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COMPUTER MODEL SIMULATIONS TO PREDICT IMPACTS OF GROUNDWATER WITHDRAWAL IN 2011 AND 2030 FLAGLER COUNTY, FLORIDA

Computer Model Simulations to Predict Impacts of Groundwater Withdrawal in 2011 and 2030 Flagler County, Florida

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Table of Contents

TABLE OF CONTENTS (continued)

List of Figures

List of Tables

EXECUTIVE SUMMARY

The City of Palm Coast and the coastal areas of Flagler County have been experiencing a steady growth in population. This has resulted in increased demand for freshwater from approximately 2 million gallons per day (MGD) in 1978 to nearly 11 MGD in 2000. Recent estimates of water demand for 2011 are approximately 19 MGD. The St Johns River Water Management District (District) projects that freshwater demands for freshwater for Flagler County in the year 2030 will approach 47 MGD.

Groundwater of acceptable quality is present in the Unconfined Surficial aquifer, the Confined Surficial aquifer, and the Upper Floridan aquifer. Due to low yields in the Unconfined Surficial aquifer, groundwater is primarily withdrawn from the Confined Surficial and the Upper Floridan aquifers. A large portion of the groundwater used for agricultural irrigation, which can be of lower quality than drinking water, is withdrawn from the Upper Floridan aquifer. Most of the groundwater for municipal purposes is currently withdrawn from the Confined Surficial aquifer. In order to meet projected demand in the future, both aquifers are expected to experience increased stresses. This has prompted the District to designate the Palm Coast area of Flagler County as a Priority Water Resource Caution area. There is concern that groundwater withdrawal to meet 2030 demand might adversely affect native vegetation, wildlife habitats, and further deteriorate water quality because of declines in groundwater levels.

A steady state groundwater model was developed for this study to predict drawdown impacts in the Confined Surficial and Upper Floridan aquifers, and on the water table/wetlands in the Unconfined Surficial aquifer. The model was calibrated to water levels and hydrologic conditions existing in 1995 that has been deemed by the District to represent average hydrologic conditions in the area.

A sensitivity analysis was performed for the model, calibrated to 1995 head targets and 1995 water use, to determine which parameters have the most influence on model performance and calibration. One of the more sensitive calibration parameters was the Upper Floridan transmissivity, which had a strong impact on heads in the Upper Floridan. Another sensitive calibration parameter was the Top Confining Unit leakance that strongly influenced heads in the underlying Confined Surficial aquifer. Parameters such as recharge, maximum evapotranspiration rate, and the evapotranspiration extinction depth that partition flow between inflows and outflows to the groundwater system were highly sensitivity to heads in the Unconfined Surficial aquifer. Heads in the Upper Floridan were sensitive to heads specified in the General Head Boundary package that represent heads along the edge of the model domain. It should be noted that parameters that were insensitive during sensitivity analysis either may be insensitive to variation in model parameters, or may be insensitive to the specified head targets that are clustered near the center of the model domain.

The calibrated model was used to estimate drawdown due to projected withdrawals of 19 MGD in 2011 and 47 MGD in 2030. Between 1 and 4 feet (ft) of drawdown in the Upper Floridan is projected in 2011 in the southeastern portions of the model area between Korona and Dupont due to increased pumpage from the Upper Floridan aquifer by the Palm Coast Utility.

Drawdowns of 5 to 12 ft are expected in the Confined Surficial aquifer in the expanded Palm Coast Utility wellfield northwest of the existing wellfield due to production within the Confined Surficial and Upper Floridan aquifers. Production in the Upper Floridan aquifer in the southeast portions of the study area is expected to cause 1 to 3 ft of drawdown in the Confined Surficial aquifer, and up to 7 ft locally due to pumping by the City of Bunnell. A rebound in the Confined Surficial aquifer is expected in the east-central portions of the study area in 2011 due to increased irrigation return flow.

In the Unconfined Surficial aquifer up to 1 foot of drawdown is expected by 2011 in the existing Palm Coast Utility wellfield and between 1 and 2 ft of drawdown is expected in the southeastern portions of the model. A rebound in the Unconfined Surficial aquifer is projected in the northeast portion of the study area due to increased irrigation return flow.

In 2030 between 8 to 12 ft of drawdown is projected in the Upper Floridan in the southeastern portion of the model area between Korona and Dupont, and up to 16 ft of drawdown is projected in the Upper Floridan aquifer northwest of the existing Palm Coast wellfield due to increased pumpage from the Upper Floridan aquifer by the Palm Coast Utility.

Drawdowns of 18 to 27 ft are expected in 2030 in the Confined Surficial aquifer in the expanded Palm Coast Utility wellfield northwest of the existing wellfield due to production within the Confined Surficial and Upper Floridan aquifers. Production in the Upper Floridan aquifer in the southeast portions of the study area is expected to cause 5 to 8 ft of drawdown in the Confined Surficial aquifer. A rebound in the Confined Surficial aquifer is expected in the east-central portion of the study area due to increased irrigation return flow and recharge at the Rapid Infiltration Basins (RIB) artificial recharge sites.

In the Unconfined Surficial aquifer 1 to 2 ft of drawdown is expected by 2030 in the existing Palm Coast Utility wellfield and between 1 and 4 ft of drawdown is expected in the southeastern portions of the model. A substantial increase in production from the Upper Floridan aquifer is projected in these areas. A rebound in the Unconfined Surficial aquifer is projected in the northeast due to increased irrigation return flow and recharge at the RIB sites.

A sensitivity analysis was performed for the 2011 predictive scenario based on 1995 head targets to determine which parameters have the most influence on model performance and calibration. The relevance of the 1995 head observations for analyzing the 2011 predictive scenario varies between aquifers complicating the comparison of sensitivities between aquifers. Consequently, an additional sensitivity performance metric was employed – simulated drawdown averaged over the entire model domain. The 2011 sensitivity analysis showed that the Upper Floridan transmissivity was a sensitive calibration parameter for the fit to hydraulic heads in the Upper Floridan. Sensitivity analysis also showed that the Upper Floridan heads are sensitivity to the Top Confining Unit leakance while the Unconfined Surficial aquifer is sensitive to the recharge, maximum evapotranspiration rate, and the evaptranspiration extinction depth parameters. The Upper Floridan was also sensitive to the head specified in the General Head Boundary package, the lateral boundary condition. All of the sensitive parameters described above were also shown to be sensitive in the 1995 calibrated model.

In addition to using the model as a tool to support the Water Supply Needs and Sources Assessment initiative at the District, the model can also be used for other water management purposes. The model could potentially be used to determine the optimal location and withdrawal rates of future water supply wells that can minimize drawdown impacts to the water table and surrounding wetlands. In the event that substantial increases in groundwater withdrawals are allowed for 2030, the existing model could be utilized to develop a density-dependent solute transport model to assess the impact of groundwater withdrawals on water quality and the potential for saltwater intrusion in the area.

1.0 INTRODUCTION

The primary sources of groundwater in the Palm Coast area and Flagler County, Florida are the Upper Floridan aquifer and the Confined Surficial aquifers. The Upper Floridan aquifer consists of a system of carbonate aquifers and intervening semi-confining units. The Confined Surficial aquifer, overlying the Upper Floridan aquifer, consists primarily of sand, clayey sand, shell, and thin limestone beds of the post-Miocene deposits (Clark et al. 1964). Steady growth and development in the area has resulted in increased demand for freshwater in both aquifers. Water demand is projected to increase from approximately 10 MGD in 1995 to 47 MGD in 2030.

Based on a preliminary assessment of groundwater resources in the area, the St. Johns River Water Management District (District) has designated Palm Coast and vicinity as a Water Resource Caution Area (Vergara, 2000). This study quantifies the potential changes in groundwater resources due to projected pumpage in the year 2011 and 2030. The primary tool towards this end will be a computer model that simulates groundwater flow in the subsurface. The specific objectives of the modeling study include:

- Construction of a three-dimensional groundwater flow model and calibration of the model to observed hydrologic conditions in the year 1995.
- Utilization of the calibrated model to estimate drawdown impacts in the Unconfined Surficial, Confined Surficial, and the Upper Floridan aquifers due to projected groundwater withdrawals in the years 2011 and 2030.

This model will be used as a tool to support the Water Supply Needs and Sources Assessment initiative at the District. The model could also be used to determine the optimal location and withdrawal rates of future water supply wells that minimize drawdown impacts to the water table and surrounding wetlands. The results could be utilized to update the Water Supply Assessment of the Palm Coast area. The model study area is shown in Figure 1.

1.1 Technical Approach and Scope

The overall technical approach involved a detailed review of relevant hydrogeologic reports and compiled hydrologic data. The model domain was discretized and hydrologic 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.

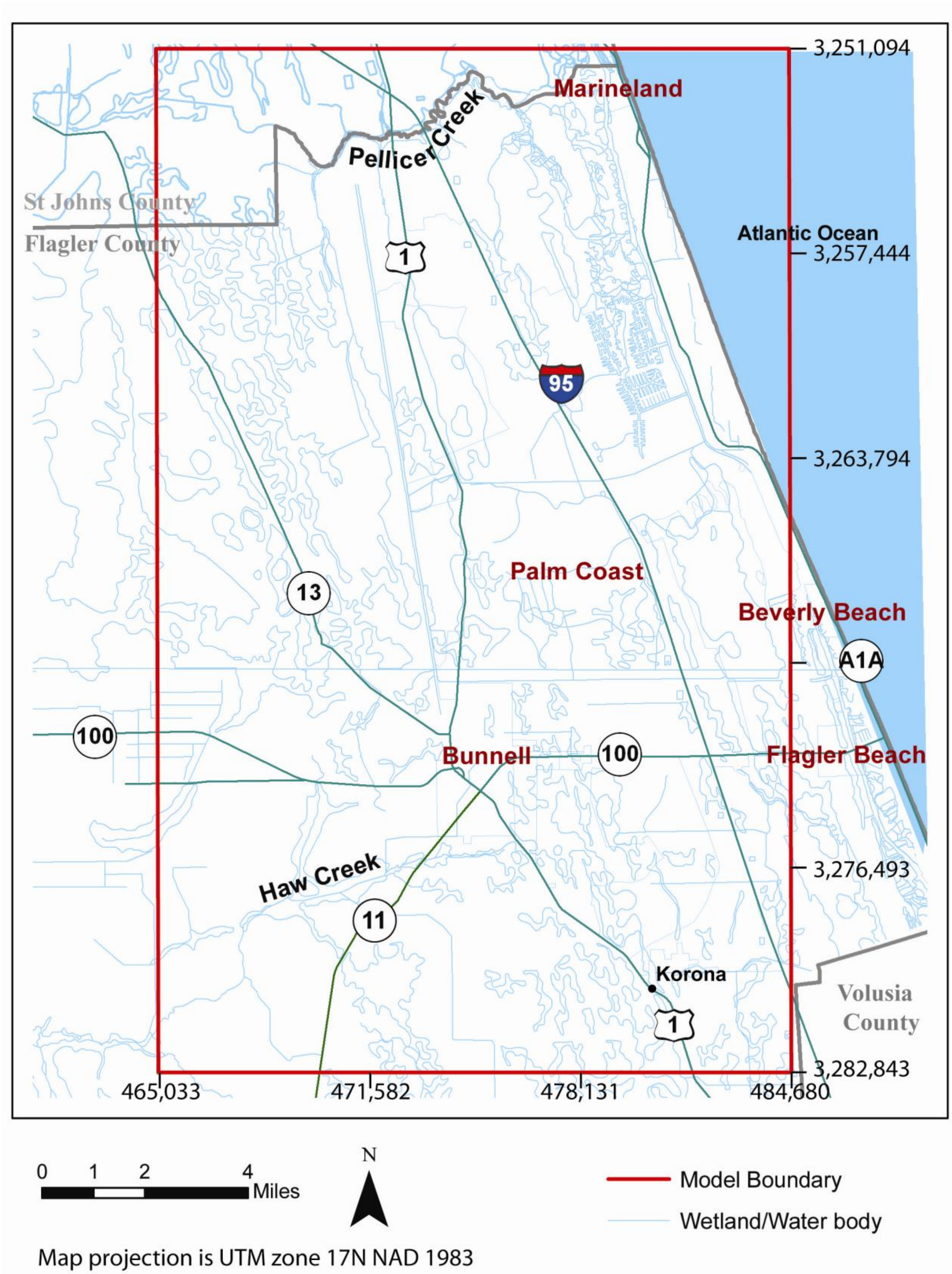


Figure 1 Model study area

The model was calibrated to the average 1995 potentiometric surface and water levels recorded at the observation wells. A sensitivity analysis was performed on the calibrated model in order to identify critical model parameters. Finally, predictive simulations were performed for the year 2011 and 2030 to estimate drawdown impacts due to projected withdrawals at existing and proposed well sites. A sensitivity analysis was also performed for the 2011 predictive scenario.

1.2 Previous Studies

Bermes et al. (1963) presented a thorough review of the groundwater resources of St Johns, Flagler, and Putnam counties with a primary focus on the Upper Floridan aquifer. As part of saltwater intrusion studies, the hydrogeologic framework in the area was further described by Frazee and McClaugherty (1979) and Munch (1979). Navoy and Bradner (1987) conducted an extensive evaluation of ground-water resources of Flagler County, Florida, describing conditions in the Unconfined Surficial, Confined Surficial, and Floridan aquifers. Black, Crow and Eidsness/CH2M Hill (1977) and CH2M Hill (1981, 1984) investigated the hydrogeology of the Confined Surficial and Floridan aquifers near Palm Coast. Blasland, Bouck and Lee (BB&L, 1990, 1991, 1992) also investigated the hydrogeology of the Floridan aquifer near Palm Coast. A geostatistical analysis of geologic and hydrogeologic data for the Palm Coast wellfield was performed by Toth (2001). Based on a detailed examination of geophysical logs of the confining units between the Unconfined Surficial aquifer, the Confined Surficial aquifer, and Upper Floridan aquifer, Davis (2006) mapped the thickness of confining units and producing zones within the study area. The delineation by Davis (2006) was used in the present study for specifying the leakance of the confining units.

Groundwater flow in the study area has also been simulated in several previous modeling studies. BB&L (1992) developed a MODFLOW (Harbaugh et al., 2000) model for the Confined Surficial aquifer system at Palm Coast. The study contained two layers, representing the Unconfined Surficial and Confined Surficial aquifer systems. BB&L (1990) developed a MODFLOW model for the Floridan aquifer system at Palm Coast. It contained five layers, representing the Unconfined Surficial, Confined Surficial, and Floridan aquifer systems. Huang (1996) developed analytical groundwater models to calculate water level changes in the Unconfined Surficial, Confined Surficial, and Floridan aquifer systems resulting from past (1988 and 1993) and projected (2010) groundwater withdrawals at Palm Coast. Withdrawals from the Confined Surficial and Floridan aquifer were modeled using two different model domains.

As part of regional modeling studies, groundwater flow in the study area was simulated by Sepulveda (2002) and Birdie (2004).

2.0 DESCRIPTION OF STUDY AREA

The study area includes southeast St Johns, eastern Flagler, and northeast Volusia counties. The principal cities in the area are Palm Coast and Bunnell. The wellfield of the city of Flagler Beach is included in the study area. Major industries in the area are agriculture, tourism, and forestry. The hydrogeologic framework in the study area has been documented in hydrogeologic reports and modeling studies mentioned above. Based on these studies and on recent data compiled from the District's database, the major hydrologic components influencing groundwater flow are summarized and discussed below.

2.1 Climate

Climate in the study area is subtropical with warm wet summers and mild dry winters. The average temperature in the area is approximately 70 degrees Fahrenheit. The mean annual rainfall for the study area for the 30-year period from 1961 to 1990 was approximately 50 inches per year (in/yr). About 65 percent of the rainfall occurs between June and October. Local thunderstorms account for most of the summer rainfall. Winter rains tend to be areal or regional in distribution and are associated with the movement of large frontal-type weather systems.

2.2 Topography

The study area spans several physiographic regions. There are three terraces, flat expanses of sand and shell deposits, which were the sea floor when sea level stood higher. These terraces, presented in Figure 2, are: (1) the Silver Bluff Terrace, elevation 0 – 10 ft above mean sea level (amsl), (2) the Pamlico Terrace, elevation 10 – 25 ft (amsl), and (3) the Talbot Terrace, elevation 25 – 50 ft (amsl).

The topography has been shaped by terrace formation during the Pleistocene Epoch. Land surface elevation (Figure 3) varies from approximately 50 ft (amsl) in the northwest to near mean sea level in the coastal areas. There is a depression in the southwest corner of the study area within the Haw Creek subbasin where elevation varies between 5 and 10 ft (amsl).

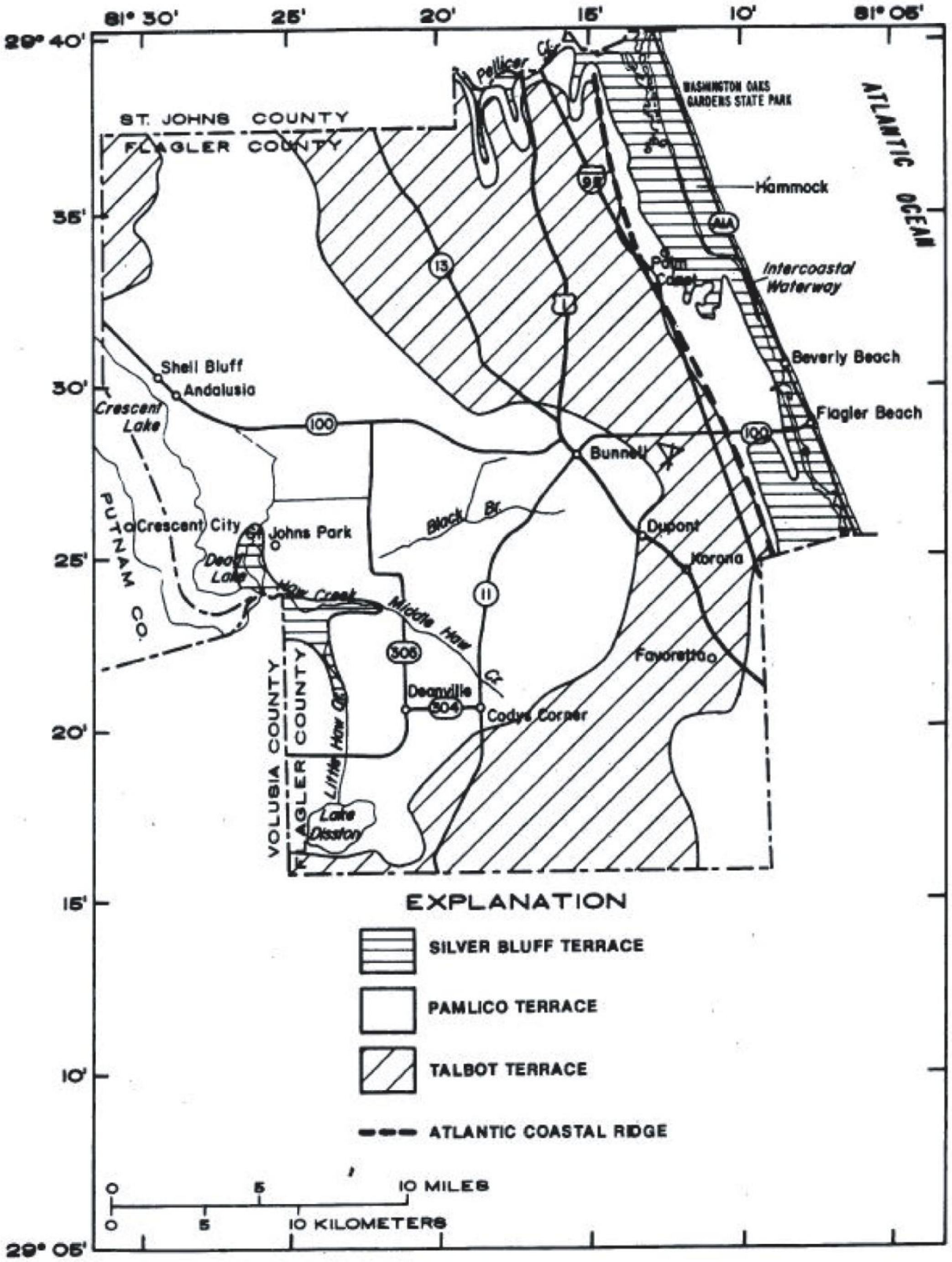


Figure 2 **Physiographic map of study area**

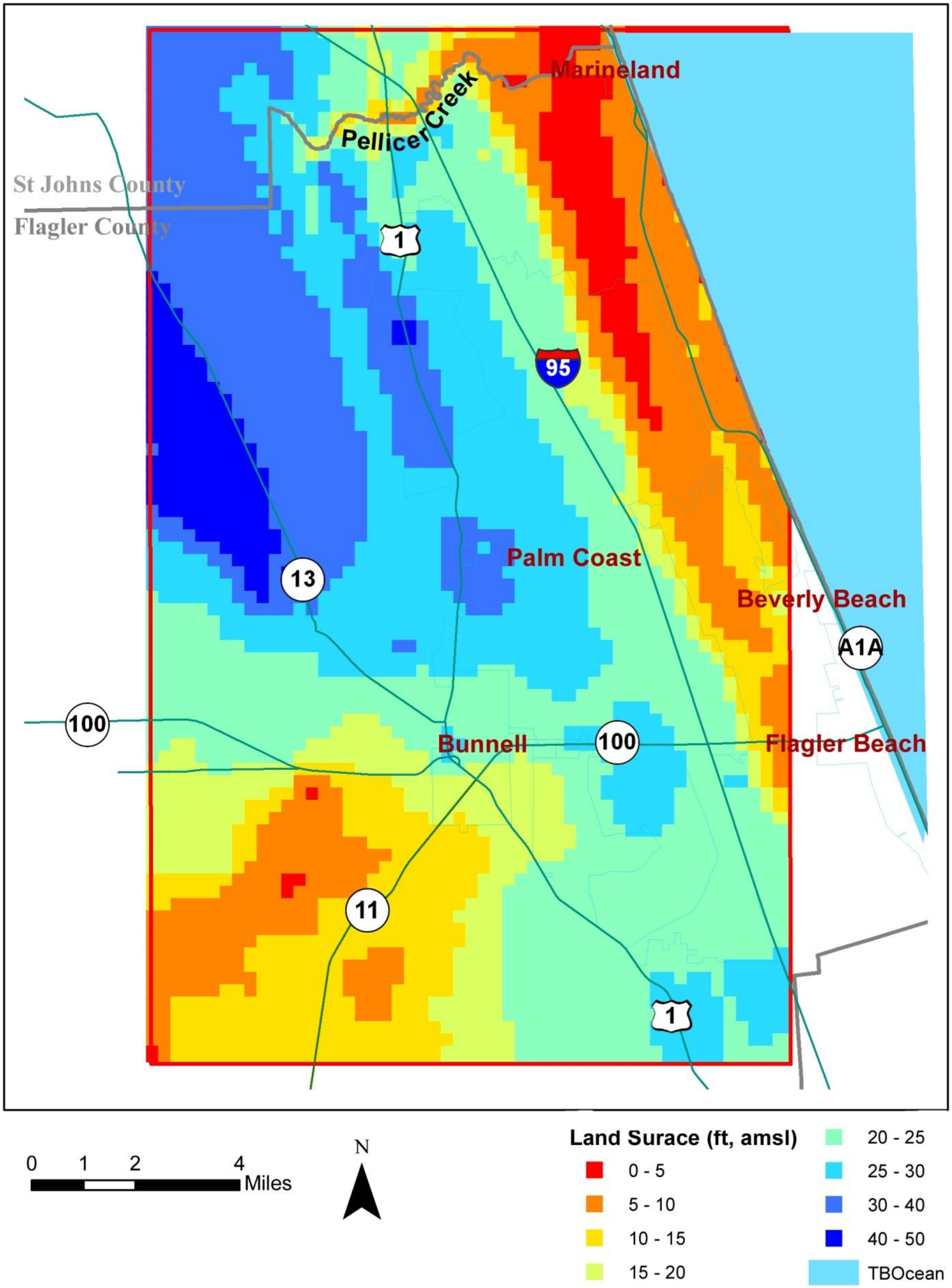


Figure 3 **Land surface elevation**

2.3 Surface Drainage and Hydrology

The study area is characterized by wetlands that are drained by a well-connected network of canals (Figure 4). It is assumed that most of the runoff exits the model study area via flow in the canal network. There are also two unregulated creeks in the area that drain groundwater and surface water in the study area. These creeks, Haw Creek and Pellicer Creek, are described below.

Haw Creek: Haw Creek is located in the southwest part of the study area. Based on an examination of the water quality distribution and the potentiometric surface of the Upper Floridan aquifer, Haw Creek appears to influence groundwater flow in the area. There are no gaging stations on the creek within the model study area. However, at gaging stations in the upper portions of the watershed there is minimal base flow, but very high rates of surface runoff to the creek. During the spring and early summer months, there is minimal flow and short periods when there is no flow in the creek. In 1995, peak discharge at the gaging station near Korona (south of the model boundary) was 1650 cubic feet per second (cfs) (Figure 5). The mean and median flow rate for 1995 was 93 and 11 cfs, respectively. During the relatively dry period from March to September 1995, the mean flow rate was 8.24 cfs.

Pellicer Creek: Pellicer Creek is located near the northern boundary of Flagler County and drains into the Intercoastal Waterway. Flow in the creek is largely comprised of surface runoff. Long-term discharge data from 1971 through 1995 indicate that on average, runoff to Pellicer Creek equals about 10.50 in/yr (Rabbani et al., 2004). Hydrographs of daily flows in Pellicer Creek from 1998 through 2000 are presented in Figure 6.

2.4 Evapotranspiration

A significant portion of the rainfall that falls on the land surface into the subsurface is lost to evapotranspiration (ET). There is limited data to substantiate the actual range of ET in the study area. ET rates can vary significantly based on surface cover, net radiation, photo-synthetically active radiation, air temperature, and depth to the water table. The upper limit of ET corresponds to pan evaporation, which is approximately 55 in/yr in the study area. The actual evapotranspiration rate varies inversely with depth from the land surface and ceases at the extinction depth. The extinction depth is a function of the soil and vegetation type as well as the

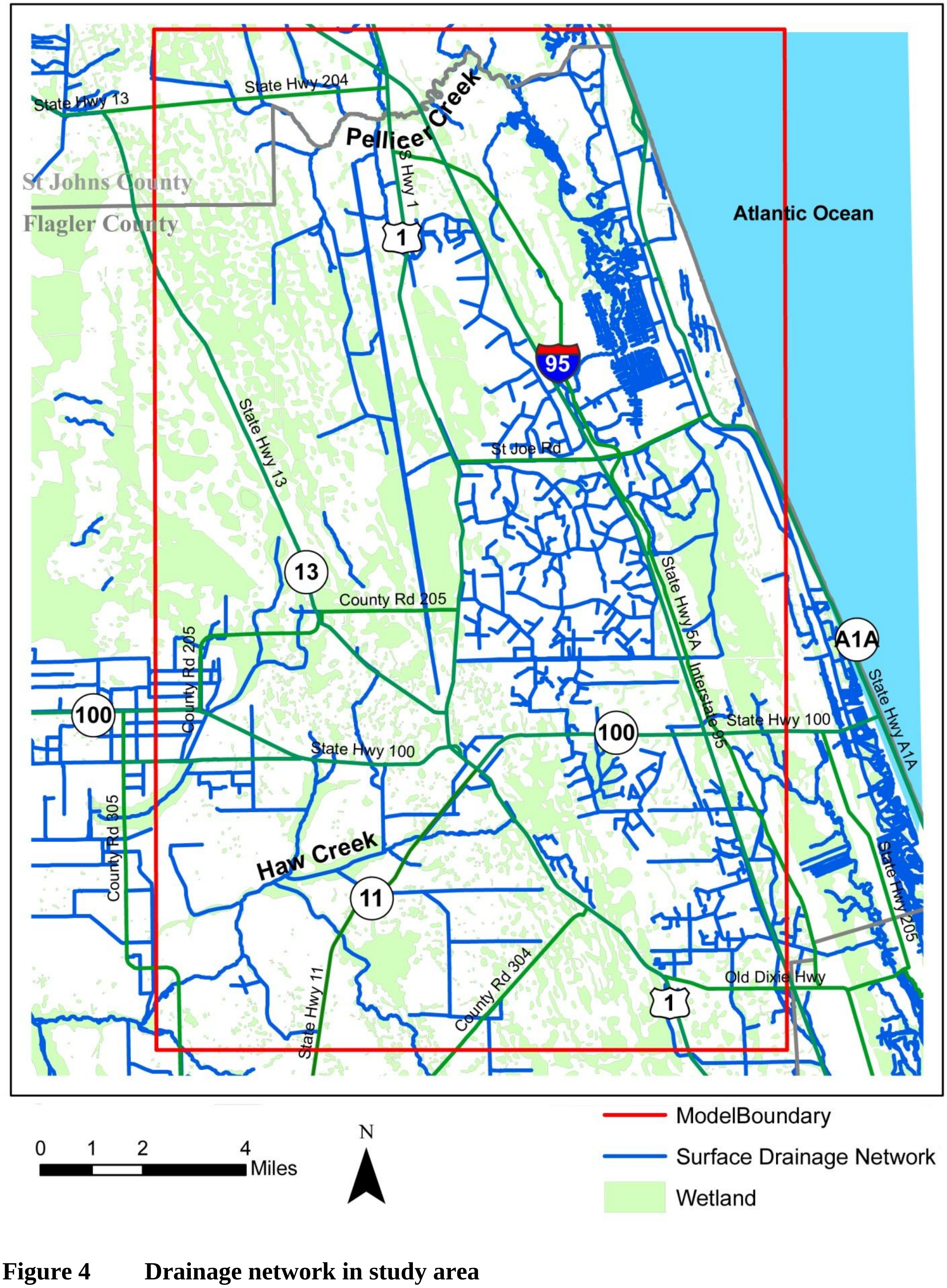


Figure 4 Drainage network in study area

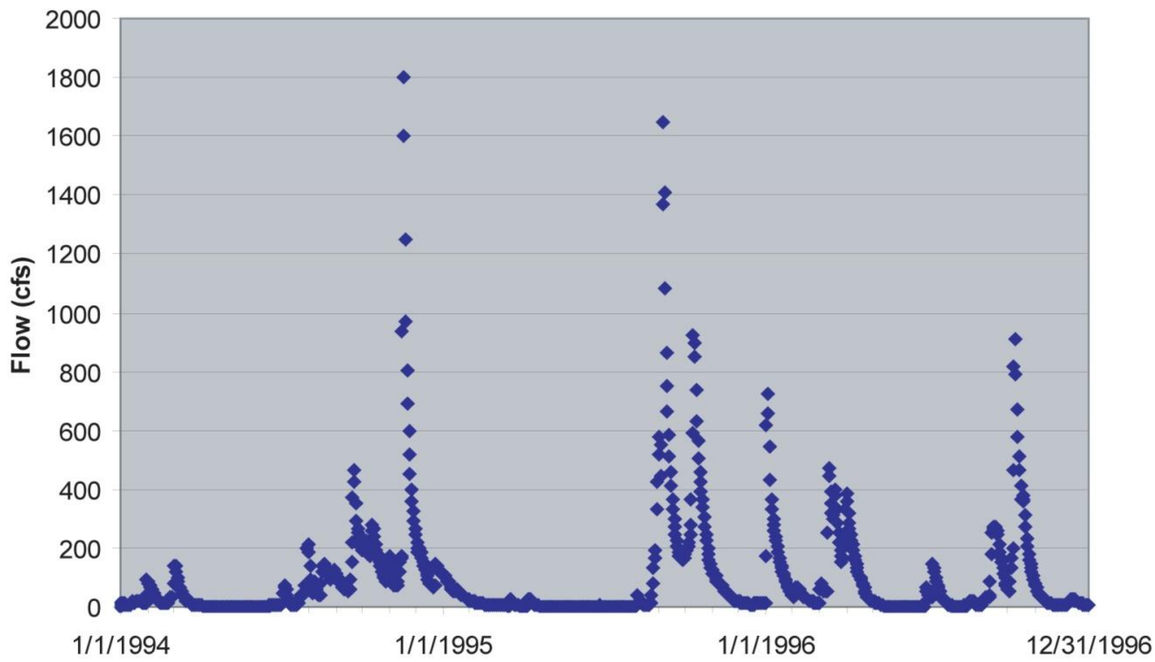


Figure 5 **Stream flow in Haw Creek near Korona, Florida**

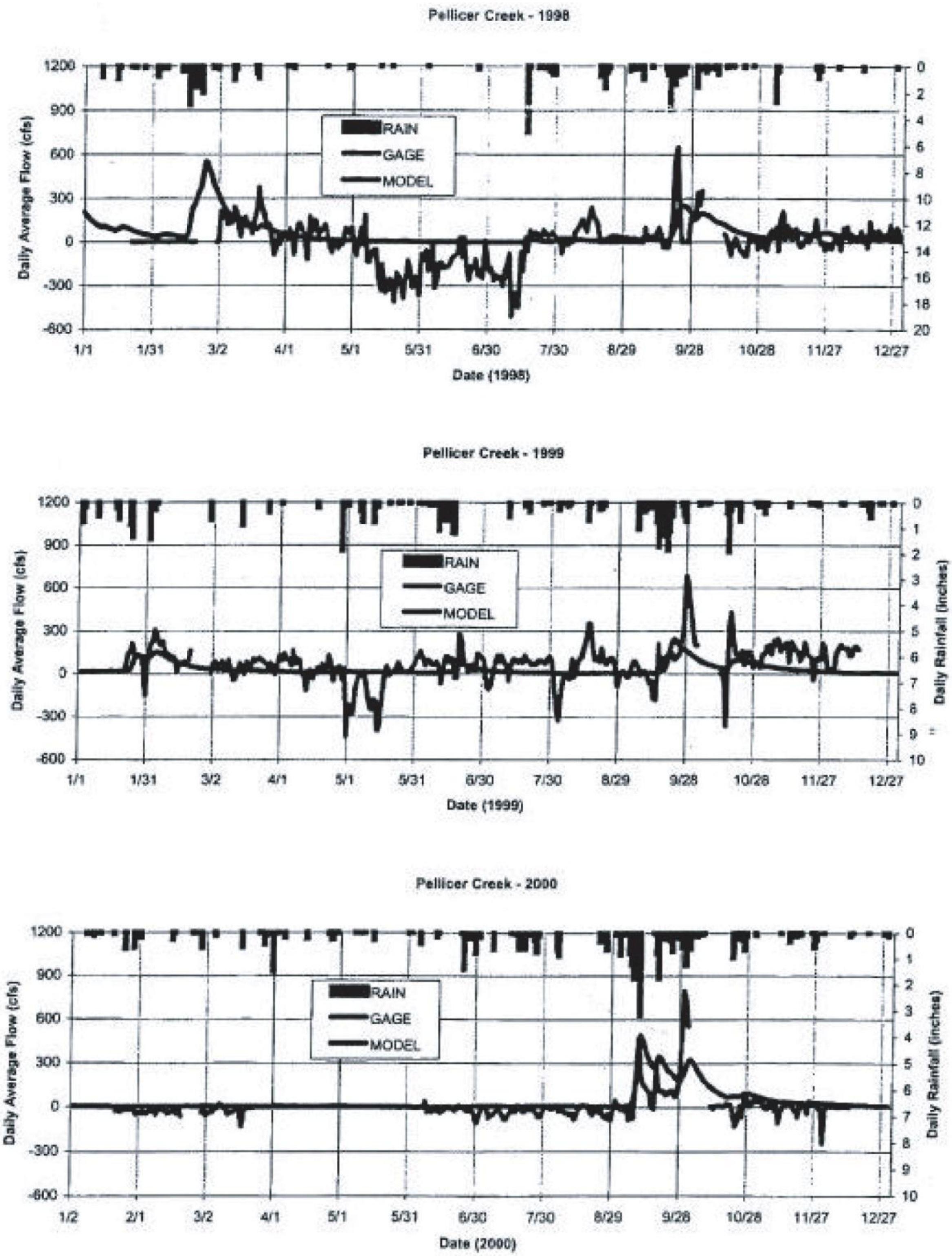


Figure 6 Flow in Pellicer Creek (CDM, 2002)

depth to the water table. No firm estimates of the extinction depth in the study area are available. It is likely that at locations where the water table is relatively deep, the extinction depth may also be deeper as plants develop deeper root systems to draw groundwater (David Sumner, USGS, personal communication).

2.5 Water Use

The Confined Surficial and the Upper Floridan aquifers are the primary sources of potable groundwater in the area. Groundwater is used for public supply, agricultural irrigation, residential irrigation, and recreation. Water for agricultural (large-scale) irrigation is withdrawn from the Upper Floridan aquifer, where groundwater is abundant but the quality does not meet drinking water standards. For small-scale or domestic (lawn) irrigation, groundwater is withdrawn from both the Unconfined and Confined Surficial aquifers. The Palm Coast Utility (PCU) at Palm Coast withdraws the largest amount of water in the study area for public supply. Other public utilities in the study area include the cities of Flagler Beach and Bunnell. The general location, as represented in the groundwater flow model, of the municipal, domestic self-supplied and agricultural wells active in 1995 in the Confined Surficial and Upper Floridan aquifers is presented in Figures 7 and 8.

Groundwater withdrawals for public supply have been increasing steadily over the years. In 1978, there was negligible production from the Unconfined Surficial aquifer, while approximately 0.16 and 1.9 MGD were withdrawn from the Confined Surficial and the Upper Floridan aquifers respectively by PCU. Approximately 1.55 MGD was withdrawn from the Upper Floridan aquifer for agricultural irrigation in the study area. The City of Flagler Beach also withdrew 0.32 MGD from five Upper Floridan wells. The City of Bunnell withdrew 0.16 MGD from two Confined Surficial wells and 0.04 MGD from one Upper Floridan well.

By 1995, production from 27 PCU Confined Surficial aquifer wells equaled 2.70 MGD, and 0.98 MGD was withdrawn from three Upper Floridan aquifer wells (Table 1). The City of Bunnell withdrew 0.22 MGD from two Confined Surficial wells and 0.05 MGD from one Upper Floridan well. The City of Flagler Beach withdrew 0.50 MGD from eight Upper Floridan wells. Residential irrigation accounted for 0.37 MGD withdrawal from several wells in the Unconfined Surficial aquifer and 1.75 MGD from numerous wells presumed to be in the Confined Surficial aquifer (John Moden, personal communication, Appendix A**).**

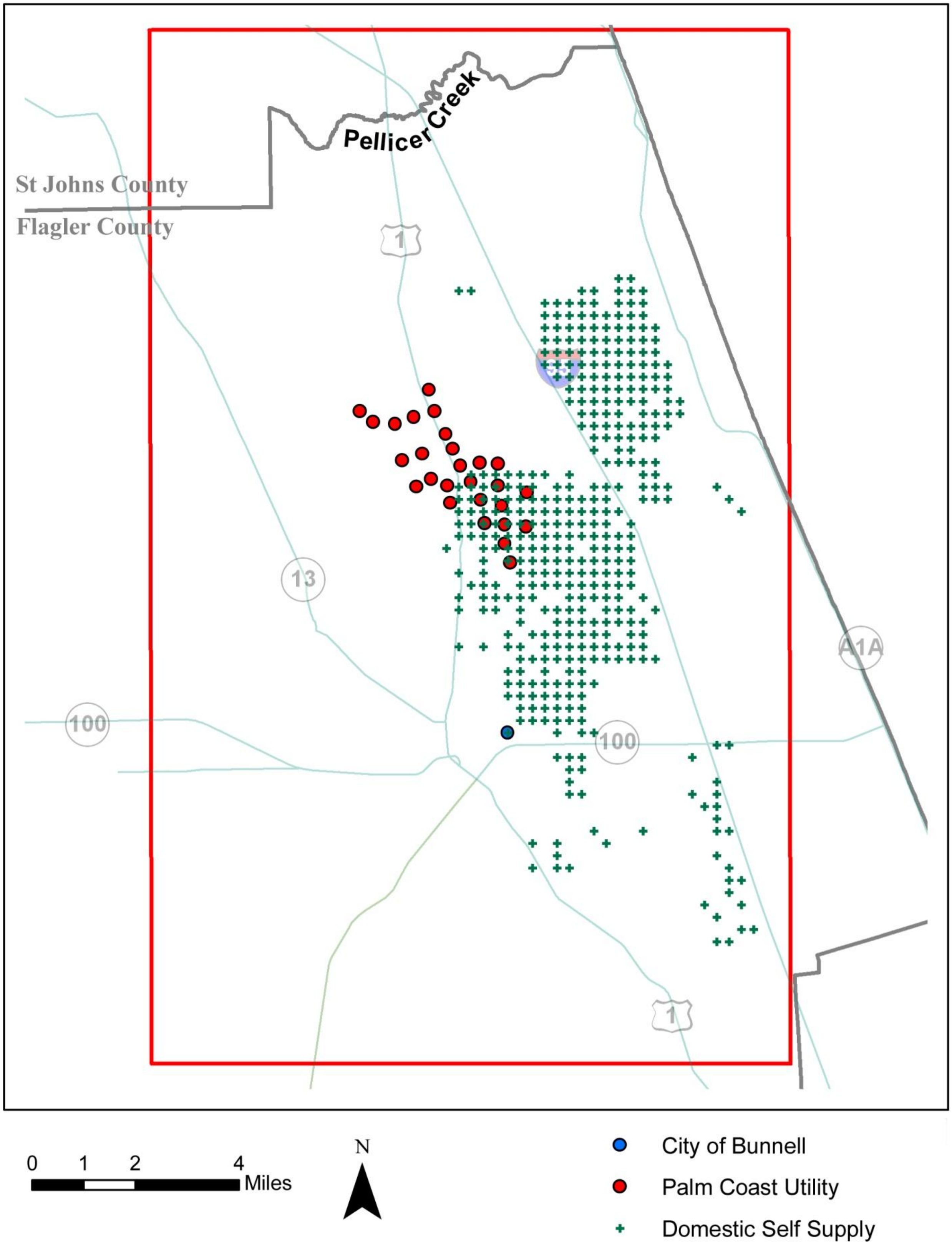


Figure 7 Production wells in Confined Surficial aquifer for 1995

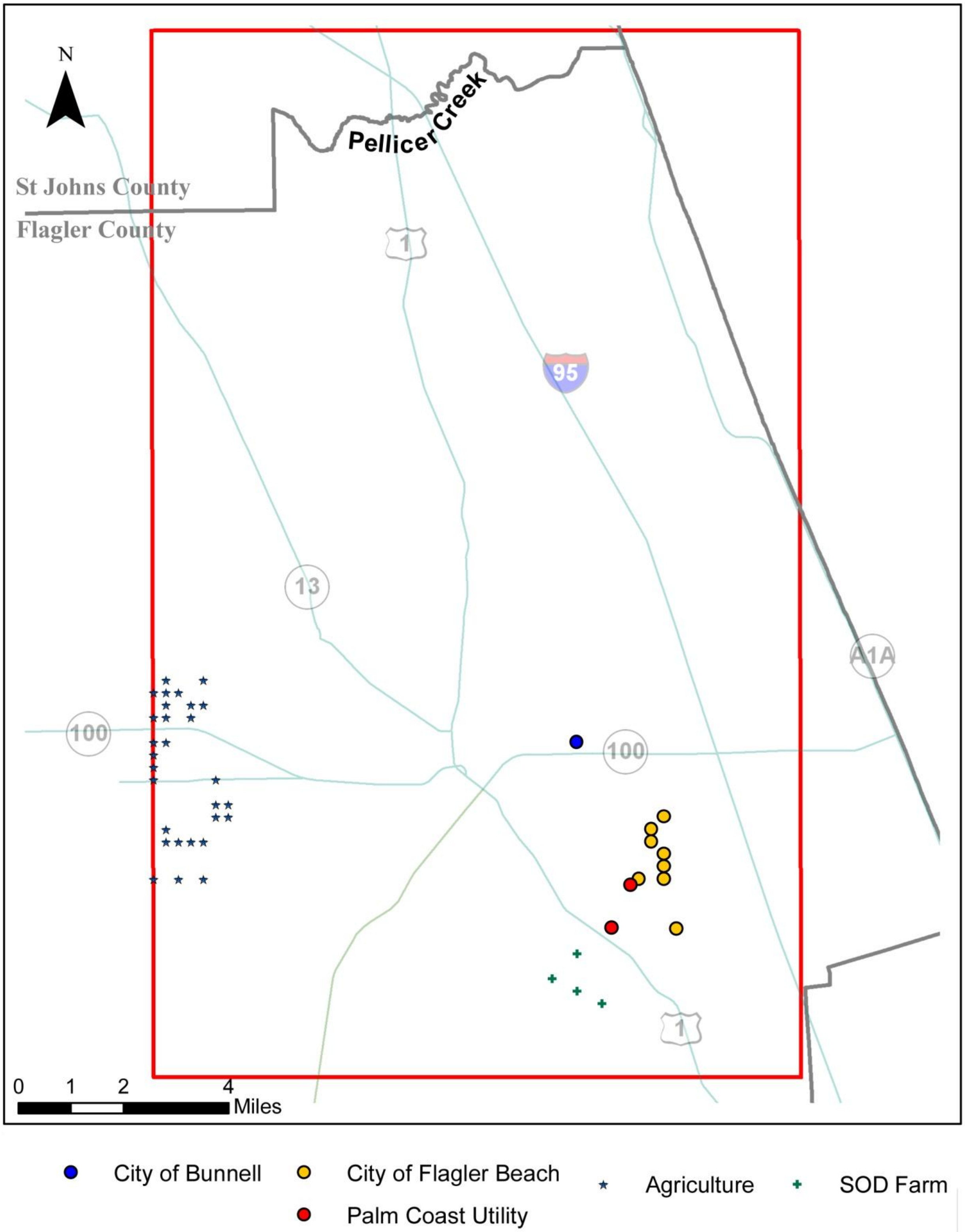


Figure 8 Production wells in Upper Floridan aquifer for 1995

Table 1 1995 groundwater withdrawal summary

	Pumpage (MGD)			Return Flow (MGD)[a]		
	Unconfined Surficial	Confined Surficial	Upper Floridan	Unconfined Surficial	Confined Surficial	Upper Floridan
Palm Coast Utility		2.70	0.98			
Agriculture			1.35*			
City of Flagler Beach			0.50			
City of Bunnell		0.22	0.05			
Residential Irrigation	0.37	1.75		0.22***		
Sod Farms	0.29		0.22	.10****		
Golf course/ Development	1.06			0.22**		
Total	**1.72**	**4.7**	**3.3**	**0.54**		

[a] All return flow percentages estimated by SJRWMD.
* Includes return flow estimate.
** 21% of pumpage
*** 10% of pumpage
**** 15% of pumpage

In 2000, withdrawals by PCU from the 27 Confined Surficial wells totaled 3.43 MGD (a 21.2 % increase over 1995), and 1.41 MGD was withdrawn from six wells in the Upper Floridan aquifer, representing a 42.4% increase over 1995 production rates. The City of Flagler Beach withdrew only 0.60 MGD from the Upper Floridan aquifer and the City of Bunnell withdrew 0.24 MGD from the Confined Surficial aquifer and 0.06 MGD from one Upper Floridan well. Treated reclaim and blended membrane concentrated water became available for application to golf courses and rapid infiltration basins (RIBS) in the study area (Figure 9). The total amount of treated water applied to the surficial aquifer is estimated to be 0.82 MGD.

An overall increase in groundwater production for the study area is projected for 2011. The general location of the production wells, as represented in the groundwater flow model, is presented in Figure 10, 11, and 12. By 2011, PCU is projected to withdraw 5.46 MGD from the Confined Surficial aquifer and 4.05 MGD from the Upper Floridan Aquifer (Table 2). The City of Flagler Beach is projected to withdraw 0.84 MGD from the Upper Floridan aquifer, and the City of Bunnell plans to withdraw 0.46 MGD from the Confined Surficial aquifer and 0.94 MGD from the Upper Floridan aquifer.

Agricultural irrigation is expected to increase from 1.35 MGD in 1995 to 1.55 MGD in 2011. Proposed withdrawals for sod farms from the Unconfined Surficial and the Upper Floridan aquifer were estimated to be 0.8 and 1.38 MGD, respectively.

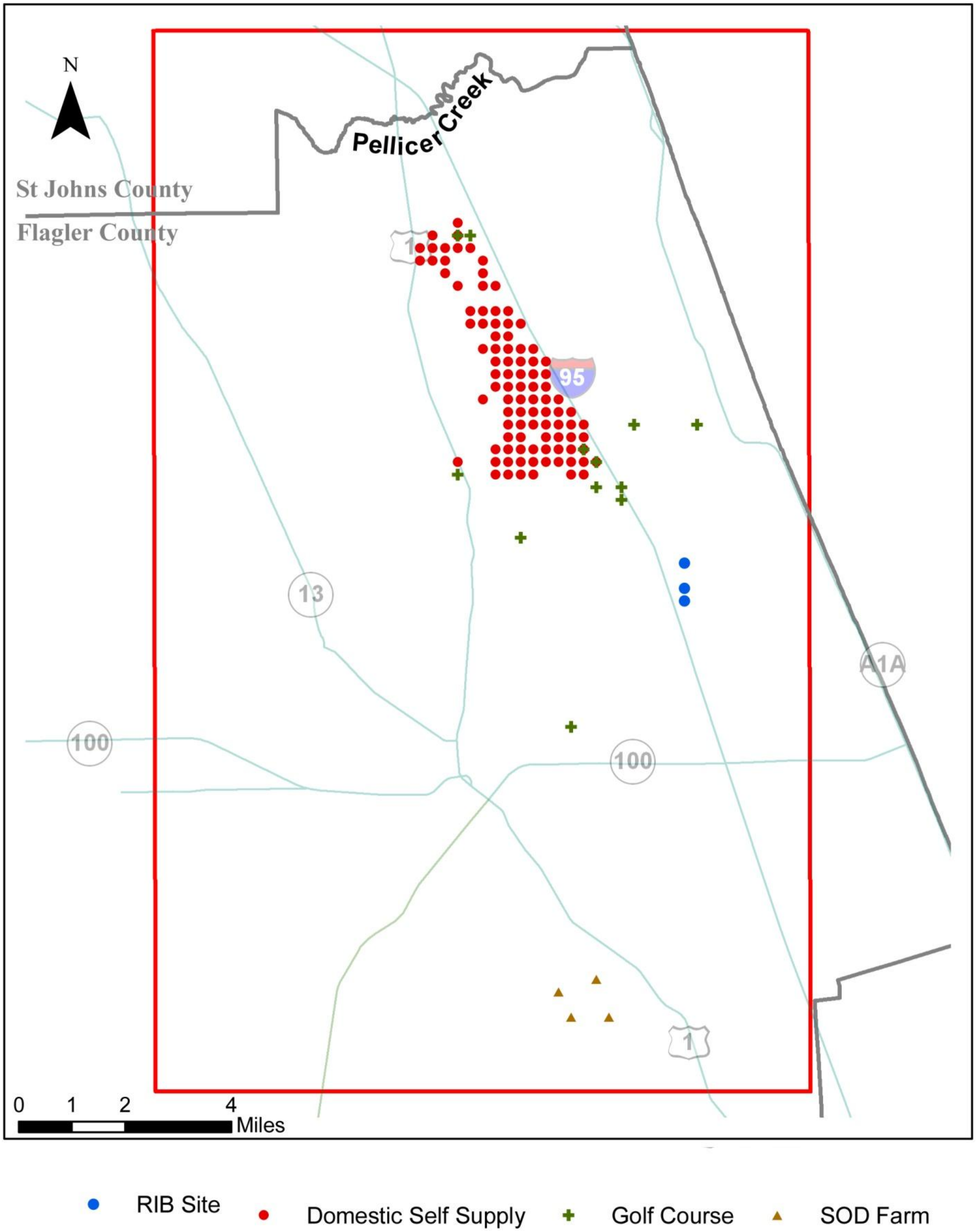


Figure 9 **Production wells in Unconfined Surficial aquifer for 1995 and location of RIB site**

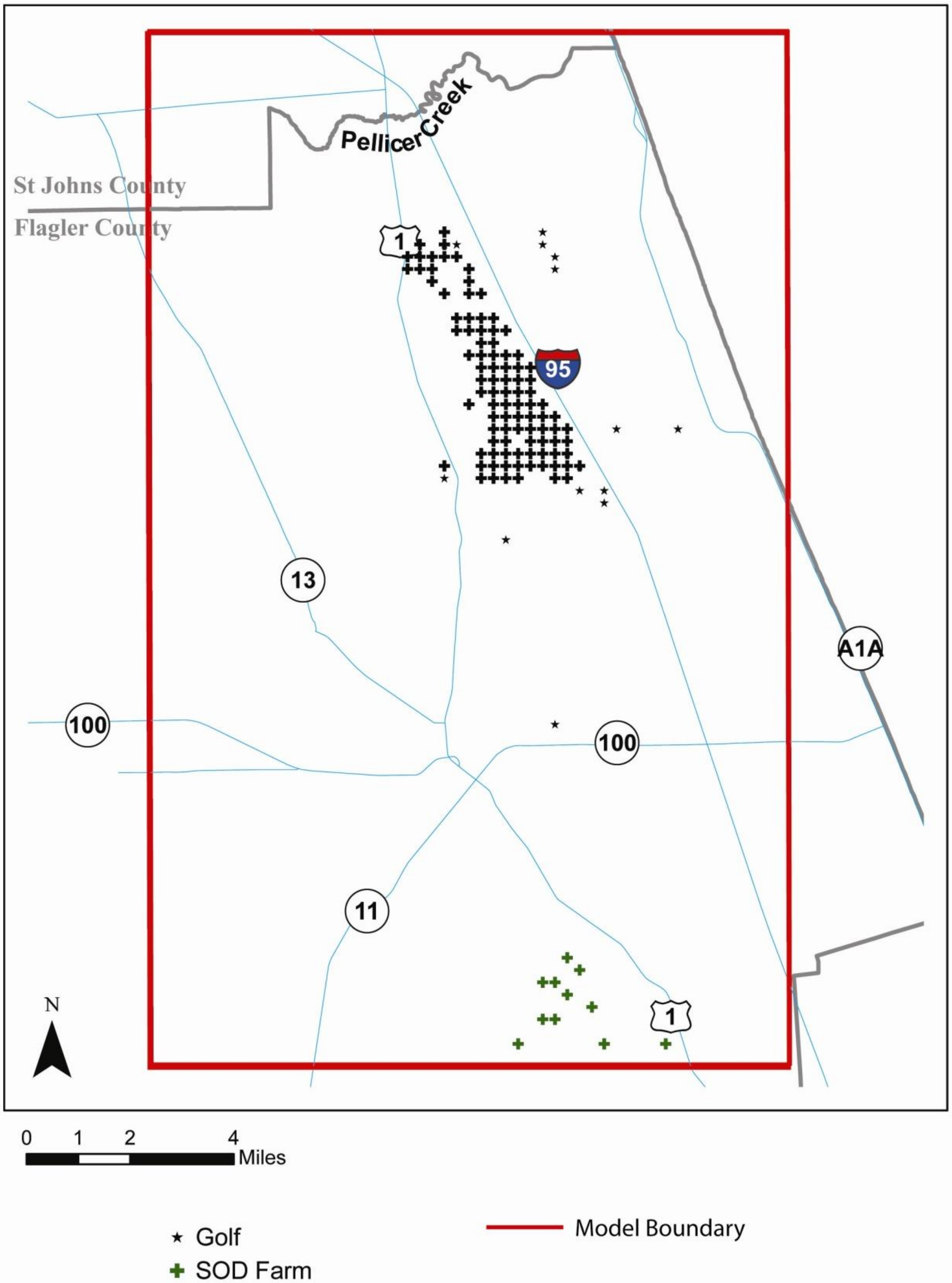


Figure 10 Production wells in Unconfined Surficial aquifer for 2011

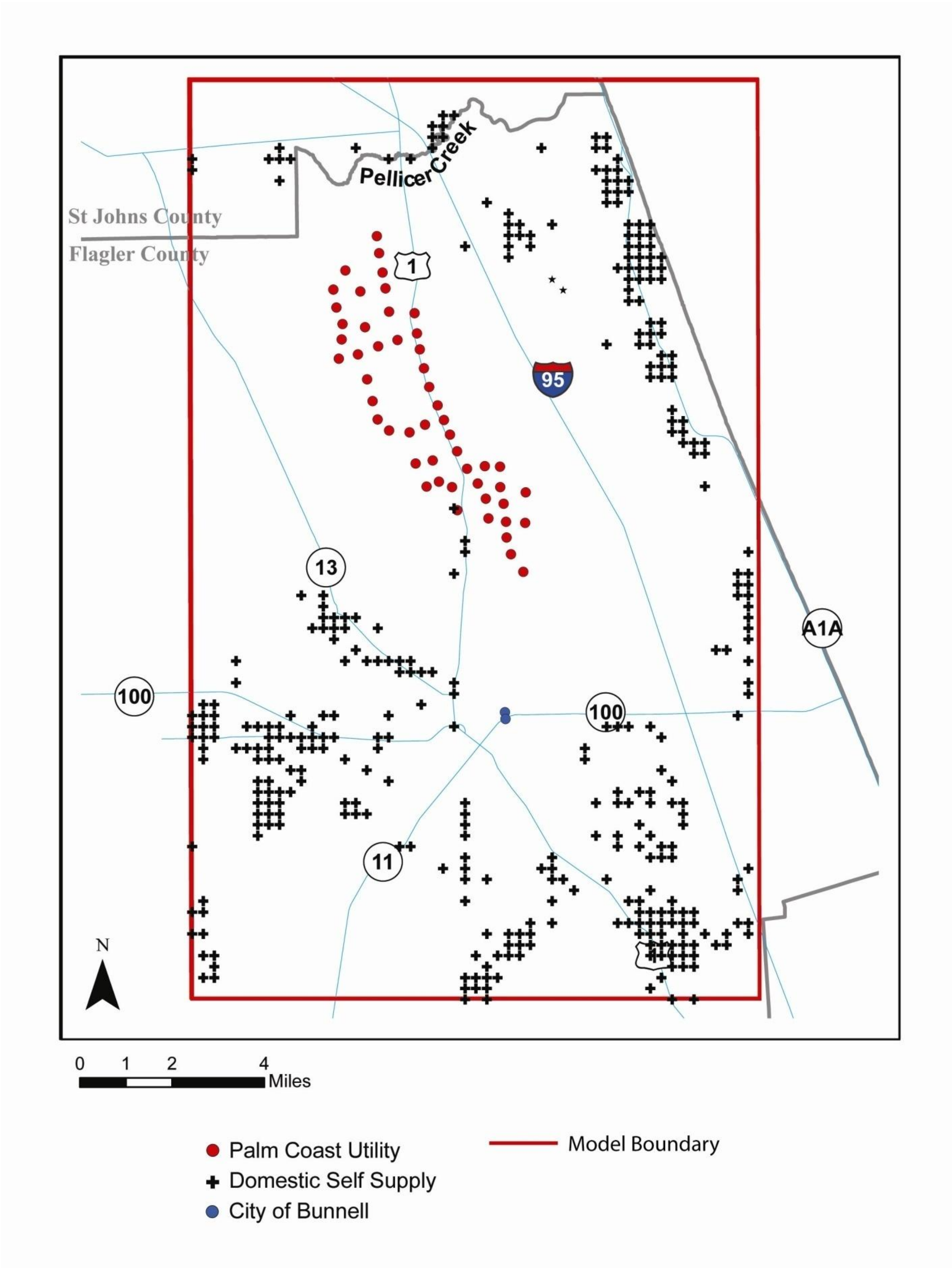


Figure 11 Production wells in Confined Surficial aquifer for 2011

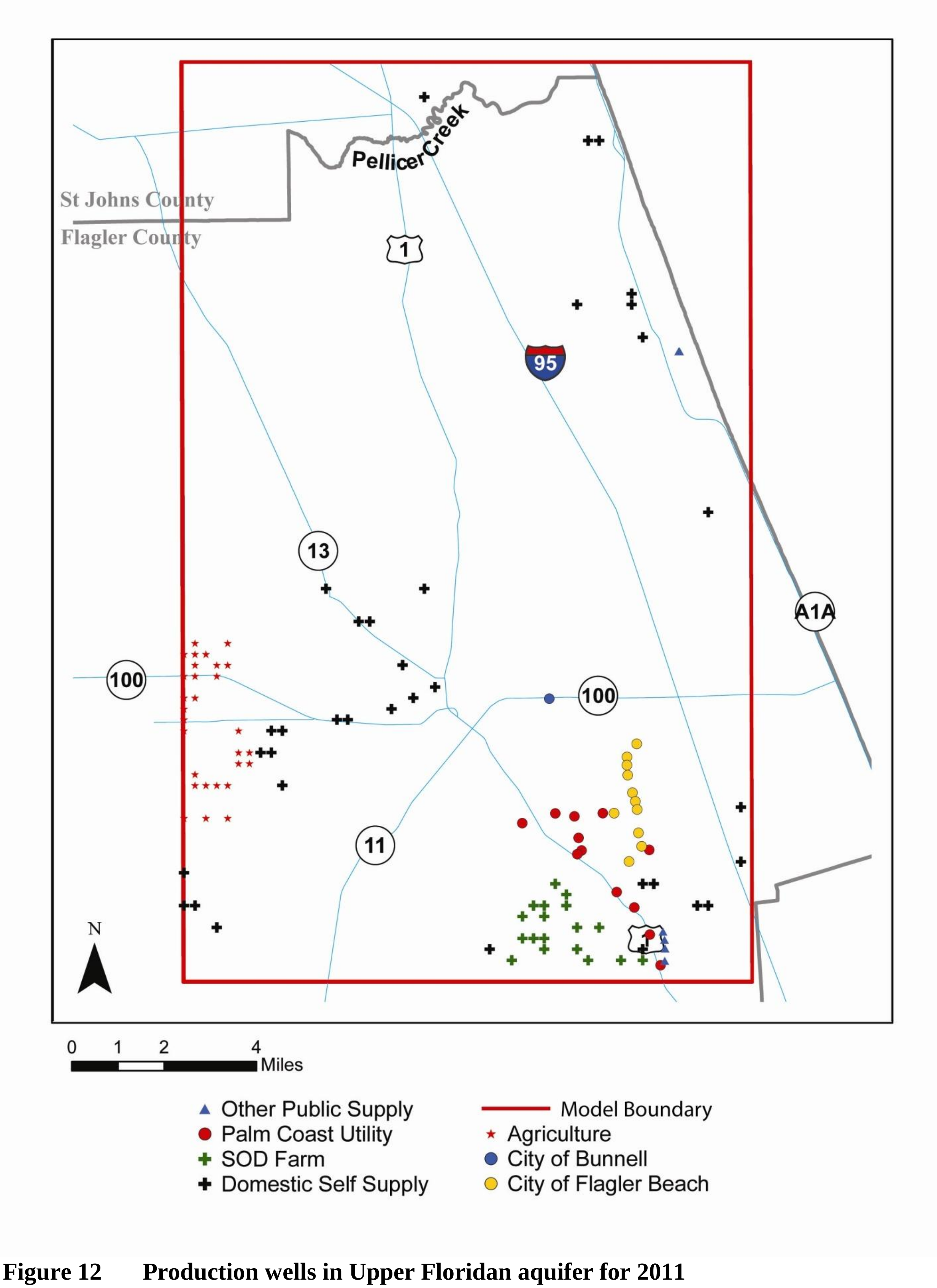


Figure 12 Production wells in Upper Floridan aquifer for 2011

Approximately 0.37 MGD is expected to be withdrawn from the Unconfined Surficial aquifer and 0.83 MGD from the Confined Surficial aquifer for domestic self-supply. In 2011, groundwater withdrawals for golf courses from the Unconfined Surficial aquifer are estimated to be 1.21 MGD. In addition to rainfall, return flows to the Unconfined Surficial aquifer from projected domestic self-supply, golf, reuse irrigation, and sod farms were estimated. Return flows from domestic self-supply were estimated assuming a 10% return rate to the Unconfined Surficial aquifer. Because the pumping scenarios for 1995 and 2011 were significantly different for domestic self-supply, these withdrawals from the Unconfined Surficial aquifer were increased, by less than 0.04 MGD, in the 2011 pumping scenario to avoid creating an artificial rebound from 1995 conditions.

Table 2 Projected groundwater withdrawal summary for 2011

	Pumpage (MGD)			Return Flow (MGD)		
	Unconfined Surficial	**Confined Surficial**	**Upper Floridan**	**Unconfined Surficial**	**Confined Surficial**	**Upper Floridan**
Palm Coast Utility		5.46	4.05			
Agriculture			1.55*			
City of Flagler Beach			0.84			
City of Bunnell		0.46	0.94			
Other Public Supply			0.59			
Domestic Self Supply	0.37	0.83	0.07	0.09**		
Sod Farms	0.80		1.38	0.33***		
Golf	1.21	0.09		0.65		
Reuse Irrigation				1.38		
Total	**2.4**	**6.8**	**9.4**	**2.4**		

* Includes return flow estimate
** 10% of pumpage (estimated by SJRWMD)
*** 15% of pumpage (estimated by SJRWMD)

A substantial increase in groundwater demand is projected for 2030. The location of the production wells is presented in Figure 13, 14, and 15. By 2030, PCU is projected to withdraw 9.51 MGD from the Confined Surficial aquifer and 22.08 MGD from the Upper Floridan aquifer (Table 3). The City of Flagler Beach is projected to withdraw 0.84 MGD from the Upper Floridan aquifer, and the City of Bunnell plans to withdraw 1.53 MGD from the Confined Surficial aquifer and 1.03 MGD from the Upper Floridan aquifer.

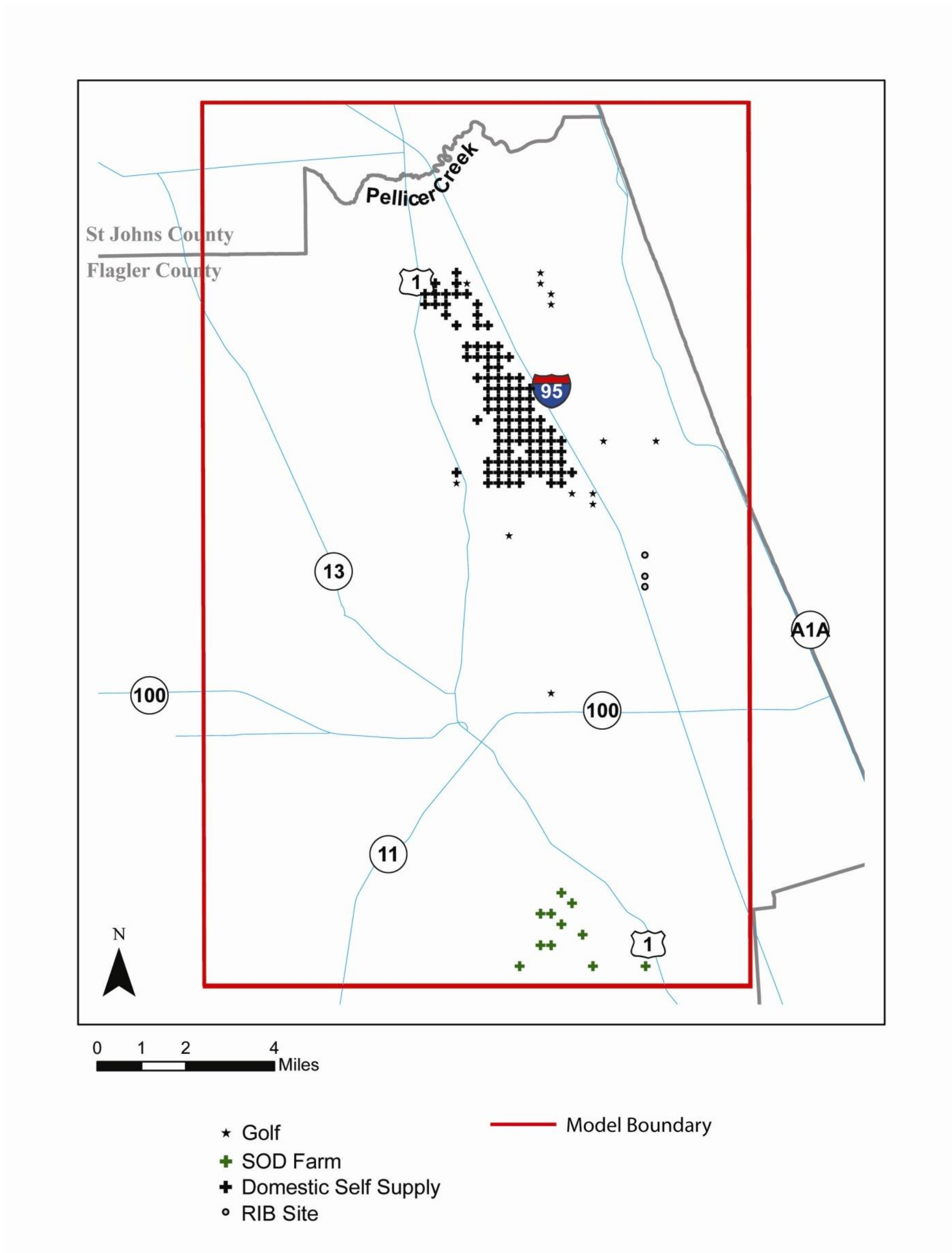


Figure 13 Production wells in Unconfined Surficial aquifer for 2030 and location of RIB sites

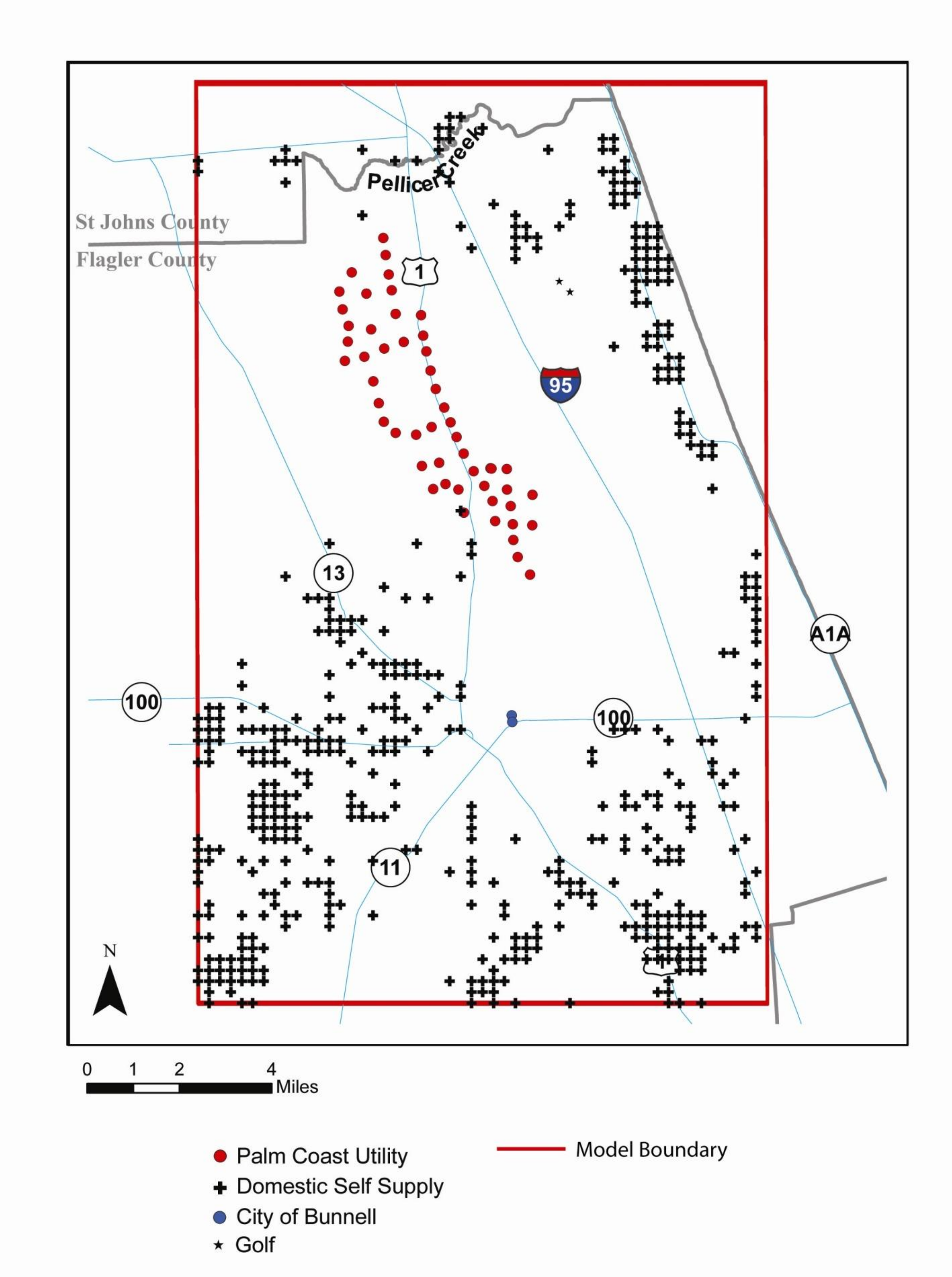


Figure 14 Production wells in Confined Surficial aquifer for 2030

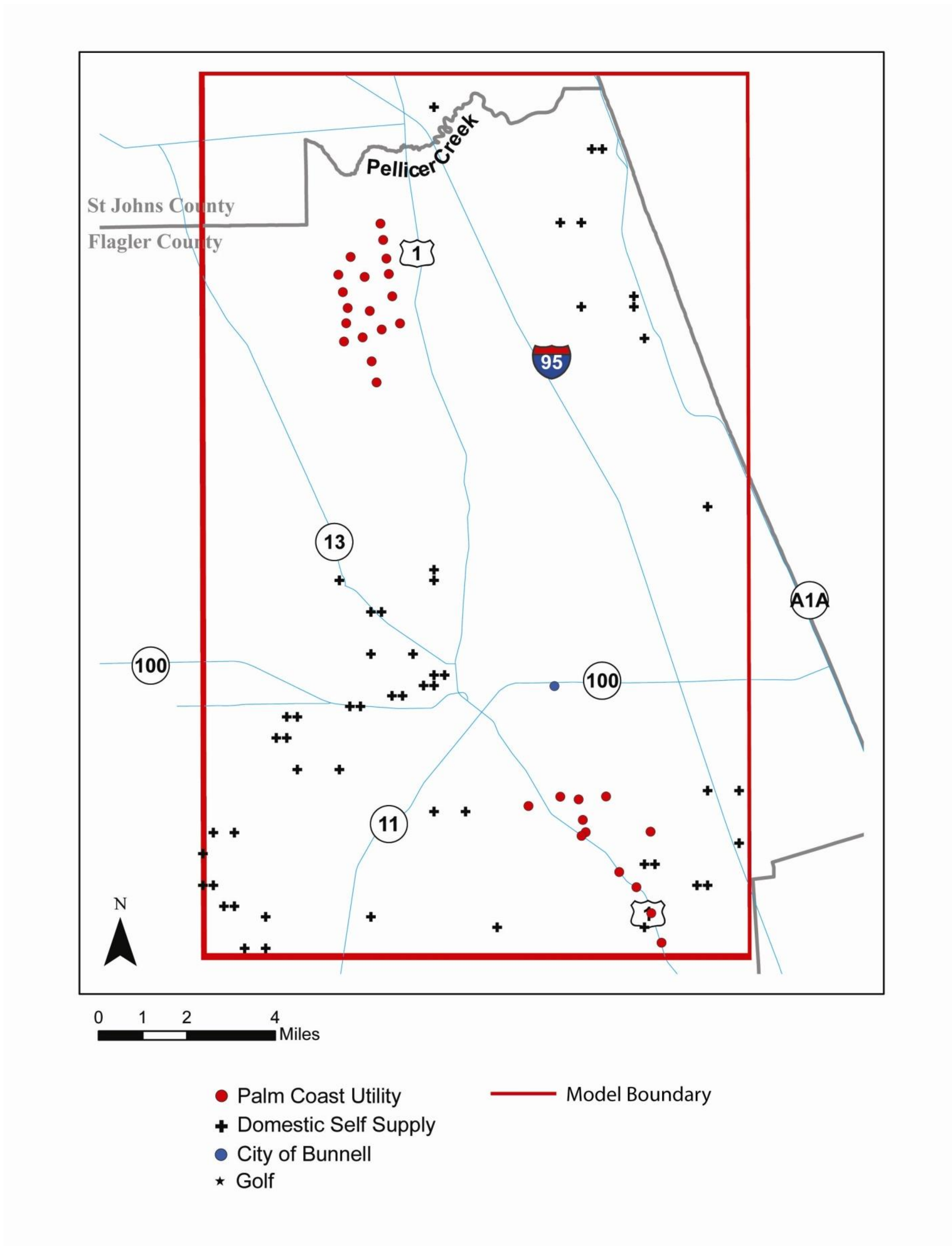


Figure 15 Production wells in Upper Floridan aquifer for 2030

Agricultural irrigation is expected to increase from 1.35 MGD in 1995 to 1.55 MGD in 2030. Proposed withdrawals for sod farms from the Unconfined Surficial and the Upper Floridan aquifer were estimated to be 0.8 and 1.38 MGD, respectively. Return flow and RIB application rates in 2030 are estimated to be 3.6 MGD. Approximately 4.37 MGD is expected to be withdrawn from the Confined Surficial aquifer and 0.37 MGD from the Unconfined Surficial aquifer for domestic self-supply. In 2030, groundwater withdrawals for golf courses from the Unconfined Surficial aquifer are estimated to be 1.21 MGD.

