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# A REGIONAL FLOW MODEL OF THE VOLUSIA GROUND WATER BASIN

by

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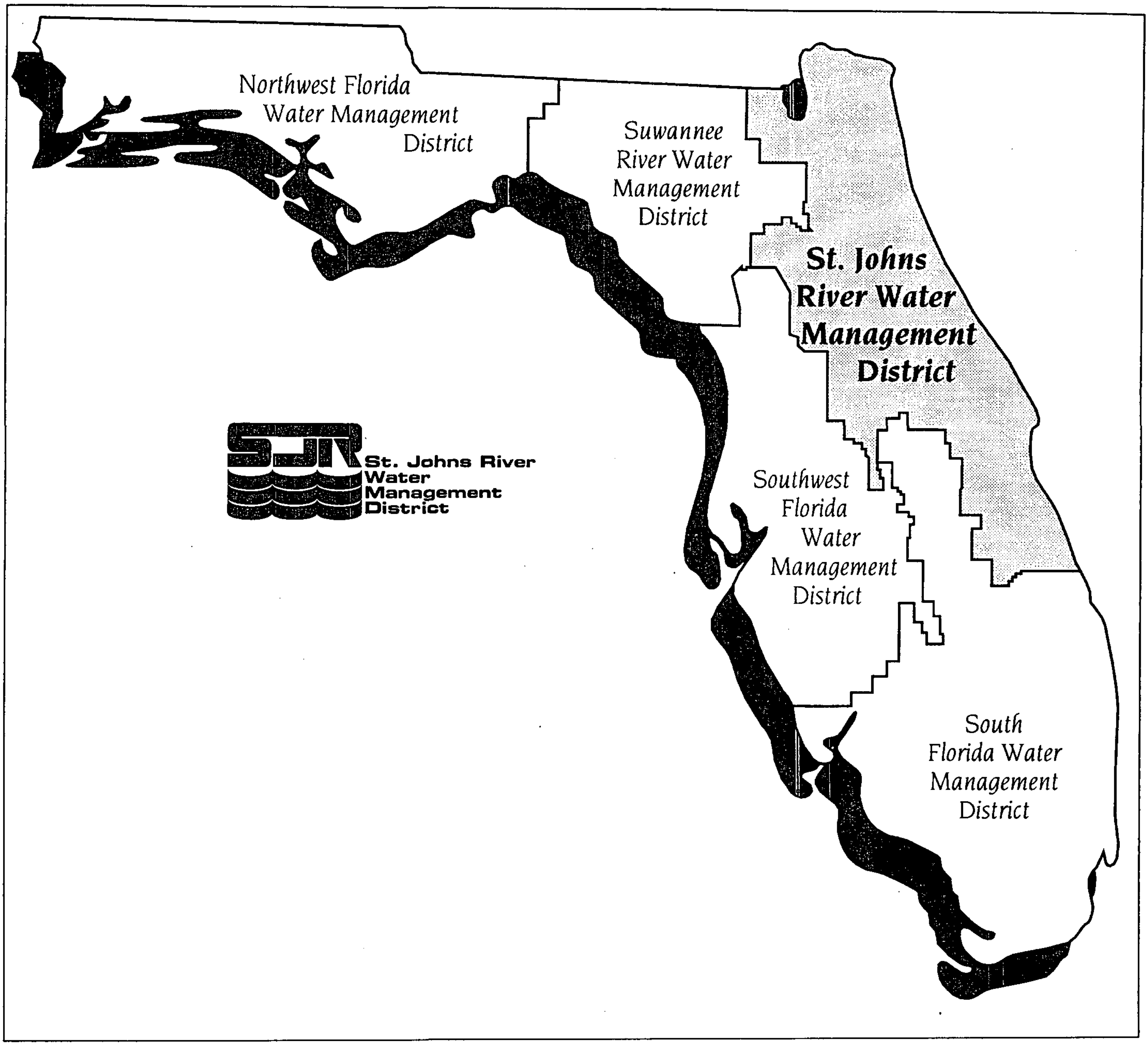
1997




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 19 counties in northeast Florida. The mission of SJRWMD is to manage water resources to ensure their continued availability while maximizing environmental and economic benefits. It 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.

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# EXECUTIVE SUMMARY

In 1989, the Florida Legislature mandated that each of the state's five water management districts perform an assessment of water resources that are available to meet current and future water supply needs. This assessment is designed to identify areas in which water resource problems have become critical or are projected to become critical by the year 2010 and to identify remedial or preventive actions designed to correct or prevent these problems.

In performing this assessment, the St. Johns River Water Management District (SJRWMD) targeted several areas that would benefit from the development of computer models of the regional ground water resources. The Volusia ground water basin (VGWB) was selected as one of these areas on the basis of current and projected ground water withdrawals and historic water resources concerns. For example, between 1988 and 2010 public supply water use is expected to more than double in VGWB, increasing from just over 45 million gallons per day (mgd) in 1988 to 95 mgd in 2010.

Therefore, a ground water flow model was developed for VGWB. The model incorporates a variety of aquifer parameters (e.g., transmissivity, leakance) and boundary conditions which are based upon the best available information. The model has been compared to a predevelopment condition and calibrated to average steady-state hydrologic conditions of 1988. The model was used to perform predictive simulations for the year 2010. Water use information for both the calibration period and the future projections was compiled from available data and reviewed with local utilities and other principal water users.

The freshwater resources in VGWB exist in the form of a relatively thick freshwater lens with its greatest thickness (1,000–1,200 feet [ft]) in west-central Volusia County. This freshwater lens has been affected by pumping which has occurred from predevelopment time to present; the lens will continue to be affected through the year 2010. Specifically, impacts from 1988 to 2010 include the following:

- Drawdowns in the elevation of the water table are predicted to be over 4 ft in the vicinity of the Daytona Beach western wellfield, 1–2 ft near the Ormond Beach wellfields, up to 6 ft in the Deltona area, and 1–2 ft around the Port Orange western wellfield. Some of these drawdown areas are in or near local wetlands; therefore, the drawdowns may have a bearing on the ecological viability of these wetlands.

- Impacts to the Upper Floridan aquifer include drawdowns of over 20 ft in the vicinity of the Daytona Beach western wellfield, 5–10 ft near Deltona, approximately 3–5 ft near the New Smyrna Beach wellfields, and up to 10 ft around the Port Orange western wellfield. Impacts also included several localized drawdowns which are due to public supply withdrawals. These drawdowns indicate a reduction in ground water storage and are a concern for the long-term viability of the ground water resource. By inference, these drawdowns also may be indicative of water quality problems, specifically upconing directly underneath major wellfields and lateral intrusion along the coast of VGWB.

- Impacts to the Lower Floridan aquifer include regional declines in the elevation of the potentiometric surface of 1–3 ft and over 7 ft in the vicinity of the Daytona Beach western wellfield.

- Impacts to the distribution of recharge to or discharge from the Upper Floridan aquifer have occurred and are caused primarily by changes in the water table and/or the potentiometric surface of the Upper Floridan aquifer.

A ground water model of VGWB has been developed and used to simulate the impacts of current and projected pumping on the hydrogeologic system. In order to enhance current understanding of the ground water flow system and to contribute to future modeling projects for this area, specific recommendations regarding additional data collection and monitoring are presented below. Finally, recommendations regarding potential improvements in management of the regional ground water resource are discussed.

An effective ground water monitoring program provides information to characterize the ground water system and provides the basis for the examination of natural or anthropomorphic influences upon that system. The following enhancements to the existing monitoring well program are recommended:

- The collection of data to facilitate a comparison of observed changes to model-simulated changes in the surficial aquifer system and in the Upper and Lower Floridan aquifers in the vicinity of major public supply wellfields

- The establishment of surface water monitoring sites to characterize water level trends in wetlands, particularly in areas of predicted declines in the surficial aquifer system

- The collection of data to describe water quality trends, with particular focus on the potential for upconing beneath major public supply wellfields and for lateral intrusion in areas seaward of major pumping in the Upper Floridan aquifer

This additional data collection will provide information for the development of future simulation models of the ground water system. SJRWMD intends to revisit, refine, and recalibrate the modeling approach for VGWB every 5 years. As additional data deficiencies are addressed, future simulation models of this area will become increasingly more reliable in an ability to approximate the actual hydrogeologic system.

In order to recommend improvements in the management of the ground water resource, specific hydrologic conditions that are undesirable must be defined. Therefore, based upon the model findings stated above, the following are undesirable hydrologic conditions that are likely to occur given projected pumping scenarios:

- Potential water quality changes could result from the predicted reduction in the elevation of the potentiometric surface of the Upper Floridan aquifer in VGWB. This reduction will lead to a decrease in the amount of ground water that is acceptable for public supply use without advanced water treatment (e.g., reverse osmosis).

- The relatively high drawdown values that are projected to occur in some areas (e.g., the Daytona Beach western wellfield) indicate the increased potential for lateral or vertical saltwater intrusion. This intrusion will eventually lead to a deterioration in the quality of water available for public supply usage.

- Projected drawdowns in the surficial aquifer system may contribute to a degradation in the ecological integrity of wetlands, a valued component of the VGWB ecology.

- Increased pumpage may contribute to reductions in spring flow at springs such as Blue Spring and Ponce de Leon Springs. These reductions could have a deleterious impact on the ecological and recreational value of these areas.

SJRWMD intends to address these potential undesirable impacts through formulation and interpretation of alternative model scenarios to maximize water supply potential while limiting any environmental impact to an acceptable level. SJRWMD will use optimization modeling to facilitate a bridge between simulation modeling and related water use strategies. These strategies could include the potential interconnection of wellfields, use of artificial recharge, development of sources of low water quality (e.g., surface water and brackish ground water), reuse of reclaimed water, and water conservation. Results of such analyses could be used to develop preferred (i.e., optimal) water management solutions.

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# INTRODUCTION

## PURPOSE AND SCOPE

In 1989, the Florida Legislature mandated that each of the state's five water management districts perform an assessment of water resources that are available to meet current and future water supply needs (Paragraph 373.0391(2)(e), *Florida Statutes*). This assessment is designed to identify areas in which water resource problems have become critical or are projected to become critical by the year 2010 and to identify remedial or preventive actions designed to correct or prevent these problems (Vergara 1994).

In performing this assessment, the St. Johns River Water Management District (SJRWMD) targeted several areas that would benefit from the development of computer models of the regional ground water resources. The Volusia ground water basin (VGWB) was selected as one of these areas on the basis of current and projected ground water withdrawals and historic water resources concerns. For example, between 1988 and 2010, public supply water use is expected to more than double in VGWB, increasing from just over 45 million gallons per day (mgd) in 1988 to 95 mgd in 2010.

The development and application of a regional ground water flow model for VGWB provides the basis for an evaluation of the long-term viability of the ground water resources of this basin for water supply. This modeling analysis was performed by assessing recent (1988) and future (2010) impacts of water use upon the ground water resources. The principal objectives for development of a ground water flow model of VGWB are

1. To develop a working tool to enhance the knowledge of the dynamics of the ground water flow system for VGWB

2. To use this tool to simulate the impacts of recent (1988) and future (2010) pumping upon the ground water flow system

3. To recommend any additional data collection that will enhance the understanding of the ground water flow system and will contribute to future modeling efforts

4. To recommend improvements in the management of the ground water resource

## STUDY AREA

The study area of the current investigation includes virtually all of Volusia County; the southern lobe of Flagler County; and small portions of Putnam, Lake, and Seminole counties (Figures 1 and 2). The area boundaries extend east approximately 8 miles offshore, west to the vicinity of the St. Johns River, north into Flagler County, and south to just north of the Brevard County line.

## PREVIOUS STUDIES

Several earlier studies are pertinent to development of a regional model of the ground water resources. Wyrick (1960) performed one of the earliest comprehensive studies in which he provided contemporary data and estimates of aquifer parameters that would be used subsequently in development of conceptual models of the ground water system for the county. In 1971, Knochenmus and Beard published a study of water quality and water quantity of the ground water resources for the county that expanded upon Wyrick's work. Bush (1978) developed one of the earlier ground water flow models of the area. This early ground water model would serve as the basis for later model developments. Simonds et al. (1980) discussed relationships between water level trends and vegetation classifications, providing documentation for the impacts of changes in water levels. Rutledge (1982) evaluated the effects of irrigation withdrawals on the Floridan aquifer system in northwestern Volusia County. He also evaluated the overall ground water hydrology of Volusia County, including a water budget analysis and extensive discussion of water quality issues (1985). McGurk et al. (1989) completed a study of lithologic and hydrogeologic characteristics of the surficial aquifer system in Volusia County. Mercer et al. (1984) developed a regional ground water flow and saltwater intrusion

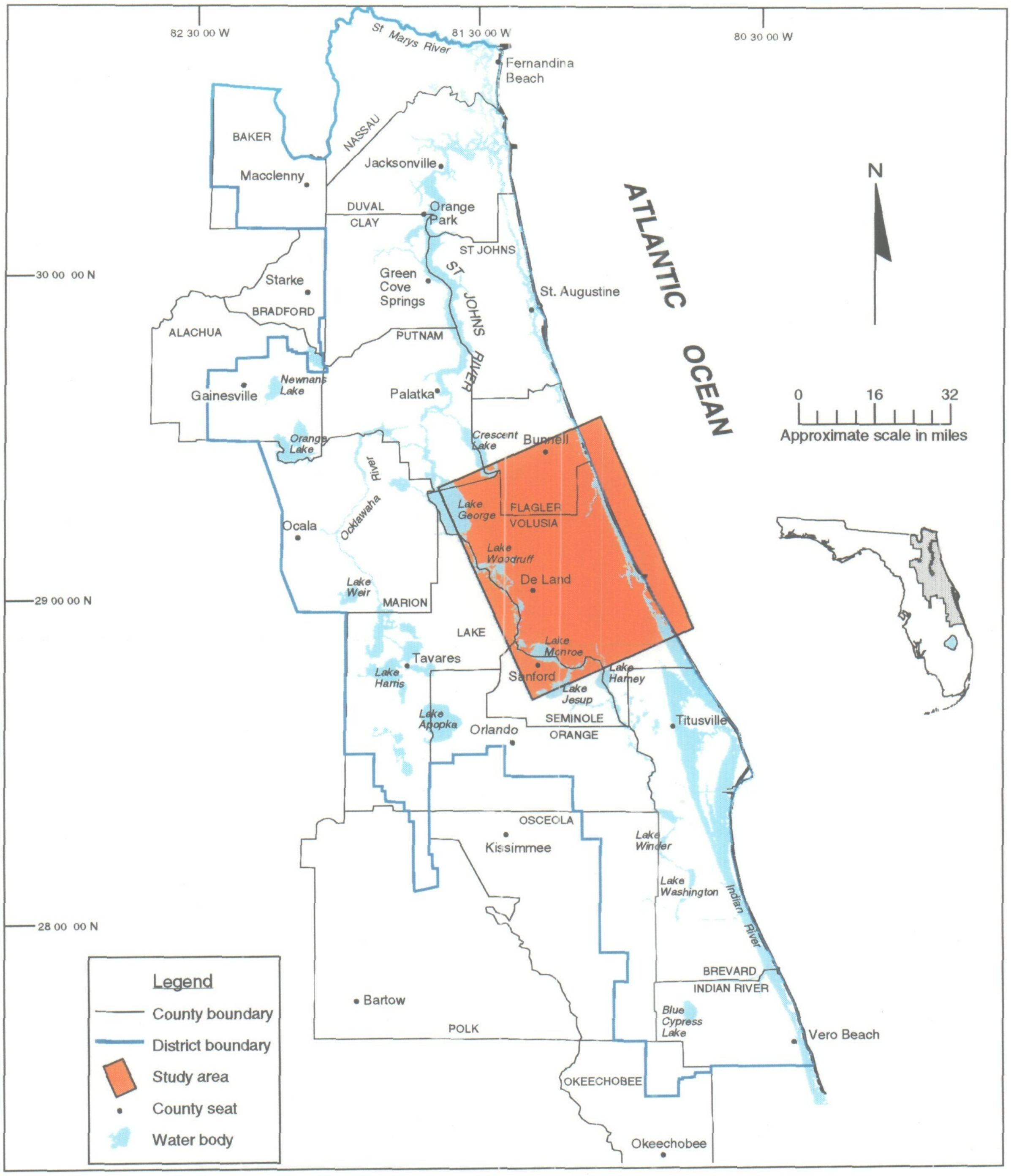



**Figure 1. The St. Johns River Water Management District and the study area for the regional model of the Volusia ground water basin**

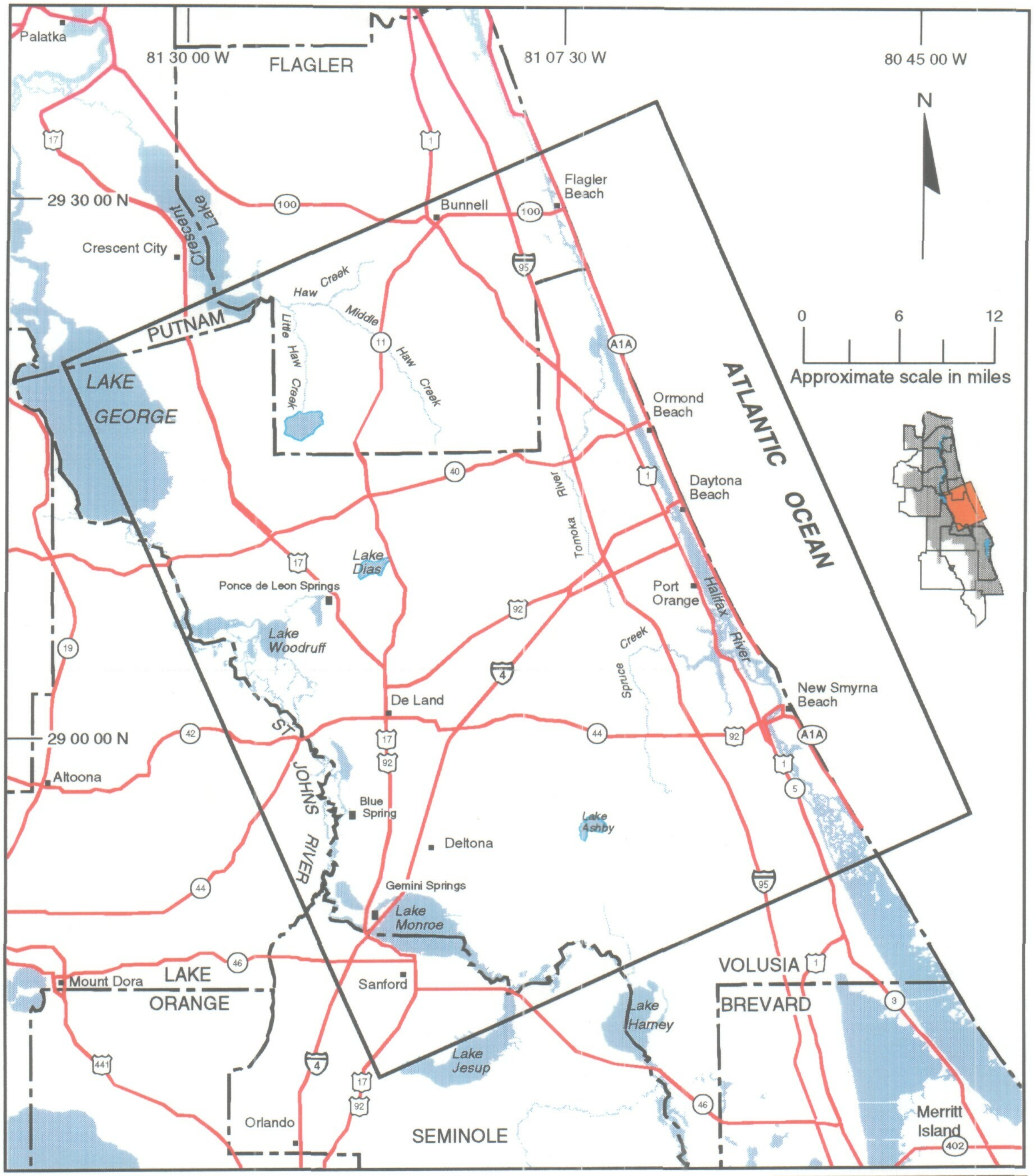



**Figure 2. Study area: Volusia basin regional model**

Legend
- County boundary
- Spring
- Town
- Model boundary
- Road
- Water body

model of VGWB. Phelps (1990) completed a review of the hydrogeology and water quality of the surficial aquifer system in Volusia County. Tibbals (1981, 1990) developed a regional ground water flow model of resources of east-central Florida as a U.S. Geological Survey (USGS) Regional Aquifer Systems Analysis (RASA) model. Finally, Geraghty & Miller (1991) developed a regional ground water flow and seawater intrusion model for VGWB.

## TECHNICAL APPROACH

The ground water flow modeling code used in the present investigation is MODFLOW, a three-dimensional, finite-difference model developed by USGS (McDonald and Harbaugh 1988). This code was selected because (1) it has been well validated through numerous field applications both within and outside of USGS and (2) it can simulate a variety of boundary conditions and hydrologic processes.

The present study is a revision of a previous model developed by Geraghty & Miller (1991), under contract to SJRWMD. SJRWMD has modified the previous model using available data, including water level measurements, aquifer performance test results, geophysical logs, water use data, and related information distilled from previous studies. This report provides an explanation of these modifications, including the following:

- A revised distribution of recharge to the surficial aquifer system
- Incorporation of the effect of evapotranspiration on the water budget of the surficial aquifer system
- A revised distribution of leakance between the surficial aquifer system and the Upper Floridan aquifer
- A revised distribution of transmissivity in the Upper Floridan aquifer based upon aquifer performance test data and observed elevations of the potentiometric surface

- Modifications to the eastern lateral boundary conditions for the surficial aquifer system and the Upper and Lower Floridan aquifers

- Recalibration of both the surficial aquifer system and the Upper Floridan aquifer through consideration of available water level data and spring flux data

# HYDROGEOLOGIC FRAMEWORK

An assessment of the hydrogeologic framework for a given study area is an essential complement to the development of a ground water model for that area. The current study took into consideration all processes and components of the physical system that have an impact upon the quantity and quality of the ground water resources. Relevant hydrologic processes include precipitation, ground water recharge and discharge, evapotranspiration, leakage between hydrogeologic units, and spring discharge. Significant components of the hydrologic system include surface water features, land surface topography, geomorphology, water table elevation, potentiometric surfaces of the Upper and Lower Floridan aquifers, and the hydrostratigraphic configuration of the underlying geologic system.

## SURFACE WATER

Although surface water features are not rigorously considered to be part of the hydrogeologic system, these features have a direct impact upon the simulation of an active surficial aquifer system. The existence of lakes, wetlands, and surface water drainage patterns all affect the hydrology of the surficial aquifer system.

### Lakes

Volusia County has approximately 120 lakes with areas greater than 5 acres (Knochenmus and Beard 1971). Ninety percent of these lakes are in the karst ridge areas, where high vertical hydraulic gradients and dissolution of carbonate rocks in the underlying carbonate sediments have facilitated the development of sinkholes. Sinkholes often become clogged with organic deposits which retard the downward movement of water, thereby facilitating the development of sinkhole lakes (Wyrick 1960). Some of these lakes are significant to the ground water system as local points of relatively high recharge for the underlying Upper Floridan aquifer. The lakes also act as control points for the surficial aquifer system.

## Wetlands

Based upon SJRWMD data, much of VGWB is characterized as a type of freshwater wetland (Figure 3). Wetlands may function as surface water storage reservoirs that contribute recharge to the surficial aquifer system, given a downward head gradient between the surface water and the surficial aquifer system. Wetlands, through the process of evapotranspiration, also function to remove water that is potential recharge to the underlying ground water system. Wetlands may be affected by the ground water system as changes in ground water levels (e.g., due to pumping or seasonal effects) may cause lower surface water levels and shorter periods of inundation than existed prior to the changes. These effects of the ground water system on wetlands may influence the viability of wetlands as a habitat for freshwater flora and fauna. The existence of wetlands in VGWB is largely a function of land surface elevation. Figure 4, based upon SJRWMD data, portrays land surface elevations and physiographic features in the study area.

## Drainage Patterns

Natural surface drainage accounts for the second largest outflow (after evapotranspiration) from the surficial aquifer system in VGWB. In Volusia County, there are three primary surface water basins: (1) a basin in north-central Volusia County with water flowing north to Middle Haw and Little Haw creeks (Figure 2), (2) a basin in western and southern Volusia County with surface water flowing into the St. Johns River, and (3) a coastal basin with surface water flowing seaward into the Atlantic Ocean and the Halifax River (Rutledge 1985). These basins are delineated based upon direction and destination of local surface water flow. In spite of the existence of these natural surface water basins, surface water features in VGWB are generally not well developed. For example, the Crescent City and De Land ridges in western Volusia County (Figure 4) are noted for an absence of surface drainage features. Also, much of the county, especially the eastern part of Talbot Terrace, is wetlands with little development of actual surface stream systems for drainage. Spruce Creek and the Tomoka River are the principal water bodies that drain the eastern part of the county (Figure 2), and small tributaries

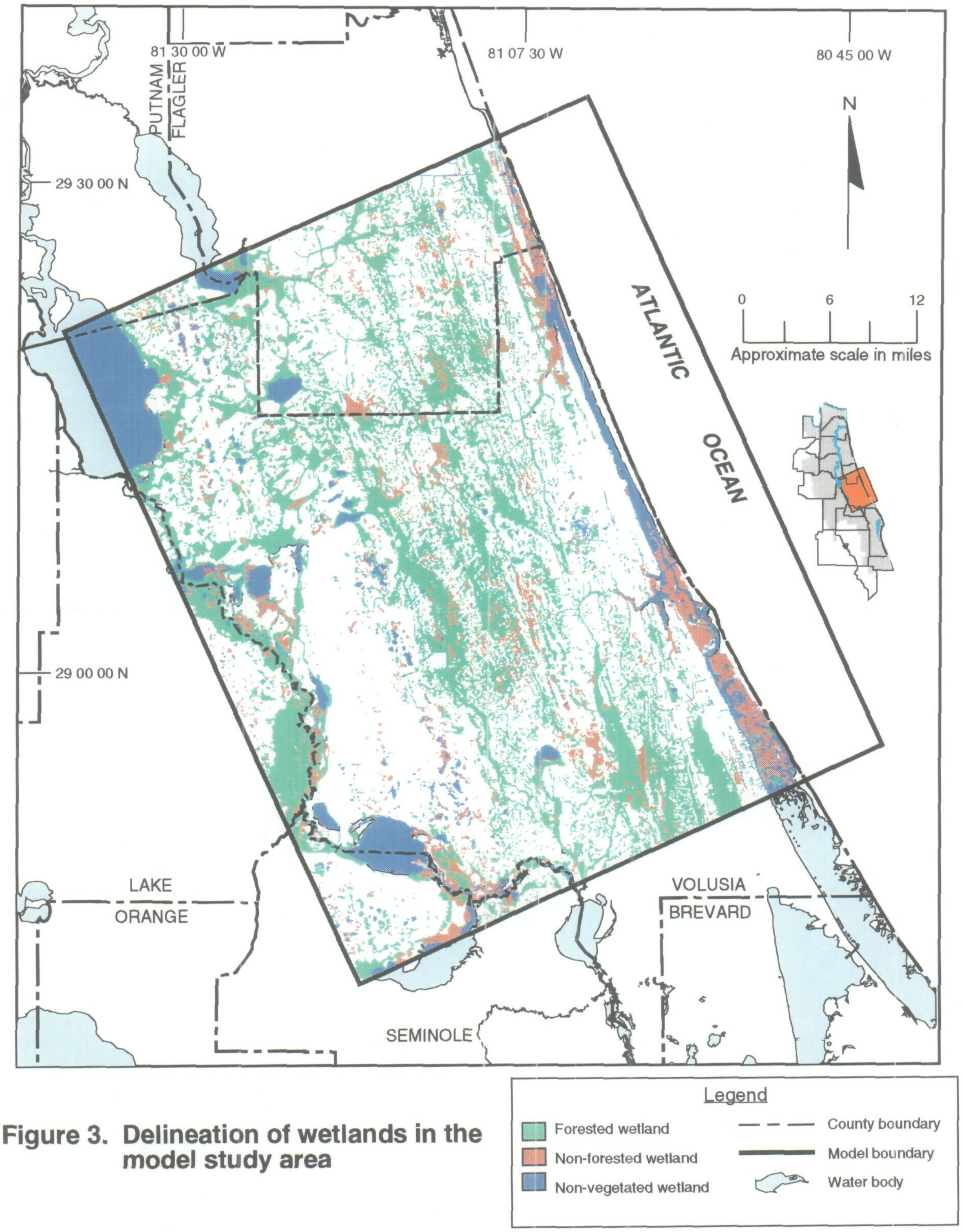



**Figure 3. Delineation of wetlands in the model study area**

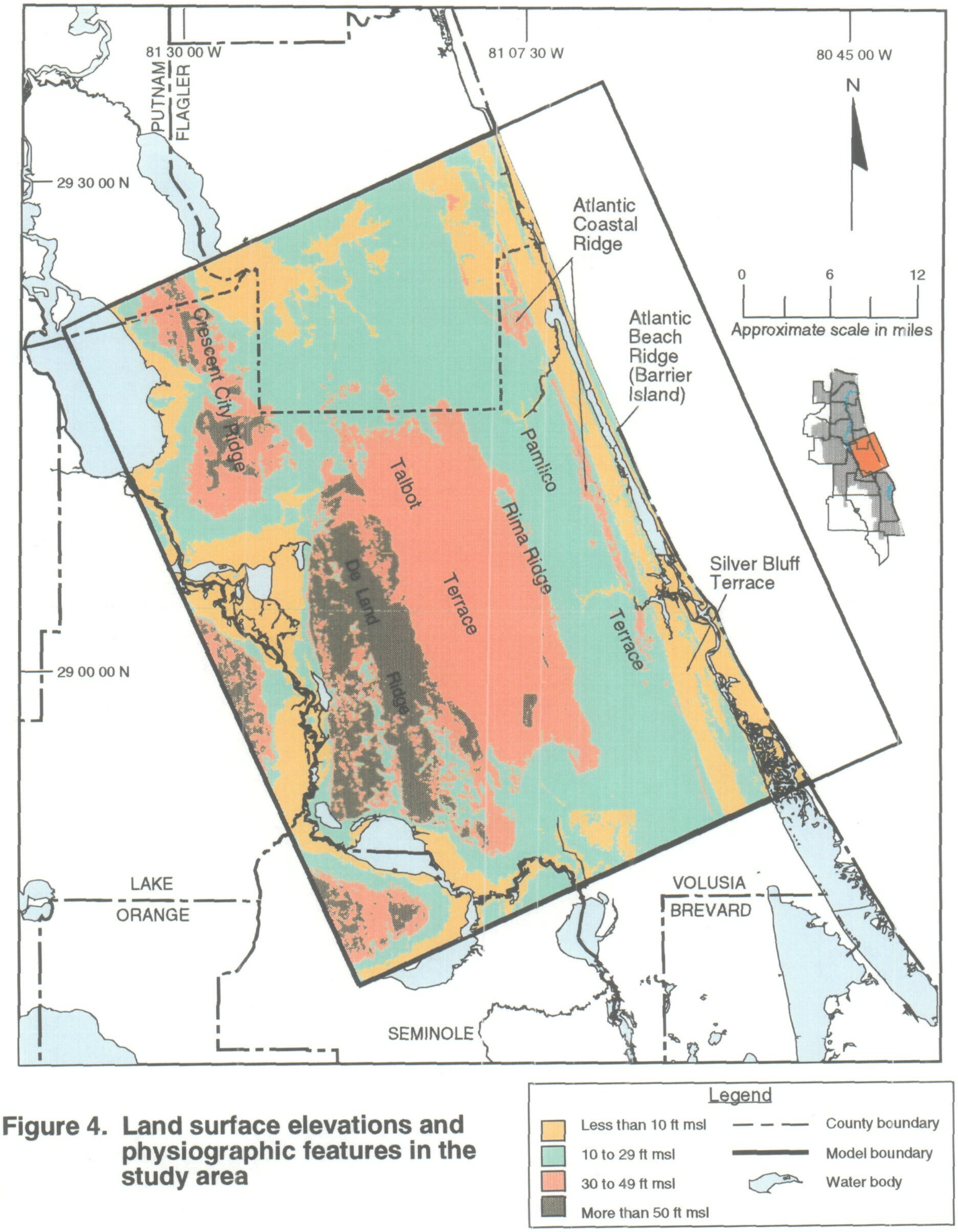



**Figure 4. Land surface elevations and physiographic features in the study area**

of the St. Johns River provide some natural drainage in the western portion of VGWB.

