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REGIONAL GROUND WATER FLOW MODEL OF THE SURFICIAL AQUIFER SYSTEM IN THE TITUSVILLE/MIMS AREA, BREVARD COUNTY, FLORIDA

by

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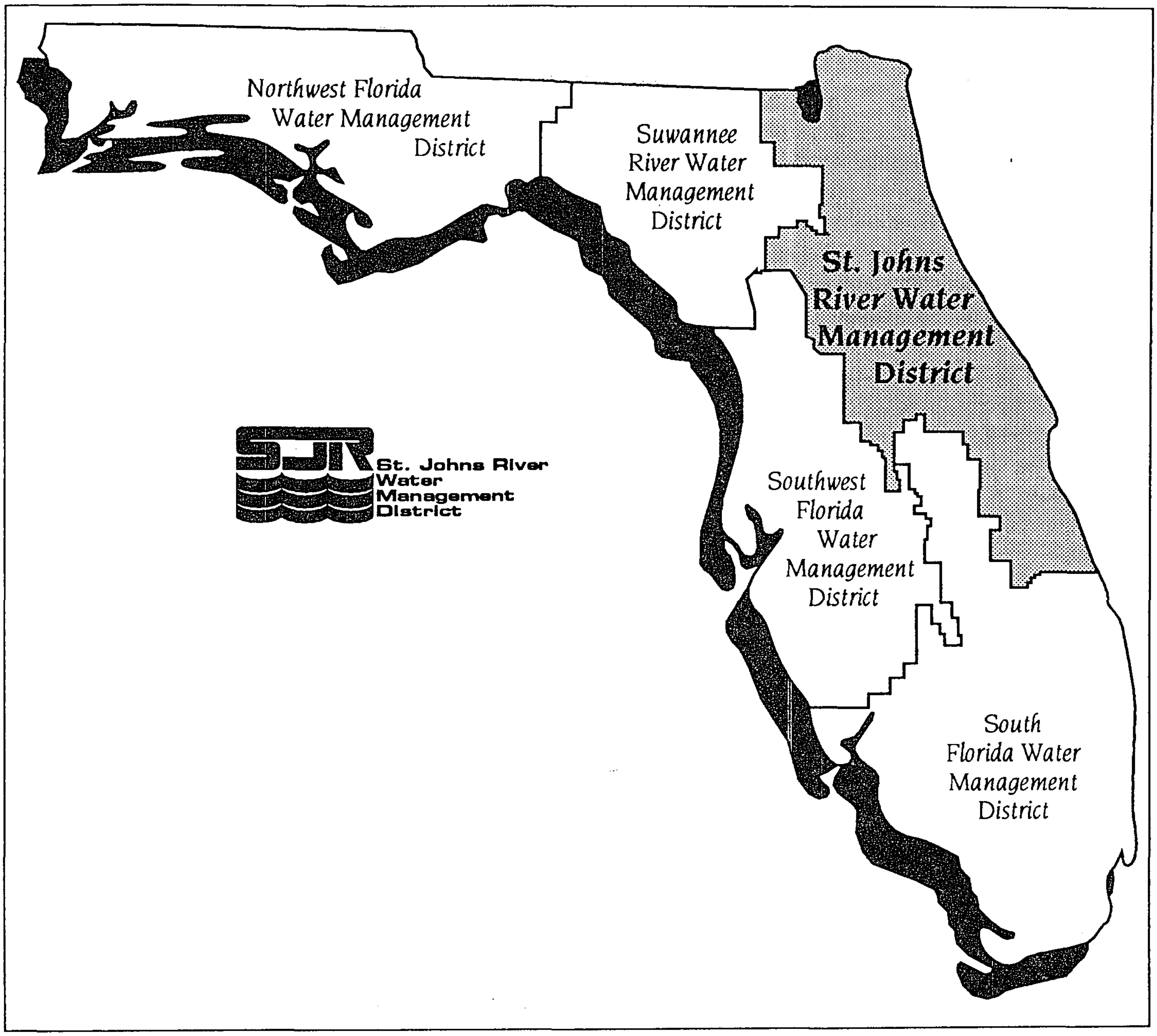

The **St. Johns River Water Management District** (SJRWMD) was created by the Florida Legislature in 1972 to be one of five water management districts in Florida. It includes all or part of 19 counties in northeast Florida. The mission of SJRWMD is to manage water resources to ensure their continued 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 five water management districts perform an evaluation of regional water resource needs and sources for the planning period of 1990 to 2010 (Paragraph 373.0391(2)(e), *Florida Statutes;* Chapter 62-40.520, *Florida Administrative Code*). This evaluation is known as the Water Supply Needs and Sources Assessment.

In performing its Needs and Sources 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 area of northern Brevard County, including the communities of Titusville and Mims, is one of these selected areas. These communities have been in a tenuous situation for several years in regard to the ability to satisfy water supply needs. The primary resource for water supply for these communities is a freshwater lens within the surficial aquifer system. A freshwater lens is a relatively thin reservoir of fresh water that is perched upon more saline water. This type of hydraulic configuration exists for two reasons: (1) the relatively high topography along the Atlantic Coastal Ridge facilitates freshwater recharge in this area and (2) this fresh water is of lower density than the more saline water that surrounds it both vertically and horizontally, allowing it to be perched upon the more mineralized water in the underlying Floridan aquifer system.

Due to the tenuous nature of these ground water resources and to the growth to date of the City of Titusville, northern Brevard County was identified as an area where available ground water supplies may not be adequate to fulfill projected needs for these resources. Therefore, SJRWMD has developed a regional ground water flow model of the ground water resources in this area as part of its Water Supply Needs and Sources Assessment. A ground water flow model, in this instance, refers to a computerized set of information that describes the aquifer system based upon existing data and a set of constraining assumptions.

Subsequent to its development, this model can be used to perform hydrogeologic assessments for the area in question.

STUDY AREA

The study area for the development of the referenced ground water model is in northern Brevard County. The area extends north from the Addison Point Canal (south of Indian River City) to just south of the Brevard-Volusia county line, and from the Indian River west to the St. Johns River. The focus of the study is on the ground water resources of the surficial aquifer system along the Atlantic Coastal Ridge in the vicinity of the City of Titusville.

TECHNICAL APPROACH

A computer-based ground water flow model of the water resources of northern Brevard County has been developed to evaluate the availability of these resources to meet current and projected demand for the 1990–2010 planning period. The model focuses specifically on the ground water of the surficial aquifer system within the Atlantic Coastal Ridge. Development of the model has been based upon the best available information describing water use and aquifer parameters. Its calibration is based upon measurement data for water levels in the surficial aquifer system and for the elevation of the potentiometric surface in the underlying Upper Floridan aquifer (the potentiometric surface of the Upper Floridan aquifer refers to the level to which water would rise in a tightly cased piezometer placed in the aquifer). The model has been calibrated to both predevelopment and postdevelopment conditions. The postdevelopment condition represents the hydrologic configuration that existed in September 1988. The model is used to perform predictive assessments for future water use scenarios for the year 2010. The model incorporates available information on water use for the postdevelopment calibration (September 1988) and water use estimates for the predictive simulations (2010).

HYDROGEOLOGIC FRAMEWORK

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 South and Fox lakes near Titusville, several lakes in the St. Johns River valley, the St. Johns River, the Indian River, several natural wetlands, and a series of man-made drainage canals.

The geomorphology of the area is that of a series of ridges and terraces that originated during periods of fluctuating sea levels. One of the prominent features of the system in this area is the Atlantic Coastal Ridge, a series of interconnected dunes and swales that is of generally higher elevation than the surrounding terraces.

The surficial aquifer system, the targeted aquifer for the current study, is an unconfined system with freshwater storage concentrated in the vicinity of the Atlantic Coastal Ridge. Underlying the surficial aquifer system is an upper confining unit and the Floridan aquifer system. The upper confining unit is relatively thin within the study area, and thus the hydraulic connection between the surficial and Floridan aquifer systems is significant. The Floridan aquifer system is composed of the Upper and Lower Floridan aquifers and the middle semiconfining unit.

The water quality of the study area is governed by the close interconnection between the surficial and Floridan aquifer systems. Throughout most of the study area, the hydraulic heads in the Floridan aquifer system are higher than those in the surficial aquifer system, thereby creating upward discharge of more mineralized water into the surficial aquifer system. In the vicinity of the Atlantic Coastal Ridge, however, where surficial heads are higher than the underlying Floridan heads, downward recharge occurs between the surficial and Floridan aquifer systems, causing freshwater zones in the surficial aquifer system and the Upper Floridan aquifer.

Model Development

A computer-based finite-difference model has been developed to evaluate the ground water resources in northern Brevard County. The computer code MODFLOW, developed by the U.S. Geological Survey, was used for the development of the model. The finite-difference mesh for the model is non-uniform, with smallest grid cells in the vicinity of the Atlantic Coastal Ridge near Titusville. The model is targeted at impacts in the surficial aquifer system, and it also includes both the Upper and Lower Floridan aquifers and intervening confining layers to complete the hydrogeologic framework. Aquifer parameters (e.g., confining unit leakance, aquifer transmissivity) have been characterized within the model with the best available information from previous studies.

The Titusville/Mims regional ground water flow model was calibrated to both a predevelopment and a postdevelopment condition. The postdevelopment condition represents the September 1988 time period, which includes the effects of pumping wells and is the more rigorous calibration because much more monitoring data are available for this condition.

After calibration, the model was used to develop predictive simulations for the year 2010. Water use estimates for 2010 were developed based upon information from local utilities and review of the Brevard County Comprehensive Plan. Findings from these predictive simulations indicate that significant drawdowns will occur in the surficial aquifer system in the vicinity of Titusville and that upward discharge of lower quality water in the Floridan aquifer system will continue to be a primary constraint upon the availability of fresh water in the surficial aquifer system.

Conclusions and Recommendations

The SJRWMD Needs and Sources Water Supply Assessment provides a long-term perspective on the status and availability of water resources. This assessment is to be repeated every 5 years and has as a primary goal the identification of gaps in current knowledge in order to ensure future collection of this missing information.

The Titusville/Mims regional ground water flow model is designed to provide analyses regarding the long-term viability of these resources for water supply. This analysis is performed through the interpretation of recent (1988) and future (2010) impacts of water use upon the ground water resource. The ultimate goal of this analysis is to provide recommendations regarding the best fit between available water resources and needs for those resources while minimizing any potential resource degradation. Thus, in order to continue to ensure the viability of this resource, additional data are needed to interpret water quality trends, impacts of long-term drought conditions, and impacts of specific pumping scenarios.

The following conclusions are derived from this regional model.

- The principal freshwater resources in northern Brevard County are stored in relatively small freshwater lenses in the Atlantic Coastal Ridge deposits of the surficial aquifer system.

- These freshwater lenses are being gradually depleted, primarily due to pumping for public supply. For example, the City of Titusville is approaching the maximum potential capacity available from these freshwater lenses and therefore must identify an additional public supply source within the next few years.

- Impacts to the freshwater resources in the surficial aquifer system are characterized by drawdowns of up to 16 feet in the vicinity of the City of Titusville and up to 8 feet in the area of the public supply wells for the community of Mims.

- Impacts to the Upper Floridan aquifer include modest drawdowns of up to 2 feet immediately underneath the City of Titusville's public supply wellfields and upward discharge of this Upper Floridan aquifer water to the surficial aquifer system.

Based upon this regional model, these are my recommendations.

- Enhance the existing monitoring program to include the following:
  - Establishment of five to ten monitoring sites to monitor trends in water levels in the surficial aquifer system in the vicinity of the major public supply wellfields.
  - Establishment of five to ten monitoring sites to monitor trends in water levels in wetlands, particularly those in areas of predicted declines in the surficial aquifer system.
  - Establishment of two to three monitoring sites to monitor trends in water quality in the Upper Floridan aquifer, with particular focus on the potential for upward leakage of lower quality water from the Upper Floridan aquifer into the surficial aquifer system.
- Investigate water supply alternatives through the use of optimization modeling and evaluation of alternative water use scenarios.
- Emphasize methods of water re-use and conservation to minimize long-term impacts to the ground water resources.
- Develop a plan (City of Titusville in cooperation with SJRWMD) to identify an additional source for future public supply use.

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INTRODUCTION

PURPOSE AND SCOPE

In 1989, the Florida Legislature mandated that each of the five water management districts perform an evaluation of regional water resources that are available to meet current and future projected water supply needs (Paragraph 373.0391(2)(e), *Florida Statutes*; Chapter 62-40.520, *Florida Administrative Code*). This evaluation is known as the Water Supply Needs and Sources Assessment. This assessment is to be repeated every 5 years and has as a primary goal the identification of gaps in current knowledge in order to ensure future collection of this missing information.

In performing its Needs and Sources 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 area of northern Brevard County, encompassing the communities of Titusville and Mims, was one of the areas selected. These communities have been in a tenuous situation for several years in regard to the ability to satisfy water supply needs. Titusville and Mims have been tapping a freshwater lens within the surficial sediments of the Atlantic Coastal Ridge that is delicately balanced upon the more saline and mineralized water resources of the Upper Floridan aquifer. A freshwater lens is a relatively thin zone of fresh water that is perched upon more saline water. This type of hydraulic configuration exists because the fresh water is of lower density compared to the salt water, allowing it to "float" upon the more saline water in the underlying porous media. Due to the delicate nature of these ground water resources and the recent and projected growth of the City of Titusville, this area was identified as an area where existing ground water supplies may not be adequate to fulfill projected needs for these resources. Therefore, SJRWMD has developed a regional ground water flow model of the ground water resources in northern Brevard County as part of its Water Supply Needs and Sources Assessment. A ground water flow model, in this instance, refers to a computerized set of information that describes the aquifer system based upon existing data and a set of limiting assumptions. This model can be used to perform hydrogeologic assessments for the area in question.

STUDY AREA

The study area for the development of the referenced ground water model is in northern Brevard County (Figures 1 and 2). The area extends north from the Addison Point Canal (south of Indian River City) to just south of the Brevard-Volusia county line, and from the Indian River west to the St. Johns River. The focus of the study is on the ground water resources of the surficial aquifer system along the Atlantic Coastal Ridge in the vicinity of the City of Titusville.

TECHNICAL APPROACH

The computer-based ground water flow modeling code MODFLOW (McDonald and Harbaugh 1988) was used to develop a regional model of the water resources of northern Brevard County. This model has been developed to evaluate the availability of these ground water resources to meet current and projected demand for the 1990–2010 planning period. The model focuses specifically on the ground water of the surficial aquifer system within the Atlantic Coastal Ridge. Development of the model has been based upon the best available information regarding water use and aquifer parameters. Its calibration is based upon measurement data for water levels in the surficial aquifer system and for the elevation of the potentiometric surface in the underlying Upper Floridan aquifer (the potentiometric surface of the Upper Floridan aquifer refers to the level to which water would rise in a tightly cased piezometer placed in the aquifer). The model has been calibrated to both predevelopment and postdevelopment conditions. The postdevelopment condition represents the hydrologic conditions that existed in September 1988. The model is used to perform predictive assessments of

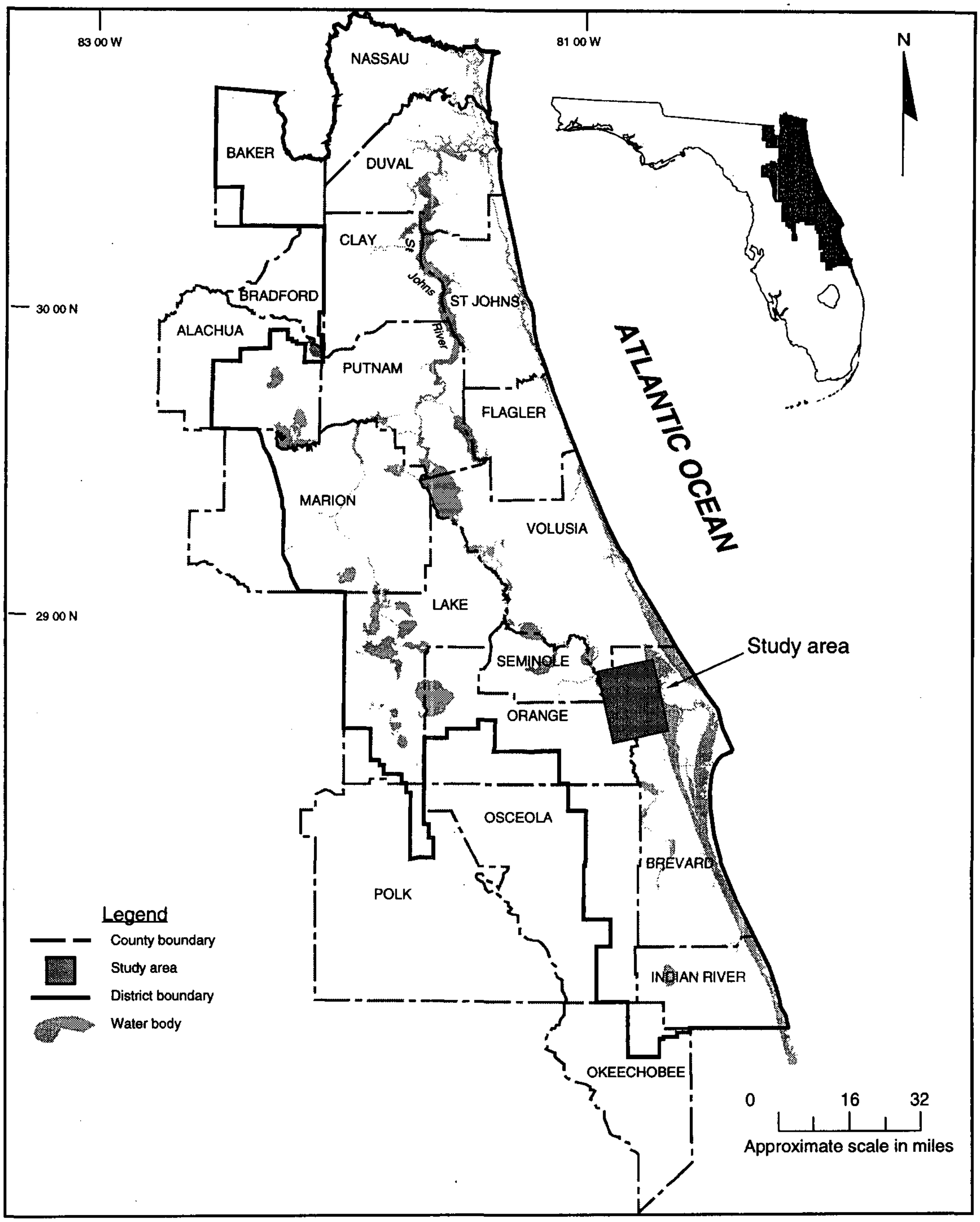

Figure 1. Study area location

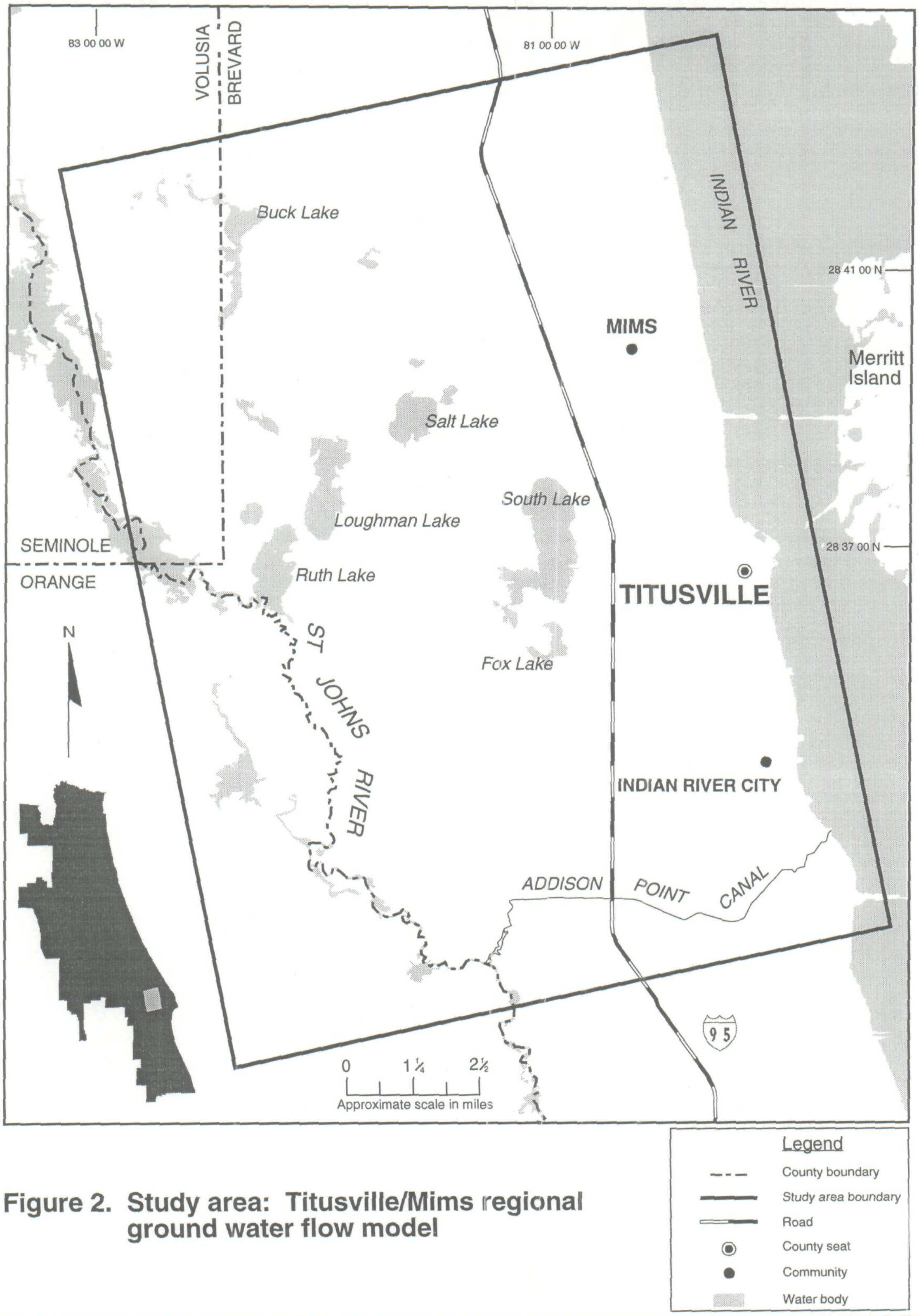

Figure 2. Study area: Titusville/Mims regional ground water flow model

future water use scenarios for the year 2010. The model incorporates available information on water use for the postdevelopment calibration (September 1988) and water use estimates for the predictive simulations (2010).

PREVIOUS STUDIES

Several previous investigations are relevant to a study of the ground water resources in northern Brevard County. Brown et al. (1962a) published a complete review of the ground water resources of Brevard County. In 1973, the U.S. Geological Survey (USGS) performed a test-drilling study to develop a greater understanding of the available freshwater resources in northern Brevard County (Kimrey 1973). In 1978, Reynolds, Smith and Hill (RS&H) developed a water supply master plan for the City of Titusville and, in 1979, performed a study of the potential for development of the ground water in an area located just south of the City of Titusville.

Timmons (1982) performed a comprehensive review of the ground water conditions in Brevard County. In 1983, the Brevard County Water Resources Department developed a restoration study for South Lake which included a complete discussion of environmental, hydrologic, and water quality issues relevant to South Lake (Brevard County Water Resources Department 1983). In 1985, Dyer, Riddle, Mills, and Precourt (DRMP) published a freshwater management study which focused on the hydrology and delineation of surface water basins, along with the interconnected ground water supplies.

In 1984, USGS published a report that described the development of a regional ground water flow model for Osceola, eastern Orange, and southwestern Brevard counties which includes a part of the current model study area (Planert and Aucott 1985). Missimer & Associates (1985, 1986a, 1986b, and 1987) developed a series of reports on the ground water resources of the surficial aquifer system in the vicinity of Titusville. In 1988, SJRWMD developed a regional ground water flow model of Brevard, Indian River, Orange, Osceola, and Seminole counties in east-central Florida (Skipp 1988) and also a water quality study of saltwater intrusion in Volusia, Brevard, and Indian River counties (Toth 1988).

In 1990, Barker, Osha, and Anderson performed a water supply evaluation for the Mims service area north of Titusville. Also in 1990, DRMP completed a wellfield management study of an area of historical freshwater development just northwest of the City of Titusville in support of the city's consumptive use permit (CUP) application to SJRWMD. Finally, in 1990, CRA-Sunbelt Surveyors, under contract with SJRWMD, performed a hydrographic survey of South and Fox lakes.

HYDROGEOLOGIC FRAMEWORK

The hydrogeologic framework includes all processes and components of the physical system which have an impact upon the quality and quantity of the ground water resources. Relevant processes include recharge and discharge, evapotranspiration, and leakage. Significant components of the hydrologic system include surface water features, land surface topography, geomorphology of the area, and the hydrostratigraphic configuration of the underlying geologic system.

SURFACE WATER

Lakes

The principal lakes in the study area include South and Fox lakes immediately to the west of Titusville and Loughman, Buck, and Salt lakes to the north and west of Titusville in the St. Johns River valley (Figure 2). South and Fox lakes are valued for recreational and aesthetic reasons, as well as for natural habitat for a variety of freshwater species. These lakes are hydraulically interconnected with the ground water resources of the surficial aquifer system. These lakes may have an impact upon the availability of ground water in the vicinity of the Atlantic Coastal Ridge to the east (the Coastal Ridge is the area that is greater than 30 feet mean sea level [ft msl] and runs parallel to the coastline in Figure 3). Due to the hydraulic interconnection with the surficial aquifer system, South and Fox Lakes may serve as a water source or sink for the ground water, depending upon the hydraulic gradient between the lake levels and the water table. Conversely, Loughman, Salt, and Buck lakes are shallow lakes, which are in a discharge area for the Floridan aquifer system. In a discharge area, the ground water flows up from the Floridan aquifer system into the surficial aquifer system because there is an upward vertical gradient (i.e., the potentiometric surface of the Floridan aquifer system is higher than the water table and this difference drives the upward flow of water). Because the

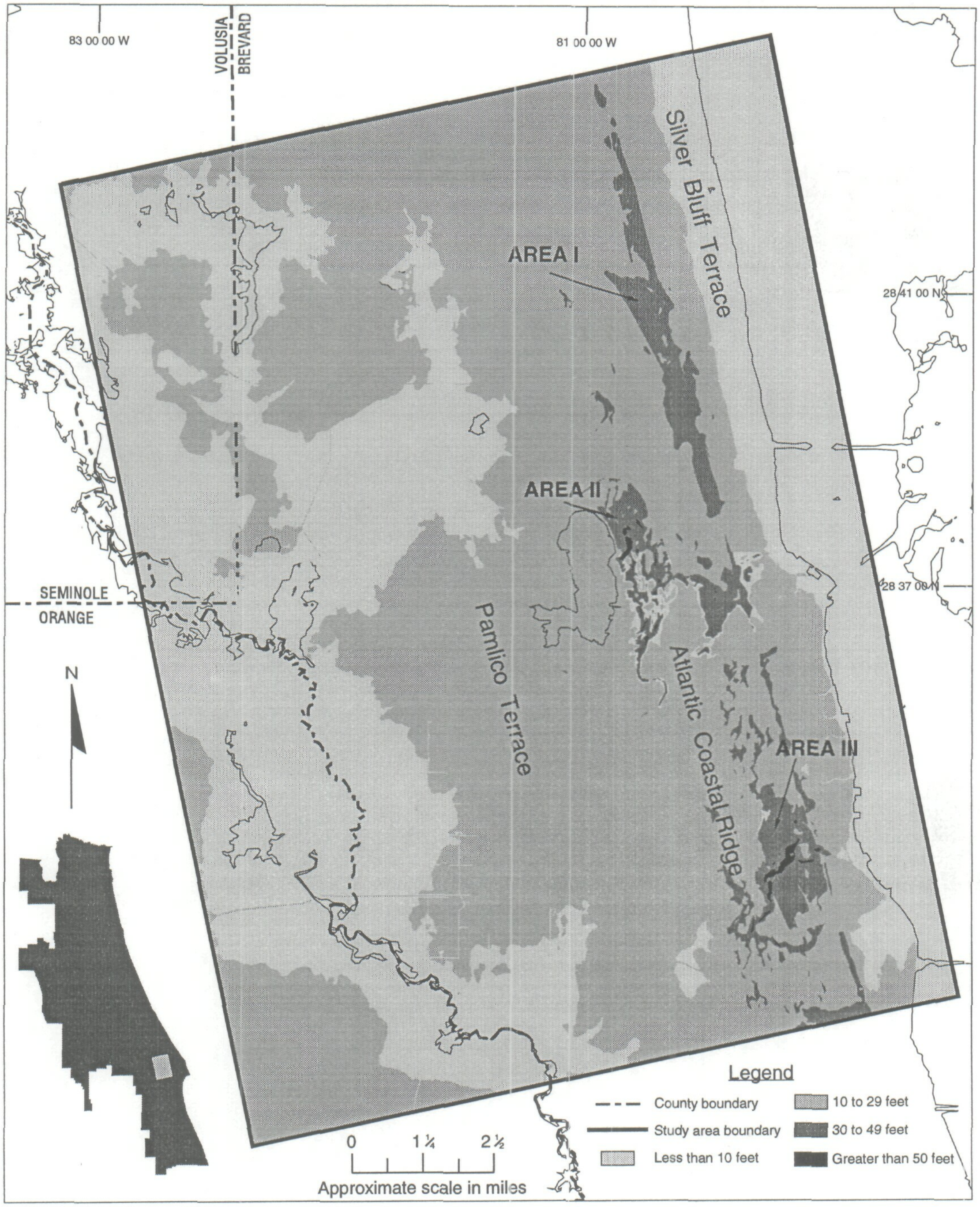

Figure 3. Land surface elevations and geomorphic features in the study area

Floridan aquifer system is brackish and highly mineralized in this area, these lakes receive upward discharge of brackish water from upward seepage of water from the Floridan aquifer system. The chemical characterization of these lakes is similar to that of the underlying Upper Floridan aquifer. Also, these lakes exhibit relatively high accumulations of brackish water components (e.g., chloride, sodium, magnesium, potassium) due to high evaporation rates that facilitate a build-up of these residual salts over time.

Wetlands

Several wetlands exist in the study area (Figure 4). In the coastal ridge area in the eastern part of the study area, several small, interconnected wetlands exist in the lower parts of the ridge system. However, many of these wetlands have been drained for development purposes (Timmons, pers. com. 1991). Wetlands provide surface water storage during wet periods. As water levels recede, the stored surface water is available to become ground water recharge. Northwest Brevard County also includes several wetland environments in the St. Johns River valley.

Drainage Patterns

Drainage patterns in the study area are an indicator of flow patterns in the surficial aquifer system. Natural drainage occurs in the form of streams or overland flow toward shallow topographic depressions, or toward the Indian River to the east and the St. Johns River valley to the west. Artificial drainage exists in the form of canals combined with weirs or control structures that often serve to lower the water table in nearby areas. Both natural and artificial drainage patterns are of interest to the current study because these patterns serve as control points for the surficial ground water system (i.e., these patterns provide some definition to the ground water system).