Table 3 Projected groundwater withdrawal summary for 2030

	Pumpage (MGD)			Return Flow (MGD)		
	Unconfined Surficial	Confined Surficial	Upper Floridan	Unconfined Surficial	Confined Surficial	Upper Floridan
Palm Coast Utility		9.51	22.08			
Agriculture			1.55*			
City of Flagler Beach			0.84			
City of Bunnell		1.53	1.03			
Other Public Supply			1.35	0.00		
Domestic Self Supply	0.37	4.37		0.48**		
Sod Farms	0.8		1.38	0.33***		
Golf	1.21	0.09		0.65		
RIB sites				0.82		
Reuse Irrigation				1.38		
Total	**2.4**	**15.5**	**28.7**	**3.6**		

* Includes return flow estimate
** 10% of pumpage (estimated by SJRWMD)
*** 15% of pumpage (estimated by SJRWMD)

2.6 Geologic Framework

2.6.1 Stratigraphy

A thick sequence of marine sedimentary rock underlies the study area. The geologic units, described in Table 4, include the pre-Hawthorn Tertiary carbonate units, the Hawthorn Group, and the post-Miocene deposits. The geologic strata, in ascending order, are the Cedar Keys Formation of Paleocene age, the early Eocene Oldsmar Formation, the middle Eocene, the Avon Park Formation, the late Eocene Ocala Limestone, the middle Miocene Hawthorn group, and the 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 described below. 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 that impede groundwater flow in the formation. The Avon Park Formation of middle Eocene age is composed primarily of limestone and dolomite that occasionally contains cavities. The Ocala limestone of late Eocene age overlies the limestone and dolomite of the Avon Park Formation. In places, the lower portions of the formation contain variable amounts of dolomite (Miller, 1986). The limestone has experienced dissolution over the years that enhanced the overall permeability by adding secondary porosity in addition to the original primary porosity. The permeability enhancement by dissolution also includes the dolostone in the Oldsmar and Avon Park formations. The Hawthorn Group of middle Miocene age consists of phosphate, clay, sand, and carbonate which occurs in its most common form, dolomite. Being highly heterogeneous, and due to the fine texture of its constituents, both clastic and carbonate, the group as a whole possesses relatively low permeability and acts as a confining unit between the Eocene age limestone underneath it and the post-Miocene deposits above. 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 dispersed in the study area. They consist primarily of sand, clayey-sand, sandy clay, marl, shell, and clay.

Table 4 Geologic units in study area

Geologic Epoch	Stratigraphic Unit	Lithology
Pleistocene and Recent	Pleistocene and recent deposits	Discontinuous beds of loose sand, clayey sand, sandy clay, clay, marl, and shell
Pliocene	Pliocene deposits	Clay, clayey sand, sandy clay, sand, shell and carbonate rock
Middle Miocene	Hawthorn Group	Interbedded clay, quartz sand, carbonate, and phosphate
Late Eocene	Ocala Limestone	Limestone
Middle Eocene	Avon Park Formation	Interbedded limestone and dolomite
Early Eocene	Oldsmar Formation	Interbedded limestone and dolomite
Paleocene	Cedar Keys Formation	Interbedded dolomite and anhydrite

2.7 Hydrogeologic Framework

The primary water bearing units in the study area include, in descending order, the Unconfined Surficial aquifer, the Confined Surficial aquifer (or the Intermediate aquifer), and the Floridan aquifer system. The upper two water-bearing units, along with the Top Confining Unit that separates them are not formally named units in the Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition (1986) since they are not laterally extensive on a regional basis. The hydrogeology of each of the primary units is described below in further detail.

2.7.1 Unconfined Surficial Aquifer

The Unconfined Surficial aquifer consists of deposits of Pleistocene and Holocene age, and is composed of sand and shell with varying fractions of finer material. Sands are the dominant lithology in east-central Flagler County and shell material (coquina) is dominant along the coast. The thickness of the Unconfined Surficial aquifer (Figure 16) ranges from less than 20 to 75 ft in the study area. The deposits are thickest along the western boundary, and thinnest along the coast and in the Haw Creek subbasin in the southwest, and along Pellicer Creek in the north.

2.7.2 Confining Units

2.7.2a Confined Surficial Aquifer and Top Confining Unit

The base of the Unconfined Surficial aquifer can be recognized in many areas by sediments that consist of an increase in clay and other fine-grained material. These sediments are semi confining and the thickness and degree of confinement varies from site to site. The top and bottom of this unit was estimated by Toth (2001) based on picks made in production wells. Testing in these wells indicated that more water production was available from the sediments below this semi-confining interval. In this report, the sediments between the base of the Unconfined Surficial aquifer and the top of the underlying Confined Surficial aquifer are referred to as the “top confining unit” (TCU). The TCU may be discontinuous between wells and varies in degree of confinement based on the type of sediments present.

The confined surficial aquifer (CSA) consists of all sediments lying between the base of the TCU and the top of the Hawthorn Group. It consists of deposits of sand, loosely cemented shell, clayey sand, and limestone of Pliocene and Pleistocene age.

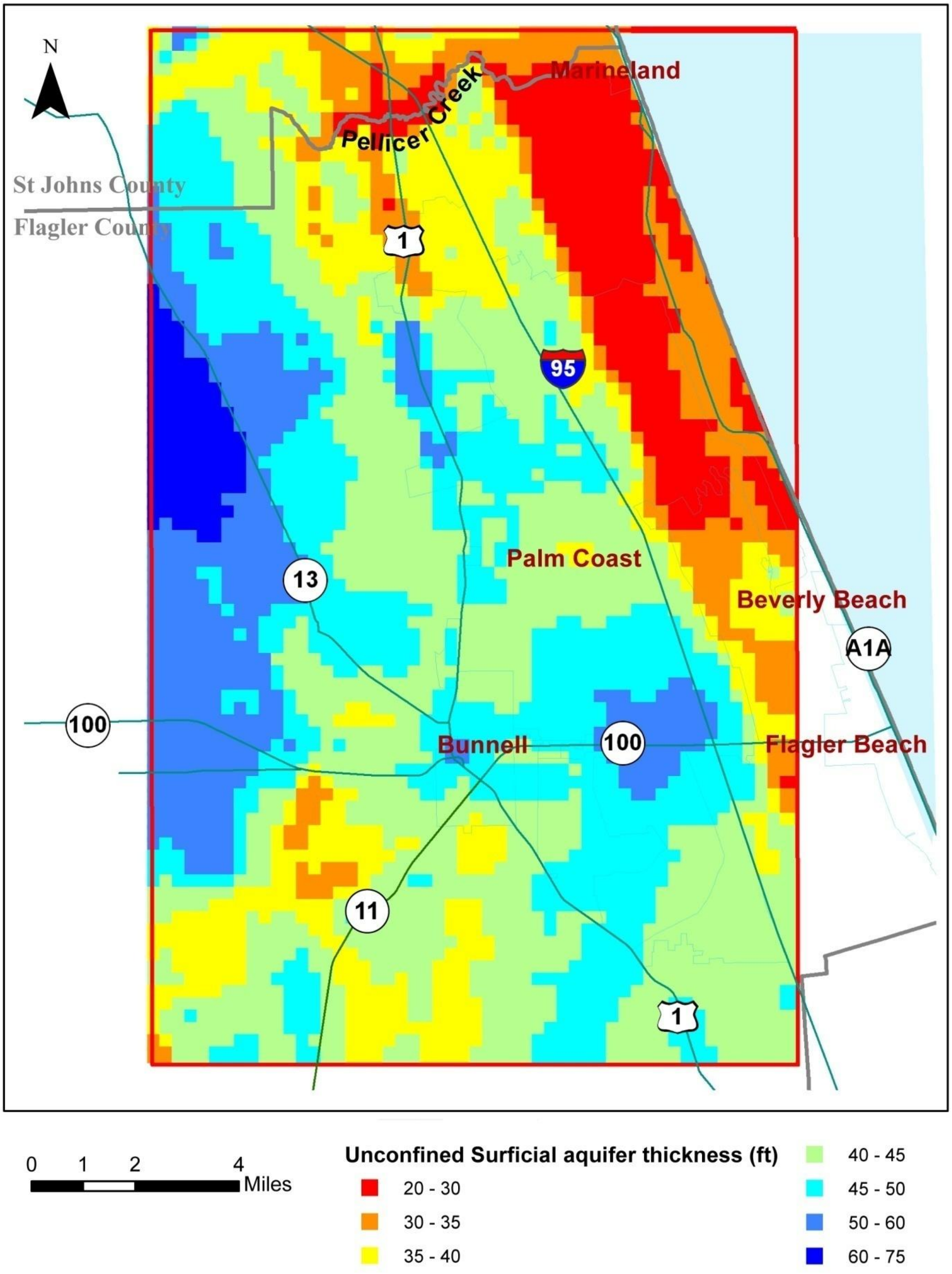


Figure 16 Thickness of Unconfined Surficial aquifer

The primary water-bearing zones are relatively thin lenses of permeable sand, shell, and limestone that vary in thickness throughout the study area. The thickness of the CSA ranges from less than 15 ft to 35 ft. The CSA thickness was determined by subtracting the grid for the elevation of the underlying intermediate confining unit (essentially the Hawthorn Group) from the grid for the elevation of the top of the CSA. An isopach (thickness map) of the thickness of the CSA is presented in Figure 17. An isopach of the TCU was created similarly by subtracting the grid for the elevation of the top of the CSA from the grid for the elevation of the top of the TCU (Figure 18). The thickness of the TCU ranges from less than 2 ft in east-central Flagler County to 30 ft in north-central Flagler County. The TCU is composed of sandy clay, clay, shell with clay interbedded with small grain sized sediments that impede downward movement of water to lower water bearing units. The lateral variation in the composition of the sediments comprising the TCU can account for lateral variations in vertical hydraulic conductivity.

2.7.2b Intermediate Confining Unit

This unit corresponds to the intermediate aquifer system or confining unit of the Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition (1986). In this area, it is primarily an intermediate confining unit and is referred to as ICU in this report. The ICU consists of Miocene marls, clays, and carbonates of the Hawthorn Group. The thickness of the ICU ranges from less than 15 ft in the south to 90 ft in the northeast of the study area. The contact between the ICU and the CSA may be transitional as there was reworking (erosion and redeposition) of Hawthorn Group sediments as sea level rose and receded in post Miocene time.

2.7.3 Upper Floridan Aquifer

The Upper Floridan aquifer includes the highly permeable Ocala Limestone of Late Eocene age and the upper portion of the Avon Park Formation. The high degree of permeability in this aquifer is attributed to the formation of cavities developed over the ages because of chemical/mechanical reactions in the groundwater flow system. Elevation of the top of the Upper Floridan aquifer (Figure 19) changes from –70 ft (amsl) in the south to -150 ft (amsl) in the north. The thickness of the Upper Floridan aquifer (Figure 20) varies less than 500 ft in the south to over 700 ft in the north.

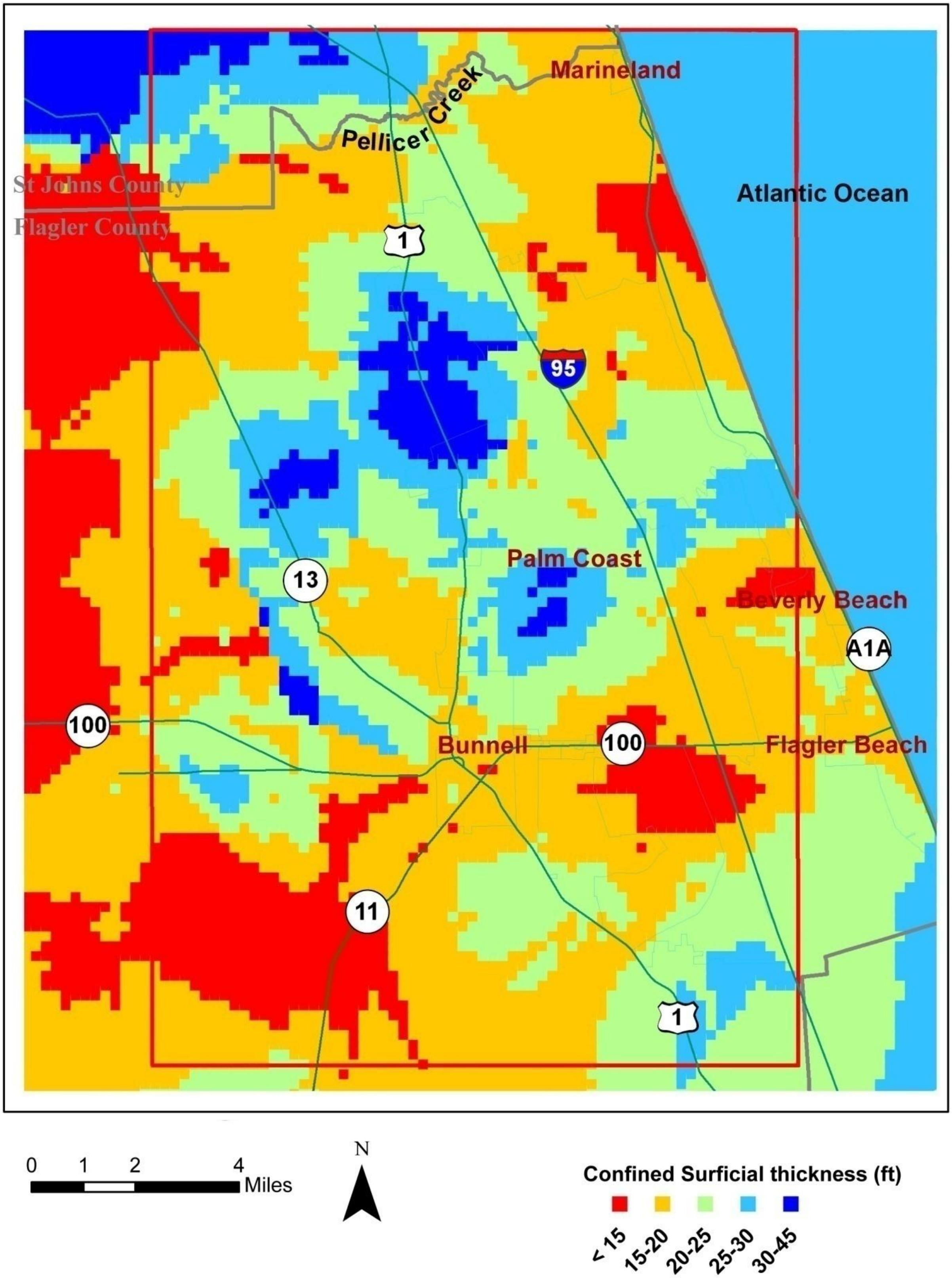


Figure 17 Thickness of Confined Surficial aquifer

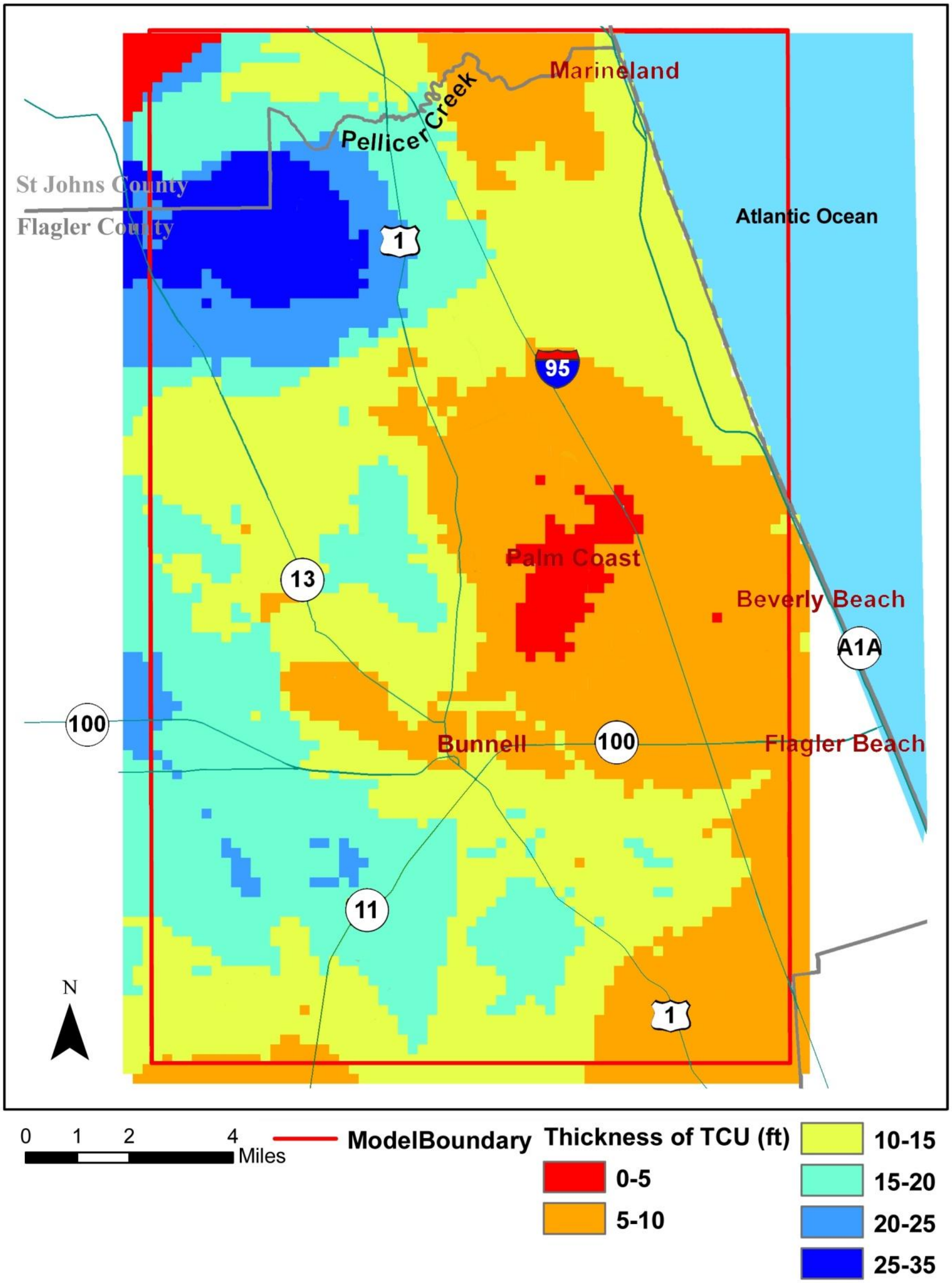


Figure 18 Total thickness of Top Confining Unit

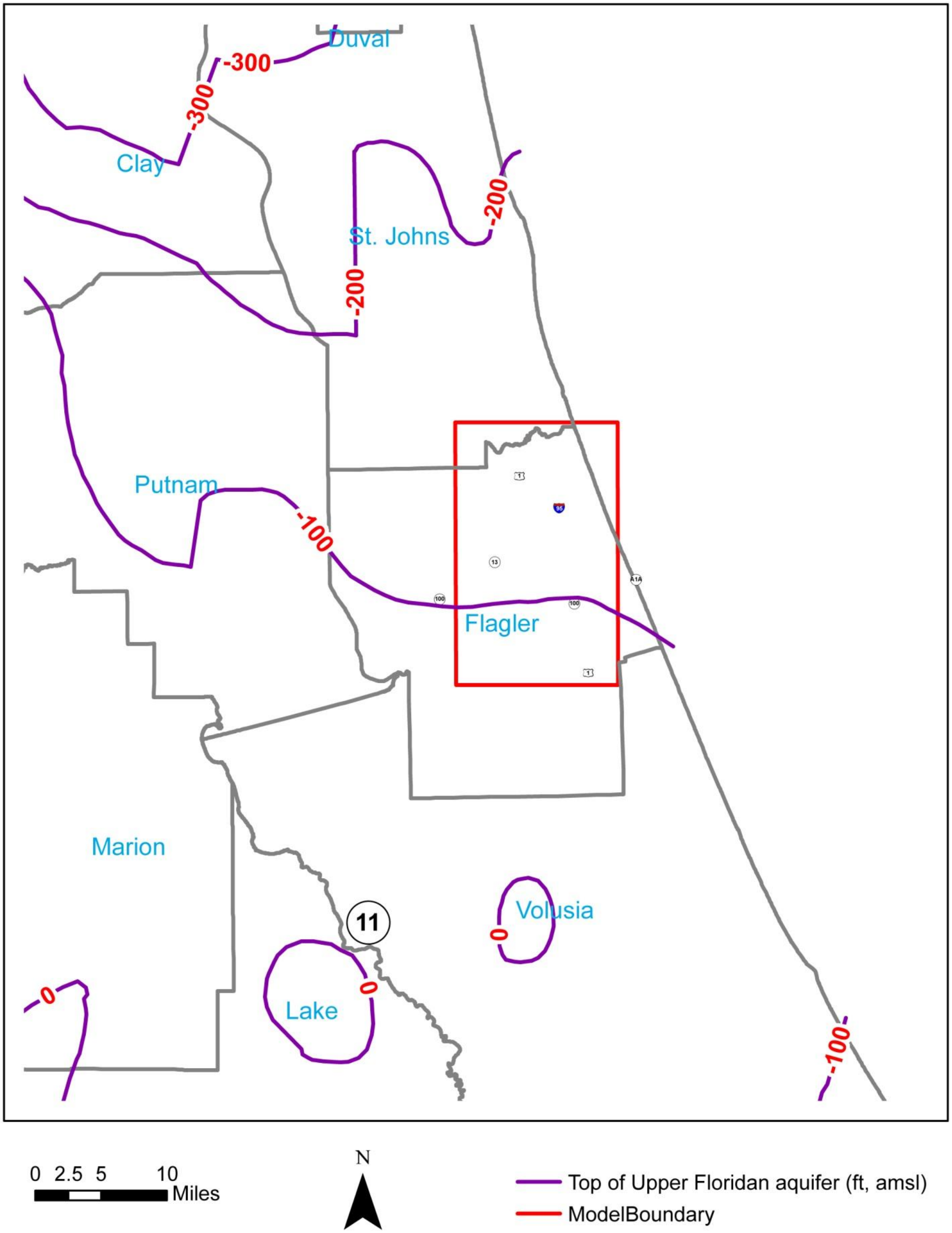


Figure 19 Elevation to top of Upper Floridan aquifer

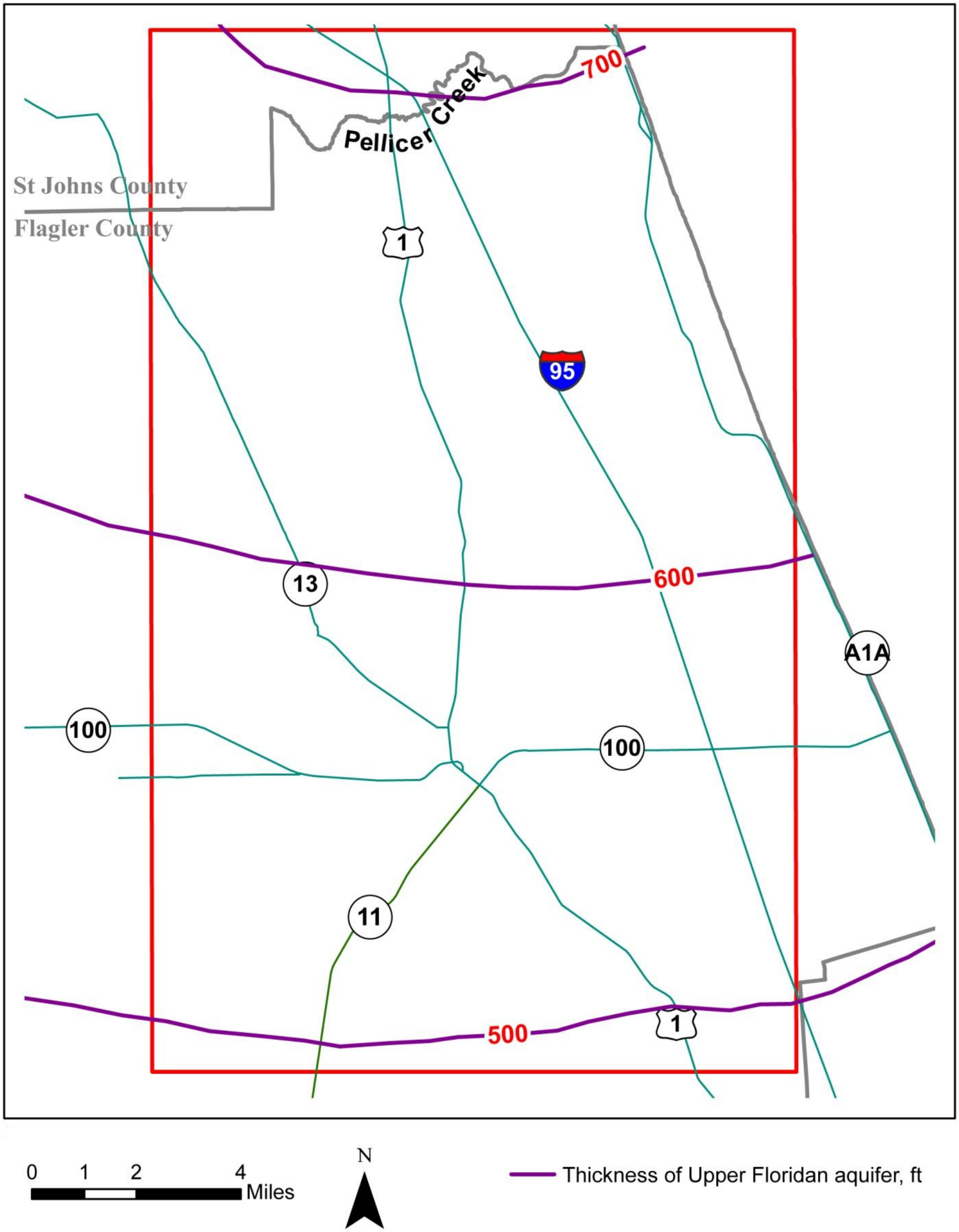


Figure 20 Thickness of Upper Floridan aquifer

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 and lies within the Avon Park Formation. The base of the unit is assumed to coincide with the top of the Lower Floridan aquifer. The geologic units within the Lower Floridan aquifer include the Avon Park Formation, the Oldsmar Formation, and the upper part of the Cedar Keys Formation. The amount of water exchanged between the Lower and Upper Floridan aquifers is relatively minor compared to the amount of lateral flow within the Upper Floridan aquifer.

2.8 Estimation of Effective Thicknesses of Confining Units

The intervals that were used to define the confining units by Toth (2001) were also used in this report to derive an effective confining thickness based on facies (a distinctive geologic unit that formed under certain conditions of sedimentation reflecting a particular process or environment) Davis, 2006). In this study area, the end member facies or variation in the composition of the facies range from clean sand or shell beds, to fine-grained sediments (clay, silt, fine sands) or low permeability carbonates. The effective confining thickness may be the same as, or less than the thickness derived from subtracting the boundary surfaces depending on the thickness of the confining sediment facies at a particular location. For example, if the TCU were comprised of a five-foot layer of impermeable clay, overlain by a five foot layer of permeable shell, which is overlain by a ten foot layer of impermeable clay, then the effective thickness, as it relates to confinement, of the entire section would be fifteen feet.

CH2MHILL (1981) has recognized the importance of natural gamma logs in identifying confining zones in Flagler County. Gamma ray logs are used in oil exploration to estimate shale (clays subjected to low grade alteration by temperature and pressure) content. Low gamma response in this area is typical of clean quartz sands and shell beds with few fines. Higher gamma log response is an indication of higher potassium, uranium or thorium that is a part of, or associated with, clay or other fines that typically exhibit lower vertical hydraulic conductivity. Some clay minerals such as kaolinite or montmorillonite contain less than 1% potassium. However, natural radioactivity may be a result of residual potassium in the pore space (Bateman, 1984). Evaluations of individual natural gamma logs were used herein to derive an effective confining thickness of the confining units. The large number of wells with gamma logs and the supporting lithologic and well construction data provided a reasonable basis for mapping the production intervals and confining facies based on gamma log response. It is recognized that factors such as cementation, phosphate content, grain size, and sorting can affect the relationship between gamma response and degree of confinement. However, field data suggest that gamma ray logs provide a semi-quantitative means of defining the location of confining beds and their properties in Flagler County.

The gamma response in counts per second (cps) within the production zones was used to define facies. A review of logs from wells that were logged and tested (CH2MHILL, 1981) indicate the production zones tended to correlate extremely well with a gamma log response of less than 40 cps whereas the confining units tended to be 40 cps or greater. Since many of the production zones had intervals of less than 25 cps and many of the confining zones had intervals with greater than 60 cps, four facies ranges were used to create a three dimensional (3D) geologic model to define the aerial distribution of effective confining thickness. An example of a typical log with the facies delineations is shown in Figure 21. A geostatistical analysis was conducted using ISATIS software (Bleines et al., 2000) to map the distribution of the four facies. Three dimensional plurigaussian simulations were used to generate a 3D grid representing the facies distribution for the sediment package from the top of the Floridan aquifer to land surface. With this technique the facies distribution between wells was estimated so the effective confining thickness could be determined based on the presence of the two higher cps facies. This modeling approach is commonly used in the oil industry to map traps and pay zones within an oilfield. The procedure uses the cps of normalized gamma logs and converts the cps to a facies code based on the desired cell thickness and the specified ranges. For this report, a 4 foot cell thickness and four ranges of facies codes were used (Facies 1 = 0 – 25 cps, Facies 2 = 26 – 40 cps, Facies 3 = 41 – 60 cps and Facies 4 > 60 cps). Facies 1 and 2 are considered production zones, and Facies 3 and 4 are considered confining zones. The two end members, Facies 1 and 4, represent the most productive and most confining sediments, respectively; Facies 2 and 3 are intermediate productive and confining sediments. To determine effective confining unit thickness for any given interval at a specific point in the resulting grid, the total thickness of the cells belonging to Facies 3 and Facies 4 was calculated. As an example, a location may have a total confining unit thickness of 40 ft. The 3D simulation shows that of those 40 ft, 32 ft are comprised of Facies 3 and 4, and 8 ft are comprised of Facies 1 and 2.

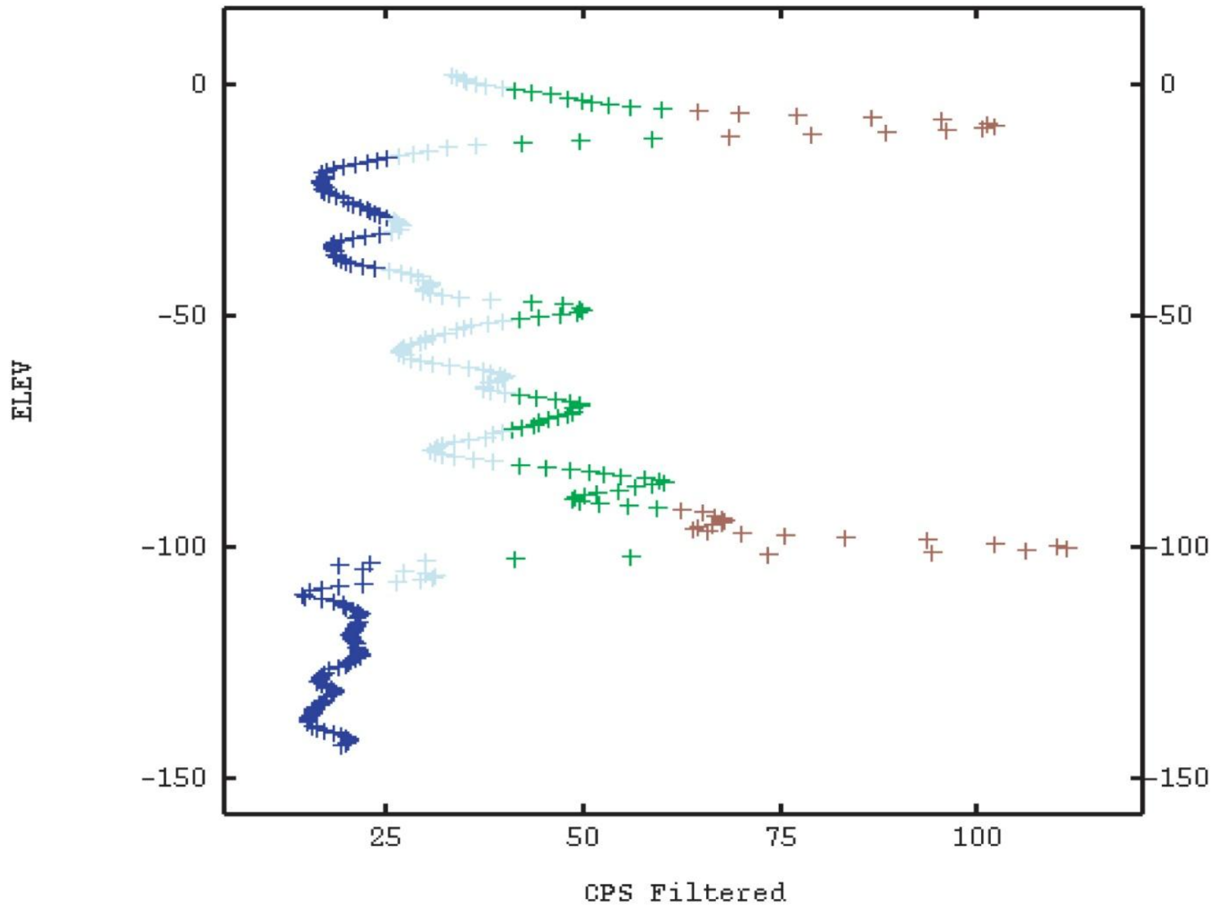


Figure 21 **Facies delineation based on natural gamma log response**

An effective confining unit thickness of 32 ft would therefore be used in the calculations of leakance at a particular location for a specific unit (TCU or ICU). Maps of Effective Thickness of the TCU and the ICU confining units are presented in Figures 22 and 23. The elevation of the top and bottom of the confining units, interpreted from natural gamma logs produced from wells in the Palm Coast area, were provided to the District by Gary E. Eichler of Connect Consulting. These were used for geostatistical analysis (Toth, 2001) and for construction of spatial grids representing the top and bottom surfaces of the confining units. To be consistent with this previous work, the total thickness of the units were derived by subtracting the elevation of the CSA estimated by Toth (2001) from the elevation of the TCU estimated by Toth (2001).

2.9 Aquifer Hydrogeologic Properties

2.9.1 Unconfined Surficial Aquifer

There is no verifiable field data for hydraulic conductivity or transmissivity of the Unconfined Surficial aquifer. Previous modeling studies by Blasland (1992) and Huang (1996) reported an estimated value of 25 ft/day. A seepage study by Blasland (1991) reported an average value of 0.5 ft/day that was the result of slug tests performed on small diameter monitoring wells placed in the upper 10 ft of the saturated zone.

2.9.2 Top Confining Unit

During construction of production and monitoring wells in the Confined Surficial aquifer by PCU, site-specific leakance values were estimated from either pump tests or examination and interpretation of geophysical logs. Characterizing the distribution of leakance for the confining units is critical for groundwater flow modeling efforts. Leakance is defined as the ratio of vertical hydraulic conductivity (Kv) to the thickness of the confining unit. Leakance values for the Top Confining Unit (TCU) in the study area range from 3×10^{-5} (1/day) to 1×10^{-3} (1/day) (Figure 24). However, nearly 49% of the data points lie with the 3×10^{-5} to 4×10^{-5} (1/day) range (Figure 25). Vertical hydraulic conductivity for the Top Confining Unit was estimated from the results of aquifer performance tests (CH2MHill, 1981; CH2MHill, 10/1984; CH2MHill, 12/1984; Blasland, 1990, V1&2; Blasland, 1991) and from the review of geophysical borehole logs of the wells utilized in the test. Based on the leakance values reported and the estimated thickness of the Intermediate Confining Unit at the test sites, the estimated range of Kv varies between 0.001 and 0.1 ft/day (Appendix B).

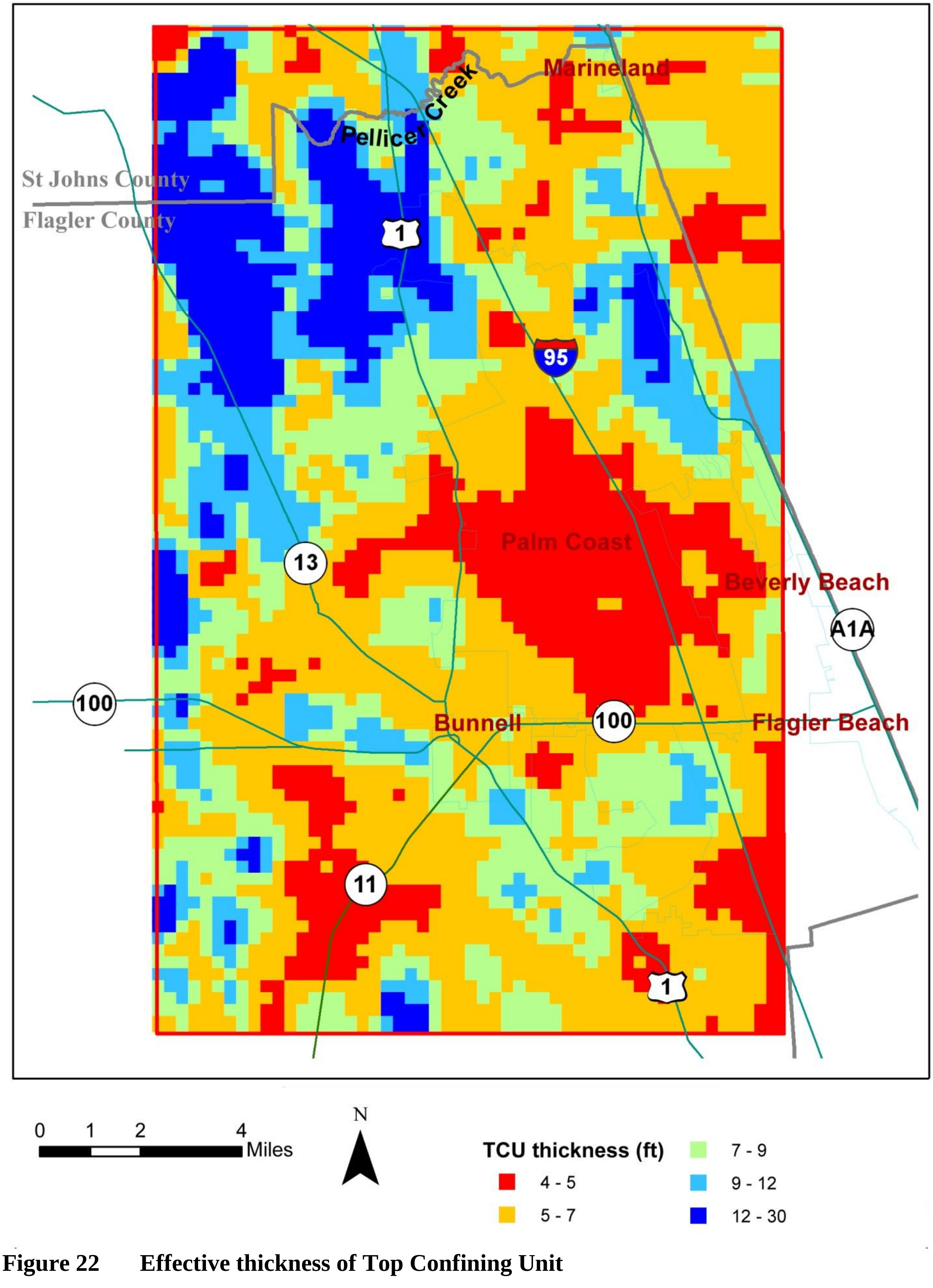


Figure 22 Effective thickness of Top Confining Unit

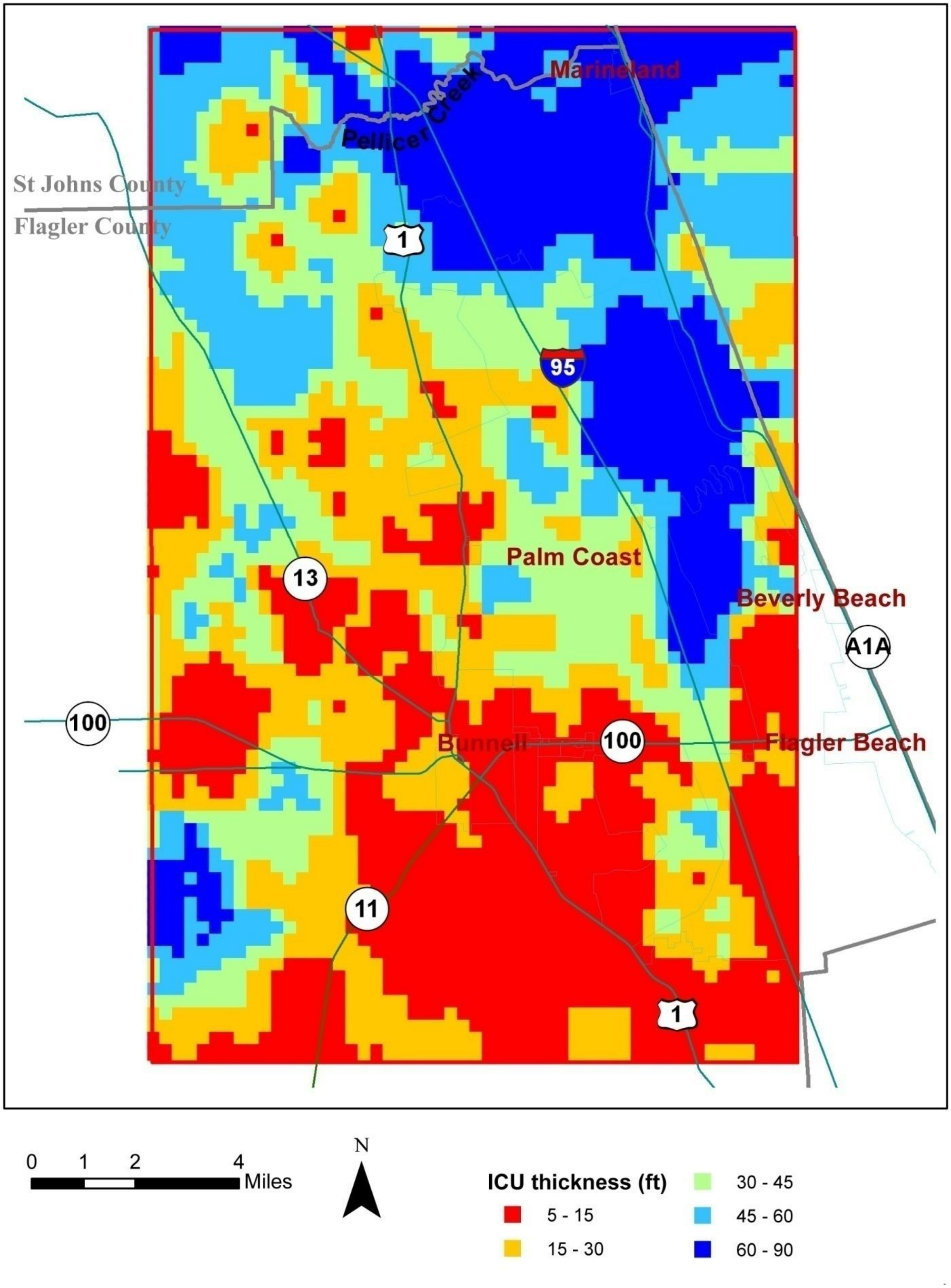


Figure 23 Effective thickness of Intermediate Confining Unit

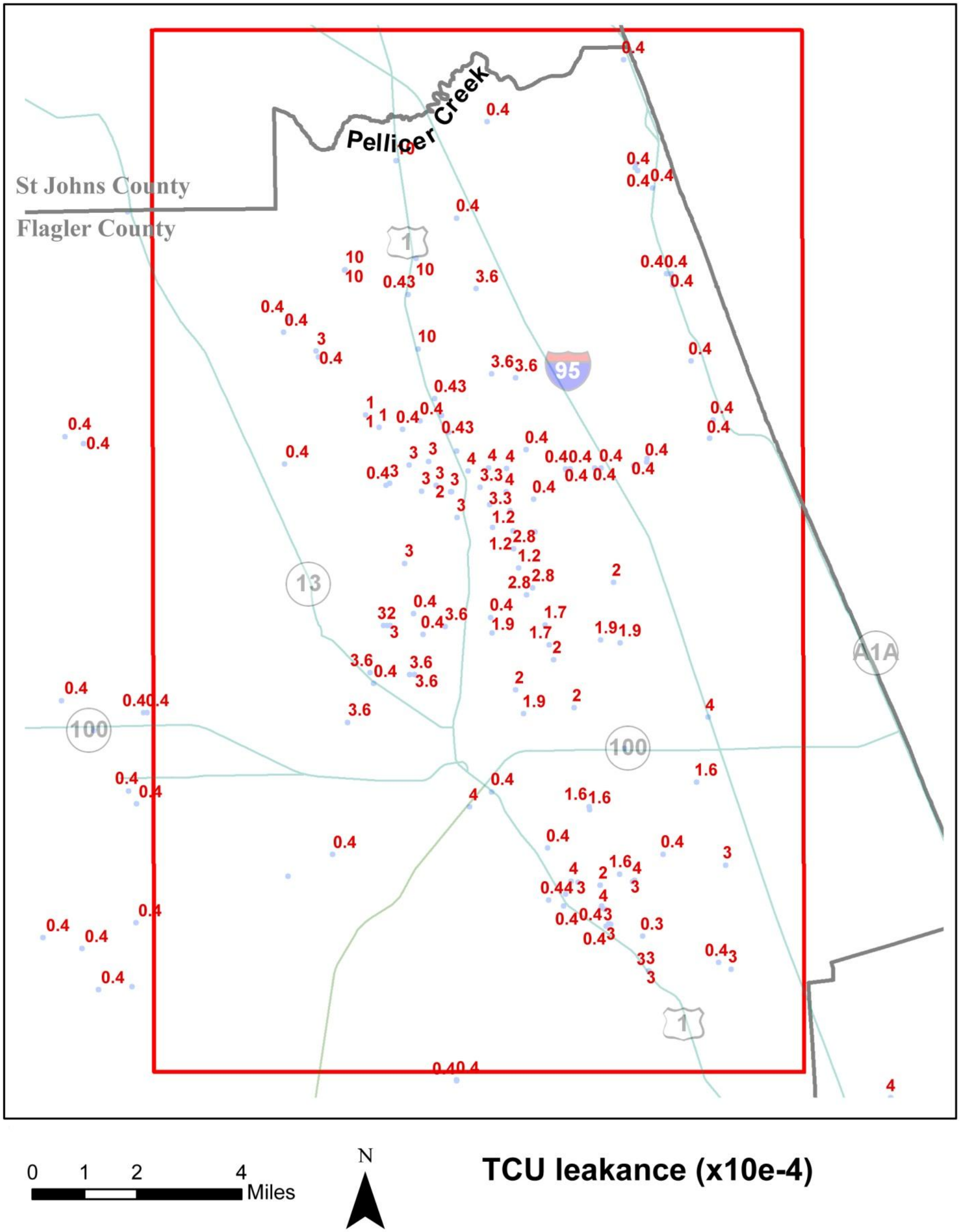


Figure 24 **Field based leakance of Top Confining Unit (x10e-4)**

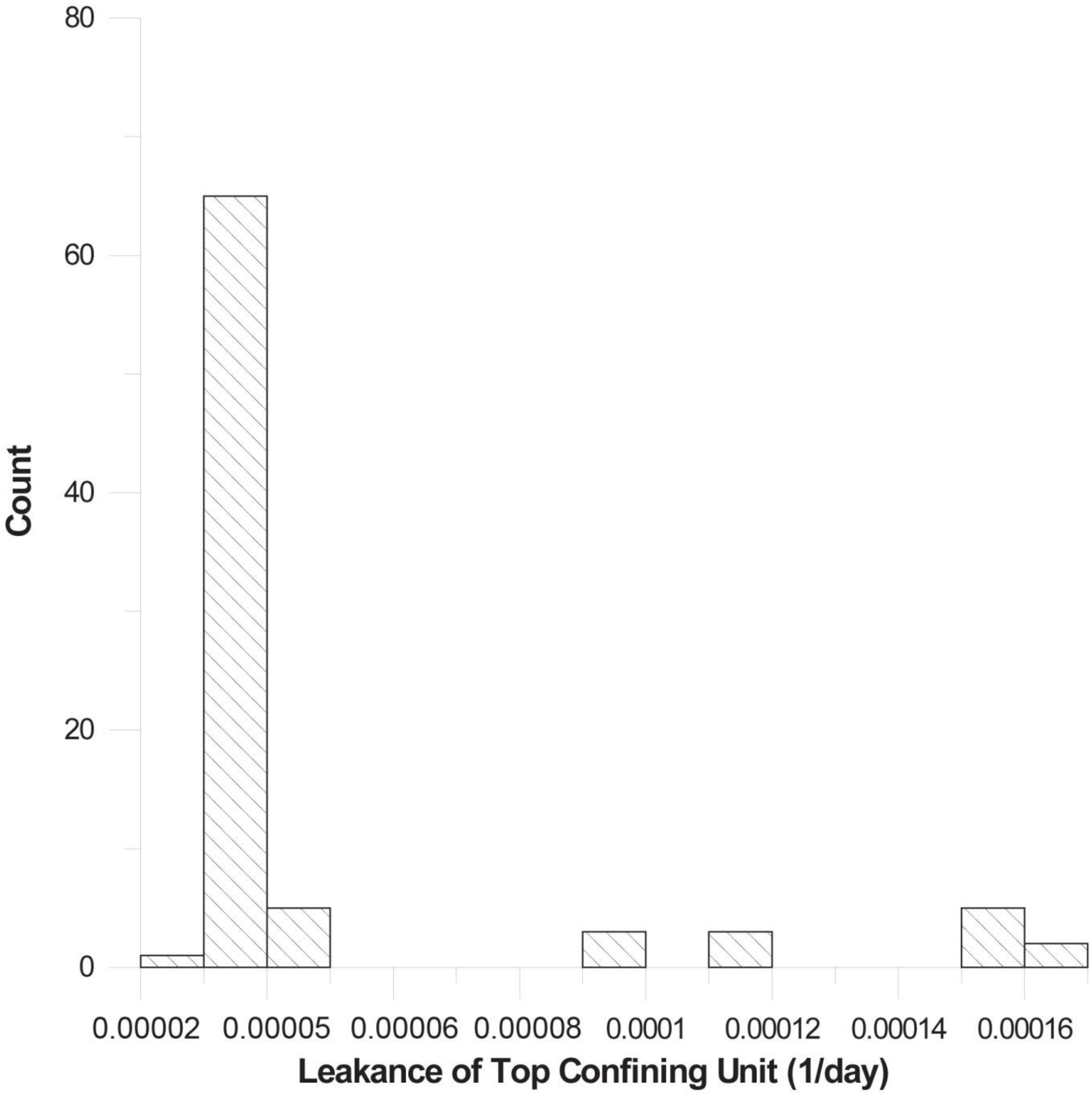


Figure 25 Histogram of field based leakance of Top Confining Unit

This Kv range of 0.001 to 0.01 ft/day was applied to the spatial distribution of the effective thickness for the TCU as presented in this report to map the upper and lower range of leakance (Figures 26 and 27).

2.9.3 Confined Surficial Aquifer

The distribution of hydraulic conductivity of the Confined Surficial aquifer was estimated from 143 data points by Toth (2001) using geostatistics. Hydraulic conductivity was calculated by dividing the transmissivity of the Confined Surficial aquifer by its thickness. Most values for the transmissivity at the data points were estimated from geophysical logs and pump and specific-capacity tests at 52 wells. The minimum and maximum values for the hydraulic conductivity are 6.7 and 404.8 feet per day (ft/day), respectively. The mean and median hydraulic conductivity values are 101.24 and 100 ft/day. The field-estimated transmissivity at the well sites is presented in Figure 28. A histogram of hydraulic conductivity of the Confined Surficial aquifer is presented in Figure 29.

An examination of the data revealed that the field-derived transmissivity is correlated with the diameter of the well. In general, lower transmissivity values are associated with smaller diameter (mostly monitoring) wells as these wells can only pump small quantities of water. Since transmissivity is a scale-dependent property, there is a tendency for low transmissivities to be associated with small diameter wells in the Confined Surficial aquifer. Therefore, transmissivities associated with realistic production rates in production wells are more meaningful and representative for characterizing effective hydraulic properties. Based on these observations, transmissivity in the Confined Surficial aquifer has an average and median value of 2,700 and 2,000 ft^2/day at the production well sites.

2.9.4 Intermediate Confining Unit

Based on a review of geophysical logs obtained from wells utilized for aquifer performance tests (CH2MHill,1981;CH2MHill,10/1984;CH2MHill,12/1984; Blasland,1990,V1&2; Blasland,1991) within the study area , the estimated thickness of the ICU where present ranges between 6 to 87 feet at these specific sites. Given the coefficient of leakance values resulting from the aquifer performance tests and the thickness of the ICU at these sites, the range of Kv can likely vary between 0.001 and 0.1 ft/day (Appendix B).

Using the estimated effective thickness distribution as discussed earlier, the estimated lower and upper bounds of leakance in the ICU is presented in Figures 30 and 31.

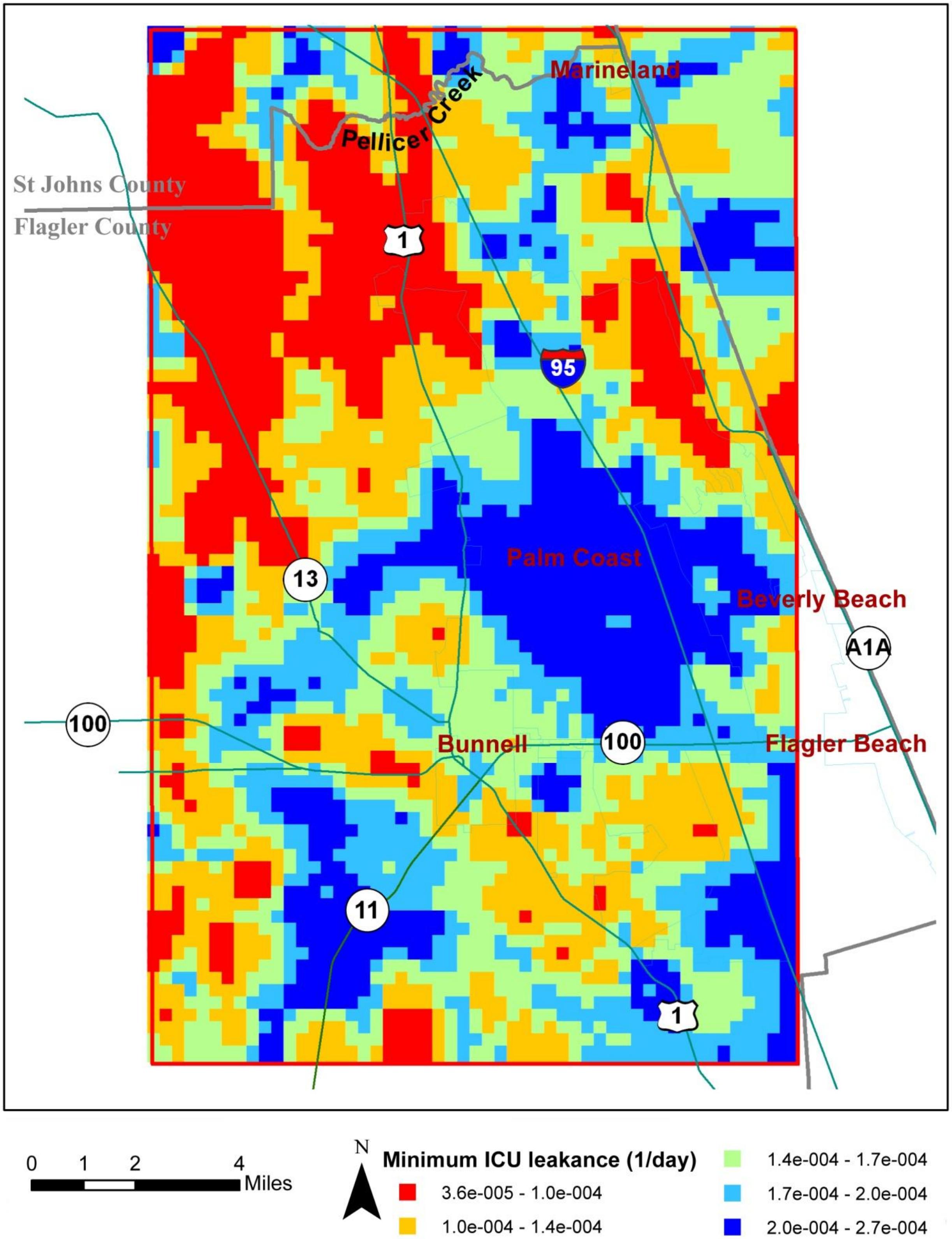


Figure 26 Minimum estimated leakance of Top Confining Unit

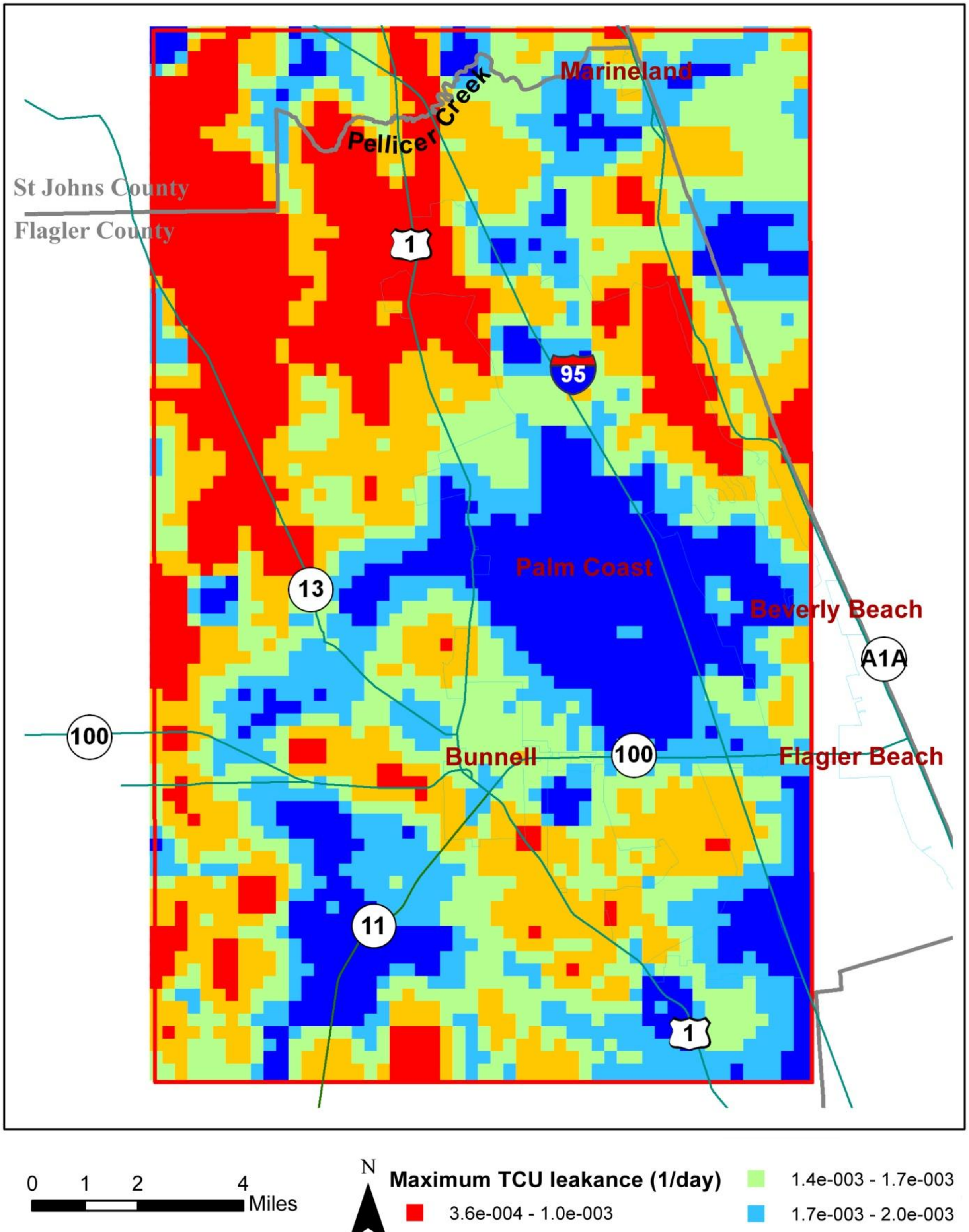


Figure 27 Maximum estimated leakance of Top Confining Unit

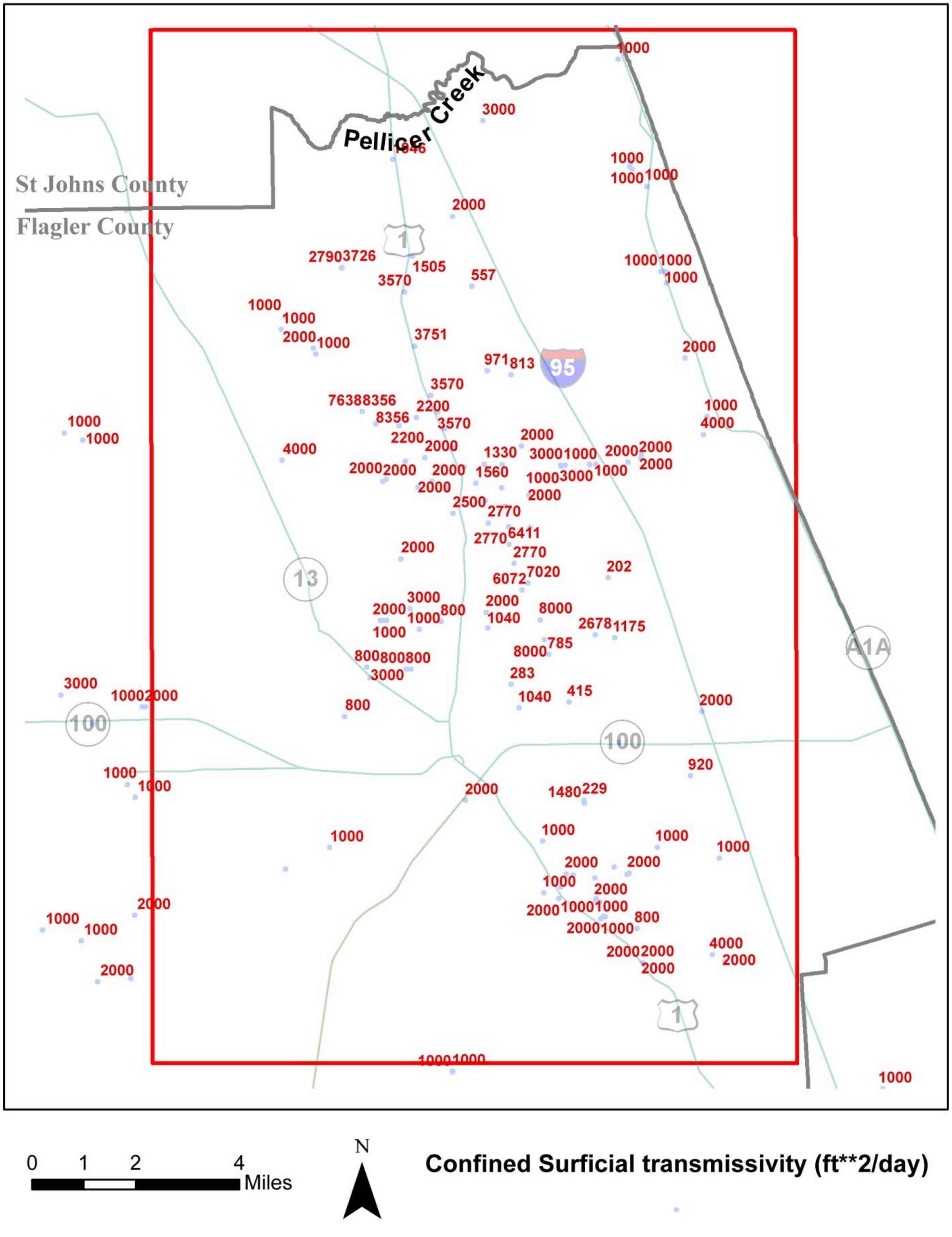


Figure 28 **Field based transmissivity of Confined Surficial aquifer**

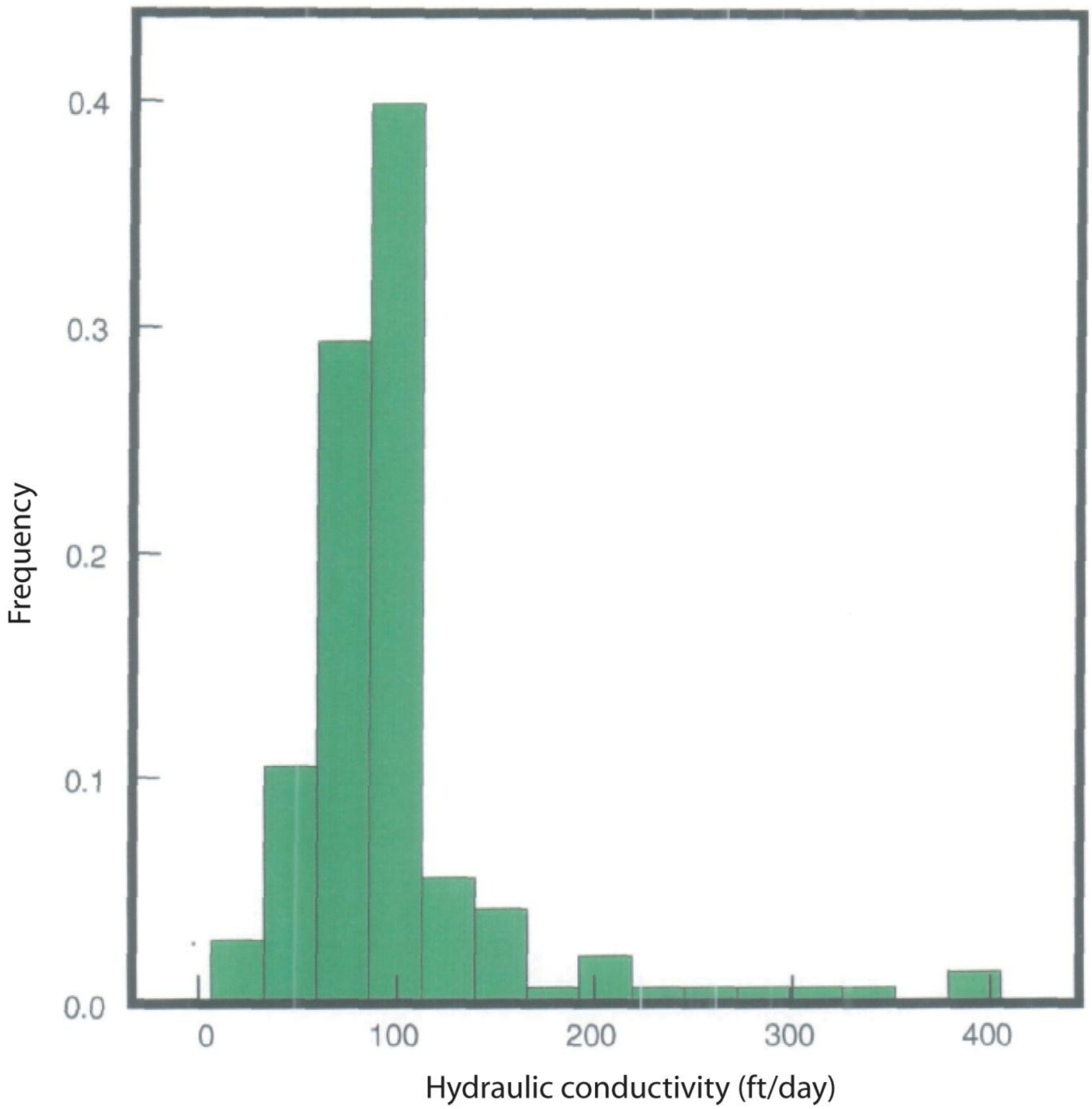


Figure 29 Histogram of hydraulic conductivity of the Confined Surficial aquifer

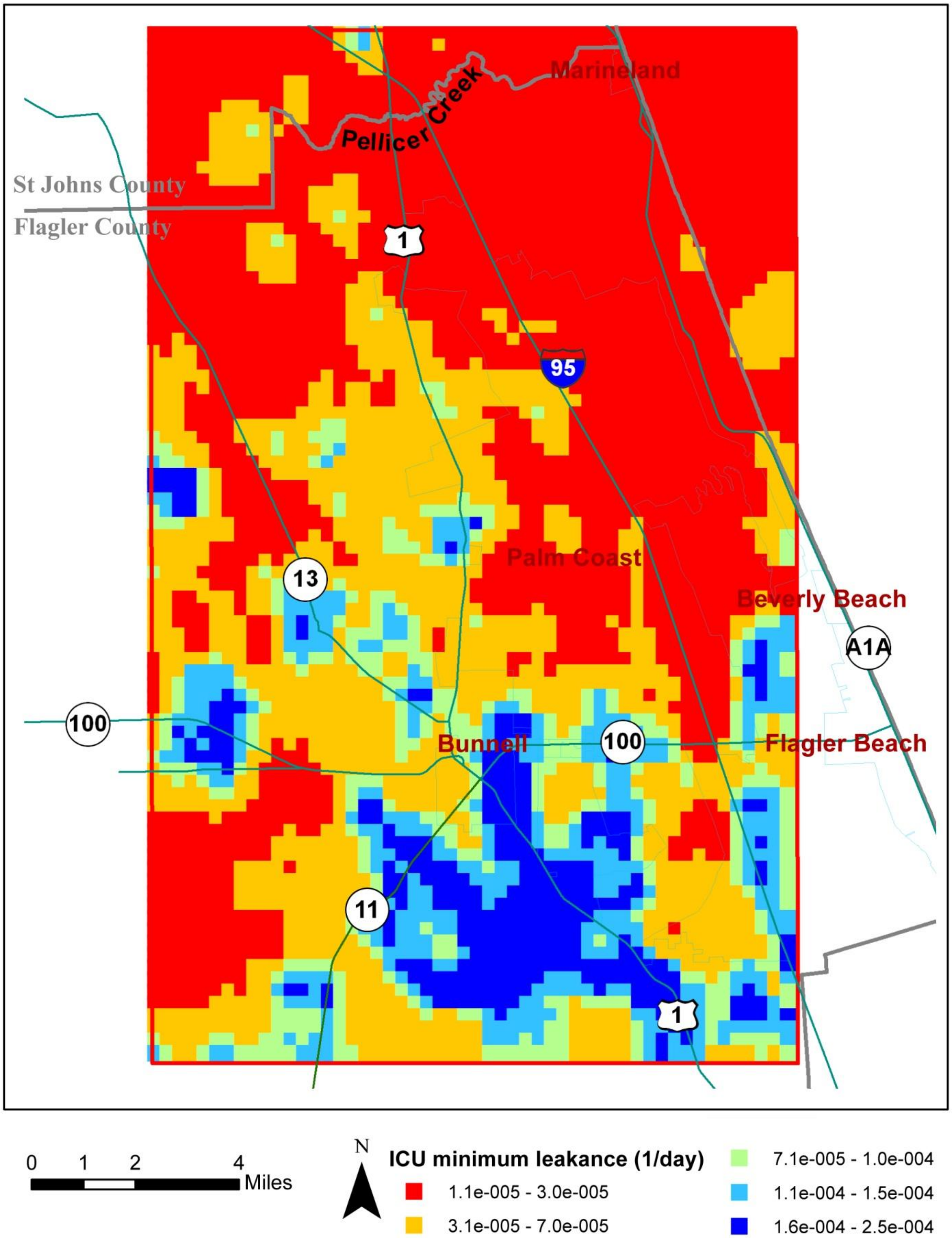


Figure 30 **Minimum estimated leakance of Intermediate Confining Unit**

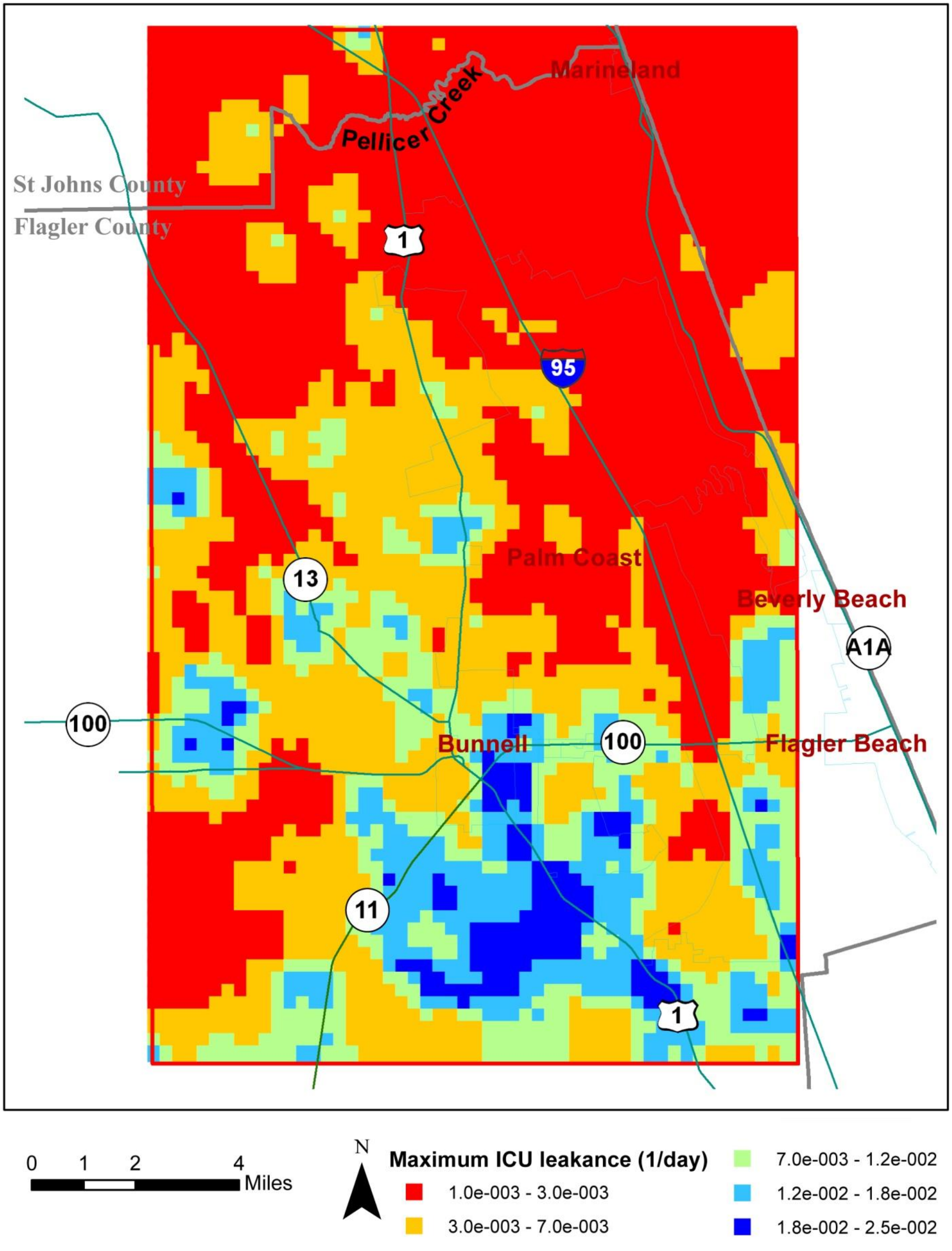


Figure 31 Maximum estimated leakance of Intermediate Confining Unit

2.9.5 Upper Floridan Aquifer

Due to the karstic nature of the dolomite and limestone Floridan aquifer, the transmissivity of the Upper Floridan is quite variable. Values of transmissivity calculated from aquifer performance tests found in the District's database are presented in Figure 32. The values range from 9,000 to 132,000 ft^2/day. The maximum value of 132,000 ft^2/day appears to be an outlier in the observations. Discarding this value, the average and median transmissivity in the aquifer is 22,300 and 20,000 ft^2/day, respectively.