In addition to natural drainage patterns in VGWB, the push for commercial and residential development has necessitated construction of a network of drainage canals and associated control structures. The extent of artificial drainage is greatest in Daytona Beach and Port Orange and around Lake Ashby (Figure 2) (Rutledge 1985). As a result, these three areas have been subjected to the largest long-term declines in the elevation of the water table.

## GEOLOGIC SETTING

The geologic setting of the study area provides the structural and lithologic underpinnings for the local hydrogeologic system. This setting includes surface geomorphology and the underlying stratigraphic sequence.

### Geomorphology

The geomorphology of the study area results from repeated periods of sea level fluctuations due to cycles of glaciation and deglaciation that occurred during the Pleistocene Epoch, some 10,000 to 2,000,000 years B.P. (White 1970). The surface geomorphology is a series of sandy coastal ridges and marine terraces that formed as the coastal dunes and the near-shore sea bottoms during periods of sea level fluctuation. This pattern of ridges and terraces affects the recharge/discharge distribution to the surficial aquifer system and the Upper Floridan aquifer.

**Terraces.** The terraces in the study area are the Talbot, Pamlico, Silver Bluff, and Penholoway (Figure 4). In western Volusia County, the Crescent City and De Land ridges are remnants of the Penholoway Terrace, which has been eroded by sinkhole formations. The Talbot, Pamlico, and Silver Bluff terraces, in central and eastern Volusia County, are largely unchanged from the time of formation and are relatively flat.

**Ridges.** The principal ridges in the study area are the Crescent City and De Land ridges in western Volusia County and Rima Ridge and the Atlantic Coastal Ridge in coastal Volusia County. The De Land Ridge is the highest and oldest geomorphologic feature in Volusia County. It was part of the Wicomico shoreline, which was formed during the Sangamon interglaciation. The Sangamon interglaciation ended about 100,000 years B.P., when sea level was about 70–80 feet (ft) higher than at present (Wyrick 1960). Karst development, found along the De Land Ridge, is the result of dissolution of underlying carbonate material and is characterized by irregular, pitted topography, sinkhole lakes and ponds, and subsurface drainage (McGurk et al. 1989). Almost all precipitation in karst areas drains downward into sinks or is lost to evapotranspiration. White (1970) considered the Crescent City and De Land ridges to be relict Atlantic shoreline features that have been altered by karst development. The Atlantic Coastal Ridge separates the Pamlico and Silver Bluff terraces. The Atlantic Beach Ridge, a barrier island, is an active feature of present-day sea level conditions (Phelps 1990).

The absence of surface drainage on the ridges, particularly on the De Land Ridge, has reinforced karst development. In the ridge areas, limestone dissolution has contributed to the development of irregular land surfaces. Karst systems are characterized by the lack of surface drainage; the presence of sinkholes, springs, and round lakes; and wide variation in altitude of contemporaneous relict shorelines (e.g., the Wicomico shoreline) (Phelps 1990). Karst dissolution patterns are most developed on the De Land Ridge because this is the highest topographic region in the county and it has not been modified repeatedly by seawater inundations (Phelps 1990).

## Soils

The soils of VGWB vary from the sandy soils of the coastal ridges to the organic mucks of the wetlands and swampy lowlands (Table 1; see Figures 3 and 4). Soil characteristics are important to the ground water resources because they have a significant influence upon infiltration of precipitation into the ground water system. The more

**Table 1. Summary of soil associations**

| Landscape Type | Soil Association(s) | Drainage | Slope | Characteristics | Location |
|---|---|---|---|---|---|
| Sand ridges | Paolla-Pomello-Astatula; Canaveral-Palm Beach-Welaka | Excessively to moderately well-drained | Nearly level to strongly sloping | Sandy to 80 inches or more | Coastal ridges, De Land Ridge, and Crescent City Ridge |
| Broad grassy flats | Pompano | Poorly drained | Nearly level | Sandy to 80 inches or more | Eastern edge of lowlands along the St. Johns River |
| Flatwoods | Myakka-Eau Gallie-Immokalee; Pineda-Wabasso | Poorly drained | Nearly level | Sandy over weakly cemented sandy layer | Between ridges and lowlands along the St. Johns River |
| Hammocks and low ridges | Myakka-Bradenton-shallow Copeland; Copeland-Wabasso | Poorly to very poorly drained | Nearly level | Loamy subsoil; weakly cemented layers; may be less than 40 inches deep over hard limestone | Marine terraces throughout the Volusia ground water basin |
| St. Johns River floodplains | Felda-Floridana-Winder; Floridana-Chobee-Felda | Poorly to very poorly drained | Nearly level | Loamy subsoil | Lowlands along the St. Johns River |
| Swamps and marshes | Montverde-Micco-Tomoka; Swamp; Tidal Marsh-Tidal Swamp | Poorly to very poorly drained | Nearly level | Organic | Floodplain of the St. Johns River and along saltwater rivers, creeks, and lagoons |

Source: Baldwin et al. 1980

sandy soils of the coastal ridges facilitate recharge, and the mucky, organic soils of the lowlands may inhibit recharge.

## Stratigraphy

The stratigraphic sequences that are pertinent to the current study area range from recent clastic deposits through carbonate deposits of Eocene age to the anhydrite beds of the Paleocene age (Table 2). Interfingering of sediments is common, and abrupt changes often occur. Generally, the Miocene and younger sediments comprise a clastic facies that covers the older carbonates, except where these

**Table 2. Summary of stratigraphic sequences of the Volusia ground water basin**

| Series | Formation or Group | Deposition | Comments |
|---|---|---|---|
| Holocene (Recent) | (unnamed) | Alluvial, lake, and windblown deposits | Thin, sand-and-gravel deposits adjacent to present-day streams; dune, estuary, and lagoon sediments contiguous to modern coast |
| Pleistocene | Pamlico | Series of constructional sandy marine terraces and coastal ridges deposited at shoreline of fluctuating seas | Medium- to coarse-grained tan, white, or brown sand with local trace amounts of carbonaceous material and broken shell fragments; underlies series of marine terraces formed during Pleistocene during periods of rising and falling seas in response to glacial and interglacial episodes |
| | Anastasia | | Cemented coquina reduced to small fragments, cemented by calcium carbonate, iron oxide, or other cements |
| Pliocene | Caloosa-hatchee | Shallow to marginal marine environment | Scattered patches of shallow marine rocks; thin sequence of interbedded clay, calcareous clay, and sand with much locally broken shelly material; upper part of Caloosahatchee is Pleistocene |
| Miocene | Hawthorn | Shallow to moderately deep marine water; inner to middle shelf in basin that receives copious clastic material | Elevation of top is -50 to -100 feet mean sea level (ft msl), thickness about 100 ft; surface deeply eroded, eroded through in some places; very thin in north-central Florida; poorly understood due to complexity of facies changes; Hawthorn Group is most widespread and thickest Miocene unit in southeastern United States; in eastern Florida, most of Miocene strata consists of complex interbedded, highly variable sequences consisting mostly of clay, silt, and sand beds with scarce to abundant phosphate; can be divided roughly into basal calcareous unit, middle clastic unit, and upper highly variable mixture of clastic and carbonate rocks; phosphate deposited in formation due to upwelling of cold marine water; comprises most of upper confining unit for Floridan aquifer system |
| Eocene (late) | Ocala | Warm, shallow, clear water on carbonate bank | Most extensive and widespread transgression of Tertiary seas in southeastern United States; elevation of top is approximately -100 ft msl, thickness about 100 ft; prolific source of ground water; thickness highly variable due to erosion and/or dissolution; one of most permeable units in Floridan aquifer system |
| Eocene (middle) | Avon Park and Lake City | Shallow, warm water on carbonate bank | Elevation of top is approximately -300 ft msl; thickness is 1,300–1,500 ft; middle third of Avon Park Formation in east-central Florida is micritic, low permeability limestone |
| Eocene (early) | Oldsmar | Shallow open marine to marginal marine | Elevation of top is -1,750 to -1,500 ft msl; highly developed intergranular and dissolution porosity; not areally extensive |
| Paleocene | Cedar Keys | Tidal flat, sabkha conditions | Elevation of top is -2,500 to -2,200 feet above mean sea level; extensive anhydrite beds; effective base of Floridan aquifer system |

Source: Summarized from Miller 1986 and Tibbals 1990 younger sediments have been removed by erosion. Most units are separated by surfaces where the sequence of rock units has been interrupted by either erosion or nondeposition (i.e., unconformities).

The existence of faults in the VGWB portion of the Floridan aquifer system has been postulated by several ground water investigators. Miller (1986) indicated that the Coastal Plain sediments of Florida exhibit a gentle seaward slope that is interrupted by several prominent depositional features including a peninsular arch extending through north-central Florida in a northwest to southeast orientation and several faults in east-central Florida. Some researchers (Wyrick 1960; Knochenmus and Beard 1971) have claimed that VGWB is an uplifted fault block bounded by a north-south fault on the west and an east-west fault on the south and that a third fault cuts through Volusia County 5–15 miles inland from the coast to complete this fault block. Knochenmus and Beard (1971) ascertain that most of the county is on the uplifted part of this fault block. Johnson (1981) investigated the potential for the existence of faults in VGWB. He found little support for faults based on geophysical well-log data. He did conclude, however, that a fault may cut through Volusia County perpendicular to the St. Johns River, extending from Lake Dias west to the vicinity of Altoona in Lake County (Figure 2). In general, however, his investigation found little evidence in geophysical logs to support the existence of the previously referenced faults.

## Hydrogeologic System

The hydrogeologic system generally is comprised of two aquifer systems, the surficial and the Floridan (Table 3). The surficial aquifer system is described as

> any permeable material, other than that which is part of the Floridan aquifer system, that is exposed at land surface and that contains water under mostly unconfined conditions. (Miller 1986)

The Floridan aquifer system is described as

**Table 3. Hydrostratigraphic sequences of the Volusia ground water basin**

| Aquifer or Aquitard | Geologic Series and Formation or Group | Characteristics |
|---|---|---|
| Surficial aquifer system | Pleistocene and Holocene; Anastasia Formation | Rainfall easily infiltrates, percolates to water table; water levels fluctuate widely and rapidly in response to rainfall, evapotranspiration, and local streamflow; water table is generally a subdued replica of topography; water table serves as a source/sink bed for the Floridan aquifer system; water table generally consists of unconsolidated sand and shelly sand; significant storage reservoir for fresh water in ridge areas |
| Upper confining unit | Miocene and Pliocene; Hawthorn Group | More sandy where less than 100 feet (ft) thick because represents upbasin deposit sites where coarser clastic were laid down; lowermost Hawthorn Group is somewhat permeable, but still much less so than underlying Floridan aquifer system |
| Upper Floridan aquifer | Late/middle Eocene; Ocala Group and upper Avon Park Formation | Hydraulic conductivity generally much greater than that of Lower Floridan aquifer; thickness about 300–500 ft; most ground water circulation in Floridan aquifer system is in this unit; water is less mineralized than in lower units, due to more vigorous circulation; high permeability, which facilitates circulation, is the result of high intergranular or moldic porosity in the Ocala Group and the Avon Park Formation, coupled with secondary porosity (i.e., large dissolution cavities) |
| Middle semiconfining unit | Middle Eocene; middle and upper Avon Park formations | Consists of soft, micritic limestone and fine-grained dolomitic limestone, both low porosity; top is generally at base of Upper Floridan aquifer (i.e., -400 to -600 feet above mean sea level [ft msl]); minor variations in head, water quality, and flow-meter data indicate the unit functions as a confining bed even though its lithology is similar to units that are vertically adjacent |
| Lower Floridan aquifer | Late Paleocene to early Eocene; upper Cedar Keys and Oldsmar formations | Top is -1,200 to -1,000 ft msl, thickness is 1,500 ft, bottom is -2,600 to -2,400 ft msl; the top of the areally extensive anhydrite beds of the Cedar Keys Formation is the bottom of the Lower Floridan aquifer; hydraulic characteristics are not well known; both large and small head gradient with the Upper Floridan aquifer, depending on local character of middle semiconfining unit; ground water flow is sluggish except where there is direct connection with the Upper Floridan aquifer |

Source: Miller 1986; Tibbals 1990

a vertically continuous sequence of carbonate rocks of generally high permeability that are mostly of middle and late Tertiary Age and hydraulically connected in varying degrees and whose permeability is, in general, an order to several orders of magnitude greater than that of those rocks that bound the system above and below. (Miller 1986)

The surficial aquifer system is separated from the Floridan aquifer system by a highly variable sequence of confining sediments of Miocene, Pliocene, and early Pleistocene origin.

The Floridan aquifer system is generally divided into two hydrologic units, known as the Upper and Lower Floridan aquifers (Table 3). The Upper and Lower Floridan aquifers are separated by a confining unit, known as the middle semiconfining unit, which serves to separate these two aquifers hydraulically. The Upper Floridan aquifer is much more productive and generally produces higher quality water than does the Lower Floridan aquifer. The Upper Floridan aquifer therefore is used most often for water supply purposes.

## Surficial Aquifer System

The surficial aquifer system is a critical component in the overall hydrogeology of VGWB. It is an unconfined system that is in close hydraulic connection with the underlying Upper Floridan aquifer due to a thin, areally heterogeneous confining unit. Due to this connection, the surficial aquifer system functions as a storage reservoir for ground water that will ultimately become recharge to the Floridan aquifer system. In areas where the elevation of the potentiometric surface of the Upper Floridan aquifer is higher than the elevation of the water table in the surficial aquifer system, a discharge pattern exists between the Floridan and surficial aquifer systems. The surficial aquifer system receives recharge from precipitation, much of which is lost to evapotranspiration. The water table in this aquifer is closely interconnected with surface water features such as lakes, wetlands, natural stream systems, and man-made canal networks.

**Lithology.** In most of VGWB, the surficial sediments are between 50 and 100 ft thick. In eastern Volusia County, however, the thickness exceeds 100 ft in some areas, and in the western part of the county the thickness may be as much as 175 ft. Phelps (1990) describes the surficial aquifer system as follows:

> The upper 30 ft of the system is comprised of primarily sand, with some shell and silt. This sandy layer comprises what is known as the upper permeable zone of the system. Below this layer is an areally discontinuous semiconfining layer which is composed of 5 to 10 ft of clay or clayey silt. Below this discontinuous layer is an additional layer of sand and shell which is about 20 ft thick and is known as the lower permeable zone.

Generally, in eastern Volusia County this lower zone is composed primarily of indurated shell or coquina. Clay and silt underlie the lower zone and comprise the confining unit between the surficial aquifer system and the Upper Floridan aquifer (Phelps 1990). Figure 5 represents the elevation of the bottom of the surficial aquifer system, based upon SJRWMD data. This surface also represents the top of the confining unit between the surficial and Floridan aquifer systems.

**Hydraulic Conductivity.** Various researchers have found that the sediments in the surficial aquifer system are very heterogeneous and exhibit a range of values for hydraulic conductivity (Table 4). Knochenmus and Beard (1971) concluded that variations in permeability are as great within a physiographic division in VGWB as between divisions. The hydraulic characteristics of the aquifer vary with the lithology. The lithology of the study area is very heterogeneous because the aquifer materials were deposited during a period of repeated transgression and regression of the sea. In an investigation of the surficial aquifer system in Volusia County, Phelps (1990) found that clay layers could not be correlated from one monitoring well to another and that, therefore, the clay layers within and at the base of the sediments in the surficial aquifer system are not continuous.

**Water Budget.** Hydrologic inputs to the surficial aquifer system include infiltration from precipitation, irrigation application of water from the Upper Floridan aquifer, streamflow, and upward leakage from the Upper Floridan aquifer. Outputs from the surficial aquifer system include evapotranspiration, streamflow, and downward discharge to the Upper Floridan aquifer. In VGWB, lateral movements in and out of the basin are slight, due to small gradients and low permeability (Rutledge 1985).

**Recharge and Discharge Patterns.** VGWB is distinctive in that virtually all of the water that recharges the ground water system in the basin is from recharge within the basin boundaries. The primary producing aquifer of the area, the Upper Floridan aquifer, is geologically contiguous to the larger regional Floridan aquifer system. However, the St. Johns River valley and the local recharge

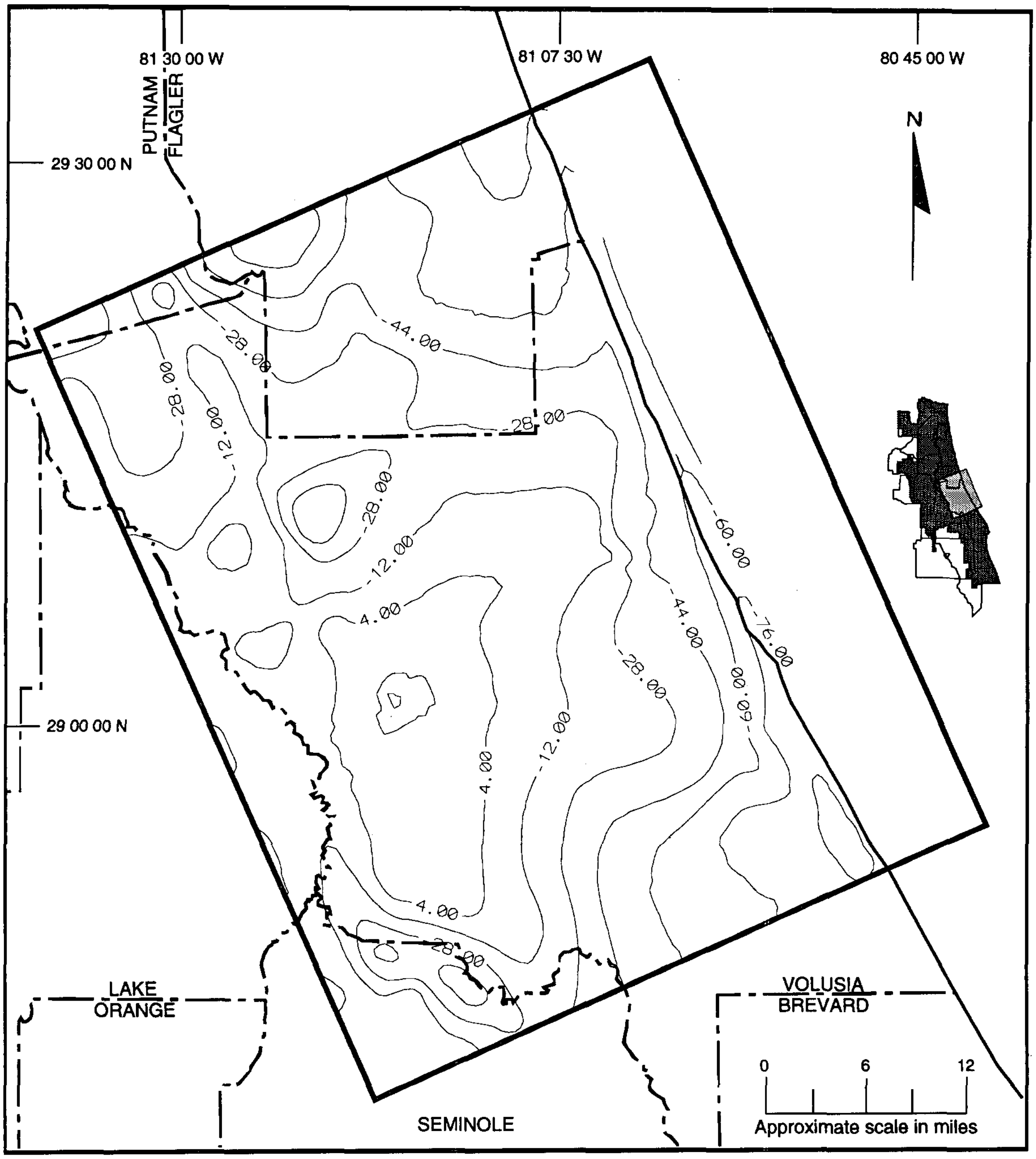



**Figure 5. Elevation of the base of the surficial aquifer system (feet mean sea level)**

Legend

—-12.00— Contour
— — — County boundary
▬▬▬ Model boundary

**Table 4. Hydraulic conductivity of the surficial aquifer system**

| Hydraulic Conductivity | Location of Test or Model | Comments | Source |
|---|---|---|---|
| 0.03 to 13.00 ft/d | Throughout Volusia County | Slug test | McGurk et al. 1989 |
| 4 to 110 ft/d | Northeast Volusia County | Aquifer performance test | Gomberg 1980 |
| 28 to 49 ft/d | Northeast Volusia County | Aquifer performance test | Gomberg 1981 |
| 30 ft/d | Oak Hill, southeast Volusia County | Aquifer performance test | Phelps 1990 |
| 25 ft/d | Volusia ground water basin | Regional ground water model | Mercer et al. 1984 |
| 25 ft/d | Volusia ground water basin | Regional ground water model | Geraghty & Miller 1991 |

Note: ft/d = feet per day

and discharge patterns serve to hydrologically isolate the area from the larger surrounding hydrogeologic system.

Within the basin, recharge and discharge patterns for the surficial aquifer system are closely related to the hydrogeologic conditions in the Upper Floridan aquifer. In many areas, the surficial aquifer system serves to store water temporarily for later percolation to the Upper Floridan aquifer. This recharge function of the surficial aquifer system to the Upper Floridan aquifer is important because most of the water that is withdrawn from the Upper Floridan aquifer, as well as natural discharge, originated as locally derived recharge.

For rainfall to become recharge to the surficial aquifer system, the uppermost aquifer sediments must be unsaturated and of sufficient permeability to allow downward percolation. In areas where these conditions occur and where the water level in the surficial aquifer system is above the potentiometric surface of the Upper Floridan aquifer, a recharge condition exists for both aquifers. As a general rule, most of the water that recharges the surficial aquifer system eventually becomes recharge to the Upper Floridan aquifer.

In areas where the potentiometric surface of the Upper Floridan aquifer is above the water table, a discharge condition exists for the Upper Floridan aquifer, and the water is discharged to the surficial aquifer system. However, where this condition exists, there also could be recharge to the surficial aquifer system due to precipitation if the surficial sediments have an unsaturated zone that is sufficiently thick to accommodate this infiltration. Therefore, in these areas the surficial aquifer system can receive recharge from above and below (i.e., the areas are recharge areas for the surficial aquifer system and discharge areas for the Upper Floridan aquifer) (Phelps 1990).

Surface drainage also affects the extent to which precipitation may become recharge. Where the definition of surface drainage is low, more water is available from gross precipitation to become recharge to the surficial aquifer system. Conversely, where stream systems are well defined, more precipitation is lost to runoff and less is available to recharge the aquifer. For example, the De Land Ridge area has almost no surface drainage and functions as a relatively high recharge area for the surficial aquifer system. Similarly, the terrace areas are also noted for little surface drainage due to low gradients inhibiting the movement of water and a lack of deeply incised streams.

The local geomorphologic features contribute to the recharge and discharge patterns for the surficial aquifer system in VGWB (Vecchioli et al. 1990) (Table 5). The De Land and Crescent City

**Table 5. Estimates of recharge rates to the surficial aquifer system**

| Physiographic Region | Recharge Rate Estimate (in/yr) | Source |
|---|---|---|
| Western ridge | 10–18 | Rutledge 1985 |
| Nonartesian terraces | 4 | Rutledge 1985 |
| Artesian areas | 4 | Rutledge 1985 |
| Artesian flow | 0–4 | Phelps 1990 |
| Terraces | 8–9 | Phelps 1990 |
| Ridges without surface drainage | 6–18 | Phelps 1990 |
| Ridges with surface drainage | 9–10 | Phelps 1990 |

ridges (Figure 4) are recharge areas for both the surficial aquifer system and the Upper Floridan aquifer. Throughout these ridge areas, land surface elevations are generally greater than 50 ft. These ridges have only local surface drainage, and no streams provide surface drainage for the area. Recharge rates to the surficial aquifer system are high, and most of the water that enters the surficial aquifer system moves downward relatively quickly to recharge the Upper Floridan aquifer.

In contrast, in areas of lower land surface elevation between the two ridges and in the St. Johns River valley, the aquifer is not receptive to precipitation recharge due to a thin, unsaturated zone and a locally extensive upward hydraulic vertical gradient between the Upper Floridan aquifer and the surficial aquifer system (Phelps 1990). However, in the relatively flat Talbot and Pamlico terraces, there is usually a small downward hydraulic gradient. In these terraces, the surficial sediments remain saturated, or nearly so, much of the year. Therefore, in the central part of the county, the surficial aquifer system is recharged at a slow rate, and it acts as a storage bank for water that is available for slow percolation to the Upper Floridan aquifer. In this area, land surface relief of 5 ft can be the difference between a swampy "bay," where recharge is rejected (i.e., recharge to the surficial aquifer system is not possible due to a lack of an unsaturated zone) and a dry "island," where water can infiltrate and percolate downward at a slow rate (Phelps 1990).

The Rima Ridge is higher than the Talbot and Pamlico terraces. It provides a source of local recharge for both the surficial aquifer system and the Upper Floridan aquifer. However, due to its small areal extent, it is not a major source of recharge for the aquifers (as opposed to the De Land Ridge, for example).

**Evapotranspiration.** Although evapotranspiration rates are difficult to quantify, the upper and lower limits can be estimated and the factors that influence these rates can be described. The upper limit of evapotranspiration is approximately equal to the measured pan evaporation rate. The maximum annual rate of evapotranspiration in VGWB is approximately 46 inches per year (in/yr) (Visher and Hughes 1975). Several researchers have estimated the minimum evapotranspiration rate to be approximately 25–35 in/yr (Knochenmus and Hughes 1976; Tibbals 1978). The lowest rates of evapotranspiration occur in areas with a deep, well-drained soil and a deep water table. These areas (e.g., the De Land Ridge) tend to be marked with sinkholes and exhibit little or no surface runoff. In general, the amount of evapotranspiration is equal to the amount of rainfall minus the amount of springflow, runoff, and pumpage. Rutledge (1985) concluded that evapotranspiration varies locally due to differences in depth-to-water, vegetation type, and rainfall distribution.

Several researchers have estimated evapotranspiration both within VGWB and throughout central Florida. Knochenmus and Beard (1971) estimated average countywide evapotranspiration at 35 in/yr. Rutledge (1985) estimated an average rate of evapotranspiration in Volusia County of 39 in/yr. Kohler et al. (1959) estimated average annual lake evaporation in central Florida at about 46 in/yr. Pride et al. (1966) estimated evapotranspiration in the Green Swamp area of central Florida at 37 in/yr. Lichtler et al. (1968) estimated evapotranspiration in Orange County to be equivalent to 70% of rainfall, or 36 inches.

**Seasonal Fluctuations.** Springtime water levels in the surficial aquifer system are usually lower than fall levels because about 50% of annual rainfall occurs between June and September. The seasonal fluctuation patterns vary between wells tapping the upper permeable zone and wells tapping the lower permeable zone of the surficial aquifer system. In 1986, according to Phelps (1990), wells tapping the upper permeable zone showed levels that were 3–6 ft higher in the fall than in the spring. However, during the same period, other wells tapping the same zone showed fluctuations of less than 1 ft; pumping apparently did not affect water levels in the upper permeable zone (Phelps 1990). In contrast, wells tapping the lower permeable zone showed seasonal fluctuations of less than 2 ft, except in the northwestern part of Volusia County, where fluctuations were 7–11 ft due to drawdown from freeze-protection pumping.

## Upper Confining Unit

The upper confining unit lies in between the surficial aquifer system and the underlying Floridan aquifer system. It is composed of the Hawthorn Group of Miocene age and a series of discontinuous and heterogeneous low permeability zones of late Pliocene to early Pleistocene origin (Tibbals 1990) (Table 3).

**Thickness.** Figure 6 represents the thickness of the upper confining unit in VGWB based upon SJRWMD data. The upper confining unit is thicker and more continuous in eastern Volusia County than in the west, where it is absent in some locations. In the west-central part of the county, the confining unit is not continuous and not mappable. However, in this area underlying the De Land Ridge, overlying sediments contain sufficient clay and silt to confine the Upper Floridan aquifer in all but a few areas. An areal representation of bed thickness was developed through interpretation of geophysical logs from monitoring wells throughout the study area.

**Lithology.** In Volusia County, the regional upper confining unit is composed of phosphatic clay, silt, sand, and carbonate beds of the Hawthorn Group of Miocene age. Also, late Miocene or Pliocene calcareous sandy or silty clay beds are found in several areas of the county. The upper confining unit is more sandy where it is less than 100 ft thick, because this represents an upbasin depositional pattern where coarse clastic sediments of the lower Hawthorn Group were laid down (Miller 1986).

Where Miocene sediments are present, and assuming that no erosion has occurred, they can be differentiated into lower, middle, and upper zones. The lower and middle Miocene sediments consist of calcareous clays, silts, sandy phosphatic limestone, and phosphatic clays. These sediments are identifiable by varying amounts of phosphatic material (residue from shallow marine life). These layers also can be identified by a very high gamma ray signature on geophysical logs.

Confinement in east-central Volusia County and the Atlantic Coastal Ridge is not made up of a single, areally persistent confining layer.

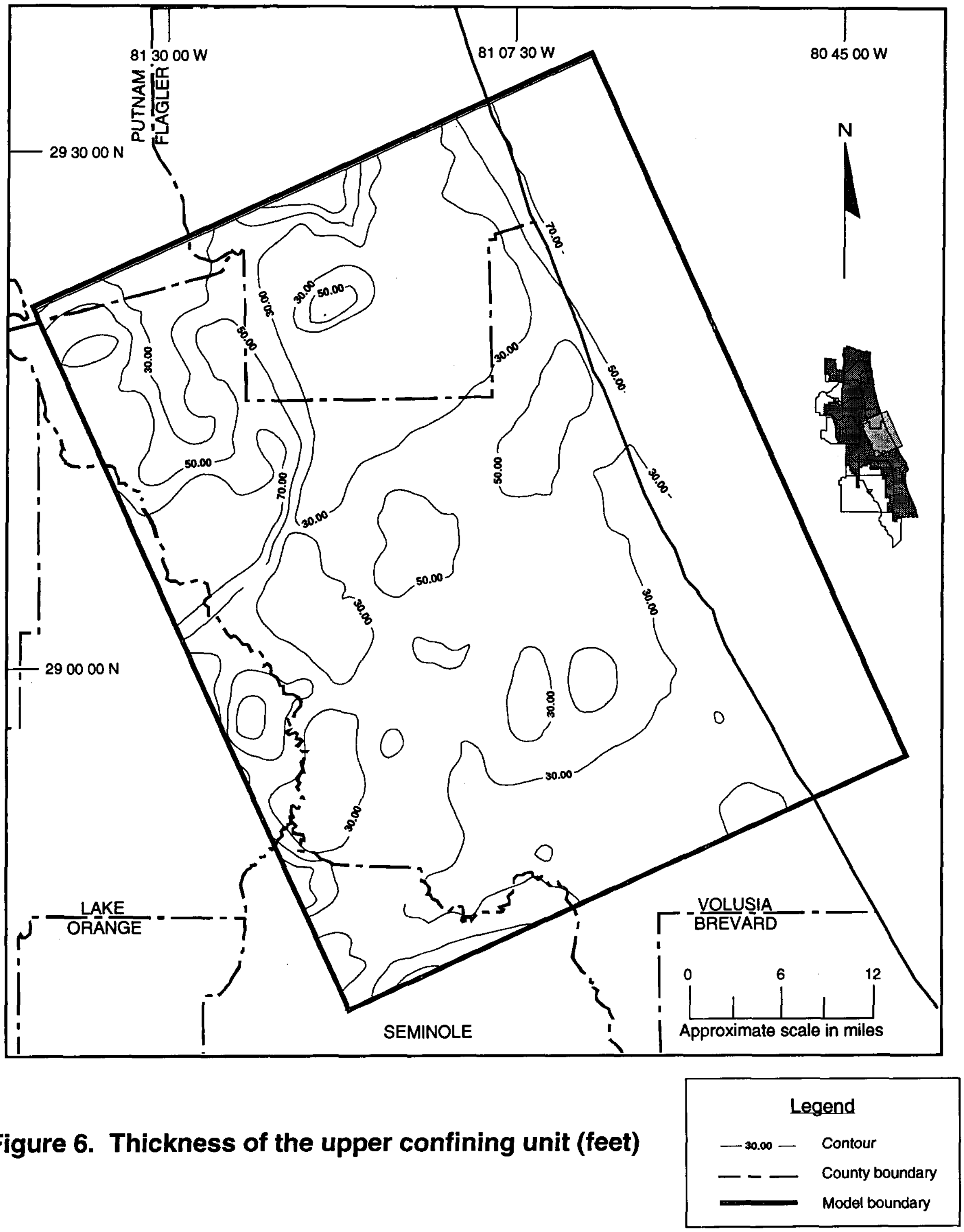



**Figure 6. Thickness of the upper confining unit (feet)**

Instead, confinement of the Floridan aquifer system is attributed to a series of clay lenses and low permeability zones (Phelps 1990). For example, most wells between Interstate 95 and the Halifax River from Ormond Beach to Port Orange (Figure 2) exhibit a zone of silty/clayey sand over Eocene sediments. This zone is 20–60 ft thick and is split by coarser layers. A similar fine-grained layer, without the sand and shell split, exists directly over the Hawthorn Group in the southeastern part of the county. Similarly, Gomberg (1980) described a continuous clay layer directly over the Floridan aquifer system, beneath the Atlantic Coastal Ridge in northeastern Volusia County.

