeast Florida and one county in southeast Georgia. The primary objective of the present study is to expand the previous model boundaries in order to encompass a

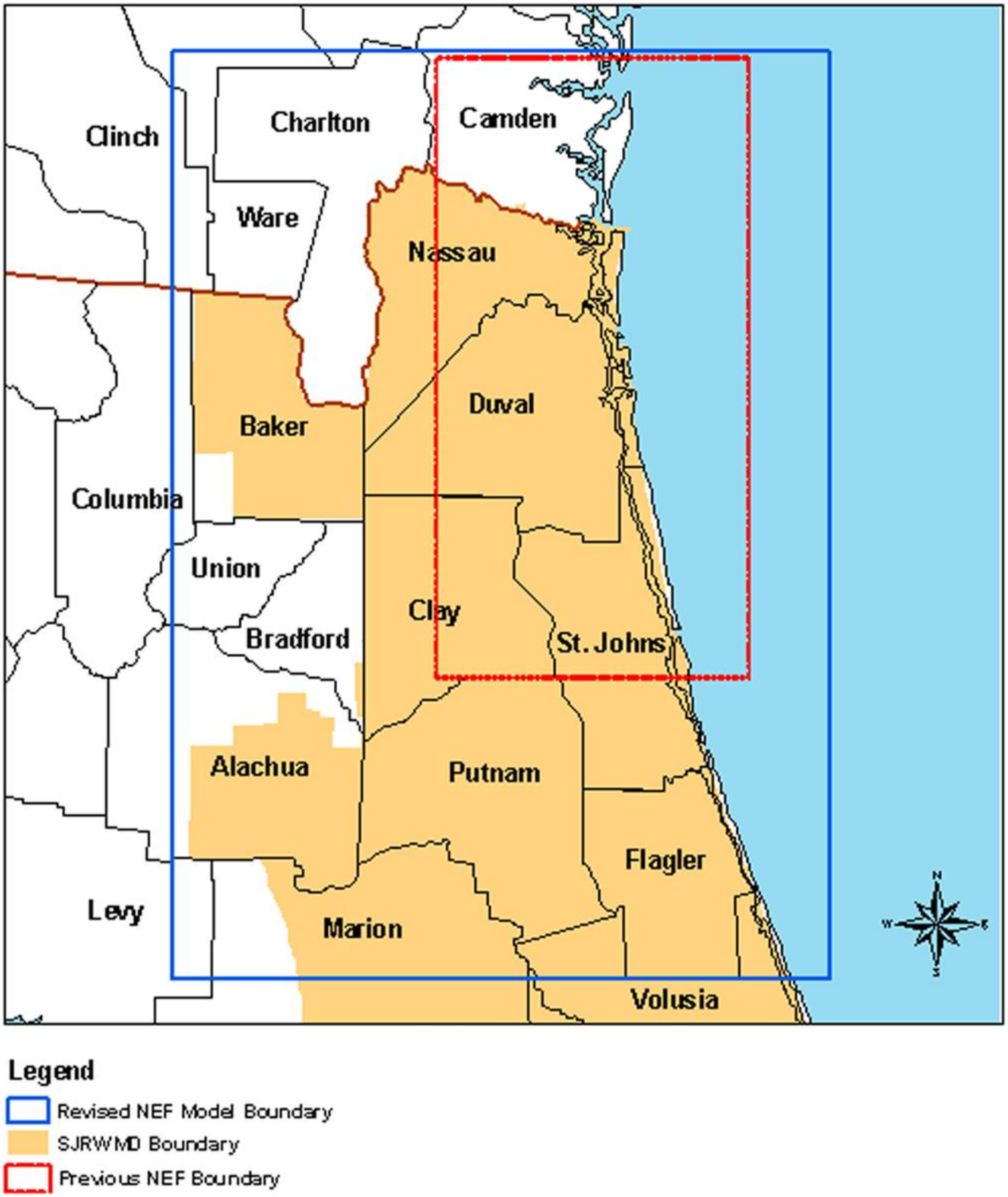



**Figure 1 Northeast Florida model study area**

larger area (15 counties in northeast Florida and 4 counties in southeast Georgia). The revised model will enhance the District's ability to better simulate the response of the Floridan aquifer system to projected groundwater withdrawals within the District's boundaries. As part of the District's water supply planning process, the proposed model will be used to conduct groundwater impact studies for projected water use in 2025. The specific objectives of the modeling study include:

- Construction and calibration of a three-dimensional, multi-aquifer groundwater flow model to average hydrologic conditions in 1995.
- Utilization of the calibrated model to estimate drawdown impacts in the Floridan and surficial aquifer systems, and changes in spring flows, due to projected groundwater withdrawals in the year 2025.

## Technical Approach

The relevant hydrogeologic reports and compiled hydrologic data were reviewed. The model domain was discretized and input parameters and boundary conditions were assigned to each grid cell based on information documented in previous modeling studies and hydrologic data in the District's database. The model was calibrated to an interpreted average 1995 potentiometric surface and average 1995 water levels recorded at individual observation wells. A sensitivity analysis was performed on the calibrated model in order to identify critical model parameters. Predictive simulations were performed for the year 2025 based on projected groundwater withdrawal rates at existing and proposed well sites.

## Previous Studies

Several modeling studies have been conducted in the past decades focusing on simulating groundwater flow and transport of saltwater in northeast Florida. As indicated above, the present model is an extension of an earlier model of coastal regions in northeast Florida and southeast Georgia (Durden, 1997). This study builds on the results of Durden's (1997) modeling effort and the recently completed regional model of the intermediate and Floridan aquifers, which cover most of the fresh groundwater regions in the state of Florida (Sepulveda, 2002).

In addition to the two studies cited above, most other modeling efforts have been localized in scope. Toth (2001) used two separate analytical models to estimate projected drawdowns in the surficial and Floridan aquifers at the Tillman Ridge wellfield operated by St. Johns County. Durden (2000B) utilized an analytical flow model to estimate the relative contribution of various entities on the overall (Upper Floridan) drawdowns in the potato-growing regions of St. Johns and Putnam counties. Estimates of regional Upper Floridan aquifer drawdowns within the coastal areas of the District were obtained by Durden (2000A) using a numerical drawdown model. Rabbani and others (2003) simulated groundwater flow in the surficial, intermediate, and Floridan aquifers in the Palm Coast area of Flagler County. The Palm Coast model was used for assessing drawdown impacts due to future pumpage. McGurk (1998) estimated impacts of projected withdrawals from the Floridan aquifer in western Volusia and southeastern Putnam counties. Motz (1997) coupled a regional flow model with a localized transport model to assess the impact of pumpage on water quality in the Jacksonville area. Durden and Motz (1991) modeled parts of Duval, St. Johns, Nassau, Clay, and Putnam counties in order to predict drawdown impacts near Jacksonville.

# HYDROGEOLOGIC BACKGROUND

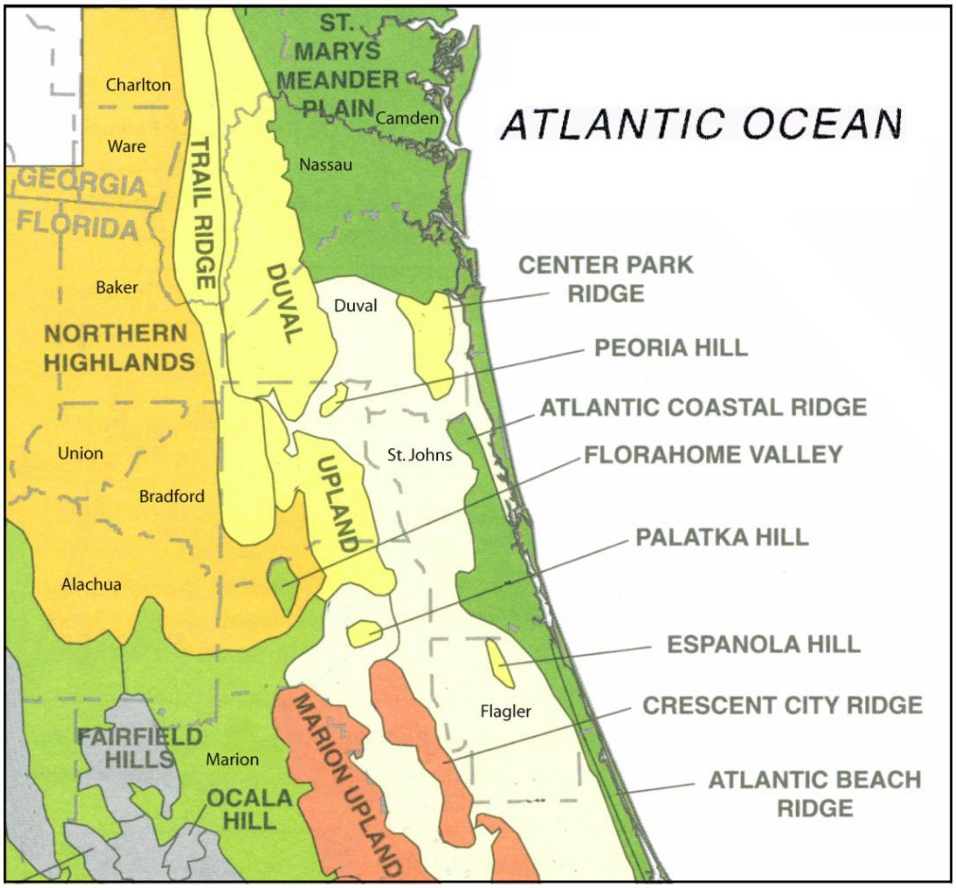
The hydrogeologic, climatic, and topographic setting in the study area has been documented in numerous hydrogeologic reports and the modeling studies. Based on these studies and data compiled from the District's database, the major hydrologic features and characteristics influencing groundwater flow in the study area are summarized and discussed below.

## Climate

The climate in the study area is subtropical with warm wet summers and mild dry winters. The average temperature in the Jacksonville area is approximately 68.5 degree Fahrenheit. The mean annual rainfall in Jacksonville during the 1867-1984 period was 51.73 inches (Motz, 1997). The average rainfall at Gainesville is 51.08 inches per year (Annabelle and Motz, 1996). Based on data collected at NOAA stations in Crescent City, Daytona Beach, Marineland, and St. Augustine for the years 1942-1982, the average annual rainfall in Flagler County is approximately 49.67 in/yr. The data, therefore, suggests that the average magnitude of precipitation, which strongly governs the hydrologic system in the subsurface, is approximately the same in the larger study area.

## Topography and Near-Surface Hydrology

The study area spans over several distinct physiographic regions as outlined by Sepulveda (2002) and presented in Figure 2. The delineation of physiographic regions is based on geomorphology and correlation of water levels between physiographic regions. The land surface elevation (Figure 3) varies from approximately 250 ft (AMSL) along Trail Ridge in the west to near mean sea level in the coastal areas. In general, the land surface elevation increases from the eastern coastal regions to highlands in the west.




(Source: Sepulveda, 2002)

**Figure 2 Physiographic regions in study area**

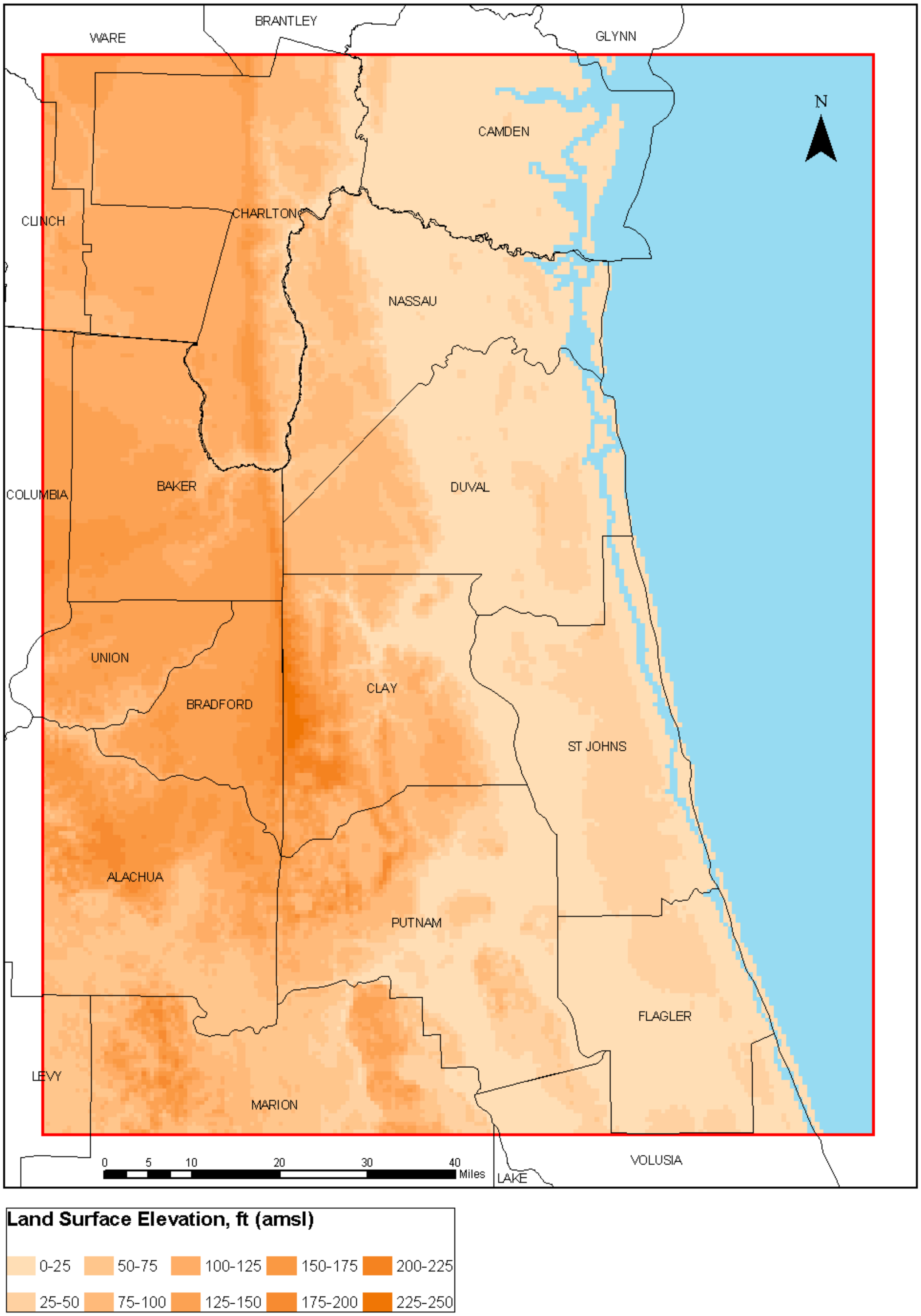



**Figure 3 Land surface elevation**

Most of the rainfall that infiltrates the subsurface is lost from the groundwater flow system as evapotranspiration (ET). There is limited data available to substantiate the actual range of ET in the study area. ET rates vary significantly based on surface cover, net radiation, photosynthetically active radiation, air temperature, and depth to the water table, etc. The upper limit of ET corresponds to pan evaporation, which is approximately 46 in/yr in the study area (Tibbals, 1990). A two-year study from a watershed in Volusia County (Sumner, 2001) resulted in an estimated ET rate of 36 in/yr for 1998 and 42 in/yr for 1999. According to Tibbals (1990), evapotranspiration largely ceases beneath the root zone, at approximately 13 feet.

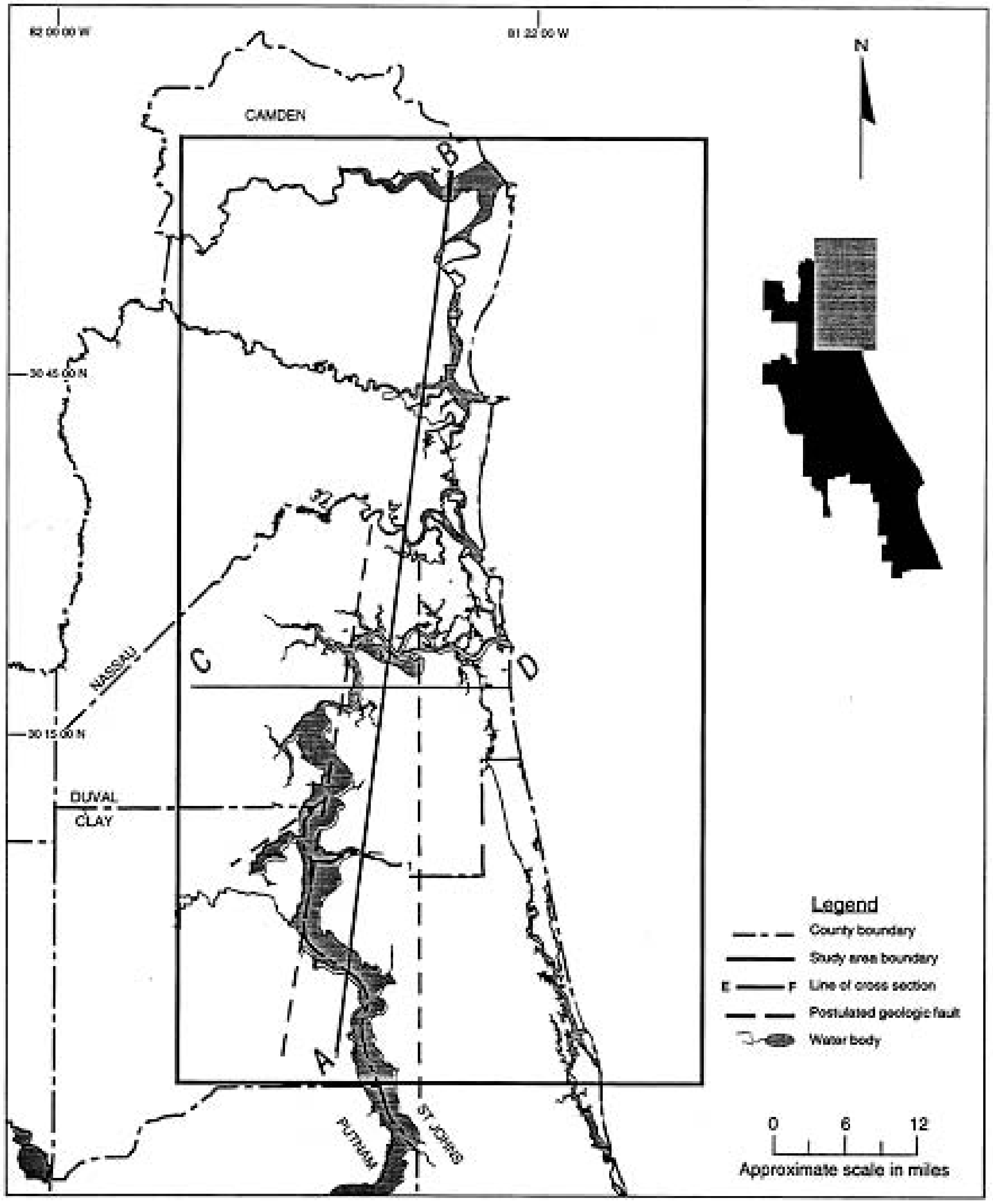
## Geologic Setting

A thick sequence of marine sedimentary rocks, resting on metamorphic strata, underlies the study area. The sedimentary deposits are the primary water-bearing unit in the area (Motz and Strazimiri, 1997). The geologic units, described in Table 1, include the pre-Hawthorn Tertiary carbonate units, the Hawthorn Group, and the post-Miocene deposits (Durden, 1997). Generalized geologic cross-sections, depicting the various geologic strata are presented in Figures 4-6. In ascending order, these are the Cedar Keys Formation of Paleocene age, the early Eocene Oldsmar Formation, the middle Eocene Avon Park Formation, late Eocene Ocala Limestone, middle Miocene Hawthorn group, and Post-Miocene deposits.

The Cedar Keys Formation consists predominantly of interbedded dolomite and anhydrite. Impermeable anhydrite beds that occur in the upper portions of the Cedar Keys Formation form the base of the Floridan aquifer system. The Oldsmar Formation of early Eocene age consists primarily of limestone and dolomite, and commonly contains cavities. The lower portions of the formation contain gypsum and thin beds of anhydrite, which impede groundwater flow in the formation (Durden, 1997). The Avon Park Formation of middle Eocene age is composed primarily of limestone and dolomite, which occasionally contains cavities. The Ocala limestone of late Eocene age overlies the limestone and dolomite of the Avon Park Formation.

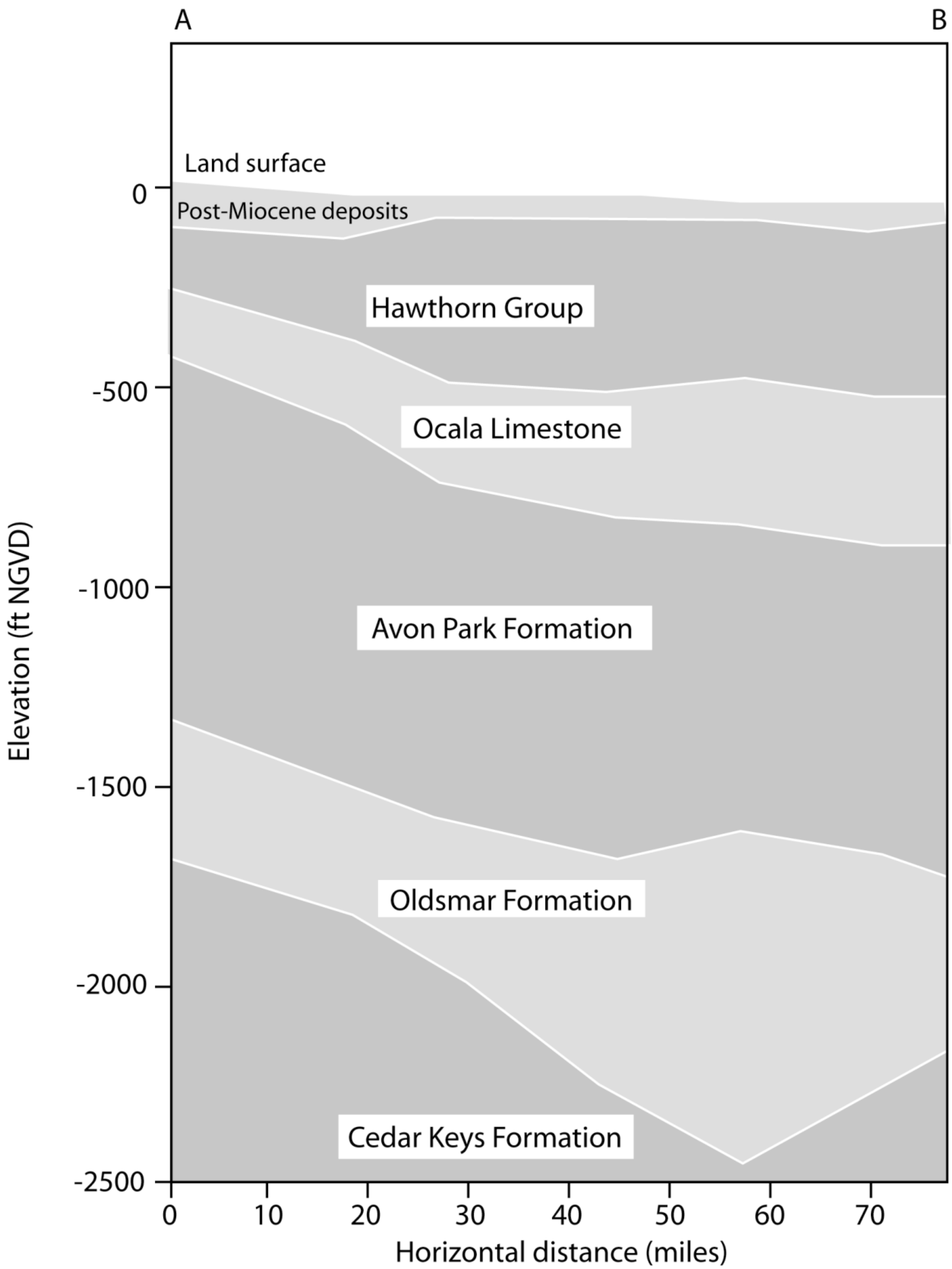
**Table 1. Geologic units in study area**

| Geologic Epoch | Stratigraphic Unit | Approximate Thickness (Feet) | Lithology |
|---|---|---|---|
| Pleistocene and Recent | Pleistocene and recent deposits | 10-100 | Discontinuous beds of loose sand, clayey sand, sandy clay, clay, marl, and shell |
| Pliocene | Pleistocene and recent deposits | 10-110 | Clay, clayey sand, sandy clay, sand, shell, and carbonate rock |
| Middle Miocene | Hawthorn Group | 100-400 | Interbedded clay, quartz sand, carbonate, and phosphate |
| Late Eocene | Ocala Limestone | 200-400 | Limestone |
| Middle Eocene | Avon Park Formation | 700-1,100 | Interbedded limestone and dolomite |
| Early Eocene | Oldsmar Formation | 400-800 | Interbedded limestone and dolomite |
| Paleocene | Cedar Keys Formation | Unknown | Interbedded dolomite and anhydrite |



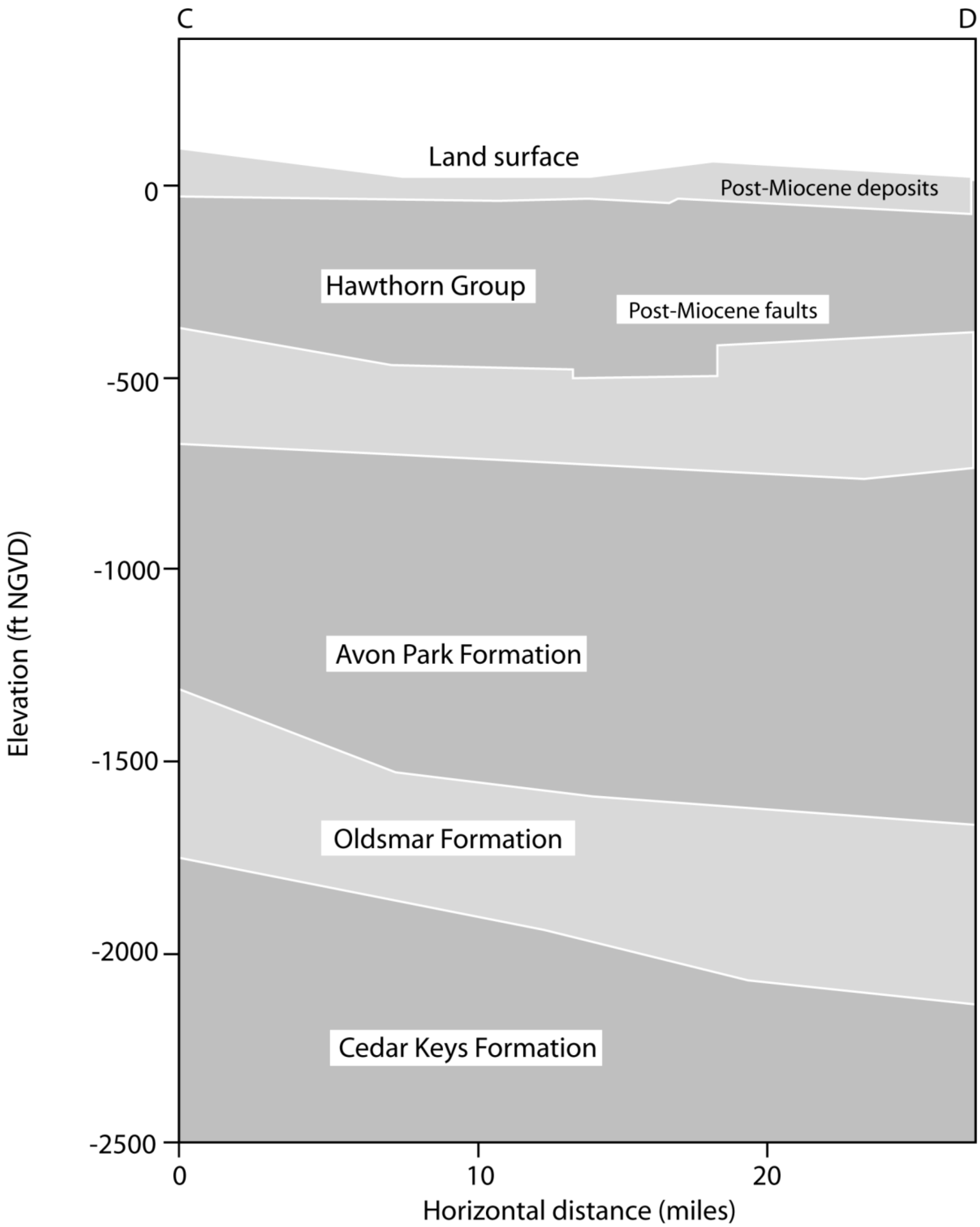

(Source: Durden, 1997)

**Figure 4 Location of geologic cross section**




(Source: Durden, 1997)

**Figure 5 Generalized geologic cross section A-B (refer to Figure 4 for location of cross section)**




(Source: Durden, 1997)

**Figure 6 Generalized geologic cross section C-D (refer to Figure 4 for location of cross section)**

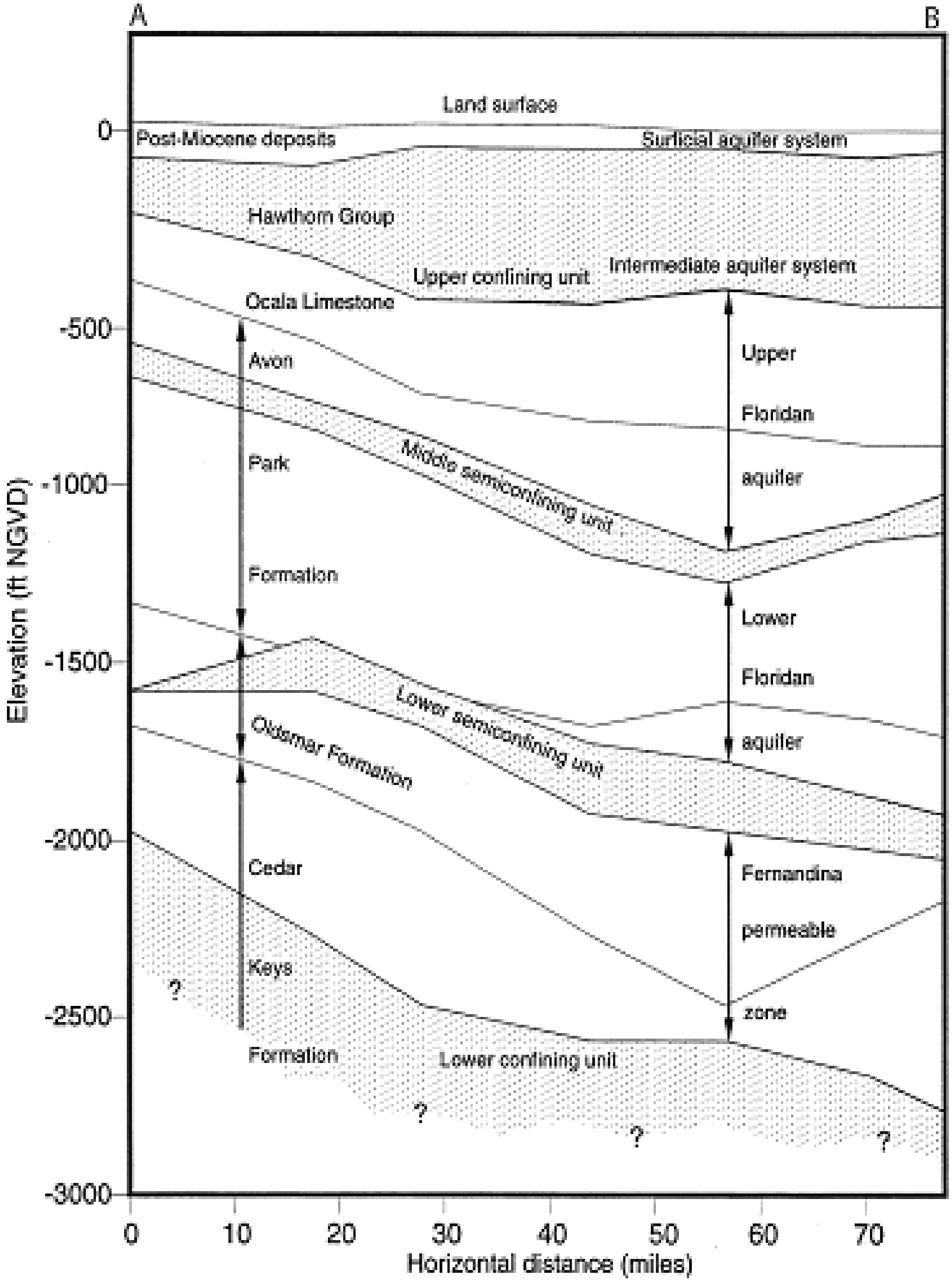
In places, the lower portions of the Ocala Limestone contain variable amounts of dolomite (Miller, 1986). The limestone has experienced dissolution over the years, which has enhanced its primary porosity (Durden, 1997). The Hawthorn Group of middle Miocene age consists of phosphate, clay, sand, and carbonate, which occur, in its most common form as dolomite. Being highly heterogeneous, and due to the fine texture of its constituents, both clastic and carbonate, the Hawthorne Group as a whole possesses relatively low permeability and acts as a confining unit between the underlying Eocene age limestone and the overlying post-Miocene deposits. Pliocene, Pleistocene, and recent deposits overlie the Miocene deposits. The Pliocene deposits are composed of clay, clayey sand, sand, shells, and/or carbonate rocks. The Pleistocene and recent deposits are generally dispersed in the study area. They consist primarily of sand, clayey-sand, sandy clay, marl, shell, and clay (Durden, 1997).

## Hydrogeologic Framework

The hydrogeologic units in the study area, as illustrated in Figures 7 and 8, consist of the surficial aquifer, the upper confining unit, the Upper Floridan aquifer, the middle semi-confining unit, the Lower Floridan aquifer, the lower semi confining unit, the Fernandina Permeable Zone, and the lower confining unit. The hydraulic characteristic of each unit is described below.

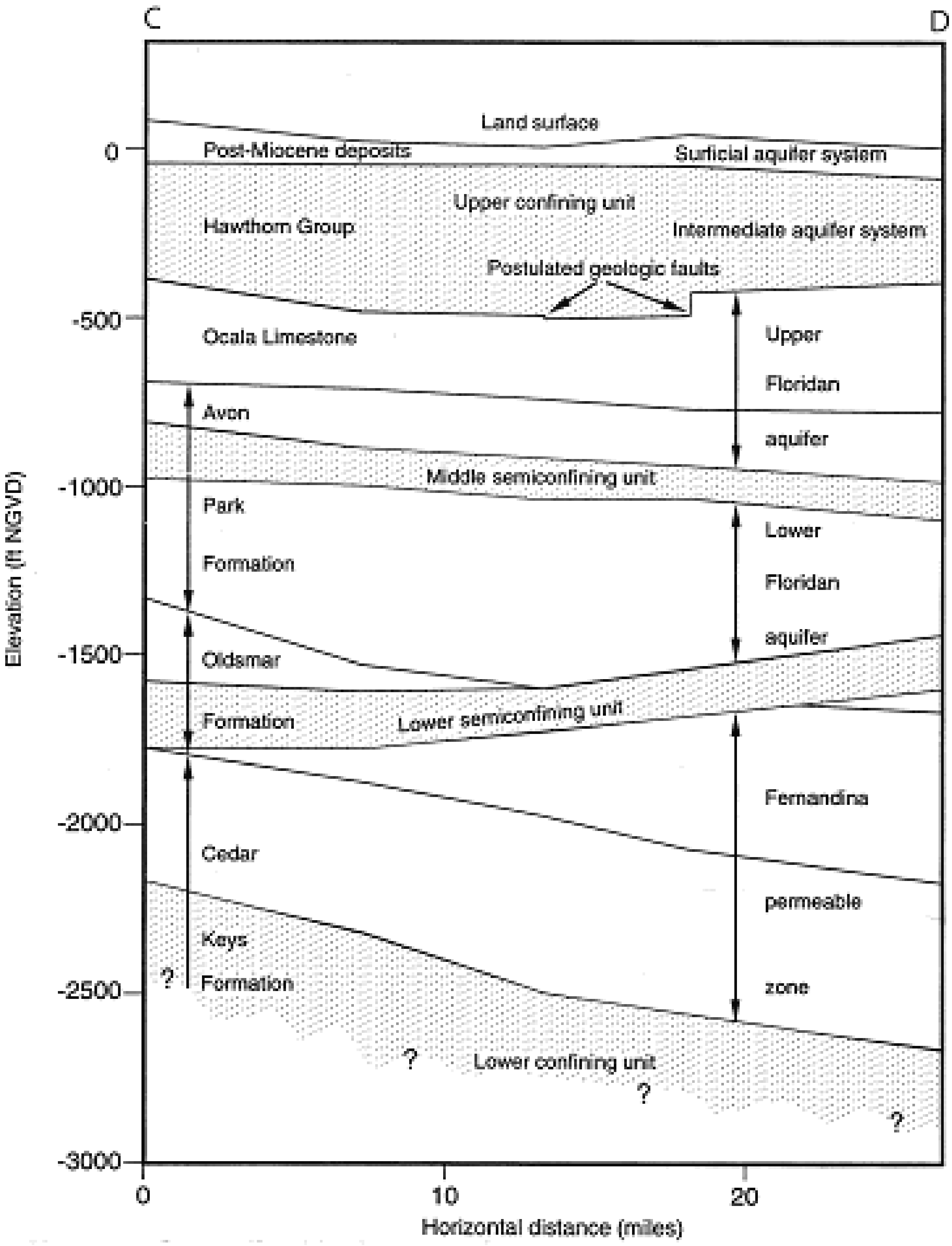
### Surficial Aquifer System

The surficial aquifer is the uppermost hydrogeologic unit in the study area and consists of Pleistocene to recent age sand, silt, clayey-sand, and shell beds (McGurk, 1998; Tibbals, 1990). This aquifer is generally under non-artesian conditions. The thickness of the surficial aquifer generally varies between 50 to 100 feet in the study area. Locally, in the Trail Ridge area, thicknesses in excess of 150 feet can be expected. Elevation to the base of the aquifer generally coincides with the top of the Hawthorn Group, and is presented in Figure 9a.




(Source: Durden, 1997)

**Figure 7 Generalized hydrogeologic cross-section A-B**




(Source: Durden, 1997)

**Figure 8 Generalized hydrogeologic cross-section C-D**

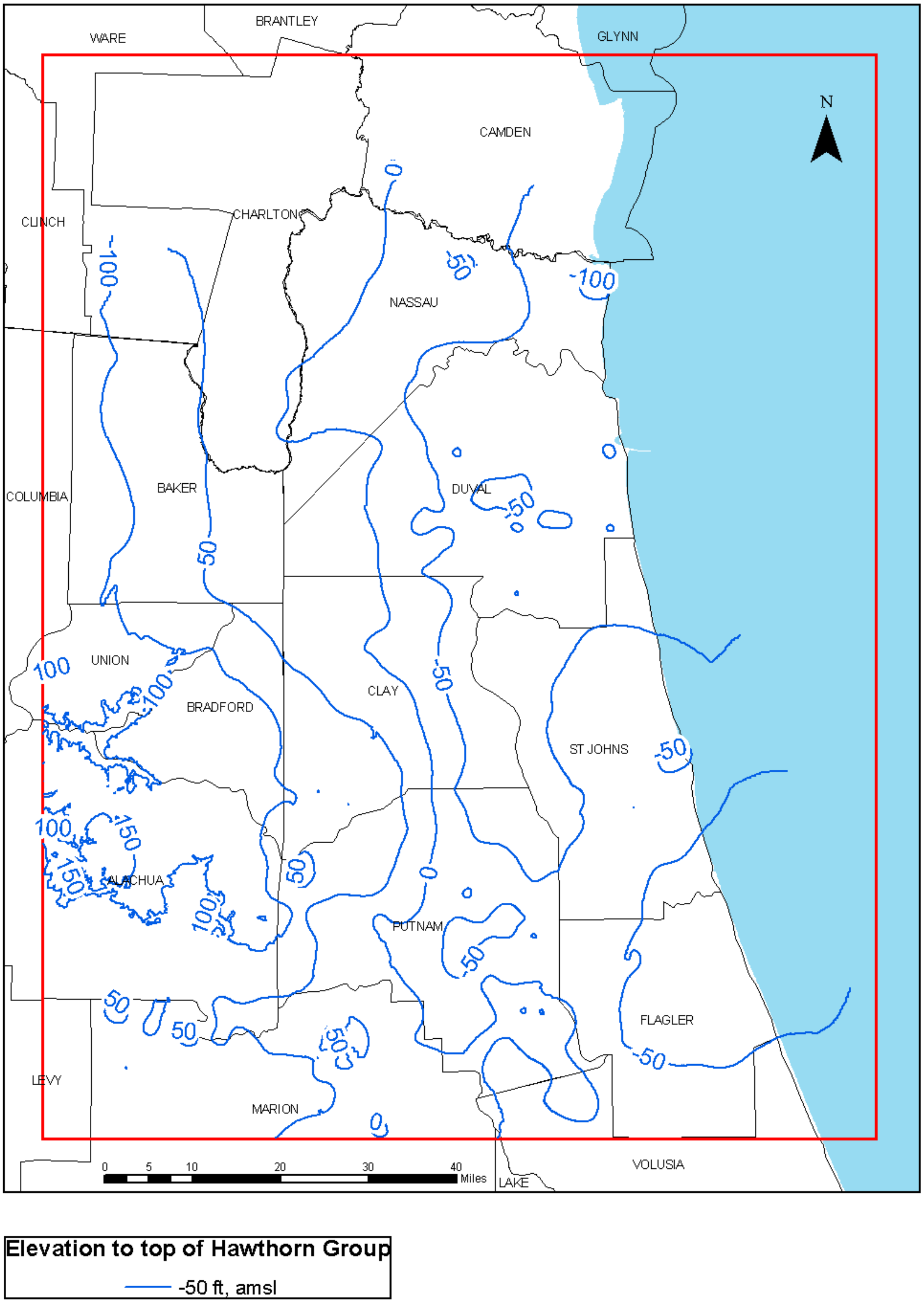



**Figure 9a Elevation to top of Hawthorn Group (source: Davis & Boniol, SJRWMD)**

There are relatively few field-derived estimates of hydraulic parameters of the surficial aquifer. In the Tillman Ridge area in St. Johns County, the hydraulic conductivity in the unconfined portion of the surficial aquifer was estimated to be 62 ft/day from a step-drawdown pumping test. In the southeastern portion of the study area, estimates of hydraulic conductivity derived from slug test range between 0.07 to 12.8 ft/day, while estimates from pumping tests in northern Volusia County are reported to range from 4 to 110 ft/day (McGurk, 1998). Based on literature review by Durden (1997): transmissivity estimates range from 100-1,000 ($ft^2$/day) near Fernandina Beach in Nassau County, 2,400 to 3,000 ($ft^2$/day) near Mayport in Duval County and 6,500 to 7,000 ($ft^2$/day) along the Atlantic Coastal Ridge west of St. Augustine in St. Johns County.