2.10 Water Quality

Water quality in all three aquifers of interest is described in detail by Navoy and Bradner (1987). In general, water quality is poorest in the Upper Floridan aquifer. The chloride distribution in the Upper Floridan aquifer is presented in Figure 33. Chloride concentrations range from 32 to 3700 milligrams/liter (mg/l). High chlorides are generally coincident with the areas of high dissolved solids. Dissolved solids in water samples from wells open to the Upper Floridan aquifer in the study area, range from an estimated 362 mg/l to 6270 mg/l (Navoy and Bradner, 1987). Water quality is poorest in west-central Flagler County in the Haw Creek discharge area. Concentrations are lowest southeast of Bunnell, near Volusia County, where high recharge occurs and where dissolved solids and chloride concentrations are below the drinking water standard of 500 and 250 mg/l, respectively. The quality of groundwater in the Upper Floridan aquifer deteriorates toward the coast and with depth within the aquifer.

Navoy and Bradner (1987) also presented the spatial distribution of chlorides in the Confined Surficial aquifer (Figure 34). Groundwater in the aquifer is generally of acceptable and much better quality than in the Upper Floridan aquifer. The chloride concentration is higher than the drinking water standard at only one coastal well located south of Flagler Beach.

Water quality in the Unconfined Surficial aquifer as mapped by Navoy and Bradner (1987) is presented in Figure 35. Chloride concentrations in the study area ranged from 17 to 2,400 mg/l and hardness as $CaCO_3$ ranged from 54 to 1,300 mg/l. Most chloride, hardness, and dissolved solids concentrations are below the EPA drinking water standards of 250, 250, and 500 mg/l, respectively. In the vicinity of the Palm Coast wellfield, chloride concentrations generally ranged from 17 to 50 mg/1, dissolved solids concentrations were below 500 mg/1, and hardness as $CaCO_3$ is less than 300 mg/1.

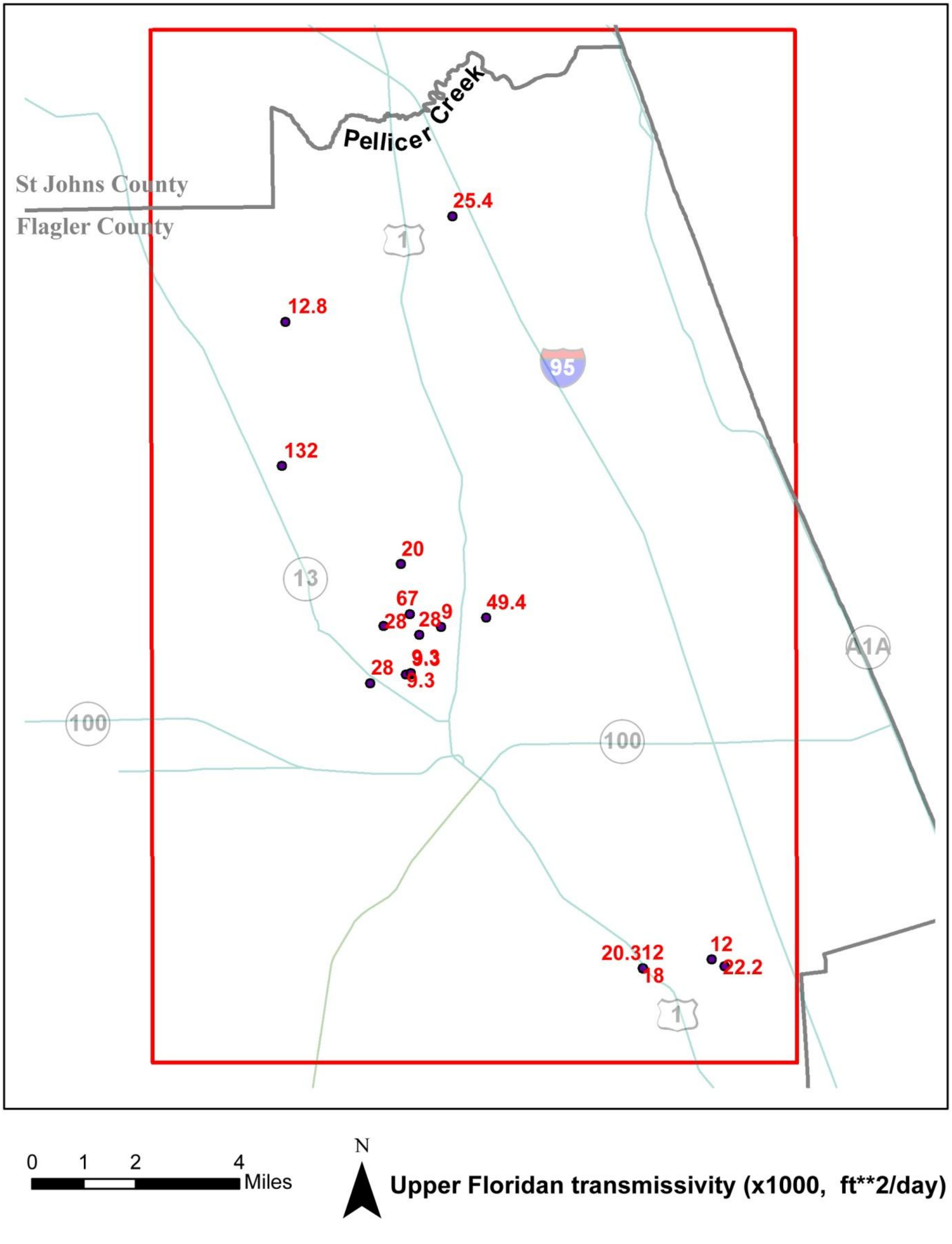


Figure 32 Pump-test based transmissivity of Upper Floridan aquifer (x1000)

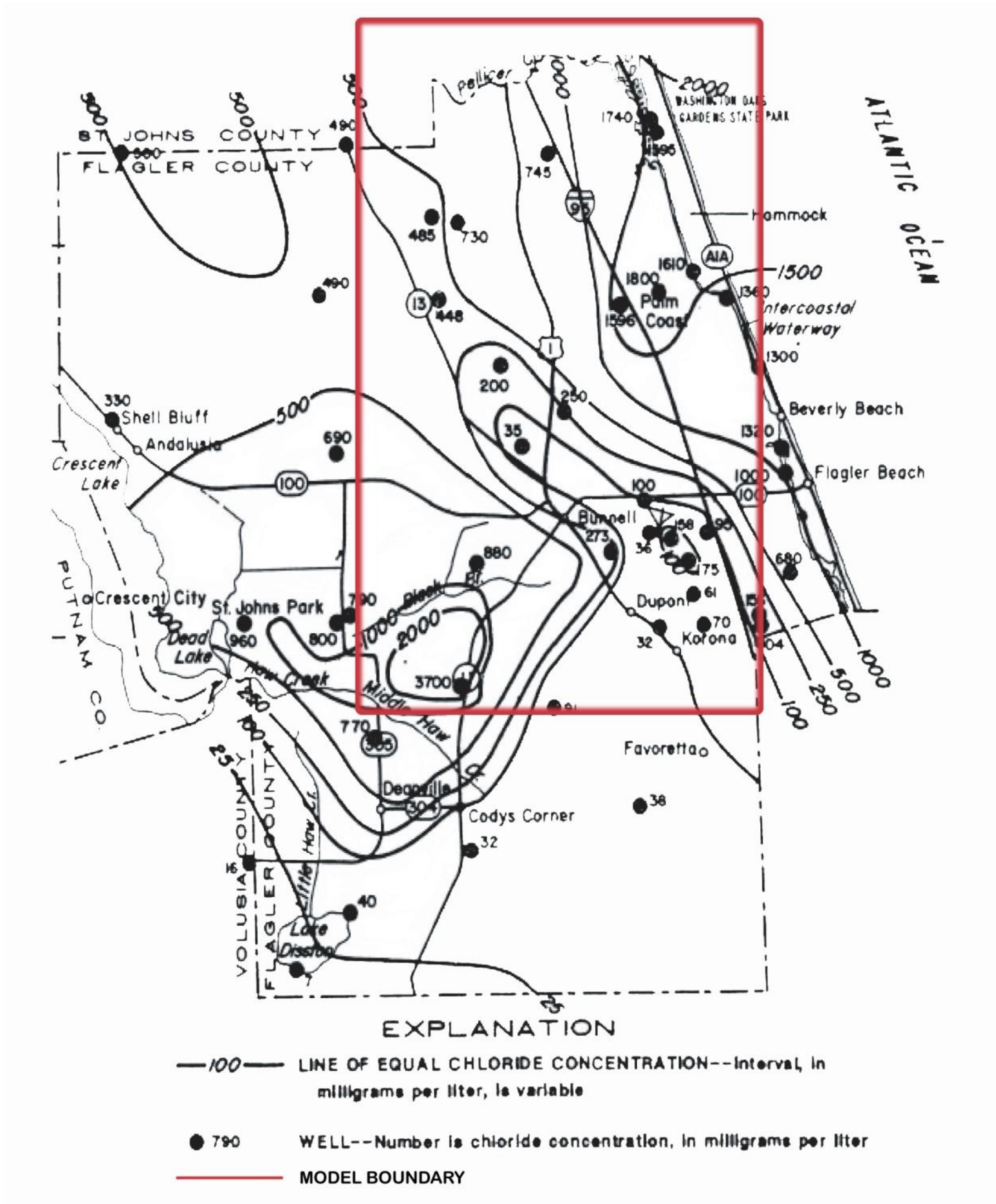


Figure 33 Chloride concentration in the Upper Floridan aquifer

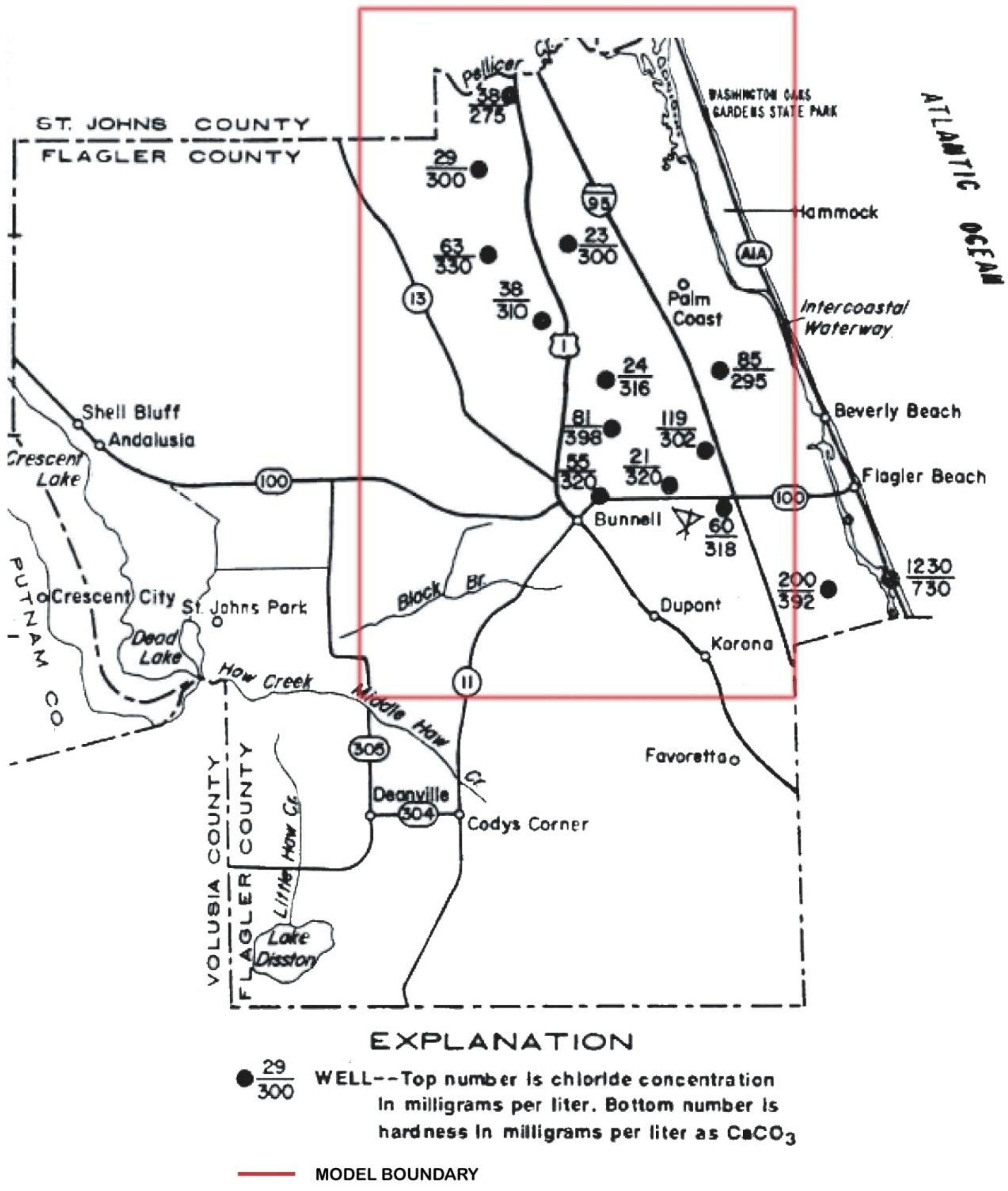


Figure 34 Chloride concentration and hardness in the Confined Surficial aquifer

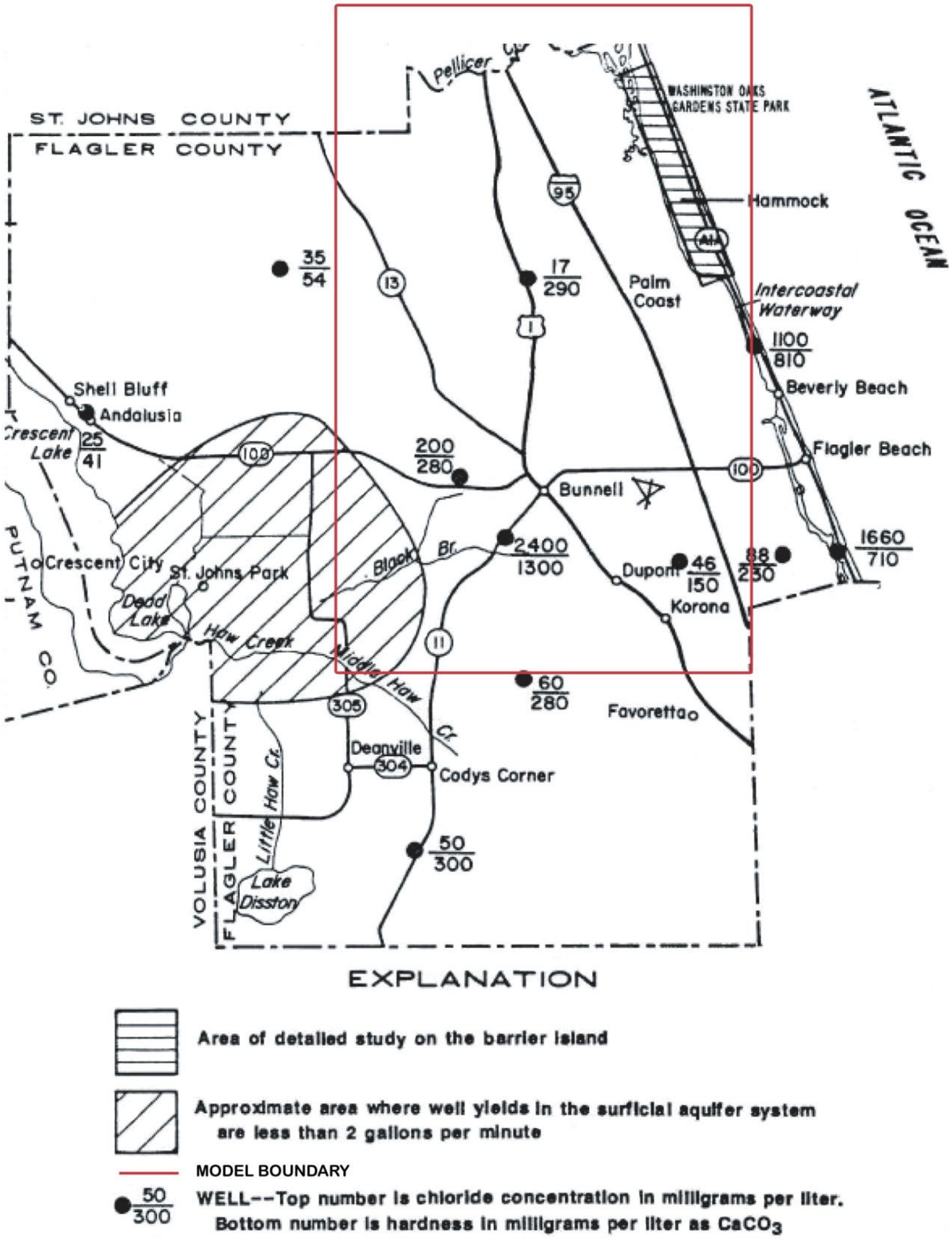


Figure 35 Chloride concentration and hardness in the Unconfined Surficial aquifer

The areal distribution of water quality discussed above is based on data collected in the 1980's. In order to determine potential changes in water quality since publication of the report, the District compiled more recent water quality data from observation wells (David Toth, personal communication). Chloride hydrographs at the Saltwater Intrusion Monitoring Wells (SWIM) and in the Upper Floridan production wells are presented in Figure 36, 37, and 38. In general, water quality has remained relatively stable over the years. The exception is at production well LW-30 that shows an increasing trend in chloride concentration from 2003 to 2004 before stabilizing.

Chloride concentrations from 27 Confined Surficial production wells ranged between 17 and 96 mg/l between January and July 1997. Chlorides in four monitoring wells were as high as 1220 mg/l during this period. Sulfate concentrations were generally below 1 mg/l but were as high as 46 mg/l in production wells. Iron concentrations ranged from 0.01 to 2.48 mg/l and total dissolved solids concentrations varied between 271 and 826 mg/l in the production wells.

2.11 Groundwater Levels

2.11.1 Unconfined Surficial Aquifer

Groundwater levels in the Unconfined Surficial aquifer are measured biannually at several observation wells in the study area. The location of the observation wells is presented in Figure 39, and selected water-level hydrographs in the observation wells are presented in Figure 40. Water-level fluctuations primarily reflect the impacts of rainfall and groundwater withdrawal variations from season to season and year to year. Water levels are highest at the end of the rainy season in September, and the lowest at the end of the dry season in May. In general, water levels are relatively stable, fluctuating less than 2 ft annually and seasonally.

The available water level-data for 1995 (the period of model calibration) are listed in Table 5 for the SW-s and LW-s wells (Appendix C). Seventeen piezometers (Pz/WPZ wells) were installed in 1998 to monitor groundwater levels in the wetlands. Given the lack of historical water level information, average water levels in the 17 Pz wells for 2000-2003 were utilized for model calibration.

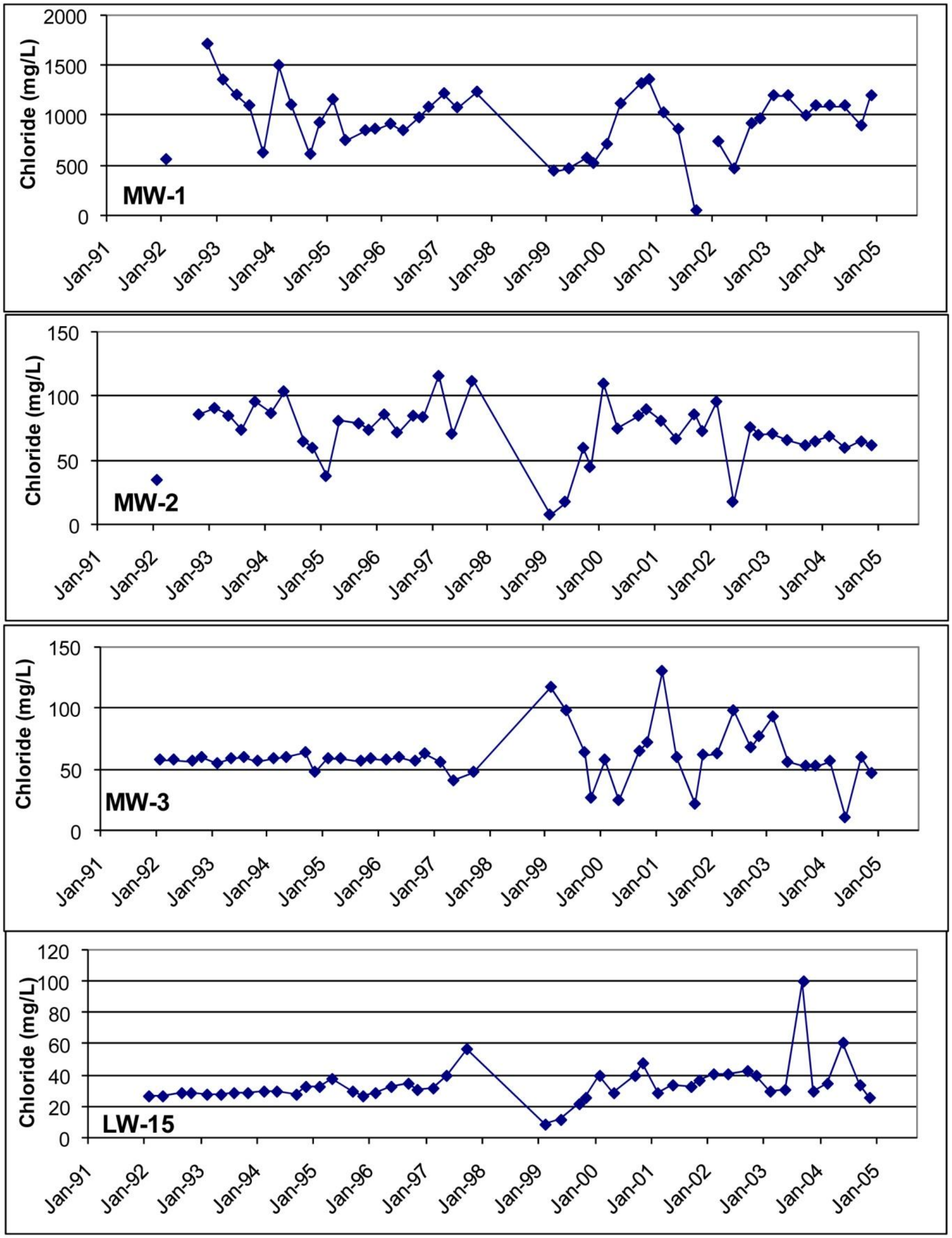


Figure 36 **Chloride concentration at Salt Water Intrusion Monitoring (SWIM) wells MW-1, MW-2, MW-3, LW-15**

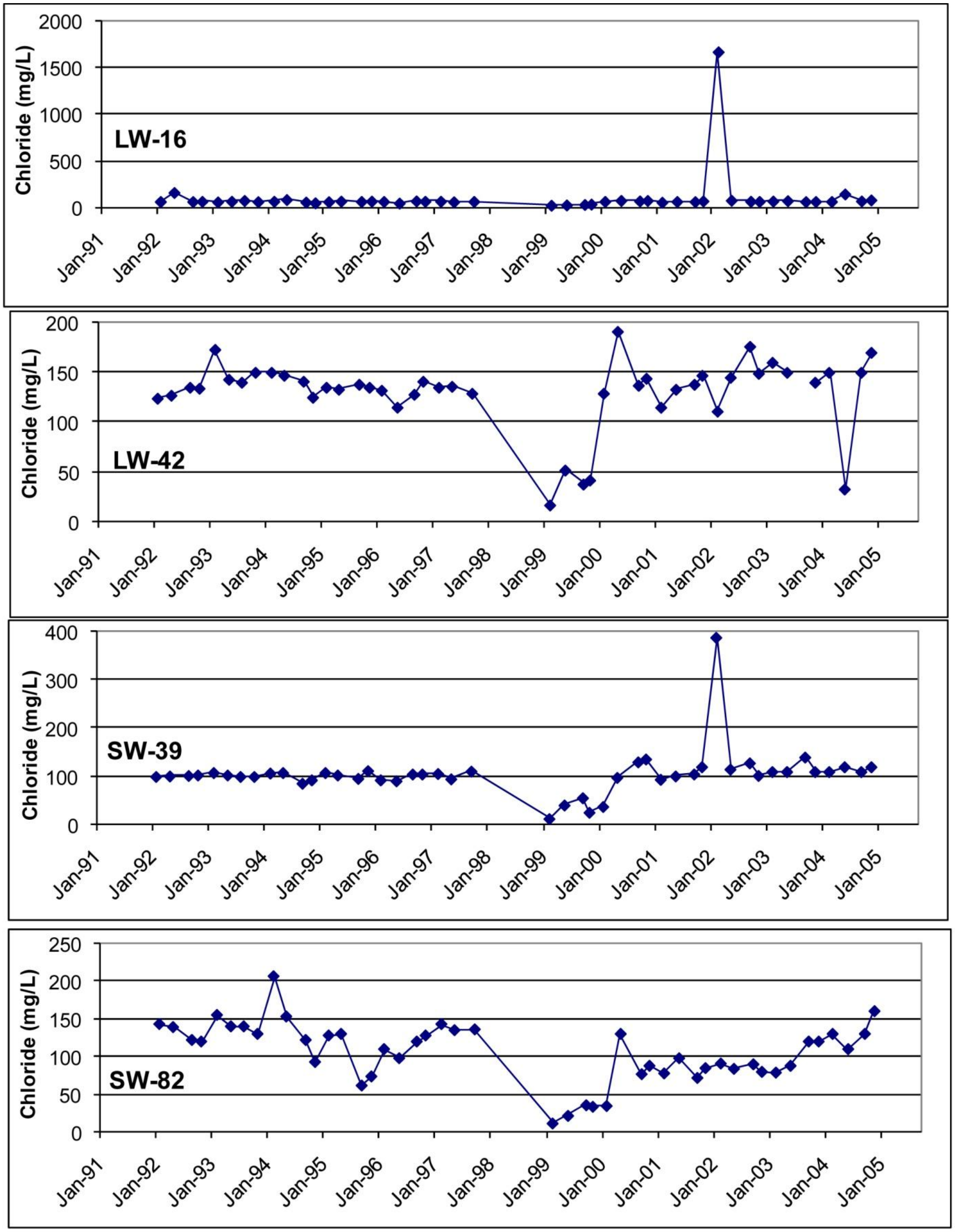


Figure 37 Chloride concentration at Salt Water Intrusion Monitoring (SWIM) wells LW-16, LW-42, SW-39 and SW-82

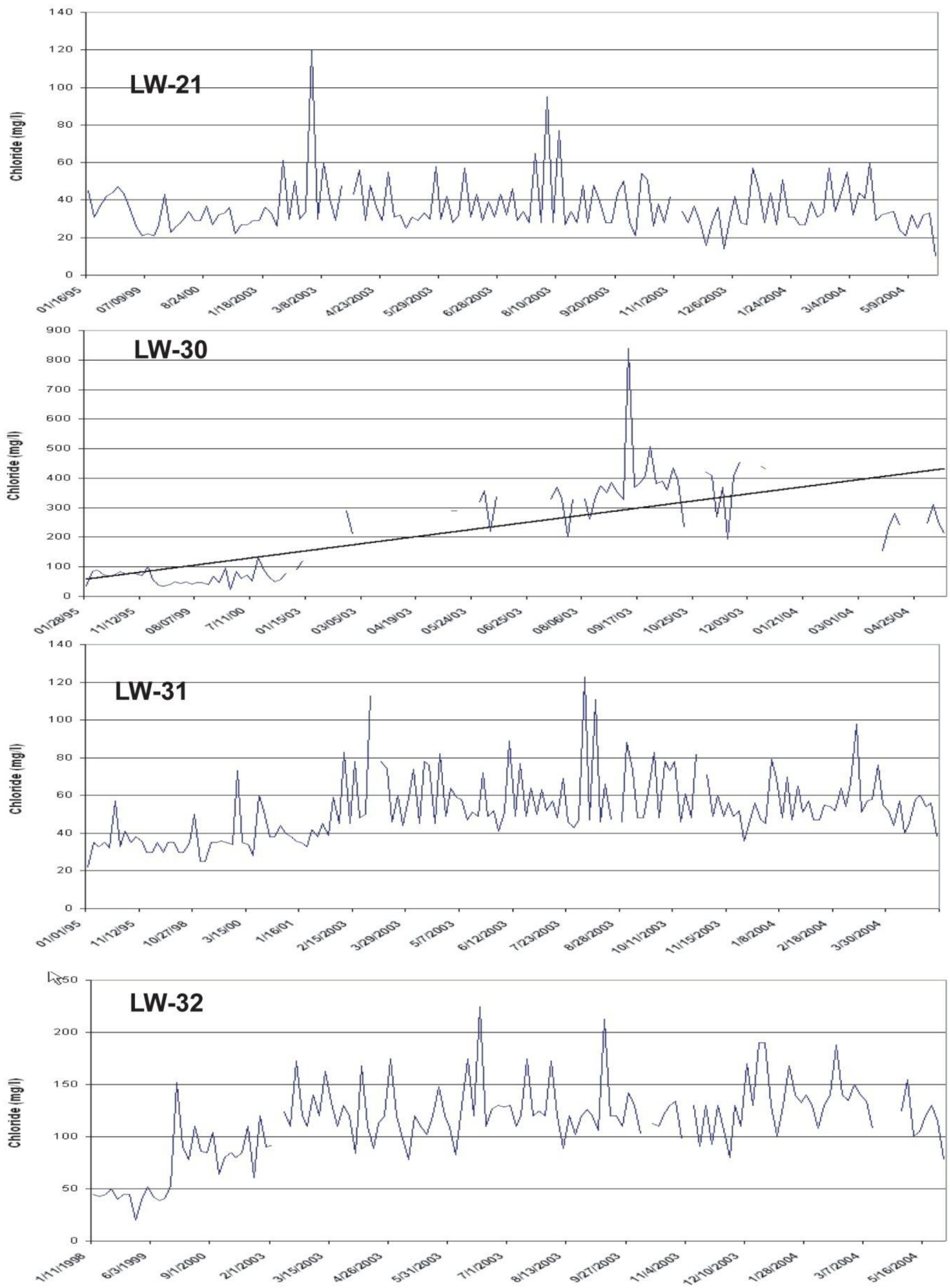


Figure 38 Chloride concentration in Upper Floridan production wells

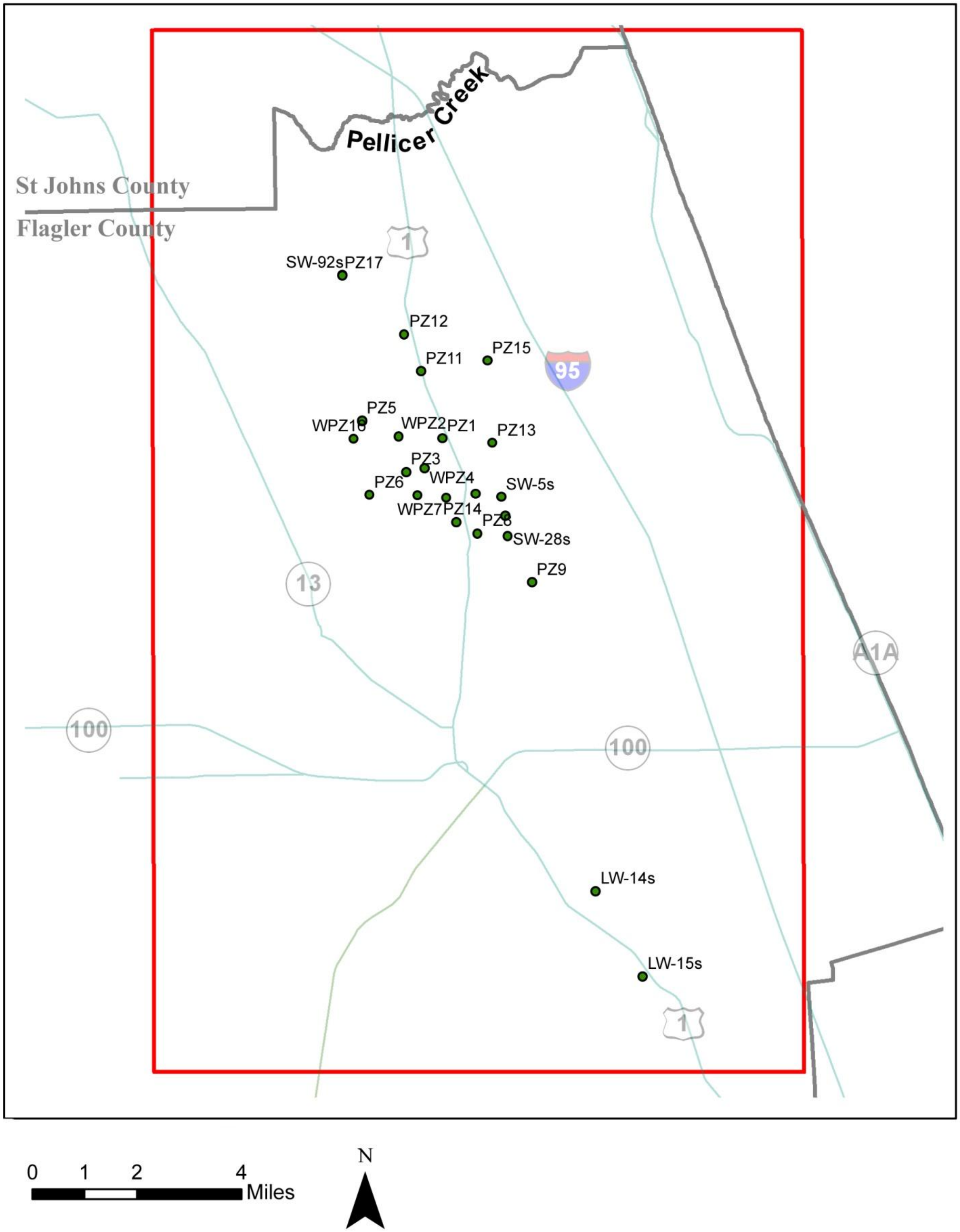


Figure 39 **Location of Unconfined Surficial aquifer monitoring wells**

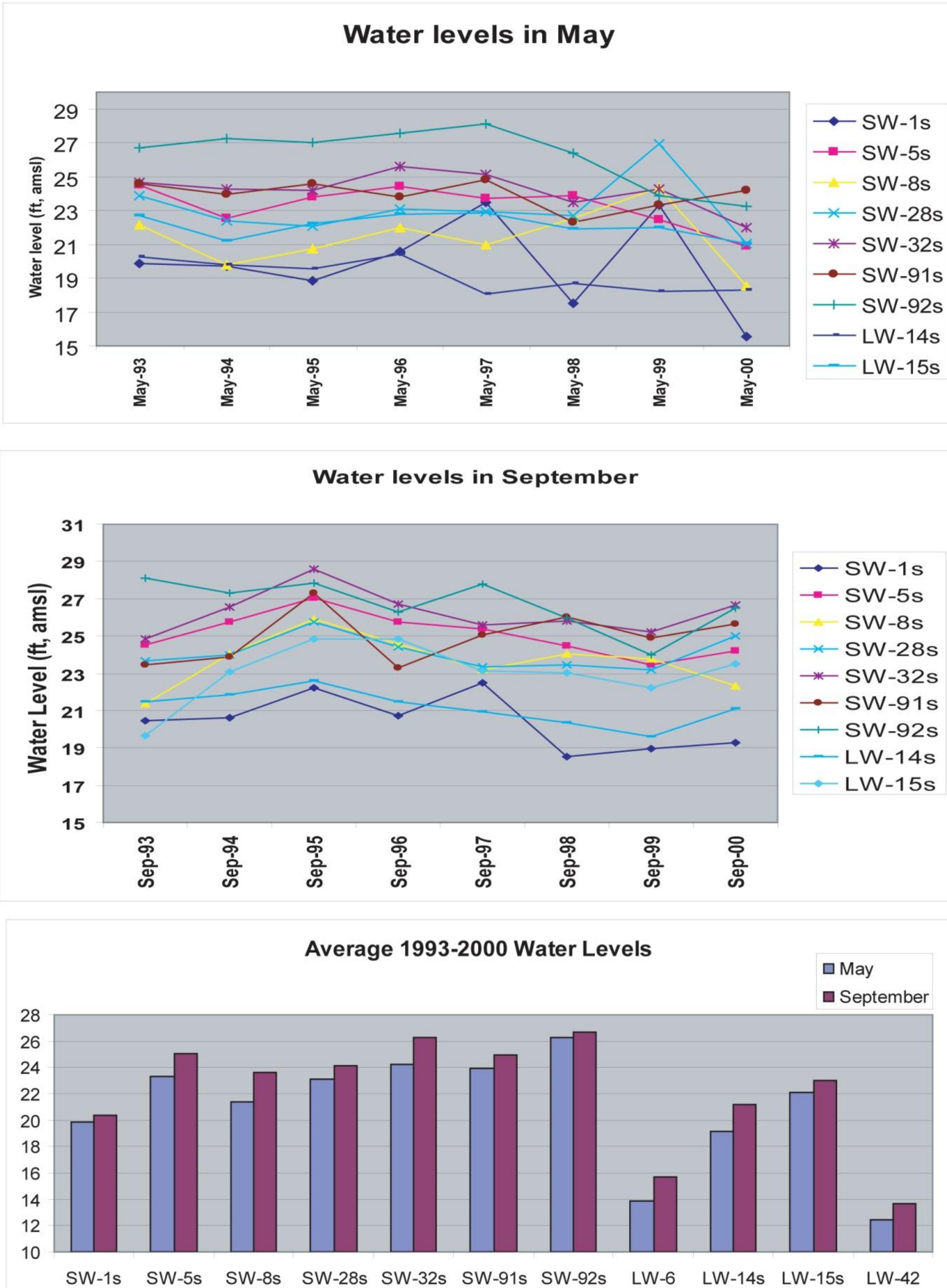


Figure 40 Water levels in Unconfined Surficial aquifer monitoring wells

Table 5 **Average 1995 water levels in Unconfined Surficial aquifer monitoring wells and average 2000-2003 water levels in Pz wells**

Well ID	Observed Water Level (ft, amsl)
SW-1s	20.52
SW-5s	25.41
SW-8s	23.33
SW-28s	23.90
SW-32s	26.41
SW-91s	25.96
SW-92s	27.25
LW-14s	21.08
LW-15s	23.53
PZ 1	31.49
PZ 11	31.22
PZ 12	36.45
PZ 13	25.81
PZ 14	26.30
PZ 15	25.96
PZ 17	26.77
PZ 3	26.06
PZ 5	26.45
PZ 6	28.52
PZ 8	22.73
PZ 9	24.37
WPZ 10	25.06
WPZ 16	29.47
WPZ 2	28.81
WPZ 4	28.74
WPZ 7	26.37

The water table in the Unconfined Surficial aquifer approximates land surface and is variable. Flow in the surficial aquifer is vertically dominant and the head at a particular location does not necessarily have much correlation with head at another observation well further away. Therefore, it is difficult to construct a water table map of this aquifer from the sparse observation well data for 1995.

To construct an approximate water table in the Unconfined Surficial aquifer, Boniol et al. (1993) developed a linear regression model that relates water table elevation to land surface elevation.

The regression model is based on measurements conducted in May 1990 from a multitude of wells. The following relationship was derived from the study:

$$WTE = -1.61 + 0.901*LSE \qquad \text{with } r = 0.90$$

Where:

WTE = the water table elevation in ft (amsl),

LSE = is the land surface elevation in ft (amsl), and

r = is the linear correlation coefficient.

To check the applicability of the above regression in the study area, average 1995 water levels in the Unconfined Surficial aquifer as a function of the land surface elevation are presented in Figure 41. Water levels in the study area, by comparison, are lower than estimates using Boniol's regression equation. This appears to be a consequence of pumpage in the Confined Surficial aquifer in the PCU wellfield.

In order to provide a more representative water table in the study area, the District undertook an initiative to improve the water table and land surface relationship developed by Boniol et al. (1993). The study attempted to estimate the water table elevation by performing a collocated cokriging geostatistical analysis. The strength of the method was in its use of a correlated secondary variable, surface elevation, in the estimation of the primary variable, water table elevation. The analysis was conducted using the ISATIS geostatistical software package (Bleines et al., 2000). The resulting water table surface is presented in Figure 42.

2.11.2 Confined Surficial Aquifer

Water levels in the Confined Surficial aquifer where present are 2 to 9 ft below land surface and generally on average 3.0 ft lower than the water levels in the Unconfined Surficial aquifer (Appendix D). However, in the higher topographic elevations, water level differences could be 8 ft or greater (Appendix D). The Confined Surficial aquifer is monitored primarily in the PCU production wells. The location of these wells is presented in Figure 43. Both pumped and non-pumped water levels are periodically measured in these wells as a condition of the water use permit (Appendix C). The pumped water levels in the production wells are, however, subject to potential well losses. Water-level hydrographs of the Confined Surficial wells are presented in Appendix E. In general, differences between the pumped and non-pumped water levels vary from 10 to 25 ft based on the specific capacity of the well and the pumpage rate.

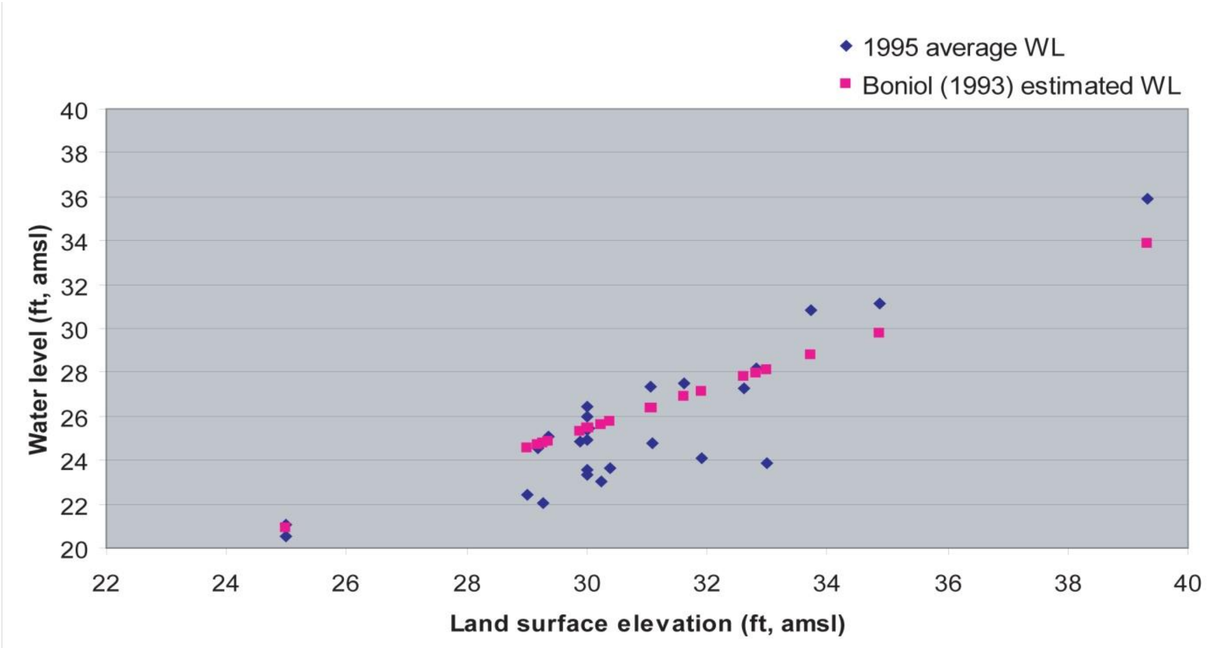


Figure 41 **Relationship between 1995 water levels in Unconfined Surficial aquifer and land surface elevation**

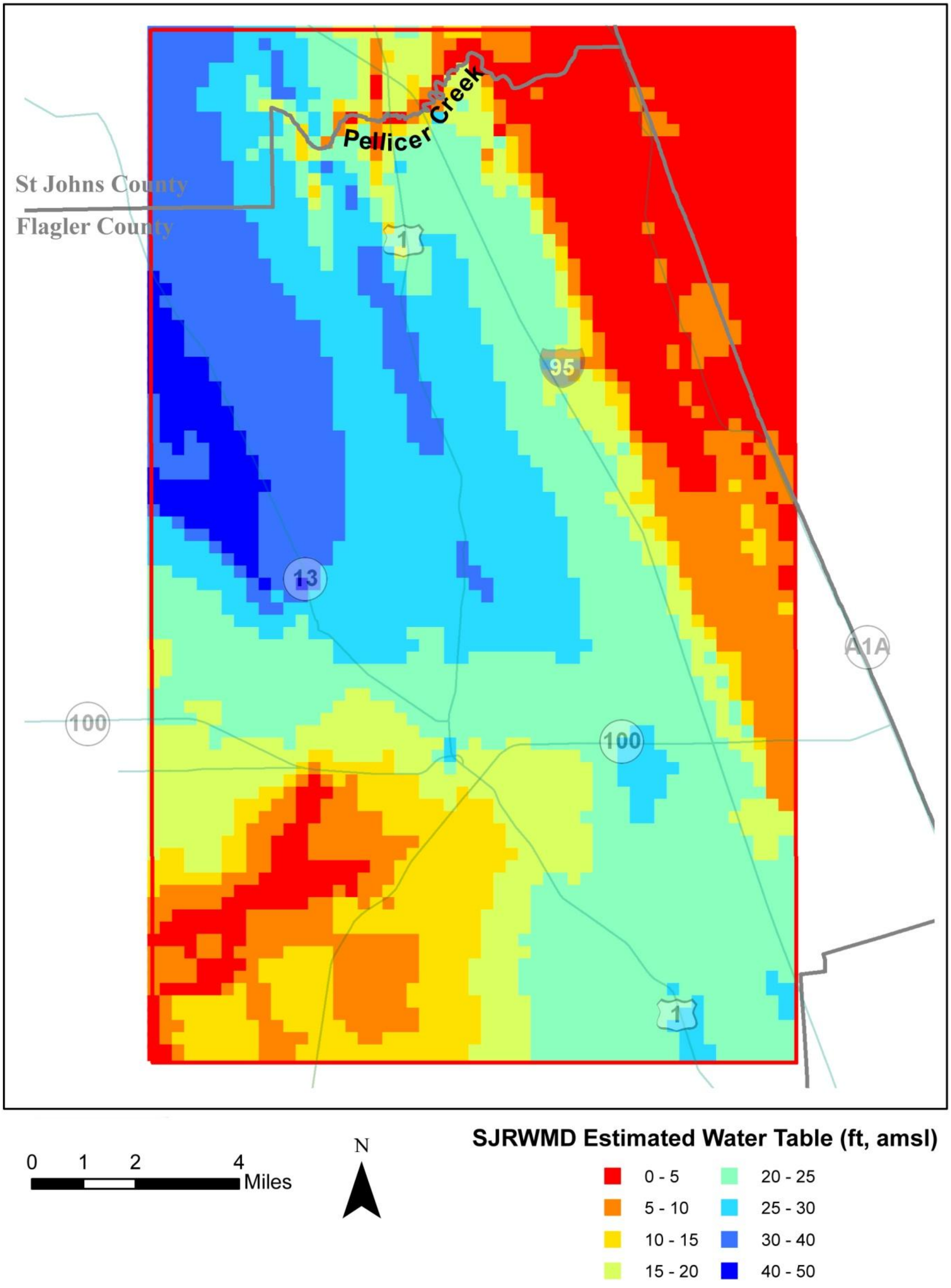


Figure 42 **Estimated water table in Unconfined Surficial aquifer**

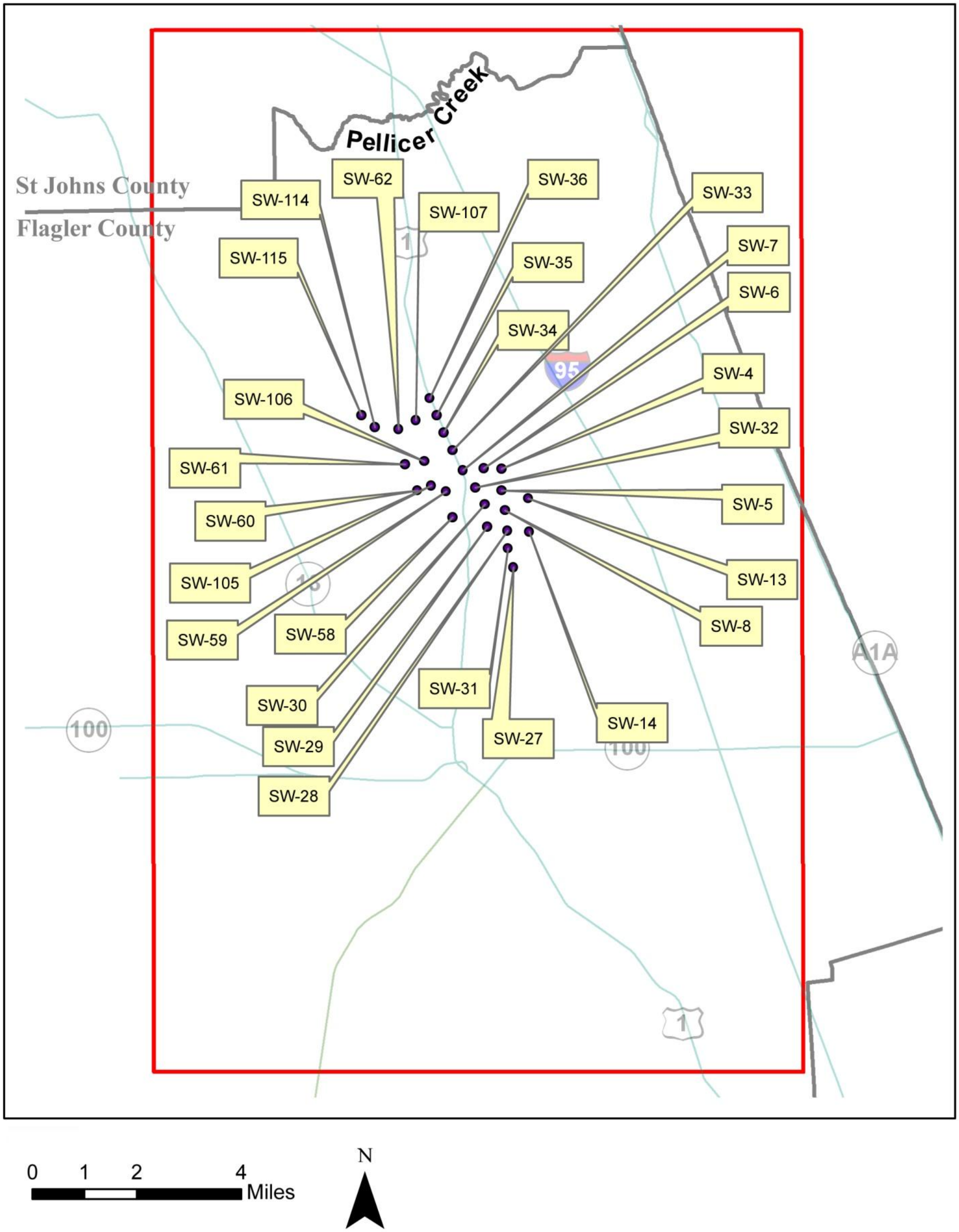


Figure 43 Location of Confined Surficial production wells monitored for water levels

Production wells are not in operation continuously. The total pumpage in each well for 1995 is presented in Table 6 along with the average 1995 well yield in each well. Using this information, the percentage of time that each well was operational in 1995 was calculated. This information was used along with the average static and pumped water-level data to determine the average water level in each well, which is also presented Table 6. The wellfield pumpage and water-level data was provided by James Hogan (City of Palm Coast, personal communication). Upon examination of the United States Geological Survey (USGS) topographic maps, it was determined that the estimates of land surface elevation on the USGS maps at SW-6, SW-7, SW-58, and SW-107 were estimated too high and resulted in reported estimated water levels to be approximately 2, 2, 1, and 2 ft lower respectively, than what likely occurred in the field. The water-level data at the four well sites was adjusted accordingly.

2.11.3 Upper Floridan

The Upper Floridan aquifer is confined throughout the study area. Water levels are measured periodically in more than 10 Upper Floridan observation wells shown in Figure 44. Water levels at 4 selected observation wells are presented in Figure 45. As evident from the figure, water level fluctuations are affected seasonally from influences of groundwater pumping and climate.

In contrast to the Unconfined Surficial and the Confined Surficial aquifers, water-level data at observation wells in the Upper Floridan can be used to construct a potentiometric surface. This is because flow in the Upper Floridan is primarily lateral and, therefore, a spatial relationship exists between water levels at different locations. The potentiometric surface of the Upper Floridan aquifer for May and September are published annually by the USGS. A composite (average) raster grid of the May and September 1995 potentiometric surfaces was generated using a series of GIS software processes. Inputs to the creation of this composite grid were digitized GIS vector data sets from each of the published USGS May and September 1995 potentiometric contour maps of the Upper Floridan aquifer. These vector datasets were converted into corresponding rater grid surfaces. From the two raster grids, a composite average raster grid was calculated using map algebra. Vector surface contours were derived from the average raster grid, representing average 1995 conditions (Figure 46). Also shown in Figure 46 are the groundwater level observation locations within the model domain. This surface was used for qualitative calibration of heads in the Upper Floridan aquifer.

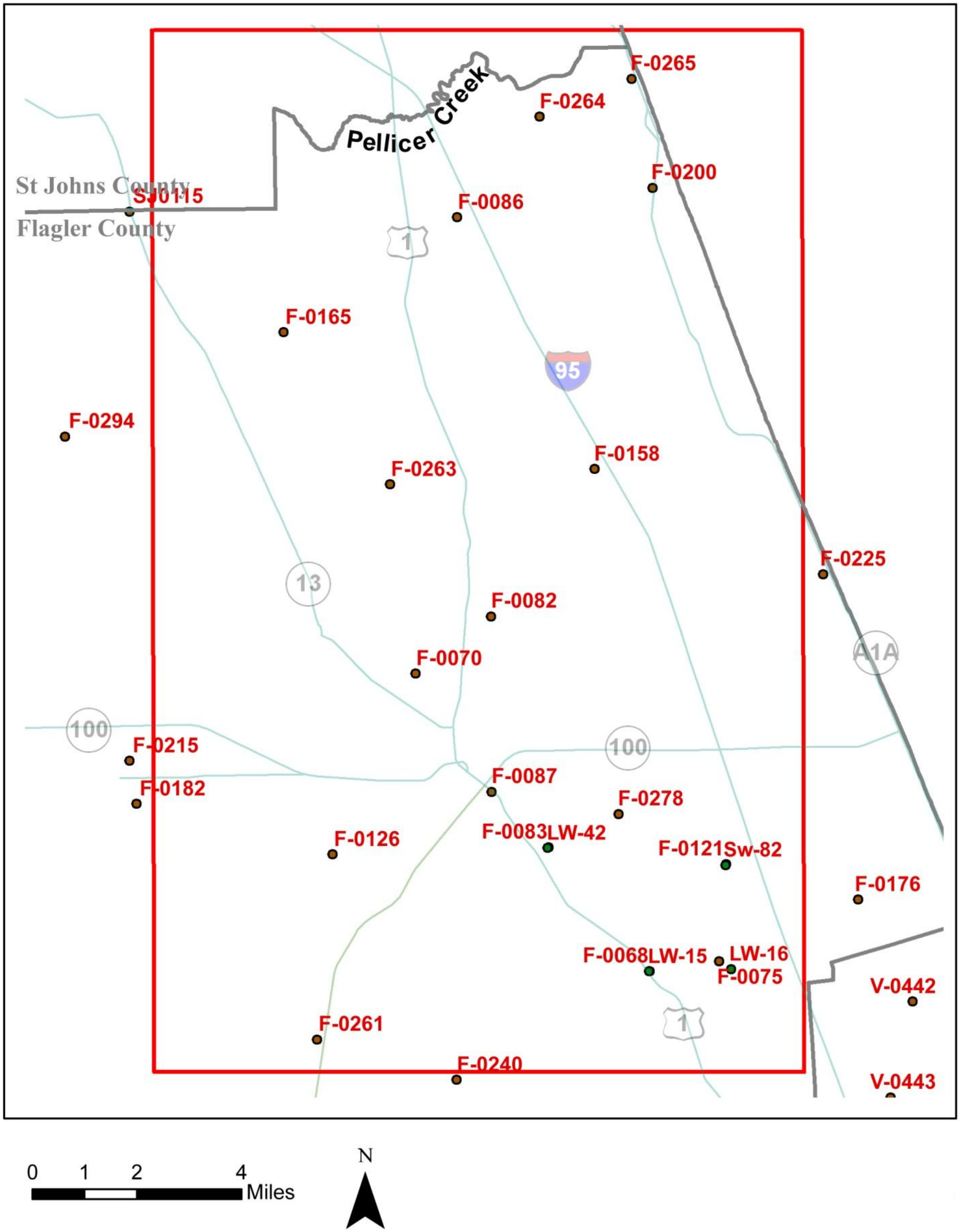


Figure 44 Upper Floridan aquifer monitoring well locations

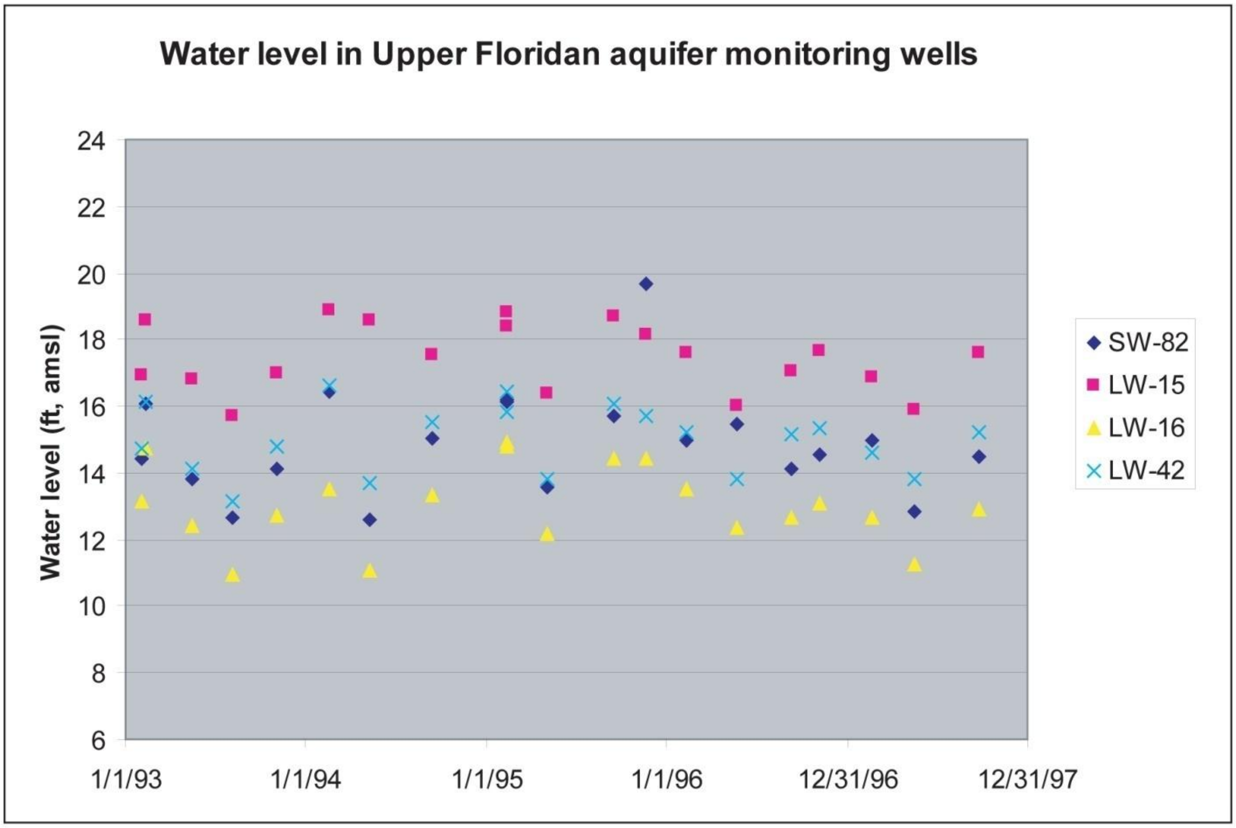


Figure 45 Water levels in Upper Floridan aquifer monitoring wells

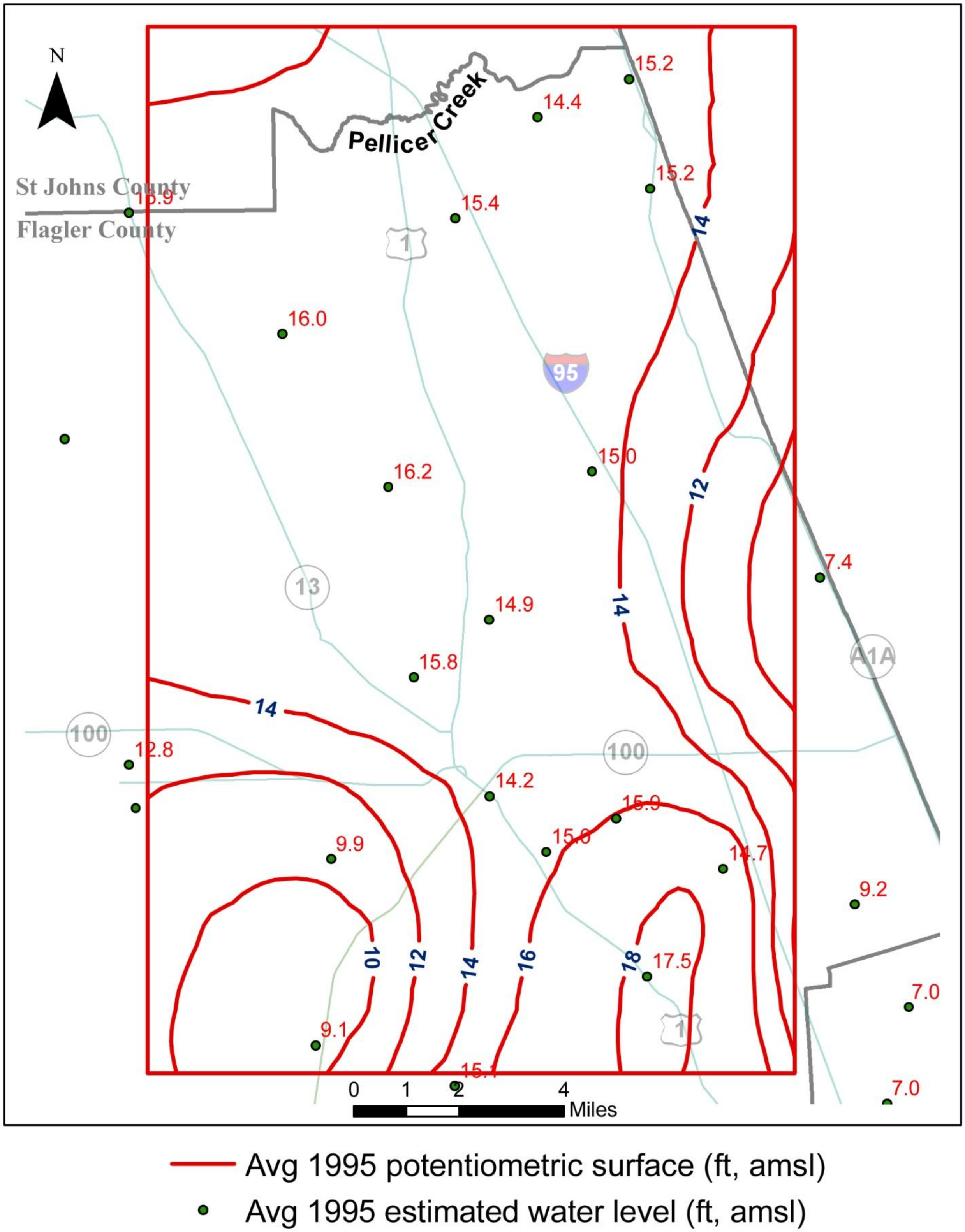


Figure 46 Interpreted average 1995 Upper Floridan aquifer potentiometric surface

Table 6 Average 1995 water level and production rate in Palm Coast Utility wells

Well	1995 Withdrawal (MG)	Average 1995 Well Yield (gpm)	Average 1995 Production Rate (gpm)	Average 1995 Water Level (ft, amsl)
SW-4	10.8	63	20.5	15.2
SW-5	66.5	222	126.5	12.7
SW-6	51.4	152	97.8	15.1
SW-7	10.3	123	19.6	21.0
SW-8	30.2	93	57.5	11.3
SW-13	32.7	109	62.2	11.7
SW-14	30.6	98	58.2	11.3
SW-27	94.2	247	179.2	10.0
SW-28	55.4	156	105.4	9.5
SW-29	34.5	136	65.6	13.8
SW-30	9.3	97	17.7	21.0
SW-31	98.4	281	187.2	12.6
SW-32	11.8	78	22.4	18.6
SW-33	47.9	163	91.2	13.2
SW-34	67.6	238	128.6	14.5
SW-35	37.1	173	70.6	16.1
SW-36	59.0	195	112.2	14.1
SW-58	30.6	228	58.2	19.7
SW-59	5.8	168	11.1	22.4
SW-60	13.3	59	25.3	15.5
SW-61	9.9	58	18.8	20.4
SW-62	22.7	84	43.2	15.2
SW-105	16.6	68	31.6	13.9
SW-106	12.6	53	24.0	14.5
SW-107	8.1	154	15.4	24.2
SW-114	60.3	237	114.7	17.0
SW-115	105.3	335	200.3	17.7

The average 1995 potentiometric surface indicates that groundwater moves from the west towards the coast on the east in the northern portions of the study area. In the south, where the TCU and ICU are more permeable, vertical flow appears to dominate. This results in a discharge area in the Haw Creek basin in the southwest portion of the study area, as evidenced by the depression in the potentiometric surface characterized by the 10 ft amsl contour. Two areas of recharge occur near north-central Flagler County near the St. Johns County line. Such a distribution is also evident from the recharge/discharge map for the Upper Floridan aquifer constructed by Boniol (1993) and presented in Figure 47.