**Leakance and Vertical Hydraulic Conductivity.** Quantifying the range for vertical hydraulic conductivity is difficult due to the degree of sediment variability. The leakance coefficients that represent the hydraulic connection between the surficial aquifer system and the Upper Floridan aquifer are also difficult to estimate. Tibbals (1990) estimated a range of leakance values of $1 \times 10^{-6}$ to $6 \times 10^{-4}$ $day^{-1}$ ($d^{-1}$) (inverse days) for the upper confining unit in this area. Miller (1986) stated that the range of vertical hydraulic conductivity of clay beds in the upper confining zone, based upon core tests, was $1.5 \times 10^{-2}$ to $7.8 \times 10^{-7}$ feet/day.

## Floridan Aquifer System

The Floridan aquifer system is the most prolific aquifer system in the southeastern United States. This system is composed of permeable carbonate beds of limestone and dolomite, which are primarily of Eocene age (Table 3). In VGWB, the aquifer is composed of the Oldsmar, Avon Park, and Ocala formations (from oldest to youngest). This aquifer system underlies all of Volusia County and is the main source of potable water for VGWB.

Figures 7, 8, and 9 represent the respective elevations of the top and bottom of the Upper Floridan aquifer and the base of the entire Floridan aquifer system. Tibbals (1990) defined the top of the Floridan aquifer system as the first occurrence of vertically persistent, permeable, consolidated carbonate rocks. He characterized the lower limit of the Upper Floridan aquifer as the first occurrence

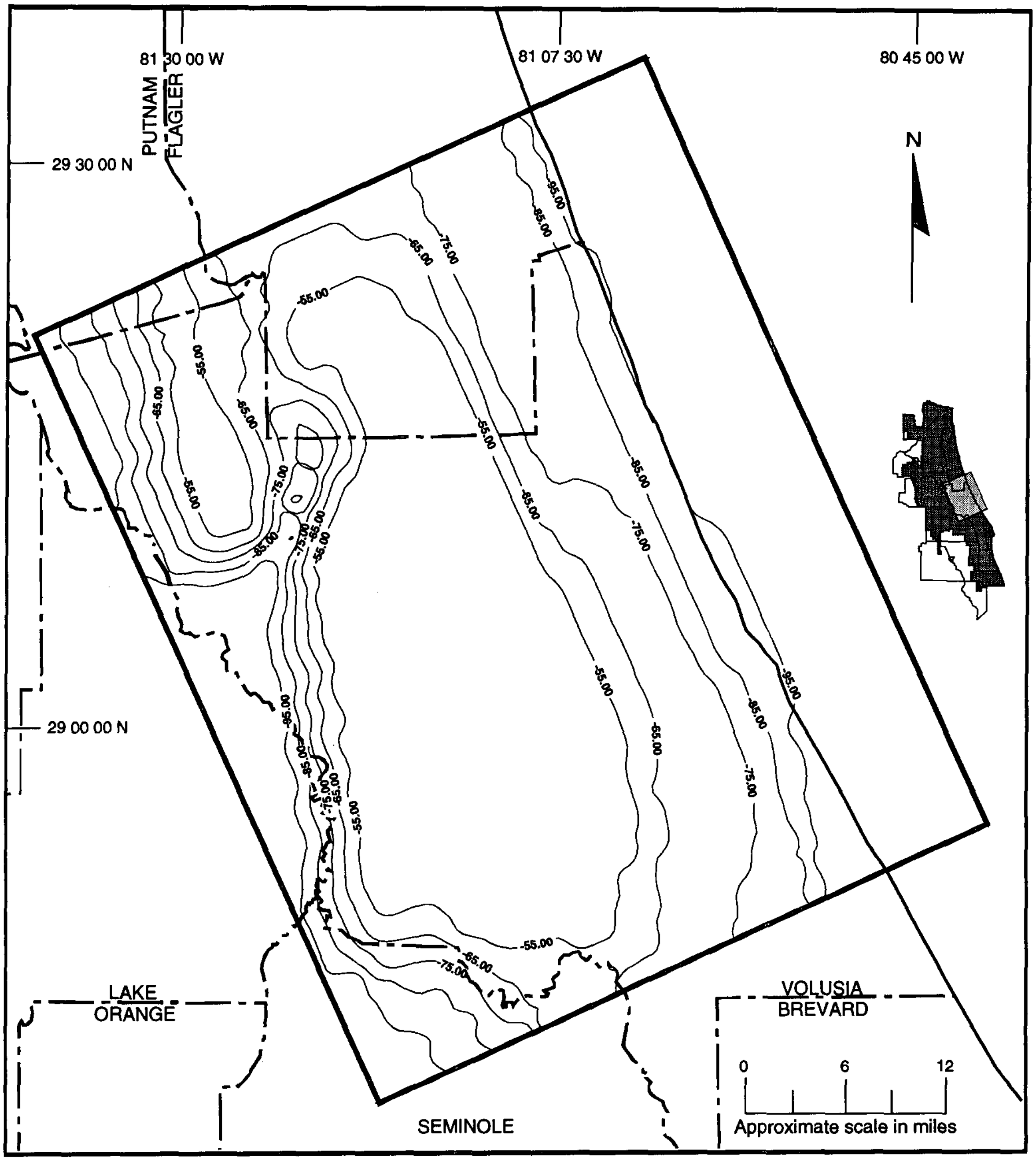



**Figure 7. Elevation of the top of the Upper Floridan aquifer (feet mean sea level)**

Legend

- -85.00 — Contour
- — — — County boundary
- ▬▬ Model boundary

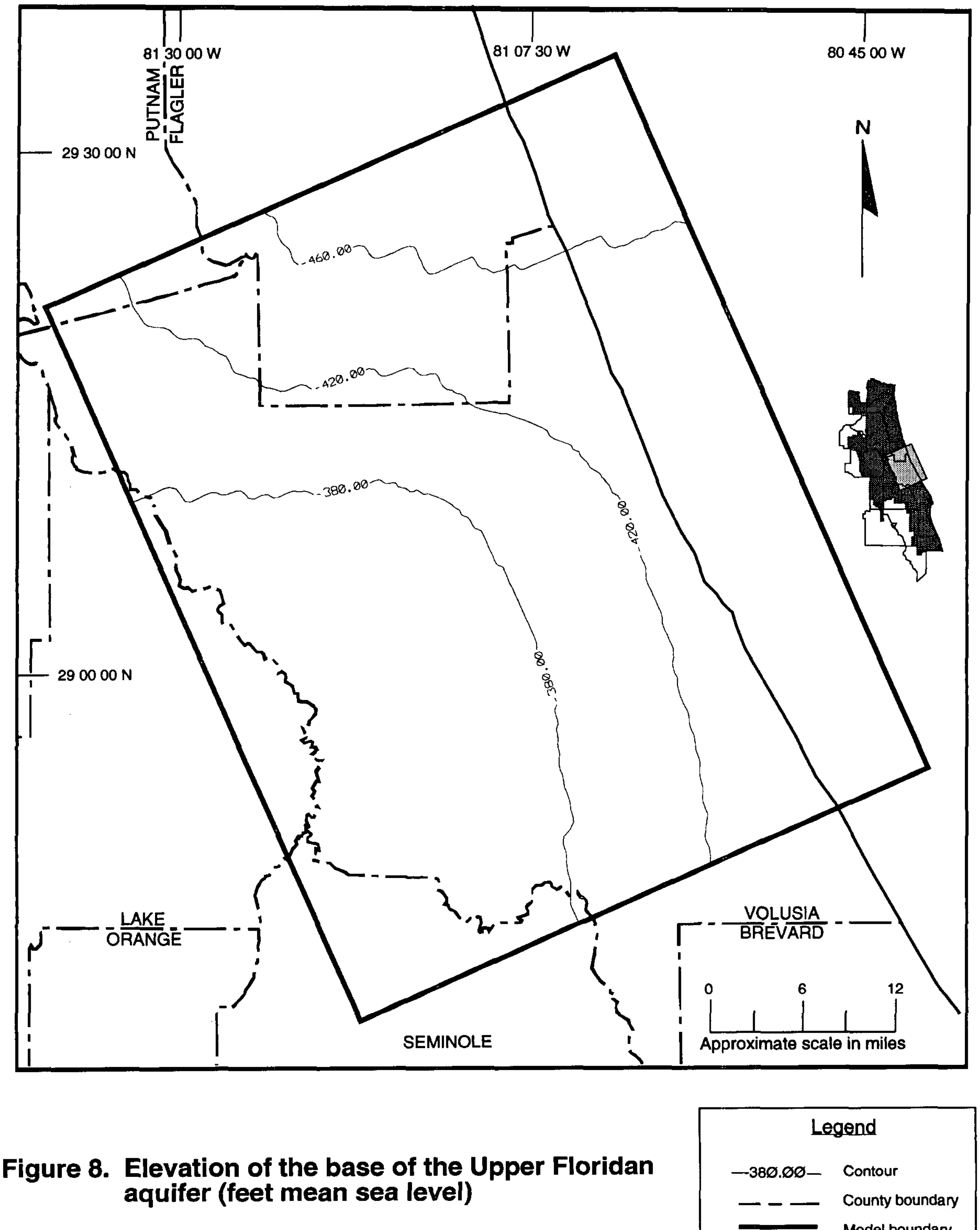



**Figure 8. Elevation of the base of the Upper Floridan aquifer (feet mean sea level)**

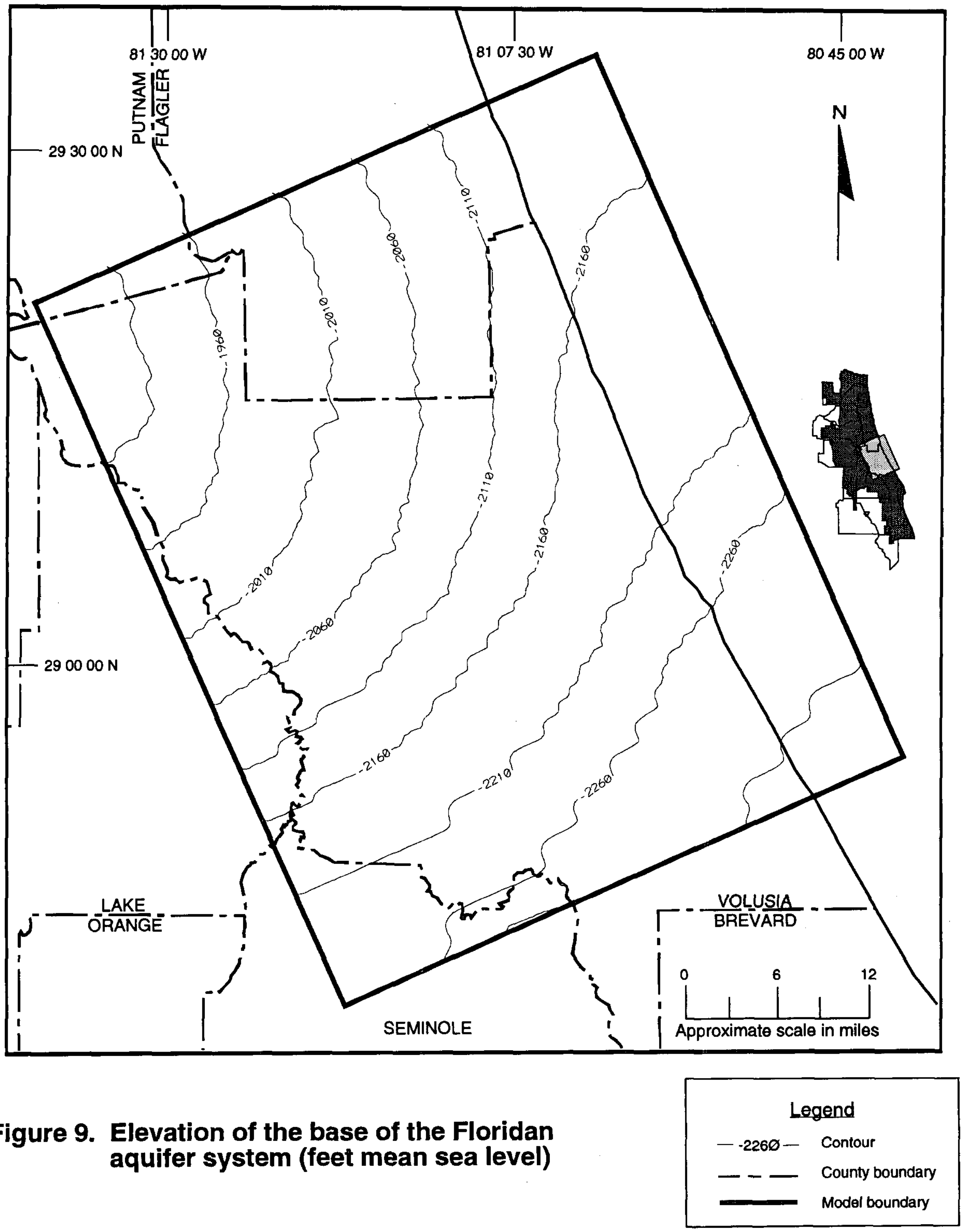



**Figure 9. Elevation of the base of the Floridan aquifer system (feet mean sea level)**

of a low permeability micritic limestone of the underlying middle semiconfining unit. This semiconfining unit, located in the middle third of the Avon Park Formation, separates the Upper Floridan aquifer from the Lower Floridan aquifer. The base of the Floridan aquifer system is defined as the first occurrence of vertically persistent beds of anhydrite. In the absence of the beds, the base of the system is the top of the transition between the sequence of permeable carbonate rocks and the less permeable gypsiferous and anhydritic carbonate beds (Tibbals 1990).

Although the Floridan aquifer system is a carbonate aquifer which is highly susceptible to karst development, almost all sinkhole occurrences are in areas where recharge rates to the aquifer are high and depth to the top of the Floridan aquifer system from land surface is less than 200 ft (Tibbals 1990). In the current study area, the Crescent City and De Land ridges are the principal areas that have been subject to karst dissolution of the carbonate rocks of the Floridan aquifer system.

**Recharge and Discharge Patterns.** Recharge to the Upper Floridan aquifer is directly proportional to the head difference between the surficial aquifer system and the Upper Floridan aquifer, directly proportional to the vertical hydraulic conductivity of the confining unit, and inversely proportional to the confining bed thickness. Recharge to the Upper Floridan aquifer is attributable primarily to downward leakage from the surficial aquifer system, where the water table is higher than the potentiometric surface. Much of this water becomes discharge to the artesian springs in VGWB. In many areas, there is no geologic evidence of regional confinement, and water level fluctuations indicate that the Upper Floridan aquifer is hydraulically connected to the surficial aquifer system (Knochenmus and Beard 1971).

Knochenmus and Beard (1971) asserted that there are no principal recharge areas in VGWB. Data suggest that areas of the highest potentiometric surface in VGWB are not principal recharge areas. The most productive recharge areas are the eastern part of the Talbot Terrace and the ridges. A greater head differential exists between the surficial aquifer system and the Upper Floridan aquifer in the eastern part of the Talbot Terrace than in the western part.

Under the ridges, where the water table is at least 10–20 ft higher than the potentiometric surface, the potential for relatively high recharge exists. Wyrick (1960) stated that the main recharge area is along the east side of the De Land Ridge. Knochenmus and Beard (1971) agreed, but they also used several methods to determine that a good hydraulic connection exists in the Talbot Terrace.

Ground water discharge from the Floridan aquifer system occurs to the east into the Atlantic Ocean, to the southwest and west to the Lake Harney area (Figure 2) and in the St. Johns River valley, and to the north in southern Flagler County (Kimrey 1990).

Tibbals (1990) indicated that unexplained depressions in the potentiometric surface indicate discharge through unknown springs in the areas along the St. Johns River and around Lake George and Lake Harney. Tibbals (1990) also attributed the depression in the potentiometric surface in west-central Flagler County to diffuse upward leakage in the Haw Creek drainage basin and to the possibility of discharge to unconfirmed springs near the southeast side of Crescent Lake (Figure 2).

Although data are limited to describe the potentiometric surface of the Lower Floridan aquifer, the general pattern of that surface is a subdued replica of that for the Upper Floridan aquifer. Therefore, areas of ground water recharge and discharge are usually analogous with those for the Upper Floridan aquifer. However, recharge and discharge flux rates are less between the Upper and Lower Floridan aquifers than those between the surficial aquifer system and the Upper Floridan aquifer due to the relatively smaller hydraulic gradients that exist between these aquifers. Additional investigation (e.g., through construction of exploratory wells) is needed in order to better characterize flow patterns in the Lower Floridan aquifer.

**Potentiometric Surface.** The potentiometric surface of the Upper Floridan aquifer in VGWB is marked by a potentiometric high (approximately 35–40 feet above mean sea level) in west-central

Volusia County. Because VGWB is surrounded by areas of ground water discharge (i.e., to the Atlantic Ocean, the St. Johns River valley, and a ground water depression in southern Flagler County), a hydraulic gradient exists between the potentiometric high and these discharge areas. Due to this hydrologic configuration (i.e., a potentiometric high surrounded by discharge areas), the thickness of potable ground water in VGWB is best characterized as a freshwater lens with its greatest thickness (approximately 1,000–1,200 ft) under the potentiometric high. The thickness of fresh water decreases gradually between this potentiometric high and the discharge areas on the periphery of VGWB.

Throughout most of VGWB, the elevation of the potentiometric surface is greater than the physical top of the aquifer. Near the St. Johns River and the coast, artesian flow conditions exist where the elevation of the potentiometric surface is above the land surface elevation. In nonartesian areas, the elevation is approximately 10–40 feet below land surface. Typical seasonal fluctuations in the potentiometric surface are 4 ft in rural areas and 5–10 ft in urban areas.

The areas of greatest historic decline in the elevation of the potentiometric surface are in the vicinities of Daytona Beach, Ormond Beach, and Port Orange. This decline is due entirely to pumping (Rutledge 1985). Rutledge concluded that, based upon analysis of hydrographs and potentiometric surface maps, no general long-term trend exists for these areas except around the major wellfields. Tibbals (1990) likewise indicated that the elevation of the potentiometric surface in the relatively undeveloped south-central portion of Volusia County has remained relatively constant historically and that declines in elevation of this surface are primarily in eastern Volusia County.

Along the coast from Flagler Beach to Merritt Island (Figure 2), the potentiometric surface is depressed naturally due to diffuse upward discharge and possible spring discharge. Tibbals (1990) simulated a model-derived discharge of about 50 cubic feet per second from Flagler Beach to Oak Hill. He further asserted that off the coast of Volusia County the top of the Floridan aquifer system is 80–100 ft below sea level and that the sea bottom is approximately 60 ft below sea level. These conditions contribute to the possibility of spring formation and/or high rates of diffuse upward leakage. One reported but unconfirmed spring has been described about 16 miles off the coast near the Volusia-Brevard county line (Tibbals 1990).

**Water Quality.** The highest concentrations of dissolved solids, an indicator for the extent of mineralization, are near the Atlantic Ocean and in the St. Johns River valley. Most of the highly mineralized water in these areas is probably a mixture of fresh water and relict seawater from an earlier time of higher sea level. Flushing may be incomplete in some areas. Conversely, areas where water is characterized with low dissolved solids generally correspond with good recharge areas for the Upper Floridan aquifer. In the discharge areas of the Floridan aquifer system along the coast and in the St. Johns River valley, the dissolved solids concentration is typically greater than 1,000 milligrams per liter (mg/L) and can be greater than 25,000 mg/L (Tibbals 1990). However, the dissolved solids concentration does not ever approach that of seawater (Toth 1988; Tibbals 1990).

Chloride concentration is the single most reliable indicator of the presence of brackish water. Results of water quality sampling and analysis of water from a test well at Blue Spring (Figure 2) indicate that, in this area, the aquifer is brackish through its entire depth and the sharpest chloride change occurs at 425 to 442 ft—from 4,000 to 9,000 mg/L (Tibbals 1990). This test well was drilled to determine if an active zone of freshwater circulation exists beneath the brackish zone in the Upper Floridan aquifer. Drilling was stopped at the brackish zone; therefore, results were inconclusive. However, it is unlikely that fresher water exists at depth in this area.

The brackish water in the Upper Floridan aquifer is stagnant from Lake Harney north along the St. Johns River. The small amount of discharge that does exist is generally believed to be replaced by upward movement of brackish water at depth. For example, the most highly mineralized water in the Upper Floridan aquifer north of Lake Harney is near areas where water from the Floridan aquifer system discharges to springs. Springs function as ground water sinks for water that entered the aquifer as flow from upgradient sources. Therefore, the aquifer system from Lake Harney north may be as flushed as it ever will be (Tibbals 1990).

Faults that are reported to exist deep in the Floridan aquifer system along the St. Johns River could be an avenue for brackish water to replenish water discharged through springs or diffuse upward leakage in the Upper Floridan aquifer. However, a natural upward gradient also could be a major control on brackish water moving into the Upper Floridan aquifer. For example, an upward gradient of 4 ft was observed during the drilling of the Blue Spring test well (Tibbals 1990), indicating zones of higher head at depth.

## SUMMARY

The hydrogeologic framework for the study area is composed of surface water features, geomorphology, the geologic configuration of underlying deposits, and hydrologic processes. The surface water features for this area include Spruce Creek and the Tomoka River along the coast, several lakes in the St. Johns River valley, the St. Johns River itself, several natural wetlands, and a series of man-made drainage canals.

The geologic setting for the study area includes an assortment of soil types, a range of geomorphologic characteristics, and a stratigraphic sequence marked by a relatively thin clastic layer overlying a prolific limestone series. The soils of this area are directly correlated with the depositional history and range between the mucky, organic soils of the lower elevation wetlands and the sandy, permeable soils of the upland ridges. The geomorphology of the area is characterized by a series of ridges and terraces which originated during periods of fluctuating sea levels. Principal ridges in the area include the Atlantic Coastal Ridge in eastern Volusia County and the De Land Ridge in west-central Volusia County. Primary terraces include the Talbot Terrace in the central wetlands area and the Silver Bluff Terrace in coastal Volusia County. The geologic setting is characterized by a relatively thin layer of clastic sediments of Pleistocene origin overlying a much thicker series of carbonate rocks that comprise the Floridan aquifer system, the most prolific aquifer system in the southeastern United States. The uppermost Pleistocene sediments are separated from the Eocene deposits of the Floridan aquifer system by a heterogeneous mix of Miocene and Pliocene sediments.

The hydrogeologic system for the study area is composed of a surficial aquifer system overlying an upper confining unit and the Floridan aquifer system. The surficial aquifer system is composed of a predominance of clastic materials with interspersed clay lenses. This system is critical to the overall hydrogeologic system as a storage reservoir of fresh water from precipitation. The surficial aquifer system is also significant as the hydrologic setting for evapotranspiration and for its influence on the recharge to and discharge from the Upper Floridan aquifer. The upper confining unit, underlying the surficial aquifer system, serves to define the extent of the hydraulic connection between the surficial and the Floridan aquifer systems, thereby affecting the amount of fresh water available as recharge to the Upper Floridan aquifer. The Floridan aquifer system is composed of the Upper Floridan aquifer—the principal source of fresh ground water for the study area, a middle semiconfining unit composed of low permeability micritic limestone, and the Lower Floridan aquifer, which overlies a relatively impermeable base of anhydrite sediments. In VGWB, the potentiometric surface is high in the west-central portion of the county. Ground water levels fall away from this potentiometric high toward the St. Johns River and the Atlantic Ocean, to the north into southern Flagler County, and to the south along the border with Brevard County. Due to the configuration of the potentiometric surface, this ground water basin is hydraulically isolated from contiguous portions of the Floridan aquifer system. The water quality of this basin is marked by a relatively thick (approximately 1,000–1,200 ft) zone of fresh water in central Volusia County which thins toward the peripheral areas of the ground water basin.

# GROUND WATER FLOW MODEL

A three-dimensional, finite-difference model was developed to simulate the ground water resources of VGWB in east-central Florida. The model incorporates an active surficial aquifer system and the Upper and Lower Floridan aquifers. Boundary conditions for the model include a mixture of specified-head, head-dependent flux, and specified-flux boundaries. In the surficial aquifer system, using rainfall-based recharge, the model simulates spatially variable evapotranspiration and recharge to and discharge from the Upper Floridan aquifer. In the Floridan aquifer system, the model simulates head-dependent springflow and outflow to agricultural and public supply wells. This model has been compared to an estimated predevelopment condition and calibrated to the postdevelopment hydrologic conditions of 1988. The model has been used for predictive simulations for the year 2010 as part of the water supply needs and sources assessment. The model also provides a basis for the concurrent development of a density-dependent saltwater intrusion model for the study area.

## CONCEPTUAL MODEL

The conceptual model for the ground water system of VGWB is based on the hydrostratigraphic sequence described in Table 3 (p. 16). The system is divided into three aquifer layers and two intervening confining units. The simulated aquifer layers represent the surficial aquifer system and the Upper and Lower Floridan aquifers. The two intervening confining units (i.e., between the surficial aquifer system and the Upper Floridan aquifer and between the Upper and Lower Floridan aquifers) are represented in the model with two distributions of leakance coefficients, which control the degree of hydraulic connection between these three aquifers. The surficial aquifer system is simulated as an unconfined system. Both the Upper and Lower Floridan aquifers are simulated with a designation of confined or unconfined. This designation implies that transmissivity of these layers may vary with time and is calculated from the saturated thickness and the hydraulic conductivity.

The ground water flow modeling code used in this investigation is MODFLOW, a three-dimensional, finite-difference model (McDonald and Harbaugh 1988). The MODFLOW model was selected because (1) it has been well validated through numerous field applications and (2) it is a flexible model which can incorporate a variety of boundary conditions and hydrologic processes.

## FINITE-DIFFERENCE GRID

The finite-difference grid (Figure 10) was developed by Geraghty & Miller (1991). The study area was divided into a grid composed of 91 rows and 86 columns, with the rows oriented generally perpendicular to the coastline and the columns oriented parallel to the coastline. Row and column numbering starts at the upper left corner of the model boundary. The size of the grid cells is variable, with the smallest grid cells measuring ¼ mile by ¼ mile. These grid cells are located in the area with the highest density of public supply wells in eastern Volusia County.

## BOUNDARY CONDITIONS

The MODFLOW model can simulate several types of boundary conditions. These include specified-flux, specified-head, and head-dependent flux boundaries (Table 6). In the current model, specified-flux boundaries are used for recharge to the surficial aquifer system and for all wells in the surficial aquifer system and the Upper Floridan aquifer. Similarly, specified-head boundaries are used to represent surface water bodies in which the hydraulic head or stage can be assumed to remain constant through time. Finally, head-dependent flux boundaries are used to represent conditions where the flux at a given location is dependent upon the head at a nearby, hydraulically connected location. Head-dependent flux boundaries are used to represent evapotranspiration, springs, drains, and lateral aquifer boundaries in the current model.

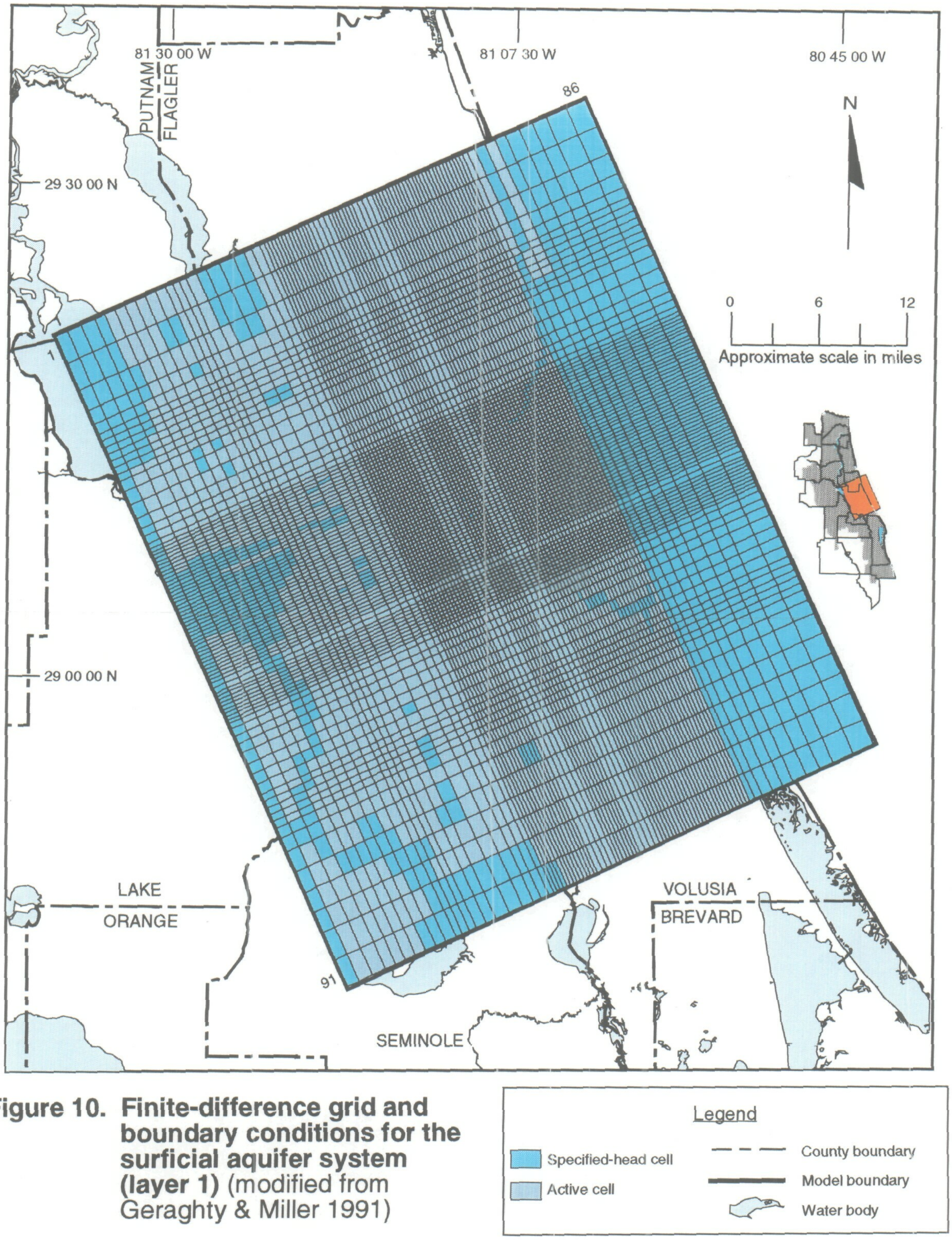



**Figure 10. Finite-difference grid and boundary conditions for the surficial aquifer system (layer 1)** (modified from Geraghty & Miller 1991)

**Table 6. Summary of boundary types and potential applications**

| General Boundary Type | Potential Applications |
|---|---|
| Specified-flux | Recharge; impermeable boundaries or areas of negligible flow; wells |
| Specified-head | Surface water features; representation of a regional hydraulic gradient |
| Head-dependent flux | Drains; evapotranspiration; springs; lateral boundaries |

## Lateral Boundaries

Lateral boundaries (i.e., along the periphery of the model domain) for the surficial aquifer system include specified-head cells along the western edge of the model to depict the St. Johns River valley and along the coastal boundary to depict the Atlantic Ocean (Figure 10). Other lateral boundaries include specified heads for Lake George and Crescent Lake to the northwest and Lake Monroe in the southwest and no-flow boundaries (implied) on the northern and southern portions of the model. These no-flow boundaries are justified on the basis that the boundaries are located within areas of negligible lateral flow for the surficial aquifer system. For the Upper Floridan aquifer, lateral boundaries include head-dependent flux boundaries to the east and west and no-flow boundaries to the north and south (Figure 11). These eastern and western boundaries are based on observed potentiometric surfaces. The no-flow boundaries to the north and south are located in areas of negligible flow for the Upper Floridan aquifer and also are situated perpendicular to local equipotential lines. All lateral boundaries for the Lower Floridan aquifer are simulated as no-flow conditions. The rationale for this designation is that, in this area, the potentiometric surface of the Lower Floridan aquifer is a subdued version of that for the Upper Floridan aquifer, and its configuration is much more dependent on vertical leakage from above then it is on lateral inflow or outflow.

