TECHNICAL PUBLICATION SJ2006-4

SIMULATION OF THE EFFECTS OF GROUNDWATER WITHDRAWALS FROM THE FLORIDAN AQUIFER SYSTEM IN VOLUSIA COUNTY AND VICINITY

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

Technical Publication SJ2006-4

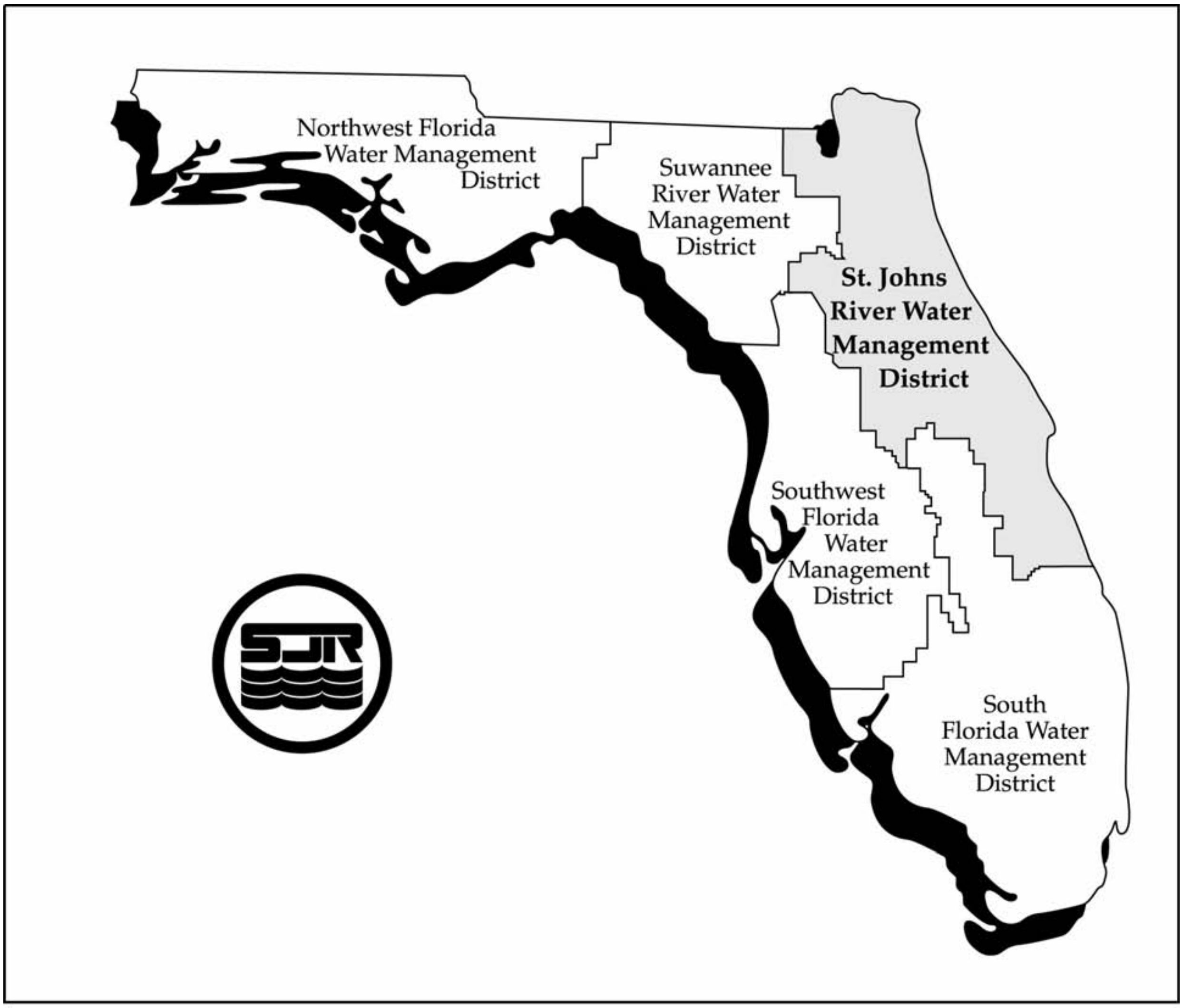
SIMULATION OF THE EFFECTS OF GROUNDWATER WITHDRAWALS FROM THE FLORIDAN AQUIFER SYSTEM IN VOLUSIA COUNTY AND VICINITY

by

Stanley A. Williams

St. Johns River Water Management District
Palatka, Florida

2006



The St. Johns River Water Management District (SJRWMD) was created by the Florida Legislature in 1972 to be one of five water management districts in Florida. It includes all or part of 18 counties in northeast Florida. The mission of SJRWMD is to ensure the sustainable use and protection of water resources for the benefit of the people of the District and the state of Florida. SJRWMD accomplishes its mission through regulation; applied research; assistance to federal, state, and local governments; operation and maintenance of water control works; and land acquisition and management.

This document is published to disseminate information collected by SJRWMD in pursuit of its mission. Copies of this document can be obtained from:

Library
St. Johns River Water Management District
4049 Reid Street • P.O. Box 1429
Palatka, FL 32178-1429

Phone: (386) 329-4132

EXECUTIVE SUMMARY

In 1989, the Florida state Legislature mandated that all water management districts within the state perform an exhaustive assessment of available water resource supplies and associated demands. An outcome of this assessment was the designation of water resource caution areas, defined as areas where current or future water resources are or are projected to become insufficient with respect to satisfaction of resource demands. As a result, considerable portions of east-central Florida, including virtually all of Volusia County, were designated as water resource caution areas. The development of groundwater simulation models was a critical component in the designation of these water resource caution areas. A groundwater flow model for the Volusia County vicinity in east-central Florida was developed and applied to facilitate the evaluation of the water resources within this area.

The project area encompasses virtually all of Volusia County in east-central Florida, parts of southern Flagler, eastern Lake, and northern Seminole counties, and small portions of Putnam, Orange, and Brevard counties. A conceptual model of groundwater flow within the surficial and Floridan aquifer systems was developed to facilitate the processing of hydrogeologic data and the model calibration process. The model was calibrated to both predevelopment hydrologic conditions and to average 1995 conditions. The calibrated model was used to predict changes in groundwater levels and flow rates between 1995 and the year 2020. Projected changes are caused by projected changes in groundwater for public supply, agriculture, and domestic self-supply, the elimination of free-flowing artesian wells, and the incorporation of additional reuse and/or irrigation associated with projected groundwater usage.

The regional groundwater flow model was used to simulate changes in water levels and flow rates caused primarily by changes in groundwater pumping between the average 1995 model calibration and the 2020 projection. Simulated changes between 1995 and 2020 were assessed with respect to the annual average water Table within the surficial aquifer system, the potentiometric surface of the Upper Floridan aquifer, and simulated rates for spring flows, evapotranspiration, and recharge/discharge between the surficial aquifer system and the Upper Floridan aquifer.

Projected simulated water Table declines are relatively high in east-central Volusia County where substantial increases in public supply pumping are

projected. In southwest Volusia County, surficial aquifer system levels are projected to decline by up to 4 feet due to increased pumping. The uncertainty associated with water Table changes was investigated with a detailed sensitivity analysis. Projected declines in the potentiometric surface of the Upper Floridan aquifer are relatively high in southwest and east-central Volusia County. In east-central Volusia County, declines in the potentiometric surface of up to 8 feet are projected to occur over an extensive area. Flow to subterranean springs is projected to decline in response to declines in the potentiometric surface of the Upper Floridan aquifer. Overall spring flow is projected to decline by approximately 10% compared to average 1995 conditions. Flow to Blue Spring, a first-magnitude spring that provides winter habitat for the endangered manatee population, is projected to decline by 8.6% between 1995 and the year 2020. An increase in lateral flow across the saltwater head boundary to the west of the St. Johns River into the Lower Floridan aquifer between 1995 and 2020 indicates the potential for water of relatively high chloride content to migrate laterally into the simulated freshwater within the Lower Floridan aquifer in eastern Lake County. Similarly, fresh groundwater moving out of the model domain within the Lower Floridan aquifer is projected to increase across the southern model boundary between 1995 and 2020. The increase in boundary discharge flow with the increase in flow from the St. Johns River area into the southwest portion of the model provides indicators for the potential for movement of high chloride water into the simulated fresh portion of the Lower Floridan aquifer. These projected system changes are directly associated with a projected reduction in potentiometric levels to the south and west of the model domain as simulated by the east-central Florida model (McGurk and Presley 2002).

Recommendations for additional investigation are presented to improve the level of understanding regarding the groundwater flow system. These recommendations include investigations of the local flow system in the vicinity of Blue Spring, refinement of methods to address the hydrologic processes that occur above the saturated zone, and development and calibration of a transient regional groundwater flow model.

CONTENTS

FIGURES

TABLES

ACKNOWLEDGMENTS

The author wishes to thank the staffs of the public supply utilities that are located within the domain of the model for Volusia County and the surrounding vicinity. In particular, staffs from the cities of Port Orange, DeLand, and Deltona, and member representatives on the Technical Advisory Committee of the Water Authority of Volusia, provided valuable feedback that contributed to the improvement and refinement of the groundwater model. The consulting firm of Post Buckley Shuh and Jernigan also provided important data and served in a review capacity. The Division of Water Supply Management of the St. Johns River Water Management District (SJRWMD) provided valuable information regarding water use and associated reuse. Staff members, particularly Brian McGurk and Patrick Burger, of the Division of Ground Water Programs of SJRWMD, provided valuable feedback regarding model development and implementation within a GIS environment, respectively. Finally, the author acknowledges the assistance of staff of the Altamonte Springs office of the U.S. Geological Survey and the valuable input of external peer reviewers.

INTRODUCTION

The assessment of the status of available groundwater and associated demands is fundamental to the mission of the St. Johns River Water Management District (SJRWMD), located in northeast Florida (Figure 1). In 1989, the Florida state Legislature mandated the investigation of available water resource supplies and demands throughout the state. In 1994, SJRWMD completed its response to this mandate in the form of a water supply needs and sources assessment that included impacts projected to the year 2010. As a result, water resource caution areas (i.e., areas where existing or future anticipated water resources are deemed insufficient to satisfy current or projected demands over a 20-year planning period) were delineated. The designated water resource caution areas included much of east-central Florida and virtually all of Volusia County. The water supply needs and sources assessment (Vergara 1994) was subsequently repeated with newly refined tools, water use projections to the year 2020, and a revised project methodology.

This report documents a groundwater flow model of the surficial and Floridan aquifer systems within an area in east-central Floridan that includes Volusia County and the surrounding vicinity (Figure 2). The model was developed based upon available land and water use and hydrogeologic data. It has been applied to assess both the current status and the projected future availability of groundwater to the year 2020.

OBJECTIVES

The general project objectives are to

- Develop and calibrate a regional groundwater flow model that sufficiently characterizes the surficial and Floridan aquifer systems within Volusia County and adjacent areas
- Apply the calibrated model as a predictive tool to assess future changes in water levels and spring flows that are directly related to future water use demands

Specific objectives of the groundwater model are to simulate

- Predevelopment and average 1995 groundwater flow conditions

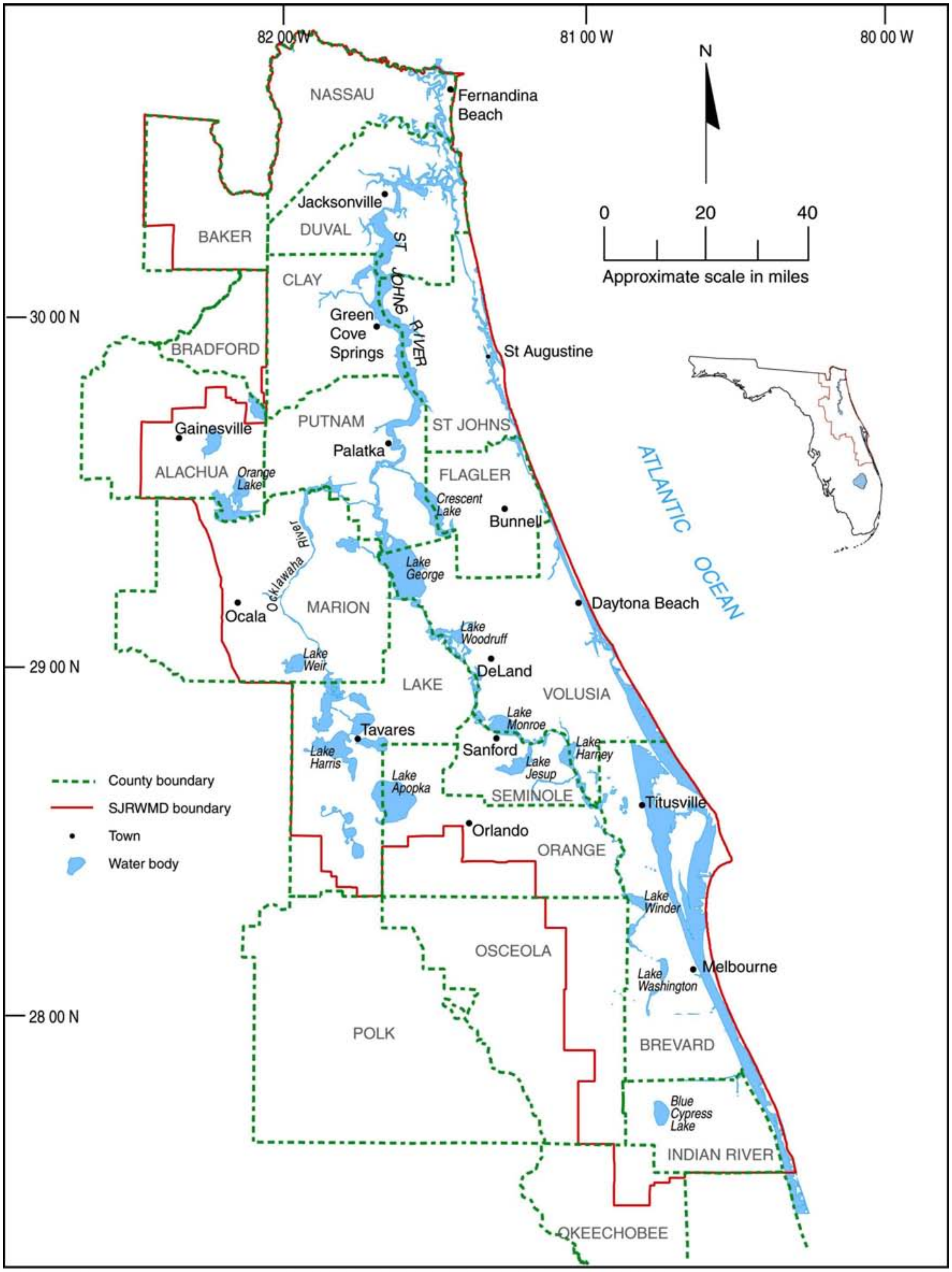


Figure 1. The St. Johns River Water Management District

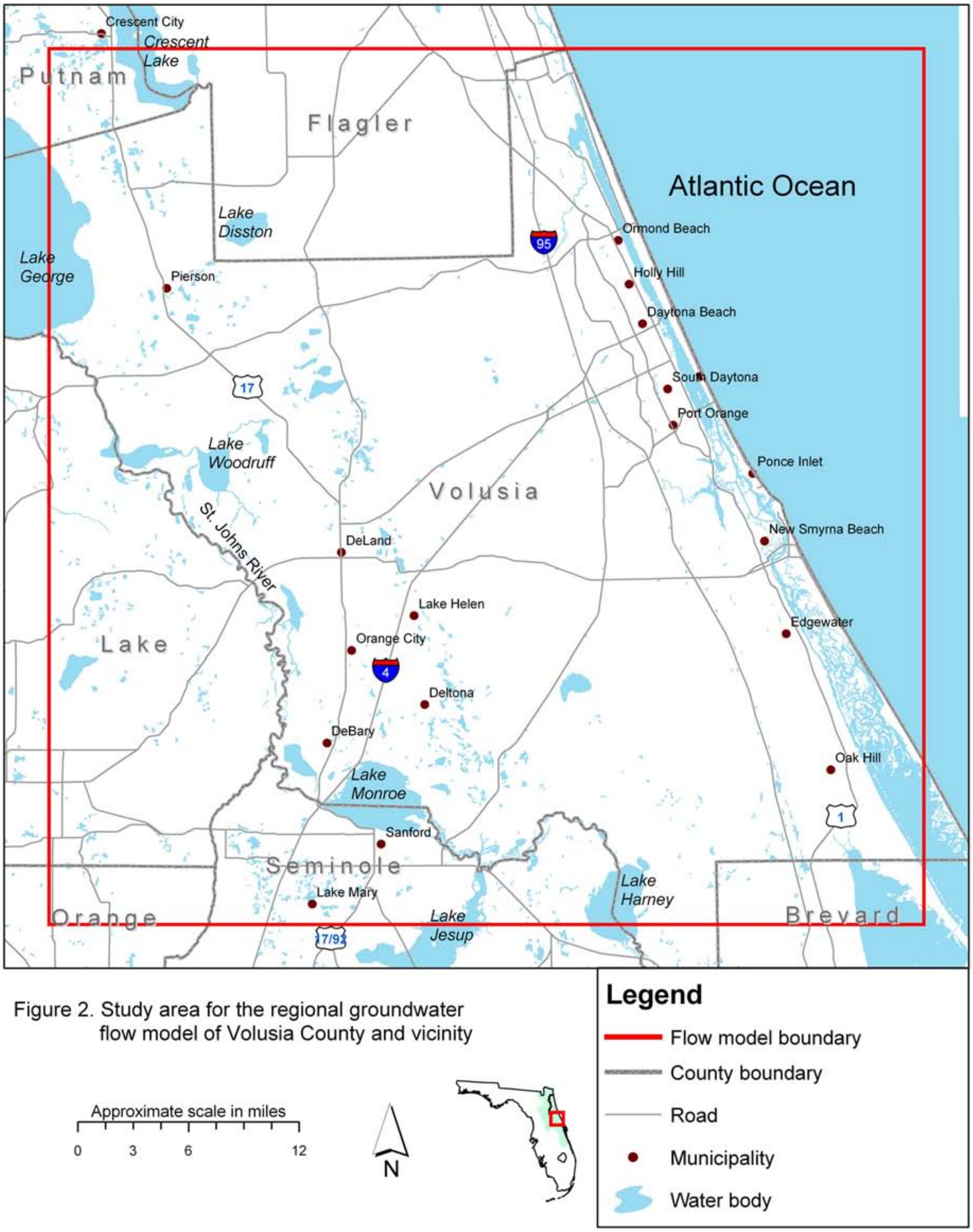


Figure 2. Study area for the regional groundwater flow model of Volusia County and vicinity

- Changes in potentiometric levels of the Upper Floridan aquifer or of the water Table caused by changes in groundwater pumping between 1995 and 2020
- Changes in spring flow and in the potentiometric surface of the Upper Floridan aquifer caused by pumping changes between 1995 and 2020
- Changes in rates of evapotranspiration from the surficial aquifer system and recharge to the Upper Floridan aquifer caused by pumping changes between 1995 and 2020

The project area includes Volusia County in east-central Florida, southern Flagler, eastern Lake, and northern Seminole counties, and small areas of Putnam, Orange, and Brevard counties (Figure 2). Principal industries in the study area include tourism, agriculture, and light manufacturing. Tourism is the predominant industry in eastern Volusia County, and agriculture is predominant in western Volusia and southern Putnam and Flagler counties. Agricultural products include ferns and foliage, citrus, turf grass, vegetables, and ornamental plants.

PREVIOUS INVESTIGATIONS

Several previous numerical modeling projects and groundwater investigations provide background material for this study. Wyrick (1960) completed a groundwater evaluation of the Volusia County area with compilations of water level data and estimates of aquifer hydraulic characteristics. Knochenmus and Beard (1971) published a comprehensive water quality assessment of Volusia County. Bush (1978) developed the first groundwater flow model of the area, providing a framework for subsequent modeling efforts. Simonds et al. (1980) investigated trends relating water levels and vegetation changes. Rutledge (1982, 1985) investigated water level changes caused by agricultural pumping in northwest Volusia County; he also developed a regional water budget and reviewed water quality data. Mercer et al. (1984) developed the first set of complementary models to simulate groundwater flow and saltwater intrusion. McGurk et al. (1989) reviewed and summarized lithologic and hydraulic characteristic data for the surficial aquifer system. Phelps (1990) provided an exhaustive review of hydrogeologic and water quality characteristics of the surficial aquifer system. Tibbals (1981, 1990) conducted an extensive study of the groundwater resources of east-central Florida that included development of a calibrated numerical groundwater model as part of the RASA (Regional Aquifer

Systems Analysis) series of U.S. Geological Survey (USGS) groundwater investigations. Geraghty and Miller (1991) developed the first groundwater model for this area that included an active surficial aquifer system. Williams (1997) developed a groundwater flow model that combined the work of Geraghty and Miller (1991) with refinements to the conceptualization of both the surficial aquifer system and the Floridan aquifer system. The current groundwater model is considered a fourth-generation model of the study area, and it effectively integrates the data and findings from previous studies with unpublished data from the files of USGS, SJRWMD, and related local sources.

DATA COLLECTION SITES

This project required the processing of a large amount of hydrologic data to facilitate the construction and calibration of the groundwater model. The locations of rainfall, lake level, spring flow, and stream gaging stations used in this study are shown in Figure 3, and descriptive information regarding these sites is provided in Appendices A and B. The locations of groundwater observation and test wells in the surficial and Floridan aquifer systems are shown in Figures 4 and 5, and corresponding well construction data are listed in Appendix C.

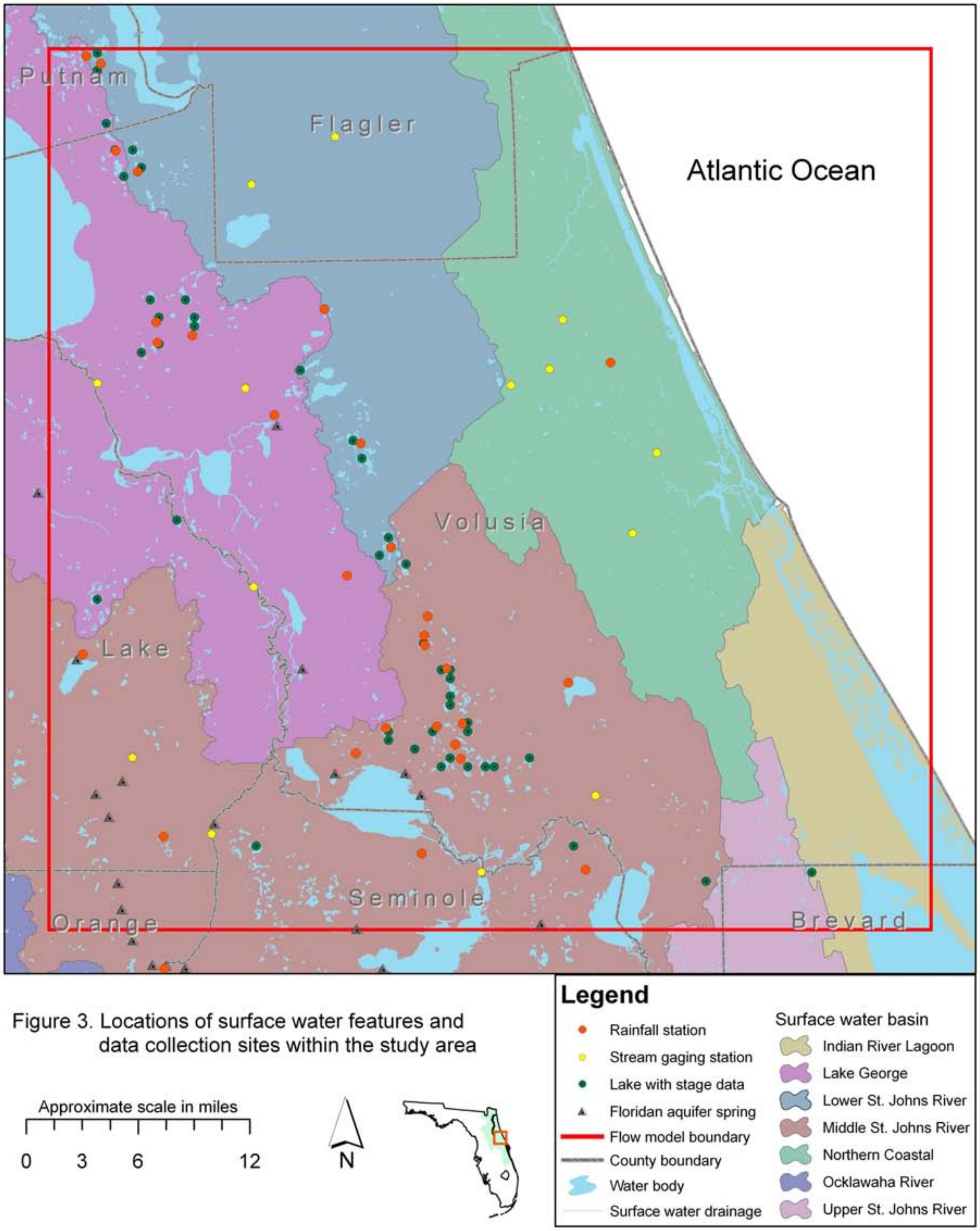


Figure 3. Locations of surface water features and data collection sites within the study area

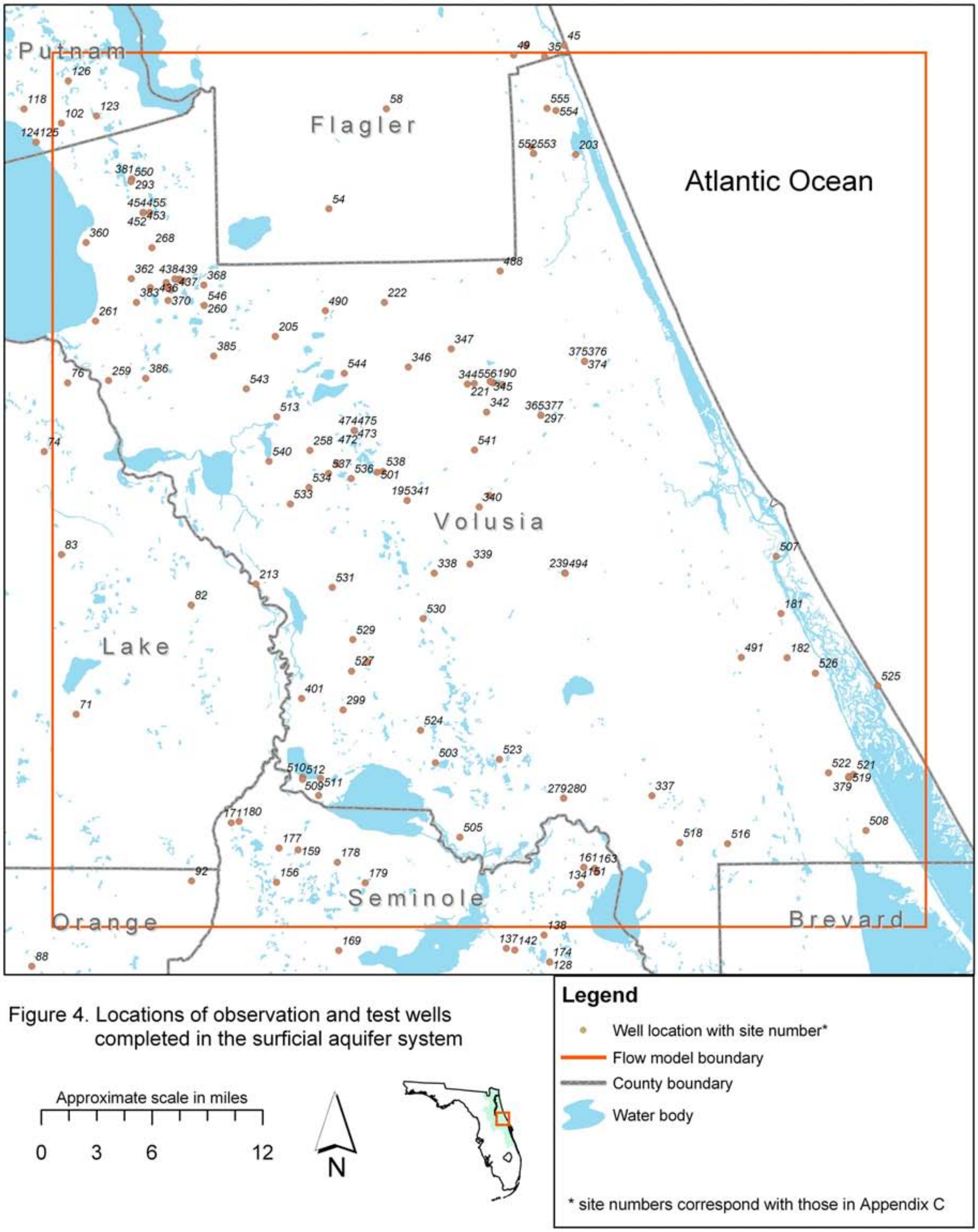


Figure 4. Locations of observation and test wells completed in the surficial aquifer system

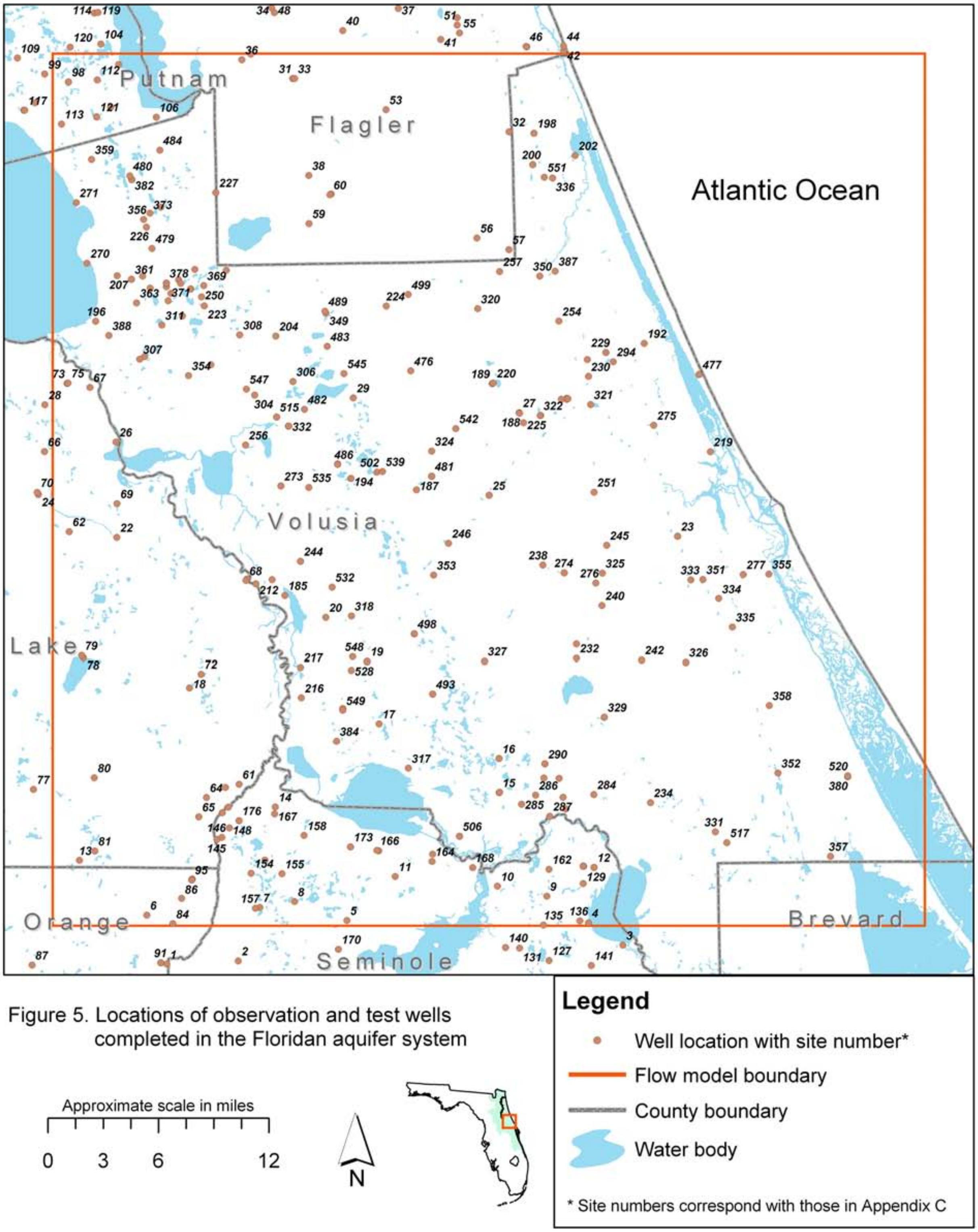


Figure 5. Locations of observation and test wells completed in the Floridan aquifer system

DESCRIPTION OF THE HYDROGEOLOGIC SYSTEM

The climatic, topographic, and hydrogeologic characteristics of the study area influence surface and groundwater levels and groundwater flow within the surficial and Floridan aquifer systems. Climatic and topographic characteristics influence the quantity and distribution of groundwater recharge and discharge. The lithology and hydraulic characteristics of the rock matrices that comprise the aquifers and confining units substantially influence both the flow rates and availability of groundwater. These and other factors are described and integrated into a conceptual model of groundwater flow.

CLIMATE

The climate of the study area is humid subtropical with an average annual temperature of 70°F and seasonal patterns of warm, wet summers and mild, relatively dry winters (Phelps 1990). Rainfall patterns are unevenly distributed spatially and temporally. Average annual rainfall for the region is between 48 and 56 inches per year (in/yr) based upon the period of record of 1961–1990 for four nearby stations monitored by the National Oceanic and Atmospheric Administration (NOAA) (Appendix A). Approximately 60% of total rainfall typically occurs between the months of June and October (Rao et al. 1997) as randomly distributed convective thunderstorms. Tropical storms or hurricanes, which occur between the months of June and November, are typically accompanied by large amounts of rainfall. Dry-season rainfall is usually the result of frontal activity that moves from northwest to southeast. These fronts cause warm air masses to lose moisture as rainfall that occurs in relatively uniform patterns (Tibbals 1990).

The process of evapotranspiration (ET) represents the largest relative loss of water that could otherwise provide recharge to the surficial aquifer system. ET rates are a function of depth to water, soil and vegetation types, and rainfall rates. For east-central Florida, the upper limit for ET is considered to be equivalent to the measured pan evaporation rate of 46 in/yr (Visher and Hughes 1975; Kohler et al. 1959). Actual ET rates approach this maximum in low-lying areas characterized by a shallow water Table and the occurrence of soils with a relatively high organic content. The lower limit for ET is estimated to be between 25 and 35 in/yr (Knochenmus and Hughes 1976; Tibbals 1977) and occurs where deep, well-drained soils and karst features such as sinkholes and / or depressional lakes are predominant. Recently, Sumner (1996) estimated a minimum annual ET of 27 in / yr for a study area characterized by shallow-rooted plants, rapidly drained soils, and a deep water table. Estimates of average countywide ET rates are between 35 and 39 in / yr (Knochenmus and Beard 1971; Rutledge 1985) (Table 1).

Table 1. Summary of estimated ranges of water budget components for the surficial aquifer system (in inches/year)

Component	Lowlands	Terraces	Eastern Ridges	Western Ridges
Evapotranspiration	42–46	36–42	30–36	27–30
Runoff	4–8	0–8	8–12	0–6
Recharge	0–4	4–8	8–10	10–18

Source: Phelps 1990; Rutledge 1985; Vecchioli et al. 1990

TOPOGRAPHY AND SURFACE WATER FEATURES

Patterns of topographic relief and surface water drainage provide visible indications of the underlying geomorphology and associated groundwater recharge / discharge patterns. Several ridges and terraces remain from periods of inundation and recession of seawater that occurred during the Pleistocene epoch (Figure 6). During periods of relatively higher sea levels, present-day ridges were beach dunes, scarps were shorelines, and terraces were offshore sea floors. For example, the DeLand Ridge, the highest and oldest geomorphic feature in Volusia County, is a surface expression of the Wicomico Shoreline from the Sangamon interglaciation (White 1970) that occurred about 10,000 years before present when the average sea level was approximately 100 feet (ft) above the current level. Smaller and younger ridges in the study area include the Crescent City Ridge in northwest Volusia County and Rima Ridge and the Atlantic Coastal Ridge in eastern Volusia County. The four terraces in the study area, listed in order of decreasing age, are the Penholoway, the Talbot, the Pamlico, and the Silver Bluff terraces (Rutledge 1982) (Figure 6). The configuration of these ridges and terraces provides a significant influence upon patterns of groundwater recharge and discharge.

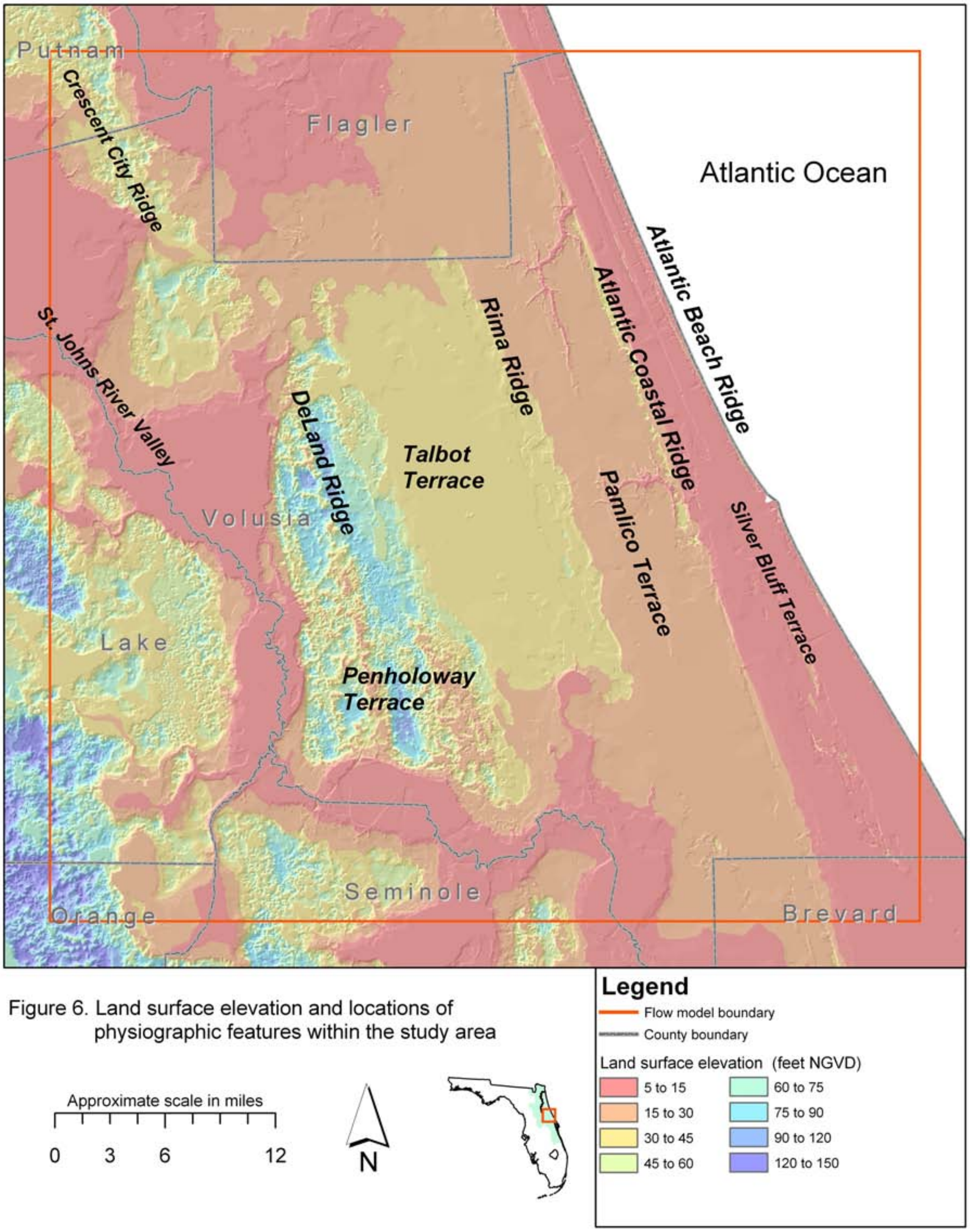


Figure 6. Land surface elevation and locations of physiographic features within the study area

Topographic relief is also associated with patterns of overland runoff (Phelps 1990). Estimated rates of overland runoff range from virtually zero in upland ridges to between 12 and 18 in / yr in low-lying terraces in central Volusia County and in the St. Johns River valley (Phelps 1990; Vecchioli et al. 1990) (Table 1). Surface hydrologic features such as sinkhole lakes in upland ridges and creeks, rivers, and wetlands in the lower terraces (Figures 3 and 6) provide definition for the patterns and quantity of overland runoff. Numerous sinkhole lakes are located in the upland areas and are associated with the karst topography of the DeLand and Crescent City ridges in western Volusia County. These lakes were formed due to two phenomena: (1) the dissolution of limestone as water moves through the rock matrix and (2) the decline in hydraulic pressure within the Upper Floridan aquifer, reducing buoyancy and diminishing the capacity of the underlying rock matrix to support the overburden. These phenomena contribute to a collapsing and coalescing of surficial sediments and subsequent development of depressions at land surface. Large lakes in the study area are primarily the result of several coalescing smaller sinkholes. In western Volusia County, some recent sinkhole formations have been linked with episodic declines in the potentiometric surface of the Upper Floridan aquifer caused by groundwater pumping for agricultural freeze protection (Rutledge 1985). Sinkhole lakes are replenished by direct rainfall, overland runoff, and groundwater inflow from the surficial aquifer system. These lakes facilitate recharge to the Upper Floridan aquifer due to the relatively high leakage that occurs between the lake bottoms and the top of the Upper Floridan aquifer.

GROUNDWATER FLOW

The hydrostratigraphic framework of the rock matrices that support the groundwater flow system is composed of an unconfined surficial aquifer system of clastic composition overlying the confined Floridan aquifer system of carbonate composition. These aquifer systems are separated vertically by three confining units: the intermediate confining unit between the surficial and Floridan aquifer systems, the middle semiconfining unit between the Upper and Lower Floridan aquifers, and the lower confining unit below the Floridan aquifer system (Figure 7). The vertical hydrostratigraphic sequence consists of undifferentiated clastic deposits of Pleistocene and Holocene age within the surficial aquifer system, unconsolidated beds of clay and sand of Miocene and Pliocene age that represent the intermediate confining unit,

Geologic Series / Stratigraphic Unit	Hydrostratigraphic Unit	Lithology / Thickness (feet)
Pleistocene and Holocene Anastasia Formation (eastern Volusia County)	Surficial aquifer system	Undifferentiated, interbedded fine- to medium-grained quartz sand, sandy clay, local shell beds; localized hardpan formed from sand with iron oxide Coquina: cemented to uncemented; varying amounts of quartz sand, silt, and organic material Thickness: 20 to 100 feet
Miocene and Pliocene Hawthorn Group	Intermediate confining unit	Unconsolidated beds of fine- to medium-grained sand, shells, and silty calcareous clay Thickness: 20 to 50 feet
Late Eocene / Ocala Formation Middle Eocene / upper third of Avon Park Formation	Upper Floridan aquifer	Soft to hard porous limestone, minor amounts of hard, crystalline dolostone Thickness: 0 to 300 feet Hard, crystalline dolostone with abundant fractures and solution cavities Thickness: 100 to 200 feet
Middle Eocene / middle third of Avon Park Formation	Middle semiconfining unit	Soft, micritic limestone and fine-grained dolomitic limestone, both low porosity; minor amount of hard crystalline dolostone Thickness: 100 to 300 feet
Middle Eocene / lower third of Avon Park Formation Early Eocene: Oldsmar Formation	Lower Floridan aquifer	Soft to hard porous limestone and hard, fractured crystalline dolostone Thickness: 600 to 800 feet White limestone with thin dolomite beds; beds of gypsum and anhydrite in lower portion; top elevation about –1,300 feet NGVD Thickness: about 500 feet
Paleocene: Cedar Keys Formation	Lower confining unit	Interbedded carbonate rocks and evaporites Thickness: 500 to 2200 feet

Source: Miller 1986; Tibbals 1990; Phelps 1990

Figure 7. Geologic and hydrostratigraphic sequence within Volusia County and vicinity

carbonate deposits of Eocene age that represent the Floridan aquifer system, and anhydrite beds of Paleocene age that characterize the lower confining unit (Figure 7).

Surficial Aquifer System

The lithology of the surficial aquifer system consists of several interfingering beds of sand, silt, clayey silt, and shell of Pleistocene or Holocene age (Phelps 1990). The thickness of the aquifer system sediments varies from less than 25 ft where pre-Pleistocene sediments are close to the land surface to greater than 150 ft in karst areas where sediments have been transported and deposited into sinkhole depressions over time (Figure 8). Figure 8 was constructed by comparison of the land surface elevation (developed from digital elevation data) with the base of the surficial aquifer (developed from interpretations of geologic logs throughout the study area) (see control points, Figure 8). In some areas of Volusia County, the surficial aquifer system is composed of two identifiable permeable zones, one occurring from land surface to about 30 ft below land surface and another between 40 and 60–70 ft below land surface (Phelps 1990).

The elevation of the water Table in the surficial aquifer system is typically at or near that of the land surface in low-lying areas and is typically several feet below land surface in upland ridge areas. Spatially, the profile of the water Table is highly variable, and generally mimics land surface elevations throughout the study area. Water levels are approximately 0–5 ft above the National Geodetic Vertical Datum of 1929 (NGVD, formerly called mean sea level) in coastal areas, approximately 30 to 40 ft NGVD along the central Talbot Terrace, and as high as 80 ft NGVD in the DeLand Ridge. A generalized map of the estimated elevation of the predevelopment water Table was constructed based upon the elevation of the land surface (Figure 6) and the estimated depth to water derived from soil drainage classifications listed in the Soil Conservation Service soil survey geographic (SSURGO) database (Figure 9).

Relatively few aquifer tests have been performed within the surficial aquifer system because it is not typically investigated as a potential source of water for public supply usage. Results from aquifer tests that have been performed indicate significant variability in estimates of horizontal hydraulic conductivity (K_h) (Table 2). This variability is associated with variations in

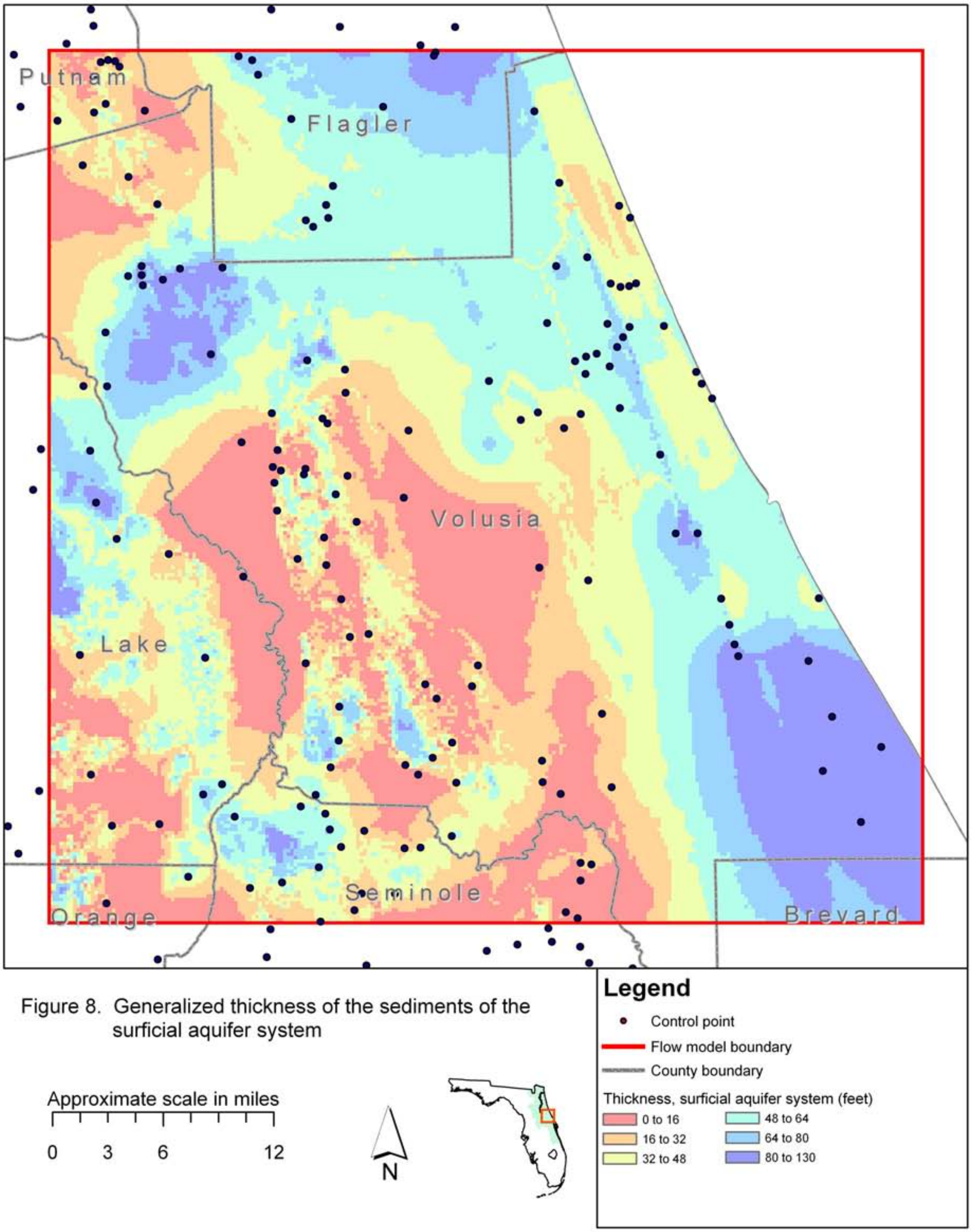


Figure 8. Generalized thickness of the sediments of the surficial aquifer system

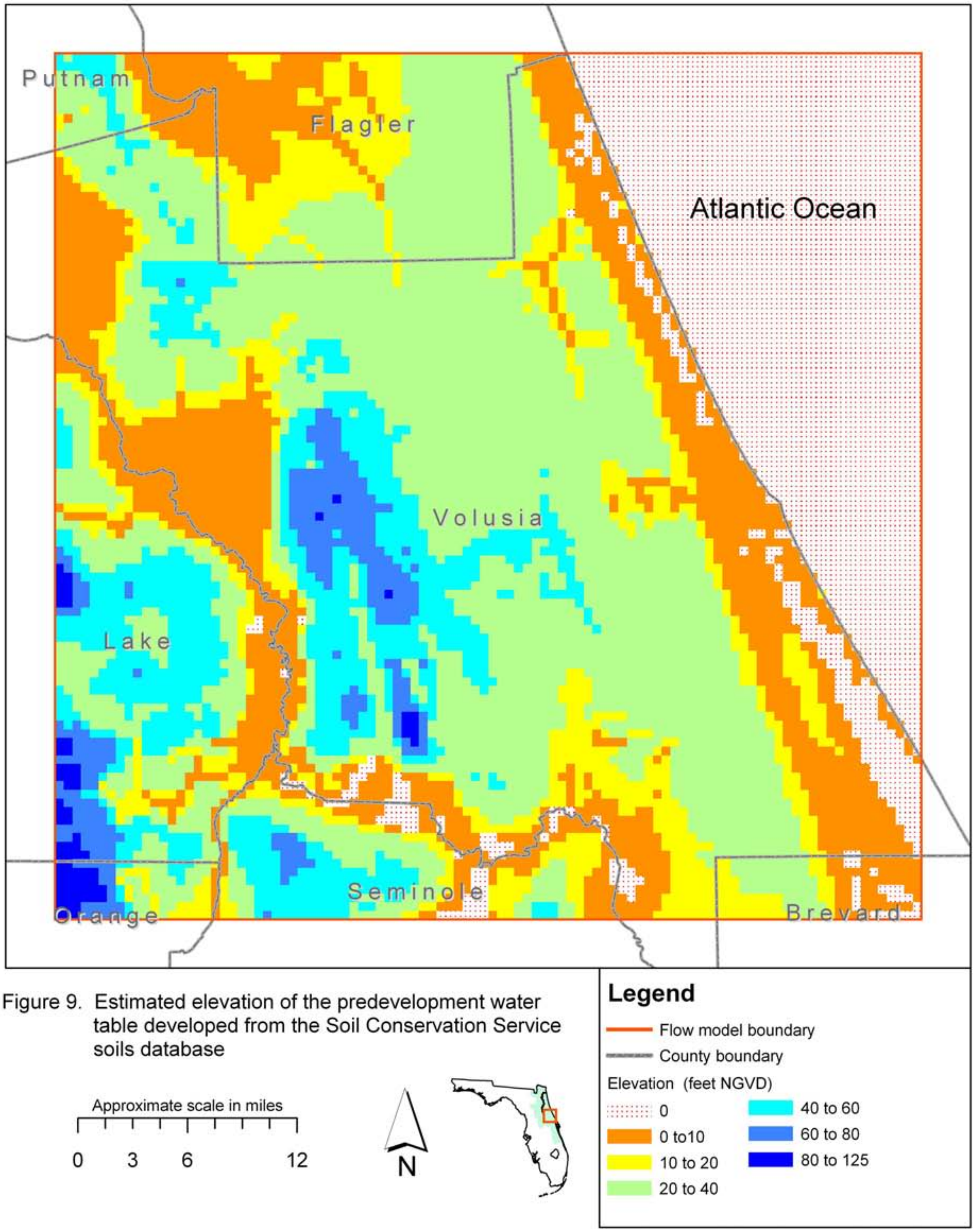


Figure 9. Estimated elevation of the predevelopment water table developed from the Soil Conservation Service soils database

Table 2. Summary of measured or estimated hydraulic conductivity for the surficial aquifer system (in feet per day)

Hydraulic Conductivity	Location of Test or Model	Comments	Source
0.03 to 13.00	Throughout Volusia County	Slug tests	McGurk et al. 1989
4 to 110	Northeast Volusia County	Aquifer performance tests	Gomberg 1980
28 to 49	Northeast Volusia County	Aquifer performance tests	Gomberg 1981
30	Oak Hill, southeast Volusia County	Aquifer performance test	Phelps 1990
25	Volusia County and vicinity	Regional groundwater model	Mercer et al. 1984; Geraghty and Miller 1991

rock lithology that are attribuTable to the depositional history of repeated periods marked by seawater transgression and regression. These aquifer test data are largely derived from slug tests and therefore only represent local aquifer conditions. Interpretations of regional distributions of K_h of the surficial aquifer system could be based upon the existing slug test data as well as trends in systemic variables such as physiographic region, soil type, or topographic elevation.

The primary source of recharge to the surficial aquifer system is infiltration derived from precipitation. Secondary sources include anthropogenic applications of water for purposes of agricultural irrigation, wastewater reuse, and discharge from septic tanks. Upward leakage from the Upper Floridan aquifer also provides supplemental recharge to the surficial aquifer system in areas where an upward hydraulic gradient exists. Overland flow occurs largely as a function of topography, land use, and soil type. Discharge from the surficial aquifer system occurs as ET, stream baseflow, and downward leakage to the Upper Floridan aquifer. The spatial pattern and relative magnitudes of recharge rates are influenced by the topographic elevation, the thickness and permeability of the unsaturated zone, and local soil permeability, vegetative cover, and land use. In the area of the DeLand Ridge, where the unsaturated zone is relatively thick and sandy, recharge to the surficial aquifer system tends to be greater than that which occurs in terraces where the unsaturated zone is relatively thin or nonexistent and the soil is organic and of lower permeability. Within the terraces, net recharge rates are comparatively low due to relatively high rates of overland runoff and ET. Many low-lying areas, such as the St. Johns River valley, are subject to artesian flow from the Upper Floridan aquifer, providing potential recharge from the Upper Floridan aquifer to the surficial aquifer system. Finally, groundwater recharge is diminished where urban and/or residential development is indicative of relatively higher percentages of impermeable surfaces.

Salinity of the groundwater within the surficial aquifer system is generally low since most water that enters the system originates as precipitation. Some areas of moderately elevated salinity occur along the St. Johns River and in the estuarine areas along the Atlantic coast. The surficial aquifer system is not typically used as a source of public supply or agricultural usage in the study area due to relatively low yields as compared to the Upper Floridan aquifer. However, the aquifer system is routinely tapped as a source of water for domestic self-supply usage.

Intermediate Confining Unit

The intermediate confining unit separates the surficial aquifer system from the underlying Floridan aquifer system and is composed of erosional remnants of the Hawthorn Group of Miocene age and discontinuous and heterogeneous low permeability zones of late Pliocene to early Pleistocene age (Tibbals 1990; Phelps 1990) (Figure 7). Although the Hawthorn Group typically comprises much of the thickness of the intermediate confining unit in north Florida, it is substantially absent in much of Volusia County. Where the Hawthorn Group is absent, the confining unit is composed of fine sands and calcareous silty clays of Miocene to early Pleistocene age. In southwestern Volusia County and eastern Lake County, numerous sinkhole depressions breach or nearly breach the intermediate confining unit and are often filled with permeable sands.

A map of the thickness of the intermediate confining unit (Figure 10) has been constructed from data derived from lithologic logs (Boniol 1993; Jeff Davis, SJRWMD, pers. com. 2001). This map was modified based upon supplemental data supplied by USGS (Rick Spechler, written com. 1999). The intermediate confining unit is relatively thin (<60 ft) throughout most of the study area. It is very thin in southern Flagler County and in isolated depressions in the upland karst ridges. The unit is relatively thick (>60 ft) in central Volusia County and in southeastern Lake and northern Seminole

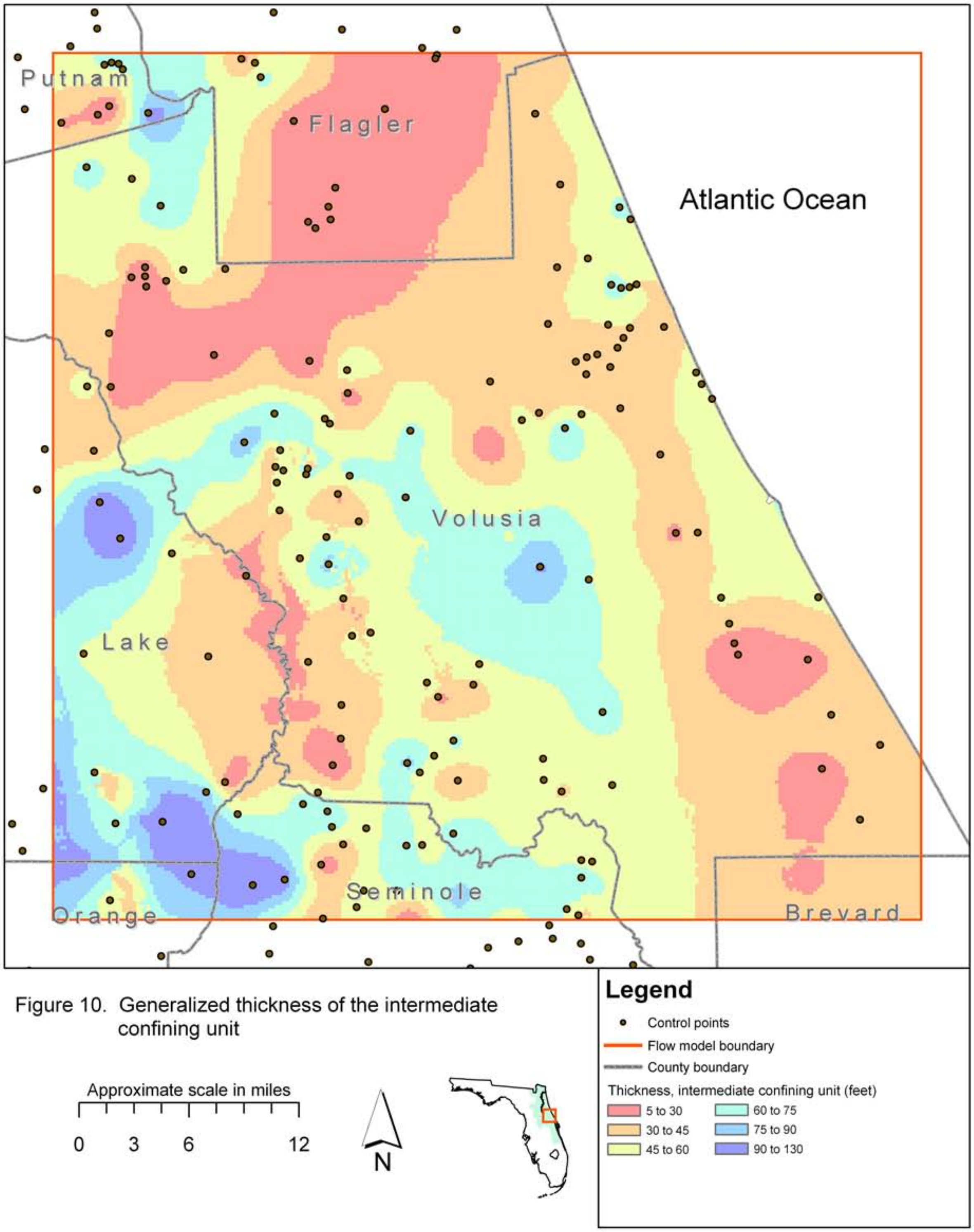


Figure 10. Generalized thickness of the intermediate confining unit

counties. Analyses of geophysical logs indicate that the intermediate confining unit is relatively continuous in eastern Volusia County and that it is characterized by greater variability in thickness and continuity in western Volusia and eastern Lake counties where karst geomorphology dominates (Phelps 1990; Rutledge 1985). The actual thickness of the intermediate confining unit at any given location may vary notably from that depicted on Figure 10 due to local erosional or karst features.

The mathematical leakance of a confining layer is equivalent to the vertical hydraulic conductivity of the layer divided by its thickness. Where sediments comprising the intermediate confining unit are primarily sand, shell, or limestone / dolostone beds, values for vertical conductivity and associated leakance are relatively high. Conversely, these values are relatively low where unit sediments are composed of lenses of silty calcareous clay and fine sand. Estimated leakance values derived largely from aquifer performance test results range between 1×10^{-6} and 0.8 day^{-1} for east-central Florida (McGurk and Presley 2002). However, leakance estimates derived from aquifer performance tests are typically higher than actual leakance values because water level responses to pumping are indications of leakage from both above and below the pumped aquifer.

Floridan Aquifer System

The Floridan aquifer system exists throughout all of Florida and parts of Georgia, South Carolina, and Alabama. The system is composed of permeable limestone and dolomite beds of Eocene and Paleocene age (Figure 7). The top of the Floridan aquifer system is defined as “the first occurrence of vertically persistent, permeable, consolidated carbonate rocks” (Tibbals 1990). The primary focus of this study is the analysis of changes in flow patterns and potentiometric levels in the Floridan aquifer system that have occurred from an estimated predevelopment condition to the year 1995 and that are projected to occur by the year 2020.

Stratigraphy and Hydrostratigraphy

The geologic formations that comprise the Floridan aquifer system in the study area are, from bottom to top, the Cedar Keys, Oldsmar, Avon Park, and Ocala Formations. These formations are carbonate beds that typically consist of interbedded limestone, dolomite, and dolomitic limestone in which the amount of primary porosity, secondary porosity, and secondary infilling of pores or fractures is highly variable with depth (McGurk and Presley 2002).

The Floridan aquifer system can be conceptualized into the hydrostratigraphic units of the Upper Floridan aquifer, the middle semiconfining unit, and the Lower Floridan aquifer based upon differences in measured and estimated hydraulic conductivity (Miller 1986; Tibbals 1990) (Figure 7).

The Upper Floridan aquifer consists of the Ocala Limestone and the upper one-third of the Avon Park Formation (Figure 7). The elevation of the top of the Upper Floridan aquifer, based upon geophysical log interpretations, ranges from less than –100 ft NGVD in eastern Volusia County and parts of eastern Lake County to approximately –20 ft NGVD in western Volusia and parts of Lake County (Figure 11). In southwestern Volusia County, the Ocala Limestone has been removed by erosion in areas, exposing the Avon Park Formation as the local uppermost unit of the Floridan aquifer system (Johnson 1981). On a local scale, the elevation of the top of the Upper Floridan aquifer is typically marked with significant irregularity due to erosion and karst development. The elevation of the base of the Upper Floridan aquifer was originally adapted from Miller (1986) and was subsequently modified based upon work of McGurk (O'Reilly et al. 2002). McGurk examined resistivity logs and test drilling data to infer an abundance of fractures within a dolostone zone that had previously been considered to be the upper portion of the middle semiconfining unit. His revision of hydrostratigraphic elevations in east-central Florida incorporates this high resistivity zone as part of the Upper Floridan aquifer and sets the base of the high resistivity zone as the revised aquifer base. The elevation of the aquifer base ranges between approximately –350 ft NGVD in southwestern Volusia and eastern Lake counties to less than –500 ft NGVD in southern Flagler and Volusia counties (Figure 12). A thickness map derived from the top and bottom surfaces illustrates a relatively thin (200–300 ft) area in southwestern Volusia county and parts of Lake County and thickening trends to the north and south (Figure 13). Previous researchers have proposed the existence of faults along the St. Johns River based upon differences in the elevation of the top of the Upper Floridan aquifer over relatively short geographic distances and along linear topographic features. Miller (1986) noted that the faults are evident for only the middle to late Eocene sediments and appear to diminish with depth. Scott (1988) emphasized that the nature of the Miocene and Eocene sediments contribute to ambiguity regarding whether these features are due to structural activity or to depositional and erosional processes.