The unconfined portion of the surficial aquifer in the Tillman Ridge area, a transmissivity value of 280 ($ft^2$/day), based on a step-drawdown pump test, was reported by Toth (2001). This equates to a hydraulic conductivity of 6.2 ft/day. In the confined portions of the aquifer, a transmissivity of 6,078 ($ft^2$/day) was derived from pump tests, along with a leakance estimate of 0.0003 per day.

**Upper Confining Unit**

The surficial aquifer and the underlying Upper Floridan aquifer are separated by a relatively thick deposit of clay, sand, sandy clay, clayey sand, marl, limestone, and dolomite. This unit is referred to as the upper confining unit (UCU). The degree of confinement provided by this unit depends on the thickness and lithologic nature of the unit, which varies considerably over short distances. Thin, discontinuous lenses of permeable sand, shell, and limestone form locally important secondary artesian aquifers (McGurk, 1998). These are at times referred to as the intermediate aquifer. The thickness of the upper confining unit is presented in Figure 9b, which indicates a relatively thick layer of up to 450 feet in Duval County, a primary area of interest of the study. Within Volusia County, estimates of vertical hydraulic conductivity from core samples in the upper confining unit range from $7.6 \times 10^{-5}$ ft/day to 0.34 ft/day (McGurk, 1998). As indicated above, there are locally important sand deposits in the area. A horizontal

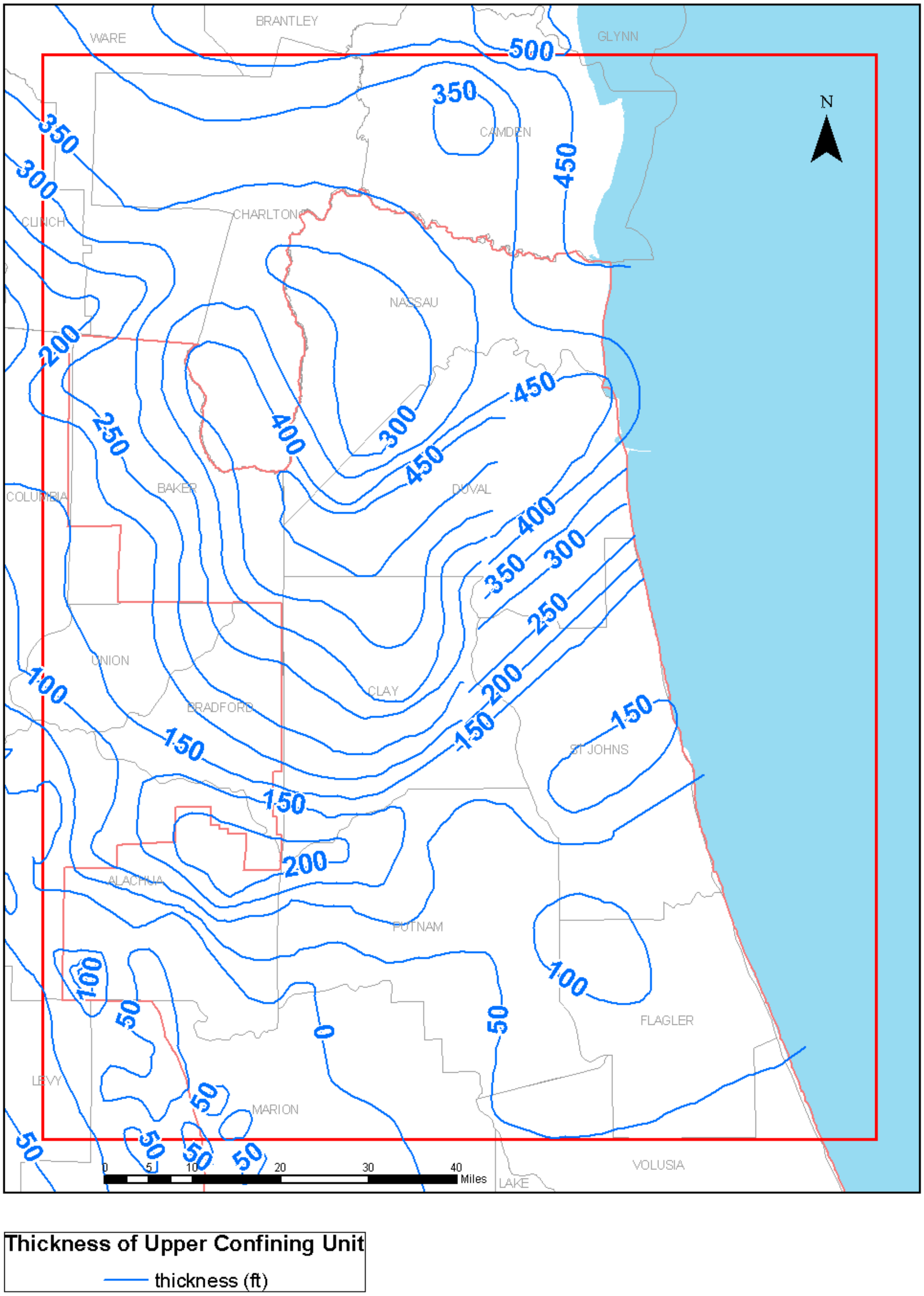



**Figure 9b Thickness of the upper confining unit (source: Miller, 1986)**

hydraulic conductivity of approximately 30 ft/day was obtained from a pump test at a well open to the intermediate aquifer in Volusia County (McGurk, 1998).

Leakance values, derived from pump tests, range from $4 \times 10^{-5}$ $day^{-1}$ to $1.5 \times 10^{-2}$ $day^{-1}$ (Szell, 1993). Based on a review of the literature, Durden (1997) reported leakance ranging from $1.0 \times 10^{-6}$ to $1.0 \times 10^{-5}$ per day in most of Duval, Nassau, and Camden counties, $1.0 \times 10^{-5}$ to $1.0 \times 10^{-4}$ per day in most of Clay and St. Johns counties, $2.5 \times 10^{-6}$ per day in the area of Fernandina Beach, and $1.0 \times 10^{-4}$ per day in the vicinity of Green Cove. Pump test at the Community Hall WTP site in Duval County resulted in leakance estimate of $9.0 \times 10^{-5}$ per day. Leakance values of $9.9 \times 10^{-6}$ and $3.1 \times 10^{-7}$ per day were also derived from two pump tests in St. Johns County (St. Johns County, 2003).

**Upper Floridan Aquifer**

The Upper Floridan aquifer is the primary source of groundwater in the area. It includes the highly permeable Ocala Limestone of Late Eocene age and the upper regions of the Avon Park Formation, also of the Eocene Epoch (Durden, 1997). The high degree of permeability is attributed to the formation of dissolution cavities and caverns developed over the ages because of chemical/mechanical weathering and erosion processes in the groundwater flow regime. Elevation to the top of the Upper Floridan aquifer (Figure 10) varies from –200 ft (amsl) along the western boundary to less than –500 ft (amsl) in Duval County. The base of the Upper Floridan aquifer, as delineated by Miller (1986) and presented in Figure 11, is marked by the top of the middle semi confining unit (MSCU). In the western regions of the study area, Miller assumed that the MSCU was largely absent and therefore the base of the Upper Floridan aquifer is equivalent to the base of the entire Floridan aquifer system. This accounts for the discontinuity of some contour lines in Figure 11. Sepulveda implemented this concept in 2002 for the USGS Mega Model. The thickness of the Upper Floridan aquifer (Figure 12) represents all strata that lie between the top of the Floridan aquifer system and the base of the Upper Floridan aquifer, where a regionally extensive middle confining unit exists, or the base of the entire aquifer system, where no appreciable thickness of low-permeability rock is present

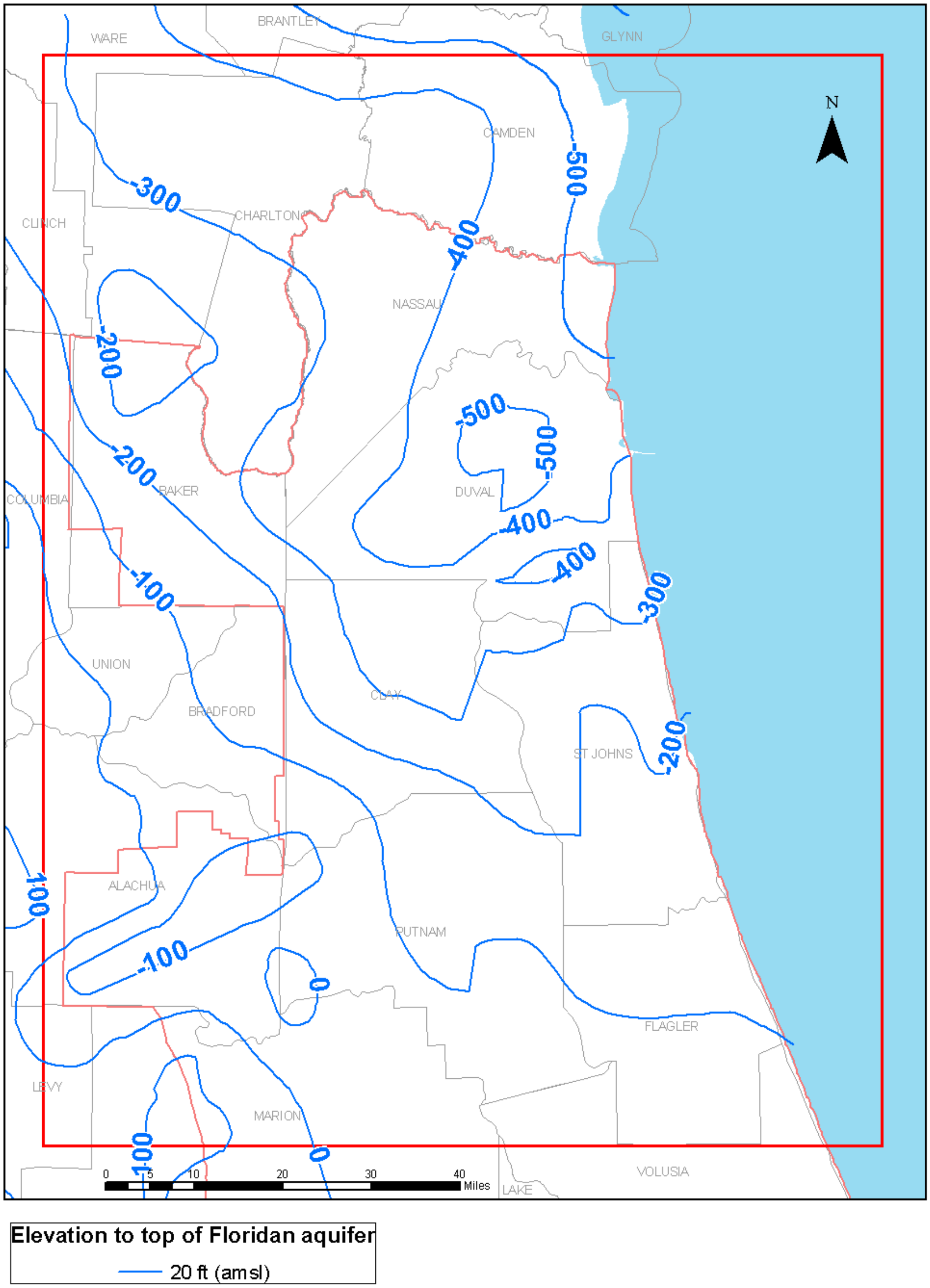



**Figure 10 Elevation to top of Upper Floridan aquifer (source: Miller, 1986)**

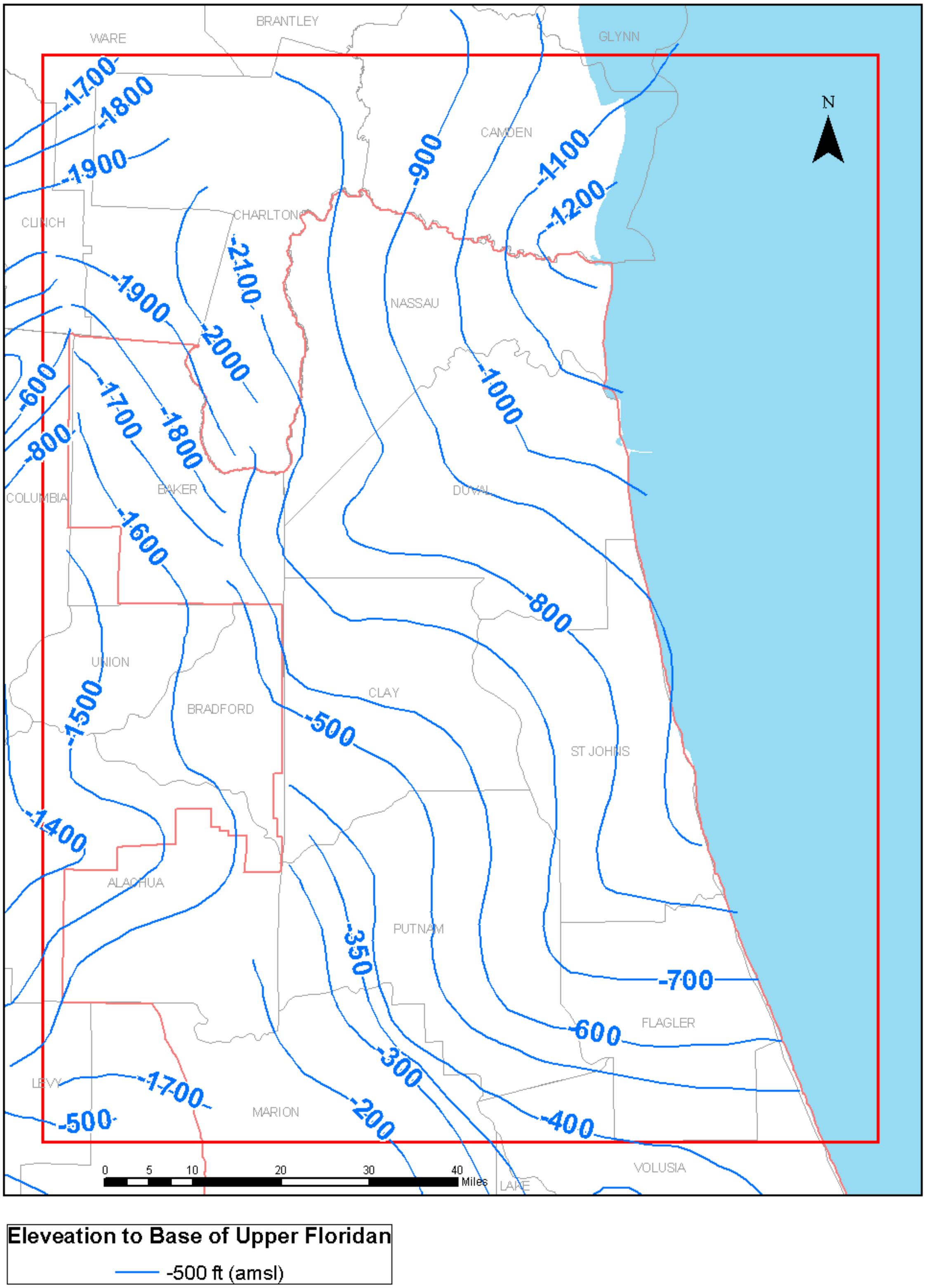



**Figure 11 Elevation to base of Upper Floridan aquifer (source: Miller, 1986)**

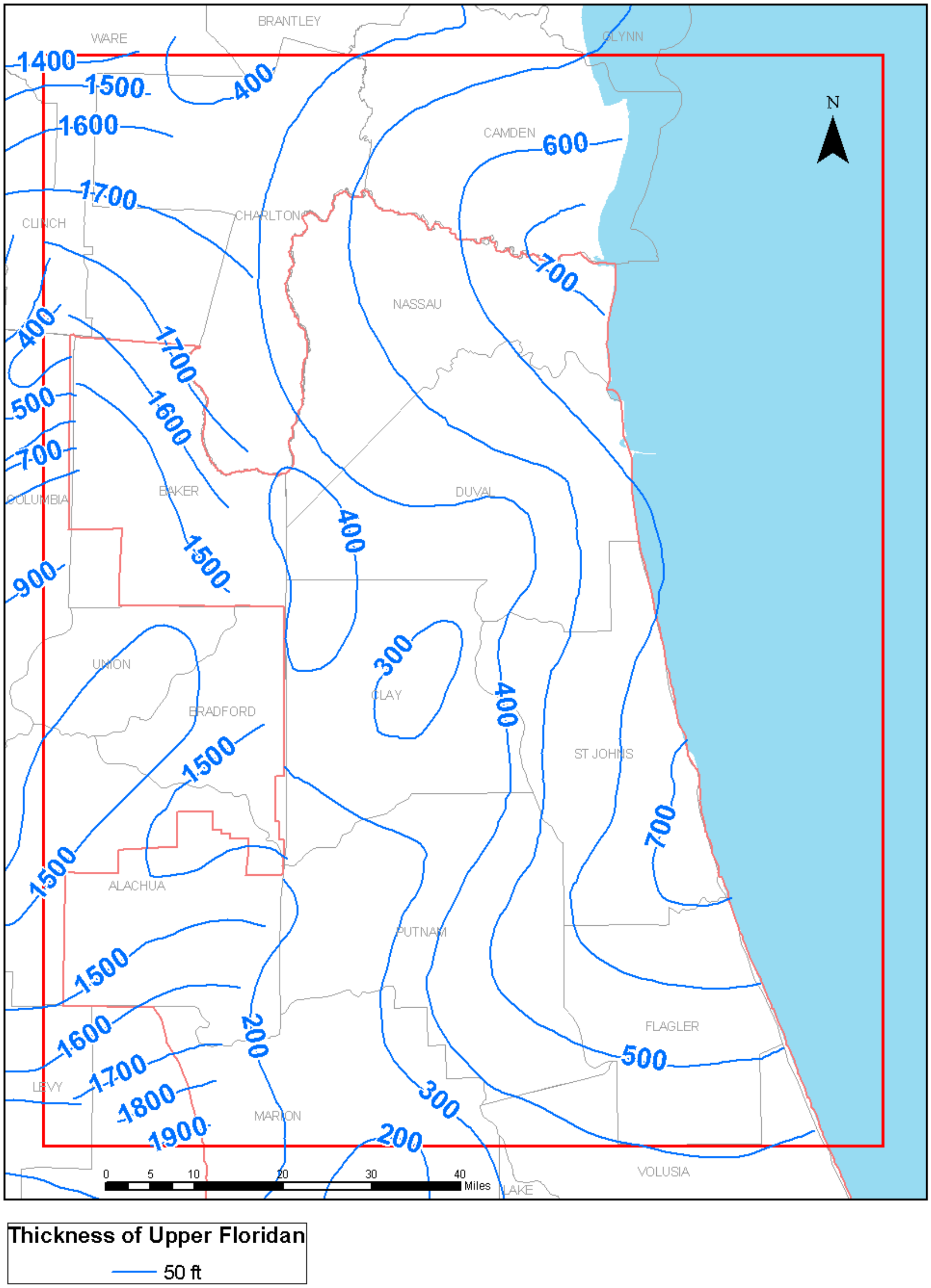



**Figure 12 Thickness of Upper Floridan aquifer (source: Miller, 1986)**

(Miller, 1986). The thickness of the Upper Floridan aquifer varies from approximately 300 feet in Clay County to greater than 1700 feet in the western portions of the study area, where the base of Upper Floridan aquifer is assumed to coincide with the base of the Floridan aquifer system.

Previous modeling studies indicate that the horizontal hydraulic conductivity of the Upper Floridan aquifer in the study area is highly variable, but generally decreases from west to the east. Based on a literature review by Durden (1997), transmissivity estimates from modeling studies and aquifer performance tests in the Upper Floridan aquifer range from 20,000 to 55,000 ($ft^2$/day) in the Fernandina Beach and St. Mary's area, 50,000 to 100,000 ($ft^2$/day) along coastal areas in St. Johns, Duval, and Nassau counties, 50,000 to 200,000 ($ft^2$/day) in most of Clay county, 100,000 to 250,000 ($ft^2$/day) in western Nassau, Duval, and northern Clay counties, 250,000 ($ft^2$/day) and higher in Camden County, and 300,000 to 450,000 ($ft^2$/day) in central and western Nassau and northern Duval counties.

Based on data collected during two pump tests in the area, transmissivities of 42,267 and 82,386 (ft2/day) were estimated in St. Johns County (St. Johns County, 2003). These transmissivity values correspond to hydraulic conductivity values of 194 and 319 ft/day, respectively. Pump test at a site in Duval County resulted in an average estimated transmissivity of 23,060 (ft2/day) (CH2M Hill, 2000). In the southeastern portions of the study area, estimated transmissivities range from 3,743 to 160,000 (ft2/day) (McGurk, 1998).

Krause and Randolph (1989) compiled data of field observed hydraulic conductivity and transmissivity values for the Upper Floridan aquifer in southeast Georgia and adjacent parts of Florida. A map of the test sites and estimated hydraulic properties is presented in Figure 13. As is evident from the figure, the hydraulic conductivity and transmissivity values vary substantially in the study area. Zones of hydraulic conductivity are delineated within a defined range that hydraulic conductivity is expected to vary. The information in the Figure 13 is useful for establishing bounds on the magnitude of hydraulic conductivity in the numerical model.

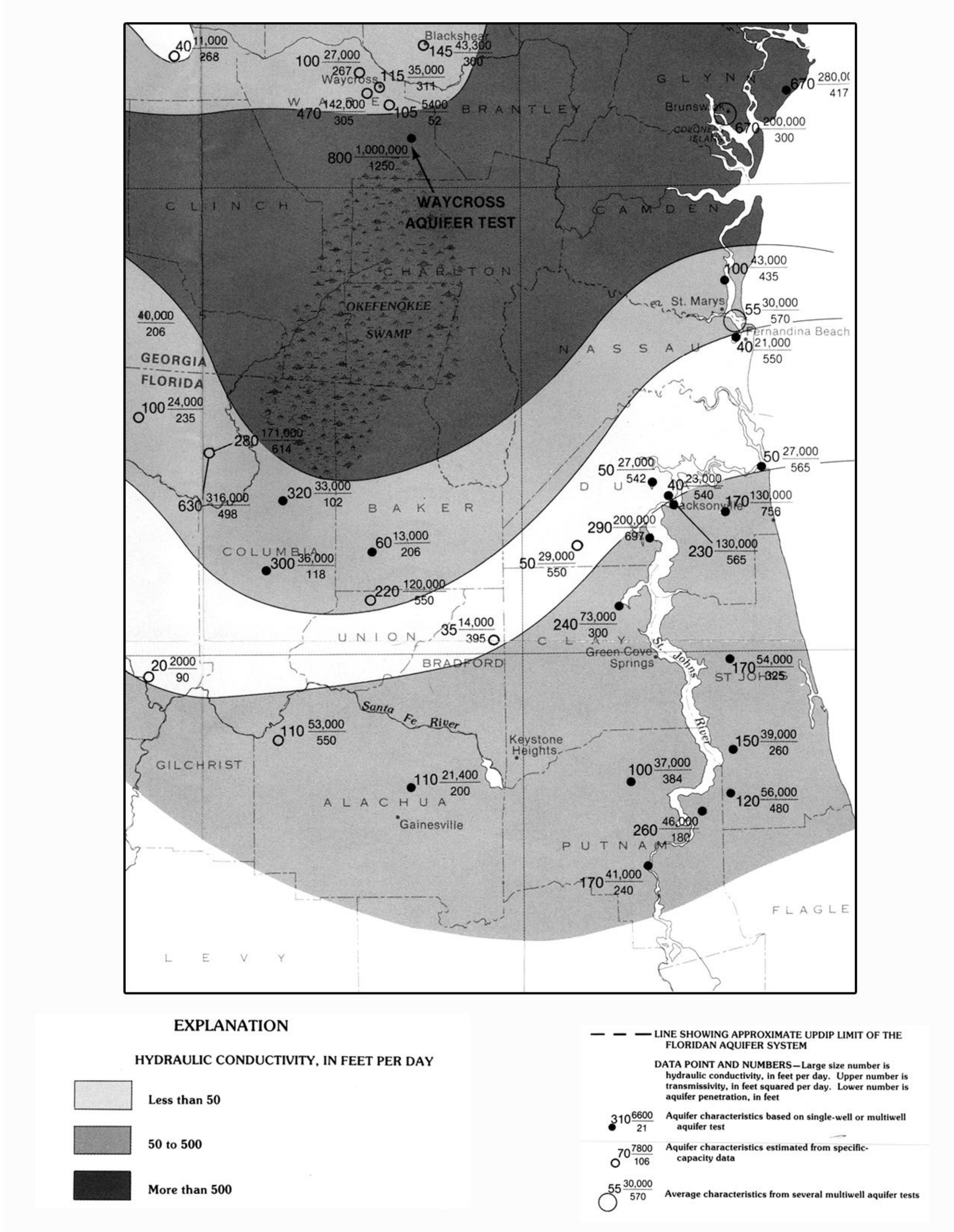



**Figure 13 Field values of hydraulic conductivity and transmissivity in Upper Floridan aquifer (source: Krause and Randolph, 1989)**

## Middle Semi confining Unit

Beds of low permeability, soft chalky limestone, and hard dolomitic limestone separate the Upper Floridan aquifer from the Lower Floridan aquifer. This unit is generally referred to as the middle semi-confining unit (MSCU) and lies within the Avon Park. The base of the unit is assumed to coincide with the top of the Lower Floridan aquifer (Figure 14). Very limited data exists regarding the magnitude of leakance of the MSCU. Durden and Motz (1991) estimated the leakance to range from $1.0 \times 10^{-8}$ to $1.0 \times 10^{-1}$ per day in most of Nassau, Duval, Clay, and St. Johns counties.

## Lower Floridan Aquifer

Geologic units within the Lower Floridan aquifer include the Avon Park Formation, the Oldsmar Formation, and the upper part of the Cedar Keys Formation. All beds in the Floridan aquifer system that lie below the base of the middle confining unit and above the base of the Floridan aquifer system are included in the Lower Floridan aquifer. The top surface of the aquifer slopes downward from the northwest to the southeast (Figure 14). The top of the Lower Floridan aquifer presented in Figure 14 is defined as the base of MSCU, and where the MSCU was not assumed to exist as a significant confining unit by Miller (1986), the Lower Floridan aquifer was not mapped.

There are no known aquifer performance tests exclusively for the Lower Floridan aquifer. Based on aquifer tests at wells open to both the Upper and Lower Floridan aquifers in Duval County, Krause and Randolph (1989) estimated the transmissivity of the aquifer to be approximately 400,000 ($ft^2$/day). A modeling study by Durden and Motz (1991) resulted in transmissivity estimates of 300,000 to 450,000 ($ft^2$/day) in most of Duval and Clay counties, 50,000 to 200,000 ($ft^2$/day) in southeastern Clay, central St Johns, and coastal Duval counties. In the Fernandina Beach area, transmissivity was estimated to be less than 50,000 ($ft^2$/day), which matches an estimate of 40,000 to 60,000 ($ft^2$/day) by Brown (1984). For the recently completed USGS Mega Model (Sepulveda, 2002) the calibrated transmissivity of the Lower Floridan aquifer in large

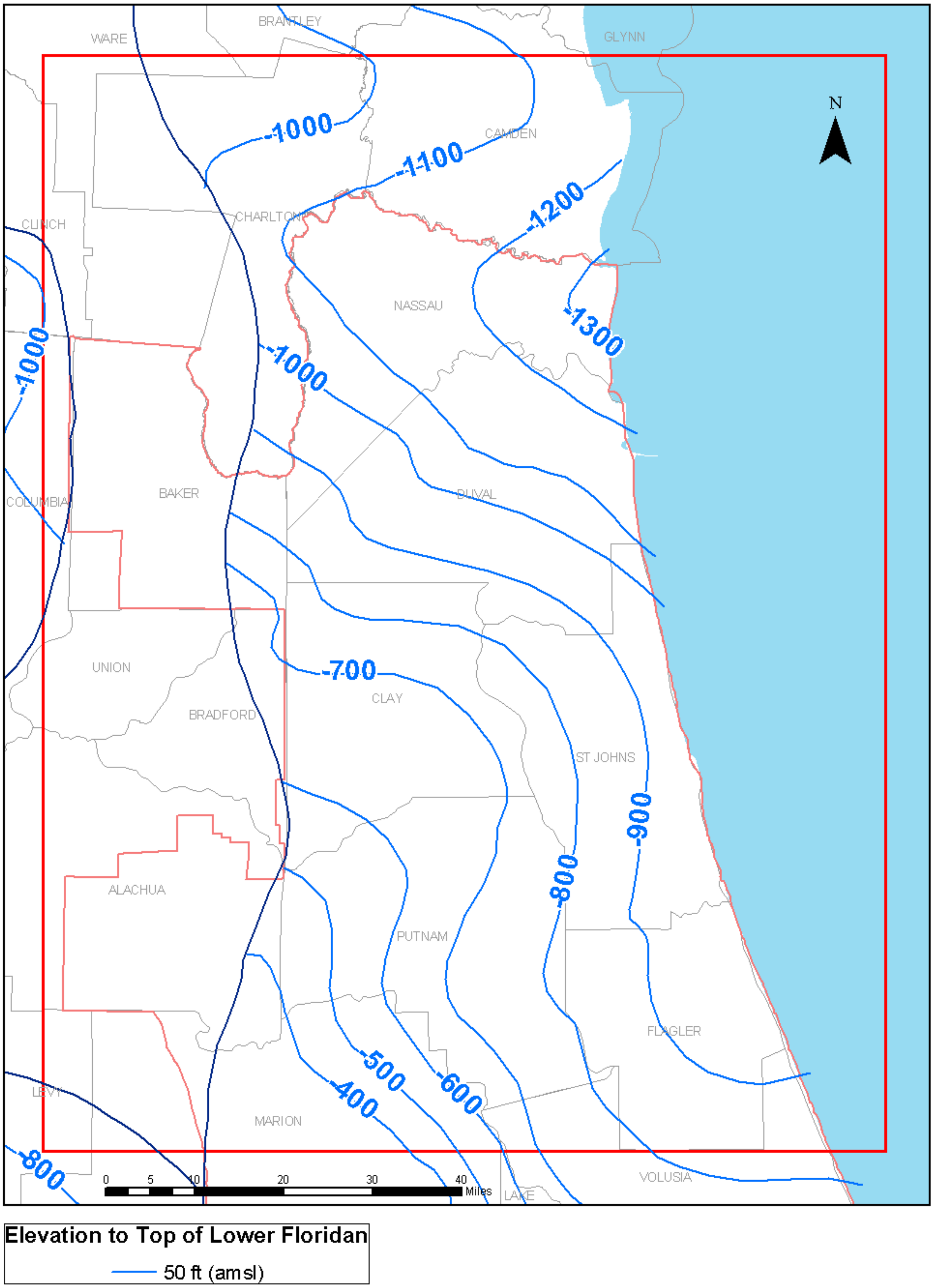



**Figure 14 Elevation to top of Lower Floridan aquifer (source: Miller, 1986)**

portions of Duval, Nassau, and Camden counties ranged from 700,000 to 760,000 (ft2/day). In other parts of the study area, the transmissivity ranged from 10,000 to 700,000 (ft2/day).

**Lower Semi confining Unit**

Within the study area, the lower semi-confining unit (LSCU) is contained within the Oldsmar, Avon Park, and Cedar Keys formations in various degrees. The unit is composed mainly of limestone and dolomite of low permeability. Very little data exists regarding the hydrogeologic properties and areal configuration of this unit.

**Fernandina Permeable Zone**

The locally cavernous Fernandina Permeable Zone (FPZ) lies in the Oldsmar and Cedar Keys Formations (Durden, 1997). This unit may also be referred to as the lower portion of the Lower Floridan aquifer. Beds of anhydrite, or in their absence, low permeability gypsiferous and anhydritic carbonate beds at the base of the FPZ form the hydraulic base of the Floridan aquifer system (Sepulveda, 2002). The elevation to the top of the Fernandina Permeable Zone, as defined by Miller (1986), is presented in Figure15a. The elevation to the base of the Floridan aquifer is presented in Figure 15b. The base varies from 1,500 to over 3,000 feet below sea level in the study area, dipping gently from the west to the east. No known field derived value of transmissivity of the Fernandina Permeable Zone exists.

**Lower Confining Unit**

The confining unit underlying the Fernandina Permeable Zone is referred to as the lower confining unit (LCU). It consists of thick anhydrite beds located in the Cedar Keys Formation. The thickness of the unit is unknown and very little is known of its hydrogeologic properties. Based on the geologic composition of the unit, it is assumed that it provides adequate confinement to the Floridan aquifer system.

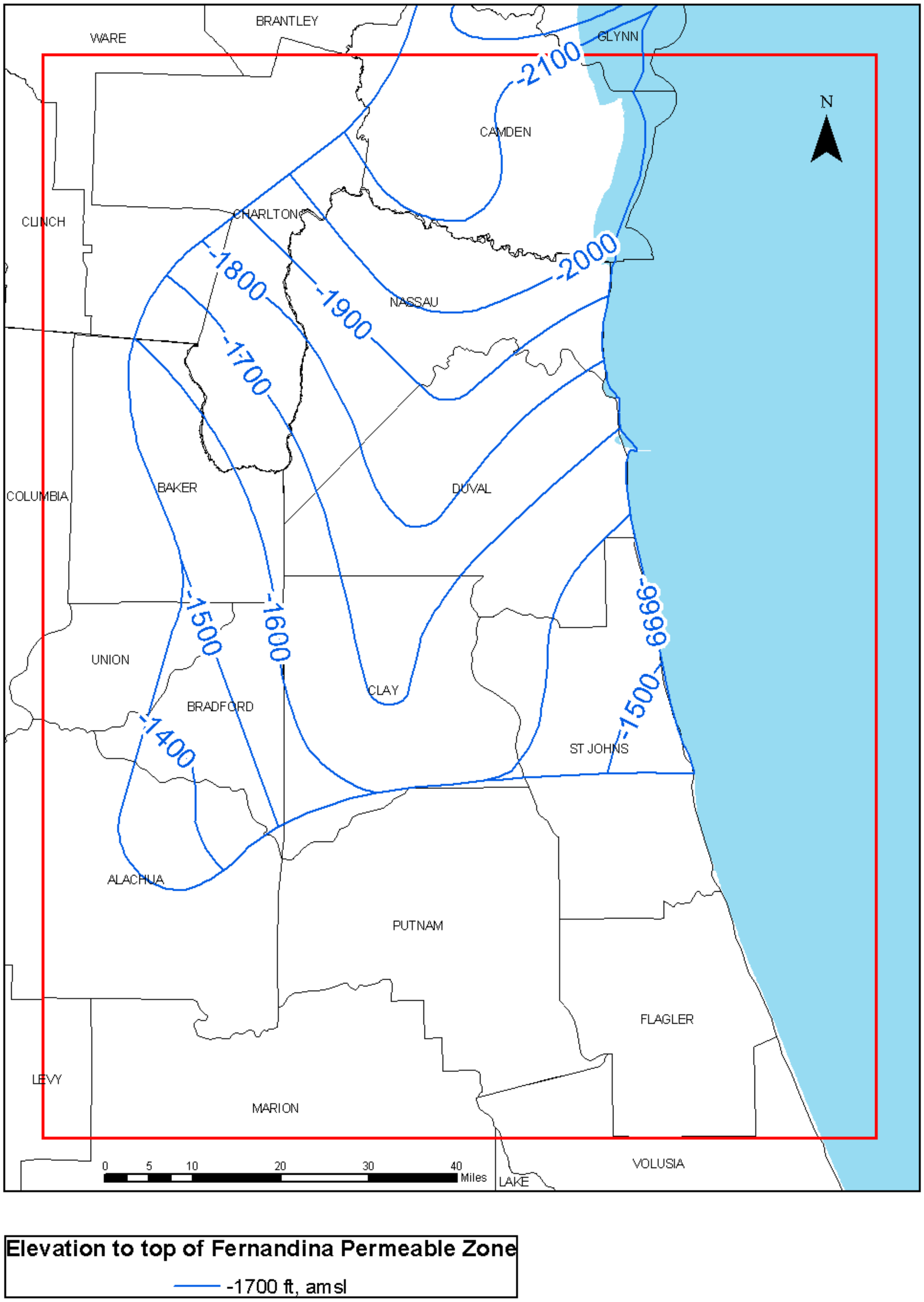



**Figure 15a Elevation to top of Fernandina Permeable Zone (source: Miller, 1986)**

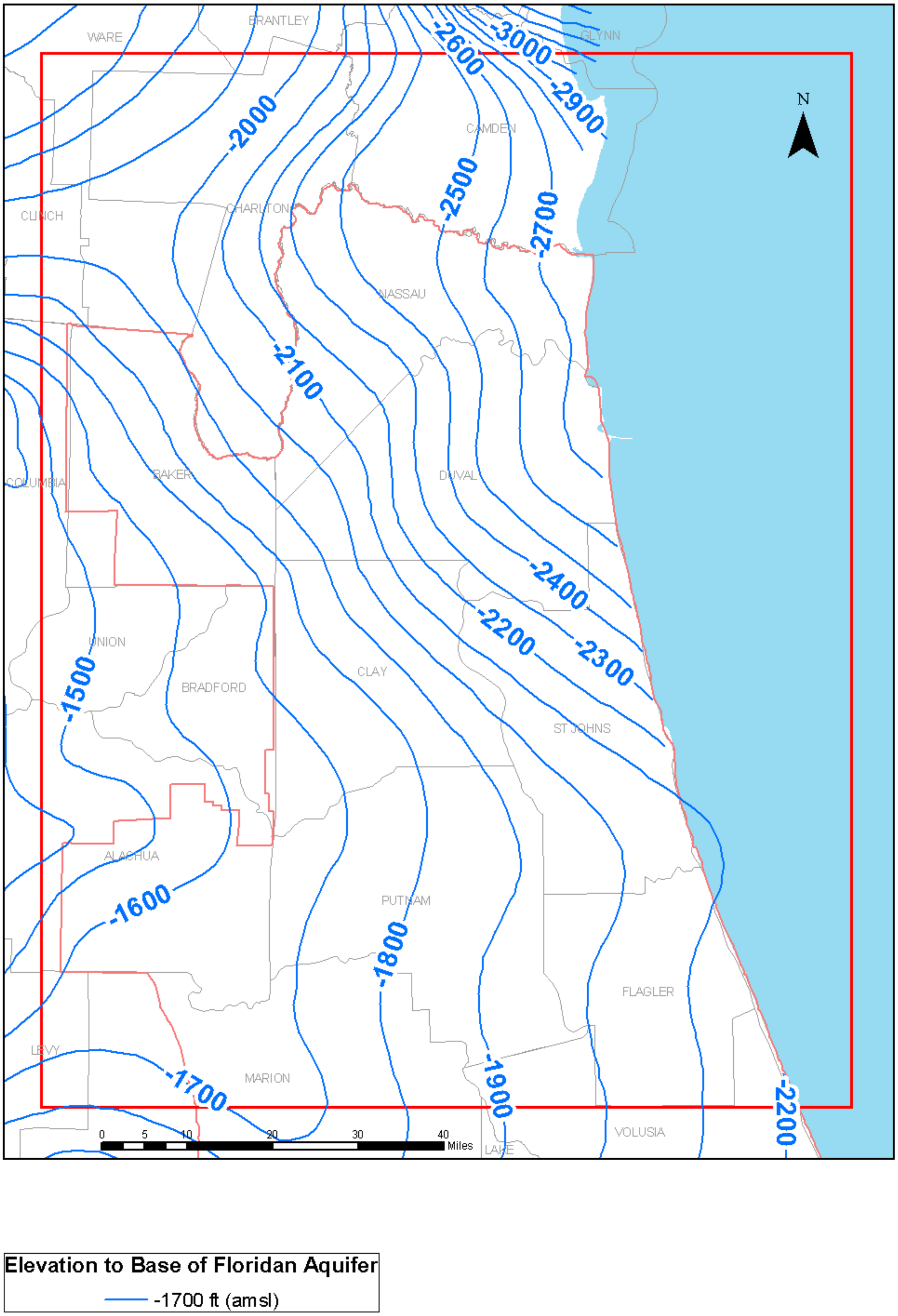



**Figure 15b Elevation to base of Floridan Aquifer System (source: Miller, 1986)**

## Surface Water Features

There are numerous lakes, wetlands, creeks, streams, and rivers in the area. The St. Johns River is the dominant surface water body, draining ground water from the surficial aquifer and receiving surface water runoff from precipitation. The Intracoastal Waterway drains areas along the coast. Principally the Nassau River drains northern Duval and southern Nassau counties, while the Satilla and St. Mary's River drain northern Nassau and southern Camden counties.