## Internal Boundaries

Aside from lateral boundaries, this model also incorporates several interior boundaries (i.e., within the areal confines of the model

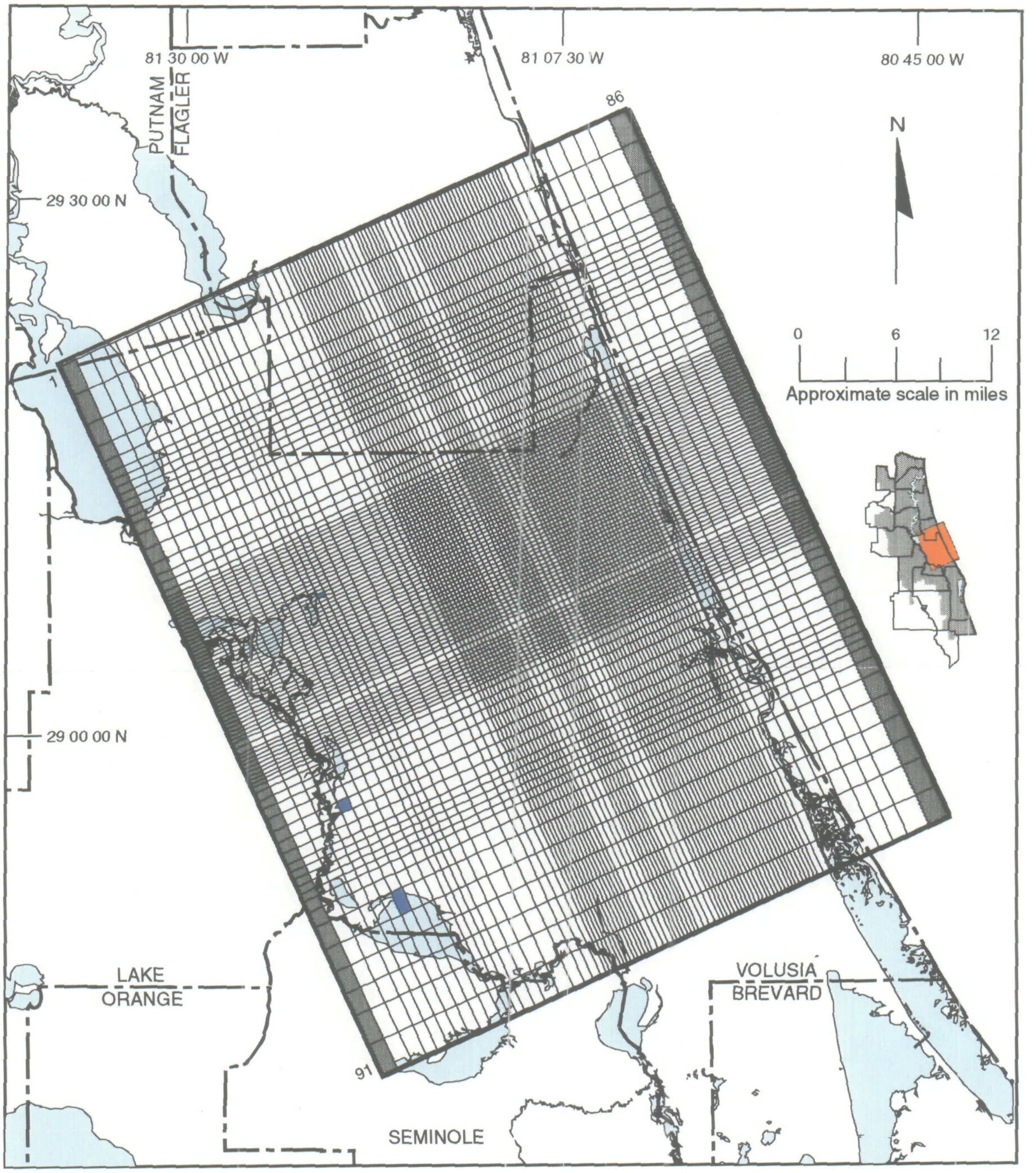



**Figure 11. Finite-difference grid and boundary conditions for the Upper Floridan aquifer (layer 2)** (modified from Geraghty & Miller 1991)

domain). These boundary conditions include evapotranspiration and streams (both forms of head-dependent flux boundaries), recharge and wells (specified-flux boundaries), and lakes and rivers (specified-head boundaries).

**Evapotranspiration.** The ground water flow model of the surficial aquifer system in VGWB simulates the evapotranspiration process explicitly. Evapotranspiration is simulated as a type of head-dependent flux boundary condition over all of the active cells in the surficial aquifer system. Within the MODFLOW simulation code, the function for evapotranspiration is a linear function specified over a range between minimum and maximum evapotranspiration values. The upper and lower limits of this range for this flow model are 46 in/yr and 27.5 in/yr, respectively. In MODFLOW, the minimum evapotranspiration value is converted to 0.0 and the maximum evapotranspiration value for this study is 18.5 in/yr (46.0–27.5). These limits are adapted from previous studies involving evapotranspiration (Tibbals 1990; Visher and Hughes 1975).

Evapotranspiration is treated in the MODFLOW model using two additional parameters, the elevation of the evapotranspiration surface and the extinction depth. The evapotranspiration surface is the elevation at which the maximum evapotranspiration rate will occur and is generally equivalent to the average land surface elevation. For this model, average land surface elevations were calculated for all model grid cells and incorporated as the evapotranspiration surface. The extinction depth is the depth below land surface at which the evapotranspiration rate reduces to its minimum value. This value is not always well known, and it may vary as a function of soil type and vegetative cover. Tibbals (1990) discusses a value of 13–15 ft in the RASA model study. An extinction depth of 10 ft is incorporated into the current model. This value was determined based upon a sensitivity analysis to compare the effects of alternative values (see p. 68).

High evapotranspiration rates occur in the terrace areas where the water table is closer to land surface (Figure 12). Lower evapotranspiration rates occur in the higher sandy ridges where the water table naturally occurs at a greater depth below land surface.

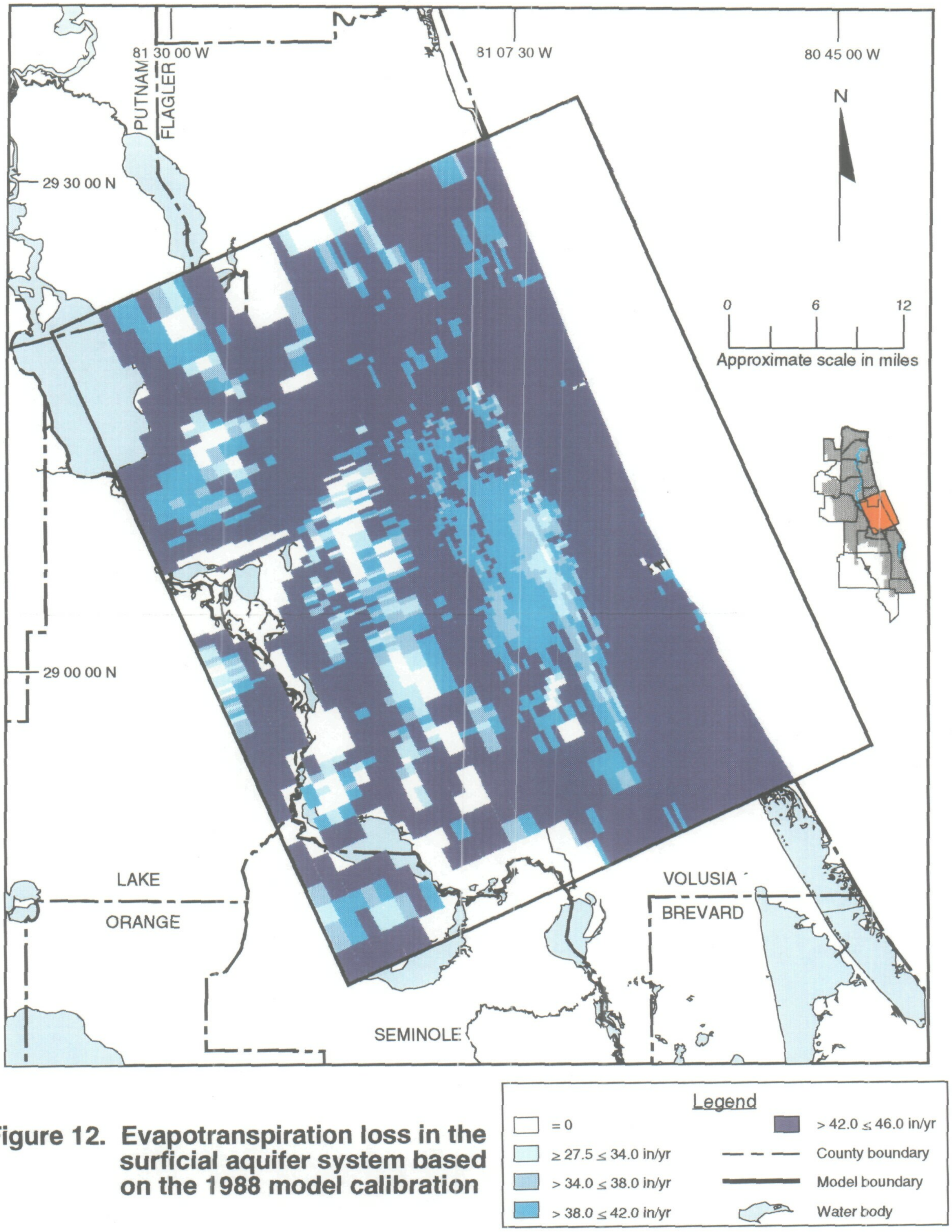



**Figure 12. Evapotranspiration loss in the surficial aquifer system based on the 1988 model calibration**

**Recharge to the Surficial Aquifer System.** Recharge to the surficial aquifer system is simulated across the top of the surficial layer as a specified flux boundary throughout the model domain. Because the model also simulates evapotranspiration, the recharge rates that are used in the model are actually gross recharge (i.e., before evapotranspiration loss has taken place). These recharge rates are based upon long-term average rainfall values of 54.57 in/yr at De Land and 48.46 in/yr at Daytona Beach (Phelps 1990). This difference in recharge between the eastern and western parts of the county is incorporated into the model. Also, only the ridges receive the maximum recharge. For all other locations in the model, the gross recharge values were adjusted downward by approximately 5–9 in/yr to account for runoff (Vecchioli et al. 1990).

Based on the above rationale, the model determines the actual or net recharge to the surficial aquifer system as the total or gross recharge less any evapotranspiration or drainage that exists in a given area of the model. Net recharge rates of greater than 10 in/yr occur in the area of the De Land Ridge; recharge rates are much less in the areas of lower elevation (Figure 13).

**Wells.** Wells also are a form of constant-flux boundary condition in the numerical model. The model includes virtually all wells in the study area. These wells can be subdivided by type into domestic irrigation and self-supply, agricultural, commercial and industrial, and public supply wells. Pumpage values for domestic irrigation and self-supply, agricultural, and commercial and industrial wells have been assigned based upon procedures and assumptions outlined in the model report by Geraghty & Miller (1991).

Virtually all increases in pumpage between 1988 and 2010 are due to public supply pumping. Based upon data collected and interpreted by SJRWMD staff, public water use for VGWB is expected to increase by greater than 100% from just over 45 mgd in 1988 to 95 mgd in 2010. Most of this increase is associated with anticipated growth of several major municipalities, including Daytona Beach, Ormond Beach, Port Orange, and Deltona. The appendix provides information about all public supply wells and the respective pumping values used in this model.

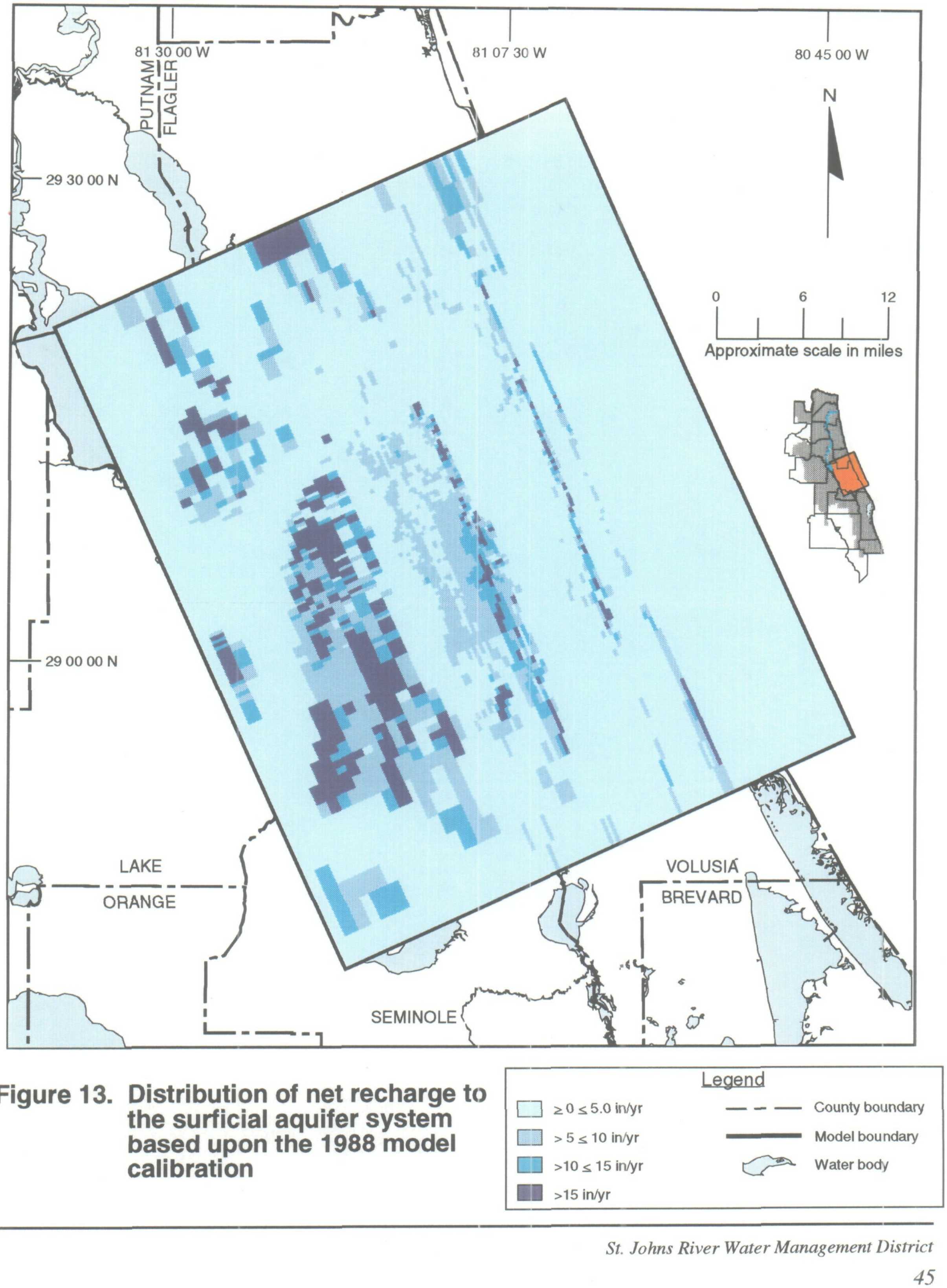



**Figure 13. Distribution of net recharge to the surficial aquifer system based upon the 1988 model calibration**

For the 1988 steady-state calibration, water use is distributed along the western ridges of Volusia county and further east in areas just west of major coastal municipalities (Figure 14). Much of the water use along the western ridges (i.e., De Land and Crescent City Ridges) is due to agricultural use while the water use in the east is primarily for public supply. Some of the highest areas for water use in 1988 occurred in the Deltona region, west of Daytona Beach, and just west of New Smyrna Beach. For the projected 2010 simulation, the distribution is similar to that for 1988 with additional high areas in the same vicinities (Figure 15). The largest differences between 1988 and 2010 pumping (i.e., greater than 100,000 $ft^3/d$) occurred in southwest Volusia County (Deltona) and in the vicinities of De Land, Daytona Beach, New Smyrna Beach, and west of Port Orange (Figure 16). The appendix provides additional information regarding specific well fluxes and proposed changes in pumping between the 1988 calibration period and the 2010 projection.

**Lakes and Rivers.** All major lakes in the study area are modeled as constant-head boundary conditions. Major lakes include Lake George, Lake Monroe, Lake Woodruff, and the southern portion of Crescent Lake (Figure 2). The Tomoka River, Spruce Creek, and the St. Johns River are also simulated as constant-head boundary conditions. However, neither the rivers nor the lakes are simulated as being in direct hydraulic connection with the underlying Floridan aquifer system.

A limitation of treating these surface water bodies as constant-head boundaries is that they can serve as limitless sources of water. However, this limitation is not a problem for the current model as most of these water bodies are relatively removed from areas of high pumping. Therefore, the primary purpose of the water bodies is to serve as control points for the water level in the surficial aquifer system as opposed to providing significant hydraulic sources or sinks.

## AQUIFER PARAMETERS

Aquifer parameters (e.g., hydraulic conductivity, leakance, transmissivity) are measures of the resistance to flow in the geologic

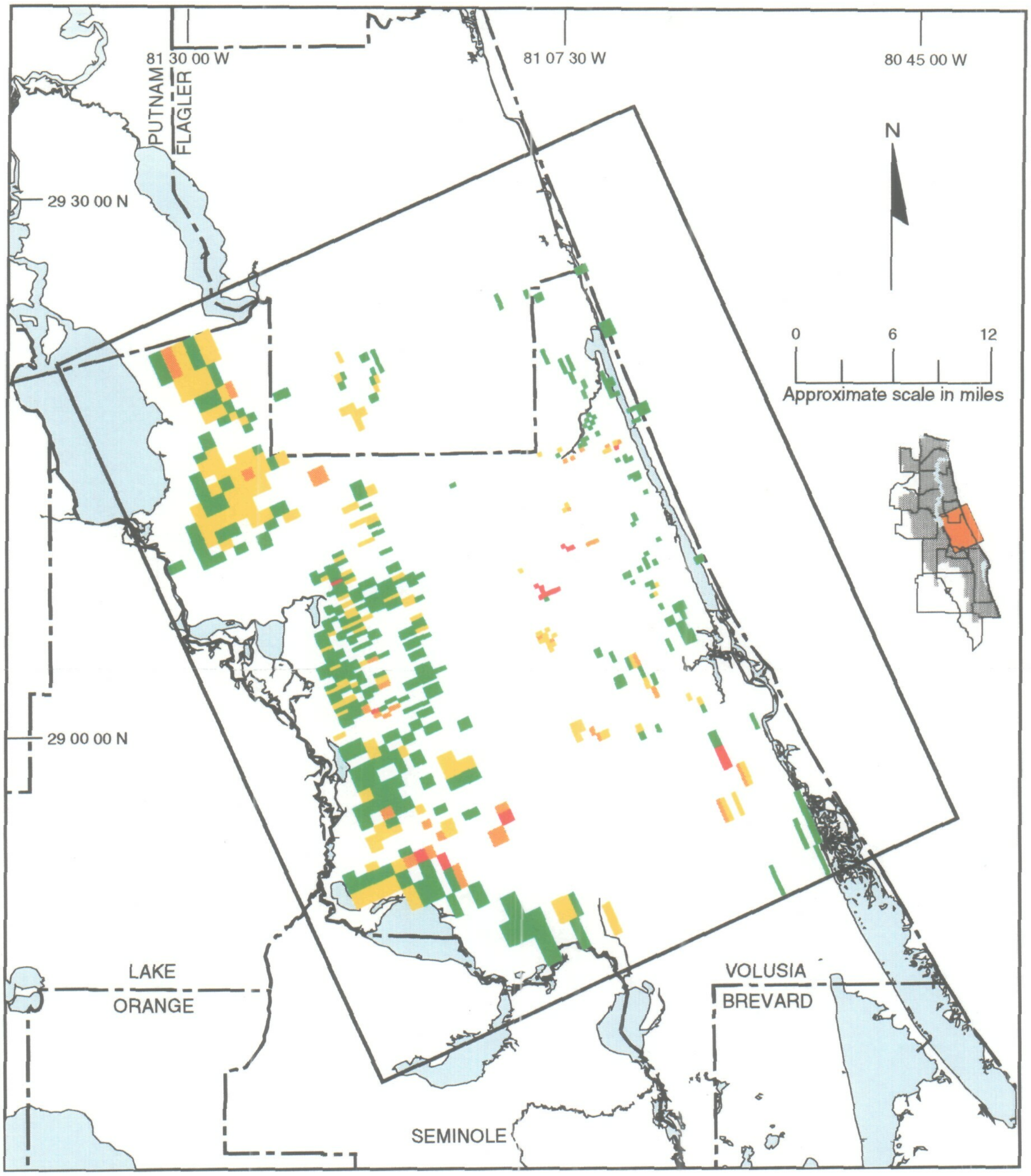



**Figure 14. Water use distribution for the 1988 calibration**

Legend
- 1,000 to 10,000 $ft^3/d$
- 10,000 to 50,000 $ft^3/d$
- 50,000 to 100,000 $ft^3/d$
- > 100,000 $ft^3/d$
- County boundary
- Model boundary
- Water body

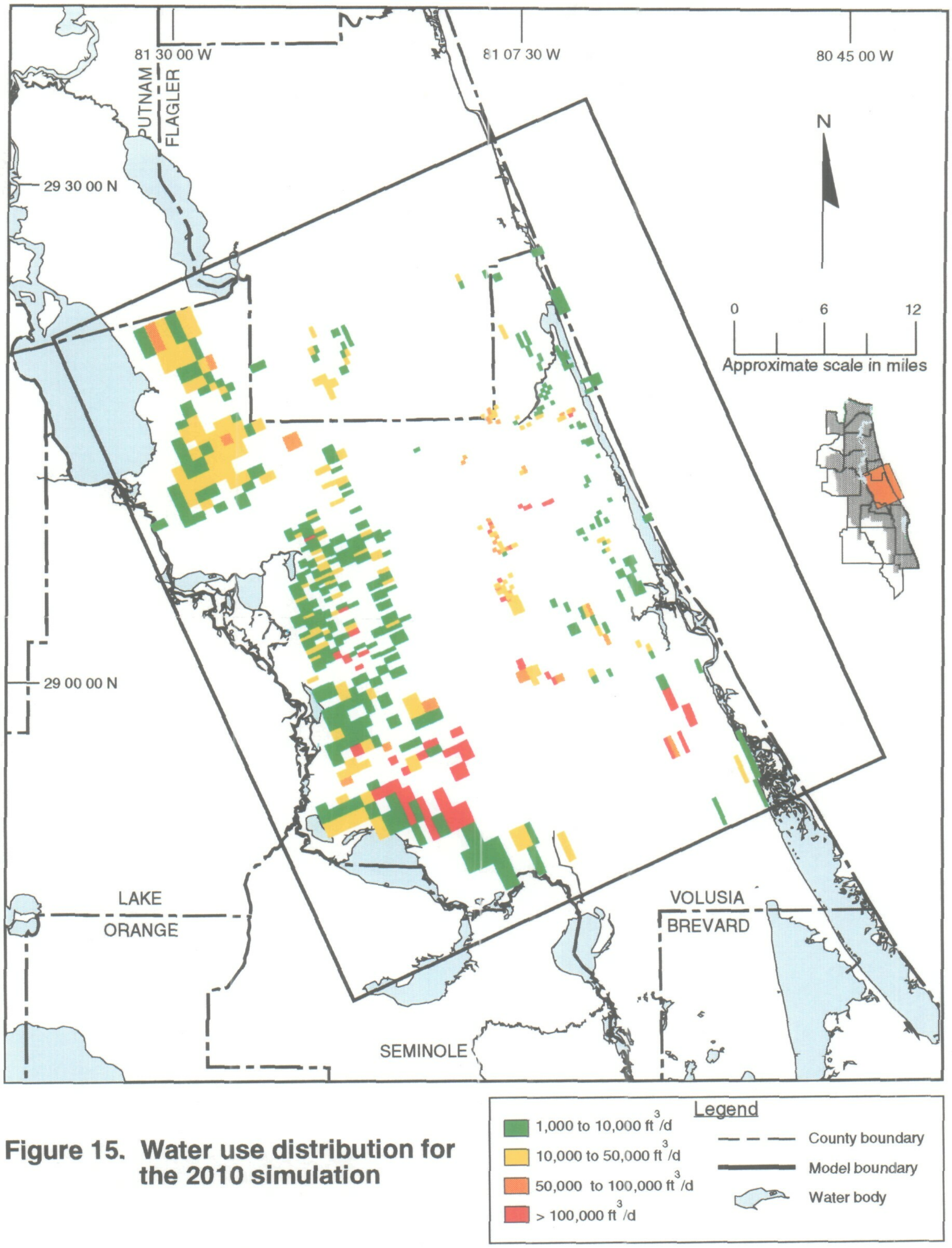



**Figure 15. Water use distribution for the 2010 simulation**

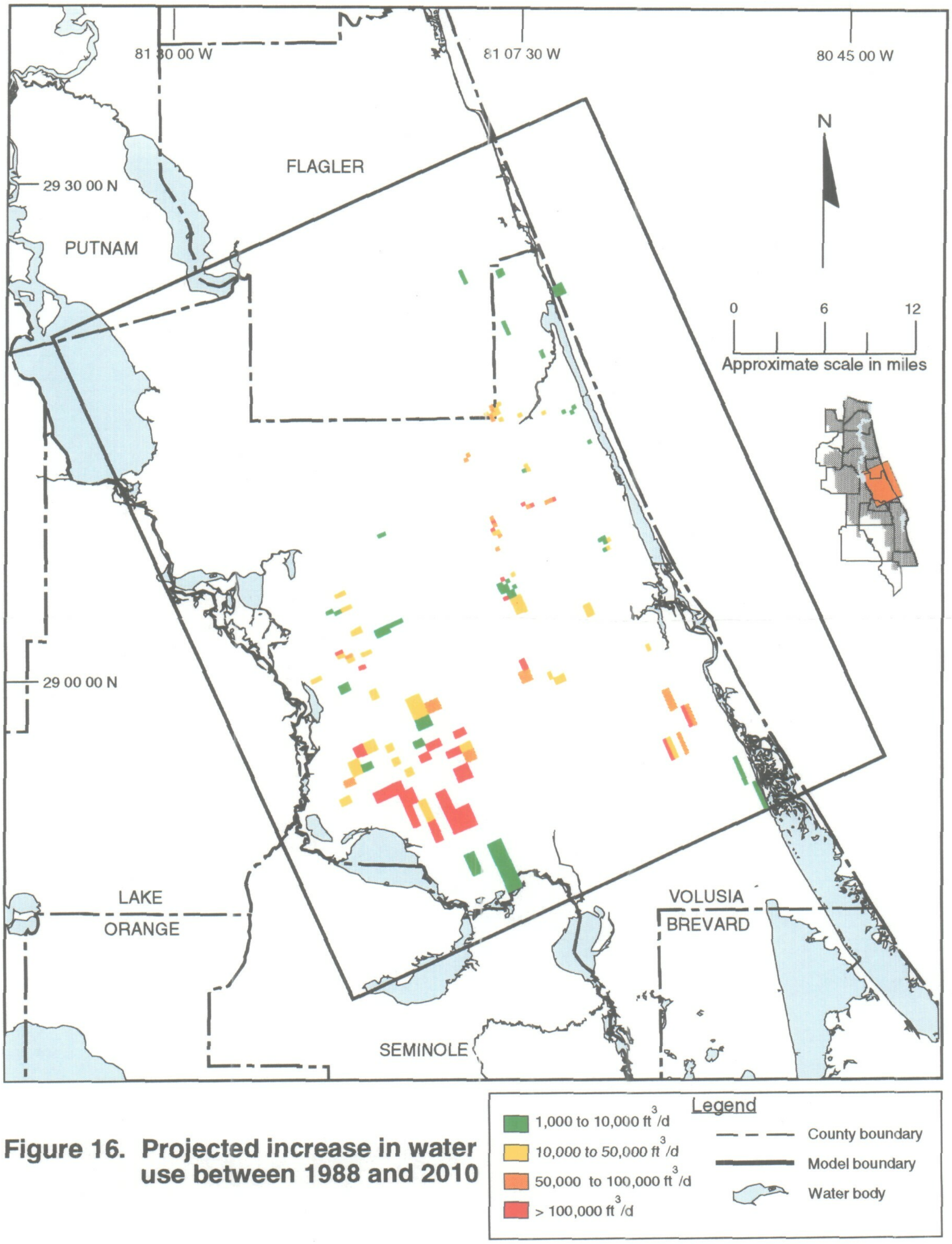



**Figure 16. Projected increase in water use between 1988 and 2010**

media. Transmissivity and hydraulic conductivity are quantifiable measures of the ability of an aquifer to transmit water under the influence of a hydraulic gradient. Transmissivity refers to the entire aquifer; hydraulic conductivity refers to a unit thickness of the aquifer. Leakance is the vertical hydraulic conductivity of a confining layer divided by its thickness and is a measure of the resistance to flow within a confining layer. For all of these parameters, high values indicate a low resistance to flow and a high capability to conduct water through the geologic media. These parameters may have uniform or heterogeneous distributions within the ground water model. The final distributions in the ground water flow model are based upon a review of data and minor adjustments performed during the model calibration process.

**Hydraulic Conductivity**

Specific estimates for hydraulic conductivity for the surficial aquifer system are available only for selected areas, and only regional estimates are available for the entire study area (Table 4). Based upon these findings, a uniform value of 30 feet/day has been used in the model for the hydraulic conductivity of the surficial aquifer system. A sensitivity analysis for the model indicates that potentiometric head values for both the surficial and the Floridan aquifer systems are relatively insensitive to changes in the hydraulic conductivity of the surficial system (see p. 68).

**Leakance**

The sediments between the surficial aquifer system and the Upper Floridan aquifer form a regional confining layer that is extremely variable in composition and is both vertically and horizontally heterogeneous. These sediments are simulated in the model through use of an array of leakance coefficients that controls the degree of hydraulic connection between these two aquifer systems. In Volusia County, this hydraulic connection is particularly important because virtually all of the fresh water that enters the Floridan aquifer system as recharge is due to vertical flow from the surficial aquifer system.

The array of leakance coefficients that has been used in the model was derived by using representative values from other studies as a starting point and refining these values through model calibration and sensitivity analysis. Mathematically, the leakance of a confining unit is proportional to its vertical hydraulic conductivity and inversely proportional to its thickness. The leakance values that the model simulates are a nonuniform distribution with a range between $2 \times 10^{-5}$ and $5 \times 10^{-4}$ $d^{-1}$ (Figure 17). Due to the high degree of vertical and horizontal heterogeneity of the confining beds in the study area, these leakance values represent the extent of hydraulic connection between the aquifer systems and not necessarily the actual leakance that is measurable locally in specific clay lenses or other confining strata that may exist.

### Transmissivity

The distribution of transmissivity for the Upper Floridan aquifer (Figure 18) was derived from aquifer performance tests and previous model calibrations and was further refined during the calibration process. The resultant distribution for the calibrated model is characterized by low to moderate (10,000–50,000 $ft^2/d$) transmissivity for much of the eastern and central portions of the study area and low transmissivity (<10,000 $ft^2/d$) in central and western parts of the study area. Low transmissivity in the central and northwestern sections are key determinants in the existence of potentiometric highs in these areas. Relatively high transmissivity (50,000–100,000 $ft^2/d$) is simulated in the St. Johns River valley, and a zone of very high transmissivity (>100,000 $ft^2/d$) exists in the vicinity of Blue Spring, along the St. Johns River. The transmissivity of the Lower Floridan aquifer has been adapted from an earlier study (Tibbals 1990). The model simulates a range of transmissivity between 25,000 $ft^2/d$ in the northern half of the study domain to 50,000 $ft^2/d$ in the southern half of the domain.