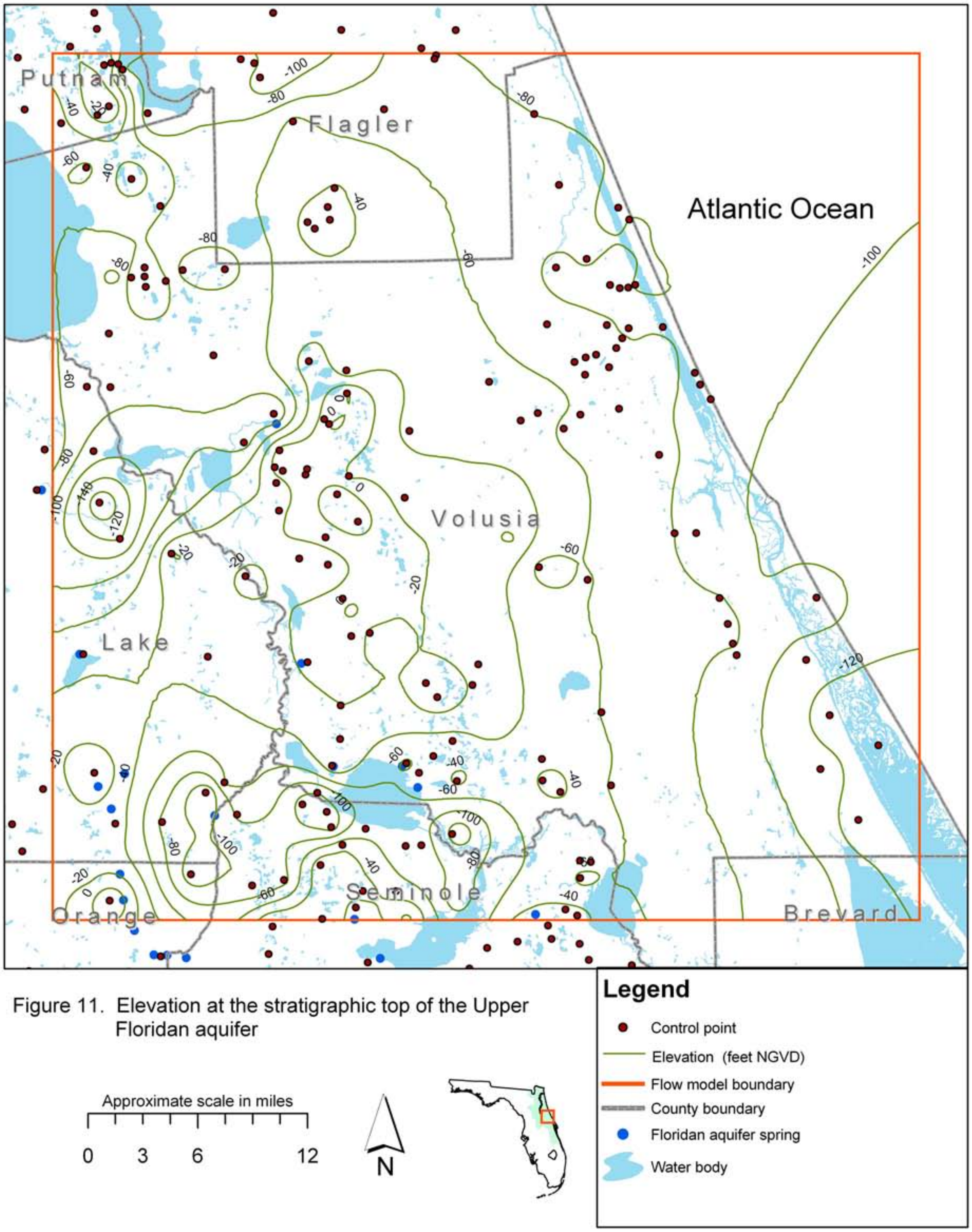


Figure 11. Elevation at the stratigraphic top of the Upper Floridan aquifer

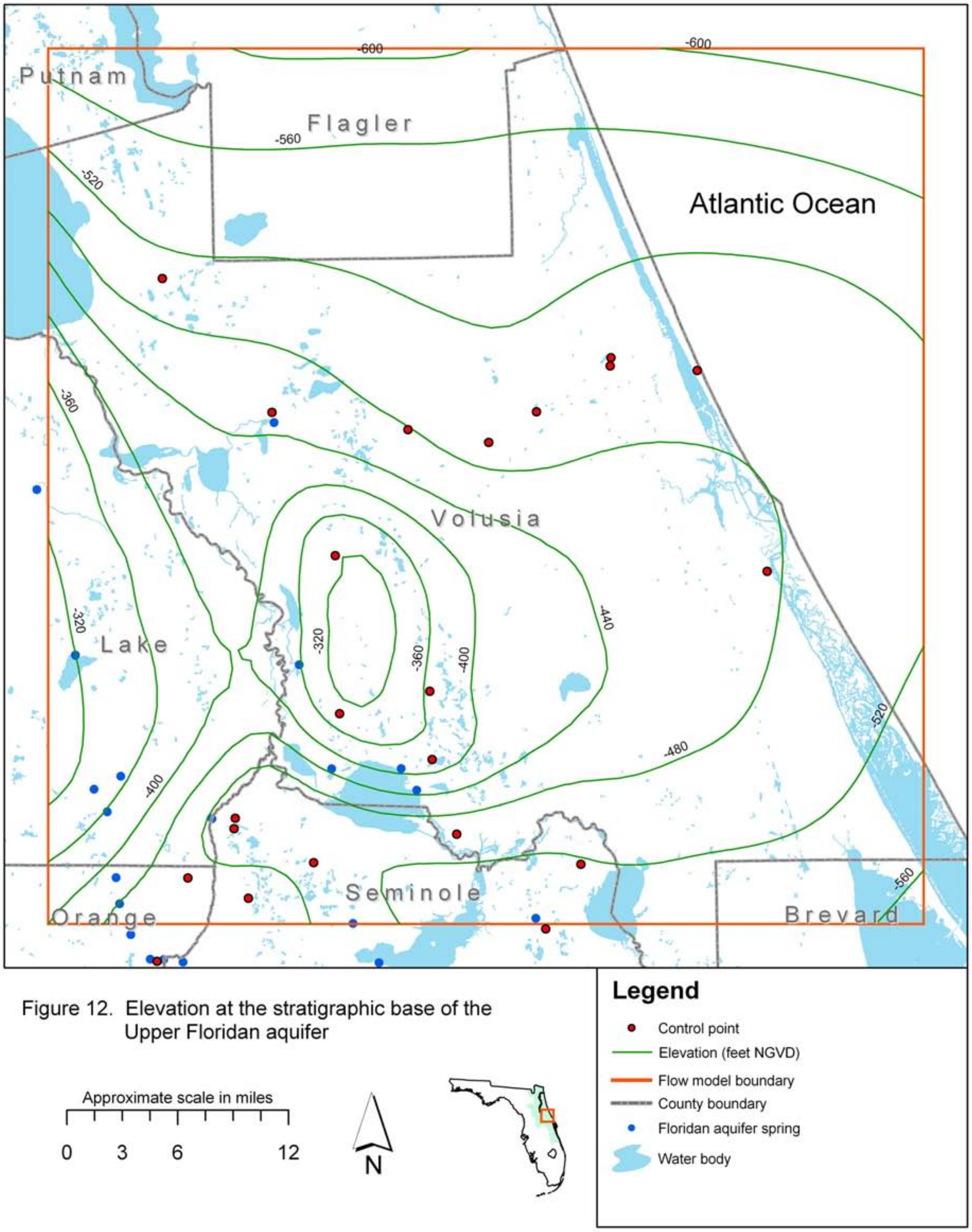


Figure 12. Elevation at the stratigraphic base of the Upper Floridan aquifer

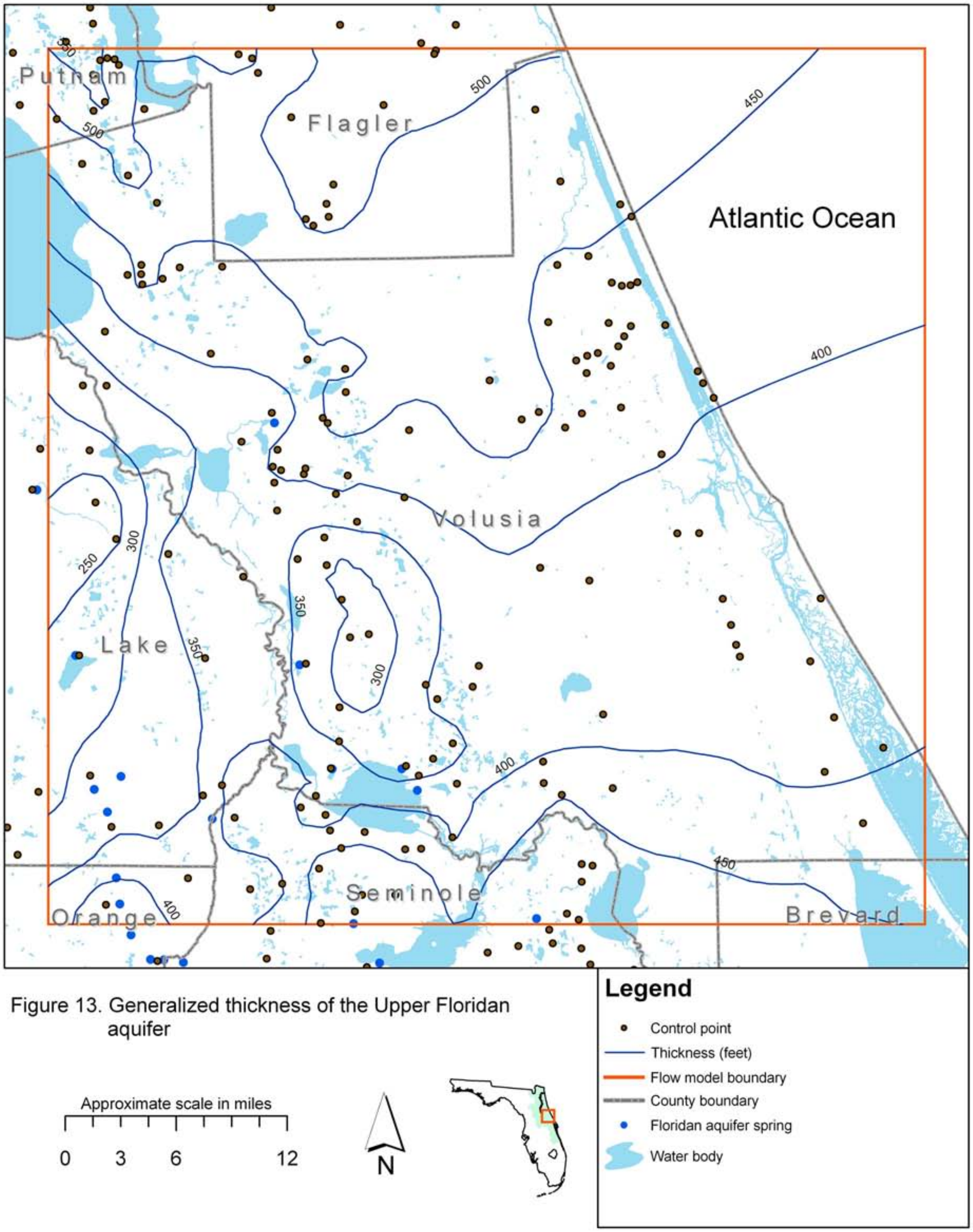


Figure 13. Generalized thickness of the Upper Floridan aquifer

Snyder et al. (1989) proposed that the apparent displacement of Miocene and Eocene sediments along the St. Johns River is due to subsidence caused by paleokarst solution collapse within the Eocene carbonates.

The middle semiconfining unit is conceptually equivalent to middle semiconfining unit I identified by Miller (1986) and consists of soft, micritic limestone and dense, dolomitic limestone. This zone is leaky, and its lithology is generally similar to that of the Upper and Lower Floridan aquifers and is considered a semiconfining unit primarily because it lacks significant secondary porosity that would be typified by abundant fracture zones and solution cavities (Lichtler et al. 1968). The top of the middle semiconfining zone is equivalent to the base of the Upper Floridan aquifer, revised to include the zone of high resistivity identified by McGurk (documented in O'Reilly et al. 2002) and discussed above. The base of the middle semiconfining zone is adapted from Miller (1986). The unit thickness ranges from approximately 180 ft to 430 ft. Zones of greatest thickness occur to the south and east, and those of least thickness occur to the west (Figure 14).

The Lower Floridan aquifer is composed of the lower Avon Park Formation and the Oldsmar Formation, both of Eocene age (Figure 7). The elevation of the top of the Lower Floridan aquifer ranges from above –600 ft NGVD in eastern Lake County to below –900 ft NGVD in Flagler County (Figure 15) and is adapted from Miller (1986). The base of the Lower Floridan aquifer is defined as the top of the Cedar Keys Formation, which is composed of relatively impermeable carbonate beds containing abundant evaporite minerals (Figure 7). The base of the Lower Floridan aquifer occurs at elevations ranging from above –2,000 ft NGVD to below –2,400 ft NGVD (Figure 16), and is also adapted from Miller (1986). Total thickness of the Lower Floridan aquifer is between approximately 1,000 ft and 1,500 ft and increases to the south and west within the study area (Figure 17).

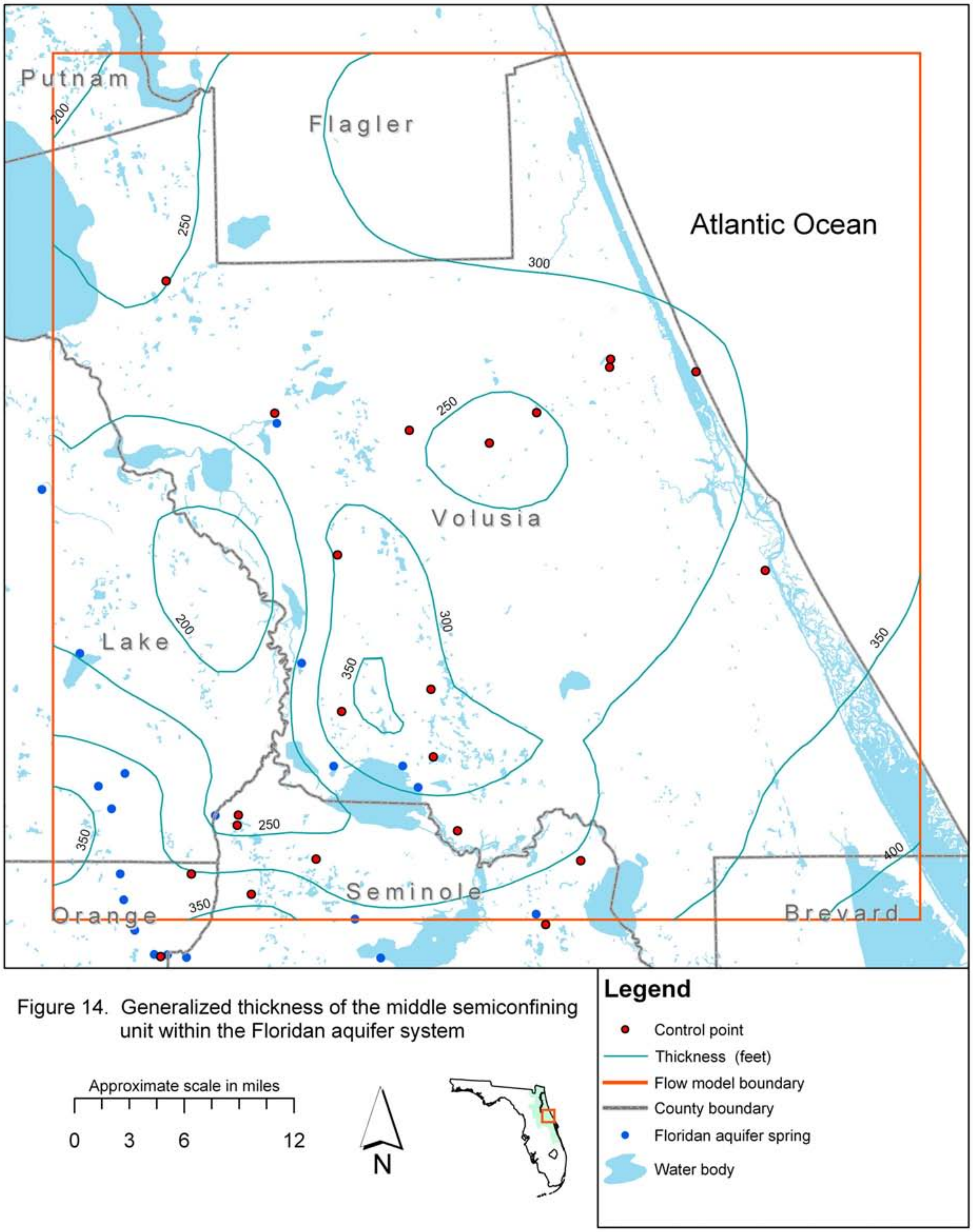


Figure 14. Generalized thickness of the middle semiconfining unit within the Floridan aquifer system

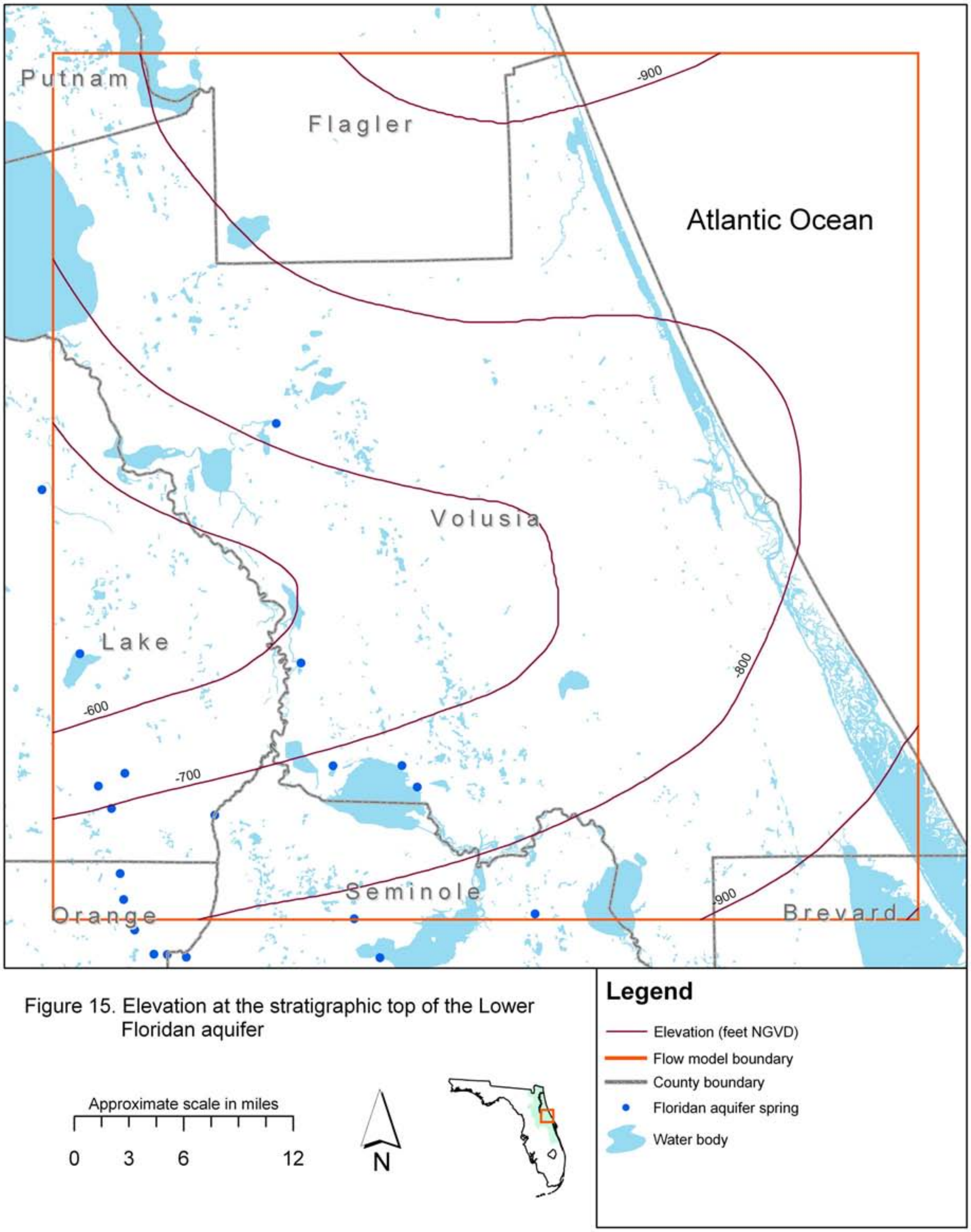


Figure 15. Elevation at the stratigraphic top of the Lower Floridan aquifer

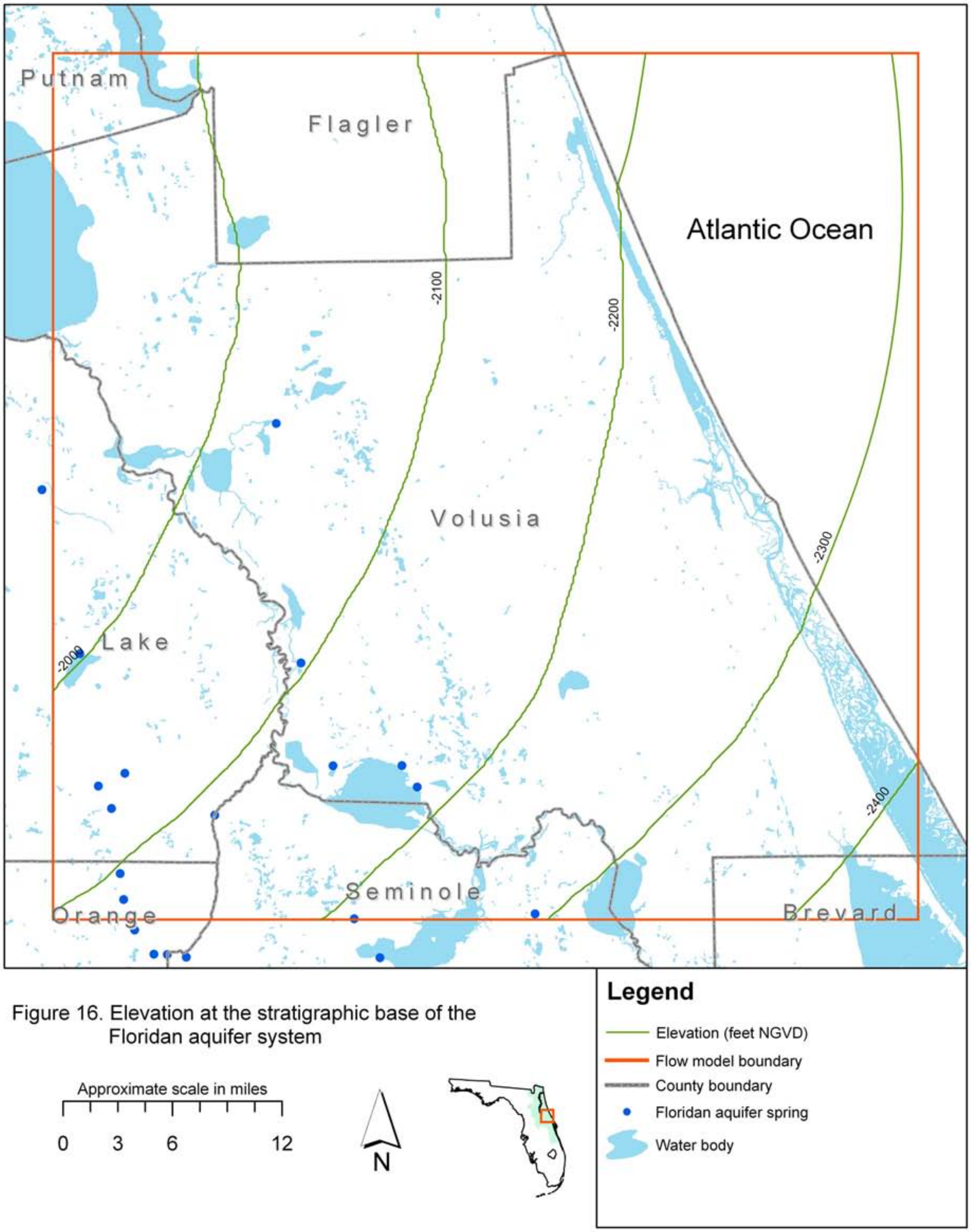


Figure 16. Elevation at the stratigraphic base of the Floridan aquifer system

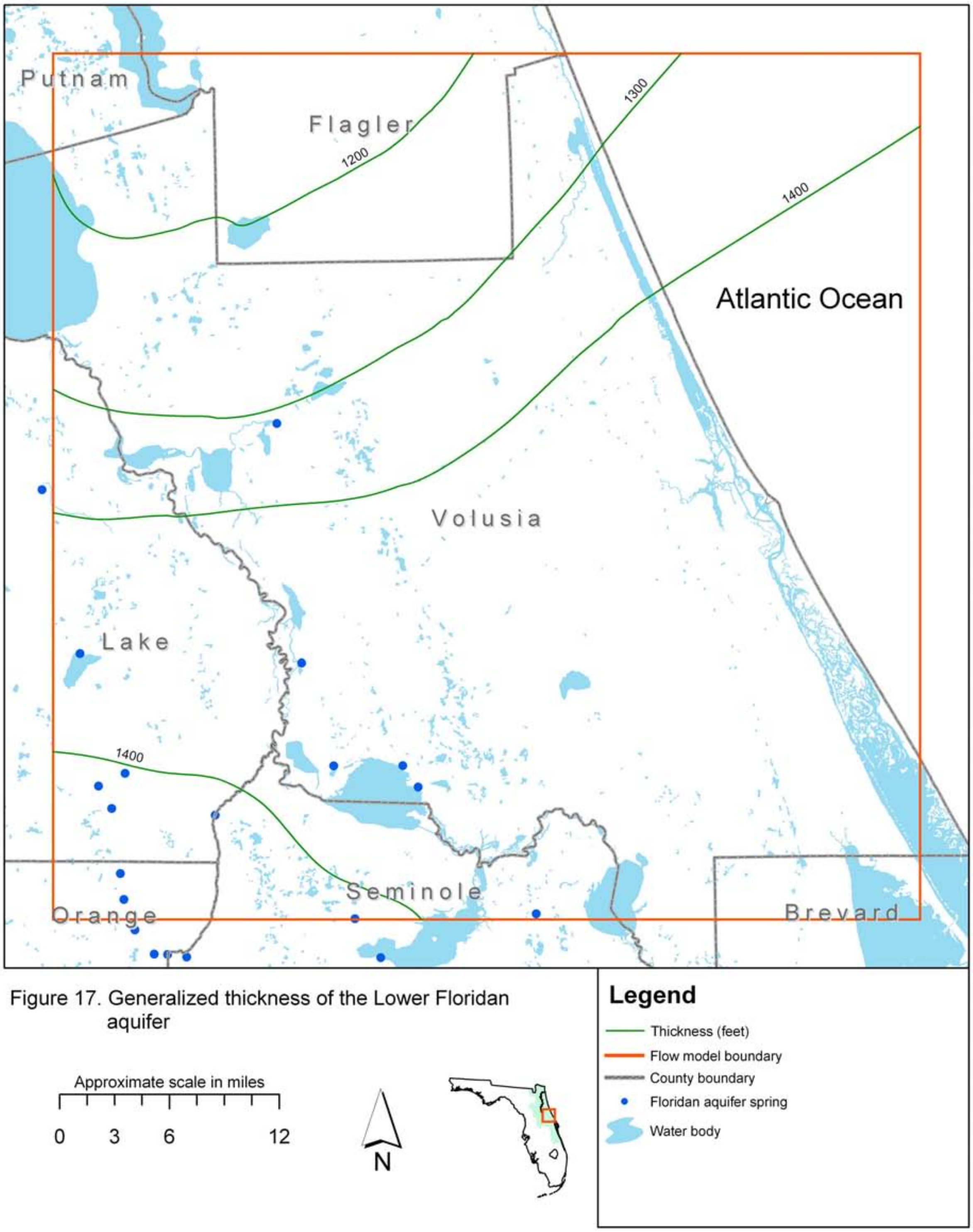


Figure 17. Generalized thickness of the Lower Floridan aquifer

Hydraulic Characteristics

Analyses of aquifer tests performed at wells open to the Upper Floridan aquifer indicate a transmissivity distribution, ranging from as low as 6,000 square feet per day (ft^2/d) to as high as 250,000 ft^2/d (Szell 1993) (Figure 18). These data indicate that transmissivity in central Volusia County is relatively low, ranging from 6,000 to 20,000 ft^2/d. High transmissivities have been measured near the St. Johns River (242,000 ft^2/d) and in the vicinity of the Wekiva River (253,000 ft^2/d). Aquifer test results also indicate a high transmissivity zone in the vicinity of Daytona Beach in northeast Volusia County. Much of the remainder of the study area is characterized by low to moderate transmissivity. Shaded zones shown on Figure 18 represent a kriged interpolation of the areal distribution of transmissivity based upon available aquifer performance test data.

Specific capacity data derived from packer tests performed at test wells open to the Lower Floridan aquifer in central Volusia County (J. Sego, SJRWMD, pers. com. 1998) have indicated comparatively low transmissivity values (5,000 to 15,000 ft^2/d). Tibbals (1990) calibrated transmissivities for the Lower Floridan aquifer of 30,000 ft^2/d and 60,000 ft^2/d in northern and southern Volusia County, respectively. For the larger area of east-central Florida, estimates of transmissivity of the Lower Floridan aquifer vary between 200,000 ft^2/d and 670,000 ft^2/d (McGurk and Presley 2002). However, these estimates are derived from analyses of aquifer test results for the Lower Floridan aquifer in the greater Orlando area, and are therefore not specifically representative of the Volusia County vicinity.

Limited data are available regarding leakance terms associated with the middle semiconfining unit. Post, Buckley, Schuh and Jernigan (1990) estimated a range from 0.005 feet per day (ft/d) to 2 ft/d for vertical hydraulic conductivity at the Bull Creek Wildlife Management Area in eastern Osceola County. Using an average thickness for the middle semiconfining unit of 300 ft (Figure 14), a leakance range of 1.7×10^{-5} to 7.0×10^{-3} d^{-1} can be estimated. Tibbals (1990) determined a model-calibrated estimate for leakance of the confining unit of 5×10^{-5} d^{-1}, with the highest leakance in the immediate vicinity of Blue Spring.

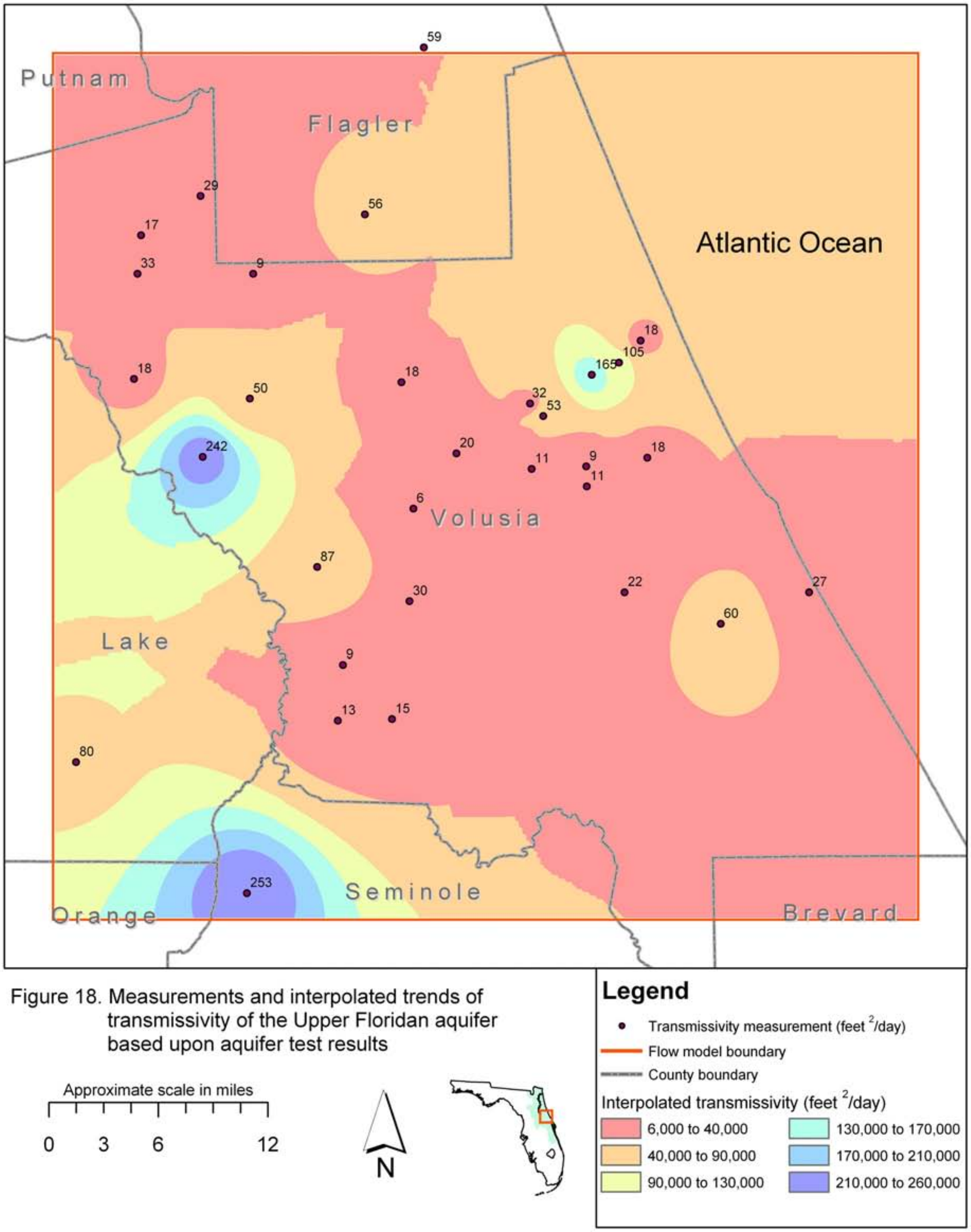


Figure 18. Measurements and interpolated trends of transmissivity of the Upper Floridan aquifer based upon aquifer test results

Potentiometric Levels

The potentiometric level in an aquifer is defined as the level to which water will rise in a well that is open within that aquifer. USGS constructs maps depicting the potentiometric surface of the Upper Floridan aquifer semi-annually, based upon water level data measurements. Stringfield (1936) developed one of the earliest maps of the potentiometric surface as it would have existed prior to extensive groundwater development. As part of the USGS RASA investigation, Johnston et al. (1980) constructed a map of the estimated predevelopment potentiometric surface of the Upper Floridan aquifer for the state of Florida (Figure 19). In 1985, Rutledge refined the map for Volusia County, depicting potentiometric levels of the Upper Floridan aquifer that would have occurred in November 1955. By comparing these levels to those measured in May 1981 and September 1982, he described an area in coastal Volusia County where water levels had declined by more than 10 ft relative to predevelopment levels. If compared to the map developed by Johnston et al. (1980) (Figure 19), the map generated by Rutledge indicates a more prominent potentiometric high in north central Volusia County and more clearly defined depressions near Lake Harney in the St. Johns River valley and in southwest Volusia County between Blue Spring and Deltona. Finally, Murray and Halford (1996) published a revised version of the predevelopment surface by Johnston et al. (1980) for the greater Orlando metropolitan area that also depicts the depression near Lake Harney.

In order to facilitate model calibration, a map of the average 1995 potentiometric surface of the Upper Floridan aquifer was developed based upon USGS maps published for May and September 1995 (Knowles et al. 1995; O’Reilly et al. 1996) (Figure 20). The average 1995 potentiometric surface is considered to be substantially more representative of actual water levels than the estimated predevelopment surface due to a greater density of monitor well data for 1995 as compared to the 1930s. Similarities between the configurations of these potentiometric surfaces indicate temporally persistent patterns. The average 1995 potentiometric surface (Figure 20) is consistent with the earlier work of Rutledge (1985) and Murray and Halford (1996) regarding the depression near Lake Harney. In addition, a well-defined lateral “nose” in the potentiometric surface is indicated in eastern Lake County in the average 1995 surface. This gradient indicates the influence of Blue Spring as a significant groundwater discharge sink and is indicative of an area of relatively low transmissivity within the Upper Floridan aquifer

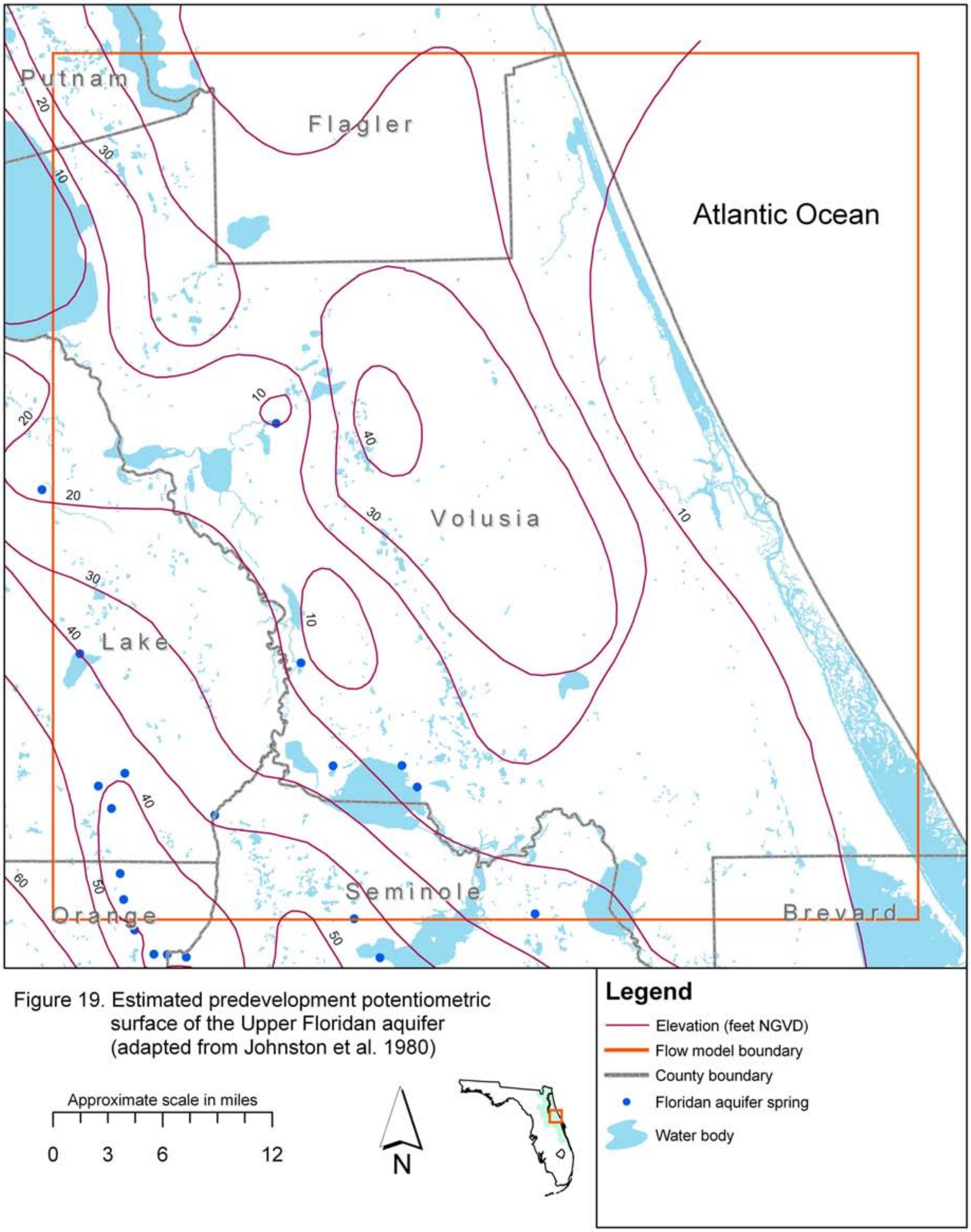


Figure 19. Estimated predevelopment potentiometric surface of the Upper Floridan aquifer (adapted from Johnston et al. 1980)

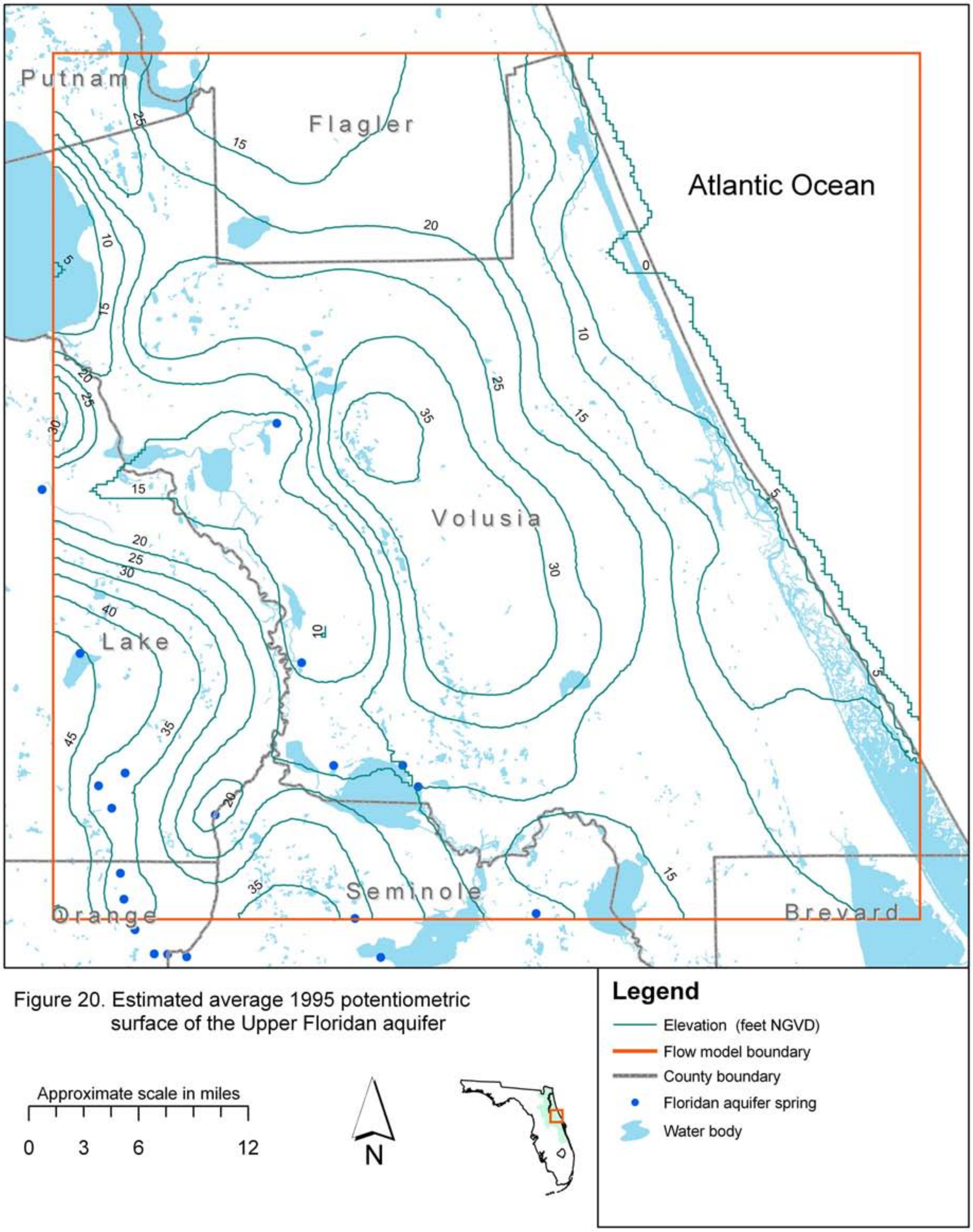


Figure 20. Estimated average 1995 potentiometric surface of the Upper Floridan aquifer

and/or high leakance from the surficial aquifer system west of the spring. The average 1995 surface indicates a depression in the vicinity of Blue Spring; however, this depression is not shown to extend eastward into north Deltona as was indicated by Rutledge (1985). Inspection of the average 1995 surface supports the work of Rutledge (1985) in which he portrayed declines in the elevation of the potentiometric surface in east-northeast Volusia County due to groundwater pumping. Comparison of the average 1995 and predevelopment surfaces also indicates that the potentiometric high in central Volusia County was slightly over 35 ft NGVD in 1995, and it was estimated to be approximately 40 ft NGVD prior to extensive groundwater development.

Measured water levels in the Lower Floridan aquifer indicate potentiometric trends that are similar to those for the Upper Floridan aquifer with less pronounced horizontal gradients. In central Volusia County, Upper Floridan aquifer potentiometric levels are approximately 10 ft higher than the corresponding Lower Floridan aquifer levels (e.g., 38.6 vs. 28.7 ft NGVD, average 1995 levels). However, measurements at a well cluster in the Deltona area indicate an upward gradient with an average 1995 potentiometric level for the Lower Floridan aquifer of over 22 ft NGVD and a corresponding Upper Floridan aquifer level of just over 13 ft NGVD. Similar measurements at a well cluster in the Crescent City Ridge indicate an upward gradient with average 1995 values of 23.5 and 27.5 ft NGVD in the Upper and Lower Floridan aquifers, respectively. However, Upper Floridan aquifer potentiometric levels in this vicinity may be influenced by agricultural pumping for irrigation and seasonal freeze protection. Potentiometric level data at a well south of Blue Spring in southwest Volusia County indicate a downward gradient between the Upper Floridan and Lower Floridan aquifers, with a vertical head difference of 5 ft. Data from sites in discharge areas of northwest Seminole County and at Wekiva Springs in northwest Orange County also indicate upward vertical gradients (McGurk and Presley 2002).

Recharge and Discharge Patterns

Recharge to or discharge from the Upper Floridan aquifer is a function of the local gradient between the water Table in the surficial aquifer system and the potentiometric surface of the Upper Floridan aquifer. The magnitude of recharge or discharge is mediated by the local leakance of the intermediate confining unit. A previous study (Boniol et al. 1993) assessed recharge to the Upper Floridan aquifer based upon a proposed correlation between the land surface and measured water Table elevations, and provided recharge estimates ranging from 0 to 2 in / yr in low-lying areas to over 16 in / yr in upland ridges (Figure 21). Typically, areas of low Upper Floridan aquifer recharge are in low-lying terraces where the vertical head gradient is relatively small, or where the intermediate confining unit is relatively thick or of low permeability. High rates of recharge occur in the sandy upland ridges where the vertical head gradient is relatively high and where the intermediate confining unit is thin and / or of relatively high vertical hydraulic conductivity. The highest rates of localized recharge typically occur in the vicinity of sinkhole lakes due to collection of overland runoff and a thin or absent intermediate confining unit underneath the lakes.

Rutledge (1985) estimated an average countywide recharge rate to the Upper Floridan aquifer of 2 in / yr for Volusia County, based on estimated average long-term values of 53, 39, and 12 in / yr for rainfall, ET, and overland runoff, respectively. Rutledge (1985) also computed a water budget for the Floridan aquifer in which he calculated downward leakage values of 0, 4, 10, and 18 in / yr for areas of artesian flow, non-ridge areas without artesian flow, ridge areas with surface drainage, and ridge areas in closed basins, respectively. Vecchioli et al. (1990) computed ranges of recharge to the Upper Floridan aquifer based upon delineation of spring basins in western Volusia County and gaged surface water basins in areas unaffected by spring discharge. Recharge rates of approximately 10–18 in / yr and 6–18 in / yr were determined for Blue and Ponce de Leon spring basins, and recharge / discharge rates ranging from –7 to 5 in / yr were computed for several surface water basins in central and eastern Volusia County (Vecchioli et al. 1990).

Natural discharge from the Floridan aquifer system occurs as diffuse upward leakage to the surficial aquifer system and as subterranean spring flow. Diffuse upward leakage occurs where the potentiometric surface of the Upper Floridan aquifer is higher than the elevation of the water Table in the surficial aquifer system. Tibbals (1990) indicated that depressions in the potentiometric surface of the Upper Floridan aquifer near the St. Johns River, Lake George, and Lake Harney (Figure 2) are due to discharge through unconfirmed springs. He also attributed the depression in the potentiometric surface in the Haw Creek drainage basin in west-central Flagler County to diffuse upward leakage and to the possibility of discharge to unconfirmed springs near southeastern Crescent Lake. Tibbals (1990) estimated discharge from several proposed springs into nearby surface water bodies through

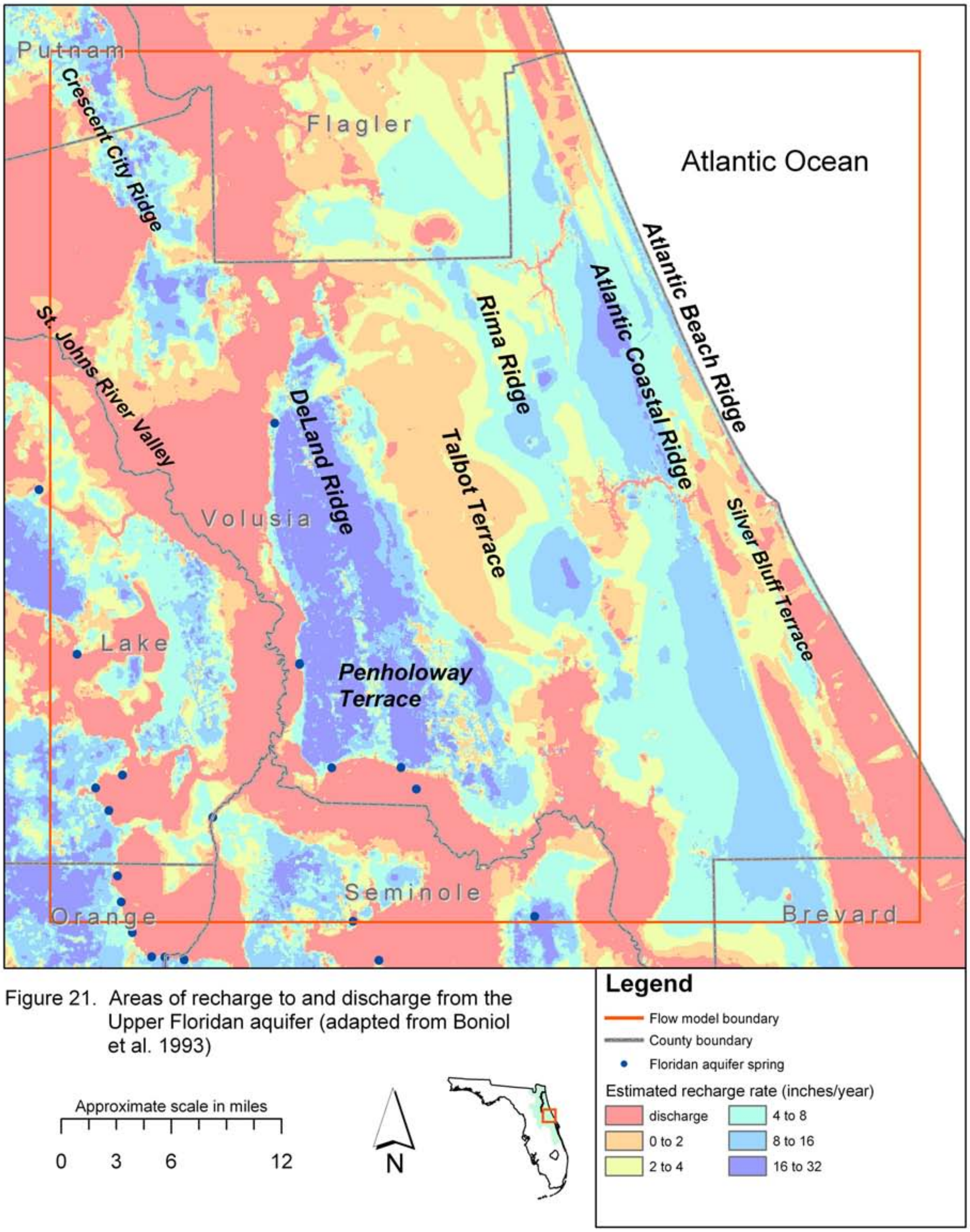


Figure 21. Areas of recharge to and discharge from the Upper Floridan aquifer (adapted from Boniol et al. 1993)

regional model simulation, including 25 cubic feet per second (cfs) to eastern Lake George, 6 cfs into Lake Jesup, and 16 cfs to south-central Flagler County. He also hypothesized the potential for groundwater discharge from the Upper Floridan aquifer into the St. Johns River between Lake Harney and Lake George due to the maintenance of a dredged navigation canal by the U.S. Army Corps of Engineers from the mouth of the river to Lake Harney (Anderson and Goolsby 1973). Tibbals (1990) simulated a combined discharge from the Upper Floridan aquifer to Lake Harney and to the St. Johns River between Lake Harney and the Lake Jesup outlet of 54 cfs. He also discussed the likelihood of diffuse upward discharge into the ocean floor offshore of Volusia County where the top of the Upper Floridan aquifer is estimated to occur at elevations of –80 to –120 ft NGVD, which, when combined with an estimated average ocean depth of 60 ft, contributes to conditions that are conducive to spring formation. Tibbals (1990) simulated a lateral flow from the Upper Floridan aquifer of 50 cfs in the direction of the coastal boundary in a steady-state simulation to 1980 conditions.

Subterranean springs are significant points of groundwater discharge from the Floridan aquifer system. Eleven documented springs exist within the study area (Figure 19), with a total average 1995 measured discharge of 312.5 cfs. Estimated predevelopment discharge from these springs was 345 cfs (Table 3). Ponce de Leon and Blue springs, the two largest springs in Volusia County, receive groundwater flow from contribution areas that have been delineated in northwest Volusia County for Ponce de Leon Springs and in southwest Volusia and eastern Lake counties for Blue Spring (Rutledge 1985; Tibbals 1990; Shoemaker et al. 2003). The groundwater discharge from Blue Spring is of interest ecologically because the spring run provides warm water habitat for manatees during winter months when air temperatures drop to near or below freezing.

Patterns of groundwater recharge to and discharge from the Lower Floridan aquifer generally mimic those for the Upper Floridan aquifer. However, recharge and discharge rates are markedly lower between the Upper and Lower Floridan aquifers as compared to those between the surficial aquifer system and the Upper Floridan aquifer due to lower vertical gradients and the relatively lower leakance of the middle semiconfining unit as compared to that of the intermediate confining unit.

Table 3. Summary of flow measurements for Floridan aquifer springs within the study area (in cubic feet per second)

Spring*	Estimated Predevelopment Flow†	Average Measured 1995 Flow‡
Blue	160	150
Rock	70	61
Seminole	40	39
Ponce de Leon	31	27
Messant	20	16
Gemini	10	8
Island	10	6
Green	1	2
Camp La No Che	1	1
Sulphur	2	1
Droty	1	1
Total	345	312

*Shading indicates first- and second-magnitude springs.
†Source: Murray and Halford 1996; Tibbals 1990
‡Average is for period of record for Green and Droty springs.

Historic and Projected Water Use

The Upper Floridan aquifer is the primary source for virtually all groundwater use that occurs within the study area. Categories of use include public supply, agricultural irrigation, commercial/industrial, recreational irrigation (i.e., parks and golf courses), and domestic self-supply. Agricultural usage increased markedly between 1970 and 1985, with modest declines in usage since 1985. Public supply usage has increased gradually with an approximate two-fold increase between 1970 and 1985 and a half-again increase between 1985 and 1995 (Marella 1995, 1999). By the year 2020, public supply use is projected to nearly double to 90.9 million gallons per day (mgd) (66% of total use) for Volusia County while agricultural/recreational use is anticipated to show a modest increase to 32.5 mgd, or 24% of total use (Vergara 1998). Agricultural use has been marked by an unusual up-and-down historical trend (Table 4). This pattern is most likely a reflection of changing agricultural practices over time, exemplified by the increased dominance of fernery production in Volusia County and the decline in citrus production in areas vulnerable to winter freezes. The pattern may also reflect changing technology relative to irrigation methods.

Table 4. Historic and projected average annual groundwater withdrawals from selected counties in the study area

County	1970	1985	1995	2020
	(pumpage in mgd)			
Agricultural and Recreational Irrigation				
Flagler	9.0	6.3	6.8	7.6
Lake	13.4	28.8	36.0	79.6
Putnam	7.6	17.2	14.4	26.5
Seminole	3.4	23.2	9.5	15.6
Volusia	6.9	36.6	27.7	32.5
Total	40.3	112.1	94.4	161.8
Public Supply				
Flagler	0.3	2.2	4.5	12.9
Lake	10.0	15.3	26.5	70.6
Putnam	2.7	3.0	3.6	5.6
Seminole	6.3	34.9	50.7	94.8
Volusia	19.2	36.4	48.8	90.9
Total	38.5	91.8	134.1	274.8
Self-Supplied Commercial, Industrial, and Power Generation				
Flagler	0.0	0.1	0.2	0.4
Lake	19.4	12.2	10.2	13.6
Putnam	15.6	43.8	11.2	14.1
Seminole	0.5	5.0	0.1	0.2
Volusia	1.0	0.8	1.1	1.7
Total	36.5	61.9	22.8	30.0
Self-Supplied Domestic				
Flagler	0.2	0.3	1.9	0.1
Lake	3.3	8.5	2.7	1.3
Putnam	2.7	6.4	8.2	5.6
Seminole	2.7	3.6	8.6	2.1
Volusia	3.7	5.3	3.6	12.0
Total	12.6	24.1	25.0	21.1
Total for all uses	127.9	289.9	276.3	487.7

Note: mgd = million gallons per day

Source: Marella 1995, 1999; Vergara 1998

Water Quality

In areas of groundwater recharge such as the DeLand and Crescent City ridges (Figure 21), the Upper Floridan aquifer typically contains fresh, relatively hard water dominated by calcium, magnesium, and bicarbonate ions. In discharge areas such as the St. Johns River valley and southern Flagler County, the Upper Floridan aquifer contains brackish water dominated by sodium, sulfate, and chloride ions. Coastal discharge from the Upper Floridan aquifer does not contain significant concentrations of sulfate, and is characterized primarily by elevated sodium and chloride levels (Rutledge 1985; Don Boniol, SJRWMD, pers. com. 2001). Rutledge (1985) suggested that sulfates are being preferentially reduced in coastal groundwater.

The generalized water quality profile for groundwater within the Floridan aquifer system suggests a large, relatively thick lens of freshwater in central Volusia County with a progressive thinning on the periphery of the lens in the vicinities of the St. Johns River valley, the coastline of the Atlantic Ocean, and southern Flagler County. McGurk et al. (1998) examined chloride concentration data with depth and developed maps for the estimated elevation of the 250- and 5,000-parts per million (ppm) chloride isochlors for east-central Florida. Freshwater (i.e., chloride <250 ppm) (Figure 22) exists to elevations of below –1,200 ft NGVD in central Volusia County and to below –1,000 ft NGVD beneath the Crescent City Ridge. The thickness of freshwater increases from the St. Johns River valley to the southwest in Seminole, Lake, and Orange counties and decreases from the potentiometric high in central Volusia County toward the coast, toward the St. Johns and Wekiva rivers, and north toward southern Flagler County. The 5,000-ppm isochlor (Figure 23) is interpreted to represent the boundary between moderately brackish water and very brackish to saline water (McGurk et al. 1998).

CONCEPTUAL MODEL OF GROUNDWATER FLOW

Elevations of hydrostratigraphic units for the model domain (Figure 24) and proposed distributions of aquifer hydraulic parameters are processed into a simplified conceptual model of the hydrogeologic system. This conceptual model provides a simplified foundation for groundwater model formulation which preserves regional scale hydrogeologic features. Cross sections depicting the hydrostratigraphic layering and the directions of groundwater flow are presented (Figures 25 and 26), based upon model input data.

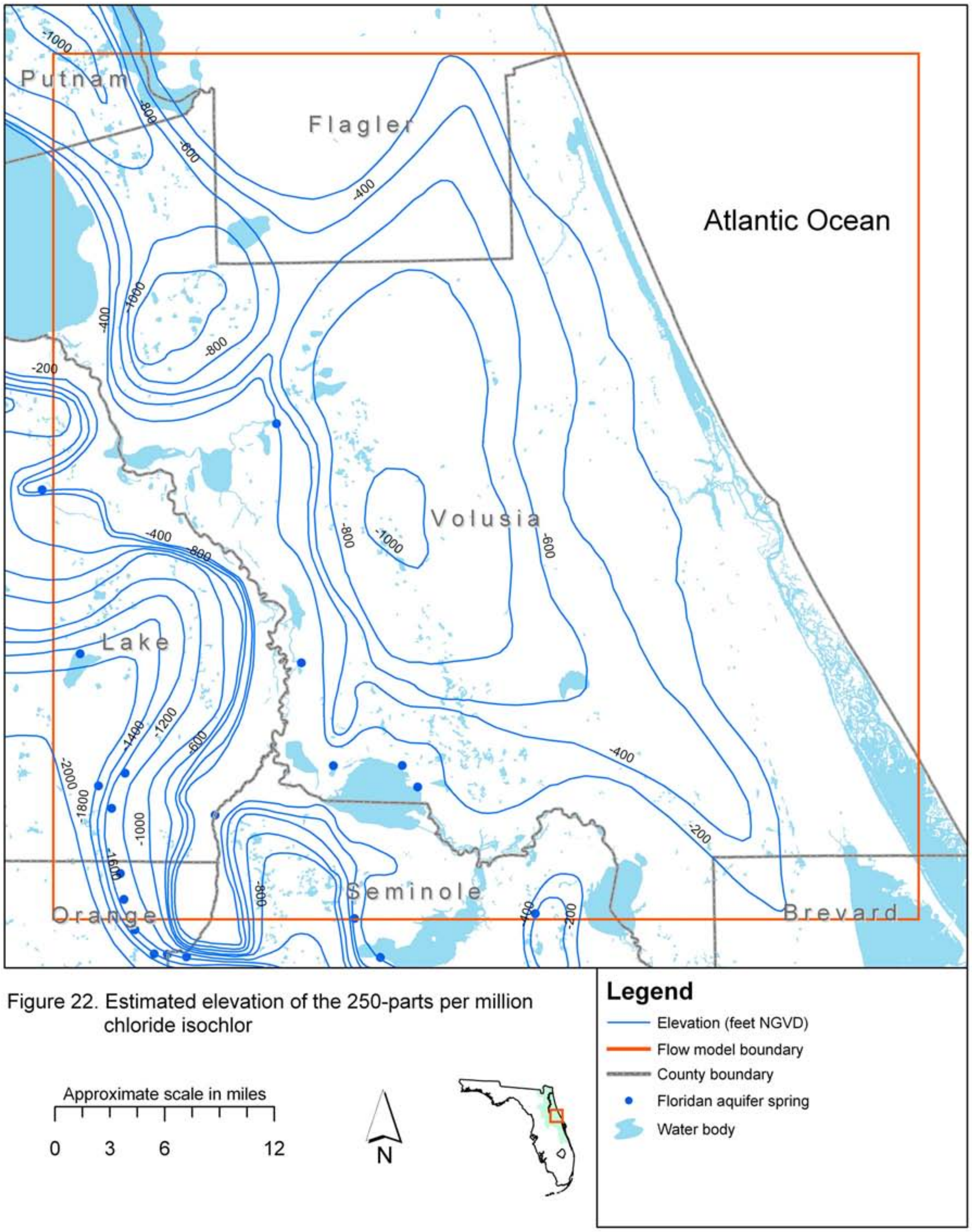


Figure 22. Estimated elevation of the 250-parts per million chloride isochlor

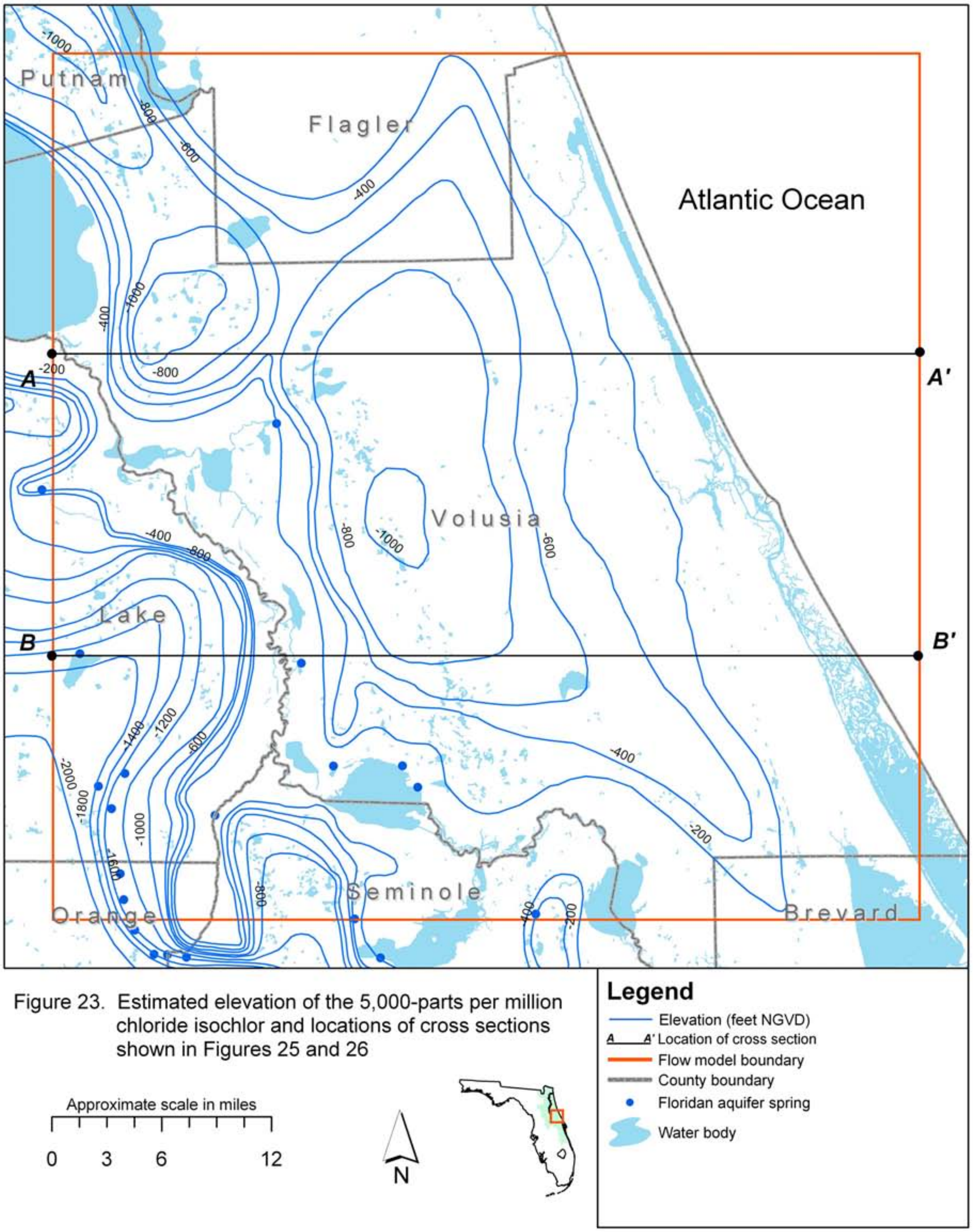


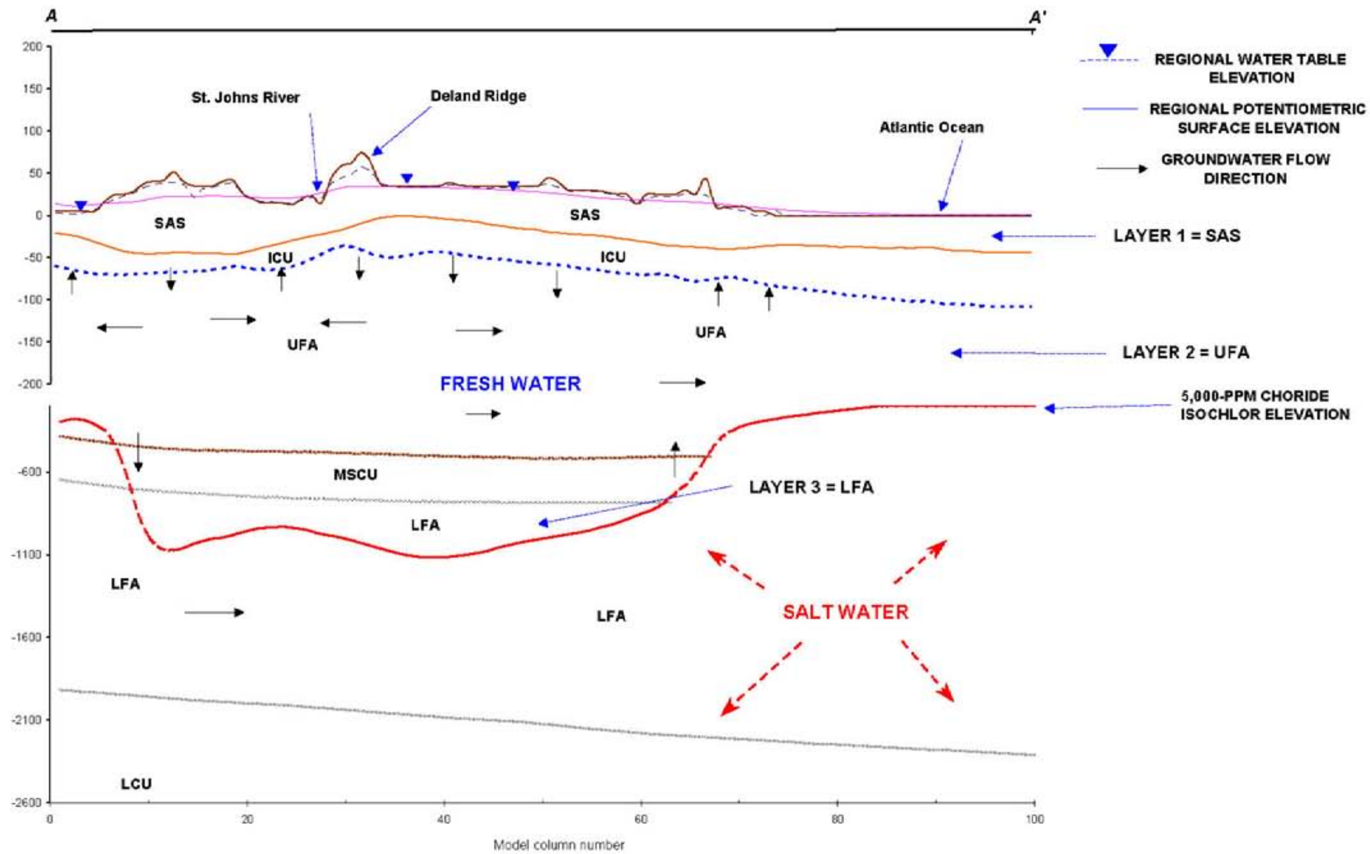
Figure 23. Estimated elevation of the 5,000-parts per million chloride isochlor and locations of cross sections shown in Figures 25 and 26

<table>
<tr><th>SERIES/STRATIGRAPHIC UNIT</th><th>LITHOLOGY/ THICKNESS (feet)</th><th>HYDROSTRATIGRAPHIC UNIT</th><th>MODEL LAYER</th></tr>
<tr><td>Holocene, Pleistocene/ undifferentiated</td><td>Interbedded sand, clay, marl and peat/ 0 to 150</td><td>Surficial aquifer</td><td>1</td></tr>
<tr><td>Pliocene, Miocene/ undifferentiated sediments, Hawthorn Group</td><td>Interbedded clay, sandy clay, and sand, often phosphatic, with some phosphatic limestone and dolostone/ 0 to 250</td><td>Intermediate confining unit</td><td>Vcont layer</td></tr>
<tr><td>Upper Eocene/Ocala Limestone</td><td>Predominantly soft to hard porous limestone, minor amounts of hard, crystalline dolostone/ 0 to 300</td><td rowspan="2">Upper Floridan aquifer</td><td rowspan="2">2</td></tr>
<tr><td rowspan="3">Middle Eocene/ Avon Park Formation.</td><td rowspan="3">Upper part: predominantly hard crystalline dolostone with abundant fractures and solution cavities/ 100 to 200

Middle part: predominantly soft porous limestone and dolomitic limestone, with minor amounts of hard crystalline dolostone/ <100 to 700

Lower part: soft to hard porous limestone and hard, fractured crystalline dolostone/ 600 to 800</td></tr>
<tr><td>Middle semiconfining unit</td><td>Vcont layer</td></tr>
<tr><td rowspan="2">Lower Floridan aquifer</td><td rowspan="2">3</td></tr>
<tr><td>Lower Eocene/ Oldsmar Formation</td><td>Soft to hard porous limestone and hard, fractured crystalline dolostone; minor amounts of peat, chert, anhydrite, and gypsum/ 500 to 1000</td></tr>
<tr><td>Paleocene/ Cedar Keys Formation</td><td>Interbedded carbonate rocks and evaporites/ 500 to 2200</td><td>Lower confining unit</td><td>No flow</td></tr>
</table>

Figure 24. Correlation chart of chronostratigraphic and hydrostratigraphic units and model layers for Volusia County and vicinity



SAS = Surficial aquifer system, ICU = Intermediate confining unit, UFA = Upper Floridan aquifer, MSCU = middle semiconfining unit, LFA = Lower Floridan aquifer, LCU = lower confining unit

VERTICAL SCALE GREATLY EXAGGERATED

Figure 25. Hydrogeologic cross section along model row 35 showing conceptualized hydrostratigraphy and the patterns and directions of groundwater flow

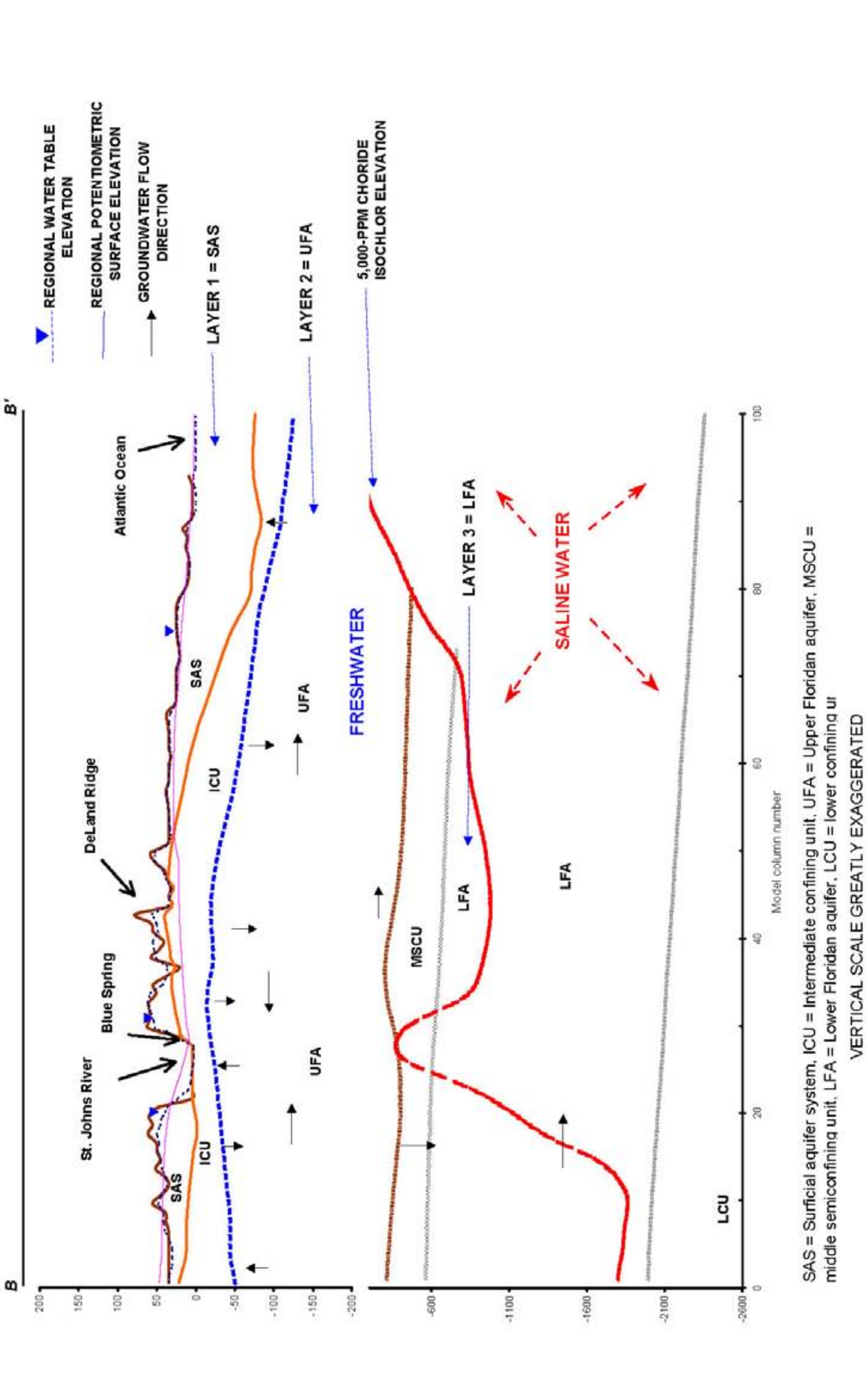


Figure 26. Hydrogeologic cross section along model row 70 showing conceptualized hydrostratigraphy and the patterns and directions of groundwater flow

The layering scheme is conceptualized as three aquifer layers with two intervening confining layers. The approach to simulation of aquifer heads is quasi-three-dimensional, meaning that all groundwater flow within aquifer units is assumed to be horizontal and all flow within confining layers is assumed to be vertical. The uppermost layer is the unconfined surficial aquifer system, and simulated water levels represent the regional water table. Flow between surface water bodies and the surficial aquifer system is assumed to be directed toward the surface water body. The K_h of the surficial aquifer system is generally lower than that of the Upper Floridan aquifer. Patterns of recharge and discharge between the surficial and Upper Floridan aquifers are influenced by the leakance of the intervening intermediate confining unit and the vertical head differential between the aquifers. The leakance of the confining unit is conceptualized as a non-uniform spatial distribution of terms that represent the vertical hydraulic conductivity of the unit divided by its thickness. Leakance of the intermediate confining unit is relatively high in karst areas such as the Crescent City and DeLand ridges, allowing for downward leakage due to sinkhole lakes and karst features. Leakance is comparatively low in the terraces where the confining layer is more clayey in composition, thicker, and more continuous. The Upper and Lower Floridan aquifers are conceptualized as aquifer layers separated by the middle semiconfining zone, also characterized by a distribution of leakance terms. The modelwide distributions for T (aquifer transmissivity) and K_h for the Upper Floridan aquifer from aquifer tests are assumed to provide reasonable lower estimates for model calibration. The Lower Floridan aquifer is assumed to have virtually no exchange with the underlying lower confining unit.