The Atlantic Coastal Ridge forms a drainage divide for surface water in northern Brevard County. Several streams in the east drain to the Indian River. In the western ridge area, drainage

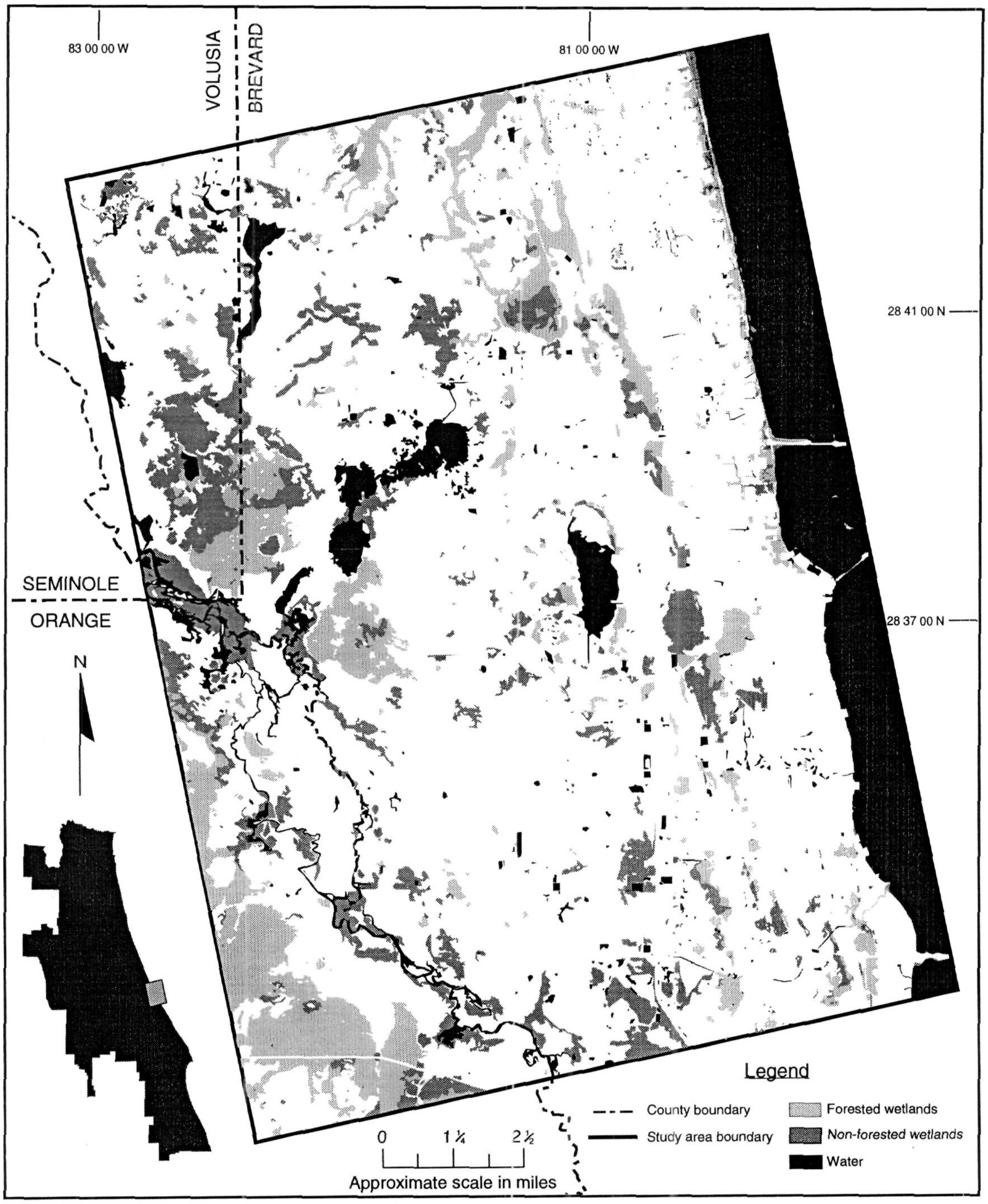

Figure 4. Delineation of wetlands within the study area

occurs toward the west to a series of small, interconnected depressions that channel water to the St. Johns River valley (Brown et al. 1962a).

THE GEOLOGIC SYSTEM

Geomorphology

The geomorphology of the study area is made up of a series of coastal ridges and marine terraces that are the result of periods of repeated sea level fluctuations due to glaciation/deglaciation during the Pleistocene Epoch (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 this period of sea level fluctuation. An understanding of this pattern of ridges and terraces is useful because it facilitates the analysis of trends in the variations of the geologic media in the surficial aquifer system.

Terraces. The Pleistocene Epoch, also known as the Great Ice Age, was a period of alternating glaciation and deglaciation when repeated retreat and growth of glaciers caused associated periods of sea level fluctuations. During times when the sea level was constant, a shoreline, marked by an escarpment, developed, and the sea floor formed a level surface or terrace. Several shorelines and terraces both above and below the present sea level have been recognized. The terraces that are pertinent to the current study area are the Silver Bluff and Pamlico terraces. The Silver Bluff Terrace is near the Indian River and is generally about 5 to 8 ft msl; the Pamlico Terrace is further inland, in the Eastern Valley, and is approximately 25 to 35 ft msl (Brown et al. 1962a) (Figure 3).

Atlantic Coastal Ridge. The Atlantic Coastal Ridge is the principal geomorphic feature in the surficial aquifer system of northern Brevard County. It serves as a storage reservoir of ground water, and its higher topography combined with increased hydraulic conductivity of the underlying sandy geologic media facilitate relatively high rates of freshwater recharge to the water table. The Atlantic Coastal Ridge also serves as a natural surface water divide between the Indian River and the St. Johns River. Its east-west width in Brevard County varies between 1.5 and 3 miles. Geographically, the Atlantic Coastal Ridge extends from the St. Marys River north of Jacksonville south to the Everglades in south Florida. It was formed as the primary shoreline during the Pamlico inundation of the Pleistocene Epoch, when the sea level was approximately 30 ft higher than at present (White 1970).

The Atlantic Coastal Ridge exhibits a mature dune-type topography with parallel elongated ridges and intervening swales which contain many shallow ponds, lakes, and long, narrow sloughs. In the Titusville area, the land surface elevation is up to 70 ft msl. Vegetation consists of saw palmetto, sand pine, scrub oak, and shrubbery. The eastern slope of the ridge resembles the present submarine slope in that it drops off seaward, steeply at first, then gently progresses seaward until the profile is almost flat at about 30 ft deep, about one-half to one mile offshore (White 1970). In many places, contours of the Pamlico relict offshore slope are almost identical to depth curves of the present offshore submarine slope (White 1970). The Atlantic Coastal Ridge represents a clean emergence that resulted from a regression of the sea, which was caused by a rapid onset of glaciation. Geomorphically, it is characterized as an erosional shoreline (White 1970).

The Atlantic Coastal Ridge was a barrier island when sea level was about 30 ft higher than at present, approximately 35,000 years ago. Its topography and subsurface conditions reflect the deposition of relict dune sands as part of a barrier island complex during the Pamlico time.

To the west of the coastal ridge is the Eastern Valley, which includes the St. Johns River valley and South Lake. The Eastern Valley also contains relict beach ridges. These relict beach ridges are believed to have been higher prior to the Pamlico time and have suffered dissection and reduction due to dissolution and subsequent subsidence of the underlying limestone and shell sediment. Also, recurrent estuarine conditions that existed during periods of high sea levels contributed to the dissolution of the underlying limestone and shell sediment (White 1970).

The Atlantic Coastal Ridge in northern Brevard County is relatively free of carbonates. It still exists in full stature as in the Pamlico time and has not subsided due to carbonate dissolution, which indicates it has always been low in carbonate material. In contrast, the relict beach ridges of the Eastern Valley lost much of their stature through solution of the originally dominant shell content (White 1970). This is true because the Pamlico Scarp was made by an erosional shoreline at the crest of the shoreline's transgression. This lack of carbonate material is the reason that the Atlantic Coastal Ridge is wider and higher than the more common relict progradational beach ridges, which have been reduced by leaching of the shell content (White 1970).

St. Johns River Valley. In northern Brevard County, the St. Johns River valley includes much of the area west of the Atlantic Coastal Ridge. The river's source is in the marshy area in southern Brevard County. From Lake Poinsett, southwest of the current study area, the river forms the western boundary of the county up to a point just west of Titusville, where it flows out of the county and toward Lake Harney. At low stage, the river falls about 15 ft in 275 miles, or 0.05 feet per mile, and, during flood stage, it falls about 0.2 feet per mile. Its channel is tortuous and interrupted by many lakes.

The land adjacent to the river is generally marshland, which functions as part of the river when the river is at flood stage and, during low stage, drains water back into the river and helps to sustain flow (Brown et al. 1962a). In Brevard County, this marshland adjacent to the river generally is not present where the land surface elevation is greater than 20 ft msl. Between the marshland and the Atlantic Coastal Ridge is a moderate upland area which is a mixture of a sandy prairie zone and a pine flatwoods forest. The sandy prairie zone is considered part of the floodplain; the pine flatwoods forest is a relatively flat, poorly drained area with scattered intermittent ponds, lakes, and sloughs. Land surface elevations in the St. Johns River valley range from 5 to 25 ft msl (Figure 3) (Brown et al. 1962a).

Indian River. The Indian River is an estuarine lagoon which exists parallel to the coast in northern Brevard County. The river ends about one-half mile north of the northern boundary of Brevard County. The river is significant in relation to the ground water resources in that it serves as a lateral boundary for the surficial aquifer system and it is an area of upward discharge of water from the Floridan aquifer system.

Soils. The soils of northern Brevard County vary between the sandy soils of the coastal ridges and the organic mucks of the wetlands and swampy lowlands (Figures 3 and 4). Soil characteristics are important to the ground water resources because these characteristics affect the extent to which precipitation may recharge the water table. The more sandy soils of the coastal ridges facilitate recharge, and the mucky, organic soils of the lowlands generally inhibit recharge. Table 1 provides a descriptive review of the soil associations and the general locations in the study area. In a later section of this report (p. 52), a method is presented that correlates these soil associations with the potential for recharge to the surficial aquifer system.

Stratigraphy

Generally, two facies (i.e., a part of a rock or group of rocks that differs from the whole formation) comprise the stratigraphic sequences of the Coastal Plain sediments that underlie east-central Florida: (1) an upper facies that is predominantly clastic with minor amounts of limestone and (2) a lower facies composed of a thick, continuous sequence of shallow-water platform carbonates (Miller 1986).

The stratigraphic sequence that is pertinent to the current study area is outlined in Table 2. Interfingering of these various sediments is common, with abrupt changes often occurring. Generally, the Miocene and younger sediments comprise a clastic

Table 1. Summary of soil associations

Landscape Type	Soil Associations	Drainage	Slope	Characterization	Locations
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
Broad grassy flats	Pompano	Poorly drained	Nearly level	Sandy to 80 inches or more	Eastern edge of lowlands along St. Johns River
Flatwoods	Myakka-Eau Gallie-Immokalee; Pineda-Wabasso	Poorly drained	Nearly level	Sandy over weakly cemented sandy layer	Between coastal ridge and lowlands along 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 north of Titusville
St. Johns River floodplains	Felda-Floridana-Winder; Floridana-Chobee-Felda	Poorly and very poorly drained	Nearly level	Loamy subsoil	Lowlands along St. Johns River
Swamps and marshes	Montverde-Micco-Tomoka; Swamp; Tidal Marsh-Tidal Swamp	Poorly and very poorly drained	Nearly level	Organic	Floodplain of St. Johns River and along salt-water rivers, creeks, and lagoons

Source: Huckle et al. 1974

Table 2. Summary of stratigraphic sequences

Epoch	Formation	Deposition	Comments
Holocene	Unnamed alluvial lake and windblown deposits	Fluvial origin or weathering of older rocks	Thin, sand and gravel deposits adjacent to present-day streams; dune, estuary, and lagoon sediments contiguous to modern coast
Pleistocene	Pamlico Formation and marine and estuarine terrace deposits	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 periods of rising and falling seas in response to glacial/interglacial episodes
	Anastasia Formation		Cemented coquina reduced to small fragments, cemented by calcium carbonate, iron oxide, or other cements
Pliocene	Caloosahatchee Formation	Shallow to marginal marine environments	Scattered patches of shallow marine rocks; thin sequence of interbedded clay, calcareous clay, sand with much locally broken shelly material
Miocene	Hawthorn Formation	Shallow to moderately deep marine water; inner to middle shelf in basin that receives copious clastic material	Elevation of top is −50 to −100 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; most widespread and thickest Miocene unit in southeastern United States; in eastern Florida, most of Miocene strata consists of complexly interbedded, highly variable sequence 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 the Floridan aquifer system

Table 2—*Continued*

Epoch	Formation	Deposition	Comments
Eocene (early)	Oldsmar Formation	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
Eocene (middle)	Avon Park Formation	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 (late)	Ocala Limestone	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; a fault exists along the St. Johns River west of Titusville, which tends to decrease with depth; prolific source of ground water; thickness highly variable due to erosion and/or dissolution; one of most permeable units in the Floridan aquifer system
Paleocene	Cedar Keys Formation	Tidal flat, sabkha conditions	Elevation of top is -2,500 to -2,200 feet mean sea level (ft msl); extensive anhydrite beds; effective base of the Floridan aquifer system

Source: Summarized from Miller 1986

facies that covers the older carbonates, except where 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).

Some faults exist in the Floridan aquifer system, particularly along the St. Johns River. Generally, these faults are of limited extent with little vertical displacement, and, according to Miller (1986), the faults do not appear to affect ground water flow in the Floridan aquifer system. In the western part of Brevard County, the Eocene formations have been offset by a north-south trending fault which forms the eastern boundary of the Osceola low (Brown et al. 1962a).

THE HYDROGEOLOGIC SYSTEM

The hydrogeologic system is comprised of the surficial and Floridan aquifer systems (Figure 5). The surficial aquifer system is described by Miller (1986) 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." The Floridan aquifer system is described by Miller (1986) as "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."

The surficial aquifer system is separated from the Floridan aquifer system by a heterogeneous 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. The Upper Floridan aquifer is the more productive of the two units and also generally produces higher quality water than the Lower Floridan aquifer. Therefore, the Upper Floridan aquifer is most often used for water supply purposes. The Upper and Lower Floridan aquifers are separated by a confining unit, known as the

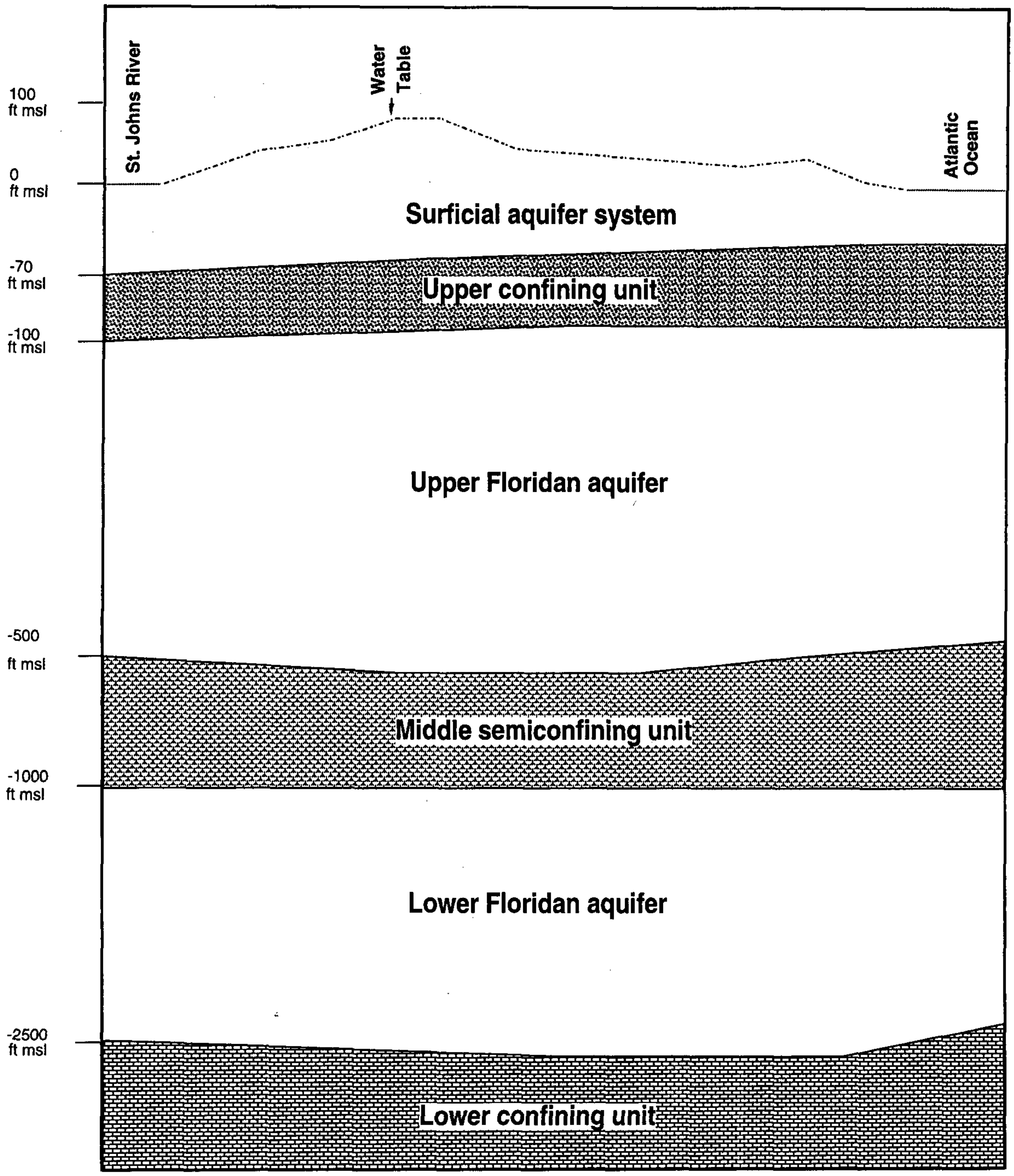

Figure 5. Generalized depiction of the hydrostratigraphic sequence in east-central Florida. *All elevations are approximate (feet mean sea level).*

middle semiconfining unit, which serves to separate these two aquifers hydraulically. Table 3 provides a synopsis of the hydrostratigraphic sequences that are pertinent to the current study.

The Surficial Aquifer System

Lithology. In northern Brevard County, two units comprise the sediments of the surficial aquifer system: a lower marl which is 50 to 150 ft thick and an upper sand which is 0 to 50 ft thick. The marl is a lens of sand, shell, clay, and sandy clay formed in beach, lagoonal, tidal flat, and channel systems, and it correlates with the Anastasia Formation of the Pleistocene series. The sand layer, also of Pleistocene origin, is composed of dune sands associated with the Pamlico marine terrace. It is a clean sand with possibly local shell fragments. The contact between the sand and the marl and between the marl and the underlying Eocene sediments is unconformable (i.e., separated by a surface where the sequence of rock units has been interrupted by either erosion or nondeposition [Birkeland and Larson 1989]) (Cooke 1945). Figure 6 provides an illustration of the elevation of the base of the sediments in the surficial aquifer system.

Aquifer Parameters. Many hydrologic investigations have been performed in the study area due to the need to evaluate the surficial aquifer system as a potential source of public water supply for the communities of Mims and Titusville. Table 4 provides a summary of locations and results of aquifer performance tests that are pertinent to the current investigation.

Water Budget. Analysis of regional water budget components is a key factor in understanding local hydrologic patterns and therefore critical in the development of a regional ground water flow model. In the water budget for the surficial aquifer system, inputs include precipitation recharge; drainage due to irrigation; inflow from lakes, ditches, and streams; septic tank effluent; sewage or holding pond effluent; and upward leakage (discharge) from the Upper Floridan aquifer. Water budget outputs from the surficial aquifer system include seepage to lakes, ditches, and

Table 3. Hydrostratigraphic sequences

Aquifer/Aquitard	Geologic Epoch and Formation	Characteristics
Surficial aquifer system	Pleistocene and Holocene epochs; 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 the vicinity of the Atlantic Coastal Ridge
Upper confining unit	Miocene and Pliocene epochs; Hawthorn Formation	More sandy where less than 100 feet (ft) thick due to upper basin deposit sites where coarser clastic materials were laid down; in Brevard County, lowermost Hawthorn Group is somewhat permeable, but still much less so than the underlying Floridan aquifer system
Upper Floridan aquifer	Late–middle Eocene epochs; Ocala and upper Avon Park limestones	Hydraulic conductivity generally much greater than that of the Lower Floridan aquifer; thickness about 300–500 ft; most ground water circulation in the 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 result of high intergranular or moldic porosity in the Ocala Limestone and Avon Park Formation, coupled with secondary porosity (i.e., large dissolution cavities)
Middle semiconfining unit	Middle Eocene Epoch; middle and upper Avon Park limestones	Consists of soft, micritic limestone and fine-grained dolomitic limestone, both low porosity; top is generally at base of the Upper Floridan aquifer, that is, -400 to -600 ft below mean sea level; minor variations in head, water quality, and flow-meter data indicate the unit behaves as a confining bed even though its lithology is similar to units that are vertically adjacent
Lower Floridan aquifer	Late Paleocene to early Eocene epochs; lower Avon Park and Oldsmar limestones	Top is -1,200 to -1,000 ft mean sea level (msl), thickness is 1,500 ft, bottom is -2,600 to -2,400 ft msl; bottom is areally extensive anhydrite beds of Cedar Keys Formation; 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

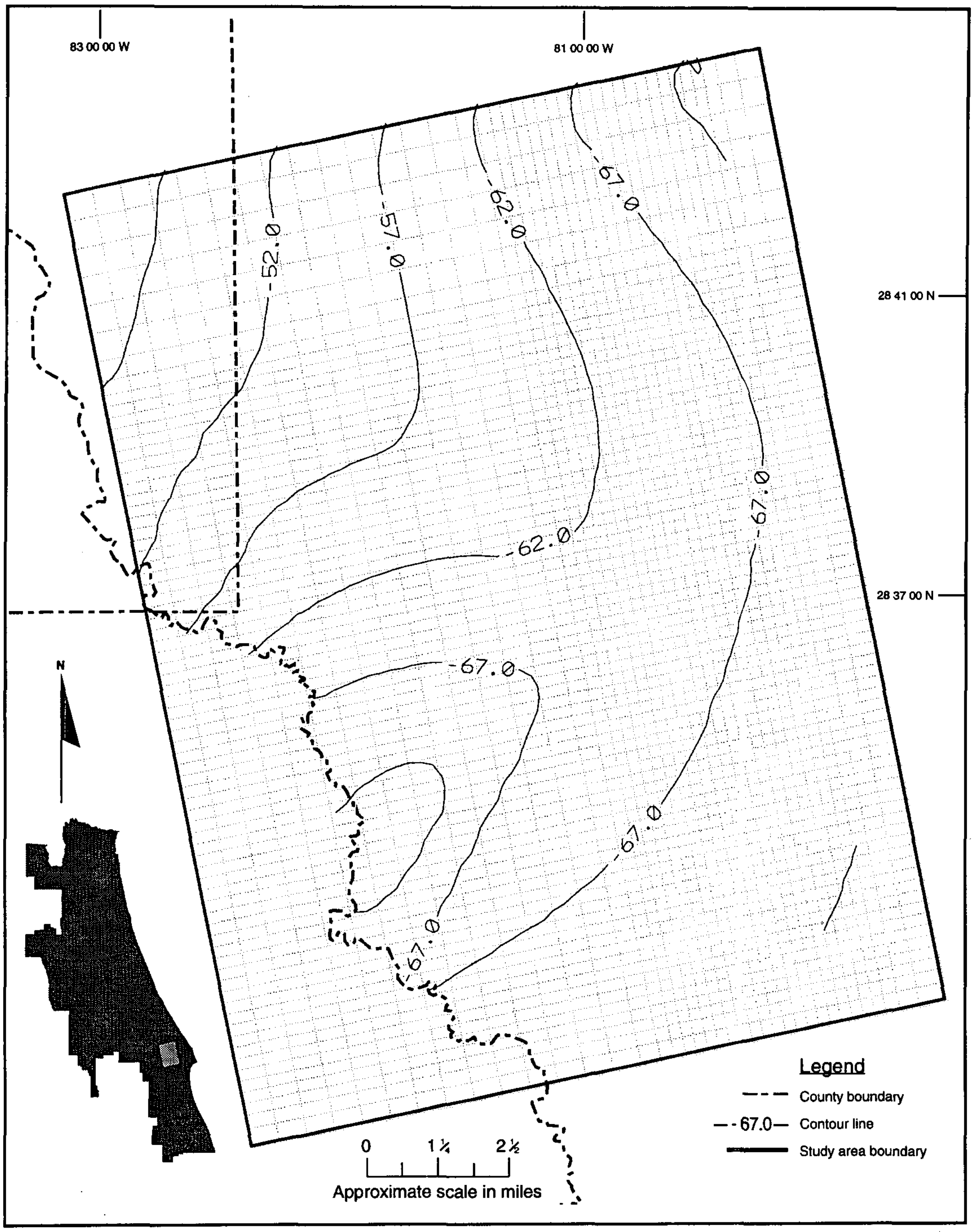

Figure 6. Elevation of base of the sediments of the surficial aquifer system (feet mean sea level) (modified from Boniol et al. 1993)

Table 4. Summary of aquifer performance tests for the surficial aquifer system

Location of Test	Transmissivity (ft^2/day)	Hydraulic Conductivity (ft/day)[a]	Source
Area II, PW #3	3,000	30	DRMP 1990
Area II, PW #12	700	7	DRMP 1990
Area II, PW #42	10,000	100	DRMP 1990
Area II, PW #4	1,000	10	BC&E 1962
Area II, PW #5	400	4	BC&E 1962
Area II, PW #6	600	6	BC&E 1962
Area II, PW #10	700	7	BC&E 1962
Area II, PW #11	600	6	BC&E 1962
Area II, PW #12	500	5	BC&E 1962
Area I, TW101A	90	1	BC&E 1962
Area I, TW102A	200	2	BC&E 1962
Area I, TW103A	1,000	10	BC&E 1962
Mims	20,000	200	BOA 1990
Area III	2,000	20	Missimer & Associates 1986a
Area III	1,000	10	RS&H 1979
Hopkins Avenue, Titusville	2,000	20	DRMP 1985
Park Avenue, Titusville	4,000	40	DRMP 1985

Note: ft^2/day = feet squared per day
ft/day = feet per day
PW = pumping well
TW = test well

Areas I, II, and III are areas of northern Brevard County that were identified in an earlier U.S. Geological Survey study as areas of potential freshwater development. These areas are described in Table 5 and can be located on Figure 3.

[a]The hydraulic conductivity calculation is based on a saturated thickness of 100 feet.

streams; loss due to evapotranspiration; pumpage; and downward leakage (recharge) to the Upper Floridan aquifer (Tibbals 1990).

Recharge and Discharge Patterns. Recharge to the surficial aquifer system is due primarily to local rainfall and to minor amounts of irrigation water and upward leakage from the Upper Floridan aquifer. Recharge is relatively higher in summer months because, in east-central Florida, approximately 50% of the total annual precipitation occurs between June and September as slow, steady showers, with occasional torrential rains coming from the convective storm systems that are typical of a subtropical environment. Discharge from the surficial aquifer system occurs as seepage, springflow, well discharge, flow to drainage ditches, and evapotranspiration.

Where the water table is near the land surface, land surface inundation occurs quickly, and excessive runoff serves to inhibit the recharge potential. In the higher ridge areas, where the distance between land surface and the water table is higher, more ground water storage potential exists, allowing greater recharge to the system. The amount of recharge to the surficial aquifer system is dependent on several factors:

- The intensity and duration of rainfall events
- The shape of the land surface
- The amount of runoff into local streams and canals
- The existence of small lakes or depressions that can capture water and facilitate subsequent percolation
- The porosity and permeability of the soil
- The local vegetative cover or land use

Precipitation recharge to the surficial aquifer system occurs on the high dunes, in closed depressions, and in adjacent lowlands. The high dunes of the coastal ridges facilitate recharge due to high permeability and a relatively thick unsaturated zone. Closed depressions in and around the ridge areas facilitate recharge by capturing precipitation for subsequent percolation before it can run off into local surface drainage networks. Adjacent lowland areas also facilitate recharge to the surficial aquifer system. Wetlands in these areas store precipitation for eventual recharge to the aquifer, and also perform a buffering function to ground water fluctuations by providing recharge water when the water table is decreasing. Kimrey (pers. com. 1973) asserted that the closed depressions on the ridges and the adjacent lowlands are critical to continued maximum recharge in this area, and that drainage of the high wetlands would decrease the fresh water available for area recharge. Past estimates of recharge to the surficial aquifer system have included 12 inches per year (in/yr) (BC&E 1962), 16 in/yr (Crain et al. 1975), and 24 in/yr (Ranney Water Collector Corporation 1947).

Evapotranspiration. Evapotranspiration is the amount of total precipitation that is lost to the combined processes of evaporation to the atmosphere and transpiration by the vegetation. Evapotranspiration rates are difficult to quantify due to measurement difficulties and the spatial variability of the process. However, it is possible to estimate the upper and lower limits of evapotranspiration and to describe the factors that influence the process.

Several researchers have estimated the minimum evapotranspiration rate in northern and central Florida to be approximately 25 to 35 in/yr (Knochenmus and Hughes 1976; Tibbals 1978). The lowest rates of evapotranspiration usually occur in areas with a deep, well-drained soil and a deep water table. These areas (e.g., the Atlantic Coastal Ridge) are often marked with sinkholes, and the areas tend to exhibit little or no surface runoff.

The upper limit of evapotranspiration is approximately equal to the rate at which water will evaporate from a free water surface under natural conditions (Tibbals 1990). The maximum annual rate of evapotranspiration in the study area is approximately 46 in/yr (Visher and Hughes 1975).

Estimates of evapotranspiration rates in the surficial aquifer system of northern Brevard County have included 30 in/yr (Ranney Water Collector Corporation 1947), 35.5 in/yr (Crain et al. 1975), and 39 in/yr (DRMP 1985).

Seasonal Fluctuations. During the wet season and when the water table is high, the water table response to precipitation events may occur within minutes, particularly in lower elevation areas. In the upland sand ridge areas, the lag time may be up to an hour (Edward E. Clark Engineers-Scientists 1987). During dry conditions, response to precipitation can take more than 24 hours in pine flatwoods, which may be underlain by a humic sandstone or hardpan that serves to inhibit percolation to the water table. In addition to the potential existence of a hardpan layer, the leakage through the unsaturated zone may also be dependent on moisture content and hydraulic conductivity of the soil, thickness of the hardpan, and characteristics of the rainfall event. Figure 7 is a hydrograph of a surficial aquifer well near Titusville (BR0584), and it provides an illustration of the general trend of seasonal variability of water levels in this system.

Water Quality. In most of northern Brevard County, a natural upward hydraulic gradient exists between the potentiometric surface in the Upper Floridan aquifer and the water table in the surficial aquifer system. This upward gradient causes an upward flux of brackish water and a generally widespread occurrence of salty water in the water table. Other factors that influence the water quality in the surficial aquifer system include (1) the persistent presence of connate ground water that has not been flushed from the surficial aquifer system by local recharge and (2) lateral and/or vertical encroachment due to pumping. Figure 8 provides a generalized depiction of water quality trends in the surficial aquifer system.