## Model Calibration

The calibration of this model is a postdevelopment steady-state calibration to the average ground water conditions for 1988. Development in this instance refers to use of the ground water

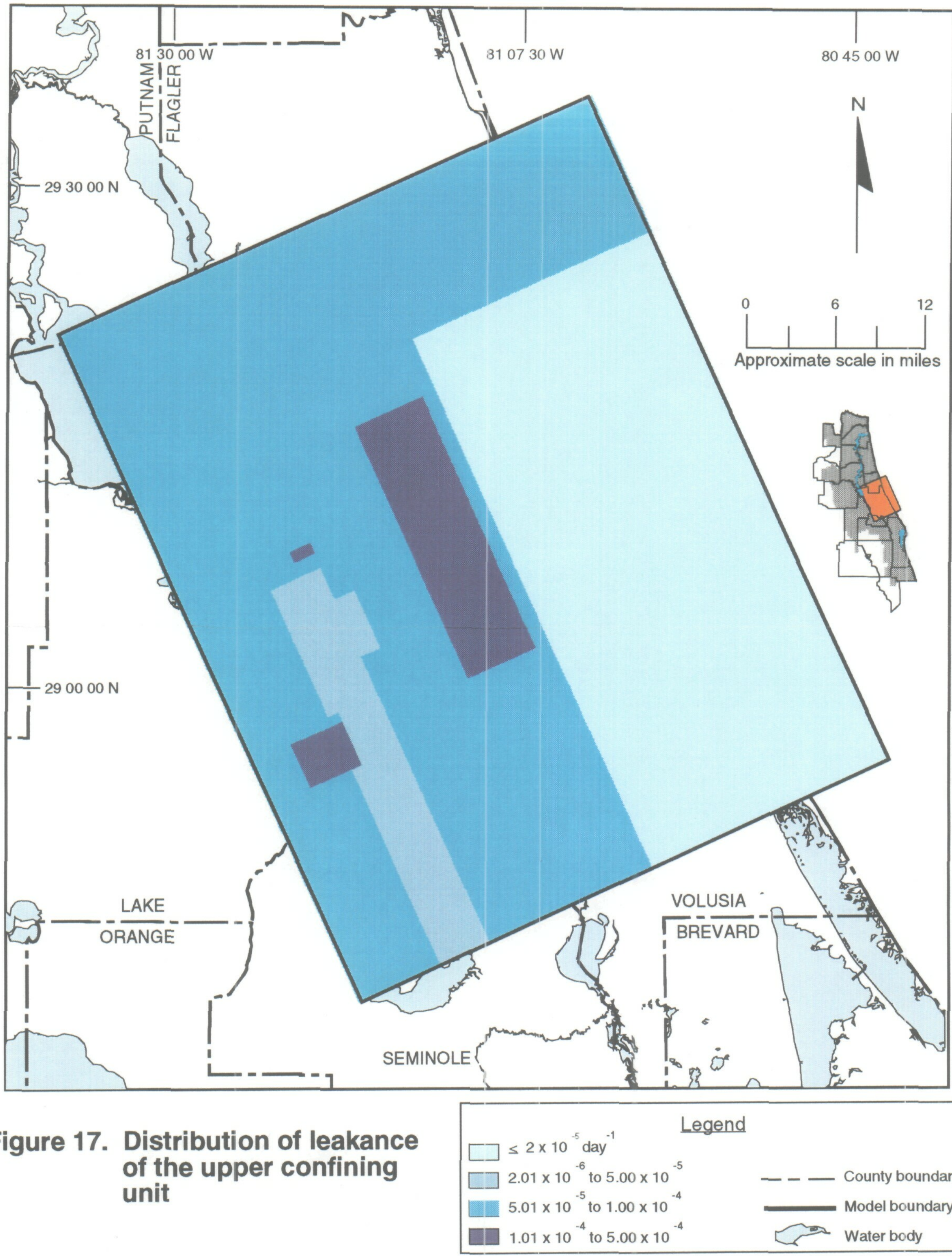



**Figure 17. Distribution of leakance of the upper confining unit**

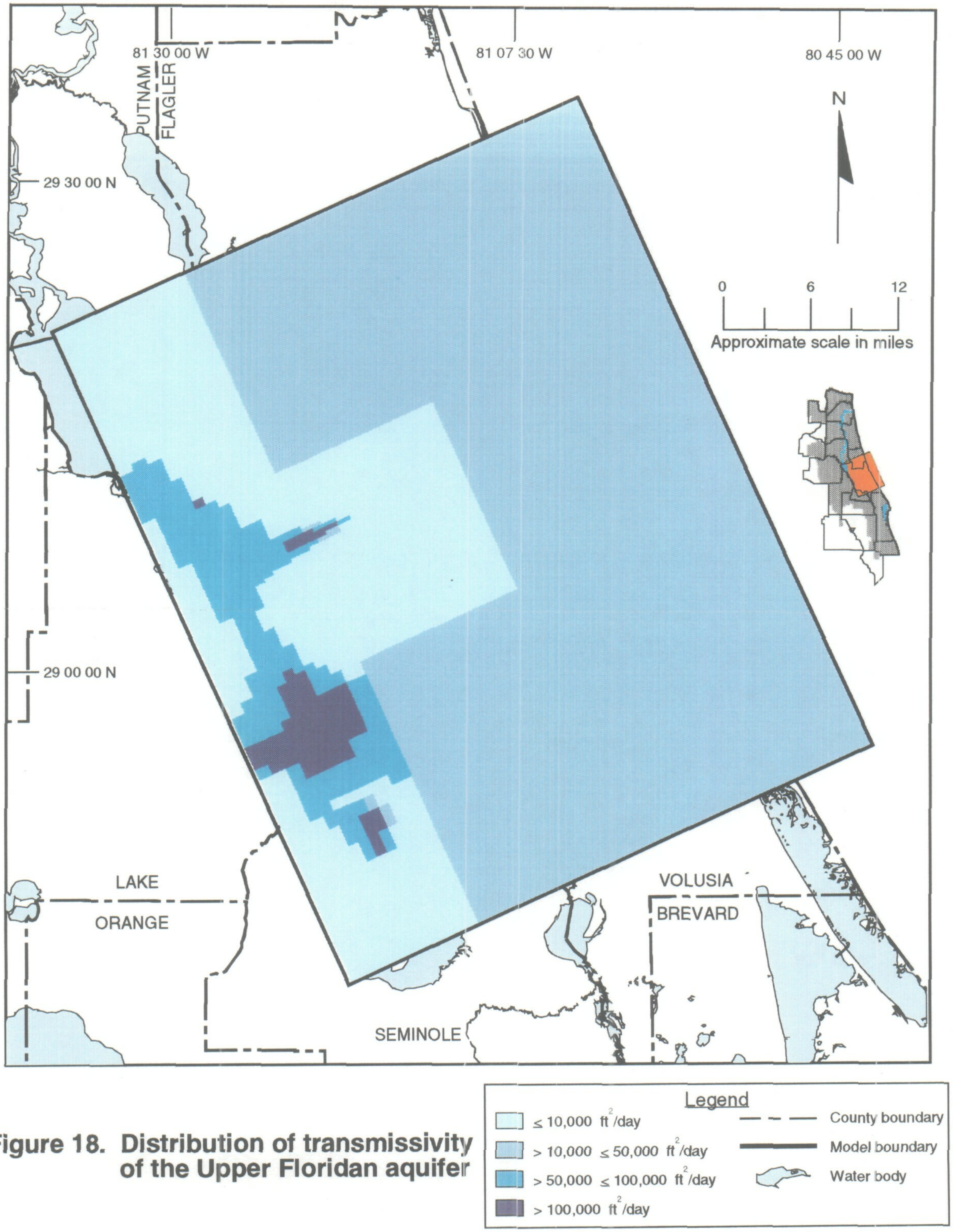



**Figure 18. Distribution of transmissivity of the Upper Floridan aquifer**

resources for public supply, agricultural, or commercial and industrial purposes. Calibration efforts were restricted to the postdevelopment condition because information regarding the observed hydrogeologic system is much more extensive for the postdevelopment period than for the predevelopment comparison.

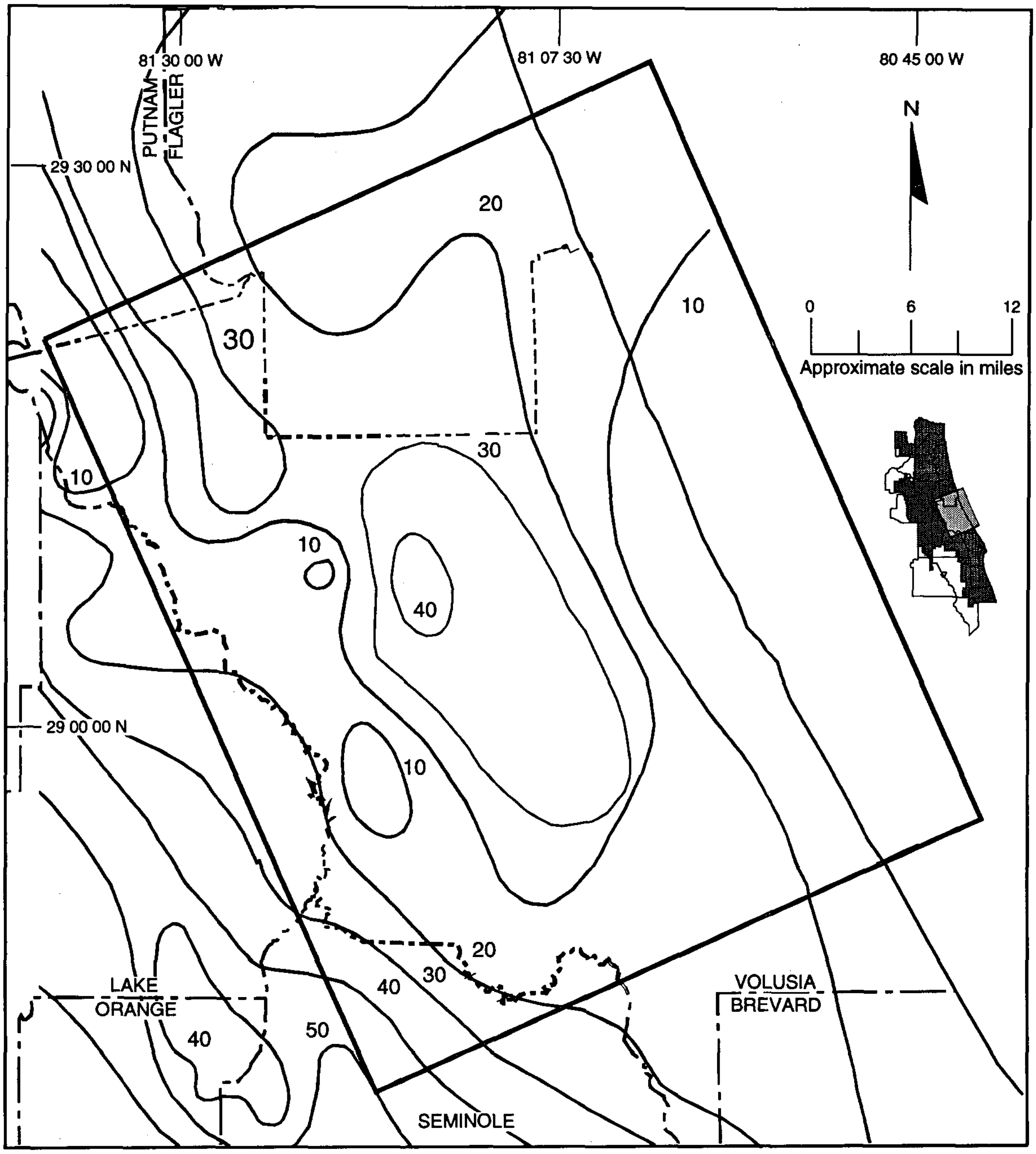
## Predevelopment Conditions

Although a predevelopment calibration was not performed, some comparisons are presented to show the reliability of the model for the predevelopment condition (Figures 19 and 20). Figure 21 illustrates the elevation of the simulated predevelopment water table conditions. The development of a water table map based upon observed conditions (i.e., similar to potentiometric surface maps for the Upper Floridan aquifer) is not appropriate, due to the relative paucity of data points. Therefore, because no water table map based upon observed predevelopment conditions exists, the simulated water table cannot be compared to a reference for calibration.

## Postdevelopment Calibration

The postdevelopment calibration for this ground water flow model was based on average hydrologic conditions for 1988. The year 1988 was chosen because analysis of long-term hydrographs indicated that this was a time when the aquifer was in a quasi-steady-state condition. In other words, the average water level measurements for 1988 are representative of a long-term average condition. The average water level measurements for 1988 were calculated from all available data for wells that are representative of the regional aquifer system.

**Procedure.** The general calibration process is an iterative procedure that entails determination of the best set of aquifer parameter values and boundary conditions that best characterize the hydrogeologic system and that produce the most credible results based on comparison with the observed hydrologic system. The specific mechanisms for verifying the reliability of the calibration for this model include the following:



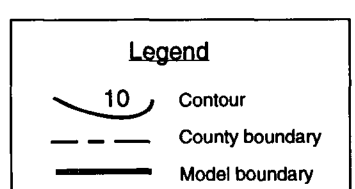




**Figure 19. Estimated elevation of the predevelopment potentiometric surface of the Upper Floridan aquifer (feet mean sea level)** (modified from Johnston et al. 1980)

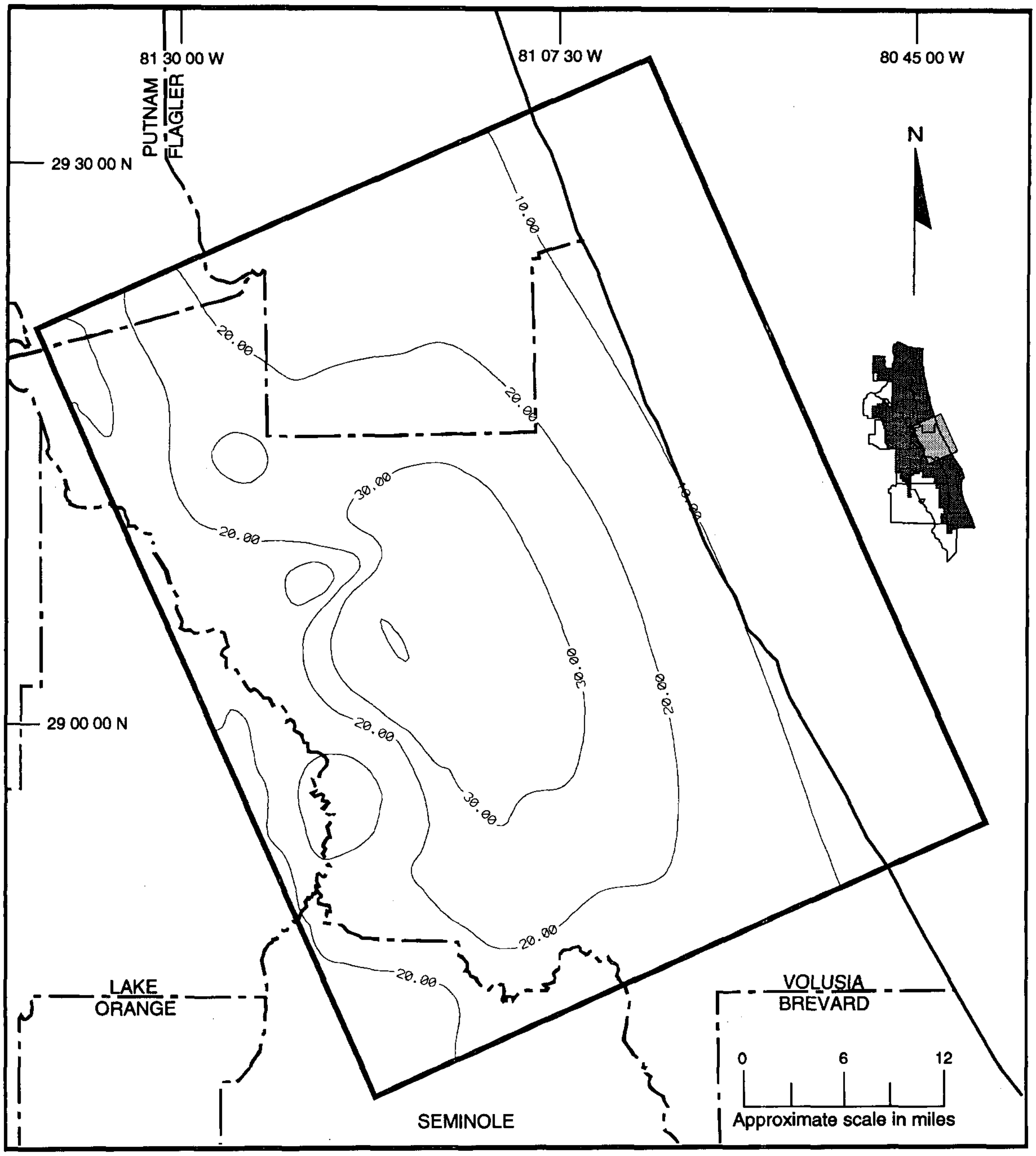



**Figure 20. Simulated elevation of the predevelopment potentiometric surface of the Upper Floridan aquifer (feet mean sea level)**

Legend
20.00 Contour
County boundary
Model boundary

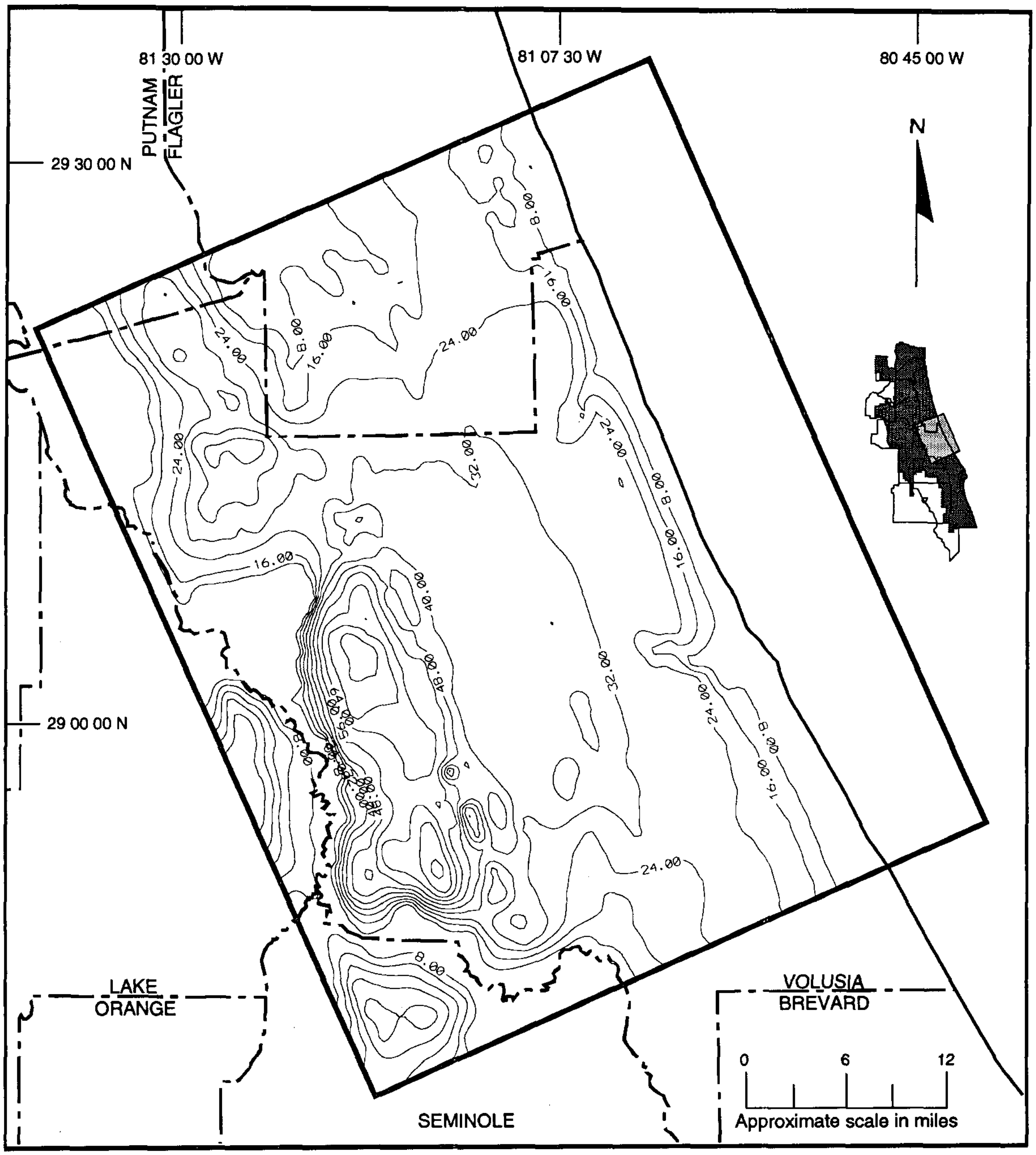
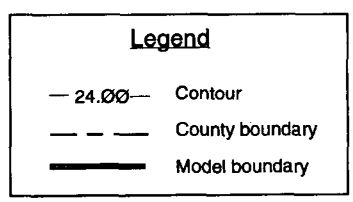



**Figure 21. Simulated elevation of the predevelopment water table in the surficial aquifer system (feet mean sea level)**



- The match between observed potentiometric head values in selected monitoring wells for both the Upper Floridan aquifer and the surficial aquifer system and respective simulated potentiometric head values

- The match between the potentiometric surface map for the Upper Floridan aquifer developed by USGS and that produced by the model

- The match between recharge/discharge flux values between the surficial aquifer system and the Upper Floridan aquifer that have been developed in earlier studies and those simulated by the model

- The match between measured or estimated spring flux values and those values simulated by the model

**Monitoring Wells.** Two sets of monitoring wells were chosen for use from a larger set, the locations of which are illustrated in Figure 22. Wells not chosen from the larger set met one of the following criteria:

- Wells with relatively shallow or deep screened intervals that are therefore not necessarily representative of general aquifer conditions

- Wells within close proximity to a major public supply wellfield that could cause the water levels in the well to not be representative of general ground water conditions

- Wells for which no information regarding screened intervals is available

In virtually all cases, the match between observed and simulated hydraulic head values for the monitoring wells in the Upper Floridan aquifer and the surficial aquifer system used in the 1988 calibration is acceptable (Tables 7 and 8).

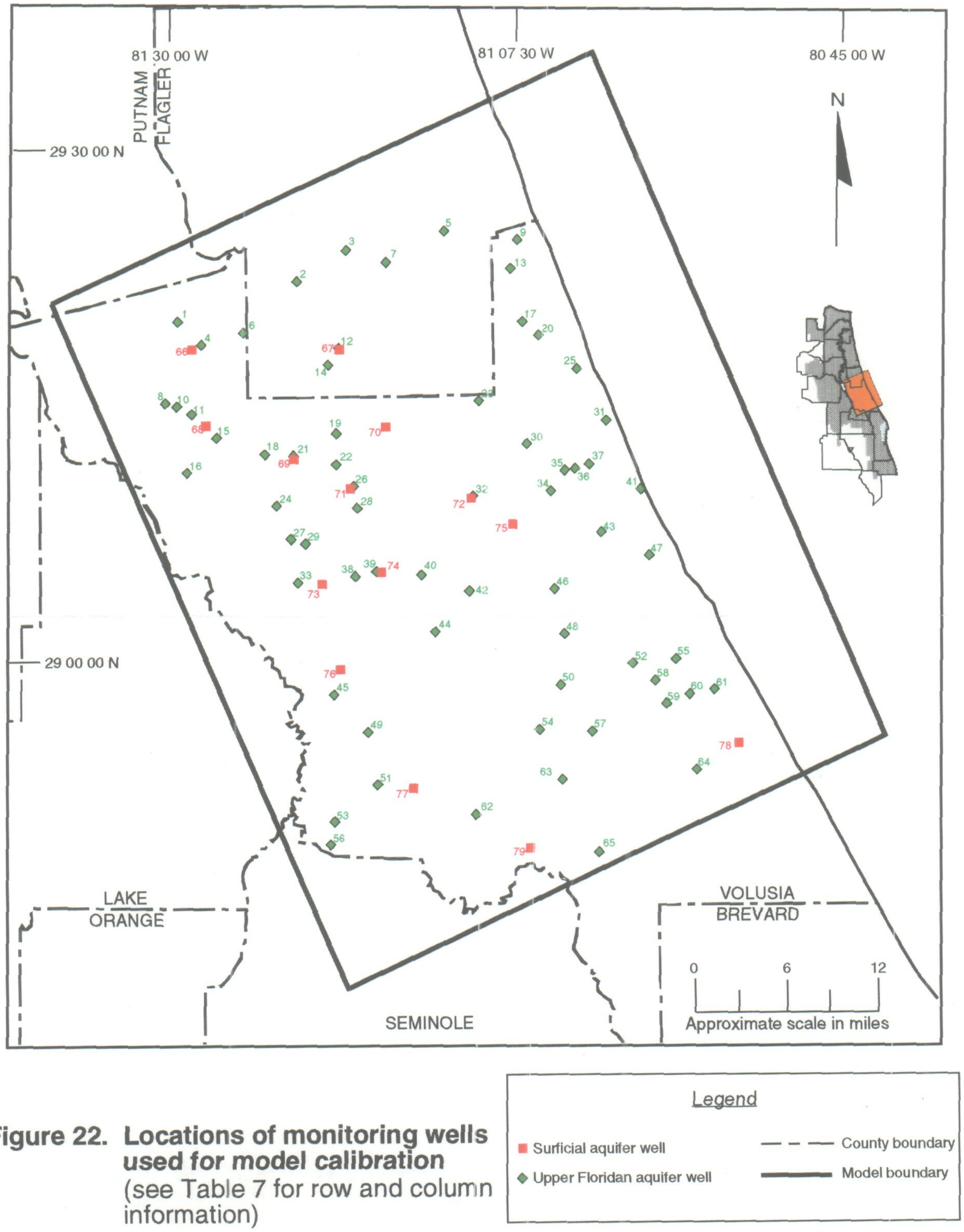



**Figure 22. Locations of monitoring wells used for model calibration** (see Table 7 for row and column information)

**Table 7. Summary of observed versus simulated potentiometric head for monitoring wells in the Upper Floridan aquifer used in the 1988 calibration**

| Map Identification Number on Figure 22 | Well Identification | Model Row | Model Column | Observed Head* (ft msl) | Simulated Head (ft msl) | Residual (ft) |
|---|---|---|---|---|---|---|
| 1 | SJR V-0184 | 3 | 9 | 26.21 | 21.56 | -4.65 |
| 2 | SJR F-0260 | 3 | 22 | 9.63 | 12.61 | 2.98 |
| 3 | SJR F-0261 | 3 | 36 | 8.40 | 12.94 | 4.54 |
| 4 | SJR V-0064 | 4 | 10 | 23.62 | 21.59 | -2.03 |
| 5 | USGS 292448081121301 | 4 | 59 | 16.74 | 14.37 | -2.37 |
| 6 | SJR V-0096 | 5 | 15 | 19.46 | 18.84 | -0.62 |
| 7 | SJR F-0240 | 5 | 43 | 12.26 | 15.49 | 3.23 |
| 8 | SJR V-0065 | 9 | 5 | 13.31 | 16.12 | 2.81 |
| 9 | SJR V-0442 | 9 | 75 | 5.85 | 7.77 | 1.92 |
| 10 | SJR V-0068 | 10 | 6 | 17.46 | 19.17 | 1.71 |
| 11 | SJR V-0066 | 11 | 7 | 21.85 | 21.34 | -0.51 |
| 12 | SJR F-0251 | 12 | 25 | 16.64 | 20.03 | 3.39 |
| 13 | SJR V-0443 | 12 | 71 | 5.67 | 9.33 | 3.66 |
| 14 | SJR F-0256 | 13 | 21 | 19.04 | 21.14 | 2.10 |
| 15 | USGS 291315081270301 | 14 | 8 | 26.29 | 24.07 | -2.22 |
| 16 | SJR V-0206 | 15 | 5 | 16.14 | 18.58 | 2.44 |
| 17 | SJR V-0446 | 16 | 68 | 6.09 | 8.93 | 2.84 |
| 18 | SJR V-0217 | 17 | 12 | 22.85 | 22.52 | -0.33 |
| 19 | USGS 291332081191001 | 18 | 19 | 30.10 | 26.10 | -4.00 |
| 20 | SJR V-0447 | 18 | 71 | 1.53 | 6.74 | 5.21 |
| 21 | SJR V-0062 | 19 | 15 | 24.59 | 24.10 | -0.49 |
| 22 | USGS 291149081190801 | 25 | 18 | 25.41 | 28.07 | 2.66 |
| 23 | SJR V-0130 | 25 | 49 | 14.81 | 16.57 | 1.76 |
| 24 | SJR V-0213 | 28 | 11 | 17.00 | 13.64 | -3.36 |
| 25 | SJR V-0449 | 29 | 77 | -4.66 | 2.27 | 6.93 |
| 26 | USGS 291036081175801 | 32 | 18 | 30.62 | 28.34 | -2.28 |
| 27 | USGS 290737081220301 | 37 | 11 | 8.70 | 5.95 | -2.75 |
| 28 | USGS 290923081174301 | 37 | 18 | 34.35 | 28.44 | -5.91 |

**Table 7—*Continued***

| Map Identification Number on Figure 22 | Well Identification | Model Row | Model Column | Observed Head* (ft msl) | Simulated Head (ft msl) | Residual (ft) |
|---|---|---|---|---|---|---|
| 29 | USGS 290723081210601 | 40 | 13 | 12.08 | 14.32 | 2.24 |
| 30 | SJR V-0127 | 41 | 57 | 7.38 | 8.35 | 0.97 |
| 31 | SJR V-0451 | 44 | 78 | 3.22 | 3.58 | 0.36 |
| 32 | USGS 291006081101004 | 47 | 40 | 26.10 | 25.15 | -0.95 |
| 33 | SJR V-0156 | 48 | 10 | 15.05 | 20.10 | 5.05 |
| 34 | SJR V-0456 | 51 | 57 | 5.98 | 3.09 | -2.89 |
| 35 | SJR V-0098 | 51 | 63 | 2.96 | 7.45 | 4.49 |
| 36 | SJR V-0454 | 52 | 66 | 2.37 | 7.40 | 5.03 |
| 37 | SJR V-0453 | 52 | 70 | 2.50 | 6.65 | 4.15 |
| 38 | SJR V-0027 | 53 | 16 | 35.11 | 36.20 | 1.09 |
| 39 | USGS 290550081162601 | 54 | 17 | 38.12 | 35.58 | -2.54 |
| 40 | SJR V-0081 | 60 | 22 | 36.16 | 33.47 | -2.69 |
| 41 | SJR V-0200 | 63 | 78 | 2.37 | 5.09 | 2.72 |
| 42 | SJR V-0120 | 68 | 31 | 35.23 | 31.50 | -3.73 |
| 43 | SJR V-0162 | 69 | 66 | 3.58 | 9.32 | 5.74 |
| 44 | SJR V-0118 | 72 | 20 | 34.21 | 31.51 | -2.70 |
| 45 | USGS 285859081191001 | 74 | 9 | 5.02 | 8.71 | 3.69 |
| 46 | SJR V-0123 | 74 | 49 | 18.55 | 17.72 | -0.83 |
| 47 | USGS 290651080582802 | 74 | 75 | 2.08 | 7.27 | 5.19 |
| 48 | SJR V-0117 | 77 | 47 | 20.55 | 19.61 | -0.94 |
| 49 | SJR V-0104 | 78 | 10 | 12.08 | 10.91 | -1.17 |
| 50 | SJR V-0110 | 83 | 42 | 24.20 | 22.30 | -1.90 |
| 51 | USGS 285359081161701 | 84 | 9 | 16.40 | 13.49 | -2.91 |
| 52 | SJR V-0381 | 84 | 60 | 6.18 | 12.15 | 5.97 |
| 53 | USGS 285156081190302 | 85 | 5 | 11.85 | 13.61 | 1.76 |
| 54 | SJR V-0101 | 85 | 34 | 28.79 | 24.83 | -3.96 |
| 55 | SJR V-0164 | 85 | 70 | 4.20 | 8.15 | 3.95 |
| 56 | USGS 285040081192101 | 86 | 3 | 17.35 | 13.33 | -4.02 |
| 57 | SJR V-0113 | 86 | 45 | 17.57 | 19.55 | 1.98 |

**Table 7—*Continued***

| Map Identification Number on Figure 22 | Well Identification | Model Row | Model Column | Observed Head* (ft msl) | Simulated Head (ft msl) | Residual (ft) |
|---|---|---|---|---|---|---|
| 58 | SJR V-0407 | 86 | 63 | 4.59 | 7.42 | 2.83 |
| 59 | SJR V-0435 | 87 | 64 | 4.94 | 8.78 | 3.84 |
| 60 | USGS 285904080554601 | 87 | 70 | 5.25 | 7.33 | 2.08 |
| 61 | USGS 285921080541001 | 87 | 76 | 6.59 | 6.62 | 0.03 |
| 62 | SJR V-0102 | 88 | 17 | 21.71 | 22.89 | 1.18 |
| 63 | SJR V-0198 | 88 | 34 | 16.22 | 19.72 | 3.50 |
| 64 | SJR V-0521 | 90 | 64 | 8.52 | 10.61 | 2.09 |
| 65 | SJR V-0103 | 91 | 35 | 15.87 | 15.27 | -0.60 |

*Observed head values for USGS wells (USGS 1989)

Note: ft msl = feet mean sea level
ft = feet
SJR = St. Johns River Water Management District identifier
V = Volusia County
F = Flagler County
USGS = U.S. Geological Survey identifier

**Table 8. Summary of observed versus simulated water levels for monitoring wells in the surficial aquifer system used in the 1988 calibration**

| Map Identification Number on Figure 22 | Well Identification | Model Row | Model Column | Observed Head (ft msl) | Simulated Head (ft msl) | Residual (ft) |
|---|---|---|---|---|---|---|
| 66 | USGS 291806081284301 | 5 | 9 | 33.5* | 34.0† | 0.5 |
| 67 | SJR F-0252 | 12 | 25 | 24.2 | 24.6 | 0.4 |
| 68 | USGS 291441081254801 | 13 | 8 | 48.1* | 50.6 | 2.5 |
| 69 | SJR V-0063 | 19 | 15 | 20.2 | 27.1 | 6.9 |
| 70 | SJR V-0088 | 21 | 28 | 31.1 | 31.3 | 0.2 |
| 71 | USGS 291032081181301 | 32 | 18 | 39.4* | 39.7 | 0.3 |
| 72 | USGS 291007081101613 | 47 | 40 | 35.5 | 33.8 | -1.7 |
| 73 | USGS 290508081200601 | 51 | 12 | 83.2 | 80.3 | -2.9 |
| 74 | USGS 290554081160801 | 55 | 17 | 54.3* | 49.4 | -4.9 |
| 75 | SJR V-0193 | 58 | 46 | 32.6 | 36.4 | 3.8 |
| 76 | USGS 290025081185001 | 71 | 10 | 59.5* | 60.2 | 0.7 |
| 77 | USGS 285343081140401 | 85 | 13 | 68.2* | 66.6 | -1.6 |
| 78 | USGS 285625080525201 | 89 | 76 | 11.7* | 8.9† | -2.8 |
| 79 | SJR V-0167 | 90 | 20 | 14.4 | 18.7† | 4.3 |

*Indicates that observed levels for these wells are average values from 1986 to 1987 (Phelps 1990)
†Indicates that the monitoring well is near an intersection of grid cells and therefore the simulated value is an average of up to four adjacent grid cells

Note: ft msl = feet mean sea level
ft = feet
SJR = St. Johns River Water Management District identifier
V = Volusia County
F = Flagler County
USGS = U.S. Geological Survey identifier

In addition to a comparison of observed versus simulated potentiometric head values, a statistical analysis was developed to further document and validate the 1988 model calibration. The calculated statistical parameters were the residual sum of squares, the root mean squared error, and the mean absolute error. The residual sum of squares is the total of the squared values of all differences between observed data and the corresponding simulated values. The root mean squared error is the average squared residual (i.e., the residual sum of squares divided by the number of observation wells). The mean absolute error is the average of the absolute values of the residuals. The calibration goals for these parameters were (1) to have a mean absolute error of less than 3.0 ft, (2) to have a root mean squared error of less than or equal to 10.0, and (3) to have a value for the residual sum of squares of less than 1,000. For the calibrated model, these statistics were 2.79 for the mean absolute error, 10.25 for the root mean squared error, and 666.39 for the residual sum of squares. These statistics provide an additional check on the validity of the model calibration.