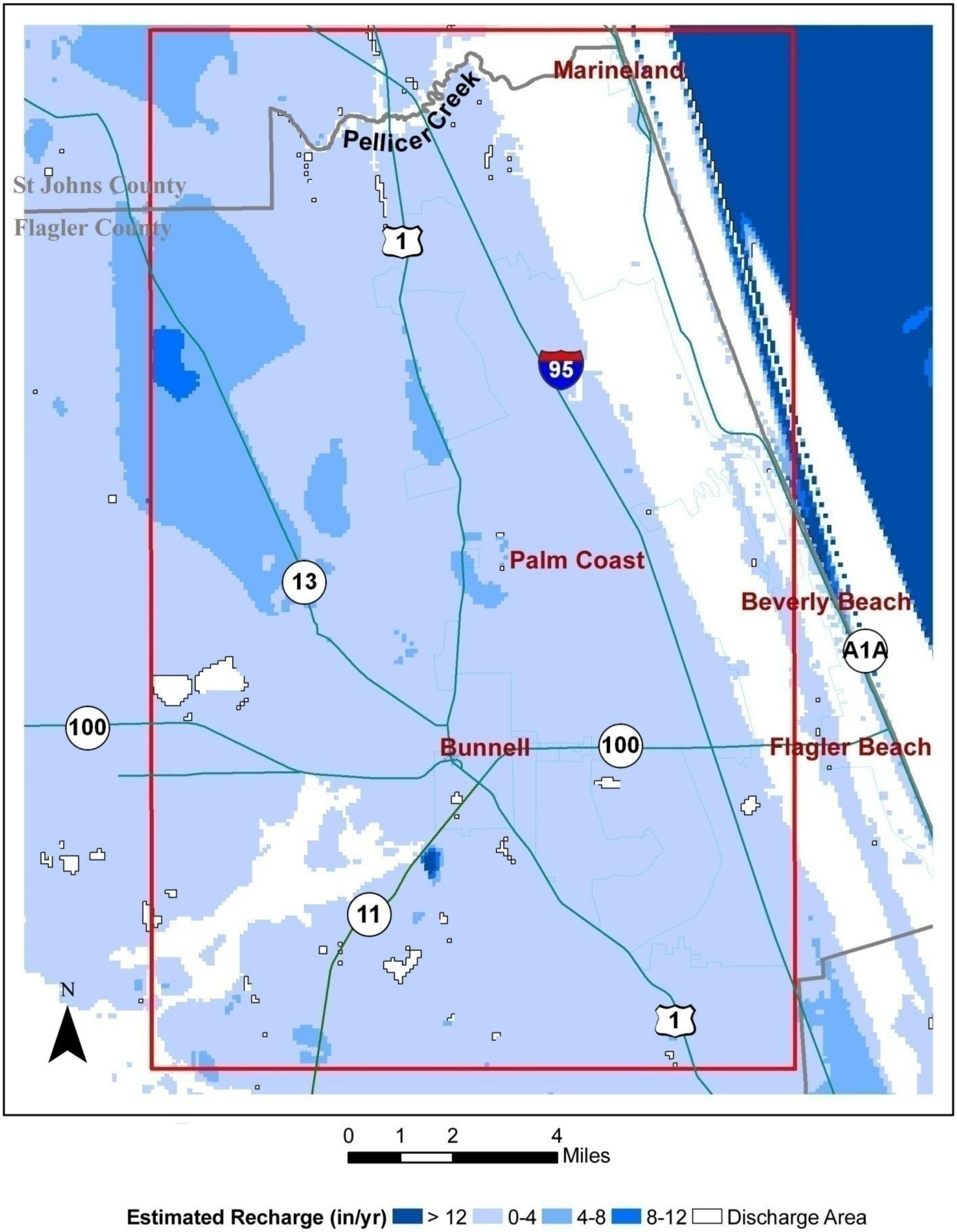


Figure 47 Estimated recharge to Upper Floridan aquifer from surficial aquifer

3.0 SIMULATION OF THE GROUNDWATER FLOW SYSTEM

Based on a literature review and data compiled from the District's database, a conceptual model of groundwater flow was developed. The conceptualization was translated into a numerical flow model, which was calibrated to observed average 1995 hydrologic conditions. Finally, the model was used to estimate drawdown impacts due to projected pumpage for the years 2011 and 2030.

3.1 Conceptual Model of Groundwater Flow System

A schematic of flow in the groundwater system is presented in Figure 48. The primary source of recharge to the system is infiltration from precipitation. A significant portion of rainfall returns to the atmosphere due to evapotranspiration. Runoff is drained by a series of canals that were not simulated explicitly and therefore runoff was assumed to exit the area without interacting with the groundwater system. Water from precipitation recharges the Unconfined Surficial aquifer, which is the topmost hydrogeologic unit and is under unconfined conditions. Due to relatively low hydraulic permeability and thickness of the surficial material, this aquifer cannot yield sufficient quantities of water for water supply needs. Water that is not lost to evapotranspiration and runoff infiltrates into the Confined Surficial aquifer, which is separated from the Unconfined Surficial aquifer by the Top Confining Unit.

The Confined Surficial aquifer is presently the primary source of water for public supply needs. In areas where water levels in the Confined Surficial aquifer are greater than water levels in the Upper Floridan aquifer, the potential exists for recharge to occur. In this study area, the Upper Floridan aquifer is separated from the overlying Confined Surficial aquifer by a low permeability unit referred to as the Intermediate Confining Unit (ICU). The Upper Floridan aquifer, however, contains brackish water in the coastal regions and in the southwest portion of the study area (the Haw Creek subbasin). Hence, production from this aquifer, which is more hydraulically conductive than the Confined Surficial aquifer, has been limited historically for public supply purposes. In the study area, the Upper Floridan aquifer also receives lateral flow along the western and southern boundaries, and groundwater exits this aquifer along the eastern boundary. The Upper Floridan aquifer is separated from the underlying Lower Floridan aquifer by the Middle Semi-Confining Unit.

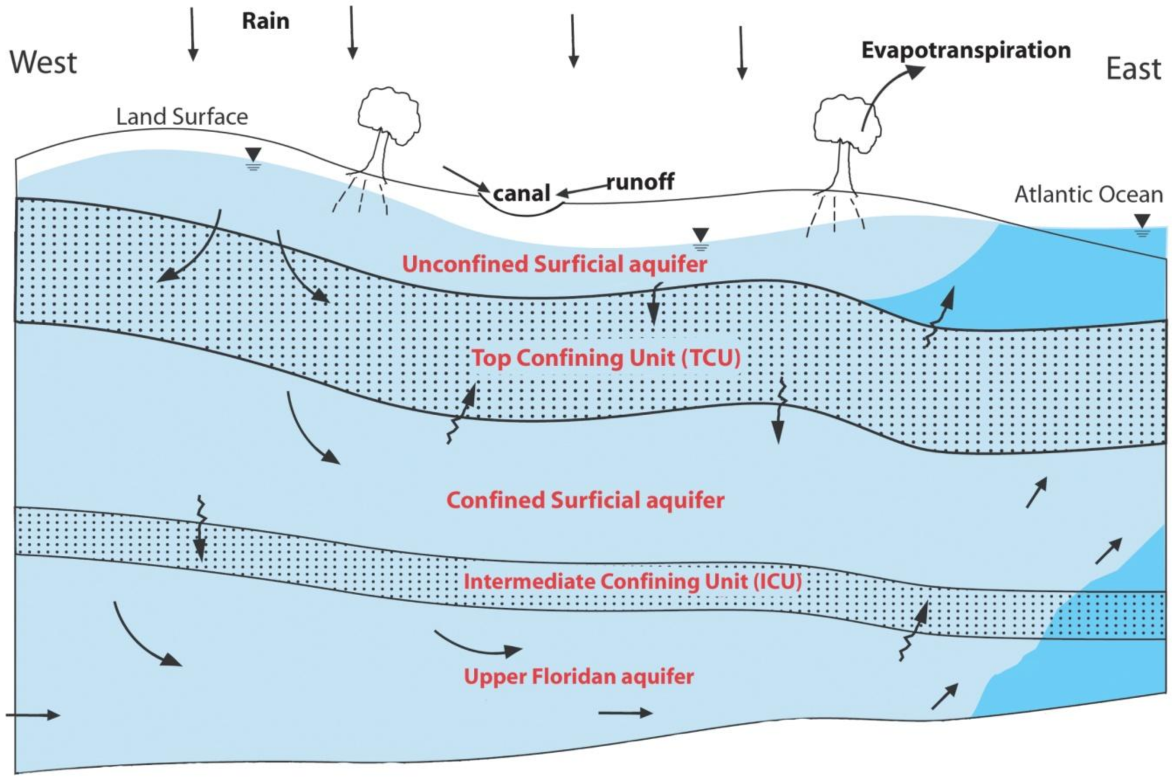


Figure 48 Conceptual model of groundwater flow

This rather dense unit restricts the exchange of water between the two aquifers. The Lower Floridan aquifer contains highly brackish to saline water. Hence, for modeling purposes, the Upper Floridan aquifer was chosen as the lowermost aquifer unit for this study. As previously discussed, the Upper Floridan aquifer in a majority of the study area contains brackish to saline water. Generally, in the southern portion of the study area water in the Upper Floridan is relatively fresh and is a result of localized recharge from the surficial aquifer and lateral inflow from the freshwater flow system emanating from the Volusia County area. Because of the presence of the brackish water in the Upper Floridan aquifer, this results in a smaller effective saturated thickness of freshwater, and therefore a relatively lower effective freshwater transmissivity.

Since the goal of the study was to estimate long-term drawdown impacts due to projected 2030 pumpage, groundwater flow has been conceptualized as occurring under steady quasi-three-dimensional conditions. That is, horizontal flow occurs within the aquifer layers and vertical flow occurs between aquifer layers (Figure 49). The aquifers represented in the model include: the Unconfined Surficial aquifer (model layer 1), the Confined Surficial aquifer (model layer 2), and the Upper Floridan aquifer (model layer 3). Vertical flow occurs between model layers 1 and 2 through the TCU, and through the ICU for model layers 2 and 3. No flow was assumed to occur between the Upper and Lower Floridan aquifers.

3.2 Computer Code Selection

The numerical groundwater flow model was developed using the USGS MODFLOW-2000 computer code (Harbaugh et al., 2000). MODFLOW-2000 is designed to simulate steady state and transient groundwater flow through heterogeneous, anisotropic porous medium in three dimensions. It uses a modular method to simulate various aspects of the flow system. These aspects 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 aquifer characteristics such as aquifer thickness, hydraulic conductivity, storativity, recharge, etc. are defined for each model cell.

MODFLOW-2000 calculates groundwater head at the center of each model cell. Since calibration data for the Confined Surficial aquifer exists only at production wells, it was necessary to incorporate a scheme for determining head within a production well.

This was achieved by utilizing the Multi-Node Well (MNW) package of MODFLOW-2000 (Halford and Hanson, 2002), which calculates the head within a well.

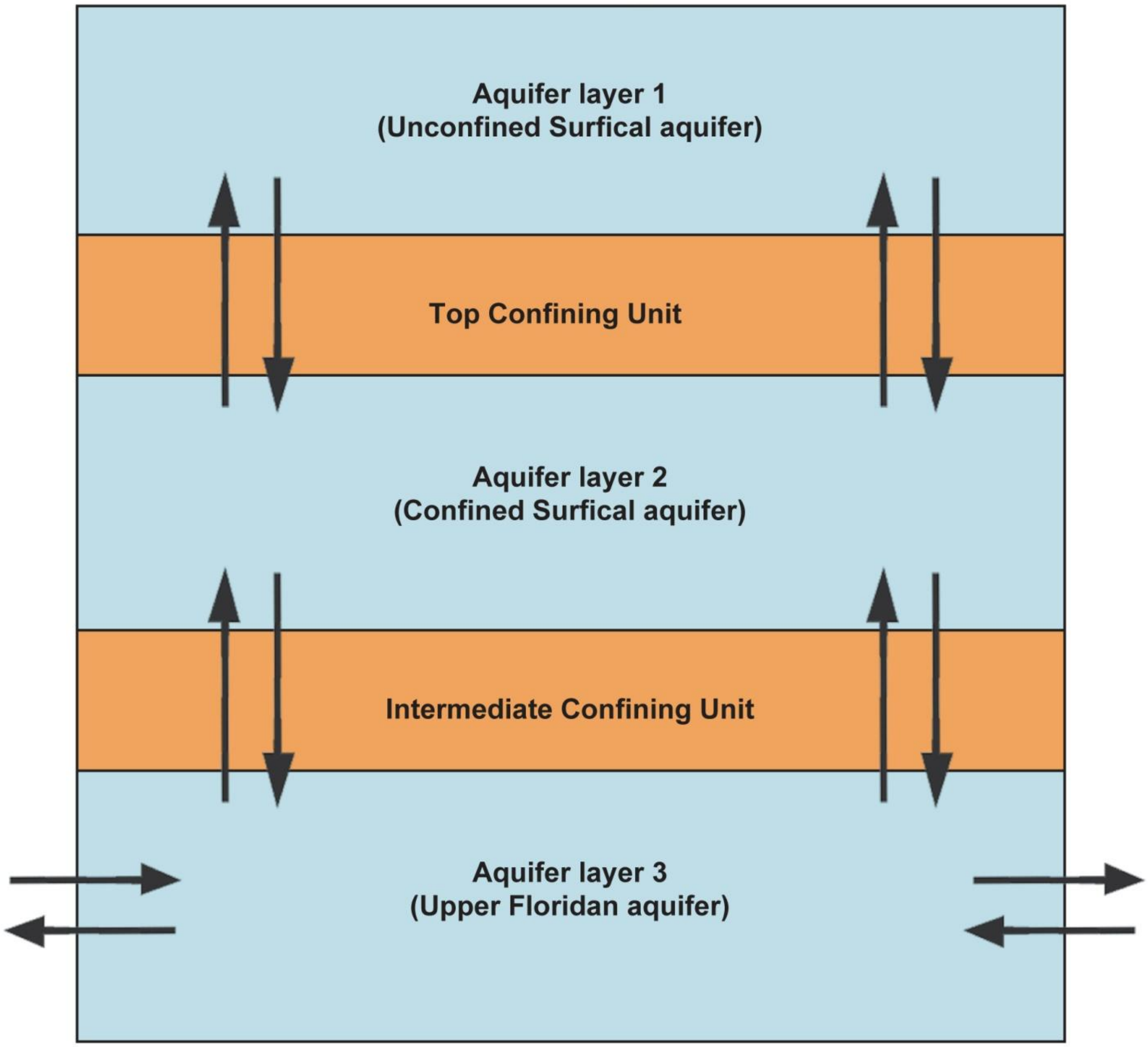


Figure 49 **Conceptualization of groundwater model**

3.3 Model Grid and Discretization

The model domain spans between latitude 29.38727° North and 29.67571° North and longitude 81.15815° West and 81.36335° West and was discretized with 84 rows and 52 columns. All rows and columns are equally spaced and each grid cell spans 1,250 ft in the east-west and north-south direction. The model is oriented North-South similar to the Northeast Florida regional groundwater flow model (Birdie, 2004) which facilitates transfer of data between the two models.

Based on the conceptual model, the subsurface was discretized vertically into three aquifers and two low permeability semi-confining units. The surficial aquifer was modeled as an unconfined hydrogeologic unit, while the Confined Surficial aquifer and the Upper Floridan aquifers were represented as confined aquifers.

3.4 Boundary Conditions

3.4.1 Top Boundary

A combination of recharge and evapotranspiration (ET) was specified along the top model boundary. Recharge represents the following hydrologic components:

Recharge = Rainfall – Runoff - Minimum ET (27 in/yr)

The initial distribution of rainfall in the model area was determined by the District using Doppler radar data for 1995. The initial estimate of runoff was calculated using a Natural Resource Conservation Service (NRCS) curve numbers (CN) approach. It was assumed that runoff flowed into the extensive network of canals and creeks in the area and eventually exited the model study area without interacting with the groundwater system. Both recharge and runoff were modified minimally during model calibration. Minimum ET is the minimum amount of evapotranspiration that is expected to occur regardless of the depth to water and the extinction depth. The extinction depth was assumed to be 27 in/yr. Irrigation return flow and recharge at the Rapid Infiltration Basins (RIBS) were specified in the MODFLOW-2000 well package.

The ET package of MODFLOW was used to simulate evapotranspiration along the top model layer. The ET package requires specification of the land surface evapotranspiration rate. For this study, this was defined as the maximum evapotranspiration minus the minimum evapotranspiration as defined above. The maximum evapotranspiration was assumed to be 58 in/yr.

The extinction depth is the depth (below ground) at which ET ceases. The ET package of MODFLOW-2000 assumes a linear variation in the ET rate between land surface and the extinction depth. An extinction depth of 6 ft was assumed throughout the study area.

Groundwater discharge into Pellicer Creek and the swampy areas between I-95 and the Atlantic Ocean was simulated by the Drain package of MODFLOW-2000. The drain stage was set to land surface elevation in the respective drain cells. The Unconfined Surficial aquifer underlying the Atlantic Ocean was prescribed as a constant-head boundary and set to a head of zero ft (amsl).

3.4.2 Lateral Boundaries

No-flow boundaries were specified along the lateral boundaries in both the Unconfined Surficial and the Confined Surficial aquifers because flow in these aquifers is largely vertical. General Head Boundaries (GHB) were applied along lateral boundaries in the Upper Floridan aquifer. This boundary type was the most appropriate for two reasons. Firstly, there was not enough available information to estimate the flow rates along the boundaries. Secondly, if locations of projected future withdrawals indicated a potential for drawdown to reach the lateral boundaries then the head-dependent flux boundary conditions allows the model to adjust flow across the model boundaries based upon changes in head along the boundaries. The average general head flow length was eight grid cells or about 2 miles. The boundary conductance was based upon average conductance across the grid cells at the boundary, and the assigned head on the boundary was based on the estimated average 1995 potentiometric surface of the Upper Floridan aquifer.

3.4.3 Lower Model Boundary

The base of the Upper Floridan aquifer was prescribed as a no-flow boundary since relatively minor quantities of groundwater are assumed to be exchanged between the Upper Floridan and the underlying Lower Floridan aquifer. The transmissivity of the Upper Floridan was adjusted in order to account for only the freshwater portion of the Upper Floridan.

3.4.4 Pumpage

Groundwater withdrawals were simulated using the Well or MNW package of MODFLOW-2000. Head loss from flow through the formation for all MNW wells was specified with input variables for the dimensionless well skin coefficient and the well radius (0.833 ft) which are used to calculate the cell-to-well conductance (Halford and Hanson, 2002).

3.5 Model Calibration

Model calibration was performed in order to develop a reasonable simulation model of the groundwater system. The model was calibrated to average groundwater levels in 1995. In most cases, 1995 generally represents average climatic and hydrologic conditions throughout the District. Additionally, water use data was most complete for the year 1995. Typically, a model is validated against another stress period with substantially different hydrologic conditions. However, because the present model is an enhancement to several existing models, which were calibrated to stress periods other than 1995, it was decided to restrict the calibration to a single period. The estimated average 1995 water-level data is specified above in section 2.11 entitled Groundwater Levels.

A combination of automated parameter estimation and a trial/error approach was implemented for model calibration. The Parameter ESTtimation (PEST) code (Doherty, 2002; Doherty and Johnston, 2003) was used for automatic calibration. The hydraulic conductivity of the Unconfined Surficial aquifer, the transmissivity of the Confined Surficial and Upper Floridan aquifers, leakance of the semi-confining units, and the ET rates were the primary calibration parameters. Numerous simulations were conducted during which calibration parameters were varied until the simulated water levels matched the observed water levels satisfactorily. PEST and MODAC, parameter estimation package for groundwater flow model calibration, were used initially in order to derive estimates of leakance of the upper and lower confining units, and the transmissivity of the Upper Floridan aquifer. For leakance calibration, each parameter zone consisted of a block of four rows and columns. For transmissivity estimates, each model cell in layer 3 (Upper Floridan) was permitted to vary independently. Following successful automated calibration of the leakances and the Upper Floridan transmissivity, a minor trial and error calibration effort was expended in order to reproduce the observed heads in the unconfined and confined surficial aquifers. During this phase of the calibration, the hydraulic conductivity of the unconfined and confined surficial aquifers was the primary hydrogeologic parameters that were varied.

3.5.1 Calibration Targets

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 1 ft in the Upper Floridan aquifer.
- The absolute mean head residual error in the Upper Floridan aquifer should also be less than 1 ft for the 1995 calibration period.
- The simulated Upper Floridan potentiometric surface should closely match the shape and gradients of the interpreted average 1995 Upper Floridan potentiometric surface.
- The absolute average and mean head residual at production wells in the Confined Surficial aquifer should be less than 2 ft.
- The absolute average and median head residual at the observation wells in the Unconfined Surficial aquifer should be less than 1.5 ft.
- The difference in the slope and y-intercept of the (simulated Unconfined Surficial water levels versus land surface elevation) regression line should be minimized with respect to the regression parameters for the estimated water table regression line. The slope and y-intercept for the estimated water table surface are 0.901 and -1.61 respectively as discussed above. That is, the estimated water table is expressed as:

$$\text{Water Table} = 0.901\ (\text{Land Surface Elevation}) - 1.61$$

The calibrated slope should be within 2% of the estimated slope (i.e., 0.883 and 0.919), the y-intercept should be within 1 ft of the estimated y-intercept (i.e., between -2.61 and -0.61). To ensure acceptable dispersion, the R^2 square should be 0.97 or higher.

3.5.2 Calibration Results

The simulated average 1995 water table in the Unconfined Surficial aquifer is presented in Figure 50. The head residuals (observed minus simulated) at the observation wells for 1995 and the residual statistics are presented in Figure 51 and 52. Negative (red) residuals imply that the simulated heads are higher than observed heads, while positive (blue) residuals imply the opposite. In general, a satisfactory match between model simulated and field observed water levels can be inferred from Figure 51. At most sites, head differences are less than one foot.

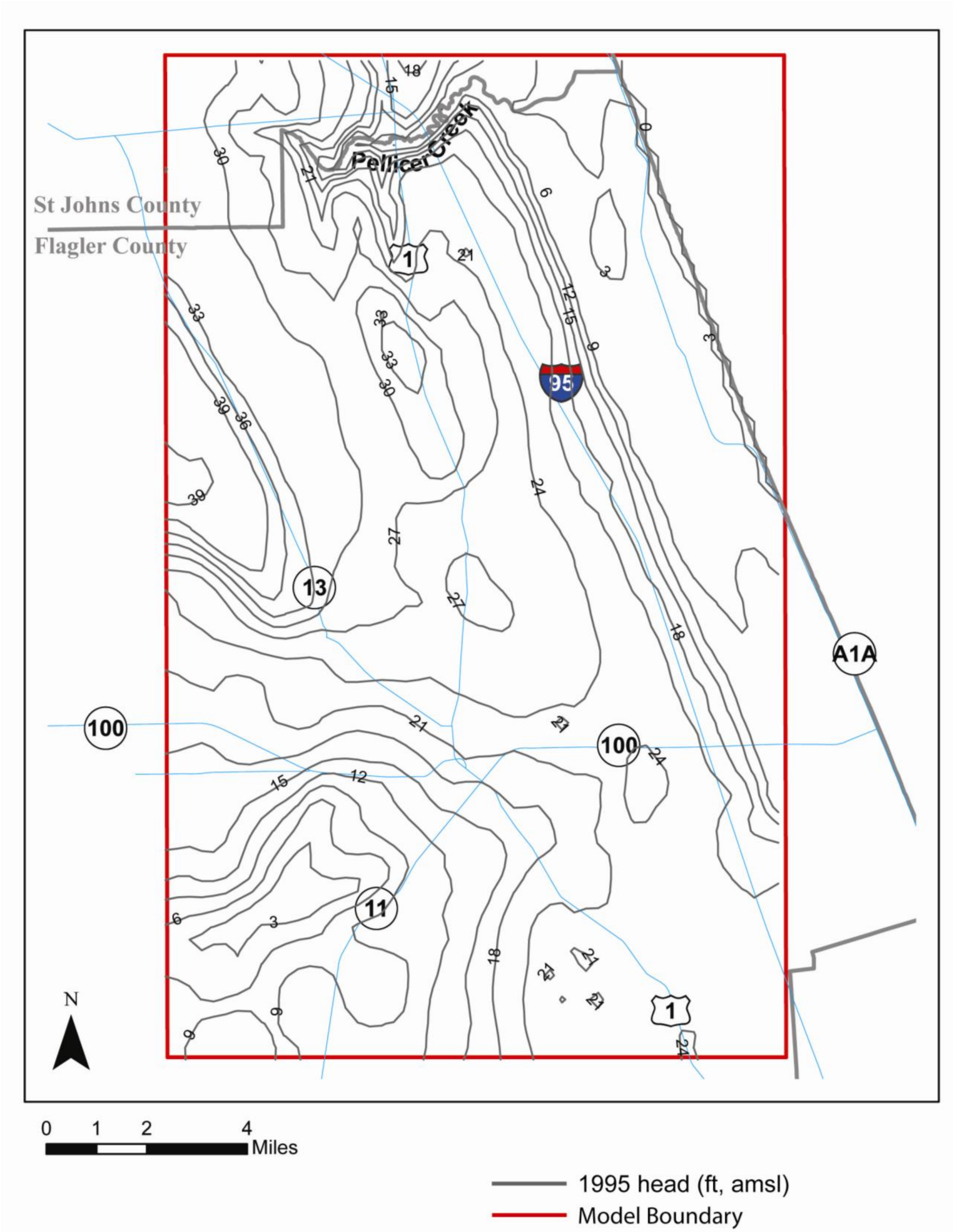


Figure 50 Simulated average 1995 water table in Unconfined Surficial aquifer

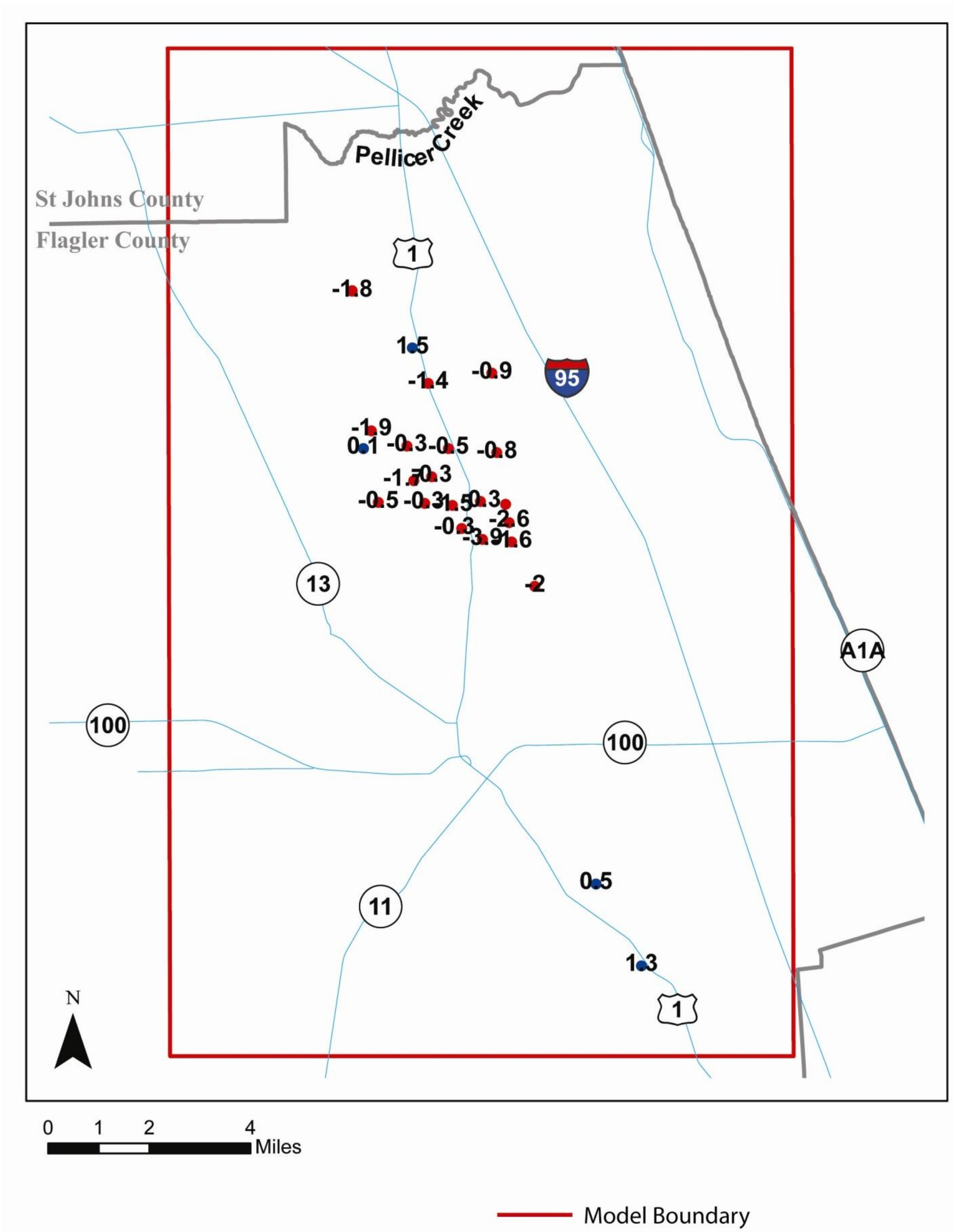


Figure 51 Average 1995 head residuals (Observed - Simulated) at Unconfined Surficial aquifer monitoring wells layers

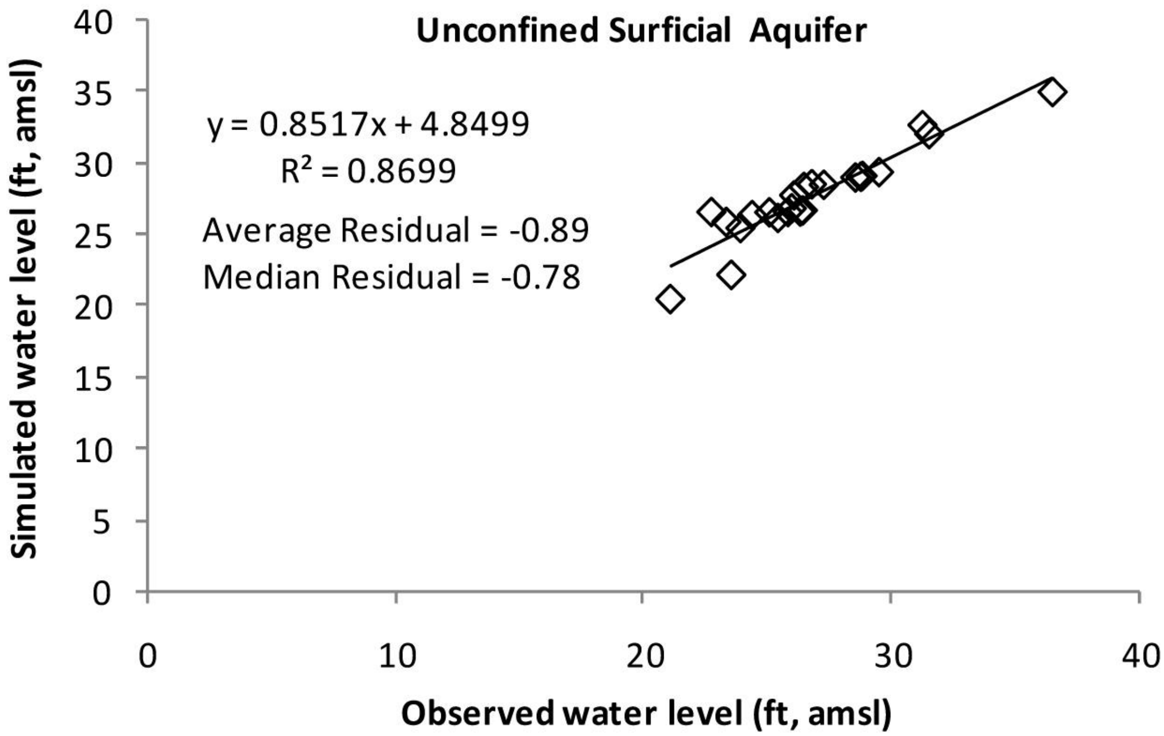


Figure 52 Observed versus simulated water levels in the Unconfined Surficial aquifer for 1995

The simulated heads are also generally higher within the PCU wellfield. This is likely the result of MODFLOW simulating a grid cell averaged water level. The regression statistics for the Unconfined Surficial aquifer indicate a reasonable match between simulated and ob-served water levels at the observation well sites. The average and median residuals are -0.89 and -0.78 ft respectively.

As expected, the water table is a subdued replica of the land surface. The relationship between the simulated 1995 water levels and the land surface is presented in Figure 53 and is expressed by:

$$\text{Water Table} = 0.94\ (\text{Land Surface Elevation}) - 1.4$$

This compares favorably with the equation obtained by Boniol (1993),

$$\text{Water Table} = 0.901\ (\text{Land Surface Elevation}) - 1.61$$

The slope of the observed and simulated regressed equations is off by 4.3%. The y-intercept is offset by only 0.19 ft, and R^2 is 0.979. With the exception of the slope, these are all within the range of calibration targets as discussed above.

The simulated average 1995 potentiometric surface in the Confined Surficial aquifer is presented in Figure 54 and the head difference between the Unconfined Surficial and Confined Surficial aquifers is presented in Figure 55. The general configuration of the potentiometric surface is similar to that in the Unconfined Surficial aquifer. In most of the study area, the head difference between the two aquifers is less than three ft. The head in the Confined Surficial aquifer is higher in the discharge areas near Haw Creek, Pellicer Creek, and the Atlantic Ocean. High head differences exist in the uplands along the western boundary and in the (sharply dissected) Pellicer Creek in the north. The head residuals (observed minus simulated) at the production wells is presented in Figure 56 and the residual statistics provided in Figure 57. In general, a satisfactory calibration match was achieved. The average and median head difference is -0.12 and -0.15 ft respectively. It should be noted that due to well losses, a skin factor of 1 was specified at the production wells based upon model calibration. Typical skin factors lie between 1 and 3 as suggested by the author of the MNW package (Keith Halford, USGS, personal communication). The skin factor enables accounting for head losses due to resistance encountered as groundwater flows through the well screen. In the present model, a skin factor in the range of 1 to 3 lowered water levels within the well bore by 1 to 3 ft.

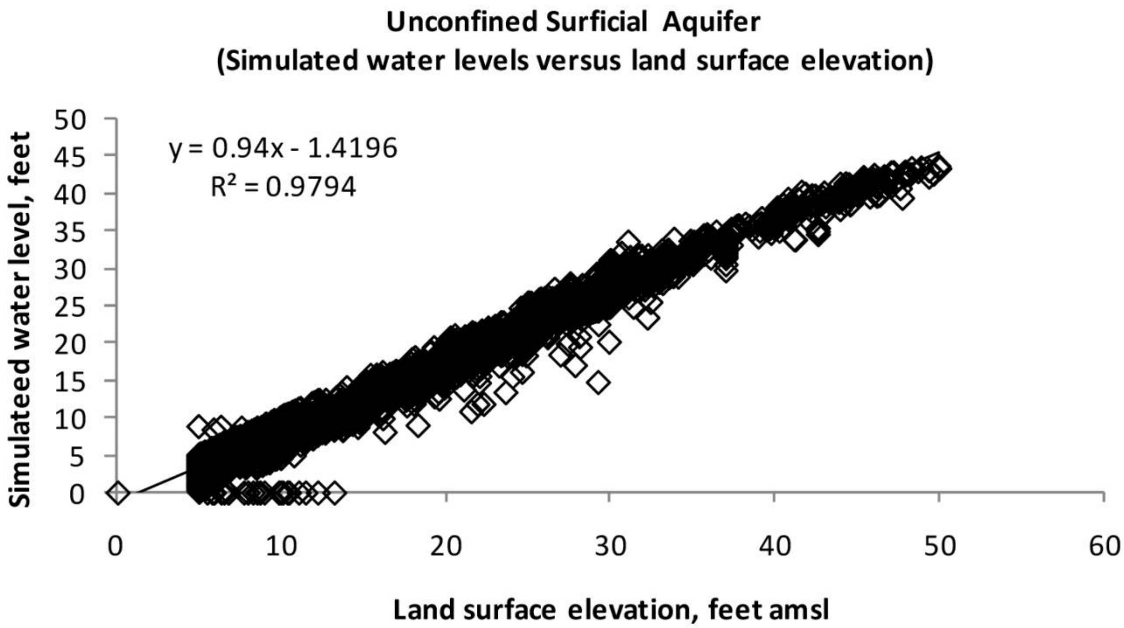


Figure 53 Simulated 1995 water levels versus land surface elevation in Unconfined Surficial aquifer

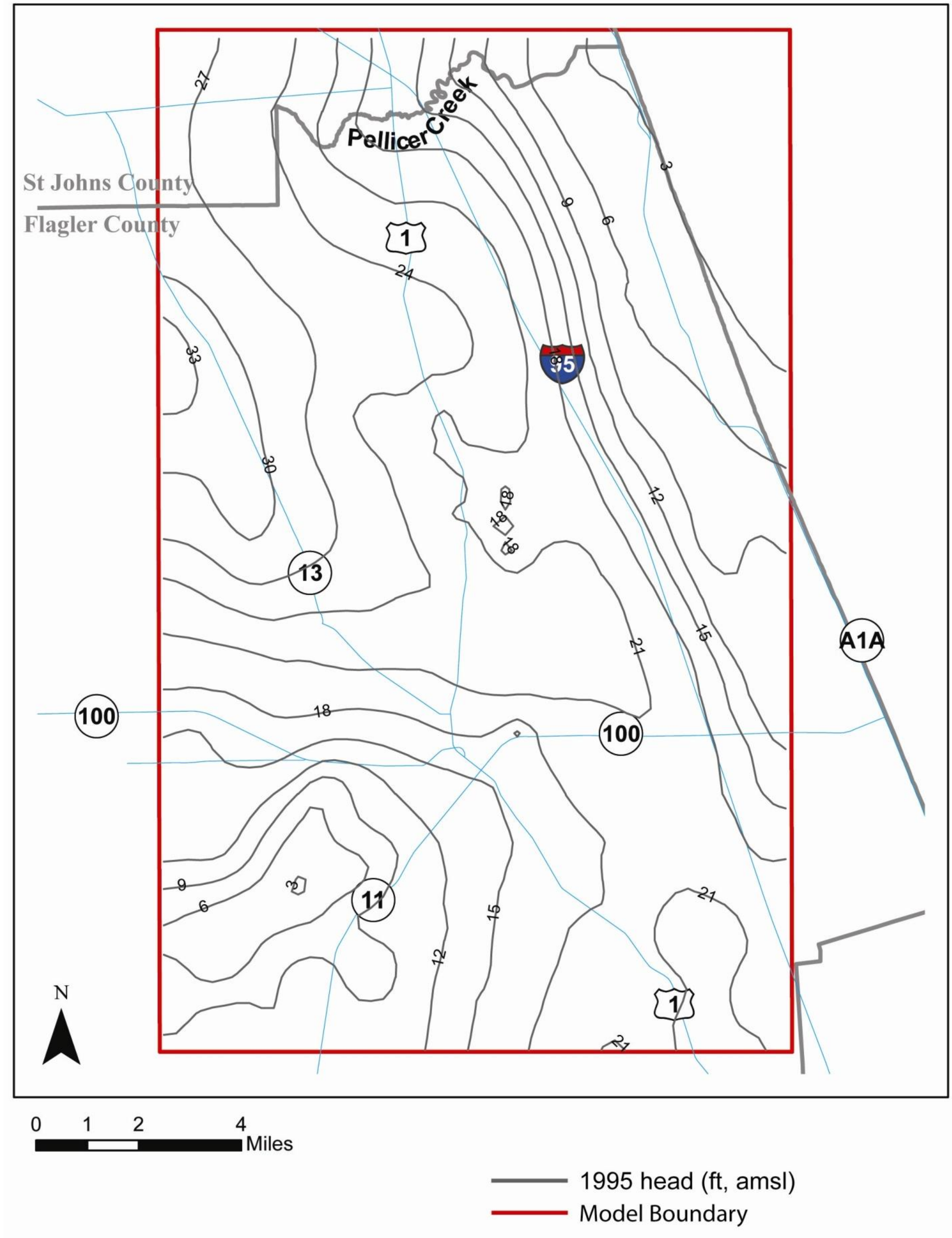


Figure 54 Simulated average 1995 potentiometric surface in Confined Surficial aquifer

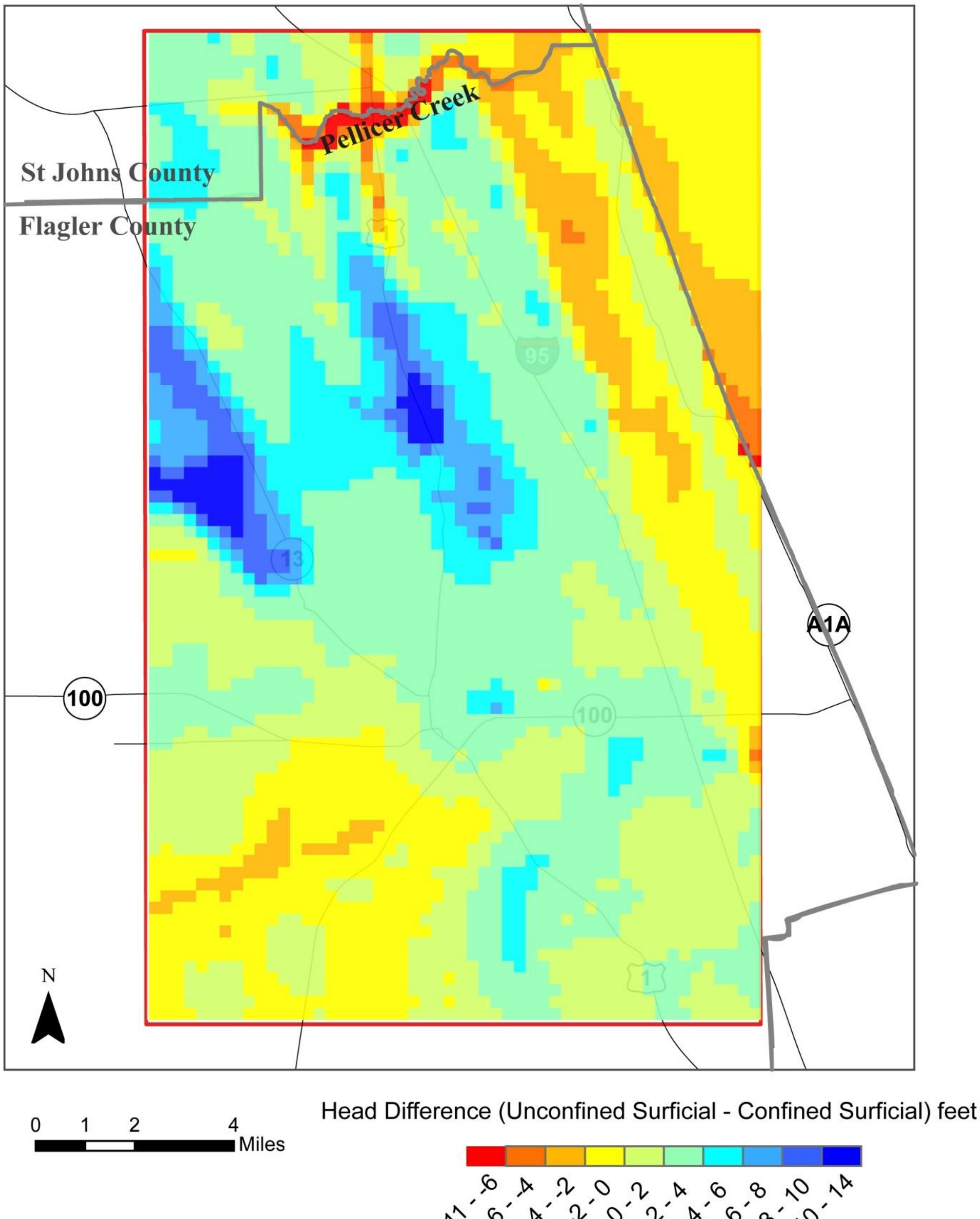


Figure 55 Simulated average 1995 head difference between Unconfined Surficial and Confined Surficial aquifers

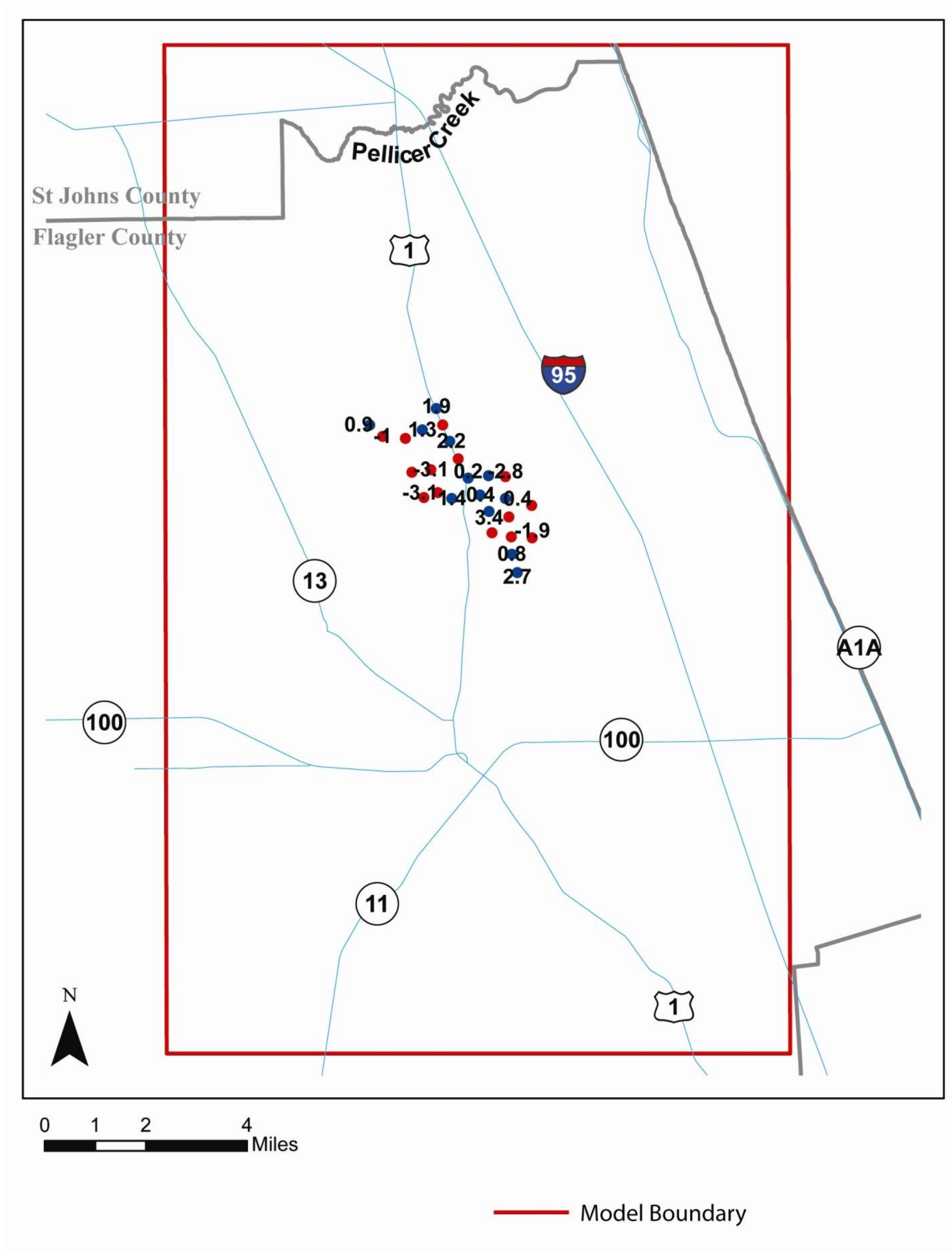


Figure 56 Average 1995 head residuals (observed - simulated) at Confined Surficial aquifer wells

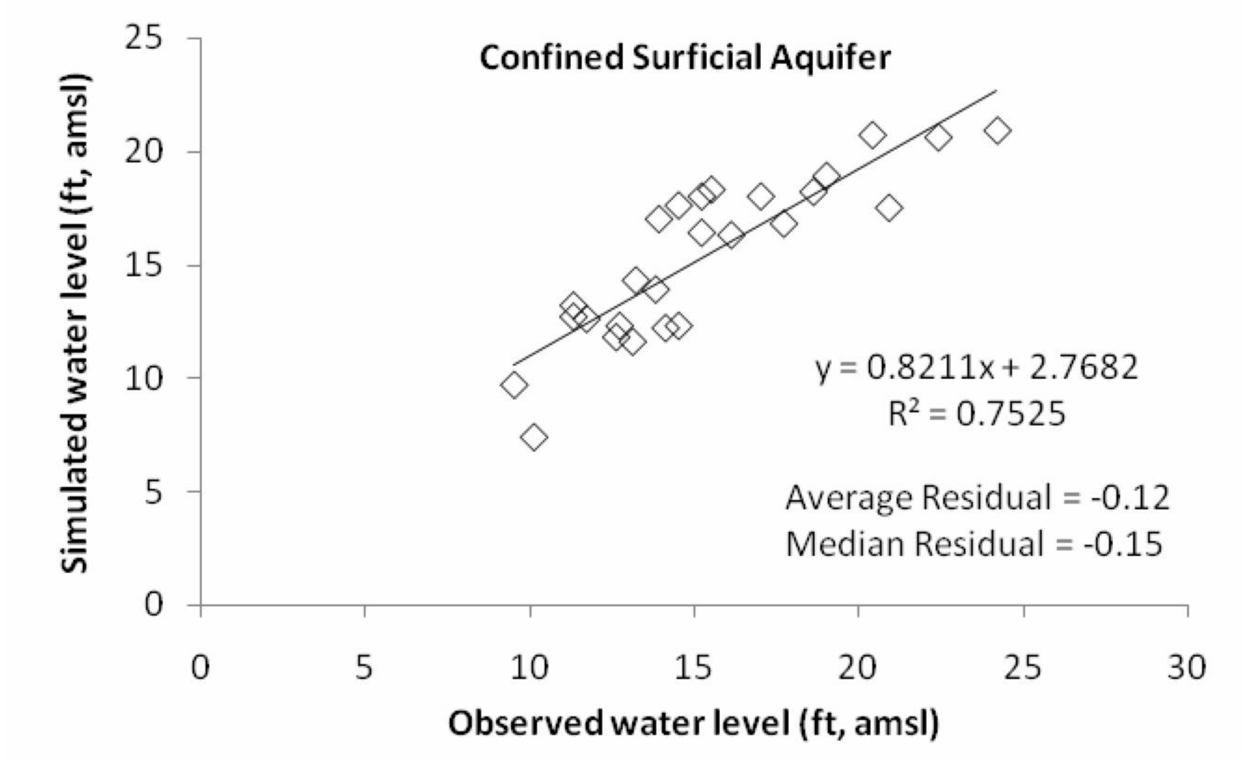


Figure 57 Observed versus simulated water levels in the Confined Surficial aquifer for 1995

The simulated average 1995 potentiometric surface in the Upper Floridan is presented in Figure 58. The head residuals (observed minus simulated) at the observation wells in the Upper Floridan aquifer are presented in Figure 59. The regression statistics at the observation well location are presented in Figure 60. In general, a good match between simulated and interpreted potentiometric surfaces can be inferred from the calibration statistics. At most of the observation well sites, the error is less than one foot. The average residual in the Upper Floridan aquifer is -0.18 ft, while the median residual is -0.21 ft. The difference between the District interpreted heads and simulated head at each model cell is provided in Figure 61. There is an area of high positive residuals in the southeast. This appears to be an artifact of contouring as can be inferred from the interpreted potentiometric surface, where the 18 ft elongated isoline is not supported by data in the monitoring wells. Another area of high residuals is in the northwest. Here too, the error is due to anomalous contouring of the average 1995 heads as can be inferred from the interpreted heads, where two observation wells indicate average 1995 water level of 16.0 and 16.2 ft, but the interpreted potentiometric surface is approximately 15 ft.

The head difference between the Confined Surficial and the Upper Floridan aquifers is presented in Figure 62. The largest head difference is in the northwest where heads in the Confined Surficial aquifer heads are locally higher by up to 18 ft than in the Upper Floridan aquifer, and where the land surface elevation is nearly 50 ft (amsl). As expected, Upper Floridan heads are higher than the Confined Surficial aquifer heads in discharge areas of Haw Creek, Pellicer Creek, and along the coast.

3.6 Simulated Water Budget for 1995

The mass balance summary for 1995 for the entire model is presented in Table 7 and Figure 63. Approximately 208.1 MGD enters the model through the top boundary as the net sum of rain minus runoff minus minimum ET of 27 in/yr. The mass balance summary indicates both positive and negative recharge fluxes that reflects both values of recharge (as the net sum of rain minus runoff minus minimum ET of 27 in/yr) and discharge (ET, wells and boundary outflows). Water lost through the top boundary in the form of ET (excluding minimum ET of 27 in/yr) is 180.8 MGD. Approximately 2.8 MGD of groundwater from the Unconfined Surficial aquifer discharges into the Atlantic Ocean.

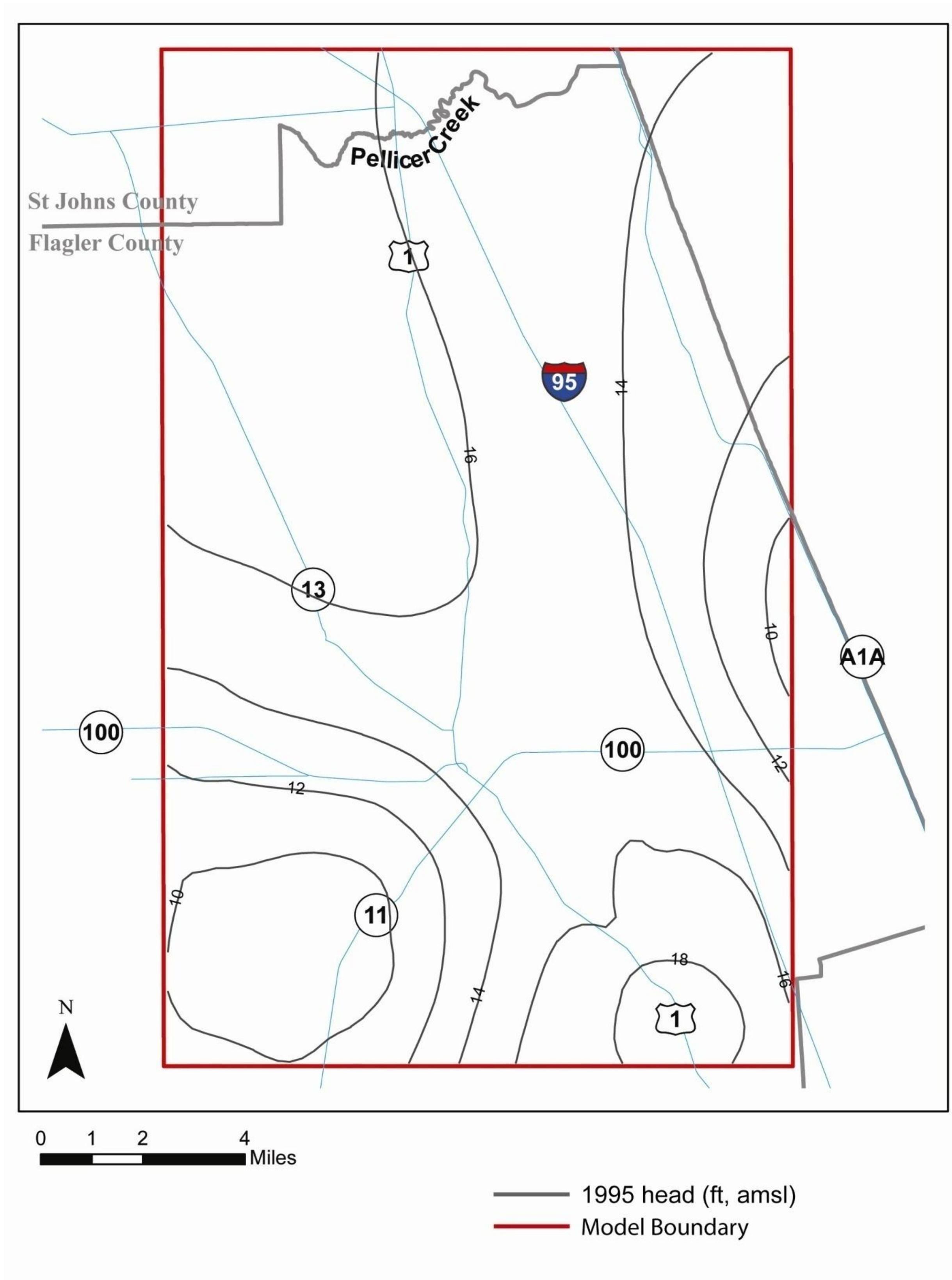


Figure 58 Simulated average 1995 potentiometric surface in Upper Floridan aquifer

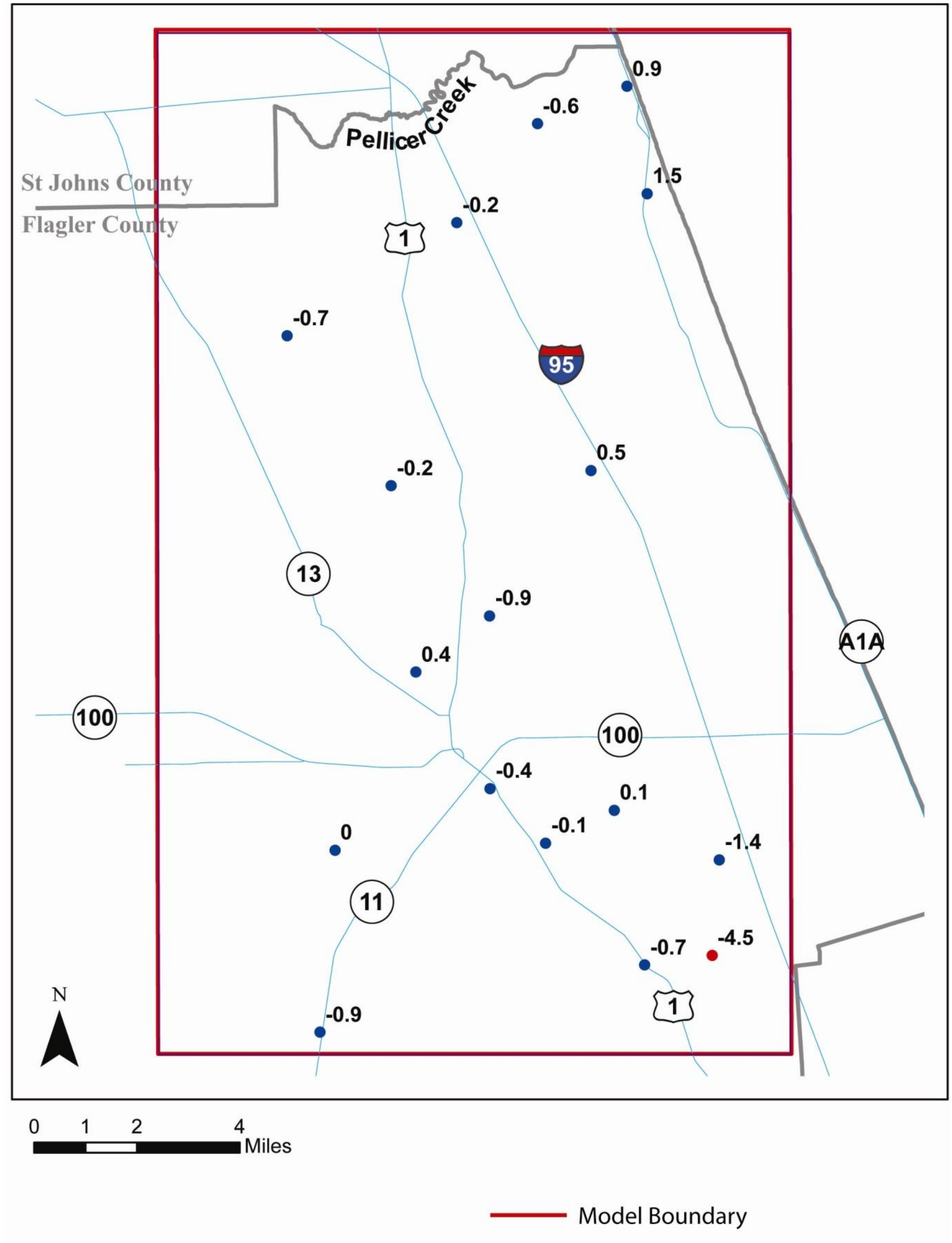


Figure 59 **Average 1995 head residual (observed-simulated) at Upper Floridan aquifer monitoring wells**

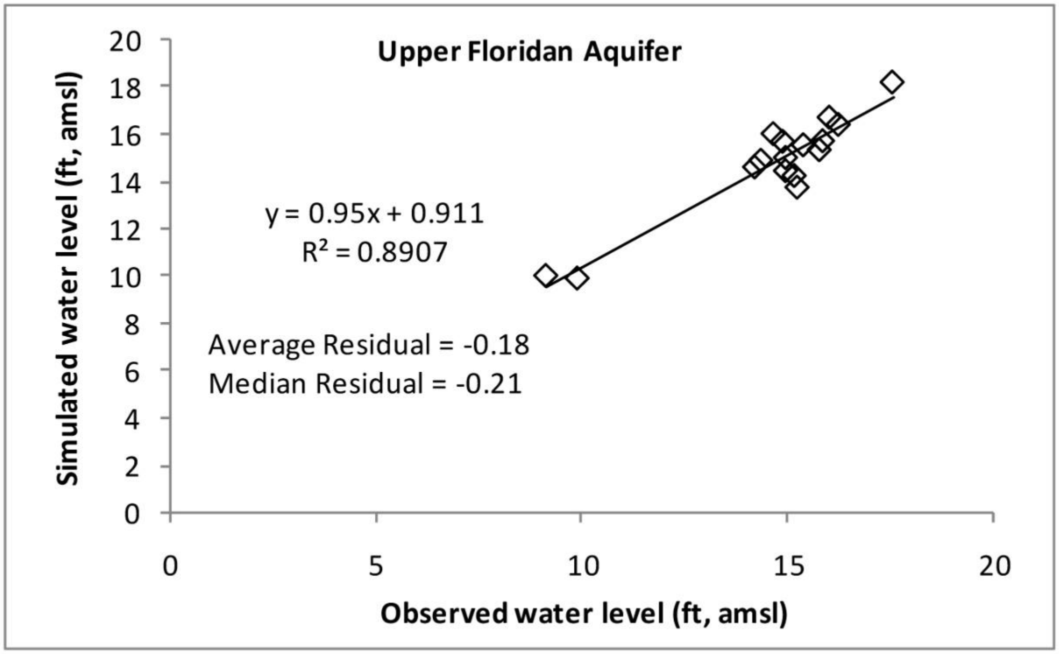


Figure 60 Observed versus simulated water levels in the Upper Floridan aquifer for 1995

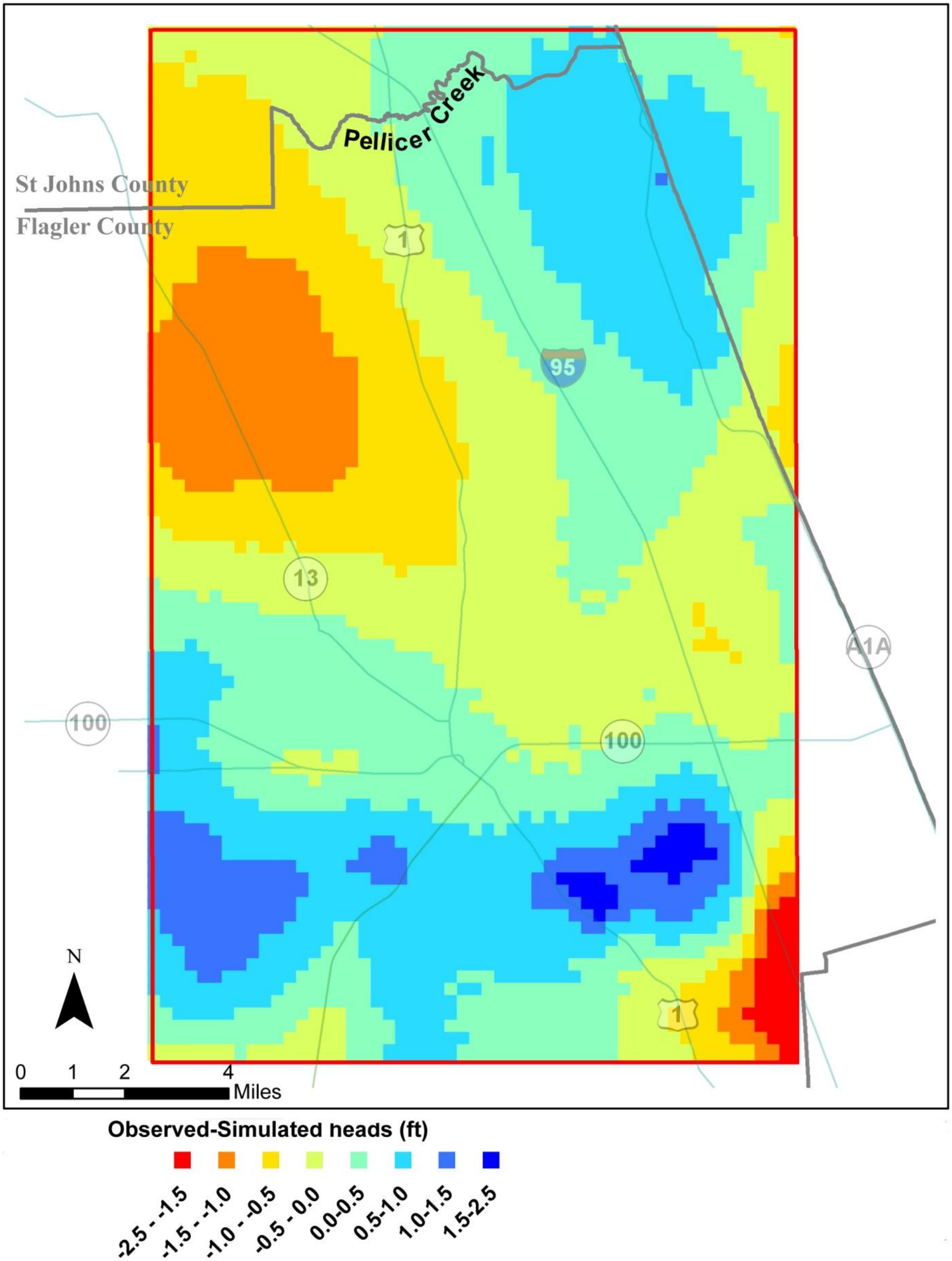


Figure 61 **Difference between simulated and interpreted average 1995 potentiometric surface in Upper Floridan aquifer**

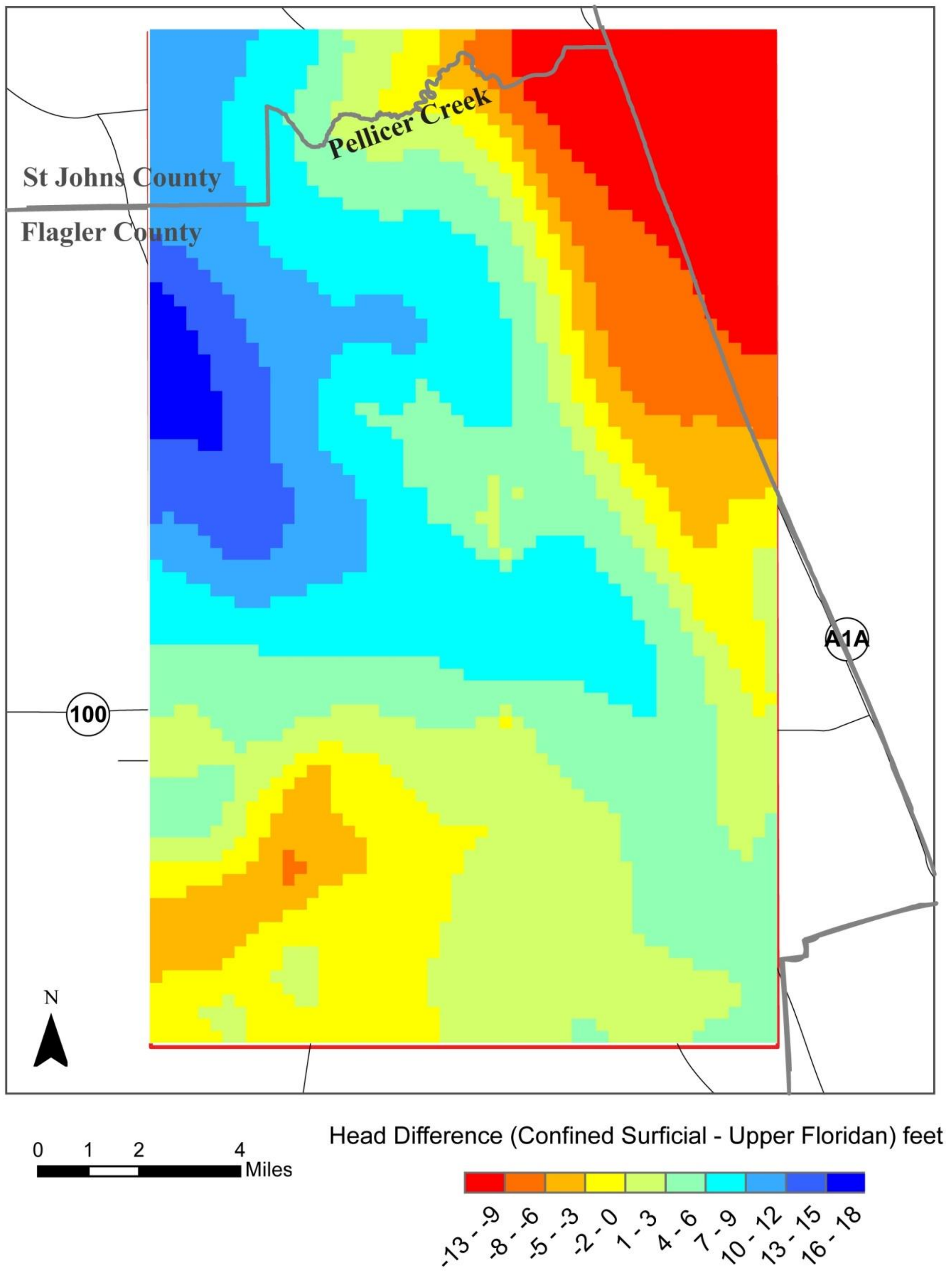


Figure 62 Simulated average 1995 head difference between Confined Surficial and Upper Floridan aquifers

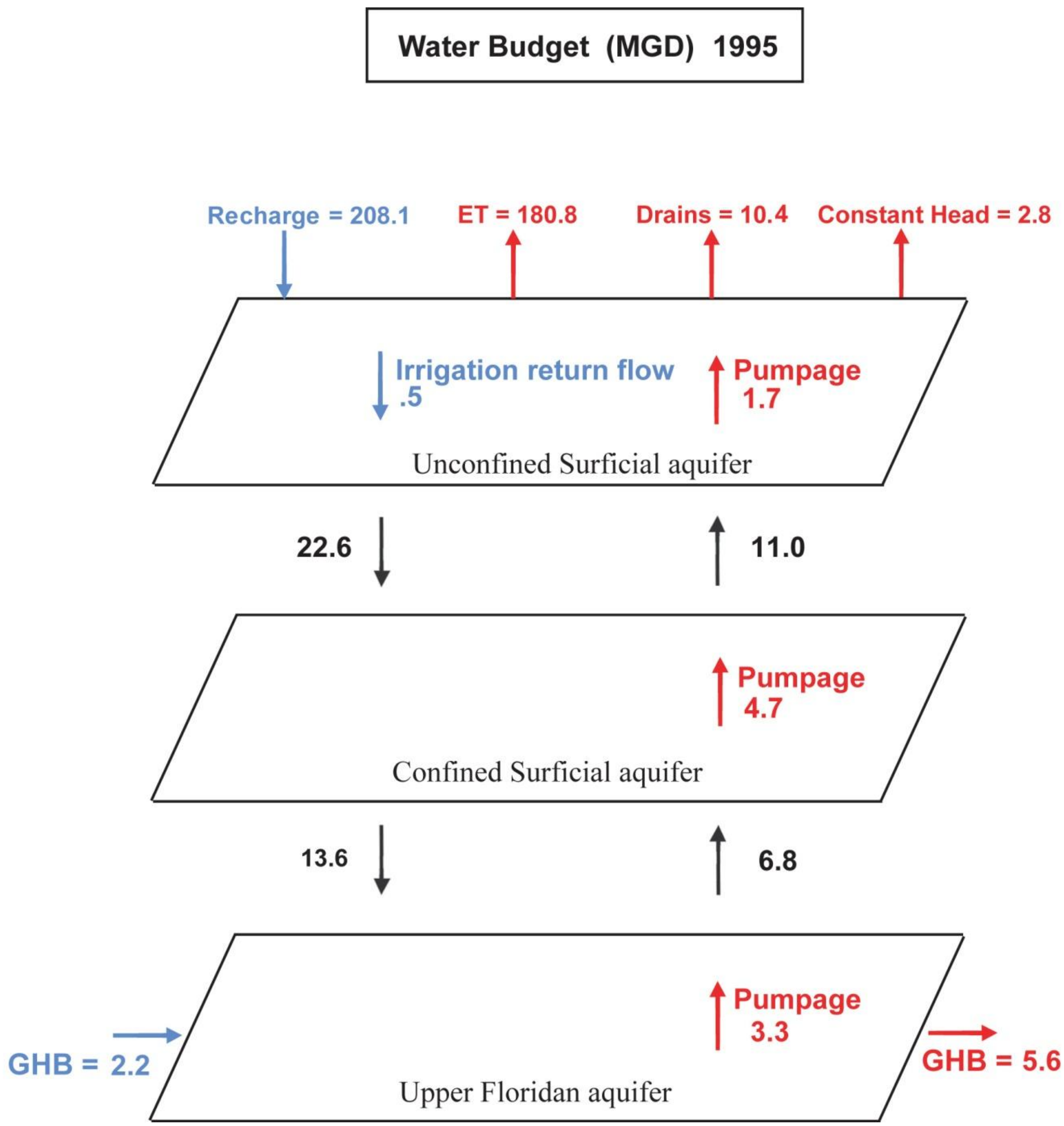


Figure 63 Model simulated water budget for 1995

Irrigation return flow is less than 0.5 MGD and approximately 1.7 MGD is withdrawn from the Unconfined Surficial aquifer for irrigation and domestic uses. Flow into the drainage network, which is simulated by the drains, equals 10.4 MGD.

