Hydrogeologic Conditions and Simulation of Ground-Water Flow in the Greater Orlando Metropolitan Area, East-Central Florida

By L.C. Murray, Jr., and Keith J. Halford

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CONVERSION FACTORS, VERTICAL DATUM, ABBREVIATIONS AND ACCRONYMS

Multiply	By	To obtain
	Length	
inch (in)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	0.4047	hectare
square mile (mi^2)	2.590	square kilometer
	Flow Rate	
foot per day (ft/d)	0.3048	meter per day
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per day (ft^3/d)	0.02832	cubic meter per day
million gallons per day (Mgal/d)	0.04381	cubic meter per second
inch per year (in/yr)	25.4	millimeter per year
	Pressure	
pound per square foot (lb/ft^2)	0.04788	kilopascal
	Density	
pound per cubic foot (lb/ft^3)	16.02	kilogram per cubic meter
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day
	****Transmissivity***	
foot squared per day (ft^2/d)	0.09290	meter squared per day

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:
°C=(°F-32)/1.8

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

***Transmissivity:** The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness $[(ft^3/d)/ft^2]ft$. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

Acronyms and additional abbreviations used in report

mg/L	milligrams per liter
µS/cm	microsiemens per centimeter at 25 degrees Celsius
CUP	Consumptive Use Permit
FDEP	Florida Department of Environmental Protection
GHB	General-Head Boundary
MODFLOW	U.S. Geological Survey Modular Three-Dimensional Ground-Water Flow Model
OCERW	Orange County eastern regional well field
OUC	Orlando Utilities Commission
RASA	Regional Aquifer-System Analysis
RCID	Reedy Creek Improvement District
SFWMD	South Florida Water Management District
SJRWMD	St. Johns River Water Management District
T/S	Transmissivity/Storage coefficient (referred to as aquifer diffusivity)
VCONT	Vertical conductance term

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ABSTRACT

A finite-difference ground-water flow model was used to simulate the effects of both modern-day (1988) and projected 2010 ground-water withdrawals on the Floridan aquifer system in the greater Orlando metropolitan area. This area covers about 2,500 square miles and includes all of Orange and Seminole Counties and parts of Lake, Volusia, Brevard, Osceola, and Polk Counties.

The hydrogeology of the area is characterized by a thin surficial aquifer underlain by the thick, highly productive rocks of the Floridan aquifer system. Water in the Upper Floridan aquifer is brackish (chloride concentrations greater than 1,000 milligrams per liter) in discharge areas beneath and near the St. Johns and Wekiva Rivers and is freshest (chloride concentrations less than 100 milligrams per liter) in recharge areas. A slight trend toward increasing concentrations of dissolved solids, chloride, and sulfate has been observed at Upper Floridan aquifer springs. Chloride concentrations in the Upper Floridan aquifer measured between 1966 and 1993 at the Cocoa well field have increased from 50 milligrams per liter to 120 milligrams per liter; concentrations measured in the Lower Floridan aquifer between 1966 and 1993 have increased from 600 milligrams per liter to 3,000 milligrams per liter.

The flow model was calibrated by comparing (a) simulated and estimated Upper Floridan aquifer predevelopment (unstressed) potentiometric surfaces, (b) simulated and measured heads at 142 Upper Floridan aquifer monitoring wells in 1988 (average absolute error of 1.8 feet), (c) simulated and measured discharge rates at 15 Upper Floridan aquifer springs in 1988 (306 cubic feet per second), and (d) simulated and measured drawdowns at 134 Upper Floridan aquifer monitoring wells between 1988 and May 1990 (58 and 95 percent of simulated drawdowns were within plus or minus 25 and 50 percent of measured drawdowns, respectively). Relative to predevelopment conditions, model simulations indicate that about half of the 305 million gallons per day of water pumped from the Floridan aquifer system in 1988 was accounted for by increased recharge from the surficial aquifer system. About 23 cubic feet per second was derived from increased lateral inflow. A storage coefficient of 1×10^{-3} provided the best comparisons of measured-to-simulated data during the transient simulation from January to May 1990. This storativity probably is greater than the true storativity of the Upper Floridan aquifer because storage contributions from the intermediate confining unit were not accounted for during model design and development.

Calibrated transmissivity ranged from 10,000 to greater than 400,000 feet squared per day in the Upper Floridan aquifer, and from 5,000 to 600,000 feet squared per day in the Lower Floridan aquifer. Calibrated intermediate confining unit leakance ranged from 1×10^{-5} to 4×10^{-3} per day and was highest in areas where the unit is thin or has been breached by numerous sinkholes. In general, calibrated transmissivity and leakance values were higher than associated aquifer-test values. Simulated recharge rates to

the Upper Floridan aquifer from the surficial aquifer system ranged from less than 3 to 21 inches per year. Recharge rates of greater than 10 inches per year were simulated in areas of west Seminole, west Orange, east Lake, and southwest Volusia Counties. Recharge rates of less than 3 inches per year were simulated in east Orange and northeast Osceola Counties.