Water quality in the surficial aquifer system is good (i.e., characterized by low total dissolved solids and relatively low

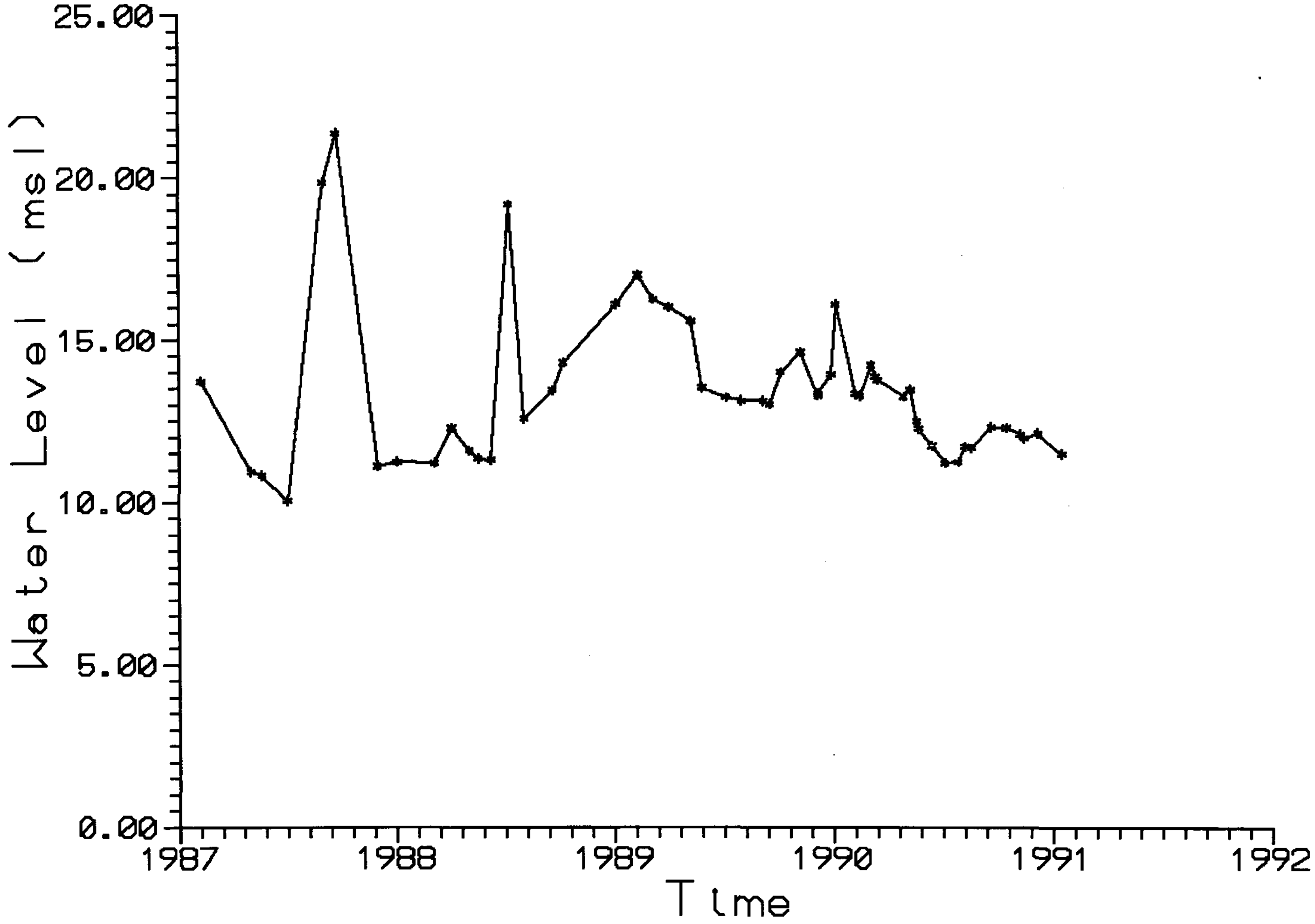

Figure 7. Hydrograph of BR0584, unconfined well near Astronaut High School, Titusville

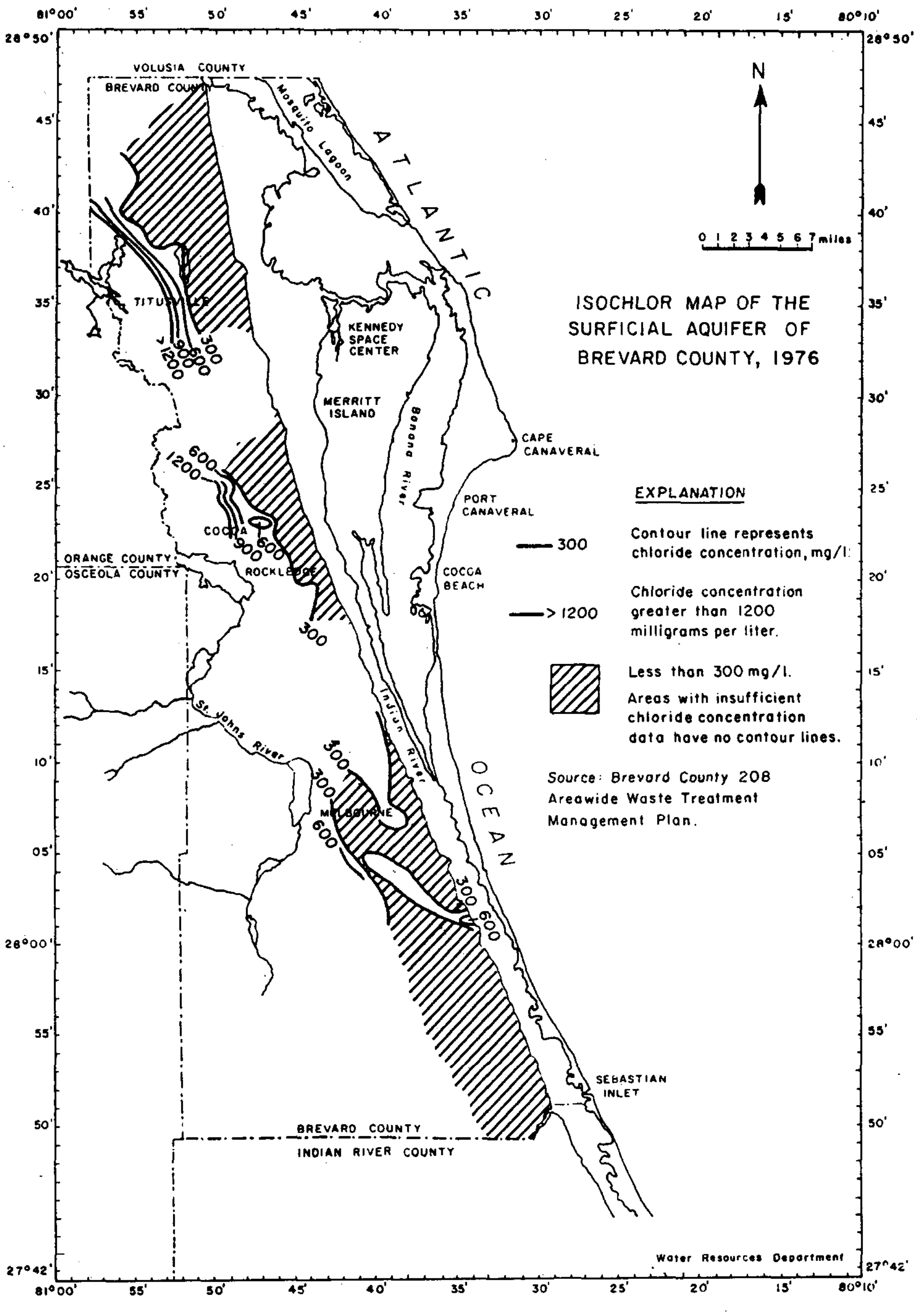

Figure 8. **Isochlor map of the surficial aquifer system of Brevard County, 1976** (Timmons 1982)

concentrations of dissolved ions) in the coastal ridges and marginal in lowlands, where the quality is influenced by upward leakage from the Floridan aquifer system. Timmons (1982) delineated chloride concentration profiles for the surficial aquifer system for 1976 and 1980. He described a west-to-east water quality gradient from higher chloride water (greater than 1,200 milligrams per liter [mg/L]) in the St. Johns River valley to relatively fresh water (<300 mg/L chloride concentration) in the vicinity of South Lake and the Atlantic Coastal Ridge (Figure 8). Based on Timmons' data, this latter area of fresh water extends east to the Indian River and north almost to the Volusia County line.

In the vicinity of South Lake, chloride concentrations in the surficial aquifer system are as low as 20 mg/L east of the lake and as high as 8,900 mg/L southwest of the lake (Timmons 1982). In the area near South Lake, upward leakage from the Upper Floridan aquifer is serving as a control on the available fresh water in the surficial aquifer system. Therefore, the surficial aquifer system is primarily brackish in the immediate vicinity of South Lake. To the west of the lake, the surficial aquifer system is brackish at depth and fresh at the surface.

Timmons' (1982) interpretation of tri-linear diagrams indicates that sodium chloride water is dominant in the surficial aquifer system to the north and west of South Lake due to upwelling of Upper Floridan aquifer water, that the water is transitional in the central and south areas of the lake, and that the surficial ground water is dominated by freshwater recharge to the southeast and northeast of South Lake (Brevard County Water Resources Department 1983).

Results of a chloride sampling program by RS&H (1979) confirmed that water in the surficial aquifer system that is less than 250 mg/L chloride and is generally limited to the higher ridge areas of northern Brevard County. Based upon this sampling program, RS&H depict cross-sectional diagrams of the configuration of the chloride concentrations and the approximate depth of the 250 mg/L isochlor. The general findings were that the depth of fresh water may be up to 100 to 150 ft immediately under the ridge areas, but that the depth of fresh water is probably 50 ft or less off of these ridge areas (RS&H 1979).

Delineation of Zones of Fresh Water. Virtually all of the available fresh water in the surficial aquifer system in northern Brevard County is in the form of freshwater lenses in the vicinity of the Atlantic Coastal Ridge. Several factors contribute to the potential for formation of freshwater lenses in the study area. Formation of a freshwater lens in the surficial aquifer system requires that the aquifer have the capacity to receive recharge from precipitation and that sufficient storage capacity exists for development of a lens of fresh water.

In areas of upward discharge, the water that flows from the Floridan aquifer system into the surficial aquifer system is a major component of the water budget for the surficial aquifer system, and the surficial aquifer system will not have sufficient storage capacity for the development of freshwater lenses. In Brevard County, freshwater lenses have developed in two areas: south (toward Cocoa) and west of Titusville within the Atlantic Coastal Ridge (Kimrey, pers. com. 1973). Near Titusville, a lens can form due to the existence of both of the following conditions.

1. A relatively high coastal ridge with land surfaces ranging to greater than 50 ft msl.

2. The coincidence of the coastal ridge area with a depression in the potentiometric surface. This depression is caused by discharge of the Upper Floridan aquifer to the Indian River and the Atlantic Ocean.

In 1973, USGS performed a preliminary study to evaluate the extent of the freshwater resources in the northern Brevard County area (Kimrey, pers. com. 1973). In this study, Kimrey determined that several factors affect the chloride content of the water in the surficial aquifer system. These factors are land surface elevation, distance from the St. Johns and Indian rivers, and elevation of the potentiometric surface in the Upper Floridan aquifer.

Based upon the USGS investigation, three areas were delineated in northern Brevard County where reserves of fresh water exist for potential development. This delineation is based upon two criteria: a chloride content less than 250 mg/L and a land surface elevation greater than 30 ft msl (Kimrey, pers. com. 1973). These areas have become known as Areas I, II, and III (Figure 3). Table 5 provides a descriptive review of these delineated areas. Both Areas II and III have been developed for freshwater supply for the City of Titusville.

Table 5. Description of freshwater zones in the surficial aquifer system

Area	Location	Characteristics
Area I	Long, narrow ridge from Lagrange to Buckholm Road, near Indian River (north of Titusville)	Not a good source for freshwater development; relatively low well yields; lower recharge due to low topography; thin, unconsolidated sediments; low permeability north of Mims
Area II	East of South Lake and immediately north and west of City of Titusville	Width of ½–¾ mile; relatively higher land surface elevations (40–50 feet mean sea level); closed depressions facilitate aquifer recharge
Area III	South of Titusville between Knox-McRae Road and NASA Parkway	Width of ¾ mile; land surface elevations up to 40–50 feet; closed depressions facilitate aquifer recharge

Areas I, II, and III are areas of northern Brevard County that were identified in an earlier U.S. Geological Survey study as areas of potential freshwater development. These areas can be located on Figure 3.

The Upper Confining Unit

Thickness. The upper confining unit that separates the surficial aquifer system from the underlying Upper Floridan aquifer includes sediments of the Hawthorn Group of the Miocene Epoch and a series of discontinuous and heterogeneous clay lenses and low-permeability zones of late Pliocene to early Pleistocene origin. In northern Brevard County, the Hawthorn Group is thin or absent in the vicinity of the Atlantic Coastal Ridge (Timmons 1982). As a general trend, the Hawthorn Group thickens to the west of the Coastal Ridge, with a maximum thickness of approximately 50 ft near the St. Johns River.

Northern Brevard County is characterized as an uplifted area of the underlying carbonate system, and this uplift allowed the upper portions of the Eocene and Miocene sediments to be eroded away before additional deposition could occur (White 1970). The thickness of the Miocene sediments depends on the extent of erosion of the Ocala Formation. These sediments grade into silts and clays of the upper Miocene and are sometimes grouped with the Pliocene sediments. The upper confining unit in the study area is, therefore, primarily a combination of clay lenses and low-permeability zones of late Pliocene to early Pleistocene origin. The confining unit is very heterogeneous both in terms of thickness of low-permeability zones and the vertical hydraulic conductivity of these zones. Figure 9 depicts the thickness of the upper confining unit in the study area as interpreted from geophysical logs.

Lithology. Where Miocene sediments are present, and assuming that no erosion has occurred, sediments 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 which are residue from shallow marine life (Edward E. Clark Engineers-Scientists 1987). These layers also can be identified by a very high gamma ray signature on geophysical logs, an indicator of high phosphate content in the confining unit sediments. Due to erosion, the upper zone of Miocene sediments is generally absent in the study area. Geophysical logs indicate thicknesses for the Hawthorn Group of 20 ft to the southeast of South Lake. A geophysical log east of the lake indicates the presence of a shelly, sandy dolostone of the Tampa Stage limestone of Miocene or Oligocene age (Brevard County Water Resources Department 1983). In general, the upper confining unit has a higher sand content where it is less than 100 ft thick because this thinner zone represents a depositional pattern where coarse clastics of the lower Hawthorn Group were laid down (Miller 1986). In Brevard County, the

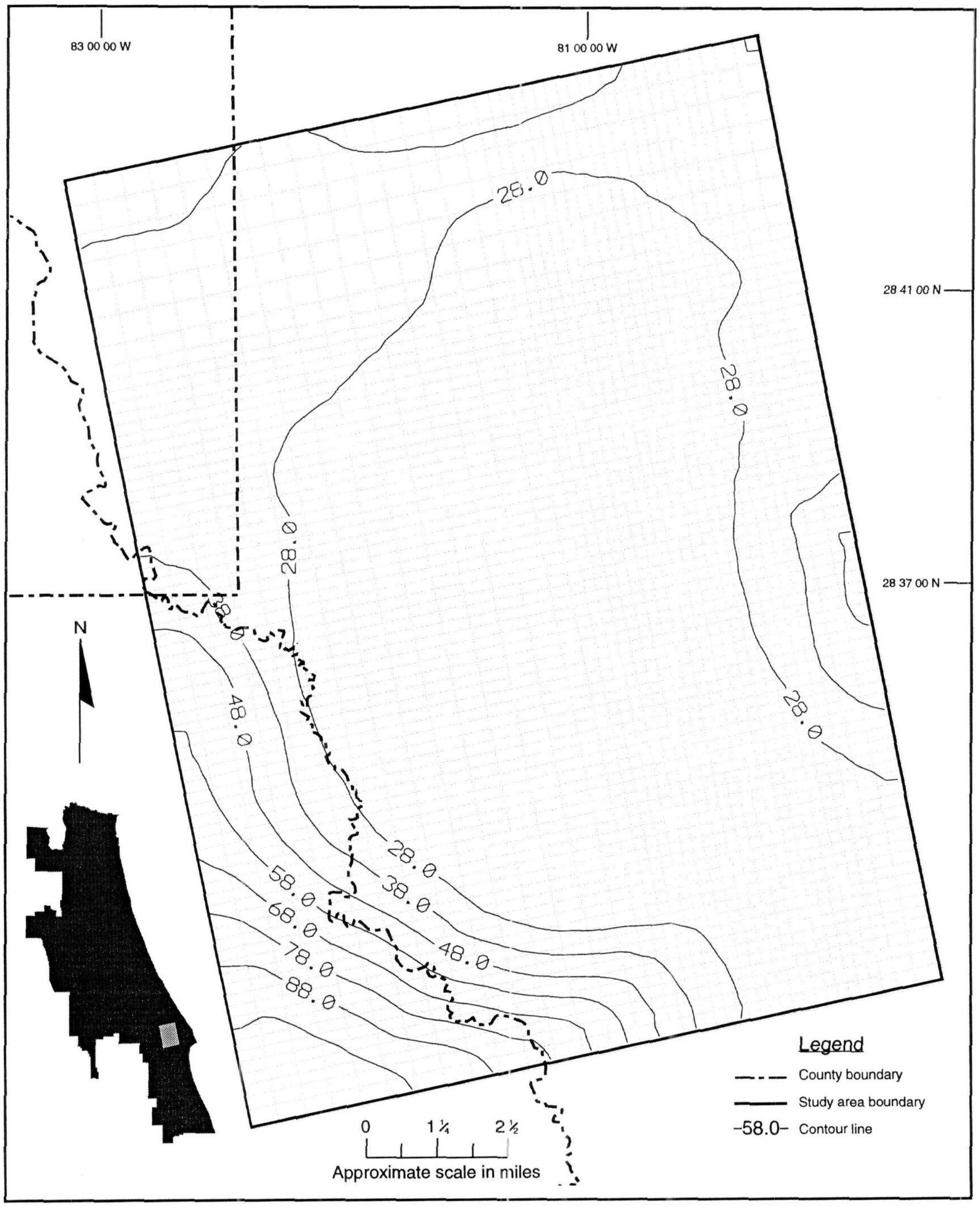

Figure 9. Thickness of upper confining layer sediments (feet mean sea level)
(modified from Boniol et al. 1993)

lowermost portion of the Hawthorn Group is somewhat permeable but is, nevertheless, much less so than the underlying the Floridan aquifer system.

Leakance and Vertical Hydraulic Conductivity. Leakance is a measure of the degree of hydraulic connection between two vertically adjacent aquifers separated by a semiconfining zone. Mathematically, leakance is equal to the vertical hydraulic conductivity of the confining unit divided by the thickness of the unit.

The vertical hydraulic conductivity of a confining unit is a measure of the potential for water to flow vertically within the unit. Due to the degree of sediment variability that exists in the upper confining unit, quantifying the vertical hydraulic conductivity range and associated leakance values is difficult. Tibbals (1990) has estimated a range of leakance values for the upper confining unit of 1×10^{-6} to 6×10^{-4} inverse days (d^{-1}) in this area. Miller (1986) states that the range of vertical hydraulic conductivity of clay beds based upon core tests of samples from the upper confining unit is 8×10^{-7} to 2×10^{-2} d^{-1}.

The Floridan Aquifer System

The Floridan aquifer system is composed of carbonate rocks which are primarily of Eocene age. The Floridan aquifer system is a carbonate aquifer that is highly susceptible to karst development. However, almost all sinkhole occurrences are in areas where recharge rates to the aquifer are high and the depth to the top of the sediments of the Floridan aquifer system from land surface is less than 200 ft (Tibbals 1990). The current study area has not been subjected to significant sinkhole development due to the relatively low land surface elevations and low recharge rates to the Floridan aquifer system.

The top of the Floridan aquifer system (Figure 10) is defined as the first occurrence of vertically persistent, permeable, consolidated, carbonate rocks (Tibbals 1990). The base of the Floridan aquifer system is defined as the first occurrence of

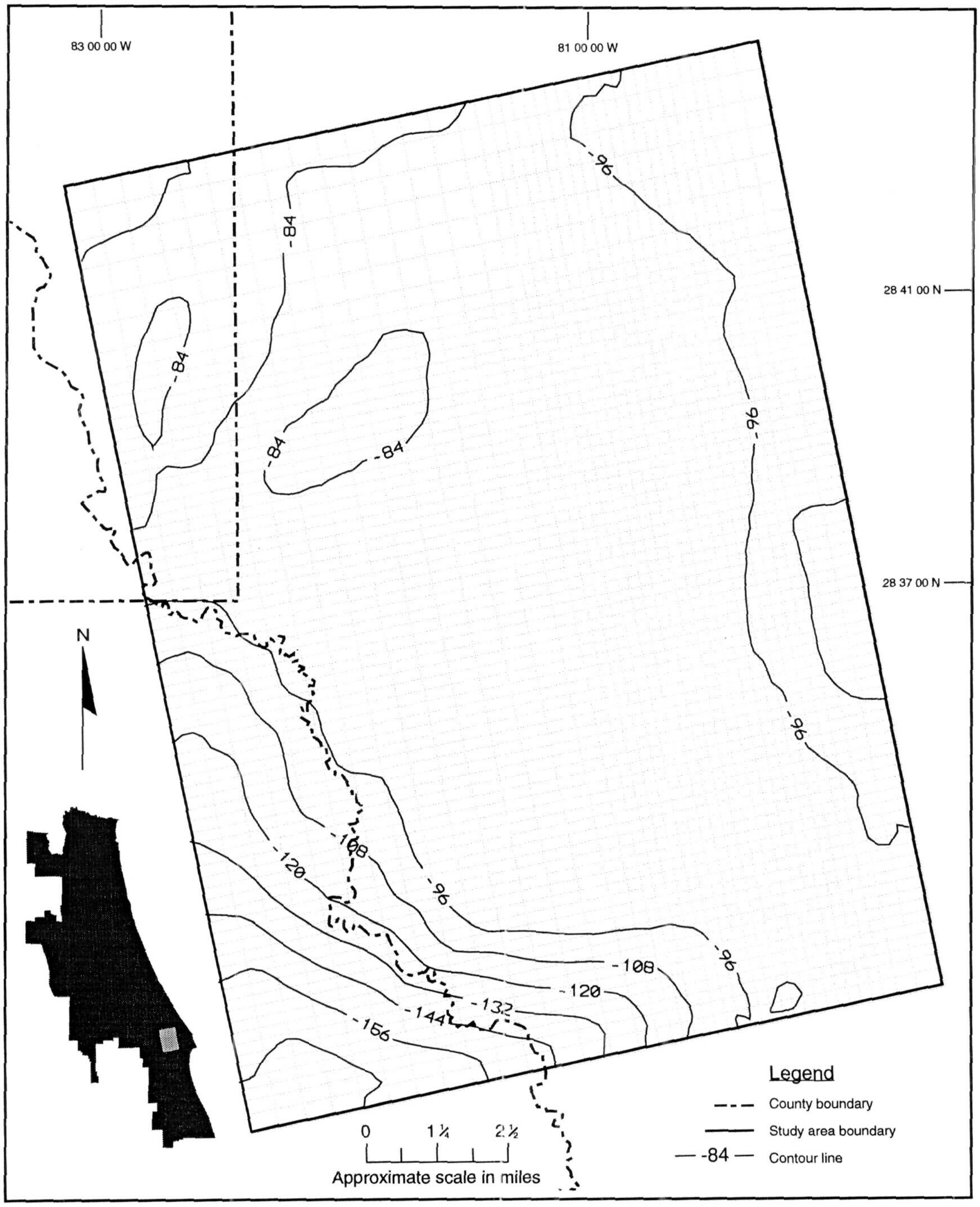

Figure 10. Elevation of top of the Floridan aquifer system (feet mean sea level) (modified from Boniol et al. 1993)

vertically persistent beds of anhydrite. In the absence of these anhydrite bases, the base of the Floridan aquifer system is the top of the transition of the generally permeable sequence of carbonate rocks to the much less permeable gypsiferous and anhydritic carbonate beds (Tibbals 1990).

Aquifer Parameters. Due to the highly mineralized character of the ground water in the Upper Floridan aquifer within the study area, this system has not typically been considered as a water supply source in northern Brevard County. Therefore, relatively few aquifer performance tests have been performed to evaluate the potential productivity of the aquifer. However, several researchers have estimated the transmissivity of the system as a result of model calibration (Table 6).

Table 6. Review of transmissivity estimates for the Upper Floridan aquifer

Transmissivity (ft^2/day)	Location of Model/Aquifer Performance Test	Source
<50,000	Western lowlands[1]	Skipp 1988
50,000 to 100,000	Coastal ridge, St. Johns River area[1]	Skipp 1988
40,000	Northern Brevard County[2]	Brown et al. 1962a
35,000 to 100,000	Northern Brevard County[1]	Tibbals 1990
27,000	Northwestern Brevard County[1]	Blandford and Birdie 1992

Note: ft^2/day = feet squared per day

[1]Model-derived
[2]Aquifer performance test

Immediately below the Upper Floridan aquifer in the stratigraphic sequence are the middle semiconfining unit and the Lower Floridan aquifer. The middle semiconfining unit is a layer of soft, micritic limestone and dolomitic limestone of middle Eocene age which, due to its relatively lower porosity and permeability, serves to hydraulically separate the Upper and Lower Floridan aquifers. On a regional basis, this hydraulic separation has been verified through analysis of head differentials, water quality, and flow meter data (Miller 1986). Tibbals (1990) estimated a leakance for the middle semiconfining layer of 5×10^{-5} d^{-1}.

The Lower Floridan aquifer is of late Paleocene to early Eocene age. In coastal east-central Florida, the Lower Floridan aquifer is not generally investigated as a potential water supply source due to typically sluggish ground water flow and the highly mineralized water quality. Therefore, the transmissivity of the Lower Floridan aquifer has not been rigorously investigated. However, Tibbals (1990) has estimated a value of 60,000 feet squared per day (ft^2/day) for aquifer transmissivity in northern Brevard County, based on model calibration.

Recharge and Discharge Patterns. Recharge and discharge patterns are driven by the hydraulic gradient between the water table and the potentiometric surface of the Upper Floridan aquifer and characteristics of the upper confining unit. A positive head gradient (i.e., the water table elevation is greater than the corresponding potentiometric surface of the Upper Floridan aquifer) indicates a recharge situation, and a negative head gradient indicates a discharge situation. Recharge to or discharge from the Upper Floridan aquifer is proportional to the gradient between the water table elevation and the elevation of the potentiometric surface of the Upper Floridan aquifer and the confining bed permeability (Tibbals 1990). Recharge to or discharge from the Upper Floridan aquifer also is inversely proportional to the confining bed thickness (Tibbals 1990). That is, higher differences between the water table and the potentiometric surface of the Upper Floridan aquifer and higher values for vertical hydraulic conductivity of the confining unit will tend to increase recharge to or discharge from the Floridan aquifer system. Conversely, higher thicknesses for the sediments of the confining unit will tend to decrease recharge to or discharge from the Floridan aquifer system.

Most of northern Brevard County is a discharge area for the Upper Floridan aquifer. In most areas, the elevation of the potentiometric surface is above the elevation of land surface, thus creating artesian conditions in the aquifer (i.e., wells will flow at ground surface). The exception to this condition is a long, relatively narrow finger of land that extends south from the northern boundary of the county to just south of Titusville (Skipp 1988; Phelps 1984). This area is collinear with and within the Atlantic Coastal Ridge and provides a low to moderate recharge area for the Upper Floridan aquifer.

The high topographic elevations and resultant high water table in the Atlantic Coastal Ridge facilitate recharge to the Upper Floridan aquifer. This configuration of the water table, when combined with relatively low elevations of the potentiometric surface of the Upper Floridan aquifer, creates a downward vertical head gradient between the water table and the potentiometric surface of the Upper Floridan aquifer. Tibbals (1990) has suggested recharge rates along the Atlantic Coastal Ridge of 0 to 3 in/yr, with the rest of northern Brevard County designated as a discharge area to the surficial aquifer system. In order to better illustrate regional patterns of recharge and discharge, Figure 11 provides an illustration of calculated rates of recharge to the Floridan aquifer system based upon a previous study that combined a regression approach for water levels in the surficial aquifer system with leakance values for the upper confining unit (Boniol et al. 1993). This study suggests recharge rates to the Upper Floridan aquifer of 4 to 8 in/yr in this area.

The area of the Floridan aquifer system under the Indian River and northeast of Brevard County is a discharge area for the aquifer. In his regional flow model of the ground water resources of east-central Florida, Tibbals (1990) identified this area as the site of several small proposed but unconfirmed springs. Tibbals proposed that springs exist in this area in order to simulate the natural depression that exists in the potentiometric surface from the Titusville area northeast to the submarine shelf of the Atlantic Ocean (Tibbals, pers. com. 1991). One documented but unconfirmed spring is located about 16 miles

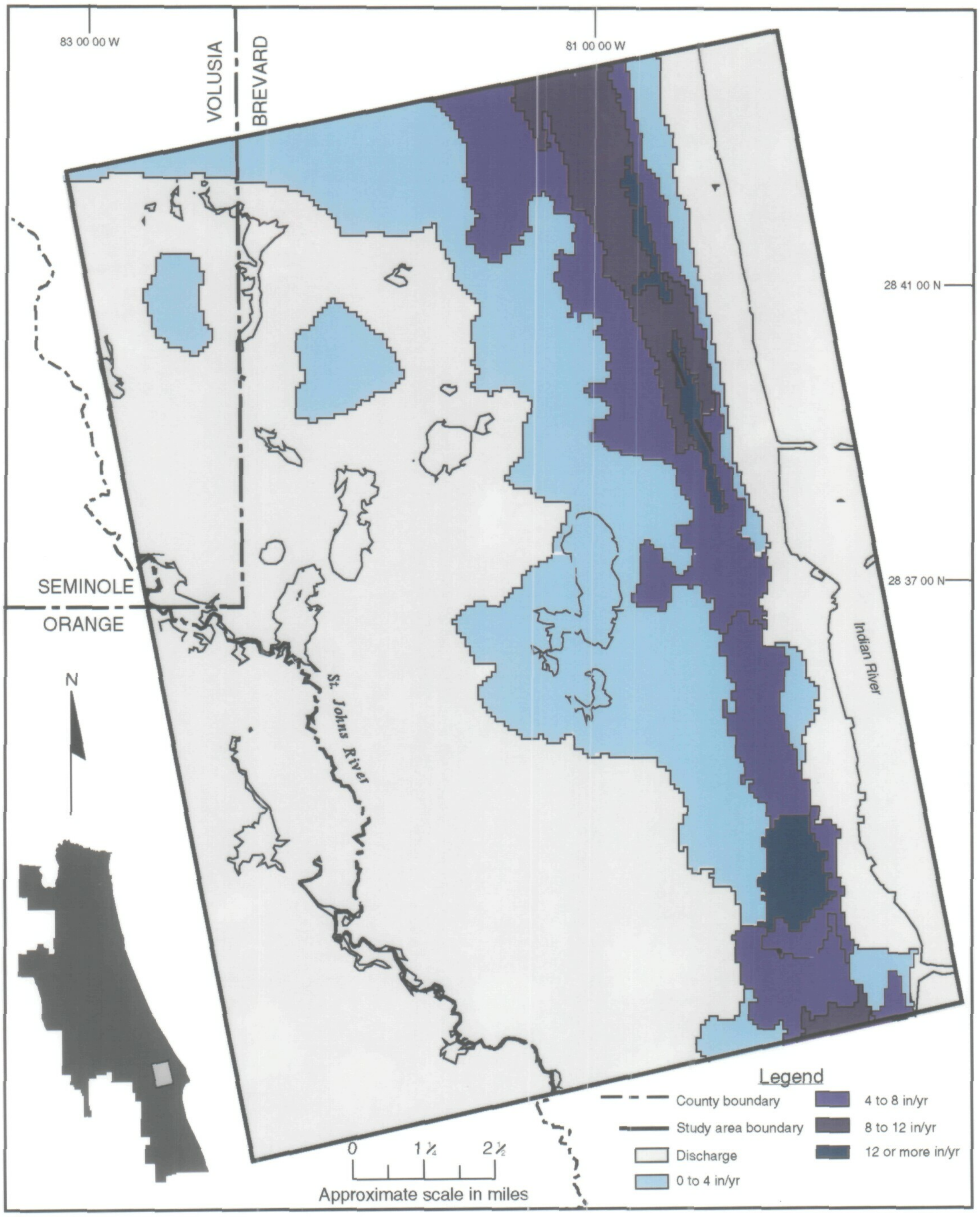

Figure 11. Recharge to the Floridan aquifer system for northern Brevard County based upon districtwide analysis (inches per year) (Boniol et al. 1993)

offshore, east of the Volusia-Brevard county line (Tibbals 1990; Stringfield 1936). The offshore area between St. Augustine and Brevard County generally is considered to be an area of potential spring development, due to thinning or absence of the confining unit which generally overlies the Upper Floridan aquifer. In this offshore zone, the top of the Floridan aquifer system is 80 to 100 feet below sea level (ft bsl), and the sea bottom is about 60 ft bsl. Therefore, the overburden overlying the Floridan aquifer system is as thin as 20 ft, and conditions are favorable for spring formation or for high rates of diffuse upward leakage.

The primary recharge area that influences the hydraulic gradient of the potentiometric surface in northern Brevard County is in west Osceola County and south Orange and Polk counties (Figure 1). The relatively high land surface elevations, the paleobeach ridge soils with high percolation rates, and the absence or thinning of the Hawthorn Group in this inland area contribute to the high recharge potential of this portion of central Florida (Edward E. Clark Engineers-Scientists 1987).

Water Quality. The water quality of the Floridan aquifer system is primarily the result of its depositional history. This history has been marked with repeated periods of sea level fluctuations, which provided periods of seawater inundation and subsequent flushing and dilution of this water with freshwater recharge.

Timmons (1982) investigated water quality in the Upper Floridan aquifer in Brevard County and concluded that no significant trends toward increased mineralization were evident in the area under the coastal ridge, except around the Arthur Dunn Airpark (north of Titusville). The increase noted around the airpark is most likely due to pumping combined with relatively low hydraulic conductivity in the surficial aquifer system, contributing to connate intrusion.