Recharge from the Unconfined Surficial to the Confined Surficial aquifer is approximately 22.6 MGD, and discharge from the Confined Surficial aquifer into the Unconfined Surficial aquifer equals 11.0 MGD. Groundwater pumpage from the Confined Surficial aquifer totals 4.7 MGD.

Recharge from the Confined Surficial aquifer to the Upper Floridan aquifer totals 13.6 MGD, and approximately 6.8 MGD of groundwater recharges the Confined Surficial aquifer from the Upper Floridan aquifer. Cross-boundary influx to the Upper Floridan aquifer (mainly along the west) equals 2.2 MGD, and about 5.6 MGD of groundwater exits the Upper Floridan aquifer across its lateral boundaries primarily along the eastern coastal boundary. Pumpage from the Upper Floridan aquifer equals 3.3 MGD.

Table 7 Simulated average 1995 water budget (MGD)

Aquifer	Recharge*		ET**		Well		Drain		GHB		CHD	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Unconfined Surficial	208.1	1.3		180.8	0.5	1.7		10.4				2.8
Confined Surficial						4.7						
Upper Floridan						3.3			2.2	5.6		

* Recharge=Rain – Runoff – Min ET of 27 in/yr
** Excludes Min ET of 27 in/yr

3.7 Calibrated Hydraulic Parameters

The sum of 1995 rainfall minus runoff in/yr (minus minimum ET of 27 in/yr) was applied to the top model boundary using the Recharge package of MODFLOW. The District derived the distribution of average 1995 rainfall using Doppler radar data. The District used a USDA runoff curve numbers (CN) procedure to calculate the runoff distribution. The rainfall and runoff distribution was adjusted slightly during the calibration process on a trial and error basis. In most of the study area, recharge minus runoff is between 40 and 55 in/yr (Figure 64). In the Haw Creek basin, it is much lower (< 35 in/yr) due to relatively large runoff to Haw Creek.

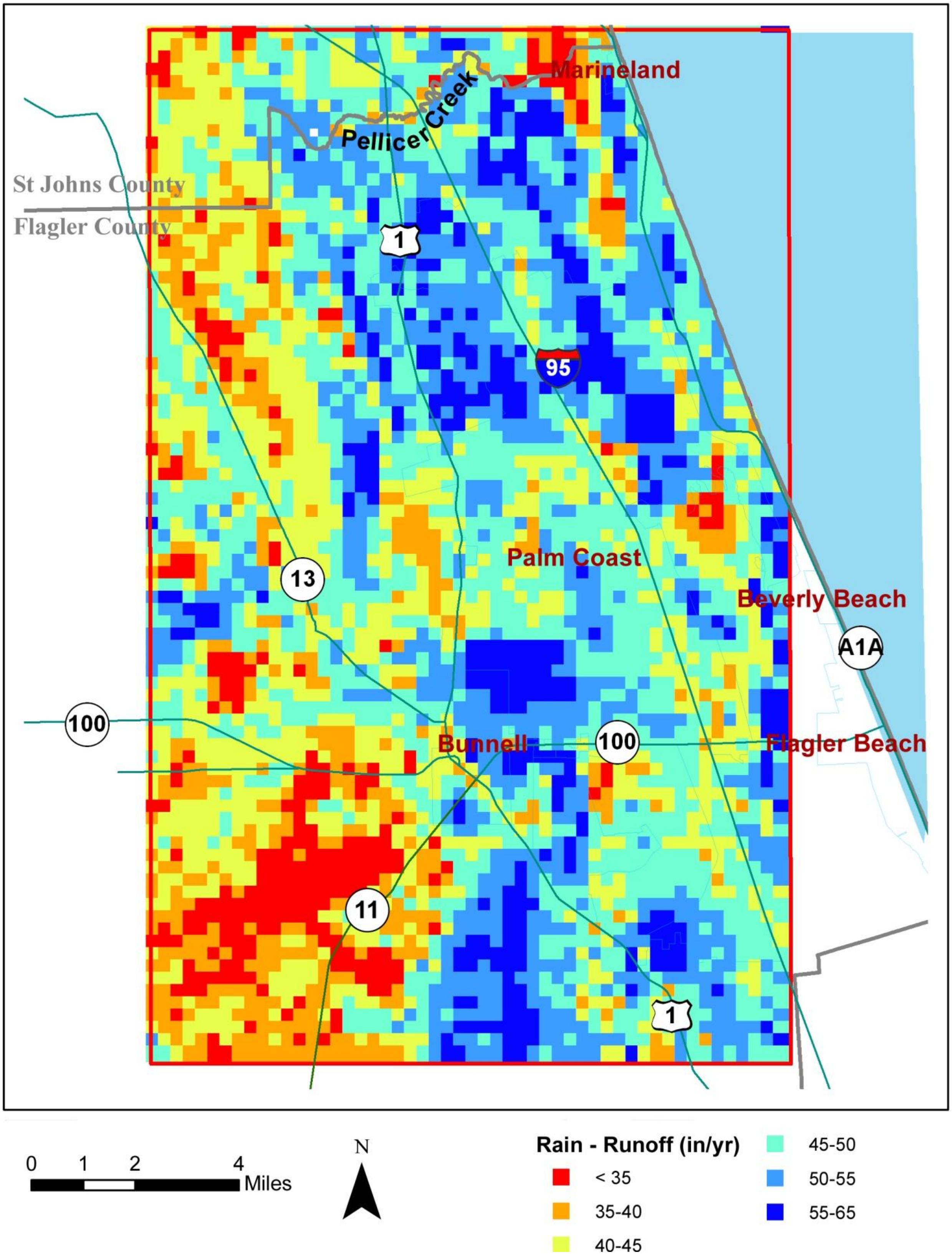


Figure 64 Average 1995 calibrated rain minus runoff distribution

In the southeast portions of the study area, net recharge is high (locally exceeding 60 in/yr) due to low runoff rates in the area. The simulated evapotranspiration is presented in Figure 65. In most of the study area, annual ET rates vary between 35 and 58 in/yr. ET is highest in areas where the water table is closest to land surface. Simulated ET is low in the upper reaches of Pellicer Creek partly due to the fact it is a sharply dissecting creek, and the model grid spacing of 1250 ft cannot account for the sharp drop in land surface elevation along the banks of the creek and its tributaries.

Net recharge to the water table, which is the difference between recharge in the MODFLOW-2000 recharge package and model simulated ET is presented in Figure 66. In most of the study area, recharge to the water table varies between 0 and 10 in/yr. In several areas, there is net discharge from the water table. These areas are characterized as locations where surface runoff is high and the water table is close to land surface. Such places are generally located along the edge of topographic ridge features. The Haw Creek subbasin is also a region of high net discharge due to the relatively high runoff rates in the area.

The model-derived distribution of recharge/discharge from the Unconfined Surficial aquifer to the Confined Surficial aquifer is presented in Figure 67. An area of relatively high discharge exists in the Haw Creek subbasin, and high recharge occurs in the southeast. In large portions of the study area, recharge to the Confined Surficial aquifer varies between 0 and 4 in/yr. Larger recharge (4-10 in/yr) occurs near the PCU wellfield and in higher elevation areas along the western boundary. Discharge from the Confined Surficial to the Unconfined Surficial aquifer occurs along Pellicer Creek, along Haw Creek, and in the hydraulically drained areas east of I-95.

Recharge/discharge distribution to/from the Upper Floridan (Figure 68) is similar to the distribution between the Unconfined and Confined Surficial aquifers. In most of the study area, recharge varies between 0 and 2 in/yr. The Haw Creek basin is a discharge area with rates locally exceeding 10 in/yr. Discharge also occurs in the low-lying coastal areas. Recharge as high as 10 in/yr occurs in the southeast at rates similar to those between the Unconfined and Confined Surficial aquifer suggesting a pass-through of most of the water infiltrating from the surface. A comparison of the model simulated Upper Floridan recharge/discharge to a GIS based estimate of the same by Boniol, presented earlier in the report, indicates similar trend by both approaches.

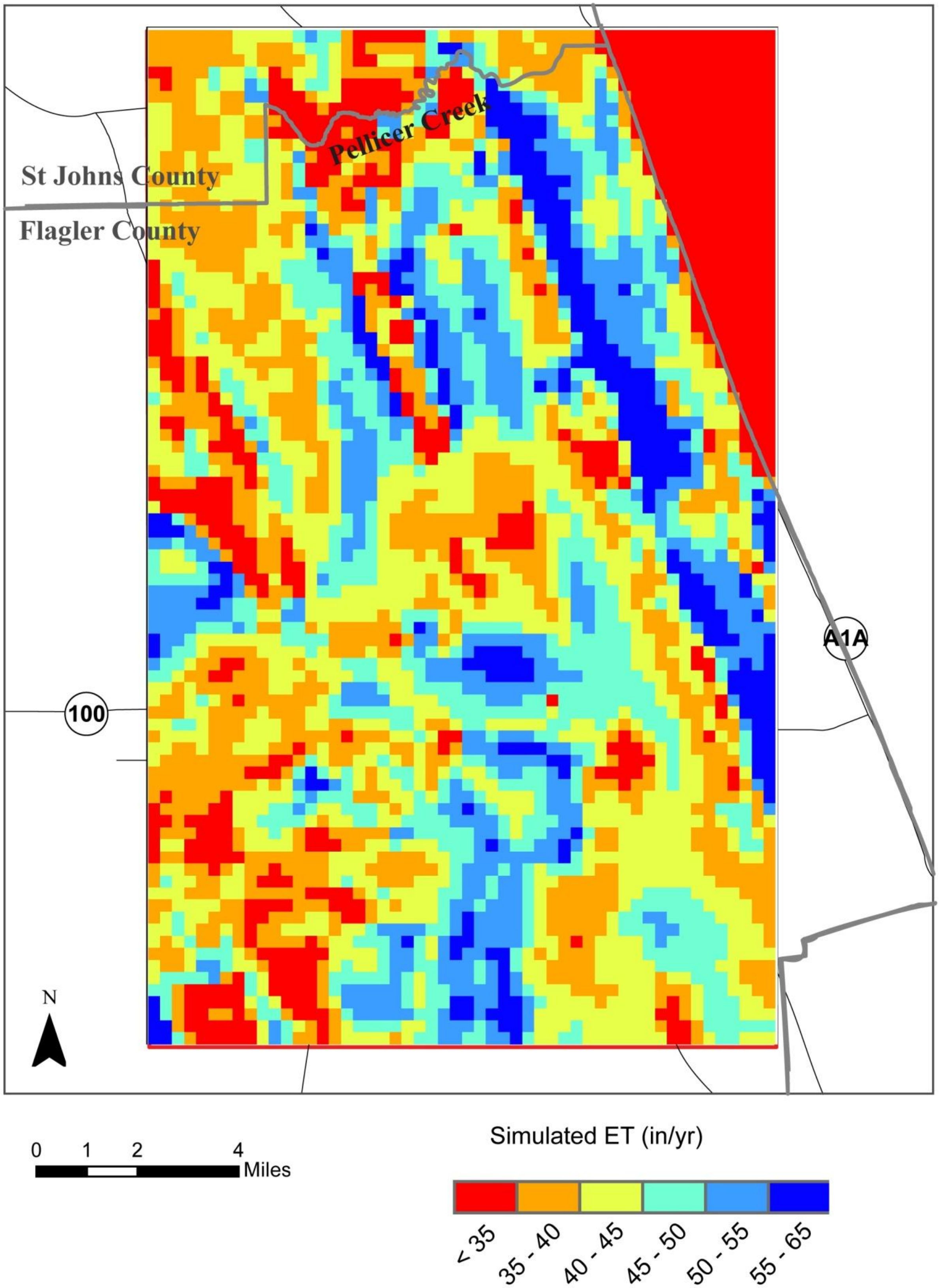


Figure 65 Average 1995 simulated evapotranspiration

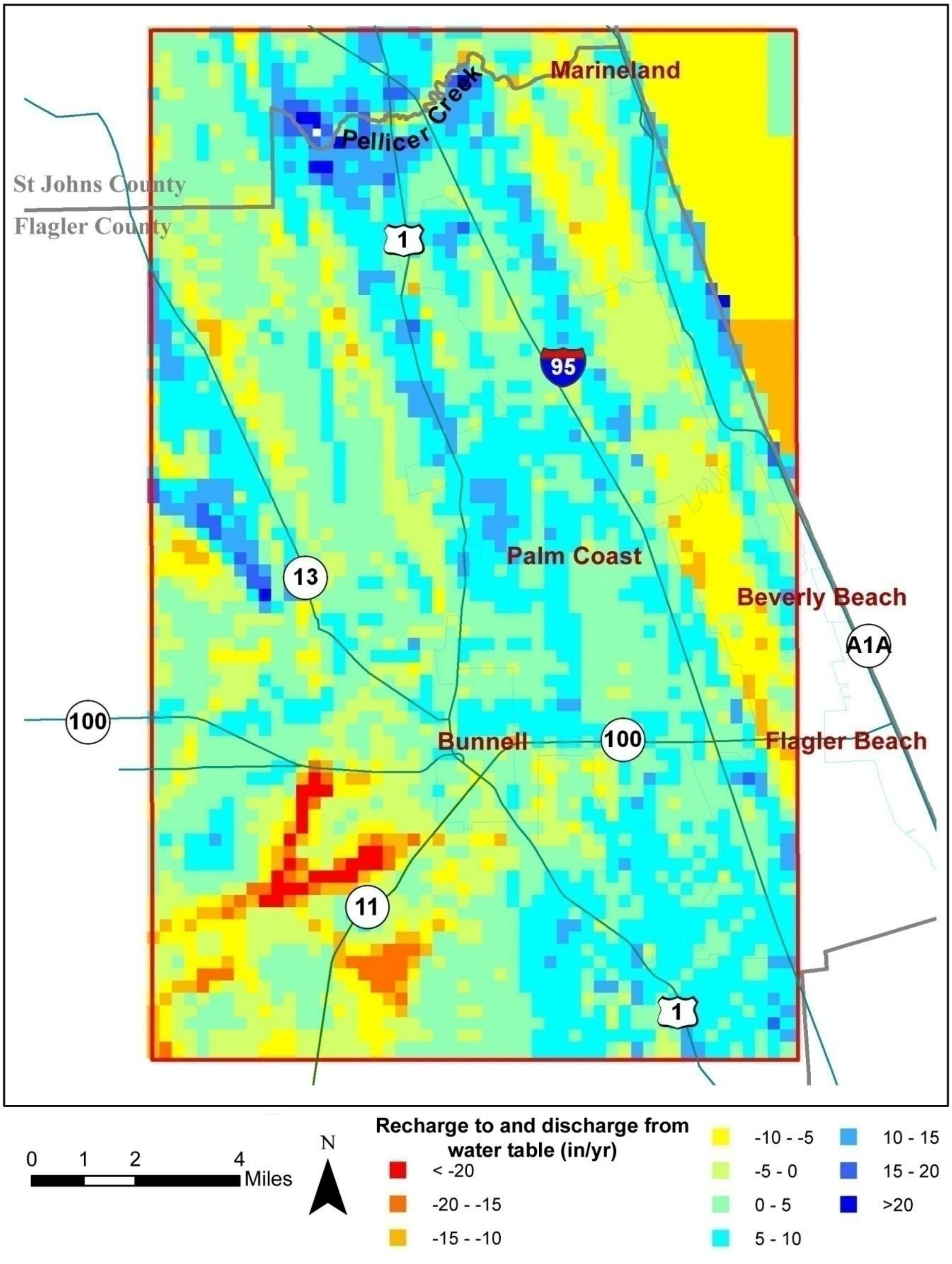


Figure 66 Average 1995 simulated net recharge to Unconfined Surficial aquifer

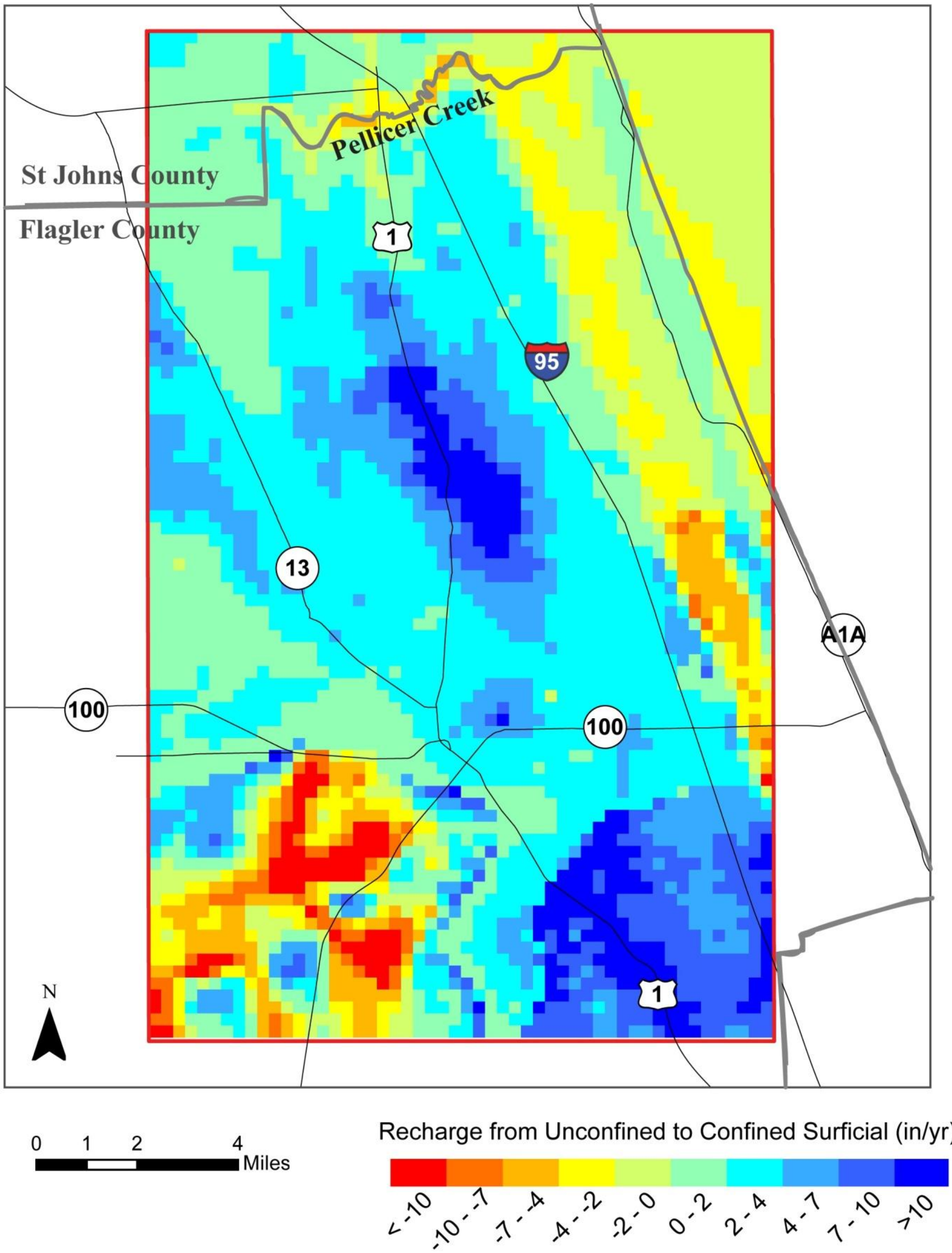


Figure 67 Average 1995 simulated recharge from Unconfined to Confined Surficial aquifer

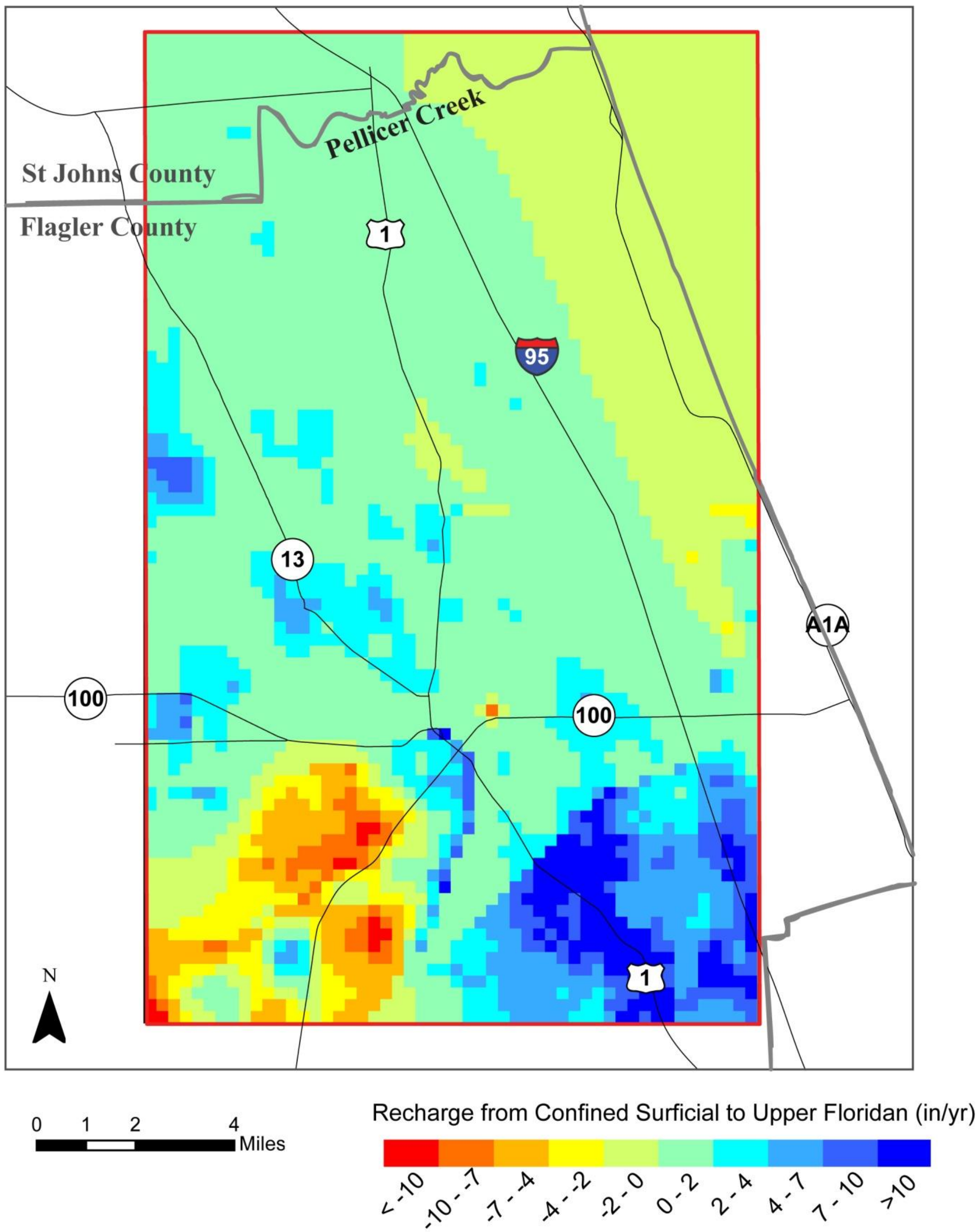


Figure 68 **Average 1995 simulated recharge from Confined Surficial to Upper Floridan aquifer**

In most of the study area, there is recharge to the Upper Floridan of between 0 and 4 in/yr. Higher recharge occurs in the west central areas and in the southeast corner of the study area. There is net discharge from the Upper Floridan aquifer along Haw Creek and east of I-95.

The Haw Creek basin is a discharge zone for the Upper Floridan aquifer even though water levels are below land surface in the area. Based on Doppler rainfall data, USDA Curve Number (CN) analysis, and results of model calibration, rainfall recharge (rainfall minus runoff) in the area is between 35 and 45 in/yr. The land surface elevation in the area is 10 ft (amsl) or less and assuming the water table is at 0.9 times land surface elevation based on the regression analysis used in this study, depth to groundwater in the area is approximately one foot below land surface. Assuming a potential ET rate of 60 in/yr and an extinction depth of 6 ft, the average ET in the area is approximately 50 in/yr resulting in a net groundwater discharge in the area between 5 to 15 in/yr (50 minus 35-45). The source of this groundwater discharge is upward leakage from the Upper Floridan aquifer that results in a depression in the potentiometric surface in the Haw Creek subbasin.

A value of 45 ft/day was specified for the hydraulic conductivity of the Unconfined Surficial aquifer in most of the study area to provide the best fit between simulated and observed hydraulic head. Model derived transmissivity in the Unconfined Surficial aquifer is presented in Figure 69. The distribution of transmissivity in the Confined Surficial aquifer is presented in Figure 70. The distribution is similar to that derived by Toth (2001) except that the minimum transmissivity in the aquifer was specified as 2,200 ft^2/day. This value is between the median and average transmissivity of 2,000 ft^2/day and 2,700 ft^2/day estimated at the PCU production wells.

The calibrated distribution of transmissivity in the Upper Floridan aquifer is presented in Figure 71. The range varies between 16,400 and 57,000 ft^2/day, and the average value for the model is 29,500 ft^2/day. As discussed above under section Aquifer Hydrogeologic Properties, the field derived average transmissivity is 22,347 ft^2/day.

Leakance in TCU and ICU was calculated by dividing the model calibrated vertical hydraulic conductivity (Kv) with the thickness of the corresponding confining unit estimated by Davis (2006). Based on analysis of pump test data and geophysical logs, the estimated range of Kv in the TCU is 0.001 to 0.01 ft/day, and 0.001 and 0.1 ft/day in the ICU.

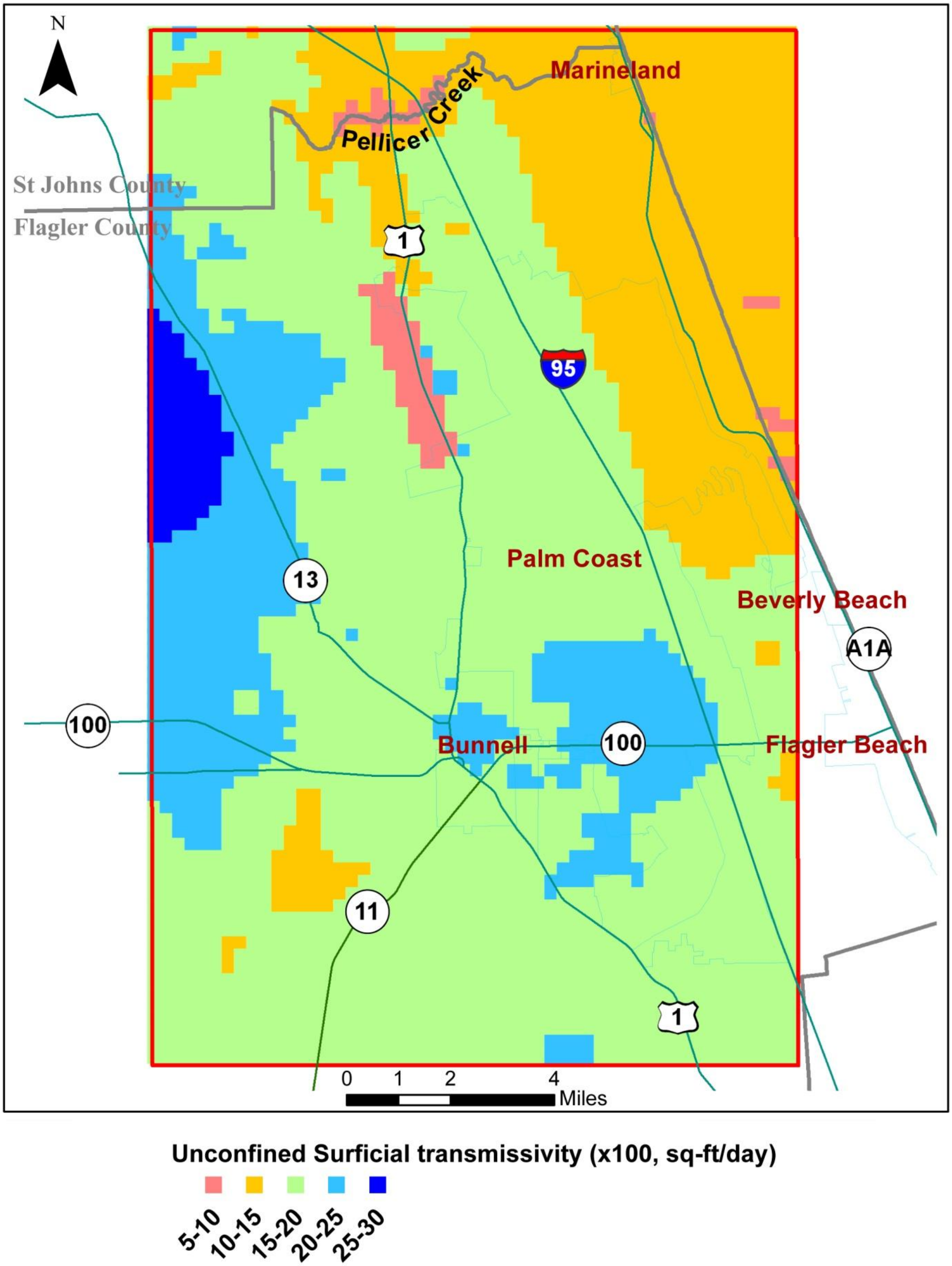


Figure 69 **Model derived Unconfined Surficial aquifer transmissivity**

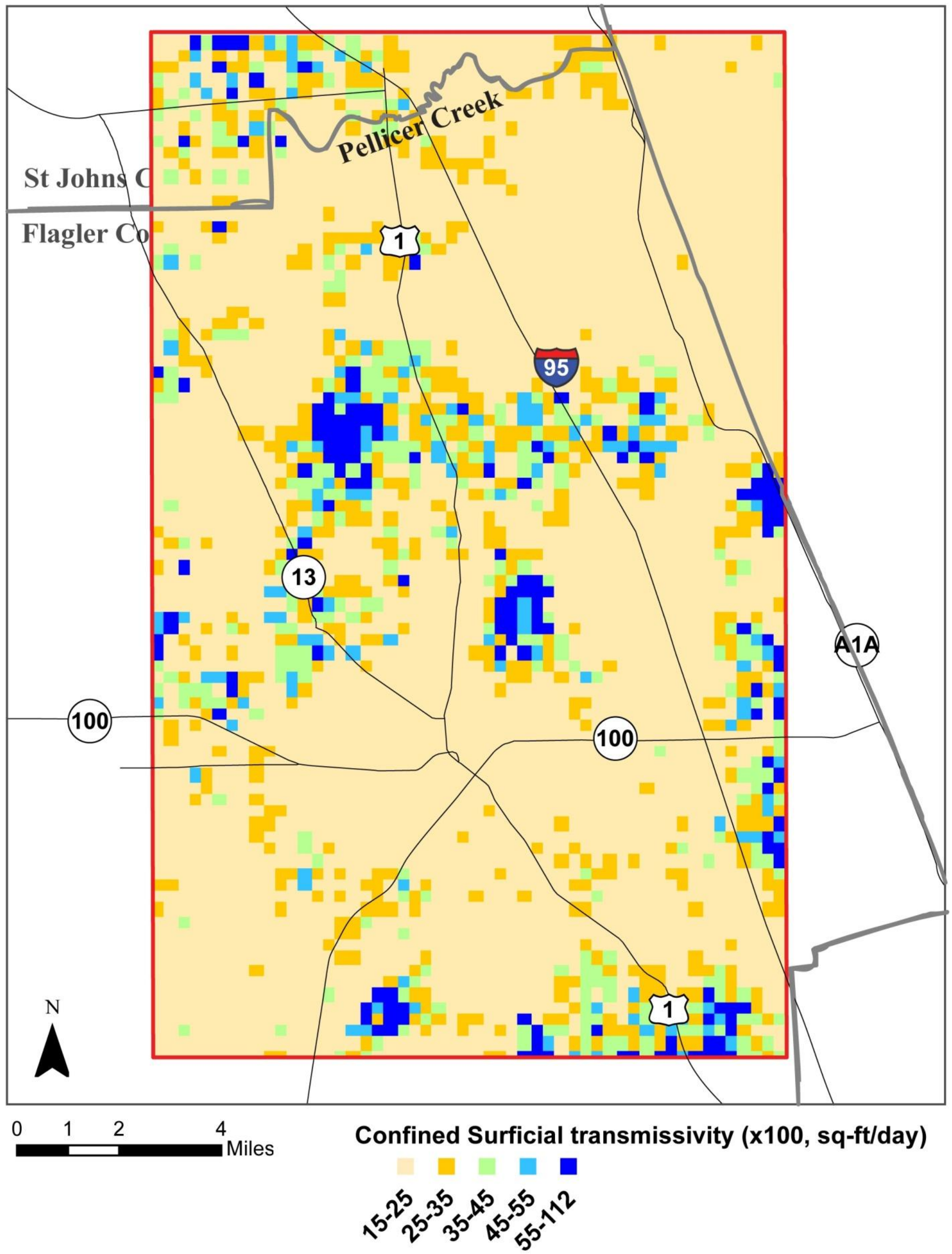


Figure 70 Model derived Confined Surficial aquifer transmissivity

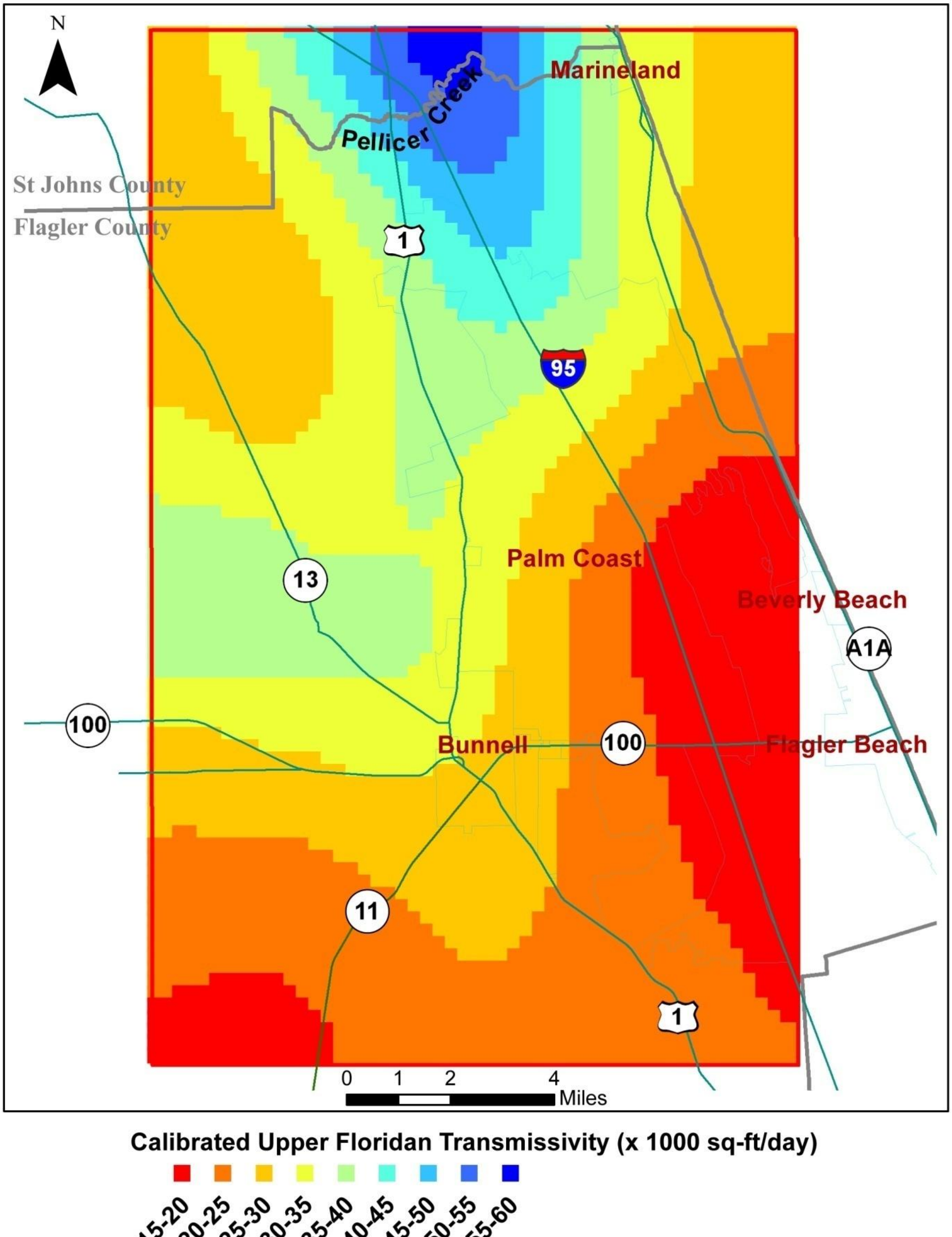


Figure 71 **Calibrated Upper Floridan aquifer transmissivity**

The model calibrated distribution of Kv in the TCU and ICU is presented in Figures 72 and 73, respectively. In most of the model area, a uniform value of 0.001 ft/day was required for calibration. In the southern portions of the model, the confining unit appears to be more permeable and Kv is in the field estimated upper range in both confining units. The leakance in the TCU and ICU is presented in Figures 74 and 75.

3.8 Sensitivity Analysis

Sensitivity analysis is conducted to quantify the relationship between various model parameters, boundary conditions, stresses, and model results. The goal is to identify model input data sets that have most influence on model results. This process allows a verification analysis of some of the physical processes represented in the model. For sensitivity analysis, the input parameters are varied within reasonable ranges and the system response is computed and evaluated. Results from sensitivity analyses accelerate the process of model calibration and assist in directing additional field data collection by identifying critical parameters with sparse information.

A series of runs were conducted during which various calibrated aquifer parameters, stresses, and boundary conditions were varied, and the corresponding impact on simulated heads in all three aquifers recorded for the 1995 simulation period. The model input data sets that were examined include the aquifer hydraulic conductivities, confining unit leakance, recharge, surface evapotranspiration rates, evapotranspiration extinction depth, general-head boundary conductance and heads, and the well skin factor for wells in the Confined Surficial aquifer. Each parameter was varied globally over a range of values that was deemed to encompass the uncertainty in that parameter. The root mean square error (RMSE) between the simulated and observed head values in each aquifer is presented in Figures 76-79.

Heads in all three aquifers were insensitive to transmissivity variation in the Unconfined Surficial aquifer. Varying transmissivity in the Confined Surficial and Upper Floridan aquifers primarily affects heads in the particular aquifer where the variation was invoked.

Variation in leakance of the TCU affects heads in the Confined Surficial aquifer the most of all three aquifers. It should be mentioned that the residuals in the Confined Surficial aquifer are based on observations estimated at the PCU production wells.

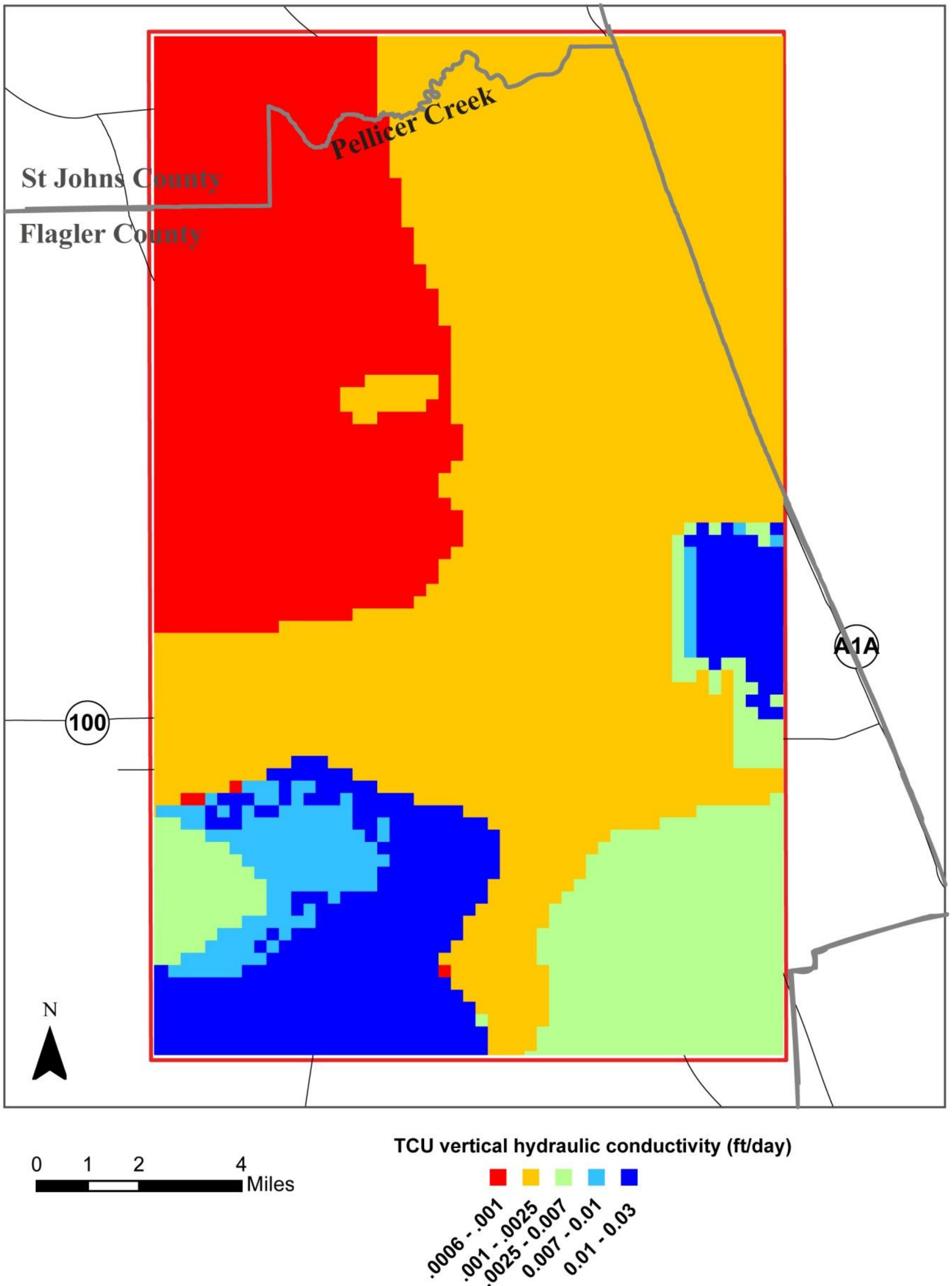


Figure 72 Model derived vertical hydraulic conductivity of Top Confining Unit

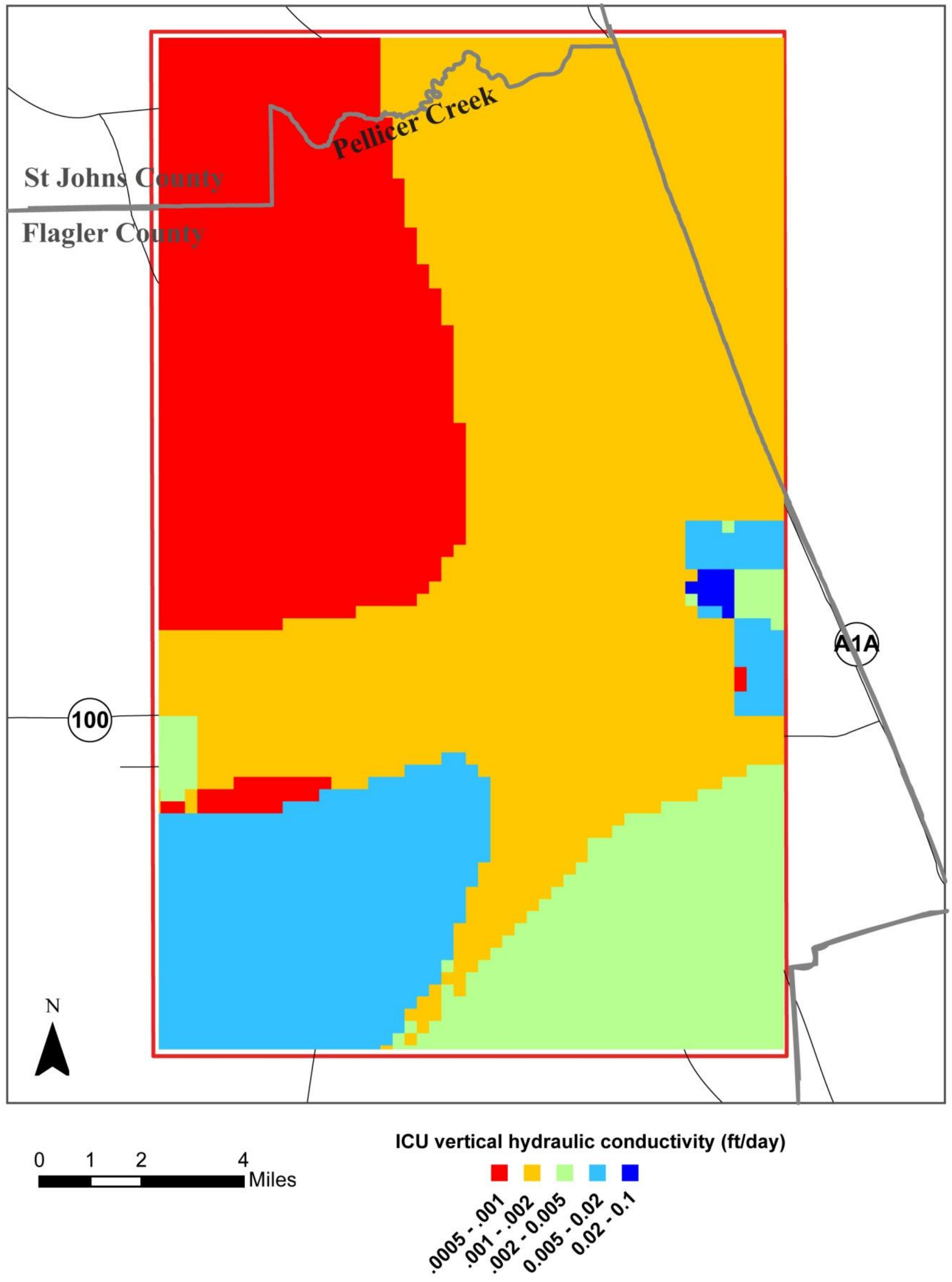


Figure 73 **Model calibrated vertical hydraulic conductivity of Intermediate Confining Unit**

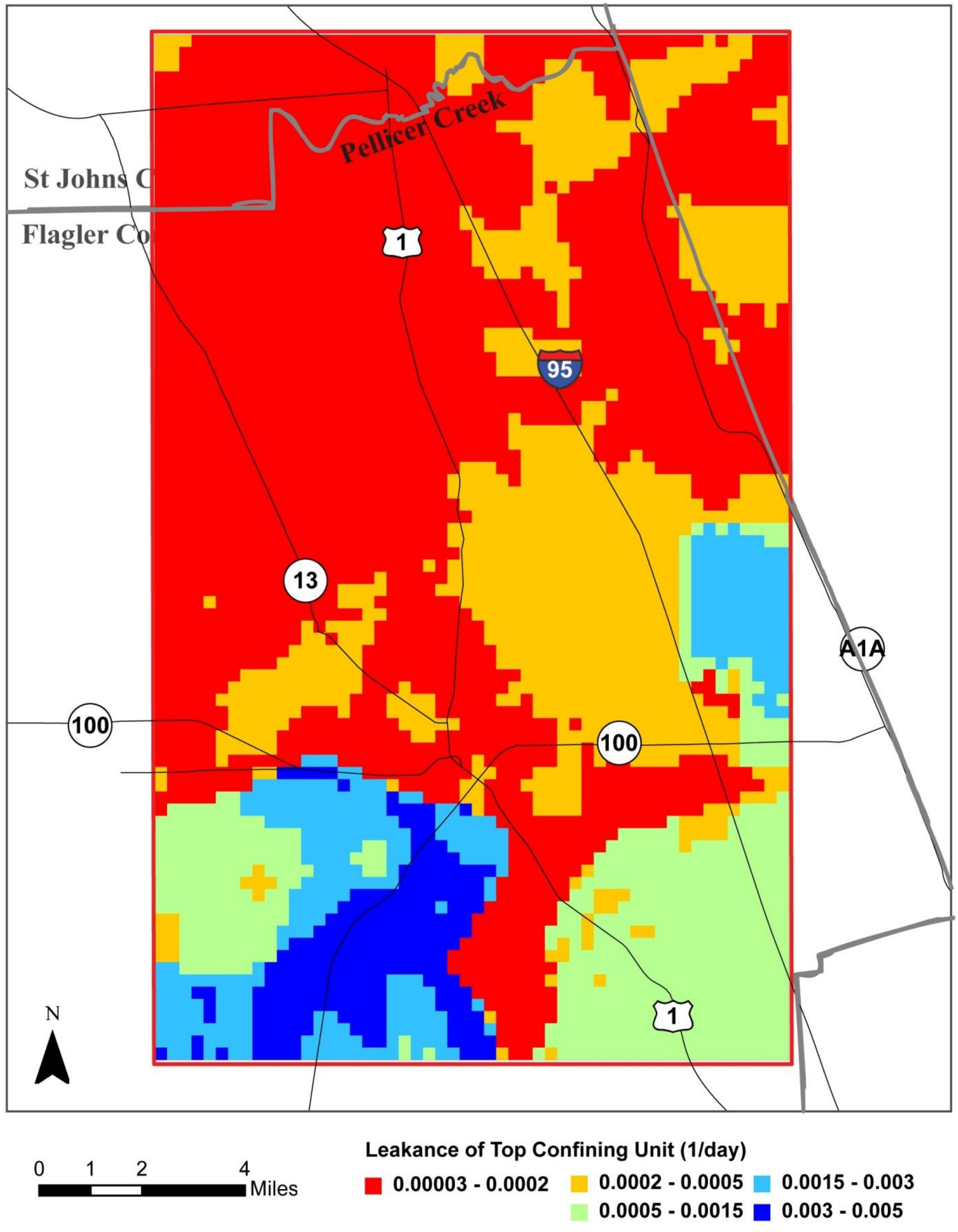


Figure 74 Model derived leakance of Top Confining Unit

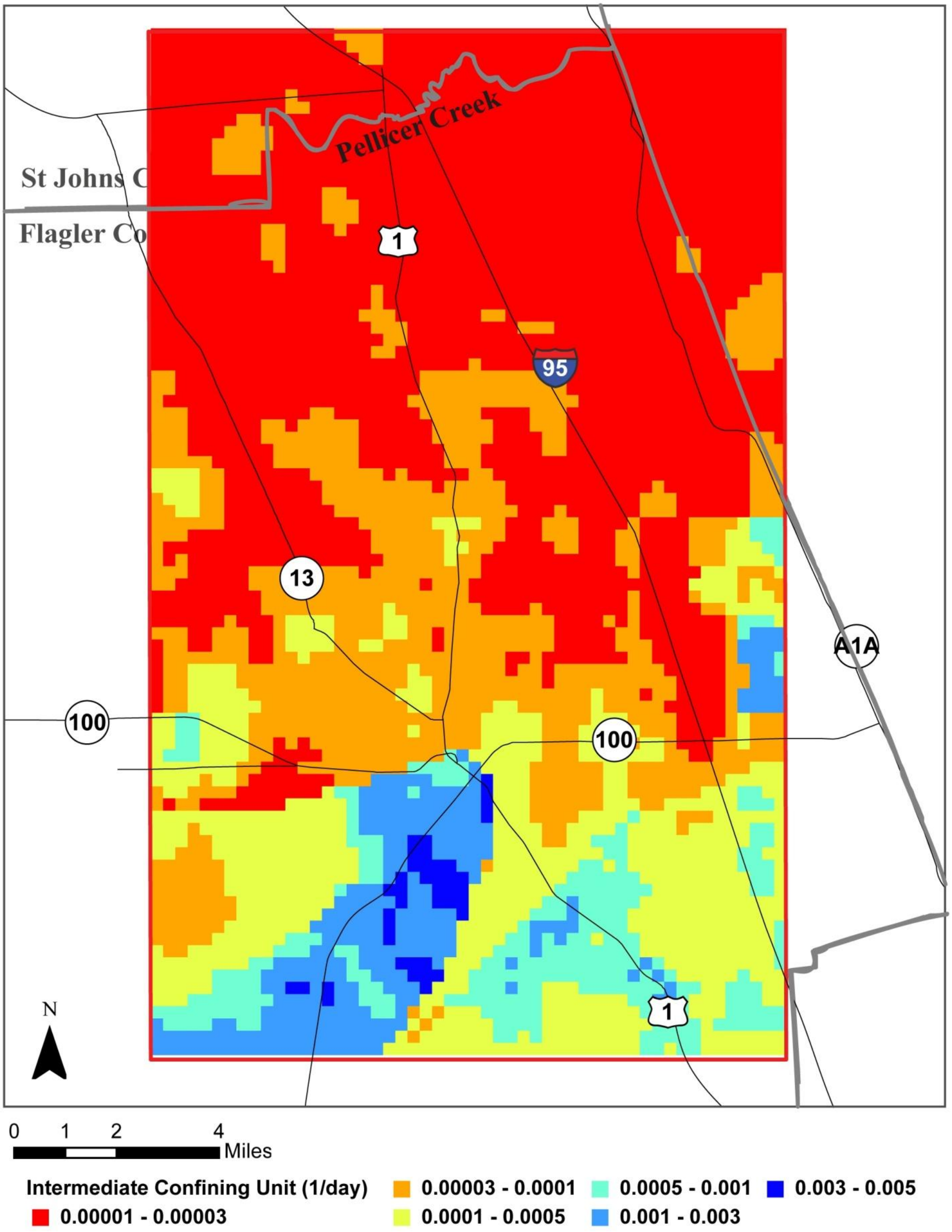


Figure 75 **Model derived leakance of Intermediate Confining Unit**

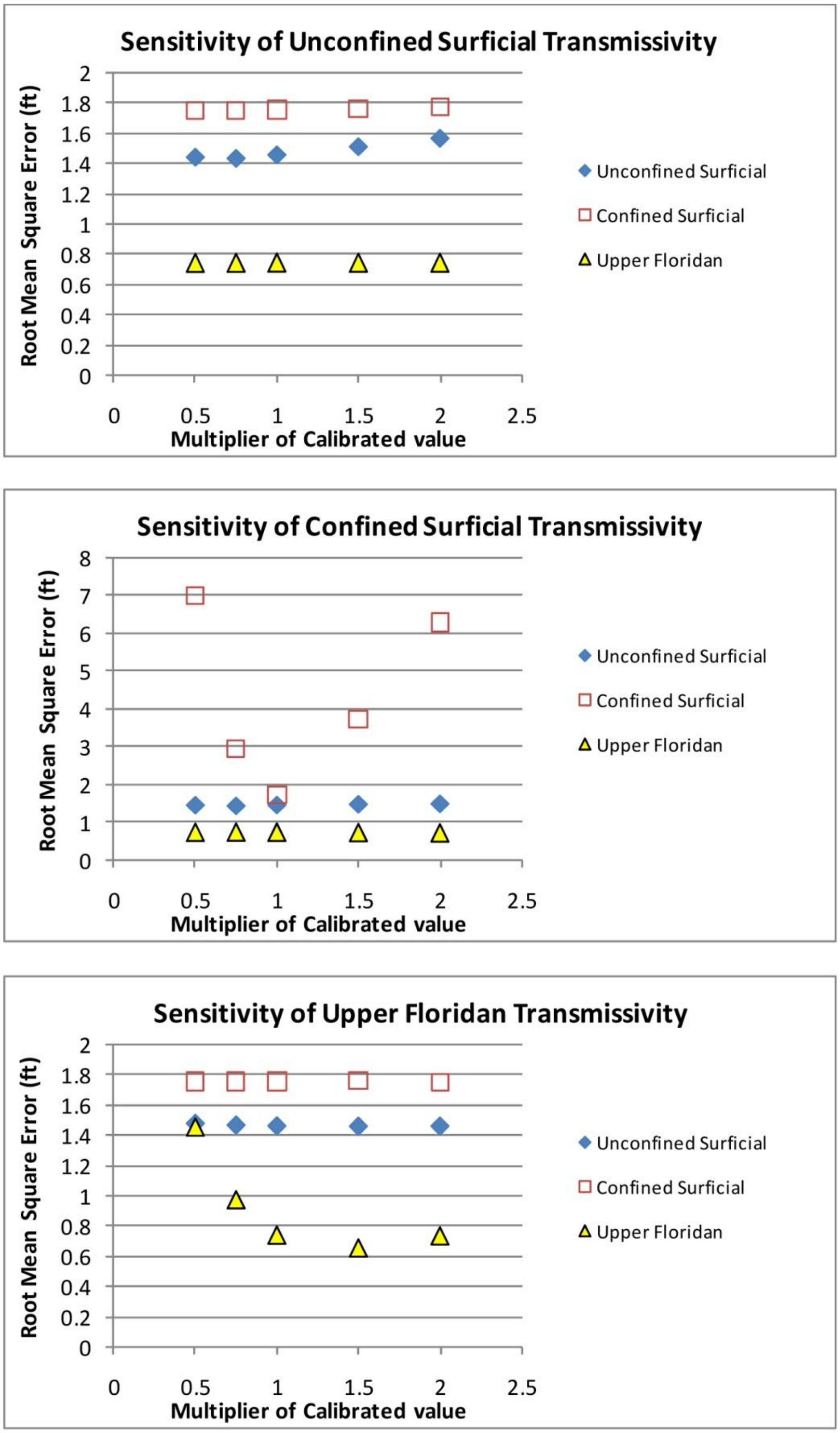
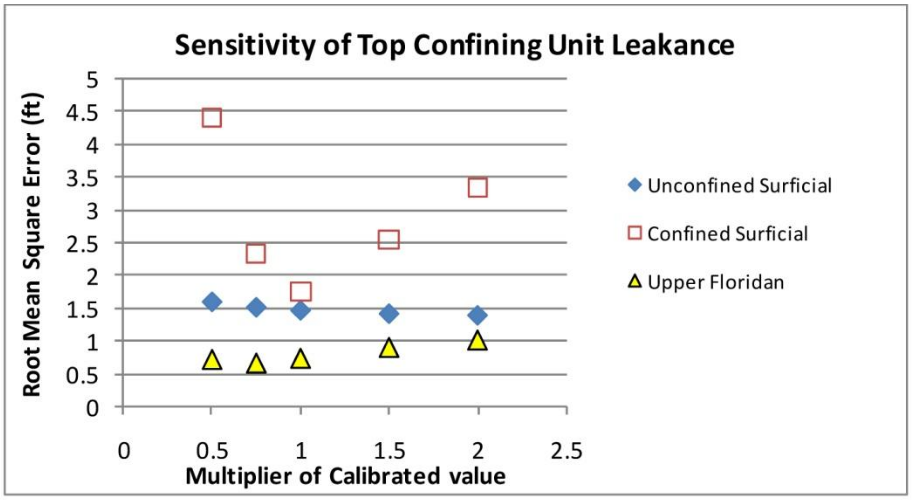


Figure 76 Aquifer transmissivity sensitivity results for 1995 calibration period



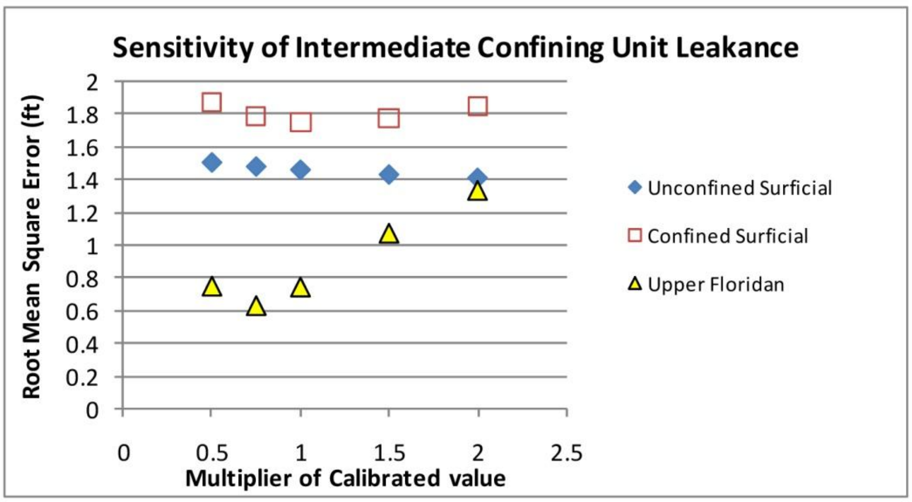


Figure 77 Confining unit leakance sensitivity results for 1995 calibration period

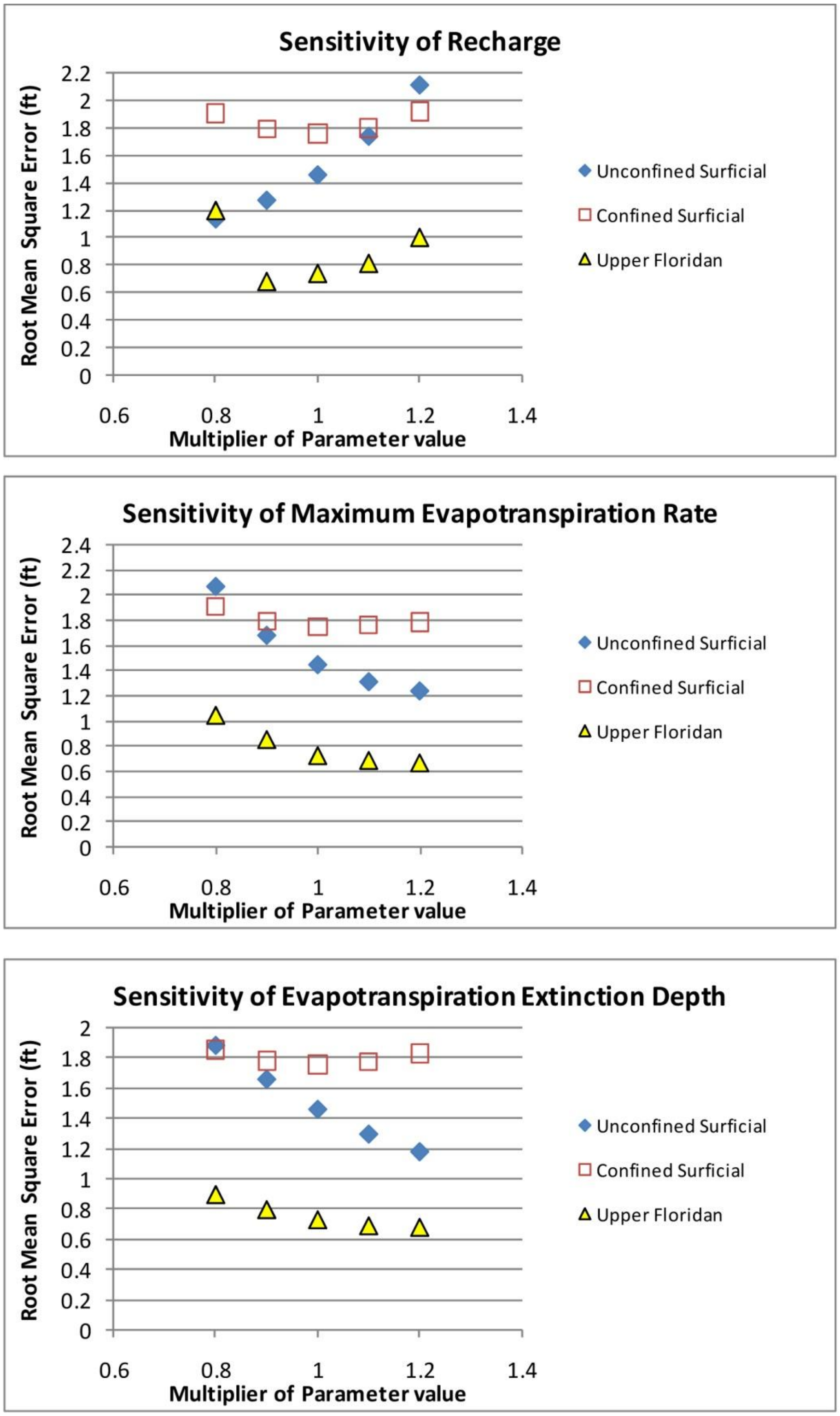


Figure 78 Recharge and evapotranspiration sensitivity simulation results for 1995 calibration period

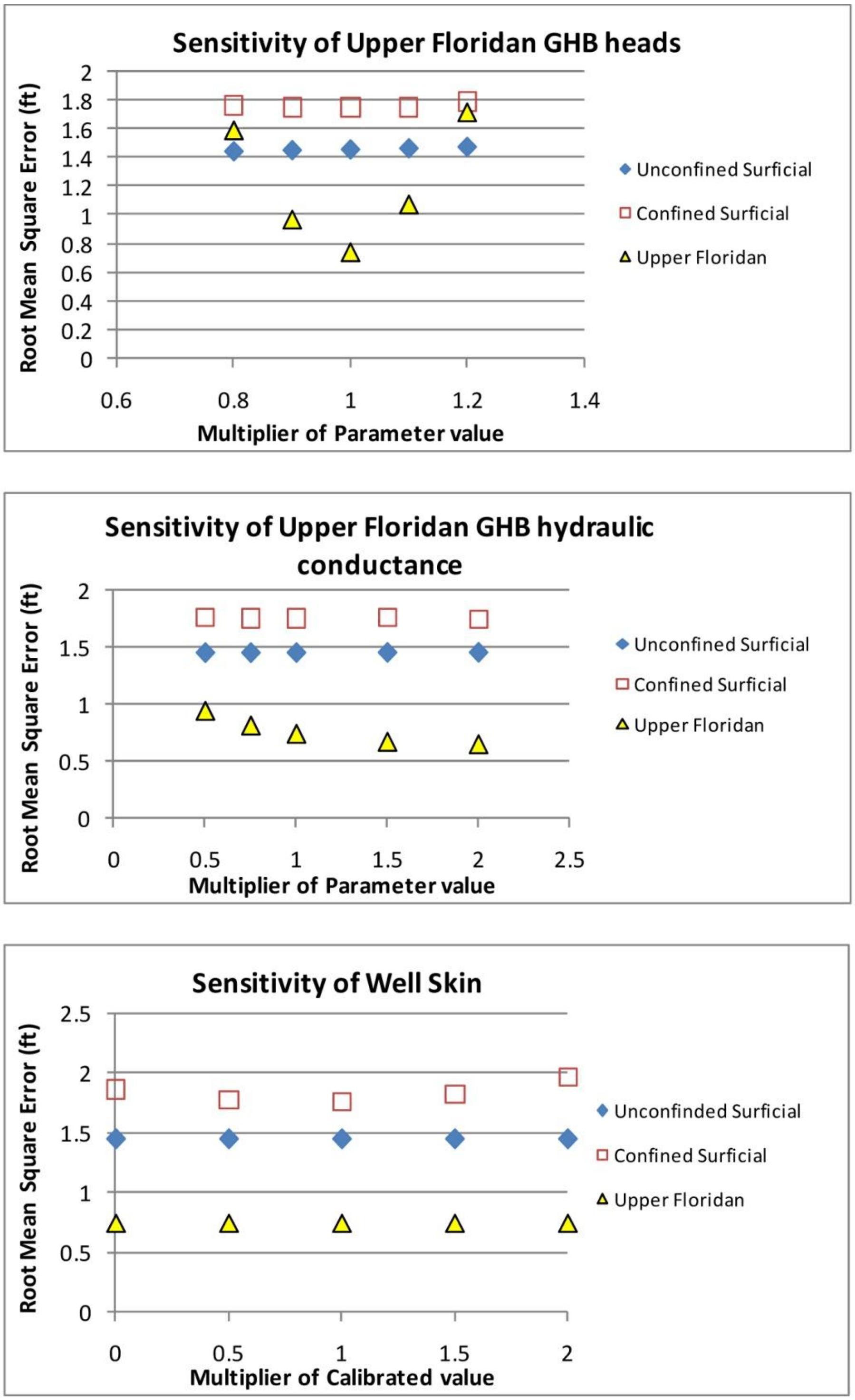


Figure 79 General-Head Boundary and well skin sensitivity simulation results for 1995 calibration period

Hence, heads at the data points in this aquifer (i.e., production wells) are expected to be highly sensitive to leakance as small changes in this parameter can cause large changes in well drawdown. It is unlikely that heads would be as sensitive at locations not affected by wellfield pumpage. Since the ICU is relatively less permeable than the TCU, heads in the Upper Floridan aquifer are not as affected by variations in leakance of the TCU. Variation in leakance of the ICU affects heads in both the Upper Floridan and Confined Surficial aquifers.