Average annual recharge to the water Table occurs as a generalized function of average annual rainfall minus overland runoff, while discharge occurs as flow to surface water bodies and downward leakage to the Upper Floridan aquifer. ET occurs both above and within the saturated groundwater zone. ET within the saturated zone can be approximated as a linear function varying from a maximum value that occurs at the land surface and a minimum value that occurs at a specified depth below the land surface.

Recharge to the Floridan aquifer system occurs primarily as downward leakage from the overlying surficial aquifer system and through the intermediate confining zone. Discharge occurs both as diffuse upward leakage where the potentiometric surface is higher than the elevation of the water Table and as flow to subterranean springs. Recharge to the Upper Floridan aquifer at a given location is less than rainfall minus ET_{MIN} except where sinkholes receive overland runoff from surrounding higher elevation areas. Heterogeneities within the Floridan aquifer are conceptualized as variations in permeability within aquifer layers. No data are available to characterize the anisotropy of the groundwater flow field, and isotropic conditions are assumed. The spatial distributions of lithologic thickness of the Upper and Lower Floridan aquifers are based upon assessed elevations of the tops and bottoms of the hydrostratigraphic units. The bases for these aquifers are modified to restrict the simulation model to the freshwater portions of the aquifer system. Specifically, the aquifer bases were adjusted upward to the estimated elevation of the 5,000-ppm chloride isochlor wherever that elevation is stratigraphically higher than the lithologic base of the aquifer. The 5,000-ppm chloride isochlor is assumed to represent the midpoint of the freshwater/saltwater interface.

SIMULATION OF GROUNDWATER FLOW

The aforementioned characteristics of the hydrogeologic system are integrated into a groundwater flow model for the outlined geographic domain (Figure 2). The conceptual model of groundwater flow integrates and brings focus to the model development process. The model was constructed using the USGS MODFLOW code (McDonald and Harbaugh 1988), a three-dimensional finite-difference simulation tool designed for the analysis of saturated groundwater flow. The model was calibrated to predevelopment hydrologic conditions and to a postdevelopment average 1995 condition. The calibrated model was used to simulate changes in the groundwater flow system that are projected to occur between 1995 and the year 2020. Projected changes are directly related to changes in public supply, agricultural, and domestic self-supply pumping, applications of reuse and irrigation, and the elimination of the effects of all inventoried free-flowing artesian wells within the study area.

MODEL DESIGN

The geographic domain for the groundwater flow model encompasses virtually all of Volusia County, southern Flagler County, and much of northeast Seminole and eastern Lake counties. The domain is discretized horizontally into a finite-difference grid of 100 rows by 100 columns, with uniform cell dimensions of 2,500 by 2,500 ft (Figure 27). The domain is subdivided vertically into three aquifer layers, representing the surficial aquifer system and the Upper and Lower Floridan aquifers, and two intervening confining units, representing the intermediate confining unit and the middle semiconfining zone (Figure 24). Aquifer layers are simulated explicitly based upon elevation data presented in the previous section, and confining units are simulated as non-uniform areal distributions of leakance terms. The elevation of the land surface is calculated as an area-weighted average elevation from the topographic digital elevation model represented in Figure 6. The elevation is used in the calculation of ET and in the estimation of the depth to water used in the algorithm for recharge to the surficial aquifer system. The top of the surficial aquifer system (i.e., the water table; Figure 9) is computed by the model. The aquifer base is defined as the first occurrence of either an identifiable confining layer or the top of the Upper Floridan aquifer and is based upon picks from well logs throughout

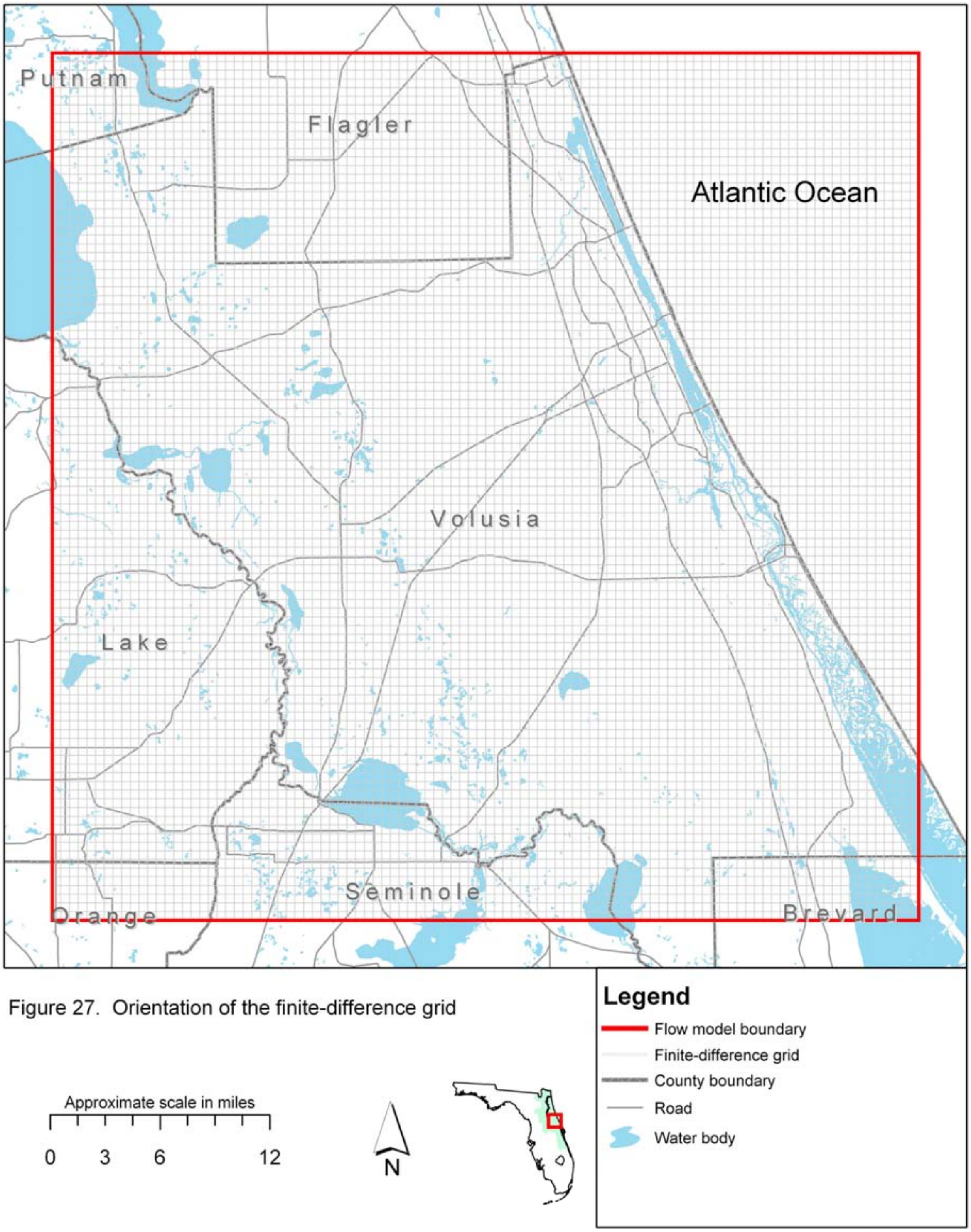


Figure 27. Orientation of the finite-difference grid

the study area. The stratigraphic elevation of the top of the Upper Floridan aquifer (Figure 11) was adapted initially from Miller 1986 and revised based upon additional data from USGS (Rick Spechler, written com. 2000) and SJRWMD databases. The base of the Upper Floridan aquifer (Figure 12) was also adapted from Miller 1986 and refined by McGurk et al. 1998. The elevations of the top and bottom of the Lower Floridan aquifer (Figures 15 and 16) were taken from Miller 1986 without modification. The base elevations for both the Upper Floridan and Lower Floridan aquifers were revised during model development in order to restrict the model to simulation of freshwater flow. Initial estimates and potential ranges for aquifer and confining unit hydraulic characteristics were derived from available data and previous groundwater model investigations.

HYDROLOGIC DATA INPUT

Several types of hydrologic data were required to construct the groundwater flow model (Table 5). These data facilitate the characterization of model boundary conditions, aquifer stratigraphy, and aquifer and confining unit hydraulic characteristics. Boundary conditions include precipitation-based recharge, groundwater outflow to streams and rivers, flow to subterranean springs, lateral flow to and from model perimeter boundaries, and flow to pumping wells.

BOUNDARY CONDITIONS

Several types of boundary conditions are used in the model to characterize key features of the groundwater system. Specified head conditions are used to describe large bodies of water that are relatively constant in elevation through time, including large lakes, the Indian River Lagoon and the Atlantic Ocean. Head-dependent flux conditions are used to characterize groundwater interchange between aquifers and rivers, streams, and canals and to characterize groundwater flow between the simulated hydrogeologic system and areas external to the model domain. Modified forms of the head-dependent flux condition, facilitating groundwater discharge from the flow system, are used to simulate the processes of evapotranspiration (ET) and groundwater flow to subterranean springs. Specified flux conditions are used to simulate recharge to the surficial aquifer system and pumpage from both the Upper Floridan aquifer and the surficial aquifer system. Initially, a no-flow condition was assigned at the vertical elevation of the 5,000-ppm

Table 5. Summary of data required to construct the groundwater flow model

Hydrostratigraphic Unit/Model Unit	Type of Data Required for Active Model Grid Cells	Data Item Needed to Estimate MODFLOW Input Item	MODFLOW Input Item Applied to All Cells in Model Unit	MODFLOW Input Item Applied Only to Boundary Condition and/or Applied Stress Cells
Surficial aquifer system/layer 1	Major soil type and depth to water table	X		
	Land use (1995)	X		
	SCS soil curve number	X		
	Total 1995 precipitation	X		
	Total 1995 overland runoff	X		
	Total 1995 flow to rapid infiltration basins or from septic tanks	X		
	Total 1995 applied irrigation (reclaimed or potable)	X		
	Recharge			X
	Land surface elevation			X
	Average free-water surface evaporation			X
	Evapotranspiration extinction depth			X
	Average 1995 stream stage			X
	Streambed elevation			X
	Streambed vertical hydraulic conductivity	X		
	Streambed thickness	X		
	Streambed conductance			X
	Fixed head at constant-head cells			X
	Horizontal hydraulic conductivity			X
	Elevation of top of intermediate confining unit (base of layer 1)		X	
Intermediate confining unit	Vertical hydraulic conductivity	X		
	Leakance		X	
Upper Floridan aquifer/layer 2	Top elevation		X	
	Bottom elevation*		X	
	Horizontal hydraulic conductivity		X	
	Vertical hydraulic conductivity	X		

Table 5—*Continued*

Hydrostratigraphic Unit/Model Unit	Type of Data Required for Active Model Grid Cells	Data Item Needed to Estimate MODFLOW Input Item	MODFLOW Input Item Applied to All Cells in Model Unit	MODFLOW Input Item Applied Only to Boundary Condition and/or Applied Stress Cells
Upper Floridan aquifer/layer 2	Leakance between layer 2 and layer 3		X	
	Fixed GHB source head			X
	Distance from model edge to GHB source head			X
	GHB boundary conductance			X
	Drain conductance			X
	Spring pool elevation			X
	Average 1995 stream stage			X
	Streambed elevation			X
	Streambed vertical hydraulic conductivity			X
	Streambed thickness			X
	Streambed conductance			X
	Well discharge			X
Middle semiconfining unit	Vertical hydraulic conductivity	X		
	Leakance		X	
Lower Floridan aquifer/layer 3	Top elevation		X	
	Bottom elevation*		X	
	Horizontal hydraulic conductivity		X	
	Vertical hydraulic conductivity	X		
	Fixed GHB source head			X
	Distance from model edge to GHB source head			X
	GHB conductance			X

Note: GHB = general head boundary

*Stratigraphic bottom elevations for layers 2 and 3 were adjusted to conform to 5,000-parts per million chloride isochlor elevation.

chloride isochlor in order to restrict the flow characterization to the freshwater domain. This boundary condition was modified during model calibration to a head-dependent flux condition in order to assess potential hydraulic exchange between fresh and saline portions of the aquifers. Figures 28–30 show the locations of the various boundary conditions pertinent to each model layer.

Specified Head Boundaries

Specified head boundaries are assigned to surface water bodies that are greater than 500 acres in areal extent (i.e., approximately four model grid cells). These water bodies include Crescent Lake, Lake George, Lake Monroe, Lake Jesup, Lake Harney, the Intracoastal Waterway, the Indian River Lagoon, and the Atlantic Ocean (Figure 28). Lake stage data were obtained from USGS and averaged over calendar year 1995. These average stage values were used for both the average 1995 and the predevelopment calibration. Stage values for the Atlantic Ocean and the Intracoastal Waterway were set at 0 ft NGVD.

Head-Dependent Flux Boundaries

The head-dependent flux boundary establishes a condition whereby water may enter or leave the model domain based on an observed or estimated hydraulic head external to the model and a corresponding model-simulated head. Head-dependent flux conditions are used to simulate flow to and from lateral boundaries, springs, rivers and streams, and ET. The general form of the equation for this boundary is

$$Q = C * (HB - HS) \quad \textbf{(1)}$$

where

Q = model-calculated flow into or out of the boundary
C = conductance between the boundary cell and a source location
HB = specified head at the boundary source location
HS = simulated head at the boundary cell

The conductance and source head terms are predetermined as input to the model. This generalized equation is modified to conform to specific model boundaries as outlined below.

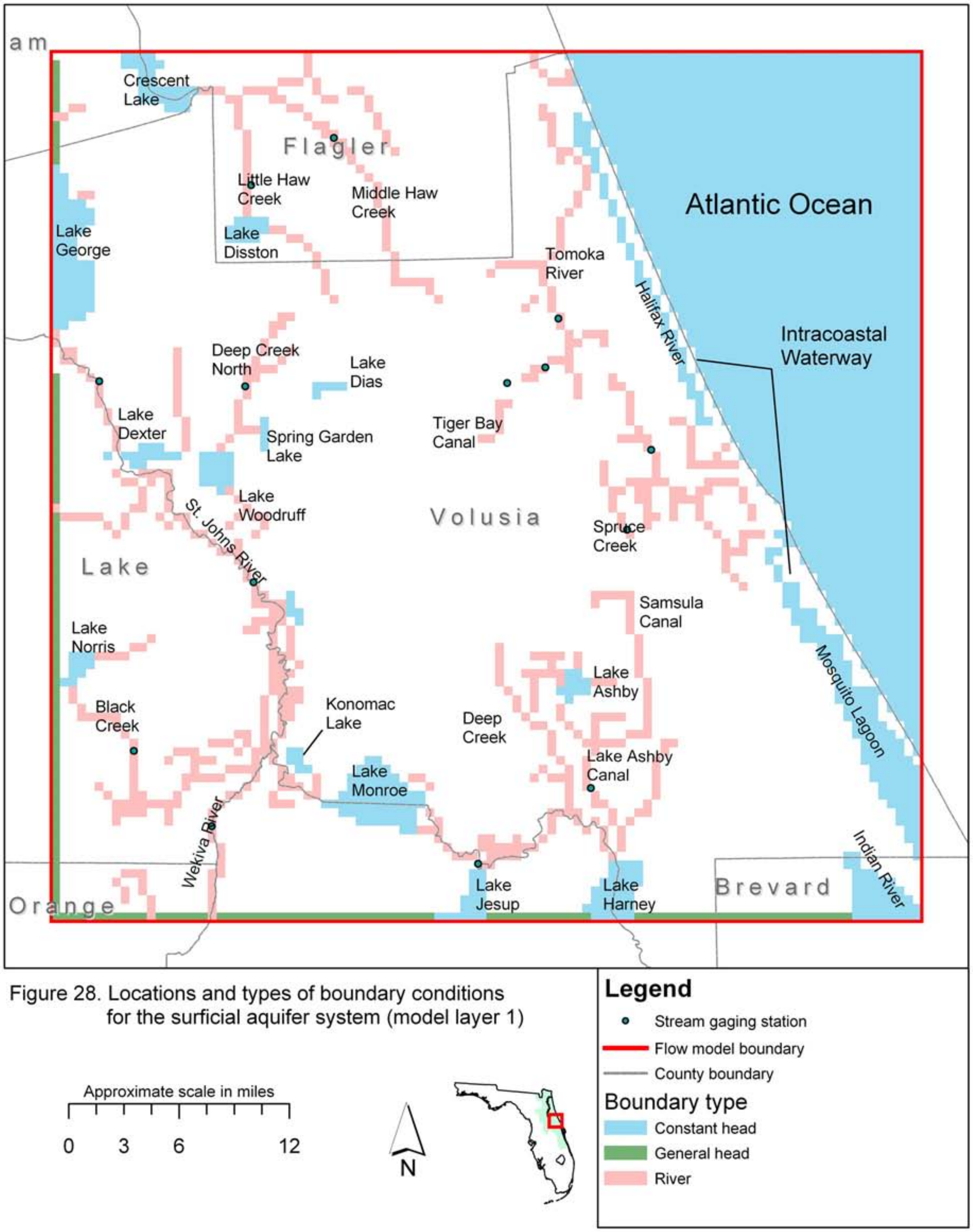


Figure 28. Locations and types of boundary conditions for the surficial aquifer system (model layer 1)

Lateral Head Boundaries

A head-dependent flux boundary is often utilized in a groundwater flow model to characterize the influence of a regional hydraulic gradient or a specific physically based far-field condition. However, water levels within the surficial aquifer system are typically more influenced by the processes of recharge and ET and the prevalence of local surface water bodies. In contrast, the influence of a regional hydraulic gradient corresponding to the elevation of the potentiometric surface is fundamental to the flow field for the Floridan aquifer system. However, lithostratigraphic discontinuities or hydraulic features that provide a definitive physical basis upon which to assign lateral boundary conditions are not common to the Floridan aquifer system. Accordingly, lateral boundary conditions for model layers 2 and 3 were assigned based upon the configuration of the observed potentiometric surface within this system. The general head boundary (GHB) package of MODFLOW (McDonald and Harbaugh 1988; Harbaugh and McDonald 1996) was used to assign a head-dependent flux condition along the periphery of the model domain for all aquifers (Figures 28–30). The equation for this condition follows the general form of Equation 1 with the conductance term defined as

$$C=\frac{(K_h*b*W)}{L} \tag{2}$$

where

K_h = the horizontal hydraulic conductivity of the aquifer (ft / d),
b = the layer thickness (ft)
W = the width of the cell face perpendicular to the direction of flow (ft)
L = the distance between HS and HB (ft)

The equation for the lateral GHB becomes

$$Q=(K_h*b*W)*\left[\frac{(HB-HS)}{L}\right] \tag{3}$$

K_h*b is equal to the aquifer transmissivity. L is specified as a value of 5,000 ft to correspond to a distance of two model grid cells, and values for HB were estimated from average potentiometric levels at the corresponding locations

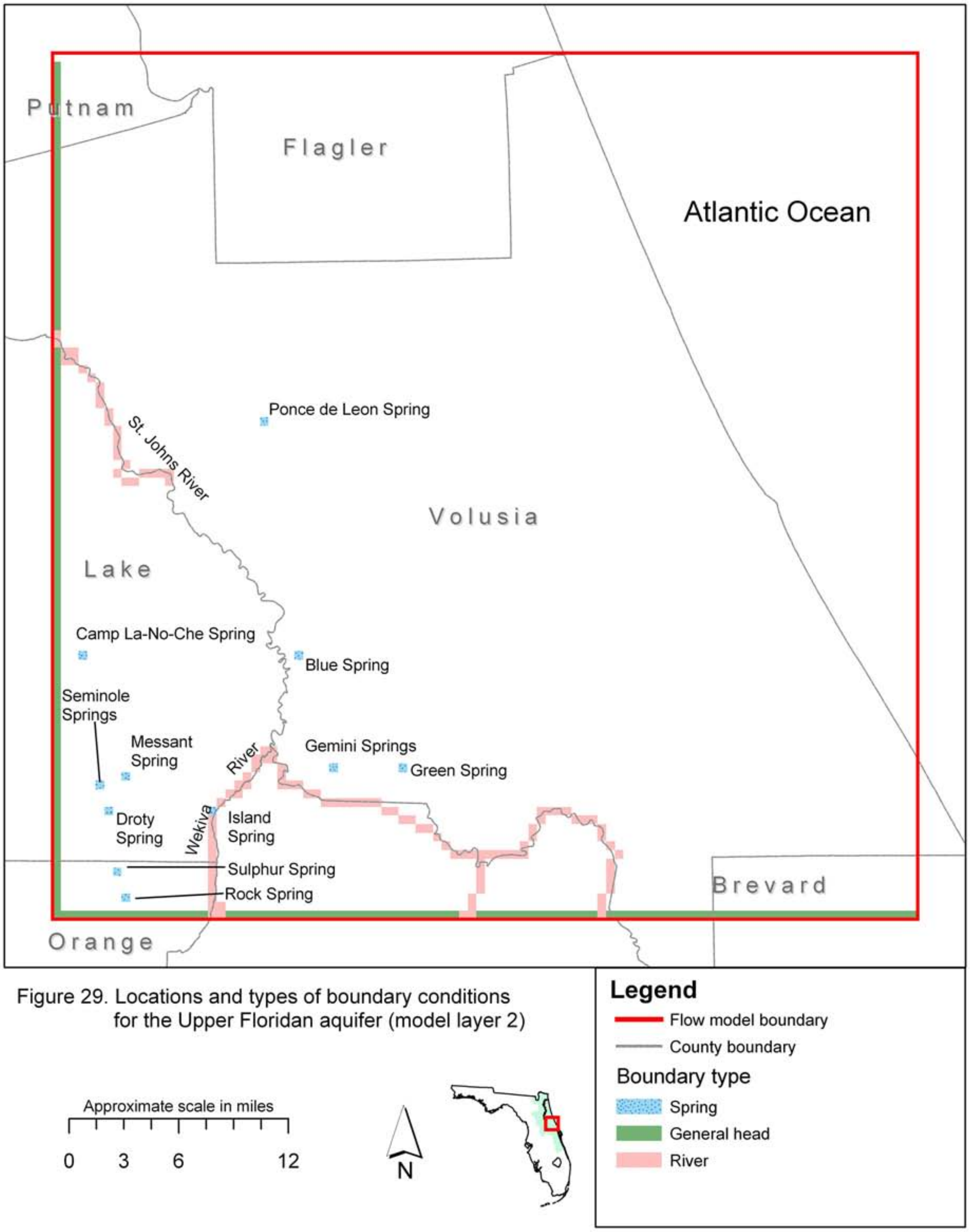


Figure 29. Locations and types of boundary conditions for the Upper Floridan aquifer (model layer 2)

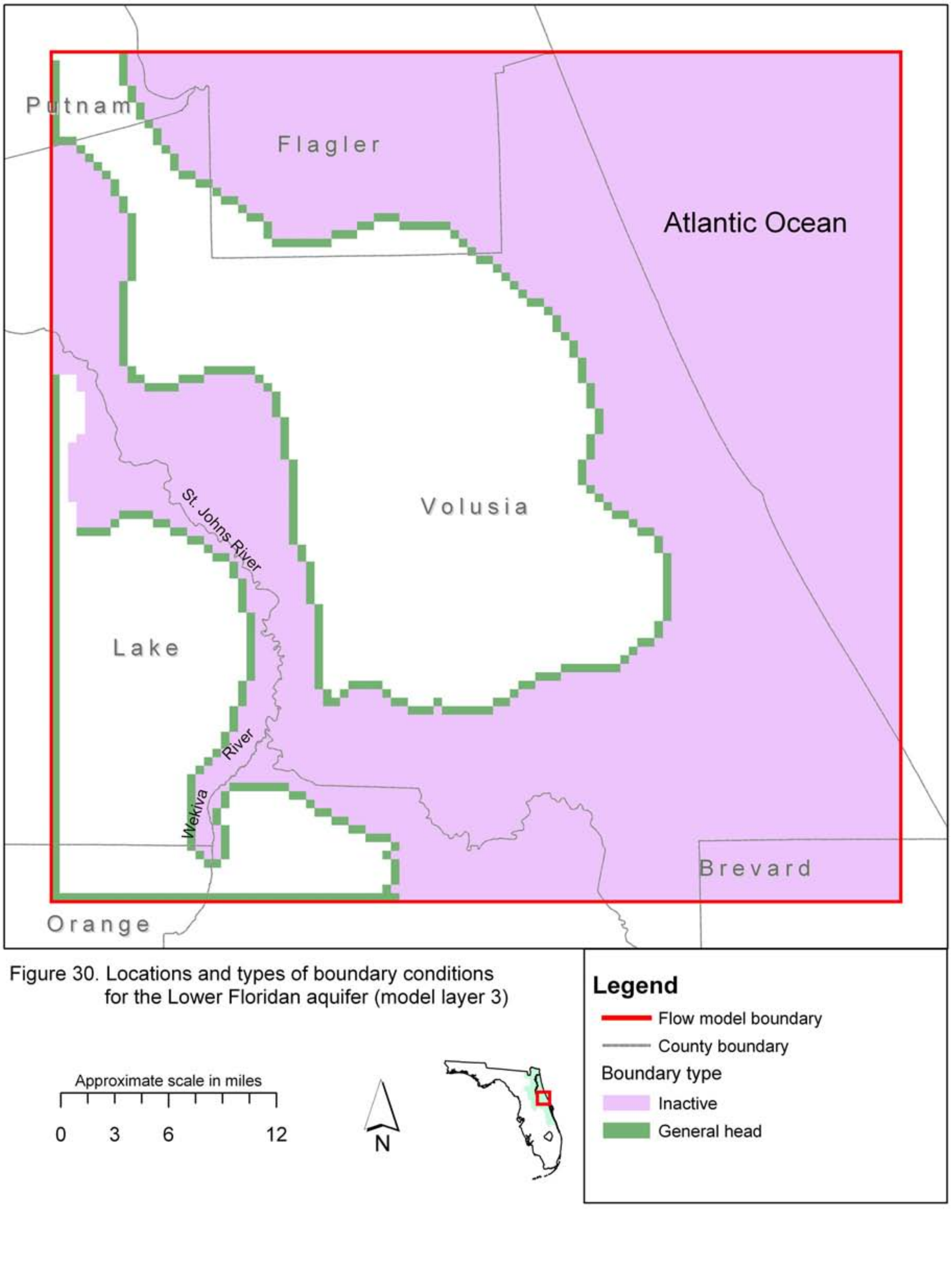


Figure 30. Locations and types of boundary conditions for the Lower Floridan aquifer (model layer 3)

(i.e., two grid cells outside of the model domain). For the predevelopment calibration, HB values were estimated from the interpreted predevelopment potentiometric surface (Figure 19, Johnston et al. 1980). For the 1995 calibration, these values were assigned as the average of the May and September observed potentiometric surfaces. The values for Q and HS are calculated by the model. For the Lower Floridan aquifer, HB values were assigned to correspond with those for the Upper Floridan aquifer. Specifically, in areas of moderate to high recharge to the Upper Floridan aquifer (i.e., greater than 4 in/yr)(Figure 21), cell-by-cell HB values were assigned to be 2 ft less than corresponding values for lateral head boundaries for the Upper Floridan aquifer, based on a review of available potentiometric level data. Similarly, for discharge areas, HB values for the Lower Floridan aquifer were assigned values that were 2 ft higher than those for the Upper Floridan aquifer. In areas of low recharge or discharge, HB values for the Lower Floridan aquifer were assigned values equal to those for corresponding boundaries in the Upper Floridan aquifer.

During model calibration, a special case of the general head boundary condition was assigned in order to assess the potential for saltwater movement across the freshwater/saltwater interface (i.e., the estimated location of the 5,000-ppm chloride isochlor), originally set as a no-flow boundary condition. For the revised configuration, a head-dependent flux condition was imposed immediately adjacent to all lateral no-flow boundaries that occur at the estimated location of the freshwater/saltwater interface. The source heads (the HB term) for these boundary cells were set at calibrated predevelopment head values, and conductance values were estimated as a combined function of the distance between the source head and the chloride isochlor and the aquifer transmissivity. Lateral flow across these boundaries was evaluated during model simulation with the objective of achieving negligible flow for the predevelopment calibration. These boundaries were imposed to represent the dynamic equilibrium between freshwater and salt water at the interface, and were subsequently used as general indications of potential saltwater movement under the stressed conditions that represent the 1995 calibration and the 2020 projection. The freshwater/saltwater interface at the base of the model was maintained as a no-flow boundary condition.

Springs

The impact of groundwater flow to subterranean springs is simulated by the imposition of one-way head-dependent flux conditions. Groundwater discharge to each of 11 springs (Figure 29) was simulated using the following equation:

$$QD = CD(HS - HD) \tag{4}$$

where

QD = model-calculated drain discharge (ft^3/d)
CD = the drain conductance (ft^2/d)
HS = the simulated aquifer head within the grid cell containing the spring (ft)
HD = the spring pool elevation (ft)

This boundary condition is formulated such that only groundwater discharge occurs across these boundaries. If the simulated aquifer head (HS) drops below the assigned spring pool elevation (HD), the drain discharge becomes zero. The magnitude of the drain conductance is a function of the hydraulic characteristics of the aquifer media in the immediate vicinity of the drain (McDonald and Harbaugh 1988). Ranges for drain conductance values were estimated for springs by rearranging Equation 4:

$$CD = \frac{QD}{(HM - HD)} \tag{5}$$

where

HM = the estimated Upper Floridan aquifer head in the model grid cell that contains the spring (ft)

The average measured values of QD, HD, and HM for the 1995 calibration were tabulated for each spring (Table 6). Values for HM were estimated by overlaying the model grid with the May 1995 and September 1995 Upper Floridan aquifer potentiometric surface maps (Knowles et al. 1995 and O'Reilly et al. 1996, respectively) (Figures 31 and 32). The ranges for CD

Table 6. Estimated ranges of spring conductance

Spring*	Average Measured 1995 Flow (cfs)†	Average 1995 Pool Elevation (ft NGVD)	Estimated High: Upper Floridan Aquifer Head (ft NGVD)	Estimated Low: Upper Floridan Aquifer Head (ft NGVD)	Lower Limit Conductance (ft^2/d)	Upper Limit Conductance (ft^2/d)	Calibrated Conductance (ft^2/d)
Blue	150.4	1.60	8	3	2,030,400	9,281,829	2,050,000
Rock	61.4	26.20	36	33	541,322	780,141	540,000
Seminole	38.9	32.00	36	33	840,240	3,360,960	850,000
Ponce de Leon	26.5	2.00	10	5	286,200	763,200	310,000
Messant	16.4	26.00	35	30	157,440	354,240	200,000
Gemini	8.1	2.00	15	10	53,834	87,480	57,000
Island	6.4	6.50	20	12	40,960	100,538	41,000
Green	1.9	5.00	20	16	10,714	14,609	12,000
Droty	0.7	21.00	36	35	4,032	4,320	4,032
Sulphur	0.8	27.00	36	34	7,680	9,874	7,680
Camp La No Che	1.0	34.00	46	44	7,200	8,640	8,640

Note: cfs = cubic feet per second
ft^2/day = square feet per day
ft NGVD = feet National Geodetic Vertical Datum

*Shading indicates first- and second-magnitude springs (based upon estimated predevelopment flows).

†Source: USGS 1996, 1997, 1998; SJRWMD internal database

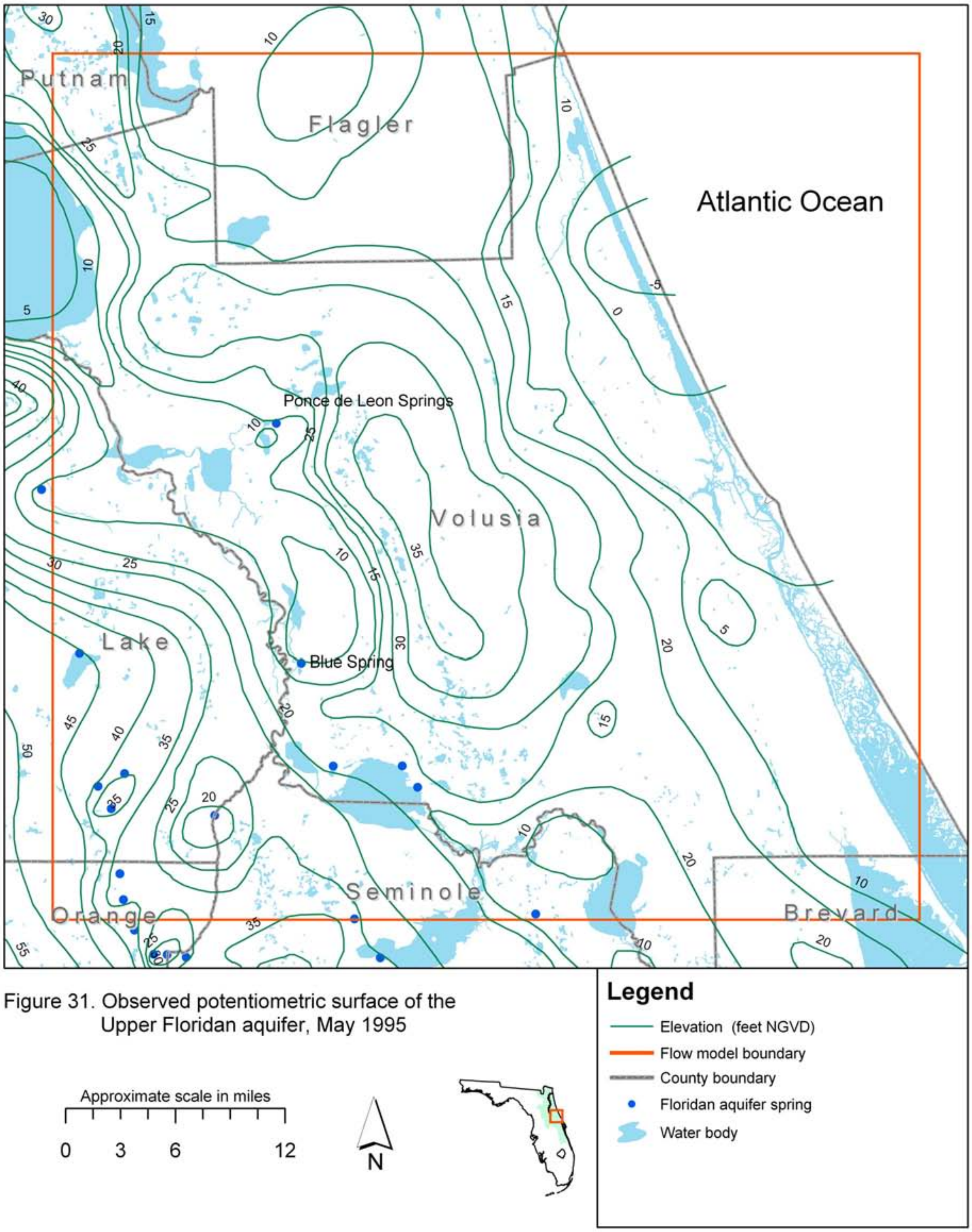


Figure 31. Observed potentiometric surface of the Upper Floridan aquifer, May 1995

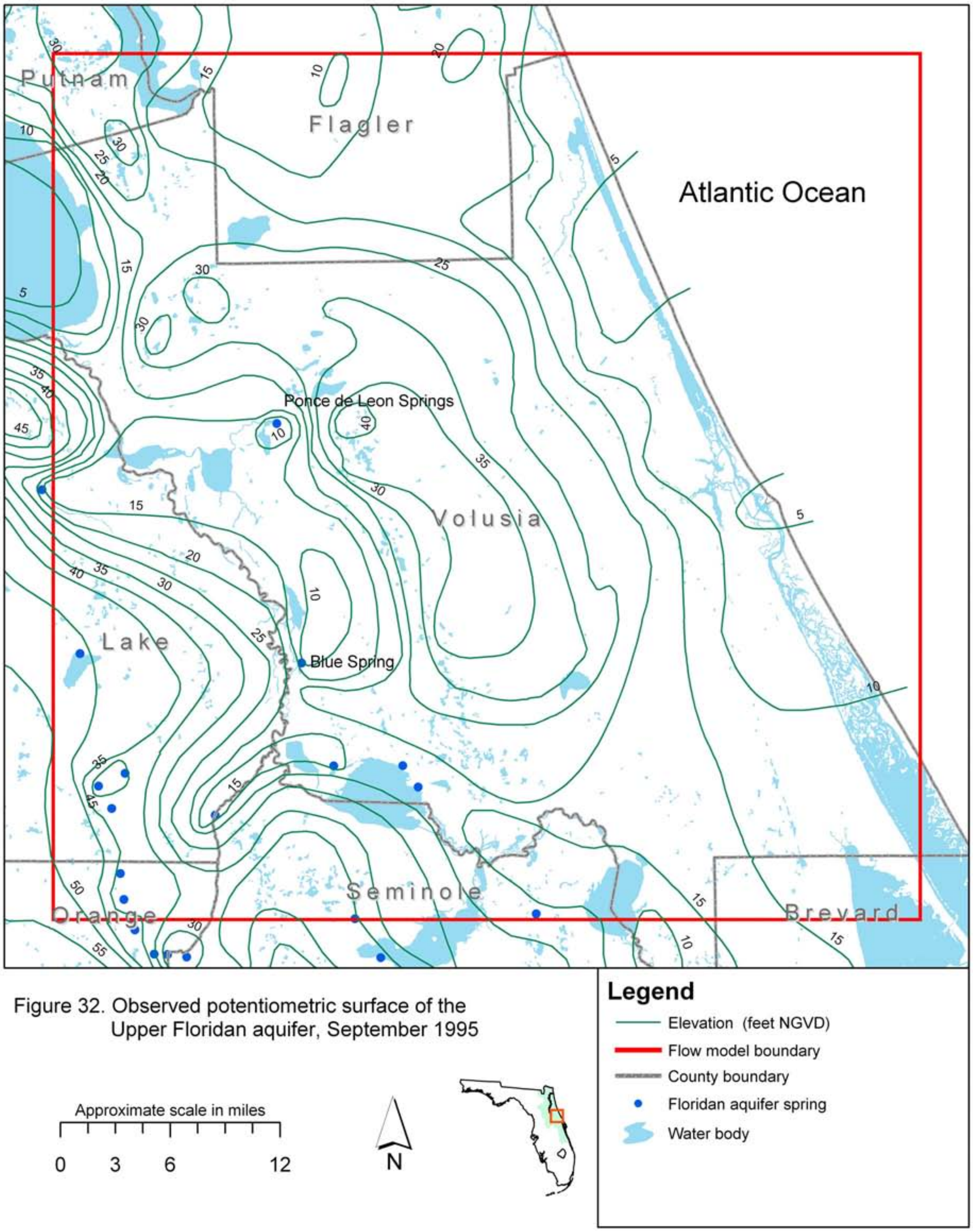


Figure 32. Observed potentiometric surface of the Upper Floridan aquifer, September 1995

values were computed for each spring using Equation 5 and the estimated ranges for HM, and were used to adjust CD values during model calibration (Table 6).

Streamflow

Discharge of groundwater to rivers and streams was simulated using the MODFLOW river package. This package calculates flow rates using two forms of Equation 4 (McDonald and Harbaugh 1988):

$$QRIV = CRIV(HRIV - HS), \text{ for } HS > RBOT \quad \textbf{(6)}$$

and

$$QRIV = CRIV(HRIV - RBOT), \text{ for } HS \leq RBOT \quad \textbf{(7)}$$

where

QRIV = the simulated discharge rate to the stream (ft^3/d)
CRIV = the hydraulic conductance between the aquifer and the stream (ft^2/d) (= $K_v LW/M$)
HRIV = the stage elevation of the stream (ft)
HS = the model-simulated head at the grid cell containing the stream (ft)
RBOT = the elevation of the streambed (ft)
K_v = the vertical hydraulic conductivity of the streambed material (ft/d)
L = the length of the stream reach within each grid cell (ft)
W = the width of the stream reach (ft)
M = the thickness of the streambed (ft)

Groundwater flow to rivers and streams from the surficial aquifer system was simulated for all major streams and tributaries (Figures 3 and 28). Stage data collected from USGS gaging stations were used to specify HRIV. Where stage data were not available, HRIV was estimated by superimposing the model grid on 1:24,000-scale topographic maps. Initial estimates for CRIV were determined by estimating width (W) from topographic maps, assuming the grid cell width of 2,500 ft for the length of the reach (L), and 1 ft/d and 1 ft for streambed conductivity (K_v) and streambed thickness (M), respectively.

Some researchers (Tibbals 1990; Murray and Halford 1996) have proposed that a hydraulic connection exists between the St. Johns River and the Upper Floridan aquifer in the vicinities of Lake George and Lake Harney. They hypothesized that these connections were due to both undocumented spring flow and dredging of the river channel for navigation. These proposed connections are accounted for within the model through use of the river package as a boundary condition within the Upper Floridan aquifer at model grid cells located along the St. Johns River (Figure 29). Input parameter values for the treatment of rivers connected to the Upper Floridan aquifer were obtained using the same methodology as that used for the surficial aquifer system, with the exception that initial values for K_v were derived from estimates of intermediate confining unit leakance.

Evapotranspiration

ET from the saturated zone was simulated using the MODFLOW ET package. ET is applied to all surface cells except those specified as constant head boundaries and is a function of the land surface elevation, the simulated water Table elevation, predetermined minimum and maximum bounds for ET, and a specified depth beyond which ET becomes negligible. The specific formulation for saturated zone ET (ET_{SAT}) for this model is adapted from McDonald and Harbaugh 1988 and is of the form

$$ET_{SAT} = ET_{MAXSAT} \qquad \text{where } HS \geq ETSRF \tag{8}$$

$$ET_{SAT} = ET_{MAXSAT} * \left[\frac{(HS - (ETSRF - EXDEP))}{ESDEP} \right] \tag{9}$$

$$\text{where } (ETSRF - EXDEP) < HS < ETSRF$$

$$ET_{SAT} = 0 \qquad \text{where } HS \leq ETSRF - EXDEP \tag{10}$$

where

HS = model-simulated head at each active layer 1 grid cell (ft)
ET_{MAXSAT} = the maximum allowed ET rate from the saturated zone (ft/d), or $ET_{MAX} - ET_{MIN}$ (i.e., maximum total ET – minimum ET)
EXDEP = the ET extinction depth (ft)
ETSRF = the ET surface elevation at which ET_{MAXSAT} occurs (ft)

In this formulation, simulated ET varies linearly between a maximum (ET_{MAXSAT}) where the simulated water Table surface is at or above the ET surface and a minimum, where the simulated water Table is below a specified extinction depth. The maximum total ET (ET_{MAX}) is set at a spatially uniform value of 46 in / yr, based upon the work of Visher and Hughes (1975), in which they estimated maximum ET throughout the state of Florida using measured pan ET rates. The minimum total ET (ET_{MIN}) is defined as the average annual ET that would occur in a natural setting with a deep, well-drained soil and a minimum of vegetative cover. ET_{MIN} was estimated as a spatially uniform value of 27 in / yr based upon the work of Sumner (1996). He used climatological data from a site with shallow-rooted vegetation, a well-drained soil, and a deep water Table to develop ET models based upon average rainfall conditions for a 1-year period. The models were calibrated using eddy correlation measurements of actual ET collected at the site within the same period (September 1993 to September 1994). According to Sumner (1996), the data from this site approximate the lower limit of ET from vegetated surfaces in central Florida. This minimum ET estimate was applied throughout the model domain in order to account for evaporation from vegetative canopy surfaces and from ponding that may occur above the water table.

ETSRF, the elevation at which total ET is equal to the maximum (ET_{MAX}), is set equal to the area-weighted average of land surface elevation within each grid cell. Values for EXDEP (i.e., ET extinction depth) were set to a modelwide depth of 6 ft, based upon the typical depth of the soil horizon.

Specified Flux Boundaries

Specified flux boundaries are those in which a known or calculated flux is assigned to the groundwater model. Specified flux conditions are used to simulate recharge to the surficial aquifer system and groundwater pumping from the surficial aquifer system and the Upper Floridan aquifer.

Recharge to the Surficial Aquifer System

Recharge to the surficial aquifer system is imposed with the MODFLOW recharge package. A water budget algorithm has been developed to facilitate implementation of the recharge conceptualization, following this formulation:

$$P + R_{SEPTIC} + R_{APP} + L_{UP} + Q_{SWB} = ET_{UNSAT} + ET_{SAT} + L_{DOWN} + R_{O} + Q_{RIV} \tag{11}$$

where

P = precipitation (ft / d)
R_{SEPTIC} = septic tank effluent (ft / d)
R_{APP} = water applied to the land surface as irrigation (ft / d)
L_{UP} = upward leakage from the Upper Floridan aquifer to the surficial aquifer system (ft / d)
Q_{SWB} = surface water flow to the surficial aquifer system (ft / d)
ET_{UNSAT} = evapotranspiration that occurs above the saturated zone (ft / d)
ET_{SAT} = evapotranspiration that occurs within the saturated zone (ft / d)
L_{DOWN} = downward leakage from the surficial aquifer system to the Upper Floridan aquifer (ft / d)
R_{O} = overland runoff (ft / d)
Q_{RIV} = discharge from the surficial aquifer system to surface water (ft / d)

The water budget equation includes terms that are calculated external to the groundwater model and terms that are output from the model simulation. The model-simulated terms are L_{UP} and L_{DOWN} for leakage between the surficial aquifer system and the Upper Floridan aquifer; Q_{SWB} and Q_{RIV} for flow between surface water bodies and the surficial aquifer system; and ET_{SAT}, representing ET simulated from the saturated zone. The remaining terms are estimated or calculated prior to model execution and can be arranged into the following equation for N, the net recharge to the surficial aquifer system:

$$N = R_{MR} + R_{SEPTIC} + R_{APP} - ET_{UNSAT} \tag{12}$$

where

R_{MR} = $P - R_{O}$ (i.e., precipitation – overland runoff)

Precipitation (P): Rainfall data were tabulated for an area that encompassed the model domain and that of the overlapping east-central Florida model (McGurk and Presley 2002). A total of 66 rainfall stations were identified that exhibited daily rainfall records for 1995. A Thiessen polygon analysis was used to distribute station data to subregional polygons (Figure 33). This

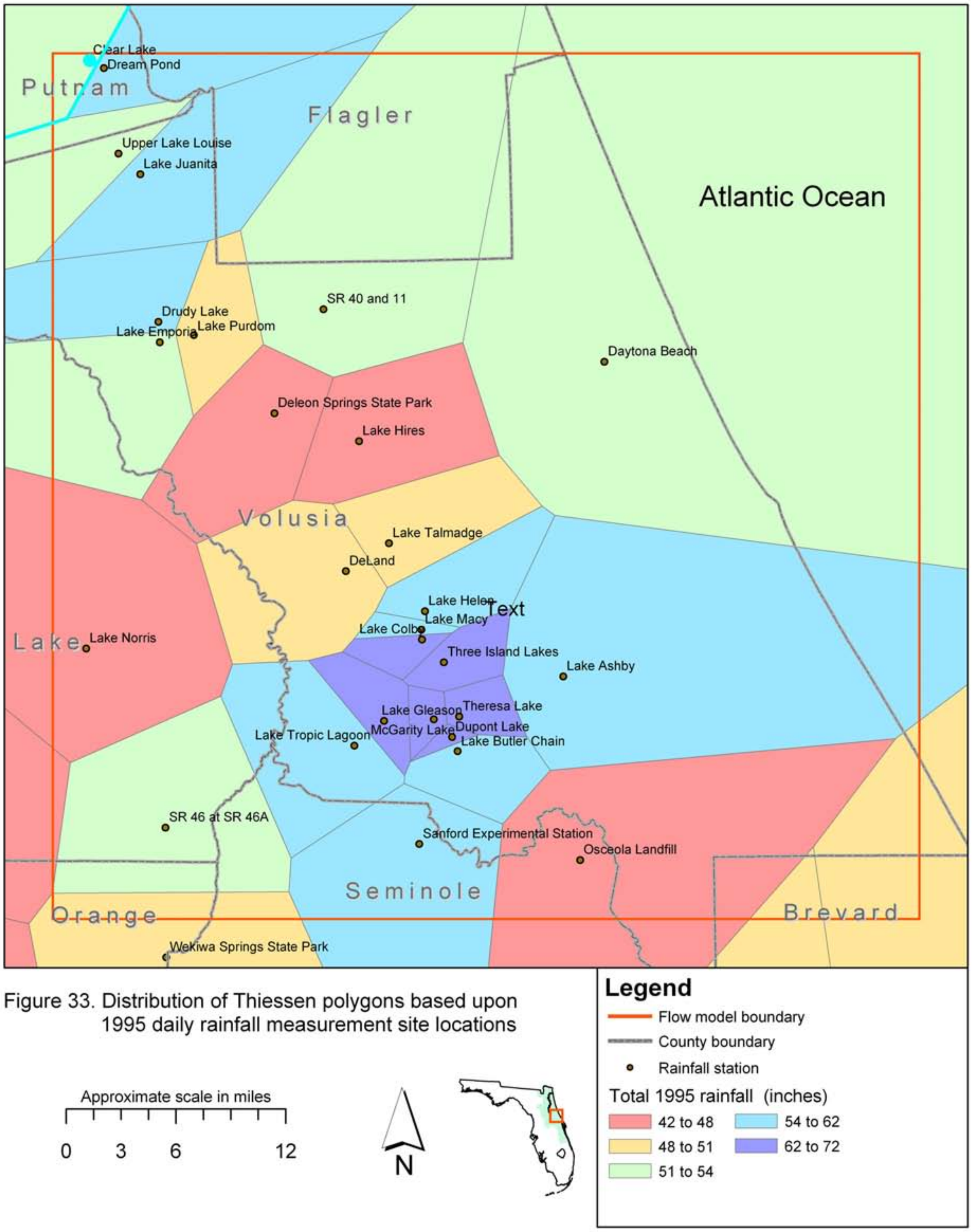


Figure 33. Distribution of Thiessen polygons based upon 1995 daily rainfall measurement site locations

method of rainfall distribution is based on the mathematical certainty that the perpendicular bisectors that circumscribe a station enclose an area that is everywhere closer to that station than to any other station. The corresponding assumption is that rainfall at a given station is representative of the entire area within the surrounding Thiessen polygon.

Runoff (R_O): In order to develop estimates for overland runoff, a method was developed that incorporates the U.S. Soil Conservation Service (SCS) curve numbers (CN) (U.S. Department of Agriculture, 1986; Grove et al. 1998). CN values range between 30 and 100 and represent the relative potential for overland runoff to occur within a given model cell. For example, the CN for a karst area with virtually no runoff would be close to 30, whereas the CN for a wetland is generally over 90. Geographic information system (GIS) coverages for hydrologic soil groups and 1995 land use were used to develop CN values that are appropriate for assignment to grid cells throughout the model domain (Figure 34). Cell-based CN and rainfall values were used to calculate estimates for daily overland runoff. This method combines land use and soil type as the primary environmental variables that affect overland runoff with the intensity and duration of rainfall events. The calculated distribution of total overland runoff during 1995 (Figure 35) indicates a pattern of little to no runoff in the sandy upland ridges of western Volusia County and relatively high rates of runoff in the low-lying terraces in east-central Volusia County and in the St. Johns River valley. Previous investigations have indicated estimates of virtually no runoff for the DeLand Ridge; between 1 and 6 in / yr along the Crescent City Ridge and the smaller coastal ridges; 6–12 in / yr in south-central and northwest Volusia County; and 12–18 in / yr in central Volusia County and the St. Johns River valley (Table 1) (Phelps 1990).

Septic tank effluent (R_{SEPTIC}): Septic tanks represent the primary mode of disposal of residential wastewater for many communities in southwestern Volusia and eastern Lake counties. The influence of septic tanks in these areas is explicitly incorporated into the model in order to account for this discharge and any potential effects upon the water table. In the recharge algorithm, effluent from septic tanks is simulated water applied at the land surface since septic systems generally occur within the primary vegetative root zone. Discharge from these septic systems is therefore subject to loss to ET within the model. Estimates for R_{SEPTIC} and residential irrigation were developed based on utilitywide estimates calculated from comparison of public supply usage with corresponding flows to wastewater treatment plants (Appendices D and E). Utility-based estimates for R_{SEPTIC} were incorporated into the

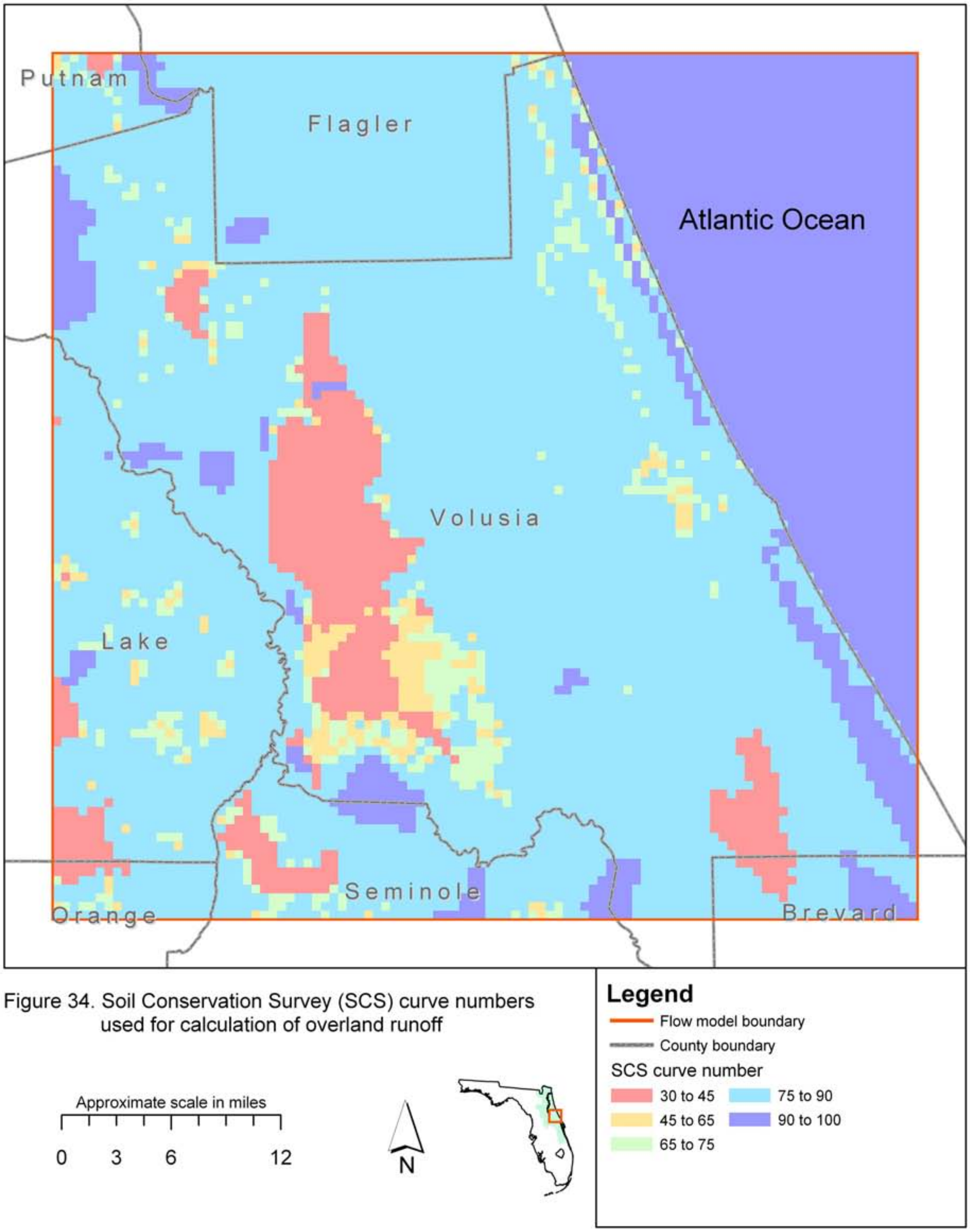


Figure 34. Soil Conservation Survey (SCS) curve numbers used for calculation of overland runoff

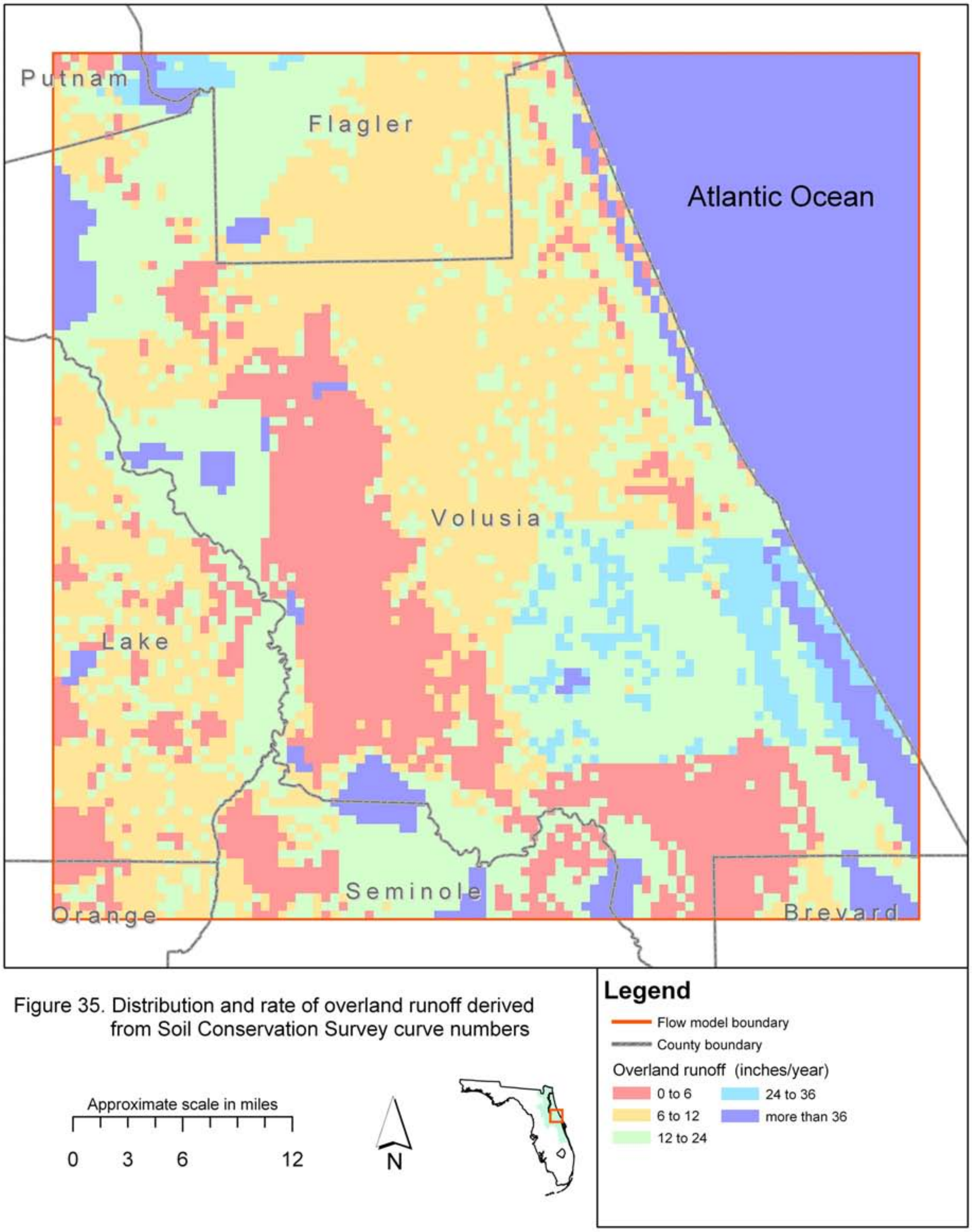


Figure 35. Distribution and rate of overland runoff derived from Soil Conservation Survey curve numbers

recharge algorithm throughout the residential portions of public supply service areas. For the 1995 calibration, a total of 7.22 mgd was distributed throughout 333 model cells within selected public supply service areas (Figure 36), primarily in southwest Volusia County.

Applied Irrigation (R_{APP}): Irrigation water (R_{APP}) is composed of four components:

$$R_{APP} = R_{AG} + R_{REUSE} + R_{PSLI} + R_{DSS} \tag{13}$$

where

R_{AG} = agricultural and golf course irrigation
R_{REUSE} = treated wastewater used for landscape irrigation, sprayfields, or percolation ponds
R_{PSLI} = poTable public supply water used for landscape irrigation
R_{DSS} = residential irrigation attributed to domestic self-supply pumping

All groundwater pumped for agricultural and golf course irrigation (R_{AG}) is also applied to the land surface as a component of the R_{APP} term of the recharge equation. A total of 26.9 mgd was pumped in 1995 for agricultural purposes, primarily in western Volusia County (Figure 37). Wastewater that is applied to the land surface is also simulated as potential recharge to the surficial aquifer system (Figure 38). A total of 10.15 mgd was estimated for 1995 R_{REUSE} from records of wastewater discharge (Appendix E). Where locations of specific reuse sites are known, actual or estimated reuse flows are assigned to the appropriate model cells. Where reuse is distributed throughout a municipality as landscape irrigation, the reported amount is applied throughout residential areas in the vicinity of existing reuse lines. Estimates for R_{PSLI}, poTable public supply water used for landscape irrigation, were developed by comparison of public supply utility records of water use with those for wastewater treatment. This irrigation water was applied to areas within public service areas with significant concentrations of residential development and public parks and easements where reuse water had not been applied for the same purpose. The modelwide total for applied public supply landscape irrigation was 16.62 mgd for 1995 (Figure 39). Finally, residential irrigation supplied by domestic self-supply pumping (R_{DSS}) is estimated to be 50% of the water used and is applied in the recharge

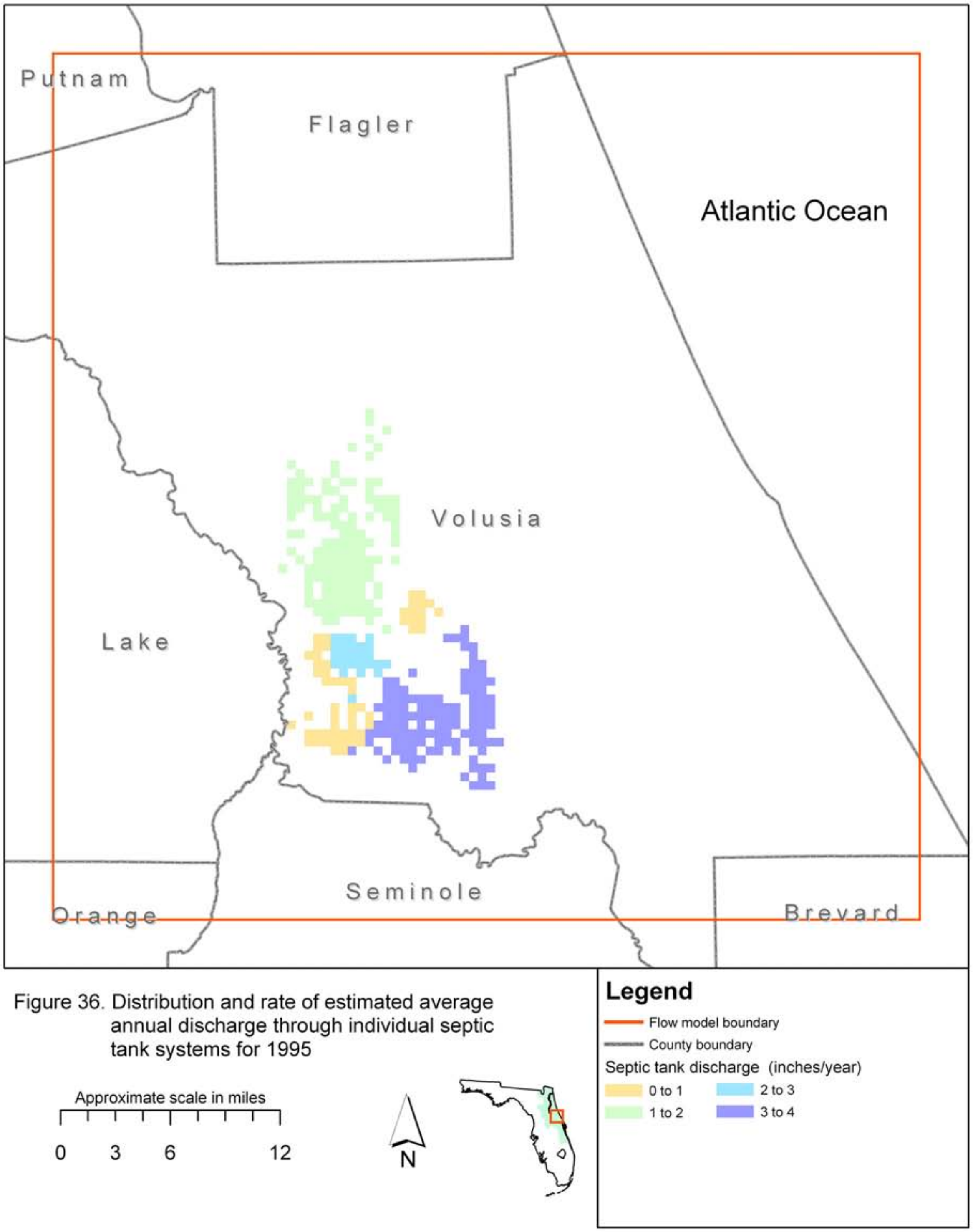


Figure 36. Distribution and rate of estimated average annual discharge through individual septic tank systems for 1995

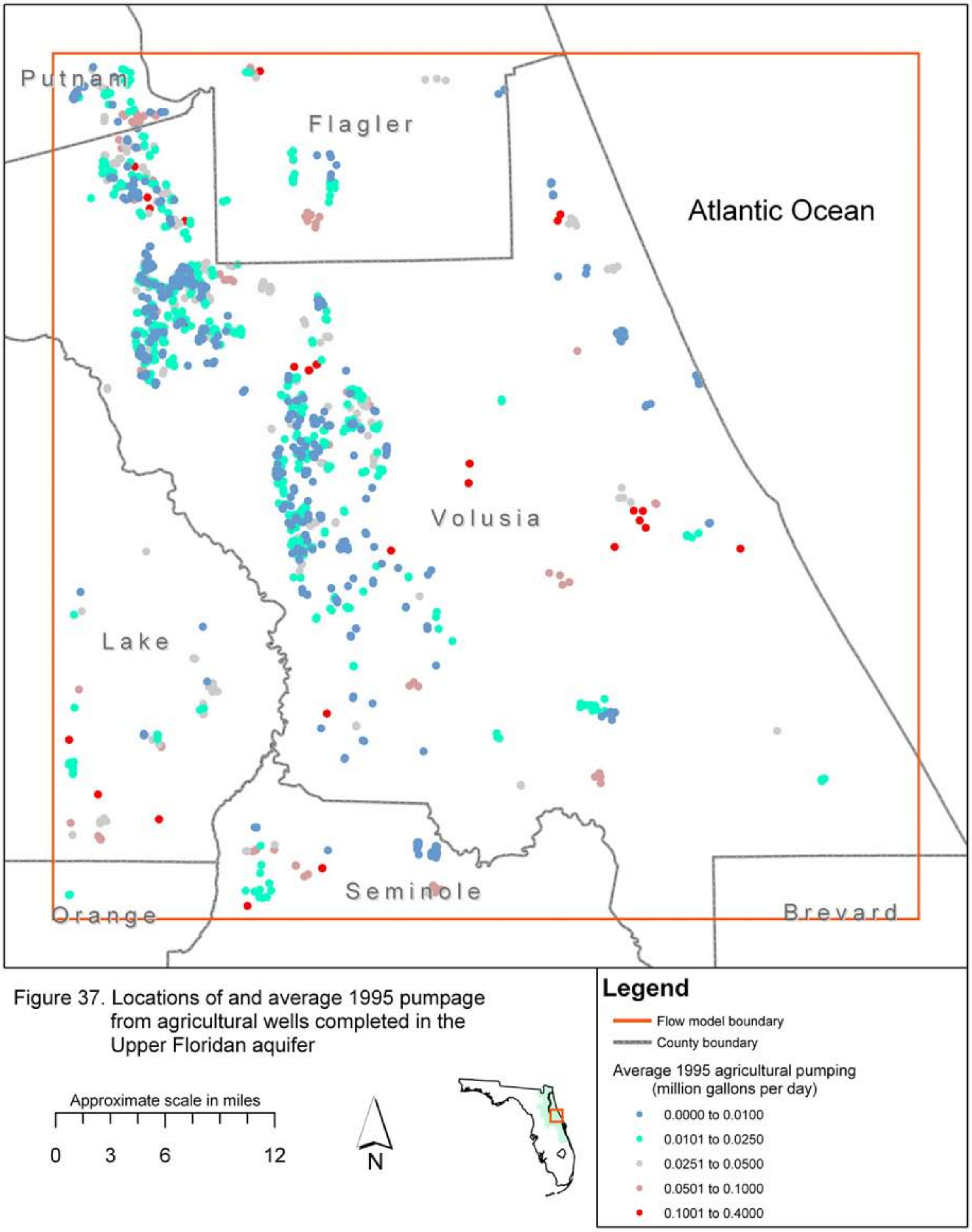


Figure 37. Locations of and average 1995 pumpage from agricultural wells completed in the Upper Floridan aquifer

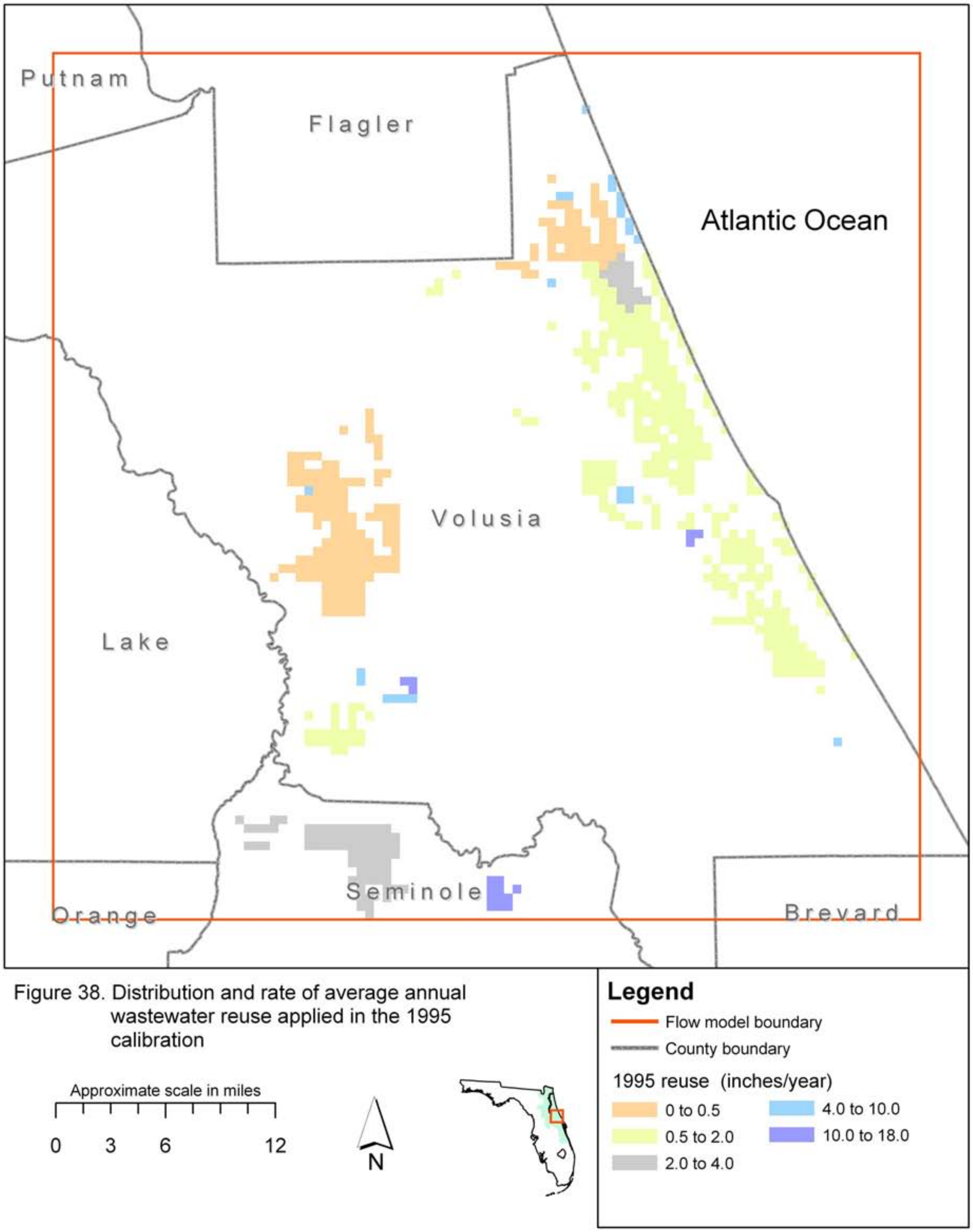


Figure 38. Distribution and rate of average annual wastewater reuse applied in the 1995 calibration

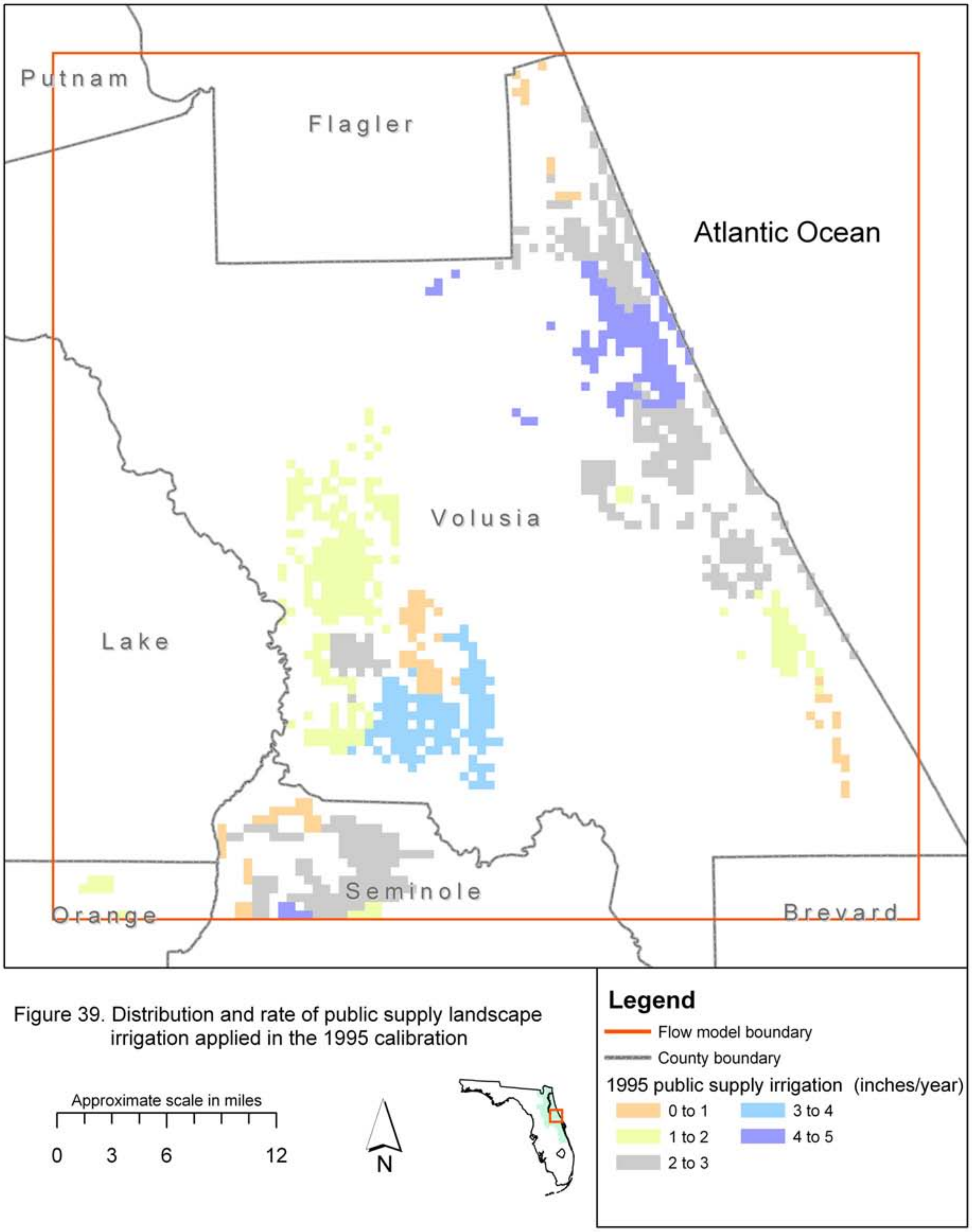


Figure 39. Distribution and rate of public supply landscape irrigation applied in the 1995 calibration

algorithm as landscape irrigation. Volumetric flow rates for R_{AG}, R_{REUSE}, R_{PSLI}, and R_{DSS} were converted to linear rates (ft/d), and summed to obtain the total applied irrigation (R_{APP}) component of the recharge algorithm (Figure 40).