Three distinct geochemical types of water exist in the Upper Floridan aquifer in the study area (Figure 12). Recharge water is characterized by the dominance of bicarbonate anions and a relatively low concentration of total dissolved solids. Connate

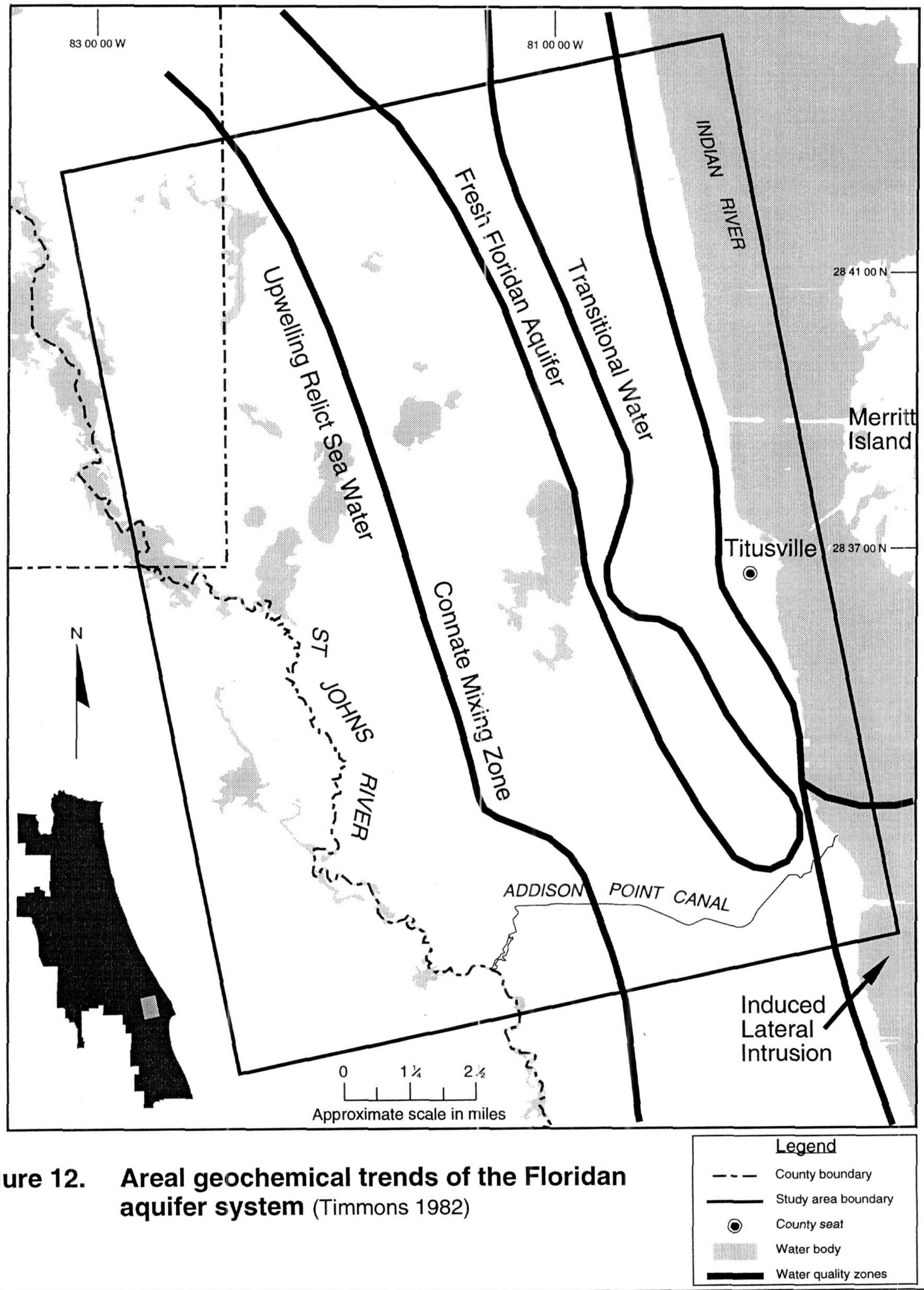

Figure 12. Areal geochemical trends of the Floridan aquifer system (Timmons 1982)

water is highly mineralized, has been entrapped during deposition, and often contains the same constituents as sea water, with different proportions. Water that has been subject to lateral intrusion is characterized by a high chloride-to-bicarbonate ratio.

Through a ground water sampling program and subsequent interpretation by use of tri-linear diagrams, Timmons (1982) delineated the following five areal geochemical trends in the Upper Floridan aquifer of northern Brevard County (Figure 12).

1. Lateral saltwater intrusion along the Indian River and under northern Merritt Island

2. Transitional water extending in a narrow band between the Indian River and the coastal ridge area

3. Fresh water that receives recharge from the surficial aquifer system in a long band under the Atlantic Coastal Ridge

4. A mixing zone of connate water and fresh water under the lowland area to the west of the coastal ridge

5. Upwelling relict sea water under the St. Johns River valley

In the Upper Floridan aquifer around South Lake, there is a rapid change in water quality from east to west, with chloride values of less than 50 mg/L east of the lake to more than 8,000 mg/L to the west (Brevard County Water Resources Department 1983).

Few data exist on the water quality of the Lower Floridan aquifer in this area. Based on regional trends, the water is generally more highly mineralized in the Lower Floridan aquifer and the middle semiconfining unit than in the Upper Floridan aquifer in east-central Florida (Tibbals 1990).

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 South and Fox lakes near Titusville, several lakes in the St. Johns River valley, the St. Johns River, the Indian River, several natural wetlands, and a series of man-made drainage canals.

The geomorphology of the area is that of a series of ridges and terraces that originated during periods of fluctuating sea levels. One of the prominent features of the system in the study area is the Atlantic Coastal Ridge, a series of interconnected dunes and swales that is of generally higher elevation than the surrounding terraces.

The surficial aquifer system, the targeted aquifer for the current study, is an unconfined ground water system with freshwater storage concentrated in the vicinity of the Atlantic Coastal Ridge parallel to the coastline. Underlying the surficial aquifer system is an upper confining unit and the Floridan aquifer system. The upper confining unit controls the hydraulic connection between the surficial and Floridan aquifer systems. The Floridan aquifer system is composed of the Upper and Lower Floridan aquifers and the middle semiconfining unit.

The water quality of the study area is governed by the interconnection between the surficial and Floridan aquifer systems. Ground water in the Floridan aquifer system is highly mineralized, and in most of the area, an upward hydraulic gradient contributes to poor water quality in the surficial aquifer system. However, along the coast and near the Atlantic Coastal Ridge, surface topography and a local downward hydraulic gradient allow the formation of freshwater lenses that provide freshwater storage.

THE DIGITAL GROUND WATER FLOW MODEL

THE CONCEPTUAL MODEL

The conceptual model for the Titusville/Mims regional ground water flow model is based on the hydrostratigraphic sequence presented in Table 3 and discussed in the previous chapter. This sequence is divided into three aquifer layers with two intervening semiconfining units. The three aquifer layers represent the surficial aquifer system and the Upper and Lower Floridan aquifers. These three aquifer layers are interconnected through the use of leakance values, which control the extent of hydraulic connection between aquifers and represent the semiconfining units. The surficial aquifer system is modeled as unconfined and the Upper and Lower Floridan aquifers are both modeled as confined aquifers.

The ground water flow modeling package that was used for this investigation is MODFLOW, a quasi-three-dimensional finite-difference code that was developed by USGS (McDonald and Harbaugh 1988). This computer code was selected for the following reasons.

1. It has been validated through numerous field applications both within and outside of USGS.

2. It is capable of simulating a variety of boundary conditions and hydrologic processes.

THE FINITE-DIFFERENCE GRID

In the initial phase of the model development process, a finite-difference grid was developed to circumscribe the study area. This grid is composed of 74 rows and 38 columns, with the rows oriented perpendicular to the coastline and the columns oriented parallel to the coastline. The grid cells are variable in size, with a range in size between 2,500 × 2,500 ft and 1,000 × 1,000 ft. The finest grid resolution is in the vicinity of the Atlantic Coastal Ridge, the principal area of interest. Along this ridge is where virtually all of the major water uses occur and where the greatest amount of hydraulic gradient exists both within the surficial aquifer system and between the surficial and Floridan aquifer systems.

BOUNDARY CONDITIONS

Boundary conditions in a ground water flow model are hydrologic constraints that are translated into mathematical conditions at specified locations within the study area. The MODFLOW ground water simulation code is capable of simulating several types of boundary conditions. These can be characterized generally as specified flux, specified head, and head-dependent flux boundaries (Table 7). The specified flux

Table 7. Summary of boundary types and potential applications

General Boundary Type	Potential Applications
Specified flux	Recharge; impermeable boundaries or areas of negligible flow (no flow); wells
Specified head	Surface water bodies; to represent a regional hydraulic gradient
Head-dependent flux	Drains; evapotranspiration; springs; lateral boundaries where flux is unknown

boundaries in the model include recharge to the surficial aquifer system, all wells in the surficial aquifer system and the Upper Floridan aquifer, and no-flow boundaries along lateral edges where no other boundary type has been specified. Specified head boundaries are used primarily 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 actually a combination of specified flux and specified head conditions and thus sometimes are known as mixed-type boundary conditions. Mixed-type boundary conditions are used to represent conditions where the flux at a given location is dependent upon the head at a nearby and hydraulically connected location. In the model, head-dependent flux boundaries are used to represent evapotranspiration, springs, drains, and lateral aquifer boundaries. Tables 8 and 9 provide a descriptive summary of the boundary conditions that have been employed in the development of the model.

Table 8. Summary of boundary conditions for the surficial aquifer system

Location in Study Area	Boundary Type	Justification/Comments
Indian River	Specified head	Stage measurements indicate that the Indian River remains relatively constant through time; it is hydraulically connected to the surficial sediments
Northern extent of model	No-flow	Sluggish area for flow from the surficial aquifer system; negligible effect on the water table in higher areas of the coastal ridges
Northwest corner, east of St. Johns River	Specified head	Simulation of surficial flow to the St. Johns River; head values set to represent long-term stage values of the river in this area
Along St. Johns River	Specified head	Hydraulic connection between the river and the surficial aquifer system; head values set to represent long-term stage values of the river in this area
Addison Point Canal along southern boundary of active area	Specified head	Canal serves as effective barrier for flow across this area
Internal: South and Fox lakes, Salt Lake, Loughman Lake, Buck Lake, Ruth Lake	Specified head	Surface water features that are hydraulically connected to the surficial aquifer system but that remain relatively constant in elevation through time
South of Addison Point Canal and west of St. Johns River	Inactive (no flow)	Ground water flow in these areas has negligible impact on the area of interest; areas are outside of existing, modeled hydrologic boundaries

Table 9. Summary of boundary conditions for the Upper and Lower Floridan aquifers

Location in Study Area	Boundary Type	Justification/Comments
West and southwest along St. Johns River	Head-dependent flux	Allow simulation of effect of regional recharge to the west on the hydraulic gradient; head values are determined based upon the potentiometric surface upgradient from the boundary location
Northern extent of study area	No-flow	Examination of potentiometric surface maps indicates virtually no flow across this boundary
Eastern extent under Indian River	Head-dependent flux	Simulation of regional discharge to the east/northeast of the study area; an area of potential spring development and diffuse upward leakage
Southern extent of study area, east of St. Johns River	No-flow	Examination of potentiometric surface maps indicates that this boundary is parallel with the direction of flow and that flow across the boundary is therefore negligible

Lateral Boundaries

Lateral boundary conditions are those imposed on the outside perimeter of the model study area. In layer 1 of the model (the surficial aquifer system), specified head boundaries are used to simulate the Addison Point Canal to the south, the St. Johns River to the west, the Indian River to the east, and several of the larger lakes which exist throughout the model domain (Figure 13; Table 8). The values that are used to represent hydraulic head at these locations are based upon stage elevation data. For example, the boundary of the surficial aquifer system along the St. Johns River is set at a specified head of between 8 ft msl at the upstream end of the model domain and 4 ft msl at the downstream end. Similarly, heads along the Addison Point Canal are set at 2 to 7 ft msl, and heads in the surficial aquifer system along the Indian River are set to 0 ft msl. All of these boundaries are based upon the long-term period of record for stage in these water bodies (USGS 1989). The areas along the inland side of the

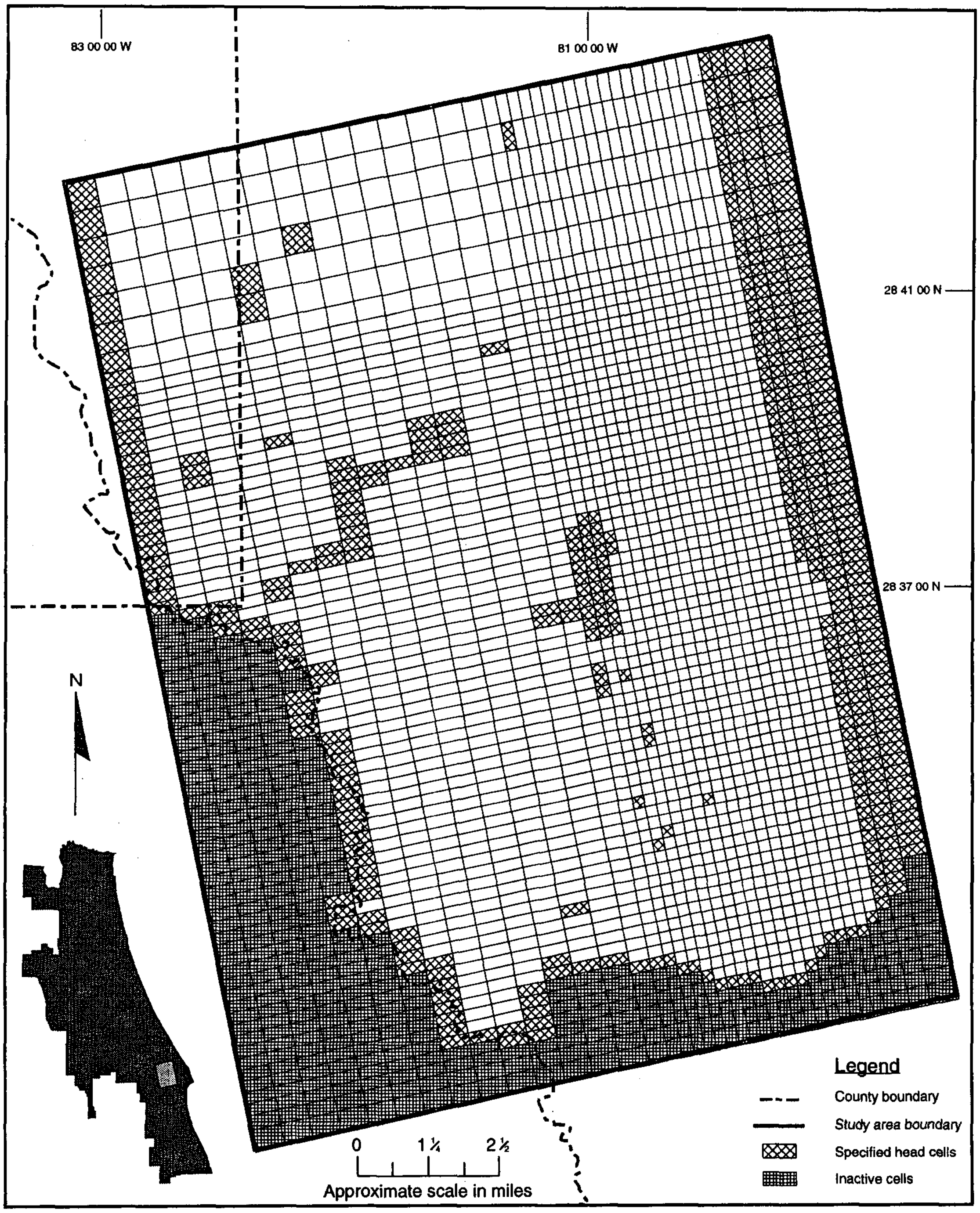

Figure 13. Finite-difference grid and boundary conditions for the surficial aquifer system (layer 1)

St. Johns River and south of the Addison Point Canal are inactive areas in the model. These areas are outside of the primary area of study and do not contribute significant amounts of flow to the model domain. The lateral boundary to the north is simulated as a no-flow boundary, which is implicit to the model at the edge of the finite-difference grid.

For layers 2 and 3 (the Upper and Lower Floridan aquifers), lateral boundary conditions employed are head-dependent flux conditions that represent the potentiometric surface along the upgradient (west/southwest) and the downgradient (east/northeast) sides of the principal area of interest (Figure 14; Table 9). The head-dependent flux boundary to the west and southwest is located along the St. Johns River to coincide with the boundary of the surficial aquifer system. Floridan aquifer heads along this boundary are set by interpolation of nearby potentiometric head contours from available regional potentiometric surface maps. For example, for the predevelopment simulations, the 40-ft potentiometric contour was used to set these boundaries, and a conductance value was calculated based upon the aquifer transmissivity and the distance from the model boundary to that potentiometric contour. Similarly, for the 1988 and 2010 simulations, these boundaries were set using the nearby 30-ft and 25-ft potentiometric contours, respectively. The heads in the Lower Floridan aquifer were set at 1 ft greater than those in the Upper Floridan aquifer because this area is generally a discharge area and therefore a modest upward hydraulic gradient exists. The northern edge of the inactive zone to the southeast is oriented perpendicular to the equipotential lines (contour lines along which the elevation of the potentiometric surface is represented with a single value) and represents a no-flow zone for the Floridan aquifer system. The areas to the north and south where no boundaries are specified are no-flow boundaries at the edge of the study area (Figure 14; Table 9).

The southern boundary for the Upper Floridan aquifer is not directly underneath the overlying boundary for the surficial aquifer system at the Addison Point Canal. This does cause a

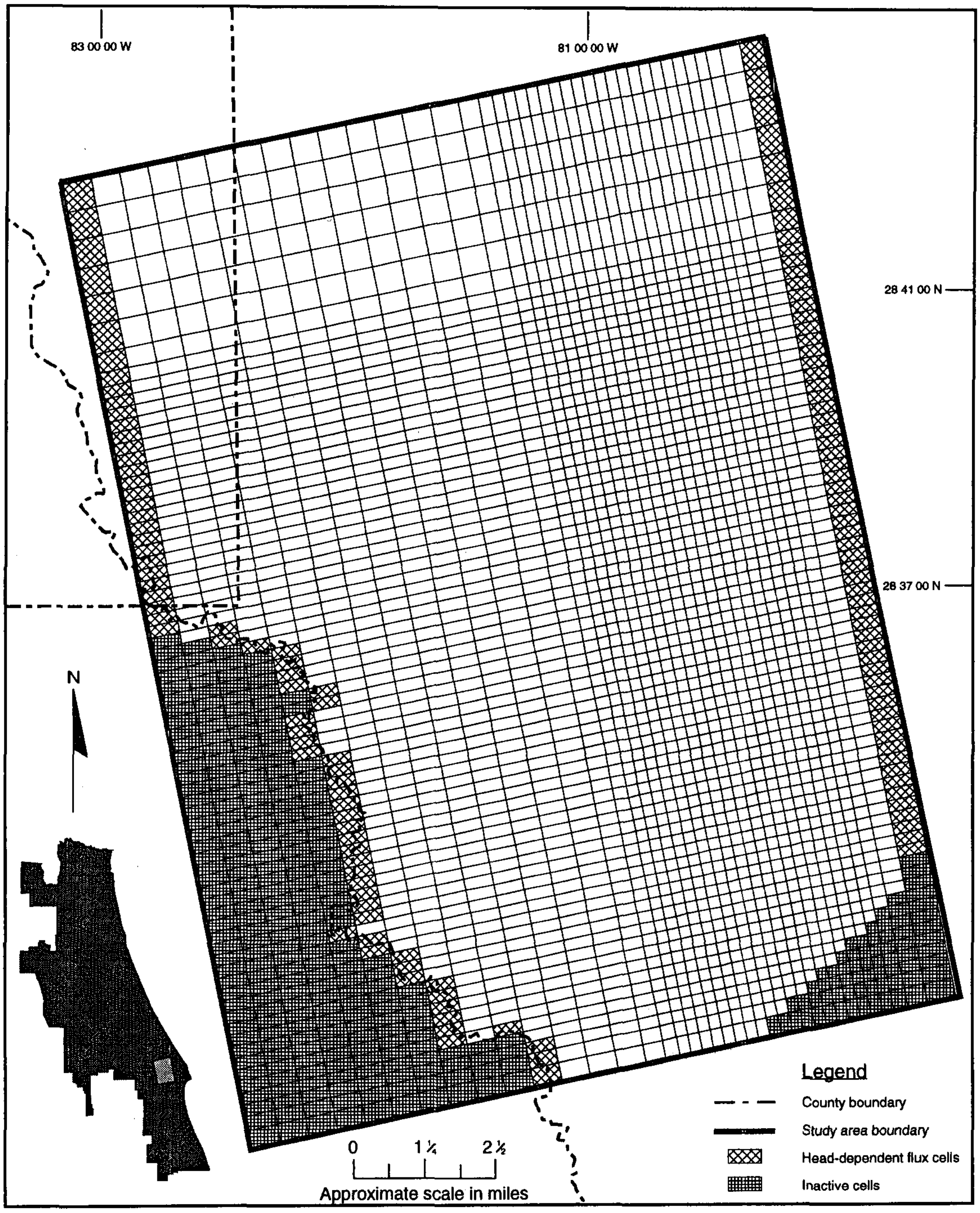

Figure 14. Finite-difference grid and boundary conditions for the Upper and Lower Floridan aquifers (layers 2 and 3)

minor conceptual problem for the model in this area. Specifically, a small area exists where the Floridan aquifer system is active but the overlying surficial aquifer system is inactive, thus leading to a misrepresentation of the hydraulic connection between the aquifers in this area. However, this sacrifice is reasonable given that the two boundary configurations are valid for the respective aquifers, and any loss of reliability for the overall model is trivial in regard to the area of focus—the vicinity of Titusville.

Internal Boundaries

Internal boundary conditions are those imposed throughout the interior of the study domain. For the current model, these conditions include evapotranspiration, recharge to the surficial aquifer system, wells, and lakes.

Evapotranspiration. The ground water flow model of the surficial aquifer system 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. Using the MODFLOW code, the function for evapotranspiration is a linear function specified over a range between minimum and maximum evapotranspiration values. For the current ground water flow model, the upper and lower limits of this range are 46 in/yr and 25 in/yr, respectively. These limits are adapted from previous studies involving evapotranspiration (Tibbals 1990; Visher and Hughes 1975; also see discussion of evapotranspiration on p. 25).

The treatment of evapotranspiration in MODFLOW also incorporates two additional parameters, 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. The extinction depth is the depth below land surface at which the evapotranspiration rate reduces to the minimum value. The extinction depth is not always well known, and it varies as a function of soil type and vegetative cover. Tibbals (1990) estimated a value of 13 to 15 ft in the RASA (Regional

Aquifer System Analysis) model study; however, in areas where the root zone is relatively shallow, a more shallow extinction depth may be more representative of local conditions (Tibbals, pers. com. 1992). An extinction depth of 12 ft is incorporated into the current model.

Figure 15 illustrates the evapotranspiration rates that are derived from the 1988 calibration of the model. As expected, higher rates of evapotranspiration occur in the terrace areas where the water table is closer to land surface. Lower evapotranspiration rates occur in the higher sandy ridges where the water table naturally occurs at a greater depth below land surface and where, in areas of pumping, the water table may be artificially depressed to levels well below the evapotranspiration extinction depth.

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 incorporated into the model are actually gross recharge (i.e., before evapotranspiration has occurred). The actual recharge that replenishes the surficial aquifer system is equal to gross recharge less evapotranspiration and runoff.

Rates for gross recharge were developed through analysis of soil type, following this rationale:

- The amount of precipitation that ultimately recharges the water table is dependent upon the storage potential of the unsaturated zone, the permeability of the soil, and relative rates for surface runoff and evapotranspiration.

- The thickest unsaturated zone exists in the coastal ridges where the soil is most permeable and where the potential for upward leakage from the Upper Floridan aquifer is low due to a predominant downward hydraulic gradient.

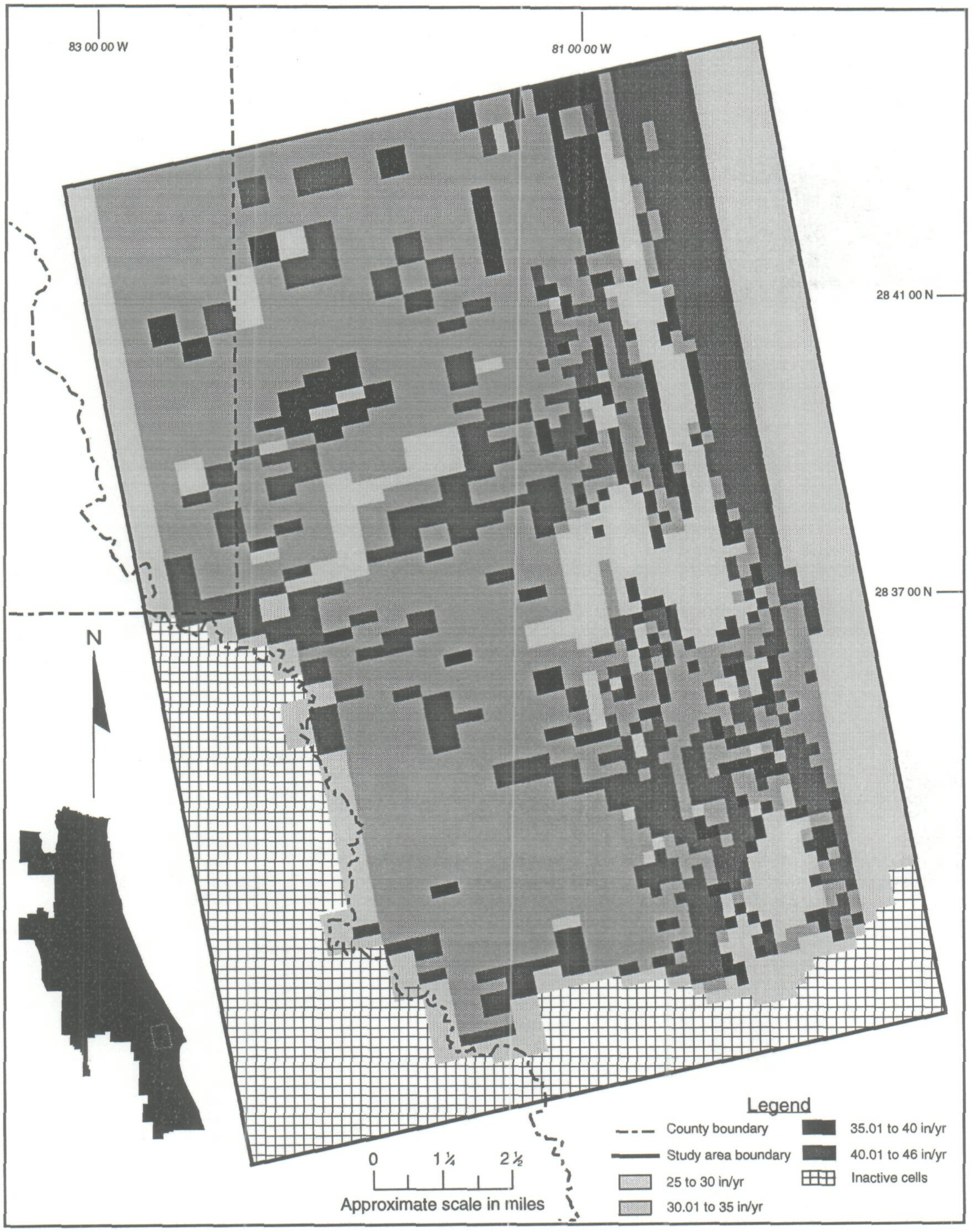

Figure 15. Simulated distribution of evapotranspiration in the surficial aquifer system based on the 1988 calibration (inches per year)

- The permeability of the soil directly affects the ability of the system to capture rainfall before it can become runoff or evapotranspiration.

- Evapotranspiration and runoff will be greatest (consequently recharge will be lowest) where low permeability of the soil or a thin unsaturated zone limit the potential of the water to infiltrate the soil.

The analysis to determine the gross recharge to the surficial aquifer system included the following steps.

1. A dominant soil type was determined for each surficial cell of the model through interpretation of a soils data base and analysis of the grid cell locations of the model.

2. Laboratory test results were used to rank area soils according to the saturated moisture content and the minimum hydraulic conductivity. The top-ranking soils were those with the lowest moisture content and the highest minimum hydraulic conductivity; these soils were designated as having the greatest recharge potential. Appendix A includes a list of area soil types, with associated values for moisture content and minimum hydraulic conductivity.

3. Five categories were developed to simulate a range from lowest to highest recharge potential.

4. Numerical values (in inches per year) were assigned to the ranked categories following the review of the findings of other researchers and through model calibration.

The soils are sorted into five categories for recharge potential. Figure 16 illustrates the distribution of potential recharge to the surficial aquifer system in the study area. In the sandy ridge areas, a low moisture content and a relatively high minimum hydraulic conductivity of the soil combine with a relatively thick unsaturated zone to facilitate the greatest potential for recharge. The recharge potential is lowest in the marshy areas of the

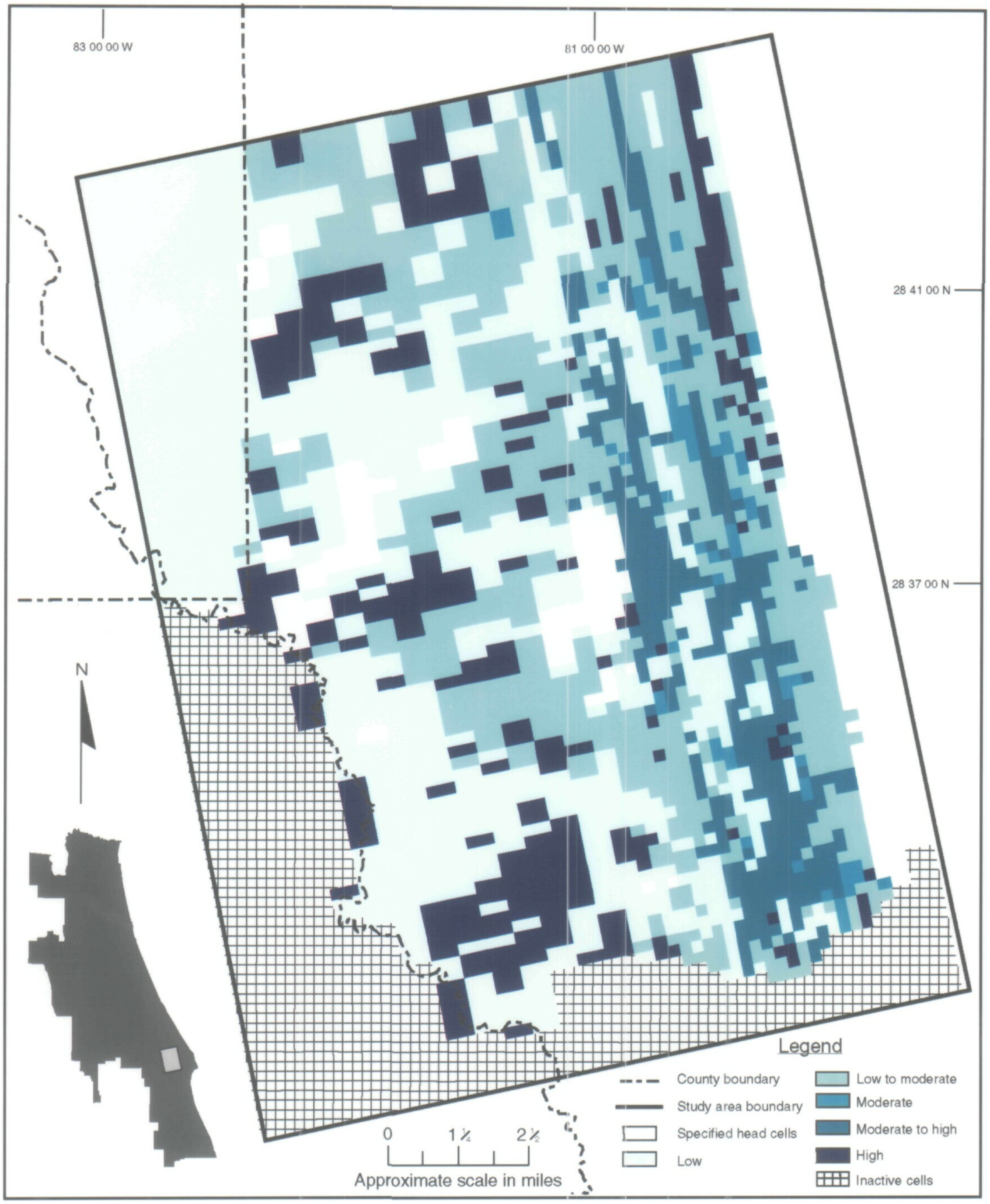

Figure 16. Potential recharge to the surficial aquifer system in the model area

St. Johns River valley and the lower elevation terraces. In these areas, a high moisture content and a relatively low minimum hydraulic conductivity combine with a thin or nonexistent unsaturated zone to reduce recharge potential.

With gross recharge values as input, the model then could simulate the actual or net recharge to the surficial aquifer system. In the model, this calculated recharge is equal to the total or gross recharge minus evapotranspiration and surface water drainage that exists. Figure 17 illustrates the range of net recharge for the surficial aquifer system that occurs in the 1988 calibration of the model. Recharge rates of greater than 12 in/yr occur in the area of the Atlantic Coastal Ridge, but rates of recharge are much less in the lower elevation areas.