**Potentiometric Surface.** The next check on the accuracy and reliability of the model was a comparison between the average observed and the simulated average potentiometric surfaces for the Upper Floridan aquifer (Figures 23 and 24). The average observed potentiometric surface for 1988 (Figure 23) is based on average annual values for all wells that are representative of the regional potentiometic surface. Review of these figures indicates an excellent match. The model appears to do a good job of simulating the primary features of the potentiometric surface within the study area. Good matches are achieved for the potentiometric highs in west-central and northwest Volusia County and for the potentiometric lows near the St. Johns River (specifically around Blue Spring) and in southern Flagler County. The simulated potentiometric surface also closely mimics the observed hydraulic gradient.

As there is little knowledge of the actual elevation of the potentiometric surface for the Lower Floridan aquifer in the study area and because this aquifer was not actually calibrated but included only as a source/sink for flux rates between it and the Upper Floridan aquifer, no comparisons with actual data are possible. See Figure 25 for the simulated potentiometric surface for the Lower Floridan aquifer for the 1988 calibration.

**Recharge and Discharge Patterns.** The configuration of recharge and discharge between the surficial aquifer system and the Upper

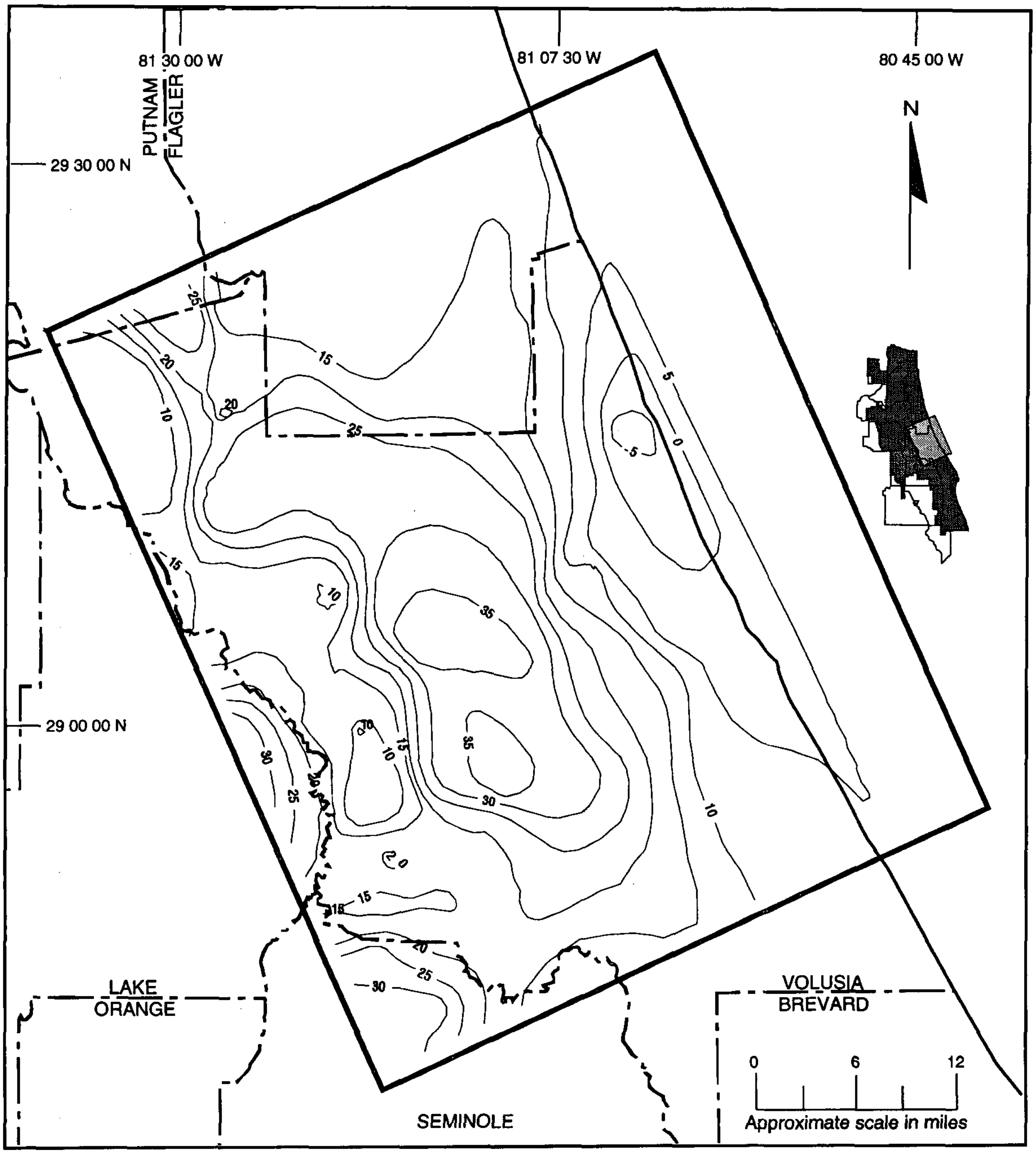



**Figure 23. Average of observed elevation of the 1988 potentiometric surface for the Upper Floridan aquifer (feet mean sea level)**

Legend

| | |
|---|---|
| — 10 — | Contour |
| — — — | County boundary |
| ——— | Model boundary |

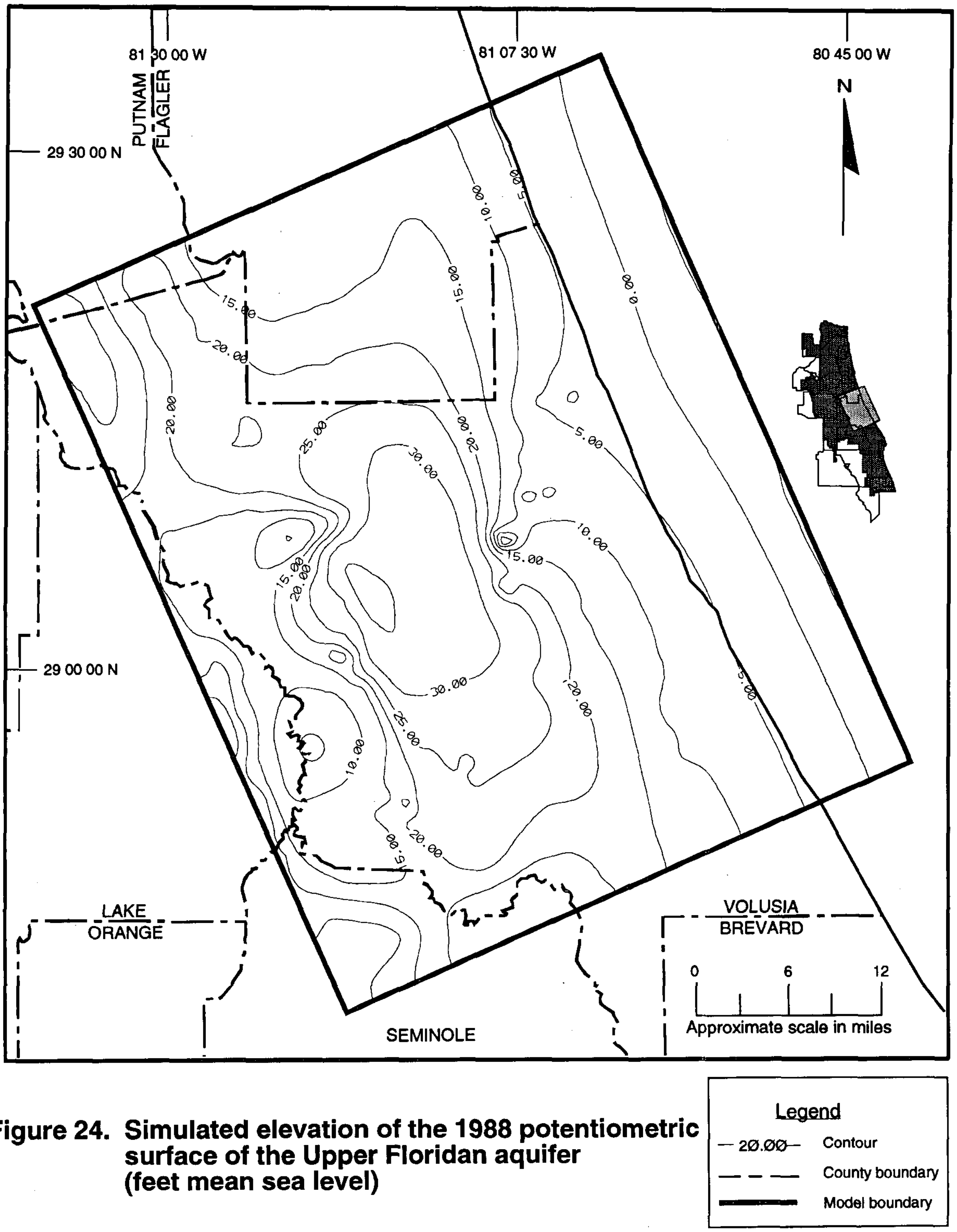



**Figure 24. Simulated elevation of the 1988 potentiometric surface of the Upper Floridan aquifer (feet mean sea level)**

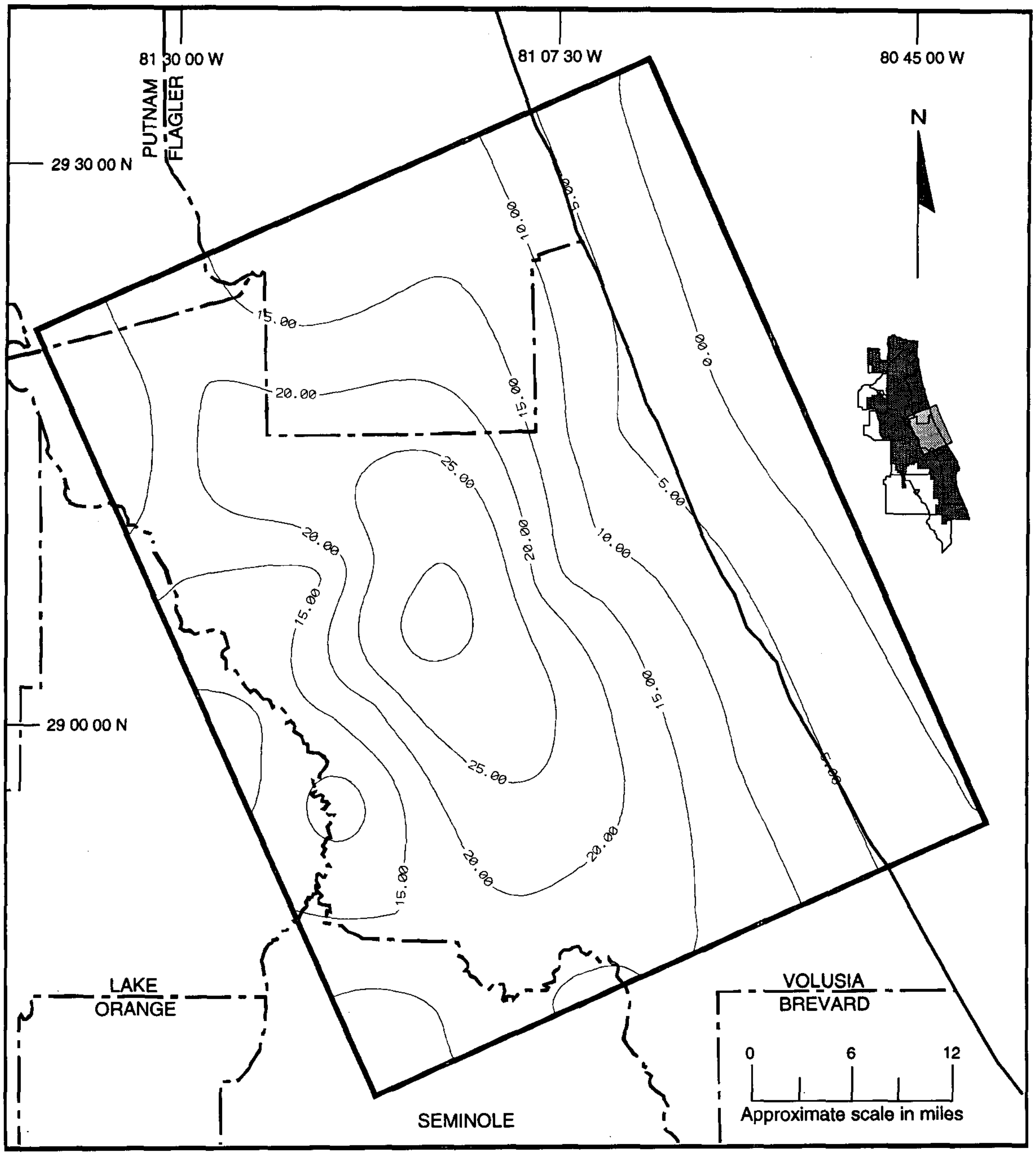



**Figure 25. Simulated elevation of the 1988 potentiometric surface of the Lower Floridan aquifer (feet mean sea level)**

Floridan aquifer is also pertinent to the assessment of the quality of the calibration. Relatively high recharge rates are simulated in the sandy ridge areas such as the De Land Ridge and the Rima Ridge (Figure 26). Moderate rates (0–6 in/yr) of recharge are simulated in the terrace areas where the water table is slightly higher than the potentiometric surface. Discharge from the Upper Floridan aquifer is simulated along the St. Johns River, in southern Flagler County, and in low-lying areas around Lake Woodruff. These patterns are consistent with the findings of other researchers (Tibbals 1990; Phelps 1984; Boniol et al. 1993).

**Spring Flux Rates.** Calibration of spring flux rates provides an additional check on the reliability of the model. The springs that are modeled within the study area are Blue Spring, Ponce de Leon Springs, and Gemini Springs. These springs were modeled as head-dependent flux boundaries, with a spring pool elevation of 1.0 ft used as the source head and an estimate of the local hydraulic conductivity used to calculate the spring conductance terms. These spring fluxes were replicated through minor adjustments to the conductance terms, the surrounding transmissivity of the Upper Floridan aquifer, and the leakance of the upper confining unit. The fit between the observed and simulated spring fluxes (Table 9) is acceptable, with residual values of less than or equal to 3%.

## SENSITIVITY ANALYSIS

A sensitivity analysis was performed to evaluate the relative sensitivity of the model-generated potentiometric heads to changes in aquifer parameters and boundary conditions. The procedure for this analysis was to select several aquifer parameters and boundary conditions, to vary them independently by ±20%, and to perform simulations with these changes incorporated. Potentiometric head results were then compared between these simulations and the calibrated base case. Sensitivities were quantified by comparing the average change in hydraulic head values to the average head value for the base case and presenting these as percentages. The following items were evaluated in the sensitivity analysis:

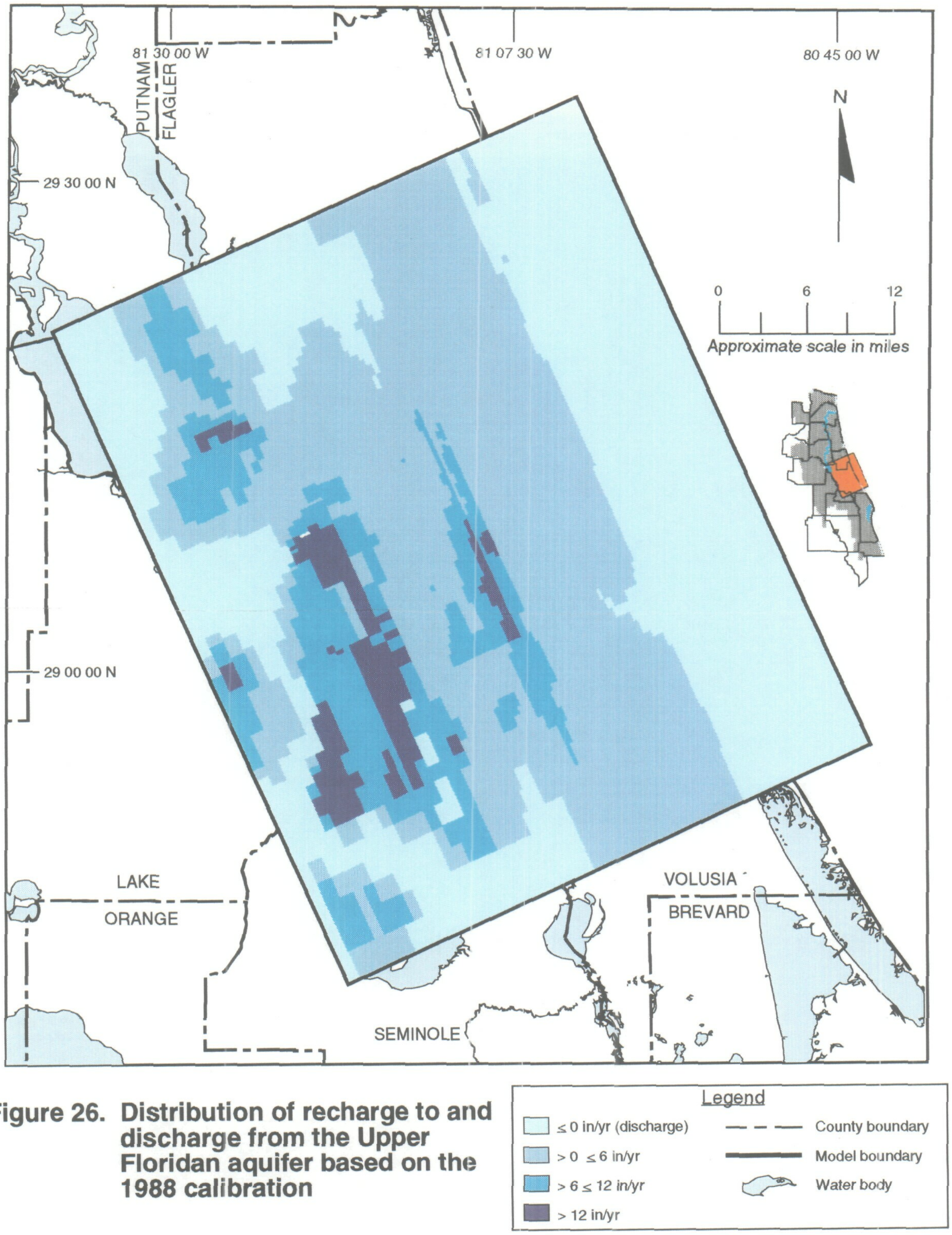



**Figure 26. Distribution of recharge to and discharge from the Upper Floridan aquifer based on the 1988 calibration**

**Table 9. Observed versus simulated spring flux rates**

| Spring | Row | Column | Layer | Observed Rate (mgd)* | Simulated Rate (mgd) | Residual (%) |
|---|---|---|---|---|---|---|
| Ponce de Leon Springs | 35 | 12 | 2 | 16.2 | 16.7 | 3.0 |
| Blue Spring | 76 | 6 | 2 | 91.6 | 92.6 | 1.1 |
| Gemini Springs | 86 | 7 | 2 | 4.96† | 5.09 | 2.6 |

Note: mgd = million gallons per day

*USGS 1989
†Indicates 1986 observed flow rate

- Hydraulic conductivity of the surficial aquifer system
- Leakance of the upper confining unit
- Transmissivity of the Upper Floridan aquifer
- Leakance of the middle semiconfining unit
- Transmissivity of the Lower Floridan aquifer
- Recharge to the surficial aquifer system
- Eastern head boundary for the Upper Floridan aquifer
- Extinction depth for evapotranspiration

Of the eight items evaluated, water levels in the surficial aquifer system are most sensitive to recharge, the extinction depth for evapotranspiration, the leakance of the upper confining unit, and the transmissivity of the Upper Floridan aquifer (Figure 27). Conversely, hydraulic head values in the surficial aquifer system are least sensitive to the hydraulic conductivity of the surficial aquifer system, the leakance of the middle semiconfining unit, the transmissivity of the Lower Floridan aquifer, and the eastern potentiometric head boundary for the Upper Floridan aquifer (implied by absence from the figure). Similarly, for the Upper Floridan aquifer, of the eight items evaluated, the potentiometric head results for the Upper Floridan aquifer are most sensitive to recharge to the surficial aquifer system, the extinction depth for evapotranspiration, leakance of the upper confining unit, and the transmissivity of the Upper Floridan aquifer (Figure 28). Conversely, the potentiometric head results for the Upper Floridan aquifer are least sensitive to the hydraulic

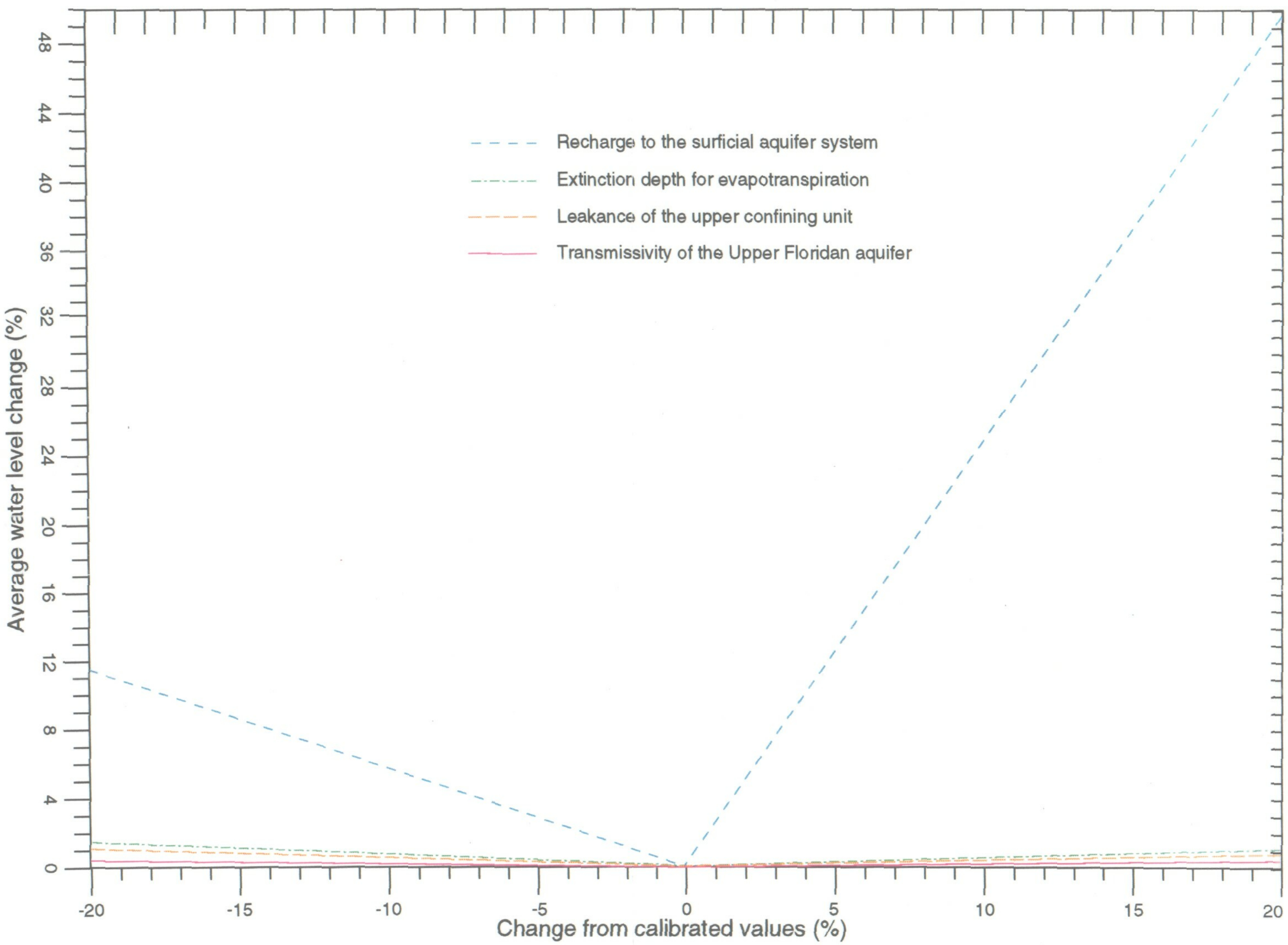



**Figure 27. Sensitivity analysis for the surficial aquifer system**

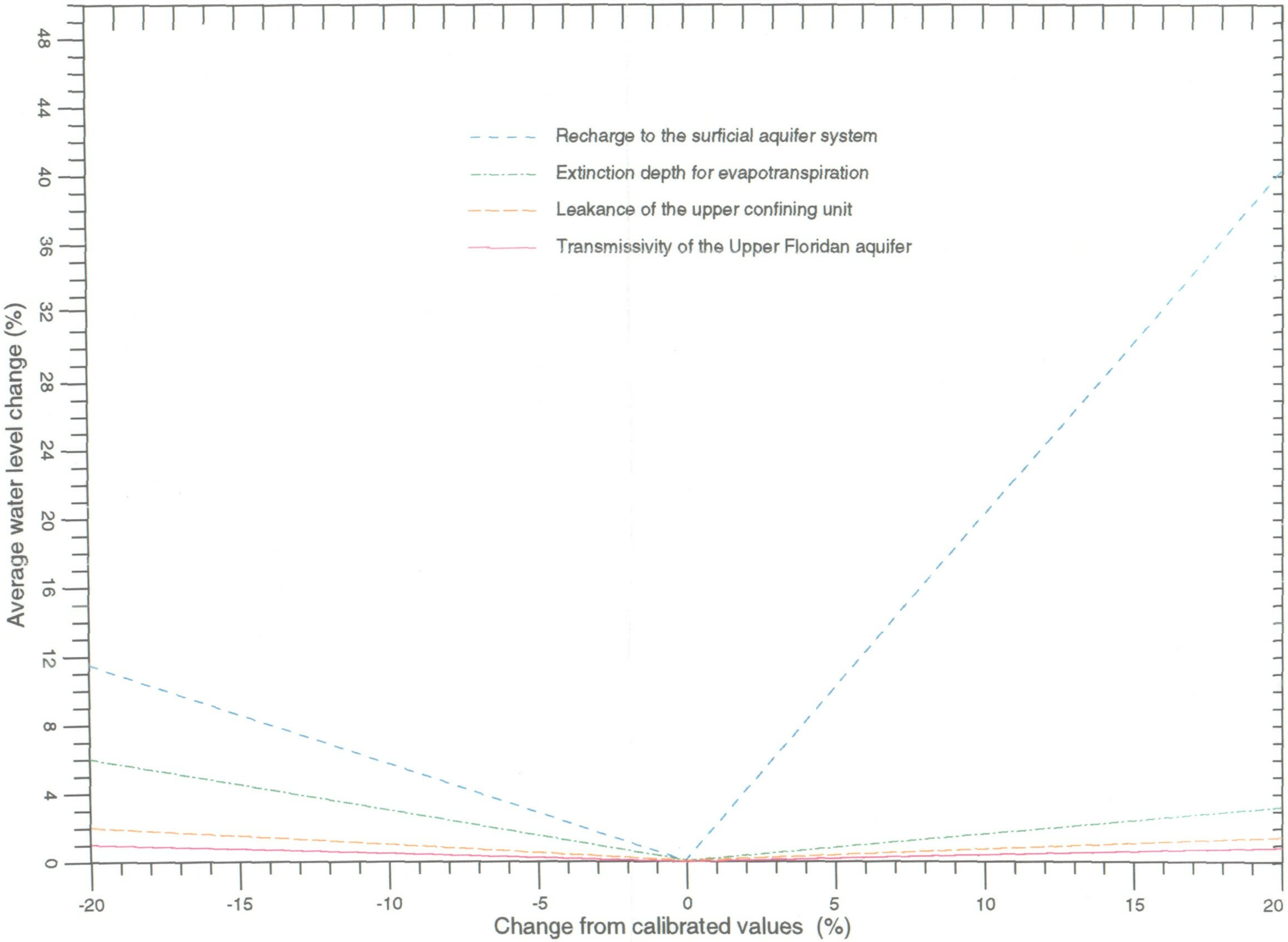



**Figure 28. Sensitivity analysis for the Upper Floridan aquifer**

conductivity of the surficial aquifer system, the leakance of the middle semiconfining unit, the transmissivity of the Lower Floridan aquifer, and the eastern head boundary for the Upper Floridan aquifer. In summary, these analyses indicate that the most critical items for calibration of the model are the recharge to the surficial aquifer system, the simulation of evapotranspiration, the leakance of the upper confining unit, and the transmissivity of the Upper Floridan aquifer.

## PREDICTIVE SIMULATIONS

The calibrated ground water flow model was used to develop predictive simulations of the ground water resources in the study area for 2010. In these simulations, all aquifer parameter values and boundary conditions were identical to those of the 1988 calibration. The primary difference between the 1988 and the 2010 simulations is in the use of a new set of well data, which represents projected water use conditions for 2010. Actual pumping locations and rates for public supply wells are listed in the appendix.