There are several perched lakes in the Upper Etonia Creek Basin located in Alachua, Bradford, Clay, and Putnam counties. These are a source of water to the underlying surficial and Upper Floridan aquifers. Along the south-central boundary of the study area, Lake George appears to be well connected with the surficial and underlying Upper Floridan aquifer. The location of major surface water features represented in the groundwater model is presented in Figure 16.

## Recharge and Discharge

The surficial aquifer system is recharged by rainfall percolating through the vadose zone. It is also recharged by seepage from lakes, streams, and rivers in the area. Additional recharge to the aquifer is in the form of upward leakage from the underlying Upper Floridan aquifer in areas where the potentiometric head in the Upper Floridan aquifer is higher than the head in the surficial aquifer. Discharge from the aquifer occurs in the form of downward leakage to the underlying Upper Floridan aquifer and the Atlantic Ocean, evapotranspiration, withdrawals from shallow wells, and seepage to streams and lakes in the area.

The Upper Floridan aquifer is recharged largely by downward leakage from the surficial aquifer. This occurs in areas where water level in the surficial aquifer is at a higher elevation than the potentiometric surface of the Upper Floridan aquifer. These areas are generally associated with topographic highs in the western regions of the model. The Upper Floridan aquifer is also recharged by groundwater percolating upward from the Lower Floridan aquifer. This occurs mainly along the coastal region in the study area, where the Upper Floridan aquifer discharges


**Figure 16 Modeled surface water features in study area**

into the overlying surficial aquifer. The rate of diffuse recharge/discharge is a direct function of the difference in the potentiometric head between the aquifers and the leakance of the confining unit separating the two aquifers. A small number of drainage wells also recharge the Upper Floridan aquifer.

Groundwater from the Upper Floridan aquifer exits the study area as outflow along the lateral model boundaries, through spring discharge, and as withdrawals from productions wells. The average 1995 flow rates in the production and drainage wells are discussed below (refer to Groundwater Withdrawals).

In the western region of the study area, recharge from the surficial aquifer to the Upper Floridan aquifer continues into the Lower Floridan aquifer. Due to thinning of the Upper Confining unit in the western regions of the study area, recharge to the Upper Floridan Aquifer is less constrained. Based on interpreted potentiometric surfaces, groundwater in the Floridan aquifer exits the model along the western boundary into the adjacent Suwannee River Water Management District. Groundwater is also withdrawn from the Upper and Lower Floridan aquifers through pumping.

A Geographic Information System based study (Boniol and others, 1993) was conducted by the District to delineate zones of recharge/discharge that occurs between the Upper Floridan aquifer and the surficial aquifer (Figure 17). Discharge was shown to occur along the coastal regions, the St. Johns River, Nassau River, and St. Mary's River drainage basins, and near Lake George. Recharge varies between 0-4 in/yr in most of the areas except along the southwestern boundary, near Keystone Heights, and areas surrounding Lake George, where recharge in excess of 12 in/yr can be expected. Locally, recharge rates maybe as high as 20 in/yr (Tibbals, 1990), and higher rates can be expected in closed sinkhole depressions. Recharge also occurs near the coast along the Atlantic Coastal Ridge in St Johns County and Central Park Ridge in Duval County.

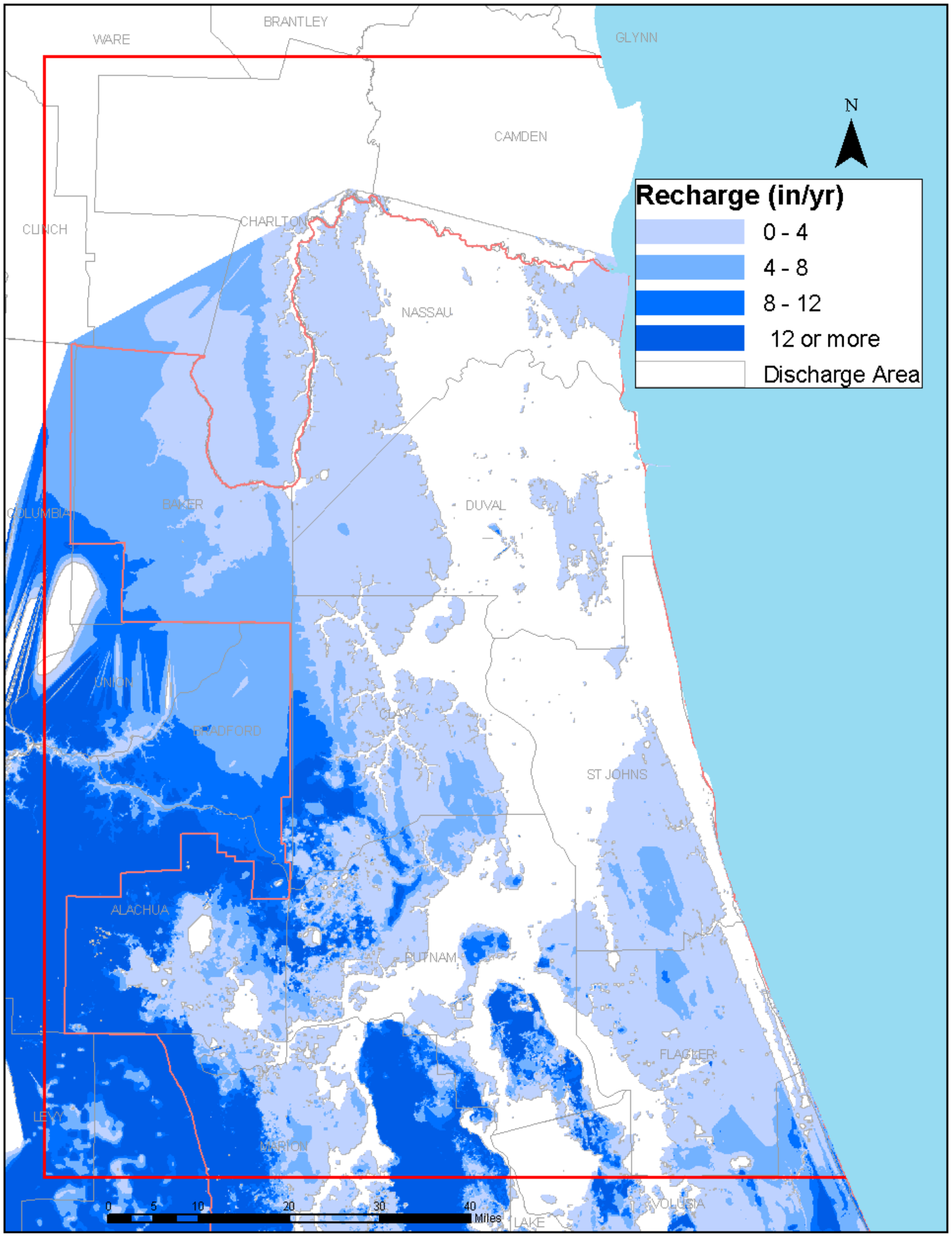



**Figure 17 Estimated recharge to the Upper Floridan aquifer from the surficial aquifer**

## Springs

A large portion of discharge from the Upper Floridan aquifer occurs through springs in the area (Figure 18). The average 1995 discharge and spring pool elevation at 14 documented springs in the model area is presented in Table 2. Most of the springs are located in the southern half of the study area and discharge relatively minor quantities of groundwater. The exceptions are Crescent, Croaker Hole, and Salt Springs, which discharged on average 30, 83, and 79.5 cubic feet per second (cfs), respectively, in 1995. The total 1995 discharge at the 14 springs was 225 cfs, which is 39.5% of the total groundwater pumpage from the Upper Floridan aquifer in 1995 as discussed below.

**Table 2 Modeled springs in study area**

| Spring | Stage (ft, amsl) | Estimated Average 1995 Flow (cfs) |
|---|---|---|
| Wadesboro | 24 | .94 |
| Green Cove | 21 | 3.11 |
| Crescent Beach | .5 | 30.0 |
| Whitewater | 23.5 | 1.40 |
| Orange | 54.5 | 2.86 |
| Blue (submerged in Rodman Reservoir) | 31 | 0.5* |
| Camp Seminole | 54.5 | .79 |
| Welaka | 11 | 1.10 |
| Mud | 8.3 | .65 |
| Beecher | 2 | 9.04 |
| Croaker Hole | 6.8 | 83.00 |
| Tobacco Patch | 30.8 | 2.80 |
| Wells Landing | 30.8 | 9.88 |
| Salt | 1.8 | 79.53 |
| Total | | 225.6 |

* Estimated from Mega Model (Sepulveda, 2000)

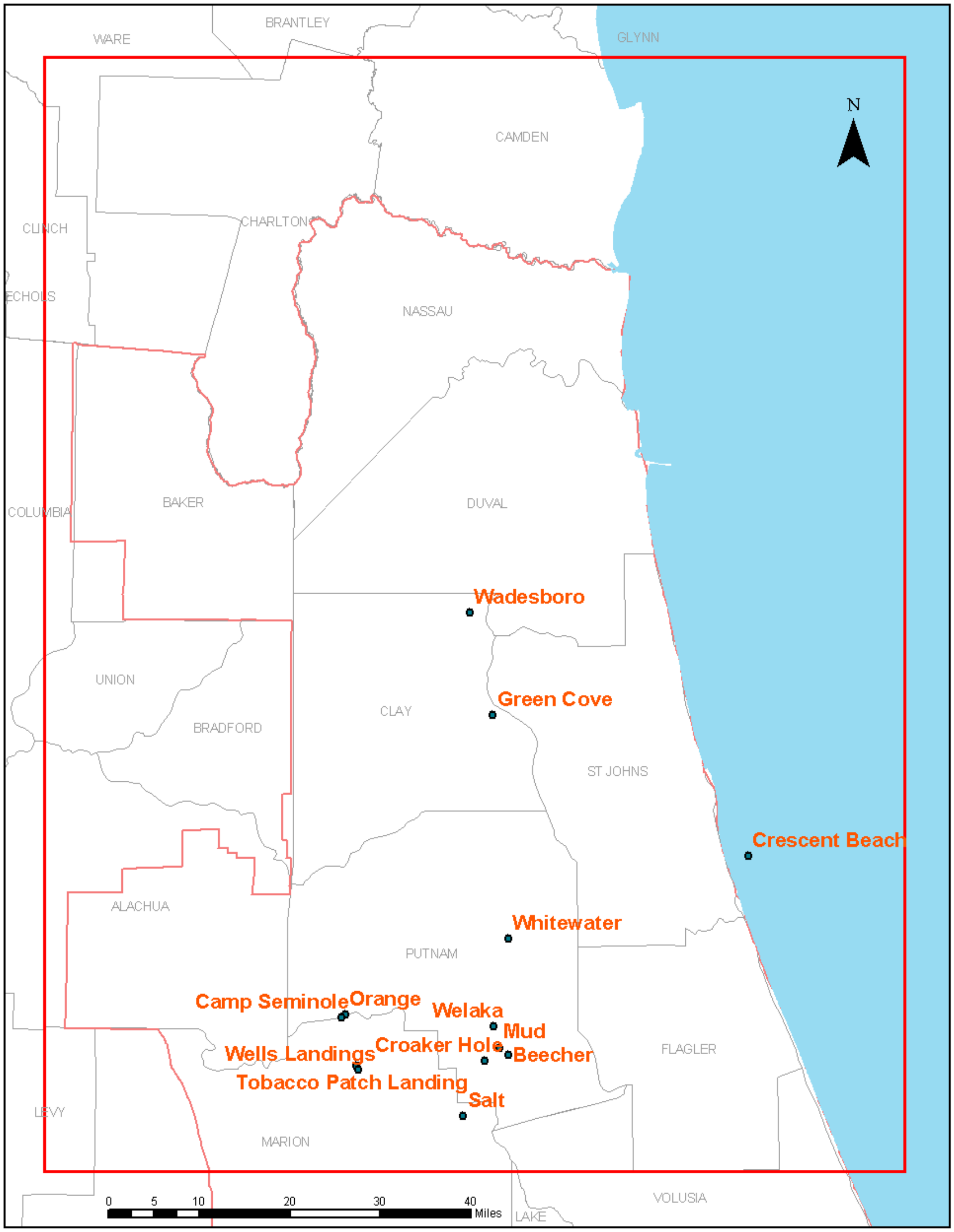



**Figure 18     Modeled springs in study area**

## Potentiometric Levels

The water table in the surficial aquifer is highly variable and generally understood to mimic the land surface. Due to sharp variations in the topographic surface, and the presence of numerous lakes and other surface water bodies in the area, it is difficult to construct a water table map of the surficial aquifer from the sparse observation well data. This is because flow in the surficial aquifer is vertically dominant and, therefore, the head at a particular location does not necessarily have much correlation with the head at another observation well. Water levels in the surficial aquifer are measured periodically at several observation wells in the study area. The location of the observation wells in 1995 is presented in Figure 19. As explained above, it was not possible to construct a water table map from the observation well data as the water levels are highly correlated with surface topography and soil conditions, and there was inadequate data to account for this variation over the various physiographic regions in the area.

Similar attempts in previous investigations (Durden and Motz, 1991), water levels in the surficial aquifer were derived though a regression relationship between water levels and land surface elevation. Water level elevations, as a function of the land surface elevation, at observation wells are presented in Figure 20. It is evident from the figure that there are multiple physiographic regions in the study area. In this study, a linear regression analysis was conducted in order to derive a relationship between water table and land surface elevations for the entire model area. Based on the regression analysis,

$$\text{Water Table} = 0.88\ (\text{Land Surface Elevation}) - 1.91$$

The water table elevations obtained from the above relationship were used as a calibration target for the surficial aquifer.

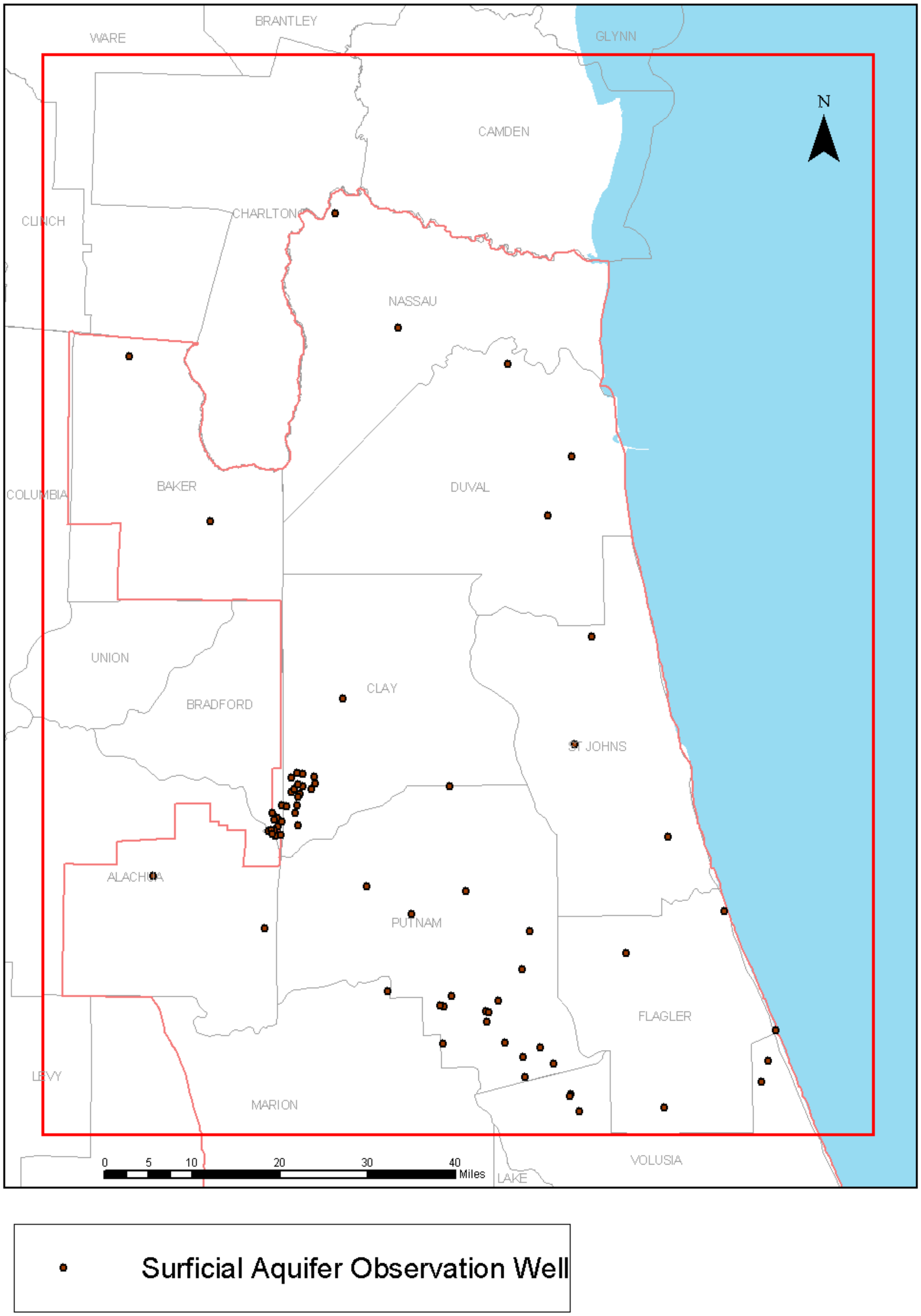



**Figure 19 Location of observation wells in surficial aquifer**

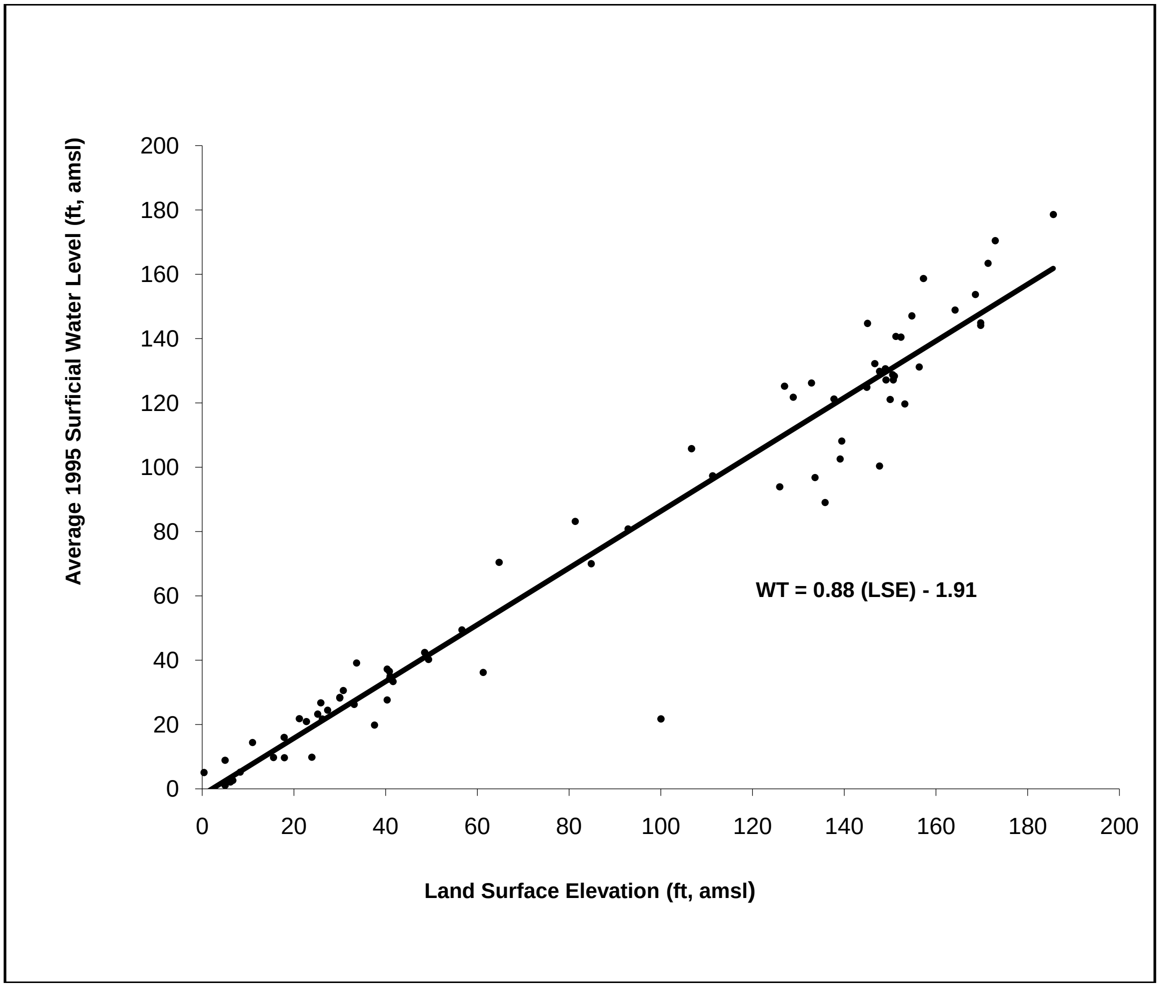



**Figure 20** **Average 1995 water level elevations in surficial aquifer (as a function of land surface elevation)**

In contrast to the surficial aquifer, water levels in the Upper Floridan aquifer are fairly well defined. The Upper Floridan aquifer is confined in most of the model area except in the southwest portions, where it outcrops. Therefore, water levels are generally above the top elevation of the aquifer. The potentiometric surface of the Upper Floridan aquifer for May and September are published annually by the United States Geological Survey (USGS). Typically, the September potentiometric surface is higher and represents wet conditions following the above-average rainfall experienced during the summer months, and a corresponding reduction in groundwater withdrawals. The May potentiometric surface represents relatively dry conditions prevailing in late winter and early spring and an increase in demand for groundwater. The potentiometric surface for May and September however are similar as can be noted in Figures 21 and 22, which depict conditions existing in May and September 1995, respectively. The average of the May and September 1995 potentiometric surfaces, representing average 1995 conditions, is presented in Figure 23. This surface was used for qualitative calibration of heads in the Upper Floridan aquifer. The locations of observation wells used to construct the potentiometric surface of the Upper Floridan for 1995 are presented in Figure 24.

A review of the potentiometric surface suggests that the surficial aquifer recharges the Upper Floridan aquifer along the topographic highs in the Keystone Heights area in the southwest portions of the study area. Groundwater, on infiltrating into the Upper Floridan aquifer, moves radially and then eastward towards the coastal regions and westward into the Suwannee River Water Management District. Natural discharge to the surficial aquifer occurs near Lake George in the south, and in the coastal areas. The drawdown impacts of pumpage at Fernandina Beach are quite pronounced, while those near Jacksonville area are relatively mild. The impact of municipal withdrawals in the Gainesville area is also evident in the potentiometric surface maps.

The potentiometric surface of the Lower Floridan aquifer is generally assumed a subdued reflection of the potentiometric surface of the Upper Floridan aquifer (Durden, 1997). Due to the absence of water level data in 1995 for the Lower Floridan aquifer, it was not possible to

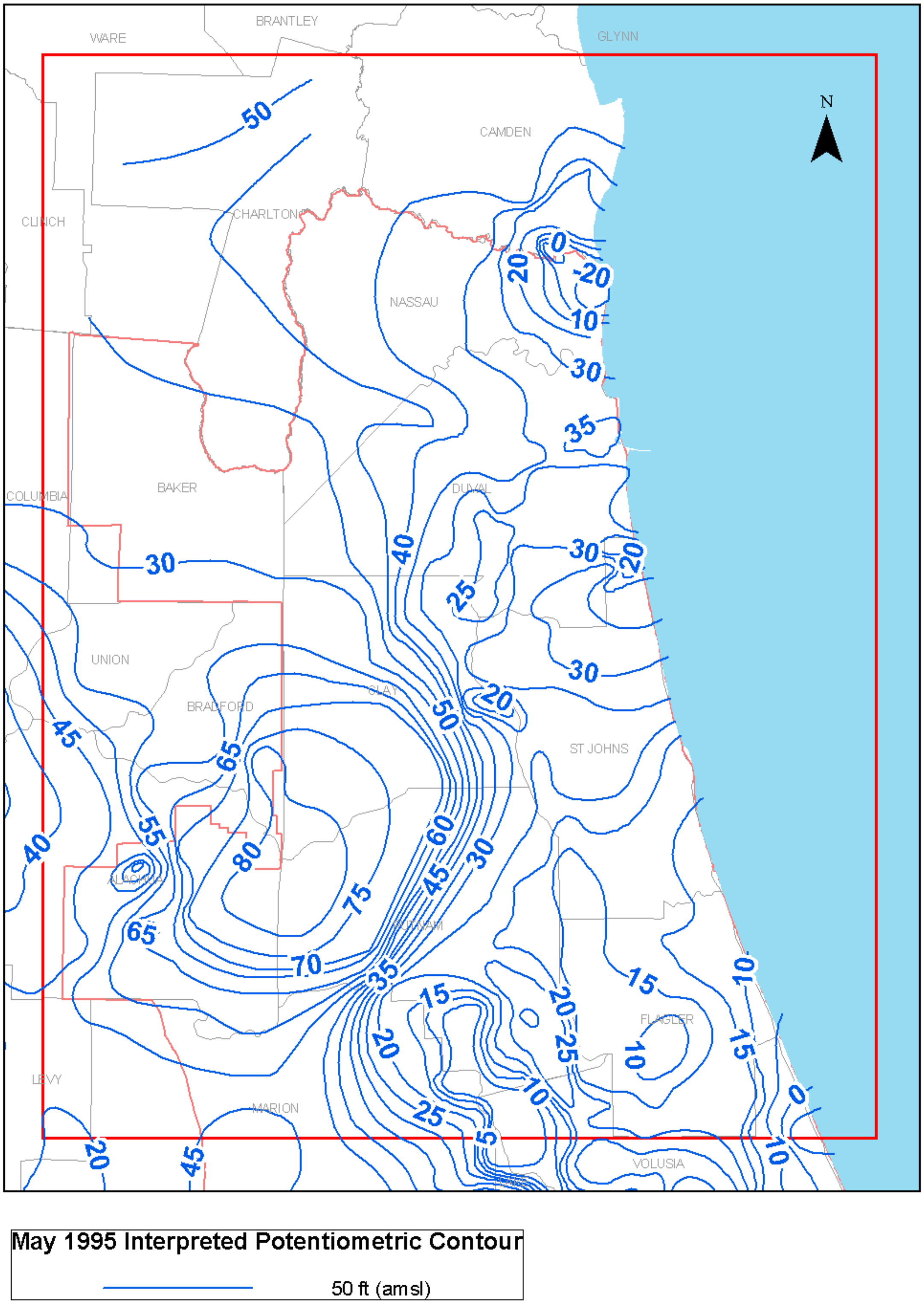



**Figure 21 Estimated May 1995 potentiometric surface in the Upper Floridan aquifer**

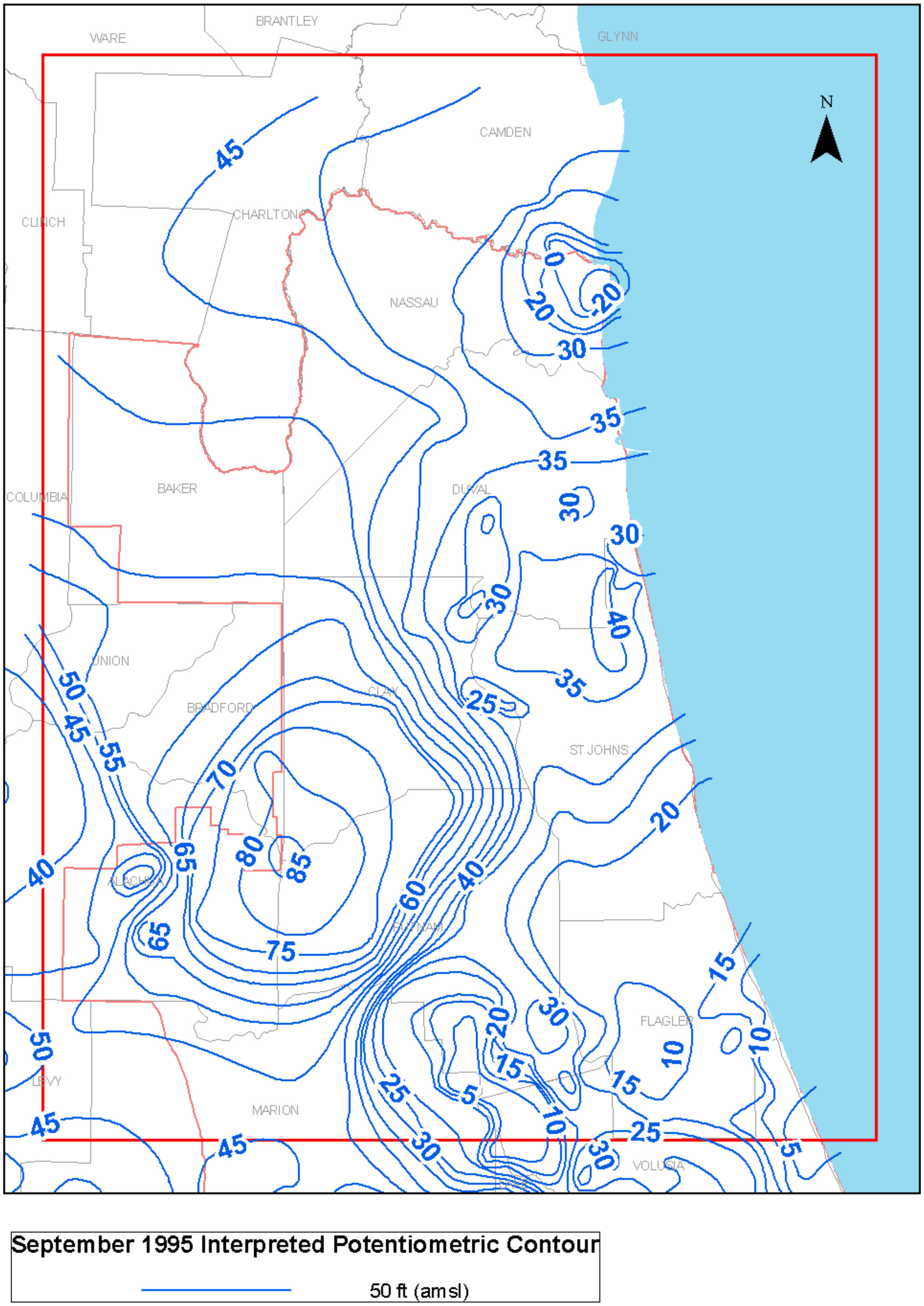



**Figure 22 Estimated September 1995 potentiometric surface in the Upper Floridan aquifer**

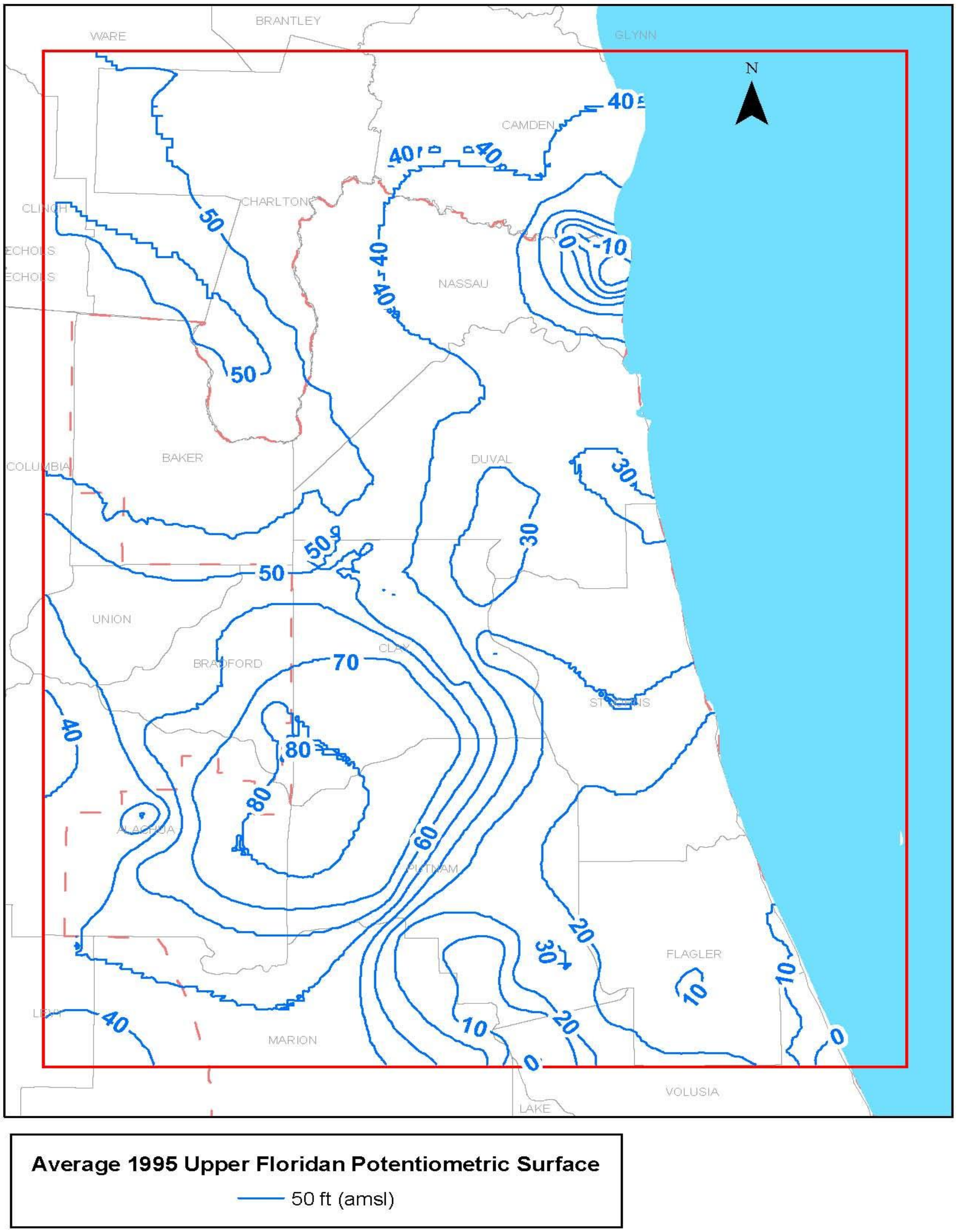



**Figure 23 Estimated average 1995 potentiometric surface in the Upper Floridan aquifer**

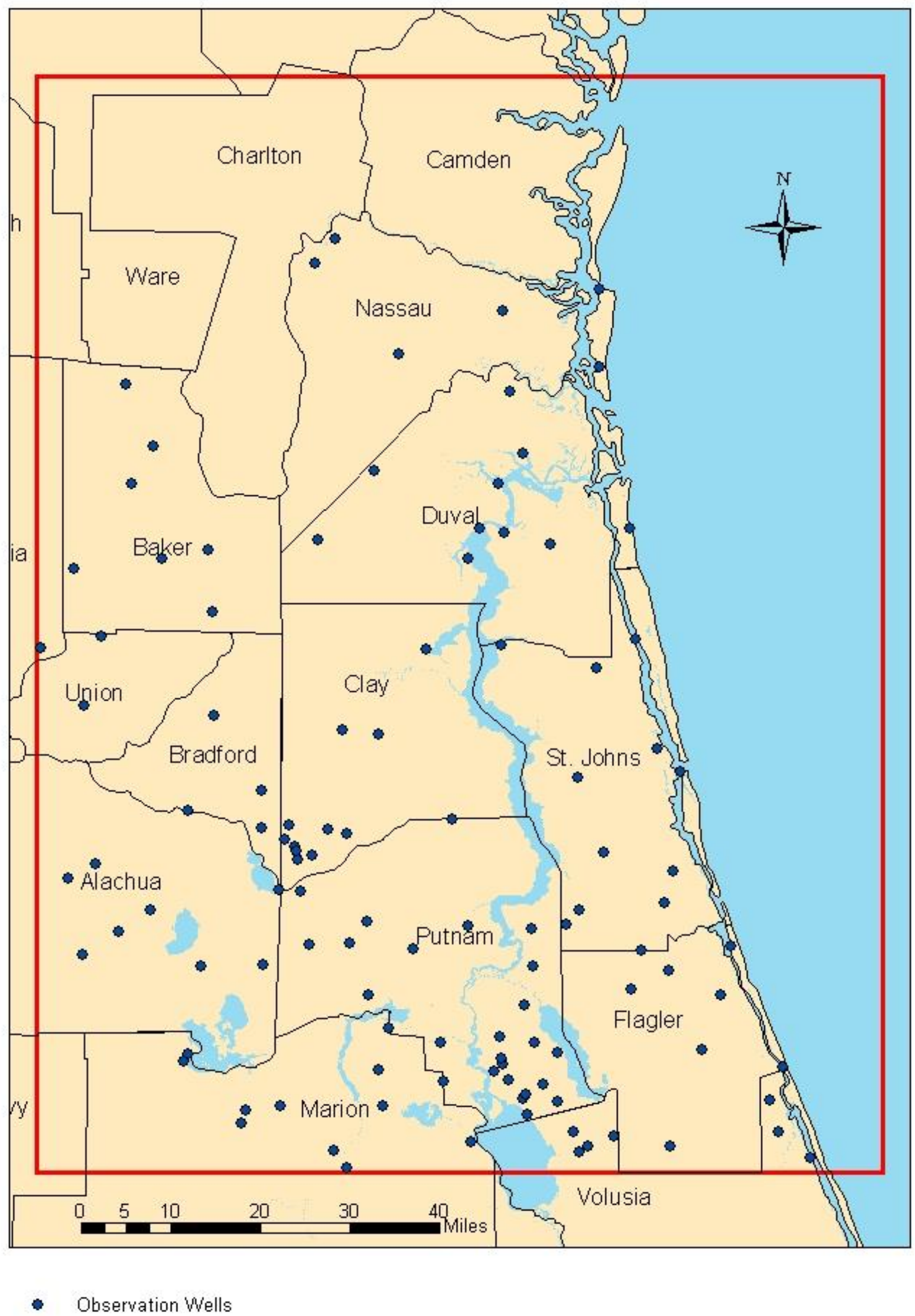



**Figure 24 Locations of Upper Floridan observation wells in study area.**

ascertain the relationship between the heads in the Upper and Lower Floridan aquifers. There is inadequate data to establish the head relationship between the Fernandina Permeable Zone and the Upper and Lower Floridan aquifers.

## Groundwater Withdrawals

The Floridan aquifer is the primary source of potable groundwater in the area. Only minor quantities of water are withdrawn from the surficial aquifer. Major withdrawals from the Floridan aquifer can be attributed to the following water use categories: public supply and commercial/industrial, agricultural, recreational irrigation (golf courses), and domestic self-supply. Within the model boundary, the estimated 1995 water use for these categories totaled 300, 84, 37, and 32 million gallons per day (MGD), respectively. Approximately 11 MGD was injected into the Upper Floridan aquifer via drainage wells. The location of the production and drainage wells in 1995 is presented in Figure 25.

The 1995 records of public water supply were obtained from the District's Division of Water Supply Management. Average pumping rates were then distributed to each well based upon capacity or pump run-time data. If those data were not available, the average rates were distributed evenly among the appropriate wells. The same process was applied to the commercial/industrial wells to arrive at a withdrawal rate at each well location. Permitted average withdrawal rates were used for several commercial/industrial users for which no metered pumpage data were available. Average 1995 public supply and commercial/industrial water use data were collected and applied similarly for wells located within the Suwannee River Water Management District and Georgia. The District is in the process of obtaining water use in Georgia for non-municipal and commercial/industrial water use categories. These data will be incorporated during future model updates.