Wells. Pumping wells are also a type of specified flux boundary condition in the model. Wells are included for all types of water use (p. 61–66). Pumpage values are assigned based on the assumptions outlined therein. Appendix B provides a complete summary of all pumping well characteristics and flux rates. Figure 18 illustrates the locations of all pumping wells that were incorporated into the model.

Lakes. All major lakes in the study area are modeled with specified head boundary conditions. These include South and Fox lakes, set at 16 ft msl (CRA-Sunbelt Surveyors 1990); and Loughman, Salt, and Buck lakes, set at 5, 6, and 7 ft msl, respectively, based upon interpretation of local topography; and several smaller lakes (Figures 2 and 13).

AQUIFER PARAMETERS

Hydraulic Conductivity

Hydraulic conductivity is a constant of proportionality that quantifies the ease with which a fluid can move through a porous media. It incorporates both characteristics of the fluid and the porous media. Results of aquifer performance tests that have been performed in the surficial aquifer system (Table 4) indicate

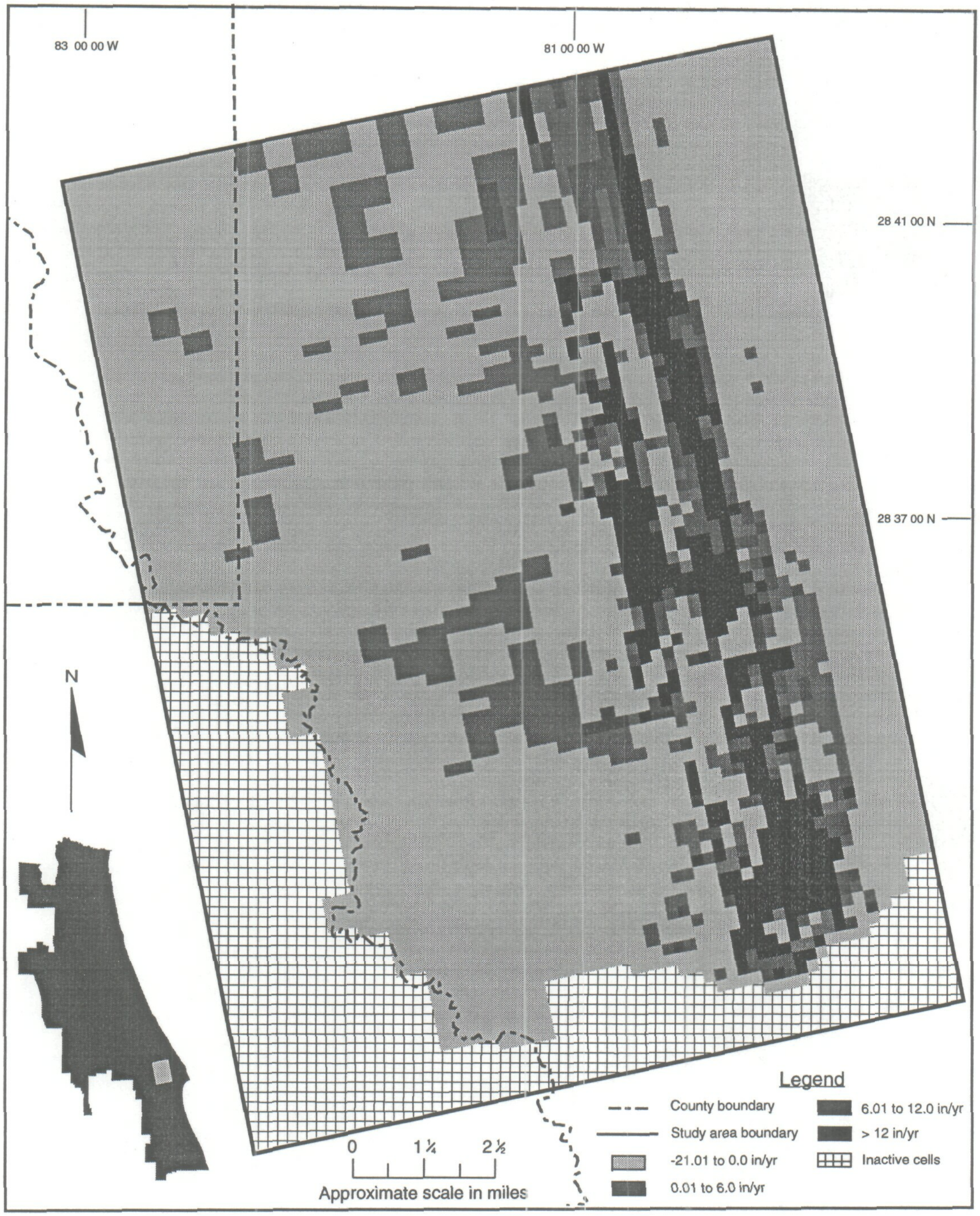

Figure 17. Simulated distribution of net recharge to the surficial aquifer system based on the 1988 calibration (inches per year)

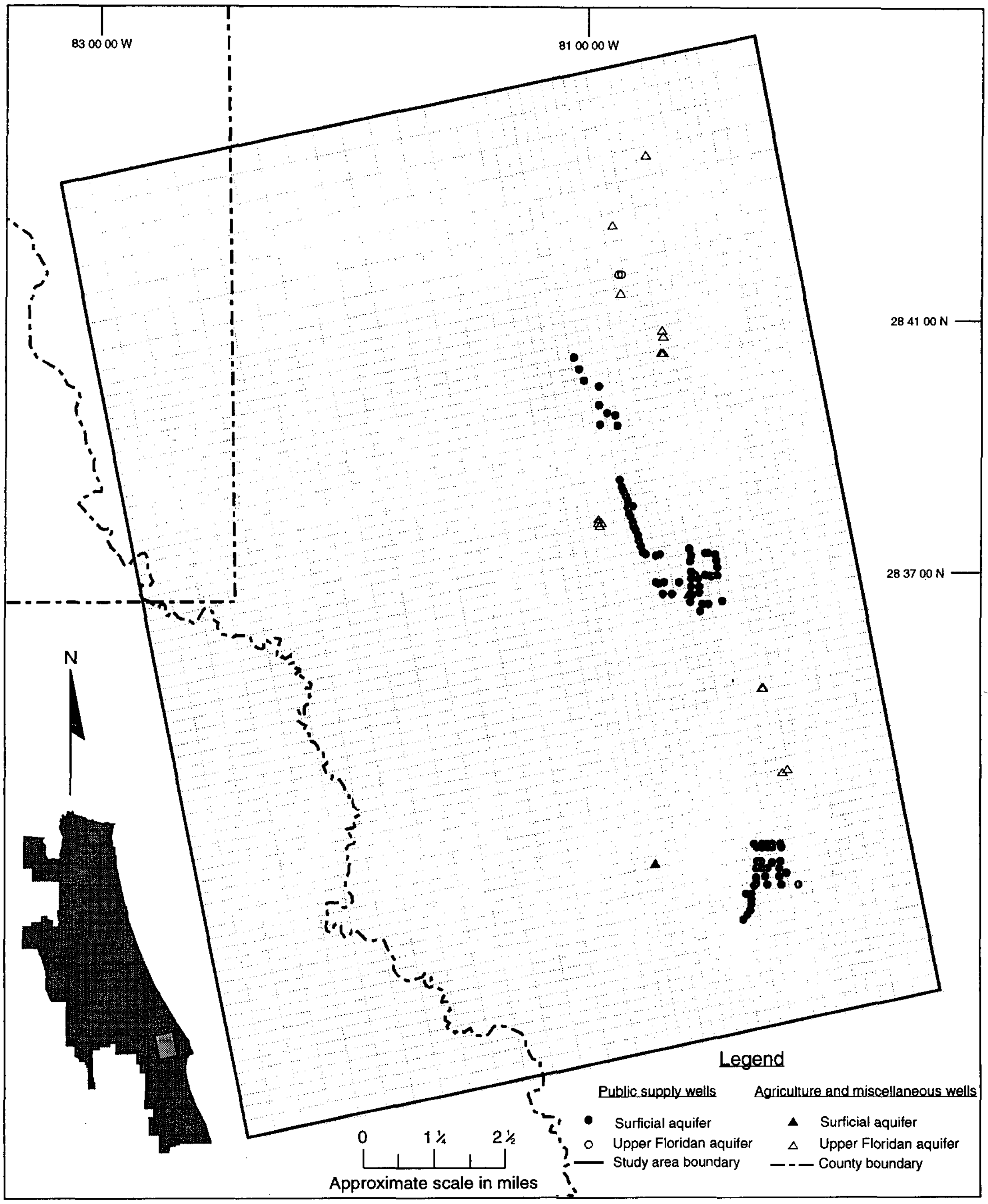

Figure 18. Locations of pumping wells used in the model

that estimates for hydraulic conductivity are available for Areas I, II, and III along the Atlantic Coastal Ridge and in the ridge areas near Mims. For the remaining parts of the study area, there is virtually no knowledge regarding the permeability of the sediments other than that regarding the soils or general characteristics of the ridge and terrace areas from other studies. The hydraulic conductivity values that have been used in the model are based upon the aquifer performance test results, information regarding the depositional history and soil types throughout the study area, and trial-and-error efforts that are inherent to the model calibration process. The range for hydraulic conductivity of the surficial sediments is between 5 feet per day (ft/day) in the lower terrace areas and 80 ft/day in parts of the Atlantic Coastal Ridge. Figure 19 depicts the ranges of hydraulic conductivity values for the surficial aquifer system that were used in the final calibrated model.

Leakance

The sediments that underlie the surficial aquifer system and overlie the Upper Floridan aquifer form a regional confining layer, which is extremely variable in composition and is both vertically and horizontally heterogeneous. These sediments are simulated in the model through use of leakance values that determine the sensitive hydraulic connection between these two aquifer systems. High leakance values could contribute to water quality problems in the surficial aquifer system because the freshwater lenses of this system are perched upon the highly mineralized water of the Floridan aquifer system, with the potential for significant hydraulic connection between these two aquifer systems.

Mathematically, the leakance of a confining unit is proportional to its vertical hydraulic conductivity (K_v) and inversely proportional to its thickness (b) (i.e., higher K_v contributes to higher leakance values; greater thickness contributes to lower leakance values). Values for the thickness of the confining sediments are available from an SJRWMD study of recharge to the Upper Floridan aquifer (Boniol et al. 1993).

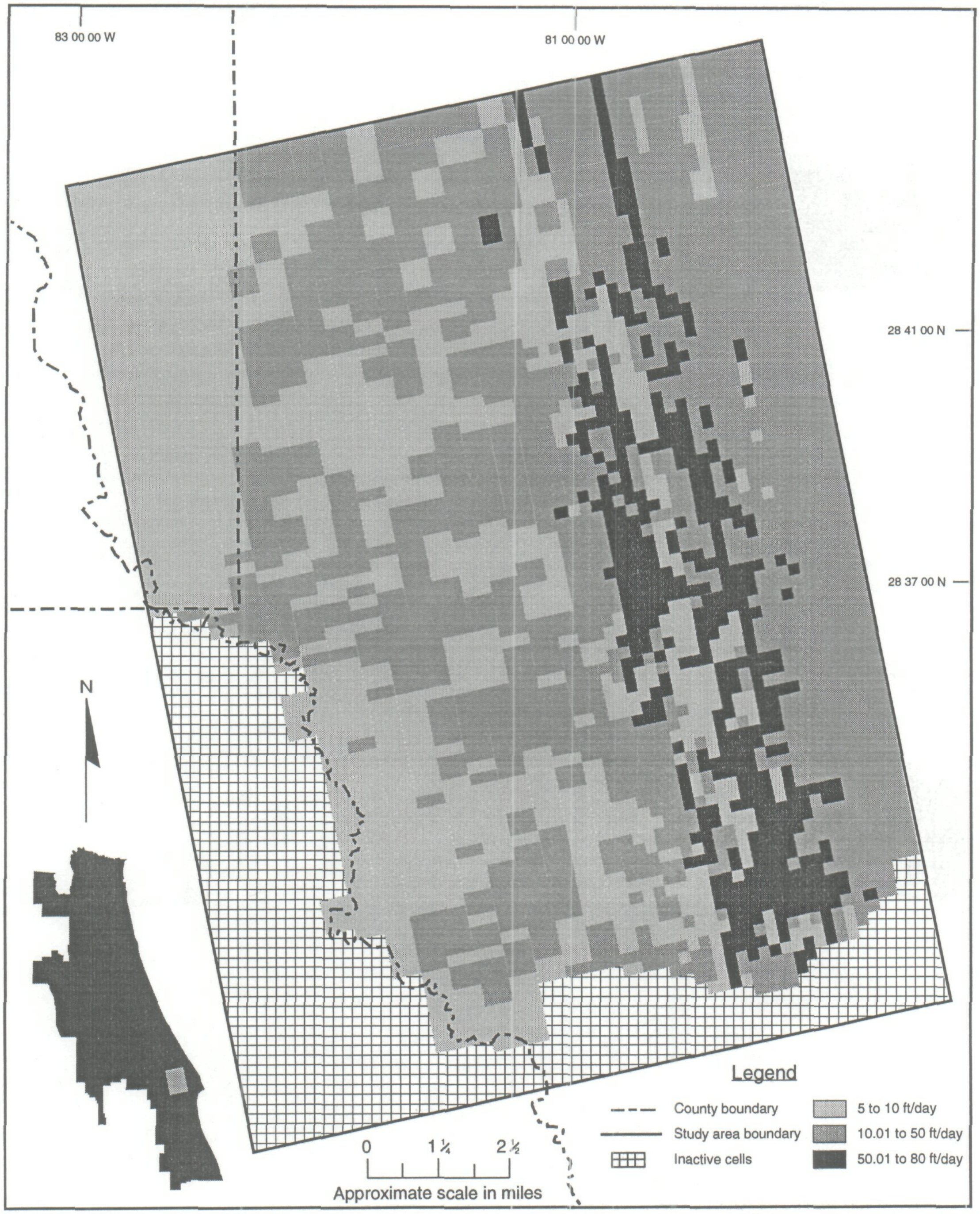

Figure 19. Simulated distribution of hydraulic conductivity in the surficial aquifer system (feet per day)

Leakance values were derived by dividing the vertical hydraulic conductivity by the thickness of the upper confining unit as depicted in Figure 9. The value for vertical hydraulic conductivity that was used for this study was 2.83×10^{-3} ft/day.

This value is in line with median vertical hydraulic conductivity values from selected core samples from the confining layer, which were interpreted in a concurrent study of recharge to the Upper Floridan aquifer (Boniol et al. 1993). Due to the high degree of vertical and horizontal heterogeneity of the confining beds in the study area, the leakance values that are used in the model represent only the extent of the hydraulic connection between the Floridan and surficial aquifer systems. These leakance values do not necessarily represent the actual leakance and vertical hydraulic conductivity that is measurable in specific clay lenses or other confining strata that may exist in the study area.

Leakance values also are used to characterize the hydraulic connection between the Upper and Lower Floridan aquifers. These leakance terms represent the low permeability, micritic limestone of the middle third of the Avon Park Formation. In the characterization of the middle semiconfining unit, a spatially uniform leakance value of 5×10^{-5} d^{-1} (Tibbals 1990) was used for the entire study area.

Transmissivity

Transmissivity of the Upper Floridan aquifer is set at a spatially uniform value of 60,000 ft^2/day. This value is within reasonable bounds established by previous studies (Table 6).

Transmissivity of the Lower Floridan aquifer was set at 60,000 ft^2/day and was based upon that used by Tibbals (1990) in the regional flow model of east-central Florida.

WATER USE

The regional ground water flow model was calibrated to both a predevelopment and a postdevelopment condition. For the postdevelopment calibration (September 1988 conditions), water use values were compiled for public supply, agricultural, and miscellaneous uses. Similarly, representative water use projections were estimated for the year 2010 based upon comprehensive plans, information from local public supply utilities, and related sources. These projected water use values were then used in the calibrated model to perform predictive simulations for the year 2010.

Public Supply

The primary water user in the study area is the City of Titusville. The city has developed two major wellfields to serve its public water supply needs. Both wellfields have been developed in the surficial aquifer system and tap the freshwater resources available in the previously defined Areas II and III (Figure 3).

The Area II wellfield (Figures 3 and 18) consists of 49 wells, with depths of between 80 and 120 ft bls. The total rated capacity of the wellfield is 8.5 million gallons per day (mgd) (DRMP 1990). RS&H (1978) calculated a maximum safe yield for the wellfield of 6.0 mgd, with a recommendation that 60% of pumped water should come from the higher yield wells along Interstate 95 (I-95) and 40% from the remaining 28 wells to the east. This recommendation was based on general findings that the specific capacity of the I-95 wells was generally higher than that of the older, eastern wells. Also, the older wells were more subject to poor water quality and greater drawdowns due to lower transmissivity than that exhibited for the wells along I-95.

The communities of Titusville and Mims are the two primary public supply users in northern Brevard County. In order to determine water use values for the 1988 calibration of the regional flow model, the following methodology was applied.

1. The total amount of pumping for September 1988 was obtained from the Monthly Operating Reports (MORs) filed with the Department of Environmental Regulation.

2. SJRWMD obtained information from the local utilities and from MORs regarding wells that had been abandoned and average discharge rates for wells in use.

3. A total average discharge value was determined for each wellfield or service area for September 1988.

4. Flow rates for individual wells were assigned, based upon the ratio of the average discharge rate for each well to the total average discharge value.

For example, if the average discharge rate for a well is 300 gallons per minute and the total discharge value for a wellfield is 10 mgd (or 6,944.44 gallons per minute), then the ratio for that well is 300 ÷ 6,944.44 or 0.0432 (4.32%). Therefore, if the total wellfield flux for September 1988 was 6 mgd, then the flux value assigned to that one particular well was 0.0432 × 6 mgd or 0.2592 mgd. All pumpage values were converted to units of cubic feet per day for use in the model.

Aggregate pumpage values for the City of Titusville are 4.73 mgd for the Area II wellfield and 0.95 mgd for the Area III wellfield for the 1988 calibration. For the Mims wellfield, total 1988 pumpage used was 0.56 mgd. One minor public supply exists in the area—Northgate Properties. The pumpage was not available on an MOR; the permitted value from the CUP was used.

Public Supply—Impacts Upon Water Quality

In 1980, pumping in the Area II wellfield decreased water levels to 0 to −10 ft msl in the I-95 wells and to 0 to −20 ft msl in the eastern wells, with individual well drawdowns of up to −60 ft msl (Frazee, pers. com. 1980). These high individual well drawdowns were attributable to high amounts of fine sediment buildup around the wellbores. The western wells in Area II, which have been drilled into the thickest part of the freshwater lens, produce the most stable water quality; similarly, the eastern wells in Area II have shown wide fluctuations in water quality due to seasonal stress, low specific yield, and a thinner freshwater lens. In these eastern wells of Area II, geochemical analysis has indicated that chloride increases are attributable to the connate intrusion of the Floridan aquifer system water (as opposed to lateral intrusion). In 1980, 18 of these eastern wells showed indications of connate intrusion.

Agricultural and Miscellaneous Use

In northern Brevard County, agricultural and miscellaneous water use plays a relatively small part in the impacts upon the aquifer system. Agricultural use includes citrus, foliage, and pasture; and miscellaneous uses include emergency fire protection, golf course irrigation, and other applications. Pumpage estimates for agricultural wells were developed through use of a value for use per acre for a given crop from a regional study of agricultural water use (Lynne and Kiker 1992) and multiplying this value by the total acreage for a given use. Uses for golf course irrigation and miscellaneous other applications were adapted from the average permitted values listed in the SJRWMD CUPs. Use for emergency fire protection was set at zero, based on frequency of use.

Many smaller wells exist in the study area for the purposes of domestic self-supply and lawn irrigation. In 1980 there were approximately 2,000 wells within the Area II boundary. Of this number, private wells made up approximately 97.5% of the total. Of the private wells, 78% were used for lawn irrigation, of which less than 10% were coupled with water-to-air systems (Frazee, pers. com. 1980). These smaller wells for domestic self-supply and lawn irrigation were not specifically included in this model for the following reasons.

1. The calibration period of September 1988 is during the wet season, when most lawn irrigation wells would not be used.

2. Most wells for domestic self-supply exist outside of the service areas for Titusville and Mims and would have only a very localized effect on the freshwater resources at those locations.

3. Where wells for domestic self-supply do exist, the effect in the model can be viewed as a net decrease in recharge to the surficial aquifer system.

4. There is no existing digital data base of these wells. Estimating the locations and flux rates for these wells could introduce more error into the model than would be justified by including the flux rates.

Projections for 2010 Use

Public supply use for the year 2010 was estimated after a review of the potable water supply element of the Brevard County Comprehensive Plan (Brevard County Planning Department 1988). Growth estimates were verified with local government contacts. These figures were applied to individual wells in a similar manner as in the 1988 calibration, with the following exceptions.

1. Well discharge values for the Titusville Area II wellfield were modified to account for a planned wellfield renovation program that would increase the specific capacity of many of these wells (DRMP 1990).

2. Total pumping from the Titusville Area III wellfield was limited to 1.1 mgd based upon discussions with staff from the city's water department (Chaffee, pers. com. 1994).

3. Where a plan exists for addition of proposed wells to satisfy future demand (e.g., Mims utility), these proposed wells are included in the 2010 projections.

Water for agricultural and miscellaneous uses was kept constant at the values used in the 1988 calibrated model. The rationale for this is as follows.

1. The IFAS (Institute of Food and Agricultural Sciences, University of Florida) report (Lynne and Kiker 199) projects

virtually no increase in agricultural water use in Brevard County.

2. There is no basis on which to project a significant change in the agricultural or miscellaneous water use patterns in the study area for the period of 1988 to 2010.

All 2010 water use values were incorporated into a new data base for the ground water flow model in order to develop the predicted hydrologic impacts of these projected water use values.

The aggregate pumpage values for the City of Titusville for 2010 are 5.7 mgd for the Area II wellfield and 1.1 mgd for the Area III wellfield. These values are based upon a projected need of 9.8 mgd less 3 mgd which is planned as part of an interconnection agreement with the City of Cocoa Beach (Chaffee, pers. com. 1994). The projected value for the community of Mims is 1.9 mgd, based upon projections in a recent CUP application.

MODEL CALIBRATION

The Titusville/Mims regional ground water flow model was calibrated both to a predevelopment condition and to the postdevelopment condition of September 1988. The postdevelopment calibration served as the primary focus of the calibration process for this model for these reasons: (1) there is significantly more calibration data for this time period and (2) aquifer parameter estimates derived from a postdevelopment calibration are more reliable than those estimated when no stress has been imposed on the aquifer system.

Calibration of a ground water model is an iterative process of integrating the best available information about the aquifer system into the model. The first step in the process is determination of the optimal set of aquifer parameter values (e.g., hydraulic conductivity, leakance, transmissivity) and boundary conditions that best characterize the hydrogeologic system. These values and conditions are incorporated into the model, and the effectiveness of the model is assessed by comparing its results with the observed hydrologic system. During calibration, aquifer parameters are tested within reasonable ranges determined through either aquifer testing or previous studies of the system. The model parameters that were adjusted during the calibration process for this model included the following.

- Recharge rates of the surficial aquifer system
- Extinction depth for evapotranspiration
- Hydraulic conductivity distribution in the surficial aquifer system
- Vertical hydraulic conductivity of the upper confining unit

Measures of the reliability of a model calibration may be either quantitative or qualitative. Quantitative calibration checks could include comparisons with monitoring well data or measured spring flows. An example of a qualitative calibration check is a comparison of model results with existing potentiometric surface maps. The specific mechanisms for verifying the reliability of the calibration of the current model included one quantitative check and one qualitative check.

- An assessment of the match between the monitoring well data for both the Upper Floridan aquifer and the surficial aquifer system and model results for these locations
- An assessment of the match between the potentiometric surface map for the Upper Floridan aquifer developed by USGS and that produced by the model

In addition to these calibration criteria, the model also was subjected to two general reliability checks to ensure that model results are within reasonable ranges based on existing knowledge. These checks included the following.

- A comparison of the distribution of recharge/discharge flux values between the surficial aquifer system and the Upper

Floridan aquifer that had been developed in earlier studies with those derived from the model

- An evaluation of water table values throughout the study area based upon development and application of a polynomial regression equation

Predevelopment Calibration

A model calibration to predevelopment conditions is necessarily qualitative due to the degree of uncertainty associated with interpretation of these conditions. The map of the predevelopment potentiometric surface that was developed by Johnston et al. (1980) was based on a composite of recent potentiometric surface maps for the Floridan aquifer system for locations relatively unaffected by pumping and of older or modified potentiometric surface maps in areas of heavier pumping. The predevelopment surface, as developed, also represents a long-term average condition. In reality, the predevelopment surface fluctuated both seasonally and in response to long-term wet and dry cycles (Tibbals 1990).

Procedure. As discussed, the calibration process entails determination of the best set of boundary conditions and aquifer parameters which, when put together into the simulation model, will achieve the objectives of the calibration process. For the predevelopment calibration, the primary calibration criterion is the match between the simulated and interpolated potentiometric surfaces for the Upper Floridan aquifer in the study area. An additional check on the reliability of the predevelopment calibration entailed a comparison of the pattern for recharge/discharge fluxes between the Upper Floridan aquifer and the surficial aquifer system with those in earlier studies.

Results and Discussion. Figures 20 and 21 depict the estimated and simulated predevelopment potentiometric surfaces of the Upper Floridan aquifer, respectively. Comparison of these figures indicates a good match, particularly given the qualitative nature of the estimated predevelopment condition.

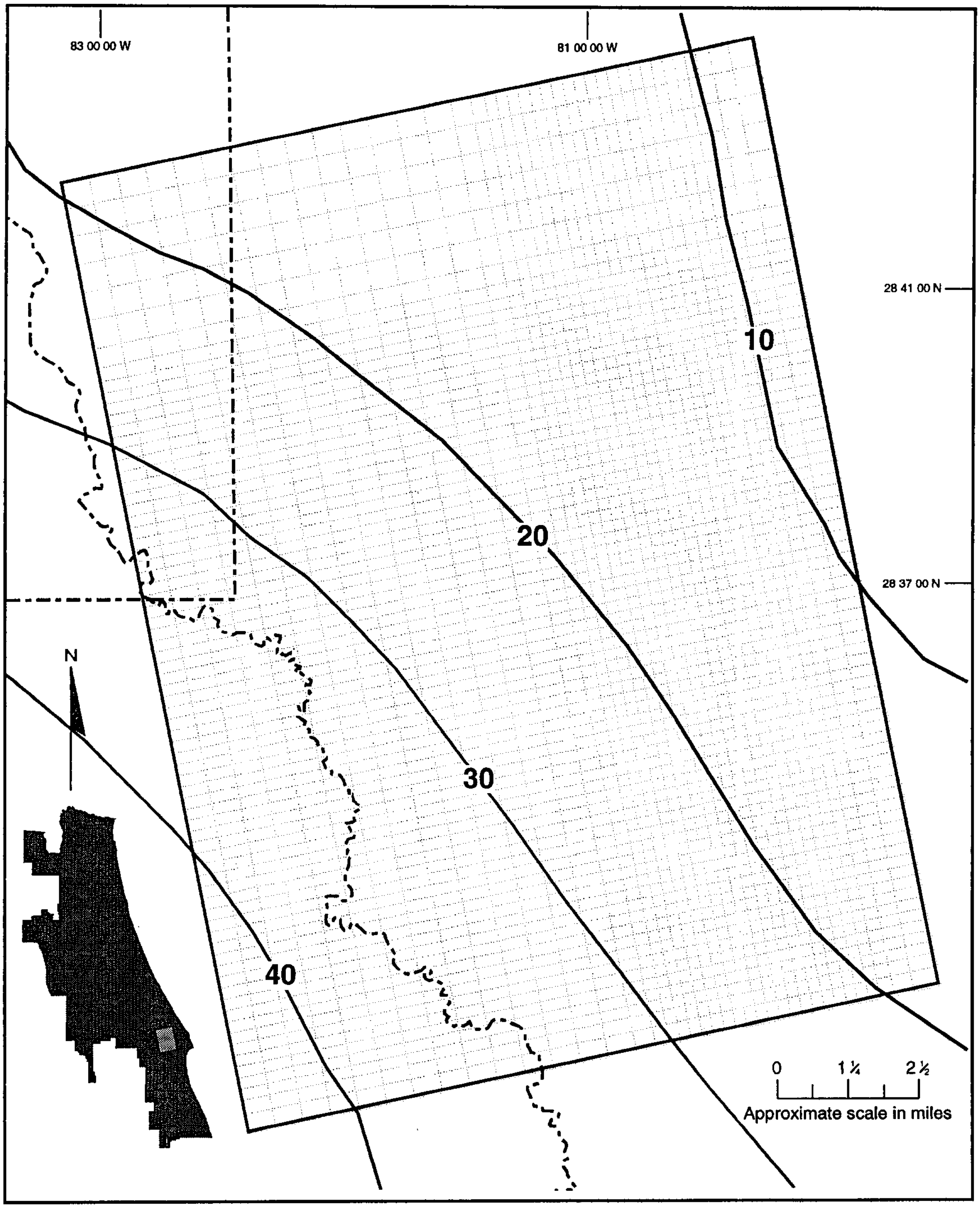

Figure 20. Estimated predevelopment potentiometric surface of the Upper Floridan aquifer (feet mean sea level) (Johnston et al. 1980)

Legend
County boundary
Study area boundary
—10— Potentiometric surface contour

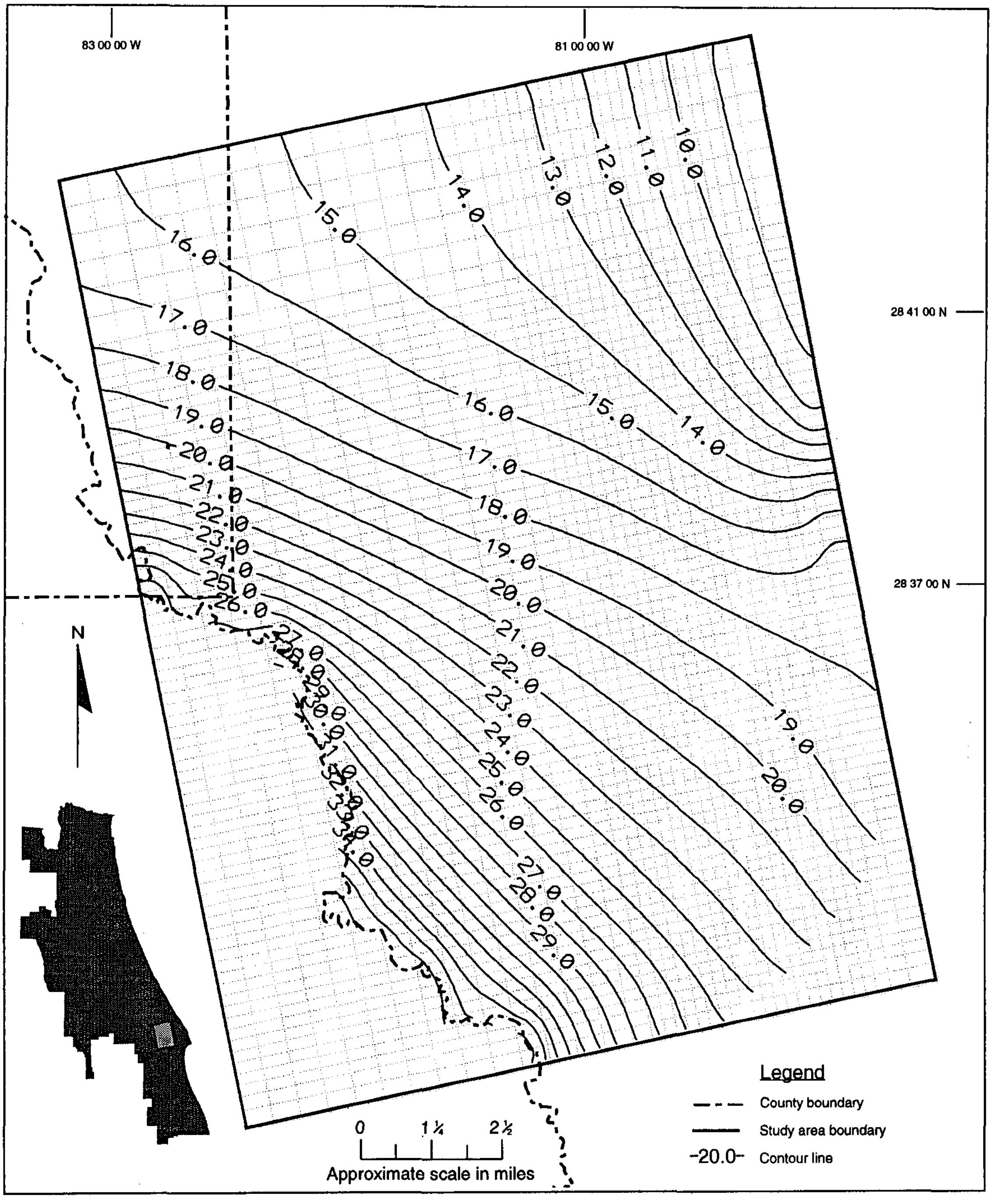

Figure 21. Simulated predevelopment potentiometric surface of the Upper Floridan aquifer (feet mean sea level)

Figure 22 provides an illustration of the simulated predevelopment water table elevation in the surficial aquifer system. Lack of information regarding the predevelopment water table precludes making an observed water table map that would be analogous to the estimated predevelopment potentiometric surface map for the Upper Floridan aquifer. Therefore, no rigorous comparison can be made between the observed and model-simulated water table configurations.