The calibrated model was used to simulate the effects of increased Floridan aquifer withdrawals in the year 2010 (542 million gallons per day) on water levels and spring flow. Projected effects were simulated for both "wet" conditions (using 1988 fixed-head arrays) and for "dry" conditions (using May 1990 fixed-head arrays), thus bracketing a potential range of effects. Relative to simulated 1988 conditions, simulated 2010 spring flow decreased by 43 cubic feet per second (14 percent) for wet conditions and by 67 cubic feet per second (22 percent) for dry conditions. Increased pumpage from the Lower Floridan aquifer accounted for about 17 cubic feet per second (40 percent) of reduced spring-flow rates. Simulated drawdowns in the Upper Floridan aquifer ranged from 10 to 20 feet in central Orange County, with a local maximum of about 30 feet at a well field in southwest Orange County. About 4 to 8 feet of the drawdown simulated in central Orange Country was attributed to increased Lower Floridan aquifer pumpage. Simulated drawdowns ranged from less than 2 feet in east Seminole County to about 10 feet in the south-central part of the county.

Particle-tracking simulations indicate that water discharged at Seminole, Messant, Rock, Wekiva, Miami, Sanlando, Palm, and Starbuck Springs is derived largely from high-rate recharge areas in northwest Orange and east Lake Counties. Water pumped from the Cocoa well field in 1988 was captured from low-rate recharge areas in central Orange and north Osceola Counties. Pumpage from the proposed Orange County eastern regional well field in 2010 captured much of the water in central Orange County that contributed to the Cocoa well field in 1988. As a result, the projected Cocoa well field contributing area was displaced further south, capturing more water from Osceola County and less water from Orange County.

The simulated flow paths and destinations of surface waters that recharge the Upper Floridan aquifer through the Lake Killarney and Lake Underhill drainage wells (2.5 and 2.1 million gallons per day, respectively) were significantly affected by increased 2010 withdrawals. About 70 percent of inflow to these wells in 1988 moved toward the northeast and was discharged in east Seminole County, either to the surficial aquifer system or to the St. Johns River. In 2010, about 95 percent of the simulated inflow was captured and discharged by three Lower Floridan aquifer well fields located in north-central Orange County. The remaining 5 percent was captured and discharged by two Upper Floridan aquifer well fields in north-central Orange County.

INTRODUCTION

The Orlando metropolitan area includes all of Orange and Seminole Counties and adjacent parts of Lake, Volusia, Brevard, Osceola, and Polk Counties (fig. 1). Virtually all the water required to meet municipal, industrial, commercial, and agricultural demands in the area is pumped from the Floridan aquifer system. Withdrawals from the Floridan aquifer system are regulated by the St. Johns River and South Florida Water Management Districts.

The population of the Orlando metropolitan study area has increased by about 50 percent since 1980 and was estimated at about 1.3 million people in 1994. Projected population and commercial growth are expected to increase demands on the ground-water resource. Favorable areas for future ground-water development are limited by the presence of saltwater, zones of relatively low aquifer transmissivity, and by the proximity of existing well fields. Increased withdrawals also could lower the potentiometric surface of the Upper Floridan aquifer and decrease the flow from Upper Floridan aquifer springs, which are valuable recreational and aesthetic resources. Springs in the study area are identified in figure 1.

The long-term effects of increased ground-water withdrawals on the Floridan aquifer system are difficult to evaluate because previous ground-water flow models of east-central Florida did not encompass the