The elevation of the simulated water table for 2010 (Figure 29) is generally similar to that simulated for the 1988 calibration (Figure 30). The principal difference is a decline in water levels (in 2010) in the vicinities of the primary public supply wellfields. The difference in the water tables between 1988 and 2010 is areally distributed with values of over 4 ft in the area of the Daytona Beach western wellfield, 1–2 ft around the Ormond Beach wellfields, up to 6 ft in the Deltona area, and 2–4 ft near the Port Orange western wellfield (Figure 31; appendix). Some of these drawdown areas are in or near local wetlands; therefore, the drawdowns may have a bearing on the ecological viability of these wetlands (Figure 3).

Due to changes in elevation of both the water table in the surficial aquifer system and in the potentiometric surface of the Upper Floridan aquifer, the distribution of recharge to and discharge from the Upper Floridan aquifer also changes (Figure 32). However, the patterns are generally similar to those in the 1988 calibration (Figure 26).

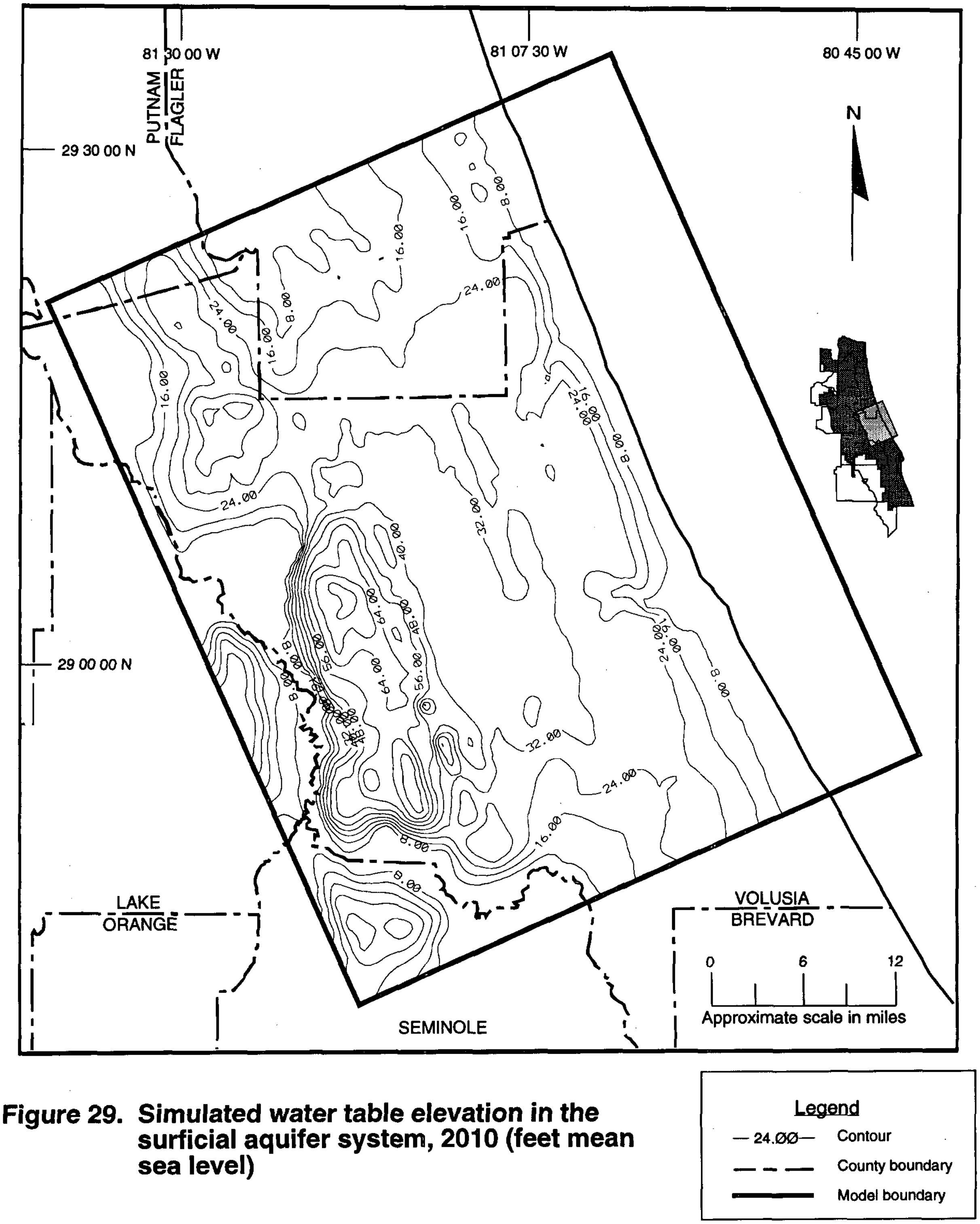



**Figure 29. Simulated water table elevation in the surficial aquifer system, 2010 (feet mean sea level)**

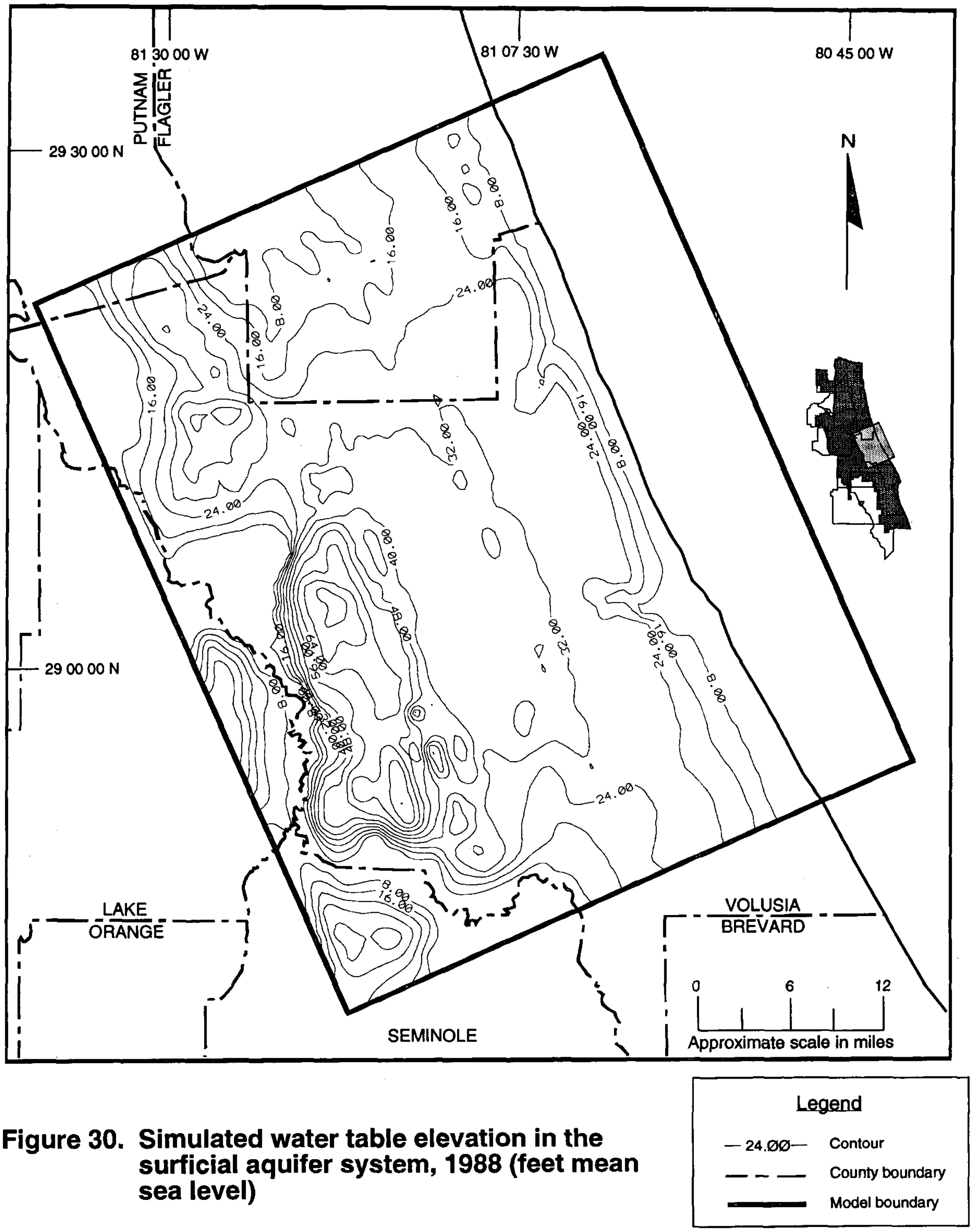



**Figure 30. Simulated water table elevation in the surficial aquifer system, 1988 (feet mean sea level)**

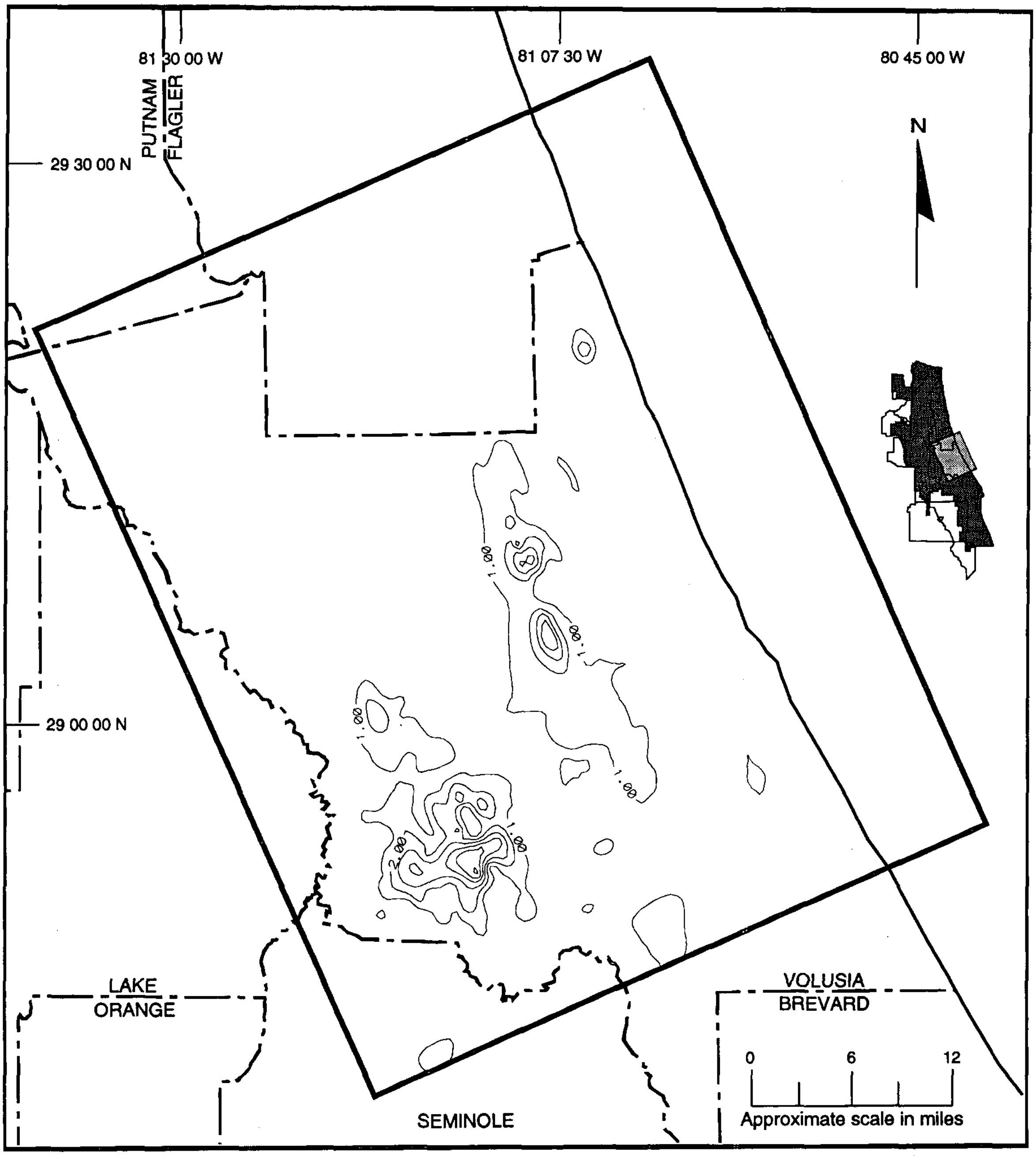



**Figure 31. Drawdown in the elevation of the simulated 2010 water table relative to the elevation of the simulated 1988 water table (feet)**

| Legend | |
|---|---|
| — 1.00 — | Contour |
| — — — | County boundary |
| ——— | Model boundary |

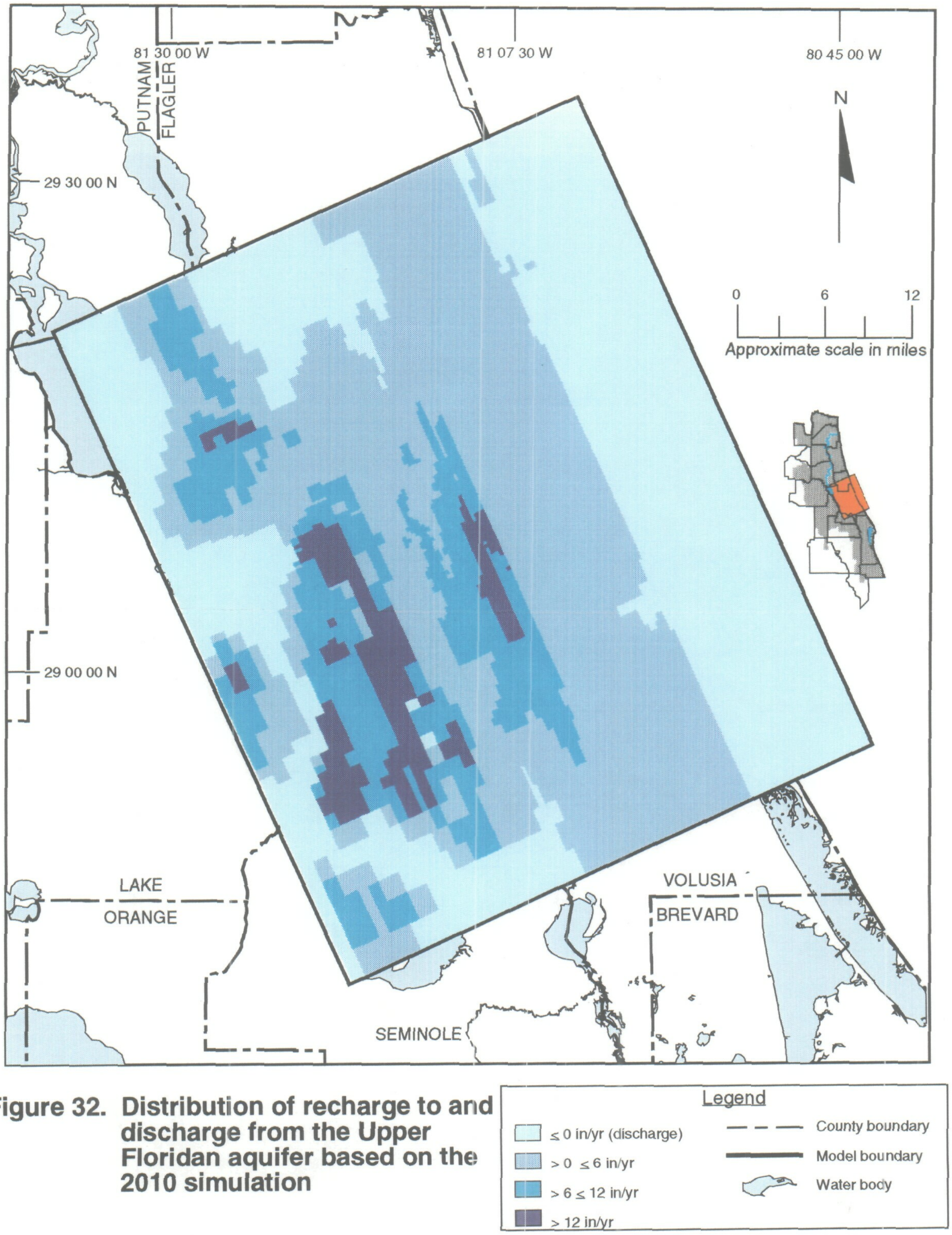



**Figure 32. Distribution of recharge to and discharge from the Upper Floridan aquifer based on the 2010 simulation**

The Upper Floridan aquifer receives the greatest impact in terms of depletion of freshwater storage between the 1988 calibration period (Figure 24) and the 2010 simulation (Figures 33 and 34). Projected declines in the elevation of the potentiometric surface of the Upper Floridan aquifer (from the base year of 1988) are over 20 ft in the area of the Daytona Beach western wellfield, 5–10 ft near Deltona, 3–5 ft around the New Smyrna Beach wellfields, and up to 10 ft around the Port Orange western wellfield (Figure 34). Several other localized drawdowns relate primarily to public supply withdrawals. These drawdowns indicate a reduction in ground water storage and are a concern for the long-term viability of the ground water resource. By inference, these drawdowns also may be indicative of potential water quality problems, specifically upconing directly underneath major wellfields and lateral intrusion along the coast of VGWB.

The model simulates a modest decline in the elevation of the potentiometric surface of the Lower Floridan aquifer in 2010 compared to the elevation in 1988 (Figures 35 and 25). This surface declines regionally by approximately 1–3 ft and over 7 ft in the vicinity of the Daytona Beach western wellfield (Figure 36).

## SUMMARY

A computer-based finite-difference model was developed to evaluate the ground water resources in VGWB. The finite-difference mesh for the model has a non-uniform configuration, with the smallest grid cells located in the vicinity of the public supply wellfields in eastern Volusia County. The model evaluates impacts to the Upper Floridan aquifer. It also includes representations of both the surficial aquifer system and the Lower Floridan aquifer and intervening confining units to complete the hydrogeologic framework. Aquifer parameters (e.g., aquitard leakance, aquifer transmissivity) have been characterized within the model with the best available information from previous studies.

The regional ground water flow model for VGWB was qualitatively compared to a predevelopment condition and calibrated to the postdevelopment condition represented by average 1988 conditions.

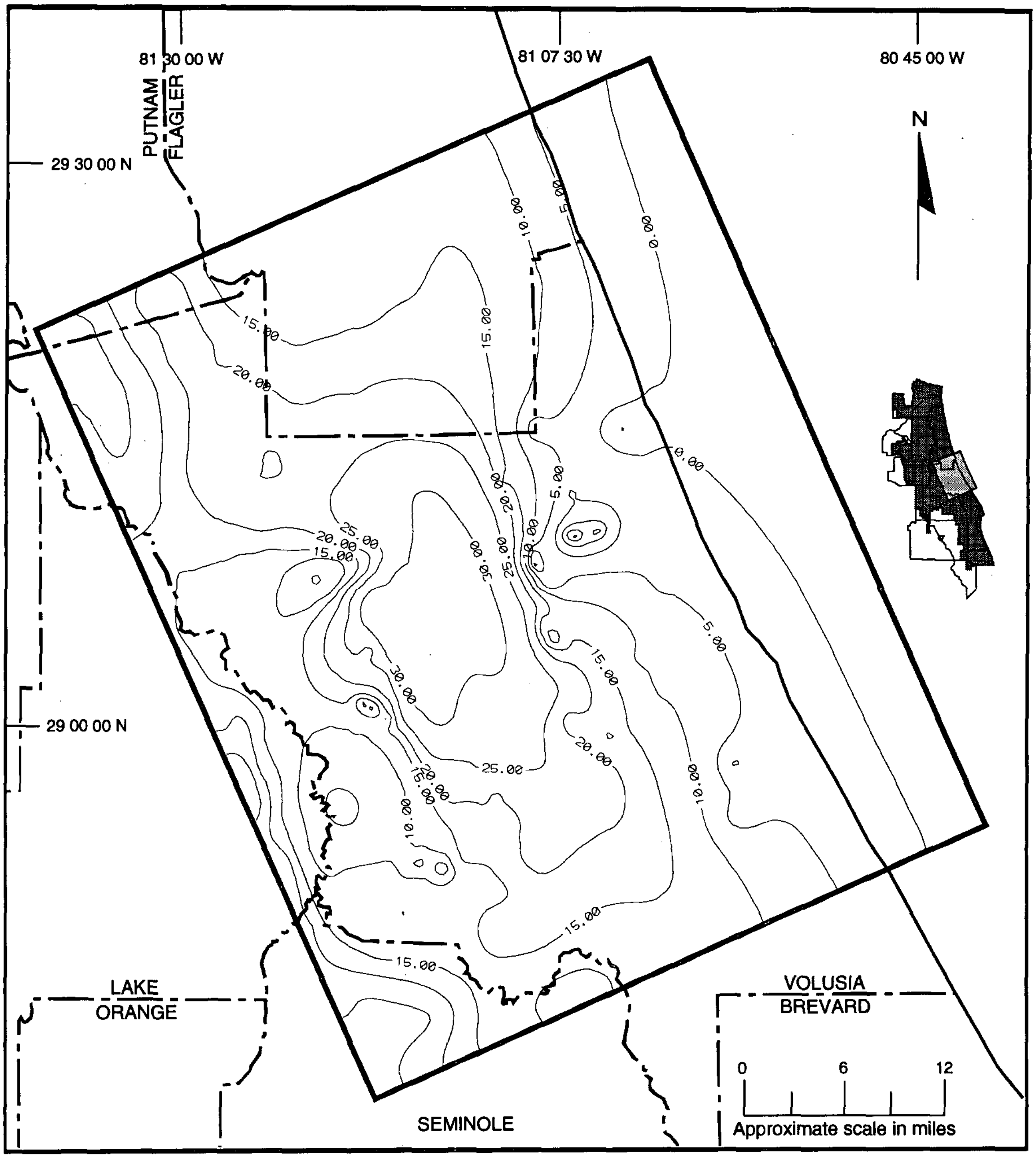



**Figure 33. Simulated elevation of the 2010 potentiometric surface of the Upper Floridan aquifer (feet mean sea level)**

Legend

— 15.ØØ— Contour

— — — County boundary

——— Model boundary

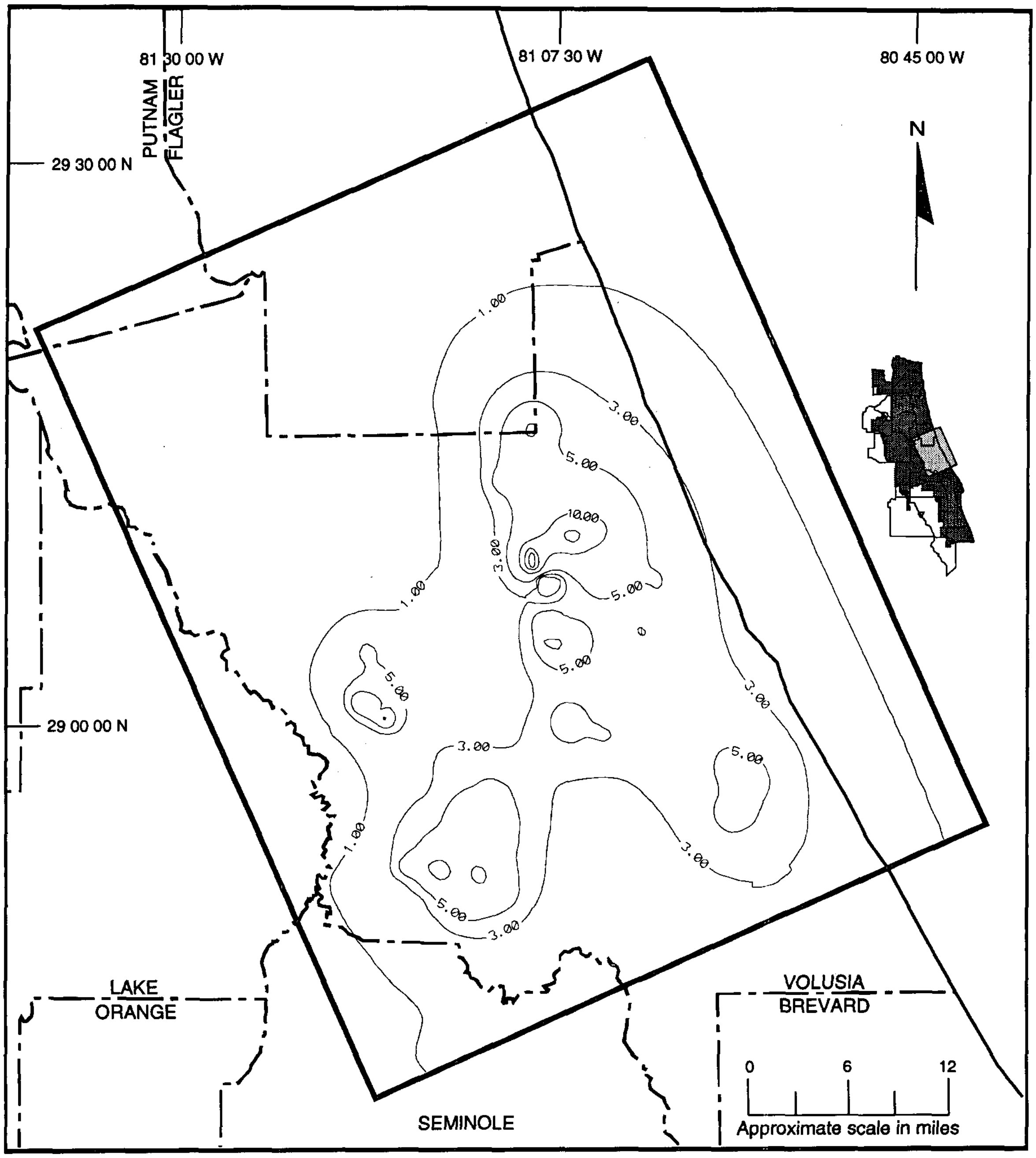



**Figure 34. Drawdown in the elevation of the simulated 2010 potentiometric surface for the Upper Floridan aquifer relative to the elevation of the simulated 1988 potentiometric surface (contour intervals: 1, 3, 5, 10, 15, and 20 feet)**

Legend

— 5.00 — Contour

— — — County boundary

——— Model boundary

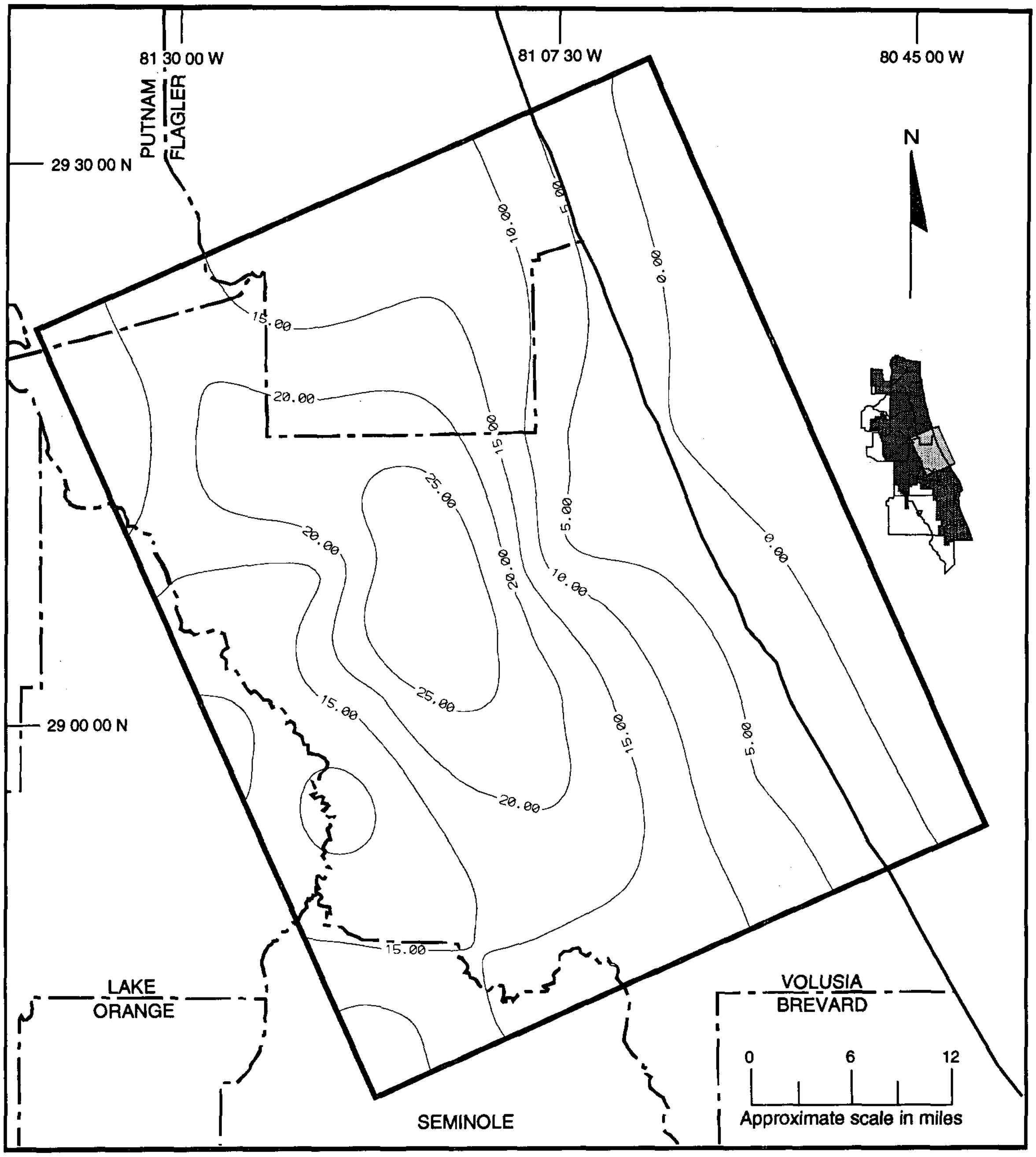



**Figure 35. Simulated elevation of the 2010 potentiometric surface of the Lower Floridan aquifer (feet mean sea level)**

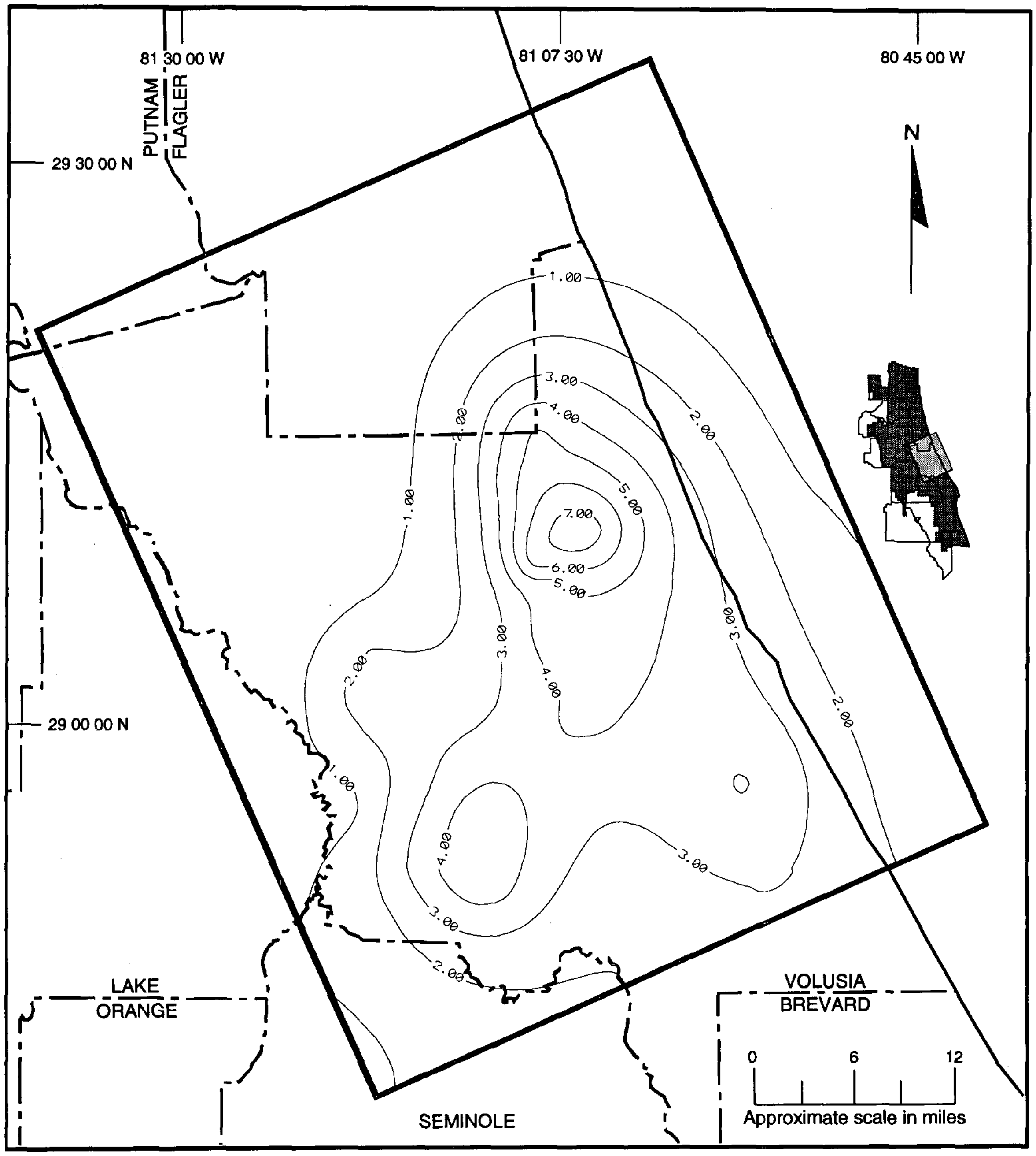



**Figure 36. Drawdown in the elevation of the simulated 2010 potentiometric surface of the Lower Floridan aquifer relative to the elevation of the simulated1988 potentiometric surface (feet)**

Legend

— 2.00 — Contour

— — — County boundary

▬▬ Model boundary

Upon calibration, the model was used to develop predictive simulations for 2010. Water use estimates for 2010 were developed based upon information from local utilities and review of local comprehensive plans. Findings from these predictive simulations indicate that drawdowns are predicted to occur in the surficial aquifer system and in the Upper Floridan aquifer in the vicinity of major public supply wellfields. Some minor changes are predicted in the elevation of the potentiometric surface of the Lower Floridan aquifer and in the distribution of recharge to or discharge from the Upper Floridan aquifer.