Most of the study area is a discharge area for the Upper Floridan aquifer, with a relatively narrow band of low to moderate (2–4 in/yr) recharge under the area of the Atlantic Coastal Ridge and extending north to the Volusia County line (Figure 23). The distribution of recharge to and discharge from the Upper Floridan aquifer that is simulated in the current model fits very well with results from previous USGS studies (Tibbals 1990; Phelps 1984) and from an earlier study at SJRWMD (Boniol et al. 1993) (Figure 11).

Postdevelopment Calibration

The postdevelopment calibration for the ground water flow model represents hydrologic conditions that existed in September 1988. The year 1988 was chosen because analysis of long-term hydrographs indicated that this was a time when the surficial aquifer system and the Floridan aquifer system were in a quasi-steady-state condition. In other words, the water level trends for 1988 are representative of long-term average conditions.

Procedure. The first step in the postdevelopment calibration process involved identifying and locating all significant water uses in the study area (p. 61). These water use values were incorporated into the model at the appropriate locations.

Next, the boundary conditions for the potentiometric surface of the Upper Floridan aquifer were modified to be representative of conditions that existed in 1988. Conductance values and source heads for these head-dependent flux boundaries were modified in order to simulate the effects of the regional potentiometric surface

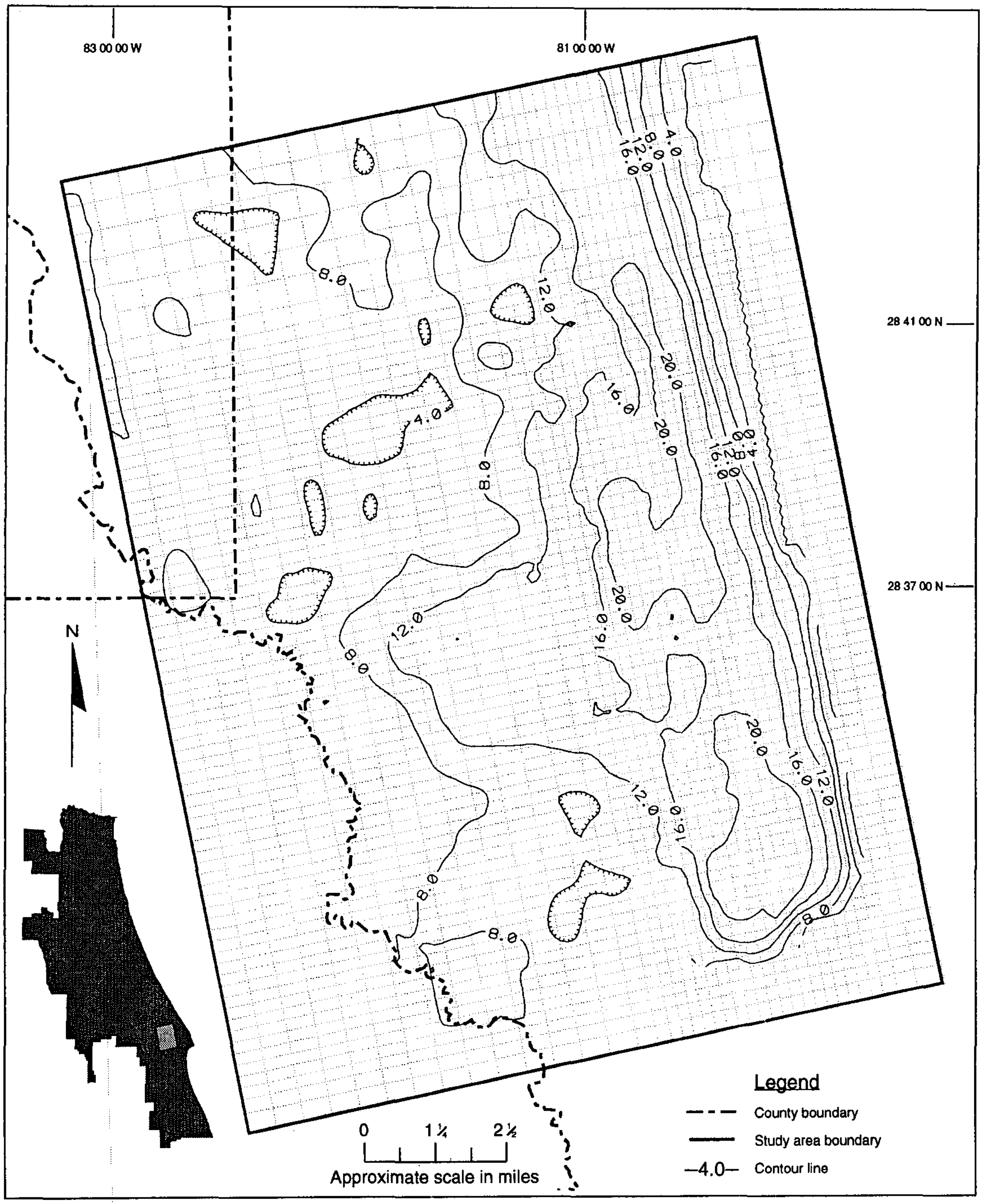

Figure 22. Simulated predevelopment water table elevation in the surficial aquifer system (feet mean sea level)

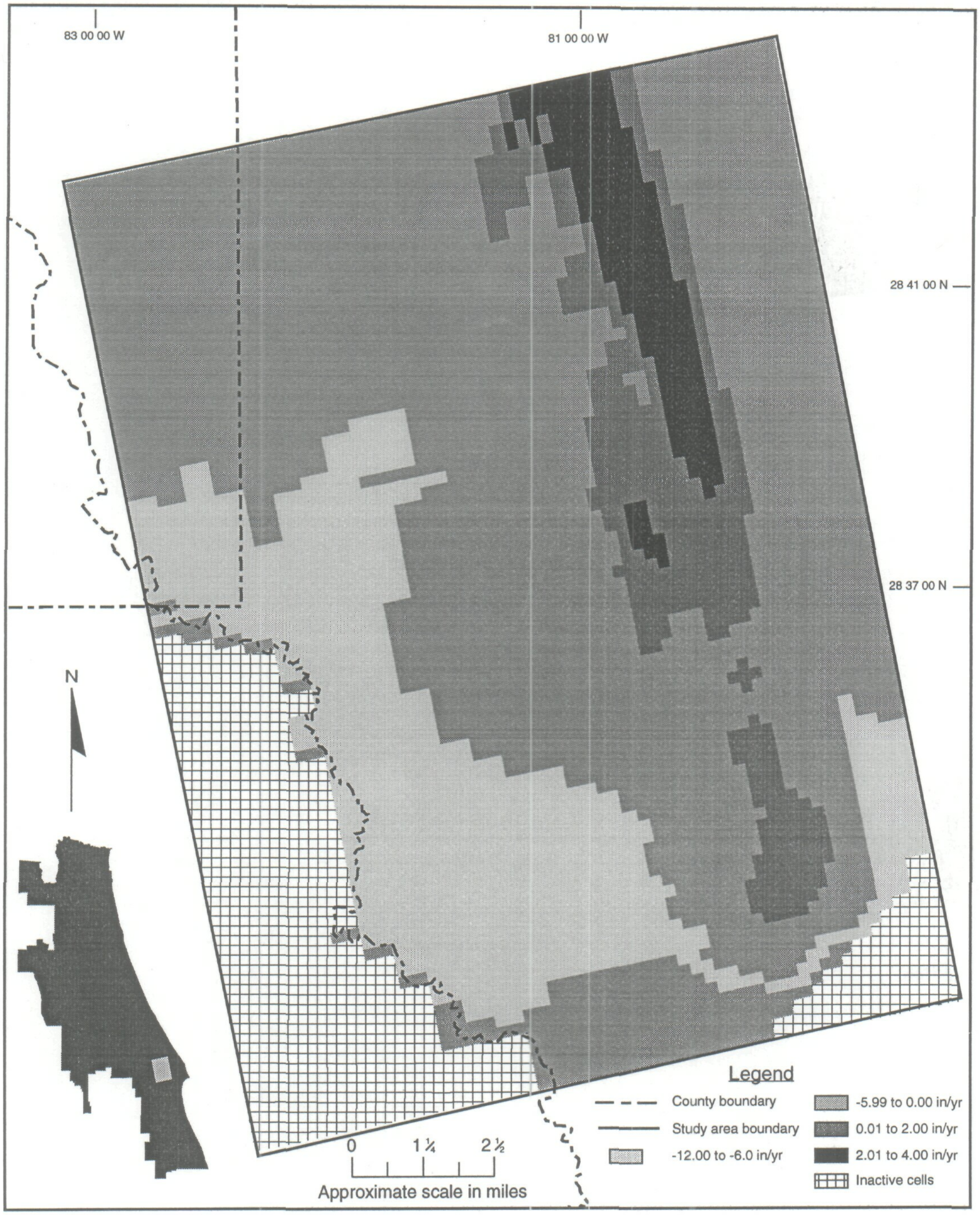

Figure 23. Distribution of recharge to and discharge from the Upper Floridan aquifer based on the predevelopment calibration (inches per year)

upon the smaller area within the model domain. All other aquifer parameter values and boundary conditions are identical to those used in the predevelopment calibration. The specific mechanisms for verifying the reliability of the postdevelopment calibration include comparison of the following.

- The match between monitoring well data for both the Upper Floridan aquifer and the surficial aquifer system and model results at these locations

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

Additional checks on the reliability of the postdevelopment calibration entailed the following.

- An evaluation of water table values throughout the study area through development and application of a polynomial regression correlation analysis

- An assessment of the match between simulated internal flux rates (e.g., recharge, evapotranspiration) for the surficial aquifer system and the Upper Floridan aquifer with those described in earlier studies

Results and Discussion. Table 10 provides a summary of the match between the simulated and the observed piezometric head values for all monitoring wells used for the 1988 calibration. Figure 24 illustrates the locations of these wells, and Appendix C is a descriptive list of associated monitoring well characteristics.

The next check on the reliability of the model is a comparison of the observed versus the simulated potentiometric surface for the Upper Floridan aquifer (Figures 25 and 26). The fit is very good, with one exception. The observed surface shows a depressed area in the northeast part of the model area. The primary reason for this dip is a monitoring well, USGS #284116080514001, that registered a measured head value of 6.66 ft msl in September

Table 10. Summary of observed versus simulated piezometric head values for monitoring wells used in the September 1988 calibration

Well Identification*		Row	Column	Aquifer	Observed (ft msl)	Simulated (ft msl)	Residual (ft)
Brevard Co. #841052014	1	8	21	Surficial	15.71	15.79	0.08
Brevard Co. #841052013	2	9	20	Surficial	13.16	15.30	2.14
Brevard Co. #839051006	3	22	21	Surficial	13.17	14.18	1.01
Brevard Co. #837052008	4	29	15	Surficial	13.97	10.37	-3.60
SJRWMD BR0584	5	32	23	Surficial	13.45	13.01	-0.44
Brevard Co. #843050002	6	4	30	Upper Floridan	10.41	11.81	1.40
USGS #283955080565701	7	11	7	Upper Floridan	13.58	12.29	-1.29
USGS #283906080514501	8	22	21	Upper Floridan	14.32	13.32	-1.00
Brevard Co. #837052007	9	29	15	Upper Floridan	12.89	14.03	1.14
SJRWMD BR0585	10	32	23	Upper Floridan	14.55	14.03	-0.52
USGS #283644080574901	11	32	4	Upper Floridan	16.4	16.26	-0.14
USGS #283627080512001	12	38	20	Upper Floridan	16.04	14.72	-1.32
USGS #283236080535101	13	58	10	Upper Floridan	18.4	18.80	0.40

*Column 1 indicates agency number; column 2 corresponds to identification number on Figure 24.

Note: ft msl = feet, mean sea level
ft = feet

1988. However, examination of the record for this well and discussions with staff of the Brevard County Water Resources Department indicated that this well measurement was not reliable due to its proximity to a nearby public supply well (Bud Timmons, Brevard County Water Resources Department, pers. com. 1992). As a consequence, both USGS and Brevard County have now dropped this well from the monitoring networks.

Figure 27 illustrates the simulated potentiometric surface for the Lower Floridan aquifer in the 1988 calibration. No comparisons with actual data are possible for this aquifer as there is little data regarding the actual potentiometric surface for the Lower Floridan aquifer in the study area. Therefore, this aquifer was

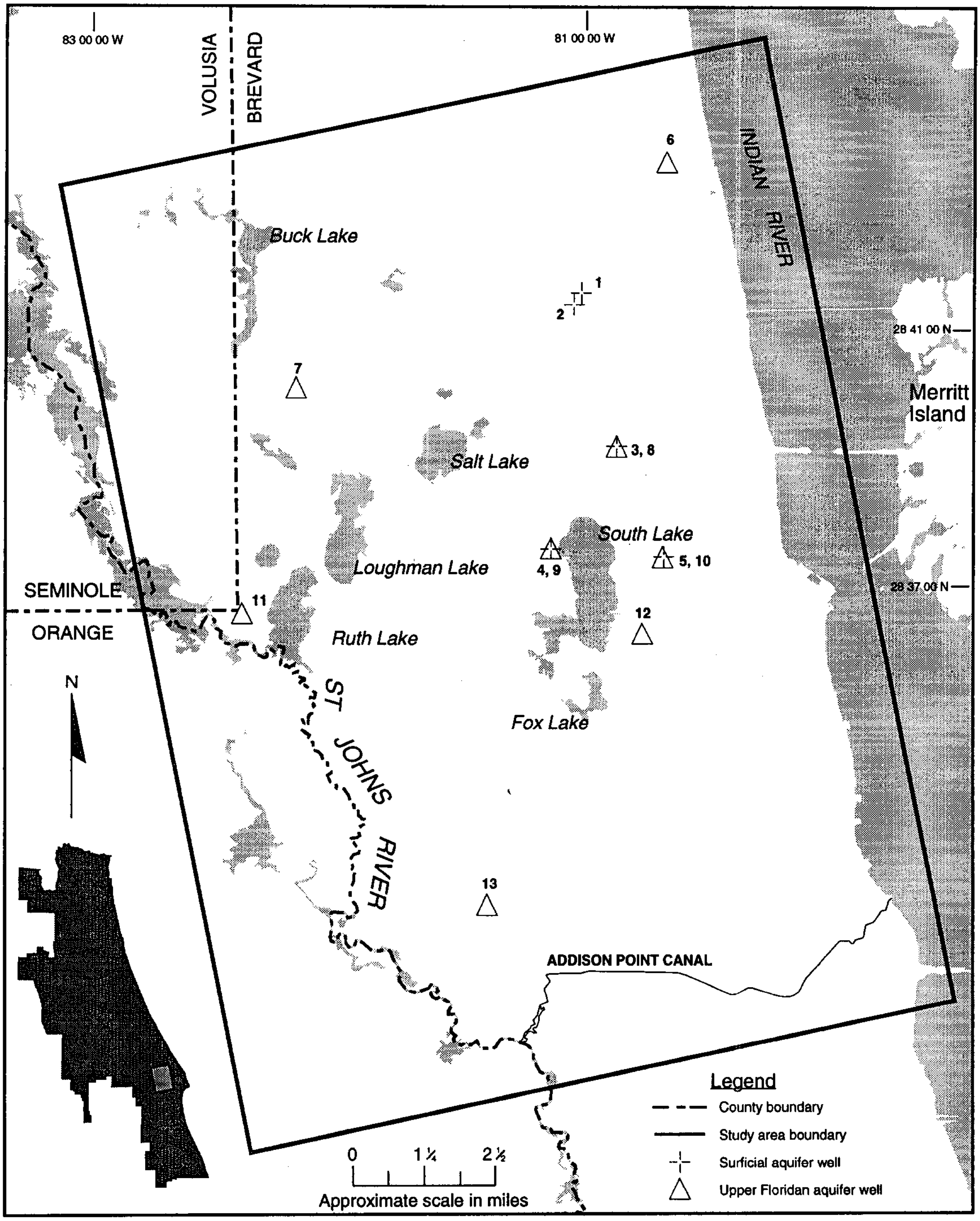

Figure 24. Locations of monitoring wells in the study area (see Table 10 for identification of well numbers)

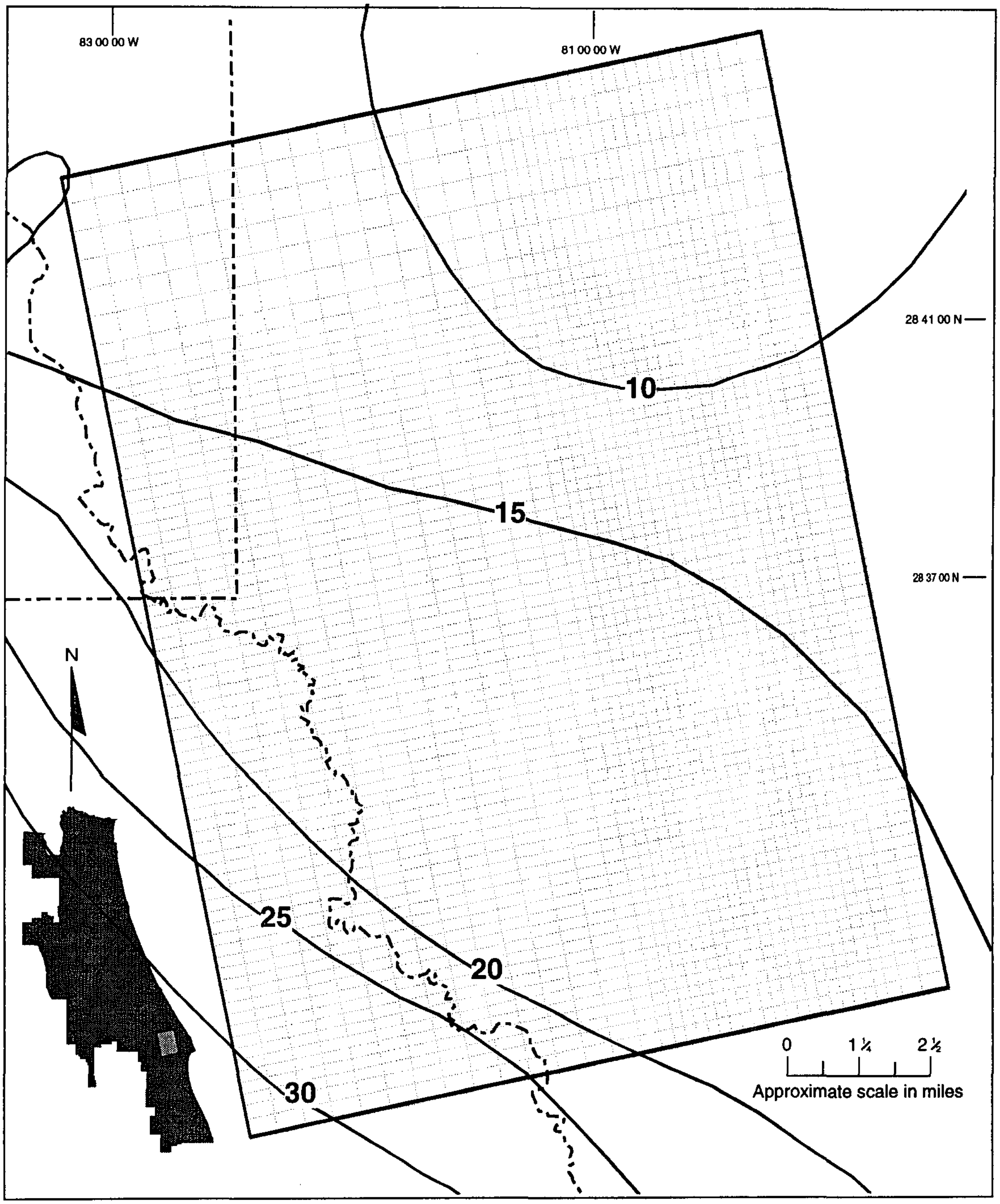

Figure 25. Observed potentiometric surface of the Upper Floridan aquifer, September 1988 (feet mean sea level)
(Rodis 1989)

Legend
- County boundary
- Study area boundary
- 10 Potentiometric surface contour

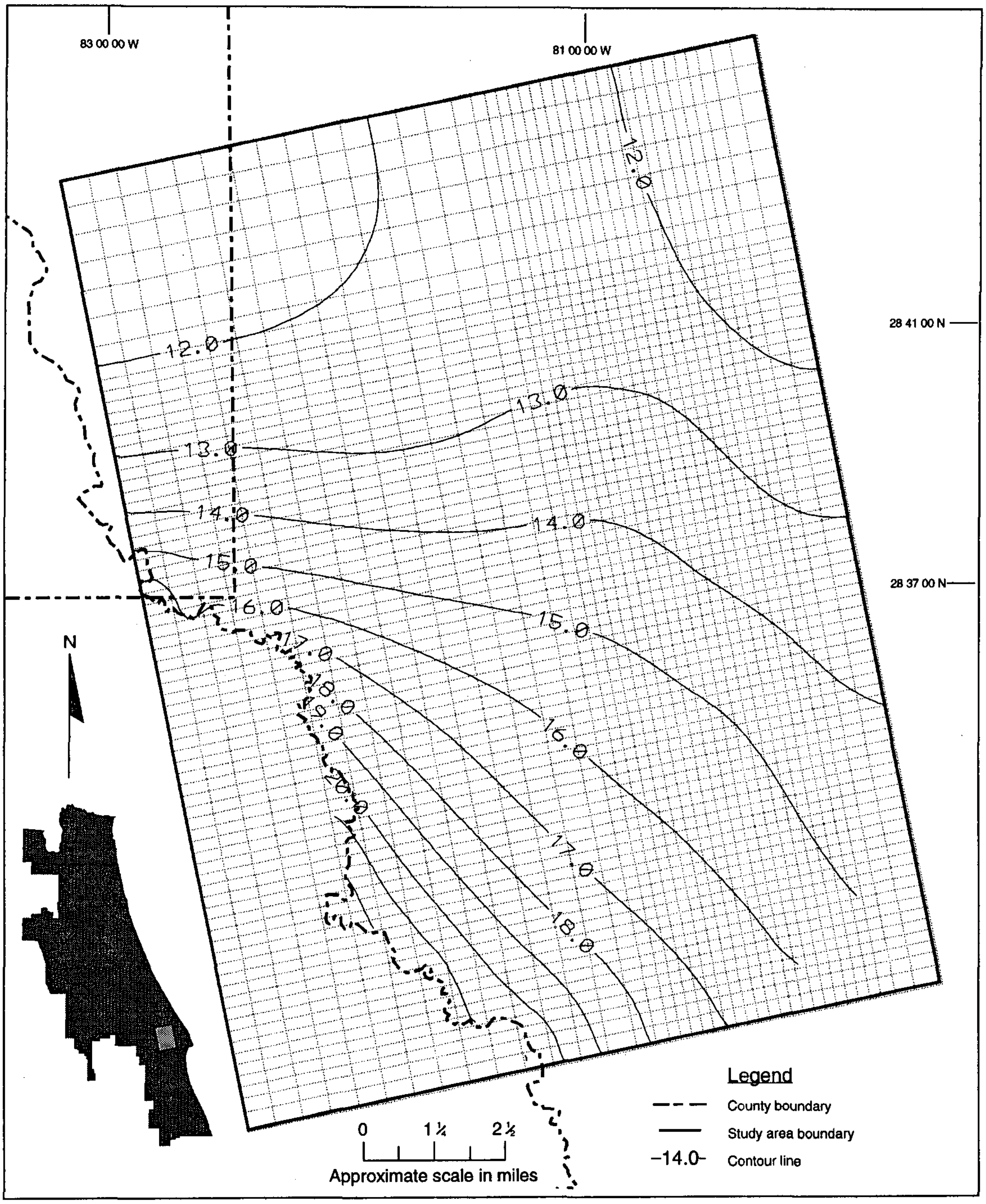

Figure 26. Simulated September 1988 potentiometric surface of the Upper Floridan aquifer (feet mean sea level)

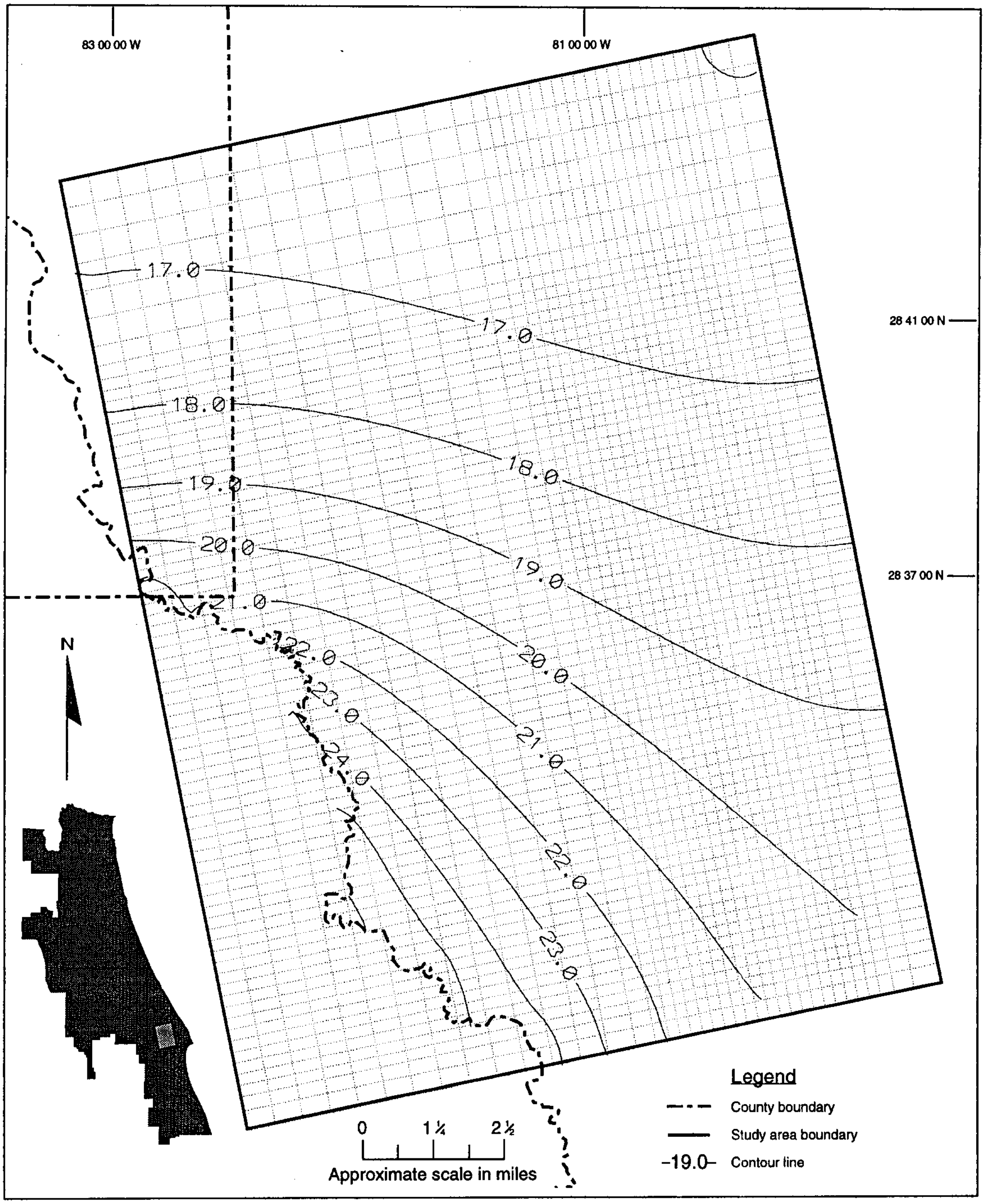

Figure 27. Simulated potentiometric surface of the Lower Floridan aquifer, September 1988 (feet mean sea level)

not actually calibrated and was included for completeness, as it is hydraulically connected with the Upper Floridan aquifer.

A water table map that is reliable throughout the study area is difficult to develop due to the paucity of monitoring well data for the surficial aquifer system. Therefore, an additional qualitative check on the validity of the model involved development of a polynomial regression equation, which correlates the land surface elevation with monitoring well levels based upon several wells in the study area.

To develop the regression equation, a data base was developed based upon wells that had a water level measurement for the September–October period during any year from 1957 to 1990 (Brown et al. 1962b). This data base was refined by culling all wells that may be influenced by proximity to active producing wells or to surface water features. The resulting set of 14 wells (Figure 28) was used to develop a polynomial regression equation. The specific analysis and results of the regression equation are provided in Appendix D. The equation is of the general form.

$$y = ax^3 + bx^2 + cx$$

where y is the predicted water table elevation; x is the land surface elevation at a monitoring well; and a, b, and c are equation coefficients. Upon performing the regression analysis, the resulting equation has a correlation coefficient (R^2) of 0.981 for the September–October analysis period and a standard error of 0.706 for the y estimate. Therefore, an excellent correlation exists (for these wells) between the land surface elevation and the water level in the wells.

The regression equation provides a tool for assessment of the reliability of the simulated water table in the model. This assessment was performed by applying the equation to values for average land surface elevation throughout the model domain and comparing these values to results of the model for the surficial aquifer system. Based upon this comparison, a good correlation

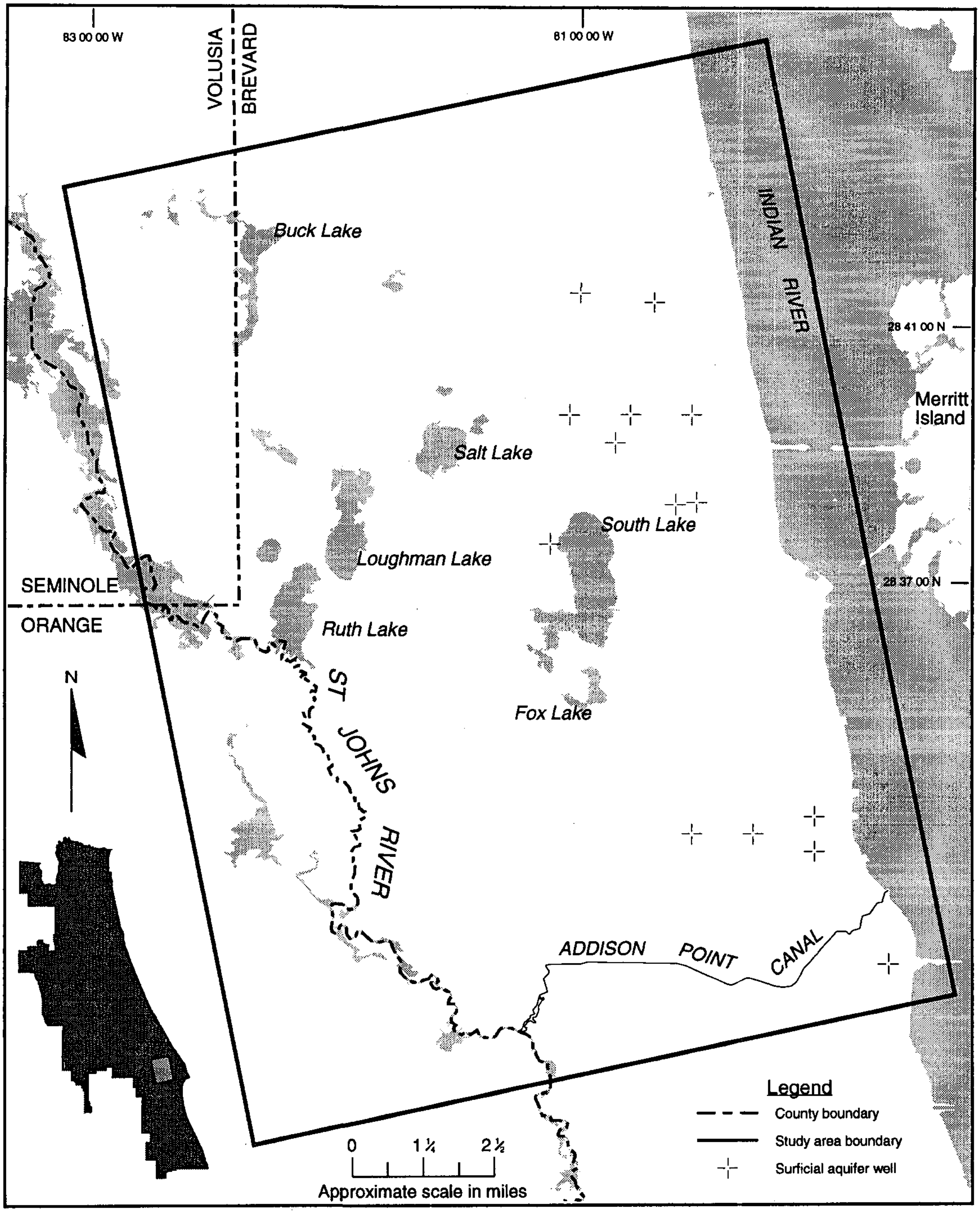

Figure 28. Locations of wells monitoring the surficial aquifer system used in the polynomial regression analysis

(R^2 = 0.86) exists between the model-simulated water table values and the regional application of the polynomial regression equation. This regression equation does have limitations. It loses validity in areas close to wells that pump from the surficial aquifer system and close to surface water features such as lakes and streams. It also becomes invalid for land surface elevations greater than 40 ft msl. However, these findings do illustrate a qualitative check on the credibility of the model results for the surficial aquifer system in lieu of the existence of an actual map of the regional water table.