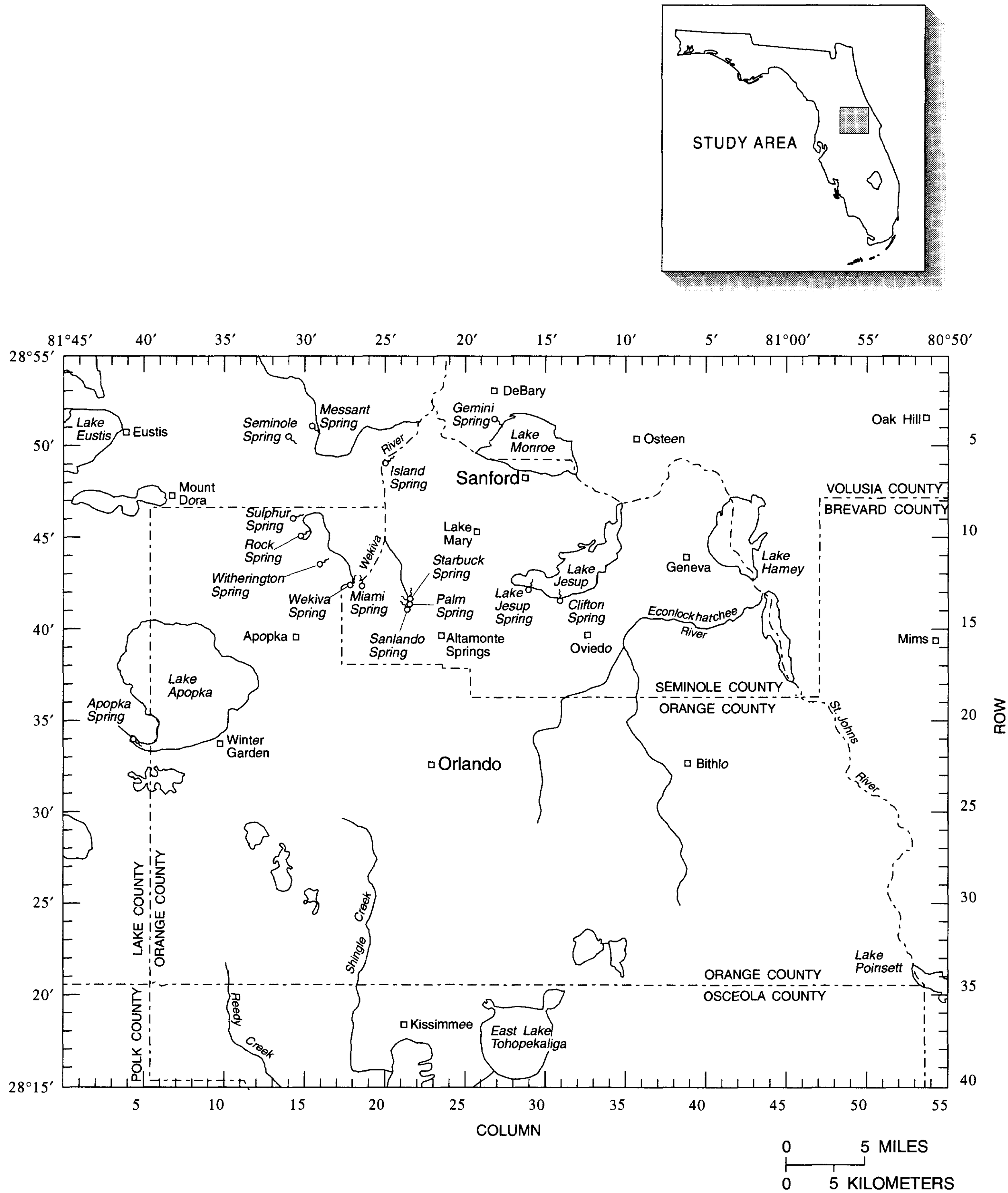


Figure 1. Locations of study area and Upper Floridan aquifer springs.

entire metropolitan Orlando area or were more regional in scope and coarsely discretized. Although the earlier Regional Aquifer-System Analysis (RASA) study conducted by the U.S. Geological Survey (Tibbals, 1981; 1990) includes the study area, the RASA model is coarsely discretized and was developed to simulate more regional flow systems. In order to improve understanding of ground-water flow conditions in the Floridan aquifer system and the possible effects of future withdrawals, the U.S. Geological Survey (USGS), in cooperation with the St. Johns River Water Management District (SJRWMD), the South Florida Water Management District (SFWMD), and the Florida Department of Environmental Protection (FDEP), began a 5-year project to develop and calibrate a more highly resolved digital ground-water flow model of the study area.

Purpose and Scope

This report describes the results of a cooperative study designed to (1) update information on the hydrogeologic and water-quality conditions in the Floridan aquifer system in the study area; (2) estimate, by computer simulation, the hydraulic characteristics of the confining units and aquifers that underlie the study area and the distribution of Upper Floridan aquifer recharge rates from the surficial aquifer system; and (3) to assess the possible effects of projected 2010 ground-water withdrawals on flow conditions in the Floridan aquifer system.

Many of the data referenced in this study were collected since the RASA study was completed. Together with the existing data, these more recent data were used to develop a conceptual model of the ground-water flow system in the study area. A digital computer model constructed from the conceptual model was used to simulate (a) the steady-state flow conditions observed in the Floridan aquifer system prior to extensive ground-water development; (b) modern-day (1988) stressed conditions; (c) declines in Upper Floridan aquifer heads observed during a period of deficient rainfall from January through May 1990; and (d) the effects of increased Floridan aquifer pumpage in the year 2010 on water levels and spring discharge from the Upper Floridan aquifer. Generalized water budgets were developed and used to compare historic and projected flow conditions within and between the Upper and Lower Floridan aquifers. Particle-tracking simulations were used to delineate areas that contribute recharge to selected Upper Floridan aquifer springs and well fields during 1988 and projected 2010 conditions. The possible routes and destinations of surface water that recharges the Upper Floridan aquifer through two high-capacity drainage wells located near downtown Orlando also were simulated.

Previous Studies

The results of regional, multistate studies of the Floridan aquifer system have been described by Miller (1986); Johnston and Bush (1988); and Bush and Johnston (1988). Johnston and others (1980) constructed a potentiometric surface map of the Upper Floridan aquifer in the southeast United States as it existed prior to extensive ground-water development. Maps showing the current potentiometric surface of the Upper Floridan aquifer in central Florida are published semiannually by the USGS. Investigations have been conducted in all or parts of Orange County by Stringfield (1936a), Unklesbay (1944), Lichtler and others (1968), Lichtler (1972), Knochenmus (1975), Tibbals and Frazee (1976), Watkins (1977), Kimrey (1978), Shaw and Trost (1984), German (1989), Toth and others (1989), and Bradner (1991); in Seminole County by Barraclough (1961, 1962), Anderson and Hughes (1975), Tibbals (1977), Phelps and Rohrer (1987), and Toth and others (1989); in Volusia County by Wyrick (1960), Knochenmus and Beard (1971), Rutledge (1982, 1985), McGurk and others (1989), Kimrey (1990), Phelps (1990), and Vecchioli and others (1990); in Lake County by Knochenmus and Hughes (1976), Grubb (1978), Grubb and Rutledge (1979), Johnson (1979), and Toth and others (1989); in Osceola County by Frazee (1980), Shaw and Trost (1984), and Schiner (1993); in Polk County by Stewart (1966), Grubb (1978), Grubb and Rutledge (1979), Johnson (1979), and Barr (1992); and in Brevard County by Brown and others (1962). Ground-water flow modeling studies have been performed for all or parts of the study area by Bush (1978), Grubb and Rutledge (1979), Planert and Aucott (1985), Skipp (1988), and Tibbals (1981,1990).