Withdrawal estimates for agricultural and golf course irrigation wells located within the District's boundary were obtained using irrigation application rates and acreages provided in the District's Annual Water Use Survey for 1995 (Florence and Moore 1997). Withdrawal estimates for wells outside the District's boundary were obtained from Sepulveda (2002). The estimated

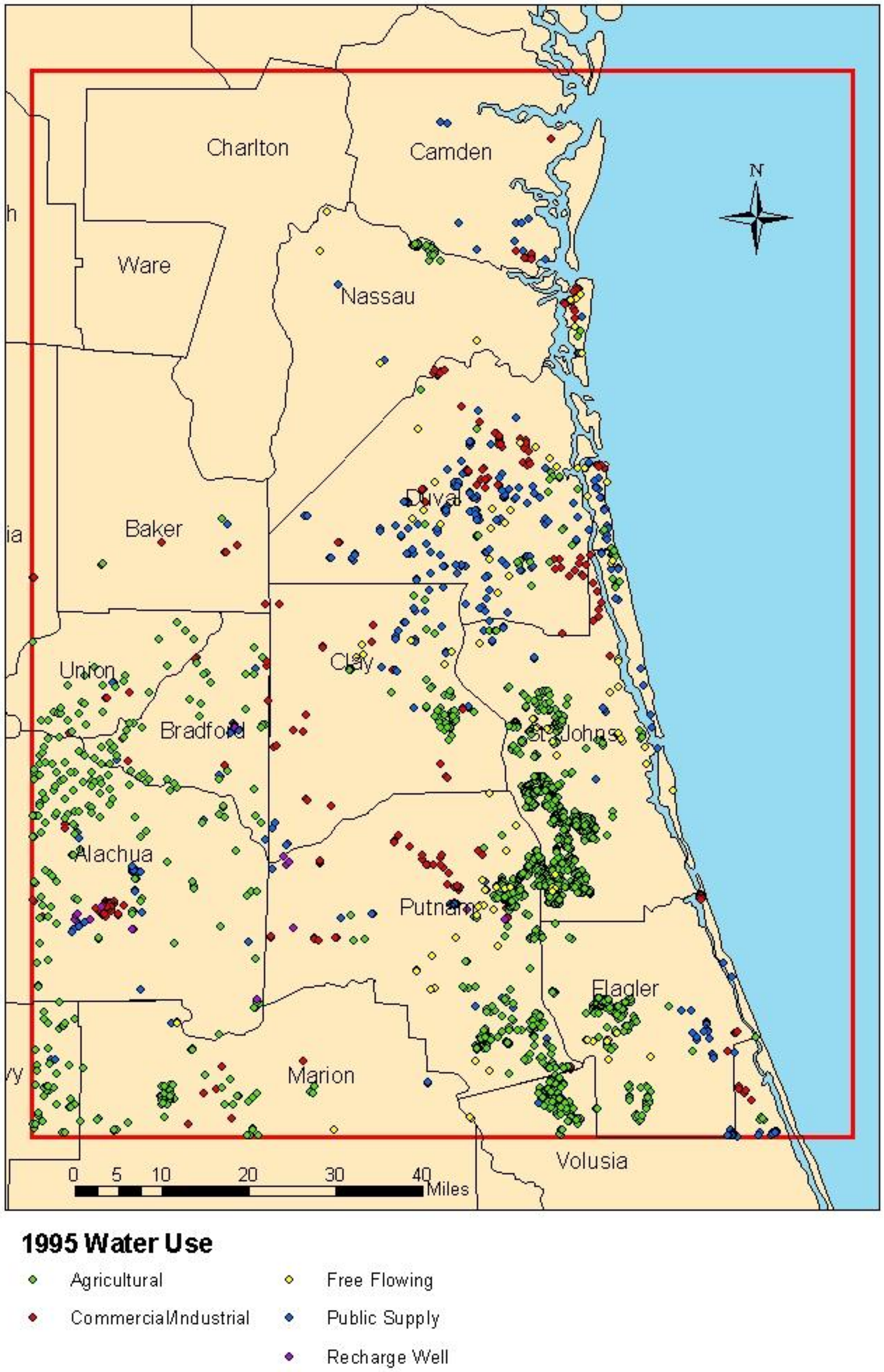



**Figure 25 Location of production and drainage wells and water use categories for 1995**

agricultural and golf course irrigation withdrawals rates for 1995 were then distributed based on well location and distribution ratios from Sepulveda (2002).

The locations of self-supply domestic withdrawals from the Floridan aquifer system were incorporated into the model using GIS method by comparing the 1995 representative land use category of low-density residential use to the boundaries of public-water supply service areas to locate plausible areas outside of public water supply service areas where self-supply domestic withdrawals exist. Countywide withdrawal rates for self-supply pumpage from the Floridan aquifer were obtained from Florence and Moore (1997).

Projected 2025 water use data were obtained from the District's Division of Water Supply Management. The distribution of projected well locations for 2025 is shown in Figure 26. The average daily 2025 withdrawal rate for the major water use categories of public supply and commercial/industrial, agricultural, recreation, and domestic self-supply is projected to be 440, 84, 57, and 32 MGD respectively. The flow in the drainage wells was assumed the same as the 1995 rate of approximately 11 MGD. Projected 2025 water use for agricultural and domestic self-supply was estimated to be the same as those estimated for 1995; any growth in domestic self-supply wells would be offset by those abandoned to incorporation of households into public supply networks. It is assumed the District has identified and plugged any free-flowing wells in the model area by 2025. The total withdrawal from all categories for 2025 totals 614 MGD, which is 30.2% higher than the total 1995 withdrawal of 453 MGD.

## Groundwater Quality

The model was developed to simulate groundwater flow only in the freshwater zones of the aquifers in the area. Therefore, it was necessary to exclude saltwater zones from the active flow system. It is assumed that the fresh and saline water regimes are separated along the 5,000 mg/l chloride isosurface in aquifers experiencing seawater intrusion. The poor quality water in the study area, however, does not entirely represent saline water occurring via lateral intrusion of seawater. For example, within the Upper Floridan aquifer, the seawater wedge is located far offshore (Durden, 1997). The Upper Floridan aquifer’s source of high chloride water is suspected to be a combination of poor quality water emanating from deeper layers and relict

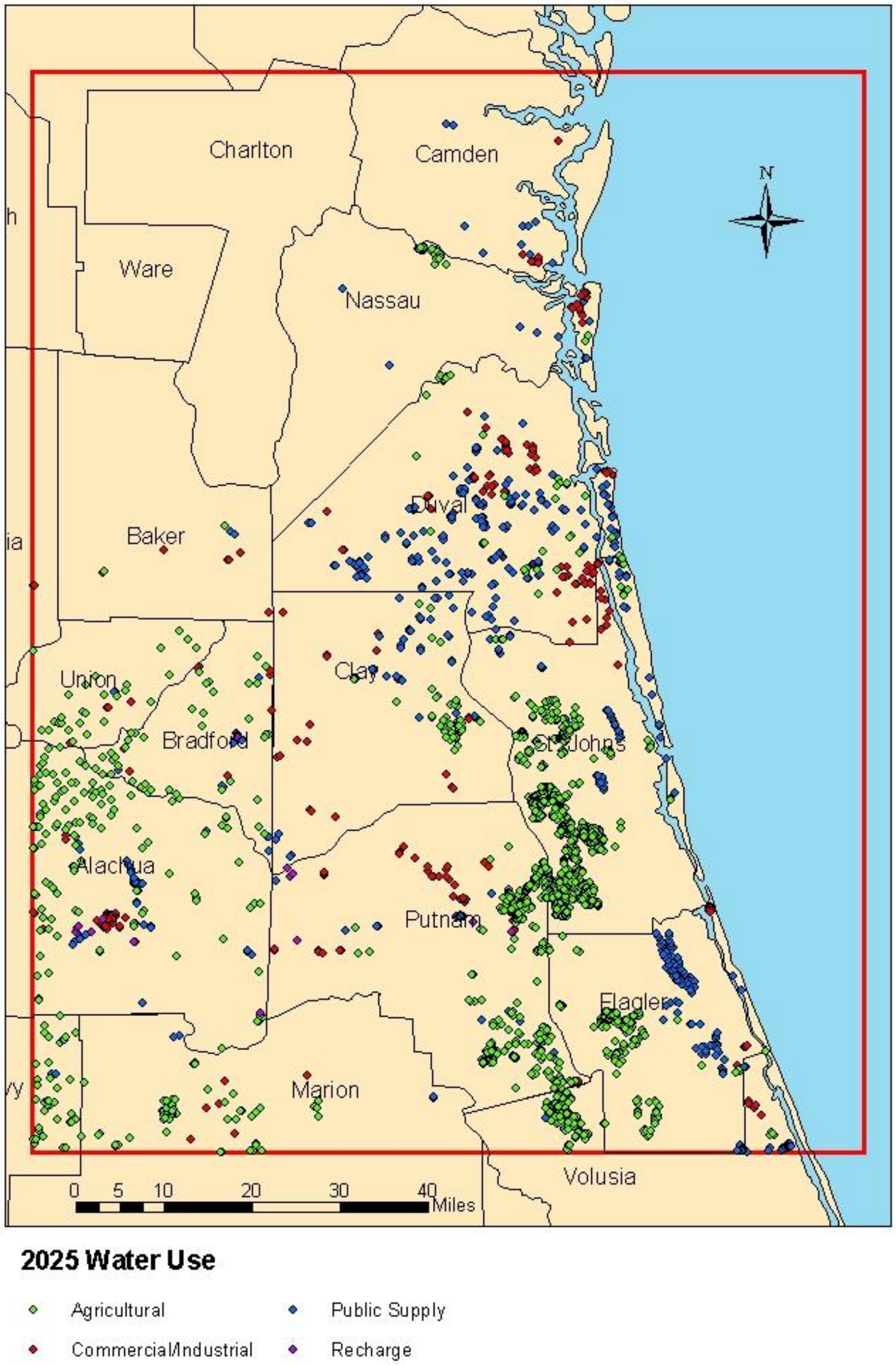



**Figure 26 Location of production and drainage wells and water use categories for 2025**

seawater not flushed from the system (Tibbals, 1990). It was assumed that the 5,000 mg/l isochlor represents a reasonable boundary between the freshwater flow region and the saltwater zones. The estimated elevation of water containing chloride concentration of 5,000 mg/l (McGurk, 2003) is presented in Figure 27. The 5,000 mg/l isochlor was assumed to be the no flow boundary in the model domain.

## Model Development

Model development commenced with a literature review of existing groundwater flow models that encompassed and bordered the Northeast Florida study area (Durden, 1997; 2000 A; 2000 B; McGurk, 1998; McGurk and Presley, 2002; Motz and Strazimiri, 1997; Sepulveda, 2002; Toth, 2001; Huang and Williams, 1996; and Williams, 1997). The purpose of the literature review was to extract information that could be incorporated in the model and to consider interactions at model boundaries. Additional reports describing the hydrogeologic properties and characteristics of the various aquifers units were also reviewed (Bush and Johnston, 1988; Johnston and Bush, 1988; Krause and Randolph, 1989; Miller, 1986; Bentley, 1977; Szell, 1993; and Toth, 1990).

Based on the reviewed literature and data compiled from the District's database, the conceptual model of groundwater flow system was developed. The conceptual model was translated into a numerical flow model, which was calibrated to observed hydrogeologic conditions, and finally used to estimate drawdown impacts due to projected pumpage in the year 2025.

## Conceptual Model of Groundwater Flow

The groundwater flow system is recharged by water from precipitation infiltrating into the subsurface. The water then moves only a short distance laterally within the surficial aquifer and primarily moves vertically into the Upper Floridan and underlying aquifers (Figure 28). Within the Floridan aquifer system and the Fernandina Permeable Zone, groundwater flow is largely in the lateral directions towards the Atlantic coast or westward towards the Suwannee River Water Management District. Groundwater also enters the model study area along the lateral boundaries and through infiltration from surface water bodies in the area.

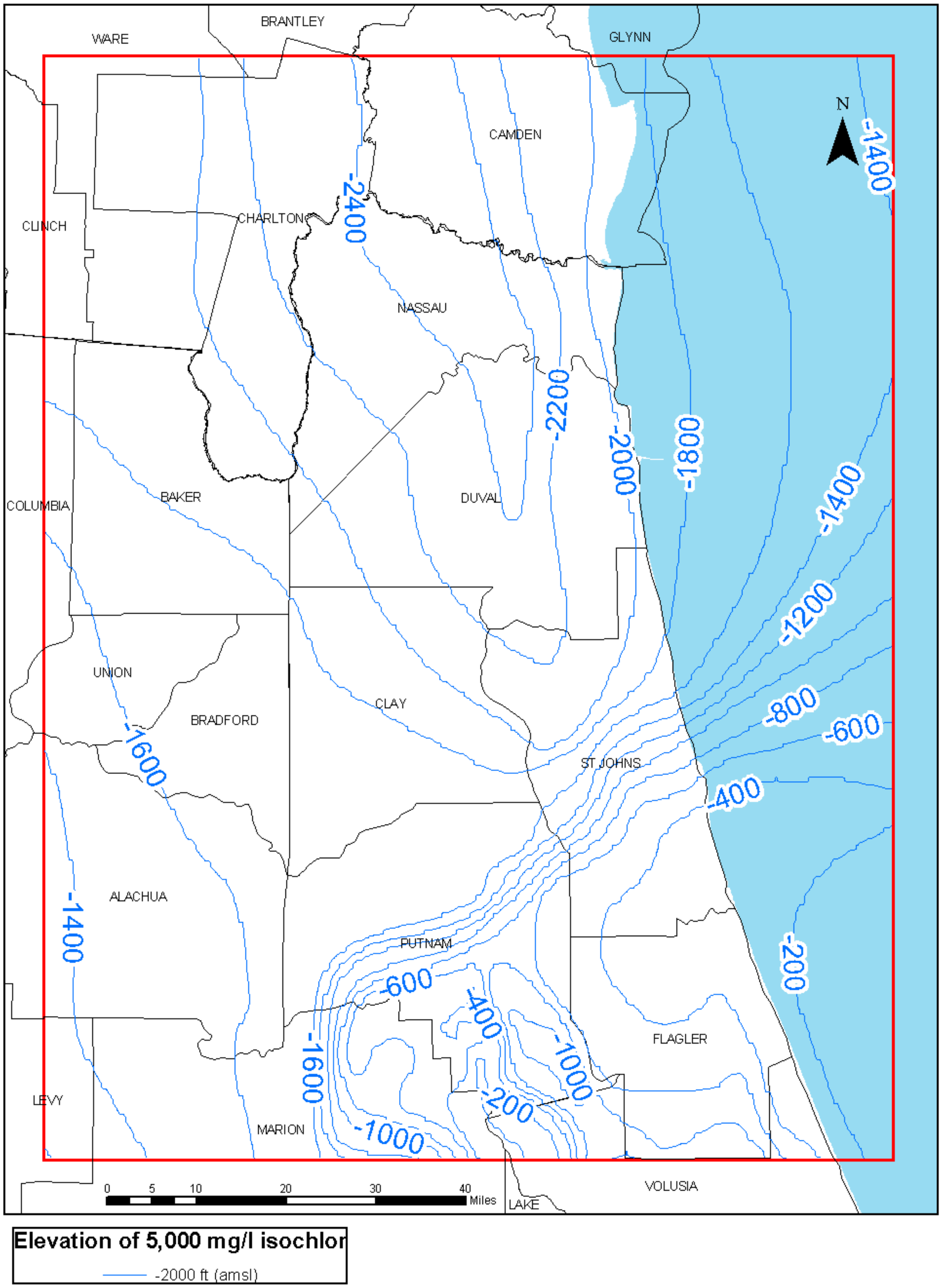



**Figure 27. Estimated elevations to 5,000 mg/l isosurface**

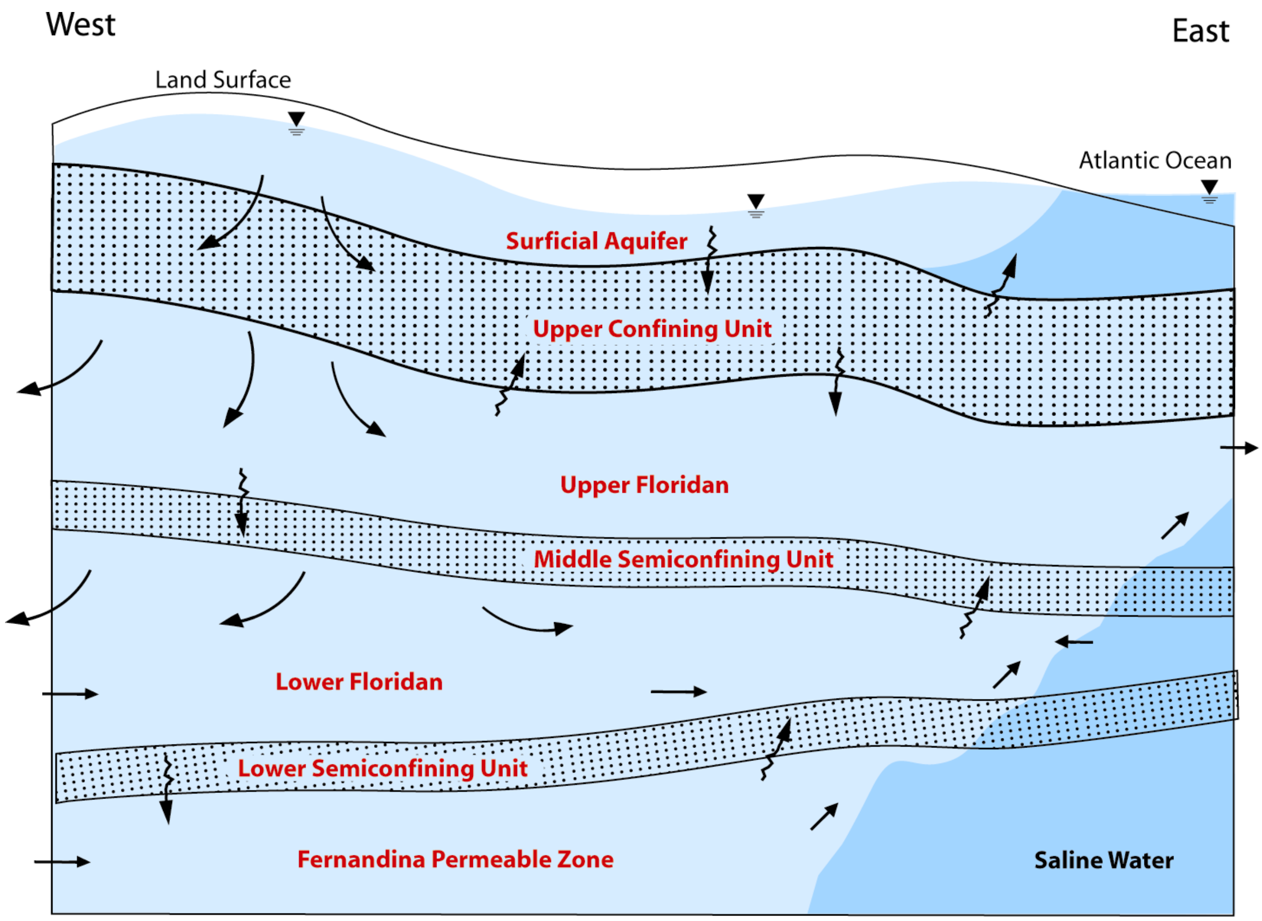

West
East
Land Surface
Atlantic Ocean
Surficial Aquifer
Upper Confining Unit
Upper Floridan
Middle Semiconfining Unit
Lower Floridan
Lower Semiconfining Unit
Fernandina Permeable Zone
Saline Water

**Figure 28. Conceptual model of groundwater flow system**

Groundwater exits the system due to evapotranspiration, withdrawals from production wells, discharge from springs, and along the lateral model boundaries. Along the coastal areas, the movement of groundwater within the Floridan aquifers and the Fernandina Permeable Zone is largely in the vertical direction into the surficial aquifer.

The goal of the study was to primarily simulate the drawdown in the Upper Floridan aquifer due to projected 2025 pumpage, and since the Upper Floridan aquifer achieves head equilibrium to changes in stresses in months (Durden, 1997), a steady-state modeling framework was adopted.

Based on reviewed hydrogeologic data, the conceptual model of groundwater flow consists of four aquifers separated by three semi-confining units, and underlain by a confining unit (Figure 29). This is similar to the previously developed groundwater flow model (Durden, 1997). Groundwater flow has been conceptualized as quasi-three-dimensional, i.e., horizontal flow occurs within the aquifer layers and vertical flow occurs between the aquifer layers. The aquifers represented in the model: the surficial aquifer system (model layer 1), the Upper Floridan aquifer (model layer 2), Lower Floridan aquifer (model layer 3), and the Fernandina Permeable Zone (model layer 4).

Vertical flow occurs through the upper confining unit between model layers 1 and 2, through the middle semi-confining unit between model layers 2 and 3, and through the lower semi-confining unit between model layers 3 and 4. No flow was assumed to occur between the Fernandina Permeable Zone and the lower confining unit. Flow within the semi-confining units was not simulated since, steady state simulations were conducted, and flow in the semi-confining units is largely in the vertical direction. The impedance to vertical flow between the aquifers accounted for in the model by the leakance parameter (vertical hydraulic conductivity of the confining unit, divided by the thickness of the confining unit).

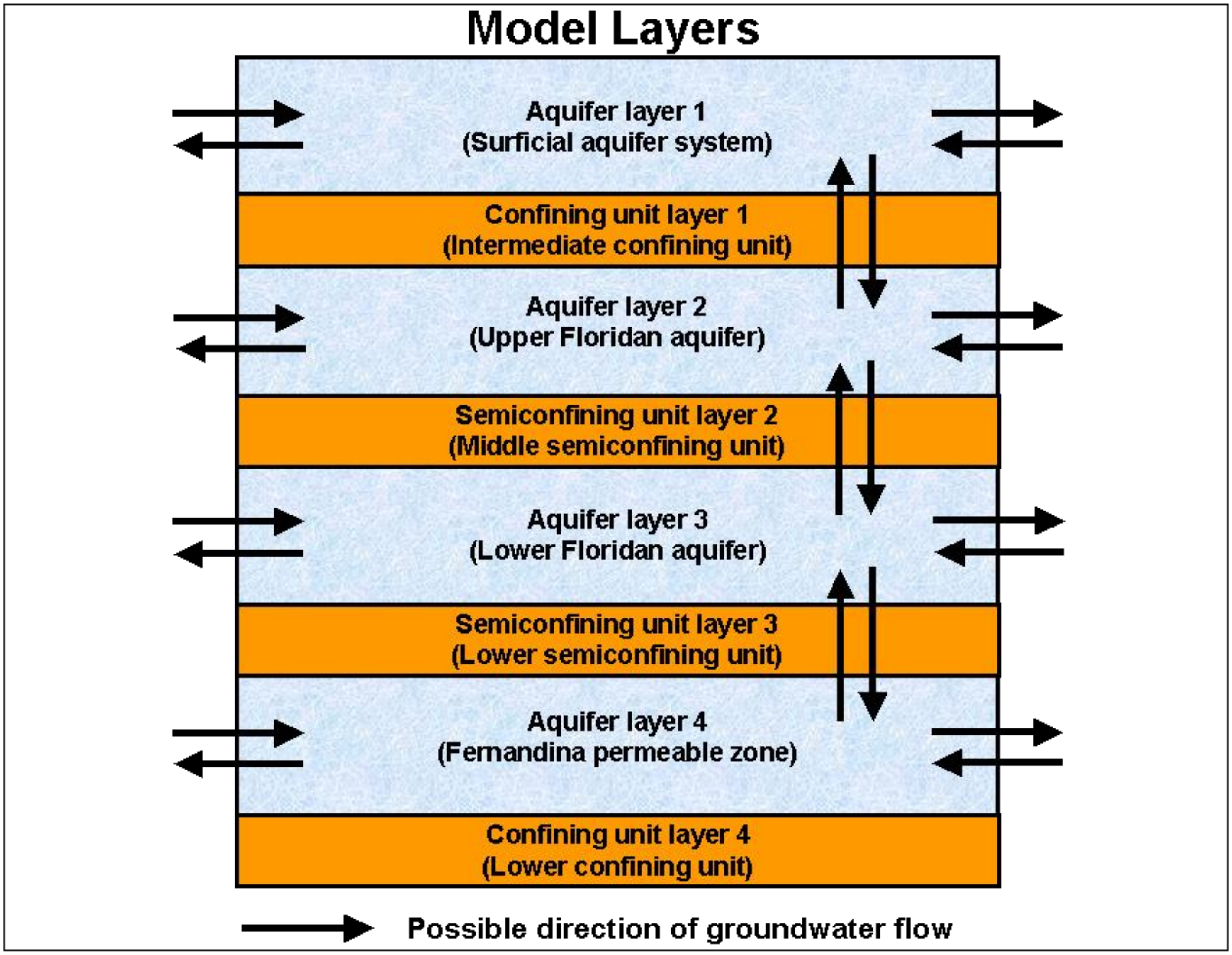



**Figure 29 Conceptualization of aquifer model layers**

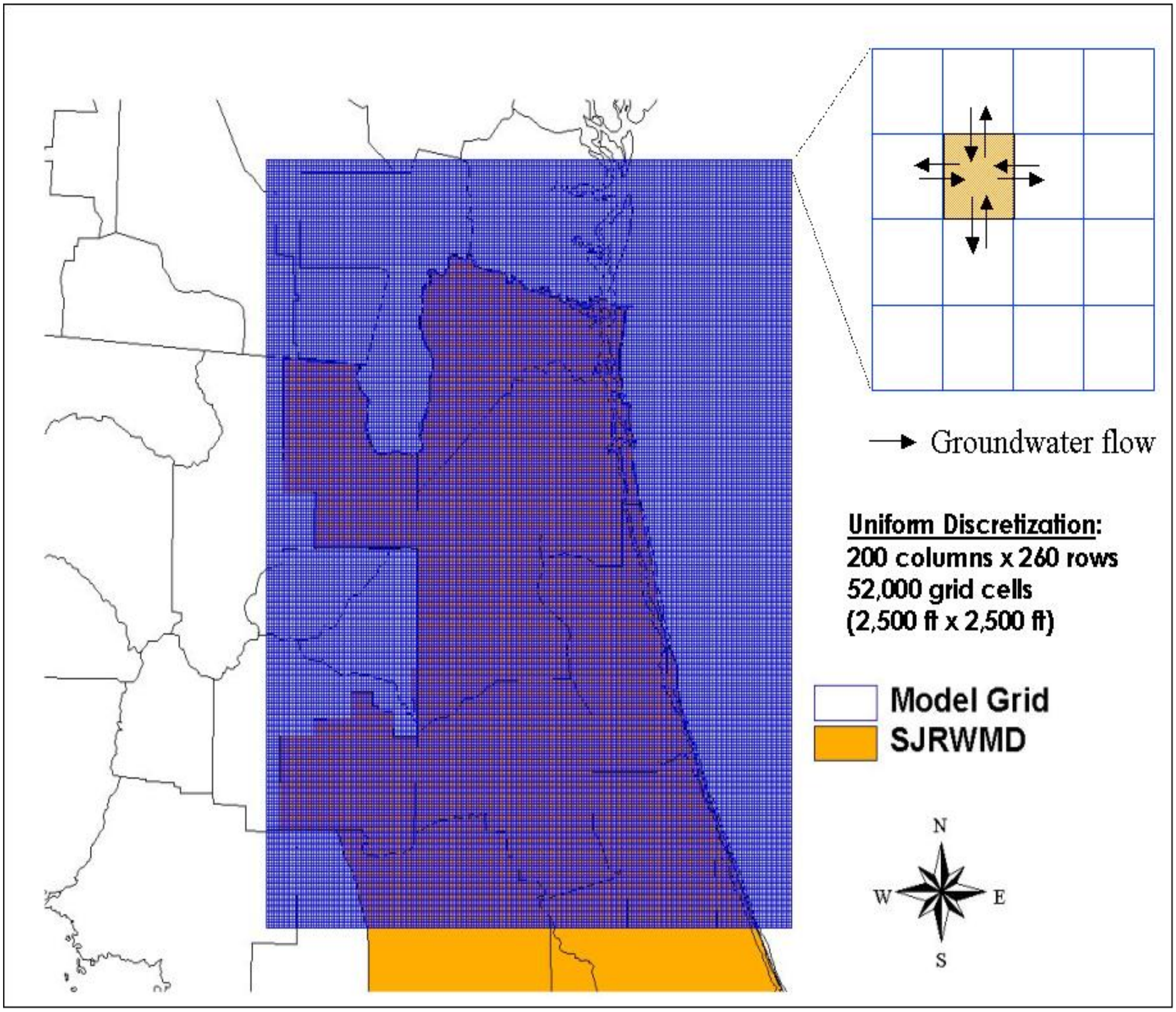
## Computer Code Selection

The numerical groundwater flow model was developed using the USGS MODFLOW computer code (McDonald and Harbaugh 1988). MODFLOW is designed to simulate steady state and transient groundwater flow through heterogeneous, anisotropic porous medium in three dimensions. It uses a modular method of data entry to simulate various aspects of the flow system. These include wells, rivers, recharge, evapotranspiration, aquifer properties, and boundary conditions. The aquifer is represented in the model by a series of grid cells. Information about the aquifer characteristics such as aquifer thickness, hydraulic conductivity, storativity, recharge, etc. are input to each model cell. This enables the simulation of flow in highly heterogeneous porous medium.

## Model Design

The model's aerial extent was discretized into 200 columns and 260 rows for a total of 52,000 grid cells (Figure 30). The grid cells were of uniform dimension (2500 ft by 2500 ft). The model domain was discretized vertically using the ARCGIS software utilizing hydrostratigraphy delineated by Miller (1986). Since the model simulated groundwater flow only in the freshwater regions, areas within each model layer containing highly saline water were excluded from the active flow system. It is generally accepted that the fresh and saline water regimes can be separated along the 5,000 mg/l chloride isosurface. This approximation is strictly valid for the case of lateral seawater intrusion, but was assumed to apply in the study area.

In order to delineate inactive model cells with high chloride content, contour maps of each of the modeled hydrostratigraphic units, and the 5,000 mg/l chloride isosurface in the District's database, were converted into GIS grids. Each GIS grid was then compared to the model grid in order to create a series of top and bottom aquifer and confining unit elevations, and a saline water interface elevation for each grid cell. At model cells where the saline water interface (5,000 mg/l) elevation was calculated to be above an aquifer bottom, the bottom elevation of the flow domain was assumed equal to the saline water interface elevation. Model grid cells were



Groundwater flow
Uniform Discretization:
200 columns x 260 rows
52,000 grid cells
(2,500 ft x 2,500 ft)
Model Grid
SJRWMD
N
W
E
S

**Figure 30 Northeast Florida Model numerical grid**

considered to be saline and inactive if the saline water interface elevation was within 20 ft of the top of the corresponding aquifer layer.

The surficial aquifer was modeled as an unconfined hydrogeologic unit, while the Upper Floridan was modeled as a confined/unconfined unit. In regions where the potentiometric surface in the Upper Floridan is above the top of that aquifer, the aquifer was assumed as confined, and the transmissivity in the cell corresponds to the product of the hydraulic conductivity and the aquifer thickness. In regions where the potentiometric surface is below the top of the Upper Floridan aquifer, such as in the southwestern portions of the study area, the aquifer was assumed unconfined and the transmissivity corresponds to the product of the horizontal hydraulic conductivity and the saturated thickness. The Lower Floridan aquifer and the Fernandina Permeable Zone were both modeled as confined hydrogeologic units.

## Boundary Conditions

The Floridan aquifer system underlies all of peninsular Florida and extends beyond the model domain. Appropriate hydraulic conditions must be specified along the lateral boundaries in order to represent flow that occurs across model domain boundaries. Lateral boundary conditions used to address flow conditions were limited to one of three types: (1) prescribed potentiometric levels/heads (Constant Head boundary), (2) prescribed flow rates (wells), or (3) head-dependent flux (General Head boundary). Each boundary type is appropriate under particular circumstances as discussed by McDonald and Harbaugh (1988). In this study, the General Head boundary (GHB) was applied along lateral boundaries of the model domain. This boundary type was the most appropriate for two reasons: first, there was not enough available information to independently estimate flow rates along boundaries. Second, locations of projected future withdrawals indicated a potential for predicted potentiometric changes (drawdowns) reaching lateral boundaries. Application of head-dependent flux/GHB boundary conditions allows the model to adjust flow across the model boundaries based upon changes in head along the boundaries, which could be caused by projected future withdrawals.

Cell assignments and boundary conditions for each model layer are shown in Figures 31-34. The surficial aquifer system (Figure 31) is represented with variable head cells, prescribed/constant head cells, and inactive head cells. The variable head cells represent the portions of the study area that are actively simulated by MODFLOW code. All surface water bodies, including the Atlantic Ocean, were represented as specified head cells. The lateral boundaries were not specified as either head or flux boundaries because flow in the surficial aquifer is largely in the vertical direction on a regional scale. Initial and prescribed head values for layer 1 were based upon measured 1995 water levels, and estimated specified heads from the USGS Mega Model (Sepulveda, 2002). In the southwestern portion of the study area, the upper confining unit and portions of the Upper Floridan are exposed, and the surficial aquifer system is absent. In these areas, the surficial aquifer system is designated as inactive. In the southeastern portion of the study area, the inactive portions of the surficial aquifer system correspond to areas where chloride concentrations exceed 5,000 mg/l as discussed above.

The boundary conditions in the Upper Floridan (layer 2), Lower Floridan (layer 3), and Fernandina Permeable Zone (layer 4) are shown in Figures 32, 33, and 34, respectively. Each of these layers is composed of variable-head cells or variable-head cells with General Head boundaries. The initial head values specified for layer 2 were based upon the estimated average potentiometric surface of the Upper Floridan for 1995 (Figure 23). The inactive zones of the Upper Floridan aquifer were based upon estimated grid cell chloride concentrations equal or greater than 5,000 mg/l. For lack of data, the initial head values of layer 3 and 4 were also set equal to those in layer 2. The inactive portions of these layers were also established based upon estimated grid cell chloride concentrations equal or greater than 5,000 mg/l.

The General Head boundary package (McDonald and Harbaugh 1988) was used to assign head-dependent flux conditions at lateral boundaries for aquifer layers 2, 3, and 4. The average general head flow length was three grid cells or 7500 ft. The boundary conductance was based upon average conductance across the grid cells, and the assigned boundary head was based on the estimated Upper Floridan aquifer average 1995 potentiometric surface. A no-flow boundary