The distribution of recharge to and discharge from the Upper Floridan aquifer is also important in the assessment of the quality of the calibration. Figure 29 illustrates the model-derived recharge/discharge patterns for the Upper Floridan aquifer as derived from the 1988 calibration. The patterns exhibited in this figure indicate that most of the study area is a discharge area for the aquifer and that a narrow finger exists under the Atlantic Coastal Ridge where the Upper Floridan aquifer is receiving low to moderate amounts of recharge (0 to 4 in/yr) from the surficial aquifer system. This is consistent with the findings of previous recharge analyses (Tibbals 1990; Phelps 1984; Boniol et al. 1993).

There is a marked pattern of discharge from the Upper Floridan aquifer in the vicinities of the Area II and Area III wellfields, which are just west of and directly south of the City of Titusville, respectively (Figure 29). An upward gradient exists in these areas due to the reduction of pressure that exists in the vicinity of these wellfields in the surficial aquifer system. This upward flux of water from the Upper Floridan aquifer has contributed to water quality problems in these areas due to the highly mineralized character of the water of the Upper Floridan aquifer directly underlying these areas.

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

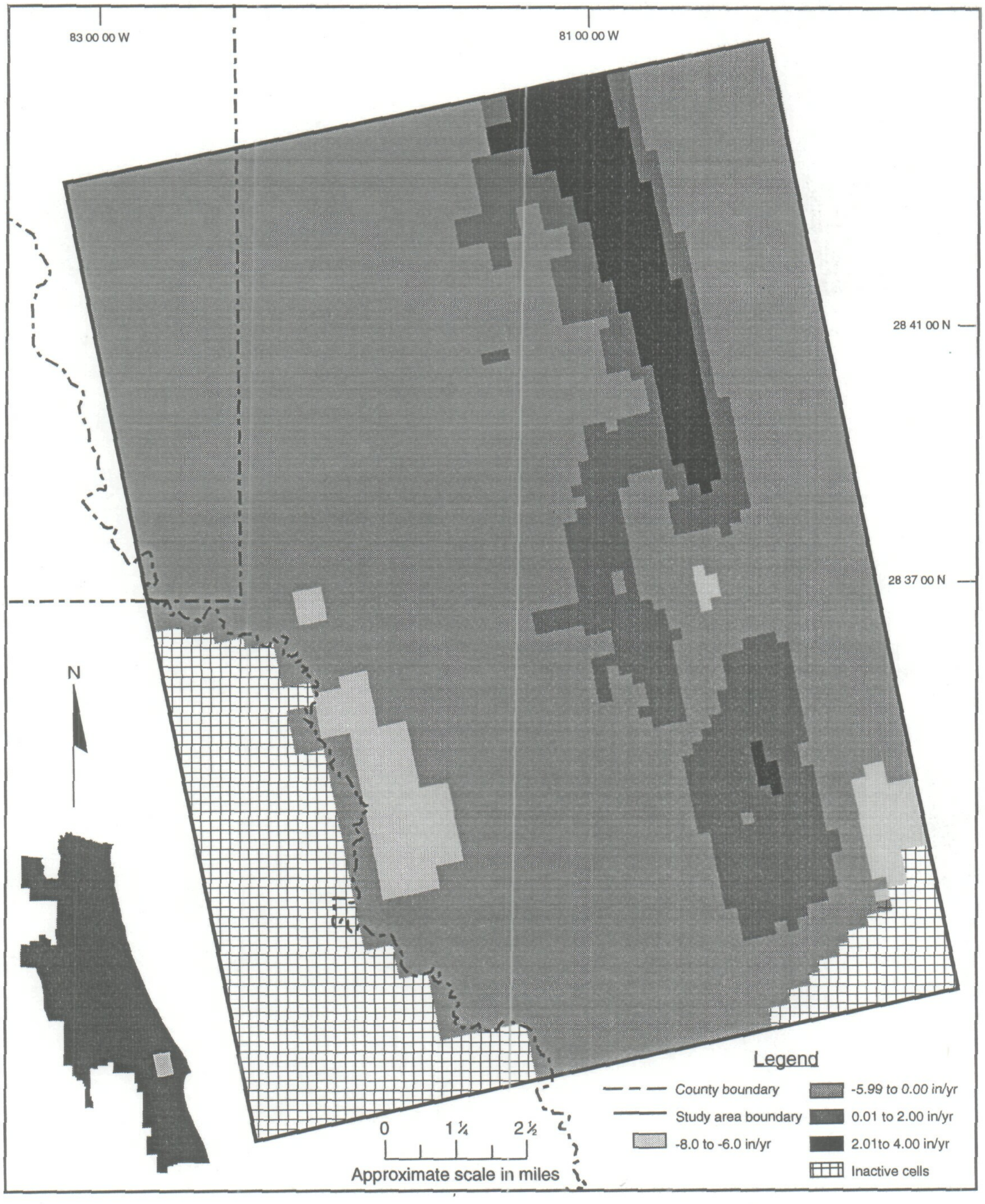

Figure 29. Distribution of recharge to and discharge from the Upper Floridan aquifer based on the 1988 calibration (inches per year)

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.

- Hydraulic conductivity of the surficial aquifer system
- Leakance of the upper confining unit
- Transmissivity of the Upper Floridan aquifer
- Transmissivity of the Lower Floridan aquifer
- Western boundary heads for the Upper Floridan aquifer
- Western boundary heads for the Lower Floridan aquifer
- Recharge to the surficial aquifer system
- Extinction depth for evapotranspiration

The sensitivity analyses for the surficial aquifer system and the Upper Floridan aquifer depict the relative sensitivities of the four most sensitive aquifer parameters or boundary conditions for each aquifer. Of the eight items evaluated, water levels in the surficial aquifer system are most sensitive to recharge, the head boundary of the Upper Floridan aquifer, the hydraulic conductivity of the surficial aquifer system, and the extinction depth for evapotranspiration (Figure 30). Conversely, the surficial aquifer system is least sensitive to the leakance of the upper confining unit, the transmissivity of the Upper and Lower Floridan aquifers, and the potentiometric head boundary for the Lower Floridan aquifer. Similarly, for the Upper Floridan aquifer, of the eight items evaluated, the potentiometric head results for the Upper Floridan aquifer are most sensitive to the head boundary of the Upper Floridan aquifer, the head boundary of the Lower Floridan aquifer, leakance of the upper confining unit, and recharge to the surficial aquifer system (Figure 31). Conversely, the potentiometric head results for the Upper Floridan aquifer are least sensitive to the hydraulic conductivity of the surficial aquifer system, the transmissivity of both the

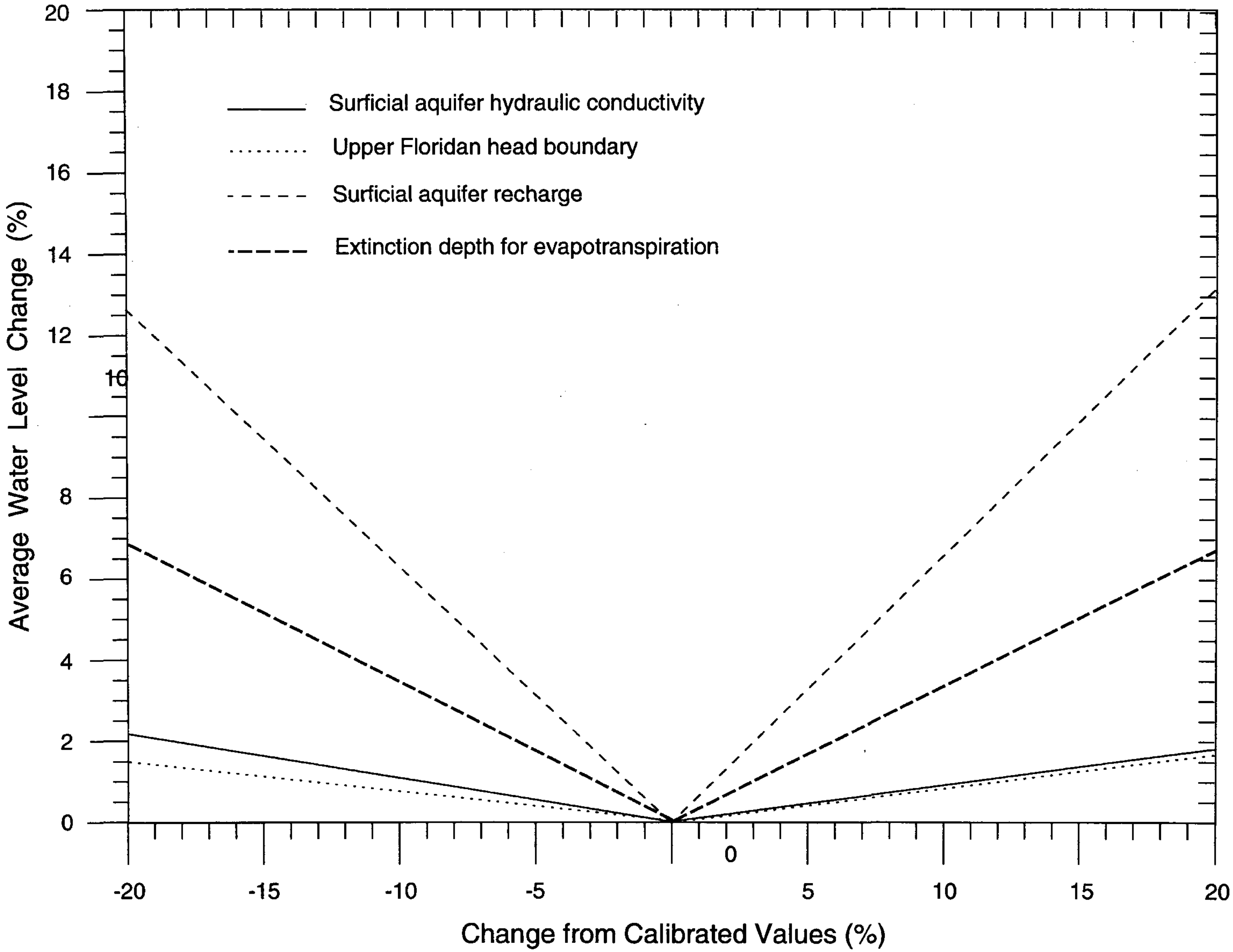

Figure 30. Sensitivity analysis for the surficial aquifer system

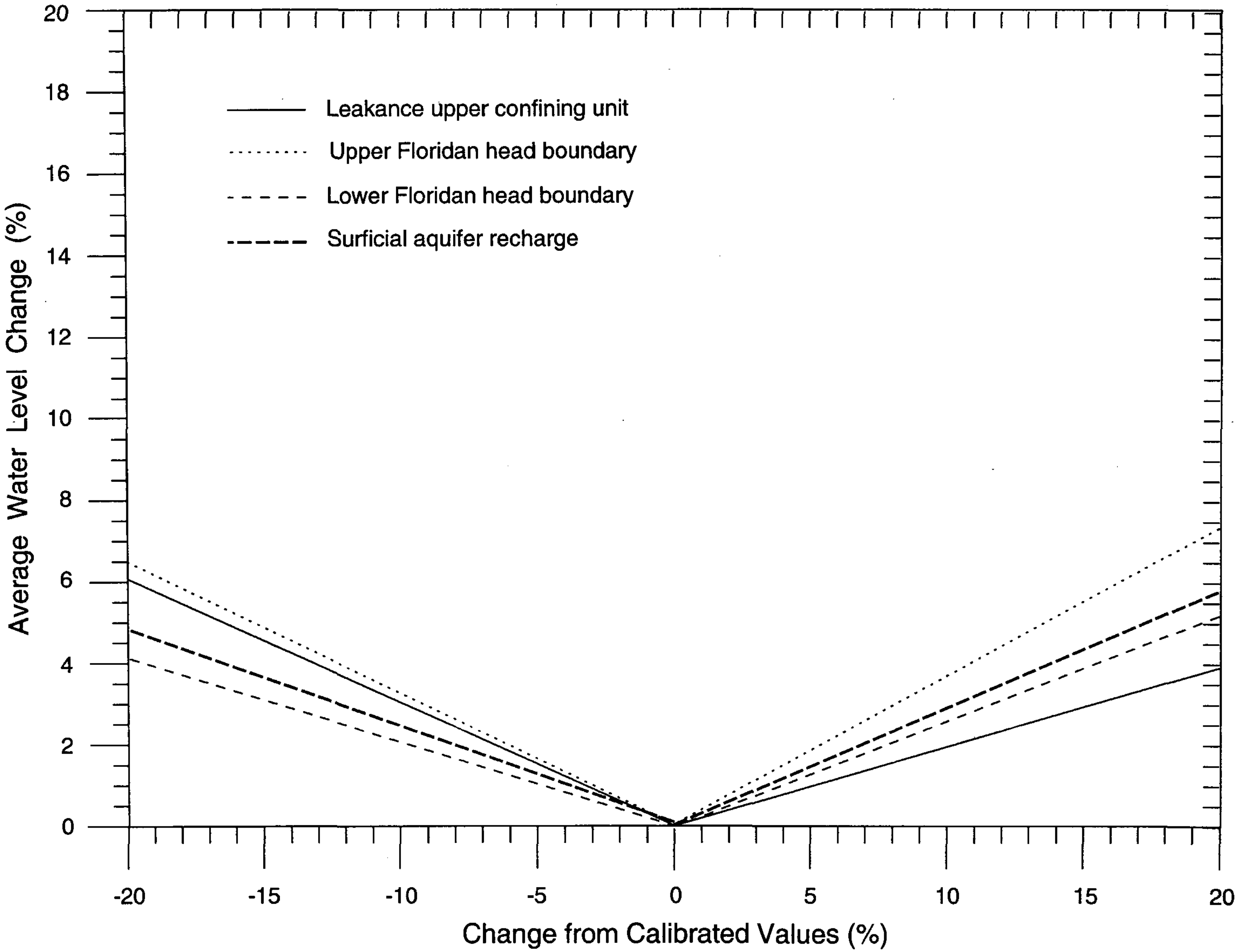

Figure 31. Sensitivity analysis for the Upper Floridan aquifer

Upper and Lower Floridan aquifers, and the extinction depth for evapotranspiration. 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, and the boundary conditions for the Upper Floridan aquifer.

PREDICTIVE SIMULATIONS

The calibrated model was used to project the impacts upon the ground water system of projected water use for the year 2010. For these predictive simulations, all aquifer parameter values are identical to those of the 1988 calibration. The two primary differences between the 1988 and the 2010 simulations are the treatment of the western boundary condition and the use of a new set of well data representing projected water use conditions for 2010. These projected water use values are based on the assumptions discussed earlier (p. 61–66). Appendix B includes all wells and pumping rates for the 2010 simulations. The modification to the western boundary condition is based upon consideration of the regional impact of pumping upon the potentiometric surface of the Upper Floridan aquifer in the vicinity of Orange County, west of the current study area. A previous SJRWMD ground water modeling project involved the development of a large-scale regional model of the ground water resources of east-central Florida (Blandford and Birdie 1992). The projected potentiometric surface for the year 2010 in that regional model indicates significant declines throughout east-central Florida. The western boundary modification for the Titusville/Mims regional flow model entails superimposing the results from the larger regional ground water flow model upon the boundary conditions for the current model of northern Brevard County. These modifications were incorporated in order to simulate effects of changes in the regional potentiometric surface on the Upper Floridan aquifer potentiometric surface in the smaller study area of the Titusville/Mims regional ground water flow model.

Analysis of the regional model for east-central Florida indicates that the potentiometric surface will decline by approximately 5 ft in the vicinity of the upgradient (west/southwest) boundary of the current model. Therefore, the projected simulations were performed with this adjustment to the western boundary of the current model.

The simulated water table in the surficial aquifer system for the year 2010 (Figure 32) is similar in configuration to that for the 1988 calibration (Figure 33), with greater drawdowns, up to 16 ft, in the vicinity of Titusville's Area II public supply wellfield. Projected increased drawdowns in the vicinity of the Area III wellfield are virtually zero because the City of Titusville does not anticipate increased use in this area. Water table drawdowns of up to 8 ft are also projected in the area of the Mims current and proposed wellfield locations. These locations are immediately to the north of the Titusville Area II wellfield along the I-95 corridor. Figure 34 portrays the difference between simulated water tables for 2010 and 1988.

These simulated declines in the water table indicate that the freshwater lenses in the surficial aquifer system will continue to be depleted. Based upon estimated yields of between 6.0 mgd for Area II (RS&H 1978) and 8.5 mgd (DRMP 1990) and the projected use of 5.7 mgd for Area II, the use for this wellfield is approaching its maximum capacity. Many wells have already been subject to saltwater intrusion problems (Frazee, pers. com. 1980) and these problems will only be exacerbated as use increases and lower quality water moves up from the Upper Floridan aquifer. Therefore, the City of Titusville is in a situation where it must identify an additional source for public supply within the next few years.

Figures 35 and 36 illustrate the simulated potentiometric surface of the Upper Floridan aquifer for 2010 and the difference between this projected surface and that for the 1988 calibration. Because there are minimal ground water withdrawals from the Floridan aquifer system within the study area, the primary differences between the 2010 and the 1988 potentiometric surfaces are due to (1) the imposition of the effects of the regional potentiometric surface of the Upper Floridan aquifer and (2) the upward

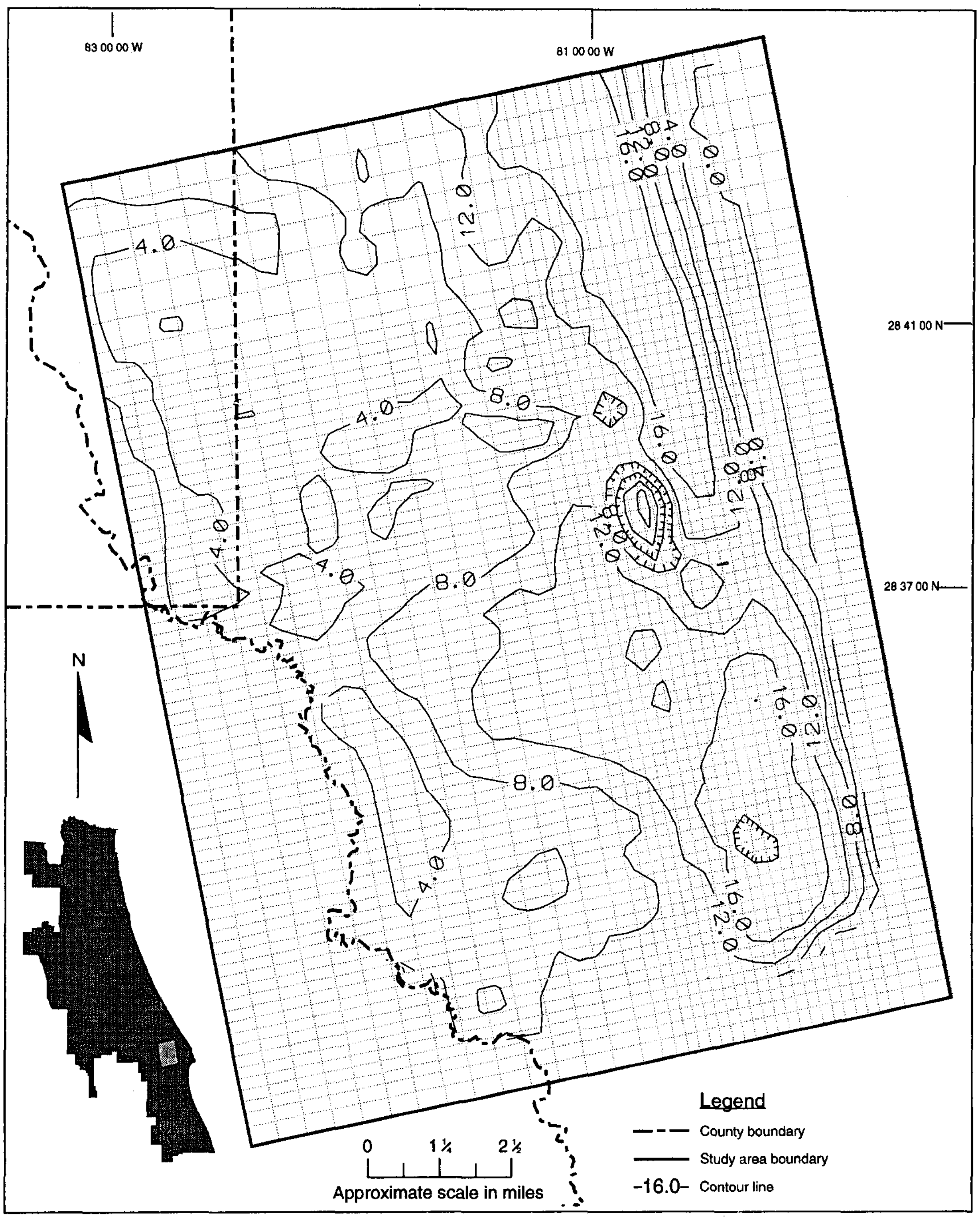

Figure 32. Simulated water table elevation in the surficial aquifer system, 2010 (feet mean sea level)

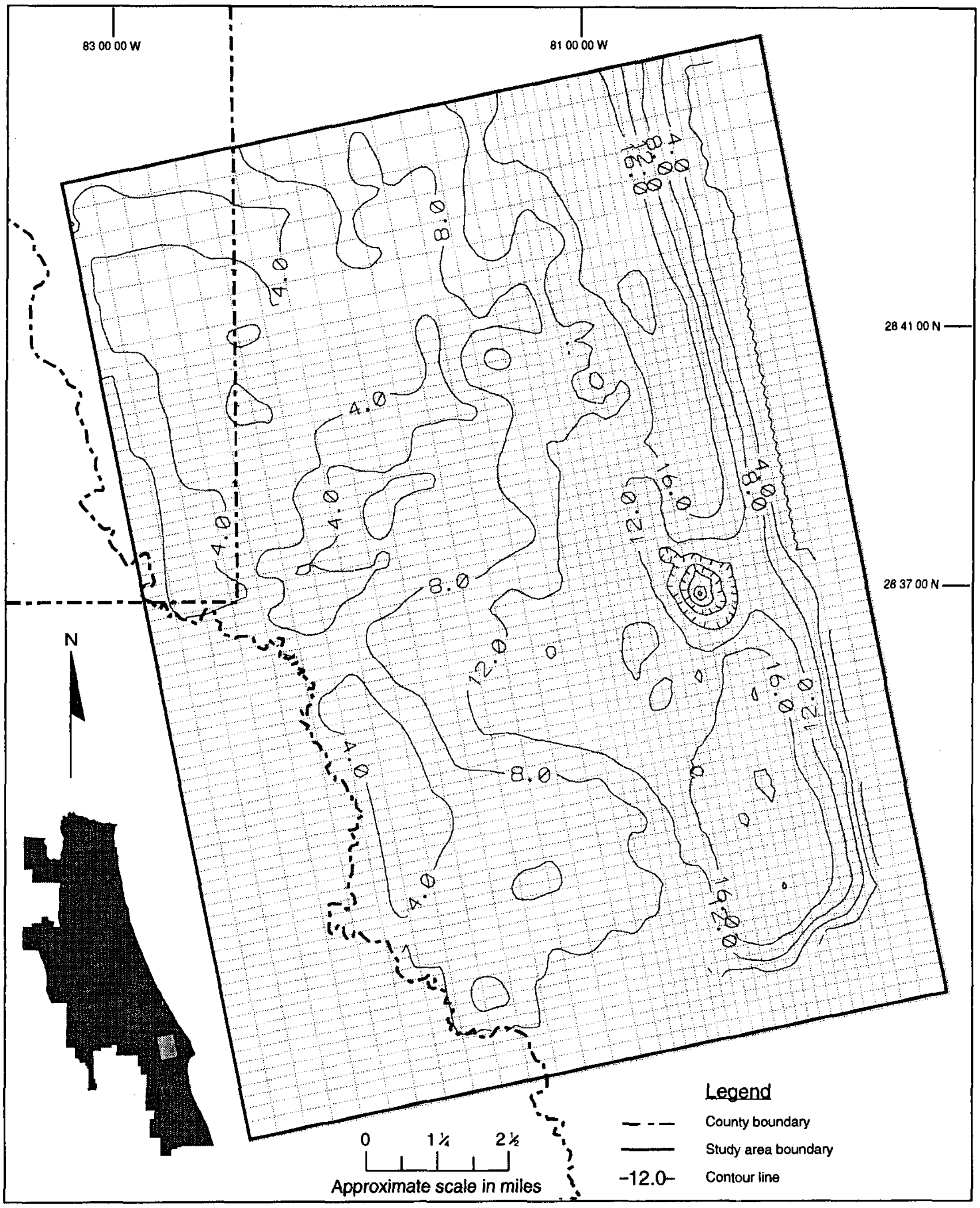

Figure 33. Simulated water table elevation in the surficial aquifer system, September 1988 (feet mean sea level)

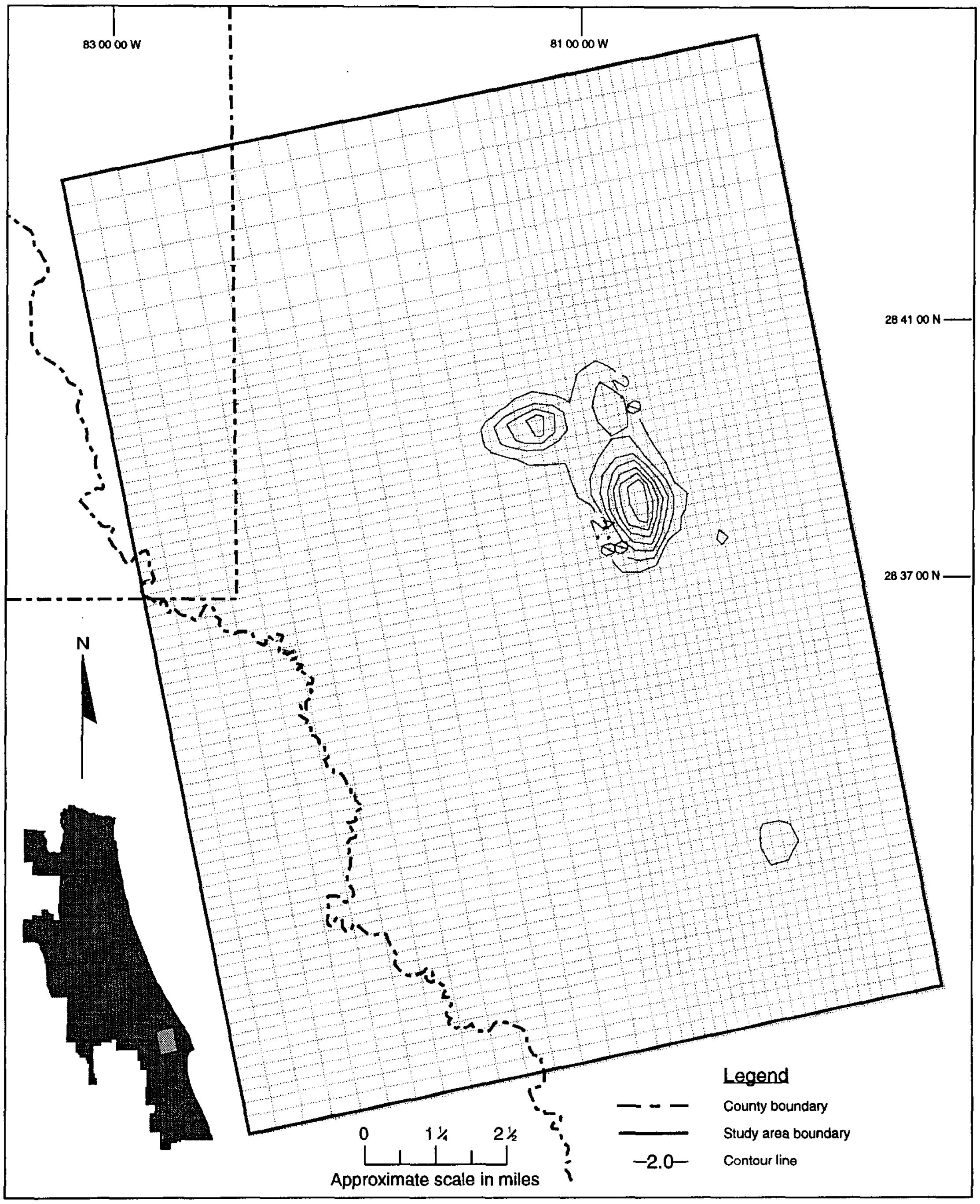

Figure 34. Difference between simulated water table elevation profiles: September 1988 minus 2010 (contour interval = 2 ft)

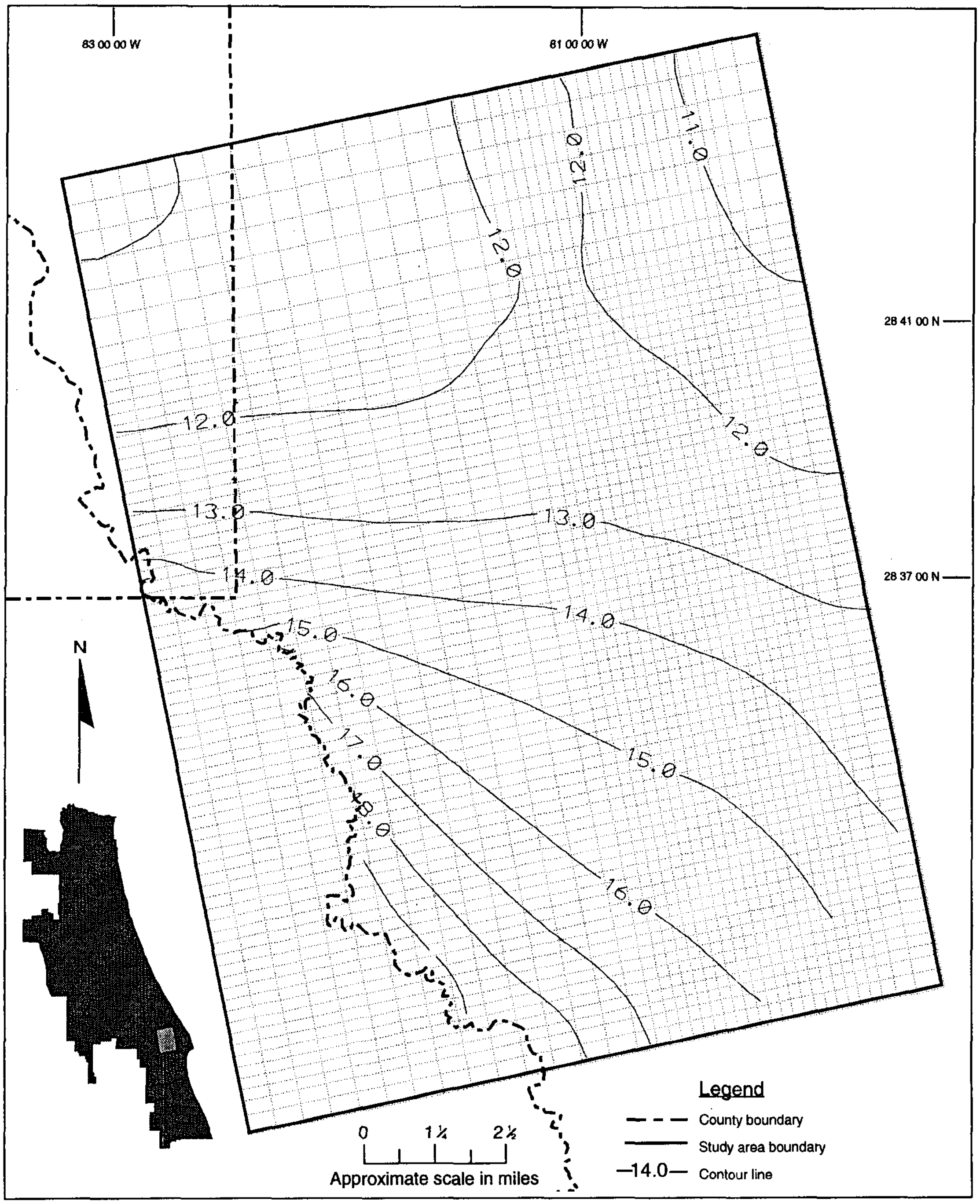

Figure 35. Simulated potentiometric surface of the Upper Floridan aquifer, 2010 (feet mean sea level)