Acknowledgments

The authors wish to thank Barbara Vergara and Douglas Munch (SJRWMD); Keith Smith (SFWMD);

and Rodney DeHan (FDEP) and their respective staffs for assistance in this investigation.

Data-Collection Sites

Wells inventoried by the USGS are assigned a unique identification number based on latitude and longitude. Wells identified by other sources are assigned the number given in the respective reference. The locations of wells used in this study are shown in figure 2. Sites related to well data used in this study are listed in Appendix A. Most surface-water data-collection sites are identified by the USGS using an 8-digit number sequenced in downstream order. Sites related to surface-water data used in this study are listed in appendix B.

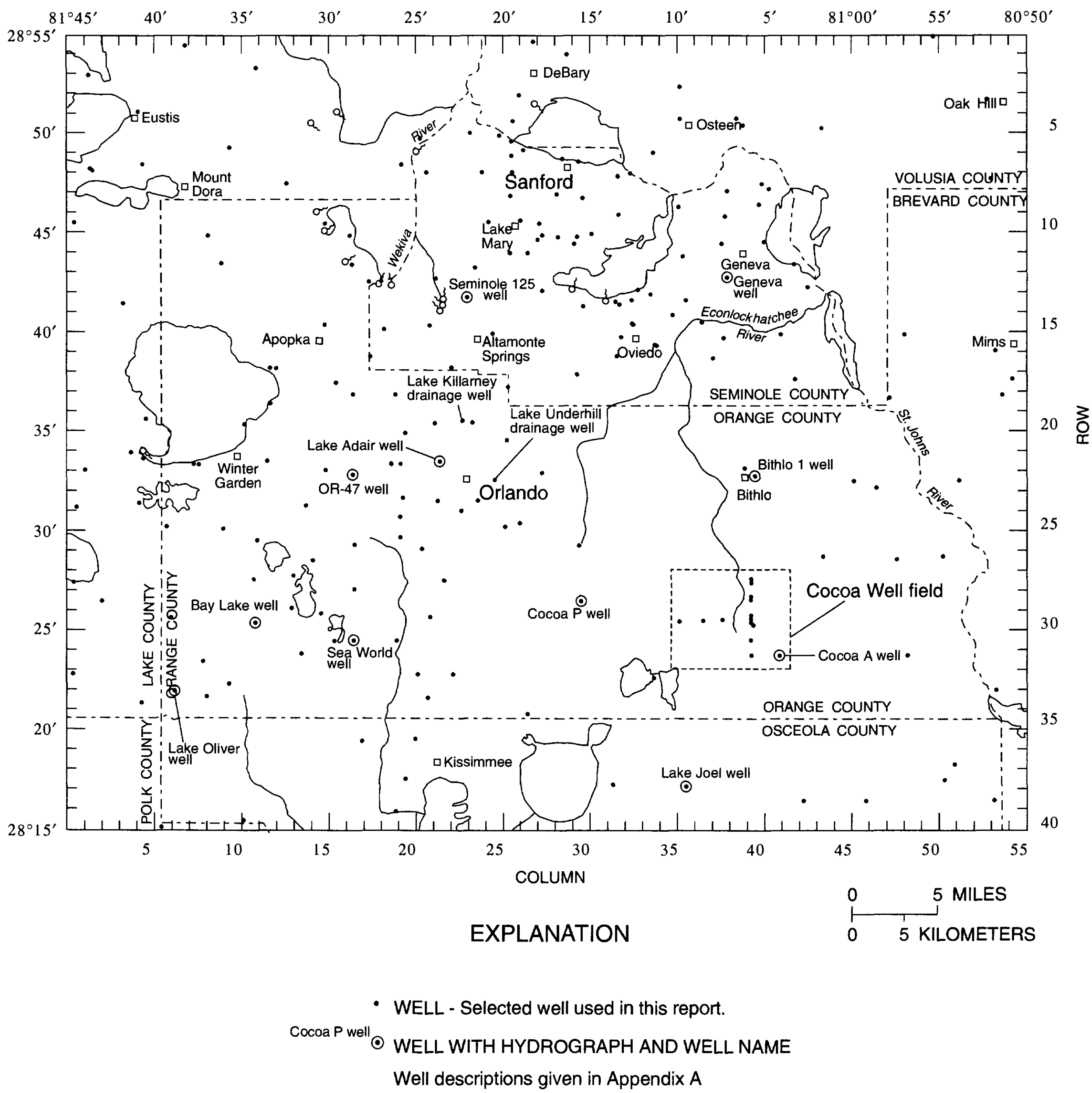


Figure 2. Locations of wells used in this study.

Description of the Area

The study area encompasses 2,500 mi^2 in east-central Florida and includes all of Orange and Seminole Counties and parts of Lake, Volusia, Brevard, Osceola, and Polk Counties (fig. 1). The principal industries of the area are tourism, agriculture, space research, and light manufacturing. Agricultural products include citrus, cattle, vegetables, ornamental plants, poultry, timber, and pulpwood.