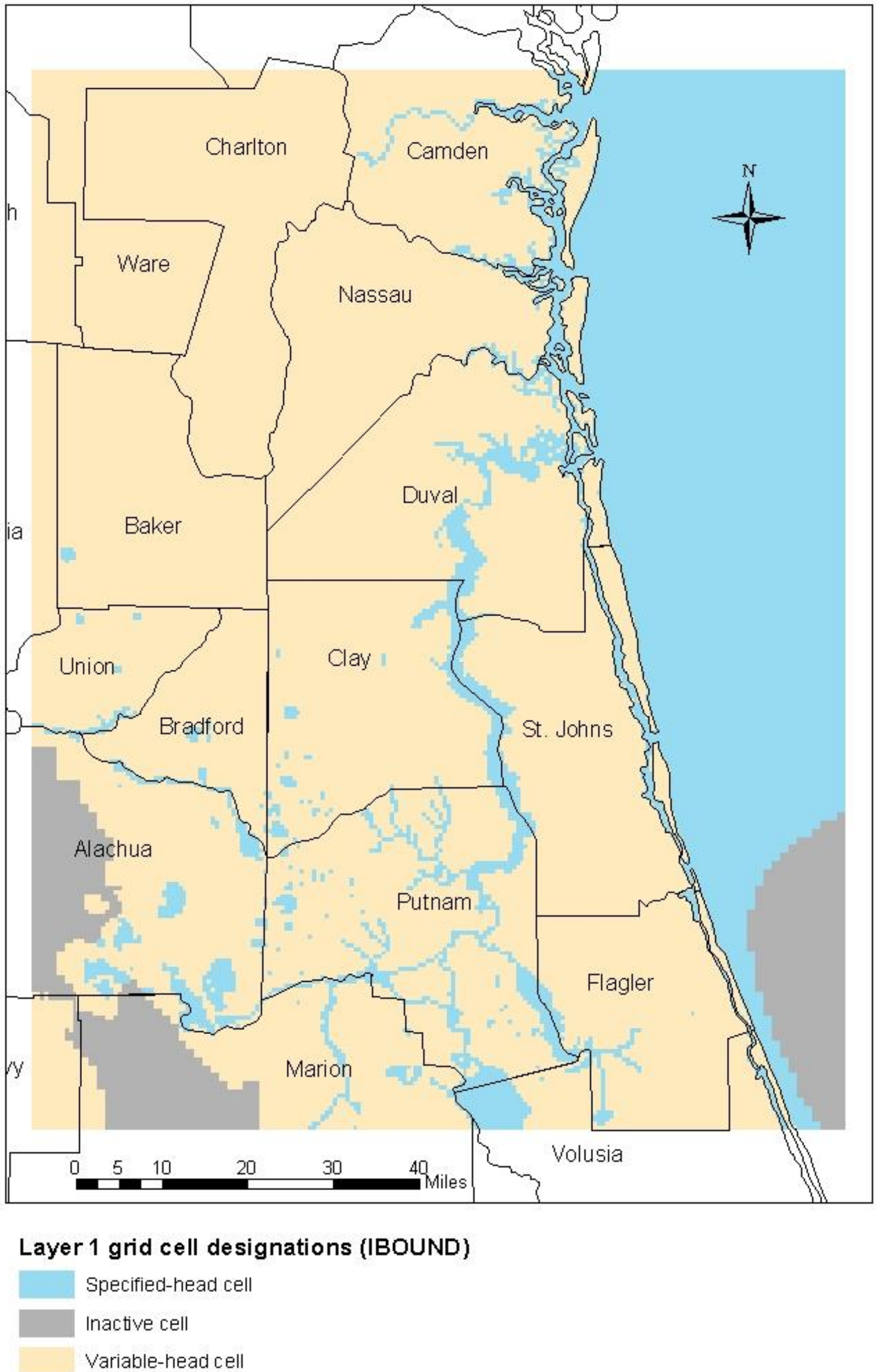



**Figure 31 Boundary conditions and cell designations for model layer 1.**

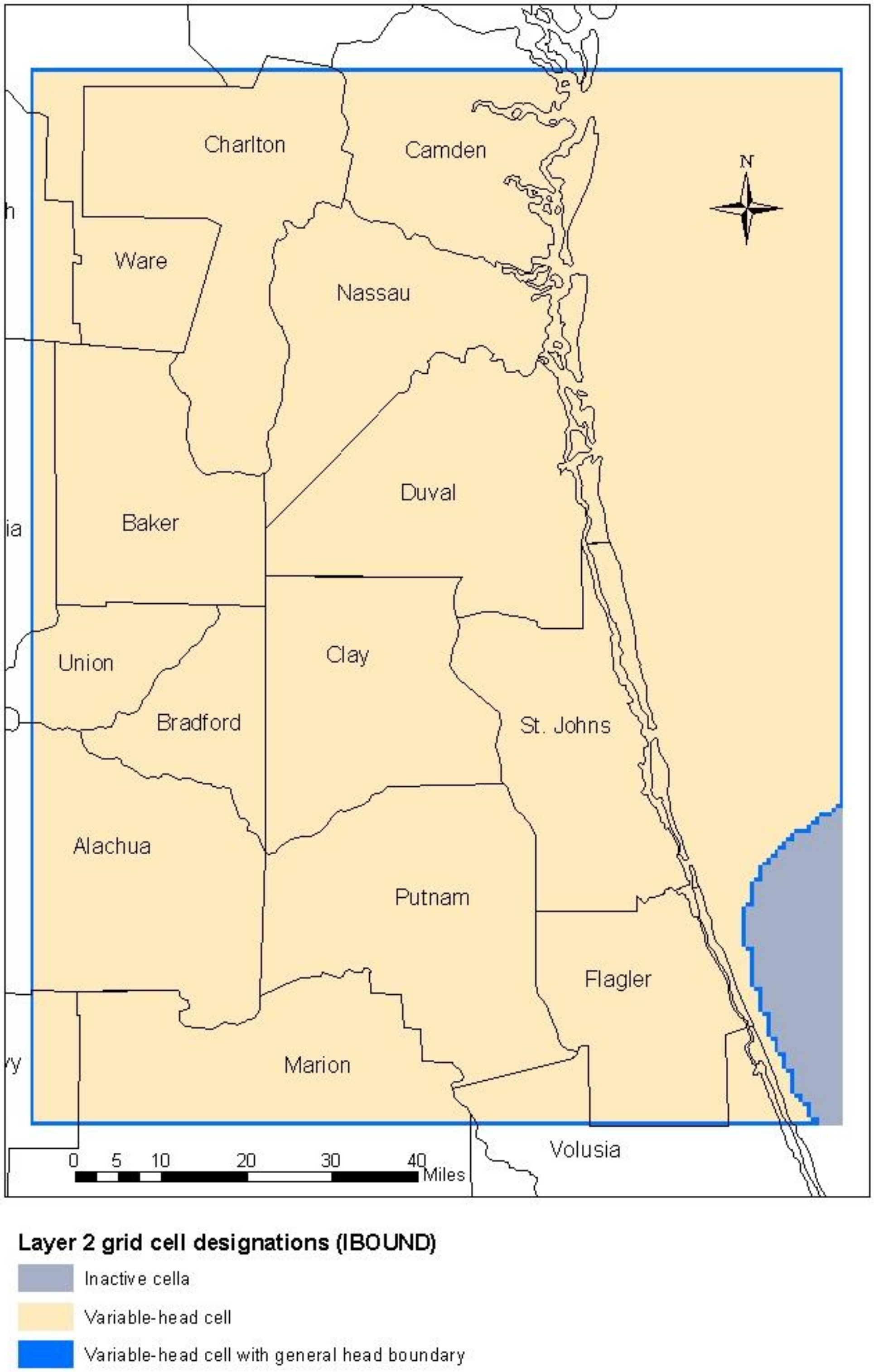



**Figure 32 Boundary conditions and cell designations for model layer 2.**

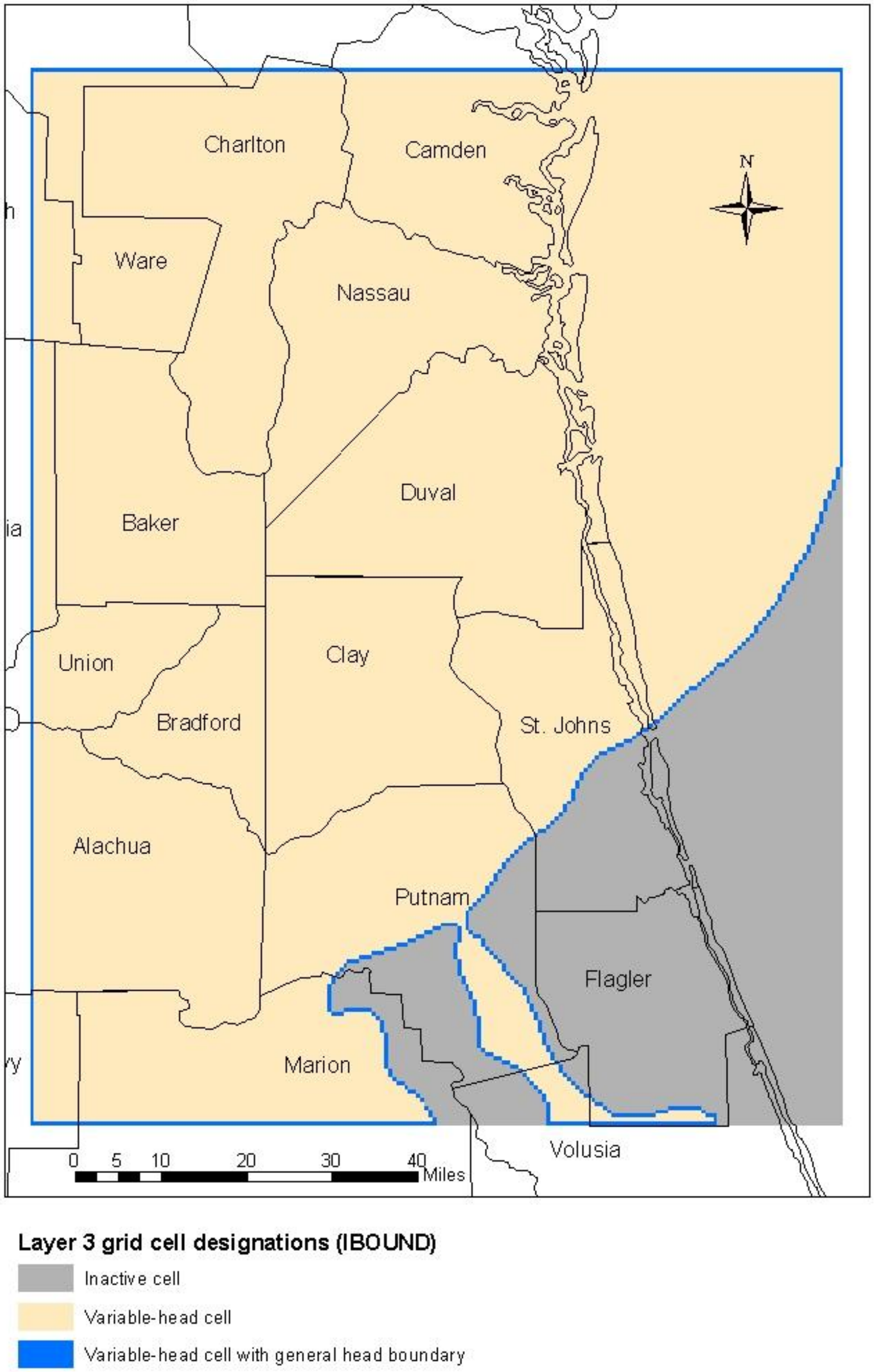



**Figure 33 Boundary conditions and cell designations for model layer 3.**

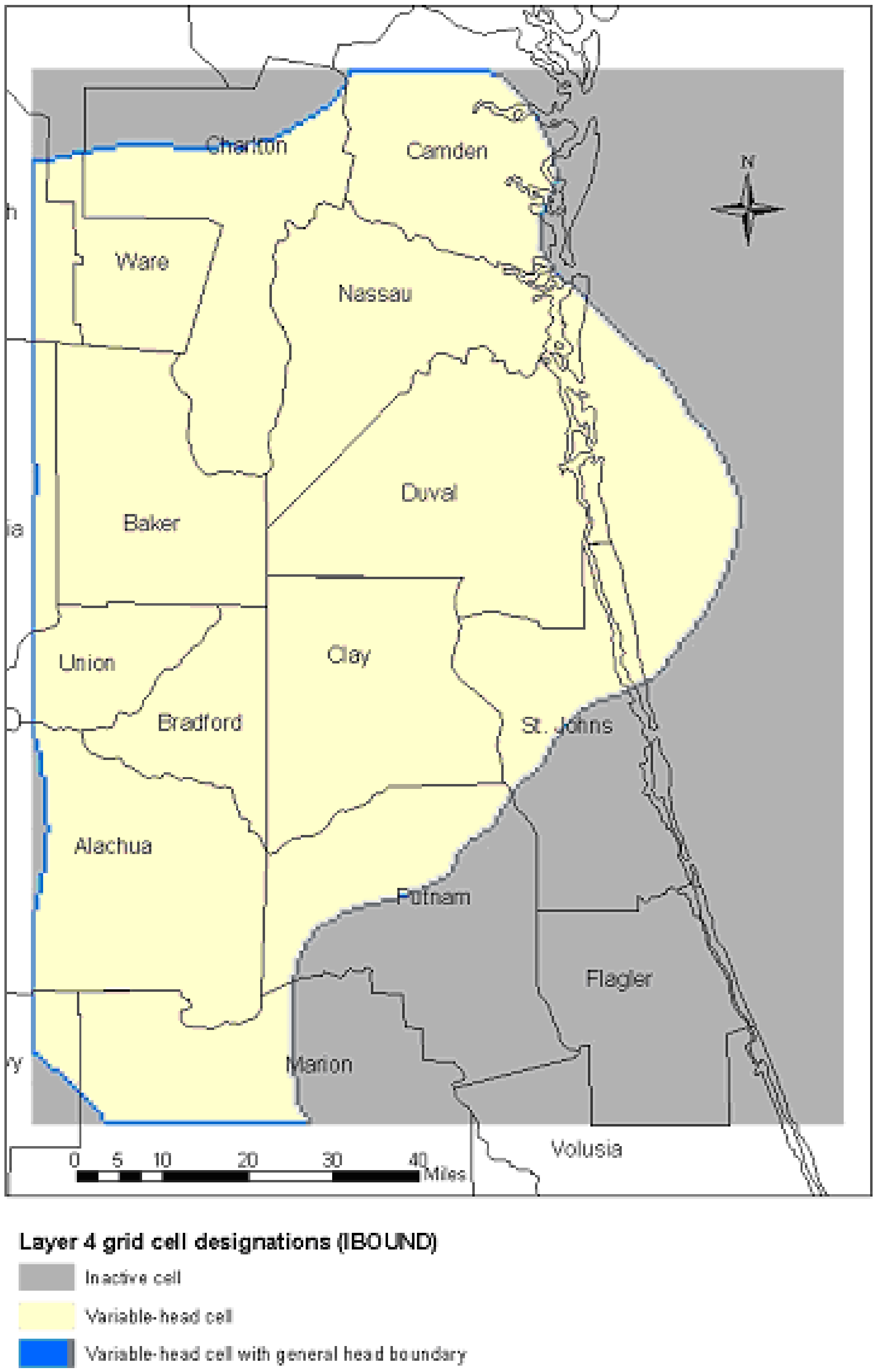



**Figure 34 Boundary conditions and cell designations for model layer 4.**

condition along the eastern boundary in the Fernandina Permeable Zone was implemented since: a) the layer boundary is along the seawater interface which forms a natural flow barrier for freshwater, b) it was not possible to estimate the head in this layer along the eastern boundary, which underlies stressed regions in the Upper Floridan aquifer, such as the Fernandina Beach area, and c) model results indicated that the simulated heads were not sensitive to specification of this boundary as either a General Head or no-flow boundary.

## Model Components

### Layer Delineation and Properties

The primary sources of information for layer delineation were Miller (1986) and supplemental hydrostratigraphic information maintained by the District. As discussed earlier, the hydrostratigraphic information was compared to the 5000 mg/l isochlor surface in order to designate the freshwater flow zones within each layer. In the western portions of the study area where Miller assumed the MSCU non-existent, the bottom of the Upper Floridan was assumed to coincide with the top of the Lower Floridan aquifer. It should be noted, however, that in this study, the MSCU was specified throughout the model domain, and the leakance of the MSCU was a calibration parameter. The delineation of the Fernandina Permeable Zone was based on Miller's (1986) configuration.

A majority of the initial values for the aquifer hydraulic conductivities and confining unit leakances were based on the calibrated USGS Mega Model data sets (Sepulveda 2002). However, not all layers of the USGS Mega Model and the present Northeast Florida regional model are represented identically. The four most notable differences: 1) in the northwest portion of the study area, the current study utilizes variable head cells for all layers while the USGS model utilized inactive cells; 2) the USGS modeled the upper confining layer as an active layer, while the current model accounted for the upper confining layer by specifying a leakance value for the unit; 3) the USGS model represented the surficial aquifer system as a specified head layer, while one of the objectives of this study was to represent the surficial aquifer system as an active model layer; 4) the Fernandina Permeable Zone is also an active layer in the current model, where it was neglected in the Mega Model.

In instances where initial values for hydrogeologic parameters could not be estimated from the USGS model, the estimated values were based upon information obtained from literature review and specified in the model by the District (Mark Newman, personal communication). The hydraulic conductivity of the surficial aquifer was initially specified at 20 ft/day, while the transmissivity of the Fernandina Permeable Zone was set to a uniform value of 40,000 $ft^2$/day, which is similar to the average value of 43,000 $ft^2$/day from Durden (1997).

**Drains**

Discharge from 14 Upper Floridan aquifer springs was simulated with the Drain Package (McDonald and Harbaugh 1988). The magnitude of the drain conductance depends upon the hydraulic characteristics of the convergent flow pattern in the immediate vicinity of the drain (McDonald and Harbaugh 1988); i.e., characteristics of the spring and hydrogeologic properties at and around the spring. Plausible ranges for drain conductance values can be estimated for each spring through application of Equation 2 from McGurk and Presley (2002). The springs considered in the Northeastern Florida Regional model are presented in Figure 18. Average 1995 daily flow rates and spring pool elevation (stage) are presented in Table 2.

**Recharge/Discharge**

The recharge/discharge dynamic was addressed with two MODFLOW packages: Recharge and General Head boundary (GHB). The Recharge package was used to simulate the combined affects of precipitation, septic tank effluent, irrigation return flow, flow in drainage wells, and evapotranspiration from the saturated and unsaturated zones for both 1995 and 2025 simulations. Each model cell in the Recharge package was assigned a single lumped value. In addition, the recharge rates in the Recharge package were considered a calibration parameter and the final calibrated distribution is presented and discussed below. The GHB package was used to simulate the affects of induced recharge/decreased evapotranspiration due to a general lowering of the water table elevation, relative to 1995 elevation, for the 2025 simulation; or the reverse with an increase in water table elevation and a corresponding increase in ET. The GHB package designed to address both boundary and induced recharge issues was applied only to the 2025 predictive simulation; it is different from the GHB package designed only to address boundary issues for the baseline 1995 simulation.

### Water Use

Groundwater withdrawals were simulated using the Well package of MODFLOW. The methodology for estimating pumpage from each well is described in detail above (refer to Groundwater Withdrawals). For a well open to both the Upper and Lower Floridan aquifers, the total withdrawal rate was distributed in each model layer based on the relative magnitude of transmissivities in the Upper and Lower Floridan aquifers. Recharge to the Upper Floridan aquifer from drainage wells was also simulated using the MODFLOW Well package. The location and corresponding recharge rates were obtained from Sepulveda (2002).

## Calibration Targets

The model was calibrated to measured groundwater levels and spring flows for 1995. Typically, a model is validated against another stress period such as, those existing prior to development. However, this limitation was not considered very critical since the present model is an enhancement to several existing models, which were calibrated to stress periods other than 1995. The following calibration targets were adopted for the 1995 calibration period:

- Achieve an average absolute difference between average 1995 observed and simulated water levels of less than 3 ft in the Upper Floridan aquifer.

- Mean head residual error in the Upper Floridan aquifer should be less than 1.5 feet for the 1995 calibration period.

- Minimize the root mean square (RMS) error (standard deviation of the residuals) in the Upper Floridan aquifer for the 1995 calibration period.

- Closely match the shape and gradients of the interpreted average 1995 Upper Floridan potentiometric surface.

- Minimize the difference in the slope and y-intercept of the regression line (simulated surficial water table level versus land surface elevation) with respect to the regression parameters for the estimated water table regression line (Equation 1). The slope and y-intercept for the estimated water table surface are 0.88 and -1.91, respectively. The estimated water table elevation is expressed:

$$\text{Water Table Elevation} = 0.88\,(\text{Land Surface Elevation}) - 1.91$$

For calibration targets, the slope should be within 2% of the estimated slope (i.e., .862 and .897), the y-intercept should be within 2 feet of the estimated y-intercept (i.e., between –3.91 and 0.09). To ensure acceptable dispersion, the $R^2$ square should be 0.98 or higher.

- Simulated 1995 spring flows should be within 10% of observed values at first- and second-magnitude springs.

## Calibration Results

The process of model calibration involved adjusting model input parameters within reasonable ranges until the model output (water levels) replicated observed field values. The aquifer hydraulic conductivity, recharge, and leakance of the semi-confining units, were the primary calibration parameters. Numerous simulations were conducted, during which the calibration parameters were varied on a trial and error basis until the simulated water levels matched the observed water levels satisfactorily. The Upper Floridan aquifer is the primary source for groundwater in the study area, therefore the focus of model calibration was on providing an accurate representation of the its flow regime.

The calibrated potentiometric surface in the Upper Floridan aquifer for 1995 is presented in Figure 35. The head residuals (observed minus simulated) at the observation wells in the Upper Floridan aquifer are presented in Figure 36. The regression analysis for the observation well locations is presented in Figure 37, while the head-residual histogram and the cumulative

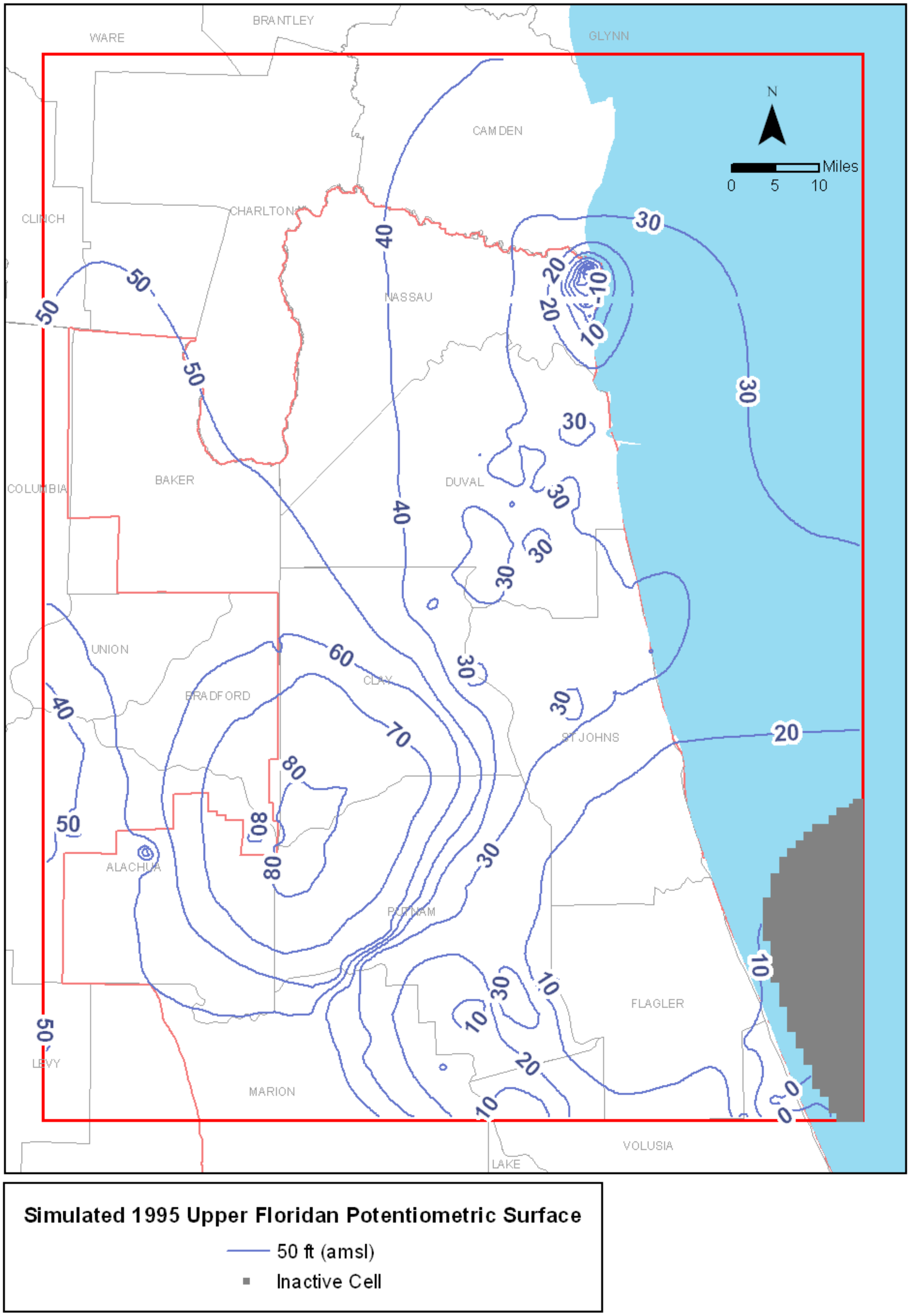



**Figure 35 Simulated 1995 Upper Floridan potentiometric surface**

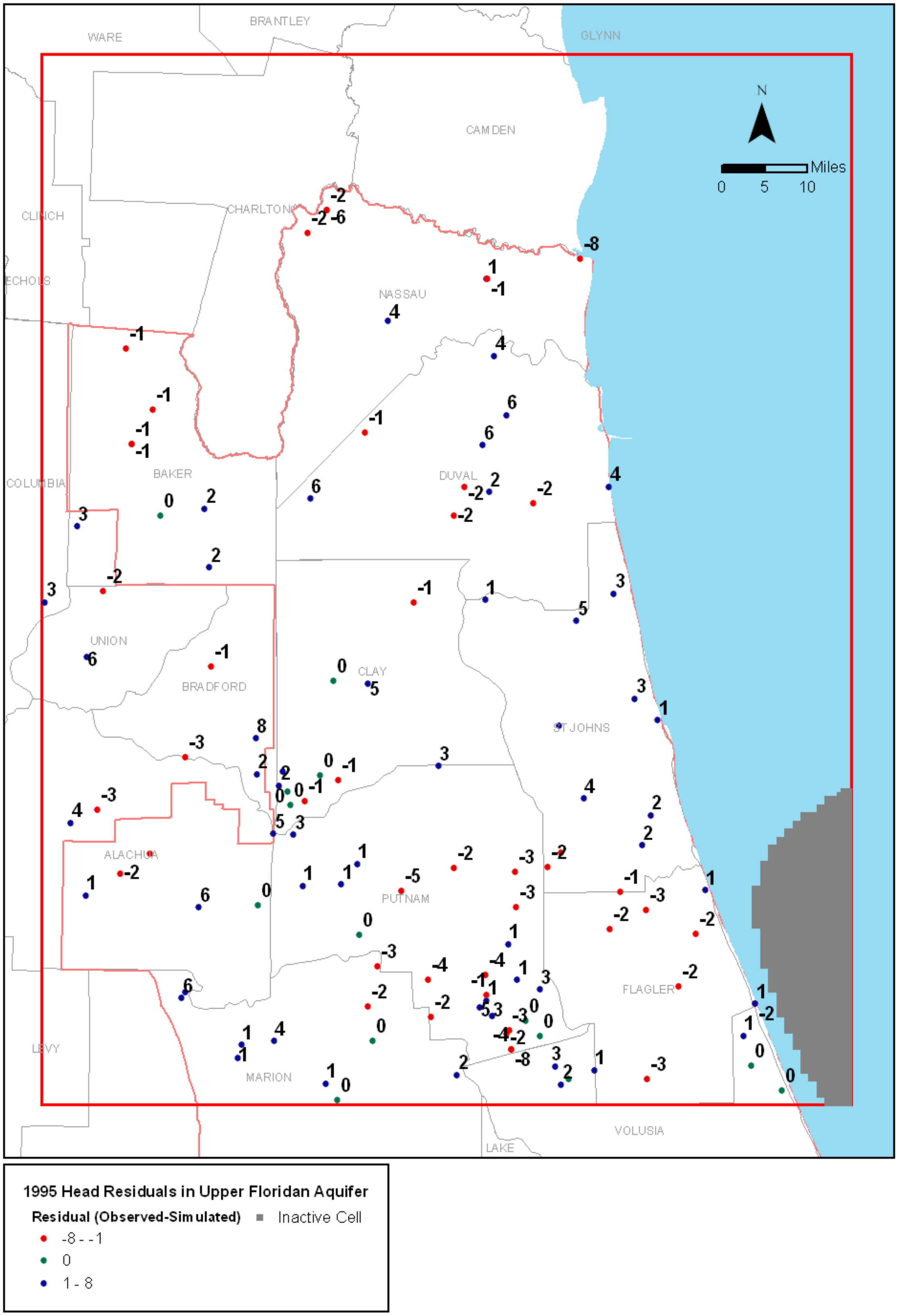



**Figure 36 Head residuals in Upper Floridan aquifer for 1995 calibration**

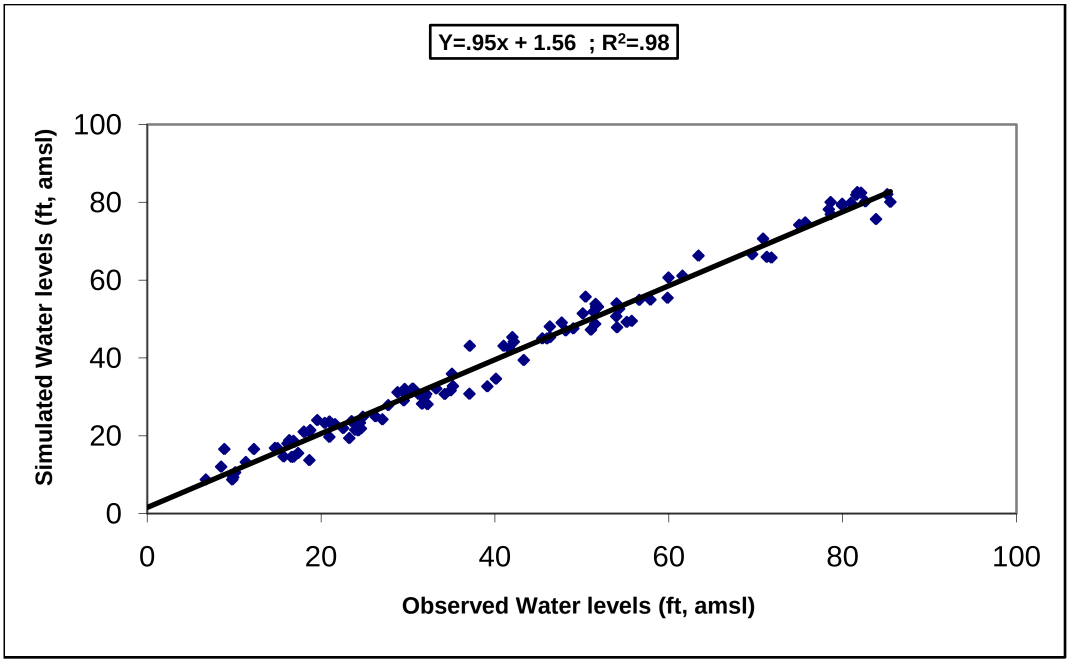



**Figure 37 Observed versus simulated water levels in Upper Floridan aquifer for 1995**

residual percentile are presented in Figures 38 and 39, respectively. In general, a good match between simulated and interpreted potentiometric surfaces can be inferred from the calibration statistics and by visually comparing the simulated and observed (average 1995) potentiometric surfaces. The general flow trends in the Upper Floridan are reproduced well by the model.

The average absolute residual in the Upper Floridan aquifer is 2.39 ft (Figure 38). The mean and standard deviation of the residuals are relatively low at 0.36 and 2.85 ft, respectively. From the cumulative residual plot (Figure 39), it is evident that the residuals at approximately 55% of the observation wells are less than 2 ft, and nearly 75% of the observation wells have residuals of less than 3 ft.

An area of relatively large residuals can be noted in north-central Duval County along the St Johns River (Figure 36). The simulated heads in this area are locally lower by about 6 ft at two observation well locations. The reason for this difference is not clear. The area contains production wells open to both the Upper and Lower Floridan aquifers, which may cause groundwater with higher heads in the Lower Floridan to discharge into the Upper Floridan aquifer. There may also possibly be local (vertically oriented) solution cavities or faults along the St Johns River in the area. The high positive residuals are in (localized) high chlorides areas documented by Durden (1997), raising the possibility of preferential flow paths connecting the upper and lower regions of the Floridan aquifer system. A head error of 6 ft however strongly raises the possibility that water entering the Upper Floridan aquifer at many sites does not occur under ambient condition, and that it contains energy imparted from well pumps. A close examination of well construction and pump details, along with measurements of vertical flow within the well bore, should provide some clarification on the matter.

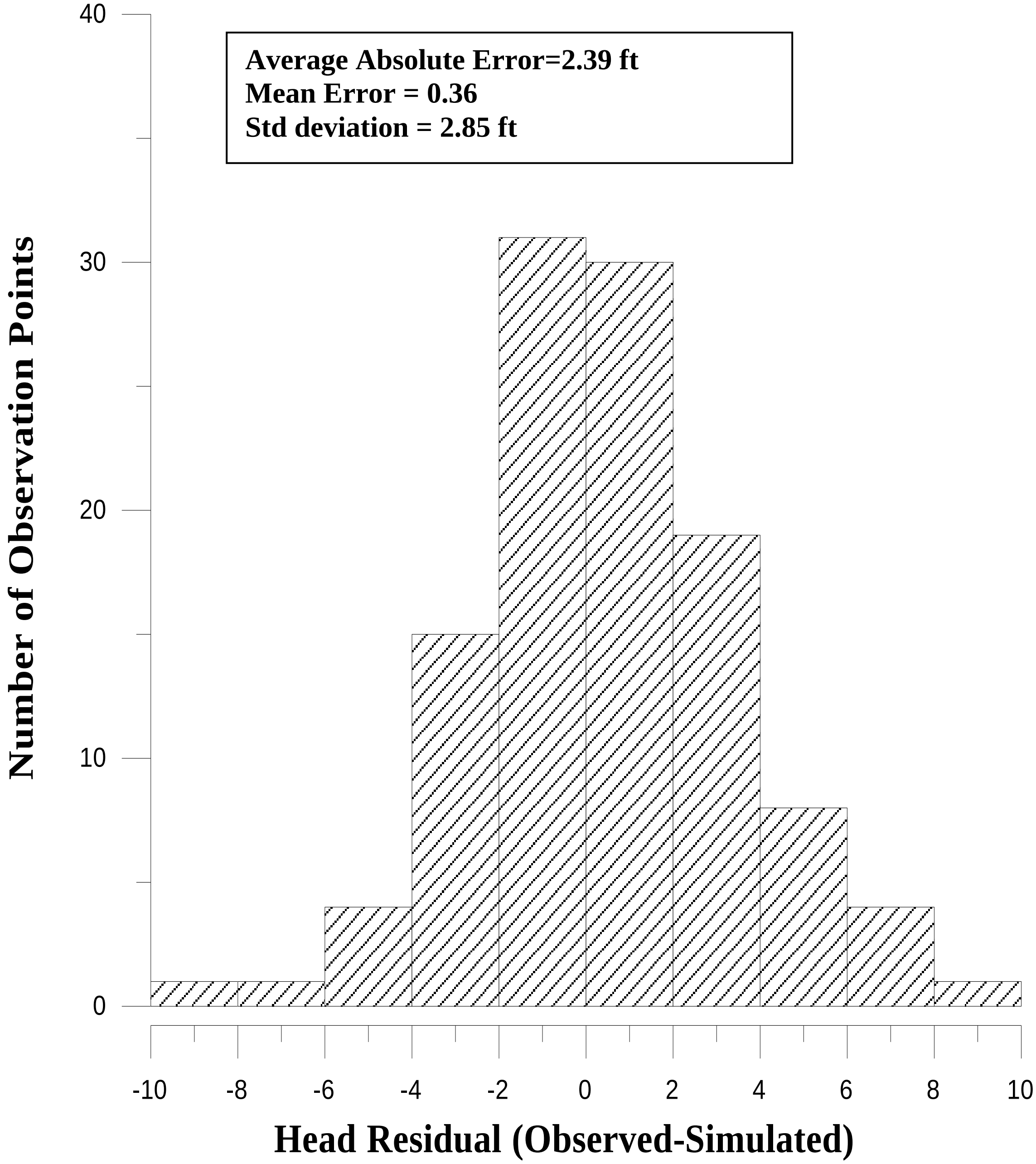



**Figure 38 Head residual histogram for 1995 Upper Floridan calibration**

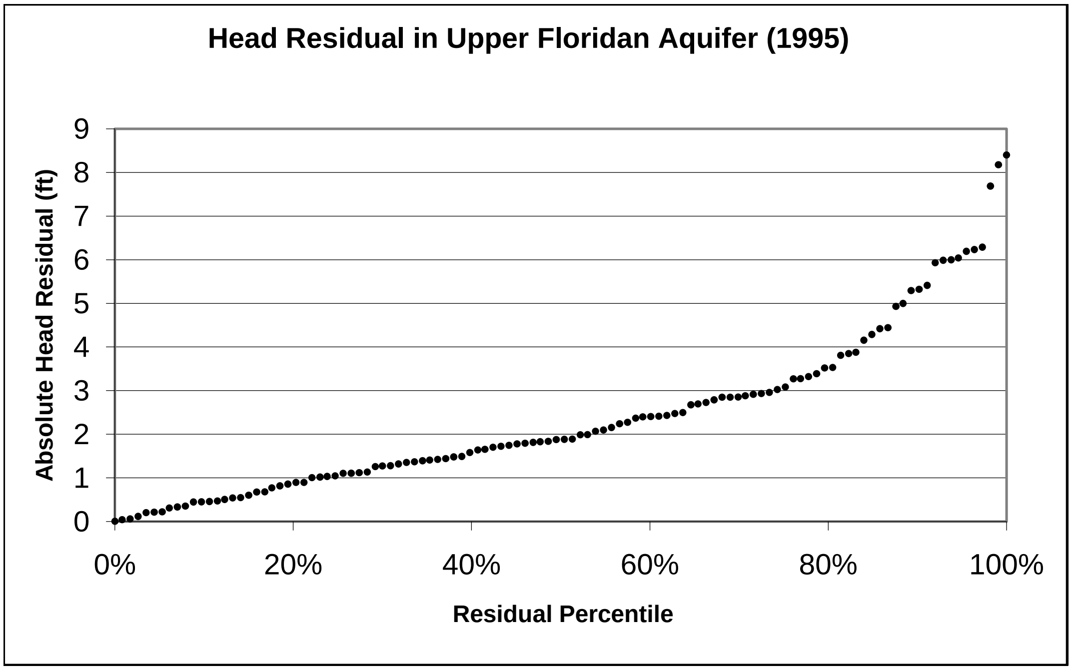



**Figure 39 Cumulative Head Residual Percentile in Upper Floridan Aquifer for 1995 calibration**

Another area of persistent positive residuals (i.e. lower simulated heads) is along the Atlantic Ridge (Figure 36) in St Johns County. At the southeastern corner of Duval County, the residual is 6 ft within the sand dunes in the area. It is likely that a) recharge in this general area is higher than that specified in the model, and b) the leakance in the upper confining unit is higher than specified. Increasing recharge without increasing leakance of the upper confining unit resulted in head values in the surficial aquifer to be above the land surface. Increasing leakance on the other hand resulted in relatively high drawdowns for the 2025 simulation period, which is contrary to what has been observed. It therefore appears that the metric used to measure drawdown impacts in the surficial aquifer, which is, the difference in the average 1995 and 2025 heads, needs to be refined by rigorously simulating flow with an integrated surface-groundwater model.

The simulated potentiometric surface indicates that a large portion of groundwater infiltrates into the Upper Floridan aquifer from the overlying surficial aquifer in the Keystone Heights area, from where it moves towards the Atlantic coast, Lake George, and the western boundary. Pumpage in the Fernandina Beach area affects the flow regime regionally, while pumpage at Gainesville has a localized impact. It should be noted that the interpreted 1995 potentiometric surface (Figure 23) is subject to data limitations, both spatially and temporally, which result in contouring artifacts in the interpreted potentiometric surface. Therefore, the simulated and interpreted potentiometric surfaces should be compared only qualitatively, and head residuals at the observation wells relied on for measuring the quality of calibration.

The simulated 1995 spring flow rates are presented in Table 3 along with the percent error between the simulated and estimated discharge for 1995. The total model simulated spring flow is 225.43 cfs, which is almost identical to the observed total and well within the calibration target of 10 %. At most of the springs, the error is less than 1%. The exception is Blue Spring at Rodman Reservoir, where it was not possible to maintain flow at the site without arbitrarily adjusting recharge and leakance locally in the area. The spring pool elevation at the site should be re-examined. The lack of flow at Blue Spring (estimated at 0.5 cfs) however is fairly inconsequential on the simulated potentiometric surface of the Upper Floridan aquifer. The total estimated spring flow in the model area for 1995 is 225.6 cfs.

**Table 3 Simulated 1995 spring flows**

| Spring | Stage (ft) | Estimated Flow (cfs) | Simulated Flow (cfs) | Percent Difference |
|---|---|---|---|---|
| Wadesboro | 24 | .94 | .94 | 0.0 |
| Green Cove | 21 | 3.11 | 3.11 | 0.0 |
| Crescent Beach | .5 | 30.0 | 29.75 | 0.83 |
| Whitewater | 23.5 | 1.40 | 1.64 | -17.14 |
| Orange | 54.5 | 2.86 | 2.86 | 0.0 |
| Blue (Submerged in Rodman Reservoir) | 31 | 0.5* | 0 | na |
| Camp Seminole | 54.5 | .79 | .79 | -0.0 |
| Welaka | 11 | 1.10 | 1.13 | -2.73 |
| Mud | 8.3 | .65 | .66 | -1.54 |
| Beecher | 2 | 9.04 | 9.05 | -0.11 |
| Croaker Hole | 6.8 | 83.00 | 83.23 | -0.28 |
| Tobacco Patch | 30.8 | 2.80 | 2.78 | 0.71 |
| Wells Landing | 30.8 | 9.88 | 9.92 | -0.40 |
| Salt | 1.8 | 79.53 | 79.57 | -0.05 |
| Total | | 225.6 | 225.43 | |

Estimated from Mega Model (Sepulveda, 2000)

The simulated water levels in the Lower Floridan aquifer and the Fernandina Permeable Zone are presented in Figures 40a and 40b, respectively. The potentiometric surface of the Lower Floridan aquifer is a subdued reflection of the potentiometric surface of the Upper Floridan aquifer, while the potentiometric surface of the Fernandina Permeable Zone is a subdued reflection of the potentiometric surface of the overlying Lower Floridan aquifer.

Observed water level data for the Lower Floridan and the Fernandina Permeable Zone are extremely sparse. No data was available for the 1995 calibration period. In recent years, however, data has been collected from a number of observation wells open to multiple aquifers. This data was crucial for calibrating the Lower Floridan aquifer. The approach involved deriving the head difference between the various aquifers at an observation well site and then attempting to reproduce the derived head differences for the 1995 calibration period.

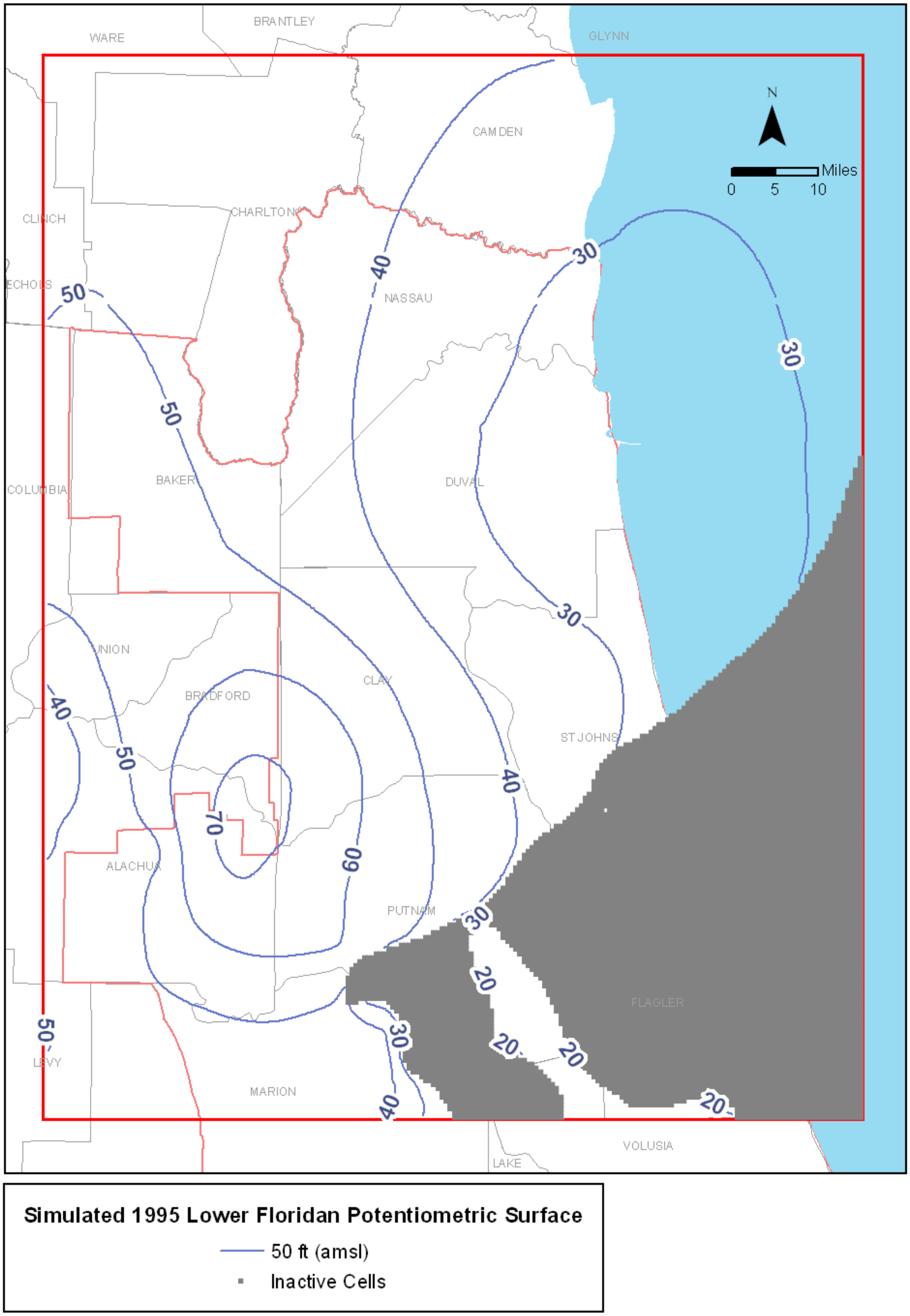



**Figure 40a Simulated 1995 Lower Floridan potentiometric surface**

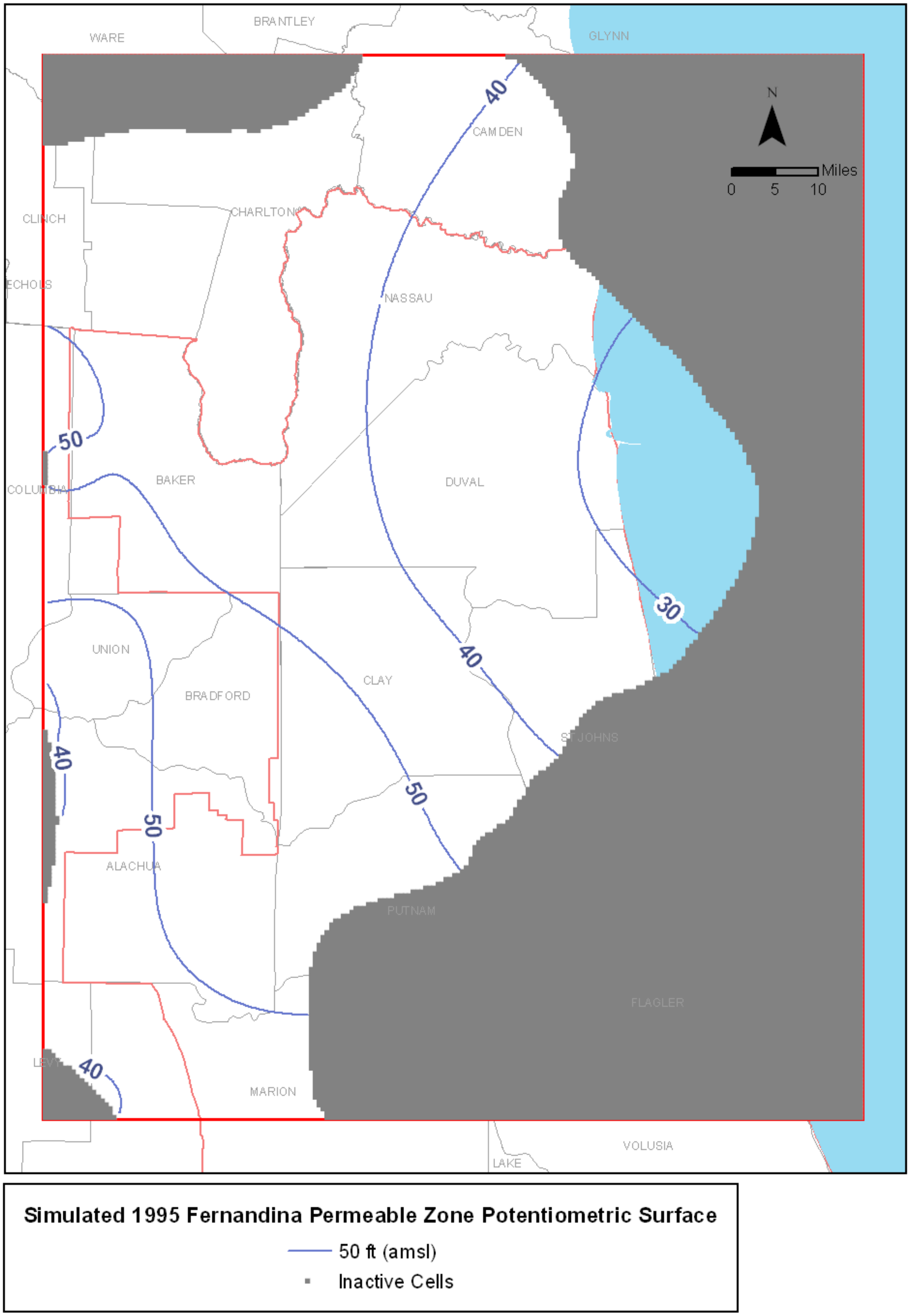



**Figure 40b Simulated 1995 Fernandina Permeable Zone potentiometric surface**

Site locations of paired observation wells or observation wells open to multiple aquifers are presented in Figure 40c. The hydrograph at each of the sites is presented in Figure 40d. The average observed head difference at each site is indicated in Table 4, along with the simulated 1995 head differences for the calibration run. Overall, the observed and simulated head differences are fairly close. At all sites, the vertical direction of groundwater flow is the same for the observed and simulated cases. The error (or residual) in head-difference at the Callahan, Dewey Park, Bayard Point, St. Mary's, and 12-mile Swamp are –0.85, 1.05, 1.92, -0.84, and 1.6 ft, respectively. In general, if the residuals are positive, and assuming that the pumpage is accurately represented, then it is possible the model leakance between the corresponding aquifers is larger than actual leakance, thereby indicating a stronger hydrologic connection than actual. From the head-difference residuals in Table 4, this is the case between the Upper Floridan and the underlying aquifers in the St Johns, Clay, and Duval County areas, while the opposite case exists in Nassau and Camden counties. This discrepancy further supports the argument above that leakances in the UCU need to be increased in order to allow more recharge through the surficial aquifer in coastal areas of Duval and St Johns counties. However, as discussed above, this requires simulations to be conducted with an integrated surface-groundwater model if the surficial drawdowns are to be accurately projected.