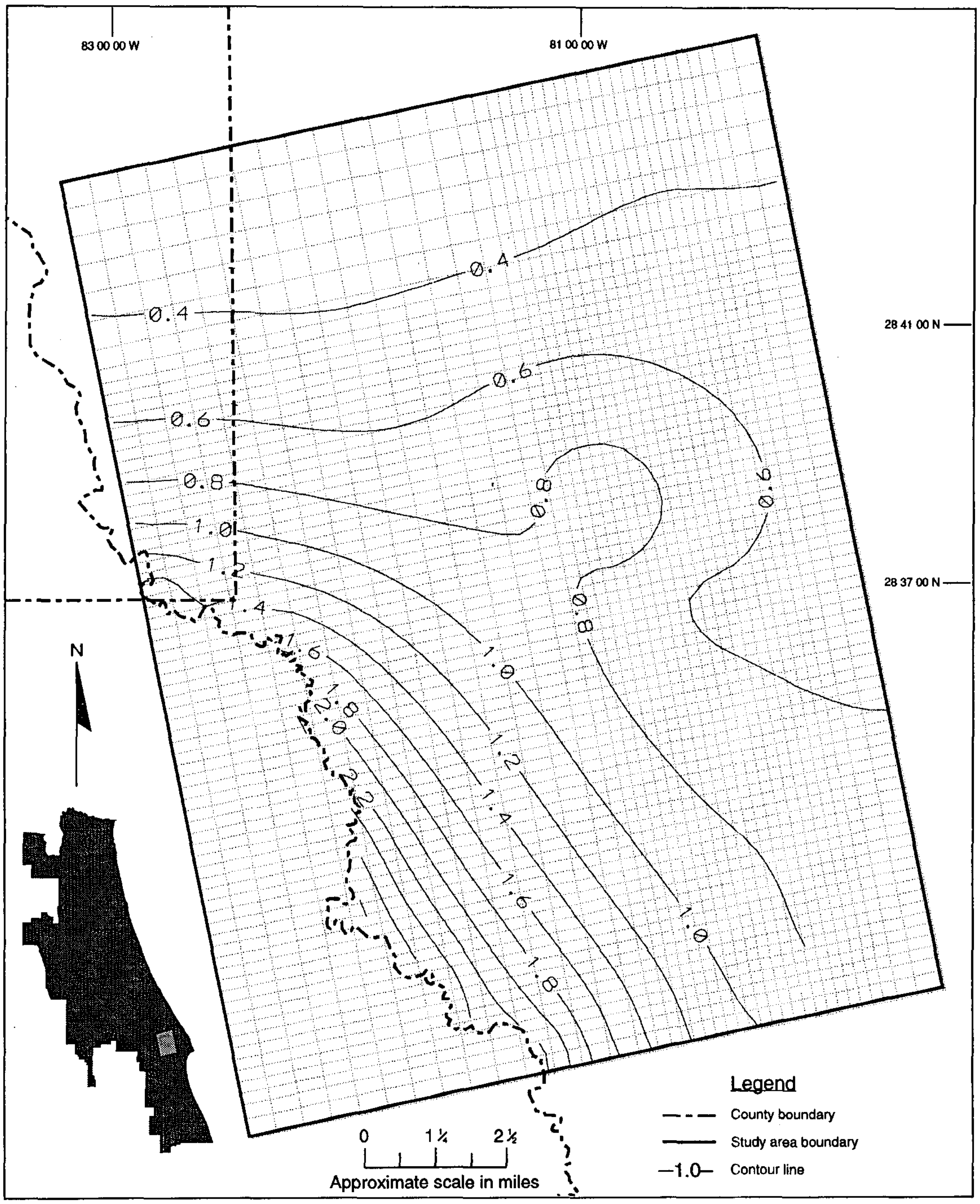

Figure 36. Difference between simulated potentiometric surfaces of the Upper Floridan aquifer: September 1988 minus 2010

hydraulic flux in areas where declines in the water table contribute to an upward hydraulic gradient between the Upper Floridan aquifer and the surficial aquifer system. Specific impacts to the Upper Floridan aquifer include drawdown of up to 2 ft in the vicinity of Titusville and upward discharge of ground water from the Upper Floridan aquifer into the surficial aquifer system.

SUMMARY

A computer-based finite-difference model has been developed to evaluate the ground water resources in northern Brevard County. The finite-difference mesh for the model has a non-uniform configuration with smallest grid cells in the vicinity of the Atlantic Coastal Ridge near Titusville. The model is targeted at impacts in the surficial aquifer system, and it also includes both the Upper and Lower Floridan aquifers and intervening confining layers 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 Titusville/Mims regional ground water flow model was calibrated to both a predevelopment and a postdevelopment condition. The postdevelopment condition represents the September 1988 time period and is the more rigorous calibration, as it includes the effects of pumping wells and because much more monitoring data are available for the postdevelopment condition.

Upon calibration, the model was used to develop predictive simulations for the year 2010. Water use estimates for 2010 were developed based upon information from local utilities and review of the Brevard County Comprehensive Plan. Findings from these predictive simulations indicate that drawdowns of up to 16 ft will occur in the surficial aquifer system in the vicinity of the City of Titusville. Regional declines in the potentiometric surface of the Upper Floridan aquifer also will occur due to large-scale pumping outside of the model area. Also, upward discharge of lower quality water from the Floridan aquifer system will continue to be a primary constraint upon the availability of fresh water in the surficial aquifer system.

CONCLUSIONS AND RECOMMENDATIONS

The SJRWMD Needs and Sources Water Supply Assessment provides a long-term perspective on the status of its water resources and availability. This assessment is to be repeated every 5 years and has as a primary goal the identification of gaps in current knowledge in order to ensure future collection of this missing information.

A primary concern in the development and application of the Titusville/Mims regional ground water flow model is the lack of adequate data to characterize the hydrogeologic system and to conduct rigorous calibrations of the existing ground water flow system. If this area is to continue to be developed for ground water supply, then additional data must be collected to better characterize the elevation of the water table, evapotranspiration rates, recharge rates to the surficial aquifer system, and the vertical hydraulic conductivity of the upper confining unit. Without this additional data, any model developed for the area will be useful for producing only general conclusions regarding the future of the water supply in the area.

The Titusville/Mims regional ground water flow model is designed to provide analyses regarding the long-term viability of these resources for water supply. This analysis is performed through the interpretation of recent (1988) and future (2010) impacts of water use upon the ground water resources. The ultimate goal of this analysis is to provide recommendations regarding the best fit between available water resources and needs for those resources while minimizing any potential resource degradation. Thus, in order to continue to ensure the viability of this resource, additional data is needed to interpret water quality trends, impacts of long-term drought conditions, and impacts of specific pumping scenarios.

The following conclusions are derived from this regional model.

- The principal freshwater resources in northern Brevard County are stored in relatively small freshwater lenses in the Atlantic Coastal Ridge deposits of the surficial aquifer system.

- These freshwater lenses are being gradually depleted, primarily due to pumping for public supply. For example, the City of Titusville is approaching the maximum potential capacity available from these freshwater lenses and therefore must identify an additional public supply source within the next few years.

- Impacts to the freshwater resources in the surficial aquifer system are characterized by drawdowns of up to 16 ft in the vicinity of the City of Titusville and up to 8 ft in the area of the public supply wells for the community of Mims.

- Impacts to the Upper Floridan aquifer include modest drawdowns of up to 2 ft immediately underneath the City of Titusville's public supply wellfields and upward discharge of this water from the Upper Floridan aquifer to the surficial aquifer system.

Based upon this regional model, these are my recommendations.

- Enhance the existing monitoring program to include the following:

    - Establishment of five to ten monitoring sites to monitor trends in water levels in the surficial aquifer system in the vicinity of the major public supply wellfields.

    - Establishment of five to ten monitoring sites to monitor trends in water levels in wetlands, particularly those in areas of predicted declines in the surficial aquifer system.

    - Establishment of two to three monitoring sites to monitor trends in water quality in the Upper Floridan aquifer, with particular focus on the potential for upward leakage of lower quality water from the Upper Floridan aquifer into the surficial aquifer system.

- Investigate water supply alternatives through the use of optimization modeling and evaluation of alternative water use scenarios.

- Emphasize methods of water re-use and conservation to minimize long-term impacts to the ground water resources.

- Develop a plan (City of Titusville in cooperation with SJRWMD) to identify an additional source for future public supply use.

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APPENDIX A—SOIL TYPES AND ASSOCIATED HYDRAULIC PROPERTIES

Table A1. Soil types and associated hydraulic properties

Soil Series	Drainage	Permeability	Saturated Hydraulic Conductivity (cm/hr)	Available Water Content (cm/cm)	Minimum Saturated Vertical Hydraulic Conductivity (cm/hr)	Maximum Available Water Content (cm/cm)	Recharge Code
St. Lucie	Excessive	Very rapid	69–125	.02–.03	69	0.03	5
Paola	Excessive	Very rapid	67–146	.02–.08	67	0.08	5
Galveston	Excessive	Rapid		.02–.05	60	0.05	5
Welaka	Excessive	Rapid	58–161	.02–.05	58	0.05	5
Palm Beach	Excessive	Very rapid	53–131	.03–.07	53	0.07	5
Astatula	Excessive	Very rapid	50–57.9	.03–.06	50	0.06	5
Satellite	Excessive	Very rapid	47–57	.03–.05	47	0.05	5
Tavares	Moderately well	Rapid	26–42	.04–.09	26	0.09	4
Orsino	Moderately well	Rapid	23–51	.03–.06	23	0.06	4
Cocoa	Moderately well	Rapid	23–52	.05–.09	23	0.09	4
Canaveral	Moderately well	Very rapid	20–50	.05–.10	20	0.1	4
Holopaw	Poor	Rapid to moderate	12–50	.02–.15	12	0.15	3
Pompano	Poor	Rapid	12–59	.06–.23	12	0.23	3
Anclote	Very poor	Rapid	11–50	.10–.15	11	0.15	3
Valkaria	Poor	Rapid	10–18	.08–.17	10	0.17	3
Myakka	Poor	Rapid to moderate	10–38	.05–.22	10	0.22	3
Pomello	Somewhat poor	Very rapid to moderate	10–61	.04–.15	10	0.15	3
Malabar	Poor	Rapid to very slow	6–35	.05–.22	6	0.22	3
Copeland	Very poor	Slow	3–4	.26–.28	3	0.28	3
Immokalee	Poor	Rapid to moderate	1–24	.06–.21	1	0.21	3

Table A1—*Continued*

Soil Series	Drainage	Permeability	Saturated Hydraulic Conductivity (cm/hr)	Available Water Content (cm/cm)	Minimum Saturated Vertical Hydraulic Conductivity (cm/hr)	Maximum Available Water Content (cm/cm)	Recharge Code
Parkwood	Poor	Rapid to moderate	1–17	.05–.15	1	0.15	3
Micco	Very poor	Rapid to moderate	NA	.05–.25	0	0.25	2
Chobee	Very poor	Slow	0–3	.17–.27	0	0.27	2
Winder	Poor	Rapid to very slow	0–24	.13–.28	0	0.28	2
Oldsmar	Poor	Moderate	0–34	.05–.22	0	0.22	2
Basinger	Poor	Rapid	0.1–24.6	.07–.21	0	0.21	2
Pineda	Poor	Slow to very slow	0–19	.06–.23	0	0.23	2
Felda	Poor	Rapid to moderate	0–25	.08–.29	0	0.29	2
Montverde	Very poor	Rapid to slow	NA	.05–.25	0	0.25	2
Eau Gallie	Poor	Moderate	0–21	.04–.30	0	0.3	2
Bradenton	Poor	Rapid to moderate	0.1–6.9	.11–.22	0	0.22	2
St. Johns	Poor	Rapid to moderate	0–21	.05–.40	0	0.4	2
Pineda	Poor	Rapid to very slow	0–40	.04–.18	0	0.18	2
Canova	Very poor	Rapid to slow	0–266	.05–.41	0	0.41	1
Tomoka	Very poor	Moderate to moderately slow	NA	.05–.25	0	0.25	1
Floridana	Very poor	Rapid to moderate	0–27	.05–.24	0	0.24	1
Wabasso	Poor	Rapid to slow	0–28	.04–.20	0	0.2	1
Terra Ceia	Very poor	Rapid	0–100	.14–.70	0	0.7	1

Note: cm/hr = centimeters per hour
cm/cm = centimeters per centimeter

Blank cells indicate data are not available.

Source: Carlisle et al. 1978, 1985, 1988, and 1989; Sodek 1990

APPENDIX B—SUMMARY OF PUMPING WELL DATA

Table B1. Public supply wells: descriptive characteristics and pumping rates

Description	No.	Lat	Long	dia	Model		csg	ttl	lse	aq	Average Discharge 09/88 to 10/88 (gpm)	MOR 09/88 (mgm)	Well Flux 09/88 (ft^3/d)	Projected Discharge 2010		Ex/prop Well Flux 2010 Average (ft^3/d)
					row	col								gpm	mgd	
Titusville Area II wellfield	1	283654	805022	8	37	26	68	95	35.2	SA	320	172.5	28129.14	270	12.58	43428.74
	2	283701	805023	8	36	26	79	99	29.6	SA	120		10548.43	125		20105.9
	3	283708	805023	8	35	26	85	106	40.0	SA	150	172.5	13185.53	125	12.58	20105.9
Permit No. #2-009-0008aum2gr	4	283714	805023	8	35	26	93	103	30.5	SA	145		12746.02	125		20105.9
	5	283723	805024	8	34	26	90	105	29.9	SA	80		7032.284	150		24127.08
Total of 49 wells	6	283728	805023	8	33	26	90	100	26.6	SA	110		9669.391	62		9972.526
	7	283656	805015	8	37	26	85	106	NA	SA	240		21096.85	100		16084.72
	8	283701	805015	8	36	27	78	104	47.6	SA	145		12746.02	83		13350.32
	9	283708	805016	8	36	27	74	94	34.0	SA	115		10108.91	107		17210.65
Abandoned	10	283711	805009	8	36	27	90	100	35.3	SA	0		0	0	NA	0
	11	283710	805003	8	36	28	90	100	35.3	SA	75		6592.767	83		13350.32
	12	283711	804957	8	36	28	90	100	35.9	SA	0		0	28		4503.721
	13	283705	805035	8	36	25	101	135	30.4	SA	160		14064.57	25		4021.18
	14	283711	805019	8	35	25	90	105	40.9	SA	0		0	83		13350.32
	15	283648	805024	10	37	26	65	104	32.8	SA	140		12306.5	41		6594.735
	16	283640	805014	10	38	26	78	112	40.9	SA	190		16701.68	0		0
	17	283646	805012	10	38	27	74	109	40.6	SA	140		12306.5	91		14637.09
	18	283646	805006	10	38	27	82	107	39.5	SA	165		14504.09	107		17210.65
	19	283649	804952	10	38	28	123	146	35.6	SA	220		19338.78	43		6916.429
	20	283718	804957	10	35	29	51	106	32.4	SA	185		16262.16	200		32169.44
	21	283724	804958	10	34	29	52	105	31.5	SA	0		0	200		32169.44
	22	283729	804959	10	33	29	49	104	26.0	SA	12		1054.843	200		32169.44

Table B1—*Continued*

Description	No.	Lat	Long	dia	Model		csg	ttl	lse	aq	Average Discharge 09/88 to 10/88 (gpm)	MOR 09/88 (mgm)	Well Flux 09/88 (ft^3/d)	Projected Discharge 2010		Ex/prop Well Flux 2010 Average (ft^3/d)
					row	col								gpm	mgd	
	23	283730	805006	10	33	28	61	103	24.9	SA	80		7032.284	17		2734.402
	24	283730	805009	10	33	28	60	100	25	SA	25		2197.589	27		4342.874
Abandoned	25	283734	805025	6	32	26	65	107	25.3	SA	0		0	0	NA	0
	26	283655	805042	10	36	24	49	95	22.5	SA	160		14064.57	37		5951.346
	27	283655	805051	10	36	23	39	112	35.9	SA	140		12306.5	0		0
	28	283705	805050	10	35	24	32	89	32.9	SA	0		0	14		2251.861
	29	283704	805055	10	35	23	38	78	35.7	SA	0		0	0		0
	30	283705	805058	10	35	23	36	77	36	SA	80		7032.284	0		0
	31	283729	805054	10	33	24	35	87	29.6	SA	140		12306.5	60		9650.831
	32	283728	805058	10	33	23	38	88	29	SA	185		16262.16	250		40211.8
	33	283729	805108	10	33	22	30	75	28.5	SA	135		11866.98	250		40211.8
	34	283731	805111	10	32	23	23	68	45.08	SA	225		19778.3	250		40211.8
	35	283736	805113	10	31	23	30	65	38.8	SA	100		8790.355	250		40211.8
	36	283741	805115	10	31	22	30	87	38.5	SA	95		8350.838	250		40211.8
	37	283746	805116	10	30	22	30	73	36.1	SA	135		11866.98	250		40211.8
	38	283750	805118	10	30	22	30	75	32.7	SA	0		0	250		40211.8
	39	283753	805120	10	30	22	21	65	23.6	SA	0		0	250		40211.8
	40	283757	805121	10	29	22	29	80	37.8	SA	0		0	250		40211.8
	41	283802	805123	10	29	22	40	75	47.9	SA	150		13185.53	250		40211.8
	42	283805	805125	10	28	22	36	81	33.3	SA	185		16262.16	250		40211.8
	43	283810	805126	10	28	22	38	81	34.4	SA	60		5274.213	250		40211.8
	44	283811	805121	10	28	23	34	85	27.5	SA	245		21536.37	250		40211.8
	45	283816	805126	10	27	22	31	90	22.9	SA	50		4395.178	250		40211.8

Table B1—*Continued*

Description	No.	Lat	Long	dia	Model		csg	ttl	lse	aq	Average Discharge 09/88 to 10/88 (gpm)	MOR 09/88 (mgm)	Well Flux 09/88 (ft^3/d)	Projected Discharge 2010		Ex/prop Well Flux 2010 Average (ft^3/d)
					row	col								gpm	mgd	
	46	283820	805128	10	27	22	31	92	31.3	SA	0		0	250		40211.8
	47	283824	805130	10	27	22	32	89	30.7	SA	150		13185.53	250		40211.8
	48	283828	805132	10	26	22	29	95	24.91	SA	0		0	250		40211.8
	49	283834	805134	10	26	22	29	95	19.5	SA	140		12306.5	250		40211.8
Titusville Area III wellfield	304	283247	804836	6	59	30	90	135		SA	170		14943.6	170		27344.02
	305	283257	804848	6	60	30	86	130		SA	145		12746.02	145		23322.84
	310	283322	804854	6	59	29	102	137		SA	117		10284.72	117		18819.12
	311	283319	804853	8	60	29	112	151		SA	125		10987.94	125		20105.9
Total of 35 wells	312	283307	804854	6	60	29	83	133		SA	126		11075.85	126		20266.75
	313	283301	804855	6	59	29	97	139		SA	80		7032.284	80		12867.77
	314	283254	804855	6	59	28	85	129		SA	76		6680.67	76		12224.39
	315	283247	804853	8	60	28	90	120		SA	83		7295.995	83		13350.32
	316	283322	804902	6	61	28	91	130		SA	195		17141.19	195		31365.2
	317	283319	804902	6	59	28	89	155		SA	200		17580.71	200		32169.44
	318	283306	804902	6	59	28	90	155		SA	151		13273.44	151		24287.93
	319	283322	804907	6	60	28	85	129		SA	185		16262.16	185		29756.73
	320	283319	804906	6	61	28	81	138		SA	104		9141.97	104		16728.11
	321	233307	804907	6	62	28	89	138		SA	0		0	0		0
	322	283301	804907	8	63	28	83	150		SA	0		0	0		0
	323	283254	804909	6	59	27	94	138		SA	75		6592.767	75		12063.54
	324	283247	804907	6	59	27	99	135		SA	133		11691.17	133		21392.68
	325	283322	804912	6	60	27	86	131		SA	90		7911.32	90		14476.25
	326	283319	804912	6	61	27	86	131		SA	98		8614.548	98		15763.02

Table B1—*Continued*

Description	No.	Lat	Long	dia	Model		csg	ttl	lse	aq	Average Discharge 09/88 to 10/88 (gpm)	MOR 09/88 (mgm)	Well Flux 09/88 (ft³/d)	Projected Discharge 2010		Ex/prop Well Flux 2010 Average (ft³/d)
					row	col								gpm	mgd	
	327	283307	804913	6	62	27	90	133		SA	82		7208.091	82		13189.47
	328	283301	804912	6	62	26	97	140		SA	125		10987.94	125		20105.9
	329	283322	804920	8	58	27	70	120		SA	130		11427.46	130		20910.13
	330	283319	804917	6	59	27	93	132		SA	115		10108.91	115		18497.43
	331	283307	804917	6	60	27	84	132		SA	93		8175.03	93		14958.79
	332	283301	804918	6	60	27	90	139		SA	150		13185.53	150		24127.08
		283253	804918	6	61	27	88	139		SA	0		0	0		0
		283248	804918	6	62	27	101	136		SA	0		0	0		0
		283246	804920	8	62	27	58	120		SA	0		0	0		0
		283239	804928	6	62	26	35	97		SA	0		0	0		0
		283239	804923	6	62	26	35	75		SA	0		0	0		0
	341	283234	804923	6	63	26	35	95		SA	180		15822.64	180		28952.49
	342	283230	804923	6	64	26	35	95		SA	0		0	0		0
	343	283225	804924	6	64	26	35	95		SA	175		15383.12	175		28148.26
	344	283221	804927	6	64	25	35	90		SA	185		16262.16	185		29756.73
	345	283217	804931	8	65	25	60	100		SA	165	8745	14504.09	165		26539.79
Mims wellfield—6 wells, 2 abandoned		283922	805154	8	20	21		68		SA	280	17.4	23345.41	280	1	22686.76
		283932	805147	8	19	22		85		SA	250	17.4	20844.11	250		20256.04
Abandoned		283939	805155	0	19	21	NA	NA		SA	NA		0	NA	1	0
		283955	805155	8	17	21		70		SA	190		15841.53	190		15394.59
Permit No. #2-009-0029aunmg		283921	805137	10	20	22		85		SA	180	900	15007.76	180		14584.35
Abandoned		283930	805139	0	19	22	NA	NA		SA	0		0	NA		0

Table B1—*Continued*

Description	No.	Lat	Long	dia	Model		csg	ttl	lse	aq	Average Discharge 09/88 to 10/88 (gpm)	MOR 09/88 (mgm)	Well Flux 09/88 (ft^3/d)	Projected Discharge 2010		Ex/prop Well Flux 2010 Average (ft^3/d)
					row	col								gpm	mgd	
Mims—proposed		284000	805210		20	16	NA	NA		SA	0		0	250		20256.04
		284010	805215		20	15				SA	0		0	250		20256.04
		284020	805220		20	14				SA	0		0	250		20256.04
Northgate Property		284131	805136	4	8	25		100		UF			4571.33		0.058	7724.733
Permit No. #2-009-0142		284131	805133	8	8	25		120		UF						0

Note:
aq = aquifer
col = column
csg = casing depth, in feet
dia = diameter, in inches
Ex/prop = existing and proposed
ft^3/d = feet cubed per day
gpm = gallons per minute
lat = latitude
long = longitude
lse = land surface elevation, in feet mean sea level
mgm = million gallons per month
mgd = million gallons per day
MOR = monthly operating report
NA = not available
No. = number
SA = surficial aquifer system
ttl = total depth, in feet
UF = Upper Floridan aquifer

Blank cells indicate data are not available.

Table B2. Agricultural and miscellaneous wells: descriptive characteristics and pumping rates

Description	Latitude	Longitude	dia	csg	ttl	lse	aq	Use	Water Use 09/88 (mgd)	Model Row	Model Col	Well Flux (ft^3/d)
2-009-0018	284213	805142	6		180		UF	Fire protection	0.0000	6	25	0.00
2-009-0028	283426	804847	6	114	128		UF	Golf course—80 acres	0.0000	54	31	0.00
La Cita Golf Course	283423	804852	6				UF	Supplement to surface water in drought	0.0500	53	31	6.68e+03
2-009-0030	284043	805052	6	120	140		UF	Citrus—110 acres	0.1175	13	28	1.57e+04
	284038	805051	6	125	140		UF	Supplement to surface water	0.1175	13	28	1.57e+04
2-009-0066	284024	805051	2	128	147		UF	Citrus—6 acres	0.0064	15	28	8.57e+02
	284024	805053	6	128	147		UF		0.0064	15	27	8.57e+02
2-009-0078	283305	805058	12		25		SA	Fire protection	0.0000	58	18	0.00
2-009-0113	284115	805134	8			25	UF	Citrus—50 acres	0.1068	9	25	1.43e+04
2-009-0114	284313	805109	10				UF	Citrus—30 acres	0.0641	4	29	8.57e+03
2-009-0143	283535	804911	8		300		UF	Citrus—2 acres	0.0021	46	30	2.86e+02
	283535	804912	15				UF		0.0021	46	30	2.86e+02
2-009-0175	283655	805025	6		28		SA	Gas recovery	0.0072	36	25	9.63e+02
2-009-0199	283757	805155	2		96		UF	Foliage—1 acre	0.0015	28	19	2.01e+02
	283754	805154	4		86		UF		0.0015	28	19	2.01e+02
	283800	805155	4		94		UF		0.0015	28	19	2.01e+02
	283757	805152	6		120		UF		0.0015	28	19	2.01e+02

Note:
aq = aquifer
col = column
csg = casing depth, in feet
dia = diameter, in inches
ft^3/d = feet cubed per day
lse = land surface elevation, in feet mean sea level
mgd = million gallons per day
SA = surficial aquifer system
ttl = total depth, in feet
UF = Upper Floridan aquifer

Blank cells indicate data are not available.

APPENDIX C—DESCRIPTIVE CHARACTERISTICS OF MONITORING WELLS USED IN THE 1988 CALIBRATION

Table C1. Descriptive characteristics of monitoring wells for the 1988 calibration

Well Identifier	Latitude	Longitude	Model		Depth		Land Surf Elev	Aq	Water Levels	
			Row	Col	Casing Depth (ft)	Total Depth (ft)			05/88 (ft msl)	09/88 (ft msl)
841052014	284116	805220	8	21		10	18	SA	14.87	15.71
841052013	284106	805227	9	20		30	25	SA	13.40	13.16
FGS 839052001	283955	805200	17	22	14	16	19.7	SA		
FGS 839051001	283950	805100	18	26	9	11	19.1	SA		
FGS 839050001	283950	805020	19	30	13	15	29	SA		
839051006	283906	805145	22	21	31	35	17.3	SA	11.80	13.17
837052008	283739	805249	29	15	4.5	8.5	16.4	SA	13.68	13.97
BR0584	283732	805059	32	23	32	40	28.7	SA	11.34	13.45
FGS 833050001	283330	805020	57	22	14	16	18.2	SA		
FGS 833049001	283330	804910	59	28	29	31	39	SA		
FGS 833048001	283330	804830	59	31	14	16	26.7	SA		
FGS 833048002	283330	804800	60	34	14	16	19.7	SA		
831047002	283137	804718	71	36	26	38	20	SA	16.84	17.21
FGS 843053001	284340	805315	3	18		101	25.7	UF		
FGS 843051001	284328	805105	3	30		119	11.4	UF		
843050002	284308	805057	4	30	100	140	12.7	UF	8.46	10.41
FGS 841051001	284125	805135	8	25	127	174	32.4	UF		
841051226; GS 284116080514001	284116	805140	9	24		173	25	UF	5.55	6.66
839056002; GS 283955080565701	283955	805657	11	7		97	14	UF	11.70	13.58
FGS 839054001	283952	805415	14	12	100	140	10.2	UF		
FGS 840050001	284010	805042	16	28		133	35.3	UF		
FGS 839052002	283938	805227	17	18	192	208	16.1	UF		
839051005; GS 283906080514501	283906	805145	22	21	128	132	17.4	UF	13.08	14.32
837052007	283739	805249	29	15	105	120	16.4	UF	11.69	12.89
FGS 838049002	283820	804925	29	33	90	110	4.9	UF		
FGS 838049001	283805	804955	30	30	91	162	24	UF		

Table C1—*Continued*

Well Identifier	Latitude	Longitude	Model		Depth		Land Surf Elev	Aq	Water Levels	
			Row	Col	Casing Depth (ft)	Total Depth (ft)			05/88 (ft msl)	09/88 (ft msl)
BR0585	283732	805100	32	23	107	195	30	UF	11.01	14.55
BR0660; GS 283644080574901	283644	805749	32	4	98	247	7	UF	15.00	16.40
BR0001; GS 283627080512001	283627	805120	38	20	132	136	38.7	UF	14.08	16.04
FG S836048001	283640	804830	40	35		150	11.1	UF		
GS 283237080560201	283237	805602	55	5		480	11	UF		
GS 283214080583501	283214	805835	55	0@		200	14.2	UF	24.56	27.70
GS 283617080571701	283617	805717	56	6			20	UF		
GS 283204080581801	283204	805818	56	0@		250	10	UF		
832053001; GS 283236080535101	283236	805351	58	10	149	223	11	UF	16.48	18.40

Note:
Aq = aquifer
ft = feet
ft msl = feet, mean sea level
Land Surf Elev = land surface elevation, in ft mean sea level
SA = *surficial aquifer system*
UF = Upper Floridan aquifer

@Outside model boundary

APPENDIX D—RESULTS FOR THE POLYNOMIAL REGRESSION ANALYSIS

Table D1. Results for polynomial regression analysis

Land Surface Elevation (LSE) (ft msl)	LSE Squared	LSE Cubed	May Observed (ft msl)	May Estimated (ft msl)	September Observed (ft msl)	September Estimated (ft msl)
20.00	4.0e+02	8.0e+03	16.84	16.22	17.21	17.46
16.41	2.7e+02	4.4e+03	13.68	12.77	13.97	13.69
18.00	3.2e+02	5.8e+03	14.87	14.32	15.71	15.37
21.40	4.6e+02	9.8e+03	17.94	17.51	18.30	18.88
23.45	5.5e+02	1.3e+04	20.03	19.30	21.42	20.87
19.76	3.9e+02	7.7e+03	14.08	16.00	17.42	17.22
32.25	1.0e+03	3.4e+04	24.24	24.68	27.05	27.18
26.69	7.1e+02	1.9e+04	23.21	21.79	24.19	23.70
19.65	3.9e+02	7.6e+03	15.05	15.89	16.20	17.10
39.00	1.5e+03	5.9e+04	24.85	24.77	28.00	28.02
18.21	3.3e+02	6.0e+03	15.21	14.52	16.51	15.60
29.04	8.4e+02	2.4e+04	22.77	23.26	25.44	25.42
19.09	3.6e+02	7.0e+03	16.44	15.36	17.14	16.52
19.68	3.9e+02	7.6e+03	13.13	15.92	15.63	17.13

Note: ft msl = feet, mean sea level

Table D2. Equation coefficient for regression analysis

Regression Output		May	September
Constant		0	0
Standard error of *y* estimate		1.297129	0.706441
R^2		0.918711	0.980836
Number of observations		14	14
Degrees of freedom		11	11
x Coefficients	*a*	0.360448	0.380786
	b	0.038837	0.041418
	c	-0.000815	-0.00084
Standard error of coefficients	*a*	0.245593	0.133755
	b	0.01837	0.010005
	c	0.000322	0.0001754