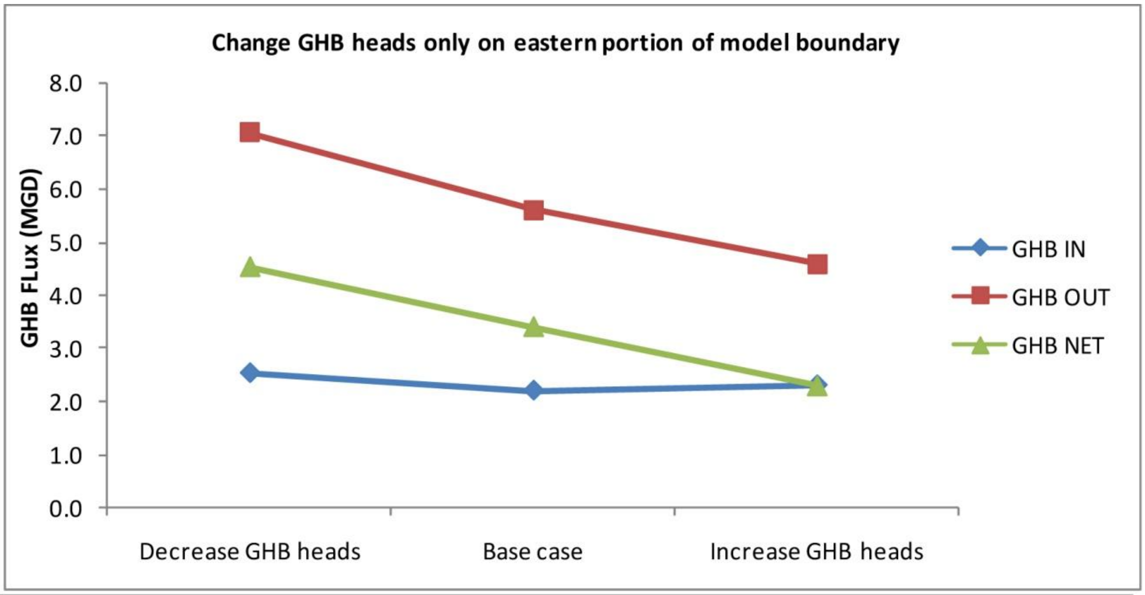
The heads in all three aquifers were sensitive to flux along the top boundary (Figure 78). Heads in the Unconfined Surficial aquifer were most affected by variation in recharge rates. Heads in all three aquifers were also highly sensitive to changes in maximum (or surface) ET rates (Figure 78) as this affects the net recharge to the Unconfined Surficial and underlying aquifers. The simulated heads in all aquifers are also sensitive to variations in the extinction depth (Figure 78). An increase in extinction depth results in decreased ET rates, while a decrease in the extinction depth had the opposite effect as long as the water table is above the extinction depth. The recharge rate, the maximum ET rate, and the ET extinction depth are highly sensitive and have optimal parameter values near 1 in the Confined Surficial aquifer and the Upper Floridan aquifer. For these three parameters, however, the Unconfined Surficial aquifer has minimum values at parameter values other than 1, indicating that the model is not optimal at the calibrated parameter values relative to the head calibration targets. Model values assigned for recharge, maximum ET rate, and the ET extinction depth parameter reflect both a calibration effort and the consideration of a consensus of peer reviewers that reflect expert knowledge about the study area and the associated data sets. This consideration is important as the net water flux applied to the water table in the Unconfined Surficial aquifer involves complex interactions between recharge and evaporation that cannot be fully captured by the head calibration targets.

Heads in the Upper Floridan aquifer were sensitive to GHB heads prescribed along the lateral boundaries in the Upper Floridan aquifer (Figure 79). The heads in the overlying Confined Surficial and Unconfined Surficial aquifers were not significantly affected by changes in GHB heads in the Upper Floridan aquifer. Heads in the Confined Surficial and Unconfined Surficial aquifers were also minimally affected by changes in hydraulic conductance of the GHBs in the Upper Floridan. Heads in the Upper Floridan aquifer were not affected as much by an increase in the GHB conductance as they were impacted by a decrease in this parameter (Figure 79). An increase in the conductance results in more lateral flow in the Upper Floridan aquifer without substantially influencing the heads in that aquifer. A decrease in the conductance results in less lateral flow across the model boundaries and a subsequent buildup of heads in the aquifer.

The well skin factor, which was applied only at the production wells in the Confined Aquifer, was varied between a value of 0 and 2. The well skin only has a local effect on heads in the Confined Surficial aquifer (Figure 79). Although a reasonable well skin range can change heads in the well bore by 1 to 3 ft, a well skin factor of 0 increased the RMSE by 6% while a factor of 2 increased it by 12% relative to the calibrated well skin factor of 1.

Since there is some uncertainty in the value of head assigned to the GHB boundaries in the Upper Floridan aquifer, a sensitivity analysis was also conducted to examine the effect of a gradient change between the western and eastern GHB heads. Two cases were analyzed. In both cases, only heads on the eastern model boundary were changed resulting in a change in the west-east head gradient in the GHBs. In the first case, all GHB heads on the eastern model boundary were decreased by 2 ft. In the second case, all GHB heads on the eastern model boundary were increased by 2 ft. Results of this sensitivity analysis, as fluxes and heads, are shown in Figure 80.

When the GHB heads along the eastern boundary were decreased, the net GHB flux out the model increased from 3.4 MGD to 4.5 MGD resulting in a net change of 1.1 MGD exiting the model from GHBs compared to the base case conditions (Table 8). The effect of decreasing GHB boundary heads on the overall fit to target model heads is only evident in the Upper Floridan aquifer and the associated increase in RMSE was 0.089 ft or about 16% (Figure 80). When GHB heads along the eastern boundary were increased, the net GHB flux out of the model decreased from 3.4 MGD to 2.3 MGD resulting in a net change of 1.1 MGD entering the model from GHBs compared to the base case conditions. This change in head at the GHBs along the eastern boundary resulted in a modest impact on the overall fit to target heads in the Upper Floridan aquifer. The RMSE in this aquifer increased by 0.095 ft or about 8%. Overall, the net change of 1.1 MGD for these scenarios is a small impact; this change equates to about 0.52 percent of the total flux in or out of the model.



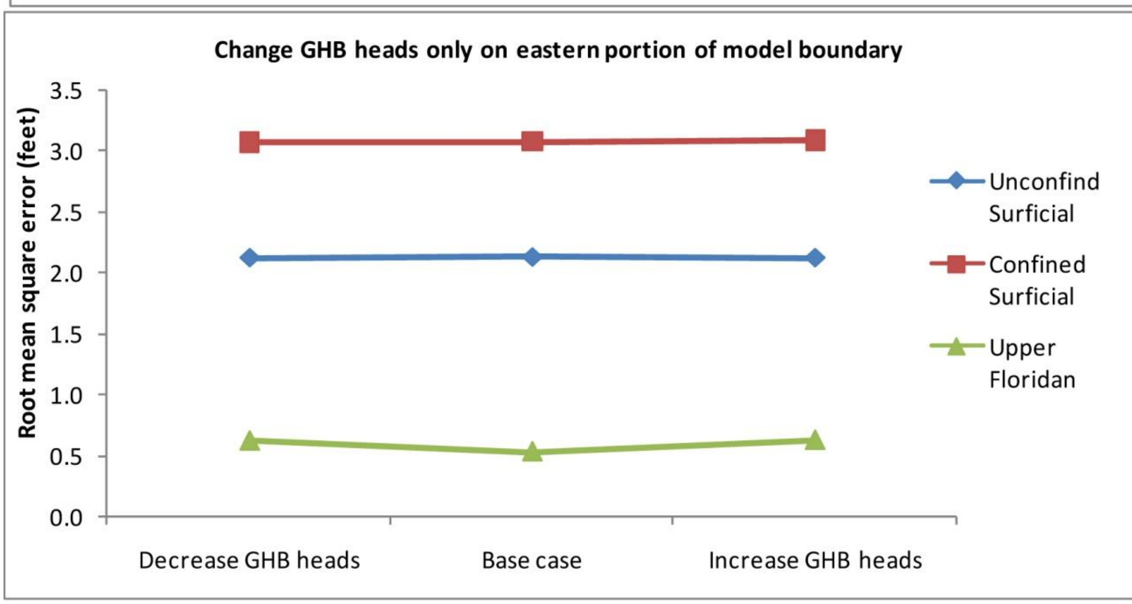


Figure 80 General-Head Boundary sensitivity simulation results for gradient change for 1995 calibration period

Table 8 Select water budget for GHB head sensitivity analysis (MGD)

Scenario	Aquifer	ET**		Drain		GHB		GHB	CHD	
		In	Out	In	Out	In	Out	Net	In	Out
Base Case	Unconfined Surficial		180.8		10.4					2.8
Base Case	Confined Surficial									
Base Case	Upper Floridan					2.2	5.6	-3.4		
Decrease GHB heads on eastern boundary by 2 feet	Unconfined Surficial		180.0		10.3					2.8
Decrease GHB heads on eastern boundary by 2 feet	Confined Surficial									
Decrease GHB heads on eastern boundary by 2 feet	Upper Floridan					2.5	7.0	-4.5		
Increase GHB heads on eastern boundary by 2 feet	Unconfined Surficial		181.6		10.6					2.9
Increase GHB heads on eastern boundary by 2 feet	Confined Surficial									
Increase GHB heads on eastern boundary by 2 feet	Upper Floridan					2.3	4.6	-2.3		

* Recharge=Rain – Runoff – Min ET of 27 in/yr
** Excludes Min ET of 27 in/yr

3.9 Data Cluster in Confined Surficial Aquifer

The existing PCU wellfield draws groundwater from the Confined Surficial aquifer. As indicated above, drawdowns in the Confined Surficial aquifer (as well as the Unconfined and Upper Floridan aquifers) are sensitive to the specified value of hydraulic conductivity in the Confined Surficial aquifer and the leakance of the confining units. Field data pertaining to hydraulic conductivity and leakance however exists only within the PCU wellfield as discussed in the Aquifer Hydrogeologic Properties section. Therefore, a logical question to address is whether this restricted hydrogeologic dataset within the Confined Surficial aquifer is a critical limitation with respect to accurately predicting drawdowns due to pumpage in the Confined Surficial aquifer.

Since the transmissivity of the Confined Surficial aquifer is relatively low, the drawdowns due to pumpage in PCU wellfield are also localized (Figure 85 and Figure 96). Therefore, at locations away from the wellfield, the Confined Surficial aquifer merely exists as a holding reservoir between the upper and lower confining units since the primary direction of groundwater flow is vertical away from the PCU wellfield. Hence, at locations away from the pumping centers, the entire depth between the Unconfined Surficial and the Upper Floridan aquifers could be represented by a single confining unit with a leakance value equal to the harmonic mean of the leakance of the upper and lower confining units. Hence, the absence of hydrogeologic data in the Confined Surficial aquifer at locations away from the PCU wellfield is not deemed a critical data deficiency.

3.10 Model Limitations and Assumptions

The construction of a numerical groundwater model is an attempt at developing a simplified tool to simulate groundwater flow in the subsurface. The geology, climate, and the magnitude and temporal distribution of groundwater withdrawals are all variables that are difficult to define precisely.

Simplification of these variables results in model limitations, which are briefly discussed below:

- Groundwater flow is assumed to occur in porous media. In reality, the geologic framework in the Upper Floridan aquifer is karstic and complex with preferential pathways due to fractures and solution cavities. Therefore, the results of the study are applicable only beyond a local scale.
- Each of the three primary hydrologic units is represented as a single model layer. In reality, each aquifer may contain several sand and clay layers and water levels within a hydrogeologic unit may be quite variable at a particular location.
- Model results depend on the grid scale of 1,250 ft. In areas with highly variable topography, this may result in gross simplification of the head distribution. Additionally, pumpage at wells within a cell area are accumulated together and withdrawals assumed to occur at the center of the cell.
- The model simulates steady-state flow thereby implying equilibrium conditions. In reality, the system is dynamic with climatic variations and variable groundwater demand rates causing fluctuations in the groundwater levels. Simulated water levels, therefore, should be viewed as representing average water level conditions over the course of a year for the particular stress period considered.
- The limited availability of hydrogeologic data precludes the derivation of unique aquifer parameter sets during model calibration.

Field data pertaining to the hydraulic properties of the Confined Surficial aquifer are clustered within the PCU wellfield. The absence of hydrogeologic data away from the PCU wellfield was not deemed a critical limitation for accurately predicting drawdown in the Confined Surficial aquifer based on localized drawdowns within the PCU wellfield and an analysis of the groundwater flow dynamics. As a groundwater model, and not a coupled surface-groundwater hydrologic model, the top boundary condition may need to be adjusted for future pumping periods being simulated. For example, there may be less runoff in the expanded wellfield area.

4.0 2011 PREDICTIVE SIMULATIONS

The calibrated groundwater flow model was used to estimate drawdown impacts due to projected withdrawals in 2011. As discussed in detail above under Water Use, total water use is projected to increase from approximately 9.7 MGD in 1995 to 18.6 MGD in 2011 with the largest increase at the PCU wellfields. The boundary conditions along the top model boundary were unchanged from 1995 levels. The lateral boundary condition was also unchanged for the 2011 simulations, which is expected to result in a slight underestimation of aquifer drawdowns because the 1995 head specified at the lateral boundary is likely higher than the 2011 head for some portions of the lateral boundary. The majority of pumping in predictive scenarios occurs in the Upper Floridan aquifer. The 1995 head targets in the Upper Floridan are distributed throughout most of the model domain, unlike the Unconfined Surficial and Confined Surficial aquifers in which the head targets are concentrated within the existing PCU wellfield. This more comprehensive target distribution provides information with which to constrain the hydraulic properties in the Upper Floridan and thus provides confidence in the head distributions for the predictive scenarios.

Based upon the calibrated model, simulated average 2011 potentiometric surface in each aquifer (Figures 81-83) and drawdowns (from 1995 conditions) were produced. Due to increased pumpage by PCU in the Upper Floridan aquifer, drawdown of 1 to 5 ft is projected in the southeastern portions of the model area, and up to 4 ft of drawdown is projected due to pumpage by the City of Bunnell (Figure 84). Pumpage in the Upper Floridan is also expected to cause 1 to 3 ft of drawdown in the Confined Surficial aquifer (Figure 85). Confined Surficial aquifer production northwest of the existing PCU wellfield is expected to result in 2-12 ft of drawdown locally in the Confined Surficial aquifer and up to 7 ft of drawdown is projected due to pumpage by the City of Bunnell in the southern portion of the model area. Due to increased irrigation return flow, a rebound is expected in the east-central portions of the study area. Within the Unconfined Surficial aquifer, 0-1 ft of drawdown is expected in the vicinity of the PCU wellfield and in the southeastern portions of the model, where there is a substantial increase in production from the Upper Floridan aquifer (Figure 86). A rebound in the Unconfined Surficial aquifer is projected in the northeast due to increased irrigation return flows, primarily attributed to reuse irrigation.

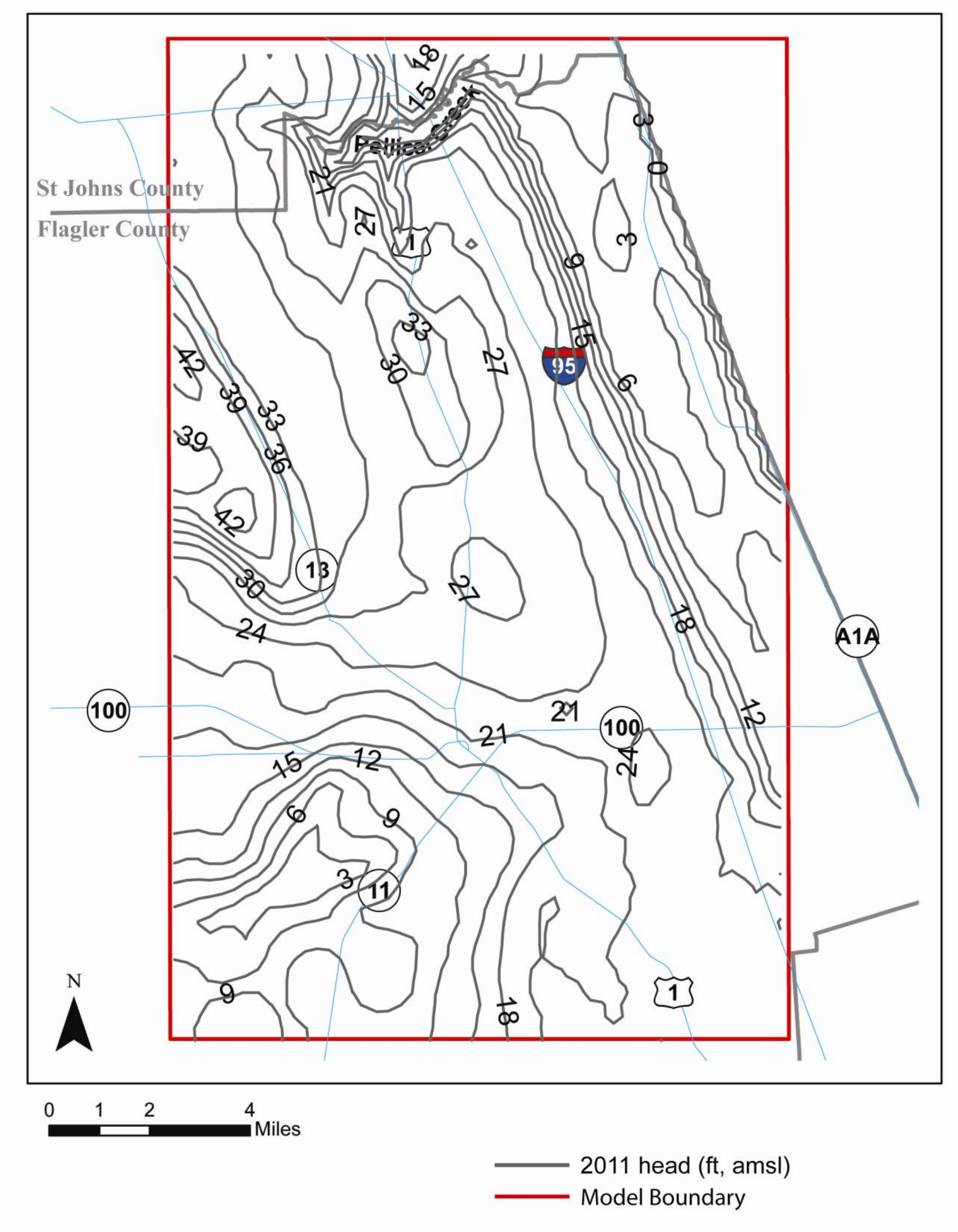


Figure 81 Model simulated potentiometric surface of Unconfined Surficial aquifer for 2011

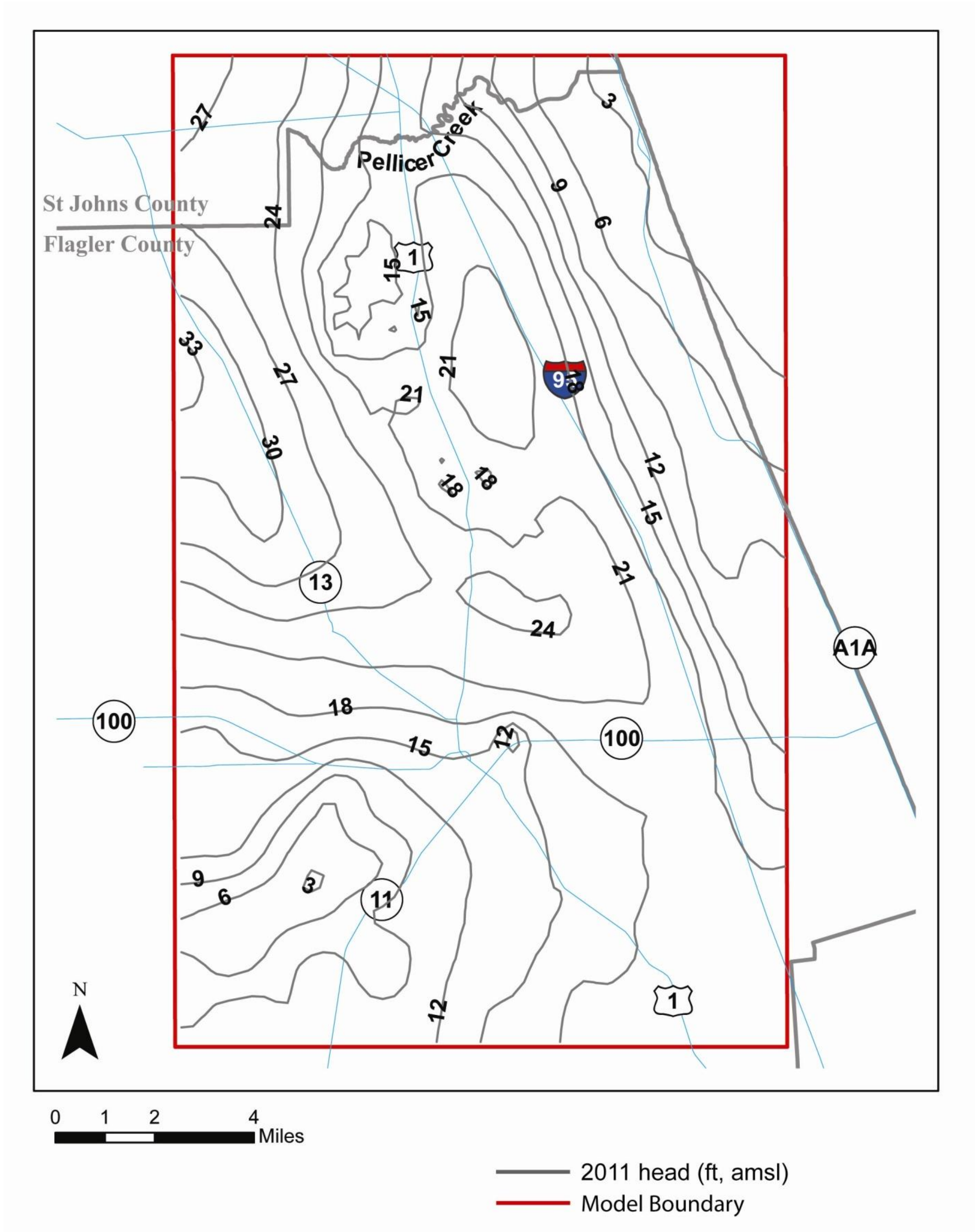


Figure 82 **Simulated 2011 potentiometric surface in Confined Surficial aquifer**

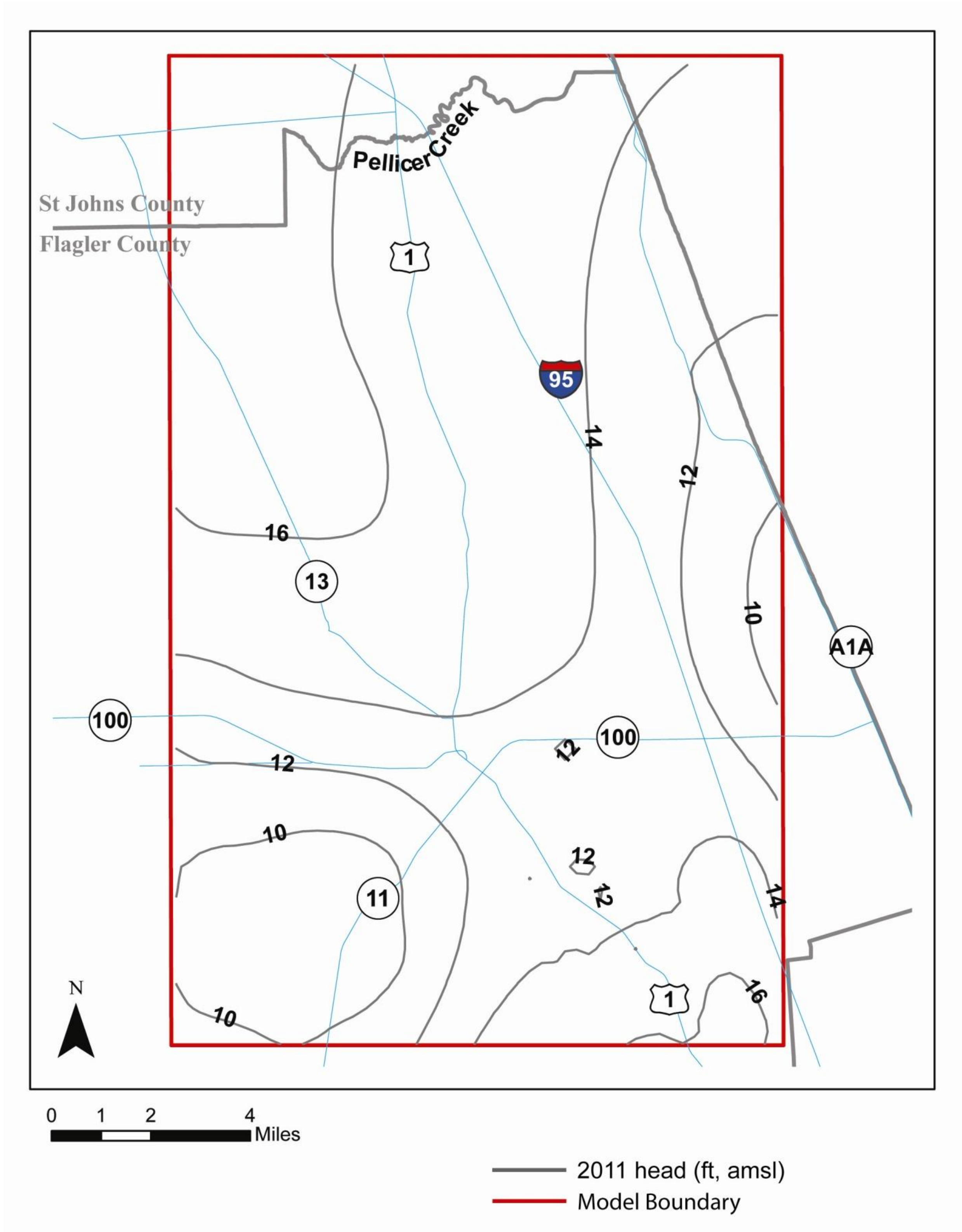


Figure 83 Simulated 2011 potentiometric surface in Upper Floridan aquifer

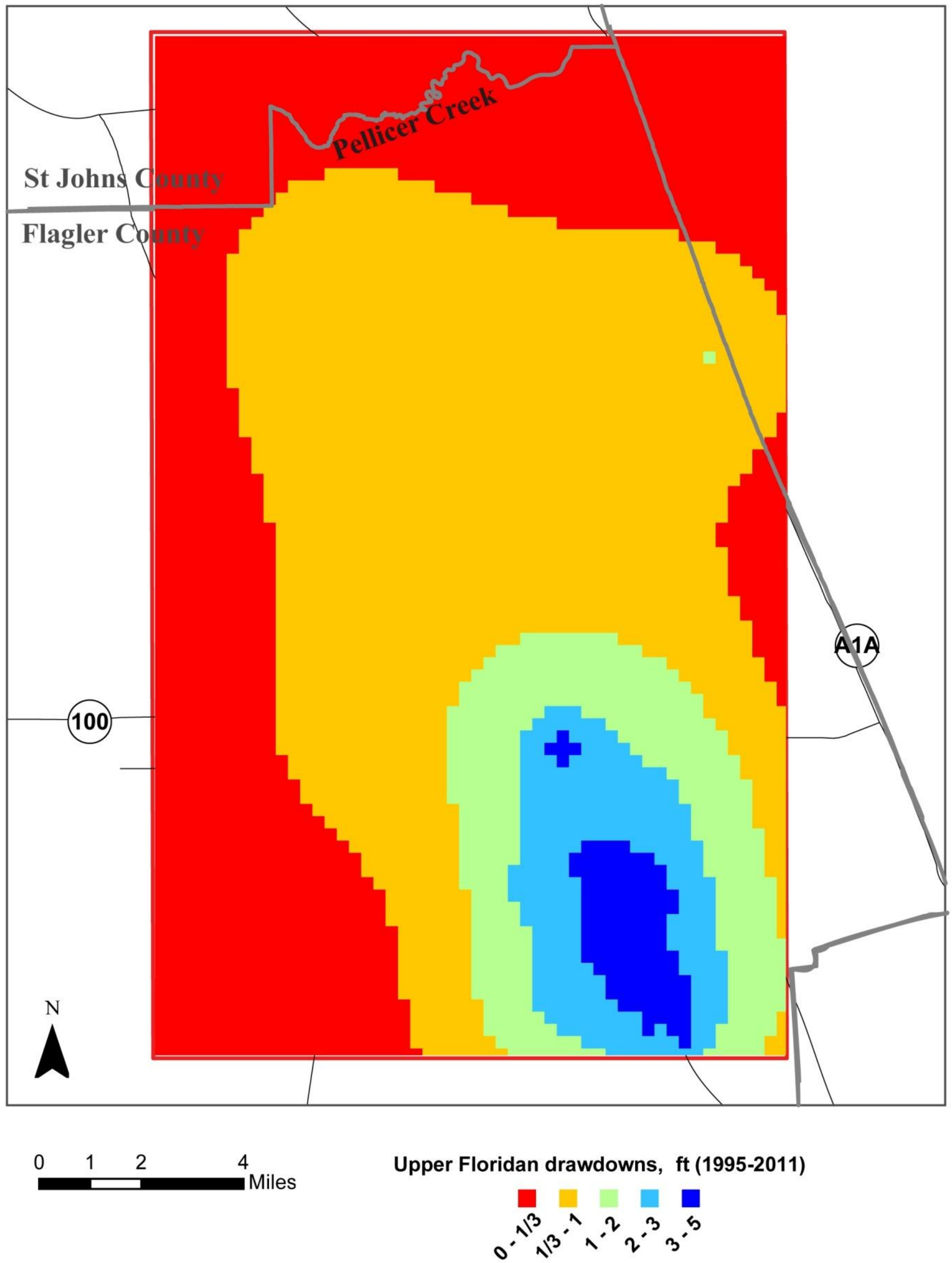


Figure 84 Simulated drawdowns in Upper Floridan aquifer (1995-2011)

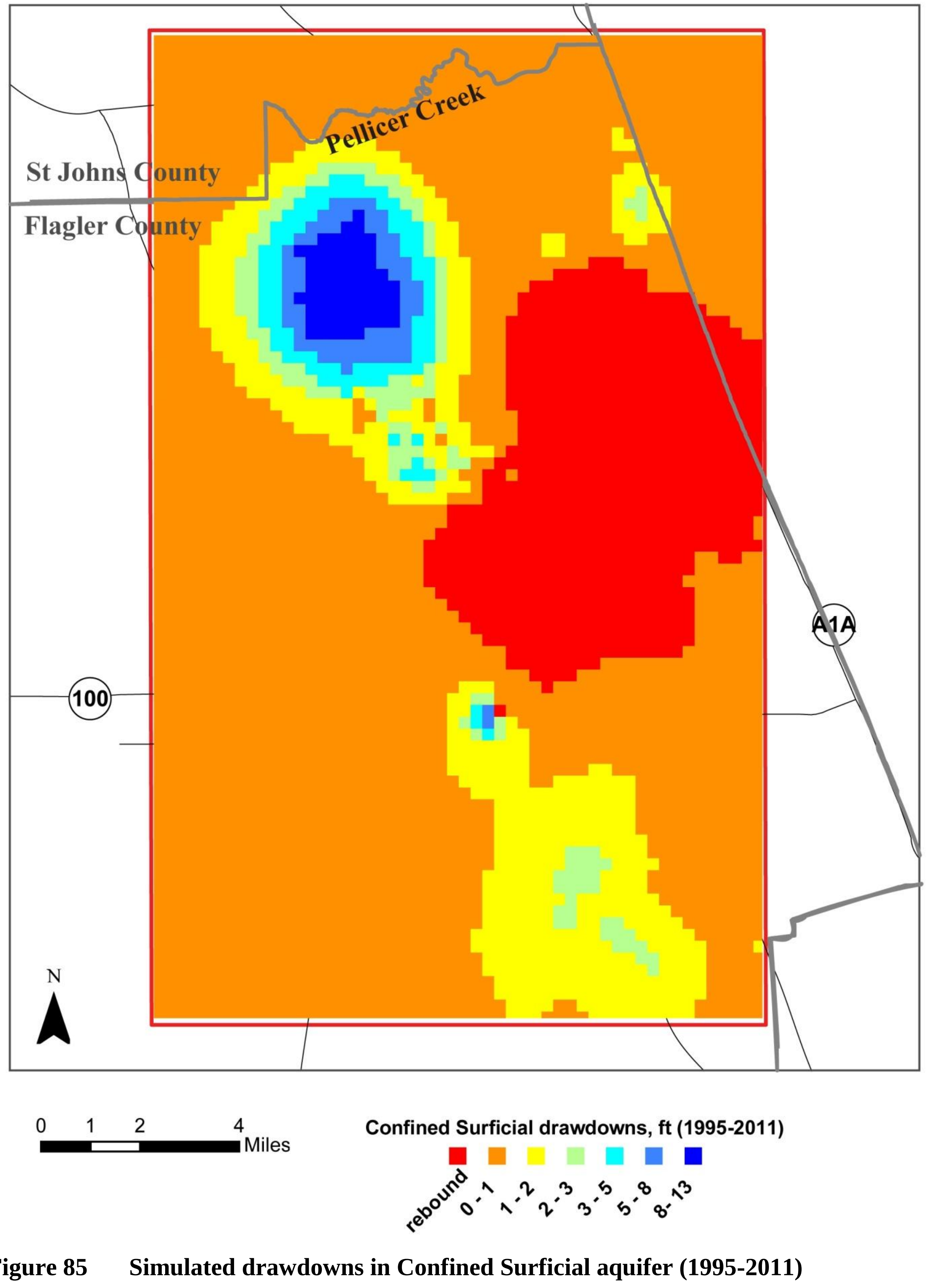


Figure 85 Simulated drawdowns in Confined Surficial aquifer (1995-2011)

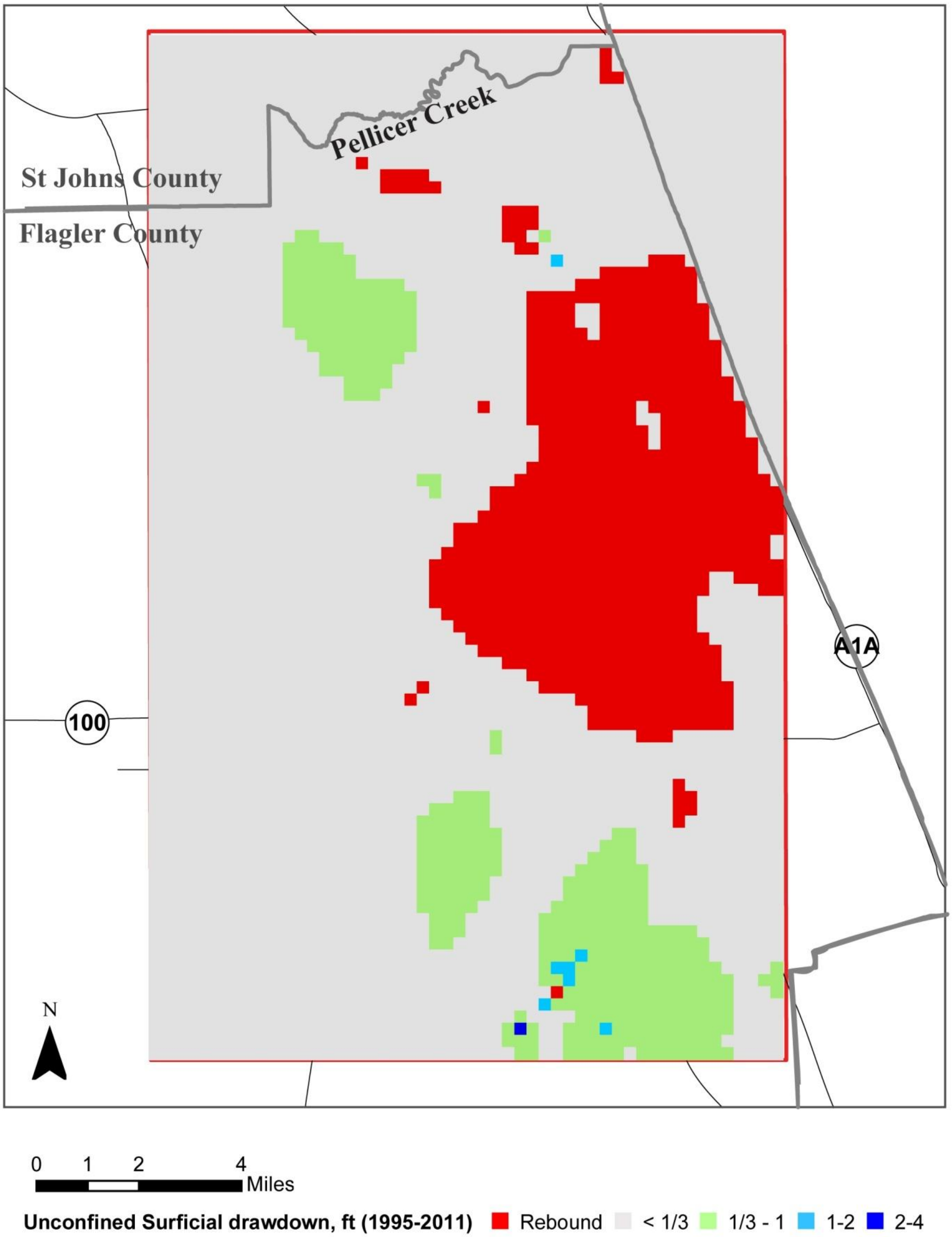


Figure 86 Simulated drawdowns in Unconfined Surficial aquifer (1995-2011)

4.1 Simulated Water Budget for 2011

The model water budget for 2011 is presented in Table 9 and Figure 87. The change for each hydrologic component from 1995 conditions is also presented in Figure 87. Pumpage for 2011 increased by approximately 8.8 MGD over 1995 rates. Irrigation return flows are projected to increase by 1.8 MGD over 1995 rates. Therefore, net increase in outflow (over 1995 rates) is approximately 7 MGD. Of this, approximately 4.6 MGD will be supplied due to less evapotranspiration from the surface, and approximately 3.7 MGD will be supplied by net change in cross-boundary flux in the Upper Floridan aquifer.

Table 9 Simulated 2011 water budget (MGD)

Aquifer	Recharge*		ET**		Well		Drain		GHB		Constant Head	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Unconfined Surficial	208.1	1.3		176.2	2.3	2.3		10.4				2.8
Confined Surficial						6.8						
Upper Floridan						9.4			3.1	4.3		

* Recharge=Rain – Runoff – Min ET of 27 in/yr
** Excludes Min ET of 27 in/yr

It should be noted that the predictive simulations are conducted assuming steady-state conditions. In reality, drawdown impacts will evolve over time and not fully develop until some time in the future after 2011.

4.2 Sensitivity Analysis

A series of runs were conducted for the 2011 pumping scenario during which various aquifer parameters, stresses, and boundary conditions were varied, and the corresponding impact on simulated heads in all three aquifers recorded. No model recalibration was conducted as part of sensitivity analysis. The model input data sets that were examined include the aquifer hydraulic conductivities, confining unit leakances, recharge, surface evapotranspiration rates, evapotranspiration extinction depth, and general-head boundary conductances and heads.

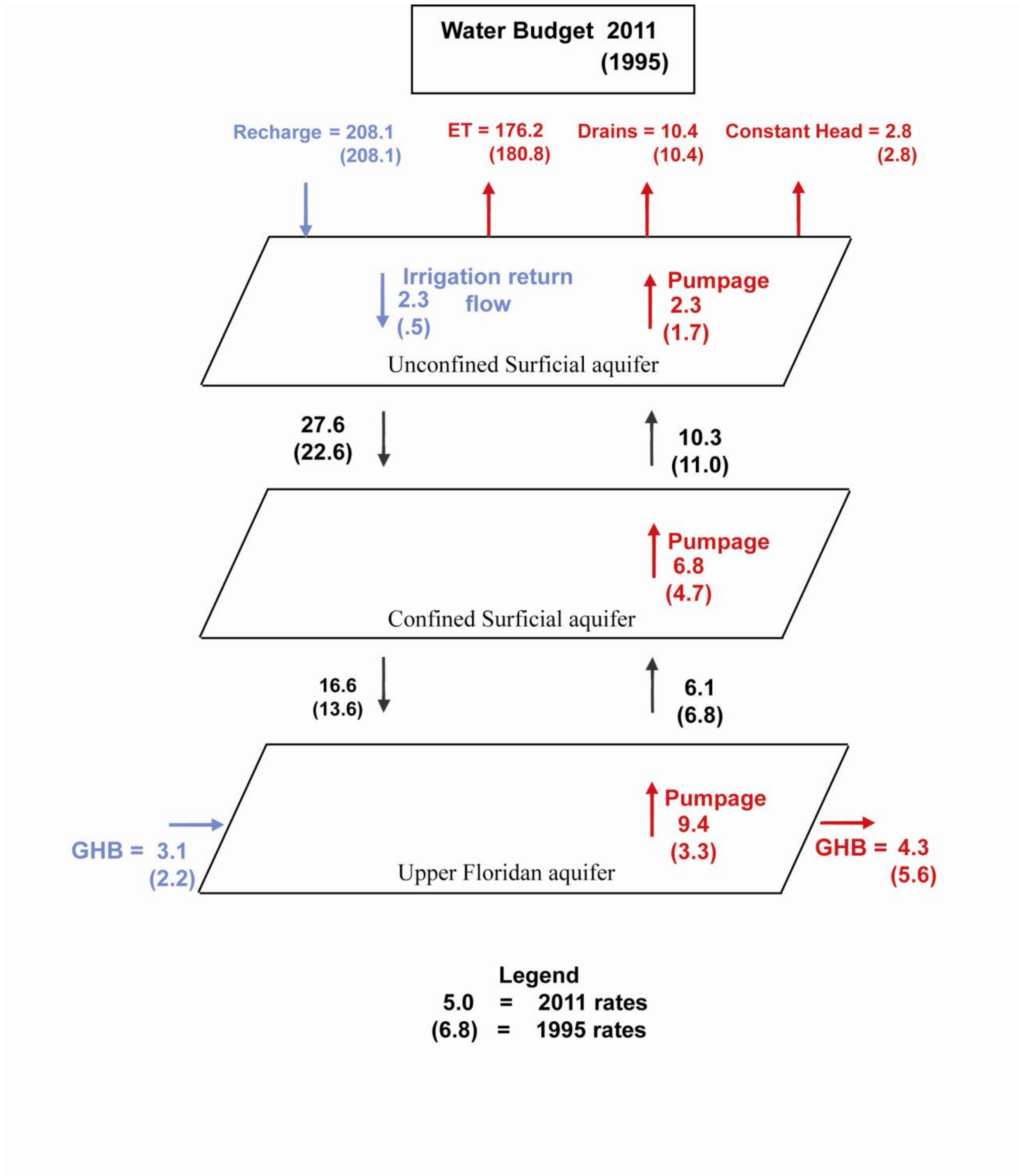


Figure 87 Model simulated water budget for 2011 (MGD)

Each of the parameters was varied globally over a range of values that was deemed to encompass the uncertainty in that parameter. The sensitivity analysis was conducted using two different performance metrics: root means square error (RMSE) and change in drawdown averaged over the entire model domain. The RMSE between the simulated heads in 2011 and observed head values in each aquifer in 1995 was calculated. Additionally, the change in drawdown from simulated heads in 2011 at base parameter values (a parameter multiplier value of 1.0) was calculated at each model grid cell and averaged over all the active cells. The relevance of the 1995 head observations to the 2011 predictions varies between aquifers due to the nature of the head targets. For example, all the head targets in the Confined Surficial aquifer are from production wells in the PCU wellfield and represent an average of pumped and non-pumped water levels over the year of 1995. As previously discussed, differences between pumped and non-pumped water levels vary from 10 to 25 ft. The pumping stress imposed on these targets varies significantly between 1995 and 2011 conditions which results in a different gradient between the water level target and the predicted water level at the model grid node. Consequently, because of model stresses and the location of the head targets, the absolute value of the average head residual in the Confined Surficial aquifer is much larger than the absolute value of average head residuals in either the Unconfined Surficial or Upper Floridan aquifers. If, for example, 1995 head targets were available in each model grid cell, resulting in a uniform sampling of the study area, the average absolute head residual in each of the three aquifers would appear more similar because heads not affected by wellfield pumpage are likely to be less sensitive than those affected by wellfield pumpage. The suitability of the head targets in the Confined Surficial aquifer is less than ideal for the 2011 predictive scenarios and the results of this sensitivity analysis should be interpreted with respect to this consideration.

Heads in the Unconfined and Upper Floridan aquifers were relatively insensitive to transmissivity variation in the Unconfined Surficial aquifer (Figure 88). Varying transmissivity in the Confined Surficial and Upper Floridan aquifers primarily affects heads in the aquifer where the variation was invoked.

Variation in leakance of the Top Confining unit (TCU) affects heads in the Confined Surficial and Upper Floridan aquifer (Figure 89). It should be mentioned that the residuals in the Confined Surficial aquifer are estimated at the PCU production wells. Hence, heads at the data points in this aquifer (i.e., production wells) are expected to be highly sensitive to leakance as small changes in this parameter can cause large changes in well drawdown. It is unlikely that heads would be as sensitive at locations not affected by wellfield pumpage. Variation in the leakance of the ICU affects heads in both the Upper Floridan and Confined Surficial aquifers.

A decrease in ICU leakance results higher heads in the Confined Surfical aquifer and lower heads in the Upper Floridan aquifer.

The heads in all three aquifers were relatively sensitive to flux along the top boundary, maximum ET rates, and the extinction depth (Figure 90). For all three parameters, inverse correlation exists between the RMSE of the Unconfined Surficial aquifer and the Upper Floridan aquifers. Essentially, the RMSE decreases when less water is supplied to the Unconfined Aquifer but this results in a greater mismatch in heads in the Upper Floridan aquifer.

Heads in the Upper Floridan aquifer were relatively sensitive to GHB heads prescribed along the lateral boundaries in the Upper Floridan aquifer (Figure 91). The heads in the overlying Confined Surficial and Unconfined Surficial aquifers were not significantly affected by changes in GHB heads in the Upper Floridan aquifer. Heads in the Confined Surficial and Unconfined Surficial aquifers were also minimally affected by changes in hydraulic conductance of the GHB.

The average change in drawdown, the second performance metric calculated for the 2011 sensitivity analysis, employs a uniform sampling of the study area and is independent of the spatial distribution of target heads. In general, most of the system responses are similar for both the average change in drawdown and the RMSE performance metrics. For example, varying transmissivity in the Confined and Upper Floridan aquifers primarily affects heads in the aquifer where the variation was invoked. Heads in the Unconfined Surficial aquifer and the Confined Surficial aquifer were both affected by variation in the transmissivity of the Unconfined Surficial aquifer; as the transmissivity of the Unconfined Surficial aquifer was increased, the cone of depression propagated further away from the pumping wells resulting in an increased average drawdown relative to the base parameter values (Figure 92). The TCU and the ICU leakance parameters both have an overall larger sensitivity to changes in head than do the transmissivity parameters (Figure 93).

One notable exception to similarities between the two performance metrics is the uniformity of the sensitivity response amongst the USA, CSA, and Upper Floridan aquifers for the recharge, maximum ET rate, and ET extinction depth parameters. If the recharge parameter multiplier is

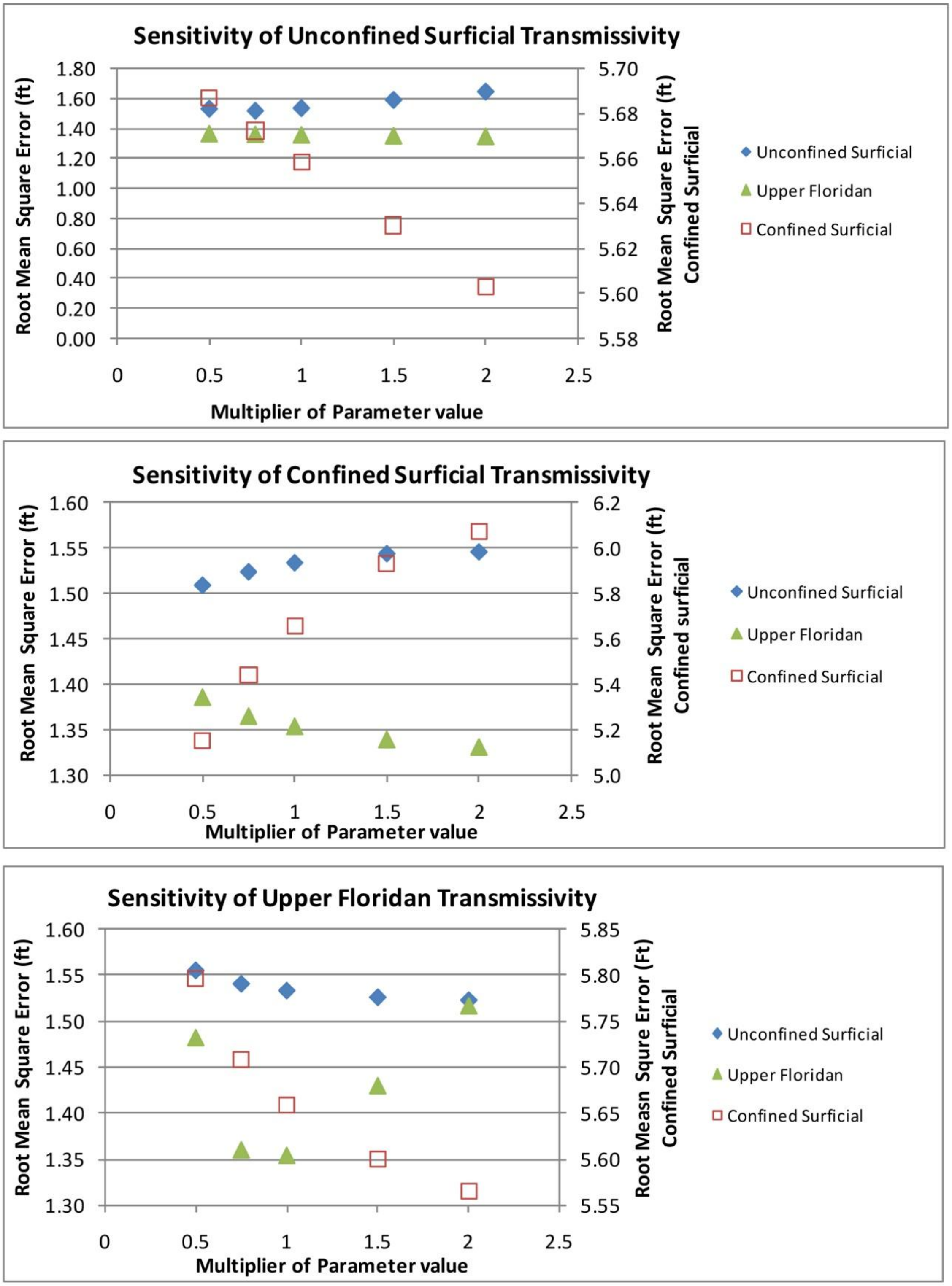
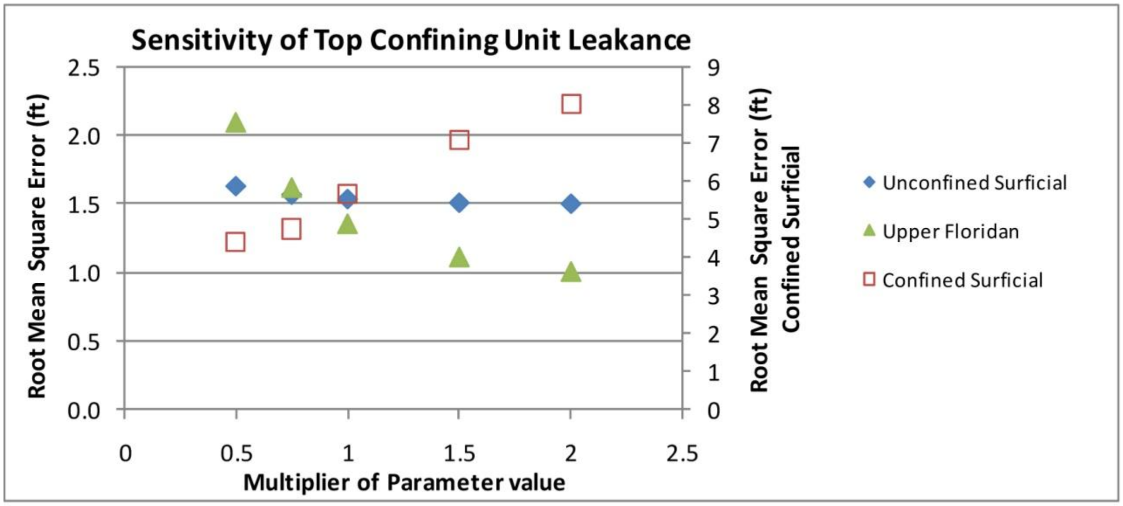


Figure 88 Aquifer transmissivity sensitivity root mean square error results for 2011



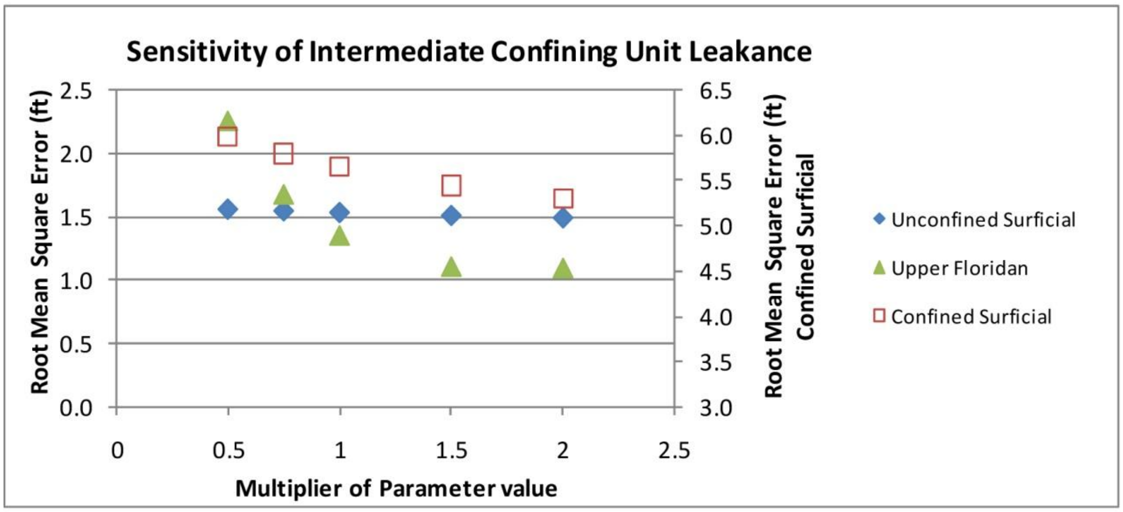


Figure 89 Confining unit leakance sensitivity mean square error results for 2011

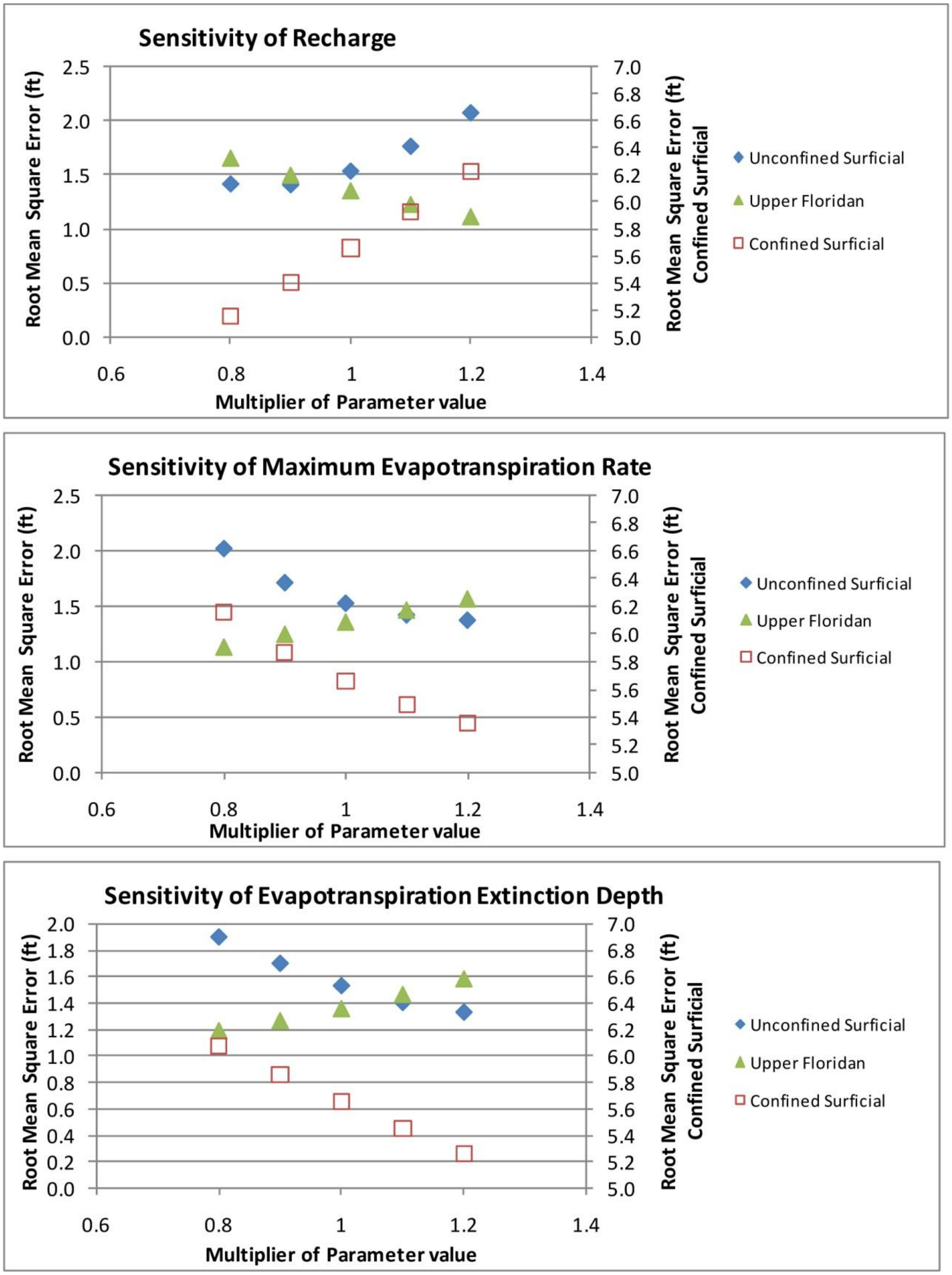


Figure 90 **Recharge and evapotranspiration sensitivity simulation mean square error results for 2011**

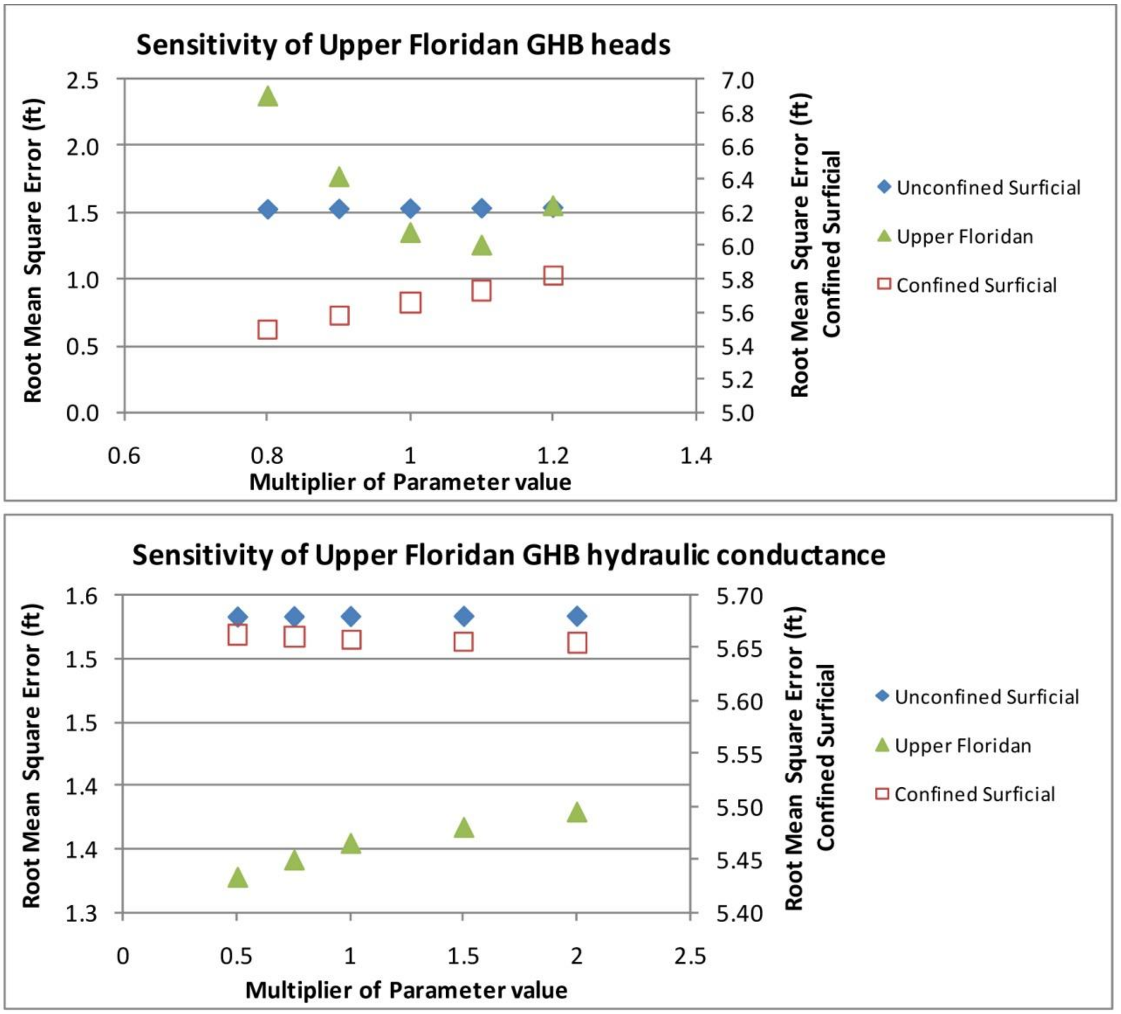


Figure 91 General-Head Boundary sensitivity simulation mean square error results for 2011

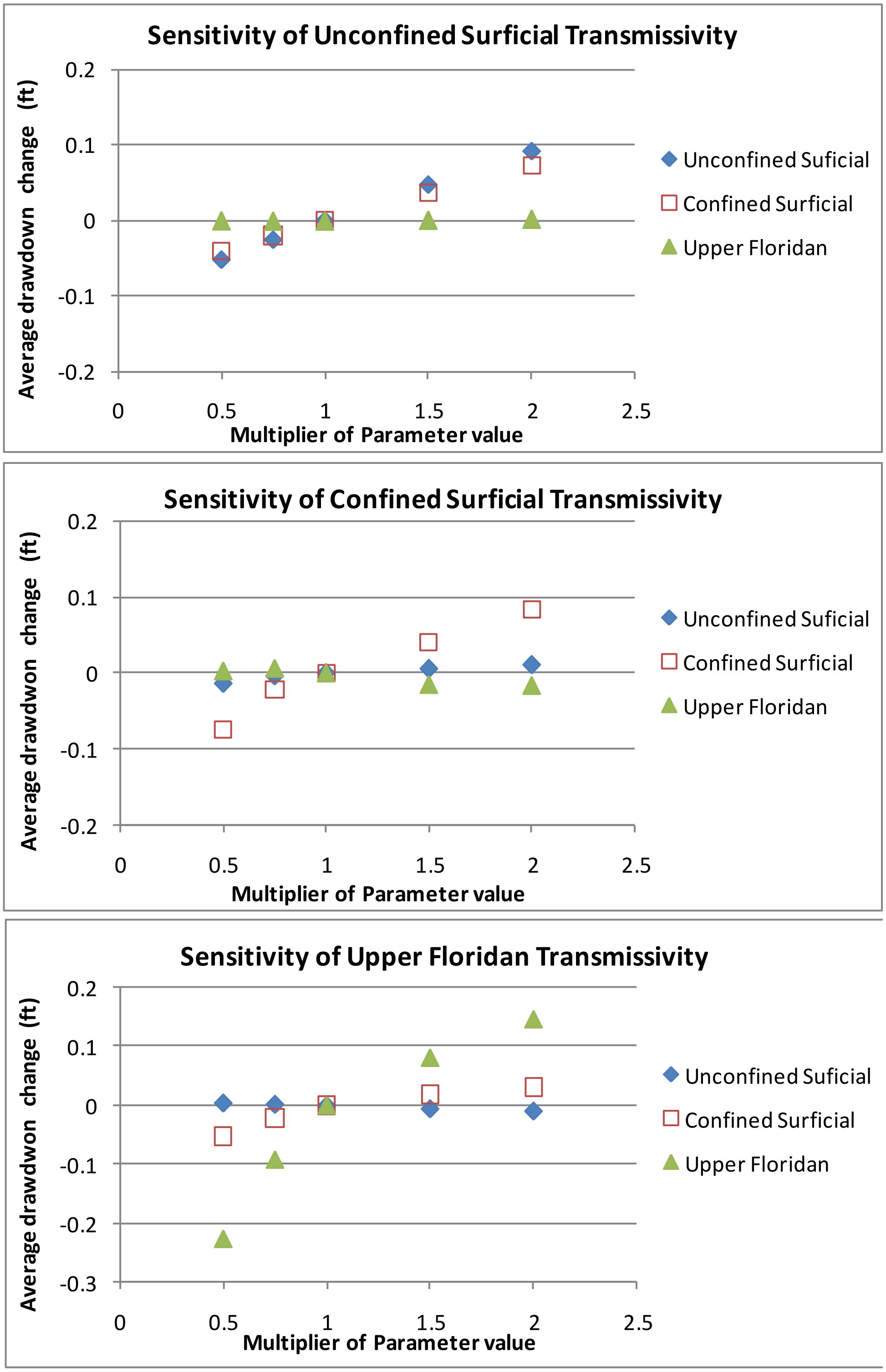


Figure 92 Aquifer transmissivity sensitivity drawdown change results for 2011

larger than 1.0, there is more water in the system and higher heads relative to the base case parameter values (or a negative average drawdown change) (Figure 94). The RMSE performance metric, in contrast, showed an inverse correlation between the Unconfined Surficial aquifer and the Upper Floridan aquifer for these three parameters.

Heads in the Upper Floridan aquifer were relatively sensitive to GHB heads prescribed along the lateral boundaries in the Upper Floridan aquifer but simulated heads in all three aquifers were minimally affected by changes in the hydraulic conductance of the GHB (Figure 95).