At the Ralph Simmons site, a large residual of 7.94 ft is noted. The simulated difference is 0.32 ft while the observed difference is 8.26 ft. A close examination of the hydrographs, and the results of the USGS Mega model (Sepulveda, 2002), suggests that the large observed head difference is a consequence of pumpage near the site. The pumpage data in the districts database indicates no major pumpage near the site. It is recommended that the District's records be examined for pumpage in the area.

The water table in the surficial aquifer is highly correlated with the topography, with large variations in water levels expected over short distances. This is because the flow in the surficial aquifer is largely in the vertical direction because of low hydraulic conductivity of the surficial aquifer and the large head differences between the surficial and Upper Floridan aquifers.

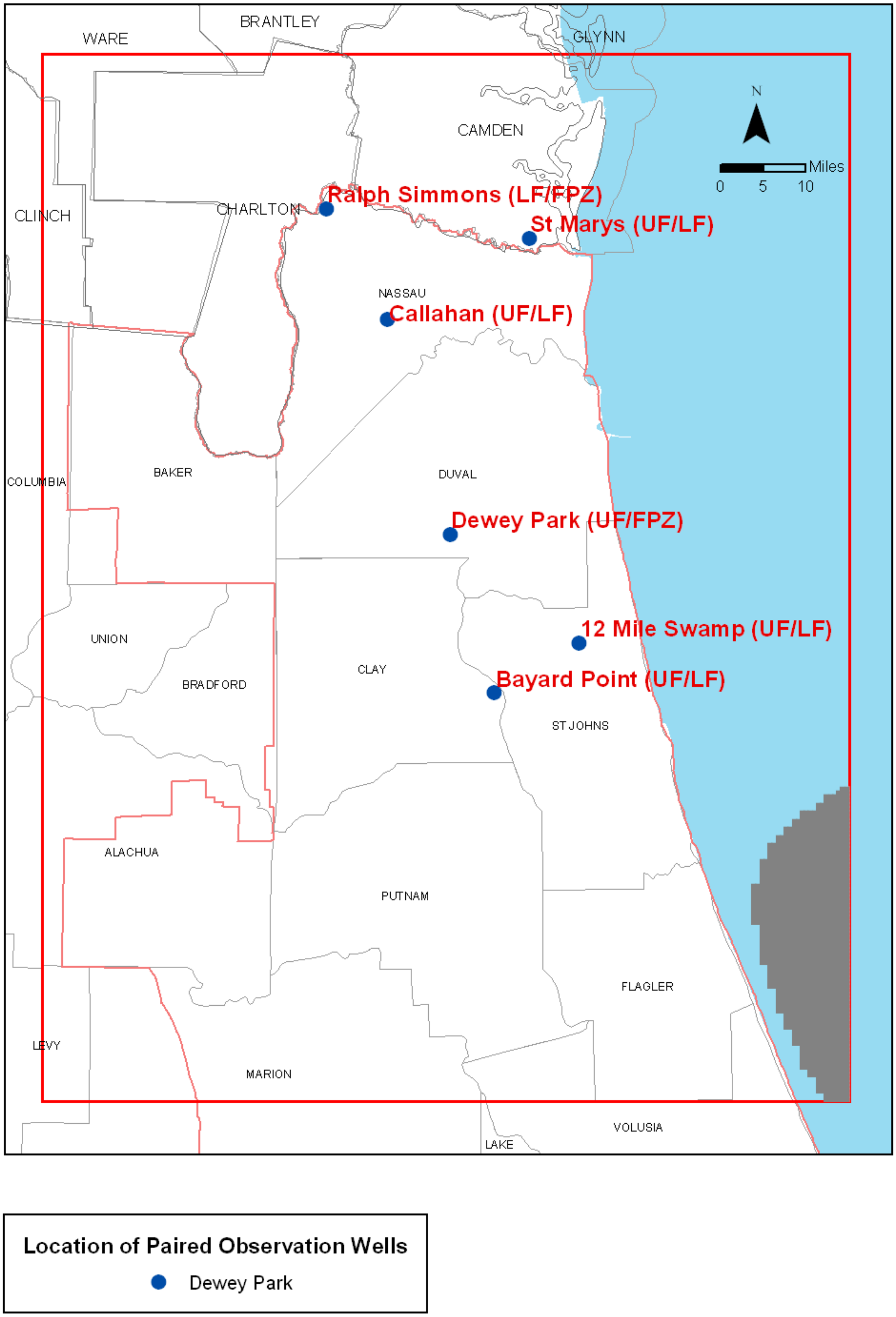
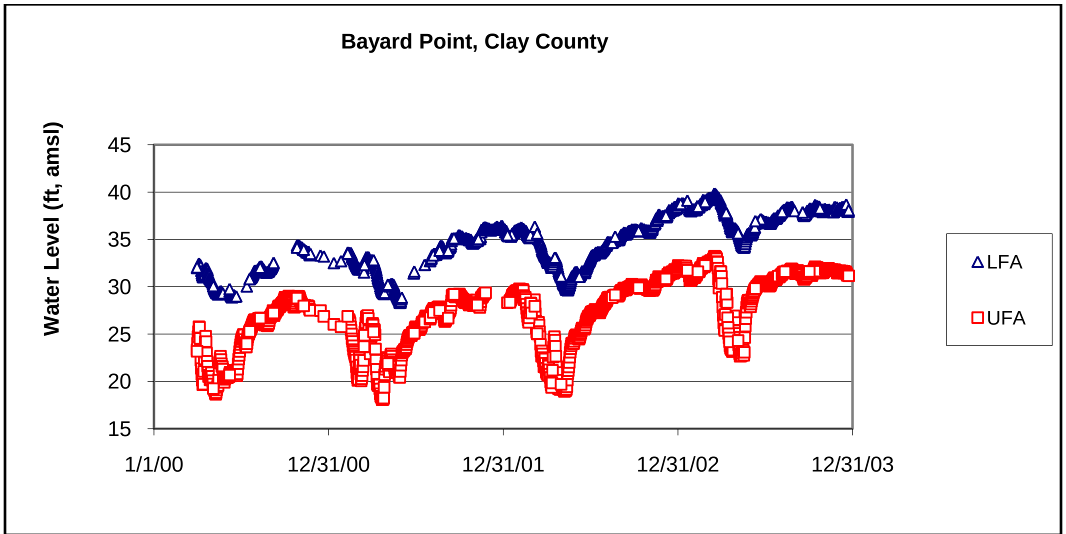
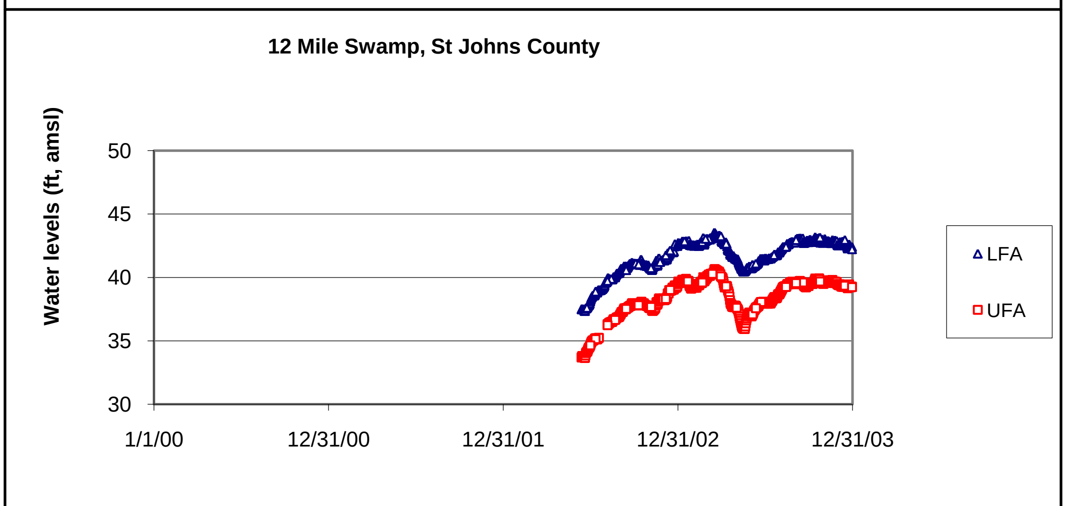



**Figure 40c   Location of paired observation wells**



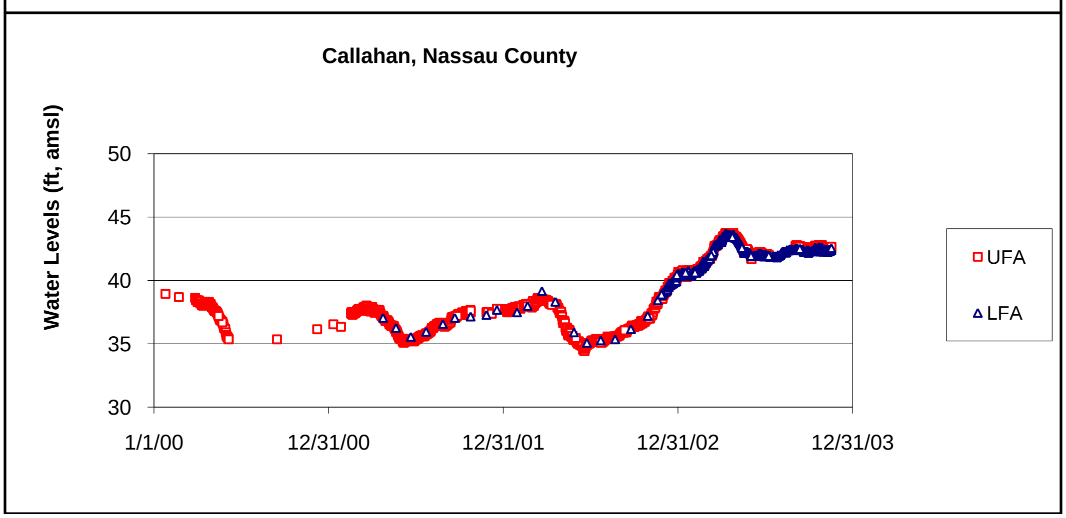
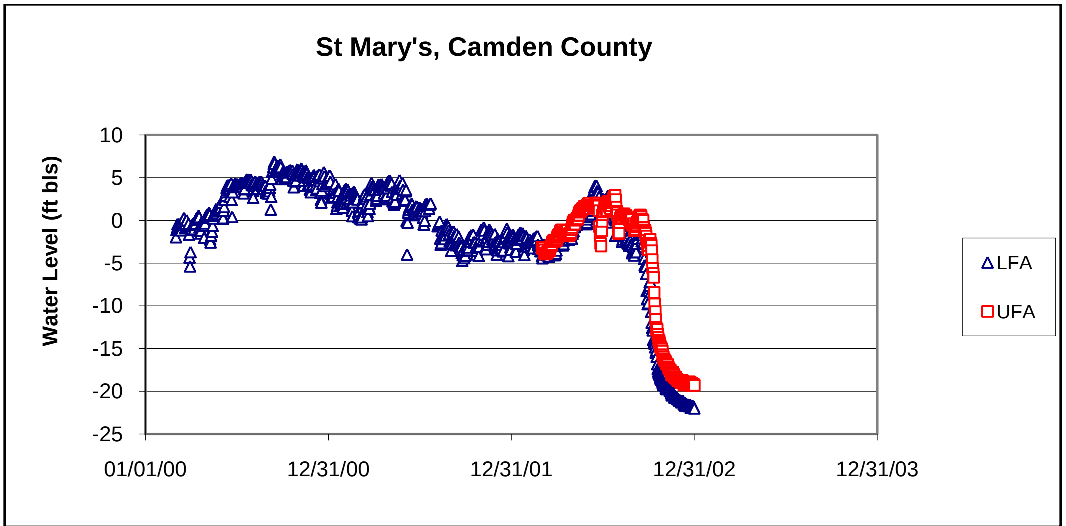
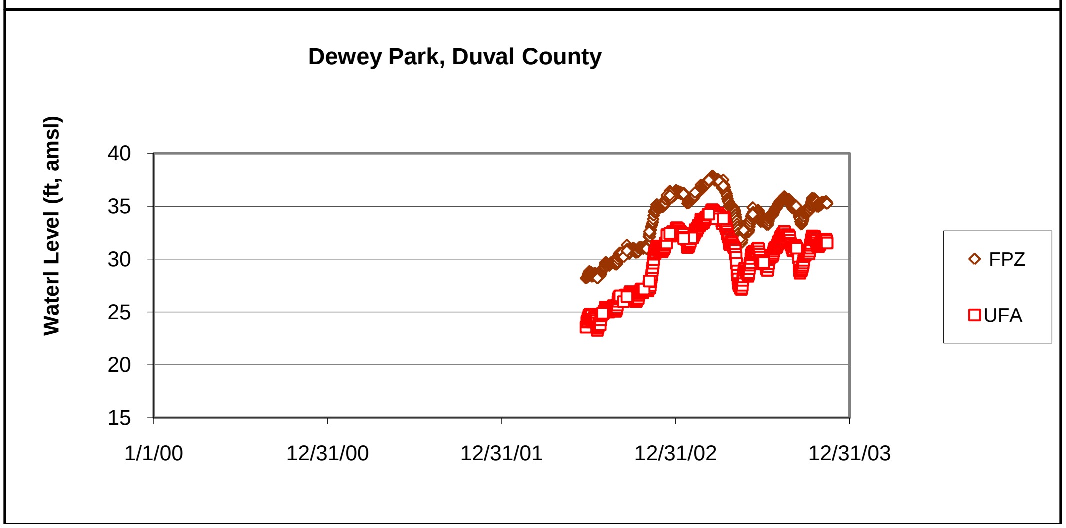




**Figure 40d Water level hydrographs at paired well locations**



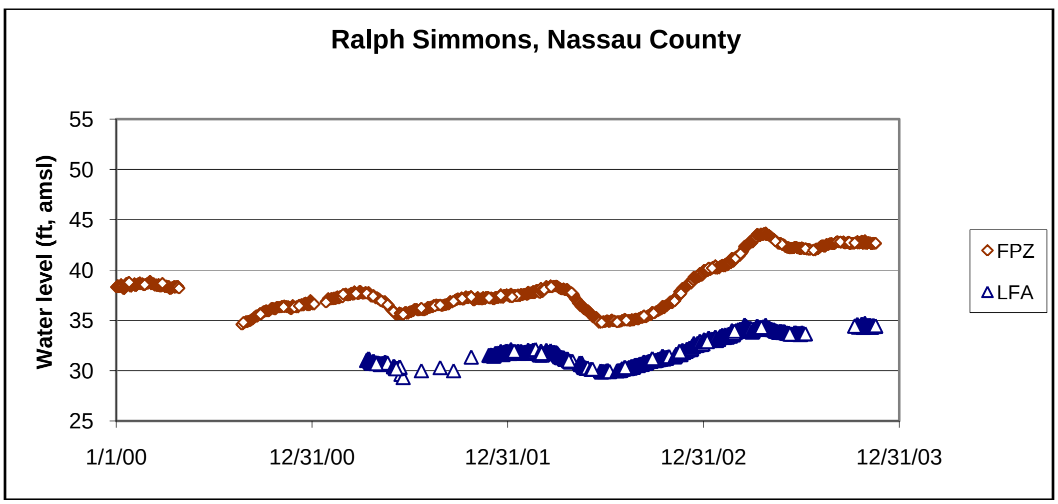




**Figure 40d—*continued***

**Table 4 Head Differences at paired observation well locations**

| Site | Well Number* | Observed Head Difference (ft) | Simulated Head Difference (ft) | Head Difference Residual (Observed-Simulated, ft) |
|---|---|---|---|---|
| Bayard Point | C-0579(UF)<br>C-0578(LF) | 7.24 | 5.32 | 1.92 |
| 12 Mile Swamp | SJ-2556(UF)<br>SJ-2551(LF) | 3.24 | 1.64 | 1.6 |
| Callahan | N-0220(UF)<br>N-0236(LF) | 0.08 | 0.93 | -0.85 |
| Dewey Park | D-1394(UF)<br>D-1344(FPZ) | 3.9 | 2.85 | 1.05 |
| St Mary's | 33D069(UF)<br>33D073(LF) | 5.68 | 6.52 | -0.84 |
| Ralph Simmons | N-0222(LF)<br>N-0221(FPZ) | 8.26 | 0.32 | 7.94 |

*LF = Lower Floridan Aquifer
UF = Upper Floridan Aquifer
FPZ = Fernandina Permeable Zone

Therefore, unlike the Upper Floridan aquifer, where a head value is useful for constructing a potentiometric surface, a single observation head value in the surficial aquifer is of importance only locally, and cannot be utilized for constructing a regional water table map. Matching the observed heads in the surficial aquifer at individual observation well sites is relatively simple as it is highly dependent on local recharge at the site. However, relying on a match at the individual well sites in the surficial aquifer as a measure of the quality of calibration may provide a false impression of the goodness-of-fit in the overall aquifer due to the reasons stated above. The most prudent approach is therefore to construct an interpreted water table for each distinct physiographic region, and to calibrate the model to the interpreted surface as well as the individual observation well data.

As discussed above, a linear regression model was used to estimate the water table elevation for the entire study area and was used as the calibration target for all cells in the surficial aquifer.

The following relationship between water table elevation and land surface elevation was derived from data at the observation wells:

$$\text{Water Table Elevation} = 0.88\ (\text{Land Surface Elevation}) - 1.91$$

The simulated water table elevation in the surficial aquifer is presented in Figure 41. Utilizing simulated surficial aquifer head values at all active nodes, the following regression model between simulated water levels and land surface elevation was obtained:

$$\text{Water Table Elevation} = 0.88\ (\text{Land Surface Elevation}) + .18$$

This is a good match to the regression equation obtained from the observation well data. The slopes of the observed and simulated regression equations are almost identical. The y-intercept is offset by 2.09 feet, and $R^2$ is 0.988. These values are all within the range of calibration targets discussed above.

Although the regressed water table was used for calibration, a plot of the observed and simulated heads at the surficial observation wells is presented in Figure 42 for documentation purposes. In general, the match between the simulated and observed water levels is reasonable except at some locations where large residuals exist. These are areas where the water table may be substantially above or below the estimated depth of 0.88 times the land surface elevation obtained from regression of the observed data. This may occur, for example, at nodes close to ponds/lakes/streams where the water table is close to the land surface, or along ridges in upland areas where the water table may be substantially below the land surface. This highlights the need to construct an interpreted water table surface for each physiographic region by applying the minimum water table approach implemented by Sepulveda (2000).

Head residual errors can also occur in areas where the land surface slopes significantly. The simulated water level represents results at the center of the grid cell. With a relatively large cell dimension of 2500 ft, it is not possible to accurately represent the water table variations within a grid cell if sharp gradients exist within a grid cell.

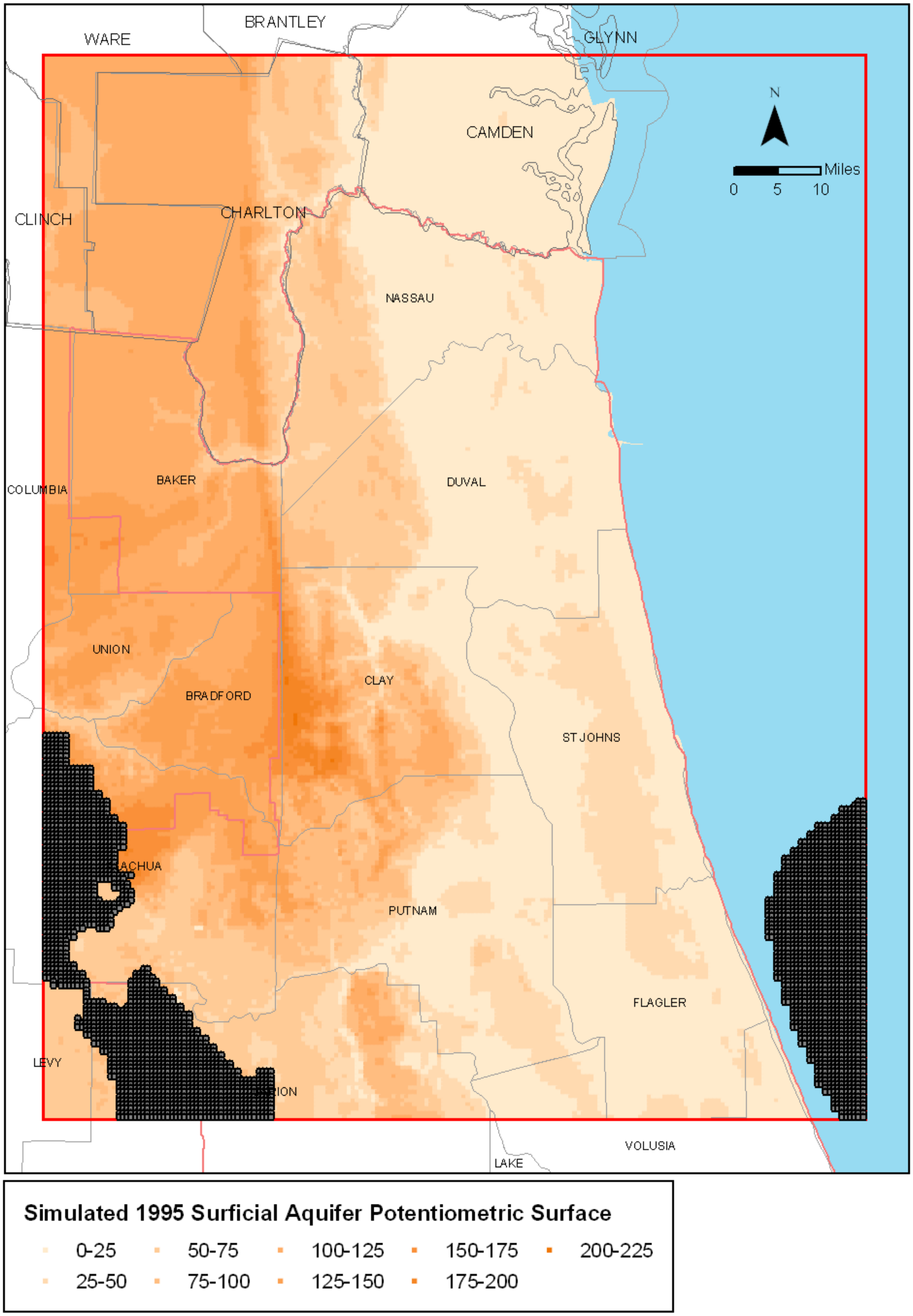



**Figure 41 Simulated 1995 surficial aquifer water table**

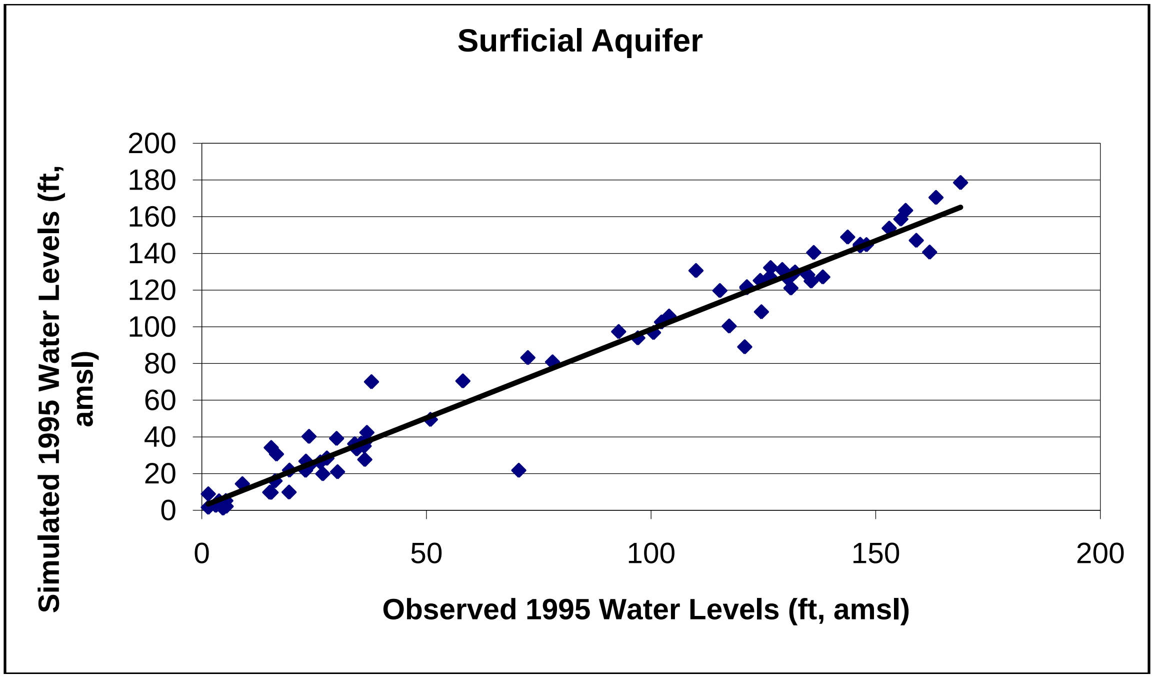



**Figure 42 Simulated versus observed water levels in surficial aquifer for 1995**

## Mass Balance

The mass balance summary for 1995 for the entire model is presented in Table 5. Approximately 2033 MGD enters the model through the top, along the lateral boundaries, and via drainage wells. Out of the 2033 MGD, 1542 MGD of water enters the surficial aquifer and Upper Floridan aquifers as recharge, while 347 MGD enters the system along the lateral boundaries, 133 MGD enters the surficial aquifer from surface water bodies, and 11 MGD of water enters the system from drainage wells. Of the total outflow, 630 MGD exits along the model lateral boundaries, 558 MGD exits the system along the top as discharge (in the form of evapotranspiration), 453 MGD is withdrawn from production wells, 248 MGD of groundwater discharges into the surface water features, and 146 MGD flows out of the system as spring discharge. Due to round-off and convergence limitations, the mass balance summations are in error by 0.02%.

The mass balance within each model layer decreases in magnitude from the topmost surficial aquifer to the bottommost Fernandina Permeable Zone (Figure 43). This highlights the dominance of recharge (from precipitation) on the groundwater flow regime. Approximately 1827 MGD flows through the surficial aquifer on an average daily basis, while flow rates in the Upper Floridan, Lower Floridan, and the Fernandina Permeable Zone are 1649, 635, and 43 MGD, respectively. As expected, the Fernandina Permeable zone is the least vigorous hydrogeologic unit.

Exchange of water between the aquifers also decreases with depth. Approximately 1029 MGD of water enters the Upper Floridan aquifer from the surficial aquifer, and 209 MGD discharges from the Upper Floridan into the surficial aquifer (Figure 44). Between the Upper and Lower Floridan aquifers, approximately 524 MGD enters the Lower Floridan aquifer, while 329 MGD of groundwater is discharged into the Upper Floridan. About 26 MGD of groundwater enters the Fernandina Permeable Zone from the Lower Floridan, and 14 MGD discharges from the Fernandina Permeable Zone into the Lower Floridan aquifer.

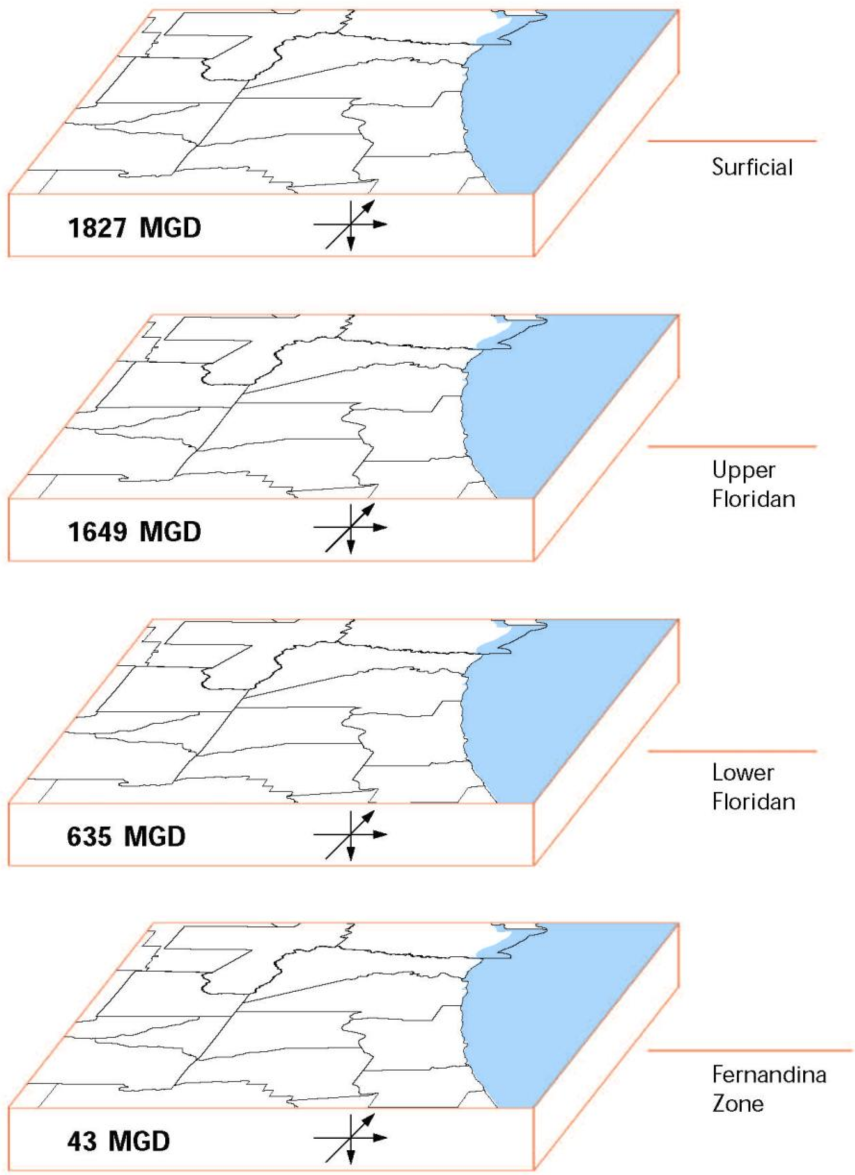



**Figure 43 Mass Balance within and across model layers for 1995**

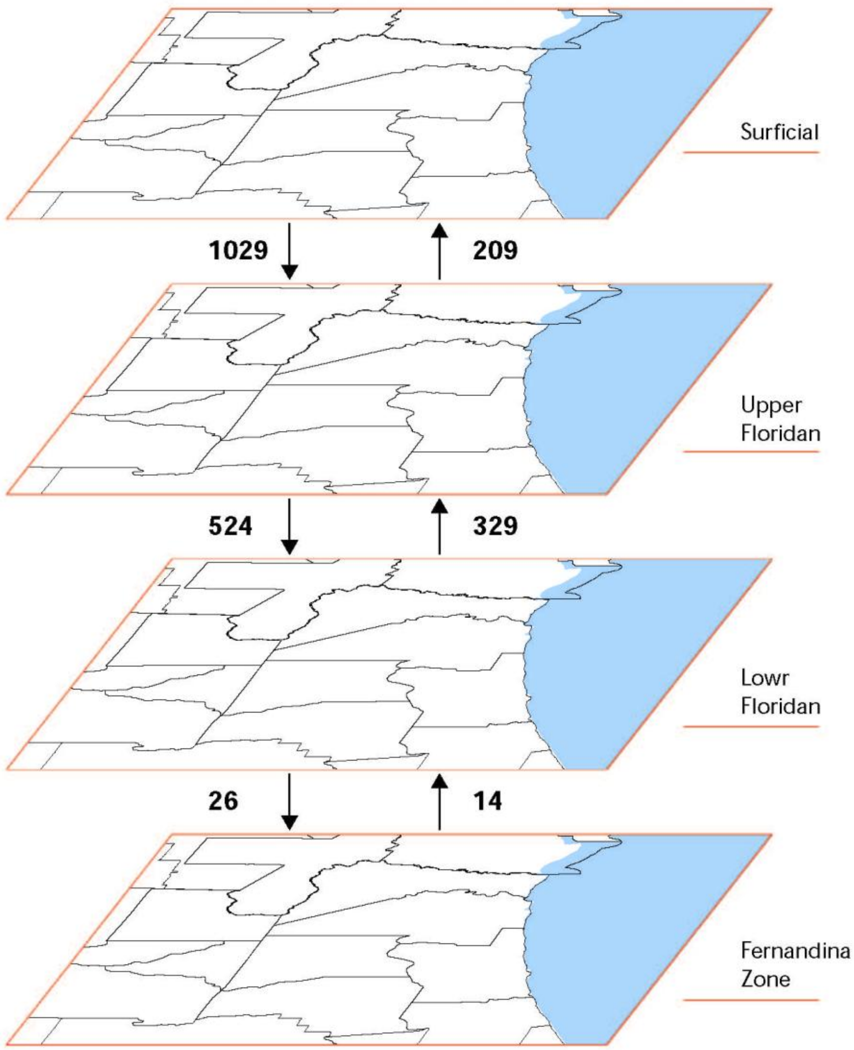



**Figure 44 Groundwater exchange between aquifers for 1995**

**Table 5 Summary of hydrologic mass balance (MGD) in model layers for 1995 calibration**

| | Recharge/ Discharge | | Constant Head | | General Head | | Well | | Drain | |
|---|---|---|---|---|---|---|---|---|---|---|
| | In | Out | In | Out | In | Out | In | Out | In | Out |
| Surficial | 1542 | 558 | 133 | 248 | | | | 3 | | |
| Upper Floridan | | | | | 233 | 412 | 11 | 359 | | 146 |
| Lower Floridan | | | | | 97 | 189 | | 91 | | |
| Fernandina Zone | | | | | 17 | 29 | | | | |
| Total | 1542 | 558 | 133 | 248 | 347 | 630 | 11 | 453 | na | 146 |

## Calibrated Hydraulic Parameters

The calibrated distribution of recharge/discharge to the surficial aquifer is presented in Figure 45a. Discharge occurs in coastal areas and further inland in low-lying areas along streams and creeks. Recharge is less than 4 in/yr in most of the study area except in topographic highs in the western portions of the study area, where recharge in excess of 12 in/yr can be expected. In general, the areas of highest recharge coincide with either topographic highs, or where the leakance of the upper confining unit (Figure 46a) is high, such as in the Lake George area. Recharge also occurs along ridges and sand dunes near the coast. It should be noted that the model recharge represents net inflow infiltrating into the surficial aquifer and eventually reaching the water table.

The model-derived distribution of recharge from the surficial aquifer into the Upper Floridan aquifer is presented in Figure 45b. The recharge/discharge distribution to/from the Upper Floridan is similar to the calibrated recharge/discharge distribution to the surficial aquifer along the top model boundary (Figure 45a). This suggests that a large portion of the water infiltrating into the deeper zones of the surficial aquifer passes on as recharge to the Upper Floridan. Discharge occurs along low-lying areas in close proximity to the point of infiltration, and in the coastal basin. The recharge distribution to the Upper Floridan is also similar to the GIS

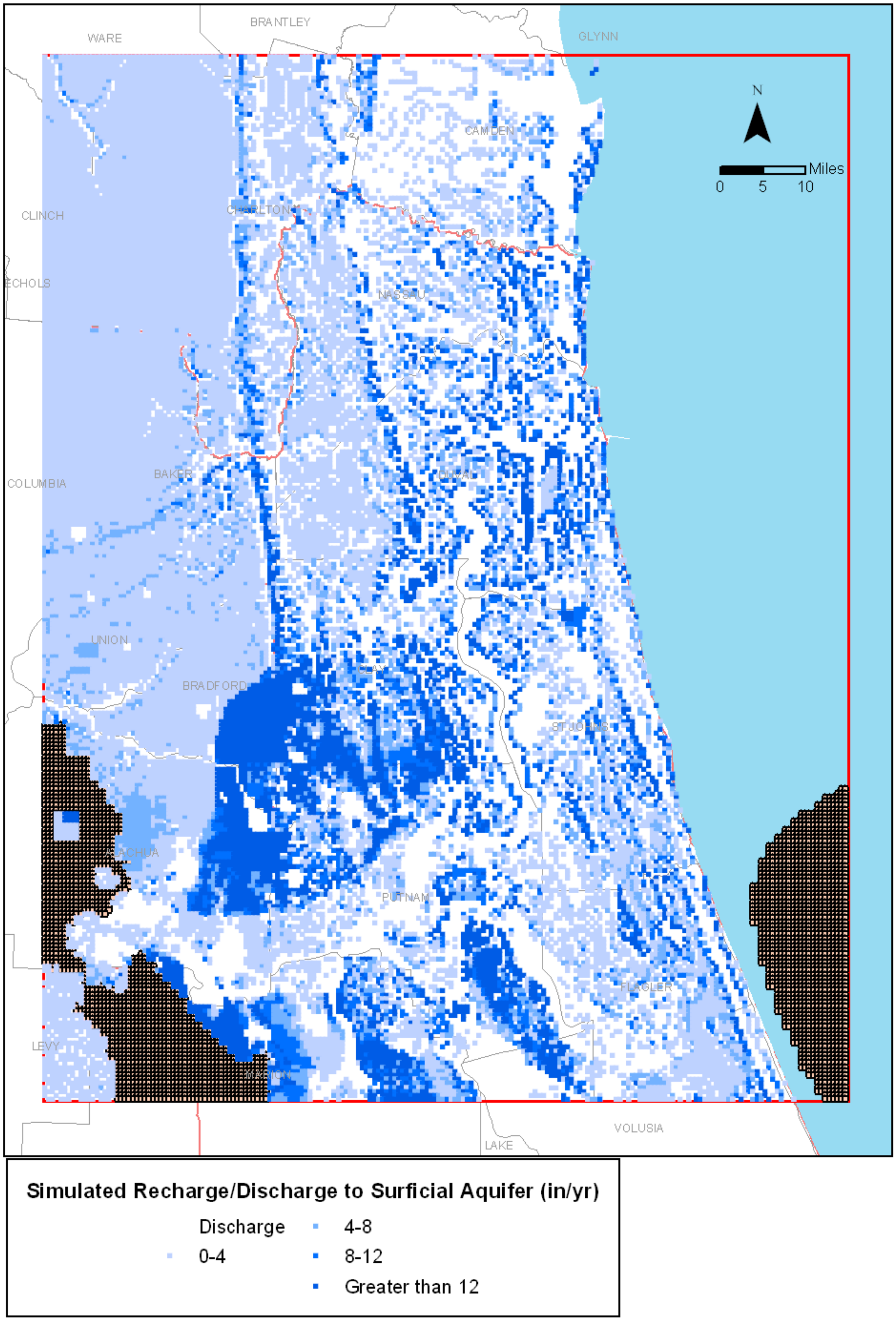



**Figure 45a Recharge to surficial aquifer**

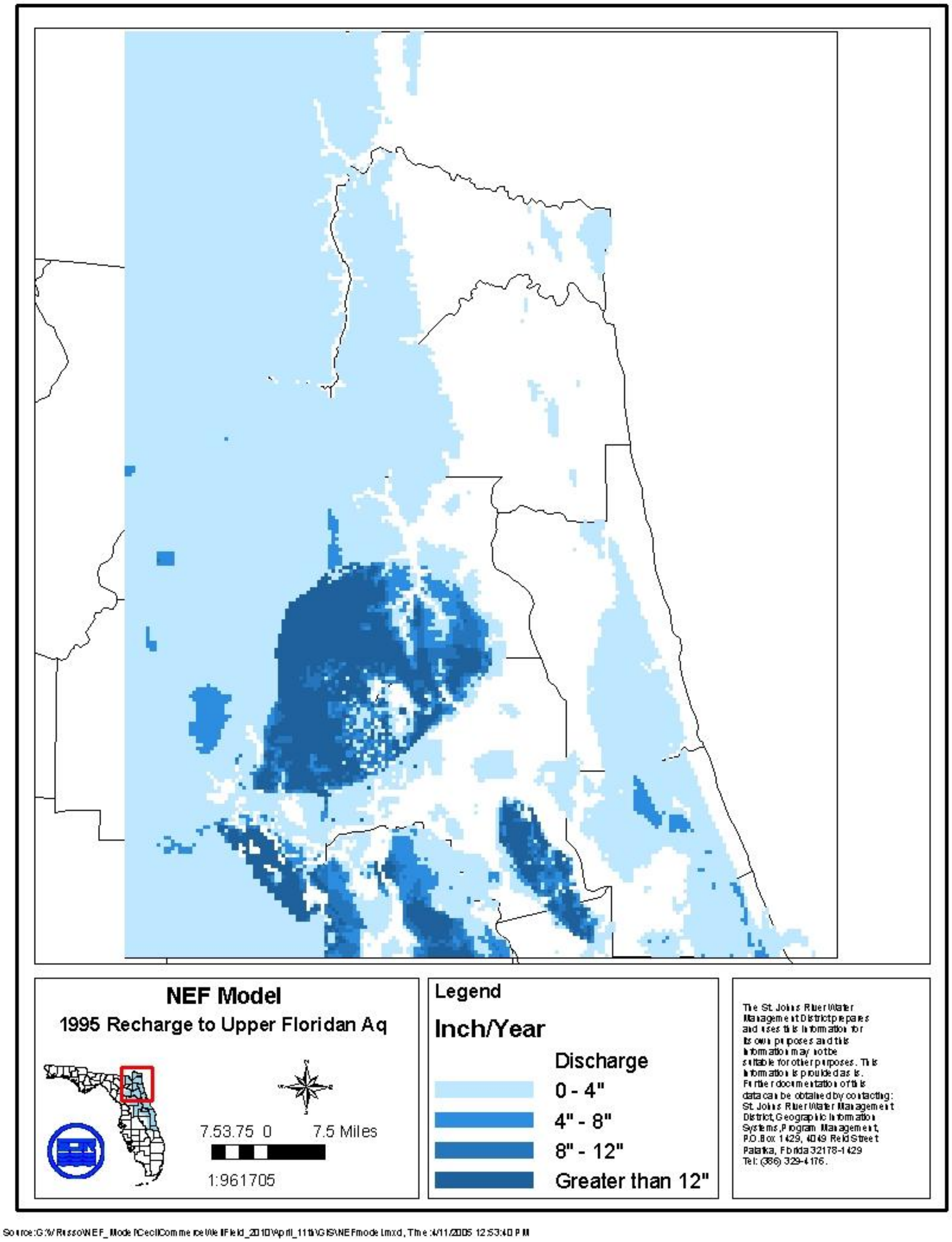



**Figure 45b Recharge to Upper Floridan aquifer from surficial aquifer**

estimated recharge map derived by Boniol (1993) and presented in Figure 17. It should be noted that the model recharge was derived in order to reproduce the estimated water table, i.e,

$$\text{Water Table Elevation} = 0.88\ (\text{Land Surface Elevation}) - 1.91$$

For an alternate water table target, the recharge distribution may vary, but the general configuration, and the relative magnitude, of recharge/discharge is expected to remain similar.