Climate

The climate of the study area is classified as subtropical and is characterized by warm, relatively wet summers and mild, relatively dry winters. Temperatures commonly exceed 90 ^{o}F during June, July, August, and September, but may fall below freezing for a few days in the winter months. The average annual air temperature in Orlando is about 72 ^{o}F. Long-term (1913-92) annual rainfall for the area is about 51 in. (averaged from rainfall data collected at Orlando and Sanford). About 55 percent of the yearly total is derived from thunderstorms that occur frequently during the months of June, July, August, and September. Thunderstorms usually are localized and distribute rainfall unevenly across the area. During the winter, rainfall usually is associated with cold fronts and is more uniformly distributed than during the rest of the year.

Topography

Topography in the study area ranges from the rolling highlands of east Lake and west Orange Counties to the flat, swampy lowlands of the St. Johns River flood plain in east Orange and west Brevard Counties. The landscape across much of the study area is characterized by hundreds of lakes and several large streams. Water levels measured in over 100 lakes were used to help define water-table altitudes in the study area, as discussed later in this report. Land-surface altitudes along the northwest-to-southeast oriented highland ridges in Orange and Lake Counties range from 150 to about 300 ft (fig. 3). The highland areas contain numerous lakes and karst features, such as depressions and sinkholes, many of which do not have surface outlets and are internally drained. Numerous depressions also are present along sandy ridges in west Volusia County, north of Lake Monroe and to the east of the St. Johns River.

The southwest part of the study area in Polk County, although topographically high, is relatively flat and swampy. Land-surface altitudes in the area range from 125 to 150 ft. Moderate topography dominates much of central Orange, north Osceola, and west Seminole Counties. Altitudes in these areas generally range from 50 to 100 ft, but altitudes are greater than 100 ft around Orlando and less than 50 ft in northeast Osceola County. Except for the higher sandy ridges in Volusia and Brevard Counties and a small area surrounding the town of Geneva in Seminole County, altitudes near the coastal areas and around the St. Johns River range from 0 to 50 ft.

Drainage

The study area is divided into three major drainage basins: the St. Johns River basin, the Kissimmee River basin, and the Coastal basin (fig. 3). The St. Johns River basin is subdivided into numerous smaller subbasins; however, for the purposes of this report, only the Upper St. Johns and Ocklawaha River subbasins are shown in figure 3. Detailed descriptions of surface-water drainage and subbasin delineations in east-central Florida are described by Lichtler (1968,1972).

The most prominent surface-water feature in the study area is the St. Johns River. The river flows southeast-to-northwest across the study area and defines the eastern boundaries of Seminole and Orange Counties. The St. Johns River discharges into the Atlantic Ocean near Jacksonville in northeast Florida, but the river is tidally influenced as far upstream as Seminole County. About two-thirds of the study area is drained by the river, including all of Seminole County, the east and northwest parts of Orange County, and parts of Osceola, Brevard, Volusia, and Lake Counties. Major tributaries within the St. Johns River basin are the Econlockhatchee River and the Ocklawaha River. The Ocklawaha River subbasin drains northwest Orange and east Lake counties. This subbasin contains few surface streams and drainage is mostly into closed depressions or lakes. The Upper St. Johns River subbasin drains all of Seminole County, east Orange, and parts of Osceola, Brevard, Volusia, and Lake Counties. Surface water in much of east-central Orange and east Seminole Counties drains to the Econlockhatchee River. Drainage within these areas, which are characterized by high water tables and numerous small streams, is more developed than in the Ocklawaha subbasin.