Evapotranspiration from above the saturated zone (ET_{UNSAT}): ET_{UNSAT} is a combination of ET_{MIN} and additional ET that may occur due to land-applied sources (i.e., R_{APP}). ET_{MIN} represents the annual minimum ET that would occur in a natural setting with a relatively deep water Table and shallow-rooted vegetation. A minimum ET rate (ET_{MIN}) of 27 in/yr was applied uniformly based upon the work of Sumner 1996.

Net recharge to the surficial aquifer system (N): In order to account for the spatial variability of applied irrigation (R_{APP}), Equation 12 was expanded, incorporating an estimation of depth to water based upon soil types described in the SSURGO database. Data related to each soil type includes an estimated depth to the mean water table. Three soil groupings were identified and plotted according to the reported depth to the mean water Table (Figure 41):

- Type 1: Depth to water is less than or equal to 2 ft.
- Type 2: Depth to water is greater than 2 ft and less than or equal to 6 ft.
- Type 3: Depth to water is greater than 6 ft.

These soil groupings are incorporated into the recharge algorithm through the treatment of ET_{UNSAT}. In areas dominated by soil type 1, ET_{UNSAT} is equal to ET_{MIN} (i.e., 27 in/yr). In areas dominated by soil types 2 or 3, ET_{UNSAT} equals ET_{MIN} plus applied irrigation (R_{APP}) and septic tank discharge (R_{SEPTIC}). The practical implication of this approach in areas with a shallow water Table is that all applied irrigation water is recharged directly to the water table. In areas with a deeper water table, an amount of R_{APP} and/or R_{SEPTIC} supplements ET_{MIN} and becomes part of ET_{UNSAT}.

Net recharge to the surficial aquifer system was calculated as follows:

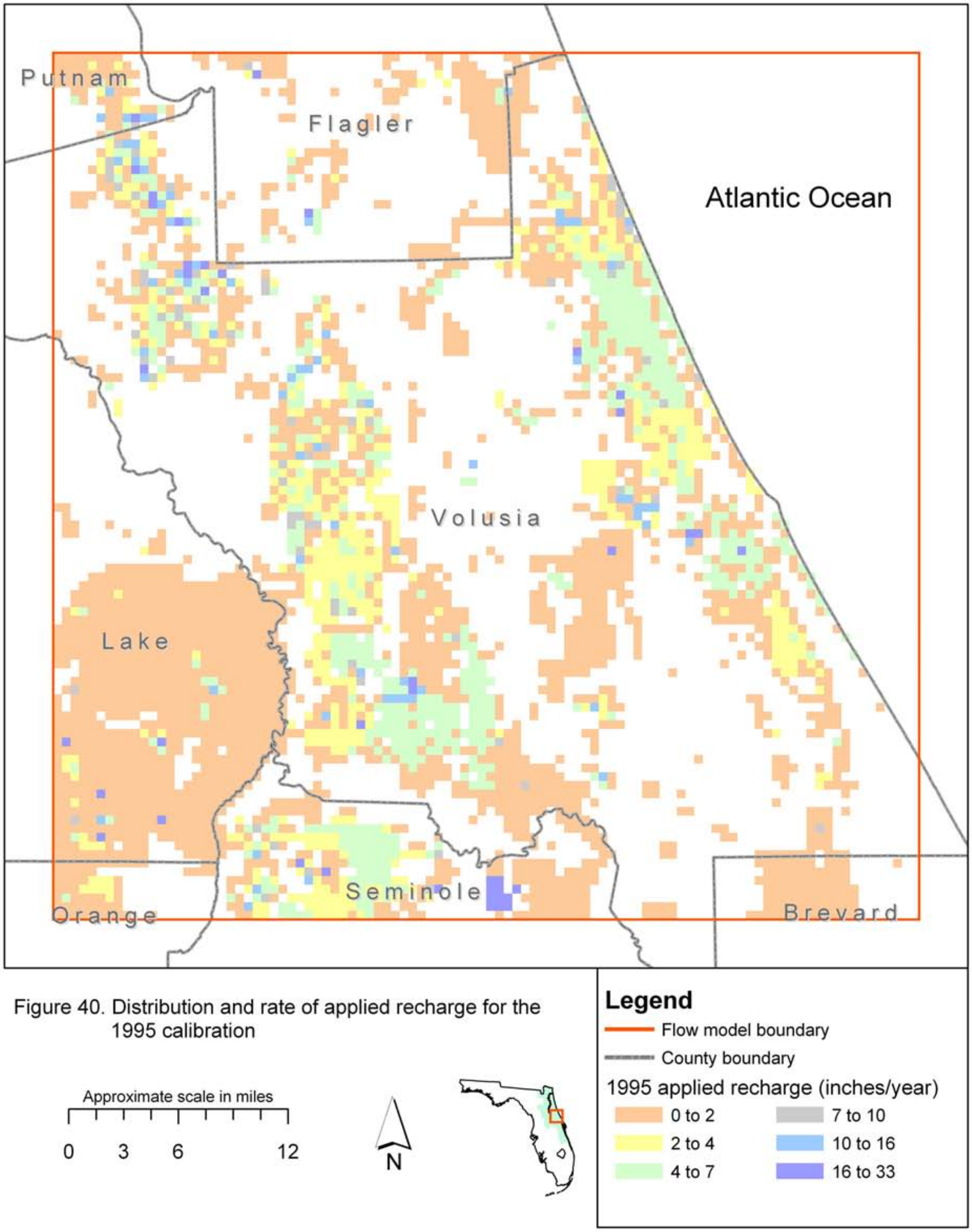


Figure 40. Distribution and rate of applied recharge for the 1995 calibration

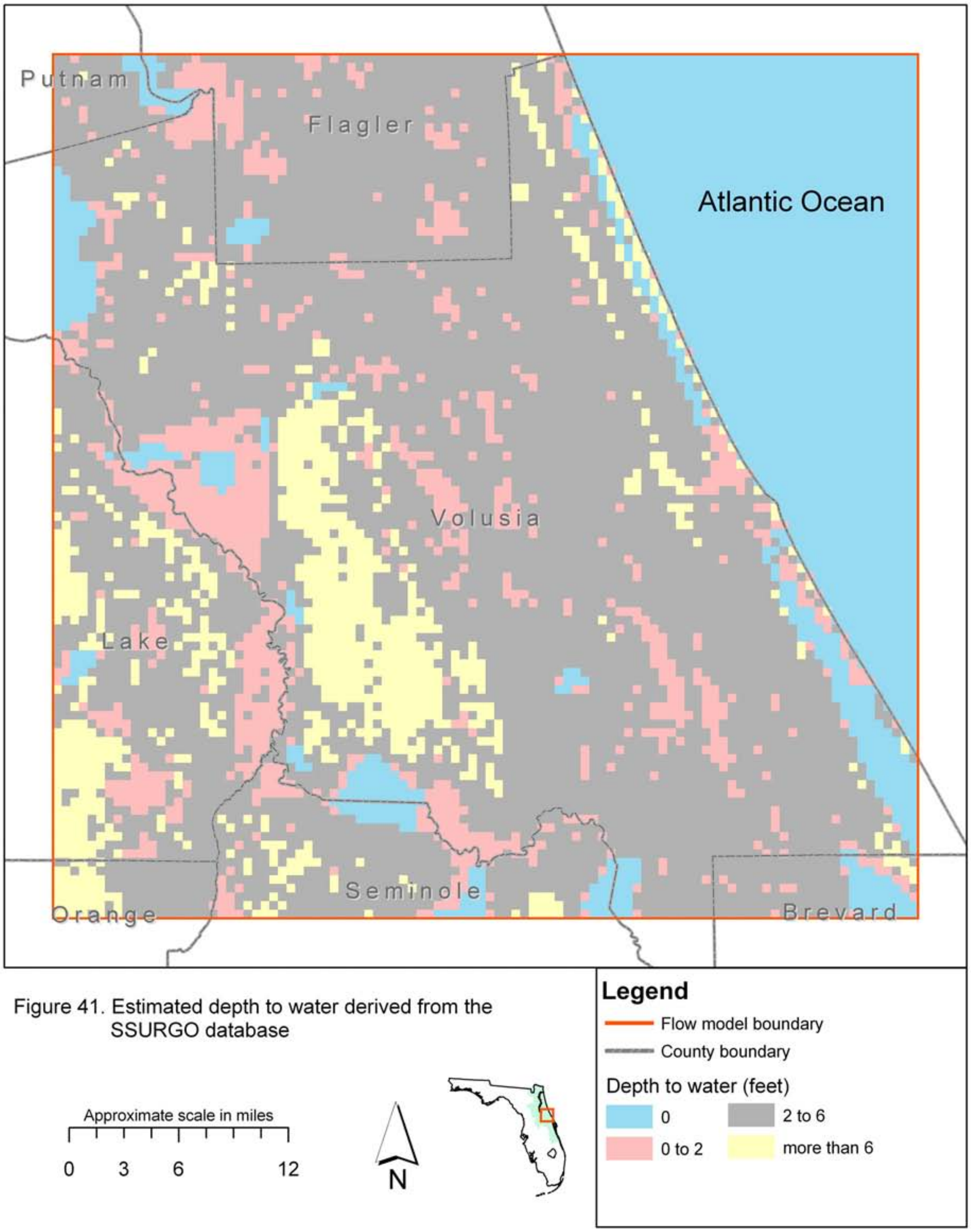


Figure 41. Estimated depth to water derived from the SSURGO database

For soil type 1:

$$N=(R_{MR}+R_{APP}+R_{SEPTIC})-ET_{UNSAT} \tag{14}$$

where $ET_{UNSAT}=ET_{MIN}$ (i.e., 27 in / yr)

For soil types 2 and 3:

If $(R_{APP}+R_{SEPTIC}) \le ET_{MAX}-ET_{MIN}$ (i.e., 19 in / yr)

then

$$N=(R_{MR}+R_{APP}+R_{SEPTIC})-ET_{UNSAT} \tag{15}$$

where $ET_{UNSAT}=ET_{MIN}+(R_{APP}+R_{SEPTIC})$

And if $(R_{APP}+R_{SEPTIC}) > ET_{MAX}-ET_{MIN}$ (i.e., 19 in / yr)

then

$$N=(R_{MR}+R_{APP}+R_{SEPTIC})-ET_{UNSAT} \tag{16}$$

where $ET_{UNSAT}=ET_{MAX}$

A fundamental assumption of this treatment is that total ET is everywhere equal to the sum of ET_{SAT} and ET_{UNSAT}. Equation 14 indicates that, for areas dominated by soil type 1, total ET is equal to ET_{MIN} (27 in / yr) plus ET simulated from the saturated zone, with no contribution of either R_{APP} or R_{SEPTIC} to unsaturated zone ET. Equation 15 indicates that when R_{APP} and / or R_{SEPTIC} are applied to areas dominated by soil types 2 and 3, total ET equals the sum of ET_{MIN}, R_{APP}, and R_{SEPTIC} plus ET simulated from the saturated zone. Equation 16 indicates that, if the sum of R_{APP} and R_{SEPTIC} is greater than (ET_{MAX} – ET_{MIN}), then R_{APP} and R_{SEPTIC} are applied directly to the water table. In this case, total ET is equal to ET_{MAX}, which is also equal to ET_{UNSAT}, thus implying that ET_{MAXSAT}, the maximum allowed ET rate from the saturated zone, is equal to zero.

A mass balance analysis of water use and subsequent fates was instrumental in accounting for components of water use or reuse (Table 7; Appendices D, E, and F). An accounting of the fate of all withdrawals from the Floridan aquifer system is possible by conceptually tracing water from withdrawal points to destinations of usage, wastewater treatment, and / or land

Table 7. Overview of water use and fate for the 1995 calibration and the 2020 projection

Category of Use	Water Use (mgd)	Category of Fate	Water Fate (mgd)
1995 Calibration			
Public supply	59.30	Public supply landscape irrigation	16.60
Agricultural	26.80	Public supply wastewater treatment	35.50
Commercial/industrial	2.10	Public supply septic tank discharge	7.20
Free-flowing wells	23.10	Agricultural irrigation	26.80
Domestic self-supply	11.30	Commercial/industrial discharge	2.10
		Free-flowing well discharge	23.10
		Domestic self-supply discharge	5.65
		Domestic self-supply irrigation	5.65
Total usage	122.60	Total fate/discharge	122.60
2020 Projection			
Public supply	112.50	Public supply landscape irrigation	33.20
Agricultural	28.10	Public supply wastewater treatment	68.10
Commercial/industrial	5.80	Public supply septic tank discharge	11.20
Free-flowing wells	11.80	Agricultural irrigation	28.10
Domestic self-supply	13.10	Commercial/industrial discharge	5.80
		Free-flowing well discharge	11.80
		Domestic self-supply discharge	6.55
		Domestic self-supply irrigation	6.55
Total usage	171.30	Total fate	171.30

application. Of the total average 1995 public supply pumping (59.30 mgd), 23.84 mgd is estimated to become landscape irrigation (16.62 mgd for R_{PSLI}) or discharge through individual septic tanks (7.22 mgd for R_{SEPTIC}) (Table 7; Appendix D). The remainder of 35.46 mgd is in excellent agreement with the total annual average reported flow of 35.51 mgd through wastewater treatment plants (Appendix E). Average wastewater treatment plant flows were either included in the recharge algorithm as reuse or were discharged to surface water bodies and therefore not simulated explicitly (Appendix E). Flows that were estimated for self-supplied commercial and industrial pumping wells and for abandoned free-flowing wells were assumed to discharge directly to surface water bodies.

Groundwater Withdrawals

For the 1995 model calibration, all withdrawals for public supply and agricultural uses are pumped from the Upper Floridan aquifer. Public supply pumping is concentrated in eastern Volusia County (e.g., Daytona Beach @ 12.4 mgd, Port Orange @ 5.3 mgd, Ormond Beach @ 4.9 mgd, and New Smyrna Beach @ 4.3 mgd) with additional pumping centers in western and southwest Volusia County (e.g., DeLand @ 5.1 mgd; Deltona @ 9.1 mgd) (Figure 42). A summary of public supply water use and ultimate fate is provided in Appendix D. Agricultural usage is concentrated in western and northwestern Volusia County (Figure 37). Primary agricultural usage types during 1995 were irrigation for ferneries (14.8 mgd), golf courses (7.6 mgd), and sod farms (4 mgd). Free-flowing wells that were inventoried in 1995 (Wesley Curtis, SJRWMD, pers. com. 2001) accounted for 23.1 mgd of discharge from the Upper Floridan aquifer. This discharge is composed of 11.8 mgd flowing to one well (Wekiva Falls) and 11.3 mgd estimated for all abandoned artesian wells that were inventoried by SJRWMD's abandoned well program in 1995.

The synthesis of water use data consists of a number of iterative steps involving data gathering from a variety of sources and processing of the data into a coherent database. For example, public supply well characteristics were obtained from the SJRWMD consumptive use permitting database, and metered water use was obtained from utility monthly operating reports filed with the Florida Department of Environmental Protection. These data were combined, and water use rates were applied at individual wells based upon available well capacities, run-time data, and / or permitted wellfield pumping distributions.

For agricultural and golf course irrigation (R_{AG}), pumpage rates were estimated based upon irrigated acreages and application rates for each crop type. Application rates were developed by SJRWMD staff from usage patterns and combined with permitted or known irrigated acreages to calculate estimated usage values. This procedure was applied modelwide for agricultural and golf course applications. As a cross-check, agricultural estimates were summed by crop and county and compared to countywide totals reported in the SJRWMD annual water use survey (Florence and Moore 1997). The agricultural usage in the water use survey was considered to be a valid cross-reference because these estimates were verified with county

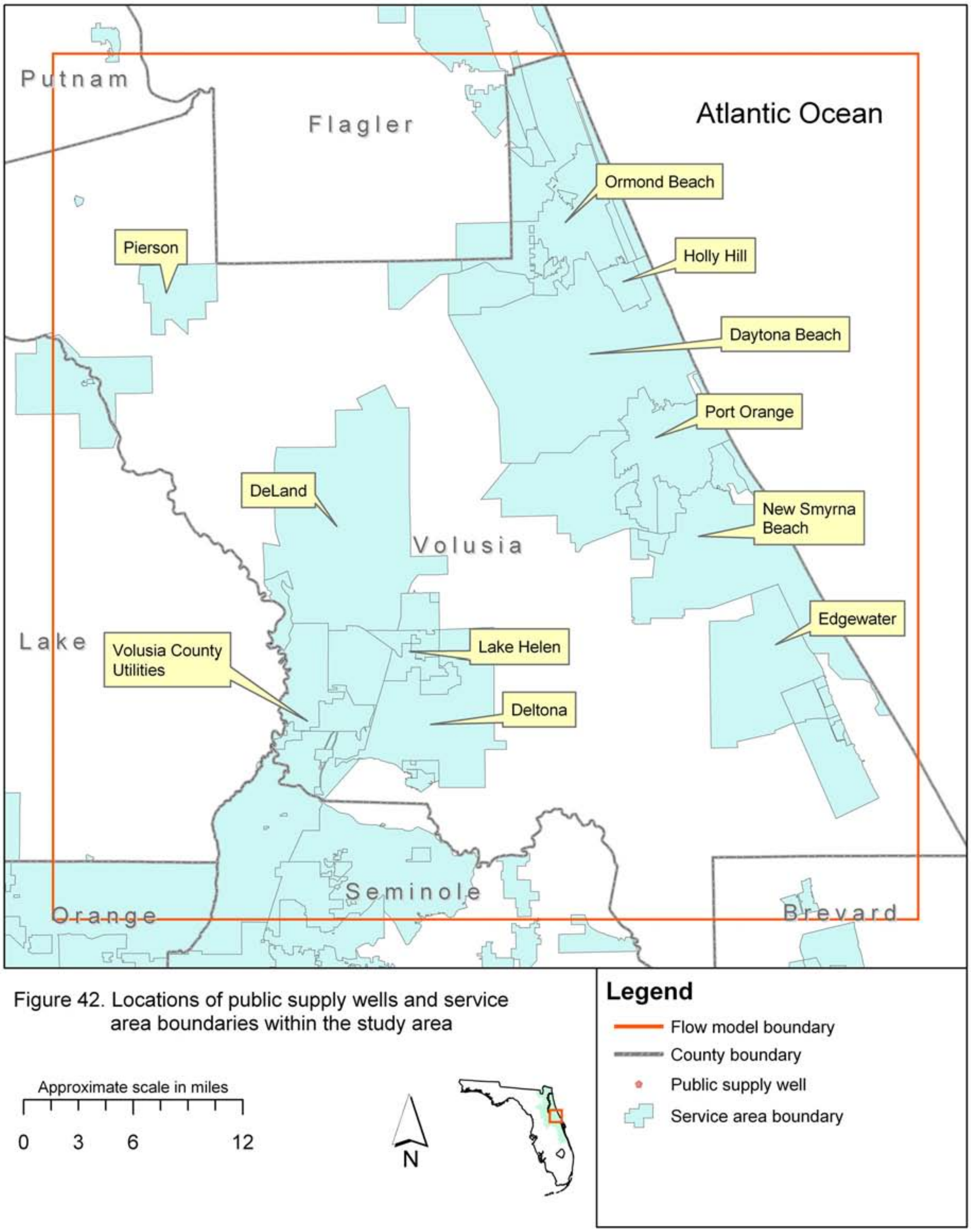


Figure 42. Locations of public supply wells and service area boundaries within the study area

government staff familiar with local agricultural practices. These water use estimates were subsequently combined with a database of pumping well locations and characteristics to create pumpage rates for agricultural and golf course usage.

For commercial and industrial applications, pumpage estimates were obtained from the SJRWMD permit files. This usage category is relatively minor for the study area (i.e., 2 mgd, or approximately 2% of total usage for 1995) and permitted pumpage values were considered to be the best available information.

A database of domestic self-supply wells was developed from an existing countywide database of wells for Volusia County and from available digital records for remaining counties (pers. com., GIS Associates, 2004). For the 1995 calibration, a total of 11.26 mgd was applied throughout the model area for domestic self-supply. This pumpage is assumed to be distributed equally between wells screened in the Upper Floridan aquifer and in the surficial aquifer system, based upon a review of the well data for Volusia County. The wells are distributed spatially throughout the study area according to reported locations (Figure 43).

No-Flow Boundaries

A no-flow boundary, a specific instance of a specified flux boundary condition, exists implicitly along all lateral boundaries wherever the boundary condition is otherwise unspecified (Figures 28–30). A no-flow condition also exists implicitly at the base of the Floridan aquifer system, which is the assigned base of the groundwater flow system. During initial model calibration, this lower boundary was assigned at the lithostratigraphic base of the Lower Floridan aquifer, representing the underlying evaporite zone of the Cedar Keys Formation. During model calibration, the base elevations of the Floridan aquifer layers were adjusted to the estimated elevation of the freshwater / saltwater interface. The 5,000-ppm chloride isochlor (Figure 23) is conceptualized as a continuous surface (based upon available data) with virtually no exchange of fresh and salt water prior to groundwater development. Therefore, wherever the lithostratigraphic elevation of the actual aquifer base is lower than the estimated elevation of the 5,000-ppm chloride isochlor, the elevation of the isochlor was assigned as the aquifer base. The use of this modified base for the Upper and Lower Floridan aquifers affects simulation results by reducing the effective

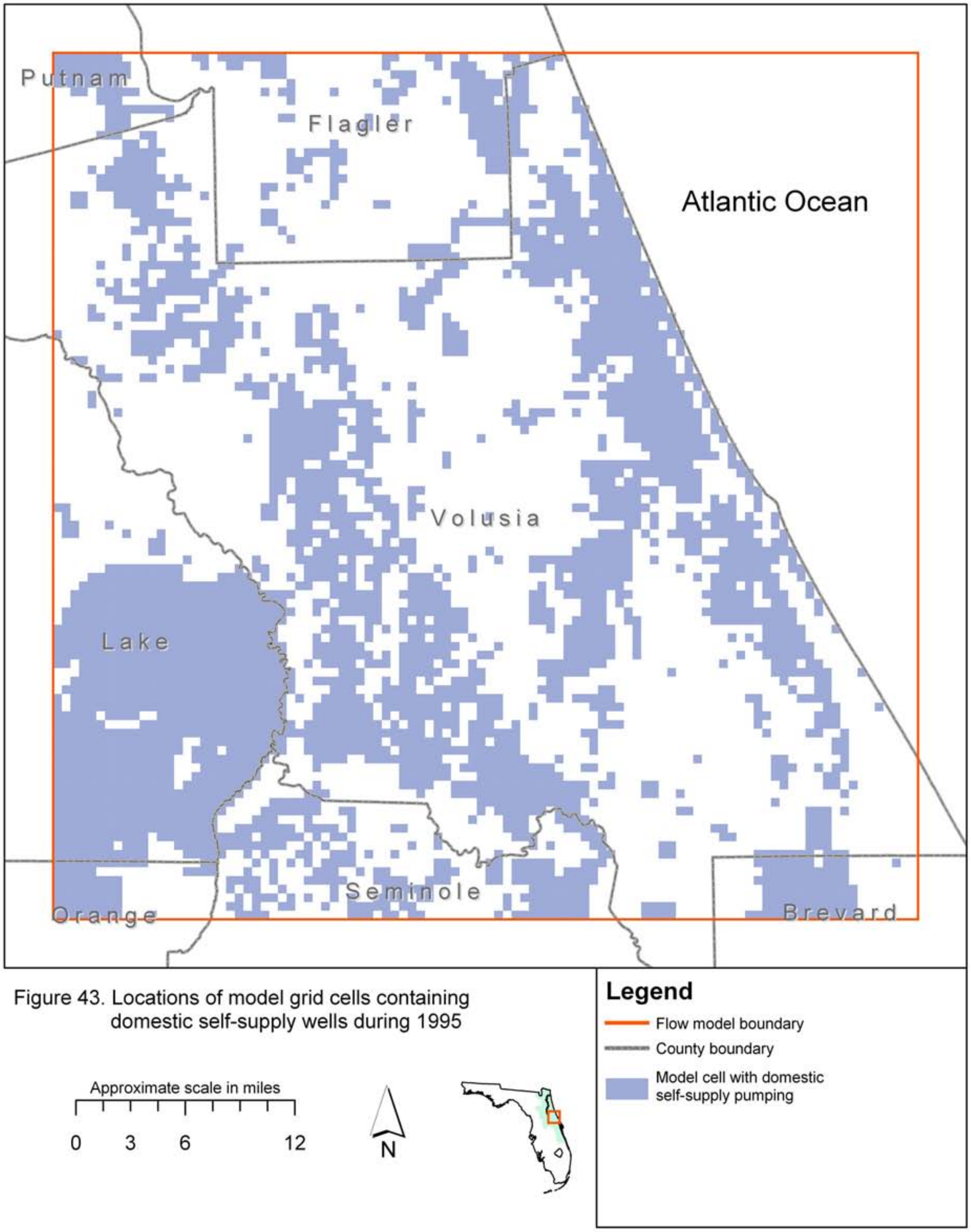


Figure 43. Locations of model grid cells containing domestic self-supply wells during 1995

transmissivities in those areas where the aquifer thickness is decreased. The Upper Floridan aquifer is only affected by this modification on the periphery of the project area (Figures 44 and 45). However, modification of the lower boundary of the Lower Floridan aquifer substantially reduced the simulated portion of the aquifer to a relatively thin or nonexistent condition in much of Volusia County (Figure 46).

AQUIFER AND CONFINING UNIT CHARACTERISTICS

Initial hydrostratigraphic elevations were based upon those presented in Miller (1986). Where appropriate, these elevations were modified based upon existing SJRWMD and USGS data. Initial values for transmissivity of the Upper Floridan aquifer and leakance of the upper confining unit were based upon a compilation of results of aquifer performance tests (Figure 18) (Szell 1993). The initial value for horizontal hydraulic conductivity of the surficial aquifer system was adapted based upon available aquifer performance tests (Table 2) and previous model development projects (Williams 1997). The leakance of the middle semiconfining zone and the transmissivity of the Lower Floridan aquifer were adapted from previous work by Tibbals (1990).

STEADY-STATE MODEL CALIBRATION

The groundwater flow model was calibrated to a predevelopment condition (i.e., conditions that existed prior to significant groundwater development) and to a postdevelopment average 1995 condition. An initial predevelopment model was developed by combining appropriate boundary conditions with initial estimates of aquifer hydraulic characteristics developed from aquifer test results. The 1995 calibration was the primary focus of the calibration process because (1) system monitor data are much more extensive for this period and (2) water use data for this stressed period was accessible. Also, calibration of the groundwater model to a stressed condition facilitated effective characterization of aquifer and confining unit hydraulic characteristics. The predevelopment calibration was revised upon completion of the average 1995 calibration by combining the calibrated distributions of aquifer properties with boundary conditions appropriate to the predevelopment condition.

The discussions regarding boundary conditions and aquifer and confining unit properties contained herein apply to both the average 1995 and the predevelopment versions of the groundwater model. Results of the initial

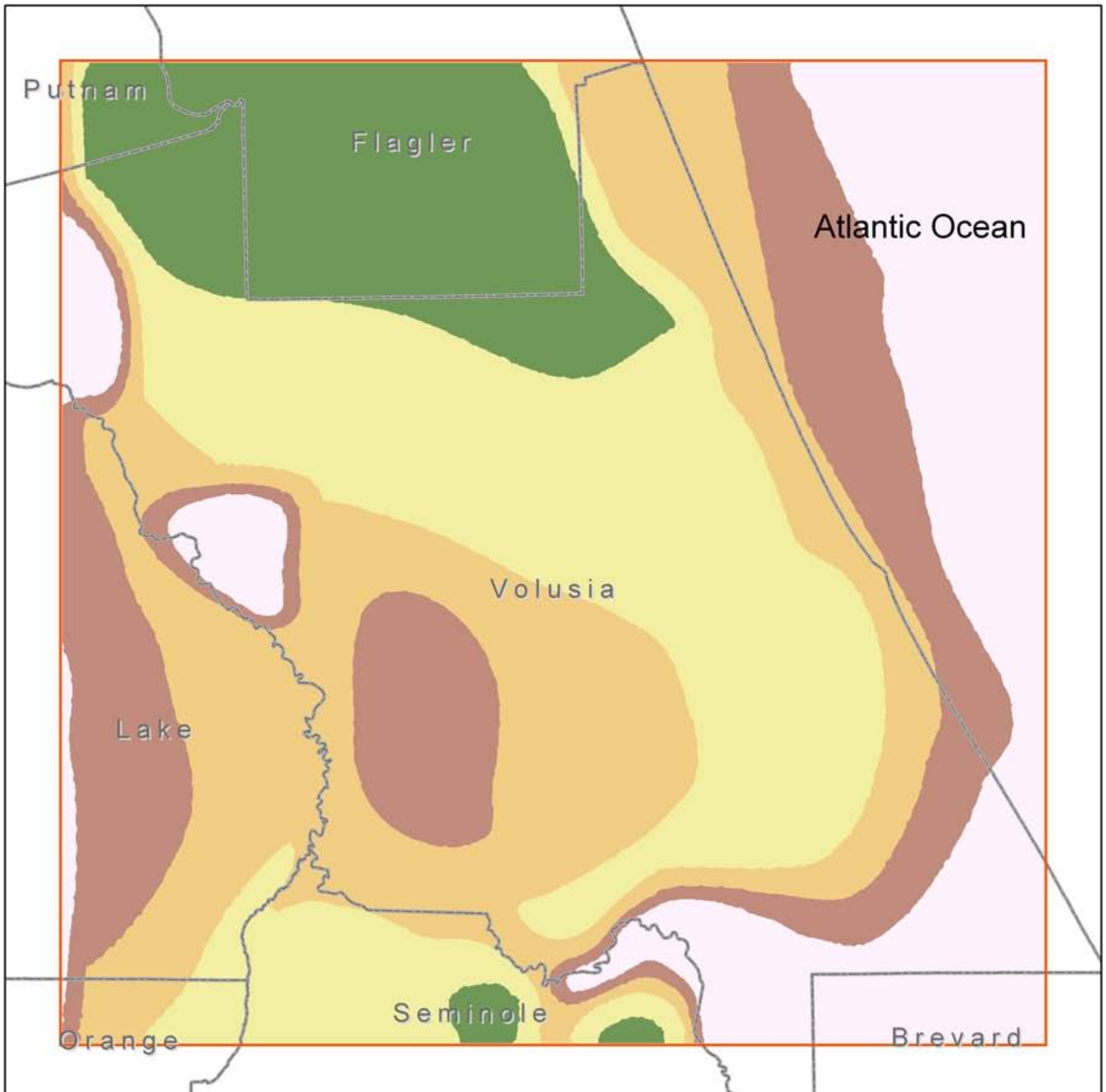


Figure 44. Estimated elevation of the base of the Upper Floridan aquifer modified to the elevation of the 5,000-parts per million chloride isochlor

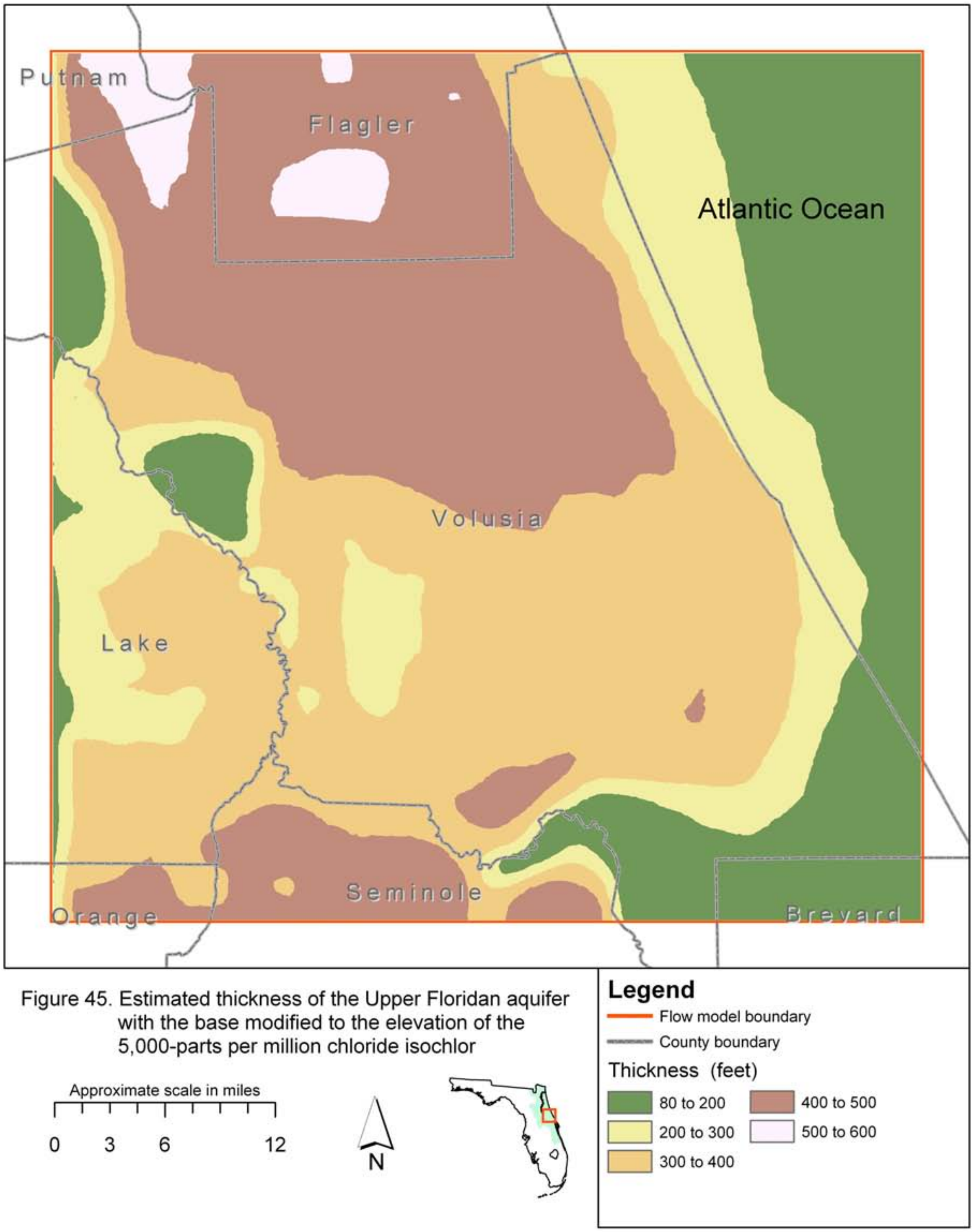


Figure 45. Estimated thickness of the Upper Floridan aquifer with the base modified to the elevation of the 5,000-parts per million chloride isochlor

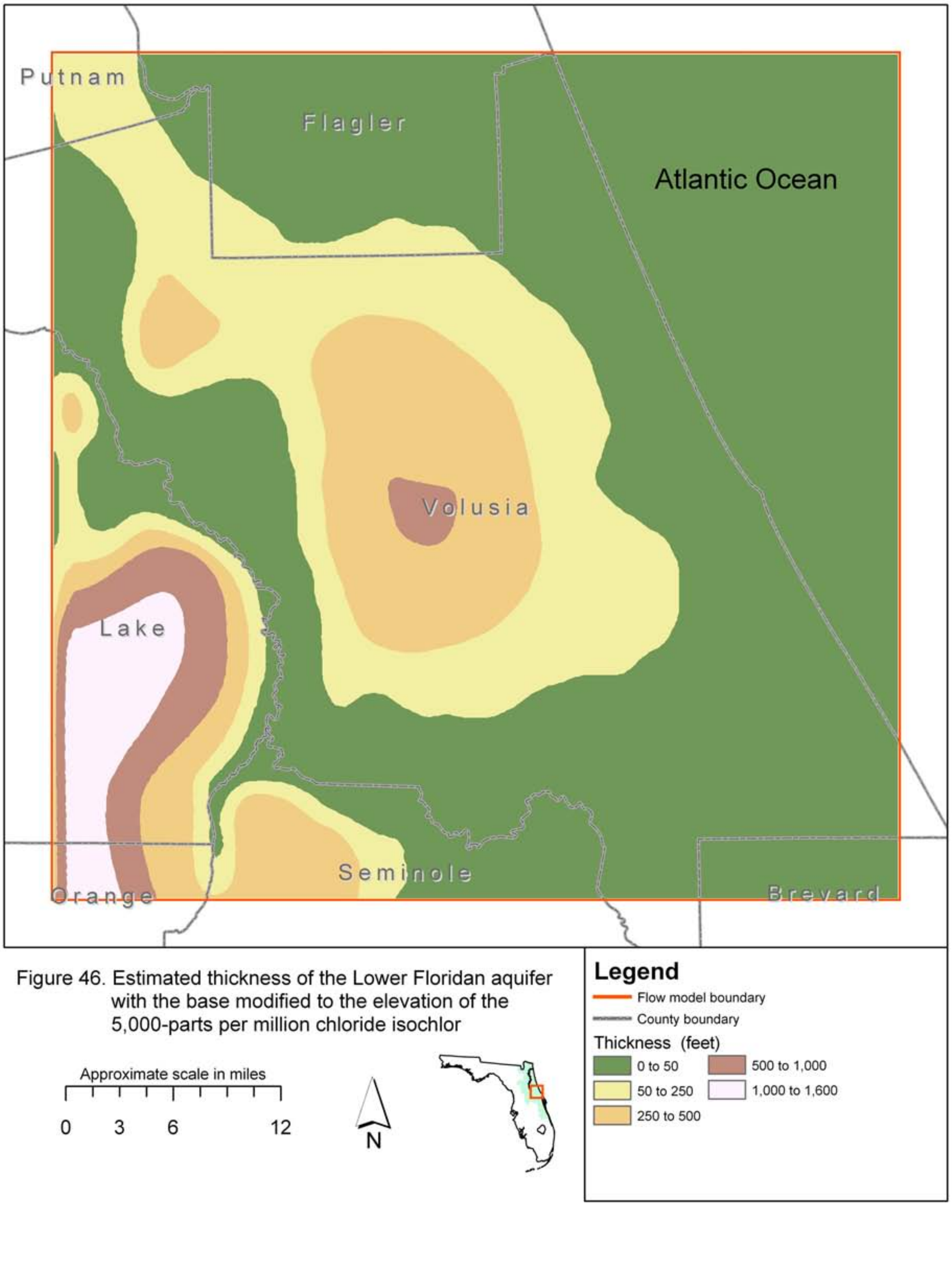


Figure 46. Estimated thickness of the Lower Floridan aquifer with the base modified to the elevation of the 5,000-parts per million chloride isochlor

predevelopment model are not presented due to the preliminary nature of this model. Results of the average 1995 calibration are emphasized in the following discussions of calibrated distributions of aquifer properties and simulated hydraulic heads and flow rates.

The year 1995 was chosen as the target year of the postdevelopment calibration because this period was deemed to represent a long-term average condition. Long-term rainfall records from the four NOAA stations located in or near this model area (Daytona Beach, DeLand, Sanford, and Titusville) (Figure 3; Appendix A) indicate that annual departures from long-term average rainfall conditions for the years 1992, 1995, and 1998 were closest to the average condition for the years between 1990 and 1999, with average departures of 4.77, 1.06, and –6.66 in / yr for the four stations. Records for these 3 years were assessed with respect to the intrayear seasonal variability in rainfall relative to the long-term average condition. For each of the four stations, the average absolute monthly departure was determined in order to assess the intrayear variability relative to long-term values. Average monthly departures for all four stations were 1.84, 1.66, and 2.17 inches for 1992, 1995, and 1998, respectively. The year 1995 was chosen because the total annual rainfall for 1995 was representative of a long-term average annual condition and the intrayear variability for 1995 indicated a long-term average seasonal distribution. The year 1995 was also chosen to be representative of the approximate hydrologic profile that existed between 1995 and 2000. This calibration was used as the initial condition in order to project impacts to the year 2020 consistent with the objectives of the water supply assessment.

Both the predevelopment and postdevelopment calibrations were steady-state, meaning that changes in storage in the aquifer units were neglected and that model calibrations represented long-term average conditions for the respective periods.

Favorable calibrations for both the predevelopment and the average 1995 periods are documented in subsequent sections of this report. The similarity between the simulated and observed attributes of the hydrologic system for these time periods substantiates the characterization of aquifer and confining unit characteristics and boundary conditions assigned to the numerical groundwater model.

The primary focal areas of the calibration process were effective quantification of (1) recharge to the surficial aquifer system, (2) the transmissivity of the Upper Floridan aquifer, and (3) the leakance of the intermediate confining unit.

The recharge algorithm described in a previous section of this report provides an integrated approach to account for rainfall, overland runoff, minimum ET, and land-applied water use and reuse. Horizontal hydraulic conductivity and associated transmissivity of the Upper Floridan aquifer is a fundamental factor influencing horizontal groundwater flow and the associated potentiometric surface within the Upper Floridan aquifer. The characterization of leakance of the intermediate confining unit determines the hydraulic connection between the Upper Floridan aquifer and the overlying surficial aquifer system. Some additional model attributes that were pertinent to the model calibration included the upper and lower limits for ET, spring and river conductance terms, and the hydraulic conductivity of the surficial aquifer system.

Calibration Criteria

A set of calibration criteria was developed and evaluated throughout the model calibration process. Calibration criteria were established for both the predevelopment and the average 1995 calibrations. These criteria were designed to assess the accuracy of simulated potentiometric levels, spring flow and streamflow and other selected model outputs with respect to measured or previously estimated values (Tables 8 and 9).

Criteria were applied to assess the output of the average 1995 calibration (Table 8), including simulated heads for all aquifer layers, simulated aquifer heads relative to corresponding observed lake levels, simulated spring flow and streamflow, and the spatial distribution of rates for recharge to the surficial and Upper Floridan aquifers and ET. Simulated heads were assessed by calculation of the mean error, the mean absolute error, and the root mean squared error for the three simulated aquifers and comparison of these values with predetermined accepTable values (Table 8). These preset values were established to correspond with calibration standards that have been typically applied in calibration of regional models in Florida. These error criteria were also applied to simulated surficial aquifer system water levels relative to corresponding lake level measurements or estimates derived from either measured 1995 stage values or estimated historic stage values from 1:24,000 USGS topographic maps. A criterion of ±10% was used to evaluate simulated spring flows; this criterion corresponds to the estimated systemic error of

Table 8. Criteria applied to the average 1995 model calibration

Criterion	Objective
Match between the measured and simulated average 1995 water levels for the surficial aquifer system	• Mean error (me) <1 ft • Mean absolute error (mae) <3 ft • Root mean squared error (rmse) <3 ft
Match between the measured and simulated average 1995 potentiometric levels for the Upper Floridan aquifer	• me <1 ft • mae <2.5 ft • rmse <3 ft
Match between the measured and simulated average 1995 potentiometric levels for the Lower Floridan aquifer	• rmse <4 ft
Match between the average measured 1995 lake levels and the simulated average 1995 water levels for the surficial aquifer system	• me <1 ft • mae <3 ft • rmse <3 ft
Match between lake levels from USGS topographic maps and simulated average 1995 water levels for the surficial aquifer system	• me <2 ft • mae <4 ft • rmse <6 ft
Match between the measured and simulated average 1995 flows to all subterranean springs	First- and second-magnitude flows within 10%
Match between measured and model-derived average 1995 streamflow	Match within ±20%
Match between the measured and simulated average 1995 potentiometric surface of the Upper Floridan aquifer	Approximate match of shape and gradients
Match between the estimated and simulated ranges of net recharge rates to the surficial aquifer system	Agreement with published reports*
Match between the estimated and simulated ranges of recharge/discharge between the surficial aquifer system and the Upper Floridan aquifer	Agreement with published reports[†]
Match between the estimated and simulated ranges of evapotranspiration rates from the surficial aquifer system	Agreement with published reports*

Note: USGS = U.S. Geological Survey

*Phelps 1990; Rutledge 1985; Vecchioli et al. 1990
[†]Tibbals 1990; Boniol et al. 1993

Table 9. Criteria applied to the predevelopment model calibration

Criterion	Objective
Match between the estimated predevelopment water Table based upon the SSURGO database and the simulated predevelopment water table	Approximate match of spatial pattern
Match between the measured and simulated predevelopment potentiometric surface of the Upper Floridan aquifer	Approximate match of shape and gradients
Match between the estimated and simulated predevelopment flows to all subterranean springs	First- and second-magnitude flows within 20%
Match between the estimated and simulated ranges of evapotranspiration rates from the surficial aquifer system	Agreement with published reports*

Note: SSURGO = soil survey geographic

*Phelps 1990; Rutledge 1985; Vecchioli et al. 1990

these measurements. Simulated streamflow was targeted to match average measured 1995 flows from gaged surface water basins by ±20%.

Simulated rates of ET, calculated rates of net recharge to the surficial aquifer system, and simulated rates of recharge to or discharge from the Upper Floridan aquifer were compared to estimates from previous investigations. Similarly, the simulated potentiometric surface of the Upper Floridan aquifer was compared to that interpreted by USGS from measurement data to assess the simulation of patterns and directions of groundwater flow.

The simulated predevelopment water Table in the surficial aquifer system was compared to that estimated from depth to water data from the SSURGO database. The simulated predevelopment potentiometric surface of the Upper Floridan aquifer was compared to that estimated by USGS (Johnston et al. 1980). The calibration criterion for the simulation of predevelopment flow to subterranean springs indicated that simulated values match measured or estimated values within ±20%. This higher allowance for error relative to the 1995 calibration is associated with the degree of uncertainty of both the predevelopment calibration and the estimated predevelopment spring flows as compared to the calibration and flow measurements for the 1995 calibration.

In addition, adherence to a set of guidelines during model calibration ensured integrity between the calibration process and principles outlined in the conceptual model.

- Leakance of the intermediate confining unit is relatively high in karst areas, allowing for downward leakage due to sinkhole lakes and karst features.
- The T and K_h distributions derived from aquifer tests for the Upper Floridan aquifer provide reasonable lower estimates for calibration.
- Recharge to the Upper floridan aquifer at a given location is less than rainfall minus $_{ETmin}$ (P - ET_{min}) except where sinkholes received overland runoff from surrounding higher elevation areas.
- Flow between surface water bodies and the surficial aquifer system is toward the surface water body.
- The K_h of the surficial aquifer system is generally lower than that of the Upper Floridan aquifer.

An additional step in the calibration process involved a comparison of simulation results with an overlapping groundwater flow model of east-central Florida (McGurk and Presley 2002). Simulated aquifer heads, springflow rates, and projected drawdowns were compared, and discrepancies between the two models were addressed. The model comparison exercise ensured consistency regarding inputs and outputs between these groundwater models.

CALIBRATION RESULTS

The Predevelopment Calibration

The simulated predevelopment water Table in the surficial aquifer system compares favorably to the water Table elevation derived from the SSURGO soils database (Figures 9 and 47). The simulated predevelopment potentiometric surface of the Upper Floridan aquifer also compares favorably to that interpreted by USGS (Johnston et al. 1980) (Figure 48). Comparison of the simulated and interpreted surfaces provides valuable insight regarding the results of the groundwater model and the accuracy of the USGS predevelopment surface. The comparison of simulated and interpreted heads in coastal Volusia County is generally favorable. However, in southern

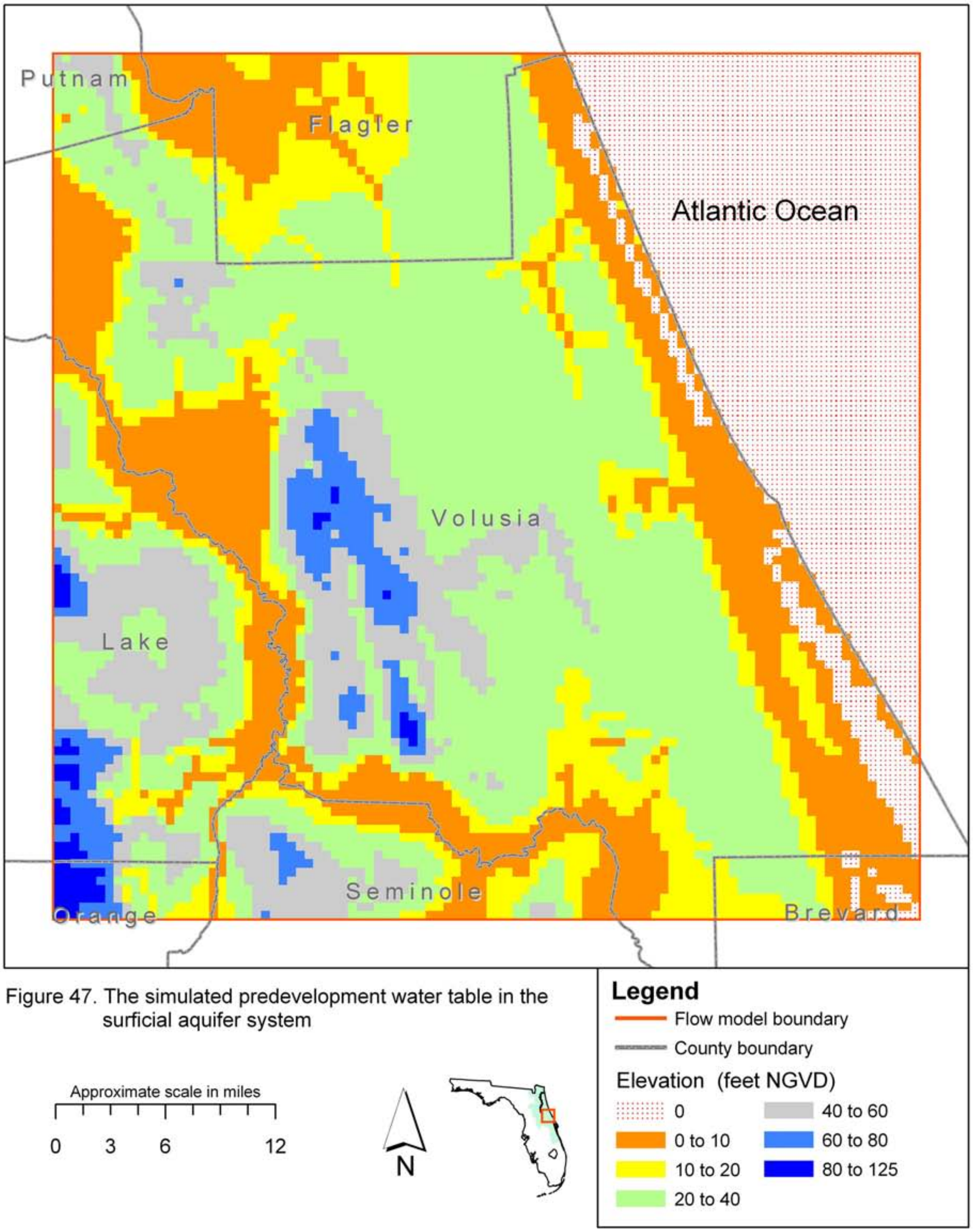


Figure 47. The simulated predevelopment water table in the surficial aquifer system

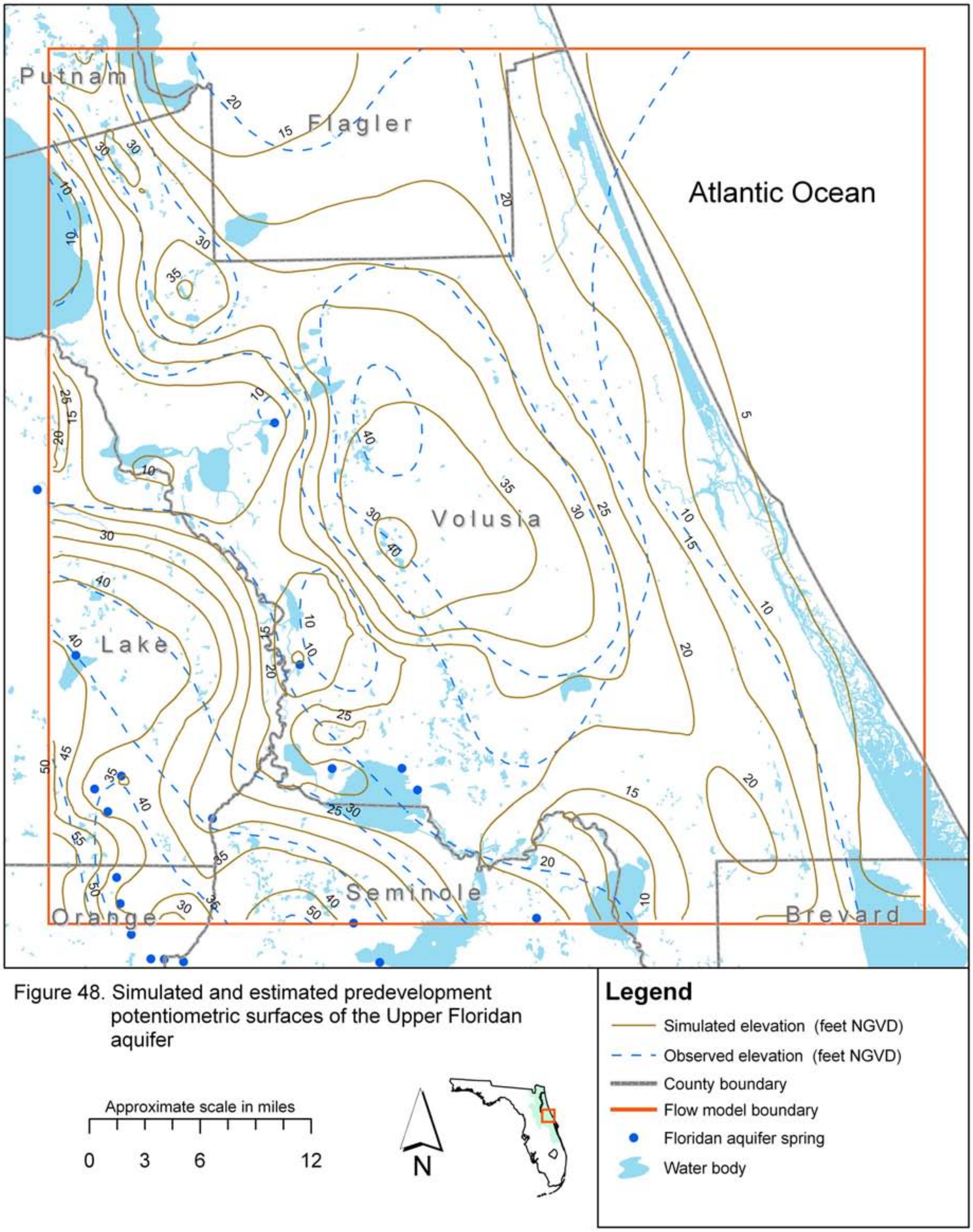


Figure 48. Simulated and estimated predevelopment potentiometric surfaces of the Upper Floridan aquifer

Volusia County, the 10-ft contour (Figure 48) in the vicinity of Lake Harney that is depicted as a depression has been persistent through time as evidenced by potentiometric surface maps representative of May 1980 and May 1987 (Figures 50 and 51). This depression is not indicated on the USGS predevelopment surface. In southwest Volusia County, the elevation of the simulated surface decreases more dramatically between the central potentiometric high and Lake Monroe in the St. Johns River valley than is indicated by the USGS interpreted surface. This corresponding simulated low area is depicted on earlier interpreted potentiometric surfaces (Figures 50 and 51). In eastern Lake County, the simulated potentiometric surface (Figure 48) indicates a sharp, well-defined hydraulic gradient toward the St. Johns River. This gradient is directly associated with the relatively low calibrated Upper Floridan aquifer transmissivity immediately west of Blue Spring. However, the gradient is not welldefined on the interpreted potentiometric surface map (Figure 48). The location of the 40-ft contour in north-central Volusia County on the USGS predevelopment potentiometric surface map and the relatively lower simulated surface in this area is a function of both uncertainty regarding actual predevelopment potentiometric levels in this area and relatively low annual average rainfall in the simulation model for this area relative to the regional average.

Flow data used to evaluate simulated spring discharges for the predevelopment calibration are either estimated or derived from sparse data sets. Table 10 indicates that simulated flows match estimated values within the calibration criterion for all first- and second-magnitude springs. Simulated values for Sulphur and Green springs do not match estimated values because these are low-flow springs for which little early-time data exist. Green Springs is a small pool with an ephemeral stream outlet that has been measured infrequently over time.

Total ET for the predevelopment calibration is within expected ranges (Figure 49, Table 1). The simulated distribution of ET approaches the lower limit of 27 in / yr in the upland ridges and is in the upper range of 42–46 in / yr in the low-lying terraces.

The Average 1995 Calibration

In order to provide assurance that potentiometric levels used for model calibration were representative of aquifer levels, monitor wells selected for calibration were culled from a set of possible wells after review of the length

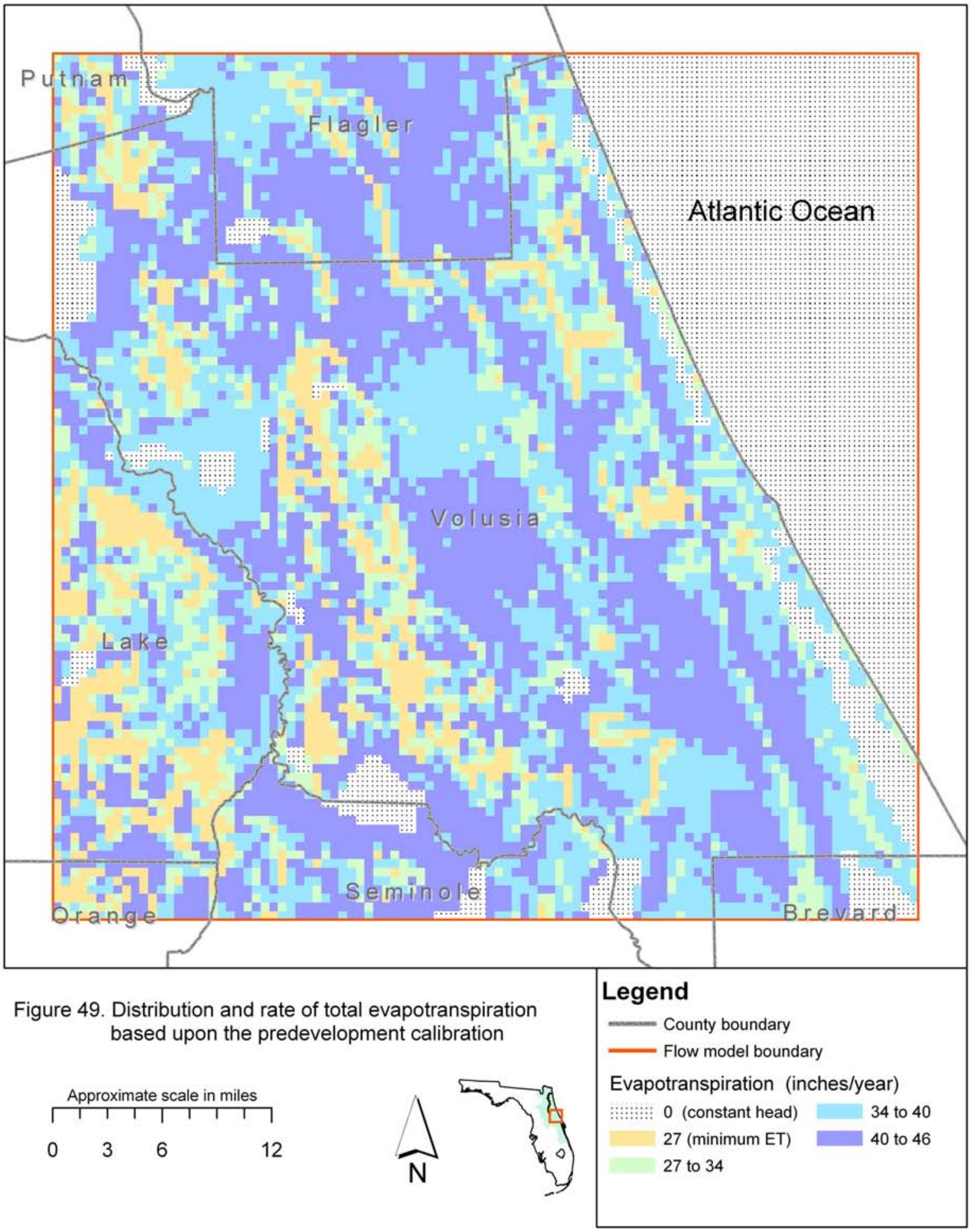


Figure 49. Distribution and rate of total evapotranspiration based upon the predevelopment calibration

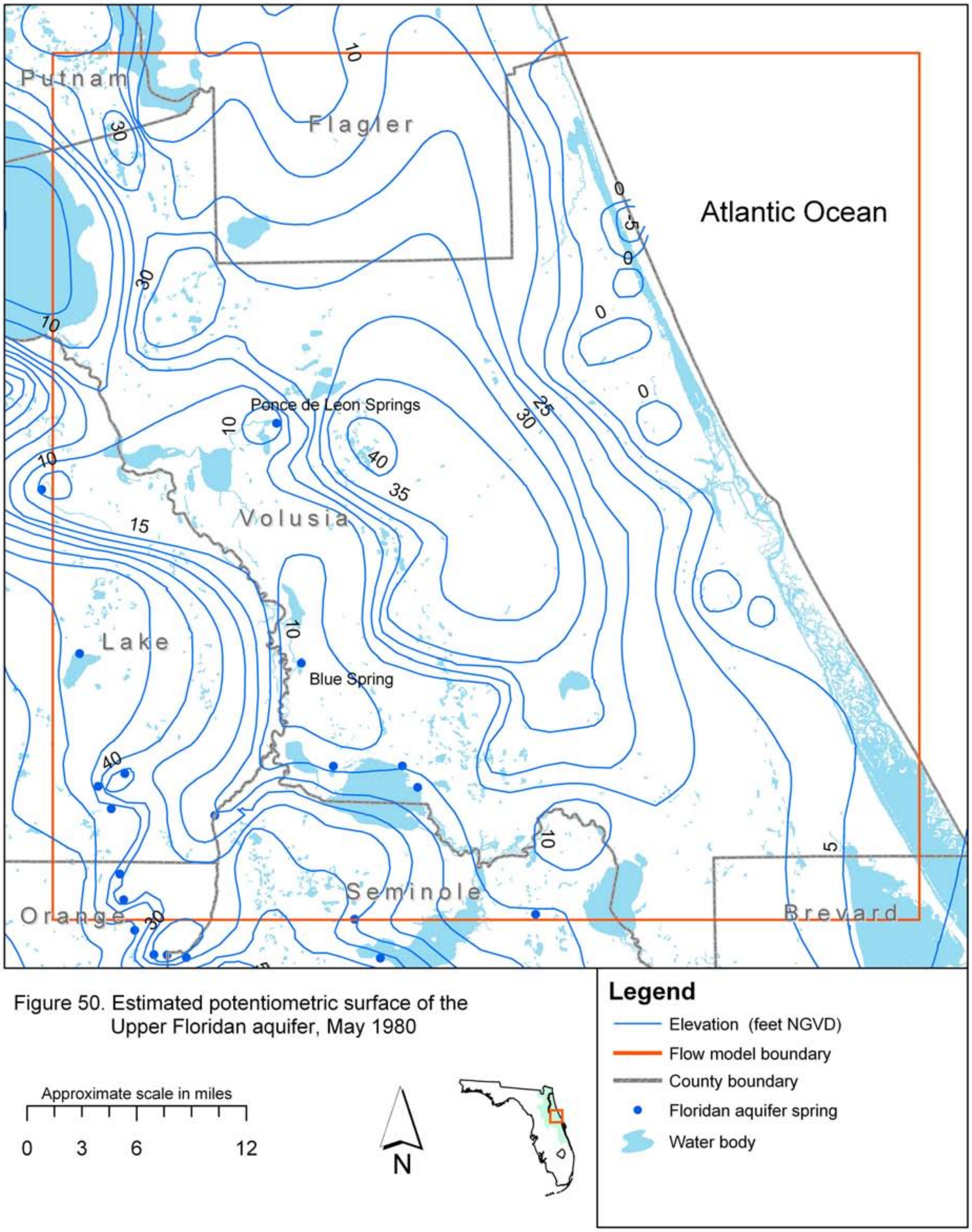


Figure 50. Estimated potentiometric surface of the Upper Floridan aquifer, May 1980

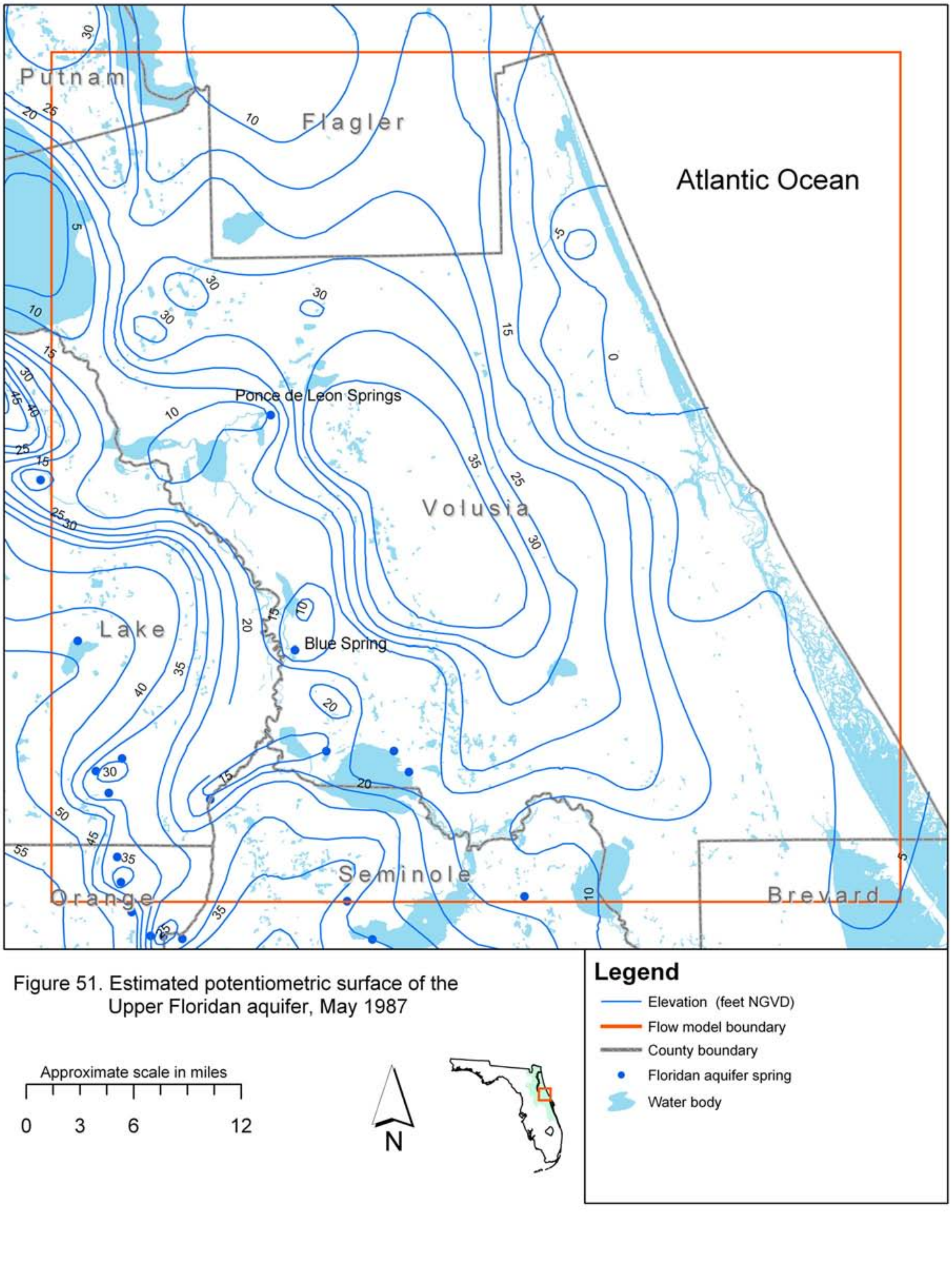


Figure 51. Estimated potentiometric surface of the Upper Floridan aquifer, May 1987

of open-hole intervals and the proximity to local pumping wells or surface water bodies. The residuals analysis for the set of 51 wells open to the surficial aquifer system (Figure 52) indicated no significant spatial bias, and showed good agreement between simulated and measured water levels. Relatively high residuals (i.e., ±3–5 ft) occurred in areas with high topographic relief, indicative of elevation differences between well locations and model cell centers. These areas of topographic relief occur where karst geomorphology predominates or in transitional zones between sandy ridges and low-lying terraces. Calibration statistics are within limits imposed by pre-established criteria (Table 8), and a comparison of measured and simulated water levels indicates a coefficient of determination of greater than 0.99 (Figure 53A).