The distribution of model estimated transmissivity in the surficial aquifer is presented in Figure 46a. In general, the transmissivity is higher in the coastal areas, and lower in upland regions. The hydraulic conductivity in these two regions, which are distinctly noticeable in Figure 46a, varies from 5-20 ft/day. There is inadequate data regarding the variation of surficial aquifer hydraulic conductivity/transmissivity in the study area. Rabbani and others (2003) utilized a hydraulic conductivity of 25 ft/day for a flow model in the Palm Coast area. This is of similar magnitude to the model estimated hydraulic conductivity of 20 ft/day near Palm Coast. Annable and Motz (1996) derived an average hydraulic conductivity of 5.6 ft/day from analyzing slug test data in the Upper Etonia Creek Basin in Alachua, Bradford, Clay, and Putnam counties. The model estimated hydraulic conductivity in these areas is 5 ft/day.

The distribution of transmissivity in the Upper Floridan, Lower Floridan, and the Fernandina Permeable Zone is presented in Figures 46b, 46c, and 46d, respectively. Transmissivity zones in the Upper Floridan aquifer correspond closely to those in the Mega Model (Sepulveda, 2002). The transmissivity in coastal regions is in the lower end of the range (10,000–50,000 $ft^2$/day), while higher values exist in the western regions.

The Lower Floridan transmissivities are highest in the coastal regions, and similar in magnitude to the range estimated by Durden (1997) and Sepulveda (2002) in their flow models. The transmissivity in the Fernandina Permeable Zone is a uniform 40,000 $ft^2$/day, which is close to the value of 43,000 $ft^2$/day used by Durden (1997). The results of sensitivity analysis indicated that the heads in the Upper Floridan aquifer were not very sensitive to this parameter.

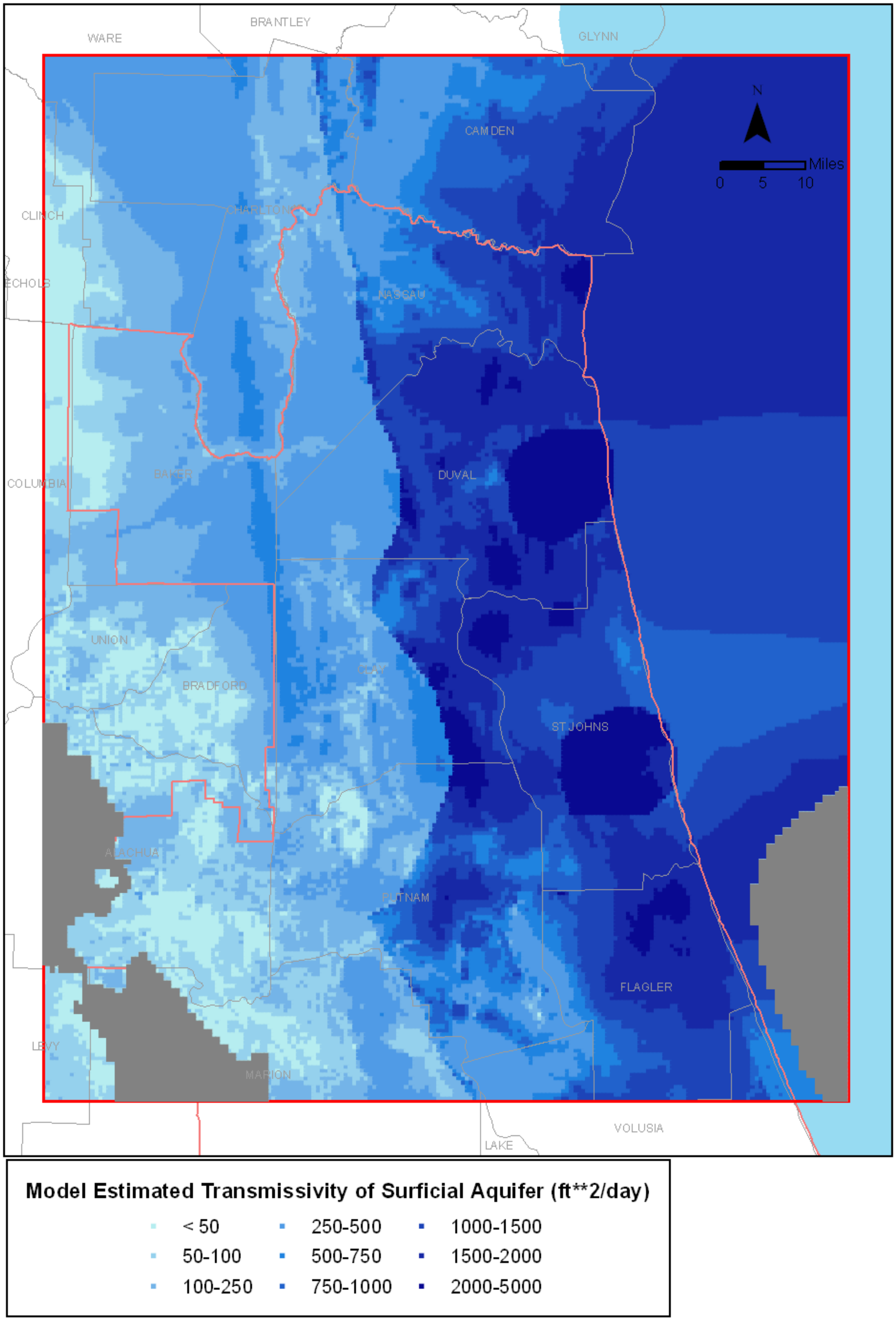



**Figure 46a   Model derived transmissivity of surficial aquifer**

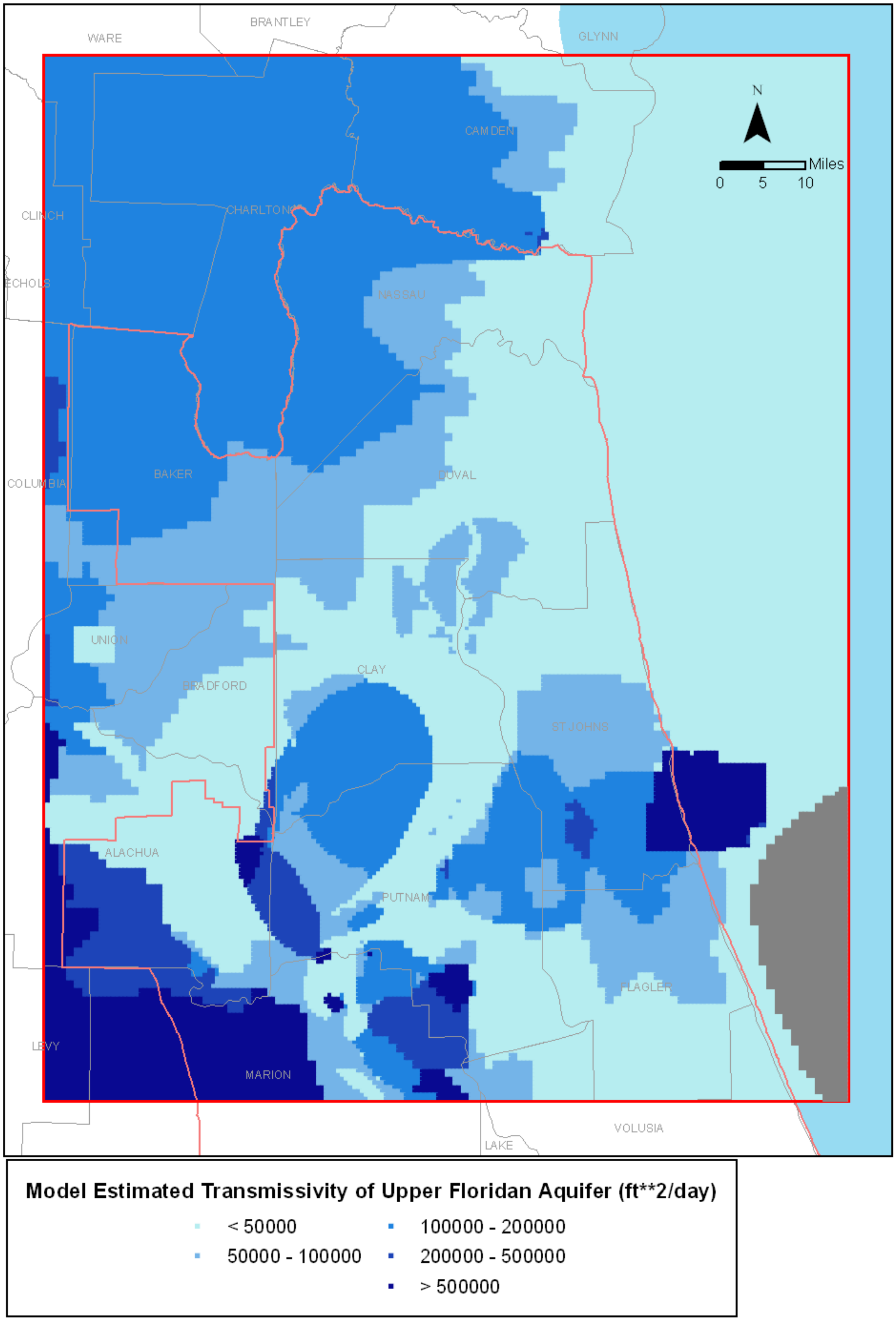



**Figure 46b Model derived transmissivity of Upper Floridan aquifer**

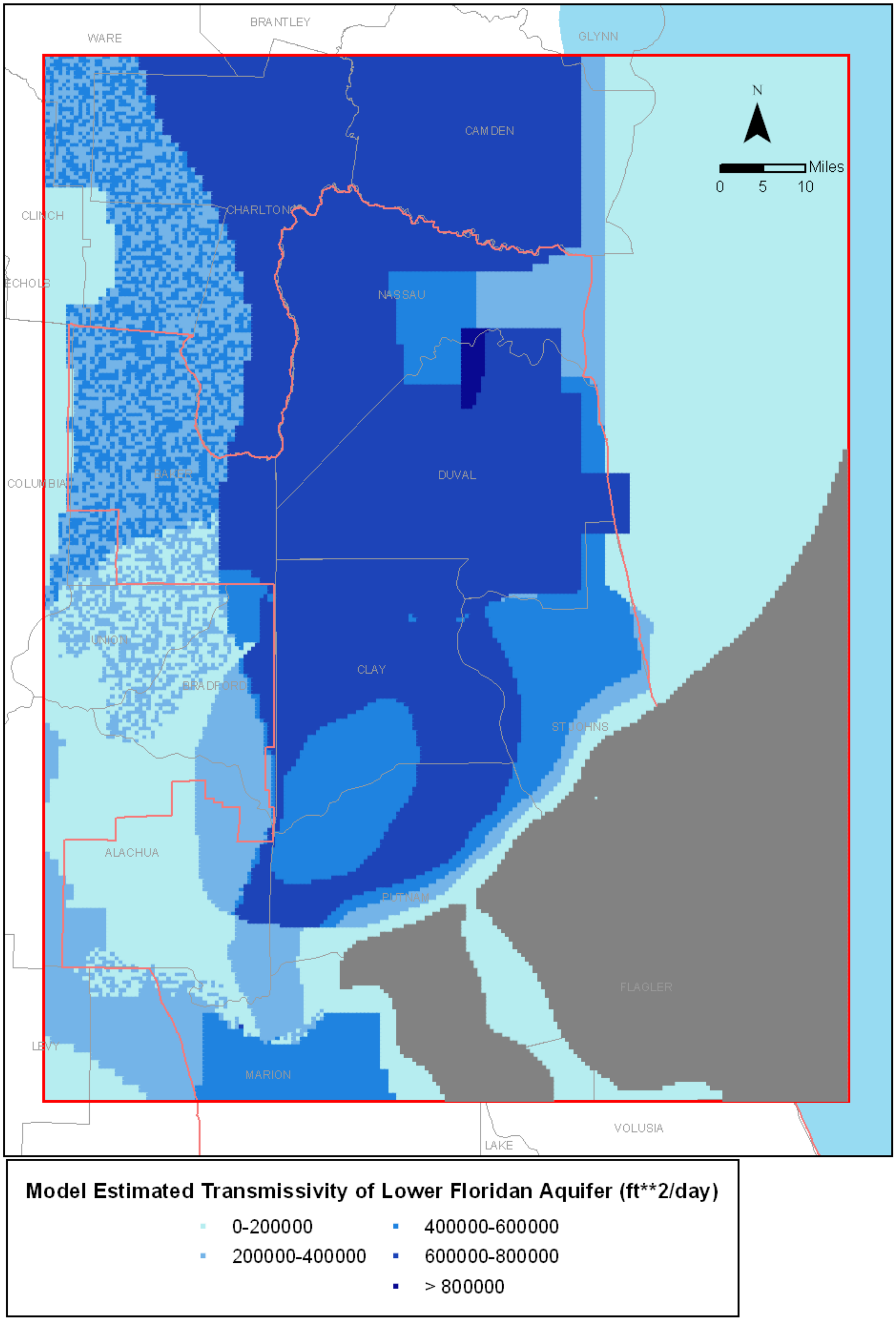
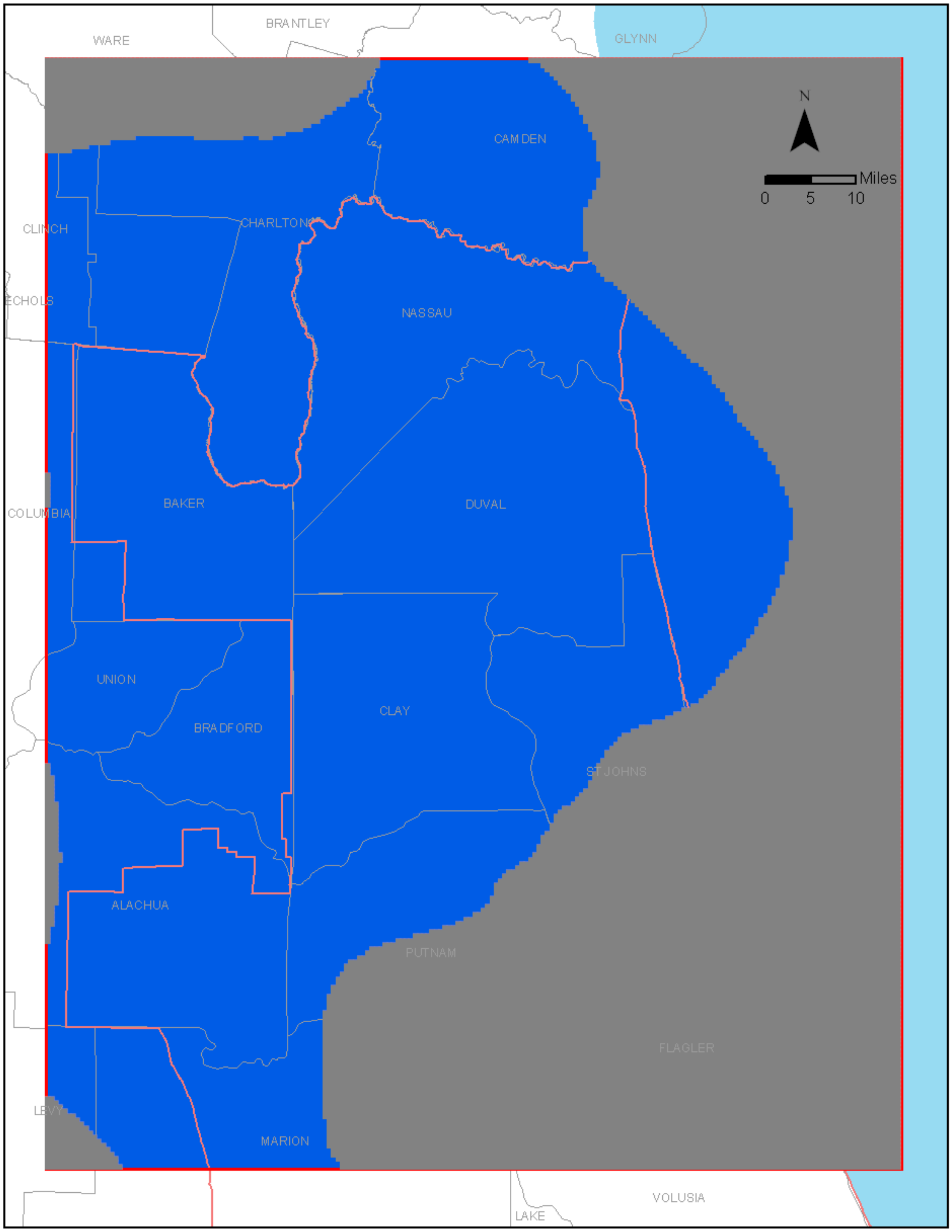



**Figure 46c Model derived transmissivity of Lower Floridan aquifer**




Model Estimated Transmissivity of Fernandina Permeable Zone (ft**2/day)

40000

**Figure 46d Model derived transmissivity of Fernandina Permeable Zone**

The heterogeneity in the final calibrated transmissivity is a consequence of the trial and error calibration approach that was implemented for the study due to time constraints. Such heterogeneity exists in other calibrated parameters as well. In future updates to the model, an attempt should be made to smoothen out these heterogeneities by using an automated parameter estimation approach.

The leakance distribution in the upper confining unit, the middle semi-confining unit, and the lower semi-confining unit are presented in Figures 47a, 47b, and 47c, respectively. The leakance distribution of the upper confining unit (UCU) and the middle semi-confining unit (MSCU) derived in the Mega model (Sepulveda, 2000) was abandoned in the present study. During initial calibration efforts, leakance from the Mega model was maintained and the resulting calibration in the Upper Floridan was quite reasonable. However, when the study scope was increased to estimate drawdowns in the surficial aquifer, large surficial drawdowns were noted within zones of high leakance, which often coincided with areas of large UCU thickness. This was deemed unrealistic, because the model was simulating drawdowns at several locations where water levels had been noted to be quite stable over time. It was therefore decided to completely recalibrate the UCU and MSCU leakances, and set it proportional to the estimated thickness of the confining unit to provide a physically defensible basis for this parameter.

After several iterations, the magnitude of the UCU leakance was specified with a vertical hydraulic conductivity of .0025 (ft/day) divided by the thickness of the unit. The exceptions are in the Keystone Heights area, the offshore model areas, and at a few locations along the St Johns River in Duval county where highly permeable vertical zones in the UCU are suspected to exist. In the Keystone Heights area, a higher leakance was required in order to calibrate the model to observed water levels in the Upper Floridan aquifer; the values ranged from 4.0e-5 to 1.0e-4 (1/day). Under several lakes in the area, the leakance is as high as 7.0e-4 1/day. Higher leakance values in the Keystone Heights area was also derived in a study by Annable and Motz (1996), where estimates ranged from 1.7e-4 to 9.6e-4 1/day under lakes Lowry, Magnolia, Geneva, and Brooklyn.

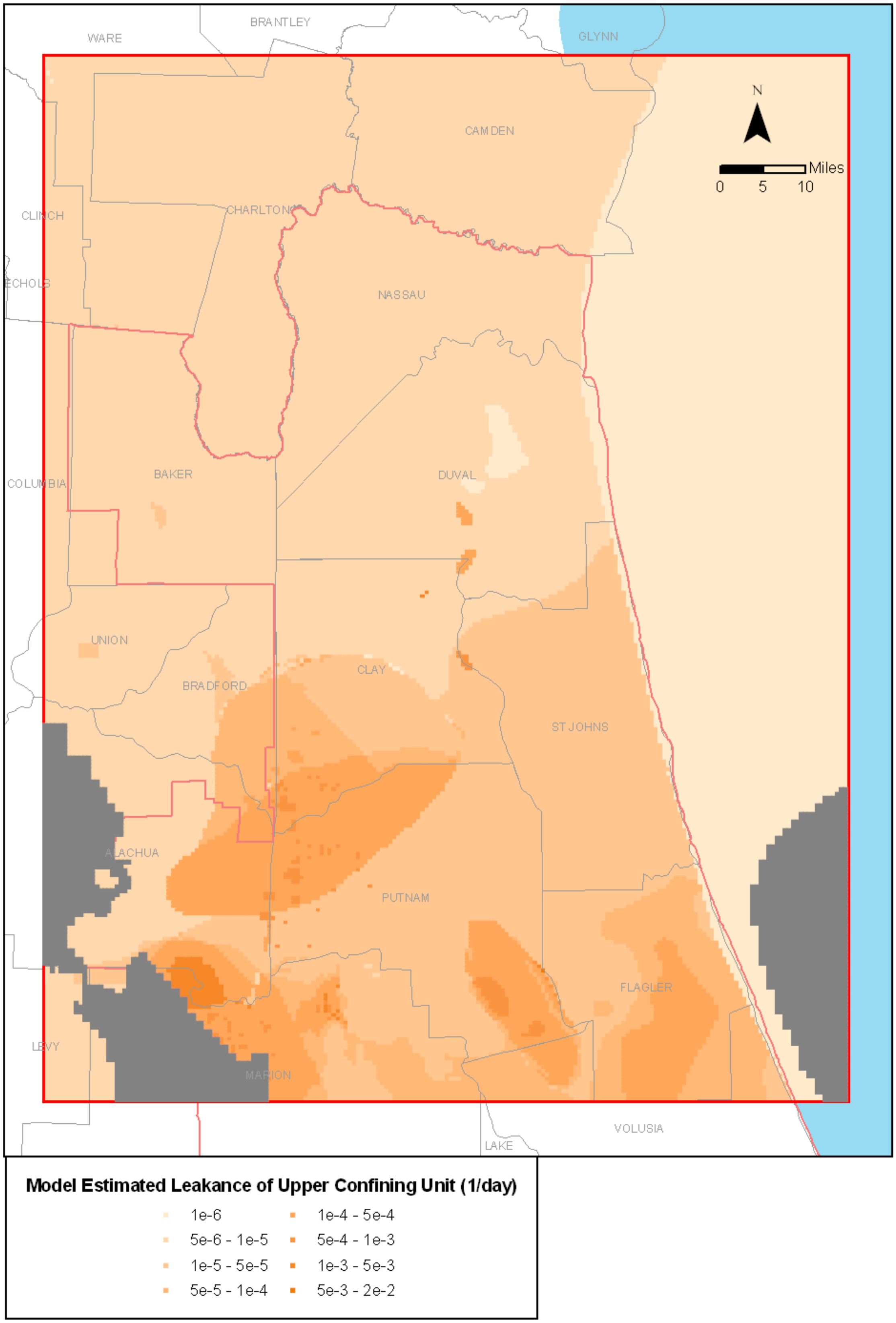



**Figure 47a Model derived leakance of upper confining unit**

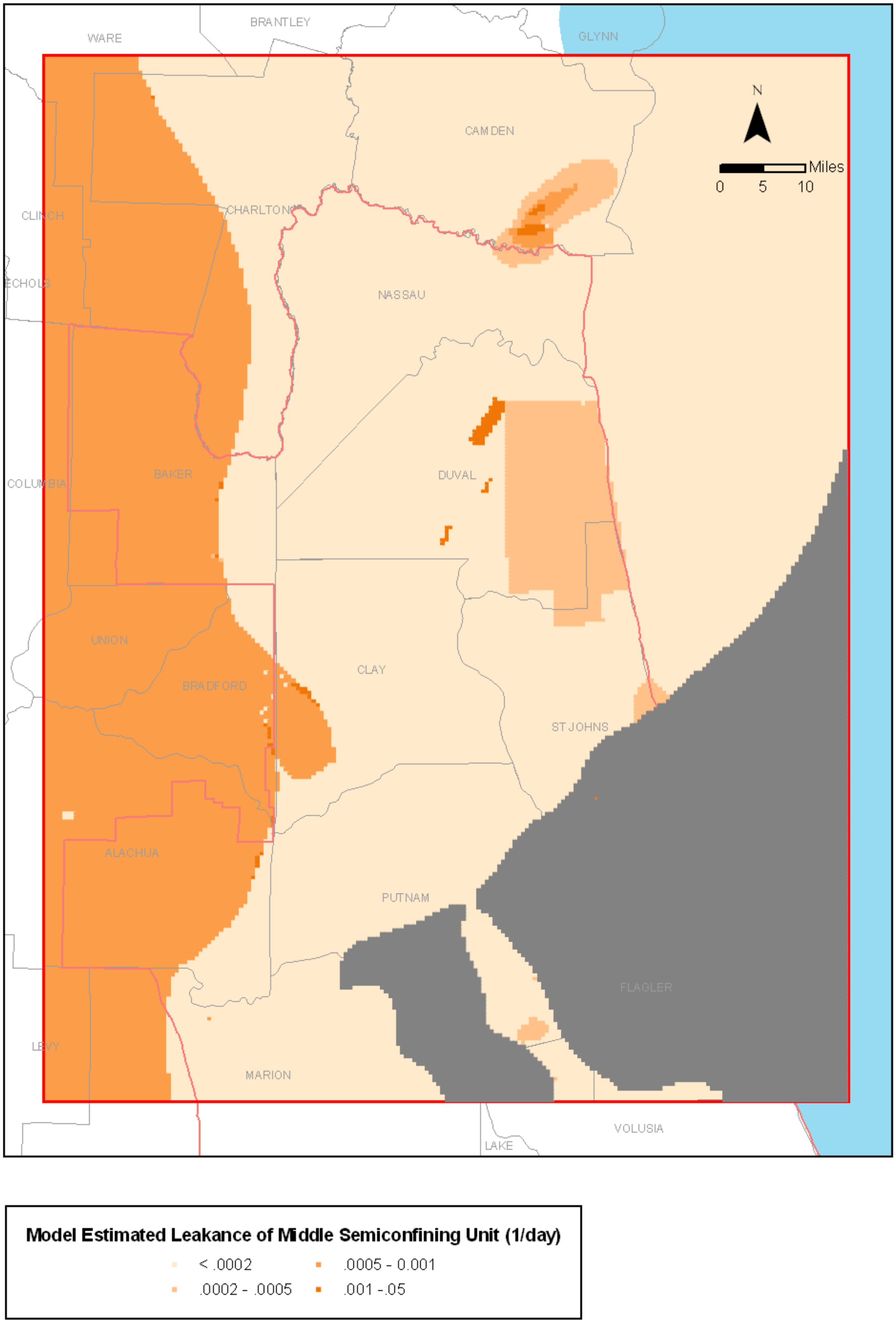
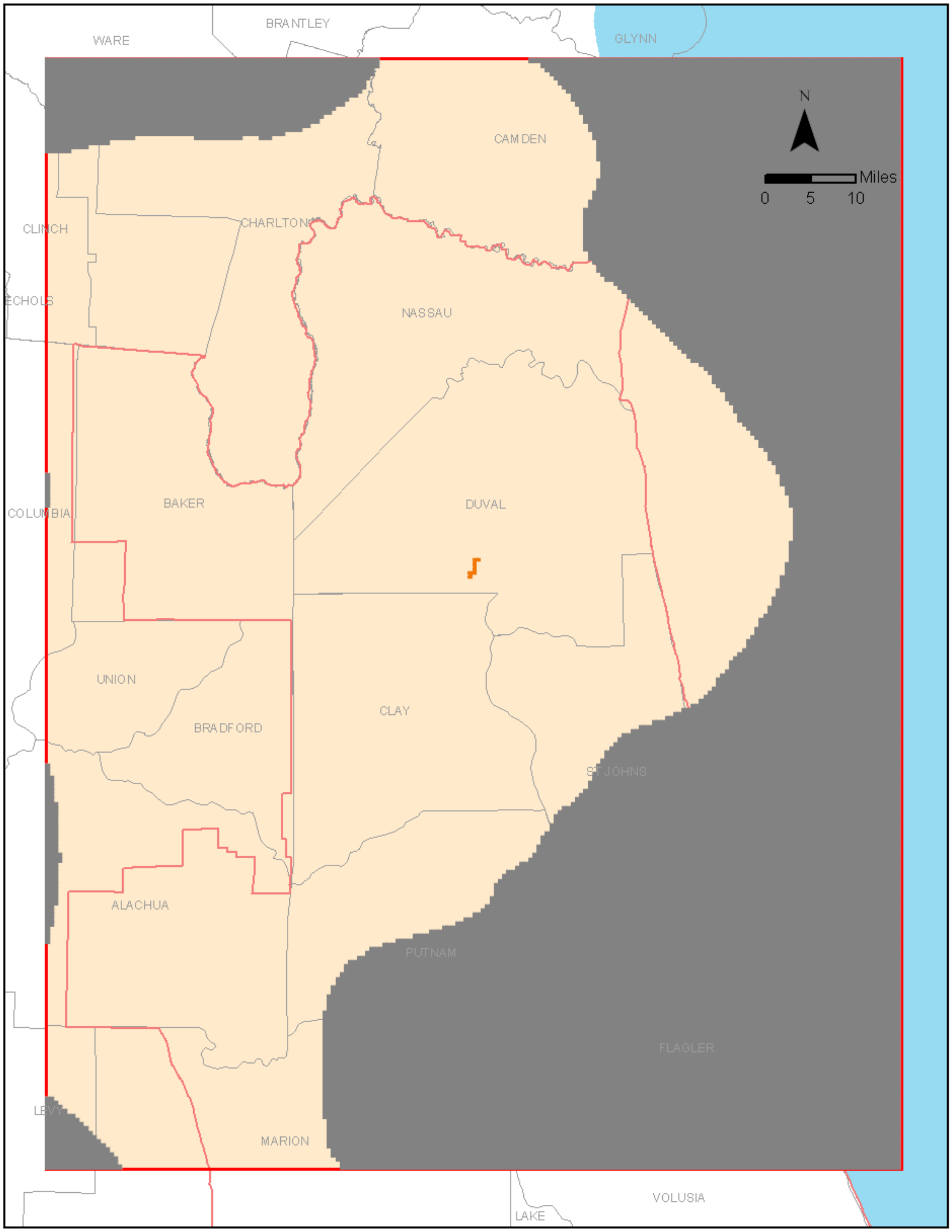



**Figure 47b Model derived leakance of middle semi-confining unit**



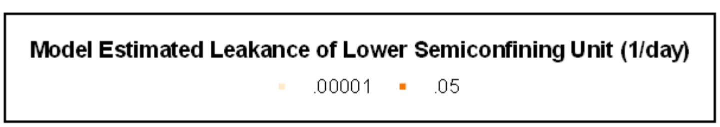




**Figure 47c   Model derived leakance of lower confining unit**

The offshore leakance was set to a low value of 1.0e-6 1/day. It is likely that in the offshore (low-energy) region with near constant heads in the surficial aquifer, the leakance is lower than inland. A low leakance was required offshore in order to maintain higher heads within the Upper Floridan aquifer in the coastal basin. However, as discussed above, it is possible that an integrated surface-groundwater model the leakance in coastal *ridge* areas, that provide recharge to the Upper Floridan, will be simulated higher without resulting in large drawdown, as experienced in the present model. This may permit the offshore leakance to be increased slightly.

The leakance of the MSCU was also set proportional to its thickness. A leakance calculated to be equal to .0075 (ft/day) divided by the thickness of the unit was specified. The exceptions are, in the western regions where the Upper and Lower Floridan aquifer are conceptualized to be fairly well connected (Sepulveda, 2002), at a few locations along the St Johns River where highly conductive vertical zones in the UCU are suspected to exist, and in the coastal regions of Duval County. The high leakance in Duval County was estimated by Durden (1997), maintained in the present model, and could be the result of wells open to both the Upper and Lower Floridan aquifers.

It is should be mentioned that the MSCU vertical hydraulic conductivity of 0.0075 ft/day estimated above may be slightly higher than actual. As already indicated, the simulated head differences at paired observation wells are slightly lower than the observed head difference between the Upper and Lower Floridan aquifers in Duval, St John's, and Clay counties. Again, this would indicate that the leakance of the MSCU is slightly higher in these areas than actual. However, a higher MSCU leakance was required to calibrate heads in the Upper Floridan aquifer in the coastal regions. Once again, this highlights the need to utilize an integrated surface-groundwater model to enable more recharge in the coastal regions without causing excessive drawdowns in the surficial aquifer.

In the lower semi-confining unit, a uniform value of .00001 per day was specified, except in a small area underneath the St. Johns River where faults/solution cavities are suspected (Figure 47c). In this small area a high degree of connection between the upper and lower portions of the Floridan aquifer system can be assumed from poor water quality observed in the Upper Floridan aquifer (Durden, 1997). Alternatively, the source of the poor quality water in this small area may be production wells open to both Upper and Lower Floridan aquifers, with water from the deeper more saline regions infiltrating into the Upper Floridan aquifer.

## Sensitivity Analysis

Sensitivity analysis is conducted to quantify the relationship between various model parameters, boundary conditions, hydraulic stresses, and model results. The goal of this exercise is to identify model input data sets that have most influence on model results. The analysis involves varying input parameters within reasonable ranges and comparing the system response. The results of sensitivity analyses accelerate the process of model calibration and assists in directing field-data collection efforts by identifying critical parameters.

A series of runs were conducted during which various aquifer parameters, hydraulic stresses, and boundary conditions were varied, and the corresponding impact on simulated heads in the Upper Floridan aquifer noted. The model input data sets that were examined include the aquifer hydraulic conductivities, confining/semi-confining unit's leakances, recharge, and General-Head boundary conductances and heads. Each of the parameters was varied globally over a range of values deemed to encompass the uncertainty in the parameter. Each sensitivity run's average absolute error was calculated and presented in Figure 48.

Among aquifer parameters, heads in the Upper Floridan aquifer were most sensitive to changes in hydraulic conductivities of the Upper and Lower Floridan aquifers, and leakances of the upper confining and middle semi-confining units. The heads were insensitive to parameter changes in the Fernandina Permeable Zone and the lower semi-confining unit, and the horizontal hydraulic conductivity of the surficial aquifer. Since flow on a regional scale in the surficial aquifer is largely vertical, variations in the hydraulic conductivity of that aquifer did not appreciably affect results in the Upper Floridan.

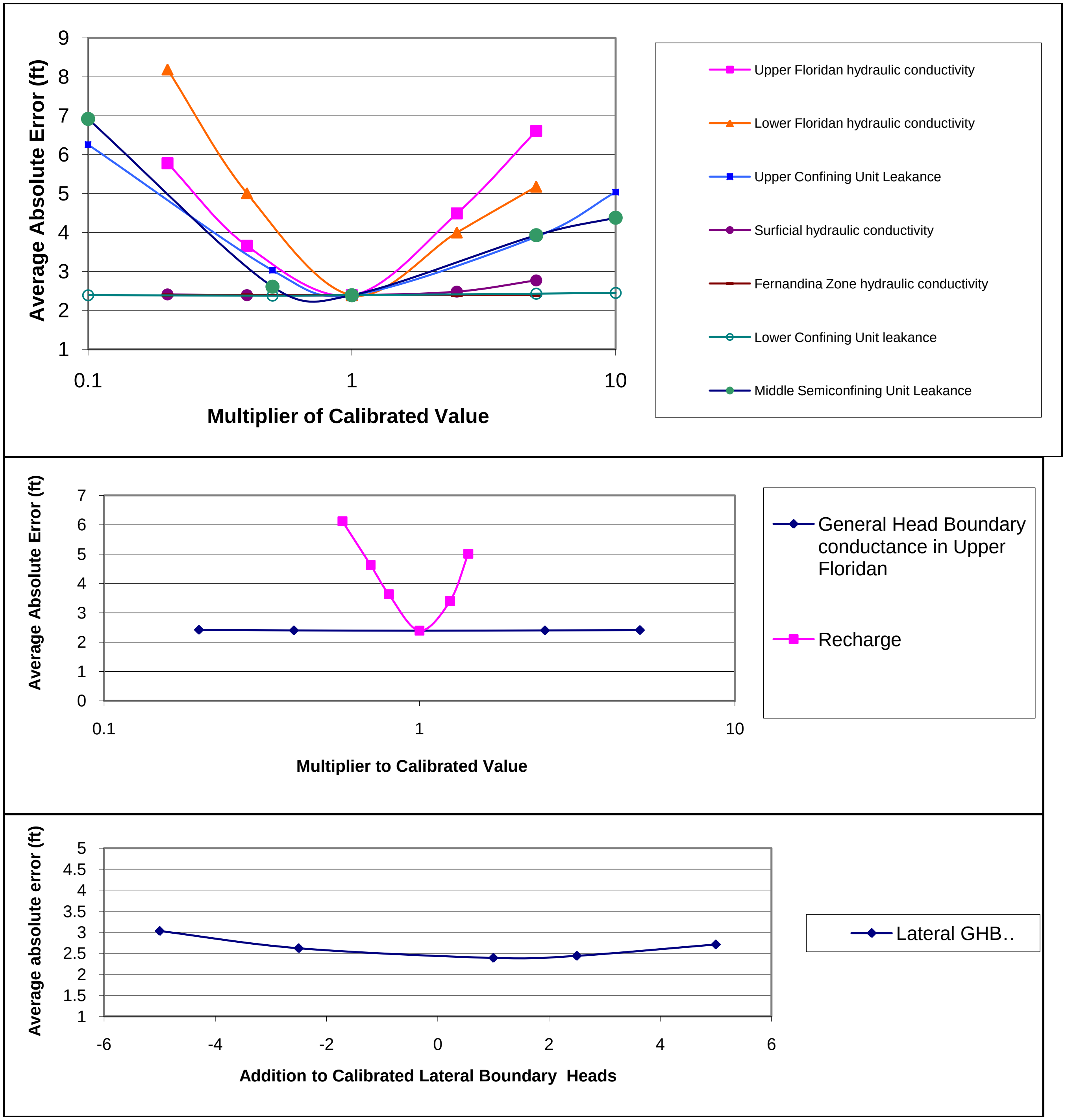



**Figure 48** **Sensitivity of Upper Floridan aquifer simulated heads to changes in aquifer and confining unit parameters, stresses, and boundary conditions**

The heads in the Upper Floridan aquifer were also highly sensitive to prescribed recharge/discharge distribution along the model top boundary. This is to be expected (refer to Mass Balance), the largest influx to the system is recharge from the top. The heads were insensitive to General Head boundary heads prescribed along the lateral boundaries in the Upper Floridan. This is owing to the facts: a) the systems is largely recharge dominated, b) raising the heads by the same amount all along the lateral boundaries does not alter the potential drop across the aquifer from the "upstream" to "downstream" boundaries. The heads were also insensitive to changes in General Head conductances along the lateral boundaries.

It is worth noting that the sensitivity curves for each parameter are symmetrical and not skewed to either side of the parameter axis. This indicates that the calibrated values of the parameters were not arbitrarily specified and is likely to be the best set of data representing field conditions.