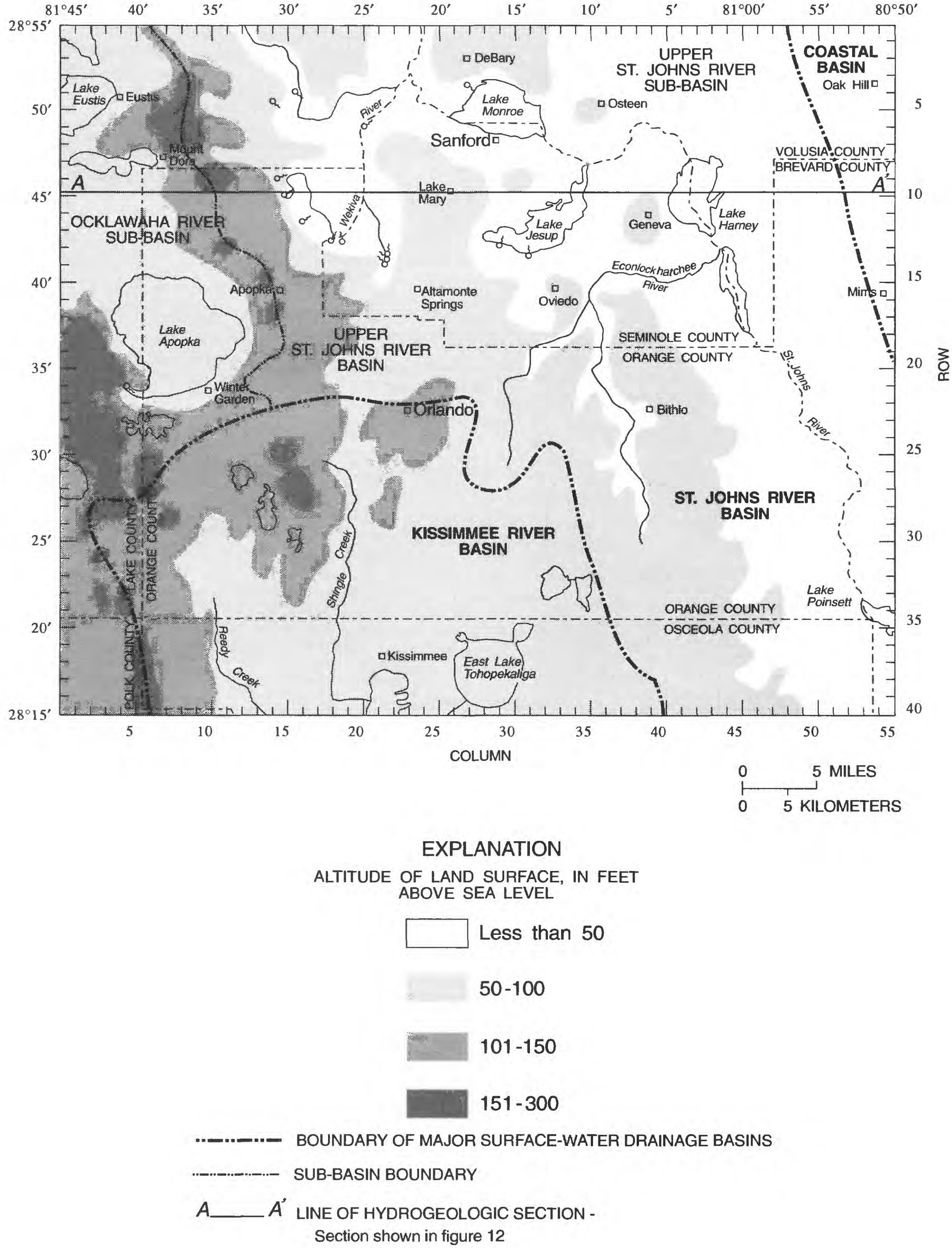


Figure 3. Generalized topography and major surface-water drainage basins.

The Kissimmee River basin drains about one-third of the study area, including the southwest and south-central parts of Orange County. Headwater streams of the Kissimmee River include the southward-flowing Reedy Creek and Shingle Creek. Drainage within this basin is poorly developed. The Coastal basin drains about 3 percent of the study area in parts of northeast Brevard and southeast Volusia Counties. The small streams that drain the Coastal basin have relatively small drainage subbasins. Water from the coastal area drains into lagoons which connect to the Atlantic Ocean through inlets.

HYDROGEOLOGIC CONDITIONS

The hydrogeologic framework of the study area includes the surficial aquifer system, the intermediate confining unit, and the Floridan aquifer system. The Floridan aquifer system is further subdivided into the Upper Floridan aquifer, the middle semiconfining unit, and the Lower Floridan aquifer. The relation between the geologic units described in this section and the Floridan aquifer system is shown in figure 4.

Surficial Aquifer System

The unconfined surficial aquifer system is the uppermost water-bearing unit in the study area. The system consists of fine-to-medium-grained quartz sand with varying amounts of silt, clay, and crushed shell and ranges in age from Pliocene to Recent. Thickness of the surficial aquifer system is highly variable, ranging from less than 10 ft in areas of the St. Johns River basin to greater than 150 ft along the high ridge areas of west Orange and east Lake Counties. With increasing depth, the surficial aquifer system sediments generally grade into less permeable clayey or silty sands that, in some areas, compose the upper part of the intermediate confining unit and elsewhere directly confine the Floridan aquifer system. The base of the surficial aquifer system is approximately 40 ft below land surface in much of Orange County (Lichtler, 1968, p. 83) and ranges from 20 to 60 ft below land surface in most of Seminole County (Tibbals, 1977, p. 2).

The surficial aquifer system is recharged by rainfall, irrigation, septic tank effluent and, in parts of southwest Orange County, by land application of reclaimed water. Water from the underlying Floridan aquifer system can also leak upward through the intermediate confining unit to recharge the surficial aquifer system in areas where the water table is lower than the potentiometric surface of the Upper Floridan aquifer. Water is discharged from the surficial aquifer system by seepage to lakes, streams, and ditches; by evapotranspiration where the water table is near land surface; by pumpage; and by downward leakage to the Floridan aquifer system in areas where the potentiometric surface of the Upper Floridan aquifer is lower than the water table. The surficial aquifer system is rarely used as a source of potable water because well yields are low and the water commonly contains high concentrations of dissolved iron and can be highly colored.