Comparison of measured and simulated average 1995 Upper Floridan aquifer potentiometric levels (Figure 54) indicates little spatial bias in the distribution of head residuals. A minor value-dependent bias is suggested in Figure 53B, with a small number of simulated heads that are lower than observed heads in areas of low head and higher than observed in areas of high head. Monitor wells where absolute residual values are greater than 3 ft occur in areas with a relatively large horizontal gradient in the potentiometric surface, such as in southwest Volusia County. A regression analysis of observed and simulated heads indicates a high degree of correlation with a coefficient of determination of 0.92 (Figure 53B). The comparison for the four monitor wells in the Lower Floridan aquifer (Figure 55) exhibits a root mean squared error of 1.94, indicative of a favorable match between measured and simulated values.

Average lake levels for 44 lakes where stage data were collected during 1995 were compared to simulated average 1995 surficial aquifer system water levels. Most of these lakes are located in the DeLand and Crescent City ridges in western Volusia County (Figure 56) where topographic relief is relatively high and lakes usually represent depressional karst features or sinkholes. Simulated groundwater levels in the surficial aquifer system were anticipated to be slightly higher than associated lake stages since these lakes receive groundwater inflow from the surrounding surficial aquifer system. Comparison of simulated water levels to observed average 1995 lake stages (Figure 57) indicates excellent agreement with a coefficient of determination of greater than 0.98. Calibration to these lake levels was helpful in refining adjustments to the leakance distribution of the intermediate confining unit. No spatial bias is indicated in the 1995 lake stage residuals (Figure 56).

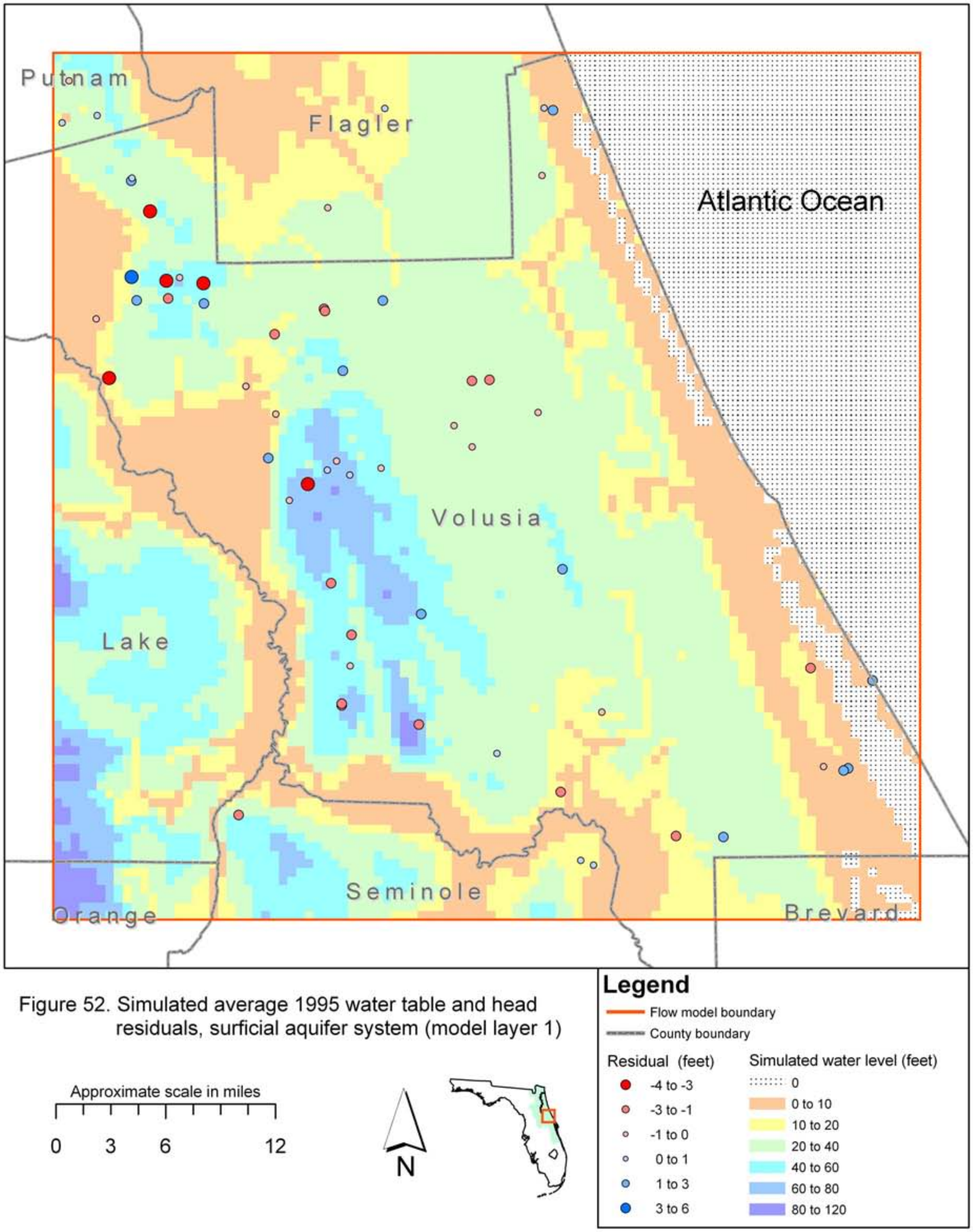


Figure 52. Simulated average 1995 water table and head residuals, surficial aquifer system (model layer 1)

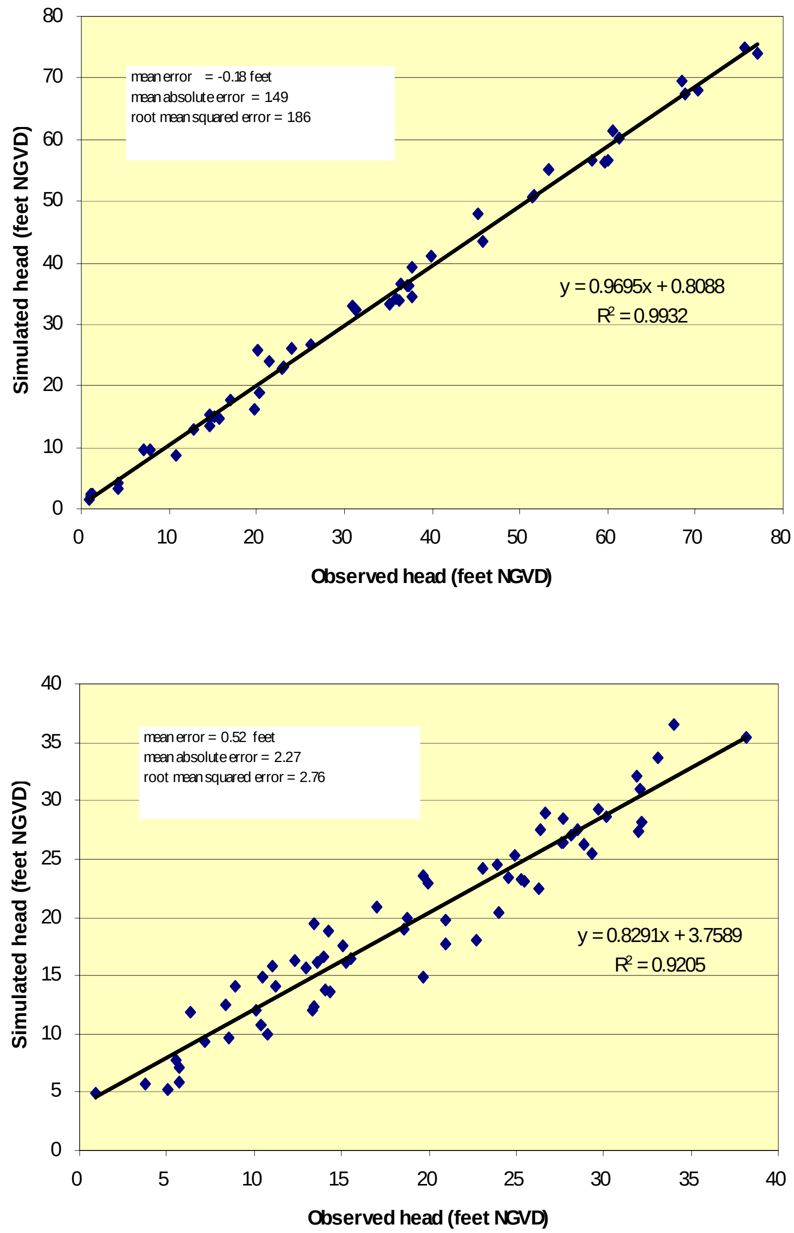


Figure 53. Trend lines of simulated and observed average 1995 heads for (A) water levels within the surficial aquifer system and (B) potentiometric levels within the Upper Floridan aquifer

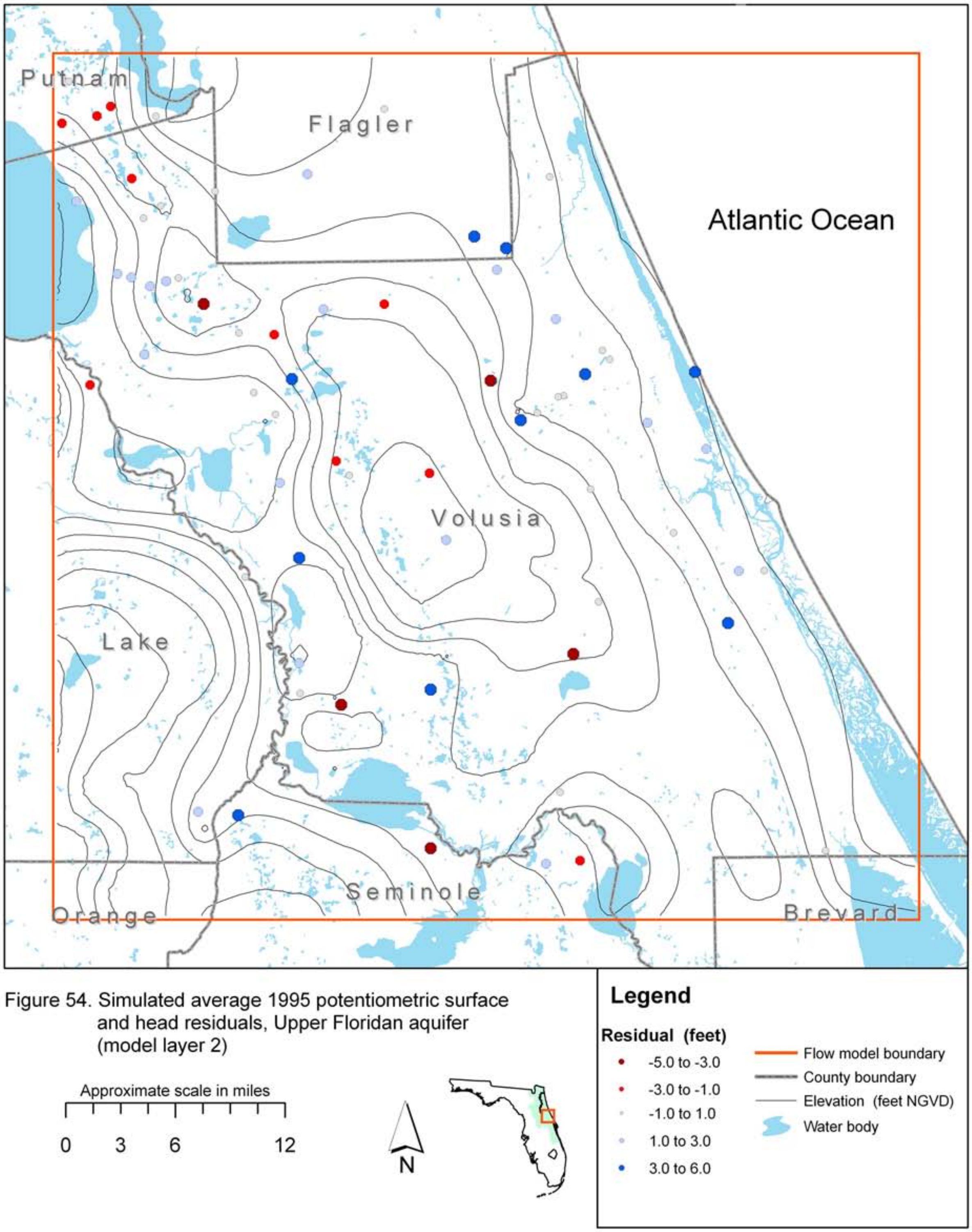


Figure 54. Simulated average 1995 potentiometric surface and head residuals, Upper Floridan aquifer (model layer 2)

Figure 55. Simulated average 1995 potentiometric surface and head residuals, Lower Floridan aquifer

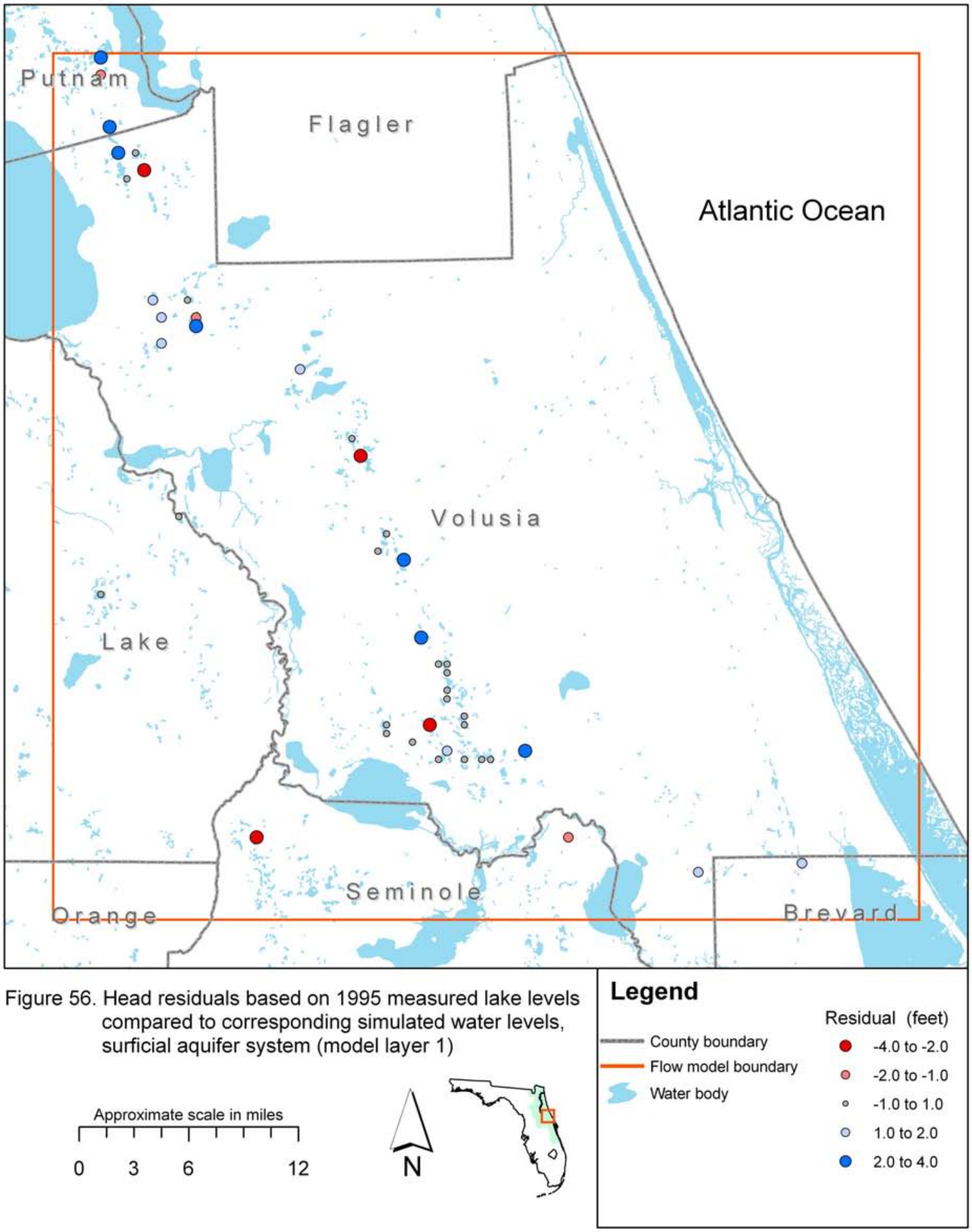


Figure 56. Head residuals based on 1995 measured lake levels compared to corresponding simulated water levels, surficial aquifer system (model layer 1)

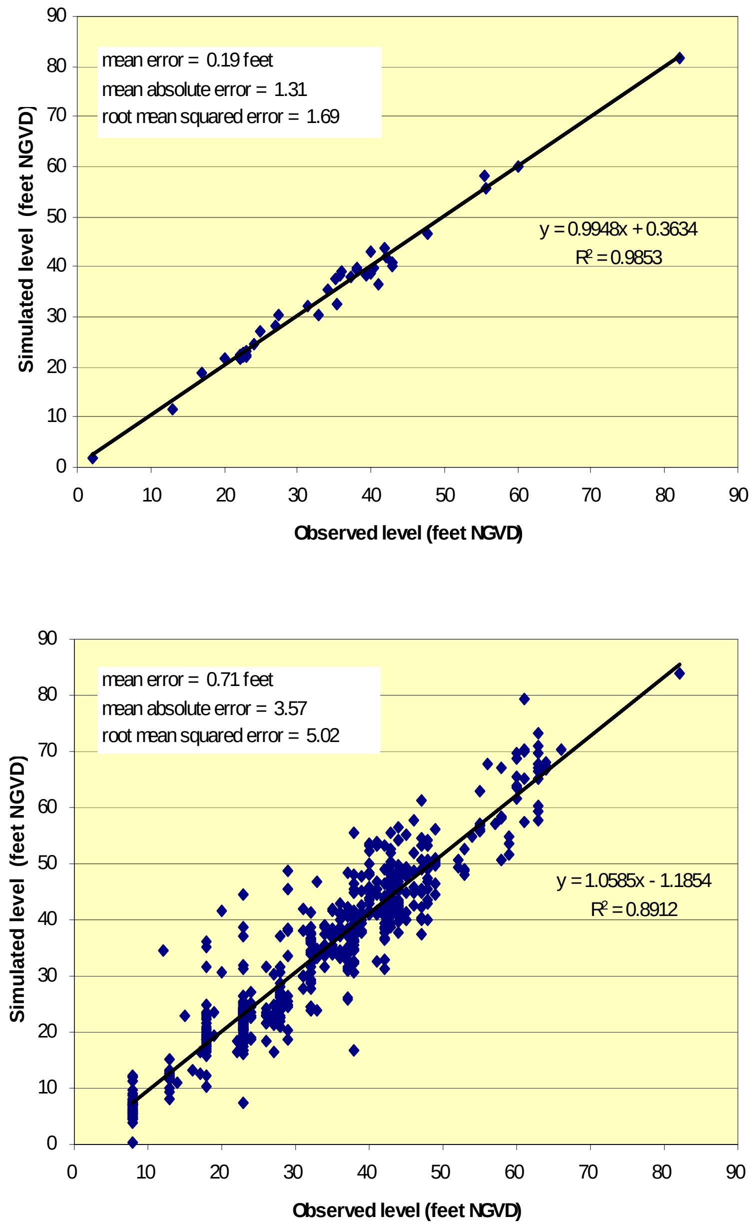


Figure 57. Trend lines of simulated and observed water levels for (A) lakes with stage data for 1995 and (B) lakes with elevations posted on the U.S. Geological Survey maps

An additional calibration criterion applied to the simulation of the surficial aquifer system entailed comparison of simulated water levels to lake elevations posted on 1:24,000-scale USGS topographic maps. Initially, water levels for over 1,000 lakes were tabulated from the most recent USGS survey or photo-revision of corresponding topographic maps. This set of lakes was reviewed for quality assurance in order to remove small lakes in areas of high topographic relief or lakes where lake levels may be much higher or lower than surrounding topographic elevations, resulting in a final set of 658 lakes for comparison with simulated water levels (Figure 58). The comparison of these lake levels to corresponding simulated water levels facilitated additional refinement of the leakance distribution of the intermediate confining unit and improved simulation of surficial aquifer system water levels. The results of this comparison indicate a good fit between observed lake levels and the simulated water Table elevation with a coefficient of determination of 0.84 (Figure 57). There is some spatial bias in this set of head residuals, with most of the relatively high residuals (i.e., >10 ft) occurring in southwest Volusia and northwest Seminole counties. These are areas that are characterized by significant karst geomorphology and significant topographic relief where lake areas may correspond to only a small part of the area represented by a model cell.

Measured or estimated average 1995 spring flows match simulated flows within ±10% for all first- and second-magnitude springs (Table 10). The methodology for calibration of spring flows entailed minor adjustments to spring conductance terms and trial-and-error adjustments to the horizontal hydraulic conductivity of the Upper Floridan aquifer within the approximated areas of the spring basins. Spring conductance values were initially set within predetermined ranges (Table 6) and subsequently adjusted within these ranges to achieve final calibration. Simulation of flow to springs was highly sensitive to the distribution of horizontal hydraulic conductivity of the Upper Floridan aquifer. The total average simulated spring flow for 1995 of 308.6 cfs corresponds well with the total average 1995 measured spring flow of 312.5 cfs (Table 10).

Average 1995 streamflows (defined as simulated baseflow + computed overland runoff), were compared to average measured flow for all gaged surface water sites within the study area. The calibration criterion required that model-based and measured streamflows match within ±20%. This criterion has a greater margin of error relative to that for 1995 spring flows because the groundwater model is primarily designed to address

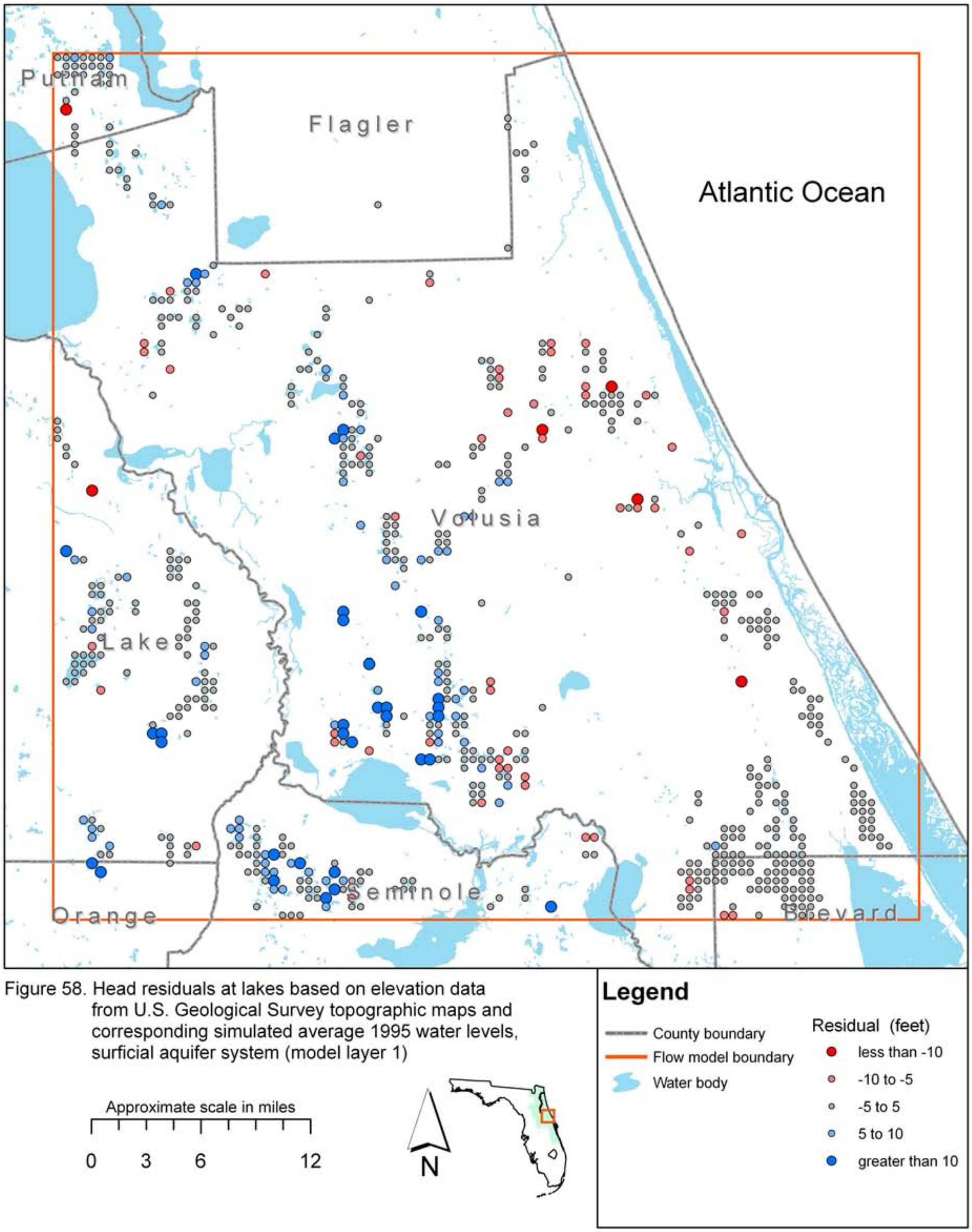


Figure 58. Head residuals at lakes based on elevation data from U.S. Geological Survey topographic maps and corresponding simulated average 1995 water levels, surficial aquifer system (model layer 1)

Table 10. Measured and simulated spring flows, predevelopment and average 1995 calibrations

Spring*	Row	Col	Estimated Predev Flow (cfs)†	Simulated Predev Flow (cfs)	Percent Difference (sim – est)	Measured Average 1995 Flow (cfs)†	Simulated Average 1995 (cfs)	Percent Difference (sim – est)	Simulated Percent Change (1995 – predev)
Blue	70	29	160	164	2.5	150.4	149.3	–0.2	–8.5
Rock	98	9	70	70	0.0	61.4	59.1	–3.7	–15.6
Seminole	85	6	40	42	5.0	38.9	36.7	–5.7	–12.6
Ponce de Leon	43	25	31	29	–6.5	26.5	26.1	–0.4	–9.0
Messant	84	9	20	18	–10.0	16.4	16.8	2.4	–6.7
Gemini	83	33	10	9	–10.0	8.1	7.8	0.0	–10.0
Island	88	19	10	9	–10.0	6.4	6.7	3.1	–26.7
Green	83	41	1	2	100.0	1.9	1.7	0.0	–5.0
Camp La No Che	70	4	1	1	0.0	1.0	1.0	0.0	0.0
Sulphur	95	8	2	1	–50.0	0.8	1.1	37.5	10.0
Droty	88	7	1	1	0.0	0.7	0.8	14.3	–20.0
Total			345	345	0.0	312.5	307.1	–1.2	–10.6

Note: cfs = cubic feet per second
est = estimated
Predev = predevelopment
sim = simulated

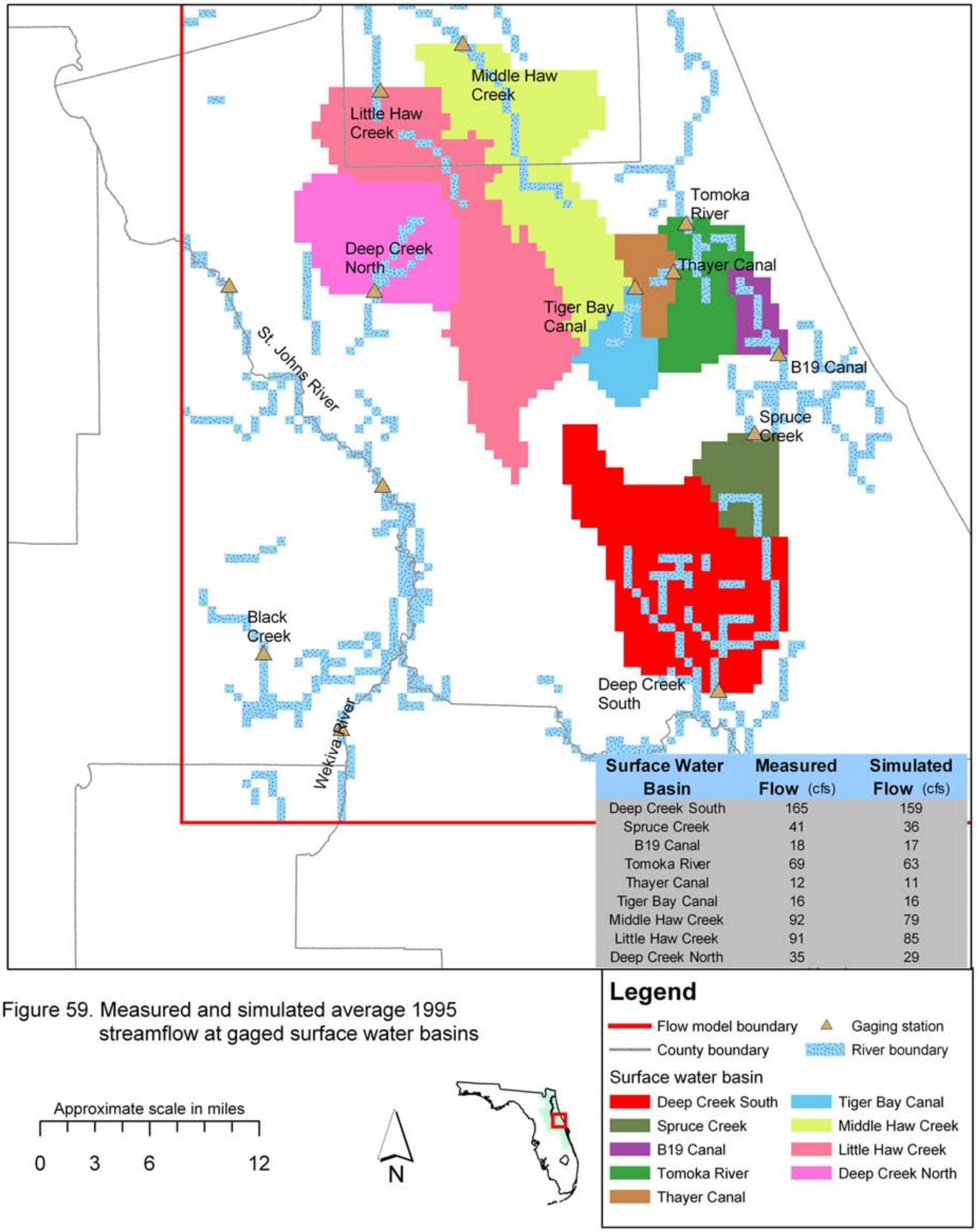
*Shading indicates first- and second-magnitude flows.

†Source: Murray and Halford 1996; USGS 1996, 1998; USGS and SJRWMD internal databases

subterranean hydrologic processes and therefore does not explicitly address the routing of overland runoff or groundwater interflow to rivers and streams. Stream basins were delineated based on previous work at SJRWMD and USGS (Adamus et al. 1997). Model results indicated excellent agreement between measured and simulated average annual flows for all surface water basins that are fully circumscribed within the project area (Figure 59).

A contour map of the average 1995 potentiometric surface for the Upper Floridan aquifer was constructed (Figure 20) based upon the USGS published potentiometric surfaces for May and September, 1995 (Figures 31 and 32). This contour coverage was compared to the corresponding average 1995 potentiometric surface simulated by the calibrated model (Figure 60). In general, the comparison is very good. However, the simulated average 1995 surface is lower than the observed surface in southwest Volusia County, the result of a hypothesized high transmissivity zone east of Blue Spring (see following section, “Calibrated aquifer and confining unit hydraulic characteristics”). The observed potentiometric surfaces for May and September 1995 (Figures 31 and 32) indicate an extension of the central Volusia potentiometric high into southwest Volusia County. Examination of previous potentiometric surfaces (Figures 50 and 51) and a review of groundwater flow zones at depth lend support to the existence of a high transmissivity zone in this area. An additional area of discrepancy is in north-central Volusia County where the potentiometric high illustrated in the predevelopment surface (Figure 19) is also depicted in the average 1995 surface (Figure 20), while the simulated surface is low in this area. The primary basis for this discrepancy is that the average 1995 rainfall for this area, used as input into the recharge algorithm was markedly lower than the regional average, contributing to the relatively low elevation of the simulated potentiometric surface. Similarly, simulated average 1995 potentiometric surface does not indicate the decline in potentiometric levels in the coastal vicinity that is exhibited in the observed surface. A possible explanation for this discrepancy is under-estimation of overland runoff (i.e., insufficiently accounting for the influence of urban development) resulting in relatively high simulated water levels for both the surficial aquifer system and the Upper Floridan aquifer.

Model-derived ET for 1995 is equivalent to simulated saturated zone ET plus calculated ET_{UNSAT} and is in good agreement with values determined in previous investigations (Figure 61, Table 1). The distribution of ET approaches the lower limit of 27 in/yr in the upland ridges and approaches



Surface Water Basin	Measured Flow (cfs)	Simulated Flow (cfs)
Deep Creek South	165	159
Spruce Creek	41	36
B19 Canal	18	17
Tomoka River	69	63
Thayer Canal	12	11
Tiger Bay Canal	16	16
Middle Haw Creek	92	79
Little Haw Creek	91	85
Deep Creek North	35	29

Figure 59. Measured and simulated average 1995 streamflow at gaged surface water basins

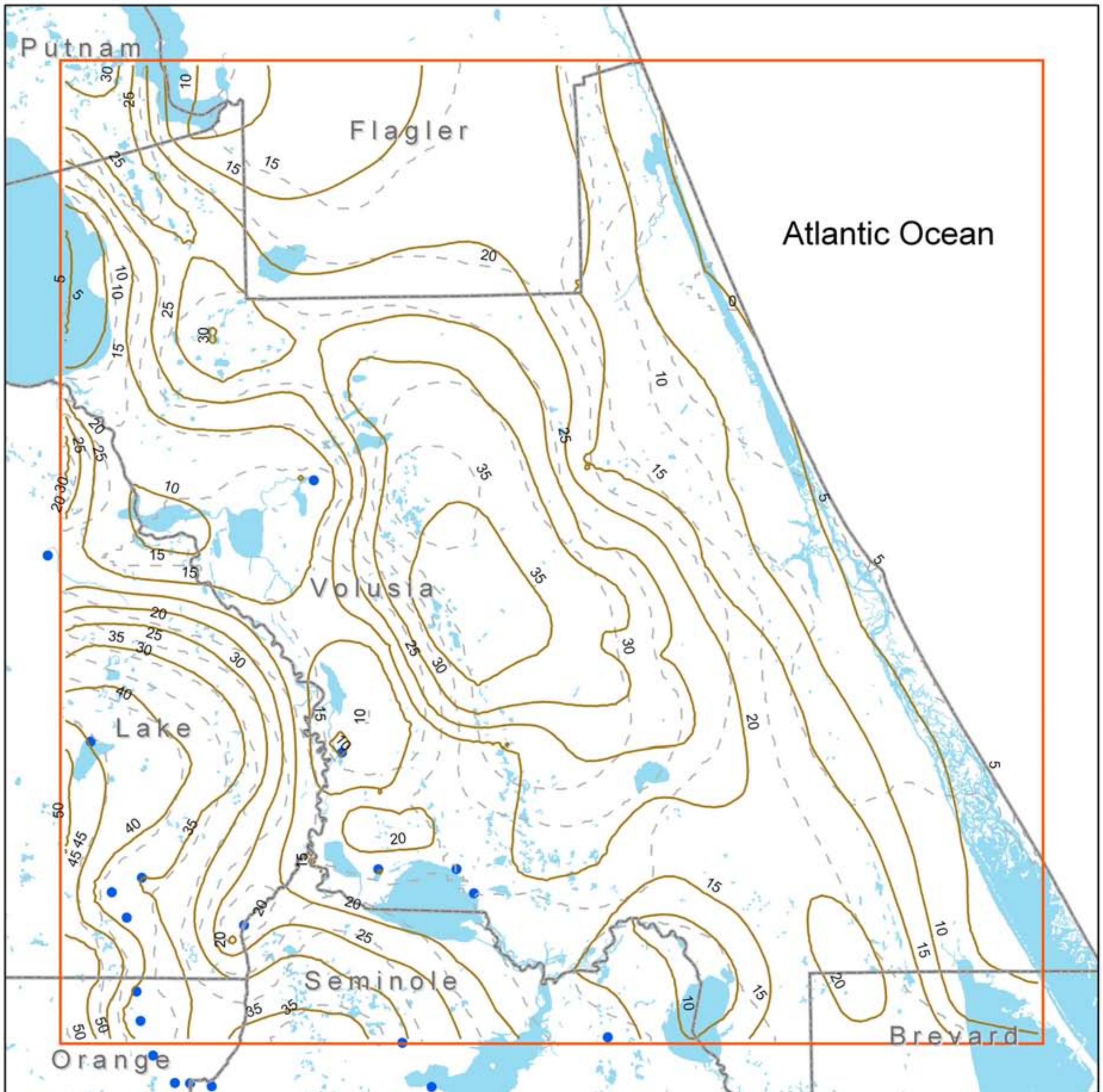
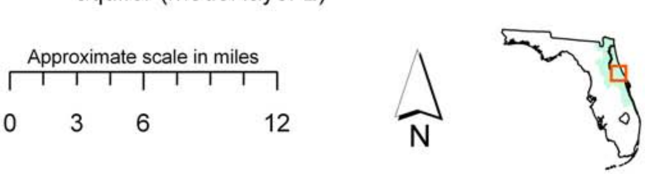
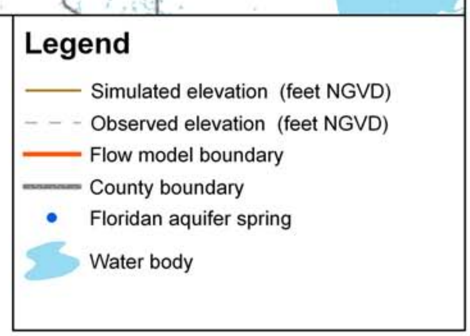


Figure 60. Simulated and estimated average 1995 potentiometric surfaces, Upper Floridan aquifer (model layer 2)





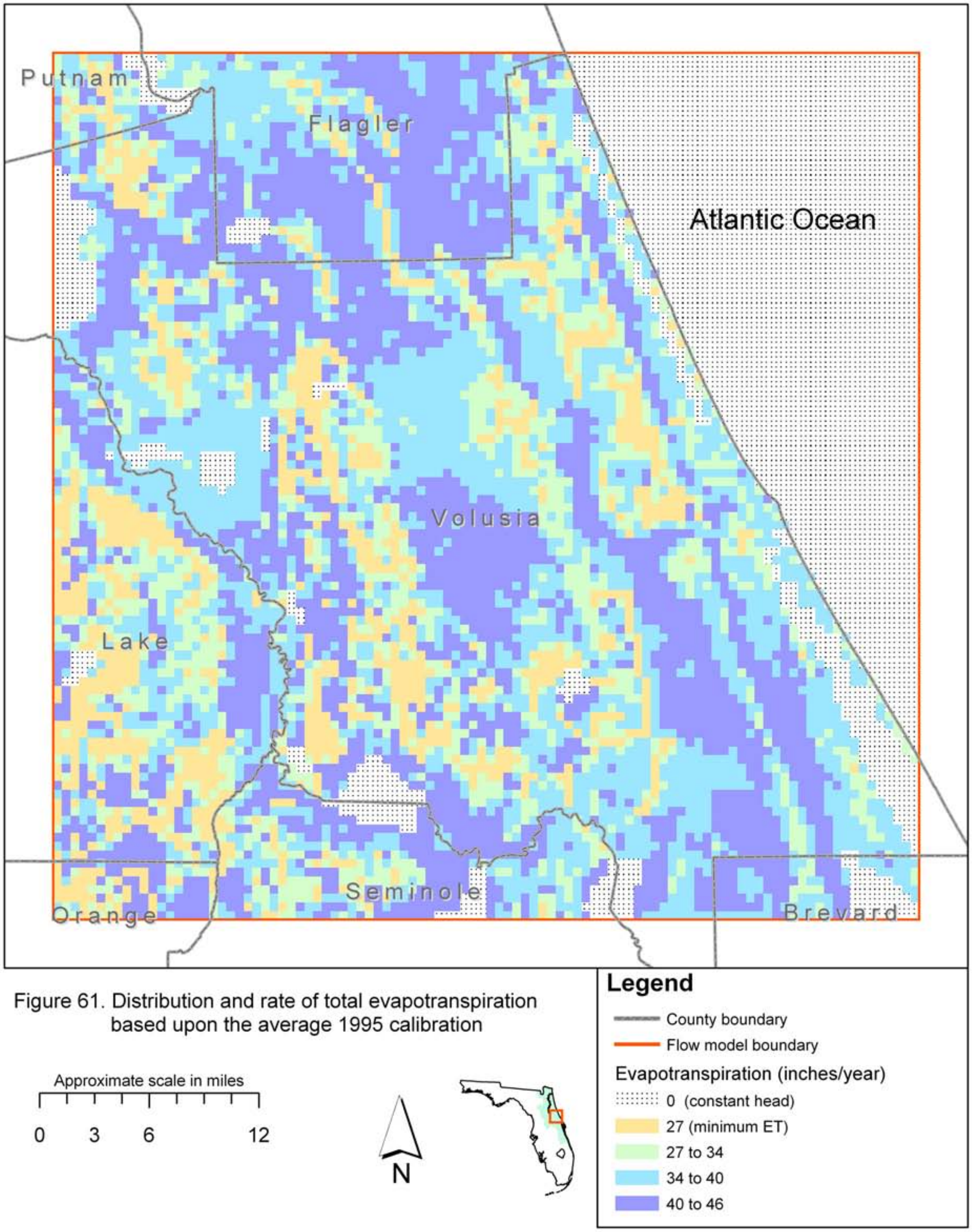


Figure 61. Distribution and rate of total evapotranspiration based upon the average 1995 calibration

the maximum value of 46 in / yr in the low-lying terraces. Simulated ET rates also approach the maximum potential ET in those areas where naturally occurring ET is augmented by ET that is attribuTable to the application of agricultural and landscape irrigation and water reuse. An association appears to exist between simulated ET rates and the distribution of average 1995 rainfall (Figure 33), with areas of relatively higher or lower rainfall corresponding to areas of higher and lower ET. This relationship is reasonable, as previous research (Sumner 1996) indicates that rainfall is one variable that may affect ET rates.

The distribution of net recharge to the surficial aquifer system (Figure 62) corresponds well with estimates from previous investigations (Table 1). However, this distribution also indicates zones of very high recharge in northwest, west-central, and southwest Volusia County and in areas of eastern Lake and northwest Seminole counties. These high recharge areas generally correspond with closed basins that are characterized by karst geomorphology and little significant overland runoff. The net recharge to the surficial aquifer system in these areas is equivalent to rainfall minus ET_{MIN}. Also, recharge during 1995 is relatively high in southwest Volusia County due to rainfall rates that were higher than those in the surrounding area. For the eastern ridges, net recharge rates fall within the ranges of 4–8 and 8–16 in / yr, in good agreement with published results (Phelps 1990). For the lower terraces (Figure 6), simulated recharge rates are within the published range of 4–9 in / yr (Phelps 1990; Rutledge 1985) (Table 1), with relatively low rates simulated in north-central Volusia County and high rates in south-central Volusia County. Finally, model simulation results for net recharge to the surficial aquifer system are in agreement with previous estimates of 0–4 in / yr in areas of artesian flow in the St. Johns River valley (Table 1).

The simulated recharge / discharge distribution to / from the Upper Floridan aquifer (Figure 63) corresponds with results published by Boniol et al. (1993) (Figure 21). The work of Boniol et al. 1993 described the correlation between the land surface elevation and the water Table in conjunction with a generalized estimate for the vertical hydraulic conductivity of the intermediate confining unit to estimate recharge to the Upper Floridan aquifer. The findings from the current study are comparable with those from Boniol et al. 1993, with the exception that relatively high recharge is simulated to the Upper Floridan aquifer in the karst areas of southwest and northwest Volusia County and northwest Seminole County. In some locations, simulated recharge is over 32 in / yr, caused by the combined effect

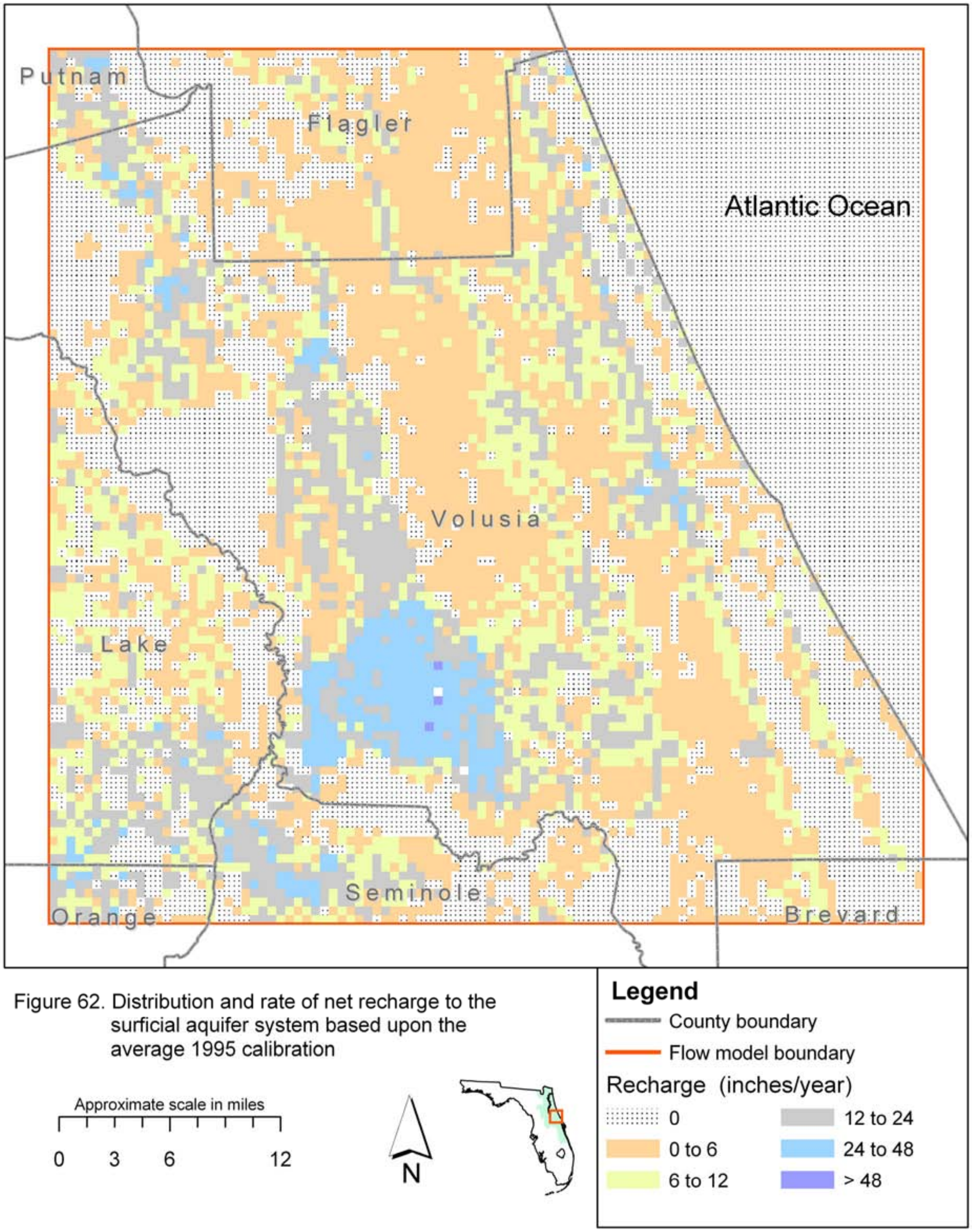


Figure 62. Distribution and rate of net recharge to the surficial aquifer system based upon the average 1995 calibration

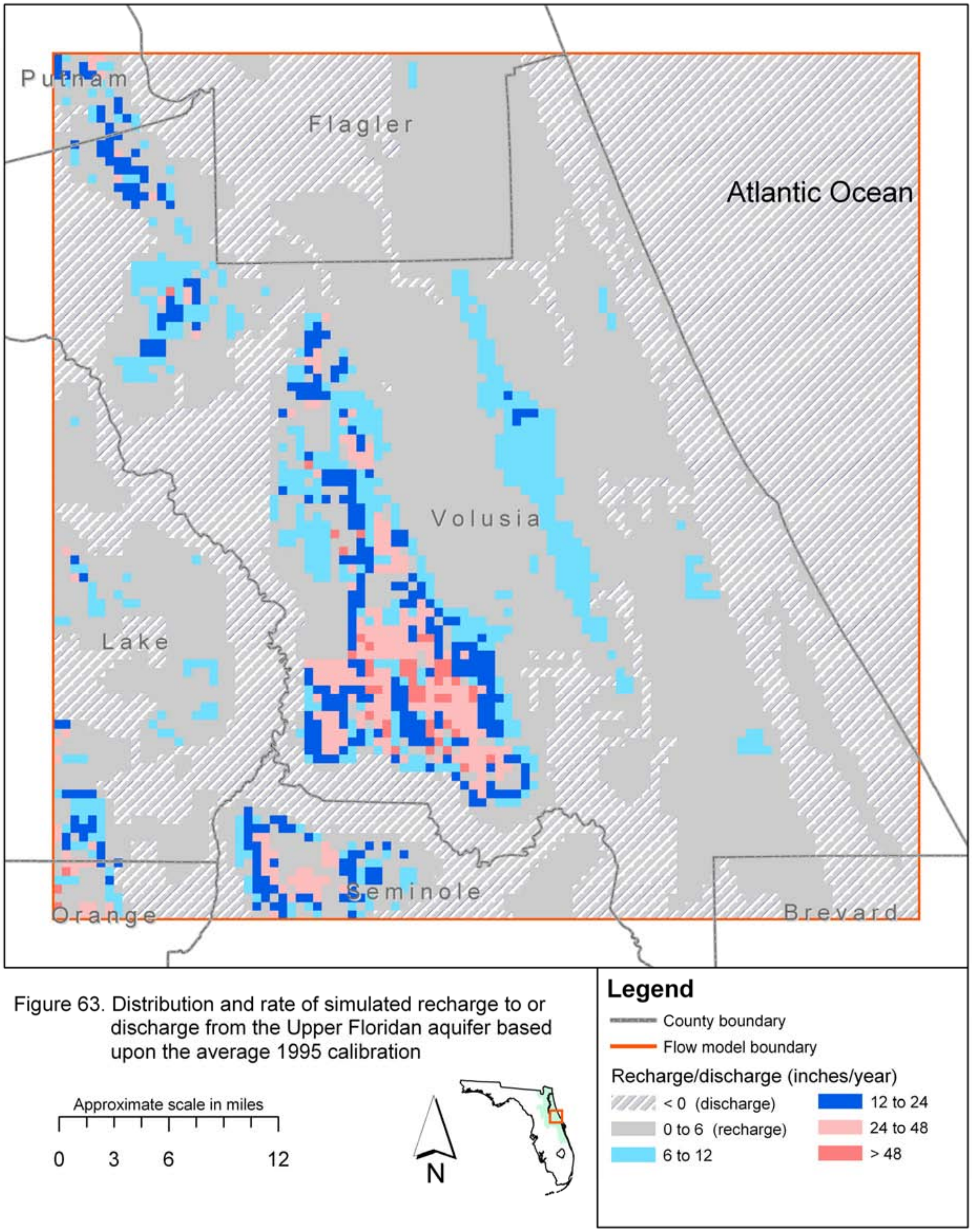


Figure 63. Distribution and rate of simulated recharge to or discharge from the Upper Floridan aquifer based upon the average 1995 calibration

of large vertical hydraulic gradients and relatively high leakance values calibrated in the intermediate confining unit in the vicinity of sinkhole lakes and depressions. The large vertical gradients are due to the combined effects of water Table elevations that tend to mimic high topographic elevations and the relatively low elevations of the potentiometric surface of the underlying Upper Floridan aquifer.

CALIBRATED AQUIFER AND CONFINING UNIT HYDRAULIC CHARACTERISTICS

Adjustments to initially assigned aquifer and confining unit hydraulic characteristics are fundamental to the model calibration process. Aquifer transmissivities and hydraulic conductivities are critical determinants of groundwater flow patterns and corresponding potentiometric levels within an aquifer. The spatial distribution of leakance of confining units determines the degree of interconnection between vertically adjacent aquifers.

Surficial Aquifer Hydraulic Conductivity

The calibrated horizontal hydraulic conductivity (K_h) of the surficial aquifer system was assigned to be a spatially uniform value of 20 ft/d. Field measurements of K_h (Table 2) indicate values that range from less than 1 to 110 ft/d. Review of these data did not reveal a discernable variability in K_h that might justify linkage with related systemic variables such as topography, location, or soil type. The spatially uniform value of 20 ft/d is within the range of reported values (Table 2) and is consistent with values used in previous groundwater model investigations (Mercer et al. 1984; Geraghty and Miller 1991, Williams 1997).

Intermediate Confining Unit Leakance

The leakance of the intermediate confining unit, equivalent to the vertical hydraulic conductivity of the unit divided by its thickness, is a quantitative measure of the hydraulic connection between the surficial aquifer system and the Upper Floridan aquifer. Initial estimates of vertical hydraulic conductivity (K_v) of the confining unit were developed from results of aquifer tests and estimates from previous model calibrations. A relatively low value for K_v of the confining unit was applicable in areas with little karst development and where lithologic logs indicate relatively low permeability. Higher values of K_v were applicable in areas with karst features and where lithologic logs indicate sediments such as sand and shell lenses with moderate permeability. The values of K_v were modified during model calibration based upon the head difference between observed and simulated water levels in the surficial and Upper Floridan aquifers at several locations. For implementation within the groundwater model, the calibrated cell-by-cell array for K_v (Figure 64) was divided by the corresponding cell-by-cell thickness of the confining unit (Figure 10) to arrive at corresponding leakance values (Figure 65).

The calibrated leakance of the intermediate confining unit varies between 1×10^{-5} and 6.4×10^{-3} day^{-1} (Figure 65). Leakance values are relatively uniform throughout the low-lying terraces in eastern and central Volusia County and in the St. Johns River valley. In contrast, leakance values are highly variable in areas with significant topographic relief and karst development such as the DeLand and Crescent City ridges in western Volusia County and portions of northeast Seminole and east Lake counties. In order to bring the leakancy distribution into calibration particular emphasis was given to locations with nested monitor wells and to lakes with measurement data. Also, simulated recharge rates for the Upper Floridan aquifer were compared to those from previous investigations as a cross-check for the distribution of leakance.

Upper Floridan Aquifer Transmissivity

Aquifer transmissivity is equivalent to the horizontal hydraulic conductivity of the aquifer multiplied by its thickness. Aquifer thickness was determined from hydrostratigraphic elevations of the top and the base of the Upper Floridan aquifer and modified to account for the revision of the aquifer base to the elevation of the 5,000-ppm chloride isochlor. Initial estimates of Upper Floridan aquifer K_h were derived from estimates of transmissivity computed from aquifer test results (Figure 18). Findings from aquifer tests were limited to those characterized by relatively long durations, moderate to high pumping rates, and adjacent observation wells. This set of aquifer test findings was used as an initial estimate of the K_h of the Upper Floridan aquifer. The final calibrated distribution of K_h was developed based upon aquifer test results, review of maps of the Upper Floridan aquifer potentiometric surface, and application of the calibration guidelines and criteria that pertain to spring flow, potentiometric levels, and the recharge/discharge distribution to/from the Upper Floridan aquifer (Tables 8 and 9).

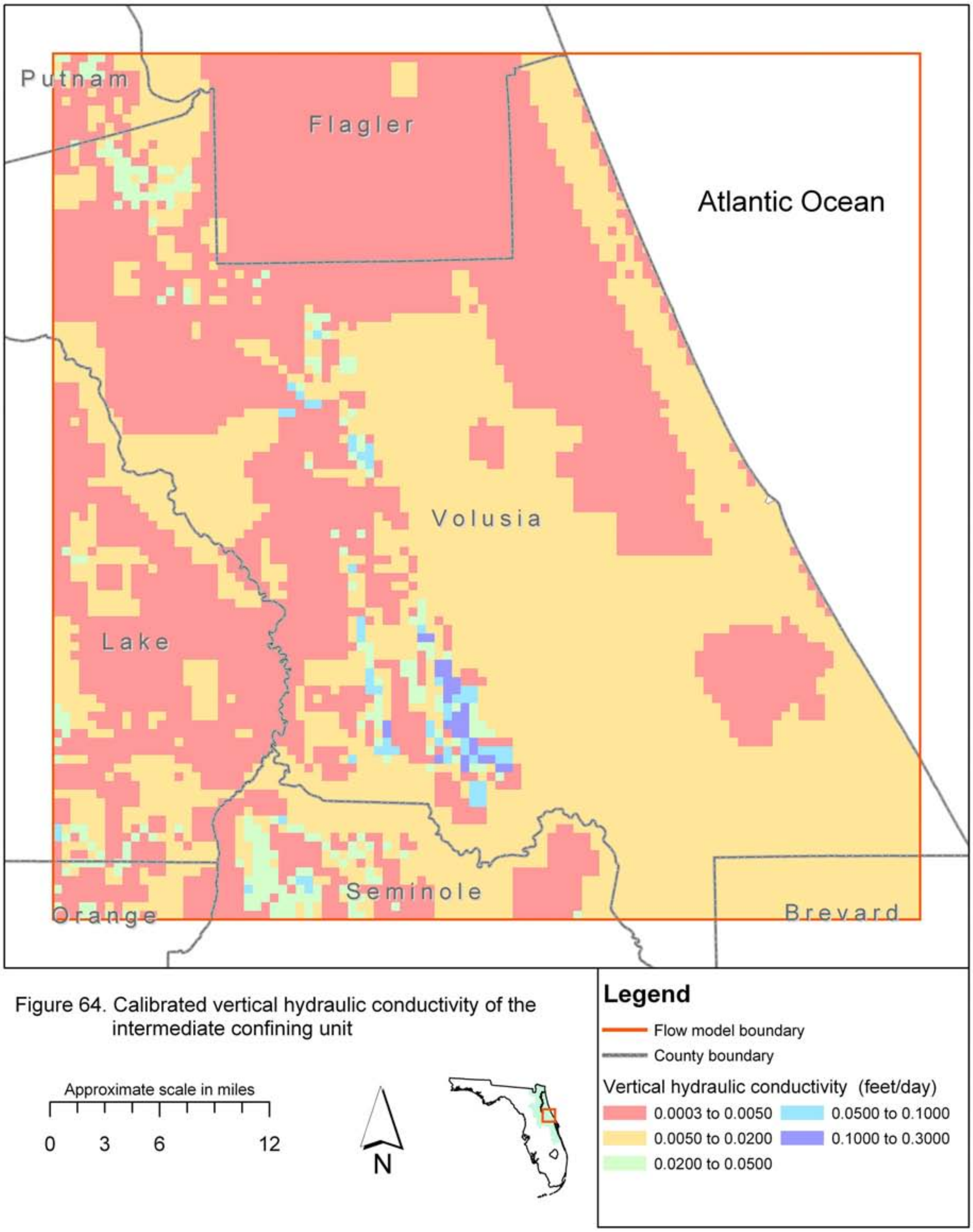


Figure 64. Calibrated vertical hydraulic conductivity of the intermediate confining unit

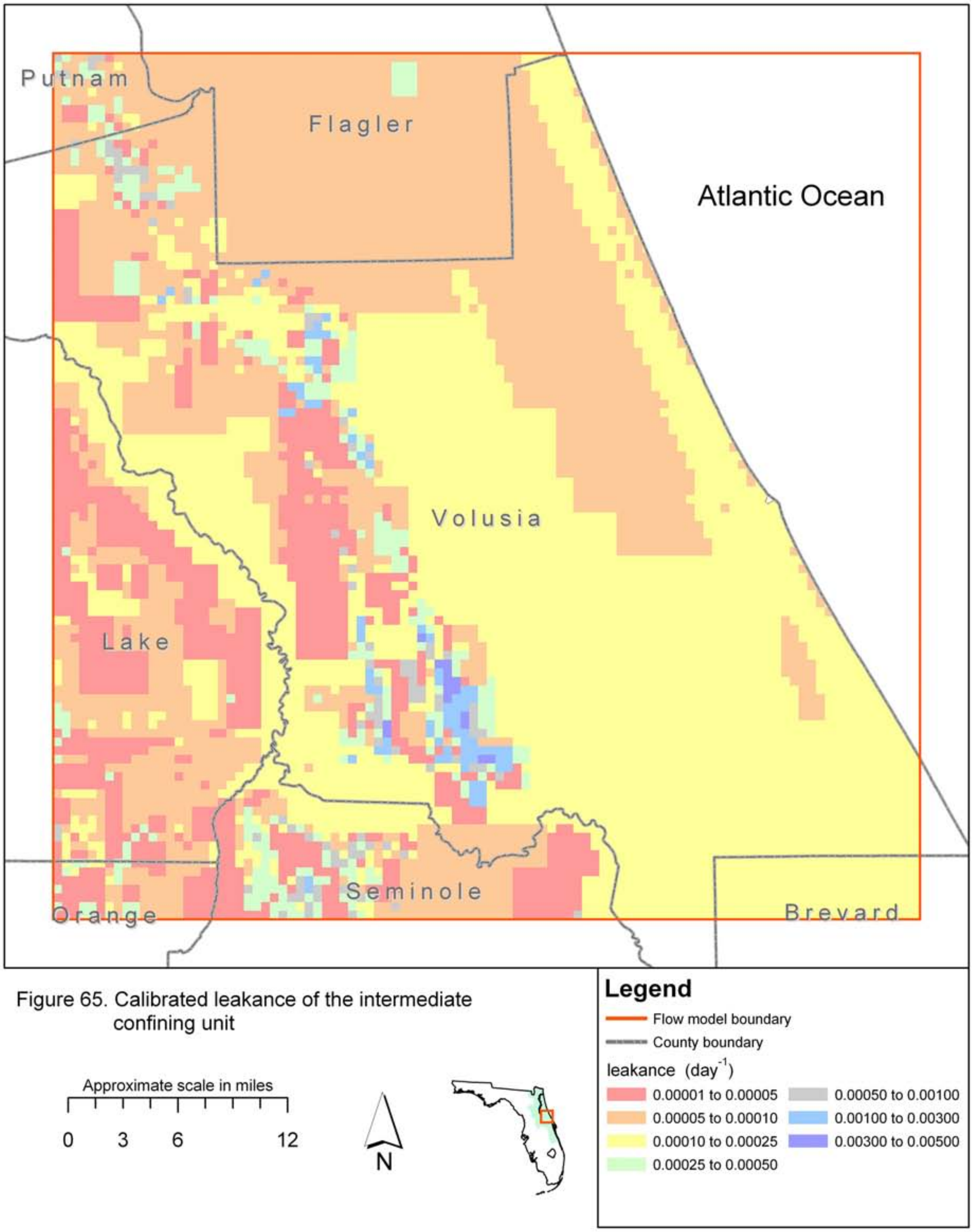


Figure 65. Calibrated leakance of the intermediate confining unit

Refinement of a spatial distribution of K_h for the Upper Floridan aquifer was focused upon comparison of simulated results with observed potentiometric levels and springflow data. The calibrated distribution of K_h for the Upper Floridan aquifer (Figure 66) covers a range of values from 25 ft/d in north-central and northwest Volusia County to 6,400 ft/d in the area east and southeast of Blue Spring in southwest Volusia County. This distribution was combined with the modified thickness of the Upper Floridan aquifer (Figure 45) to develop a spatial distribution of calibrated transmissivity (Figure 67). In general, areas of low transmissivity correspond with areas characterized by high potentiometric levels and relatively high horizontal flow gradients, and areas of high transmissivity correspond to low potentiometric levels and relatively low horizontal flow gradients. Calibrated transmissivities range from a low of 8,000 ft^2/d in west-central Volusia County to more than 1×10^6 ft^2/d in the vicinity of Blue Spring. This calibrated distribution is in general agreement with the results of aquifer tests (Figure 18). Zones of relatively low transmissivity in central Volusia County and in the Crescent City Ridge area correspond to persistent highs in the elevation of the potentiometric surface (Figures 19, 20, 31, and 32). Some areas of high transmissivity (i.e., greater than 1×10^5 ft^2/d) occur in southwest Volusia County, northern Seminole County, portions of eastern Lake County, and in the vicinity of Daytona Beach. An area where the calibrated transmissivity is substantially greater than measured values is southeast of Blue Spring in Volusia County. During model calibration, a review of maps of the potentiometric surface indicated a low trough that is persistent through time and that extends throughout southwest Volusia County. The illustration of this low area on individual USGS potentiometric surface maps is dependent upon the particular set of monitor wells used to generate the maps. This depressed area is evident in the surfaces depicted for May 1980 and May 1987 (Figures 50 and 51) while it is not evident for May or September 1995 (Figures 31 and 32). Water levels in the Upper Floridan aquifer at a well cluster near Galaxy Middle School in Deltona (i.e., located within this depressed area) are persistently several feet lower than those measured in the underlying Lower Floridan aquifer. Southwest Volusia County is an area with surface features that are indicative of an underlying complex karst geomorphology. These surface features include high topographic relief (Figure 6) and a network of sinkhole lakes formed through long-term erosion and/or dissolution of karst features. Such features provide an indication of an underlying complex system of low permeability zones interspersed with fractures or karst features of very high permeability. Geophysical logs indicate the existence of a network of high permeability

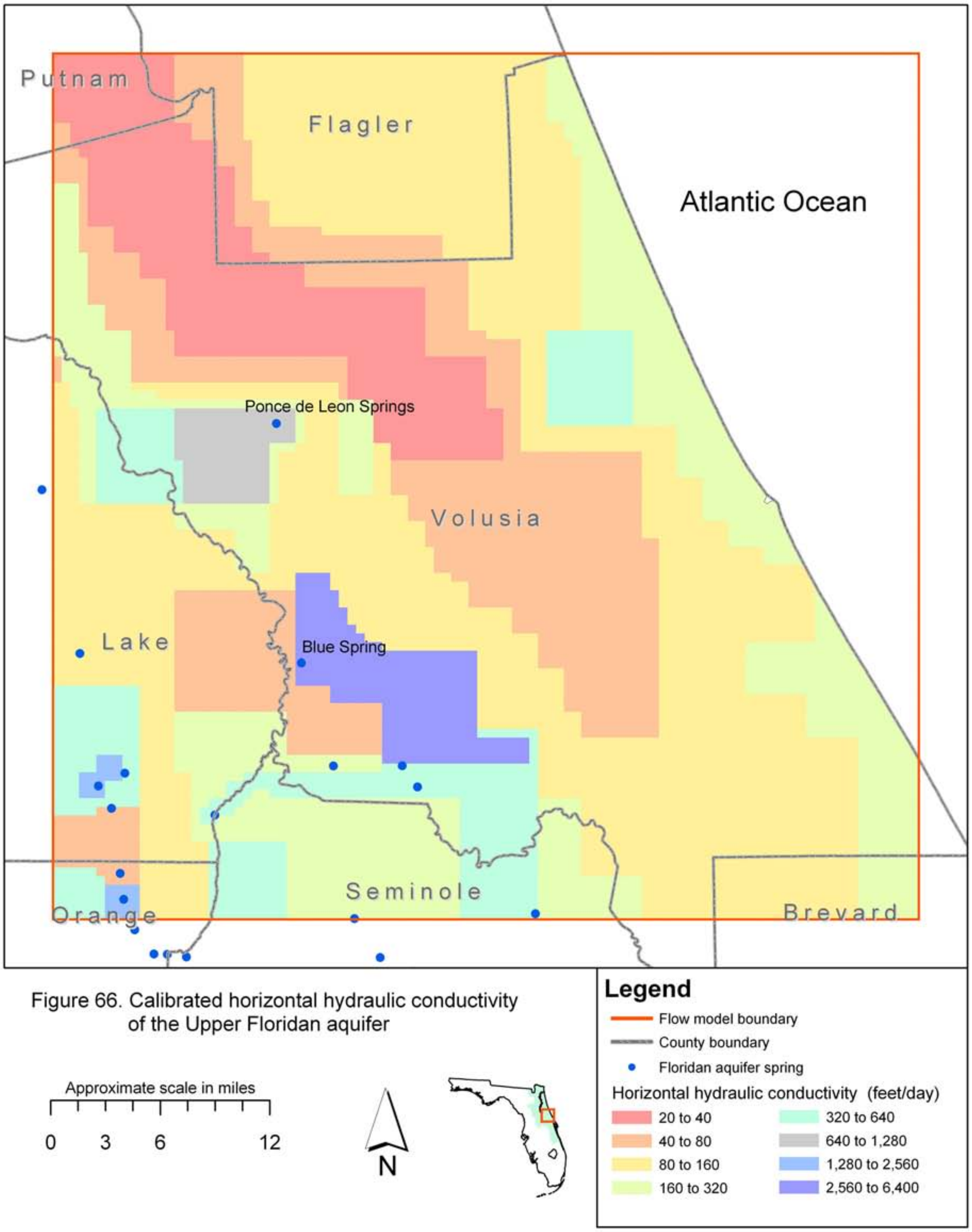


Figure 66. Calibrated horizontal hydraulic conductivity of the Upper Floridan aquifer

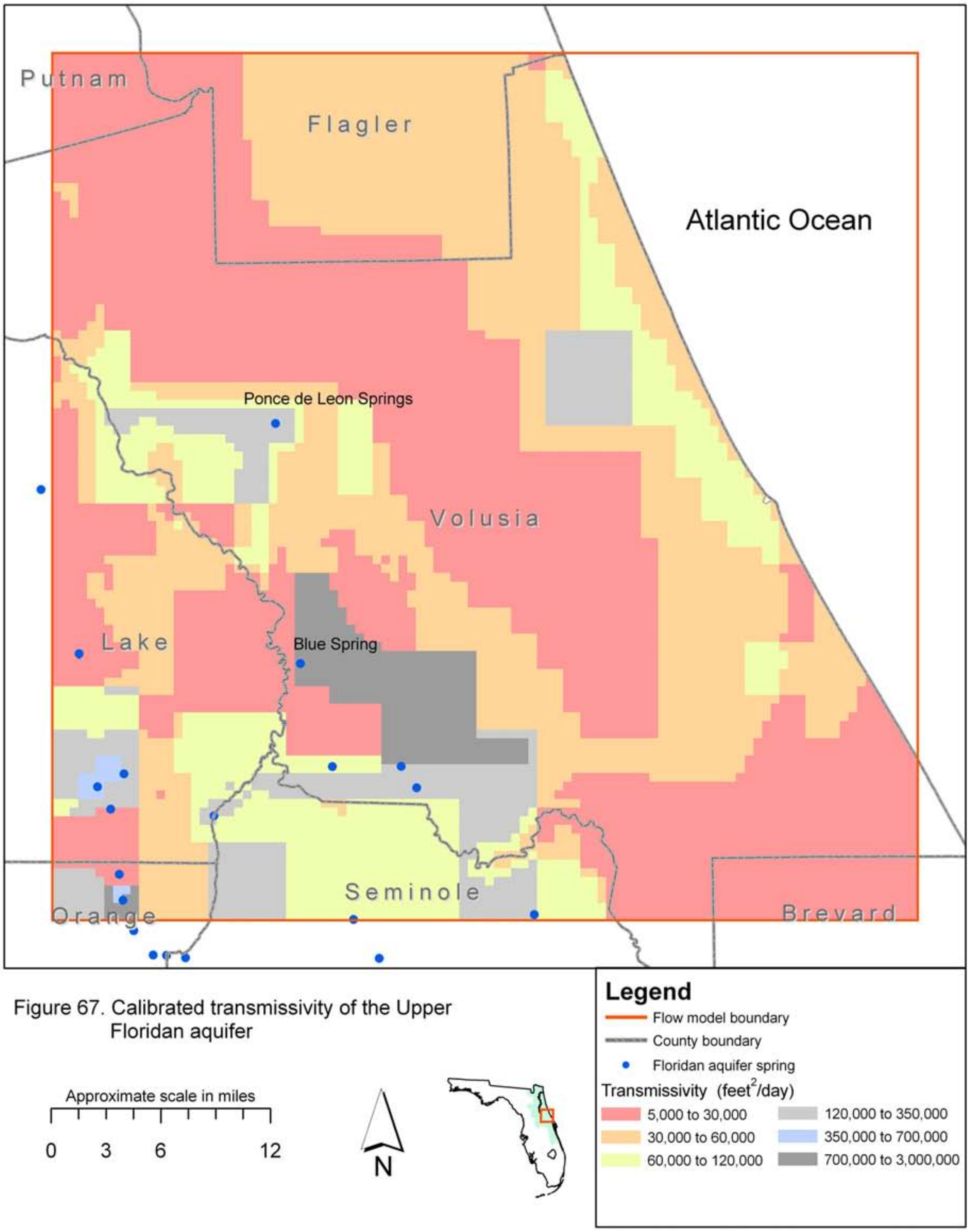


Figure 67. Calibrated transmissivity of the Upper Floridan aquifer

zones at depth within the Upper Floridan aquifer in this region. Such flow zones are characterized by high transmissivity (Figure 67) but are often not corroborated by aquifer test analyses (Figure 18). Results of aquifer tests typically represent hydraulic characteristics of the upper part of the Upper Floridan aquifer. In summary, the existence of this high transmissivity zone is hypothesized based upon examination of local potentiometric levels and borehole geophysics data.