## Predictive 2025 Simulations

The calibrated groundwater flow model was used to estimate drawdown due to projected 2025 withdrawals in the Upper Floridan and surficial aquifers. It became evident early in the model construction process that the drawdowns in the surficial aquifer for the projected 2025 period were highly sensitive to the recharge/discharge distribution specified at the upper (top) model boundary. It was observed that although withdrawals were increasing primarily in the Upper Floridan aquifer, the drawdowns seen in the surficial aquifer were of a magnitude similar to those in the Upper Floridan; this was not the case if the recharge/discharge distribution at the top model boundary was updated during the 2025 pumpage period to account for induced recharge/discharge. This induced recharge/discharge dynamic is because the horizontal hydraulic conductance of the surficial aquifer is relatively low and, therefore, groundwater flow in the surficial aquifer is primarily in the vertical direction. Hence, for the model to pass the same quantity of water (through a vertical column) in 2025 as for the 1995 period, water levels in the surficial aquifer need to drop by a magnitude similar to those in the Upper Floridan aquifer. In reality, however, drawdown impacts in the surficial aquifer have been noted to be much more muted even under large cones of depression in the Upper Floridan aquifer.

The subdued drawdown response in the surficial aquifer is due to the fact that as withdrawals increase in the Upper Floridan aquifer, causing a drop in the water table, additional water enters the surficial aquifer due to less runoff, increased irrigation return flow, and induced recharge from surface water bodies. Additionally, there is a reduction in the evapotranspiration rate due to the drop in the water table, and hence less groundwater exits the system in discharge areas.

A previous study in the NEFL area by Durden (2000, A) indicated the need for allowing induced recharge (or reduced discharge) due to increased pumpage. Durden's approach involved specifying a pseudo model layer above the surficial aquifer and setting the vertical leakance of the layer to the value estimated in a previous hydrogeologic study (Tibbals, 1990). The vertical leakance was set to 2.66x10-4/day, which equates to 1.16 inches of water induced in the surficial aquifer annually for every foot of drawdown in the surficial aquifer. As explained below, a similar approach was implemented in the present study using MODFLOW General Head boundary package at the model top boundary to simulate induced recharge for the year 2025.

**Updated 2025 Boundary Conditions**

The flux from a General-Head boundary at the model top boundary is based on the following equation:

$$Q = CD\left(h_b - h_a\right)$$

where,

$Q$ = Flux through model boundary (l3/d)

$CD$ = Hydraulic conductance (l2/d)

$h_b$ = Boundary head (l)

$h_a$ = Head in (surficial) aquifer (l)

The boundary head was specified as the calibrated 1995 surficial heads. Therefore, for the 2025 simulation run, General-head boundary conditions at the model top boundary corresponds to:

$$Q = CD_{induced\ recharge}\left(h_{surficial1995} - h_a\right)$$

The drain conductance, $CD_{induced\ recharge}$, was set to 1662.5 ft$^2$/day, which equals to the product of the vertical leakance specified by Durden (2000,A) and the horizontal cross-sectional area of the grid cell (i.e. 2.66e-4 x 2500$^2$). Given the lack of information regarding surface and groundwater interactions, and the limitations of the MODFLOW model to accurately simulate such interactions, the above approach was deemed a reasonable approximation in both recharge and discharge areas. The GHB package will induce approximately 1.16 inches of water for every foot of drawdown in the surficial aquifer. The actual amount of induced water (or conversely, increase in water exiting the subsurface) is a function of the rate of surface evapotranspiration and the extinction depth. The variability of these parameters within the model area is not well understood. In general, evapotranspiration parameters vary with soil and vegetation type. Sandy soils, for example, have a more shallow extinction depth than clayey soils and potentially higher induced recharge rates. In areas where vegetation has a relatively deeper root system, the extinction depth will also be deeper and the rate of induced recharge relatively lowers.

## Predicted Average 2025 Water Levels and Spring Flows

For 2025 simulations, it was assumed that climatic conditions would be similar to those existing in 1995. Therefore, the specified-head boundaries in the surficial aquifer, which represent hydraulic conditions in surface water features, were unchanged from 1995 levels. The lateral boundary conditions were also unchanged; General Head boundary conditions were designed to handle impacts along the boundaries. Groundwater withdrawals for 2025 were assigned as explained above under Groundwater Withdrawals and Water Use. Water Use was projected to increase from 453 MGD in 1995 to 614 MGD in 2025.

The simulated average 2025 potentiometric surface in the Upper Floridan aquifer is presented in Figure 49 and projected drawdowns from 1995 conditions are presented in Figure 50. The flow patterns in the Upper Floridan aquifer are similar to those observed for 1995. In the larger study area, drawdowns in the Upper Floridan are expected to be less than 2 feet. There are three distinct areas with large drawdowns. The largest projected drawdown is in Nassau County and can be attributed to water use by Jefferson Smurfit, Rayonier, and Florida Public Utilities. Drawdowns in excess of 10 feet are projected in the Fernandina Beach area in Nassau County. Most of Duval County is projected to experience drawdowns of between 2 to 10 feet, primarily due to increased pumpage at the JEA well sites. Localized drawdowns in excess of 10 feet can be expected in close proximity of the production wells. Localized drawdowns in excess of 10 feet are also found in the Gainesville area due to increased municipal pumpage. Another area of relatively high drawdown coincides with projected 2025 pumpage in the Palm Coast area in Flagler County. Drawdowns in the Upper Floridan aquifer in excess of 5 feet are expected in the Palm Coast area.

In contrast to drawdowns, several areas experience a rise in water levels (rebound) due to reduced groundwater pumpage. A rebound is found in Camden County, GA., and Nassau County, Fl., due to the shutdown of the Durango Paper mill. Other noticeable rebounds are projected due to reductions of water use at E.I. De Pont De Nemours Trail Ridge and the Georgia Pacific Palatka Plant.

The simulated water table in the surficial aquifer for the year 2025 is presented in Figure 51, while the projected drawdowns from 1995 conditions are presented in Figure 52. Drawdown impacts in the surficial aquifer are generally less than 1/3 ft due to increased pumpage in the Upper Floridan aquifer by the year 2025. However, larger drawdowns (greater than 10 ft) are predicted to occur in the St Augustine and Palm Coast areas, where groundwater is withdrawn directly from the surficial and the intermediate aquifer in the Hawthorn Group.

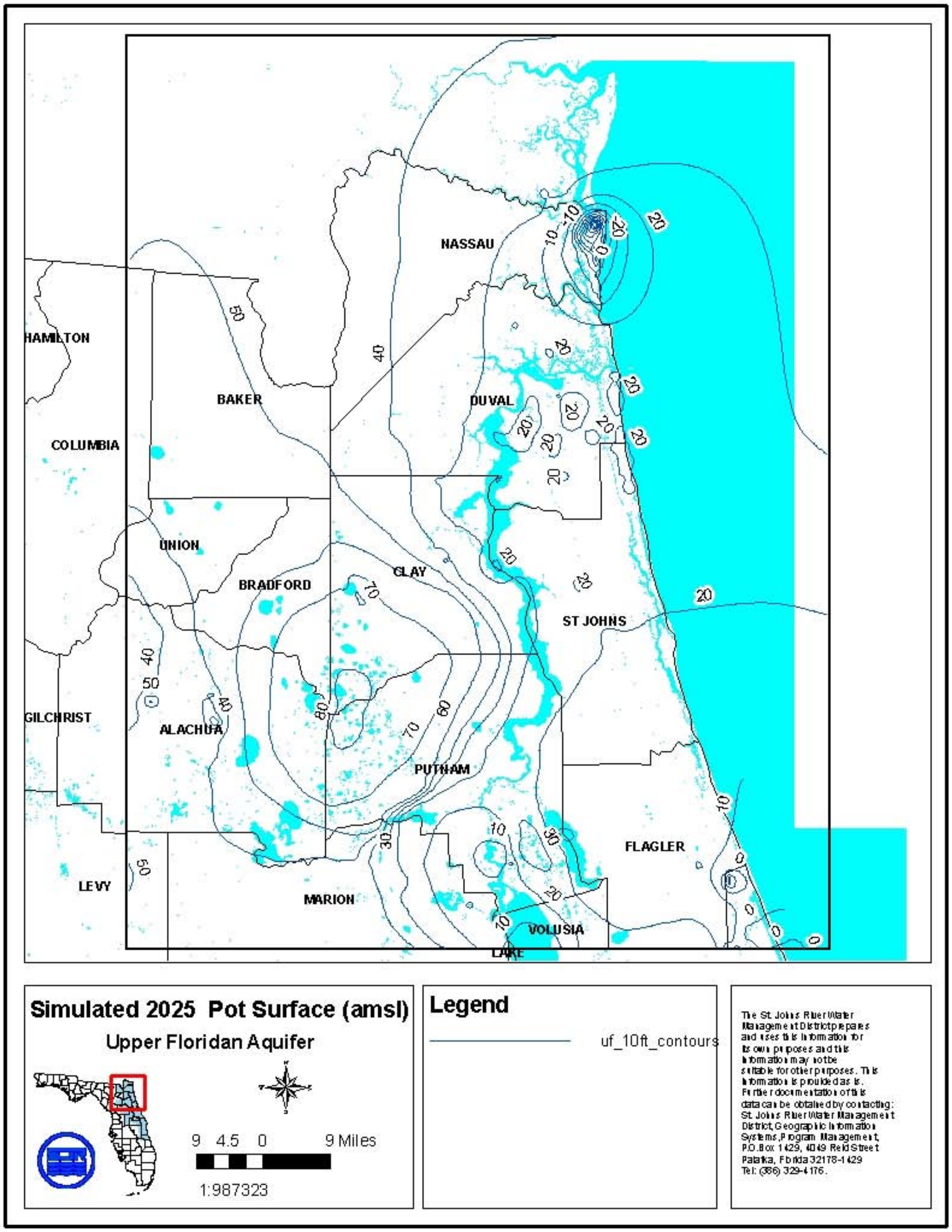



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**Figure 49 Simulated potentiometric surface in Upper Floridan for 2025**

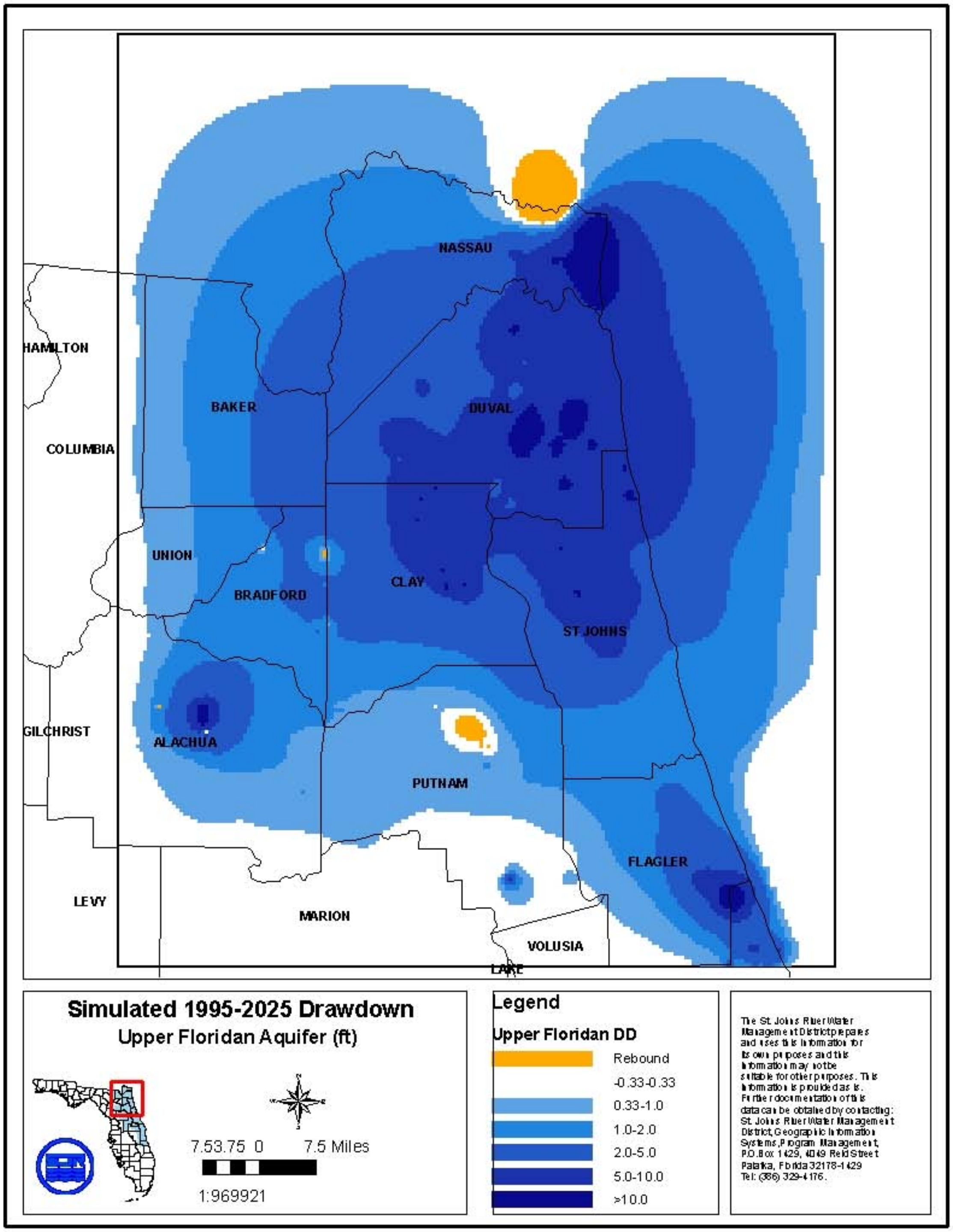


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**Figure 50 Simulated drawdowns (2025-1995) in Upper Floridan aquifer**

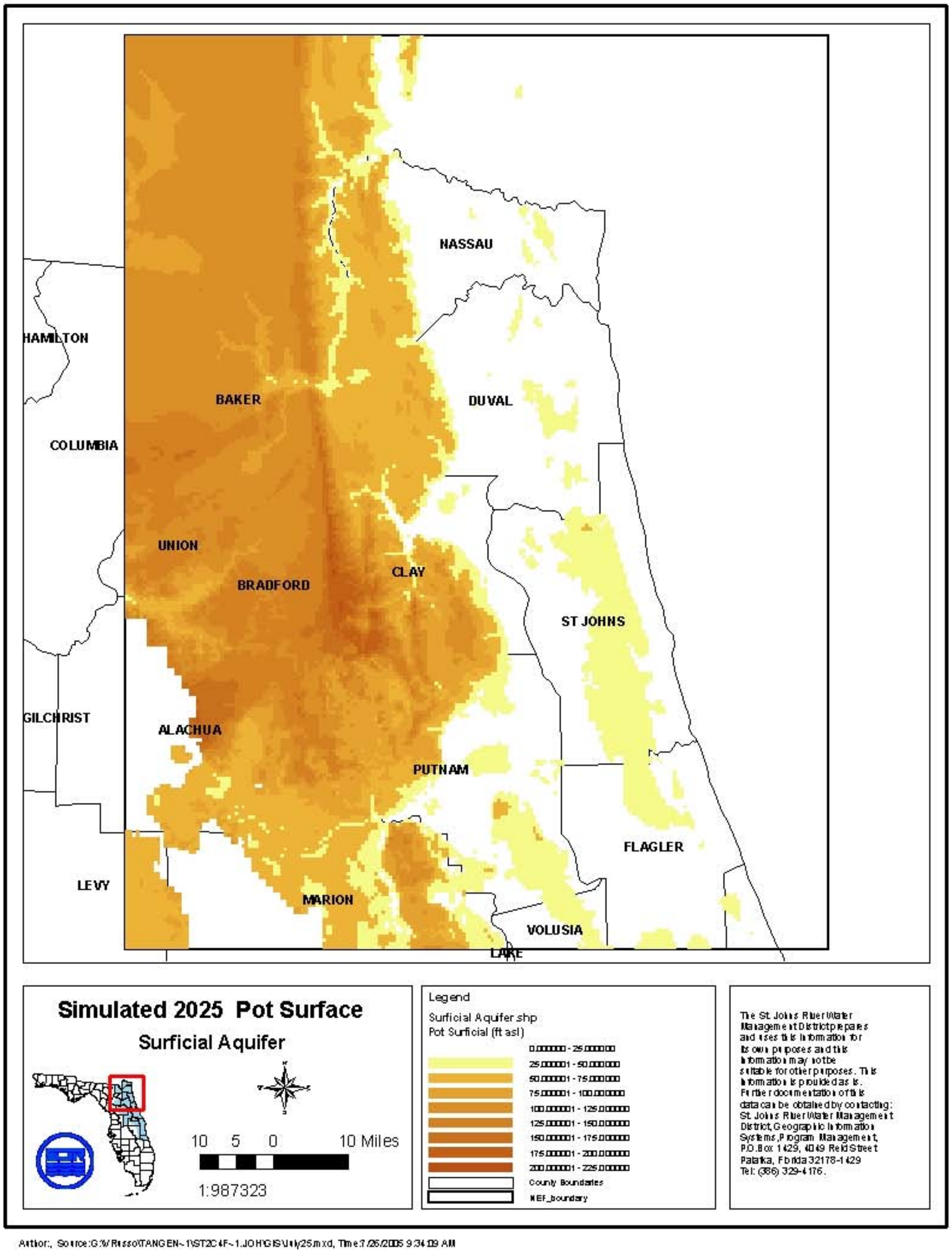


**Figure 51 Simulated 2025 water table in surficial aquifer**

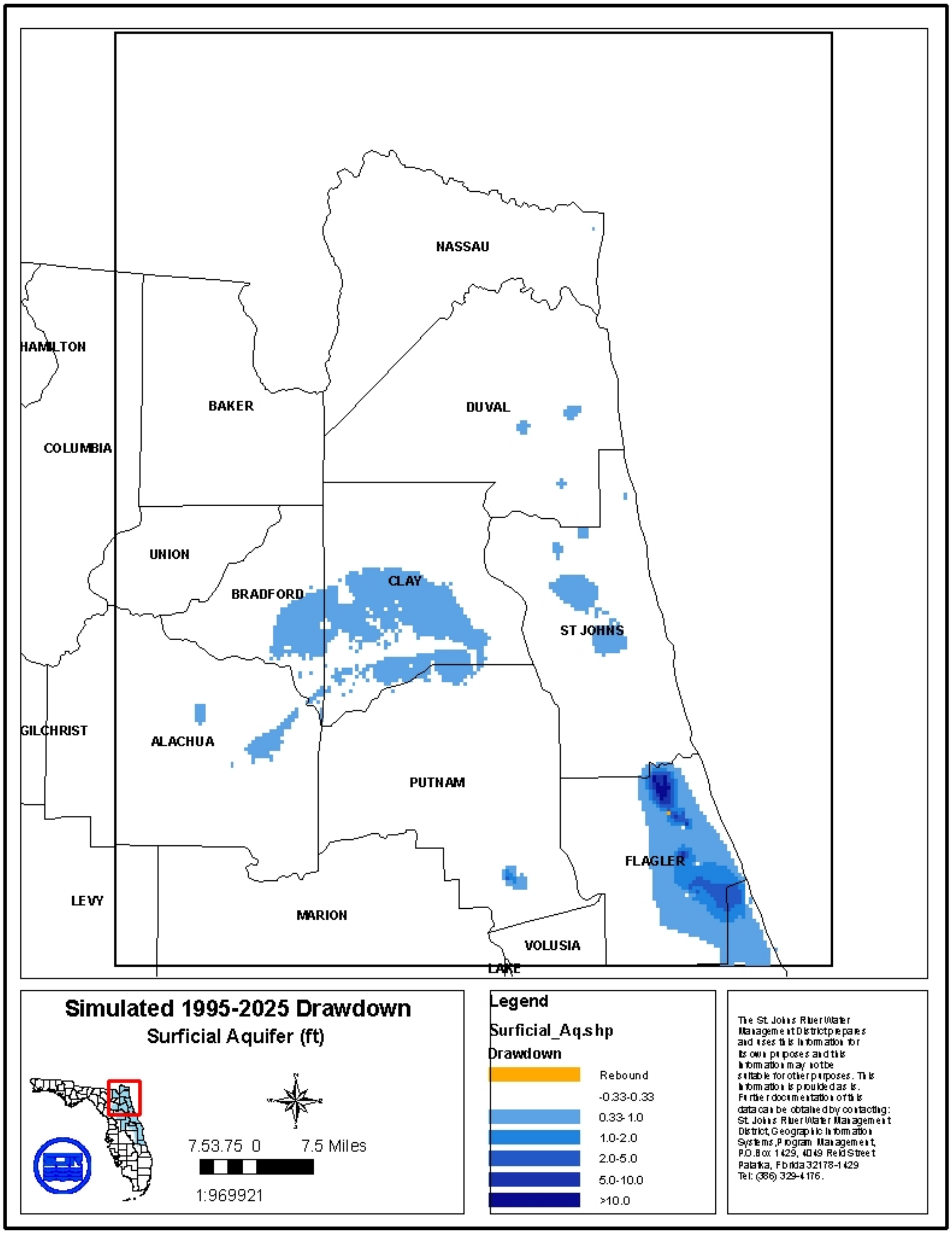


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**Figure 52 Projected drawdowns (2025-1995) in surficial aquifer**

The simulated 2025 spring flows presented in Table 6 indicate a cumulative decrease in the flow rate at the 14 springs of 8.11 cfs. Cumulative spring flow in the model area is expected to decline to 217.3 cfs in 2025 from 225.4 cfs in 1995. All of the spring flows are projected to decrease, with Wadesboro, Green Cove, Whitewater, and Welaka Springs reduction greater than 15%. On a percentage basis, flow at Wadesboro Spring is projected to decline the most (88 %) to 0.11 cfs. Green Cove Springs, Whitewater Springs, and Welaka Springs are projected to decline by 39%, 22%, and 16%, respectively.

**Mass Balance**

The mass balance summary for 2025 for the entire model is presented in Table 7. Approximately 2125 MGD enters the model through the top, along the lateral boundaries, and via drainage wells. Out of the 2125 MGD, 1542 MGD of water enters the surficial aquifer and Upper Floridan aquifers as recharge, while 379 MGD enters the system along the lateral boundaries (layers 2, 3, and 4 GHBs), 138 MGD enters the surficial aquifer from surface water bodies, and 11 MGD of water enters the system from drainage wells. Of the total outflow, 590 MGD exits along the model lateral boundaries, 558 MGD exits the system along the top as discharge (in the form of evapotranspiration), 614 MGD is withdrawn from production wells, 235 MGD of groundwater discharges into the surface water features, and 140 MGD flows out of the system as spring discharge. Due to round-off and convergence limitations, the mass balance summations are in error by 0.5%.

The mass balance within each model layer decreases in magnitude from the topmost surficial aquifer to the bottommost Fernandina Permeable Zone (Figure 53). This highlights the dominance of recharge (from precipitation) on the groundwater flow regime. Approximately 1861 MGD flows through the surficial aquifer on an average daily basis, while flow rates in the Upper Floridan, Lower Floridan, and the Fernandina Permeable Zone are 1759, 681, and 44 MGD, respectively. As expected, the Fernandina Permeable zone is the least vigorous hydrogeologic unit.

**Table 6 Simulated 2025 Spring Flows**

| Spring | Stage (ft) | Estimated 1995 Flow (cfs) | Simulated 1995 Flow (cfs) | Simulated 2025 Flow (cfs) | Simulated 2025-1995 Difference (cfs) | Percent Difference (2025-1995) |
|---|---|---|---|---|---|---|
| Wadesboro | 24 | 0.94 | 0.94 | 0.11 | -0.83 | -88.3 |
| Green Cove | 21 | 3.11 | 3.11 | 1.85 | -1.26 | -40.5 |
| Crescent Beach | 0.5 | 30.0 | 29.75 | 26.62 | -3.13 | -10.5 |
| Whitewater | 23.5 | 1.40 | 1.64 | 1.29 | -0.35 | -21.3 |
| Orange | 54.5 | 2.86 | 2.86 | 2.77 | -0.09 | -3.1 |
| Blue | 31 | 0.5* | 0 | 0 | 0 | 0 |
| Camp Seminole | 54.5 | 0.79 | 0.79 | 0.77 | -0.02 | -2.5 |
| Welaka | 11 | 1.10 | 1.13 | 0.95 | -0.18 | -15.9 |
| Mud | 8.3 | 0.65 | 0.66 | 0.61 | 0.05 | -7.6 |
| Beecher | 2 | 9.04 | 9.05 | 8.88 | -0.17 | -1.9 |
| Croaker Hole | 6.8 | 83.00 | 83.23 | 81.42 | -1.81 | -2.2 |
| Tobacco Patch | 30.8 | 2.80 | 2.78 | 2.78 | 0.0 | 0.0 |
| Wells Landing | 30.8 | 9.88 | 9.92 | 9.91 | -0.01 | -0.1 |
| Salt | 1.8 | 79.53 | 79.57 | 79.37 | -0.20 | -0.3 |
| Total | | 225.6 | 225.43 | 217.32 | | -0.02 |

* Estimated from Mega Model (Sepulveda, 2000)

**Table 7 Summary of hydrologic mass balance (MGD) in model layers for 2025 simulation**

| | Recharge/ Discharge | | Constant Head | | General Head | | Well | | Drain | |
|---|---|---|---|---|---|---|---|---|---|---|
| | In | Out | In | Out | In | Out | In | Out | In | Out |
| Surficial | 1542 | 558 | 138 | 235 | 55 | 0.5 | 0.4 | 11 | | |
| Upper Floridan | | | | | 244 | 395 | 11 | 496 | | 140 |
| Lower Floridan | | | | | 116 | 167 | | 107 | | |
| Fernandina Zone | | | | | 19 | 28 | | | | |
| Total | 1542 | 558 | 138 | 235 | 434 | 590.5 | 11.4 | 614 | na | 140 |

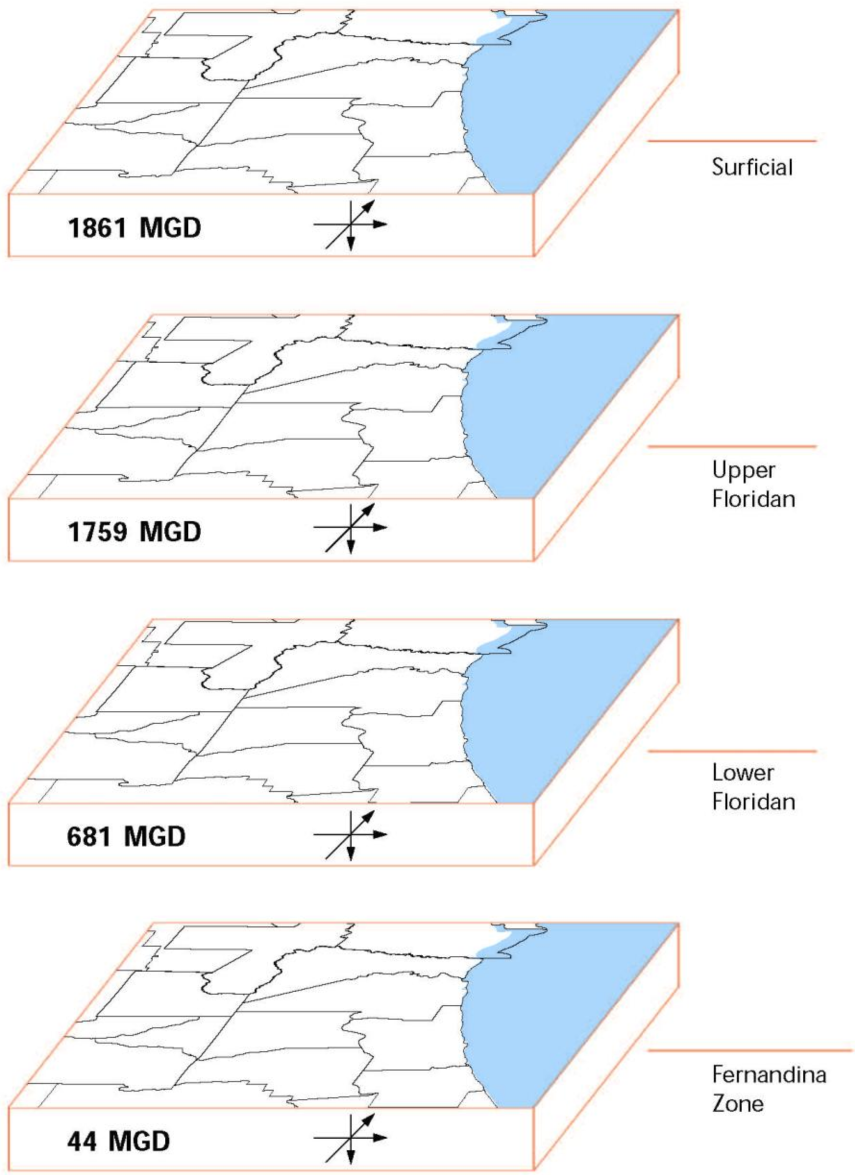


**Figure 53 Mass Balance within and across model layers for 2025**

Exchange of water between the aquifers also decreases with depth. Approximately 1068 MGD of water enters the Upper Floridan aquifer from the surficial aquifer, and 183 MGD discharges from the Upper Floridan into the surficial aquifer (Figure 54). Between the Upper and Lower Floridan aquifers, approximately 547 MGD enters the Lower Floridan aquifer, while 390 MGD of groundwater is discharged into the Upper Floridan. About 25 MGD of groundwater enters the Fernandina Permeable Zone from the Lower Floridan, and 17 MGD discharges from the Fernandina Permeable Zone into the Lower Floridan aquifer.

## Model Limitations and Assumptions

A computer groundwater model is an attempt at developing a simplified tool to simulate groundwater flow in the subsurface. The geology, the climate (which influences groundwater flow), and the magnitude and temporal/spatial distribution of groundwater withdrawals are all variables that are difficult to define precisely. The simplified representation of these variables results in model limitations, which are briefly discussed below:

- Groundwater flow is assumed to occur in porous medium. In reality, the geologic framework is fairly karst and complex with preferential flow paths existing due to fractures and solution cavities. Therefore, the results of the study are applicable only on a regional scale.

- Each of the four primary hydrologic units is represented as a single model layer. In reality, each aquifer may be highly layered and water levels within a hydrogeologic unit quite variable at any particular location. In addition, the intermediate aquifer system of the Hawthorn group is not represented as an aquifer layer and assumed to exist within the upper confining unit.

- Model results are limited to the implemented grid scale of 2,500 ft. Areas with highly variable topography may result in simulated water levels being above the average land surface for a cell. Additionally, pumpage at wells within a cell area are summed and withdrawals assumed to occur at the center of the cell.

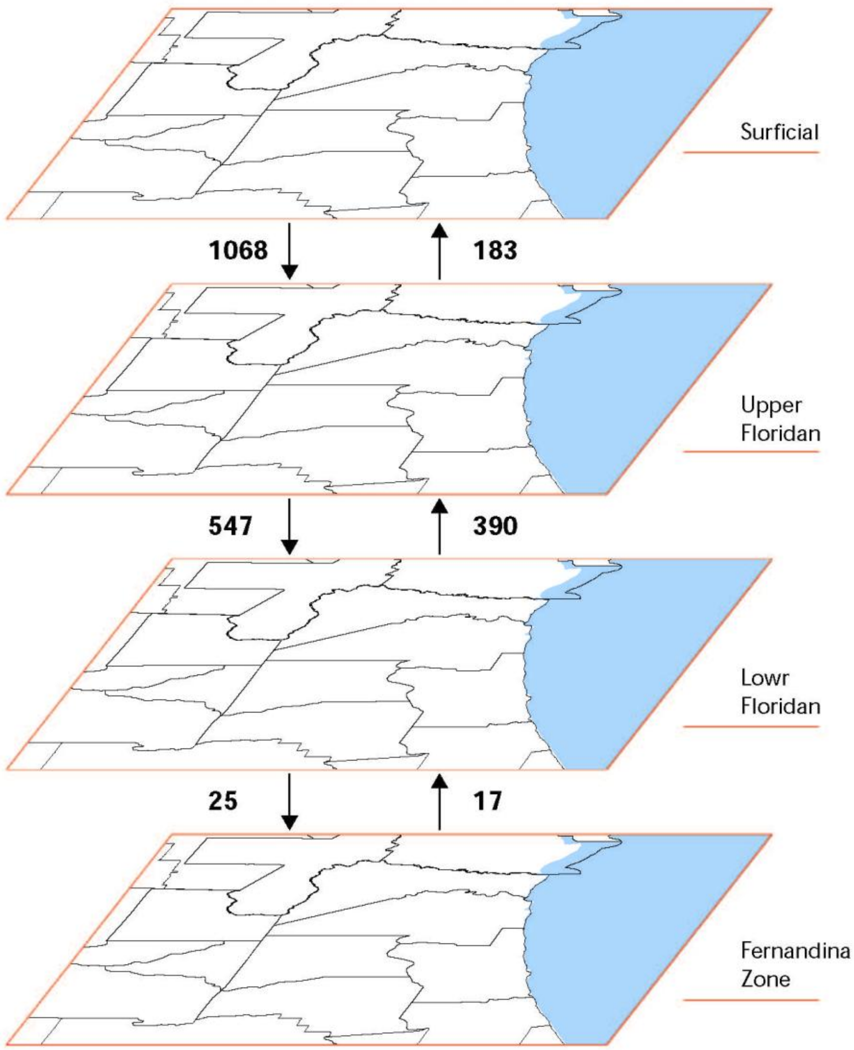


**Figure 54 Groundwater exchange between aquifers for 2025**

- The model simulates steady state flow thereby implying equilibrium conditions. In reality, the system is dynamic, with climatic variations and variable groundwater pumping rates causing fluctuations in the groundwater levels. Simulated water levels should be viewed as representing average water level conditions over a year for a particular (annual) groundwater withdrawal plan.

- Inaccuracies and limited availability of hydrogeologic data precludes the derivation of unique aquifer parameter sets during model calibration.

- Spring flow measurements can be prone to errors. In the east-central Florida region, spring flow measurements have, at best, an error of approximately 10% (McGurk, 2002).

- Being primarily a groundwater model and not a coupled surface-groundwater hydrologic model, the top boundary condition needs to be adjusted for any predictive simulation by using the GHB that addresses induced recharge.

## Recommendations for Model Improvement

As model enhancement is contemplated in the future, the following suggestions are recommended to improve model performance.

- A water table surface based on the Minimum Water Table approach outlined by Sepulveda (2002) should be constructed for each physiographic region, and be used for calibration of the surficial aquifer.

- Since the near-surface hydrologic processes are not actively simulated with a coupled surface-groundwater model, the recharge/discharge distribution needs to be updated for projected 2025 simulations.

- Constant head boundaries are presently specified for rivers, creeks, lakes, and ponds in the area. This results in highly constrained simulated water levels in the surrounding surficial aquifer cells. Additionally, for small water bodies, the model specified leakance values in the upper confining unit are artificially low in order to restrict leakage to/from the Upper Floridan aquifer. A MODFLOW RIVER boundary condition would more realistically simulate the surface and groundwater interaction at lakes, rivers, and streams.

- Water level data in the Lower Floridan aquifer and the Fernandina Permeable Zone was lacking for the 1995 calibration period. In recent years, water levels data has been collected at a number of sites in these aquifers. The model should be calibrated/validated to observation data at these sites.

- It is recommended that the District compile a database of field derived hydrogeologic parameters and provide (reliability) ranking to the estimated parameters values. The model should be validated against the compiled parameter data set.

- Simulated water levels in the Upper Floridan aquifer should be validated for a stress period substantially different from the average 1995 calibration period.

- Estimates of domestic self-supply pumpage in northeast Florida for 2025 should be updated based on latest projections. All non-municipal pumpage in Georgia should be included after completion of the data collection initiative currently underway in the state.

- In order to improve predictions of surficial aquifer drawdowns, an integrated surface-groundwater model, capable of rigorously simulating all above-land and near-surface hydrologic processes in the saturated and vadose zones should be considered. This will also remove the necessity for modifying top model boundary conditions while simulating future stress periods.

- A transient modeling effort would greatly improve the model predictive capabilities. Because a transient model deals with a more complex set of hydrologic stresses and boundary conditions, the calibration process is more thorough, resulting in a more representative model. This will not only improve the model predictive capabilities, but also provide an estimate of time frames involved for drawdowns in the surficial aquifer to fully develop.

- For production wells open to both the Upper and Lower Floridan aquifers, the amount of water withdrawn from each aquifer cannot simply be estimated by considering the transmissivity and degree of well penetration in each aquifer. The relative contribution from each aquifer is also a function of the magnitude of head in each aquifer and the well hydraulics. If the head difference between the two aquifers is of several feet, then it is possible that water from one aquifer may recharge the aquifer with lower head. To account for such situations, either a fracture well package (with a finer grid) in the immediate vicinity of well is needed, or the MODFLOW code modified to allow for specification of a well boundary condition with open hole in multiple aquifers.

## SUMMARY AND CONCLUSIONS

A numerical, finite-difference groundwater model was developed to simulate flow in the surficial and Floridan aquifer systems in Northeast Florida and Southeast Georgia. The model is to be used to support the Water Supply Needs and Sources Assessment of the St. Johns River Water Management District. The primary goal of the present modeling study was to simulate drawdown in the surficial and Floridan aquifer systems due to groundwater withdrawals in the year 2025. Withdrawals are projected to increase from 453 MGD in 1995 to 614 MGD in the 2025. Since the Upper Floridan aquifer is the primary source of groundwater in the area, the focus of the study was toward a rigorous simulation of drawdown in that aquifer.

The model was developed using the USGS MODFLOW computer code. The conceptual model, based on a detailed review of hydrogeologic data, consists of four aquifers separated by three semi-confining units, and underlain by a confining unit. Groundwater flow has been conceptualized as quasi-three-dimensional, i.e., horizontal flow occurs within the aquifer layers and vertical flow occurs between aquifer layers. The aquifers represented in the model include the surficial aquifer, the Upper Floridan aquifer, the Lower Floridan aquifer, and the Fernandina Permeable Zone. Since average drawdowns for 2025 are of interest, and since the Upper Floridan aquifer is expected to equilibrate to pumping stresses in a period of months, a steady state model was developed.

The model simulates groundwater flow only in the freshwater zones of the underlying aquifers in the area. Therefore, saline water zones were excluded from the active flow system. The 5,000 mg/l isocholor surface was utilized to delineate the boundary of the fresh water zone. A recharge/discharge boundary condition was applied at the top to account for the combined impacts of precipitation, run-off, and evapotranspiration. Specified heads were assigned to simulate the hydraulic interaction between surface water features (such as the lakes, stream, and rivers) and the surficial aquifer. A General Head boundary condition was specified along the lateral model boundaries in the Floridan aquifer system. Major groundwater withdrawal categories, such as public supply and commercial/industrial, agricultural, recreational, and domestic self-supply, were accounted in the model for the 1995 and 2025 simulations.

The model was calibrated to observed and interpreted hydrologic conditions for the year 1995. Calibration targets included water levels at observation wells in the Upper Floridan aquifer, the interpreted (average) 1995 potentiometric surface in the Upper Floridan aquifer, average 1995 flow rates at 14 springs in the study area, and the interpreted water table derived from regression analysis of water level data at observation wells in the surficial aquifer.

A satisfactory match between simulated and observed/interpreted water levels was achieved. The general groundwater flow trends were also satisfactory reproduced by the model. The average absolute residual in the Upper Floridan aquifer was low at 2.39 ft. The mean and standard deviation of the residuals were also relatively low at 0.37 ft and 2.85 ft respectively. Approximately 55% of the observation wells had residuals of less than 2 ft, and nearly 75% of the observation wells had residuals of less than 3 ft. The difference between the simulated and measured spring flows at the 14 spring sites in the area was less than 1%. The slope of the observed and simulated water table regression line was off by only 1.2%. The y-intercept was off by 2.09 ft, and an R2 of 0.98 was achieved.

The model top boundary was updated for the 2025 simulation to account for induced recharge due to lowering of water levels in the surficial aquifer. This involved having the General Head boundary package cover the top layer of model.

The simulation results indicate that in the study area, less than 2 feet of drawdowns in the Upper Floridan aquifer was simulated in 2025. The largest drawdown is projected in Nassau County and is attributed to water use by Jefferson Smurfit, Rayonier, and Florida Public Utilities. Drawdowns in excess of 10 feet were simulated in this area. Most of Duval County is projected to experience drawdowns of between 2 to 10 feet, primarily due to increased pumpage at JEA well sites. Localized drawdowns in excess of 10 feet can be expected in close proximity of the JEA production wells, and at other sites with large increases in pumpage, such as the municipal wells at Gainesville in Alachua County. Relatively high drawdowns were simulated in the Palm Coast area in Flagler County. Drawdowns in the Upper Floridan aquifer of up to 5 feet are projected in this area due to 2025 pumpage. Since most of the springs are in the southern portions of the study area, and away from major pumping centers, the cumulative spring flows in the study area are projected to decline by less than 1 percent.

Several areas were also simulated to experience a rise in water levels due to reduced groundwater pumpage. Noticeable rebound areas are in Camden and Nassau counties, and are attributed to the shutdown of the Durango Paper mill. Other minor rebound areas are attributed to projected reductions of water use at E.I. De Pont De Nemours Trail Ridge and the Georgia Pacific Palatka Plant.

Drawdowns in the surficial aquifer, due to pumpage in the Upper Floridan aquifer, are projected to be generally less than 1/3 ft for the year 2025. Larger drawdowns (of up to 5 ft) were however simulated to occur in the St Augustine and Palm Coast areas, where groundwater is withdrawn directly from the surficial aquifer and the intermediate aquifer in the Hawthorn Group.

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