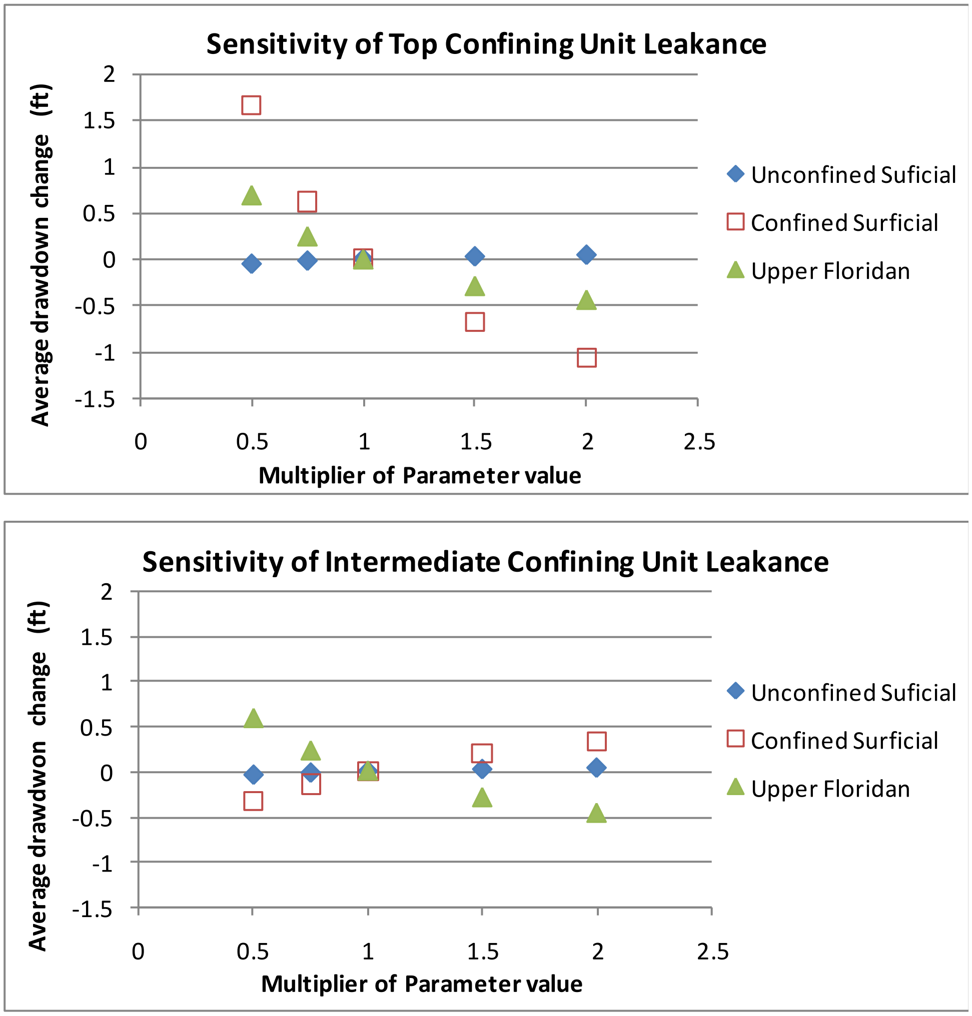


Figure 93 Confining unit leakance sensitivity drawdown change results for 2011

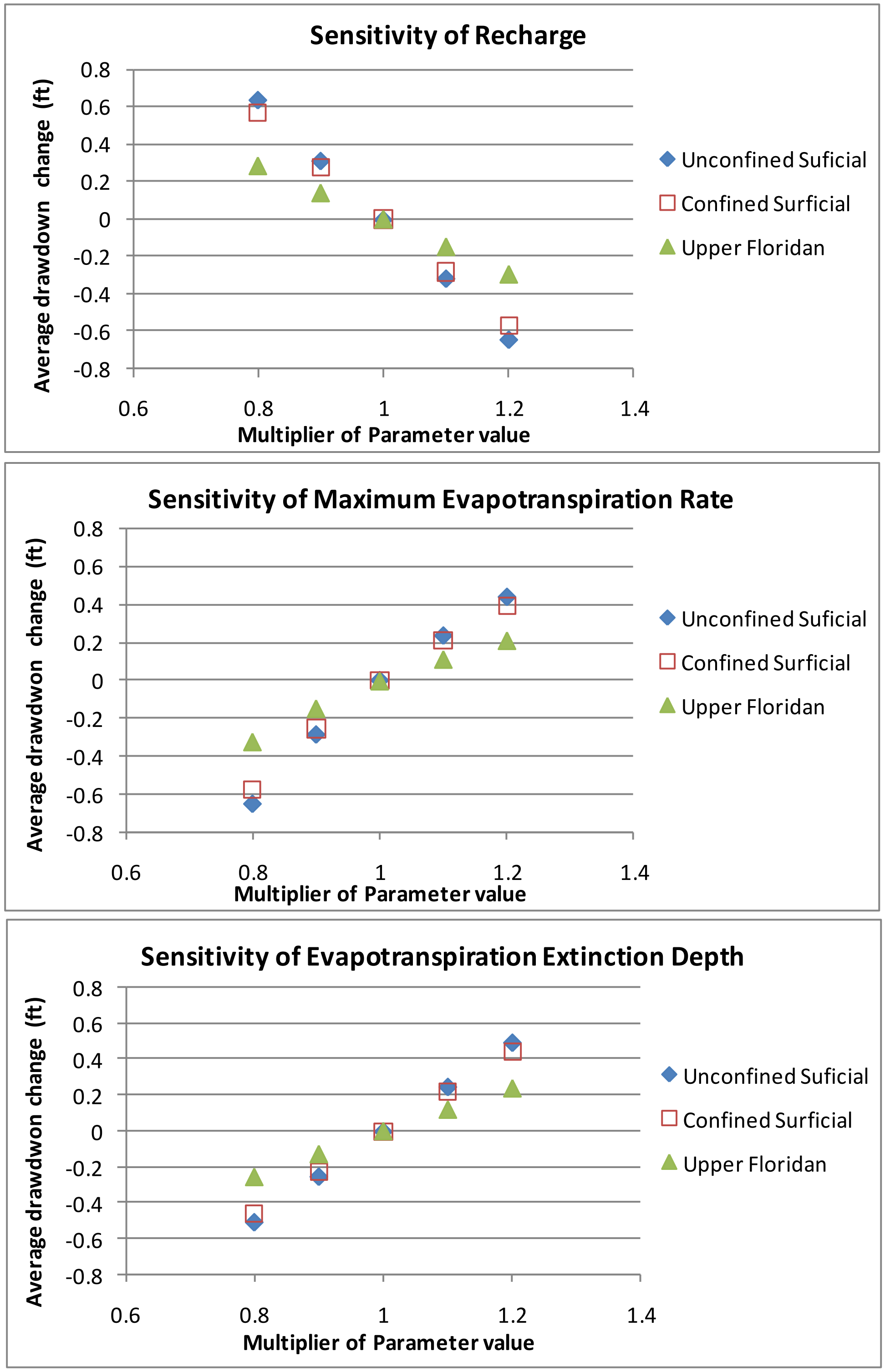


Figure 94 **Recharge and evapotranspiration sensitivity drawdown change simulation results for 2011**

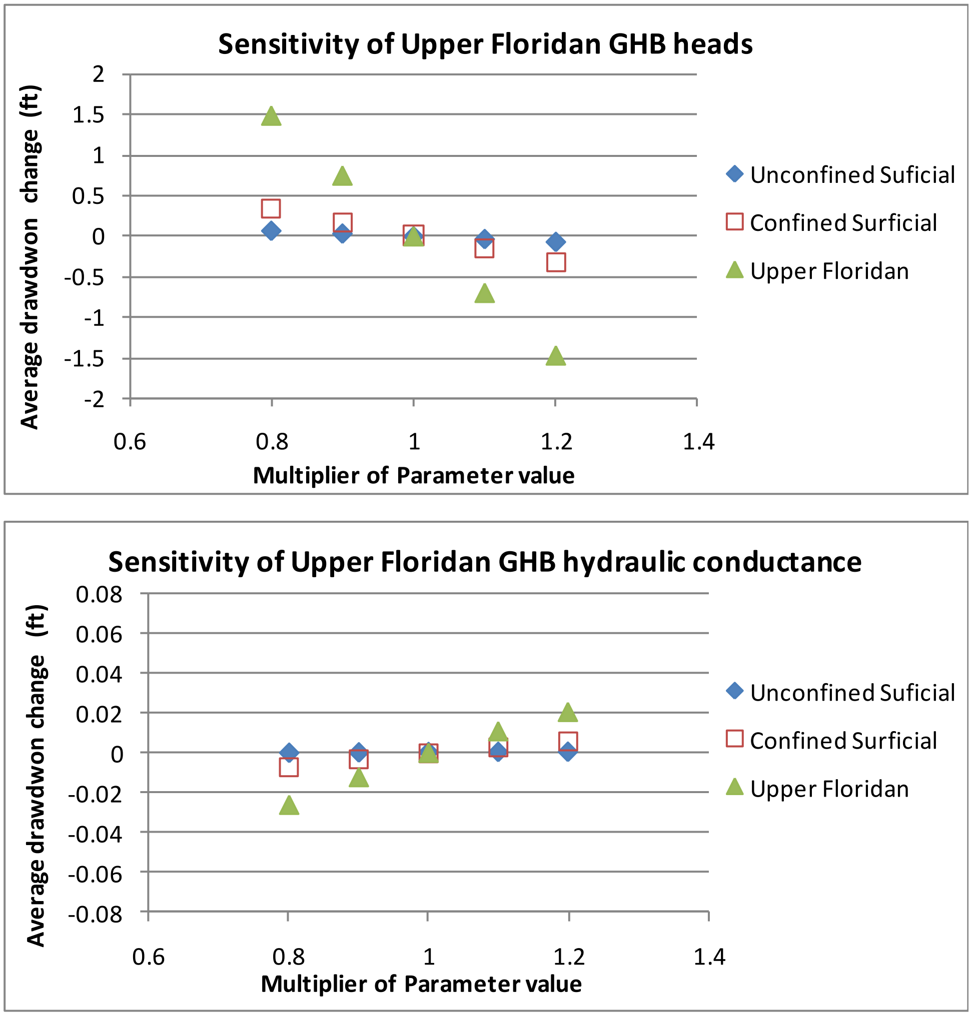


Figure 95 **General-Head Boundary sensitivity simulation drawdown change results for 2011**

5.0 2030 PREDICTIVE SIMULATIONS

The calibrated groundwater flow model was used to estimate drawdown impacts due to projected withdrawals in 2030. As discussed in detail above under Water Use, total water use is projected to increase from approximately 9.7 MGD in 1995 to 47 MGD in 2030 with the largest increase at the PCU wellfields. The boundary conditions along the top model boundary were unchanged from 1995 levels. The lateral boundary condition was also unchanged for the 2030 simulations, which is expected to result in a slight underestimation of aquifer drawdowns because the 1995 head specified at the lateral boundary is likely higher than the 2030 head for some portions of the lateral boundary. As discussed below, under Conclusions and Recommendations for Future Work, consideration should be given to increasing the lateral extent of the model during future revisions to the model in order to minimize boundary impacts.

The simulated average 2030 potentiometric surface was prepared for each aquifer (Figures 96-98) and drawdowns (from 1995 conditions) were calculated as shown in Figures 99 to 101. Due to increased pumpage by PCU in the Upper Floridan aquifer, between 8 to 12 ft of drawdown is projected in the southeastern portions of the model area, and up to 16 ft of drawdowns locally are projected in the northwest portions of the model area (Figure 99). Upper Floridan pumpage in the southeast portions of the study area is also expected to cause 5 to 8 ft of drawdown in the Confined Surficial aquifer (Figure 100). Confined Surficial aquifer production northwest of the existing Palm Coast wellfield is expected to result in 8 to 27 ft of drawdown locally. Due to increased irrigation return flow and recharge at the RIB sites, a rebound is expected in the east-central portions of the study area. Within the Unconfined Surficial aquifer, 1 to 2 ft of drawdown is expected in the vicinity of the PCU wellfield and up to 4 ft of drawdown is projected in the southeastern portions of the model, where there is a substantial increase in production from the Upper Floridan aquifer (Figure 101). A rebound in the Unconfined Surficial aquifer is projected in the northeast due to increased irrigation return flow, and recharge at the RIB sites.

The model water budget for the 2030 predictive simulation is presented in Table 10 and Figure 102 along with the change for each hydrologic component from 1995 conditions. Pumpage for 2030 increased by approximately 36 MGD over 1995 rates. Irrigation return flow and artificial

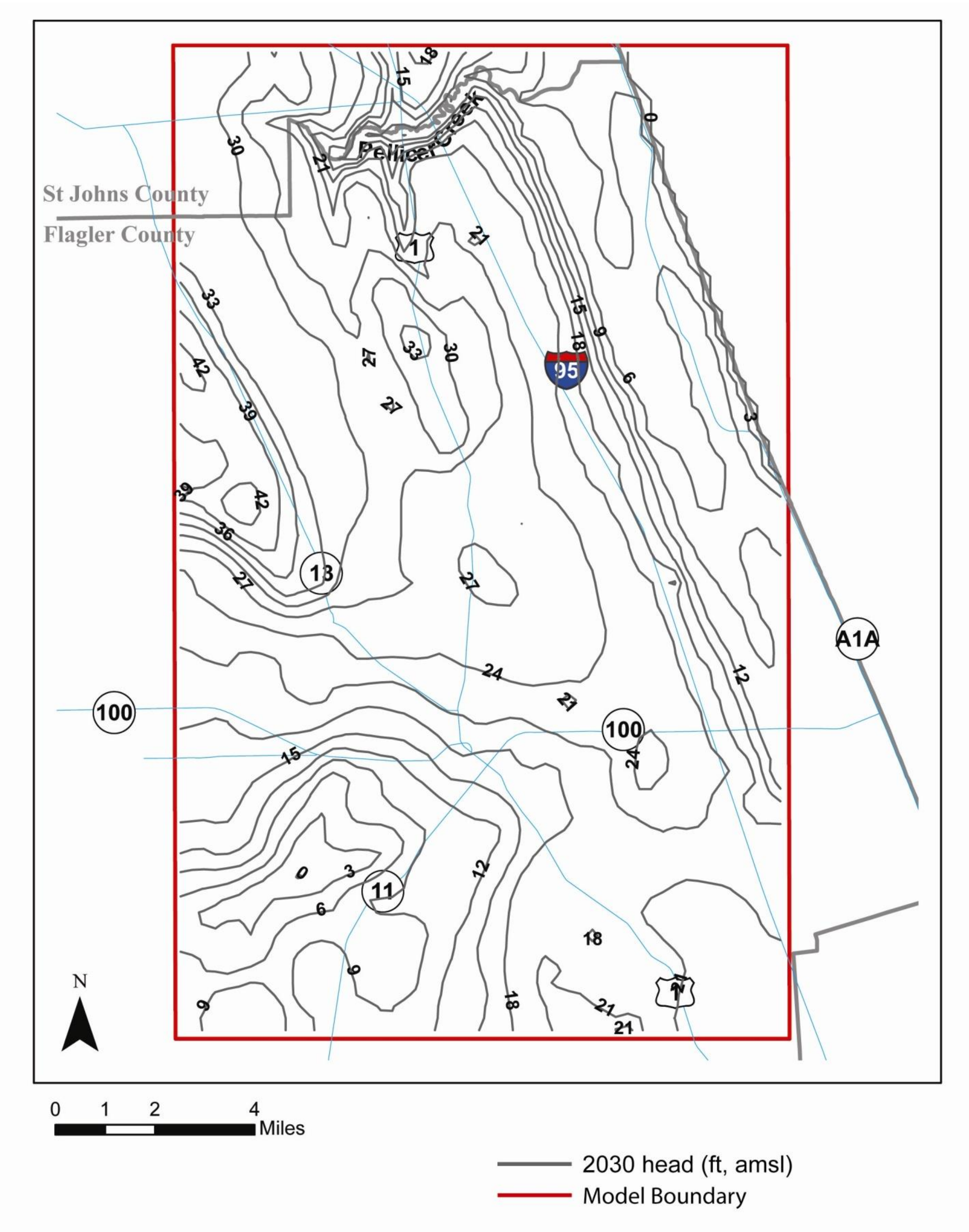


Figure 96 **Simulated average 2030 potentiometric surface in Unconfined Surficial aquifer**

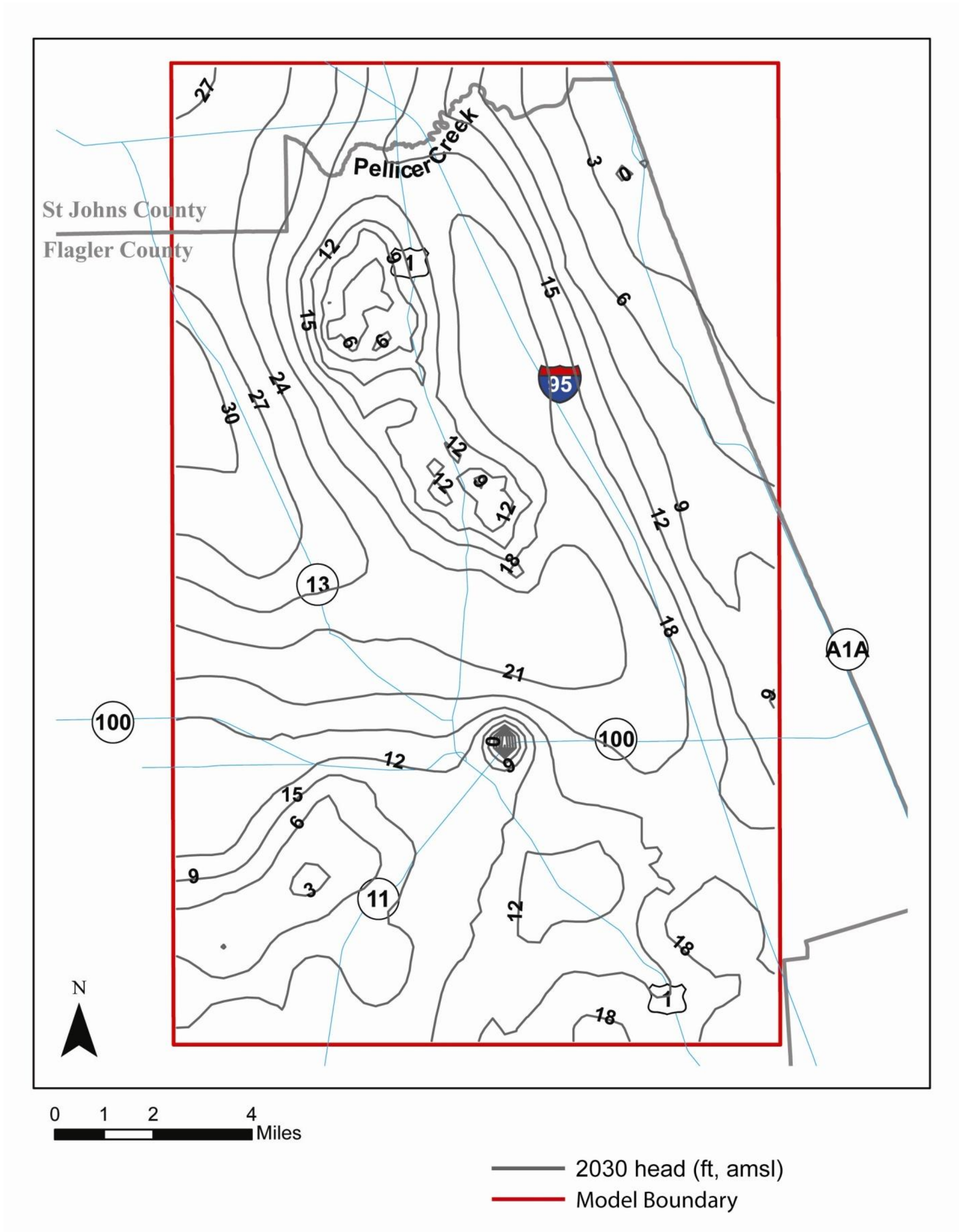


Figure 97 Simulated average 2030 potentiometric surface in Confined Surficial aquifer

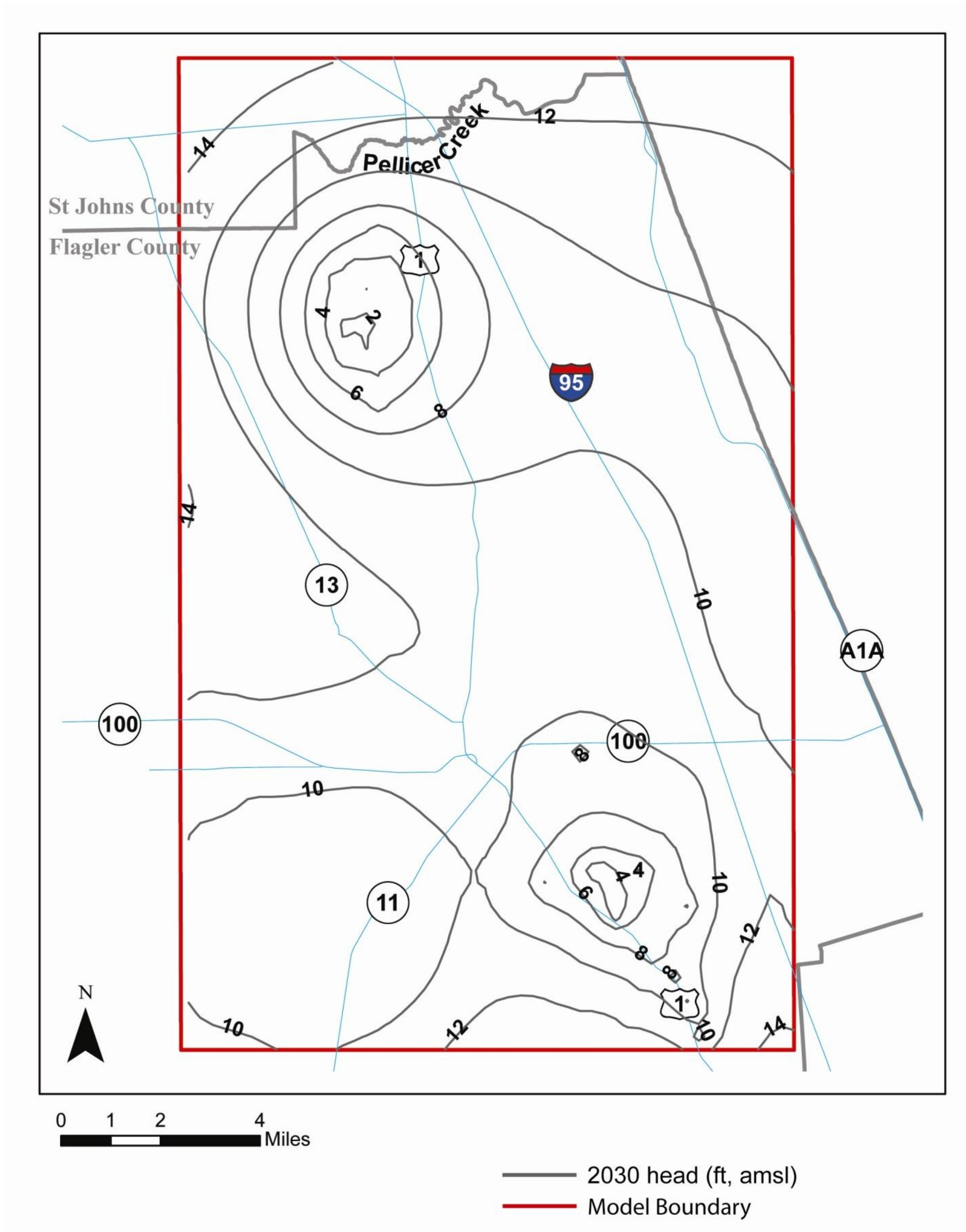


Figure 98 Simulated average 2030 potentiometric surface in Upper Floridan aquifer

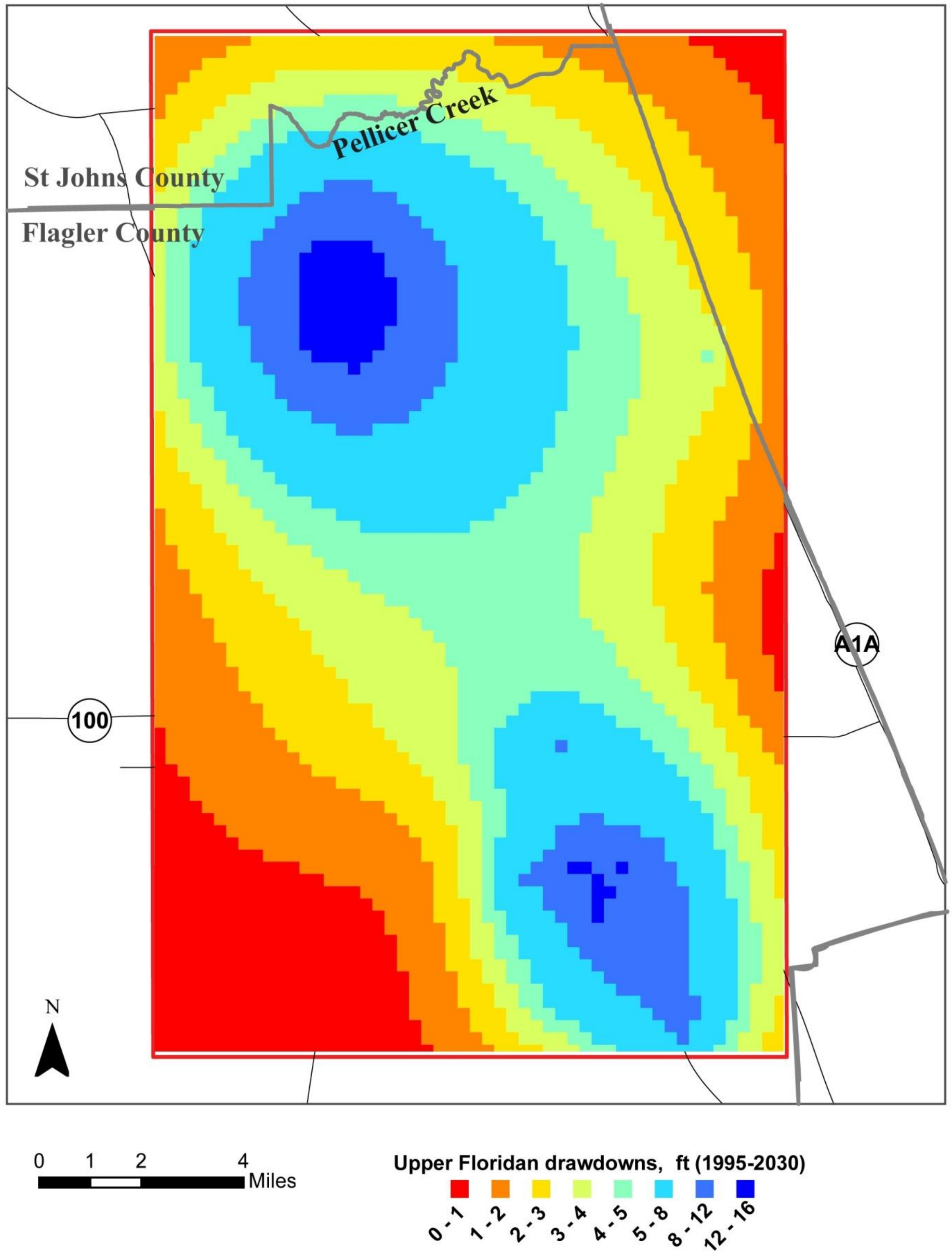


Figure 99 Simulated drawdowns in Upper Floridan aquifer (1995-2030)

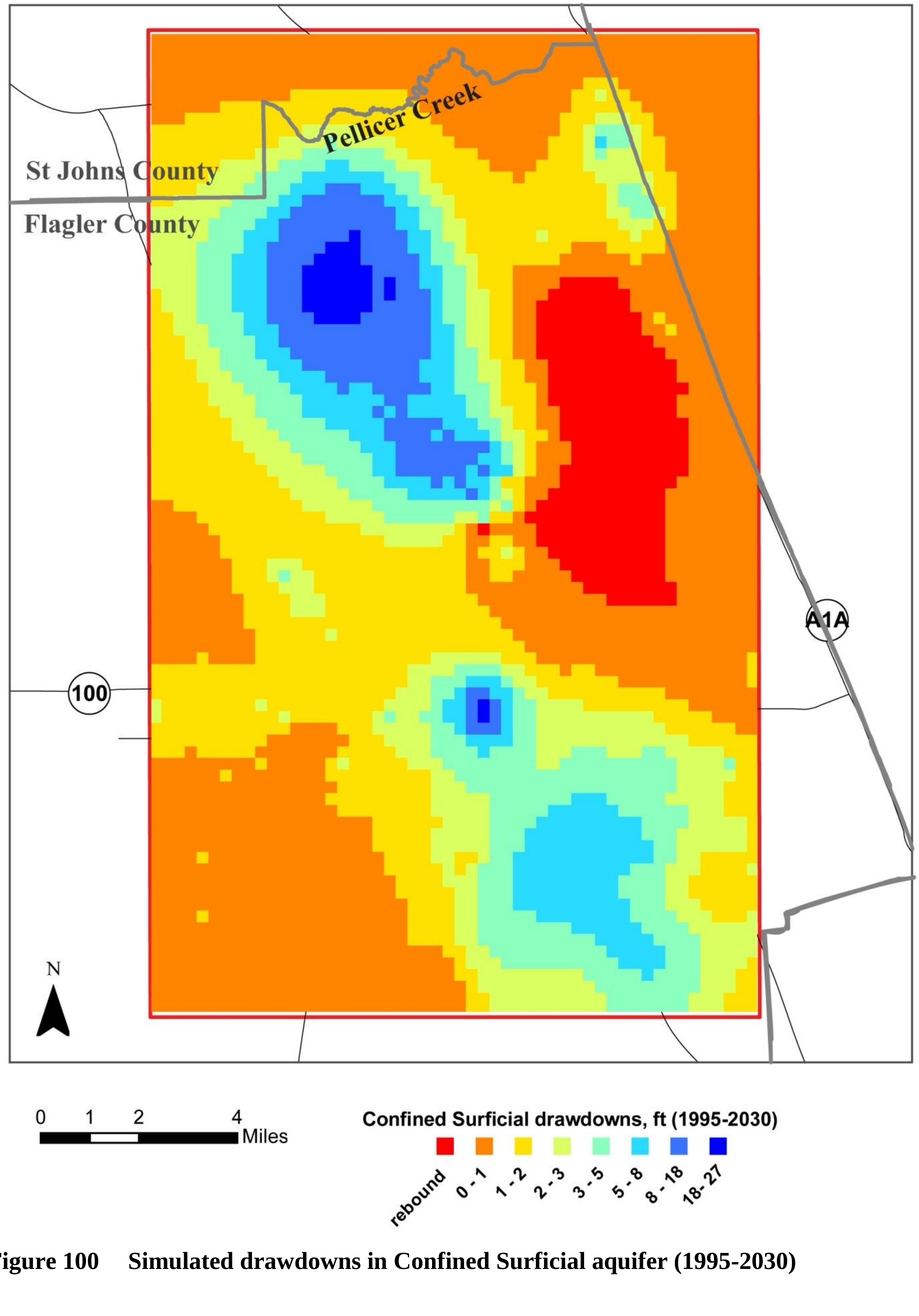


Figure 100 Simulated drawdowns in Confined Surficial aquifer (1995-2030)

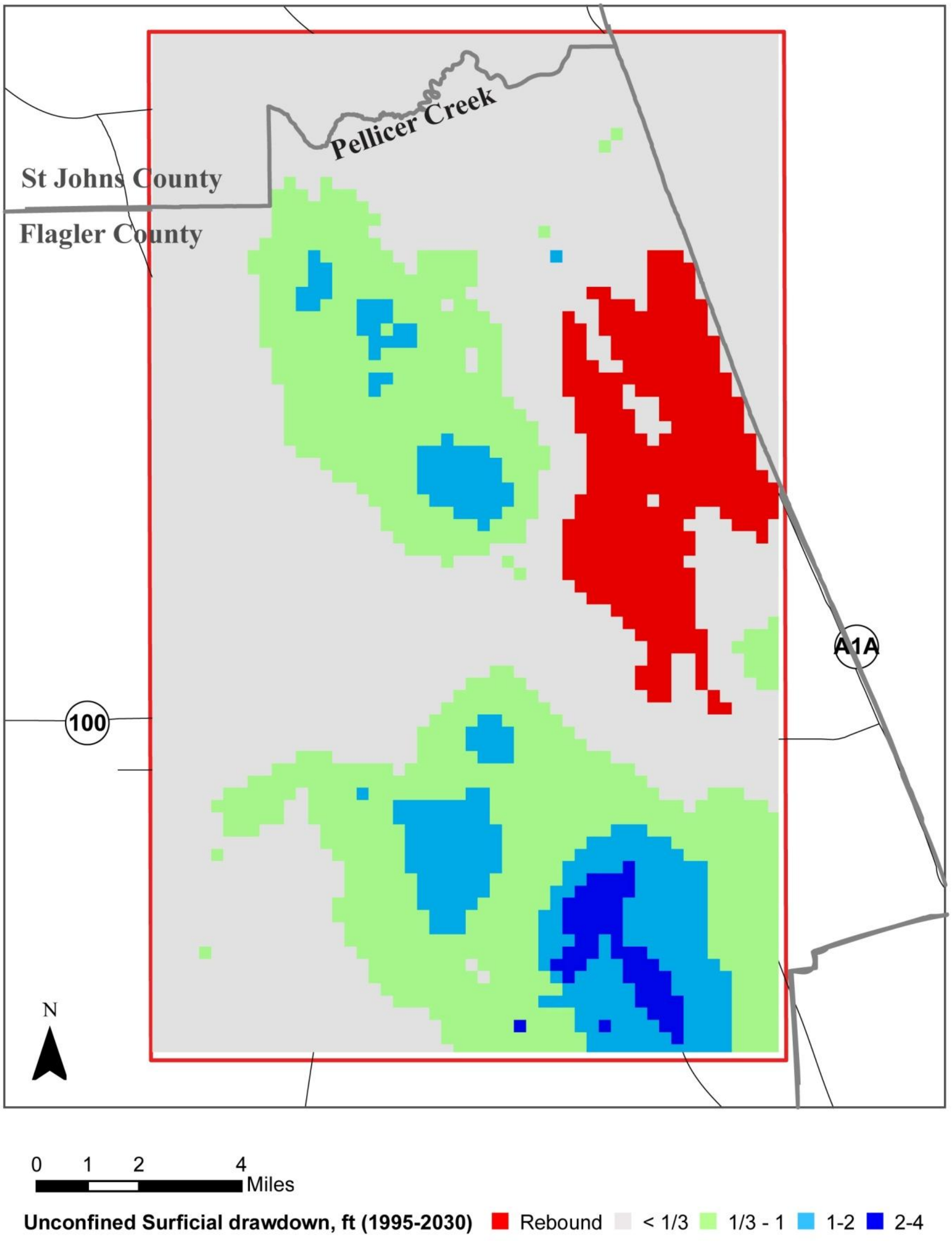


Figure 101 Simulated drawdowns in Unconfined Surficial aquifer (1995-2030)

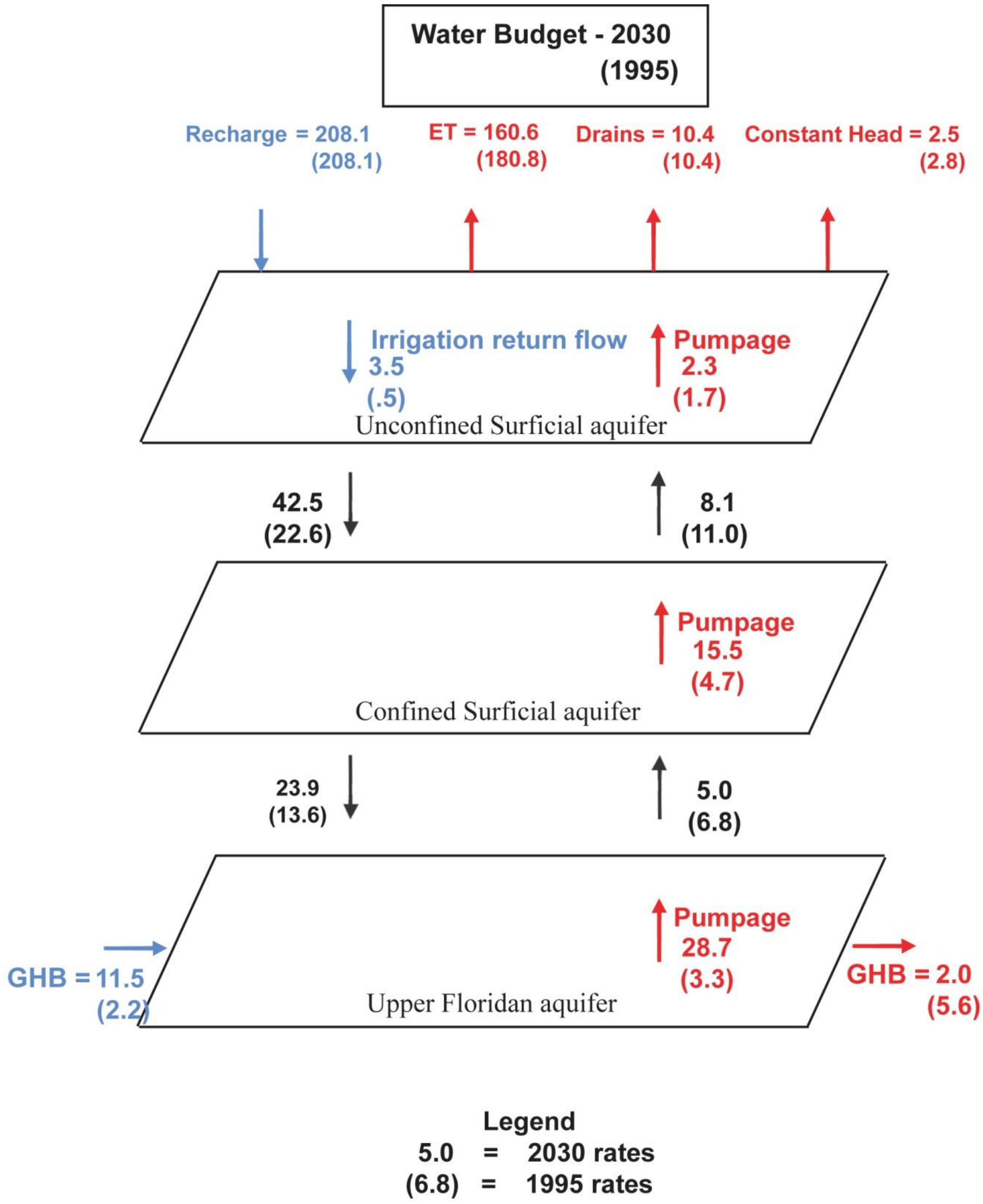


Figure 102 Model simulated water budget for 2030 (MGD)

recharge rates are projected to increase by 3 MGD over 1995 rates. Therefore, net increase in outflow (over 1995 rates) is approximately 33 MGD. Of this, approximately 20.2 MGD will be supplied due to less evapotranspiration from the surface, and approximately 12.5 MGD will be supplied by net change in cross-boundary flux in the Upper Floridan aquifer.

Table 10 Simulated 2030 water budget (MGD)

Aquifer	Recharge*		ET**		Well		Drain		GHB		Constant Head	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Unconfined Surficial	208.1	1.3		160.6	3.5	2.3		10.4				2.5
Confined Surficial						15.5						
Upper Floridan						28.7			11.5	2.0		

* Recharge=Rain – Runoff – Min ET of 27 in/yr
** Excludes Min ET of 27 in/yr

It should be noted that the predictive simulations are conducted assuming steady-state conditions. In reality, drawdown impacts will evolve over time and not fully develop until some time after 2030. In addition, it should be noted that climatic conditions for the predictive simulations are assumed similar to those in 1995, which was assumed to represent average climatic and hydrologic conditions district wide.

6.0 CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

A numerical, finite-difference groundwater model was developed to simulate flow in the Unconfined Surficial, Confined Surficial, and Upper Floridan aquifers in Flagler County, Florida. 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 modeling study was to estimate drawdown impacts due to groundwater withdrawals in the year 2011 and 2030. Withdrawals are projected to increase from approximately 10 MGD in 1995 to 47 MGD in the 2030.

The steady state model was calibrated to observed and interpreted hydrologic conditions existing in the year 1995. A satisfactory match between simulated and observed/interpreted water levels was achieved in all three aquifers. Sensitivity analysis was conducted to identify critical parameters but also to assess the quality of the calibration. The results indicate that the root mean square error of head residuals was minimized with respect to all critical parameters, giving credence to the calibration.

Calibration results indicate that the Top Confining Unit separating the Unconfined Surficial from the Confined Surficial aquifer is an order of magnitude more permeable than the Intermediate Confining Unit separating the Confined Surficial and the Upper Floridan aquifers. In the southern portion of the study area both confining units are much more permeable. Water levels in the aquifers present are similar but higher southeast where the land surface elevation is high than water levels in the southwest coincident with the depression in the potentiometric surface of the Upper Floridan aquifer in the Haw Creek subbasin.

An analysis of the 1995 water budget indicates that approximately 26 MGD infiltrates to the water table from precipitation. Of this, approximately 23 MGD infiltrates to the Confined Surficial aquifer, and about 14 MGD reaches the Upper Floridan aquifer. Pumpage in the Confined Surficial aquifer in 1995 was approximately 5 MGD. Sensitivity runs indicate that there is minimal cross-boundary flux in the Unconfined Surficial and Confined Surficial aquifers. Cross-boundary influx to the Upper Floridan aquifer is approximately 2 MGD; primarily along the western boundary. Cross-boundary flux exiting the Upper Floridan, primarily along the eastern boundary is approximately 6 MGD. In the discharge areas along the coast and in the Haw Creek and Pellicer Creek basin, approximately 7 MGD of groundwater from the Upper Floridan aquifer recharges the Confined surficial aquifer, and approximately 11 MGD discharges into the Unconfined Surficial aquifer from the Confined Surficial aquifer.

Groundwater withdrawals are expected to increase from 10 MGD in 1995 to 19 MGD in 2011. While all categories of water use are expected to increase, projected municipal withdrawals by Palm Coast Utility (PCU) accounts for the majority of increase in 2011 production rates. In 1995, PCU withdrew 2.70 and 0.98 MGD from the Confined Surficial and Upper Floridan aquifers. In 2011, the utility is interested in withdrawing 5.5 MGD from the Confined Surficial, and 4.1 MGD from the Upper Floridan aquifer. Moderate drawdowns in the Unconfined Surfical and Upper Florida aquifers are expected at these production rates while large drawdowns are expected in the Confined Surficial aquifer. Between 8 to 12 ft of drawdown is projected in the Upper Floridan aquifer in the southeastern portions of the model area, and up to 4.4 ft of drawdowns locally are projected within the Upper Floridan aquifer in the southeast portions of the model area. Pumpage from the Upper Floridan aquifer in the southeast portions of the study area is also expected to cause 2 to 3 ft of drawdown in the Confined Surficial aquifer. Production from the Confined Surficial aquifer northwest of the existing PCU wellfield is expected to result in 5 to 12 ft of drawdown locally. Pumping by the City of Bunnell is expected to result in highly localized drawdowns of up to 7 ft.

Due to increased return flow in 2011, a rebound is expected within the Confined Surficial aquifer in the east-central portions of the study area. Within the Unconfined Surficial aquifer, 1 to 2 ft of drawdown is expected in the vicinity of the PCU wellfield and up to 1 foot in the southeastern portions of the model, where there will be a substantial increase in production from the Upper Floridan aquifer. A rebound in the Unconfined Surficial aquifer is projected in the northeast due to decreases in domestic self-supply pumpage and increases irrigation return flow for 2011.

Total pumpage for 2011 is projected to increase by approximately 8.8 MGD over 1995 rates. Irrigation return flow rates are projected to increase by 1.8 MGD over 1995 rates. Therefore, net increase in outflow (over 1995 rates) is approximately 7 MGD. Of this, approximately 4.6 MGD will be supplied due to less evapotranspiration from the surface, and approximately 3.7 MGD will be supplied by net change in cross-boundary flux in the Upper Floridan aquifer.

Due to increased pumpage from the Upper Floridan aquifer by the PCU in 2011 between 1 and 4 ft of drawdown in the Upper Floridan is projected in the southeastern portions of the model area between Korona and Dupont.

Due to production within the Confined Surficial and Upper Floridan aquifers in the expanded PCU wellfield northwest of the existing wellfield, drawdowns of 5 to 12 ft are expected in the Confined Surficial aquifer in this area. Production in the Upper Floridan aquifer in the southeast portions of the study area is expected to cause 1 to 3 ft of drawdown in the Confined Surficial aquifer, and up to 7 ft locally due to pumping by the City of Bunnell. Due to increased irrigation return flow, a rebound in the Confined Surficial aquifer is expected in the east-central portions of the study area in 2011.

In the Unconfined Surficial aquifer, up to 1 foot of drawdown is expected by 2011 in the existing PCU wellfield and between 1 and 2 ft of drawdown is expected in the southeastern portions of the model. A rebound in the Unconfined Surficial aquifer is projected in the northeast due to increased irrigation return flow.

Groundwater withdrawals are expected to increase from 10 MGD in 1995 to 47 MGD in 2030. While all categories of water use are expected to increase, projected municipal withdrawals by PCU accounts for the majority of increase in 2030 production rates. In 1995, PCU withdrew 2.70 and 0.98 MGD from the Confined Surficial and Upper Floridan aquifers. In 2030, the utility is interested in withdrawing 9.5 MGD from the Confined Surficial, and 22.1 MGD from the Upper Floridan aquifer. Large drawdowns in all aquifers are expected at these production rates. Between 8 and 12 ft of drawdown is projected in the Upper Floridan aquifer in the southeastern portions of the model area, and up to 15 ft of drawdowns locally are projected within the Upper Floridan aquifer in the northwest portions of the model area. Pumpage from the Upper Floridan aquifer in the southeast portions of the study area is also expected to cause 5 to 8 ft of drawdown in the Confined Surficial aquifer. Production from the Confined Surficial aquifer northwest of the existing PCU wellfield is expected to result in 8 to 19 ft of drawdown locally.

Due to increased irrigation return flow and recharge at the RIB sites in 2030, a rebound is expected within the Confined Surficial aquifer in the east-central portions of the study area. Within the Unconfined Surficial aquifer, 1 to 2 ft of drawdown is expected in the vicinity of the PCU wellfield and in the southeastern portions of the model, where there will be a substantial increase in production from the Upper Floridan aquifer. A rebound in the Unconfined Surficial aquifer is projected in the northeast due to decreases in domestic self-supply pumpage for 2030, increased irrigation return flow, and recharge at the RIB sites.

Total pumpage for 2030 is projected to increase by approximately 36 MGD over 1995 rates. Irrigation return flow and artificial recharge rates are projected to increase by 3 MGD over 1995 rates. Therefore, net increase in outflow (over 1995 rates) is approximately 33 MGD. Of this, approximately 24 MGD will be supplied due to less evapotranspiration from the surface, and approximately 12 MGD will be supplied by net change in cross-boundary flux in the Upper Floridan aquifer.

As model enhancements are considered 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 used for calibration of the Unconfined Surficial aquifer.
- Flow in Haw Creek and Pellicer Creek should be monitored at several locations in the study area. This should be followed by a base flow analysis to improve the model calibration.
- In order to predict drawdowns in the surficial aquifer, 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.
- 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 the time frame involved for drawdowns in the surficial aquifer to fully develop.
- The model boundaries should be extended in order to minimize drawdown impacts at the current boundaries in the Upper Floridan aquifer.
- The impacts of groundwater withdrawals on water quality in the area should be examined with a solute transport model.

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8.0 APPENDICES

APPENDIX A

Shallow Self-supplied Irrigation Wells by Model Grid Cell – Row/Column

Palm Coast Residential well locations
Grid numbers according to SJRWMD map - WELL LOCATIONS PALM COAST
Contact - David Toth, Division of Groundwater Programs, 904-329-4242

	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	10	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	1	4	2	5	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	3	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	2	0	3	1	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	3	6	0	39	10	1	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	6	4	3	1	0	0	0	2	4	5	8	17	0	2	8	16	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	1	4	3	9	3	0	0	7	5	13	13	6	7	5	14	10	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	4	5	0	0	0	6	6	3	13	14	7	6	4	4	3	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	1	8	5	5	1	0	10	9	6	6	6	12	3	5	5	4	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	3	2	2	8	2	1	8	9	32	2	5	4	6	5	2	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	2	10	5	5	1	1	2	8	3	5	5	7	15	3	7	1	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	3	11	7	3	3	0	1	8	9	16	19	15	2	14	11	2	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	1	0	7	12	11	6	3	0	3	10	15	18	26	13	13	2	10	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	1	3	6	5	1	5	3	21	13	13	7	6	3	0	13	2	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	1	5	12	2	13	11	6	13	8	14	40	0	22	63	4	5	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	6	12	0	4	22	14	7	3	16	21	12	6	10	28	3	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	3	10	10	12	20	23	7	18	0	9	23	9	10	4	3	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	1	0	0	6	11	7	6	9	17	14	10	1	2	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	4	6	2	2	0	0	2	1	0	0	2	5	4	4	8	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	1	3	12	15	8	3	3	0	1	0	0	0	0	0	18	10	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	6	17	10	20	10	21	21	0	7	1	0	10	3	6	0	1	7	6	0	0	0	1	0	0	0	0	0
39	0	0	0	0	0	15	19	14	29	8	7	6	7	8	5	6	12	4	0	0	9	4	3	0	0	0	0	1	0	0	0	0
40	0	0	0	0	0	19	10	10	25	3	6	6	25	11	8	5	11	6	4	0	0	0	0	0	0	0	0	0	2	0	0	0
41	0	0	0	0	0	5	10	16	19	18	3	5	16	14	6	4	10	7	0	1	0	0	0	0	0	0	0	0	0	0	0	0
42	0	0	0	0	0	2	6	13	13	7	15	1	24	12	6	5	6	5	4	1	0	0	0	0	0	0	0	0	0	0	0	0
43	0	0	0	0	6	0	0	9	10	29	18	12	14	12	6	0	2	5	4	6	0	0	0	0	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0	0	3	0	5	8	12	6	9	7	2	3	10	11	3	0	0	0	0	0	0	0	0	0	0	0	0
45	0	0	0	0	0	1	0	2	0	0	3	5	9	17	9	17	10	8	1	4	0	0	0	0	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	3	2	11	0	1	8	5	4	1	5	4	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0
47	0	0	0	0	0	1	0	1	1	2	5	1	0	0	1	1	1	2	2	0	5	0	0	0	0	0	0	0	0	0	0	0
48	0	0	0	0	0	1	0	1	1	0	1	0	3	3	1	1	0	2	1	1	0	1	0	0	0	0	0	0	0	0	0	0
49	0	0	0	0	0	0	0	0	0	0	1	0	0	3	4	1	1	4	2	1	3	0	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	1	0	1	2	3	2	1	11	3	0	3	2	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	1	0	2	0	1	6	0	1	4	2	4	4	2	1	1	3	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	3	2	1	1	4	1	8	1	4	2	4	1	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	1	4	0	3	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	2	6	5	1	4	5	10	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0	0	0	0	1	0	0	0	0	2	10	4	1	5	7	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	0	0	0	0	0	0	0	0	0	0	2	3	5	6	3	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	0	0	0	0	0	0	0	0	0	0	2	6	2	8	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
60	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
63	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0
64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0
65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0
66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	2	0	0	0	0	0	1	1	0	0	0	0
67	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
68	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
69	0	0	0	0	0	0	0	0	0	0	0	1	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0
71	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
72	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1	0	0	0
73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
74	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
76	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	0	4	15	4	17	62	84	126	226	177	196	155	234	228	190	223	232	210	226	131	161	154	42	7	2	4	14	10	5	1	0	0

TOTAL
3140

Notes: There are a total of 670 cells with platted lots. The maximum number of platted lots within a cell is estimated to be 112. If it is assumed there would be an average of 50 % of the maximum number of lots per cell with wells. The estimated number of wells at buildout could be 112 X 50% X 670 = 37,520 wells. Currently it is estimated there are approximately 15,000 lots with houses on them which puts the percentage of houses with wells at 21%.

APPENDIX B

Estimation of Vertical Hydraulic Conductivity Values from Gamma Ray Logs and Leakance Values

WELL NO.	LEAKANCE	THICKNESS (in feet)		KV	
		20/20	30/30	20/20	30/30
14	2.0×10^{-4}				
27	1.2×10^{-4}	10	No 30 CPS	0.0012	
28	1.2×10^{-4}	16	12	0.002	0.001
29	1.2×10^{-4}				
30	3.3×10^{-4}				
31	2.8×10^{-4}	18	17	0.0050	
32	3.3×10^{-4}				
33	4.3×10^{-5}	10	No 30 CPS	#########	
34	4.3×10^{-5}	20	6	0.001	0.0003
35	4.3×10^{-5}	0			
36	4.3×10^{-5}	8	No 30 CPS		
58	3.0×10^{-4}	combo screen well			
59	3.0×10^{-4}	18	16	0.005	
60	3.0×10^{-4}				
61	3.0×10^{-4}	8		0.002	
62	4.0×10^{-5}	20		0.001	
105	3.0×10^{-4}				
106	3.0×10^{-4}				
107	4.0×10^{-5}	20		0.001	
114	1.0×10^{-4}				
115	1.0×10^{-4}	30	18	0.003	0.002
90	1.0×10^{-4}	49	40	0.005	0.004
96	3.6×10^{-4}	20	16	0.007	0.006
83	2.8×10^{-4}	24	8	0.007	0.002
84	1.9×10^{-4}				
95	1.6×10^{-4}	18	16	0.003	0.003
21	1.9×10^{-4}	6	8	0.001	0.002
51	1.9×10^{-4}	8	No 30 CPS	0.002	
24	1.7×10^{-4}	20	No 30 CPS	0.003	
25	1.7×10^{-4}	22	No 30 CPS	0.004	
43	4.3×10^{-5}				

WELL NO.	PUMPING RATE	DURATION (in hrs)	LEAKANCE	THICKNESS		KV	
				20/20	30/30	20/20	30/30
LW -17	790	53	2.6×10^{-4}	6		0.002	
LW-4	904	168	1.4×10^{-4}	87	20	0.012	0.003
	700		8.9×10^{-4}			0.01	0.017
LW-25	1004	48	1.4×10^{-4}	20	15	0.003	0.003
LW-27	820	72	1×10^{-4}		65	0.007	0.009
LW-49			2.6×10^{-4}	50	10	0.013	0.003
LW-15			3.4×10^{-3}	44		0.013	
LW -21	LW-31 APT		2.04×10^{-3}	50		0.102	
			1.8×10^{-3}	50		0.09	
LW-31	AV for Test		1.6×10^{-3}	75	30	0.12	0.048
LW-13	1000		1.1×10^{-3}				
	1400		4.2×10^{-4}				
LW-26	896	24	1.4×10^{-4}	70	50	0.01	0.007
LW-14	600	72	2.5×10^{-4}	63	60	0.016	
LW-51			1.4×10^{-4}	80	70	0.01	0.01

APPENDIX C

Consumptive Use Permit Compliance Monitoring Data – 1995, Water Levels, Pumping Rates and Water Quality

Monitor Well and Pumping Well Water Levels for Static and Pumping Conditions – May/September 1995

J. ADKINS
MI

1995

Palm Coast Utility

RECEIVED
JAN 17 1996
PALATKA PDS

2-035-0011ANM 92

January 15, 1996

Ms. Gloria Lewis, Director
Division of Permit Data Services
St. Johns River Water Management District
Highway 100 West
Palatka, FL 32178-1429

Dear Ms. Lewis:

Please find enclosed Well withdrawal data for the period 9/01/95 through 12/31/95 as required for our Consumptive Use Permit No. 2-035-0011ANM. Also enclosed is hydrogeological data for production zone wells and monitoring wells. Please note that the data has been submitted on a computer disk. Should you have any questions regarding this submittal, please contact me at (904)446-7460.

Sincerely,

James A. Hogan
Manager of Water Treatment Plant #1

James A. Hogan

ENTERED 1/18/96

Enclosure: Disk

RECEIVED
JAN 17 1996
PALATKA PDS

A Subsidiary of ITT Corporation 2 Utility Drive, Palm Coast, Florida 32137 • 904/445-3311 • FAX 904/445-1880

PALM COAST UTILITY CORPORATION
GROUNDWATER MONITORING PROGRAM
WATER LEVELS - PRODUCTION ZONE MONITOR WELLS

MONTH / YEAR MAY 1995

WELL I. D.	DATE	CASING ELEVATION FEET (MSL)	WATER ELEVATION FEET (MSL)	WATER LEVEL (TOC)	COMMENTS
SW-15	05/06/95	30.05	21.87	8.18	
SW-17	05/06/95	33.44	21.78	11.66	
SW-28	05/15/95	34.67	18.32	16.35	
SW-40	05/07/95	31.54	22.75	8.79	
SW-55	05/07/95	35.58	27.38	8.20	
SW-77	05/07/95	28.83	22.41	6.42	
SW-89	05/06/95	23.43	15.23	8.20	
SW-91	05/07/95	33.41	25.46	7.95	
SW-92	05/06/95	32.07	24.69	7.38	
LW-6	05/07/95	28.92	14.72	14.20	
LW-20		36.09	**		** (SEE SJRWMD FOR RECORDED DATA)
LW-38	05/07/95	34.29	13.96	20.33	
LW-53	05/06/95	29.67	14.75	14.92	

PALM COAST UTILITY CORPORATION
GROUNDWATER MONITORING PROGRAM
WATER LEVELS - PRODUCTION ZONE MONITOR WELLS

MONTH / YEAR SEPTEMBER, 1995

WELL I. D.	DATE	CASING ELEVATION FEET (MSL)	WATER ELEVATION FEET (MSL)	WATER LEVEL (TOC)	COMMENTS
SW-15	09/15/95	30.05	25.05	5.00	
SW-17	09/14/95	33.44	26.22	7.22	
SW-28	09/14/95	34.67	22.84	11.83	
SW-40	09/16/95	31.54	26.48	5.06	
SW-55	09/15/95	35.58	30.42	5.16	
SW-77	09/16/95	28.83	24.23	4.60	
SW-89	09/14/95	23.43	17.31	6.12	
SW-91	09/14/95	33.41	22.35	11.06	
SW-92	09/14/95	32.07	27.79	4.28	
LW-6	09/15/95	28.92	16.83	12.09	
LW-20		36.09	**	**	** (SEE SJRWMD FOR RECORDED DATA)
LW-38	09/15/95	34.29	15.79	18.50	
LW-53	09/15/95	29.67	16.19	13.48	

PALM COAST UTILITY CORPORATION
GROUNDWATER MONITORING PROGRAM
WATER TABLE MONITOR WELLS
PALM COAST, FLORIDA

MONTH / YEAR MAY, 1995

WELL I. D.	DATE	CASING ELEVATION FEET (MSL)	WATER ELEVATION FEET (MSL)	WATER LEVEL (TOC)	COMMENTS
SW-1s	05/06/95	30.80	18.82	11.98	
SW-5s	05/06/95	32.20	23.78	8.42	
SW-8s	05/06/95	30.85	20.77	10.08	
SW-28s	05/06/95	33.03	22.03	11.00	
SW-32s	05/06/95	31.72	24.22	7.50	
SW-91s	05/07/95	31.83	24.58	7.25	
SW-92s	05/06/95	29.86	26.99	2.87	
LW-6	05/07/95	28.92	14.72	14.20	
LW-14s	05/07/95	26.87	19.54	7.33	
LW-15s	05/07/95	31.32	22.2	9.12	
LW-42	05/06/95	20.34	12.84	7.50	

PALM COAST UTILITY CORPORATION
GROUNDWATER MONITORING PROGRAM
WATER TABLE MONITOR WELLS
PALM COAST, FLORIDA

MONTH / YEAR SEPTEMBER, 1995

WELL I. D.	DATE	CASING ELEVATION FEET (MSL)	WATER ELEVATION FEET (MSL)	WATER LEVEL (TOC)	COMMENTS
SW-1s	09/16/95	30.80	22.22	8.58	
SW-5s	09/14/95	32.20	27.04	5.16	
SW-8s	09/15/95	30.85	25.89	4.96	
SW-28s	09/14/95	33.03	25.76	7.27	
SW-32s	09/14/95	31.72	28.60	3.12	
SW-91s	09/14/95	31.83	27.33	4.50	
SW-92s	09/14/95	29.86	17.82	12.04	
LW-6	09/15/95	28.92	16.83	12.09	
LW-14s	09/15/95	26.87	22.62	4.25	
LW-15s	09/15/95	31.32	24.86	6.46	
LW-42S	09/15/95	20.34	15.09	5.25	

PALM COAST UTILITY CORPORATION
GROUNDWATER MONITORING PROGRAM
FOR SALTWATER INTRUSION MONITOR WELLS

MONTH / YEAR FEBRUARY, 1995

WELL I.D.	DATE	CASING ELEVATION FEET (MSL)	WATER ELEVATION FEET (TOC)	WATER ELEVATION FEET (MSL)	SPECIFIC CONDUCTIVITY	CHLORIDES	COMMENTS
SW-39	02/12/95	31.90	8.37	23.53	817	108	
SW-81	02/11/95	34.93	8.96	25.97	262	44	
SW-82	02/12/95	30.00	13.87	16.13	961	128	
LW-15	02/12/95	28.90	10.52	18.38	662	33	
LW-16	02/12/95	30.72	15.94	14.78	745	57	
LW-42	02/12/95	21.33	5.50	15.83	954	135	
MW-1	02/11/95	10.37	6.46	3.91	3870	1161	
MW-2	02/11/95	21.97	9.02	12.95	655	38	
MW-3	02/11/95	28.46	7.08	21.38	728	59	

PALM COAST UTILITY CORPORATION
GROUNDWATER MONITORING PROGRAM
FOR SALTWATER INTRUSION MONITOR WELLS

MONTH / YEAR MAY, 1995

WELL I.D.	DATE	CASING ELEVATION FEET (MSL)	WATER ELEVATION FEET (TOC)	WATER ELEVATION FEET (MSL)	SPECIFIC CONDUCTIVITY	CHLORIDES	COMMENTS
SW-39	05/04/95	31.90	9.44	22.46	451	103	
SW-81	**	34.93	**	**	**	**	ABANDONED PER SJRWMD PERMIT# 3-035-0121WB
SW-82	05/04/95	30.00	16.42	13.58	912	130	
LW-15	05/04/95	28.90	12.52	16.38	653	38	
LW-16	05/04/95	30.72	18.54	12.18	723	63	
LW-42	05/04/95	21.33	7.50	13.83	894	133	
MW-1	05/04/95	10.37	7.25	3.12	3890	754	
MW-2	05/04/95	21.97	10.31	11.66	524	81	
MW-3	05/04/95	28.46	9.44	19.02	741	59	

PALM COAST UTILITY CORPORATION
GROUNDWATER MONITORING PROGRAM
FOR SALTWATER INTRUSION MONITOR WELLS

MONTH / YEAR SEPTEMBER, 1995

WELL I.D.	DATE	CASING ELEVATION FEET (MSL)	WATER ELEVATION FEET (TOC)	WATER ELEVATION FEET (MSL)	SPECIFIC CONDUCTIVITY	CHLORIDES	COMMENTS
SW-39	09/15/95	31.90	6.79	25.11	753	96	
SW-81	**	34.93	**	**	**	**	ABANDONED PER SJRWMD PERMIT# 3-035-0121WB
SW-82	09/16/95	30.00	14.28	15.72	427	62	
LW-15	09/15/95	28.90	10.20	18.70	601	30	
LW-16	09/15/95	30.72	16.33	14.39	512	60	
LW-42	09/15/95	21.33	5.25	16.08	822	138	
MW-1	09/14/95	10.37	4.44	5.93	3390	852	
MW-2	09/14/95	21.97	7.41	14.56	428	79	
MW-3	09/14/95	28.46	5.12	23.34	617	57	

PALM COAST UTILITY CORPORATION
GROUNDWATER MONITORING PROGRAM
FOR SALTWATER INTRUSION MONITOR WELLS

MONTH / YEAR NOVEMBER, 1995

WELL I.D.	DATE	CASING ELEVATION FEET (MSL)	WATER ELEVATION FEET (TOC)	WATER ELEVATION FEET (MSL)	SPECIFIC CONDUCTIVITY	CHLORIDES	COMMENTS
SW-39	11/18/95	31.90	7.54	24.36	692	112	
SW-81	**	34.93	**	**	**	**	ABANDONED PER SJRWMD PERMIT# 3-035-0121WB
SW-82	11/18/95	30.00	10.31	19.69	575	74	
LW-15	11/21/95	28.90	10.75	18.15	690	27	
LW-16	11/21/95	30.72	16.28	14.44	710	63	
LW-42	11/21/95	21.33	5.62	15.71	847	135	
MW-1	11/18/95	10.37	6.33	4.04	3240	867	
MW-2	11/18/95	21.97	8.71	13.26	666	74	
MW-3	11/18/95	28.46	6.27	22.19	773	59	

MONTHLY RAINFALL (PCUC WTP #1) 1.15"

MONTHLY RAINFALL (17 YR. MEAN) 2.66"

MONTHLY RAINFALL (PCUC WTP #2) 1.27"

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PALM COAST UTILITY CORPORATION
WATER TREATMENT PLANT #1
RAW WATER MONITORING PROGRAM
FEBRUARY 1995
1st Quarter

HYDROLOGICAL DATA

WELL #	DATE	RECOM. YIELD (GPM)	CURR. YIELD (GPM)	CASING ELEV. (FT.MSL.)	PUMPING LEVEL (TOC)	PUMPING LEVEL (FT.MSL.)	RECOM. SPECIFIC CAPACITY	CURRENT SPECIFIC CAPACITY	DATE	STATIC LEVEL (TOC)	STATIC LEVEL (FT.MSL.)
GROUP 1											
SW-8	02/05/95	125	92	32.56	28.98	3.58	7.38	6.02	02/01/95	13.69	18.67
SW-14	02/05/95	120	90	32.63	28.87	3.76	7.25	5.21	02/01/95	11.60	21.03
SW-32	02/07/95	120	72	31.26	24.85	6.41	5.00	3.98	02/01/95	6.77	24.49
SW-33	02/05/95	200	111	34.23	26.94	7.29	13.00	6.70	02/22/95	10.38	23.85
SW-36	02/01/95	200	186	37.55	33.89	3.66	14.00	8.45	02/08/95	11.88	25.67
SW-58	02/15/95	275	225	32.73	24.50	8.23	20.00	14.81	02/01/95	9.31	23.42
SW-60	02/07/95	100	65	32.69	32.69	0.00	8.00	3.00	02/01/95	11.00	21.69
SW-62	02/01/95	200	102	33.30	31.08	2.22	8.10	4.07	02/15/95	6.02	27.28
SW-106	02/05/95	140	48	34.85	33.09	1.76	8.00	2.46	02/01/95	13.58	21.27
GROUP 2											
SW-4	02/05/95	100	56	30.31	27.16	3.15	6.70	3.34	02/01/95	9.81	20.50
SW-6	02/05/95	200	81	32.75	31.09	1.66	4.80	3.54	02/01/95	8.20	24.55
SW-27	02/01/95	275	150	33.48	23.64	9.84	12.00	22.87	02/23/95	17.08	16.40
SW-29	02/01/95	150	106	35.60	32.35	3.25	9.00	5.24	02/23/95	12.12	23.48
SW-34	02/01/95	250	228	35.04	31.46	3.58	17.00	11.13	02/15/95	10.98	24.06
SW-59	02/01/95	225	228	32.75	26.72	6.03	15.00	14.28	02/05/95	10.75	22.00
SW-105	02/05/95	100	105	33.12	32.04	1.08	9.00	5.20	02/01/95	11.86	21.26
SW-107	02/22/95	200	150	35.50	31.98	3.52	8.50	7.18	02/01/95	11.09	24.41
SW-114	02/01/95	250	235	34.00	28.83	5.17	16.00	11.20	02/15/95	7.85	26.15
GROUP 3											
SW-5	02/01/95	250	175	31.04	23.62	7.42	16.50	12.85	02/22/95	10.00	21.04
SW-7	02/07/95	150	121	32.22	24.58	7.64	7.32	8.02	02/01/95	9.50	22.72
SW-13	02/07/95	80	106	31.60	29.40	2.20	4.55	5.25	02/01/95	9.22	22.38
SW-28	02/01/95	250	161	34.67	32.58	2.09	13.00	8.99	02/23/95	14.68	19.99
SW-30	02/07/95	125	100	32.16	28.42	3.74	5.00	4.77	02/01/95	7.45	24.71
SW-31	02/01/95	250	279	32.30	26.12	6.18	22.40	18.70	02/22/95	11.20	21.10
SW-35	02/01/95	200	151	36.28	35.94	0.34	11.00	7.50	02/05/95	15.81	20.47
SW-61	02/05/95	60	61	33.11	32.09	1.02	4.78	2.25	02/01/95	4.94	28.17
SW-115	02/01/95	400	256	33.68	26.69	6.99	35.00	13.26	02/08/95	7.38	26.30
	TOTAL YIELD	7.19 (MGD)	5.39 (MGD)		AVERAGE	4.14 (FT.MSL.)			AVERAGE	10.52 (TOC)	22.86 (FT.MSL.)
WTP#2 LIMESTONE WELLS											
LW-21	02/25/95	890	850	26.56	17.23	9.33		177.24	02/16/95	11.87	14.69
LW-30	02/16/95	890	840	25.37	14.12	11.25		173.20	02/24/95	9.27	16.10
LW-31	02/16/95	890	880	25.99	14.46	11.53		171.87	02/24/95	9.34	16.65
	TOTAL YIELD	3.60 (MGD)	4.34 (MGD)		AVERAGE	10.70			AVERAGE	10.16 (TOC)	15.81 (FT.MSL.)

WATER QUALITY ANALYSIS

WELL #	CHLORIDE (mg/l)	SULFATE (mg/l)	IRON (mg/l)	COND. (um/cm)	TDS (mg/l)	PH	COLOR APP.	COLOR TRUE	TOTALI READII
SW-8	30	<1	0.380	676	338	7.0	34	19	450347
SW-14	46	<1	0.219	748	374	7.1	21	10	451572
SW-32	78	<1	1.807	816	398	6.9	104	32	260553
SW-33	26	<1	0.074	600	299	7.1	60	47	116808
SW-36	26	<1	0.392	590	295	7.1	44	32	989299
SW-58	55	<1	0.518	674	337	7.0	79	55	127103
SW-60	98	<1	0.155	954	490	7.0	29	28	229639
SW-62	60	<1	0.277	764	382	7.1	48	41	682940
SW-106	19	<1	0.818	530	265	7.2	52	14	197082
SW-4	51	<1	0.230	692	346	7.2	19	9	194937
SW-6	80	<1	1.048	800	400	7.2	84	13	531358
SW-27	45	42.20	0.275	706	353	7.1	62	44	140620
SW-29	27	<1	0.125	566	283	7.1	30	21	520256
SW-34	30	30.44	30.440	604	302	7.2	46	42	187222
SW-59	55	<1	0.518	674	337	7.0	79	55	371156
SW-105	46	<1	0.166	696	348	7.2	24	21	232472
SW-107	40	<1	0.466	626	319	6.8	37	28	101744
SW-114	65	<1	0.040	756	378	7.2	30	27	187640
SW-5	45	<1	0.585	688	344	7.2	65	24	173030
SW-7	70	<1	0.566	850	435	7.0	67	51	140207
SW-13	50	34.02	1.846	678	363	7.0	96	19	257250
SW-28	30	<1	0.503	646	323	7.1	53	33	109703
SW-30	65	<1	1.760	720	366	7.0	104	31	92907
SW-31	30	14.80	0.397	666	333	7.1	53	38	217837
SW-35	24	<1	0.211	596	298	7.2	37	27	673535
SW-61	67	<1	2.583	678	339	7.1	214	9	142490
SW-115	59	<1	0.035	746	373	7.1	32	27	227680
LW-21	31.00	<1	1.414	630	310	7.2	108	29	27
LW-30	83.00	<1	0.313	836	418	7.1	26	13	217
LW-31	35.00	<1	0.387	682	341	6.9	31	16	924

MANAGER (WTP #1)

MONTHLY RAINFALL (PCUC WTP #1) 4.20"

MONTHLY RAINFALL (17 YR. MEAN) 3.15"

PALM COAST UTILITY CORPORATION
WATER TREATMENT PLANT #1
RAW WATER MONITORING PROGRAM
MAY 1995
2nd Quarter

MONTHLY RAINFALL (PCUC WTP #2)

HYDROLOGICAL DATA

WELL #	DATE	RECOM. YIELD (GPM)	CURR. YIELD (GPM)	CASING ELEV. (FT.MSL.)	PUMPING LEVEL (TOC)	PUMPING LEVEL (FT.MSL.)	RECOM. SPECIFIC CAPACITY	CURRENT SPECIFIC CAPACITY	DATE	STATIC LEVEL (TOC)	STATIC LEVEL (FT.MSL.)
GROUP 1											
SW-8	05/01/95	125	86	32.56	28.64	3.92	7.38	5.02	05/22/95	11.52	21.04
SW-14	05/15/95	120	91	32.63	26.79	5.84	7.25	6.14	05/01/95	11.96	20.67
SW-32	05/15/95	120	64	31.26	27.20	4.06	5.00	3.38	05/01/95	8.25	23.01
SW-33	05/01/95	200	170	34.23	28.12	6.11	13.00	10.41	05/15/95	11.79	22.44
SW-36	05/01/95	200	194	37.55	31.68	5.87	14.00	10.94	05/01/95	13.95	23.60
SW-58	05/22/95	275	235	32.73	24.66	8.07	20.00	14.39	05/01/95	8.33	24.40
SW-60	05/01/95	100	57	32.69	28.44	4.25	8.00	2.94	05/22/95	9.06	23.63
SW-62	05/23/95	200	98	33.30	28.73	4.57	8.10	4.77	05/01/95	8.18	25.12
SW-106	05/19/95	140	48	34.85	31.66	3.19	8.00	2.54	05/01/95	12.75	22.10
GROUP 2											
SW-4	05/13/95	100	59	30.31	28.04	2.27	6.70	3.26	05/01/95	9.96	20.35
SW-6	05/03/95	200	158	32.75	21.66	11.09	4.80	11.85	05/01/95	8.33	24.42
SW-27	05/01/95	275	300	33.15	31.20	1.95	12.00	14.68	05/20/95	10.77	22.38
SW-29	05/15/95	150	157	35.60	32.66	2.94	9.00	8.41	05/01/95	14.00	21.60
SW-34	05/01/95	250	238	35.04	29.02	6.02	17.00	12.10	05/14/95	9.35	25.69
SW-59	05/23/95	225	161	32.75	25.18	7.57	15.00	10.41	05/01/95	9.71	23.04
SW-105	05/01/95	100	60	33.12	30.54	2.58	9.00	3.35	05/15/95	12.62	20.50
SW-107	05/22/95	200	149	35.50	31.04	4.46	8.50	7.04	05/01/95	9.87	25.63
SW-114	05/01/95	250	235	34.00	29.08	4.92	16.00	10.94	05/14/95	7.60	26.40
GROUP 3											
SW-5	05/01/95	250	240	31.04	25.64	5.40	16.50	17.92	05/20/95	12.25	18.79
SW-7	05/03/95	150	120	32.22	24.83	7.39	7.32	8.14	05/01/95	10.09	22.13
SW-13	05/15/95	80	105	31.60	29.33	2.27	4.55	5.32	05/01/95	9.60	22.00
SW-28	05/01/95	250	149	34.67	33.02	1.65	13.00	8.94	05/15/95	16.35	18.32
SW-30	05/23/95	125	91	32.16	28.81	3.35	5.00	4.60	05/01/95	9.02	23.14
SW-31	05/01/95	250	277	32.30	26.37	5.93	22.40	17.29	05/22/95	10.35	21.95
SW-35	05/01/95	200	167	36.28	33.09	3.19	11.00	7.50	05/14/95	10.81	25.47
SW-61	05/16/95	60	59	33.11	31.83	1.28	4.78	2.30	05/01/95	6.20	26.91
SW-115	05/01/95	400	243	33.68	24.60	9.08	35.00	13.56	05/14/95	6.71	26.97
	TOTAL YIELD	7.19 (MGD)	5.78 (MGD)		AVERAGE	4.79 (FT.MSL.)			AVERAGE	10.35 (TOC)	23.03 (FT.MSL.)
WTP#2 LIMESTONE WELLS											
LW-21	05/28/95	890	1150	26.56	23.60	2.96		103.98	05/14/95	12.54	14.02
LW-30	05/14/95	890	800	25.37	15.54	9.83		222.84	05/28/95	11.95	13.42
LW-31	05/14/95	890	800	25.99	14.92	11.07		248.45	05/28/95	11.70	14.29
	TOTAL YIELD	3.60 (MGD)	4.34 (MGD)		AVERAGE	7.95			AVERAGE	12.06 (TOC)	13.91 (FT.MSL.)