Middle Semiconfining Unit Leakance

The middle semiconfining unit is simulated as a non-uniform distribution of leakance terms that were initially derived from previous modeling investigations and modified during model calibration. K_v values for the middle semiconfining unit estimated from aquifer tests range from 0.005 to 1.0 ft/d (McGurk and Presley 2002). When combined with the range of thickness of the middle semiconfining unit (Figure 14), the estimated leakance range is between 1.2×10^{-5} day^{-1} and 5.5×10^{-3} day^{-1}. The final calibrated leakance array for the middle semiconfining unit was developed from this initial estimated range and hydraulic gradients exhibited by head measurements for the Upper and Lower Floridan aquifers (Figure 68). The area of highest calibrated leakance for the middle semiconfining unit is in the vicinity of Blue Spring. Tibbals 1990 presented profiles for water quality and hydraulic head from a test well that is about 0.3 mile southwest of Blue Spring. These profiles indicate an upward hydraulic head gradient characterized by a head difference of approximately 4 ft from a depth of 400 ft below land surface to the top of the Upper Floridan aquifer and chloride values increasing dramatically below depths of 300–400 ft below land surface. He suggested that the slightly brackish character of water flowing at Blue Spring is due to an undetermined amount of water flowing up from lower portions of the Floridan aquifer system. These findings were corroborated with a particle tracking procedure using MODPATH (Pollock 1994) that indicated relatively small percentages of flow moving toward Blue Spring laterally from the west and upward from the Lower Floridan aquifer (Shoemaker et al. 2003). Findings of these studies corroborate the relatively high leakance values for the middle semiconfining unit in the vicinity of Blue Spring.

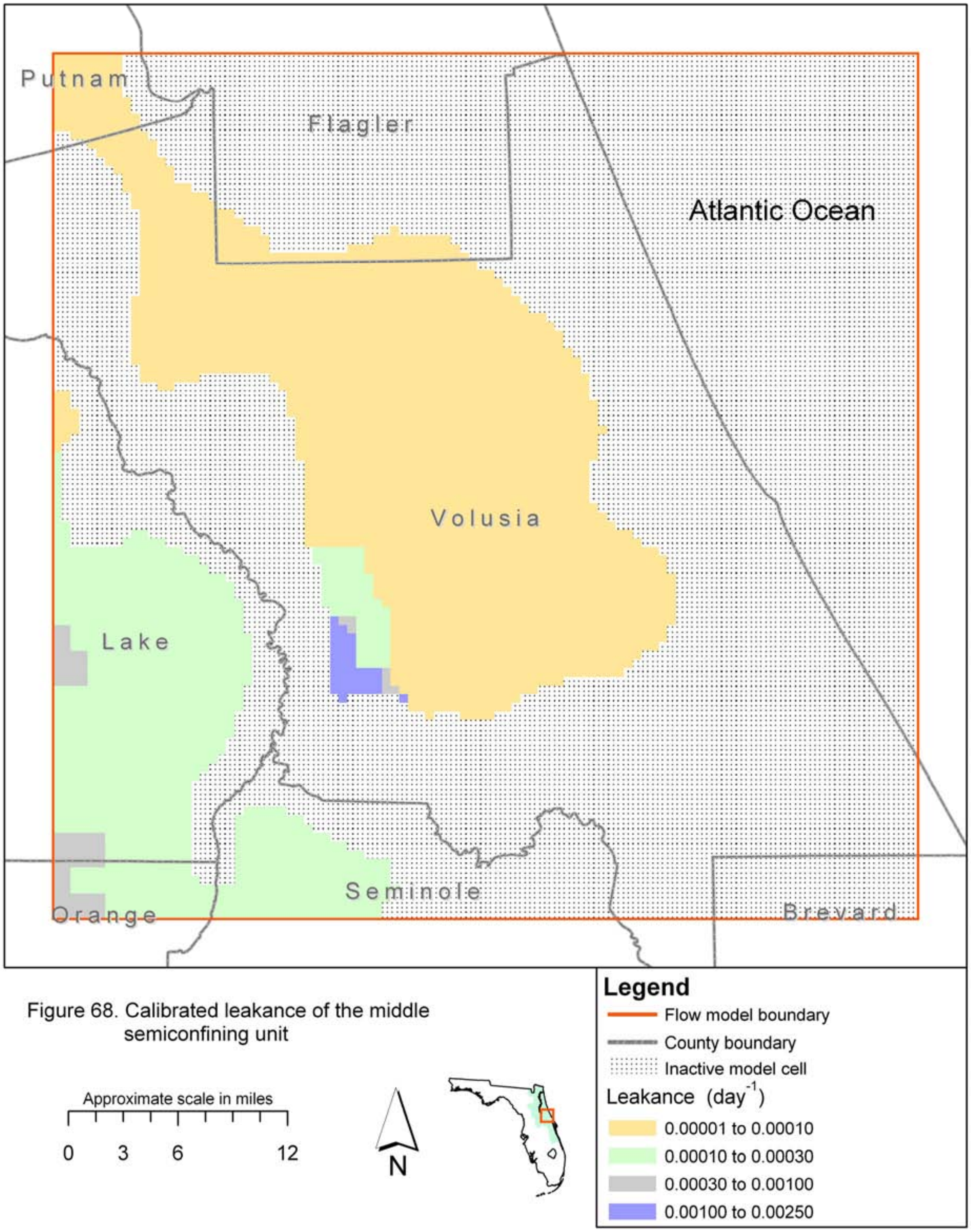


Figure 68. Calibrated leakance of the middle semiconfining unit

Lower Floridan Aquifer Transmissivity

Calibration of the transmissivity of the Lower Floridan aquifer was based upon modification of the distribution of horizontal hydraulic conductivity, with initial estimates derived from previous modeling efforts (Tibbals 1990; Mercer et al. 1984; Geraghty and Miller 1991, Williams 1997). Calibration adjustments were performed based upon observed potentiometric levels and results from a limited number of specific capacity tests performed in central Volusia County. The calibrated distribution of transmissivity in the Lower Floridan aquifer indicates relatively low values east of the St. Johns River and a trend of increasing transmissivity toward the southwest (Figure 69). These trends are a function of both aquifer thickness and assigned horizontal hydraulic conductivity. The Lower Floridan aquifer is treated as inactive over much of the model domain due to adjustments to the elevation of the aquifer base upward to correspond with the estimated elevation of the 5,000-ppm chloride isochlor (Figure 23).

WATER BUDGET SUMMARY

Simulated water budgets derived from the predevelopment and average 1995 calibrations (Table 11) indicate that the primary input to the hydrogeologic system is recharge from precipitation and the primary output is ET. For the 1995 calibration, the outflow to wells of 190 cfs is offset by combined increased inflows of 53 cfs as recharge and flow across lateral boundaries, combined decreased outflows of 170 cfs to constant heads, springs, and ET, and increased outflows to rivers and lateral GHB conditions (Table 11). When linearized over the model domain, total pumping is equivalent to 1.15 in / yr and is offset by increases in recharge of 0.10 in / yr and lateral boundary inflows of 0.21 in / yr, decreased outflow to constant heads, springs, and ET of 0.11, 0.23, and 0.69 in / yr, respectively, and increased flows to rivers (0.01 in / yr) and to lateral boundaries (0.19 in / yr).

The primary sources of water inflow to the surficial aquifer system for the predevelopment calibration are recharge (1,952 cfs) and upward leakage from the Upper Floridan aquifer of 225 cfs, with minor contributions from river leakage and lateral head boundaries. The primary predevelopment outflow from the surficial aquifer system is to ET (1,380 cfs), with lesser flows to downward leakage to the Upper Floridan aquifer (439 cfs), river discharge (247 cfs), discharge to constant head boundaries (112 cfs), and discharge to lateral GHBs (Table 12, Figure 70). The primary inflows to the Upper Floridan

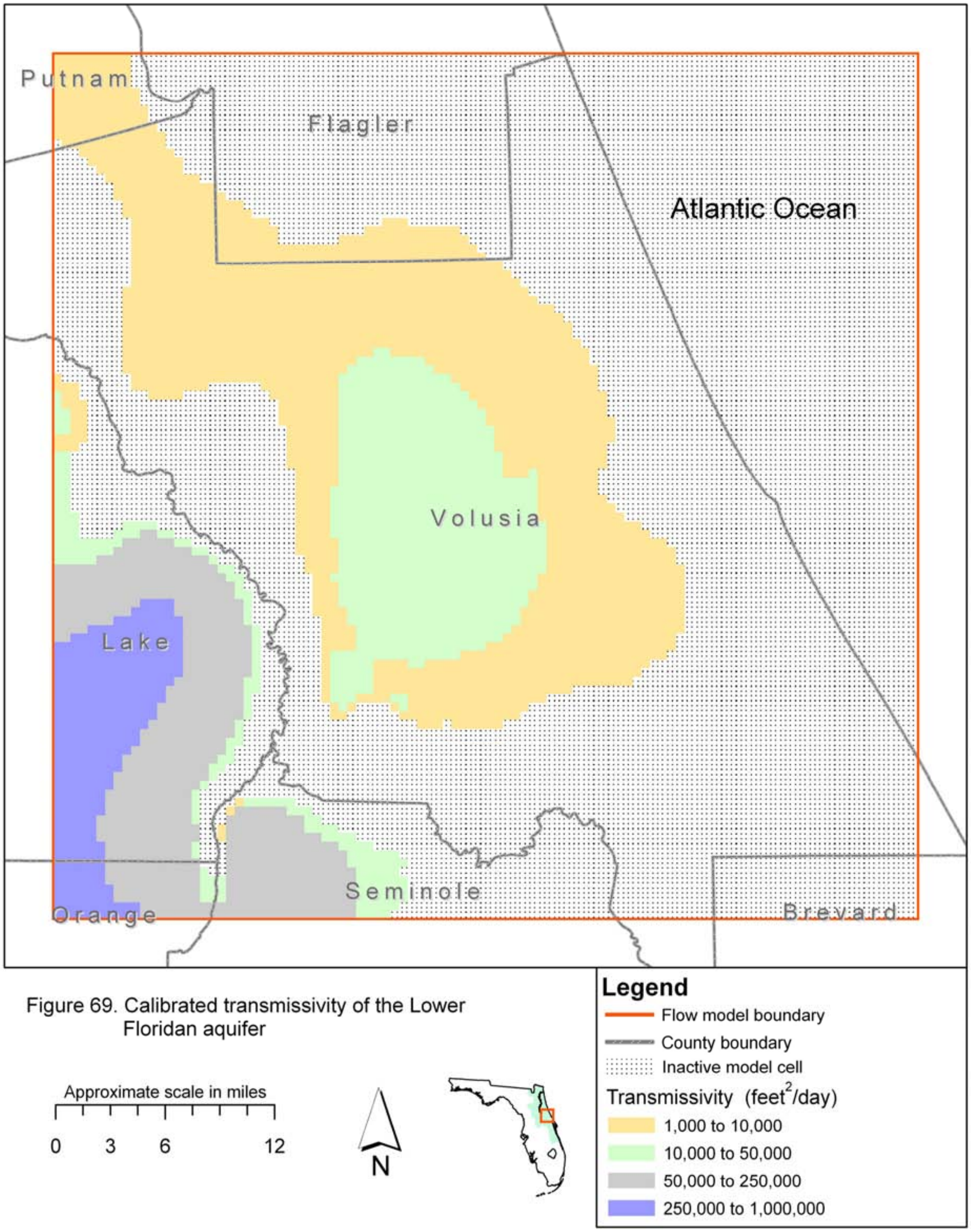


Figure 69. Calibrated transmissivity of the Lower Floridan aquifer

Table 11. Simulated modelwide volumetric water budgets, predevelopment and average 1995 calibrations

Totals by Source and Sink Type (cubic feet per second)						
Inflow	Predev	% of Inflow	1995	% of Inflow	Increase	Decrease
Constant heads	1	0.03	1	0.05	0	
River leakage	1	0.06	2	0.09	1	
Lateral boundaries	314	13.83	348	15.00	34	
Recharge	1,952	86.08	1,969	84.86	17	
Total inflow	2,268		2,321		53	
Outflow	Predev	% of Outflow	1995	% of Outflow	Increase	Decrease
Constant heads	115	5.09	97	4.20		18
Wells	0	0.00	190	8.17	190	
Springs	346	15.27	309	13.30		38
Rivers	381	16.82	384	16.53	2	
Evapotranspiration	1,364	60.14	1,250	53.85		114
Lateral boundaries	61	2.67	92	3.96	31	
Total outflow	2,268		2,321		223	170
Linearized Over Model Domain (inches per year)						
Inflow	Predev		1995		Increase	Decrease
Constant heads	0.00		0.01		0.00	
River leakage	0.01		0.01		0.00	
Lateral boundaries	1.90		2.11		0.21	
Recharge	11.82		11.92		0.10	
Total inflow	13.73		14.05		0.32	
Outflow	Predev		1995		Increase	Decrease
Constant heads	0.70		0.59			0.11
Wells	0.00		1.15		1.15	
Springs	2.10		1.87			0.2\3
Rivers	2.31		2.32		0.01	
Evapotranspiration	8.26		7.57			0.69
Lateral boundaries	0.37		0.56		0.19	
Total outflow	13.73		14.05		1.35	1.03

Note: Predev = predevelopment

Discrepancies between individual values and corresponding totals may occur due to number of significant digits displayed.

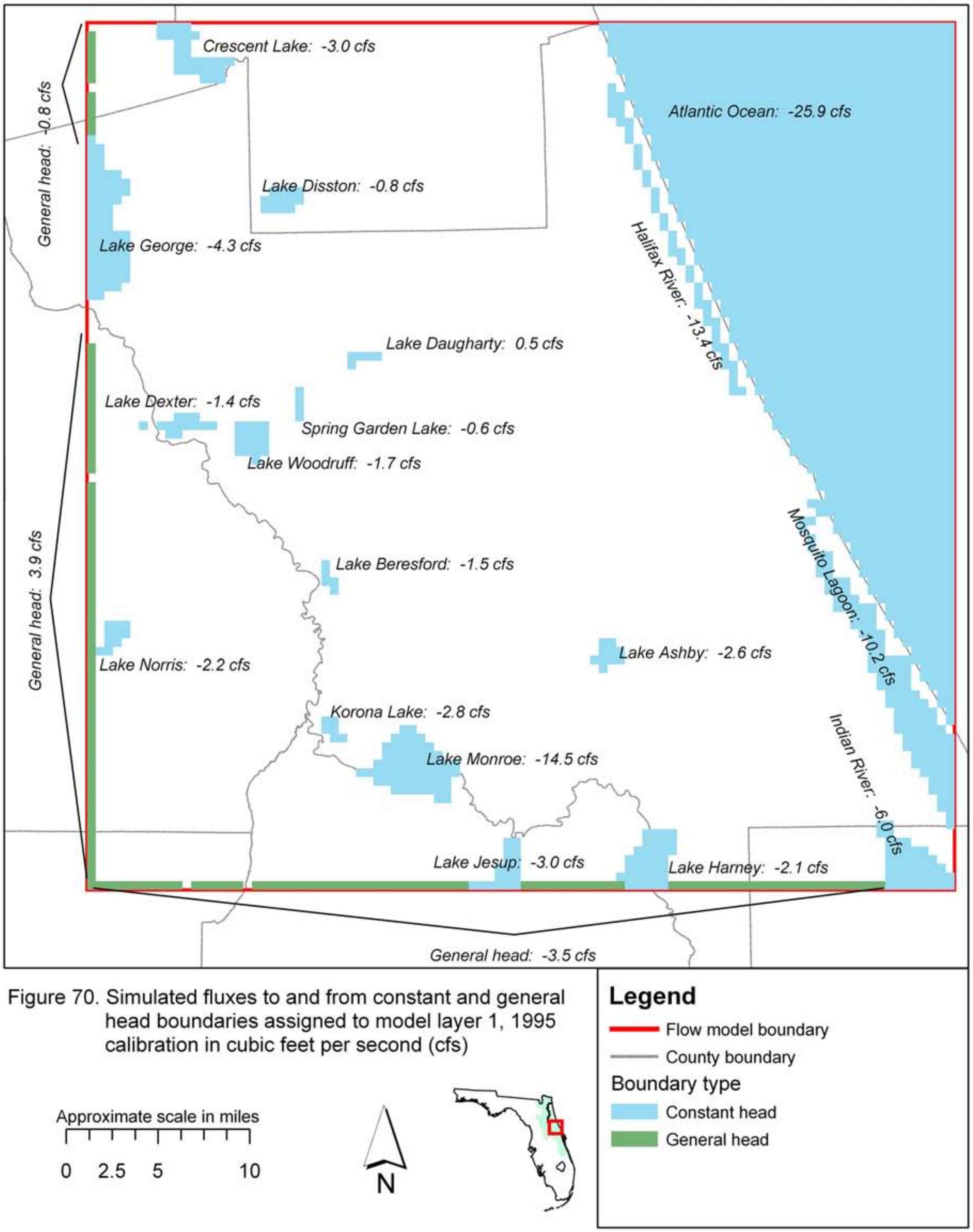


Figure 70. Simulated fluxes to and from constant and general head boundaries assigned to model layer 1, 1995 calibration in cubic feet per second (cfs)

Table 12. Simulated multilayer volumetric water budgets, predevelopment and average 1995 calibrations (in cubic feet per second)

Flux Type	Volumetric Flow Rates				Increase	Decrease	Net Change
	Predev	%	1995	%			
Layer 1							
In							
Recharge	1,952.0	89.3	1,969.0	90.9	17.0		
River leakage	1.3	0.1	2.0	0.1	0.7		
Upward leakage from layer 2	225.0	10.3	188.7	8.7		36.3	
Lateral general head boundaries	6.7	0.3	7.0	0.3	0.3		
Constant heads	0.4	0.0	0.6	0.0	0.2		
Total in	2,185.4		2,167.3		18.2	36.3	-18.1
Out							
Evapotranspiration	1,379.6	63.1	1,250.0	57.7		129.6	
Downward leakage to layer 2	438.7	20.1	527.0	24.3	88.3		
Wells	0.0	0.0	8.0	0.4	8.0		
River discharge	246.9	11.3	279.0	12.9	32.1		
Lateral general head boundaries	8.0	0.4	7.4	0.3		0.6	
Constant heads	112.3	5.1	96.0	4.4		16.3	
Total out	2,185.5		2,167.4		128.4	146.5	-18.1
Layer 2							
In							
Downward leakage from layer 1	438.7	58.2	526.7	64.5	88.0		
Upward leakage from layer 3	119.6	15.9	102.1	12.5		17.5	
Lateral general head boundaries	194.8	25.9	188.0	23.0		6.8	
Total in	753.6		816.8		88.0	24.3	63.2
Out							
Upward leakage to layer 1	225.0	29.9	189.4	23.2		35.6	
Downward leakage to layer 3	9.5	1.3	9.5	1.2	0.0		
Wells	0.0	0.0	180.4	22.1	180.4		
Springs	346.4	46.0	308.6	37.8		37.8	
Lateral general head boundaries	48.8	6.5	24.0	2.9		24.8	
River discharge	122.8	16.3	105.0	12.9		17.8	
Total out	752.5		816.9		180.4	116.0	64.4

Table 12—*Continued*

Flux Type	Volumetric Flow Rates				Increase	Decrease	Net Change
	Predev	%	1995	%			
Layer 3							
In							
Downward leakage from layer 2	9.5	7.8	9.7	6.0	0.2		
Lateral general head boundaries	110.5	90.3	99.6	61.3		10.9	
Saltwater boundaries	2.4	2.0	53.3	32.8	50.9		
Total in	122.4		162.6		51.1	10.91	40.2
Out							
Upward leakage to layer 2	119.6	97.2	102.1	62.8		17.5	
Lateral general head boundaries	2.8	2.3	60.5	37.2	57.7		
Saltwater boundaries	0.7	0.6	0.0	0.0			
Total out	123.1		162.6		57.7	17.5	39.5

Note: Predev = predevelopment

Discrepancies between individual values and corresponding totals may occur due to number of significant digits displaced.

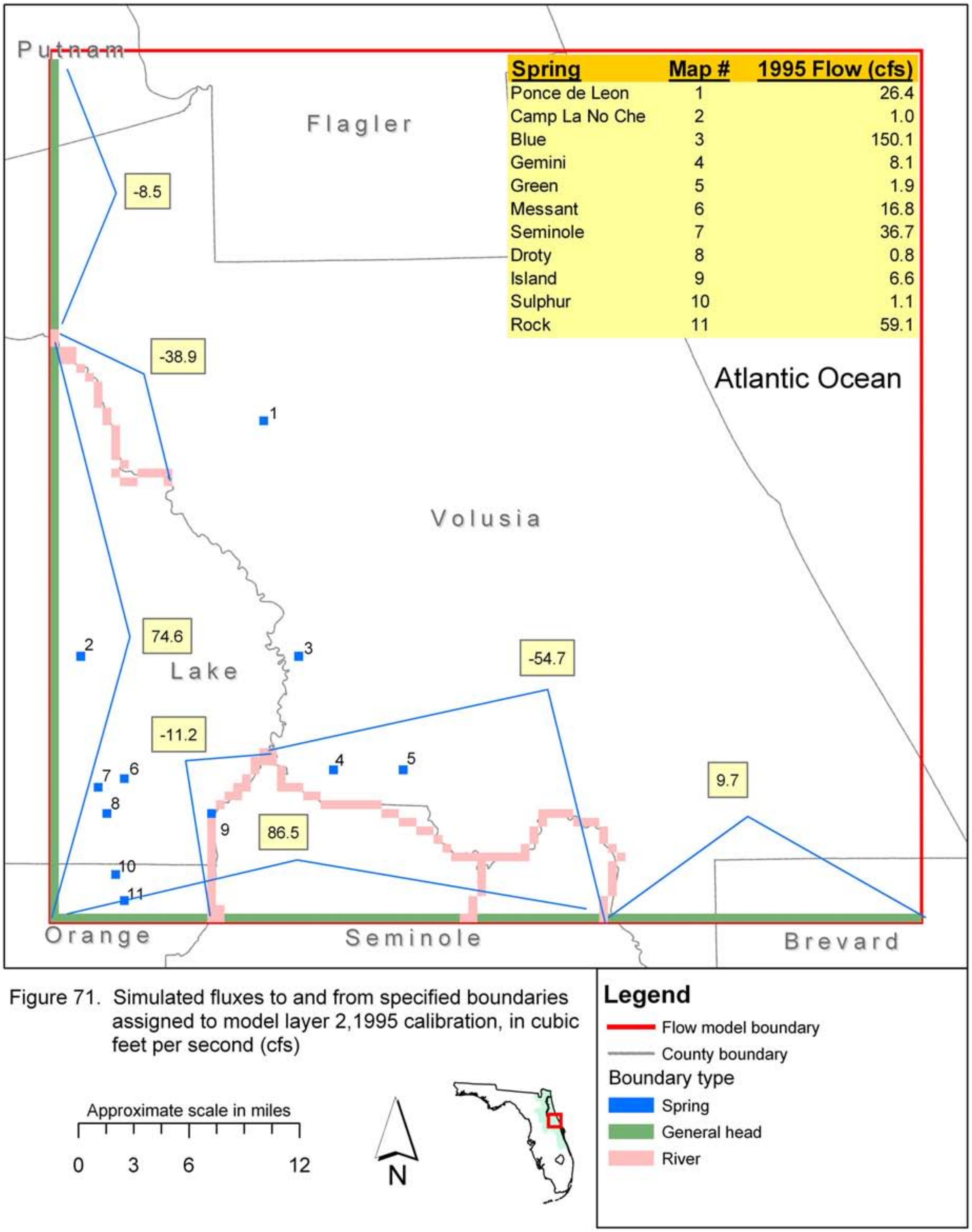
aquifer for the predevelopment calibration are recharge from the surficial aquifer system (439 cfs), upward leakage from the Lower Floridan aquifer (120 cfs), and lateral flow across GHBs (195 cfs). Predevelopment outflows from the Upper Floridan aquifer are spring flow (346 cfs), upward leakage to the surficial aquifer system (225 cfs), discharge to rivers (123 cfs), and discharge to GHBs (49 cfs). For the 1995 calibration, estimated flow rates are similar with additional water derived from recharge to the surficial aquifer system (1,969 cfs), less water lost to ET (1,250 cfs) and more lost to downward leakage to the Upper Floridan aquifer (527 cfs), and river discharge (279 cfs) (Table 12). The change in recharge to the surficial aquifer system between the predevelopment and average 1995 simulations is due to land application of groundwater withdrawals from the Upper Floridan aquifer. The decrease in ET is primarily attributed to declines in the elevation of the water Table in the surficial aquifer system. The increase in recharge to the Upper Floridan aquifer is attributed to increased differences in hydraulic head between the surficial and Upper Floridan aquifers, due primarily to lower simulated levels in the potentiometric surface of the Upper Floridan aquifer caused by pumping. The increase in river discharge from the surficial aquifer system between the predevelopment and 1995 calibrations can be attributed to the inclusion of a network of surface drainage canals that were not included in the predevelopment calibration.

The primary difference in the water budget for the Upper Floridan aquifer between the predevelopment and average 1995 calibrations is due to 180 cfs that was removed by pumping. This groundwater pumpage is compensated for by increased downward leakage from (88 cfs) and decreased upward leakage (36 cfs) to the surficial aquifer system, decreased spring flow (38 cfs), and decreased net outflow to lateral GHBs (25 cfs) and to river discharge (18 cfs) (Table 12, Figure 71).

The water budget for the Lower Floridan aquifer is composed of flow to and from the Upper Floridan aquifer, lateral flow across GHBs, and flow to and from saltwater boundaries. Saltwater boundaries were established immediately adjacent to estimated locations within the Lower Floridan aquifer of the 5,000-ppm chloride isochlor. Therefore, all GHBs illustrated in Figure 30 that are not on the periphery of the model domain are saltwater boundaries. By design, the flow at these boundaries is virtually zero for the predevelopment calibration, consistent with the conceptualization of a dynamic equilibrium between fresh and salt water for this interface prior to development. The primary inflow to the Lower Floridan aquifer for the predevelopment calibration is from lateral GHBs (111 cfs), and the primary outflow is upward leakage to the Upper Floridan aquifer (120 cfs). However, for the 1995 calibration, primary inflows are derived from both lateral head (100 cfs) and saltwater boundaries (53 cfs), with lesser inflow due to downward leakage from the Upper Floridan aquifer. Similarly, outputs are distributed between upward leakage to the Upper Floridan aquifer (102 cfs) and lateral flow to GHBs (61 cfs) (Table 12, Figure 72).

SENSITIVITY ANALYSES

Periodic sensitivity analyses were performed during model calibration to quantify the relative significance of input parameters and boundary conditions to simulation results. Findings of these sensitivity analyses facilitated focusing the model calibration process upon the most influential aquifer or confining unit properties and boundary conditions. A final sensitivity analysis was performed subsequent to model calibration and is presented herein. Model parameters investigated included the K_h of the surficial aquifer system and the Upper Floridan aquifer and leakance of both the upper and middle semiconfining units. Boundary conditions or attributes



Spring	Map #	1995 Flow (cfs)
Ponce de Leon	1	26.4
Camp La No Che	2	1.0
Blue	3	150.1
Gemini	4	8.1
Green	5	1.9
Messant	6	16.8
Seminole	7	36.7
Droty	8	0.8
Island	9	6.6
Sulphur	10	1.1
Rock	11	59.1

Figure 71. Simulated fluxes to and from specified boundaries assigned to model layer 2,1995 calibration, in cubic feet per second (cfs)

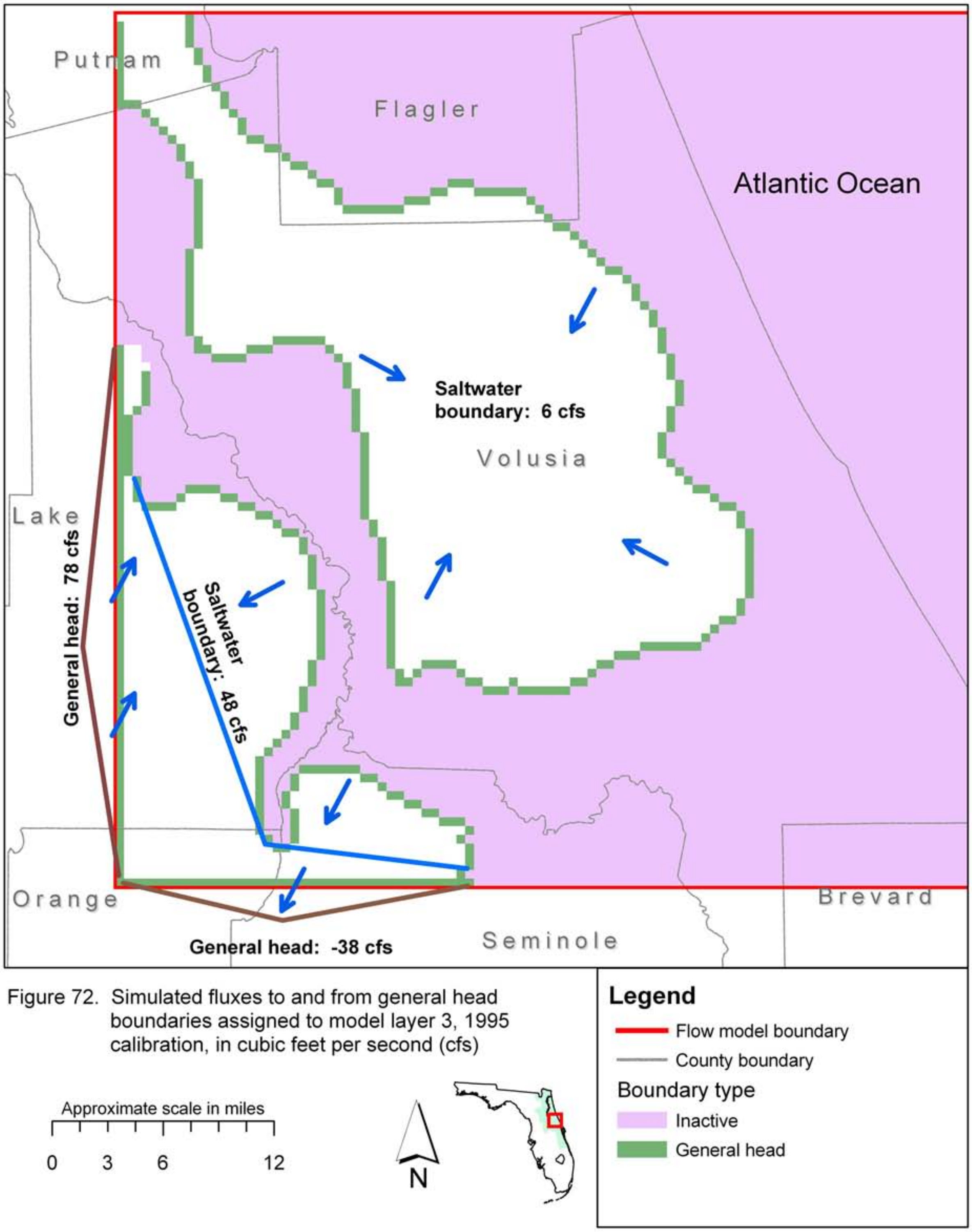
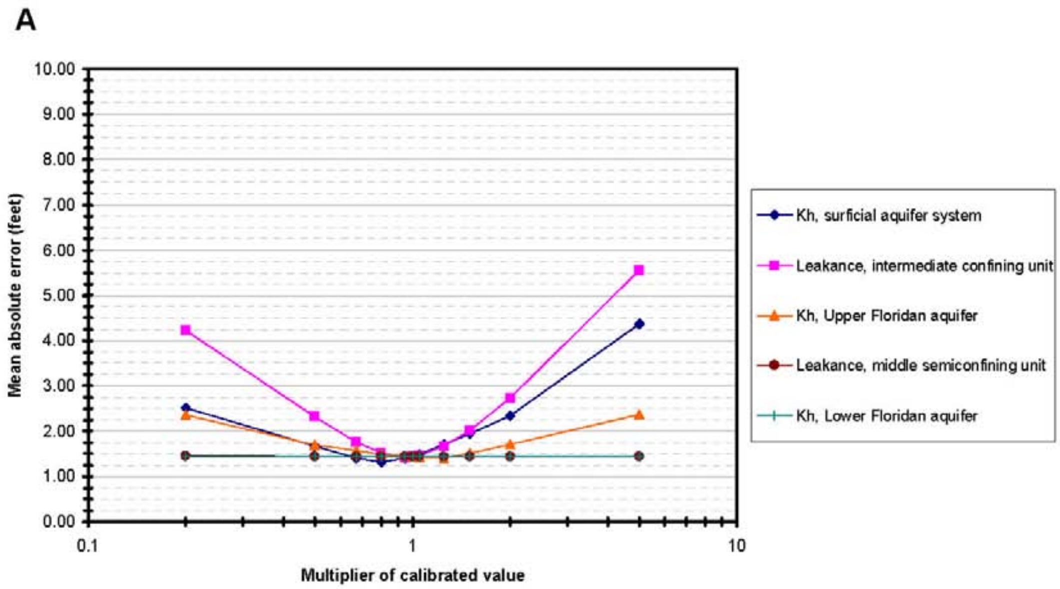


Figure 72. Simulated fluxes to and from general head boundaries assigned to model layer 3, 1995 calibration, in cubic feet per second (cfs)

thereof investigated included recharge, maximum ET (ET_{MAX}), ET extinction depth (EXDEP), river conductance, the irrigation component of recharge (R_{APP}), public supply usage, agricultural usage, and both freshwater and saltwater lateral boundary heads. Each parameter or stress was varied modelwide over a range that is equal to or greater than the estimated error in that parameter or stress. Sensitivity simulations were also performed to investigate the effects of domestic self-supply wells and free-flowing artesian wells by removing these wells from the simulation. Sensitivity was determined by plotting mean absolute error for all monitor wells and total simulated spring flow against the multiplier used for each parameter or stress.

Results of the sensitivity analysis for surficial aquifer system heads relative to aquifer and confining unit properties indicate that simulated heads are most sensitive to the leakance of the intermediate confining unit and the hydraulic conductivity of the surficial aquifer system (Figure 73). Aquifer heads are moderately sensitive to the K_h of both the Upper Floridan aquifer system and relatively insensitive to leakance of the middle semiconfining unit and the K_h of the Lower Floridan aquifer. With respect to boundary conditions, heads in the surficial aquifer system are most sensitive to recharge, ET extinction depth, and maximum ET. Aquifer heads are moderately sensitive to public supply usage and relatively insensitive to agricultural usage. Heads are also insensitive to changes in drain and lateral head boundary conductance values, and lateral boundary heads at the freshwater / saltwater interface. Surficial aquifer system heads were also relatively insensitive to pumpage for domestic self-supply and to discharge from free-flowing wells.

Results of the sensitivity analysis for Upper Floridan aquifer heads relative to aquifer and confining unit properties indicate that simulated heads are most sensitive to leakance of the intermediate confining unit and K_h of the Upper Floridan aquifer (Figure 74). Aquifer heads were relatively insensitive to leakance of the middle semiconfining zone and to the K_h of the Lower Floridan aquifer and the surficial aquifer system. With respect to boundary conditions, heads in the Upper Floridan aquifer are most sensitive to recharge, maximum ET, and lateral freshwater heads. Aquifer heads are moderately sensitive to public supply usage and agricultural usage and relatively insensitive to ET extinction depth. Upper Floridan aquifer heads were also relatively insensitive to pumpage for domestic self-supply and to discharge from free-flowing wells.



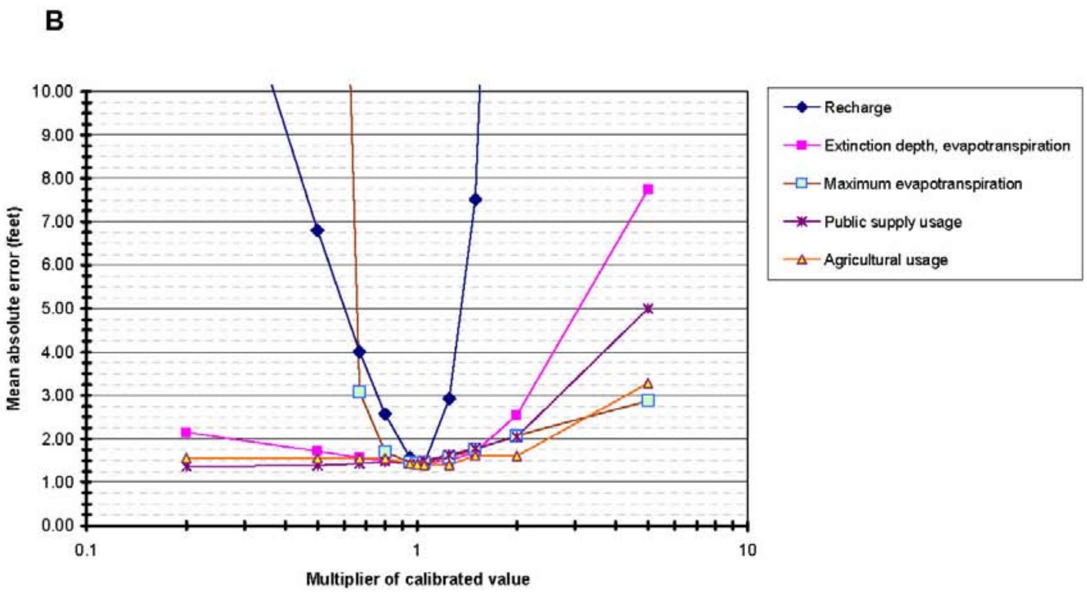


Figure 73. Sensitivity of simulated surficial aquifer system heads to changes in (A) aquifer and confining unit properties and (B) selected boundary conditions

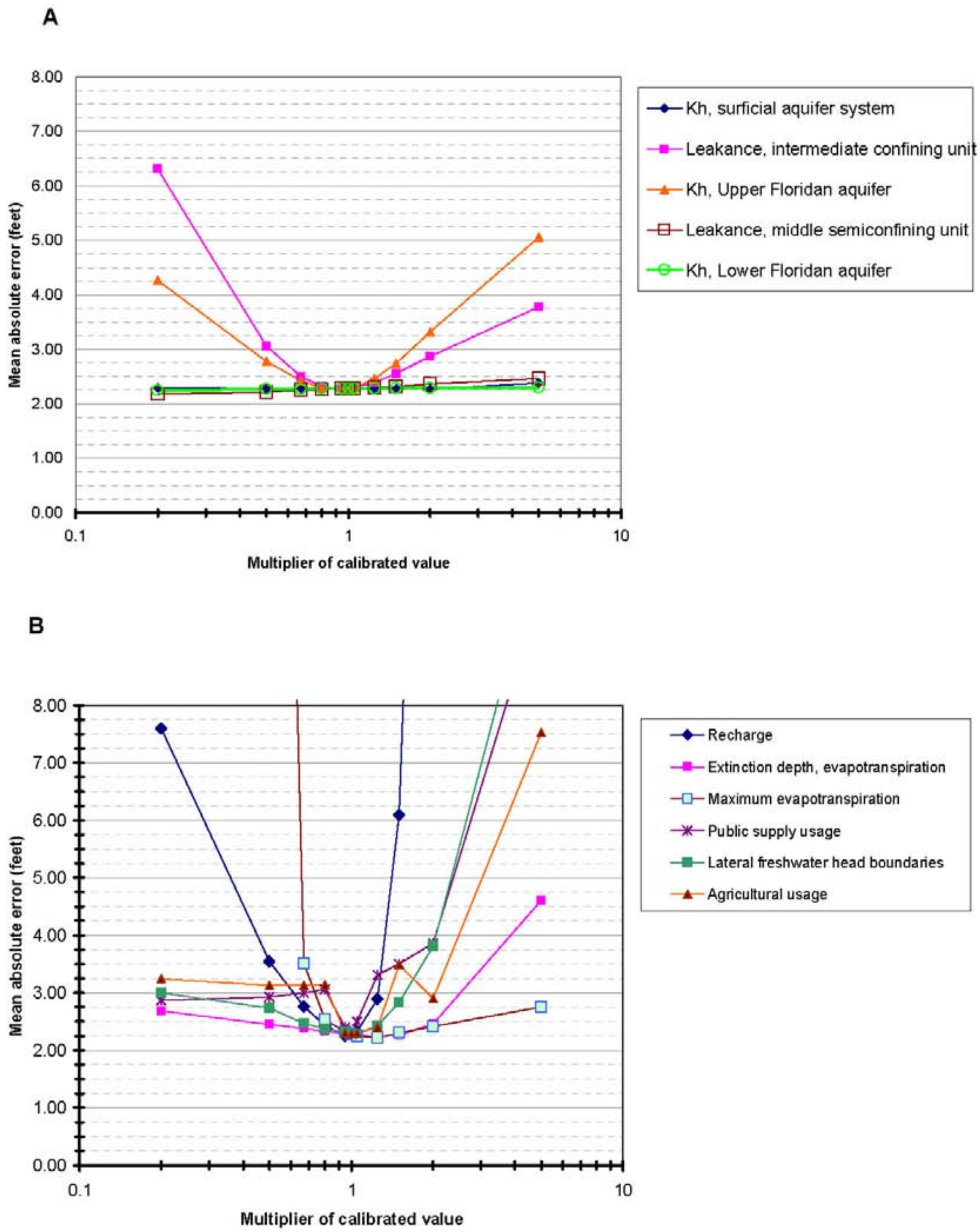


Figure 74. Sensitivity of simulated Upper Floridan aquifer heads to changes in (A) aquifer and confining unit properties and (B) selected boundary conditions

Results of the sensitivity analysis for total simulated spring flow relative to aquifer and confining unit properties indicate that simulated flows are most sensitive to changes in K_h of the Upper Floridan aquifer (Figure 75). Spring flows were moderately sensitive to changes in leakance of the intermediate confining unit, and insensitive to leakance of the middle semiconfining zone and the K_h of the Lower Floridan aquifer and the surficial aquifer system. With respect to boundary conditions, spring flows are most sensitive to recharge and lateral freshwater head boundaries. Spring flows are moderately sensitive to public supply usage and drain conductance and slightly less sensitive to agricultural usage and lateral saltwater head boundaries. Total simulated spring flows were relatively insensitive to pumpage for domestic self-supply and to discharge from free-flowing wells.

The sensitivity of model results to changes in ET_{MIN} is similar but inversely proportional to that observed for changes in recharge. This relationship is intuitive because recharge is a function of ET_{MIN} (Equations 8–11). For the majority of model grid cells, a decrease of 1 inch in ET_{MIN} results in a 1-inch increase in recharge (N); and a 1-inch increase in ET_{MIN} results in a 1-inch decrease in recharge.

Model results are generally sensitive to the head values used in the GHB package to represent lateral boundary freshwater heads. This finding suggests that predictive simulations would be affected by changes in boundary heads due to future Floridan aquifer system withdrawals outside of the model domain. Similarly, saltwater heads at the freshwater/saltwater boundary, may have an effect upon predictive simulations. Simulated heads and spring flows are sensitive to both public supply and agricultural pumpage, indicating that management of these withdrawals is critical to the effective planning and allocation of future water supplies.

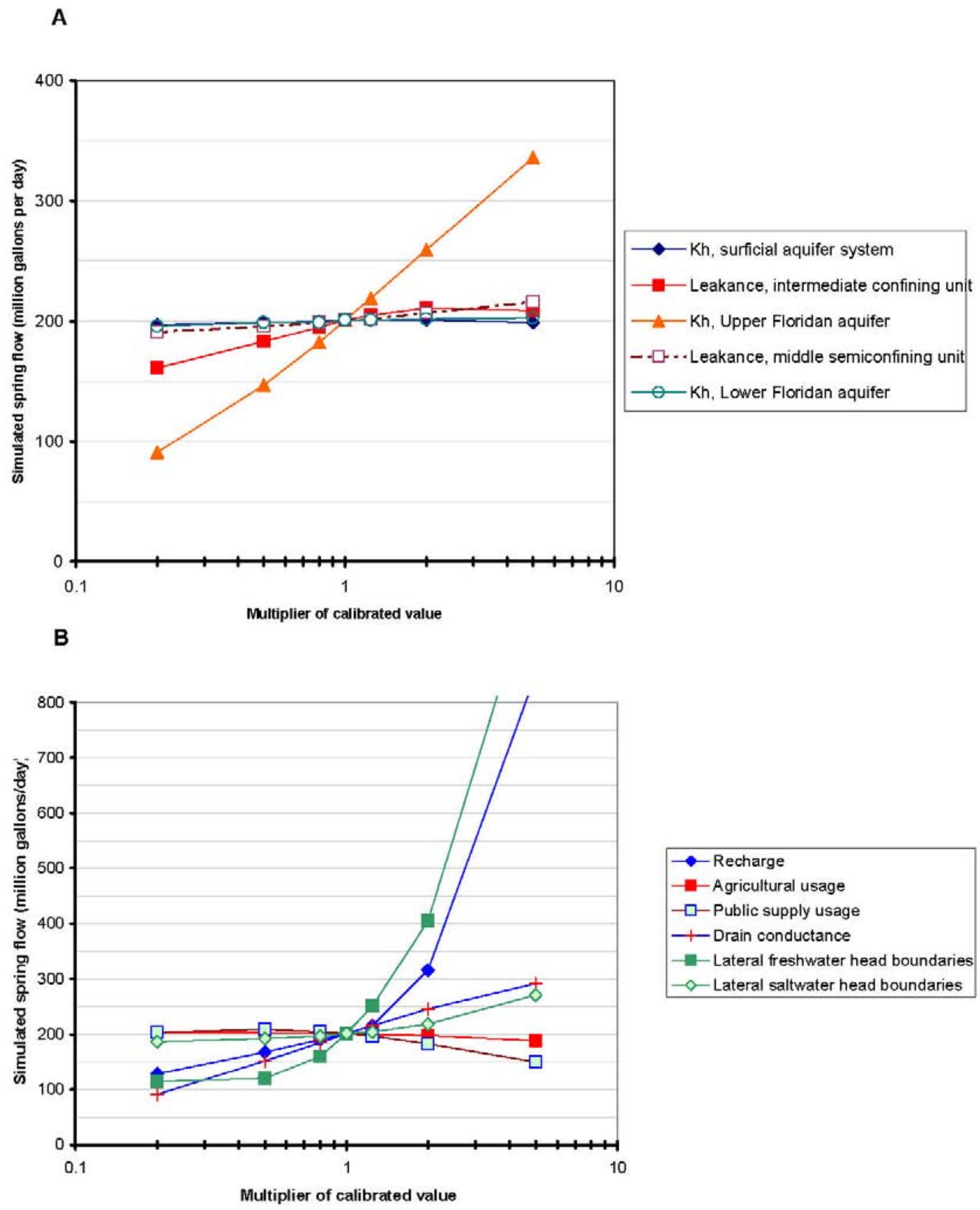


Figure 75. Sensitivity of total simulated spring flow to changes in (A) aquifer and confining unit porperties and (B) selected boundary conditions

PREDICTIVE SIMULATIONS

A primary objective of this groundwater model development is the application of the calibrated model to the assessment of projected changes in water levels and spring flows caused by projected future usage patterns. Specifically, the calibrated model was used to simulate the impacts of projected rates of groundwater pumping for the year 2020 upon water levels and flow rates within the surficial and Floridan aquifer systems. Model boundary conditions were modified to account for projected 2020 hydrologic conditions as follows:

- Groundwater withdrawals were adjusted to account for all projected 2020 pumping.
- The calculated values for recharge to the surficial aquifer system were modified to account for projected patterns of water use and reuse.
- Lateral groundwater head boundaries were adjusted to account for the effects of increased water use that is projected to occur external to the model domain.

The remaining model input parameter distributions were unchanged from 1995 calibrated values.

PROJECTED 2020 GROUNDWATER WITHDRAWALS

Of the projected water use changes for 2020, those for public supply are anticipated to cause the most significant impacts upon the groundwater systems represented in the model domain. Pumpage associated with all major public supply utilities is projected to increase between 1995 and 2020 (Vergara 1998). The largest increases were projected for Daytona Beach (8.1 mgd), Port Orange (3.7 mgd), Deltona (7.6 mgd), and Volusia County—southwest (3.8 mgd) (Appendix D) (Vergara 1998). A breakdown for year 2020 water use by type (Table 7) and a listing of public supply water use by utility (Appendix D) indicate an anticipated use of 112.5 mgd for public supply, 28.1 mgd for agriculture, 6.5 mgd for domestic self-supply, and 5.8 mgd for commercial/industrial pumping (Vergara 1998). Agricultural crop types (primarily ferneries, golf courses, sod farms, and citrus) and usage patterns are anticipated to resemble those for 1995.

An additional modification to the distribution of year 2020 water use was the removal of discharge to free-flowing wells. For 1995, the modelwide discharge assigned to free-flowing wells was estimated to be 23.1 mgd, based upon an inventory of existing wells and estimated flow rates (Curtis 1998). Based upon current work plans at SJRWMD, it is anticipated that all identified free-flowing wells will be plugged by 2020, leaving only the permitted free-flowing well at Wekiva Falls (11.3 mgd) to be simulated as part of the 2020 projection (Table 7).

RECHARGE TO THE SURFICIAL AQUIFER SYSTEM

The spatial distribution of recharge to the surficial aquifer system was modified for the 2020 projection to account for projected changes in water reuse associated with changes in water use. For example, irrigation estimates associated with increased withdrawals for agricultural and golf course use (Table 7) were revised in the recharge algorithm as part of the applied irrigation term (R_{APP}). Similarly, projected changes for public supply use necessitated revisions in the spatial distributions of landscape irrigation (R_{PSLI}) and septic tank discharge (R_{SEPTIC}). These processes were addressed in the same manner as in the 1995 calibration, with allowances made for projected increases in the size of public supply service area for some municipalities. Projected increases in wastewater treatment plant flows associated with increased public supply use also indicated changes in water reuse (R_{REUSE}) or discharge to local surface water bodies (Table 7; Appendices D & F). Specific estimates for the spatial distributions of R_{REUSE}, R_{PSLI}, and R_{SEPTIC} were determined based upon written communication from Post, Buckley, Shuh, and Jernigan (1999), and an internal review of SJRWMD consumptive use permit files.

LATERAL GENERAL HEAD BOUNDARIES

Lateral GHBs were adjusted for the 2020 simulation to account for increases in water use that are projected to occur outside of the model domain. Specifically, boundary heads along the western and southern edges of the model were lowered to allow for the influence of pumping changes that are projected to occur in the greater Orlando metropolitan area. Revised boundary heads were calculated by subtracting 2020 drawdowns that were projected at these boundaries by the east-central Florida groundwater model (McGurk and Presley 2002) from the 1995 boundary head values. Groundwater levels along the western GHB were on the order of 1–2 ft lower than those for the 1995 calibration for the surficial aquifer system, 1–4 ft lower for the Upper Floridan aquifer, and 1–5 ft lower for the Lower Floridan aquifer. Similarly, boundary heads along the southern boundary ranged from 1–4 ft lower than those used in the 1995 calibration for the surficial aquifer system, 2–5 ft lower for the Upper Floridan aquifer, and 3–6 ft lower for the Lower Floridan aquifer. Water use changes that are projected to occur for the remaining areas surrounding the groundwater flow model (i.e., north and directly west) are not projected to substantially alter groundwater flow patterns and heads within the study areas relative to those assigned for the 1995 calibration. Therefore, these GHBs were not altered for the 2020 projection.

PREDICTED AVERAGE 2020 WATER LEVELS AND SPRING FLOWS

A predictive simulation of the effects of projected groundwater usage for the year 2020 was performed, incorporating all revised boundary conditions. Water level and springflow changes were simulated for both the surficial and Floridan aquifer systems, and hydraulic fluxes were examined for ET and recharge / discharge between the surficial aquifer system and the Upper Floridan aquifer. A water budget breakdown is presented and compared to that for the average 1995 calibration.

Water Level Declines

Declines in water levels in the surficial aquifer system are projected to occur throughout much of the study area in response to increases in pumping from the Upper Floridan aquifer for the year 2020 (Figure 76). Surficial aquifer system drawdowns generally fall within a range of between 0 and 4 ft. Projected declines are highest in the vicinities of the Daytona Beach and Port Orange wellfields in Volusia County and northwest Seminole County (Figures 42 and 76). Water Table levels are projected to increase slightly in some areas in response to projected anthropogenic increases in surficial aquifer system recharge (e.g. reuse application) and changes in usage patterns for the Upper Floridan aquifer (e.g. plugging of free-flowing wells).

The distribution of projected drawdown in the potentiometric surface of the Upper Floridan aquifer (Figure 77) illustrates areas of significant decline in the immediate areas of public supply wellfields operated by Daytona Beach, Port Orange, and New Smyrna Beach in coastal Volusia County, and Volusia County utilities and Deltona in southwest Volusia County. Projected

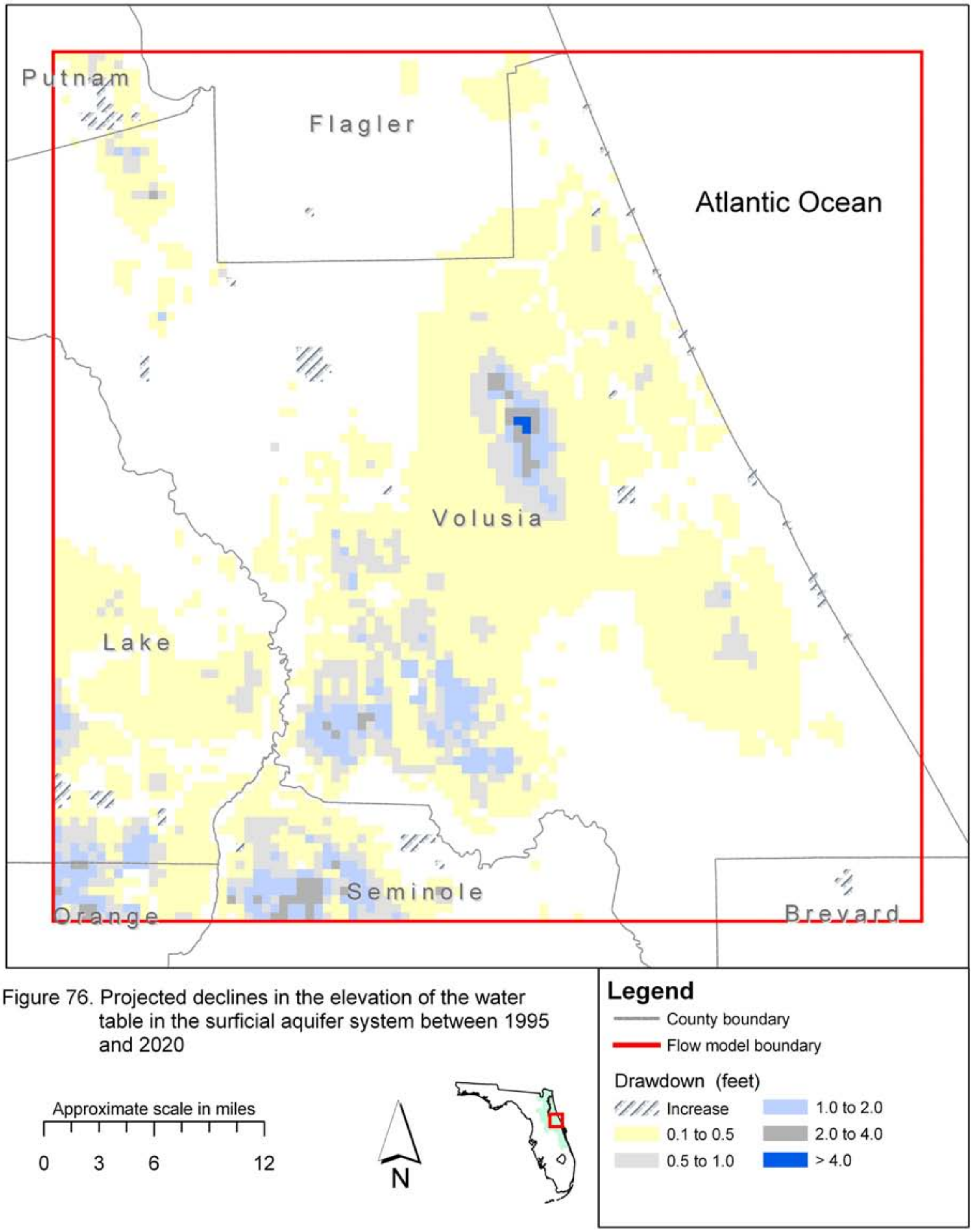


Figure 76. Projected declines in the elevation of the water table in the surficial aquifer system between 1995 and 2020

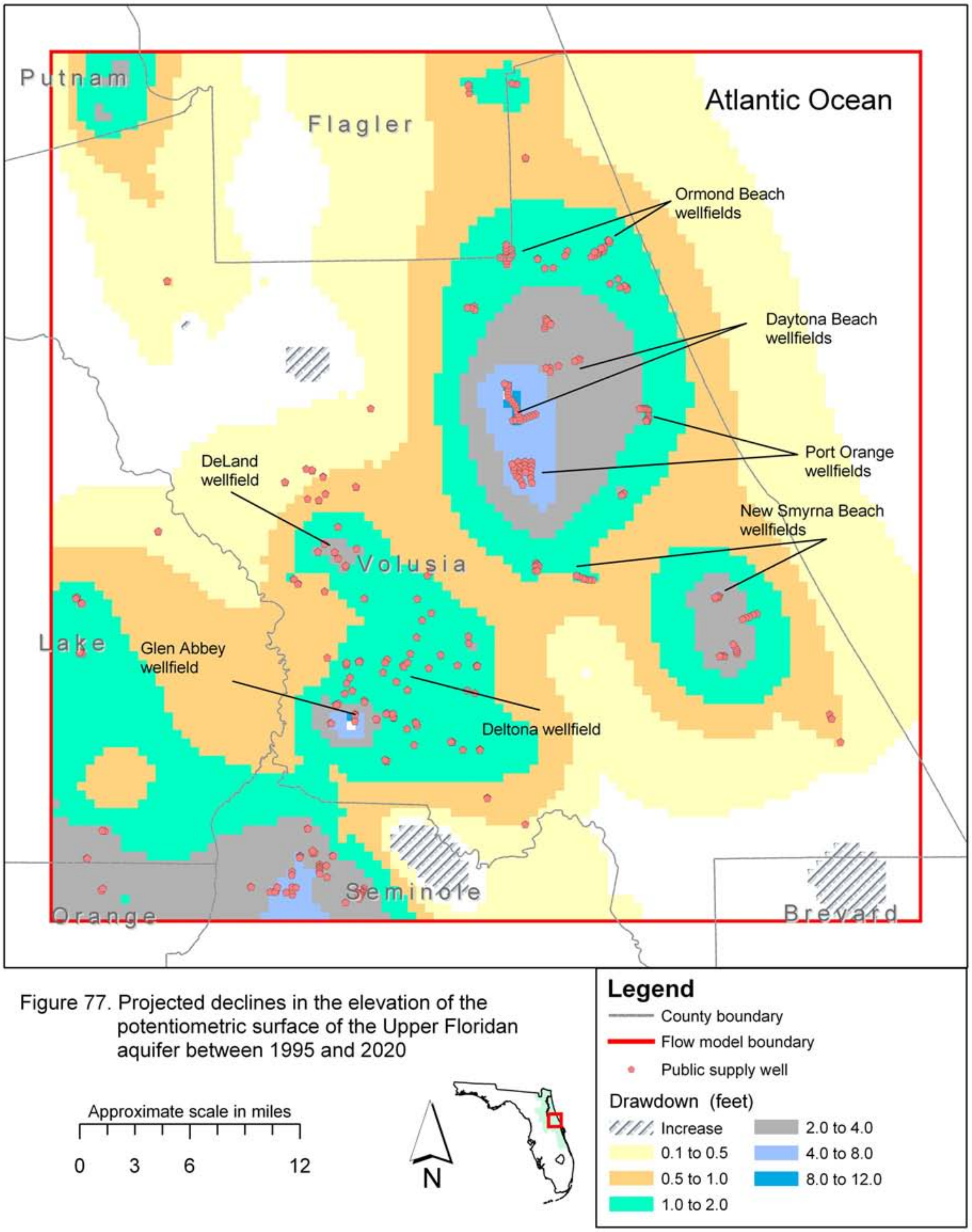


Figure 77. Projected declines in the elevation of the potentiometric surface of the Upper Floridan aquifer between 1995 and 2020

drawdown values in a localized area of southwest Volusia County are greater than 10 ft due to the combined effect of relatively high projected pumping and low calibrated transmissivities for the Upper Floridan aquifer (Figure 67). Drawdown in the southwest portion of the project area is attributed to increased public supply pumping both within and outside of the project area. In some areas potentiometric levels are projected to rise between 1995 and 2020 in response to decreased agricultural pumping in north-central Volusia County and the anticipated plugging of existing abandoned artesian wells in northern Seminole County.

The projected drawdown values for the Lower Floridan aquifer closely mimic those for the Upper Floridan aquifer (Figure 78) with values of 2–4 ft in eastern Volusia County and 4–6 ft in the southwestern portion of the project area.

Recharge and Groundwater Flow

Projected distributions for total ET and recharge / discharge between the surficial aquifer system and the Upper Floridan aquifer provide additional indicators regarding the differences between the average 1995 calibration and the simulated 2020 projection. A map of distributed differences between simulated ET rates (Figure 79) indicates areas of ET reduction in the vicinities of primary public supply wellfields (Figure 42). In these areas, ET reductions are attributed to projected declines in the elevation of the water table. ET reductions mitigate projected drawdowns in the surficial aquifer system because this reduction in ET is “captured” and augments water levels in the aquifer. Several areas in coastal and west-southwest Volusia County exhibit simulated increases in ET, attribuTable to additional reuse distributed as residential and landscape irrigation of public supply water. These areas of increased irrigation were also associated with projected changes in public service areas.