# SUMMARY OF FINDINGS AND RECOMMENDATIONS

A ground water flow model has been developed for VGWB. This model is an application of MODFLOW, a digital, three-dimensional, finite-difference simulation code which is designed specifically for the analysis of ground water flow problems. The model incorporates a variety of aquifer parameters and boundary conditions which are based upon the best available information. The model has been compared to a predevelopment condition and calibrated to average steady-state hydrologic conditions of 1988. The model was used to perform predictive simulations for the year 2010. Water use information for both the calibration period and the future projections was compiled from available data and reviewed with local utilities and other principal water users.

The freshwater resources in VGWB exist in the form of a relatively thick freshwater lens with its greatest thickness (1,000 to 1,200 ft) in west-central Volusia County. This freshwater lens has been affected by pumping which has occurred from predevelopment time to the present; the lens will continue to be affected through the year 2010. Specifically, impacts from 1988 to 2010 include the following:

- Drawdowns in the elevation of the water table are predicted to be over 4 ft in the vicinity of the Daytona Beach western wellfield, 1–2 ft near the Ormond Beach wellfields, up to 6 ft in the Deltona area, and 1–2 ft around the Port Orange western wellfield. Some of these drawdown areas are in or near local wetlands; therefore, the drawdowns may have a bearing on the ecological viability of these wetlands.

- Impacts to the Upper Floridan aquifer include drawdowns of over 20 ft in the vicinity of the Daytona Beach western wellfield, 5–10 ft near Deltona, approximately 3–5 ft near the New Smyrna Beach wellfields, and up to 10 ft around the Port Orange western wellfield. Impacts also included several localized drawdowns which are due to public supply withdrawals. These drawdowns indicate a reduction in ground water storage and are a concern for the long-term viability of the ground water resource. By inference, these drawdowns may also be indicative of water quality problems, specifically upconing directly underneath major wellfields and lateral intrusion along the coast of VGWB.

- Impacts to the Lower Floridan aquifer include regional declines in the elevation of the potentiometric surface of 1–3 ft and over 7 ft in the vicinity of the Daytona Beach western wellfield.

- Impacts to the distribution of recharge to or discharge from the Upper Floridan aquifer have occurred and are caused primarily by changes in the water table and/or the potentiometric surface of the Upper Floridan aquifer.

A ground water model of VGWB has been developed and used to simulate the impacts of current and projected pumping on the hydrogeologic system. In order to enhance current understanding of the ground water flow system and to contribute to future modeling projects for this area, specific recommendations regarding additional data collection and monitoring are presented below. Finally, recommendations regarding potential improvements in management of the regional ground water resource are discussed.

An effective ground water monitoring program provides information to characterize the ground water system and provides the basis for the examination of natural or anthropomorphic influences upon that system. The following enhancements to the existing monitoring well program are recommended:

- The collection of data to facilitate a comparison of observed changes to model-simulated changes in the surficial aquifer system and in the Upper and Lower Floridan aquifers in the vicinity of major public supply wellfields

- The establishment of surface water monitoring sites to characterize water level trends in wetlands, particularly in areas of predicted declines in the surficial aquifer system

- The collection of data to describe water quality trends, with particular focus on the potential for upconing beneath major public supply wellfields and for lateral intrusion in areas seaward of major pumping in the Upper Floridan aquifer

This additional data collection will provide information for the development of future simulation models of the ground water system. SJRWMD intends to revisit, refine, and recalibrate the modeling approach for VGWB every 5 years. As additional data deficiencies are addressed, future simulation models of this area will become increasingly more reliable in approximating the actual hydrogeologic system.

In order to recommend improvements in the management of the ground water resource, specific hydrologic conditions that are undesirable must be defined. Therefore, based upon the model findings stated above, the following are undesirable hydrologic conditions that are likely to occur given projected pumping scenarios:

- Potential water quality changes could result from the predicted reduction in the elevation of the potentiometric surface of the Upper Floridan aquifer in VGWB. This reduction will lead to a decrease in the amount of ground water that is acceptable for public supply use without advanced water treatment (e.g., reverse osmosis).

- The relatively high drawdown values that are projected to occur in some areas (e.g., the Daytona Beach western wellfield) indicate the increased potential for lateral or vertical saltwater intrusion. This intrusion will eventually lead to a deterioration in the quality of water available for public supply usage.

- Projected drawdowns in the surficial aquifer system may contribute to a degradation in the ecological integrity of wetlands, a valued component of the VGWB ecology.

- Increased pumpage may contribute to reductions in spring flow at springs such as Blue Spring and Ponce de Leon Springs.

These reductions could have a deleterious impact on the ecological and recreational value of these areas.

SJRWMD intends to address these potential undesirable impacts through formulation and interpretation of alternative model scenarios to maximize water supply potential while limiting any environmental impact to an acceptable level. SJRWMD will use optimization modeling to facilitate a bridge between simulation modeling and related water use strategies. These strategies could include the potential interconnection of wellfields, use of artificial recharge, development of sources of low water quality (e.g., surface water and brackish ground water), reuse of reclaimed water, and water conservation. Results of such analyses could be used to develop preferred (i.e., optimal) water management solutions.

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# Appendix—Public Supply Wells: Characteristics and Pumping Values

| Description | Number of Wells | Model | | Average 1988 Pumpage (mgd) | 1988 Well Fluxes (ft³/d) | Average 2010 Pumpage (mgd) | 2010 Well Fluxes (ft³/d) |
|---|---|---|---|---|---|---|---|
| | | Row | Column | | | | |
| De Land | | | | | | | |
| Water utility | 10 | 68 | 13 | 4.33 | 72335.7 | 6.91 | 0.0 |
| | | 67 | 12 | | 72335.7 | | 102780.0 |
| | | 66 | 12 | | 72335.7 | | 102780.0 |
| | | 66 | 12 | | 72335.7 | | 102780.0 |
| | | 64 | 11 | | 72335.7 | | 102780.0 |
| | | 67 | 14 | | 72335.7 | | 102780.0 |
| | | 61 | 14 | | 72335.7 | | 102780.0 |
| | | 65 | 11 | | 72335.7 | | 102780.0 |
| | | 70 | 13 | | 0 | | 102780.0 |
| | | 70 | 13 | | 0 | | 102780.0 |
| Brandywine | 1 | 55 | 14 | 0.46 | 61600.5 | 0.82 | 109540.4 |
| Spring Garden | 2 | 55 | 13 | 0.03 | 1721.3 | 0.04 | 2920.7 |
| | | 55 | 13 | | 1721.3 | | 2920.7 |
| Longleaf Plantation | 1 | 74 | 13 | 0.12 | 16041.0 | 0.26 | 34583.4 |
| Tomoka Woods | 1 | 41 | 19 | 0.01 | 1574.8 | 0.03 | 3519.5 |
| Woodland Manor | 1 | 51 | 14 | 0.06 | 7800.8 | 0.16 | 21706.7 |
| Glenwood Estates | 1 | 54 | 12 | 0.02 | 2087.5 | 0.03 | 4577.9 |
| Holiday Hills | 2 | 72 | 10 | 0.05 | 3259.5 | 0.10 | 6936.5 |
| | | 72 | 10 | | 3259.5 | | 6936.5 |
| Holly Hill | | | | | | | |
| Eastern wellfield | 6 | 41 | 73 | 0.10 | 2274.6 | 0.14 | 3078.9 |
| | | 41 | 74 | | 2274.6 | | 3078.9 |
| | | 41 | 73 | | 2274.6 | | 3078.9 |
| | | 40 | 74 | | 2274.6 | | 3078.9 |
| | | 40 | 73 | | 2274.6 | | 3078.9 |
| | | 40 | 72 | | 2274.6 | | 3078.9 |

| Description | Number of Wells | Model | | Average 1988 Pumpage (mgd) | 1988 Well Fluxes ($ft^3/d$) | Average 2010 Pumpage (mgd) | 2010 Well Fluxes ($ft^3/d$) |
|---|---|---|---|---|---|---|---|
| | | Row | Column | | | | |
| Western wellfield | 8 | 41 | 54 | 1.00 | 19496.2 | 1.40 | 23061.5 |
| | | 41 | 54 | | 19496.2 | | 23061.5 |
| | | 41 | 55 | | 19496.2 | | 23061.5 |
| | | 41 | 55 | | 19496.2 | | 23061.5 |
| | | 40 | 55 | | 19496.2 | | 23061.5 |
| | | 40 | 55 | | 19496.2 | | 23061.5 |
| | | 41 | 55 | | 19496.2 | | 23061.5 |
| | | 40 | 55 | | 0 | | 23061.5 |
| Orange City Country Village | 1 | 79 | 12 | 0.13 | 17945.4 | 0.39 | 51785.4 |
| Southern States Utilities | | | | | | | |
| Sugar Mill Estates | 8 | 81 | 65 | 0.10 | 3213.7 | 0.22 | 3609.2 |
| | | 81 | 65 | | 3213.7 | | 3609.2 |
| | | 81 | 65 | | 3213.7 | | 3609.2 |
| | | 81 | 65 | | 3213.7 | | 3609.2 |
| | | 81 | 65 | | 0 | | 3609.2 |
| | | 81 | 65 | | 0 | | 3609.2 |
| | | 81 | 65 | | 0 | | 3609.2 |
| | | 81 | 65 | | 0 | | 3609.2 |
| Port Orange | | | | | | | |
| Western wellfield | 30 | 64 | 42 | 3.98 | 35471.4 | 8.57 | 38202.9 |
| | | 67 | 41 | | 35471.4 | | 38202.9 |
| | | 68 | 40 | | 35471.4 | | 38202.9 |
| | | 68 | 40 | | 35471.4 | | 38202.9 |
| | | 69 | 39 | | 35471.4 | | 38202.9 |
| | | 70 | 39 | | 35471.4 | | 38202.9 |
| | | 65 | 40 | | 35471.4 | | 38202.9 |
| | | 66 | 39 | | 35471.4 | | 38202.9 |
| | | 67 | 39 | | 35471.4 | | 38202.9 |

| Description | Number of Wells | Model | | Average 1988 Pumpage (mgd) | 1988 Well Fluxes (ft³/d) | Average 2010 Pumpage (mgd) | 2010 Well Fluxes (ft³/d) |
|---|---|---|---|---|---|---|---|
| | | Row | Column | | | | |
| Western wellfield—*Continued* | | 68 | 39 | | 35471.4 | | 38202.9 |
| | | 65 | 38 | | 35471.4 | | 38202.9 |
| | | 66 | 38 | | 35471.4 | | 38202.9 |
| | | 66 | 38 | | 35471.4 | | 38202.9 |
| | | 69 | 40 | | 35471.4 | | 38202.9 |
| | | 67 | 38 | | 35471.4 | | 38202.9 |
| | | 64 | 39 | | 0 | | 38202.9 |
| | | 64 | 39 | | 0 | | 38202.9 |
| | | 64 | 39 | | 0 | | 38202.9 |
| | | 69 | 38 | | 0 | | 38202.9 |
| | | 69 | 38 | | 0 | | 38202.9 |
| | | 69 | 38 | | 0 | | 38202.9 |
| | | 40 | 26 | | 0 | | 38202.9 |
| | | 39 | 24 | | 0 | | 38202.9 |
| | | 41 | 28 | | 0 | | 38202.9 |
| | | 38 | 27 | | 0 | | 38202.9 |
| | | 37 | 25 | | 0 | | 38202.9 |
| | | 39 | 29 | | 0 | | 38202.9 |
| | | 42 | 25 | | 0 | | 38202.9 |
| | | 41 | 23 | | 0 | | 38202.9 |
| | | 43 | 27 | | 0 | | 38202.9 |
| Eastern wellfield | 13 | 68 | 66 | 0.40 | 4092.8 | 0.86 | 8813.2 |
| | | 68 | 66 | | 4092.8 | | 8813.2 |
| | | 68 | 66 | | 4092.8 | | 8813.2 |
| | | 68 | 66 | | 4092.8 | | 8813.2 |
| | | 68 | 65 | | 4092.8 | | 8813.2 |
| | | 66 | 66 | | 4092.8 | | 8813.2 |
| | | 66 | 67 | | 4092.8 | | 8813.2 |
| | | 66 | 67 | | 4092.8 | | 8813.2 |
| | | 66 | 67 | | 4092.8 | | 8813.2 |

| Description | Number of Wells | Model | | Average 1988 Pumpage (mgd) | 1988 Well Fluxes ($ft^3/d$) | Average 2010 Pumpage (mgd) | 2010 Well Fluxes ($ft^3/d$) |
|---|---|---|---|---|---|---|---|
| | | Row | Column | | | | |
| Eastern wellfield—*Continued* | | 65 | 66 | | 4092.8 | | 8813.2 |
| | | 65 | 66 | | 4092.8 | | 8813.2 |
| | | 65 | 65 | | 4092.8 | | 8813.2 |
| | | 65 | 65 | | 4092.8 | | 8813.2 |
| Deltona | | | | | | | |
| Deltona | 33 | 84 | 11 | 7.28 | 64886.8 | 24.90 | 100875.1 |
| | | 84 | 9 | | 64886.8 | | 100875.1 |
| | | 83 | 13 | | 64886.8 | | 100875.1 |
| | | 86 | 13 | | 64886.8 | | 100875.1 |
| | | 84 | 10 | | 64886.8 | | 100875.1 |
| | | 84 | 10 | | 64886.8 | | 100875.1 |
| | | 85 | 12 | | 64886.8 | | 100875.1 |
| | | 85 | 12 | | 64886.8 | | 100875.1 |
| | | 85 | 12 | | 64886.8 | | 100875.1 |
| | | 84 | 18 | | 64886.8 | | 100875.1 |
| | | 85 | 12 | | 64886.8 | | 100875.1 |
| | | 83 | 18 | | 64886.8 | | 100875.1 |
| | | 84 | 18 | | 64886.8 | | 100875.1 |
| | | 81 | 12 | | 64886.8 | | 100875.1 |
| | | 85 | 17 | | 64886.8 | | 100875.1 |
| | | 84 | 11 | | 0 | | 100875.1 |
| | | 81 | 16 | | 0 | | 100875.1 |
| | | 81 | 18 | | 0 | | 100875.1 |
| | | 87 | 16 | | 0 | | 100875.1 |
| | | 86 | 15 | | 0 | | 100875.1 |
| | | 87 | 15 | | 0 | | 100875.1 |
| | | 86 | 11 | | 0 | | 100875.1 |
| | | 85 | 17 | | 0 | | 100875.1 |
| | | 87 | 16 | | 0 | | 100875.1 |
| | | 86 | 15 | | 0 | | 100875.1 |

| Description | Number of Wells | Model | | Average 1988 Pumpage (mgd) | 1988 Well Fluxes (ft³/d) | Average 2010 Pumpage (mgd) | 2010 Well Fluxes (ft³/d) |
|---|---|---|---|---|---|---|---|
| | | Row | Column | | | | |
| Deltona—*Continued* | | 82 | 15 | | 0 | | 100875.1 |
| | | 81 | 18 | | 0 | | 100875.1 |
| | | 84 | 9 | | 0 | | 100875.1 |
| | | 84 | 10 | | 0 | | 100875.1 |
| | | 83 | 17 | | 0 | | 100875.1 |
| | | 87 | 13 | | 0 | | 100875.1 |
| | | 86 | 15 | | 0 | | 100875.1 |
| | | 85 | 11 | | 0 | | 100875.1 |
| *Spruce Creek* | | | | | | | |
| Spruce Creek | 5 | 75 | 54 | 0.32 | 21644.4 | 0.40 | 10738.0 |
| | | 75 | 55 | | 21644.4 | | 10738.0 |
| | | 75 | 54 | | 0 | | 10738.0 |
| | | 75 | 54 | | 0 | | 10738.0 |
| | | 75 | 55 | | 0 | | 10738.0 |
| New Smyrna Beach | | | | | | | |
| Glencoe wellfield | 7 | 86 | 65 | 2.08 | 39708.1 | 3.08 | 58753.2 |
| | | 86 | 65 | | 39708.1 | | 58753.2 |
| | | 86 | 64 | | 39708.1 | | 58753.2 |
| | | 86 | 65 | | 39708.1 | | 58753.2 |
| | | 86 | 64 | | 39708.1 | | 58753.2 |
| | | 86 | 64 | | 39708.1 | | 58753.2 |
| | | 86 | 64 | | 39708.1 | | 58753.2 |
| Samsula wellfield | 6 | 80 | 43 | 1.78 | 39708.1 | 2.64 | 58753.2 |
| | | 80 | 42 | | 39708.1 | | 58753.2 |
| | | 80 | 41 | | 39708.1 | | 58753.2 |
| | | 80 | 41 | | 39708.1 | | 58753.2 |
| | | 79 | 40 | | 39708.1 | | 58753.2 |
| | | 79 | 40 | | 39708.1 | | 58753.2 |

| Description | Number of Wells | Model | | Average 1988 Pumpage (mgd) | 1988 Well Fluxes (ft³/d) | Average 2010 Pumpage (mgd) | 2010 Well Fluxes (ft³/d) |
|---|---|---|---|---|---|---|---|
| | | Row | Column | | | | |
| Proposed State Road 44 wellfield | 6 | 78 | 36 | 0 | 0 | 2.64 | 58753.2 |
| | | 78 | 35 | | 0 | | 58753.2 |
| | | 77 | 36 | | 0 | | 58753.2 |
| | | 77 | 36 | | 0 | | 58753.2 |
| | | 77 | 36 | | 0 | | 58753.2 |
| | | 77 | 36 | | 0 | | 58753.2 |
| Halifax Plantation | | | | | | | |
| Halifax Plantation | 2 | 8 | 70 | 0.04 | 2636.9 | 0.07 | 4779.3 |
| | | 8 | 69 | | 2636.9 | | 4779.3 |
| Daytona Beach | | | | | | | |
| Eastern wellfield—Marion Street water plant | 5 | 51 | 58 | 2.93 | 78513.1 | 7.17 | 201871.7 |
| | | 51 | 57 | | 78513.1 | | 161497.3 |
| | | 51 | 56 | | 78513.1 | | 161497.3 |
| | | 50 | 52 | | 78513.1 | | 232219.3 |
| | | 50 | 52 | | 78513.1 | | 201871.7 |
| Western wellfield—Brennan water plant | 11 | 50 | 51 | 10.26 | 124789.0 | 6.84 | 196390.4 |
| | | 49 | 50 | | 124789.0 | | 235695.2 |
| | | 58 | 46 | | 124789.0 | | 36096.3 |
| | | 58 | 45 | | 124789.0 | | 62299.5 |
| | | 58 | 45 | | 124789.0 | | 63502.6 |
| | | 58 | 44 | | 124789.0 | | 65240.6 |
| | | 58 | 43 | | 124789.0 | | 28609.6 |
| | | 58 | 42 | | 124789.0 | | 54411.8 |
| | | 57 | 43 | | 124789.0 | | 44518.7 |
| | | 56 | 43 | | 124789.0 | | 42246.0 |
| | | 55 | 42 | | 124789.0 | | 84893.0 |

| Description | Number of Wells | Model | | Average 1988 Pumpage (mgd) | 1988 Well Fluxes (ft³/d) | Average 2010 Pumpage (mgd) | 2010 Well Fluxes (ft³/d) |
|---|---|---|---|---|---|---|---|
| | | Row | Column | | | | |
| Western wellfield—1988 construction | 10 | 53 | 42 | 0 | 0 | 6.49 | 41176.5 |
| | | 52 | 42 | | 0 | | 110962.6 |
| | | 52 | 42 | | 0 | | 199331.6 |
| | | 51 | 43 | | 0 | | 54144.4 |
| | | 50 | 43 | | 0 | | 108957.2 |
| | | 50 | 43 | | 0 | | 108957.2 |
| | | 49 | 43 | | 0 | | 64171.1 |
| | | 57 | 41 | | 0 | | 73663.1 |
| | | 54 | 43 | | 0 | | 70454.5 |
| | | 53 | 43 | | 0 | | 35695.2 |
| Ormond Beach | | | | | | | |
| Division Avenue | 12 | 31 | 73 | 2.71 | 30159.3 | 2.77 | 30910.7 |
| | | 31 | 73 | | 30159.3 | | 30910.7 |
| | | 32 | 72 | | 30159.3 | | 30910.7 |
| | | 32 | 72 | | 30159.3 | | 30910.7 |
| | | 32 | 72 | | 30159.3 | | 30910.7 |
| | | 32 | 72 | | 30159.3 | | 30910.7 |
| | | 31 | 70 | | 30159.3 | | 30910.7 |
| | | 32 | 70 | | 30159.3 | | 30910.7 |
| | | 32 | 69 | | 30159.3 | | 30910.7 |
| | | 31 | 73 | | 30159.3 | | 30910.7 |
| | | 31 | 72 | | 30159.3 | | 30910.7 |
| | | 31 | 70 | | 30159.3 | | 30910.7 |
| State Road 40 wellfield | 5 | 29 | 64 | 1.90 | 84892.9 | 1.16 | 30910.7 |
| | | 30 | 61 | | 84892.9 | | 30910.7 |
| | | 28 | 65 | | 0 | | 30910.7 |
| | | 29 | 65 | | 0 | | 30910.7 |
| | | 30 | 59 | | 84892.9 | | 30910.7 |
| Hudson wellfield | 13 | 25 | 52 | 0 | 0 | 3.01 | 30910.7 |
| | | 25 | 52 | | 0 | | 30910.7 |

| Description | Number of Wells | Model | | Average 1988 Pumpage (mgd) | 1988 Well Fluxes ($ft^3/d$) | Average 2010 Pumpage (mgd) | 2010 Well Fluxes ($ft^3/d$) |
|---|---|---|---|---|---|---|---|
| | | Row | Column | | | | |
| Hudson wellfield—*Continued* | | 24 | 52 | | 0 | | 30910.7 |
| | | 23 | 53 | | 0 | | 30910.7 |
| | | 23 | 53 | | 0 | | 30910.7 |
| | | 22 | 53 | | 0 | | 30910.7 |
| | | 22 | 53 | | 0 | | 30910.7 |
| | | 24 | 53 | | 0 | | 30910.7 |
| | | 24 | 54 | | 0 | | 30910.7 |
| | | 23 | 54 | | 0 | | 30910.7 |
| | | 22 | 55 | | 0 | | 30910.7 |
| | | 24 | 52 | | 0 | | 30910.7 |
| | | 23 | 51 | | 0 | | 30910.7 |
| Proposed—Rima Ridge | 4 | 32 | 43 | 0 | 0 | 0.92 | 30910.7 |
| | | 31 | 44 | | 0 | | 30910.7 |
| | | 32 | 43 | | 0 | | 30910.7 |
| | | 31 | 44 | | 0 | | 30910.7 |
| John Knox Village | | | | | | | |
| John Knox Village | 3 | 78 | 10 | 0.05 | 2112.0 | 0.14 | 6328.5 |
| | | 78 | 10 | | 2112.0 | | 6328.5 |
| | | 78 | 10 | | 2112.0 | | 6328.5 |
| Volusia County Utilities | | | | | | | |
| Indian Harbor | 1 | 91 | 76 | 0.03 | 3515.8 | 0.04 | 5493.5 |
| Orange City Industries | 1 | 79 | 9 | 0.04 | 4724.4 | 0.06 | 8564.9 |
| Four Towns | 2 | 80 | 8 | 0.40 | 26497.0 | 0.63 | 42318.3 |
| | | 79 | 8 | | 26497.0 | | 42318.3 |
| Lake Marie | 2 | 83 | 6 | 0.14 | 9357.3 | 0.25 | 16960.3 |
| | | 83 | 6 | | 9357.3 | | 16960.3 |
| Breezewood | 1 | 80 | 9 | 0.14 | 19044.1 | 0.16 | 21439.3 |
| Terra Alta | 1 | 81 | 7 | 0.04 | 4834.3 | 0.05 | 7178.2 |
| Highland Country Estates | 2 | 81 | 7 | 0.05 | 3607.4 | 0.46 | 31001.7 |
| | | 81 | 7 | | 3607.4 | | 31001.7 |

| Description | Number of Wells | Model | | Average 1988 Pumpage (mgd) | 1988 Well Fluxes ($ft^3/d$) | Average 2010 Pumpage (mgd) | 2010 Well Fluxes ($ft^3/d$) |
|---|---|---|---|---|---|---|---|
| | | Row | Column | | | | |
| West Orange City | 1 | 77 | 7 | 0.01 | 695.8 | 0.01 | 1259.8 |
| Deltona Woods | 1 | 80 | 15 | 0 | 0 | 0.05 | 6306.5 |
| Cassadaga | 1 | 78 | 16 | 0.03 | 3442.6 | 0.04 | 5640.0 |
| Ellwood Titcomb | | | | | | | |
| Ellwood Titcomb | 1 | 77 | 17 | 0.05 | 6102.6 | 0.10 | 12205.2 |
| City of Edgewater | | | | | | | |
| City of Edgewater | 11 | 87 | 68 | 2.71 | 18711.2 | 4.65 | 56599.7 |
| | | 87 | 68 | | 18711.2 | | 56599.7 |
| | | 87 | 67 | | 18711.2 | | 56599.7 |
| | | 87 | 67 | | 18711.2 | | 56599.7 |
| | | 87 | 67 | | 18711.2 | | 56599.7 |
| | | 88 | 60 | | 18711.2 | | 56599.7 |
| | | 88 | 59 | | 18711.2 | | 56599.7 |
| | | 88 | 59 | | 18711.2 | | 56599.7 |
| | | 88 | 59 | | 18711.2 | | 56599.7 |
| | | 88 | 63 | | 18711.2 | | 56599.7 |
| | | 88 | 63 | | 18711.2 | | 56599.7 |
| Howard S. Dorr | | | | | | | |
| Howard S. Dorr | 2 | 89 | 17 | 0.02 | 1204.5 | 0.03 | 2183.0 |
| | | 89 | 17 | | 1204.5 | | 2183.0 |
| Tymber Creek Utilities | | | | | | | |
| Tymber Creek Utilities | 1 | 27 | 59 | 0.09 | 12232.2 | 0.18 | 23962.7 |
| The Trails, Inc. | | | | | | | |
| The Trails, Inc. | 1 | 26 | 54 | 0.32 | 42718.1 | 0.58 | 77423.5 |
| Lake Helen | | | | | | | |
| Lake Helen | 2 | 77 | 16 | 0.22 | 14869.1 | 0.58 | 38601.0 |
| | | 76 | 16 | | 14869.1 | | 38601.0 |

| Description | Number of Wells | Model | | Average 1988 Pumpage (mgd) | 1988 Well Fluxes ($ft^3/d$) | Average 2010 Pumpage (mgd) | 2010 Well Fluxes ($ft^3/d$) |
|---|---|---|---|---|---|---|---|
| | | Row | Column | | | | |
| Hacienda Del Rio | | | | | | | |
| Hacienda Del Rio | 1 | 90 | 74 | 0.06 | 7507.8 | 0.10 | 13607.3 |
| National Gardens | | | | | | | |
| National Gardens | 24 | 15 | 73 | 0.26 | 1428.6 | 0.46 | 2589.3 |
| | | 15 | 72 | | 1428.6 | | 2589.3 |
| | | 15 | 72 | | 1428.6 | | 2589.3 |
| | | 15 | 73 | | 1428.6 | | 2589.3 |
| | | 15 | 72 | | 1428.6 | | 2589.3 |
| | | 15 | 73 | | 1428.6 | | 2589.3 |
| | | 16 | 72 | | 1428.6 | | 2589.3 |
| | | 16 | 72 | | 1428.6 | | 2589.3 |
| | | 16 | 71 | | 1428.6 | | 2589.3 |
| | | 16 | 71 | | 1428.6 | | 2589.3 |
| | | 16 | 71 | | 1428.6 | | 2589.3 |
| | | 16 | 71 | | 1428.6 | | 2589.3 |
| | | 16 | 71 | | 1428.6 | | 2589.3 |
| | | 16 | 71 | | 1428.6 | | 2589.3 |
| | | 16 | 71 | | 1428.6 | | 2589.3 |
| | | 16 | 71 | | 1428.6 | | 2589.3 |
| | | 16 | 71 | | 1428.6 | | 2589.3 |
| | | 17 | 71 | | 1428.6 | | 2589.3 |
| | | 17 | 71 | | 1428.6 | | 2589.3 |
| | | 17 | 71 | | 1428.6 | | 2589.3 |
| | | 17 | 72 | | 1428.6 | | 2589.3 |
| | | 16 | 73 | | 1428.6 | | 2589.3 |
| | | 16 | 73 | | 1428.6 | | 2589.3 |
| | | 16 | 73 | | 1428.6 | | 2589.3 |
| Orange City | | | | | | | |
| Orange City | 3 | 78 | 9 | 0.51 | 22657.6 | 3.65 | 162656.0 |

| Description | Number of Wells | Model | | Average 1988 Pumpage (mgd) | 1988 Well Fluxes ($ft^3/d$) | Average 2010 Pumpage (mgd) | 2010 Well Fluxes ($ft^3/d$) |
|---|---|---|---|---|---|---|---|
| | | Row | Column | | | | |
| Orange City—*Continued* | | 78 | 9 | | 22657.6 | | 162656.0 |
| | | 78 | 9 | | 22657.6 | | 325312.0 |
| Sunshine Holiday Park | | | | | | | |
| Sunshine Holiday Park | 1 | 14 | 65 | 0.07 | 9314.5 | 0.13 | 16881.8 |
| Kove Association | | | | | | | |
| Kove Association | 2 | 89 | 15 | 0.03 | 2142.5 | 0.07 | 4713.4 |
| | | 89 | 15 | | 2142.5 | | 4713.4 |
| Lemon Bluff | | | | | | | |
| Lemon Bluff | 2 | 90 | 17 | 0.03 | 1887.0 | 0.05 | 3420.0 |
| | | 90 | 17 | | 1887.0 | | 3420.0 |
| Holiday Trailer Park | | | | | | | |
| Holiday Trailer Park | 1 | 7 | 67 | 0.01 | 1355.1 | 0.02 | 2321.9 |
| Plantation Bay | | | | | | | |
| Plantation Bay | 3 | 6 | 60 | 0.06 | 2514.8 | 0.12 | 5444.7 |
| | | 6 | 60 | | 2514.8 | | 5444.7 |
| | | 7 | 60 | | 2514.8 | | 5444.7 |
| Kingston Shores | | | | | | | |
| Kingston Shores | 1 | 13 | 79 | 0.03 | 3369.4 | 0.04 | 5310.4 |
| Lake Beresford Water Association | | | | | | | |
| Lake Beresford Water Association | 1 | 68 | 8 | 0.16 | 21424.7 | 0.33 | 43874.8 |

Note: mgd = million gallons per day
$ft^3/d$ = cubic feet per day