Intermediate Confining Unit

The intermediate confining unit separates the surficial and Floridan aquifer systems throughout the study area. The unit includes all sediment beds of late-to-middle Miocene age (Hawthorn Group), and locally, low permeability beds of early Pliocene age (Miller, 1986, p. 43). Sediments include interbedded sands, calcareous silts and clays, shell, and phosphatic limestone and dolomite. The thickness of the intermediate confining unit ranges from less than 50 ft across much of Seminole, southwest Volusia, and east Lake Counties to greater than 250 ft in southeast Orange County (fig. 5). In east Lake and west Orange Counties, where the unit is locally breached by numerous sinkholes, thicknesses may range from 0 ft at a sinkhole to greater than 100 ft within a few tens of feet from the depression. In southwest Seminole County, the thickness of the unit ranges from 80 to 150 ft (Anderson and Hughes, 1975, p. 5), thinning to about 20 ft near the city of Lake Mary. Deposits in the east part of Seminole County near Geneva are reported to range from 20 to 60 ft in thickness (Phelps and Rohrer, 1987, p. 8). The Hawthorn Group is absent in northeast Seminole and southwest Volusia Counties and the surficial and Floridan aquifer systems are separated by deposits of fine sand, shells, and calcareous silty clays present at the base of the surficial aquifer system (Tibbals, 1977; Phelps, 1990, p. 17). In the southwest part of the study area, in Polk County, unit thicknesses range from 6 to 20 ft (Grubb, 1978; Johnson, 1979). The thickness of the intermediate confining unit at any particular site may differ markedly from the generalized ranges shown in figure 5 because of local

GEOLOGIC UNITS
(Modified from Tibbals, 1990, fig. 8)

SYSTEM	SERIES	STRATIGRAPHIC UNIT	THICKNESS (feet)	LITHOLOGY	AQUIFER
QUATERNARY	RECENT	UNDIFFERENTIATED DEPOSITS	0-150	Alluvium, freshwater marl, peats and muds in stream and lake bottoms. Also, some dunes and other windblown sand.	SURFICIAL AQUIFER SYSTEM
QUATERNARY	PLEISTOCENE	UNDIFFERENTIATED DEPOSITS	0-150	Mostly marine quartz sand, unconsolidated and generally well graded. Also, some fluviatile and lacustrine sand, clay and marl.	SURFICIAL AQUIFER SYSTEM
TERTIARY	PLIOCENE	UNDIFFERENTIATED DEPOSITS	0-100	Interbedded deposits of sand, shell, and sandy clay; base characterized by phosphatic clay and rubble.	SURFICIAL AQUIFER SYSTEM
TERTIARY	MIOCENE	HAWTHORN GROUP	0-250	Cream to light green to greenish-gray clayey quartz sand, silt, and sandy clay; often contains phosphatic sands and clays; phosphatic limestone often found at base of formation.	
TERTIARY	EOCENE – UPPER	OCALA LIMESTONE	0-200	Marine foraminiferal limestone, white to cream to tan, soft to hard, granular, highly porous, sometimes dolomitic.	FLORIDAN AQUIFER SYSTEM
TERTIARY	EOCENE – MIDDLE	AVON PARK FORMATION	600-1600	Marine limestone, light brown to brown, fragmental, poor to good porosity, highly fossiliferous, slightly carbonaceous; and dolomite, brown to dark brown, crystalline.	FLORIDAN AQUIFER SYSTEM
TERTIARY	EOCENE – LOWER	OLDSMAR FORMATION	300-1350	Marine limestone, light brown to white, chalky, porous, fossiliferous with interbedded brown crystalline dolomite.	FLORIDAN AQUIFER SYSTEM
TERTIARY	PALEOCENE	CEDAR KEYS FORMATION	500-2200	Marine dolomite, light gray, hard, slightly porous to porous, crystalline, in part fossiliferous, with considerable anhydrite and gypsum, some limestone.	

PRINCIPAL HYDROGEOLOGIC UNITS, EQUIVALENT LAYERS IN COMPUTER MODEL, AND BOUNDARY CONDITIONS

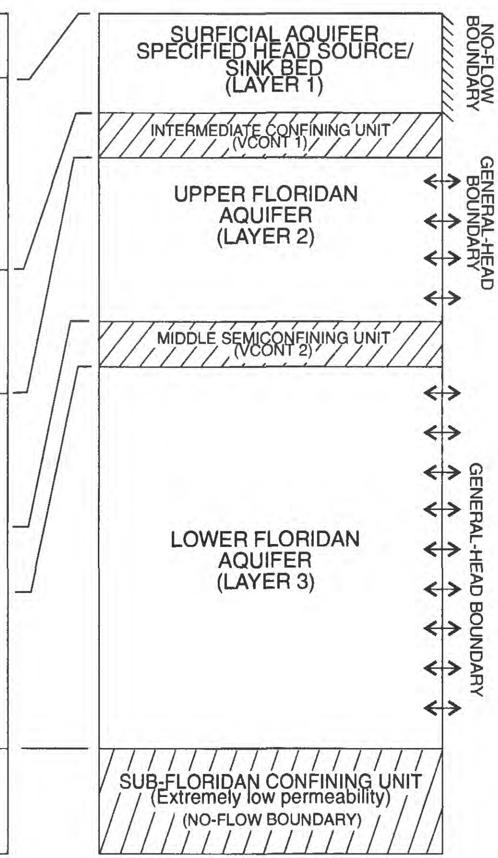


Figure 4. Geologic units, hydrogeologic units, and equivalent layers and boundary conditions used in the ground-water flow model.