A map of the projected changes in simulated recharge / discharge between the surficial aquifer system and the Upper Floridan aquifer (Figure 80) indicates projected increased recharge for much of the study area. This increased recharge to the Upper Floridan aquifer is directly attribuTable to higher vertical hydraulic gradients between the water Table and the potentiometric surface of the Upper Floridan aquifer relative to 1995 head gradients. These

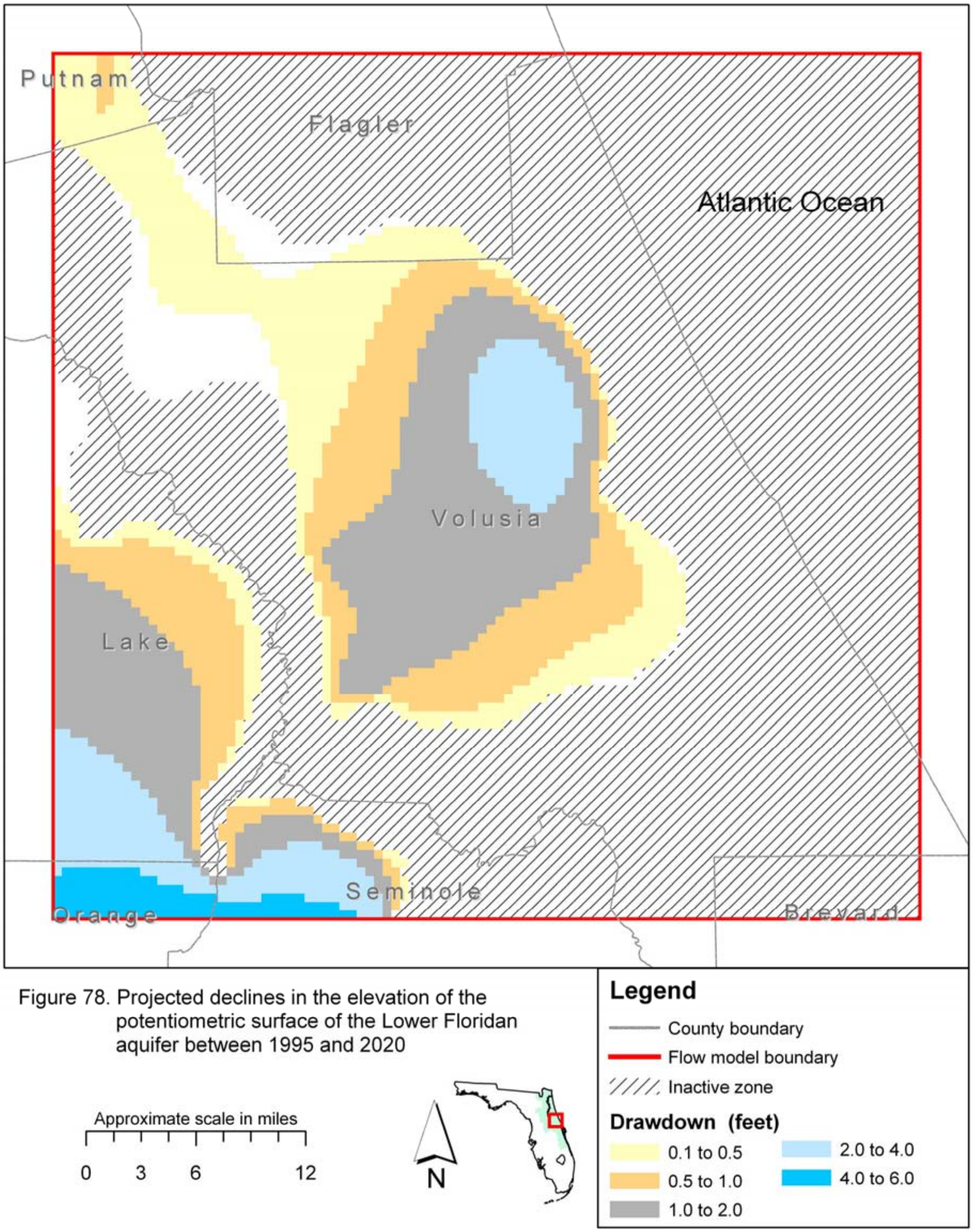


Figure 78. Projected declines in the elevation of the potentiometric surface of the Lower Floridan aquifer between 1995 and 2020

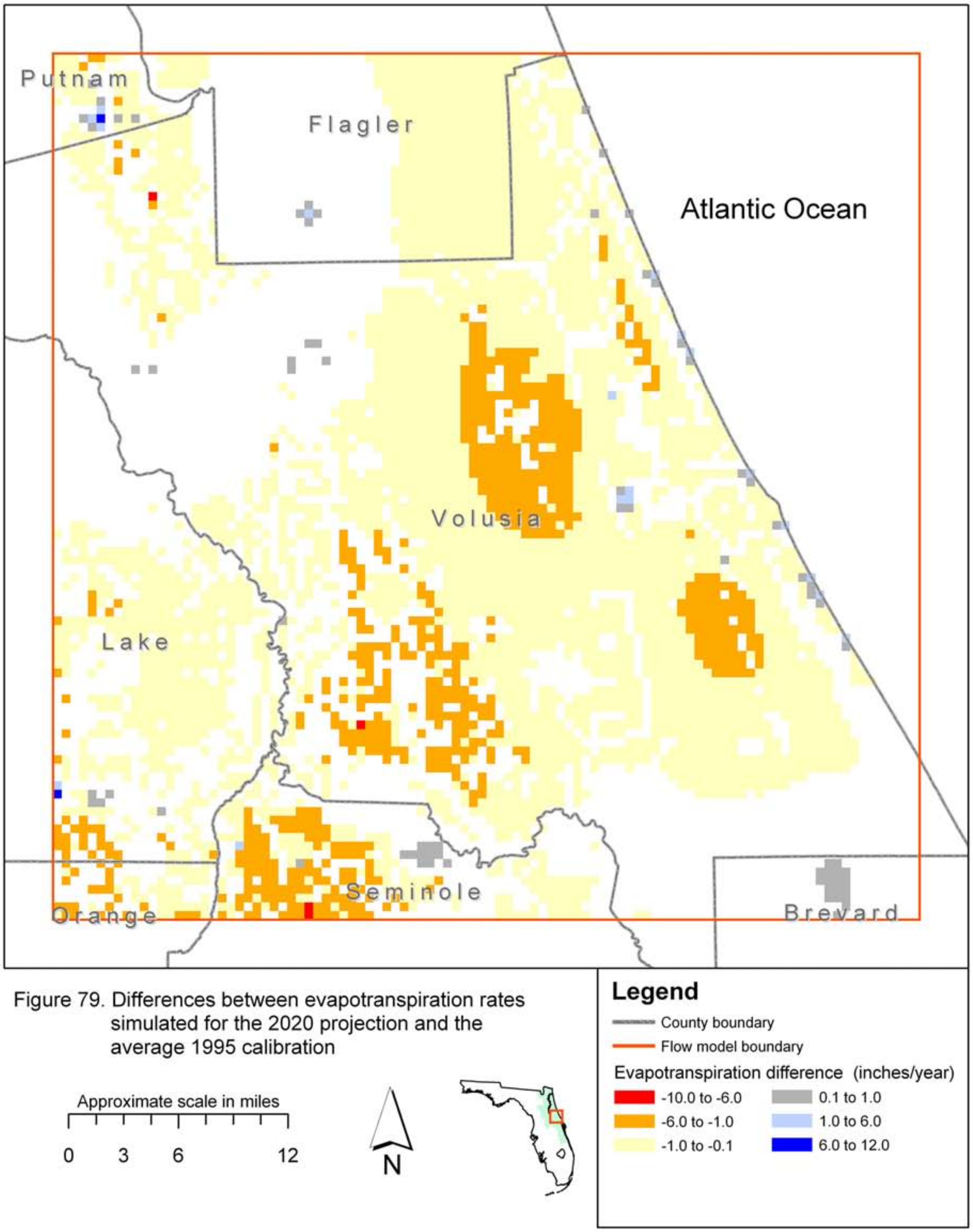


Figure 79. Differences between evapotranspiration rates simulated for the 2020 projection and the average 1995 calibration

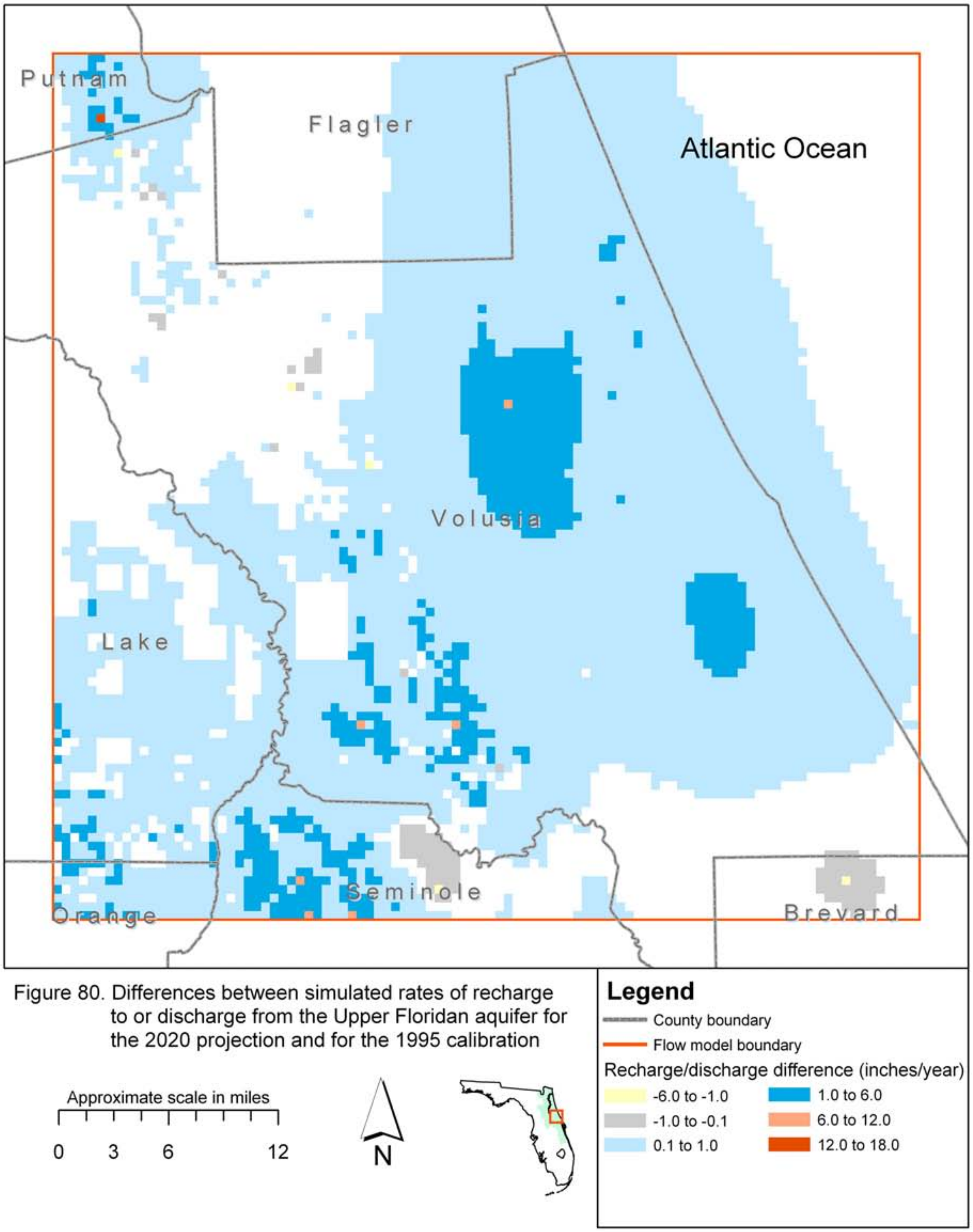


Figure 80. Differences between simulated rates of recharge to or discharge from the Upper Floridan aquifer for the 2020 projection and for the 1995 calibration

increased gradients are primarily attributed to projected drawdowns in the potentiometric surface in the Upper Floridan aquifer caused by pumping within the aquifer.

In response to projected declines in the potentiometric surface of the Upper Floridan aquifer, spring flow is projected to decline for all springs within the study area (Table 13). The most significant declines in spring flow (i.e., >10%) are projected for Rock, Seminole, Camp La No Che, and Sulphur springs. Rock and Seminole springs are projected to decline below their minimum screening flows (Table 13). These minimum screening flows are defined as the median of the annual average flow rates for the period of record minus 15%. The flow to Blue Spring, the largest spring in the study area, is projected to decline by 8.6% to an average annual discharge of 137.4 cfs.

Water Budget Summary

A water budget summary is provided for the 1995 calibration and the 2020 projection (Tables 14 and 15). All differences between the 1995 and the 2020 simulations are associated with the changes in boundary conditions as described in the previous section. Adjustments to recharge to the surficial aquifer system due to land application of poTable water and reuse water result in an increase of 3 cfs in potential recharge to the surficial aquifer system (Table 15). The additional groundwater pumpage of 75 cfs from the Upper Floridan aquifer between 1995 and 2020 is approximately offset by decreased flows to springs (33 cfs), rivers (9 cfs), constant heads (66 cfs); decreased loss to ET (45 cfs); and an increase in groundwater recharge of 3 cfs. In addition, adjustments to lateral GHBs contribute to a combined decreased inflow from and increased outflow to these boundaries to account for 21 cfs less net water available in 2020 than in 1995.

For the surficial aquifer sytem, the increase in recharge of 3 cfs projected for the year 2020 combined with decreased ET of 45 cfs and flow to rivers of 6 cfs contributes to a net increase of flow to the Upper Floridan aquifer of 44 cfs (Table 15). For the Upper Floridan aquifer, the increased flow to wells of 74 cfs combined with decreased flow from lateral boundaries (17 cfs) and a net leakage increase to the Lower Floridan aquifer (61cfs) are offset by an increase in downward flow from the surficial aquifer system (44 cfs), decreased flow to springs (33 cfs), and decreased upward leakage to the surficial aquifer system (16 cfs).

Table 13. Predicted springflow reductions between the average 1995 calibration and the 2020 projections

Spring*	Predicted Percent Change: Base Case†	Predicted Minimum Percent Change†	Predicted Maximum Percent Change†	Average Measured 1995 Flow (cfs)	Predicted 2020 Average Flow: Base Case (cfs)	Predicted 2020 Average Flow: Maximum Case (cfs)	Predicted 2020 Average Flow: Minimum Case (cfs)	Minimum Screening Flow‡ (cfs)
Blue	–7.4	–3.7	–12.3	150.4	137.4	144.8	131.9	134.7
Rock	–18.9	–18.5	–19.6	61.4	49.8	50.0	49.4	53.0
Seminole	–14.0	–13.8	–14.3	38.9	33.4	33.5	33.3	34.0
Ponce de Leon	–1.0	–0.4	–1.9	26.5	26.2	26.4	26.0	22.9
Messant	–7.9	–7.6	–8.3	16.4	15.1	15.2	15.0	12.0
Gemini	–6.9	–3.8	–9.2	8.1	7.5	7.8	7.4	7.3
Island	–9.0	–7.8	–10.8	6.4	5.8	5.9	5.7	5.2
Green	–6.6	–2.9	–11.7	1.9	1.7	1.8	1.6	1.6
Camp La No Che	–12.5	–12.0	–13.3	1.0	0.7	0.9	0.9	0.8
Sulphur	–17.0	–16.4	–18.3	0.8	0.9	0.7	0.7	No data
Droty	–6.7	–6.3	–7.2	0.7	0.7	0.7	0.6	No data
Total				312.5	279.1	287.7	272.5	

Note: Predicted percent change is based upon the difference between simulated 2020 and simulated 1995 spring flows.
Predicted 2020 flows are calculated by applying the predicted percent change to the average 1995 measured spring flow.

*Shaded spring names indicate first- and second-magnitude springs.

†Definitions:
Base case: 2020 projections using the calibrated model
Minimum percent change: Predictive sensitivity simulation with adjustments to minimize springflow change
Maximum percent change: Predictive sensitivity simulation with adjustments to maximize springflow change

‡Minimum flow rates adopted by rule are in bold. Screening flows are equal to historic median flow minus 15% where historic median flow = median of average annual flow rates for period of record.

Table 14. Simulated modelwide volumetric water budgets, average 1995 calibration and 2020 projection

Totals by Source and Sink Type (cubic feet per second)						
Inflow	1995	% of Inflow	2020	% of Inflow	Increase	Decrease
Constant heads	1	0.05	1	0.05		
River leakage	2	0.09	2	0.09		
Lateral boundaries	348	14.89	345	14.67		3
Recharge	1,969	84.98	1,972	85.19	15	
Total inflow	2,321		2,321		15	3
Outflow	1995	% of Outflow	2020	% of Outflow	Increase	Decrease
Constant heads	97	4.19	91	3.92		6
Wells	190	8.12	265	11.30	75	
Springs	309	13.16	276	11.79		33
Rivers	384	16.50	374	16.06		9
Evapotranspiration	1,250	54.08	1,205	52.24		45
Lateral boundaries	92	3.95	109	4.68	18	
Total outflow	2,321		2,321		93	91
Linearized Over Model Domain (inches per year)						
Inflow	1995		2020		Increase	Decrease
Constant heads	0.01		0.01			
River leakage	0.01		0.01			
Lateral boundaries	2.11		2.09			0.02
Recharge	11.92		11.94		0.02	
Total inflow	14.05		14.05		0.02	0.02
Outflow	1995		2020		Increase	Decrease
Constant heads	0.59		0.55			0.04
Wells	1.15		1.60		0.46	
Springs	1.87		1.67			0.20
Rivers	2.32		2.26			0.06
Evapotranspiration	7.57		7.30			0.27
Lateral boundaries	0.56		0.66		0.11	
Total outflow	14.05		14.05		0.56	0.56

Note: Discrepancies between individual values and corresponding totals may occur due to the number of significant digits displayed.

Table 15. Simulated multilayer volumetric water budgets, average 1995 calibration and 2020 projection (in cubic feet per second)

Flux Type	Volumetric Flow Rates				Increase	Decrease	Net Change
	1995	%	2020	%			
Layer 1							
In							
Recharge	1,969	90.9	1,972	91.5	3.1		
River leakage	2.0	0.1	2.1	0.1			
Upward leakage from layer 2	188.7	8.7	173.6	8.1		15.1	
Lateral general head boundaries	7.0	0.3	7.4	0.3	0.4		
Constant heads	0.6	0.0	0.6	0.0			
Total in	2,167.3		2,155.8		3.6	15.1	-11.5
Out							
Evapotranspiration	1,250.0	57.7	1,205.0	55.9		45.0	
Downward leakage to layer 2	527.0	24.3	570.7	26.5	43.7		
Wells	8.0	0.4	9.1	0.4	1.1		
River discharge	279.0	12.9	273.0	12.7		6.0	
Lateral general head boundaries	7.4	0.3	7.7	0.4	0.3		
Constant heads	96.0	4.4	90.0	4.2		6.0	
Total out	2,167.4		2,155.5		45.1	57.0	-11.9
Layer 2							
In							
Downward leakage from layer 1	526.7	64.5	570.7	67.9	44.0		
Upward leakage from layer 3	102.1	12.5	99.6	11.8		2.5	
Lateral general head boundaries	188.0	23.0	170.7	20.3		17.3	
Total in	816.8		841.0		44.0	19.8	24.2
Out							
Upward leakage to layer 1	189.4	23.2	173.6	20.7		15.8	
Downward leakage to layer 3	9.5	1.2	10.1	1.2	0.6		
Wells	180.4	22.1	254.2	30.3	73.8		
Springs	308.6	37.8	275.9	32.9		32.7	
Lateral general head boundaries	24.0	2.9	24.3	2.9	0.3		
River discharge	105.0	12.9	101.0	12.0		4.0	
Total out	816.9		839.1		74.7	52.5	22.2

Table 15—*Continued*

Flux Type	Volumetric Flow Rates				Increase	Decrease	Net Change
	1995	%	2020	%			
Layer 3							
In							
Downward leakage from layer 2	9.7	6.0	10.1	5.7	0.4		
Lateral general head boundaries	99.6	61.3	93.4	52.7		6.2	
Saltwater boundaries	53.3	32.8	73.6	41.6	20.3		
Total in	162.6		177.1		20.7	6.2	14.5
Out							
Upward leakage to layer 2	102.1	62.8	99.6	56.2		2.5	
Lateral general head boundaries	60.5	37.2	77.5	43.8	17.0		
Saltwater boundaries	0.0	0.0	0.0	0.0			
Total out	162.6		177.1		17.0		14.5

Note: Discrepancies between individual values and corresponding totals may occur due to number of significant digits displayed.

The projected 2020 water budget for the Lower Floridan aquifer is similar to that for 1995, consisting of flow to and from the Upper Floridan aquifer, lateral GHBs, and saltwater boundaries. Saltwater boundaries were established immediately adjacent to locations within the Lower Floridan aquifer where the aquifer is inactive due to the estimated proximity of the 5,000-ppm chloride isochlor (McGurk et al. 1998). For the 1995 calibration, inputs were derived from both lateral head and saltwater boundaries. This pattern was maintained for the year 2020 projections, with increased flow from saltwater boundaries of 20 cfs. Similarly, simulated 2020 outputs to lateral GHBs increased from 61 to 78 cfs. A significant change in the boundary flows occurred west of the St. Johns River where flow increased from 98 cfs in 1995 to 65 cfs in 2020, suggesting the potential for salt water to move laterally into freshwater portions of the Lower Floridan aquifer in eastern Lake County (Figure 81). Also of note is the change in flow (61 cfs for 2020 and 38 cfs for 1995) to the southwest lateral boundary, suggesting the potential for relatively higher chloride water to occur at depth in this area due to projected pumping southwest of the study area.

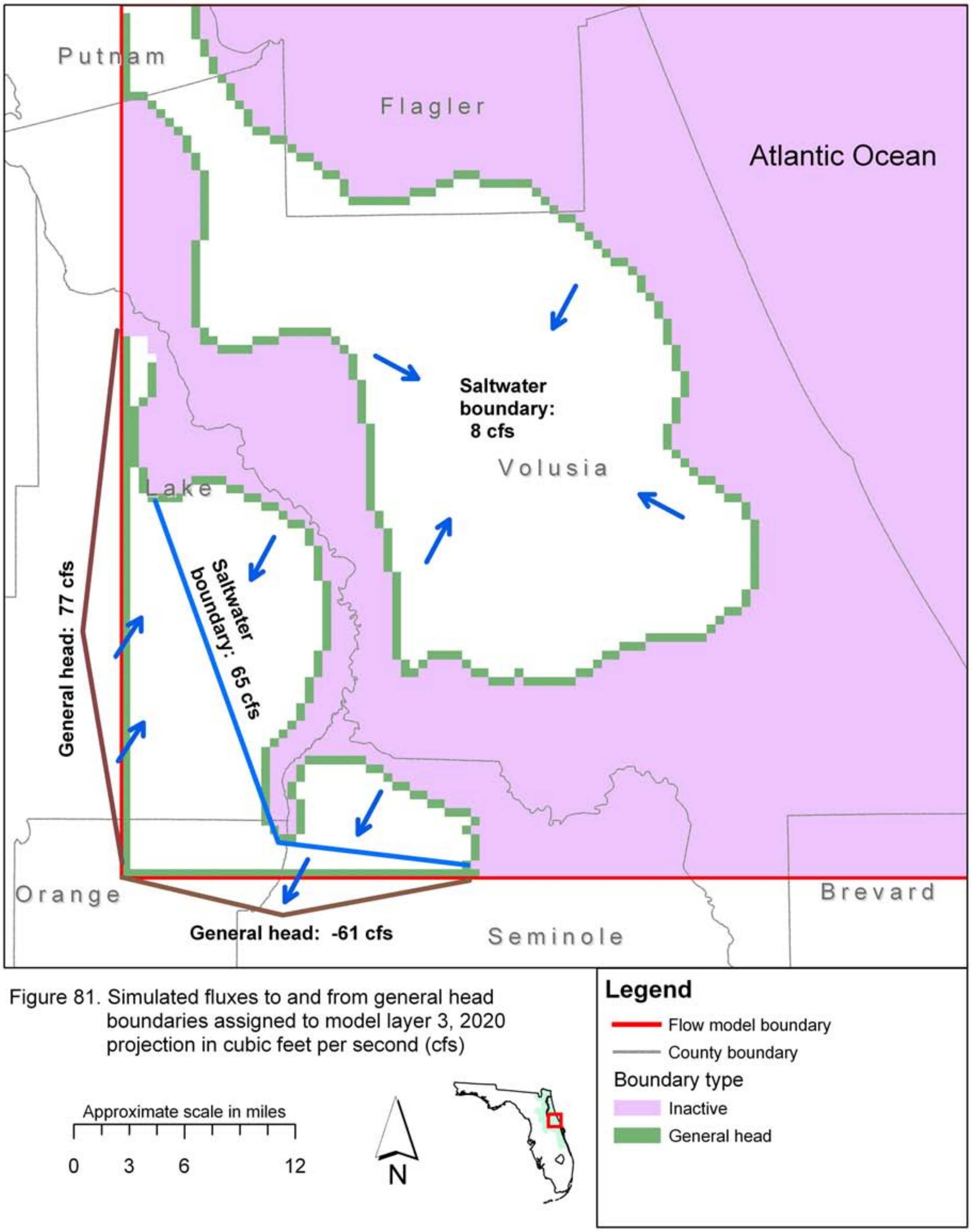


Figure 81. Simulated fluxes to and from general head boundaries assigned to model layer 3, 2020 projection in cubic feet per second (cfs)

PREDICTIVE SENSITIVITY ANALYSIS

The projected changes to Upper Floridan aquifer springflow rates and surficial aquifer system water levels are specified as constraints upon future water supply development within the SJRWMD water supply assessment (Burger 2004). In order to characterize the reliability of these projected changes, a sensitivity analysis was performed to determine the relative sensitivity of projected changes to changes in aquifer or confining unit properties and boundary conditions. Based upon this sensitivity analysis, the most influential model inputs were adjusted in order to determine reasonable ranges in predicted surficial aquifer system water level changes and springflow declines attribuTable to projected 2020 pumping increases. Specifically, simulations were completed for average 1995 and 2020 conditions, adjusting those parameters and/or boundary conditions to which the model is most sensitive. These model attributes were adjusted using multipliers adopted from the calibration sensitivity analysis that would best approximate the outer limits of the appropriate calibration range. For example, 1995 simulations were performed with R_{APP} multipliers of 0.2 and 2.0. These multiplier values served as maximum and minimum bounds of applied recharge that would satisfy the 1995 calibration criteria. Heads from the 1995 simulation became starting heads for 2020 simulation with the same adjustments to R_{APP}. This procedure was applied to a total of 12 parameters and/or boundary conditions (Table 16). The predicted surficial aquifer system water level changes and the percent declines in spring flow are compared to those for the base case (Table 16). The base case is defined as the 2020 model predictive simulation that is unaltered relative to aquifer parameters and/or boundary conditions.

A comparison between the sensitivity simulations and the base case indicates that prediction of surficial aquifer system water level change is most sensitive to the first four parameters listed on Table 16 (public supply usage, agricultural usage, ET_{MAX}, and intermediate confining unit leakance). Note that some model inputs, such as R_{APP}, were sensitive relative to surficial aquifer system water levels for the model calibration, but relatively insensitive relative to predictions of aquifer level changes (see subsequent discussion regarding sensitivity types, page 162).

The sensitivity of predicted springflow declines to parameter values and boundary conditions is assessed by comparing the percent declines for total spring flow from the base case (Table 13) to those from individual sensitivity

Table 16. Findings of the predictive sensitivity analysis recorded as departures from the base case, 2020 predictive simulation

Parameter or Boundary Condition	Multiplier/Change From Base Case	Mean Difference in Change in Water Level in the SAS (feet)*	Percent Decline in Total Spring Flow†
Public supply usage	0.80	0.05	8.0
Public supply usage	1.20	0.06	11.6
Agricultural usage	0.80	0.02	9.5
Agricultural usage	1.20	0.02	10.1
ET_{MAX}	0.80	0.06	9.7
ET_{MAX}	2.00	0.06	10.1
ICU leakance	0.67	0.04	10.7
ICU leakance	1.50	0.04	9.1
ET extinction depth	0.67	0.03	9.7
ET extinction depth	1.50	0.03	10.0
SAS K_h	0.50	0.03	10.0
SAS K_h	1.50	0.02	9.7
Applied irrigation (R_{APP})	0.20	0.01	9.8
Applied irrigation (R_{APP})	2.00	0.04	9.7
UFA K_h	0.67	0.02	10.2
UFA K_h	1.50	0.02	9.5
MSCU leakance	0.20	0.01	10.0
MSCU leakance	2.00	0.005	9.8
Drain conductance	0.67	0.005	9.6
Drain conductance	5.00	0.01	10.6
LFA saltwater boundaries	No flow	0.01	10.4
LFA saltwater boundaries	Constant heads	0.003	9.6
LFA K_h	0.20	0.005	10.0
LFA K_h	5.00	0.005	9.7

Note: ET = evapotranspiration
ICU = intermediate confining unit
K_h = horizontal hydraulic conductivity
LFA = Lower Floridan aquifer
MSCU = middle semiconfining unit
SAS = surficial aquifer system
UFA = Upper Floridan aquifer

*Modelwide average of the absolute value of the difference between the base case water level change and the predictive sensitivity simulation water level change.
†Simulated base case decline in total spring flow between 1995 and 2020 = 9.8%.

simulations. Predicted springflow declines were most sensitive to variability in intermediate confining unit leakance, public supply usage, drain conductance, and K_h of the Upper Floridan aquifer.

Four additional predictive sensitivity simulations were conducted based upon the results of the sensitivity analysis summarized in Table 16. The first two of these simulations were designed to assess the potential range of surficial aquifer system water level change due to 2020 Floridan aquifer system withdrawals, and were termed the minimum and maximum drawdown simulations. The objective of these parameter adjustments was to adjust parameter values so as to minimize the potential for decline in surficial aquifer system water levels due to projected 2020 withdrawals from the Floridan aquifer system, while maintaining the 1995 calibration within the limits defined by the calibration criteria. Multiplication factors were modified slightly from those listed in Table 16 in order to keep simulation results within the bounds of the 1995 calibration criteria. Simulations were conducted to assess the minimum and maximum projected 2020 drawdown distributions:

- Public supply usage was multiplied by 0.8 (min) and 1.2 (max).
- Maximum ET was multiplied by 1.25 (min) and 0.9 (max).
- ET extinction depth was multiplied by 0.67 (min) and 1.25 (max).
- Intermediate confining unit leakance was multiplied by 0.67 (min) and 1.25 (max).

The minimum drawdown simulation resulted in larger areas of predicted increases and smaller areas of predicted declines in surficial aquifer system water levels relative to the simulated drawdown from 1995 to 2020 for the base case (Figures 76 and 82). Similarly, the maximum drawdown simulation resulted in smaller areas of predicted increases and larger areas of predicted declines in surficial aquifer system water levels relative to the base case (Figure 76 and 83). A map of the range in the predicted change in average surficial aquifer system water levels due to 2020 Floridan aquifer system withdrawals (Figure 84) illustrates the absolute value of the range in water level change resulting from the minimum and maximum drawdown simulations.

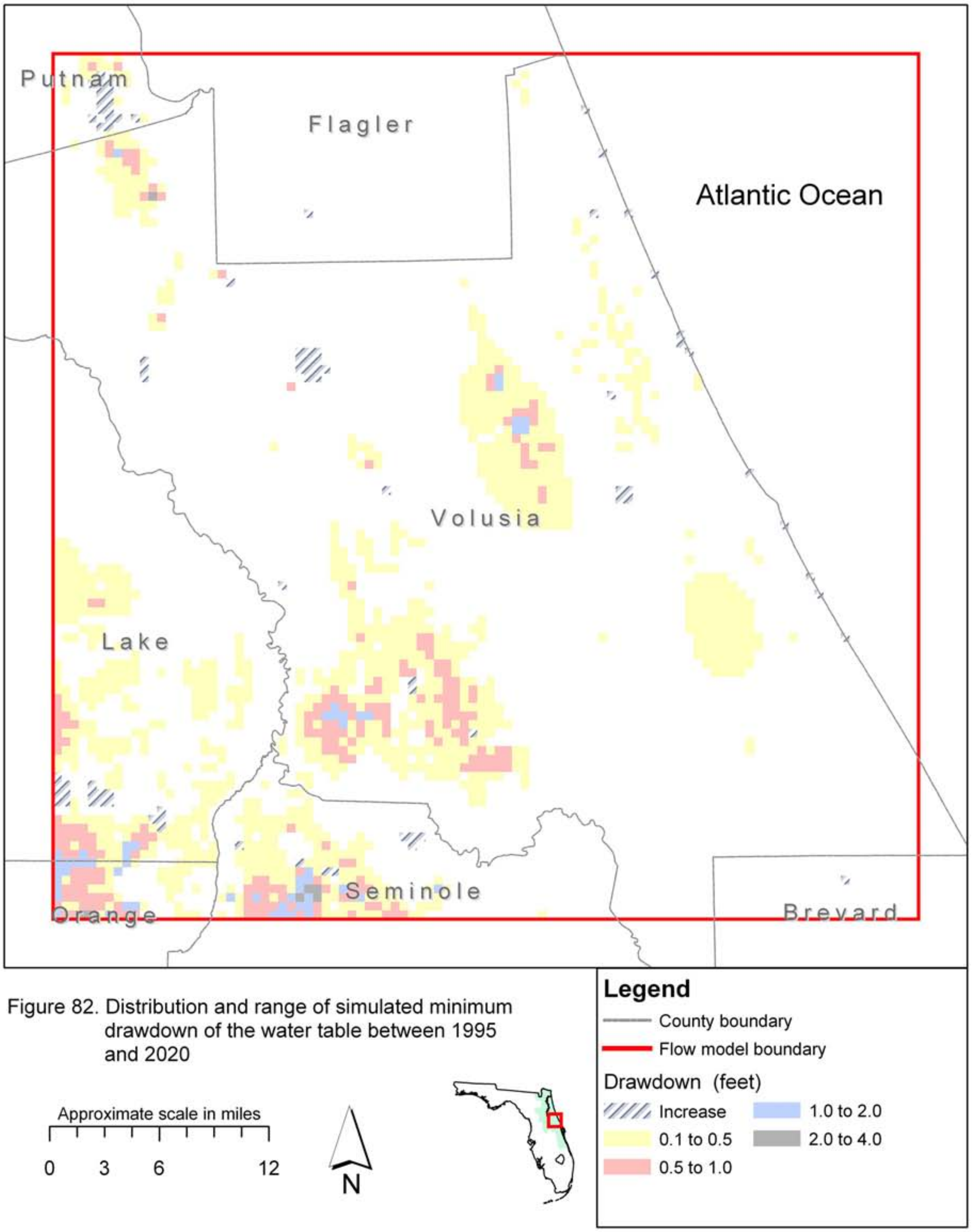


Figure 82. Distribution and range of simulated minimum drawdown of the water table between 1995 and 2020

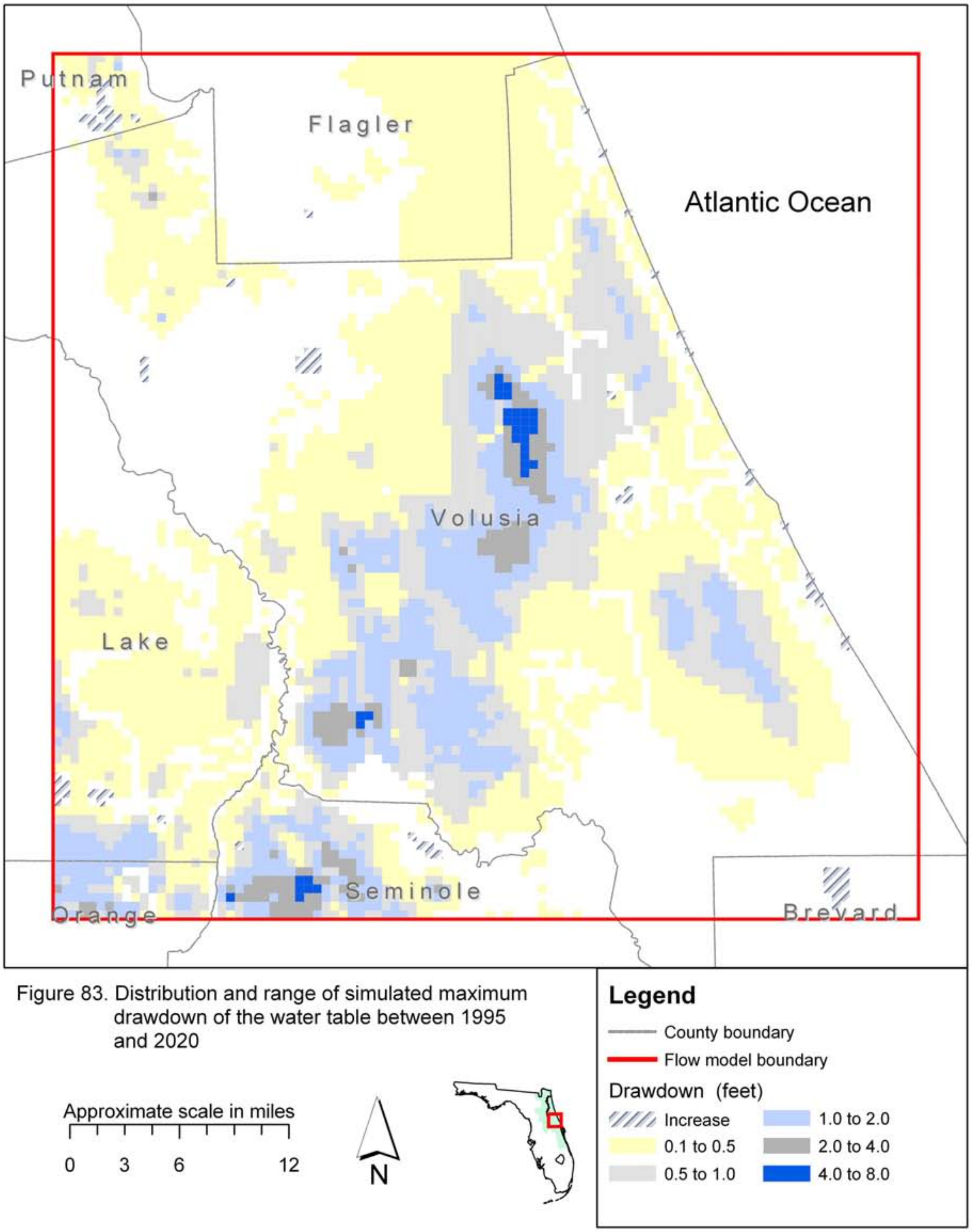


Figure 83. Distribution and range of simulated maximum drawdown of the water table between 1995 and 2020

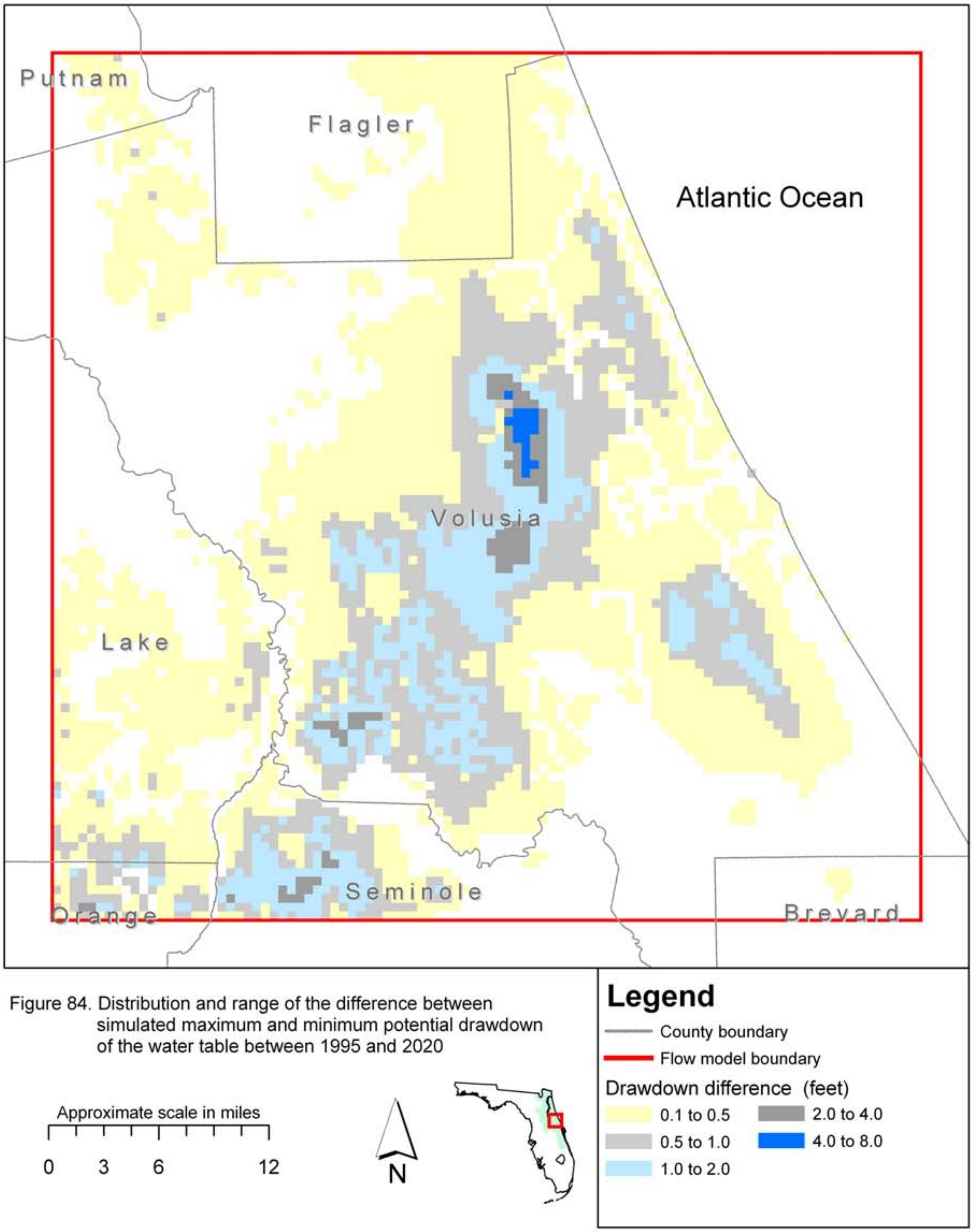


Figure 84. Distribution and range of the difference between simulated maximum and minimum potential drawdown of the water table between 1995 and 2020

Two additional predictive simulations were performed to estimate the potential range in springflow reductions due to projected 2020 withdrawals. The procedure discussed above was adapted to determine the appropriate multiplication factors for the minimum and maximum springflow reductions. To estimate the minimum and maximum reductions in average 2020 spring flows, the following adjustments to the simulation model were made:

- Intermediate confining unit leakance was multiplied by 1.2 (min) and 0.8 (max).
- Public supply usage was multiplied by 0.8 (min) and 1.2 (max).
- Drain conductance was multiplied by 1.2 (min) and 0.8 (max).
- Upper Floridan aquifer K_h was multiplied by 1.2 (min) and 0.8 (max).

The maximum and minimum predictions of average 2020 spring flows are 287.7 and 272.5 cfs, respectively (Table 13), indicating a range in total 2020 spring flow of 15.2 cfs, or approximately 5.4% of the spring flow predicted by the base case. The range in percent flow reduction for the first- and second-magnitude springs varies from 1.0% for Ponce de Leon Springs to 18.9% for Rock Springs for the base case (Table 13). The maximum predicted 2020 flow was greater than the adopted minimum or screening flow at all but two of the first- and second-magnitude springs (i.e., Rock and Seminole springs) (Table 13).

A comparison of the results of the predictive sensitivity analysis (Table 13) with those of the sensitivity analysis conducted for model calibration (Figures 73, 74, and 75) provides a mechanism to categorize model inputs into one of four sensitivity types (ASTM 1999), based upon sensitivities assessed during either the model calibration process or the prediction phase (Table 17). Variations in type I inputs do not cause significant impacts during either model calibration or model prediction. Type II inputs are sensitive relative to impacts upon model calibration, but relatively insensitive with respect to model predictions. Type III inputs are sensitive relative to both model calibration and prediction, and type IV inputs are relatively insensitive relative to model calibration and significant to the model prediction phase.

These sensitivity types are instrumental in assessment of the relative significance of model inputs to either the model calibration process or to the prediction phase. For example, variations in the K_h of the Lower Floridan aquifer and the leakance of the middle semiconfining zone are not significant

Table 17. Sensitivity types

A. Aquifer and confining unit properties

Parameter	Sensitivity Type—Surficial Aquifer System Water Levels	Sensitivity Type—Spring Flow
Layer 1 horizontal hydraulic conductivity	III	I
Layer 2 horizontal hydraulic conductivity	II	III
Layer 3 horizontal hydraulic conductivity	I	I
Intermediate confining unit leakance	III	III
Middle semiconfining unit leakance	I	I

B. Boundary conditions

Boundary Condition	Sensitivity Type—Surficial Aquifer System Water Levels	Sensitivity Type—Spring Flow
Recharge	II	II
ET extinction depth	III	I
Maximum ET	III	I
Public supply usage	III	III
Agricultural usage	III	IV
Drain conductance	I	III
Saltwater head boundaries	I	III

Note: ET = evapotranspiration

for either the model calibration or the prediction phase (Table 17). The K_h of the surficial aquifer system is significant for calibration and predictions of water levels and not for spring flow. The recharge distribution is more significant for the calibration than for model predictions (type II). Both ET extinction depth and maximum ET are important for surficial aquifer system water levels and not for springflow calibration or prediction. Simulated spring flow is relatively insensitive to agricultural pumpage as a function of model calibration due to the degree of spatial scatter regarding this type of water use. However, predictions of spring flow are sensitive to agricultural pumpage, indicating a type IV sensitivity. Finally, both drain conductance and saltwater head boundaries are significant to the calibration and prediction of spring flow and not to surficial aquifer system water levels.

MODEL CAPABILITIES AND LIMITATIONS

The regional groundwater flow model of Volusia County and the surrounding vicinity provides an excellent tool for the simulation of steady-state conditions representative of either a predevelopment or a postdevelopment time period. Based upon calibration results, the model is an excellent tool for the simulation of groundwater head and flow dynamics within both the surficial and the Floridan aquifer systems. The model incorporates a rigorous, integrated approach to the processing of recharge to the surficial aquifer system, accounting for rainfall, overland runoff, anthropogenic applications of irrigation and wastewater, and ET that occurs above the saturated groundwater zone. Model input parameters and output results have been compared with the adjacent east-central Florida regional model, providing a validation check upon the model. Finally, the model provides a credible tool for the prediction and assessment of groundwater conditions during a projected future time, specifically the year 2020. However, model capabilities must be balanced with corresponding limitations in order to present an integrated perspective regarding the merits of the model and the associated developmental approach.

A set of simplifying assumptions is necessary to conceptualize a hydrogeologic system and construct a computer-based model of sufficient complexity to adequately reproduce system responses. The characterization of the hydrogeologic system in the vicinity of Volusia County as three aquifers with intervening confining layers follows from previous modeling efforts and conforms to a reasonable and appropriate conceptualization of the hydrogeologic system. However, this conceptualization necessarily generalizes local heterogeneity, eliminating inclusion in the model of multiple permeable zones in the surficial aquifer system or the Upper Floridan aquifer. The use of a uniform value for surficial aquifer system K_h is a generalization where field data indicate a high degree of heterogeneity. The treatment of the intermediate confining unit as a heterogeneous distribution of leakance terms contributes favorably to the model design and calibration; however, direct measurement data to corroborate the physical basis for this approach are limited. In actual practice, leakance terms are generally empirical, the result of a model calibration effort that seeks to match observed potentiometric levels and hydraulic gradients. Elevations of aquifer tops and bottoms are interpolated spatial distributions based upon available point data. Actual elevations may be highly variable due to erosion, depositional patterns, and development of karst solution cavities and fracture networks. Similarly, calibration of the K_h distribution for the Upper Floridan aquifer emphasized aquifer test results.

Boundary conditions applied to the model are simplifications of hydrogeologic processes and features. For example, uncertainty exists relative to components of the recharge algorithm with respect to the application of water reuse, public supply landscape irrigation, and agricultural irrigation, as well as the appropriate locations of septic tank discharge, domestic self-supply wells, and abandoned free-flowing wells. The characterization of rainfall incorporates all available stations with sufficient daily rainfall data; however, this treatment is subject to the validity of extrapolation of data from these stations to their respective Thiessen polygons. Actual rainfall distribution data (i.e., derived from Doppler data) and direct observation indicate that rainfall patterns are highly variable spatially. Similarly, the characterization of rainfall (and other recharge components) with average annual values is a limitation of the steady-state approach to model development. Both actual rainfall and corresponding groundwater recharge are inherently transient processes with significant daily and seasonal variability. The characterization of rivers and streams requires assumptions regarding river stage and bottom elevations, river width, length of the reach within a model cell, and vertical hydraulic conductivity of the bottom sediments. Springs are characterized as head-dependent flux conditions requiring estimates of the conductance of the aquifer material surrounding the springs. GHBs include boundary heads estimated from published potentiometric surface maps and conductance terms based upon calibrated transmissivity values. Finally, the characterization of ET is limited in the selection of uniform values for extinction depth and the maximum ET value. Applied research regarding maximum ET indicates that it is a function of relative humidity, rainfall, temperature, and other variables. The ET surface is a spatial distribution of cell-based average values of land surface elevation that may not be locally representative of actual topographic elevations in areas of high local relief.

The ability to characterize and simulate changes in hydraulic heads and flow rates caused by changes in water use is limited for both the average 1995 model calibration and the 2020 projection. For public supply pumping, individual well pumping rates may not represent actual practice due to rotation schedules and seasonal variability. For agricultural pumping, withdrawal rates are estimated based on reported acreages and crop type. Reported acreage values may not represent actual practice, and crops are often rotated on a seasonal or yearly basis. Also, the simulated effects of agricultural pumping are representative of long-term average conditions, while actual agricultural irrigation is seasonal, occurring during the growing season of spring to early summer. However, given the steady-state design of the regional flow model, best efforts have been made to ensure that assumptions regarding water use are both conservative and reasonable.

All calibration data were reviewed to ensure adequate quality control. However, measurement errors exist in data used to formulate and calibrate the groundwater model. These inherent data errors affect the accuracy of groundwater and lake levels, spring flow and streamflow measurements, and rainfall quantities. The model calibration is also limited by the availability of data used to estimate overland runoff and baseflow, ET, and recharge to the surficial aquifer system and the Upper Floridan aquifer.

The accuracy of the groundwater model to depict local conditions is limited by the numerical grid resolution, or the error that is implied by the use of model cells to represent relatively small geographic sections of the regional groundwater system. Grid-scale error affects the characterization of aquifer and confining unit heterogeneity, the spatial representation of land surface elevation, simulated water levels in areas of high relief, lake stages as boundary conditions or calibration targets, groundwater flow in the vicinity of subterranean springs, and rivers and streams as boundary conditions.

Finally, interagency cooperation was emphasized during the development of water use projections for the year 2020. However, these projections are limited by uncertainty regarding future water use patterns. Future practices may dictate that growth will be faster or slower than currently projected or that agriculture may expand due to demand or diminish due to increased urban development. Similarly, impacts of water use (e.g., reduced viability of wetlands, declines in spring flows, or degradation in water quality) may dictate the need to develop alternative sources for public supply use. Future water resource management choices may provide alternative formulations of reuse that are not currently implemented in the simulation model.

SUMMARY AND CONCLUSIONS

A steady-state regional groundwater flow model was developed for the Volusia County regional area in east-central Florida as part of a water supply assessment performed for areas within the confines of SJRWMD. The calibrated groundwater model was used to assess changes in water levels and flow rates caused by water use patterns projected for the year 2020. The groundwater flow model incorporates a generalized conceptualization of aquifer hydrostratigraphy with supported assumptions to simulate hydrologic processes within the groundwater flow system. The model was favorably calibrated to both average 1995 and predevelopment water levels and hydraulic fluxes. The model calibration was evaluated with a set of pre-established criteria. Calibration criteria were implemented for the match between simulated values and measurement data for water levels in the surficial and the Upper and Lower Floridan aquifers, lake levels, spring flow in the Upper Floridan aquifer, and gaged surface water flow. Other evaluations of calibration criteria addressed ET rates, recharge / discharge rates between the surficial aquifer system and the Upper Floridan aquifer, and comparison of the simulated potentiometric surface for the Upper Floridan aquifer to field data or to potentiometric surface maps derived from this data. A comprehensive sensitivity analysis was performed to characterize the output responses of the model relative to the inputs of aquifer and confining unit properties and boundary conditions.

FINDINGS

The regional groundwater flow model was used to simulate changes in the water levels and spring flows caused largely by changes in groundwater pumping between 1995 and 2020. Simulated changes were projected in the average water Table elevation within the surficial aquifer system, in the elevation of the potentiometric surface of the Upper Floridan aquifer, and in simulated flow rates for subterranean springs, ET, and recharge / discharge between the surficial aquifer system and the Upper Floridan aquifer. Components of recharge applied to the surficial aquifer system were adjusted to allow for the inclusion of anticipated reuse applications (e.g., landscape irrigation, percolation ponds, spray fields), estimated landscape irrigation of poTable water, and expansion or contraction of areas where individual septic tank systems are the predominant method of wastewater discharge. Groundwater pumping rates were modified for 2020 based upon projected usage patterns. Peripheral GHBs were modified to account for projected pumping changes external to the model domain.

Simulated 2020 water Table declines are relatively high in east-central Volusia County where substantial public supply pumping increases are projected. In southwest Volusia County, the water Table is projected to decline in some areas by up to 4 ft due to increased pumping (Figure 76). The uncertainty of water Table declines was investigated by means of a detailed sensitivity analysis that provided a range of potential water Table declines. Projected declines in the potentiometric surface of the Upper Floridan aquifer are anticipated to be between 1 and 4 ft in southwest Volusia County, and drawdowns of over 4 ft are projected to occur in the vicinity of the Glen Abbey wellfield (Figure 77). An extensive area of decline is projected in east-central Volusia County, with water level changes between 2 and 8 ft and a maximum decline of over 10 ft near the Daytona Beach western wellfield (Figures 42 and 77). Flow to subterranean springs is projected to decline in response to declines in the potentiometric surface of the Upper Floridan aquifer. Overall spring flow is projected to decline by 31.3 cfs, or 10.0% of average 1995 flow (Table 13). Flow at two second-magnitude springs (Rock and Seminole) is predicted to decrease from a total of 100.3 cfs to 83.2 cfs. The projected 2020 flows for both springs are below their predetermined minimum flows. Flow to Blue Spring, a first-magnitude spring that provides winter habitat for manatees, is projected to decline by 13.0 cfs, or 8.6% by the year 2020.

A predictive sensitivity analysis was performed to determine the most critical aquifer parameters and / or boundary conditions relative to projected system changes. Changes to the water Table elevation in the surficial aquifer system are most sensitive to the maximum rate of ET, the ET extinction depth, the leakance of the intermediate confining unit, and the surficial aquifer system K_h. Upper and lower bounds were assigned to these model components in order to estimate maximum and minimum projected water Table changes. A similar procedure was performed for spring flow, and the most sensitive parameters were the intermediate confining unit leakance, Lower Floridan aquifer saltwater boundaries, drain conductances, and Upper Floridan aquifer K_h (Tables 12 and 15).

The maximum and minimum predictions of average 2020 spring flows are 287.7 and 272.5 cfs, respectively (Table 13), indicating a range in total 2020 spring flow of 15.2 cfs, or approximately 5.4% of the spring flow predicted by the base case. The range in percent flow reduction for the first- and second-magnitude springs varies from 1.0% for Ponce de Leon Springs to 19.0% for Rock Springs (Table 13).

An increase in lateral flow across the saltwater head boundary to the west of the St. Johns River into the simulated portion of the Lower Floridan aquifer between 1995 (48 cfs, Figure 72) and 2020 (65 cfs, Figure 81) indicates the potential for water of relatively high chloride content to migrate laterally into the simulated freshwater within the Lower Floridan aquifer in eastern Lake County. Similarly, fresh groundwater discharge (i.e., moving out of the model domain) within the Lower Floridan aquifer is projected to increase across the western portion of the southern boundary between 1995 (38 cfs, Figure 72) and 2020 (61 cfs, Figure 81). This increase in boundary discharge flow with the associated increase in flow from the St. Johns River area into the southwest portion of the model discussed above provides indicators for the potential for movement of high chloride water into the simulated fresh portion of the Lower Floridan aquifer. These boundary flux changes between 1995 and 2020 are directly related to a projected reduction in potentiometric levels to the south and west of the model domain. As discussed above, one of the modifications to model boundary conditions for the 2020 projection involves a reduction in boundary source heads in the general head boundaries along the southern and western perimeter boundaries. The magnitude of this reduction is based upon the projected 2020 simulation for the east-central Florida model that circumscribes a relatively large regional area surrounding the greater metropolitan Orlando area. The reduction in pressure within both the Upper and Lower Floridan aquifers to the south and west of the Volusia model domain is directly connected with the increase in flow across the southern boundary of the model.

RECOMMENDATIONS FOR ADDITIONAL INVESTIGATION

The objectives of the regional groundwater flow modeling project of Volusia County and the surrounding vicinity are (1) to synthesize a simulation model that sufficiently characterizes the hydrogeologic system that underlies the study area using appropriate hydrogeologic data and (2) to apply the model to predict projected changes to hydrologic levels and flow rates based upon projected water use patterns.

Recommendations for additional investigations have been developed to facilitate these objectives for future work and to improve the characterization of aquifer and confining unit parameters and hydrologic processes.

- The current groundwater model is limited by the characterization of aquifer and confining unit parameters, specifically the horizontal hydraulic conductivity of aquifer layers and the leakance of confining zones. Improvements in the characterization of the spatial distribution of the horizontal hydraulic conductivity of aquifer units are recommended. Specific methods for the performance of this objective are to perform additional aquifer performance tests and to develop a transient groundwater flow model for the study area.

- Additional investigation into the subterranean karst network in the vicinity of Blue Spring is recommended to enhance the level of understanding and associated simulation capability with respect to origins and patterns of flow within the spring basin. Investigative methods could include examination and possible correlation of hydrostratigraphic elevations and flow zones through interpretation of geophysical logs from existing wells, examination of transient water levels at monitor wells within the basin, particle tracking to interpret potential pathways of groundwater flow, and possible use of a dual-zone conduit model to better track groundwater flow.

- Leakage of the intermediate confining unit is critical with respect to groundwater levels within the surficial and Upper Floridan aquifers and associated recharge / discharge patterns between the aquifers. Refinement of the leakance of the intermediate confining unit is recommended by means of hydrograph analysis and hypothetical model simulations.

- The characterization of the distributions of water reuse, public supply landscape irrigation, septic tank discharge, and agricultural applications are important aspects of the capability to accurately determine water use and reuse patterns. Improvements in these distributions could be achieved through examination of SJRWMD consumptive use permit files, GIS-based examination of land use patterns, and investigation of locally maintained databases or related resources.

- The characterization of components of the algorithm formulated for recharge to the surficial aquifer system, including overland runoff, stream baseflow, ET, and rainfall, could benefit from additional investigation. Improvements are possible through investigation and application of methods to enhance understanding of these processes, including application of hydrograph separation for surface water flow, implementation of time-delayed recharge due to infiltration, incorporation of spatial and temporal variability in values for maximum and minimum ET, and incorporation of distributed Doppler-based radar rainfall data.

- Enhancements are recommended in the characterization of head-dependent flux boundaries, including rivers and streams, springs, and lateral GHBs. This objective could be achieved through further refinement of the components of these boundary types with respect to both spatial and temporal variability. Also, the objective could be further achieved through a series of sensitivity analyses combined with interpretation of GIS-based maps of the boundary feature in question and examination of the appropriate data.

- Model grid-scale error should be minimized by developing simulation models with a reduced grid size, thereby enhancing the characterization of the land surface elevation, water Table profiles, groundwater flow in the vicinity of subterranean springs, and the simulation of rivers, streams, and lakes as boundary conditions.

- In order to sufficiently track the impacts of spatial and temporal patterns of anthropogenic influences upon the hydrogeologic system, development of a transient regional groundwater flow model is recommended. Such a model would facilitate significant leaps in the state of understanding regarding the applied management of the groundwater resources within the study area.

BIBLIOGRAPHY

[ASTM] American Society for Testing and Materials. 1999. *ASTM standards on determining subsurface hydraulic properties and groundwater modeling*. 2d ed. West Conshohocken, Pa.

Adamus, C., D. Clapp, and S. Brown. 1997. *Surface water drainage basin boundaries: St. Johns River Water Management District: A reference guide*. Technical Publication SJ97-1. Palatka, Fla.: St. Johns River Water Management District.

Anderson, W., and D.A. Goolsby. 1973. *Flow and chemical characteristics of the St. Johns River at Jacksonville, Florida*. Information Circular 82. Tallahassee, Fla.: Florida Bureau of Geology.

Boniol, D., M. Williams, and D. Munch. 1993. *Mapping recharge to the Floridan aquifer using a geographic information system*. Technical Publication SJ93-5. Palatka, Fla.: St. Johns River Water Management District.

Burger, P. 2004 (draft). Volusia County optimization and decision model. St. Johns River Water Management District, Palatka, Fla.

Bush, P.W. 1978. *Hydrologic evaluation of part of central Volusia County, Florida*. Water-Resources Investigations Report 78-89. Tallahassee, Fla.: U.S. Geological Survey.

Curtis, W.A. 1998. *Annual report on abandoned artesian wells, 1995*. Special Publication SJ98-SP16. Palatka, Fla.: St. Johns River Water Management District.

Florence, B.L., and C. Moore. 1997. *Annual water use survey, 1995*. Technical Publication SJ97-4. Palatka, Fla.: St. Johns River Water Management District.

Geraghty and Miller, Inc. 1991. *Numerical modeling of groundwater flow and seawater intrusion, Volusia County, Florida*. Special Publication SJ92-SP6. Palatka, Fla.: St. Johns River Water Management District.

Gomberg, D.N. 1980. Available groundwater at National Gardens Trust, Volusia County, Florida. Cape Coral, Fla.

———. 1981. Water resources and available groundwater at Halifax Plantation, Volusia and Flagler counties, Florida. Cape Coral, Fla.

Grove, M., J. Harbor, and B. Engel. 1998. Composite vs. distributed curve numbers: Effects on estimates of storm runoff depths. *Journal of the American Water Resources Association* 34(5).

Harbaugh, A.W., and M.G. McDonald. 1996. *User's documentation for MODFLOW-96—An update to the U.S. Geological Survey modular finite-difference groundwater flow model*. Open-File Report 96-485. Reston, Va.: U.S. Geological Survey.

Johnson, R.H. 1981. *Structural geologic features and their relationship to salt water intrusion in west Volusia, north Seminole, and northeast Lake counties.* Technical Publication SJ81-1. Palatka, Fla.: St. Johns River Water Management District.

Johnston, R.H., R.E. Krause, F.W. Meyer, P.D. Ryder, C.H. Tibbals, and J.D. Hunn. 1980. *Estimated potentiometric surface for the Tertiary limestone aquifer system, southeastern United States, prior to development.* Open-File Report 80-406. Tallahassee, Fla.: U.S. Geological Survey.

Knochenmus, D.D., and M.E. Beard. 1971. *Evaluation of the quantity and quality of the water resources of Volusia County, Florida*. Florida Geological Survey Report of Investigations 57. Tallahassee, Fla.: Florida Bureau of Geology.

Knochenmus, D.D., and G.H. Hughes. 1976. *Hydrology of Lake County, Florida*. Water-Resources Investigations Report 76-72. Tallahassee, Fla.: U.S. Geological Survey.

Knowles, L., Jr., A.M. O'Reilly, G.G. Phelps, and L.A. Bradner. 1995. *Potentiometric surface of the Upper Floridan aquifer in the St. Johns River Water Management District and vicinity, Florida, May 1995*. Open-File Report 95-461. Altamonte Springs, Fla.: U.S. Geological Survey.

Kohler, M.A., T.J. Norderson, and D.R. Baker. 1959. *Evaporation maps for the United States*. Technical Paper 37. Washington, D.C.: U.S. Weather Bureau.

Lichtler, W.F., W. Anderson, and B.F. Joyner. 1968. *Water resources of Orange County, Florida.* Report of Investigations 50. Tallahassee, Fla.: U.S. Geological Survey.

Marella, R.L. 1995. *Water use data by category, county, and water management district in Florida, 1950–1990.* Open-File Report 94-521. Tallahassee, Fla.: U.S. Geological Survey.

———. 1999. *Water withdrawals, use, discharge, and trends in Florida, 1995.* Water-Resources Investigations Report 99-4002. Tallahassee, Fla.: U.S. Geological Survey.

McDonald, M.G., and A.W. Harbaugh. 1988. A modular three-dimensional finite-difference groundwater flow model. *Techniques of Water-Resources Investigations*: Book 6, Chapter A1. U.S. Geological Survey. Washington, D.C.: U.S. Government Printing Office.

McGurk, B., and P. Presley. 2002. *Simulation of the effects of groundwater withdrawals on the Floridan aquifer system in east-central Florida: Model expansion and revision*. Technical Publication SJ2002-3. Palatka, Fla.: St. Johns River Water Management District.

McGurk, B., P. Bond, and D. Mehan. 1989. *Hydrogeologic and lithologic characteristics of the surficial deposits in Volusia County, Florida*. Technical Publication SJ89-7. Palatka, Fla.: St. Johns River Water Management District.

McGurk, B., D. Toth, and P. Burger. 1998. *An examination of changes in salinity with depth within the Floridan aquifer system in the St. Johns River Water Management District, Florida: Delineation of the elevations of the 250, 1000, and 5,000 mg/L isosurfaces* (abstract). Annual Water Resources Conference, November 16–19. Point Clear, Ala.: American Water Resources Association.

Mercer, J.W., S.D. Thomas, B.H. Lester, and R.W. Broome. 1984. *Saltwater intrusion in Volusia County, Florida, due to groundwater withdrawals: Technical summary*. Technical Publication SJ85-1. Palatka, Fla.: St. Johns River Water Management District.

Miller, J.A. 1986. *Hydrogeologic framework of the Floridan aquifer system in Florida and in parts of Georgia, Alabama, and South Carolina.* Professional Paper 1403-B. Denver, Colo.: U.S. Geological Survey.

Murray, L.C., and K.J. Halford. 1996. *Hydrogeologic conditions and simulation of ground-water flow in the greater Orlando metropolitan area, east-central Florida.* Water-Resources Investigations Report 96-4181. Tallahassee, Fla.: U.S. Geological Survey.

O'Reilly, A.M., R.M. Spechler, and B.E. McGurk. 2002. *Hydrogeology and water-quality characteristics of the Lower Floridan aquifer in east-central Florida.* Water-Resources Investigations Report 02-4193. Tallahassee, Fla.: U.S. Geological Survey.

O'Reilly, A.M., L.A. Bradner, L. Knowles Jr., and G.G. Phelps. 1996. *Potentiometric surface of the Upper Floridan aquifer in the St. Johns River Water Management District and vicinity, Florida, September 1995.* Open-File Report 96-131. Altamonte Springs, Fla.: U.S. Geological Survey.

Phelps, G.G. 1990. *Geology, hydrology, and water quality of the surficial aquifer system in Volusia County, Florida.* Water-Resources Investigations Report 90-4069. Tallahassee, Fla.: U.S. Geological Survey.

Pollock, D.W. 1994. *User's guide for MODPATH/MODPATH-PLOT, version 3: A particle tracking post-processing package for MODFLOW, the U.S. Geological Survey finite-difference ground-water flow model.* Open-File Report 94-464. Reston, Va.: U.S. Geological Survey.

Post Buckley Schuh and Jernigan. 1990. Floridan aquifer testing and analysis: Bull Creek Wildlife Management Area, Osceola County. Orlando, Fla.

Rao, D.V., S. A. Jenab, and D. Clapp. 1997. *Rainfall analysis for northeast Florida, summary of monthly and annual rainfall data through 1995.* Special Publication SJ97-SP22. Palatka, Fla.: St. Johns River Water Management District.

Rosenau, J.C., G.L. Faulkner, C.W. Hendry Jr., and R.W. Hull. 1977. *Springs of Florida.* Bulletin 31 (revised). Tallahassee, Fla.: Florida Bureau of Geology.

Rutledge, A.T. 1982. *Hydrology of the Floridan aquifer in northwest Volusia County, Florida.* Water-Resources Investigations Open-File Report 82-108. Tallahassee, Fla.: U.S. Geological Survey.

———. 1985. *Groundwater hydrology of Volusia County, Florida, with emphasis on occurrence and movement of brackish water.* Water-Resources Investigations Report 84-4206. Tallahassee, Fla.: U.S. Geological Survey.

Scott, T.M. 1988. *The lithostratigraphy of the Hawthorn Group (Miocene) of Florida.* Bulletin 59. Tallahassee, Fla.: Florida Geological Survey.

Shoemaker, W.B., A.M. O'Reilly, N. Sepulveda, S.A. Williams, L.H. Motz, and Q. Sun. 2003. *Comparison of estimated areas contributing recharge to selected springs in north-central Florida by using multiple ground-water flow models.* Water-Resources Investigations Open-File Report 03-448. Tallahassee, Fla.: U.S. Geological Survey.

Simonds, E.P., Jr., B.F. McPherson, and P.W. Bush. 1980. *Shallow ground-water conditions and vegetation classification, central Volusia County, Florida.* Water-Resources Investigations Open-File Report 80-752. Tallahassee, Fla.: U.S. Geological Survey.

Snyder, S.W., M.W. Evans, A.C. Hine, and J.S. Compton. 1989. Seismic expression of solution collapse features from the Florida platform. In *Proceedings of the third multidisciplinary conference on sinkholes and the engineering and environmental impact of karst*, B.F. Beck, ed. St. Petersburg Beach, Fla.

Stringfield, V.T. 1936. *Artesian water in the Florida peninsula.* Water-Supply Paper 773-C. U.S. Geological Survey. Washington, D.C.: U.S. Government Printing Office.

Sumner, D.M. 1996. *Evapotranspiration from successional vegetation in a deforested area of the Lake Wales Ridge, Florida.* Water-Resources Investigations Report 96-4244. Tallahassee, Fla.: U.S. Geological Survey.

Szell, G. 1993. *Aquifer characteristics in the St. Johns River Water Management District*. Technical Publication SJ93-1. Palatka, Fla.: St. Johns River Water Management District.

Tibbals, C.H. 1977. *Availability of groundwater in Seminole County and vicinity, Florida.* Water-Resources Investigations Report 76-97. Tallahassee, Fla.: U.S. Geological Survey.

———. 1981. *Computer simulation of the steady-state flow system of the Tertiary limestone (Floridan) aquifer system in east-central Florida.* Water-Resources Investigations Open-File Report 81-681. Tallahassee, Fla.: U.S. Geological Survey.

———. 1990. *Hydrology of the Floridan aquifer system in east-central Florida—Regional aquifer system analysis.* Professional Paper 1403-E. Washington, D.C.: U.S. Geological Survey.

U.S. Department of Agriculture Soil Conservation Service. 1986. *Urban hydrology for small watersheds.* Technical Release 55. Washington, D.C.: U.S. Department of Agriculture.

[USGS] U.S. Geological Survey. 1996. *Water resources data Florida water year 1995*. Vol. 1B. *Northeast Florida groundwater*. Water-Data Report FL-95-1B. Tallahassee, Fla.: U.S. Geological Survey.

———. 1997. *Water resources data Florida water year 1996*. Vol. 1A, *Northeast Florida surface water*. Water-Data Report FL-96-1A. Tallahassee, Fla.: U.S. Geological Survey.

———. 1998. *Water resources data Florida water year 1996*. Vol. 1B, *Northeast Florida groundwater*. Water-Data Report FL-96-1B. Tallahassee, Fla.: U.S. Geological Survey.

Vergara, B., editor. 1994. *Water supply needs and sources assessment*. Technical Publication SJ94-7. Palatka, Fla.: St. Johns River Water Management District.

———. 1998. *Water supply assessment, St. Johns River Water Management District*. Technical Publication SJ98-2. Palatka, Fla.: St. Johns River Water Management District.

Visher, F.N., and G.H. Hughes. 1975. *The difference between rainfall and potential evaporation in Florida*. 2d ed. Map Series 32. Tallahassee, Fla.: Florida Bureau of Geology.

Vecchioli, J., C.H. Tibbals, A.D. Duerr, and C.B. Hutchinson. 1990. *Ground-water recharge in Florida—A pilot study in Okaloosa, Pasco, and Volusia counties*. Water-Resources Investigations Report 90-4195. Tallahassee, Fla.: U.S. Geological Survey.

White, W.A. 1970. *The geomorphology of the Florida peninsula*. Bulletin 51. Tallahassee, Fla.: Florida Bureau of Geology.

Williams, S.A. 1997. *A regional groundwater flow model of the Volusia groundwater basin*. Technical Publication SJ97-3. Palatka, Fla.: St. Johns River Water Management District.

Wyrick, G.G. 1960. *The ground-water resources of Volusia County, Florida*. Report of Investigations 22. Tallahassee, Fla.: Florida Bureau of Geology.