WATER QUALITY ANALYSIS

WELL #	CHLORIDE (mg/l)	SULFATE (mg/l)	IRON (mg/l)	COND. (um/cm)	TDS (mg/l)	PH	COLOR APP.	COLOR TRUE
SW-8	39	<1	0.396	718	360	7.1	34	20
SW-14	48	<1	0.231	745	203	7.0	12	8
SW-32	67	<1	1.665	724	388	6.9	139	31
SW-33	25	<1	0.073	605	300	7.2	40	31
SW-36	27	<1	0.427	612	304	7.2	40	21
SW-58	47	<1	0.374	726	341	7.1	51	44
SW-60	93	<1	0.139	906	453	7.0	22	21
SW-62	55	<1	0.271	730	365	7.2	33	33
SW-106	100	<1	0.123	916	458	7.1	33	29
SW-4	46	<1	0.241	631	401	7.2	21	9
SW-6	78	<1	0.994	820	410	7.1	59	12
SW-27	38	33.38	0.264	706	354	7.1	41	29
SW-29	17	<1	0.207	726	365	7.0	24	17
SW-34	21	31.09	0.181	612	305	7.2	42	30
SW-59	63	<1	1.630	775	389	7.0	110	70
SW-105	46	<1	0.201	700	349	7.1	43	25
SW-107	35	<1	0.537	620	317	7.0	51	27
SW-114	64	<1	0.032	707	354	7.3	24	19
SW-5	47	<1	0.634	679	338	7.2	50	11
SW-7	68	<1	0.549	808	404	7.0	63	46
SW-13	48	32.60	1.845	733	202	6.9	96	12
SW-28	30	<1	0.488	648	324	7.0	45	22
SW-30	50	37.10	1.533	730	368	7.0	84	32
SW-31	35	23.01	0.434	679	339	7.4	38	23
SW-35	22	<1	0.255	606	302	7.2	45	24
SW-61	64	<1	2.541	687	338	7.1	203	111
SW-115	59	<1	0.087	757	372	7.2	23	20
LW-21	44.00	<1	1.397	609	351	7.0	88	27
LW-30	68	<1	0.302	956	520	7.0	27	21
LW-31	32	<1	0.365	800	398	7.0	37	24

MANAGER (WTP #1)

MONTHLY RAINFALL (PCUC WTP #1) 16.35"
MONTHLY RAINFALL (17 YR. MEAN) 7.99"

MONTHLY RAINFALL (PCUC WTP #2) 12.41"

PALM COAST UTILITY CORPORATION
WATER TREATMENT PLANT #1
RAW WATER MONITORING PROGRAM
SEPTEMBER 1995
3rd Quarter

HYDROLOGICAL DATA

WELL #	DATE	RECOM. YIELD (GPM)	CURR. YIELD (GPM)	CASING ELEV. (FT.MSL.)	PUMPING LEVEL (TOC)	PUMPING LEVEL (FT.MSL.)	RECOM. SPECIFIC CAPACITY	CURRENT SPECIFIC CAPACITY	DATE	STATIC LEVEL (TOC)	STATIC LEVEL (FT.MSL.)
GROUP 1											
SW-8	09/18/95	125	98	32.56	27.16	5.40	7.38	6.93	09/01/95	13.02	19.54
SW-14	09/18/95	120	87	32.63	25.31	7.32	7.25	5.77	09/01/95	10.22	22.41
SW-32	09/01/95	120	69	31.26	24.33	6.93	5.00	4.13	09/11/95	7.62	23.64
SW-33	09/01/95	200	195	34.23	31.00	3.23	13.00	10.02	09/11/95	11.54	22.69
SW-36	09/12/95	200	196	37.55	30.20	7.35	14.00	10.97	09/01/95	12.33	25.22
SW-58	09/01/95	275	230	32.73	29.14	3.59	20.00	13.71	09/11/95	12.37	20.36
SW-60	09/18/95	100	60	32.69	24.81	7.88	8.00	3.52	09/01/95	7.75	24.94
SW-62	09/18/95	200	95	33.30	25.69	7.61	8.10	4.45	09/01/95	4.33	28.97
SW-106	09/20/95	140	57	34.85	31.35	3.50	8.00	2.52	09/01/95	8.77	26.08
GROUP 2											
SW-4	09/20/95	100	62	30.31	27.88	2.43	6.70	3.32	09/01/95	9.18	21.13
SW-6	09/12/95	200	175	32.75	20.08	12.67	4.80	11.85	09/01/95	5.31	27.44
SW-27	09/13/95	275	290	33.15	31.00	2.15	12.00	14.39	09/18/95	10.85	22.30
SW-29	09/13/95	150	152	35.60	33.14	2.46	9.00	7.02	09/01/95	11.50	24.10
SW-34	09/12/95	250	242	35.04	26.18	8.86	17.00	17.95	09/01/95	12.70	22.34
SW-59	09/21/95	225	162	32.75	22.98	9.77	15.00	14.24	09/01/95	11.60	21.15
SW-105	09/18/95	100	75	33.12	26.60	6.52	9.00	4.25	09/01/95	8.94	24.18
SW-107	09/20/95	200	160	35.50	30.96	4.54	8.50	6.45	09/01/95	6.16	29.34
SW-114	09/18/95	250	240	34.00	25.79	8.21	16.00	12.02	09/11/95	5.83	28.17
GROUP 3											
SW-5	09/12/95	250	242	31.04	24.75	6.29	16.50	17.54	09/11/95	10.95	20.09
SW-7	09/03/95	150	129	32.22	26.44	5.78	7.32	6.93	09/12/95	7.83	24.39
SW-13	09/18/95	80	110	31.60	27.94	3.66	4.55	5.34	09/01/95	7.33	24.27
SW-28	09/01/95	250	152	34.67	29.75	4.92	13.00	8.60	09/11/95	12.68	21.99
SW-30	09/01/95	125	97	32.16	28.16	4.00	5.00	5.62	09/11/95	10.91	21.25
SW-31	09/13/95	250	295	32.30	23.64	8.66	22.40	22.52	09/01/95	10.54	21.76
SW-35	09/01/95	200	204	36.28	30.56	5.72	11.00	10.88	09/18/95	11.81	24.47
SW-61	09/20/95	60	60	33.11	27.98	5.13	4.78	2.44	09/01/95	3.35	29.76
SW-115	09/18/95	400	400	33.68	19.27	14.41	35.00	26.58	09/01/95	4.22	29.46
	TOTAL YIELD	7.19 (MGD)	6.24 (MGD)		AVERAGE	6.26 (FT.MSL.)			AVERAGE	9.25 (TOC)	24.13 (FT.MSL.)
WTP#2 LIMESTONE WELLS											
LW-21	09/29/95	890		26.56	OFF LINE	26.56	OFF LINE	0.00	09/21/95	11.60	14.96
LW-30	09/21/95	890	800	25.37	13.81	11.56		158.10	09/29/95	8.75	16.62
LW-31	09/21/95	890	800	25.99	13.66	12.33		186.48	09/29/95	9.37	16.62
	TOTAL YIELD	3.84 (MGD)	2.30 (MGD)		AVERAGE	16.82			AVERAGE	9.91 (TOC)	16.07 (FT.MSL.)

WATER QUALITY ANALYSIS

WELL #	CHLORIDE (mg/l)	SULFATE (mg/l)	IRON (mg/l)	COND. (um/cm)	TDS (mg/l)	PH	COLOR APP.	COLOR TRUE	TOTALIZ READIN
SW-8	30	<1	0.427	550	275	7.2	37	23	636015(
SW-14	53	<1	0.220	672	336	7.1	18	9	630428(
SW-32	75	<1	1.484	772	386	6.9	110	35	333734(
SW-33	38	<1	0.156	624	312	7.2	64	34	1430854
SW-36	30	<1	0.366	569	279	7.0	37	23	1340410
SW-58	55	<1	0.341	724	362	7.1	56	48	562798(
SW-60	87	<1	0.264	944	466	7.1	38	27	319675(
SW-62	59	<1	0.273	771	385	7.1	38	25	822587(
SW-106	12	<1	0.805	593	282	7.1	53	28	262684(
SW-4	55	<1	0.247	656	335	7.0	7	6	267567(
SW-6	76	<1	0.900	722	356	7.0	60	10	787902(
SW-27	35	39.03	0.321	664	332	7.1	39	25	194989(
SW-29	23	<1	0.123	538	269	7.0	26	21	741537(
SW-34	32	29.42	0.138	580	270	7.0	46	35	2316994
SW-59	60	<1	1.608	838	419	6.9	121	63	151422(
SW-105	45	<1	0.150	683	341	7.0	26	22	333742(
SW-107	35	<1	0.472	599	298	6.8	39	29	147644(
SW-114	62	<1	0.053	776	387	7.1	20	16	2315322
SW-5	48	<1	0.666	618	321	7.0	45	13	2138649
SW-7	70	<1	0.526	796	416	7.1	68	46	203781(
SW-13	47	23.71	1.704	694	342	7.0	116	14	457782
SW-28	33	<1	0.730	686	343	7.1	67	27	1435628
SW-30	65	28.30	1.652	784	392	7.0	115	36	131591(
SW-31	35	<1	0.462	608	304	7.3	38	23	2794879
SW-35	30	<1	0.237	640	320	7.2	37	25	917481
SW-61	68	<1	2.314	743	371	6.9	176	12	202099
SW-115	50	<1	0.062	756	377	7.1	21	15	2876715
LW-21	OUT OF SERVICE								1231
LW-30	80.00	<1	0.323	806	403	7.1	37	18	12147
LW-31	35.00	<1	0.361	678	339	7.1	41	27	21528

MANAGER (WTP #1)

MONTHLY RAINFALL (PCUC WTP #1) 1.90"

MONTHLY RAINFALL (17 YR. MEAN) 3.27"

MONTHLY RAINFALL (PCUC WTP #2) 2.21"

PALM COAST UTILITY CORPORATION
WATER TREATMENT PLANT #1
RAW WATER MONITORING PROGRAM
NOVEMBER 1995
4th Quarter

HYDROLOGICAL DATA

WELL #	DATE	RECOM. YIELD (GPM)	CURR. YIELD (GPM)	CASING ELEV. (FT.MSL.)	PUMPING LEVEL (TOC)	PUMPING LEVEL (FT.MSL.)	RECOM. SPECIFIC CAPACITY	CURRENT SPECIFIC CAPACITY	DATE	STATIC LEVEL (TOC)	STATIC LEVEL (FT.MSL.)
GROUP 1											
SW-8	11/01/95	125	84	32.56	27.50	5.06	7.38	4.60	11/03/95	9.22	23.34
SW-14	11/01/95	120	95	32.63	27.33	5.30	7.25	5.01	11/06/95	8.38	24.25
SW-32	11/03/95	120	104	31.26	30.08	1.18	5.00	4.40	11/01/95	6.42	24.84
SW-33	11/03/95	200	185	34.23	29.50	4.73	13.00	8.63	11/01/95	8.06	26.17
SW-36	11/03/95	200	191	37.55	31.14	6.41	14.00	9.01	11/01/95	9.95	27.60
SW-58	11/10/95	275	224	32.73	29.02	3.71	20.00	9.99	11/01/95	6.60	26.13
SW-60	11/01/95	100	56	32.69	28.52	4.17	8.00	2.57	11/10/95	6.77	25.92
SW-62	11/07/95	200	57	33.30	27.52	5.78	8.10	2.49	11/01/95	4.65	28.65
SW-106	11/01/95	140	58	34.85	30.66	4.19	8.00	3.11	11/06/95	12.00	22.85
GROUP 2											
SW-4	11/02/95	100	73	30.31	27.08	3.23	6.70	4.29	11/01/95	10.08	20.23
SW-6	11/01/95	200	177	32.75	21.54	11.21	4.80	11.55	11/06/95	6.22	26.53
SW-27	11/01/95	275	286	33.15	31.06	2.09	12.00	11.95	11/03/95	7.12	26.03
SW-29	11/06/95	150	152	35.60	34.35	1.25	9.00	6.52	11/01/95	11.04	24.56
SW-34	OFFLINE	250	FOR	35.04	REHAB		17.00		11/01/95	7.87	27.17
SW-59	11/09/95	225	161	32.75	22.64	10.11	15.00	10.69	11/01/95	7.58	25.17
SW-105	11/01/95	100	65	33.12	30.71	2.41	9.00	3.28	11/06/95	10.90	22.22
SW-107	11/07/95	200	159	35.50	28.46	7.04	8.50	7.56	11/01/95	7.42	28.08
SW-114	11/03/95	250	246	34.00	26.41	7.59	16.00	12.28	11/01/95	6.38	27.62
GROUP 3											
SW-5	11/01/95	250	224	31.04	26.83	4.21	16.50	11.49	11/03/95	7.33	23.71
SW-7	11/06/95	150	124	32.22	25.81	6.41	7.32	6.69	11/01/95	7.27	24.95
SW-13	11/01/95	80	112	31.60	29.52	2.08	4.55	5.05	11/03/95	7.35	24.25
SW-28	11/01/95	250	149	34.67	30.08	4.59	13.00	7.78	11/03/95	10.94	23.73
SW-30	11/06/95	125	100	32.16	27.71	4.45	5.00	4.64	11/01/95	6.14	26.02
SW-31	11/01/95	250	284	32.30	23.56	8.74	22.40	17.41	11/03/95	7.25	25.05
SW-35	11/06/95	200	172	36.28	29.75	6.53	11.00	8.30	11/01/95	9.02	27.26
SW-61	11/03/95	60	57	33.11	28.94	4.17	4.78	2.13	11/01/95	2.16	30.95
SW-115	11/01/95	400	401	33.68	17.28	16.40	35.00	53.04	11/09/95	9.72	23.96
	TOTAL YIELD	7.19 (MGD)	5.75 (MGD)		AVERAGE	5.50 (FT.MSL.)			AVERAGE	7.92 (TOC)	25.45 (FT.MSL.)
WTP#2 LIMESTONE WELLS											
LW-21	OUT	890	OF	26.56	SERVICE				10/05/95	8.60	17.96
LW-30	11/12/95	890	900	25.37	12.51	12.86		205.95	11/29/95	8.14	17.23
LW-31	11/12/95	890	800	25.99	13.22	12.77		191.39	11/29/95	9.04	16.95
	TOTAL YIELD	3.60 (MGD)	4.34 (MGD)						AVERAGE	8.59 (TOC)	17.38 (FT.MSL.)

WATER QUALITY ANALYSIS

WELL #	CHLORIDE (mg/l)	SULFATE (mg/l)	IRON (mg/l)	COND. (um/cm)	TDS (mg/l)	PH	COLOR APP.	COLOR TRUE	TOTALIZER READING
SW-8	28	<1	0.383	704	352	7.1	38	20	67518800
SW-14	38	<1	0.300	782	391	7.3	23	10	67056100
SW-32	69	<1	1.301	751	386	7.0	102	37	35386700
SW-33	31	<1	0.164	626	307	7.2	51	32	150104000
SW-36	32	<1	0.372	598	320	7.1	37	20	142655500
SW-58	56	<1	0.347	702	440	7.1	60	47	63040100
SW-60	93	<1	0.139	990	495	7.1	43	30	33483000
SW-62	65	<1	0.316	736	369	7.2	35	27	84717800
SW-106	20	<1	0.773	560	280	7.2	60	16	28082800
SW-4	51	<1	0.174	680	351	7.2	19	7	27596500
SW-6	70	<1	0.876	784	392	7.1	71	14	88020400
SW-27	33	40.22	0.302	714	357	7.1	42	27	215810500
SW-29	29	<1	0.176	565	288	7.0	21	18	80705300
SW-34	OFFLINE			FOR				REHAB	242864800
SW-59	67	<1	1.619	820	410	7.0	129	54	16473600
SW-105	30	<1	0.158	718	359	7.1	35	25	36824100
SW-107	35	<1	0.719	593	296	7.1	63	31	17105900
SW-114	62	<1	0.047	768	375	7.1	22	13	236334000
SW-5	40	<1	0.656	720	360	7.2	50	10	231548000
SW-7	68	<1	0.563	815	399	7.0	61	52	22564300
SW-13	38	49.07	1.590	666	333	7.0	108	14	513377000
SW-28	25	<1	0.485	692	346	7.1	44	21	152300600
SW-30	69	31.30	1.680	740	370	7.1	79	37	16981800
SW-31	30	22.05	0.438	664	332	7.3	40	22	293538500
SW-35	30	<1	0.241	602	302	7.1	29	21	96097400
SW-61	67	<1	2.134	722	348	7.1	170	27	20248600
SW-115	38	<1	0.117	752	376	7.1	30	16	299061400
LW-21		OUT OF SERVICE							1231900
LW-30	69	<1	0.323	810	421	7.1	40	20	14001000
LW-31	36	<1	0.375	695	458	7.1	37	12	23941500

MANAGER (WTP #1) ____________

PALM COAST MODEL
1995 WATER LEVELS AT PUMPING WELLS AND MONITOR WELLS IN THE PALM COAST MODEL AREA

			UTM Coordinates			Pumping Level (ft, NGVD)		Static Level (ft, NGVD)	
NAME	**ROW**	**COLUMN**	**X**	**Y**		**May-95**	**Sep-95**	**May-95**	**Sep-95**
PUMPING WELLS GROUP 1									
SW-8	36	11	468842.938	3269382.250		3.92	5.40	21.04	19.54
SW-14	41	31	476462.938	3267477.250		5.84	7.32	20.67	22.41
SW-32	70	39	479510.938	3256428.250		4.06	6.93	23.01	23.64
SW-33	35	25	474176.938	3269763.250		6.11	3.23	22.44	22.69
SW-36	30	23	473414.938	3271668.250		5.87	7.35	23.60	25.22
SW-58	40	25	474176.938	3267858.250		8.07	3.59	24.40	20.36
SW-60	38	22	473033.938	3268620.250		4.25	7.88	23.63	24.94
SW-62	33	21	472652.938	3270525.250		4.57	7.61	25.12	28.97
SW-106	35	23	473414.938	3269763.250		3.19	3.50	22.10	26.08
PUMPING WELLS GROUP 2									
SW-4	36	29	475700.938	3269382.250		2.27	2.43	20.35	21.13
SW-6	36	27	474938.938	3269382.250		11.09	12.67	24.42	27.44
SW-27	44	30	476081.938	3266334.250		1.95	2.15	22.38	22.30
SW-29	41	28	475319.938	3267477.250		2.94	2.46	21.60	24.10
SW-34	33	24	473795.938	3270525.250		6.02	8.86	25.69	22.34
SW-59	38	24	473795.938	3268620.250		7.57	9.77	23.04	21.15
SW-105	37	23	473414.938	3269001.250		2.58	6.52	20.50	24.18
SW-107	32	22	473033.938	3270906.250		4.46	4.54	25.63	29.34
SW-114	33	19	471890.938	3270525.250		4.92	8.21	26.40	28.17
PUMPING WELLS GROUP 3									
SW-5	38	29	475700.938	3268620.250		5.40	6.29	18.79	20.09
SW-7	44	21	472652.938	3266334.250		7.39	5.78	22.13	24.39
SW-13	39	31	476462.938	3268239.250		2.27	3.66	22.00	24.27
SW-28	41	29	475700.938	3267477.250		1.65	4.92	18.32	21.99
SW-30	39	28	475319.938	3268239.250		3.35	4.00	23.14	21.25
SW-31	43	29	475700.938	3266715.250		5.93	8.66	21.95	21.76
SW-35	32	24	473795.938	3270906.250		3.19	5.72	25.47	24.47
SW-61	36	21	472652.938	3269382.250		1.28	5.13	26.91	29.76
SW-115	32	18	471509.938	3270906.250		9.08	14.41	26.97	29.46
LW WELLS									
LW-21	73	37	478748.938	3255285.250		2.96	off line	14.02	14.49
LW-30	70	35	477986.938	3256428.250		9.83	11.56	13.42	16.62
LW-31	72	37	478748.938	3255666.250		11.07	12.33	14.29	16.62
WATER TABLE MONITOR WELLS									
SW-1s	38	20	472271.938	3268620.250				18.82	22.22
SW-5s	53	18	471509.938	3262905.250				23.78	27.04
SW-8s	39	29	475700.938	3268239.250				20.77	25.89
SW-28s	41	29	475700.938	3267477.250				22.03	25.76
SW-32s	70	39	479510.938	3256428.250				24.22	28.60
SW-91s	32	18	471509.938	3270906.250				24.58	27.33
SW-92s	20	16	470747.938	3275478.250				26.99	17.82
LW-14s	70	36	478367.938	3256428.250				19.54	22.62
LW-15s	77	40	479891.938	3253761.250				22.20	24.86
LW-42s	67	32	476843.938	3257571.250				12.84	15.09
PRODUCTION ZONE MONITOR WELLS									
SW-15								21.87	25.05
SW-17	38	25	474176.938	3268620.250				21.78	26.22
SW-28	41	29	475700.938	3267477.250				18.32	22.84
SW-40	46	31	476462.938	3265572.250				22.75	26.48
SW-55	51	33	477224.938	3263667.250				27.38	30.42
SW-77	61	44	481415.938	3259857.250				22.41	24.23
SW-89	11	20	472271.938	3278907.250				15.23	17.31
SW-91	32	18	471509.938	3270906.250				25.46	22.35
SW-92	20	16	470747.938	3275478.250				24.69	27.79
LW-6	53	22	473033.938	3262905.250				14.72	16.83
LW-20	24	11	468842.938	3273954.250				**	**
LW-38	49	28	475319.938	3264429.250				13.96	15.79
LW-53	16	25	474176.938	3277002.250				14.75	16.19
SALTWATER INTRUSION MONITOR WELLS									
SW-39	45	38	479129.938	3265953.250				22.46	25.11
SW-81	28	28	475319.938	3272430.250				**	**
SW-82(LW)	68	46	482177.938	3257190.250				13.58	15.72
LW-15	77	40	479891.938	3253761.250				16.38	18.70
LW-16	77	47	482558.938	3253761.250				12.18	14.39
LW-42	67	32	476843.938	3257571.250				13.83	16.08
MW-1	35	41	480426.200	3269726.000				3.12	5.93
MW-2	36	39	479574.900	3269247.000				11.66	14.56
MW-3	37	35	478159.100	3269059.000				19.02	23.34

APPENDIX D

Depth to Water Levels in the Confined Surficial Aquifer – Selected Data

Water Level Difference Between the Unconfined and Confined Surficial Aquifers – Selected Data

WELL	ZONE	STATIC	TOP OF CASING (TOC)	DEPTH BELOW LAND SURFACE (DBLS)	DATE	
11	C	10.72	1.50	9.22	May-77	
21	C	7.70	3.00	4.70	May-79	4.7
24	C	5.91	2.35	3.56	May-79	3.65
25	C	6.75	2.00	4.75	June-79	4.75
28	C	11.47	2.70	8.77	April-79	8.77
29	C	12.73	3.70	9.03	April-79	9.03
30	C	8.66	2.30	6.36	April-79	
31	C	10.05	1.50	8.55	July-77	
32	C	6.57	2.50	4.07	April-79	4.07
39	C	7.22	1.00	6.22	May-77	
40	C	4.35	2.00	2.35	May-77	
51	C	5.78	2.00	3.78	May-79	3.78
52	C	7.34	3.50	3.84	May-77	
55	C	5.87	1.50	4.37	May-77	
58	C	7.73	0.5	7.23	August-80	
59	C	9.92	1.07	8.85	August-80	
60	C	6.18	1.00	5.18	September-80	
61	C	4.57	1.00	3.57	August-80	
62	C	5.42	1.05	4.37	August-80	
65	C	7.98	1.50	6.48	April-77	
74	C	5.08	1.50	3.58	May-77	
83	C	5.48	1.50	3.98	June-77	
84	C	6.83	2.00	4.83	July-77	
105	C	6.77	1.00	5.77	August-80	
106	C	5.07	1.00	4.07	August-80	
107	C	7.23	1.00	6.23	August-80	
114	C	3.95	1.00	2.95	February-81	
115	C	3.48	1.00	2.48	March-81	
17	N	7.48	1.50	5.98	June-77	
33	N	7.00	1.50	5.50	March-79	5.5
34	N	5.34	1.00	4.34	March-79	4.34
35	N	7.65	1.50	6.15	April-79	6.15
36	N	8.06	1.00	7.06	April-79	
43	N	3.94	2.00	1.94	Apr-79	1.94
81	N	8.01			June-77	
85	N	11.45	1.50	9.95	July-77	
86	N	3.87	1.00	2.87	July-77	
87	N	2.79	1.00	1.79	July-77	
89	N	8.44	1.50	6.94	July-77	
90	N	8.56	2.00	4.56	August-77	
91	N	5.78	1.50	4.38	July-77	
92	N	5.34	1.50	3.89	July-77	
96	N	8.56	2.00	6.56	June-77	
77	S	7.46	1.50	5.96	April-77	
93	S	10.05	1.50	8.55	July-77	
94	S	4.77	1.50	3.27	July-77	
95	S	5.26	2.00	3.26	August-77	
				Average 5.26 below landsurface(all)		Average 5.15 below landsurface(1979)

Rainfall data from USGS WRI 87-4021, Navoy p. 7... 1977 approx = 41-42 inches
1978 Av rainfall approx... 50 inches
1979 Above av. Approx 60 inches
1980 below av. 41-42 inches
1981 below av 41-42 inches

Hydrograph data from Navoy p. 28
Average wl. In obs. Well approx. 21.5 ft msl during 1978 and 1979 well no. 293313081135203 from continuous hydgrph..77-82
Flucuation during drought 5-6 ft.

USGS WRI 90-4069, Phelps Volusia report p29 confined surficial 8-9 feet lower than average during drought
p.29 also lower permeable zone fluctuates less than 2 feet.
Water level in surficial at Gombergs well 223 usually 10 feet below landsurface p. 29
p. 36 the magnitude of the differences between upper and lower zone, not more than 3 feet during the study
Average for Central Zone 4.97 feet below lsd based on above table
Average for Northern Zone 4.79 feet below lsd base on table above
Average for Southern Zone 5.28 feet below lsd based on table above
Head difference at wells 214/215 p.52 is .1-.2 feet difference.. Upper zone is higher..both zones almost the same located near intersection of US 1 and I-95

David Gomberg, National Gardens Trust, 1980 locate at intersection of I-95 and US 1 in Volusia
p43. Average depth below lsd of shell or confined surf. 6.63 wells drilled in 12/79 and 1/80
p20. Depth to water at Site 4 along Powerlines or Bluff approx 13 ft below lsd measure 3/80 other sites near landsurface
p28 water levels in surficial were .1 to .3 feet higher than confined surficial(shell) 3/80, Floridan were 8-15 feet lower than aquifers above
except Site 12 near tomoka basin to the east Fla. 5 higher than WT surficial about 2 feet above lsd.

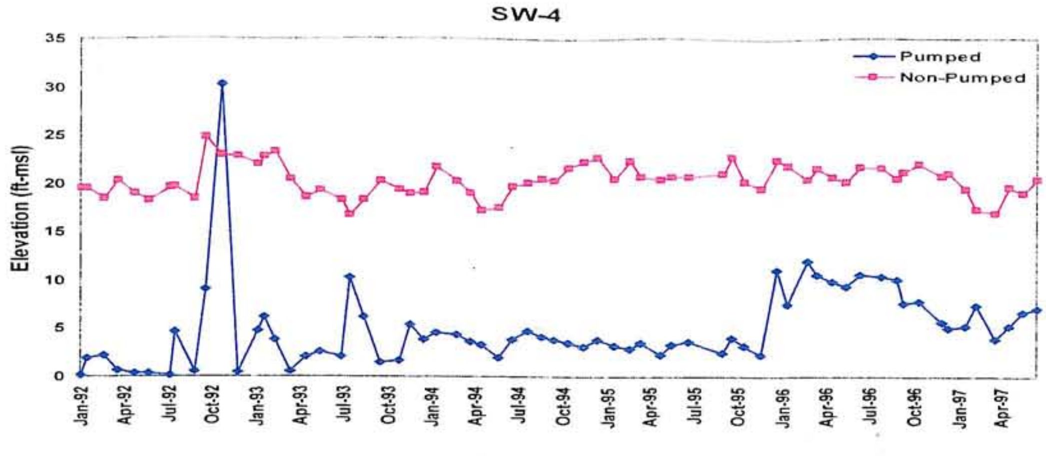
Gomberg, Halifax Plantation, 1981
p20 and 21 Upland sandy soils, wl in surficial generally 10 or more feet below lsd.. Elevations 25- 35 msl feet.
in Transistion area 10 -25 feet msl, water table is 4-8 feet below lsd
in Transition where elevations falls off abruptly from 15 feet to 10 feet msl .. WT intersects land surface
normal water table depths in lowlands... 10 feet or less are 1-4 feet below land surface.
p. 22 effects of canals Strickland and Korona affect WT elevations approx 1000 feet away.
p. 51 hydrograph of WT and CSA(shell) .. Site located 2000ft south of intersection of Old Kings RD and I-95 show less than a tenth difference
higher wls in surficial, but responses to rainfall recharge to shell also noticable.

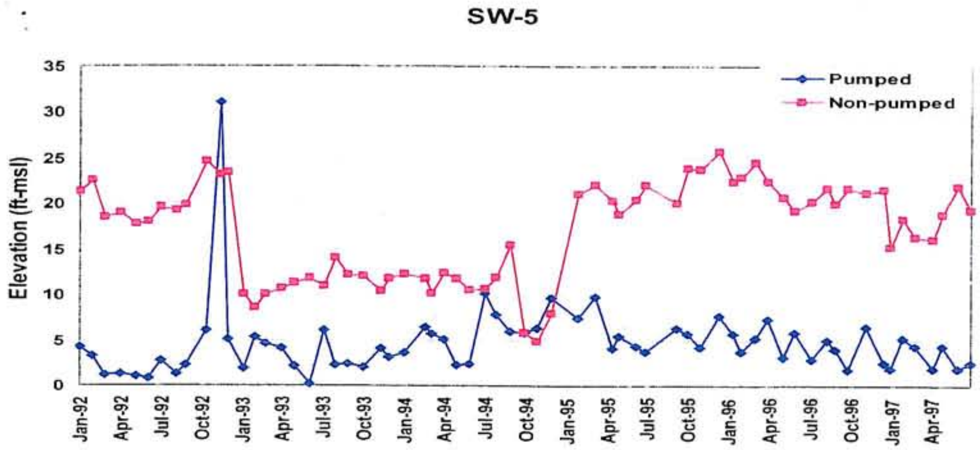
WELL_ID	ZONE	STATIC LEVEL AT CONSTRUCTION COMPLETION	TOP OF CASING (TOC)	DEPTH BELOW LAND SURFACE	LAND SURFACE ELEVATION	CONFINED SURFICIAL WATER LEVEL ELEVATION	REGRESSION ESTIMATED WT ELEVATION	WATER LEVEL Difference	Date	ROW	COLUMN	CELL_ID
SW-89	N	8	1.5	6.94	23	16.06	20.65	4.59	7/1/1977	11	20	540
SW-87	N	3	1	1.79	25	23.21	22.27	-0.94	7/1/1977	19	22	958
SW-90	N	8	2	4.56	29	24.44	26.83	2.39	8/1/1977	20	16	1004
SW-92	N	5	1.5	3.89	29	25.11	26.83	1.72	7/1/1977	20	16	1004
SW-43	N	3	2	1.94	30	28.06	27.82	-0.24	4/1/1970	22	21	1113
SW-86	N	4	1	2.87	30	27.13	27.51	0.38	7/1/1977	22	26	1118
SW-85	N	11	1.5	9.95	32	22.05	30.14	8.09	7/1/1977	26	22	1322
SW-81	N	8	0	0	30		26.94	0	6/1/1977	28	28	1432
SW-96	N	8	2	6.56	26	19.44	23.22	3.78	6/1/1977	29	30	1486
SW-36	N	8	1	7.06	34	26.94	31.76	4.82	4/1/1970	30	23	1531
SW-91	N	5	1.5	4.38	30	25.62	28.01	230	7/1/1977	32	18	1830
SW-115	C	3	1	2.48	30	27.52	28.01	0.49	3/1/1981	32	18	1830
SW-107	C	7	1	6.23	34	27.77	31.54	3.77	8/1/1980	32	22	1634
SW-35	N	7	1.5	6.15	32	25.85	29.54	3.69	4/1/1979	32	24	1636
SW-114	C	4	1	2.95	30	27.05	28	0.95	2/1/1981	33	19	1683
SW-62	C	5	1	4.37	30	25.63	27.98	2.35	8/1/1980	33	21	1685
SW-34	N	5	1	4.34	35	30.66	32.72	2.06	3/1/1979	33	24	1688
SW-106	C	5	1	4.07	32	27.93	30.14	2.21	8/1/1980	35	23	1791
SW-33	N	7	1.5	5.5	32	26.5	29.04	2.54	3/1/1979	35	25	1793
SW-61	C	5	1	3.57	30	26.43	28.01	1.58	8/1/1980	36	21	1841
SW-105	C	7	1	5.77	30	24.23	28.06	3.83	8/1/1980	37	23	1895
SW-60	C	6	1	5.18	30	24.82	28.01	3.19	9/1/1980	38	22	1946
SW-59	C	10	1	8.85	30	21.15	28	6.85	8/1/1980	38	24	1948
SW-17	N	7	1.5	5.98	30	24.02	28	3.98	6/1/1977	38	25	1949
SW-32	C	6	2.5	4.07	30	25.93	28.01	2.08	4/1/1979	38	27	1951
SW-30	C	8	2.3	6.36	30	23.64	28.08	4.44	4/1/1979	39	28	2004
SW-58	C	8	1	7.23	30	22.77	28	5.23	8/1/1980	40	25	2053
SW-29	C	12	3.7	9.03	30	20.97	28.13	7.16	4/1/1979	41	28	2108
SW-28	C	11	2.7	8.77	30	21.23	28.2	6.97	4/1/1978	41	29	2109
SW-31	C	10	1.5	8.55	30	21.45	28.87	7.42	7/1/1977	43	29	2213
SW-39	C	7	1	6.22	25	18.78	23.43	4.65	5/1/1977	45	38	2326
SW-40	C	4	2	2.35	30	27.65	27.99	0.34	5/1/1977	46	31	2371
SW-83	C	5	1.5	3.98	30	26.02	27.99	1.97	6/1/1977	46	31	2371
SW-51	C	5	2	3.78	30	26.22	27.83	1.61	5/1/1979	49	28	2524
SW-25	C	6	2	4.75	30	25.25	27.73	2.48	6/1/1979	49	32	2528
SW-24	C	5	2.35	3.56	29	25.44	27.26	1.82	5/1/1979	50	32	2580
SW-52	C	7	3.5	3.84	26	22.16	24.24	2.08	5/1/1977	50	36	2584
SW-84	C	6	2	4.83	25	20.17	23.24	3.07	7/1/1977	50	38	2586
SW-55	C	6	1.5	4.37	28	23.63	25.5	1.87	5/1/1977	51	33	2633
SW-11	C	11	1.5	9.22	25	15.78	23.01	7.23	5/1/1977	54	42	2798
SW-65	C	8	1.5	6.48	25	18.52	23.03	4.51	4/1/1977	55	34	2842
SW-21	C	7	3	4.7	25	20.3	23.04	2.74	5/1/1979	56	30	2800
SW-74	C	5	1.5	3.58	26	22.42	23.04	0.62	5/1/1977	59	38	3054
SW-77	S	7	1.5	5.96	25	19.04	23.03	3.99	4/1/1977	61	44	3164
SW-93	S	10	1.5	8.55	23	14.45	20.11	5.66	7/1/1977	63	36	3260
SW-95	S	5	2	3.26	22	18.74	19.62	0.88	8/1/1977	64	36	3312
SW-94	S	4	1.5	3.27	25	21.73	22.55	0.82	7/1/1977	69	38	3574

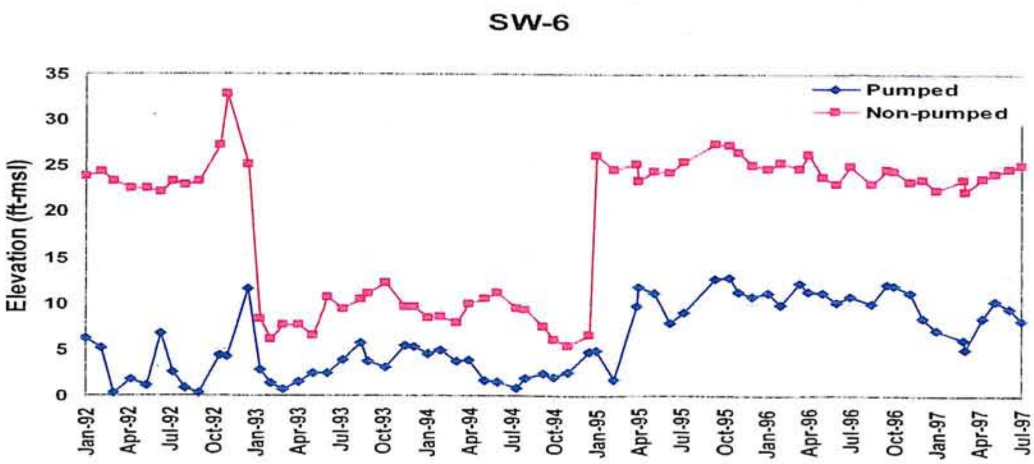
Av. Diff 3.13

APPENDIX E

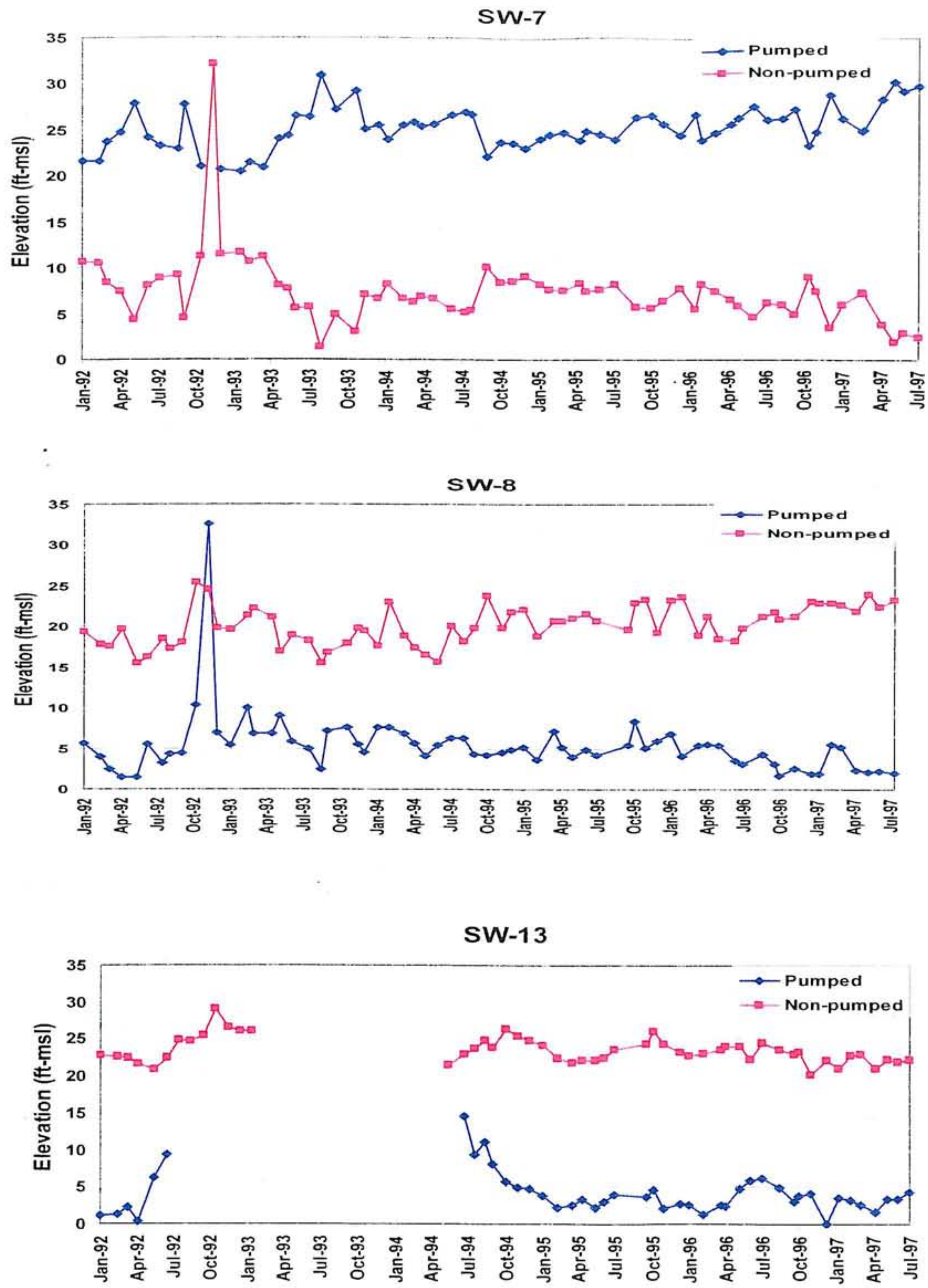
Water Level Hydrographs of Selected Confined Surficial Aquifer Production Wells



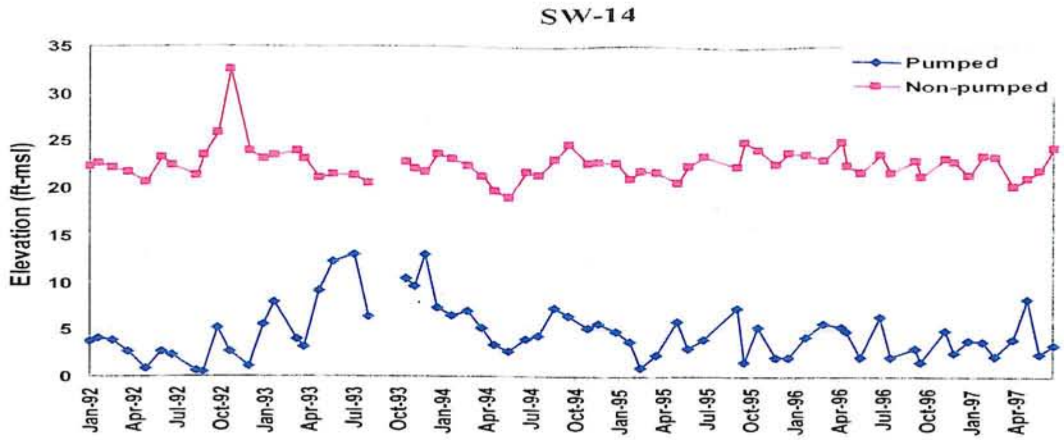


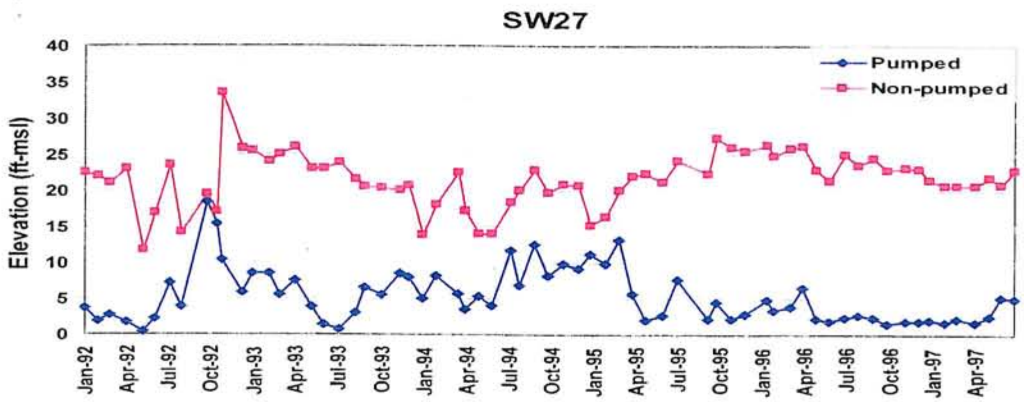


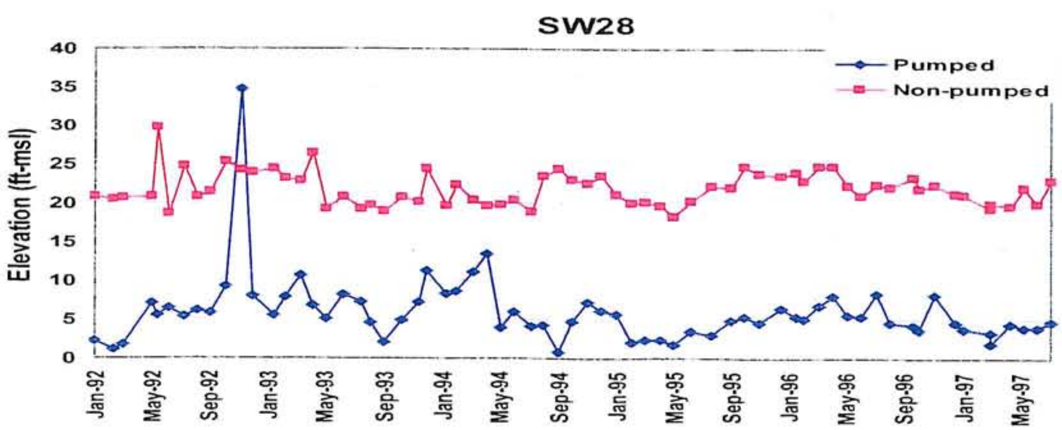
Water level hydrographs in Confined Surficial aquifer at SW-4, SW-5, and SW-6



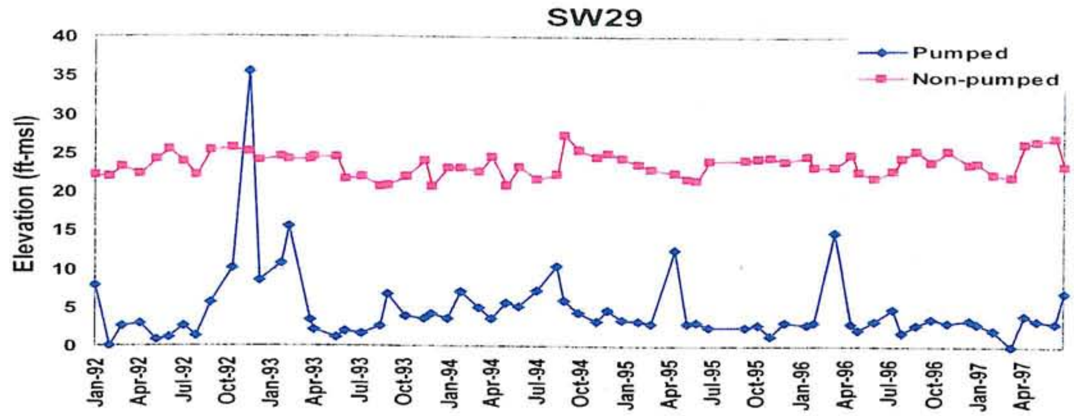
Water level hydrographs in Confined Surficial aquifer at SW-7, SW-8, and SW-13

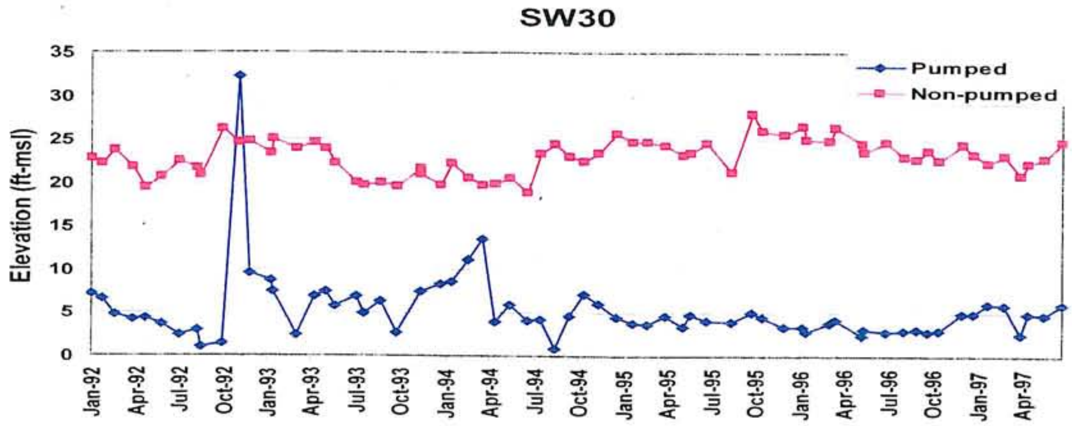


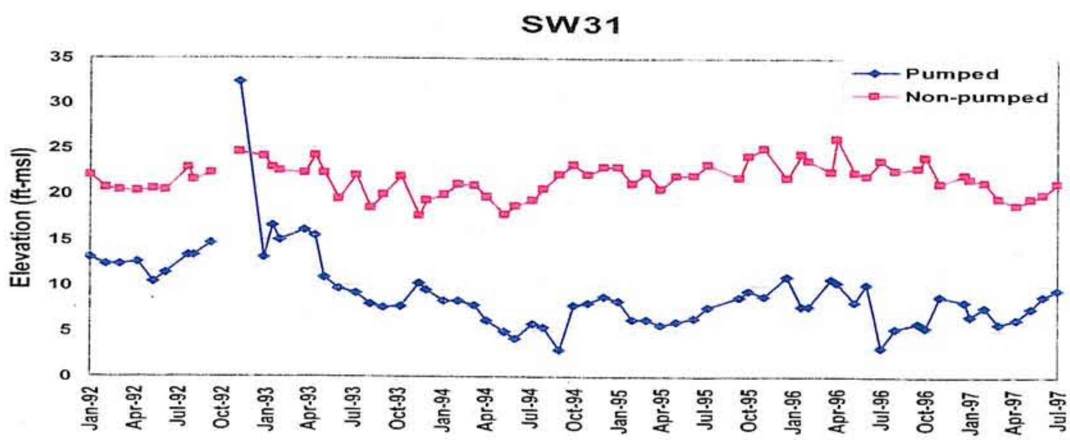




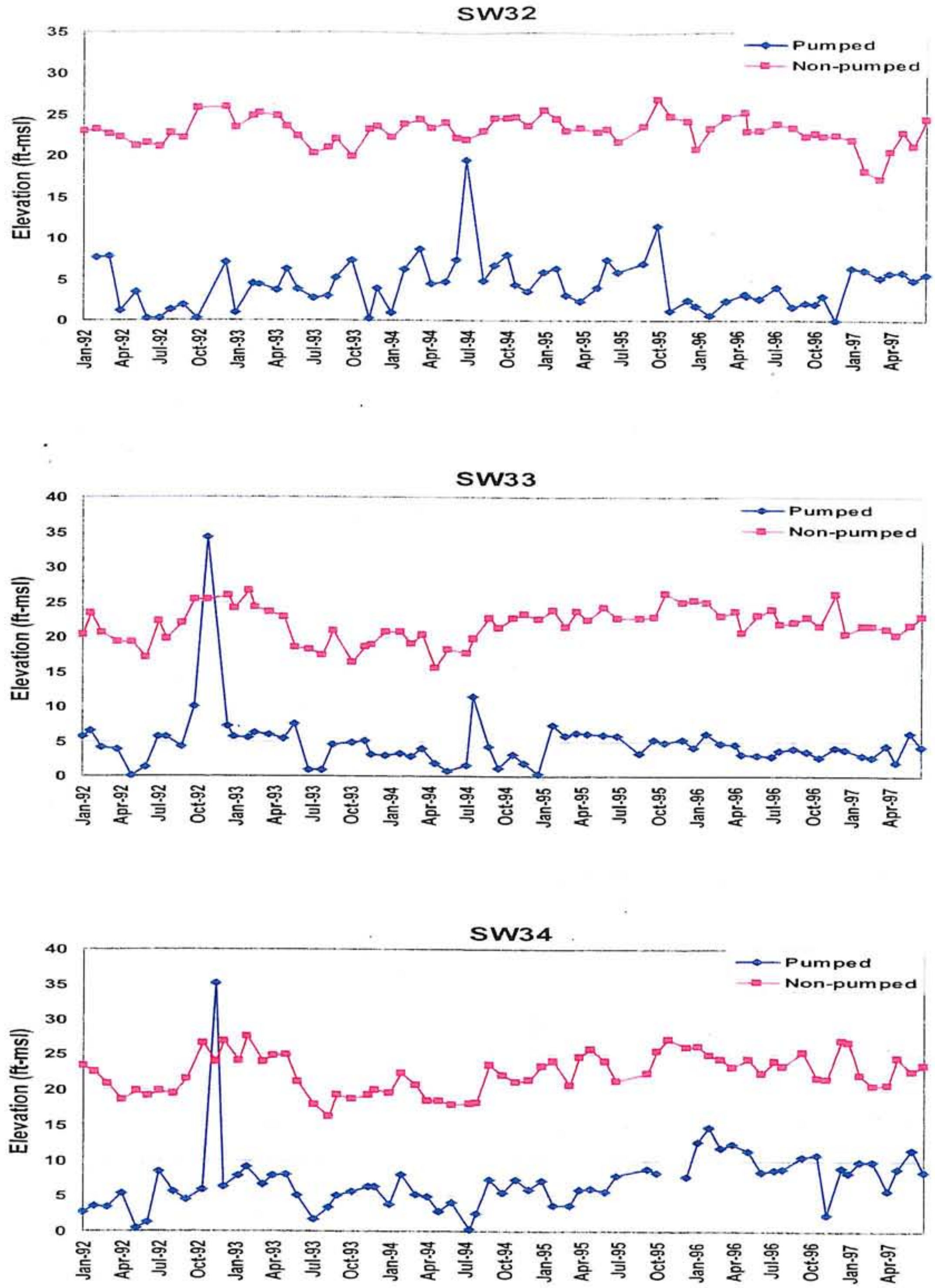
Water level hydrographs in Confined Surficial aquifer at SW-14, SW-27, and SW-28



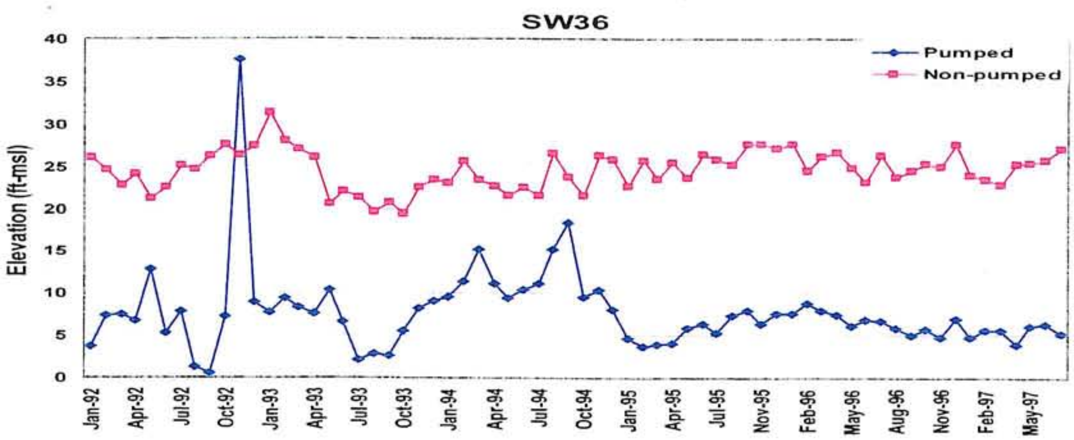


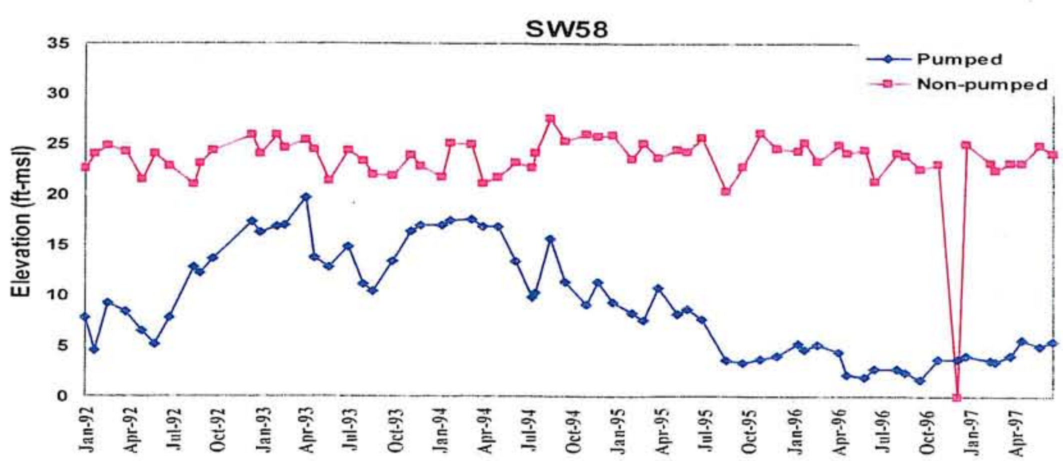


Water level hydrographs in Confined Surficial aquifer at SW-29, SW-30, and SW-31

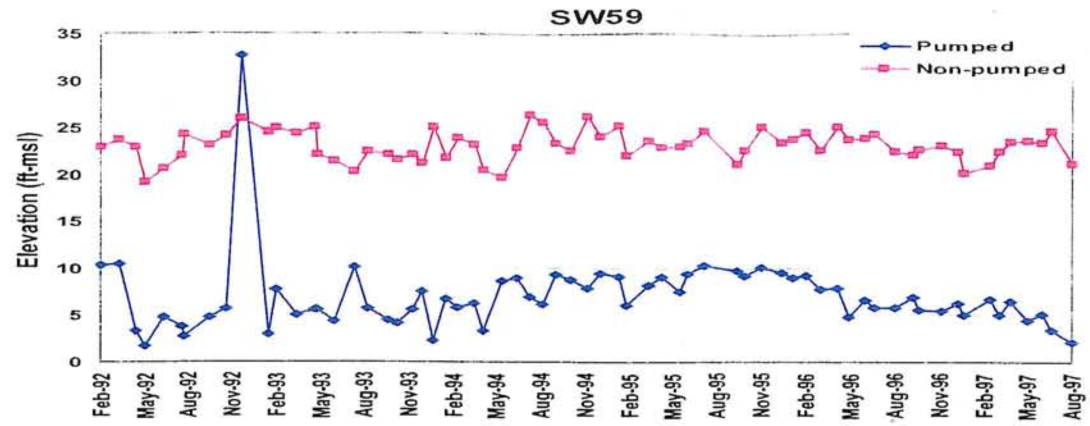


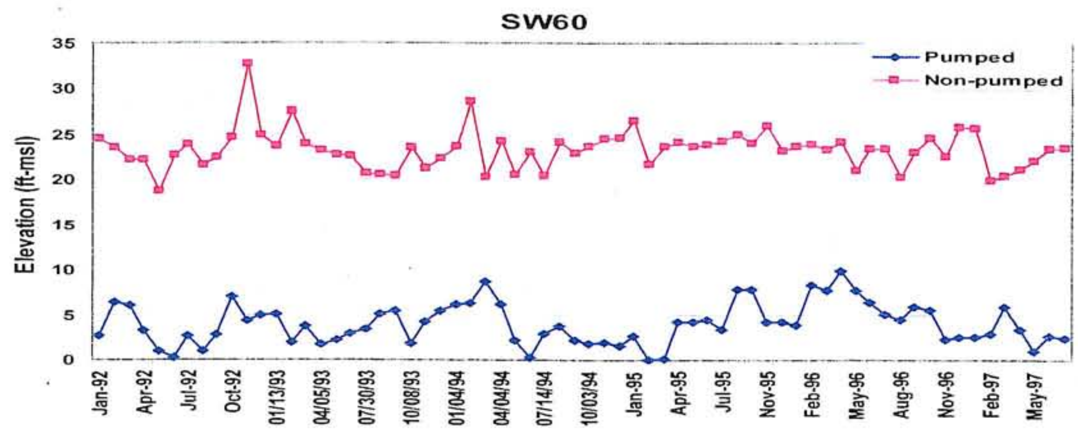
Water level hydrographs in Confined Surficial aquifer at SW-32, SW-33, and SW-34

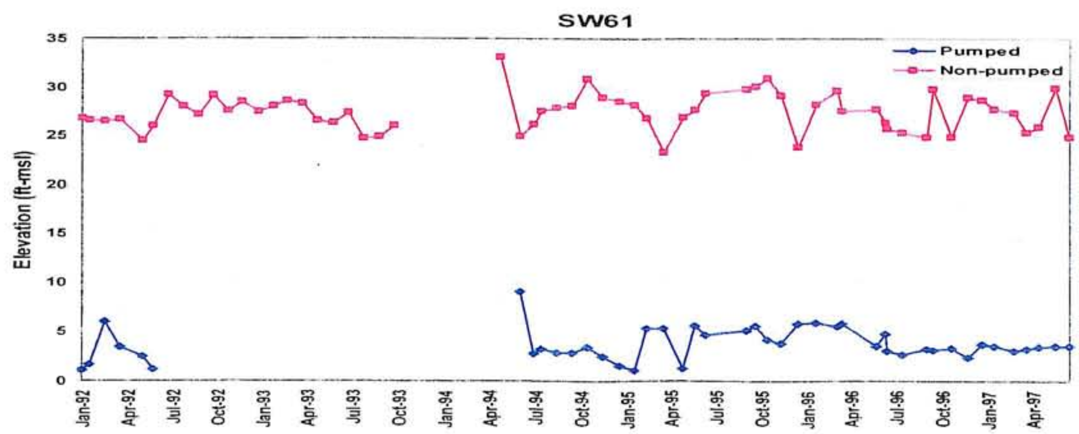




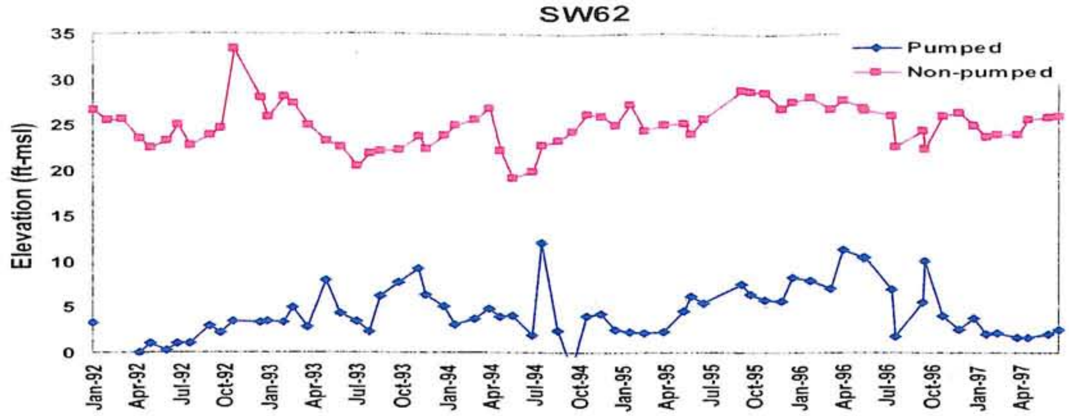
Water level hydrographs in Confined Surficial aquifer at SW-35, SW-36, and SW-58

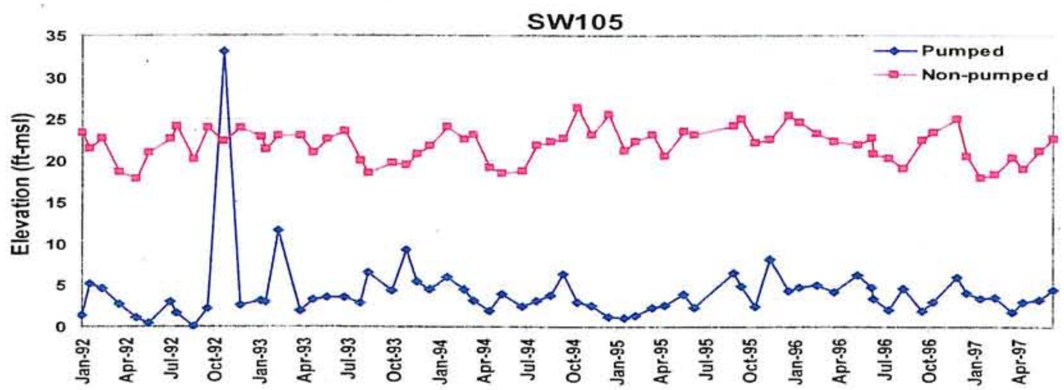


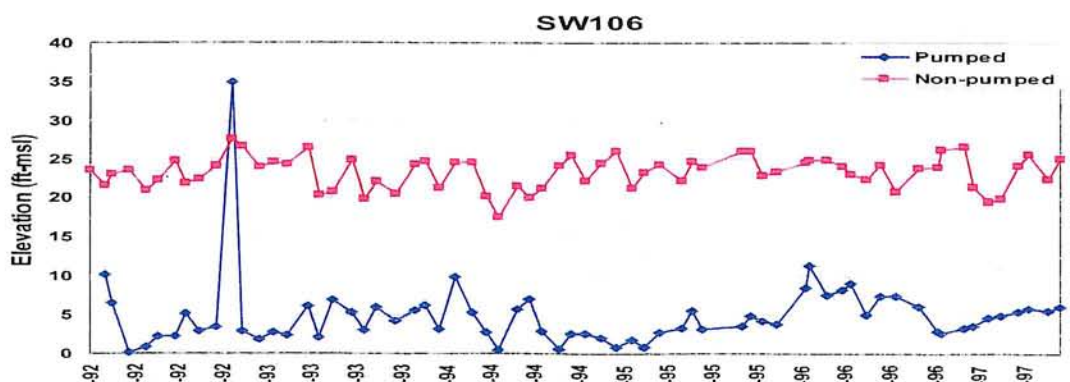




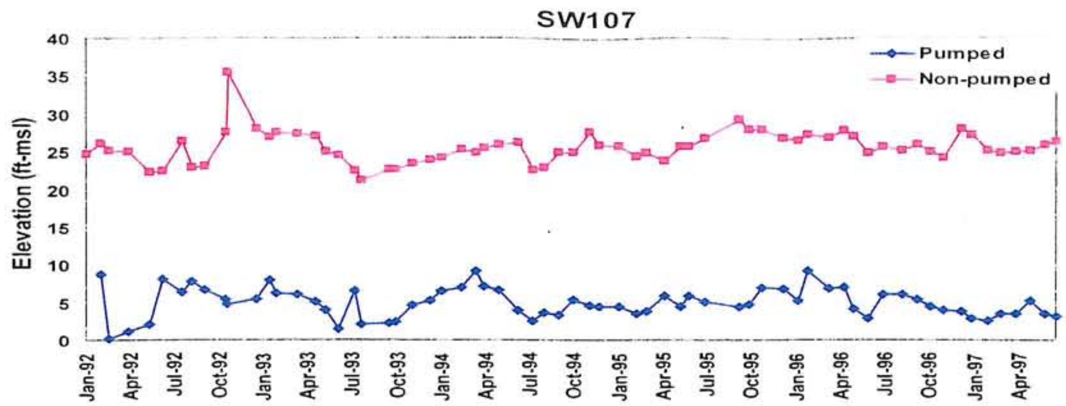
Water level hydrographs in Confined Surficial aquifer at SW-59, SW-60, and SW-61

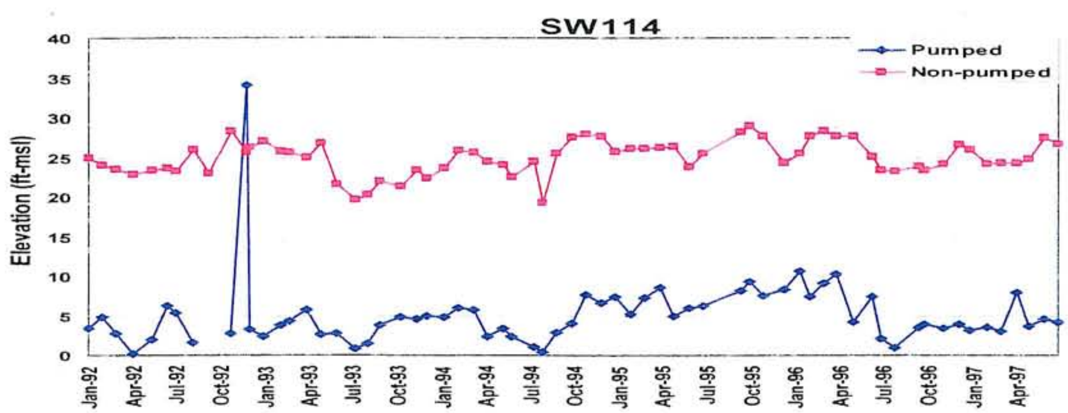


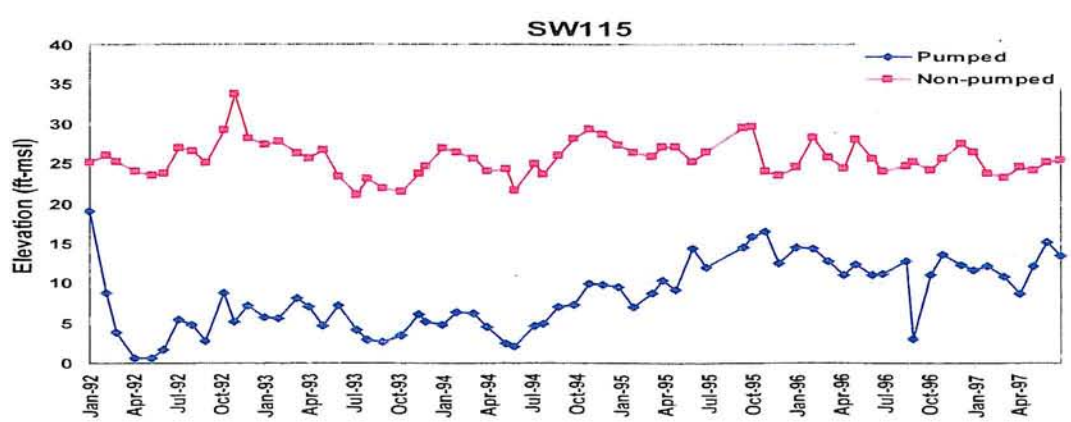




Water level hydrographs in Confined Surficial aquifer at SW-62, SW-105, and SW-106







Water level hydrographs in Confined Surficial aquifer at SW-107, SW-114, and SW-115