APPENDIX A—RAINFALL DATA COLLECTION STATIONS WITH TOTAL 1995 DAILY RAINFALL

Years of Record	Measurement Type	Rainfall Total (inches)	Normal Annual Rainfall: 1961–1990 (inches)	1995 Departure From Normal (inches)
6	Telemetry	53.86		
107	Nonrecording gage	49.95	54.07	–4.12
<5	Telemetry	52.11		
7	Telemetry	46.31		
44	Nonrecording gage	59.32	48.81	10.51
5	Telemetry	53.14		
5	Telemetry	44.31		
Unknown	Observer	59.23		
Unknown	Observer	59.34		
Unknown	Observer	65.59		
Unknown	Observer	65.26		
Unknown	Observer	62.09		
7	Observer	45.85		
9	Observer	66.03		
5	Observer	61.12		
9	Observer	59.00		
97	Nonrecording gage	48.60	56.05	–7.45
Unknown	Observer	50.60		
Unknown	Observer	56.53		
7	Observer	46.68		
<5	Telemetry	42.79		
86	Recording gage	54.44	47.89	6.55
Unknown	Observer	53.81		
Unknown	Observer	49.00		
<5	Telemetry	54.41		
Unknown	Observer	57.24		
Unknown	Observer	57.81		
Unknown	Observer	54.82		
		55.29	51.705	

APPENDIX B—SURFACE WATER DATA SITES

Table B1. Stream gaging stations

Site Number	USGS Site ID Number	Site Name	Data Type	Source of Data
STR1	2234000	St. Johns River above Lake Harney	SD	USGS
STR2	2234100	Deep Creek near Osteen	D	USGS
STR3	2234435	Lake Jesup outlet near Sanford	D	USGS
STR4	2234500	St. Johns River near Sanford	SD	USGS
STR5	2235,000	Wekiva River near Sanford	D	USGS
STR6	2235200	Blackwater Creek near Cassia	D	USGS
STR7	2236000	St. Johns River near DeLand	SD	USGS
STR8	2236120	Deep Creek near Barberville	D	USGS
STR9	2244320	Middle Haw Creek near Korona	D	USGS
STR10	2244420	Little Haw Creek near Seville	D	USGS
STR11	2247465	Bellevue Canal at Daytona Beach	D	USGS
STR12	2247480	Tiger Bay Canal near Daytona Beach	D	USGS
STR13	2247493	Bayless Blvd. Canal at Daytona Beach	D	USGS
STR14	2247496	Thayer Canal near Daytona Beach	D	USGS
STR15	2247498	Wally Hoffmeyer Canal at Daytona Beach	D	USGS
STR16	2247499	Williamson Blvd. Ditch at Daytona Beach	D	USGS
STR17	2247500	Tomoka River near Daytona Beach	D	USGS
STR18	2247508	Eleventh Street Canal near Holly Hill	D	USGS
STR19	2247510	Tomoka River near Holly Hill	D	USGS
STR20	2248000	Spruce Creek near Samsula	D	USGS
STR21	2248040	B-19 Canal at Port Orange	D	USGS

Note:
D = discharge
S = stage only
SD = stage and discharge
USGS = U.S. Geological Survey

Table B2. Lake/estuary water level stations

Site Number	USGS Site ID Number	Lake/Estuary	Treatment in Model	Source of Data
L1		Acorn Fish Lake	T	SJRWMD
L2		Banana River Lagoon	CH	TM
L3		Big Lake	T	SJRWMD
L4		Blue Lake	T	SJRWMD
L5		Cain Lake	T	SJRWMD
L6		Cow Pond	T	SJRWMD
L7		Crescent Lake	CH	USGS
L8		Dead Lake	T	SJRWMD
L9		Dream Pond	T	SJRWMD
L10		Drudy Lake	T	SJRWMD
L11		Indian River Lagoon	CH	TM
L12		Lake Akron	T	SJRWMD
L130		Lake Ashby	CH	SJRWMD
L14		Lake Butler	T	SJRWMD
L15		Lake Dan George	T	SJRWMD
L16		Lake Daugherty	T	SJRWMD
L17		Lake Dexter	CH	SJRWMD
L18		Lake Dias	CH	SJRWMD
L19		Lake Disston	CH	SJRWMD
L20		Lake Dupont	T	SJRWMD
L21		Lake Emporia	T	SJRWMD
L22	2236120	Lake George	CH	USGS
L23	2234000	Lake Harney	CH	USGS
L24		Lake Hires	T	SJRWMD
L25	2234434	Lake Jesup	CH	USGS
L26		Lake Juanita	T	SJRWMD
L27		Lake Konomac	CH	TM
L28		Lake McGarity	T	SJRWMD
L29	2234499	Lake Monroe	CH	USGS
L30		Lake Norris	CH	SJRWMD
L31		Lake Pierson	T	SJRWMD

Table B2—*Continued*

Site Number	USGS Site ID Number	Lake/Estuary	Treatment in Model	Source of Data
L32		Lake Purdom	T	SJRWMD
L33		Lake Stella	T	SJRWMD
L34		Lake Talmadge	T	TM
L35		Lake Theresa	T	SJRWMD
L36	2234160	Lake Winnemissett	T	USGS
L37	2244350	Lake Winona	T	USGS
L38		Lake Woodruff	CH	TM
L39		Lower Lake Louise	T	SJRWMD
L40		Mosquito Lagoon	CH	TM
L41		Ponce de Leon Inlet	CH	TM
L42		Shaw Lake	T	SJRWMD
L43		Silver Lake	T	SJRWMD
L44		Spring Garden Lake	T	TM
L45		Stone Pond	T	SJRWMD
L46		Sylvan Lake	T	SJRWMD
L47		Upper Lake Louise	T	SJRWMD

Note: CH = constant head
SJRWMD = St. Johns River Water Management District
T = target lake; stage used for 1995 calibration
TM = estimated from 1:24,000 topographic maps
USGS = U.S. Geological Survey

APPENDIX C—OBSERVATION AND TEST WELLS

Appendix C. Observation and Test Wells

Lat	Long	Site No.	Site Alph	USGS ID	SJR ID	Stn_Name	Aquifer	Cas Dep	Tot Dep	Calib 95	Data Src
284234	812739	1	A	284234081273901	-	84212702 20S28E36	UFA	-	-	-	USGS
284244	812349	2	A	284244081234901	-	84212302 20S29E34	UFA	-	-	Y	USGS
284331	810310	3	A	284331081031001	-	84310302 20S33E30	UFA	-	-	Y	USGS
284434	810501	4	A	284434081050101	-	84410503 POT MAP WELL NR	UFA	-	-	Y	USGS
284440	811759	5	A	284440081175901	-	84411722 20S30E15	UFA	-	75	Y	USGS
284453	812844	6	A	284453081284401	-	84412801 20S28E14	UFA	-	-	Y	USGS
284516	812240	7	A	284516081224001	-	84512203 20S29E14	UFA	-	-	Y	USGS
284533	812048	8	A	284533081204801	-	84512005 20S30E08	UFA	-	97	Y	USGS
284550	810715	9	A	284550081071501	-	84510703 CAMERON WELL NR	UFA	-	77	Y	USGS
284618	810954	10	A	284618081095401	-	84610902 20S31E12	UFA	-	-	Y	USGS
284645	811524	11	A	284645081152401	-	84611515 20S31E06	UFA	-	108	Y	USGS
284712	810443	12	A	284712081044301	-	84710401 CO. LANDFILL OS	UFA	-	70	Y	USGS
284728	813222	13	A	284728081322201	-	LAKE 847-132-1 SORRENTO	UFA	-	60	-	USGS
285002	812151	14	A	285002081215101	-	85012101 19S29E38	UFA	-	-	Y	USGS
285044	810949	15	A	285044081094901	-	85010903 OSTEEN CONVENIE	UFA	-	-	Y	USGS
285221	810950	16	A	285221081095002	-	85210902 USGS TEST WELL	UFA	-	74	Y	USGS
285359	811617	17	A	285359081161701	-	85311601 DELT. P.S. WELL	UFA	-	76	-	USGS
285539	812629	18		285539081262901	-	PINE LAKES WELL ON SR 44	UFA	-	155	Y	USGS
285655	811656	19		285655081165601	-	85611601 USGS TEST WELL	UFA	-	152	Y	USGS
285859	811910	20		285859081191001	-	85811901 MCGREGGOR RD.4"	UFA	-	-	Y	USGS
290047	812325	21		290047081232501	-	900123 17S29E	UFA	-	-	-	USGS
290244	813026	22		290244081302601	-	90213001 17S28E03	UFA	-	85	Y	USGS
290251	810014	23		290251081001401	-	90210001 USGS TEST WELL	UFA	-	316	Y	USGS
290445	813440	24		290445081344001	-	90413401 S27E	UFA	-	-	-	USGS
290447	811023	25		290447081102301	-	90411004 I-4 DEEP WELL	UFA	-	-	Y	USGS
290715	813030	26		290820081305001	-	908130 16S28E FRANK	UFA	-	135	-	USGS
290842	810846	27		290842081084601	-	90810803 USGS TEST WELL	UFA	-	95	-	USGS
290900	813420	28		290900081342002	-	909134 15S27E ASTOR	UFA	-	135	-	USGS
290923	811743	29		290923081174301	-	90911701 15S30E33 WELL	UFA	-	-	-	USGS
292539	812318	30		-	F-0028	GAISFORD, RICHARD D.	ICU	65	85	-	SJRWMD
292430	812102	31		-	F-0033	DAY, RICHARD	ICU	37	47	-	SJRWMD
292200	810920	32		-	F-0039	BIDDLES, CHERE M.	ICU	77	85	-	SJRWMD
292430	812056	33		-	F-0041	LITES, PHILLIP	ICU	84	93	-	SJRWMD
292750	812211	34		-	F-0044	KINGS FARM	UFA	170	443	-	SJRWMD
292531	810727	35		-	F-0055	DUGGINS, MICHAEL	SAS	18	24	-	SJRWMD

Lat	Long	Site No.	Site Alph	USGS ID	SJR ID	Stn_Name	Aquifer	Cas Dep	Tot Dep	Calib 95	Data Src
292523	812347	36		-	F-0066	PHILLIP FREE	UFA	95	198	-	SJRWMD
292750	811520	37		-	F-0087	KUDRNA, W.E.	UFA	888	417	-	SJRWMD
291955	812009	38		-	F-0097	KENDALL	UFA	0	0	-	SJRWMD
291902	811856	39		-	F-0108	BUD HENRY	UFA	59	325	-	SJRWMD
292647	811820	40		-	F-0126	ALLEN GEORGE	UFA	122	310	-	SJRWMD
292622	811302	41		-	F-0130	PALM COAST	UFA	102	225	-	SJRWMD
292550	810623	42		-	F-0142	OCEAN PALM GOLF COURSE	UFA	450	150	-	SJRWMD
292602	810823	43		-	F-0169	STATE OF FLA-DNR	ICU	0	95	-	SJRWMD
292604	810624	44		-	F-0174	SJRWMD	ICU	110	118	-	SJRWMD
292603	810624	45		-	F-0175	SJRWMD	SAS	14	17	-	SJRWMD
292603	810825	46		-	F-0176	SJRWMD	UFA	91	120	-	SJRWMD
292603	810827	47		-	F-0177	SJRWMD	SAS	24	43	-	SJRWMD
292737	812202	48		-	F-0182	KING	UFA	192	446	-	SJRWMD
292535	810907	49		-	F-0183	GEORGE DANCE	SAS	0	80	-	SJRWMD
292724	811209	50		-	F-0186	CITY OF FLAGLER BEACH	UFA	112	147	-	SJRWMD
292703	811209	51		-	F-0187	CITY OF FLAGLER BEACH	UFA	112	150	-	SJRWMD
292820	812210	52		-	F-0215	GRESHAM TOM	UFA	888	159	-	SJRWMD
292302	811559	53		-	F-0240	SJRWMD	UFA	92	155	-	SJRWMD
291818	811904	54		-	F-0252	SJRWMD	SAS	10	21	-	SJRWMD
292641	811201	55		-	F-0282	FLAGLER BEACH	UFA	888	159	-	SJRWMD
291658	811104	56		-	F-0285	ORMOND BEACH, CITY OF	UFA	180	247	-	SJRWMD
291625	810920	57		-	F-0286	ORMOND BEACH, CITY OF	UFA	90	270	-	SJRWMD
292302	811559	58		-	F-0291	SJRWMD	SAS	5	15	-	SJRWMD
291738	812008	59		-	F-0296	B.F. SKINNER	UFA	63	220	-	SJRWMD
291900	811900	60		-	F-0324	K.K. KNIGHT	UFA	64	350	-	SJRWMD
285106	812348	61		-	L-0006	MAJOR REALITY	UFA	101	103	-	SJRWMD
290300	813300	62		-	L-0029	KOON	ICU	104	136	-	SJRWMD
285057	812432	63		-	L-0032	BLACKWATER CREEK	UFA	96	120	-	SJRWMD
285028	812533	64		-	L-0037	SEMINOLE STATE FOREST	UFA	102	363	-	SJRWMD
284933	812558	65		-	L-0038	BLACKWATER CREEK	UFA	78	92	-	SJRWMD
290647	813421	66		-	L-0040	USGS NEAR ALEXANDER SPRINGS	UFA	140	171	-	SJRWMD
290950	813155	67		-	L-0045	ASTOR PARK	UFA	204	254	-	SJRWMD
290043	812328	68		-	L-0059	NFS CROWS BLUFF	UFA	153	170	Y	SJRWMD
290420	813026	69		-	L-0061	U.S. FOREST SERVICE	UFA	298	303	-	SJRWMD
290451	813444	70		290445081344001	L-0066	ALEXANDER SPRINGS	UFA	74	102	Y	USGS
285425	813234	71		-	L-0378	USGS	SAS	28	33	-	SJRWMD
285618	812552	72			L-0382	VICTOR ROEPKE	UFA	53	124	-	SJRWMD

Lat	Long	Site No.	Site Alph	USGS ID	SJR ID	Stn_Name	Aquifer	Cas Dep	Tot Dep	Calib 95	Data Src
291001	813309	73		-	L-0455	ASTOR, VFW	UFA	100	150	-	SJRWMD
290647	813421	74			L-0456	SJRWMD	SAS	22	32	-	SJRWMD
291002	813306	75			L-0458	SJRWMD	ICU	90	100	-	SJRWMD
291002	813306	76			L-0460	SJRWMD	SAS	20	30	-	SJRWMD
285049	813451	77			L-0575	WHITE ROSE NURSERY	UFA	56	180	-	SJRWMD
285702	813212	78			L-0577	CENTRAL FLA COUNCIL, BSA	UFA	57	140	-	SJRWMD
285709	813218	79			L-0578	CENTRAL FLA COUNCIL, BSA	UFA	63	140	-	SJRWMD
285123	813135	80			L-0582	SEMINOLE SPRINGS ELEM	UFA	94	350	-	SJRWMD
284755	813132	81			L-0583	ANDY SLADE	ICU	52	96	-	SJRWMD
285934	812625	82			L-0695	SJRWMD	SAS	20	30	-	SJRWMD
290155	813324	83			L-0702	SJRWMD	SAS	25	45	-	SJRWMD
284429	812720	84		-	OR0035	WEKIVA PRESERVE	UFA	-	-	-	SJRWMD
284636	812618	85		-	OR0060	ROCK SPRINGS	UFA	75	120	-	SJRWMD
284541	812652	86		-	OR0068	WEKIVA PRESERVE	UFA	90	95	-	SJRWMD
284230	813453	87		-	OR0106	PLYMOUTH TOWER	UFA	100	395	-	SJRWMD
284230	813453	88		-	OR0107	PLYMOUTH TOWER	SAS	20	40	Y	SJRWMD
284238	812758	89		-	OR0546	WEKIWA SPRINGS STATE PARK	ICU	50	60	-	SJRWMD
284238	812758	90		-	OR0547	WEKIWA SPRINGS STATE PARK	MSCU	440	645	-	SJRWMD
284238	812758	91		-	OR0548	WEKIWA SPRINGS STATE PARK	UFA	100	155	Y	SJRWMD
284634	812620	92		284634081262001	OR0650	ROCK SPRINGS STATE PRESERVE	SAS	5	15	-	SJRWMD
284634	812620	93		284634081262002	OR0651	ROCK SPRINGS STATE PRESERVE	ICU	62	72	-	SJRWMD
284634	812620	94		284634081262003	OR0652	ROCK SPRINGS STATE PRESERVE	UFA	450	506	-	SJRWMD
284634	812620	95		284634081262004	OR0662	ROCK SPRINGS STATE PRESERVE	UFA	150	180	-	SJRWMD
292814	813144	96		-	P-0046	BYRON BUTLER	UFA	0	0	-	SJRWMD
292222	813711	97		-	P-0050	LEROY MALUDA	UFA	55	185	-	SJRWMD
292418	813309	98		-	P-0143	SJRWMD	ICU	56	66	-	SJRWMD
292440	813426	99		-	P-0144	SJRWMD	ICU	66	76	-	SJRWMD
292318	813457	100		-	P-0145	SJRWMD	ICU	75	85	-	SJRWMD
292239	813137	101		-	P-0146	SJRWMD	ICU	45	55	-	SJRWMD
292218	813331	102		-	P-0147	SJRWMD	SAS	45	55	-	SJRWMD
292807	813308	103		-	P-0238	HULL FARMS	UFA	125	425	-	SJRWMD
292606	813125	104		-	P-0242	GAUTIER	UFA	105	135	-	SJRWMD
292824	813415	105		-	P-0246	COL. SAUL	UFA	104	144	-	SJRWMD
292239	812824	106		-	P-0255	WESNOFFSKE	UFA	0	0	-	SJRWMD

Lat	Long	Site No.	Site Alph	USGS ID	SJR ID	Stn_Name	Aquifer	Cas Dep	Tot Dep	Calib 95	Data Src
292548	813718	107		-	P-0268	PHILLIP HUNTER	UFA	0	0	-	SJRWMD
292307	813052	108		-	P-0341	UNDETERMINED	UFA	0	0	-	SJRWMD
292525	813555	109		-	P-0348	BILL PHILLIPS	UFA	82	127	-	SJRWMD
292257	813532	110		-	P-0393	PARADISE LAKES	UFA	96	186	-	SJRWMD
292508	813027	111		-	P-0401	COLLETTE	UFA	98	283	-	SJRWMD
292424	813136	112		-	P-0405	MURPHY	UFA	73	147	-	SJRWMD
292218	813331	113		-	P-0410	SJRWMD	UFA	81	156	-	SJRWMD
292734	813146	114		-	P-0417	NEWBOLD	UFA	77	254	-	SJRWMD
292223	813712	115		-	P-0426	LADKIN	UFA	82	120	-	SJRWMD
292257	813533	116		-	P-0468	SJRWMD	UFA	92	174	-	SJRWMD
292257	813530	117		-	P-0469	SJRWMD	UFA	105	190	-	SJRWMD
292258	813532	118		-	P-0470	SJRWMD	SAS	50	55	-	SJRWMD
292736	813134	119		-	P-0517	NEWBOLD FERNERY	UFA	144	202	-	SJRWMD
292557	813304	120		-	P-0690	PALMER, MIKE	UFA	70	96	-	SJRWMD
292239	813137	121		-	P-0696	SJRWMD	UFA	80	400	-	SJRWMD
292418	813309	122		-	P-0705	SJRWMD	UFA	105	400	-	SJRWMD
292239	813137	123		-	P-0724	SJRWMD	SAS	15	25	-	SJRWMD
292124	813452	124		-	P-0734	SJRWND	SAS	10	20	-	SJRWMD
292124	813452	125		-	P-0737	SJRWMD	SAS	50	60	-	SJRWMD
292418	813309	126		-	P-0742	SJRWMD	SAS	17	27	-	SJRWMD
284247	810708	127		-	S-0001	GENEVA	UFA	92	204	Y	SJRWMD
284247	810708	128		-	S-0002	SJRWMD	SAS	45	50	-	SJRWMD
284626	810518	129		284626081051801	S-0026	KAY ROAD	UFA	83	200	Y	USGS
284702	810436	130		-	S-0027	OSCEOLA LANDFILL AT ENT.	SAS	41	55	-	SJRWMD
284322	810843	131		-	S-0028	COCHRAN FOREST EAST	UFA	89	205	-	SJRWMD
284712	810443	132		-	S-0029	SEMINOLE COUNTY LANDFILL	UFA	70	141	-	SJRWMD
284712	810443	133		-	S-0030	SJRWMD	SAS	20	30	-	SJRWMD
284626	810528	134		-	S-0032	SJRWMD	SAS	42	50	-	SJRWMD
284428	810726	135		284428081072603	S-0033	AVENUE C	UFA	117	393	Y	USGS
284440	810529	136		-	S-0034	WINONA DRIVE	UFA	48	200	-	SJRWMD
284325	810927	137		-	S-0035	SJRWMD	SAS	31	35	-	SJRWMD
284403	810726	138		-	S-0036	SJRWMD	SAS	60	60	-	SJRWMD
284945	812442	139		284945081244201	S-0037	C.M. FERNANDEZ AT SR 46	UFA	-	41	Y	SJRWMD
284324	810928	140		-	S-0038	COCKRAN FOREST WEST	UFA	55	165	-	SJRWMD
284233	810452	141		-	S-0041	KILBEE #1	ICU	77	100	-	SJRWMD
284320	810900	142		-	S-0045	COCHRAN FOREST	SAS	27	37	-	SJRWMD
284715	810518	143		-	S-0086	OSCEOLA LANDFILL	UFA	80	225	Y	SJRWMD

Lat	Long	Site No.	Site Alph	USGS ID	SJR ID	Stn_Name	Aquifer	Cas Dep	Tot Dep	Calib 95	Data Src
284716	810518	144		-	S-0087	SJRWMD	UFA	76	350	Y	SJRWMD
284829	812459	145		-	S-0091	M. SECKINGER RESIDENCE	UFA	75	160	-	SJRWMD
284835	812443	146		-	S-0092	SECKINGER PASTURE	UFA	80	120	-	SJRWMD
285001	812423	147		-	S-0097	WEKIVA RIVER HAVEN	UFA	110	120	Y	SJRWMD
284902	812419	148		-	S-0098	RANGER N DWELLING	UFA	110	130	-	SJRWMD
284715	810517	149		-	S-0199	SJRWMD	UFA	70	100	-	SJRWMD
284715	810518	150		-	S-0200	OSCEOLA LANDFILL	MSCU	500	550	-	SJRWMD
284715	810518	151		-	S-0201	SJRWMD	SAS	15	25	-	SJRWMD
284715	810518	152		-	S-0202	OSCEOLA LANDFILL	ICU	60	60	-	SJRWMD
284731	812224	153		-	S-0211	C.E. HAWKE	UFA	113	137	-	SJRWMD
284653	812308	154		-	S-0214	CHARLES JONES	ICU	0	81	-	SJRWMD
284652	812129	155		-	S-0215	E.C. HAYNON	ICU	74	192	-	SJRWMD
284631	812147	156		-	S-0217	USGS	SAS	16	19	-	SJRWMD
284514	812254	157		-	S-0227	ALBERT FRITZ	ICU	92	97	-	SJRWMD
284841	812018	158		-	S-0231	HENRY RICHTER	UFA	56	103	-	SJRWMD
284803	812038	159		-	S-0235	USGS	SAS	18	21	Y	SJRWMD
284749	811323	160		284750081132301	S-0257	NEAR SANFORD	UFA	-	206	Y	USGS
284715	810518	161		-	S-0266	OSCEOLA LANDFILL	SAS	10	14	Y	SJRWMD
284706	810708	162		-	S-0305	THRASHER NEAR OSCEOLA LANDFILL	UFA	99	178	Y	SJRWMD
284712	810443	163		-	S-0306	USGS	SAS	104	143	-	SJRWMD
284728	811325	164		-	S-0307	DAN COLLINS	UFA	84	244	-	SJRWMD
284758	811617	165		-	S-0308	CITY OF SANFORD	UFA	82	206	Y	SJRWMD
284759	811623	166		-	S-0309	CITY OF SANFORD	UFA	80	171	Y	SJRWMD
284942	812153	167		-	S-0317	E.M. CAIN	UFA	106	139	Y	SJRWMD
284711	811114	168		-	S-0780	SANFORD	ICU	30	40	Y	SJRWMD
284318	811826	169		-	S-0828	ENVIRONMENTAL CENTER—OSPREY TRAIL	SAS	54	64	-	SJRWMD
284318	811826	170		-	S-0829	ENVIRONMENTAL CENTER—OSPREY TRAIL	UFA	85	180	-	SJRWMD
284919	812413	171		-	S-0830	SJRWMD	SAS	20	30	-	SJRWMD
284809	811748	172		-	S-0930	DUDLEY BLAKE	UFA	97	138	Y	SJRWMD
284809	811748	173		-	S-0931	DUDLEY BLAKE	UFA	106	138	Y	SJRWMD
284247	810708	174		-	S-1023	GENEVA	SAS	20	30	Y	SJRWMD
284923	812348	175		284923081234801	S-1225	YANKEE LAKE	LFA	945	1054	-	SJRWMD
284923	812348	176		284923081234802	S-1230	YANKEE LAKE	UFA	122	403	-	SJRWMD
284808	812139	177		-	S-1284	SJRWMD	SAS	15	25	Y	SJRWMD
284728	811831	178		-	S-1285	SJRWMD	SAS	10	20	Y	SJRWMD

Lat	Long	Site No.	Site Alph	USGS ID	SJR ID	Stn_Name	Aquifer	Cas Dep	Tot Dep	Calib 95	Data Src
284630	811701	179		-	S-1298	SJRWMD	SAS	10	30	-	SJRWMD
284923	812348	180		284923081234803	S-1310	YANKEE LAKE	SAS	25	35	-	SJRWMD
285912	805443	181		-	V-0006	MARVIN OWENS	SAS	0	30	-	SJRWMD
285707	805423	182		-	V-0007	JIM JONES	SAS	0	30	-	SJRWMD
290923	810612	183		-	V-0008	NEAR DAYTONA	MSCU	480	496	-	SJRWMD
290046	812204	184		-	V-0010	RAY WEIR	UFA	115	124	-	SJRWMD
290001	812122	185		-	V-0011	LONNIE K CLIFTON	UFA	84	90	Y	SJRWMD
290541	811329	186		-	V-0012	USGS NEAR DELAND	LFA	634	1200	Y	SJRWMD
290502	811418	187		-	V-0013	HUDSON PULP AND PAPER	UFA	73	84	-	SJRWMD
290840	810845	188		-	V-0014	RADIO STATION	UFA	0	83	Y	SJRWMD
291004	811014	189		-	V-0015	VOLUSIA COUNTY	UFA	121	221	Y	SJRWMD
291006	811010	190		-	V-0016	USGS	SAS	0	39	-	SJRWMD
290920	810612	191		-	V-0017	USGS	UFA	102	220	Y	SJRWMD
291159	810202	192		-	V-0018	DAYTONA BEACH, CITY OF	UFA	118	187	Y	SJRWMD
290534	811750	193		-	V-0027	USGS	UFA	85	114	-	SJRWMD
290534	811750	194		290534081175002	V-0028	USGS TEST WELL F-2	UFA	245	259	Y	SJRWMD
290432	811449	195		-	V-0029	USGS	SAS	4	7	-	SJRWMD
291258	813137	196		-	V-0040	EZELS	UFA	80	90	Y	SJRWMD
292156	810759	197		-	V-0042	BELLMEADE CORP.	UFA	110	160	Y	SJRWMD
292156	810759	198		-	V-0043	BELLMEADE CORP.	ICU	50	65	-	SJRWMD
292027	810803	199		-	V-0044	BELLMEADE CORP.	UFA	110	120	-	SJRWMD
292027	810803	200		-	V-0045	BELLMEADE CORP.	ICU	29	49	-	SJRWMD
292116	810809	201		-	V-0046	BELLMEADE CORP.	SAS	12	15	Y	SJRWMD
292053	810546	202		-	V-0047	BELLMEADE CORP.	UFA	94	100	-	SJRWMD
292053	810546	203		-	V-0048	BELLMEADE CORP.	SAS	15	20	Y	SJRWMD
291218	812154	204		-	V-0062	SR 40 EAST OF BARBERVILLE	UFA	131	200	Y	SJRWMD
291216	812156	205		-	V-0063	SJRWMD	SAS	10	25	Y	SJRWMD
291823	812808	206		-	V-0064	SJRWMD	UFA	113	158	Y	SJRWMD
291508	813028	207		-	V-0065	SJRWMD	UFA	97	180	-	SJRWMD
291433	812841	208		-	V-0066	SJRWMD	UFA	250	365	-	SJRWMD
291433	812841	209		-	V-0067	USGS	SAS	7	9	-	SJRWMD
291458	812942	210		-	V-0068	SJRWMD	UFA	63	125	-	SJRWMD
285745	810540	211		-	V-0070	DOT	UFA	113	121	-	SJRWMD
290034	812256	212		-	V-0071	SJRWMD	UFA	130	160	-	SJRWMD
290034	812256	213		-	V-0072	SJRWMD	SAS	16	25	-	SJRWMD
290920	810630	214		-	V-0080	USGS NEAR DAYTONA	UFA	102	235	-	SJRWMD
290541	811329	215		-	V-0081	USGS NEAR DELAND	UFA	94	575	Y	SJRWMD

Lat	Long	Site No.	Site Alph	USGS ID	SJR ID	Stn_Name	Aquifer	Cas Dep	Tot Dep	Calib 95	Data Src
285512	812028	216		-	V-0082	USGS SOUTH OF BLUE SPRING	UFA	106	200	-	SJRWMD
285638	812031	217		-	V-0083	BLUE SPRING	UFA	84	432	-	SJRWMD
291133	810406	218		-	V-0084	USGS	MSCU	483	500	Y	SJRWMD
290651	805828	219		-	V-0085	HARBOR OAKS	UFA	104	146	-	SJRWMD
291006	811010	220		-	V-0086	TIGER BAY 4A	UFA	122	222	Y	SJRWMD
291007	811016	221		-	V-0087	USGS	SAS	18	20	Y	SJRWMD
291353	811604	222		-	V-0088	UNION CAMP	SAS	20	20	-	SJRWMD
291343	812546	223		-	V-0089	JONES FERNEY	UFA	112	414	Y	SJRWMD
291344	811557	224		-	V-0090	UNION CAMP	UFA	74	151	Y	SJRWMD
290813	810832	225		290813081083201	V-0094	NEAR DAYTONA	UFA	93	217	Y	SJRWMD
291726	812854	226		-	V-0095	VADNAIS, ARMAND	UFA	0	180	-	SJRWMD
291905	812510	227		-	V-0096	NOLAN, R.	UFA	888	138	Y	SJRWMD
291113	810506	228		-	V-0097	DAYTONA BEACH, CITY OF	UFA	111	211	Y	SJRWMD
291133	810406	229		-	V-0098	USGS	UFA	115	235	-	SJRWMD
291025	810502	230		-	V-0099	I-95 AND US 92	UFA	152	498	-	SJRWMD
290541	811329	231		-	V-0100	USGS NEAR DELAND	LFA	1275	1290	-	SJRWMD
285705	810540	232		285745081054001	V-0101	ALAMANA	UFA	113	121	Y	USGS
285221	810950	233		-	V-0102	USGS	UFA	74	92	Y	SJRWMD
285016	810141	234		-	V-0103	USGS	UFA	102	107	-	SJRWMD
285655	811656	235		-	V-0104	USGS	UFA	152	171	-	SJRWMD
285655	811656	236		-	V-0105	USGS	SAS	21	32	-	SJRWMD
290107	810620	237		-	V-0106	USGS	UFA	105	111	-	SJRWMD
290129	810729	238		-	V-0107	USGS	UFA	97	241	-	SJRWMD
290107	810620	239		-	V-0109	USGS	SAS	21	21	-	SJRWMD
285934	810418	240		-	V-0110	SAMSULA	UFA	105	442	-	SJRWMD
285655	811656	241		-	V-0112	USGS	UFA	60	70	-	SJRWMD
285700	810210	242		-	V-0113	USGS	UFA	90	261	-	SJRWMD
290138	812032	243		-	V-0114	USGS	ICU	50	64	-	SJRWMD
290138	812032	244		-	V-0115	SR 44 WEST OF DELAND	UFA	252	350	-	SJRWMD
290225	810403	245		-	V-0117	USGS	UFA	97	241	Y	SJRWMD
290230	811234	246		-	V-0118	5 MILES EAST OF DELAND	UFA	72	241	Y	SJRWMD
290251	810014	247		-	V-0119	USGS	UFA	315	400	Y	SJRWMD
290447	811023	248		-	V-0120	USGS	UFA	92	241	Y	SJRWMD
290447	811023	249		-	V-0121	USGS	SAS	18	20	Y	SJRWMD
291409	812555	250		-	V-0122	BRADDOCK	UFA	110	450	-	SJRWMD
290456	810444	251		-	V-0123	USGS	UFA	90	261	-	SJRWMD
291507	812906	252		-	V-0124	BRADDOCK	UFA	120	408	-	SJRWMD

Lat	Long	Site No.	Site Alph	USGS ID	SJR ID	Stn_Name	Aquifer	Cas Dep	Tot Dep	Calib 95	Data Src
291431	812630	253		-	V-0126	USGS	UFA	85	125	-	SJRWMD
291302	810638	254		-	V-0127	USGS	UFA	84	240	-	SJRWMD
290922	810609	255		-	V-0128	USGS	UFA	18	18	-	SJRWMD
290708	812331	256		-	V-0129	JONES ISLAND	UFA	100	156	-	SJRWMD
291523	810950	257		-	V-0130	USGS	UFA	82	242	-	SJRWMD
290653	812003	258		-	V-0135	USGS	SAS	45	48	-	SJRWMD
291009	813054	259		-	V-0138	USGS	SAS	2	4	-	SJRWMD
291343	812546	260		-	V-0141	USGS	SAS	6	8	-	SJRWMD
291258	813137	261		-	V-0142	USGS	SAS	6	8	-	SJRWMD
291431	812631	262		-	V-0144	SJRWMD	UFA	85	125	-	SJRWMD
291453	812654	263		-	V-0145	USGS	SAS	7	9	-	SJRWMD
291453	812654	264		-	V-0146	USGS	SAS	19	22	-	SJRWMD
291457	812709	265		-	V-0147	USGS	UFA	128	140	-	SJRWMD
291437	812749	266		-	V-0148	USGS	SAS	4	8	-	SJRWMD
291427	812734	267		-	V-0149	ZIEBARTH	SAS	13	15	-	SJRWMD
291626	812836	268		-	V-0152	USGS	SAS	7	9	-	SJRWMD
291427	812734	269		-	V-0153	USGS	SAS	7	9	-	SJRWMD
291543	813206	270		-	V-0154	UNION BAG	UFA	90	116	-	SJRWMD
291835	813242	271		-	V-0155	USCE	UFA	120	155	-	SJRWMD
290512	812136	272		-	V-0156	GLENWOOD	UFA	65	195	Y	SJRWMD
290512	812136	273		-	V-0157	GLENWOOD	UFA	85	115	-	SJRWMD
290107	810620	274		-	V-0160	USGS	UFA	273	282	-	SJRWMD
290806	810131	275		-	V-0162	PORT ORANGE	UFA	105	224	-	SJRWMD
290038	810438	276		-	V-0163	NEW SMYRNA BEACH	UFA	106	220	-	SJRWMD
290102	805642	277		-	V-0164	NEW SMYRNA BEACH	UFA	-	220	Y	SJRWMD
285031	810623	278		-	V-0165	TOOK FARM	UFA	58	255	Y	SJRWMD
285031	810623	279		-	V-0166	TOOK FARM	SAS	25	35	Y	SJRWMD
285031	810623	280		-	V-0167	SJRWMD	SAS	20	40	-	SJRWMD
285125	810636	281		-	V-0168	SJRWMD	ICU	0	63	-	SJRWMD
285126	810725	282		-	V-0169	SJRWMD	ICU	0	70	-	SJRWMD
284958	810614	283		-	V-0171	SJRWMD	ICU	0	67	-	SJRWMD
285039	810444	284		-	V-0172	SJRWMD	ICU	0	95	-	SJRWMD
285011	810837	285		-	V-0173	SJRWMD	ICU	0	73	-	SJRWMD
285037	810752	286		-	V-0174	SJRWMD	ICU	0	65	-	SJRWMD
284937	810706	287		-	V-0175	SJRWMD	ICU	0	57	Y	SJRWMD
285206	810722	288		-	V-0176	PANDOLF FARMS	UFA	67	222	Y	SJRWMD
285206	810722	289		-	V-0177	PANDOLF FARMS	UFA	64	221	-	SJRWMD

Lat	Long	Site No.	Site Alph	USGS ID	SJR ID	Stn_Name	Aquifer	Cas Dep	Tot Dep	Calib 95	Data Src
285206	810722	290		-	V-0178	PANDOLF FARMS	UFA	65	145	Y	SJRWMD
290834	810738	291		-	V-0183	TOMOKA TOWER	MSCU	445	545	Y	SJRWMD
291941	812942	292		-	V-0184	SJRWMD	UFA	75	100	Y	SJRWMD
291941	812942	293		-	V-0185	SJRWMD	SAS	58	58	Y	SJRWMD
291107	810342	294		-	V-0187	DAYTONA BEACH AIRPORT	UFA	97	817	-	SJRWMD
290834	810737	295		-	V-0188	TOMOKA TOWER	UFA	92	150	-	SJRWMD
290834	810738	296		-	V-0192	TOMOKA TOWER	ICU	60	80	Y	SJRWMD
290834	810738	297		-	V-0193	SJRWMD	SAS	16	25	Y	SJRWMD
285440	811814	298		-	V-0196	ORANGE CITY TOWER	UFA	88	234	Y	SJRWMD
285440	811814	299		-	V-0197	ORANGE CITY TOWER	SAS	20	30	-	SJRWMD
285419	810410	300		-	V-0199	LAKE ASHBY TOWER	ICU	86	86	-	SJRWMD
291031	805904	301		-	V-0200	DAYTONA BEACH SHORES	UFA	98	879	-	SJRWMD
291457	812706	302		-	V-0202	USGS	SAS	10	10	-	SJRWMD
291118	812859	303		-	V-0206	HARPER, ROBERT	UFA	102	366	-	SJRWMD
290930	812302	304		-	V-0213	WEBSTER, TOM	UFA	143	145	-	SJRWMD
291056	812524	305		-	V-0214	UNDETERMINED	UFA	888	888	-	SJRWMD
291009	812058	306		-	V-0215	BLACKWELDER, MARHALEE	UFA	191	450	-	SJRWMD
291111	812914	307		-	V-0216	MCCOLLOUGH	UFA	888	600	-	SJRWMD
291221	812351	308		-	V-0217	RICHARDSON, CURTIS	UFA	888	100	-	SJRWMD
291447	812703	309		-	V-0218	TAYLOR, JAMES	UFA	92	302	-	SJRWMD
291314	812657	310		-	V-0219	RICHARDSON, CURTIS	UFA	888	888	-	SJRWMD
291248	812803	311		-	V-0220	TURNER, H	UFA	888	888	-	SJRWMD
291418	812734	312		-	V-0221	RICHARDSON, CURTIS	UFA	110	198	-	SJRWMD
291527	812617	313		-	V-0222	BURNSED, RALPH	UFA	888	350	-	SJRWMD
291437	812749	314		-	V-0223	PIERSON ELEMENTARY	UFA	113	150	-	SJRWMD
291524	812435	315		-	V-0224	UNDETERMINED	UFA	108	134	-	SJRWMD
291448	812749	316		-	V-0225	SJRWMD	UFA	154	1100	-	SJRWMD
285153	811442	317		-	V-0240	FORTNER	UFA	197	243	-	SJRWMD
285903	811747	318		-	V-0253	DELAND CC	UFA	210	372	-	SJRWMD
291448	812749	319		-	V-0354	SJRWMD	ICU	80	80	-	SJRWMD
291337	811101	320		-	V-0356	SJRWMD	ICU	65	65	-	SJRWMD
290905	810455	321		-	V-0357	SJRWMD	ICU	58	58	-	SJRWMD
290834	810738	322		-	V-0358	SJRWMD	ICU	0	90	-	SJRWMD
290802	812112	323		-	V-0359	SJRWMD	ICU	80	80	-	SJRWMD
290652	811329	324		-	V-0361	SJRWMD	ICU	73	73	-	SJRWMD
290106	810417	325		-	V-0363	SJRWMD	ICU	69	69	-	SJRWMD
285653	805947	326		-	V-0364	SJRWMD	ICU	50	50	-	SJRWMD

Lat	Long	Site No.	Site Alph	USGS ID	SJR ID	Stn_Name	Aquifer	Cas Dep	Tot Dep	Calib 95	Data Src
285656	811037	327		-	V-0365	SJRWMD	ICU	73	73	-	SJRWMD
285442	811814	328		-	V-0366	SJRWMD	ICU	888	90	-	SJRWMD
285419	810410	329		-	V-0367	SJRWMD	ICU	888	80	-	SJRWMD
285045	810948	330		-	V-0368	SJRWMD	ICU	60	60	-	SJRWMD
284853	805812	331		-	V-0369	SJRWMD	ICU	70	70	-	SJRWMD
290802	812111	332		-	V-0374	USGS	ICU	22	22	-	SJRWMD
290047	805931	333		-	V-0381	SR 44 AND I-95 CHEVRON	UFA	107	130	-	SJRWMD
285954	805801	334		-	V-0413	NEW SMYRNA BEACH	UFA	109	210	-	SJRWMD
285833	805717	335		-	V-0435	GLENCOE ROAD SANDMINE	UFA	100	174	Y	SJRWMD
291949	810659	336		-	V-0446	SJRWMD	UFA	104	130	-	SJRWMD
285038	810139	337		-	V-0458	UNDETERMINED	SAS	0	0	-	SJRWMD
290106	811321	338		-	V-0461	UNDETERMINED	SAS	0	0	-	SJRWMD
290132	811126	339		-	V-0462	UNDETERMINED	SAS	0	0	-	SJRWMD
290414	811056	340		-	V-0463	UNDETERMINED	SAS	0	0	-	SJRWMD
290432	811449	341		-	V-0464	UNDETERMINED	SAS	0	0	-	SJRWMD
290843	811033	342		-	V-0466	UNDETERMINED	SAS	0	0	-	SJRWMD
291001	810942	343		-	V-0467	UNDETERMINED	SAS	0	0	-	SJRWMD
291002	811135	344		-	V-0468	UNDETERMINED	SAS	0	0	-	SJRWMD
291010	811022	345		-	V-0469	UNDETERMINED	SAS	0	0	-	SJRWMD
291050	811446	346		-	V-0470	UNDETERMINED	SAS	0	0	-	SJRWMD
291142	811228	347		-	V-0471	UNDETERMINED	SAS	0	0	-	SJRWMD
291457	812709	348		-	V-0472	UNDETERMINED	SAS	8	10	-	SJRWMD
291323	811912	349		-	V-0501	STATE OF FLORIDA	ICU	60	70	-	SJRWMD
291510	810740	350		-	V-0502	STATE OF FLORIDA	ICU	75	85	-	SJRWMD
290048	805852	351		-	V-0503	STATE OF FLORIDA	ICU	90	100	-	SJRWMD
285140	805450	352		-	V-0504	STATE OF FLORIDA	ICU	85	95	-	SJRWMD
290100	811322	353		-	V-0505	STATE OF FLORIDA	ICU	72	82	-	SJRWMD
291025	812636	354		-	V-0506	ELDRIDGE	ICU	80	90	-	SJRWMD
290103	805519	355		-	V-0508	SMITH STREET AND US 1	UFA	170	210	Y	SJRWMD
291748	812903	356		-	V-0510	SJRWMD	UFA	85	130	-	SJRWMD
284743	805201	357		-	V-0520	CANTRELL ESTATES	UFA	-	197	Y	SJRWMD
285452	805518	358		-	V-0521	VOLCO ROAD	UFA	-	148	-	SJRWMD
292038	813153	359		-	V-0522	SJRWMD	ICU	61	71	-	SJRWMD
291640	813209	360		-	V-0523	SJRWMD	SAS	17	27	-	SJRWMD
291458	812942	361		-	V-0524	SJRWMD	ICU	29	39	-	SJRWMD
291458	812942	362		-	V-0525	SJRWMD	SAS	4	14	-	SJRWMD
291351	812925	363		-	V-0526	SJRWMD	ICU	50	60	-	SJRWMD

Lat	Long	Site No.	Site Alph	USGS ID	SJR ID	Stn_Name	Aquifer	Cas Dep	Tot Dep	Calib 95	Data Src
291448	812749	364		-	V-0528	SJRWMD	SAS	13	23	-	SJRWMD
290834	810738	365		-	V-0529	SJRWMD	SAS	13	23	-	SJRWMD
291448	812749	366		-	V-0530	SJRWMD	LFA	800	1060	-	SJRWMD
291448	812749	367		-	V-0531	SJRWMD	UFA	130	210	-	SJRWMD
291441	812548	368		-	V-0535	USGS	SAS	888	37	-	SJRWMD
291441	812548	369		-	V-0536	USGS	ICU	888	59	-	SJRWMD
291357	812743	370		-	V-0537	USGS	SAS	888	30	-	SJRWMD
291357	812743	371		-	V-0538	USGS	ICU	888	74	-	SJRWMD
291806	812843	372		-	V-0541	USGS	SAS	888	30	-	SJRWMD
291806	812843	373		-	V-0542	USGS	ICU	888	61	-	SJRWMD
291107	810517	374		-	V-0543	SJRWMD	SAS	7	17	-	SJRWMD
291107	810517	375		-	V-0544	SJRWMD	SAS	40	50	-	SJRWMD
291107	810517	376		-	V-0545	SJRWMD	SAS	61	81	-	SJRWMD
290834	810738	377		-	V-0546	SJRWMD	SAS	37	57	-	SJRWMD
291448	812749	378		-	V-0557	SJRWMD	ICU	88	98	-	SJRWMD
285129	805105	379		-	V-0558	OAK HILL CITY HALL	SAS	20	30	-	SJRWMD
285129	805105	380		-	V-0559	OAK HILL CITY HALL	ICU	50	60	-	SJRWMD
291941	812943	381		-	V-0565	SJRWMD	SAS	5	15	-	SJRWMD
291941	812943	382		-	V-0566	SJRWMD	ICU	42	52	-	SJRWMD
291351	812925	383		-	V-0578	SJRWMD	SAS	20	30	-	SJRWMD
285309	811834	384		-	V-0590	DEBARY LIBRARY	UFA	78	142	-	SJRWMD
291120	812515	385		-	V-0591	CARL_BROWN	SAS	34	104	-	SJRWMD
291016	812854	386		-	V-0592	RICK TONYAN	SAS	95	95	-	SJRWMD
291524	810650	387		-	V-0595	B.P. OIL CO./KOLOZY	UFA	94	129	-	SJRWMD
291218	813054	388		-	V-0596	B. THOMPSON	UFA	254	432	-	SJRWMD
291458	812721	389		-	V-0599	SJRWMD	SAS	5	15	-	SJRWMD
291458	812721	390		-	V-0600	SJRWMD	SAS	3	13	-	SJRWMD
291458	812721	391		-	V-0601	SJRWMD	SAS	4	14	-	SJRWMD
291458	812721	392		-	V-0602	SJRWMD	SAS	3	13	-	SJRWMD
291806	812905	393		-	V-0603	SJRWMD	SAS	10	20	-	SJRWMD
291806	812905	394		-	V-0604	SJRWMD	SAS	6	16	-	SJRWMD
291806	812905	395		-	V-0605	SJRWMD	SAS	10	20	-	SJRWMD
291806	812905	396		-	V-0606	SJRWMD	SAS	10	20	-	SJRWMD
290750	811740	397		-	V-0608	SJRWMD	SAS	3	13	-	SJRWMD
290750	811740	398		-	V-0609	SJRWMD	SAS	3	13	-	SJRWMD
290750	811740	399		-	V-0610	SJRWMD	SAS	7	17	-	SJRWMD
290750	811740	400		-	V-0611	SJRWMD	SAS	7	17	Y	SJRWMD

Lat	Long	Site No.	Site Alph	USGS ID	SJR ID	Stn_Name	Aquifer	Cas Dep	Tot Dep	Calib 95	Data Src
285512	812028	401		-	V-0612	UNDETERMINED	SAS	0	18	-	SJRWMD
291458	812721	402		-	V-0616	SJRWMD	SAS	5	7	Y	SJRWMD
291458	812721	403		-	V-0617	SJRWMD	SAS	7	8	-	SJRWMD
291458	812721	404		-	V-0618	SJRWMD	SAS	1	1	-	SJRWMD
291458	812721	405		-	V-0619	SJRWMD	SAS	2	2	-	SJRWMD
291458	812721	406		-	V-0620	SJRWMD	SAS	5	7	Y	SJRWMD
291458	812721	407		-	V-0621	SJRWMD	SAS	7	8	-	SJRWMD
291458	812721	408		-	V-0622	SJWMD	SAS	1	1	-	SJRWMD
291458	812721	409		-	V-0623	SJRWMD	SAS	1	1	-	SJRWMD
291458	812721	410		-	V-0624	SJRWMD	SAS	2	4	Y	SJRWMD
291458	812721	411		-	V-0625	SJRWMD	SAS	5	6	-	SJRWMD
291458	812721	412		-	V-0626	SJRWMD	SAS	1	1	-	SJRWMD
291458	812721	413		-	V-0627	SJRWMD	SAS	2	2	-	SJRWMD
291458	812721	414		-	V-0628	SJRWMD	SAS	4	6	Y	SJRWMD
291458	812721	415		-	V-0629	SJRWMD	SAS	6	7	-	SJRWMD
291458	812721	416		-	V-0630	SJRWMD	SAS	1	1	-	SJRWMD
291458	812721	417		-	V-0631	SJRWMD	SAS	2	2	Y	SJRWMD
291458	812721	418		-	V-0632	SJRWMD	SAS	3	5	Y	SJRWMD
291458	812721	419		-	V-0633	SJRWMD	SAS	5	6	-	SJRWMD
291458	812721	420		-	V-0634	SJRWMD	SAS	1	1	-	SJRWMD
291458	812721	421		-	V-0635	SJRWMD	SAS	2	2	-	SJRWMD
291458	812721	422		-	V-0636	SJRWMD	SAS	2	4	Y	SJRWMD
291458	812721	423		-	V-0637	SJRWMD	SAS	5	6	-	SJRWMD
291458	812721	424		-	V-0638	SJRWMD	SAS	1	1	-	SJRWMD
291458	812721	425		-	V-0639	SJRWMD	SAS	2	2	-	SJRWMD
291458	812721	426		-	V-0640	SJRWMD	SAS	3	5	Y	SJRWMD
291458	812721	427		-	V-0641	SJRWMD	SAS	5	6	-	SJRWMD
291458	812721	428		-	V-0642	SJRWMD	SAS	1	1	-	SJRWMD
291458	812721	429		-	V-0643	SJRWMD	SAS	2	2	Y	SJRWMD
291458	812721	430		-	V-0644	SJRWMD	SAS	3	5	-	SJRWMD
291458	812721	431		-	V-0645	SJRWMD	SAS	6	7	-	SJRWMD
291458	812721	432		-	V-0646	SJRWMD	SAS	1	1	-	SJRWMD
291458	812721	433		-	V-0647	SJRWMD	SAS	2	2	-	SJRWMD
291458	812721	434		-	V-0648	SJRWMD	SAS	2	4	-	SJRWMD
291458	812721	435		-	V-0649	SJRWMD	SAS	5	6	-	SJRWMD
291458	812721	436		-	V-0650	SJRWMD	SAS	1	1	-	SJRWMD
291458	812721	437		-	V-0651	SJRWMD	SAS	2	2	-	SJRWMD

Lat	Long	Site No.	Site Alph	USGS ID	SJR ID	Stn_Name	Aquifer	Cas Dep	Tot Dep	Calib 95	Data Src
291458	812721	438		-	V-0652	SJRWMD	SAS	3	5	-	SJRWMD
291458	812721	439		-	V-0653	SJRWMD	SAS	3	5	-	SJRWMD
291806	812905	440		-	V-0654	SJRWMD	SAS	7	9	Y	SJRWMD
291806	812905	441		-	V-0655	SJRWMD	SAS	9	10	-	SJRWMD
291806	812905	442		-	V-0656	SJRWMD	SAS	1	1	Y	SJRWMD
291806	812905	443		-	V-0657	SJRWMD	SAS	3	3	Y	SJRWMD
291806	812905	444		-	V-0658	SJRWMD	SAS	7	9	-	SJRWMD
291806	812905	445		-	V-0659	SJRWMD	SAS	9	10	-	SJRWMD
291806	812905	446		-	V-0660	SJRWMD	SAS	1	1	-	SJRWMD
291806	812905	447		-	V-0661	SJRWMD	SAS	3	3	-	SJRWMD
291806	812905	448		-	V-0662	SJRWMD	SAS	5	7	-	SJRWMD
291806	812905	449		-	V-0663	SJRWMD	SAS	7	8	-	SJRWMD
291806	812905	450		-	V-0664	SJRWMD	SAS	1	1	-	SJRWMD
291806	812905	451		-	V-0665	SJRWMD	SAS	2	2	-	SJRWMD
291806	812905	452		-	V-0666	SJRWMD	SAS	5	7	-	SJRWMD
291806	812905	453		-	V-0667	SJRWMD	SAS	7	8	-	SJRWMD
291806	812905	454		-	V-0668	SJRWMD	SAS	1	1	-	SJRWMD
291806	812905	455		-	V-0669	SJRWMD	SAS	2	2	-	SJRWMD
290750	811740	456		-	V-0670	SJRWMD	SAS	10	12	-	SJRWMD
290750	811740	457		-	V-0671	SJRWMD	SAS	13	14	-	SJRWMD
290750	811740	458		-	V-0672	SJRWMD	SAS	1	1	-	SJRWMD
290750	811740	459		-	V-0673	SJRWMD	SAS	3	3	-	SJRWMD
290750	811740	460		-	V-0674	SJRWMD	SAS	5	5	-	SJRWMD
290750	811740	461		-	V-0675	SJRWMD	SAS	10	12	-	SJRWMD
290750	811740	462		-	V-0676	SJRWMD	SAS	12	13	-	SJRWMD
290750	811740	463		-	V-0677	SJRWMD	SAS	1	1	-	SJRWMD
290750	811740	464		-	V-0678	SJRWMD	SAS	3	3	-	SJRWMD
290750	811740	465		-	V-0679	SJRWMD	SAS	5	5	-	SJRWMD
290750	811740	466		-	V-0680	SJRWMD	SAS	9	11	-	SJRWMD
290750	811740	467		-	V-0681	SJRWMD	SAS	11	12	Y	SJRWMD
290750	811740	468		-	V-0682	SJRWMD	SAS	1	1	-	SJRWMD
290750	811740	469		-	V-0683	SJRWMD	SAS	2	2	-	SJRWMD
290750	811740	470		-	V-0684	SJRWMD	SAS	4	4	-	SJRWMD
290750	811740	471		-	V-0685	SJRWMD	SAS	9	11	-	SJRWMD
290750	811740	472		-	V-0686	SJRWMD	SAS	12	13	-	SJRWMD
290750	811740	473		-	V-0687	SJRWMD	SAS	1	1	-	SJRWMD
290750	811740	474		-	V-0688	SJRWMD	SAS	2	2	-	SJRWMD

Lat	Long	Site No.	Site Alph	USGS ID	SJR ID	Stn_Name	Aquifer	Cas Dep	Tot Dep	Calib 95	Data Src
290750	811740	475		-	V-0689	SJRWMD	SAS	4	4	-	SJRWMD
291040	811437	476		-	V-0700	ORMOND BEACH, CITY OF	UFA	85	300	-	SJRWMD
291031	805904	477		-	V-0701	DAYTONA BEACH	UFA	98	879	-	SJRWMD
290541	811329	478		-	V-0709	USGS	UFA	94	639	-	SJRWMD
291626	812836	479		-	V-0717	UNDETERMINED	UFA	100	104	-	SJRWMD
291952	812949	480		-	V-0718	UNDETERMINED	UFA	89	100	-	SJRWMD
290541	811329	481		-	V-0719	USGS	UFA	640	1496	-	SJRWMD
290850	812021	482		-	V-0724	KEN HOBLICK	UFA	106	450	Y	SJRWMD
291149	811908	483		-	V-0729	L. BLACKWELDER	UFA	118	242	-	SJRWMD
292105	812812	484		-	V-0734	UNDETERMINED	UFA	74	86	-	SJRWMD
290615	811833	485		-	V-0742	BOB LEE AIRPORT	UFA	140	460	Y	SJRWMD
290614	811833	486		-	V-0743	SJRWMD	ICU	62	72	-	SJRWMD
290615	811833	487		-	V-0744	BOB LEE AIRPORT	SAS	27	37	Y	SJRWMD
291523	810950	488		-	V-0761	SJRWMD	SAS	8	18	-	SJRWMD
291329	811915	489		-	V-0769	SR 40 AND 11	UFA	85	440	-	SJRWMD
291329	811915	490		-	V-0770	SR 40 AND 11	SAS	25	35	-	SJRWMD
285708	805651	491		-	V-0771	CITY OF EDGEWATER	SAS	25	35	-	SJRWMD
285524	811324	492		-	V-0772	GALAXY MIDDLE SCHOOL	UFA	100	140	-	SJRWMD
285524	811324	493		-	V-0774	GALAXY MIDDLE SCHOOL	LFA	740	780	-	SJRWMD
290106	810618	494		-	V-0775	KIRKLAND SOD, SR 44 SAMSULA	SAS	35	45	-	SJRWMD
285813	811424	495		-	V-0776	LAKE HELEN CEMETERY	UFA	300	395	-	SJRWMD
285813	811424	496		-	V-0777	LAKE HELEN CEMETERY	UFA	115	193	-	SJRWMD
285442	811814	497		-	V-0780	ORANGE COUNTY TOWER	LFA	710	800	-	SJRWMD
285813	811424	498		-	V-0781	LAKE HELEN CEMETERY	ICU	64	74	-	SJRWMD
291417	811446	499		-	V-0788	ORMOND BEACH, CITY OF	UFA	111	300	-	SJRWMD
284840	811157	500		-	V-0801	OSTEEN RANCH	UFA	275	317	-	SJRWMD
290552	811626	501		-	V-0812	SJRWMD	SAS	15	25	-	SJRWMD
290552	811626	502		-	V-0813	SJRWMD	ICU	46	56	-	SJRWMD
285211	811316	503		-	V-0814	SJRWMD	SAS	32	42	-	SJRWMD
284840	811157	504		-	V-0818	OSTEEN RANCH	UFA	128	188	-	SJRWMD
284840	811157	505		-	V-0821	OSTEEN RANCH	SAS	12	22	-	SJRWMD
284840	811157	506		-	V-0822	OSTEEN RANCH	ICU	69	79	-	SJRWMD
290154	805458	507		-	V-0834	CITY OF NEW SMYRNA BEACH	SAS	0	0	-	SJRWMD
284859	805010	508		-	V-0836	UN	SAS	18	23	-	SJRWMD
285037	811932	509		-	V-0844	FPL	SAS	0	0	-	SJRWMD
285129	812024	510		-	V-0845	FPL	SAS	0	0	-	SJRWMD
285126	811926	511		-	V-0846	FPL	SAS	0	0	-	SJRWMD

Lat	Long	Site No.	Site Alph	USGS ID	SJR ID	Stn_Name	Aquifer	Cas Dep	Tot Dep	Calib 95	Data Src
285123	812024	512		-	V-0847	FPL	SAS	0	0	-	SJRWMD
290828	812151	513		-	V-1028	DELEON SPRINGS STATE PARK	SAS	40	50	-	SJRWMD
290828	812151	514		-	V-1029	SJRWMD	ICU	70	80	-	SJRWMD
290828	812151	515		-	V-1030	DELEON SPRINGS STATE PARK	UFA	120	200	-	SJRWMD
284822	805735	516		-	V-1032	MAYTOWN	SAS	-	30	Y	SJRWMD
284822	805735	517		-	V-1033	MAYTOWN	ICU	-	58	-	SJRWMD
284825	810009	518		-	V-1034	LAKE HARNEY ROAD	SAS	-	21	-	SJRWMD
285132	805105	519		-	V-1035	OAK HILL CITY HALL	SAS	20	30	-	SJRWMD
285132	805105	520		-	V-1036	OAK HILL CITY HALL	ICU	50	60	-	SJRWMD
285138	805050	521		-	V-1037	GAINES STREET	SAS	-	30	Y	SJRWMD
285143	805210	522		-	V-1039	LOOMIS NURSERY	SAS	-	34	Y	SJRWMD
285221	810950	523		-	V-1040	MULLER NEAR DELTONA	SAS	-	40	Y	SJRWMD
285343	811404	524		-	V-1041	BOSTER PARK	SAS	18	27	Y	SJRWMD
285549	804931	525		-	V-1043	CANAVERAL SEASHORE PARK	SAS	-	17	-	SJRWMD
285625	805252	526		-	V-1044	ROAD HOUSE REST	SAS	-	32	Y	SJRWMD
285630	811747	527		-	V-1045	COLEMAN SCHOOL	SAS	28	38	-	SJRWMD
285630	811747	528		-	V-1046	COLEMAN SCHOOL	UFA	63	73	-	SJRWMD
285757	811743	529		-	V-1049	DAVIS FERNERY	SAS	-	38	Y	SJRWMD
285857	811357	530		-	V-1050	MICHIGAN AVENUE	SAS	-	33	Y	SJRWMD
290025	811850	531		-	V-1051	S.W. MIDDLE SCHOOL	SAS	-	36	Y	SJRWMD
290025	811850	532		-	V-1052	S.W. MIDDLE SCHOOL	ICU	-	64	-	SJRWMD
290421	812106	533		-	V-1056	GRAND AVENUE	SAS	-	38	Y	SJRWMD
290508	812006	534		-	V-1058	TALL OAKS DRIVE	SAS	25	35	Y	SJRWMD
290508	812006	535		-	V-1059	TALL OAKS DRIVE	ICU	59	69	-	SJRWMD
290534	811750	536		290534081175003	V-1060	SHALLOW WELL NEAR F-2	SAS	-	11	Y	SJRWMD
290548	811903	537		-	V-1061	WOLF NEAR DELAND	SAS	-	48	Y	SJRWMD
290554	811608	538		-	V-1062	LAWRENCE FARMS	SAS	-	34	Y	SJRWMD
290554	811608	539		-	V-1063	LAWRENCE FARMS	ICU	73	75	-	SJRWMD
290622	812215	540		-	V-1064	SPRING GARDEN LAKE	SAS	-	5	Y	SJRWMD
290655	811112	541		-	V-1065	USGS	SAS	20	24	-	SJRWMD
290756	811211	542		-	V-1066	USGS	ICU	0	71	-	SJRWMD
290947	812329	543		-	V-1068	USGS	SAS	0	35	-	SJRWMD
291032	811813	544		-	V-1071	BILL HENDRIX	SAS	0	37	-	SJRWMD
291032	811813	545		-	V-1072	BILL HENDRIX	ICU	0	74	-	SJRWMD
291343	812546	546		-	V-1074	R. JONES	SAS	6	7	-	SJRWMD
290947	812329	547		-	V-1075	USGS	ICU	90	84	-	SJRWMD
285708	811743	548		-	V-1076	ED DAVIS	ICU	0	74	-	SJRWMD

Lat	Long	Site No.	Site Alph	USGS ID	SJR ID	Stn_Name	Aquifer	Cas Dep	Tot Dep	Calib 95	Data Src
285437	811814	549		-	V-1077	USGS	ICU	0	71	-	SJRWMD
291933	812945	550		-	V-1081	DEPT OF AGRICULTURE	SAS	0	31	-	SJRWMD
291951	810726	551		-	V-1082	UN	ICU	20	75	-	SJRWMD
292056	810802	552		-	V-1085	BELLMEADE CORP	SAS	0	65	-	SJRWMD
292056	810802	553		-	V-1086	BELLMEADE CORP	SAS	0	15	-	SJRWMD
292258	810650	554		-	V-1087	UN	SAS	0	18	-	SJRWMD
292304	810719	555		-	V-1088	UN	SAS	0	18	-	SJRWMD
291004	811113	556		-	V-1089	USGS	SAS	20	20	-	SJRWMD

APPENDIX D—PUBLIC SUPPLY PUMPAGE WITH WATER BUDGET ANALYSIS

Appendix D. Public Supply Pumping and Water Budget Analysis (in million gallons per day)

Water User		PoTable Use				Wastewater Treatment			
		1995		2020		1995		2020	
County	Utility	Use	PSLI	Use	PSLI	WWTP Flow	Septic	WWTP FLOW	Septic
Volusia	Daytona Beach	12.42	3.09	20.54	5.14	9.33		15.41	
Volusia	DeLand	5.08	1.15	7.38	1.85	2.78	1.15	5.54	
Volusia	Edgewater	1.49	0.15	4.10	1.03	1.34		3.08	
Volusia	Florida Water Services—Deltona	9.12	4.12	16.75	7.47	0.89	4.12	1.82	7.47
Volusia	Holly Hill	1.16	0.38	1.70	0.43	0.78		1.28	
Volusia	Lake Beresford	0.17	0.09	0.43	0.22		0.09		0.22
Volusia	Lake Helen	0.24	0.12	0.85	0.43		0.12		0.43
Volusia	New Smyrna Beach	4.27	1.43	7.13	1.78	2.84		5.35	
Volusia	Orange City	1.33	0.67	2.82	1.41		0.67		1.41
Volusia	Ormond Beach	4.90	1.11	7.23	1.81	3.79		5.42	
Volusia	Port Orange	5.28	0.24	8.98	2.25	5.04		6.74	
Volusia	Volusia County—Deltona North	0.27	0.00	1.35	0.34	0.27		1.01	
Volusia	Volusia County—Northeast	0.15	0.08	0.74	0.37		0.08		0.37
Volusia	Volusia County—Southeast	0.18	0.07	0.48	0.12	0.06	0.05	0.36	
Volusia	Volusia County—Southwest	1.29	0.40	5.10	1.28	0.50	0.40	3.83	
Volusia	Volusia County—Spruce Creek	0.27	0.10	0.62	0.16	0.17		0.47	
Volusia	John Knox Village	0.21	0.11	0.40	0.20		0.11		0.20
Volusia	Pierson	0.12	0.06	0.23	0.12		0.06		0.12
Lake	Country Squire MH Village	0.23	0.12	0.70	0.35		0.12		0.35
Lake	Oak Springs MHP	0.17	0.05	0.53	0.13	0.12		0.40	
Lake	Plantation Bay	0.20	0.10	0.60	0.30		0.10		0.30
Orange	OCU: Mt. Plymouth Lakes	1.19	0.46	3.52	0.88	0.73		2.64	
Seminole	Lake Mary	1.75	0.68	4.64	1.16	1.07		3.48	
Seminole	Sanford	5.76	0.45	11.10	2.78	5.31		8.33	
Seminole	Seminole County PWD	1.56	1.16	3.58	0.90	0.40		2.69	
Seminole	Utilities Inc. of Florida	0.22	0.13	0.35	0.09	0.08		0.26	
Various	Miscellaneous	0.27	0.11	0.62	0.31		0.16		0.31
Total		59.30	16.62	112.47	33.25	35.50	7.22	68.07	11.16

Note: MHP = mobile home park
OCU = Orange County Utilities
PSLI = public supply landscape irrigation
PWD = Public Works Department
WWTP = wastewater treatment plant

Discrepancies between individual values and corresponding totals may occur due to number of significant digits displayed.

APPENDIX E—WASTEWATER TREATMENT PLANT FLOWS AND REUSE TOTALS FOR 1995

Appendix E. Wastewater Treatment Plant Flows and Reuse Totals for 1995

Owner or Operator	Facility Name	Total Flow	Reuse Irrigation	Reuse RIBs	Reuse Industrial	Total Reuse	Discharge Surface Water
Daytona Beach, City of	Bethune Point	6.33	0.00	0.00		0.00	6.33
Daytona Beach, City of	Regional	3.00	1.50	0.00		1.50	1.50
DeLand, City of	Brandy Trails	0.12	0.12	0.00		0.12	0.00
DeLand, City of	Regional	2.66	0.27	0.00		0.27	2.39
Edgewater, City of	Edgewater	1.34	0.48	0.00		0.48	0.87
Florida Water Services	Deltona Lakes	0.89	0.00	0.89		0.89	0.00
Holly Hill, City of	Holly Hill	0.78	0.50	0.00		0.50	0.28
New Smyrna Beach	New Smyrna Beach	2.84	1.10	0.00		1.10	1.74
Ormond Beach, City of	Breakaway Trails	0.11	0.11	0.00		0.11	0.00
Ormond Beach, City of	Ormond Beach	3.64	0.29	0.00		0.29	3.35
Ormond: Tymber Creek, Inc.	Tymber Creek Subdiv.	0.04	0.00	0.00		0.00	0.04
Port Orange, City of	R. Dwayne Huffman	5.04	1.00	0.00		1.00	4.04
Volusia County	Deltona North	0.27	0.00	0.00		0.00	0.27
Volusia County	Hacienda del Rio	0.06	0.00	0.00		0.00	0.06
Volusia County	Southwest Regional	0.50	0.08	0.22		0.30	0.20
Volusia County	Spruce Creek	0.17	0.00	0.17		0.17	0.00
Boll, John	Oak Springs MHP	0.12	0.00	0.00		0.00	0.12
Orange County Utilities*	Mt. Plymouth Lakes	0.73	0.00	0.73		0.73	0.00
Lake Mary*	Lake Mary	1.07	0.00	1.07		1.07	0.00
Sanford, City of	Sanford	5.31	4.31	0.00	0.02	4.33	0.98
Seminole County	Northwest Regional	0.40	0.40	0.00		0.40	0.00
Utilities, Inc.	Lincoln Heights	0.08	0.00	0.00		0.00	0.08
Totals		35.51	10.15	3.08	0.02	13.25	22.26

Note: MHP = mobile home park
RIBs = rapid infiltration basins

*RIBs for these utilities exist outside of the model domain.

Discrepancies between individual values and corresponding totals may occur due to number of significant digits displayed.

APPENDIX F—PROJECTED WASTEWATER TREATMENT PLANT FLOWS AND REUSE TOTALS FOR 2020

Appendix F. Projected Wastewater Treatment Plant Flows and Reuse Totals for 2020

Owner or Operator	Facility Name	Total Flow	Reuse Irrigation	Reuse RIBs	Reuse Industrial	Total Reuse	Discharge Surface Water
Daytona Beach, City of	Bethune Point	7.70	0.00	0.00		0.00	7.70
Daytona Beach, City of	Regional	7.70	7.70	0.00		7.70	0.00
DeLand, City of	Brandy Trails	0.00	0.00	0.00		0.00	0.00
DeLand, City of	Regional	5.54	2.77	0.00		2.77	2.77
Edgewater, City of	Edgewater	3.08	1.54	0.00		1.54	1.54
Florida Water Services	Deltona Lakes	1.82	1.82	0.00		1.82	0.00
Holly Hill, City of	Holly Hill	1.28	0.64	0.00		0.64	0.64
New Smyrna Beach	New Smyrna Beach	5.35	2.68	0.00		2.68	2.68
Ormond Beach, City of	Breakaway Trails	0.00	0.00	0.00		0.00	0.00
Ormond Beach, City of	Ormond Beach	5.42	2.71	0.00		2.71	2.71
Ormond: Tymber Creek, Inc.	Tymber Creek Subdiv.	0.00	0.00	0.00		0.00	0.00
Port Orange, City of	R. Dwayne Huffman	6.74	3.37	0.00		3.37	3.37
Volusia County	Deltona North	1.01	0.00	1.01		1.01	0.00
Volusia County	Hacienda del Rio	0.36	0.18	0.00		0.18	0.18
Volusia County	Southwest Regional	3.83	1.92	1.92		3.83	0.00
Volusia County	Spruce Creek	0.47	0.00	0.17		0.17	0.30
Boll, John	Oak Springs MHP	0.40	0.00	0.00		0.00	0.40
Orange County Utilities*	Mt. Plymouth Lakes	2.64	0.00	1.32		1.32	1.32
Lake Mary*	Lake Mary	3.48	0.00	1.74		1.74	1.74
Sanford, City of	Sanford	8.33	4.31	0.00	0.02	4.33	4.00
Seminole County	Northwest Regional	2.69	2.69	0.00		2.69	0.00
Utilities, Inc.	Lincoln Heights	0.26	0.13	0.00		0.13	0.13
Total		68.10	32.45	6.16	0.02	38.63	29.47

Note: MHP = mobile home park
RIBs = rapid infiltration basins

*RIBs for these utilities exist outside of the model domain.

Discrepancies between individual values and corresponding totals may occur due to number of significant digits displayed.