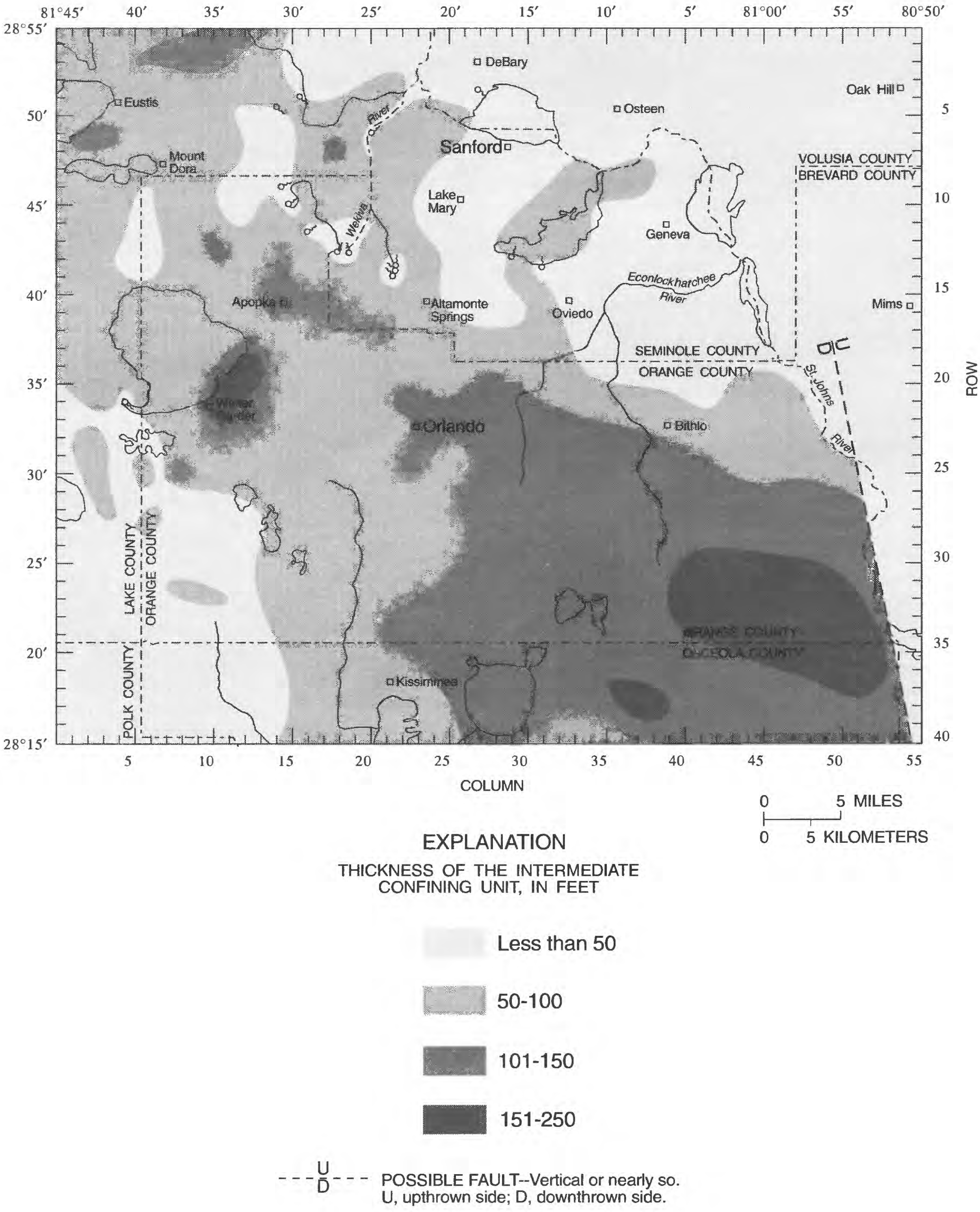


Figure 5. Generalized thickness of the intermediate confining unit (compiled from Boniol (1994); Brown (1962); Grubb and Rutledge (1979); Lichtler (1968); McGurk, Bond, and Mehan (1989); Phelps and Rohrer (1987); Schiner (1993); and Tibbals (1976)).

irregularities caused by erosion and by the occurrence of collapse features in the underlying limestone.

Hydraulic conductivity of the intermediate confining unit is highly variable. Localized beds of sand, shell, and gravel present in the upper part of the formation in east Orange County yield substantial quantities of water to wells. Much lower hydraulic conductivities characterize the clays present in the Hawthorn Group. Laboratory testing of selected clay cores yielded hydraulic conductivity values that ranged from about $8x10^{-7}$ to $2x10^{-2}$ ft/d (Miller, 1986, p. 43). Localized beds of basal Hawthorn limestone that are in direct hydraulic contact with the Upper Floridan aquifer in the north and west parts of the study area have been considered by some previous investigators to mark the top of the Floridan aquifer system. However, because the hydraulic conductivity of the Hawthorn limestone is at least an order of magnitude less than that of the underlying Floridan limestone, and because Hawthorn limestone beds occur only locally, they are not considered to be part of the Floridan aquifer system (Miller, 1986, p. 43). This report follows the conventions of Miller (1986).

Leakance of the intermediate confining unit reported from aquifer tests range from $1x10^{-4}$/d in east Orange County to about $2x10^{-2}$/d in northeast Polk County (Tibbals, 1976; 1982), and from $3x10^{-4}$/d to $1x10^{-2}$/d in Seminole County (Szell, 1993). Leakance values computed from aquifer tests generally are higher than model-calibrated RASA values because field-derived values are often calculated from an analytical solution (Hantush and Jacob, 1955) that assumes leakage to the pumped well is derived solely from the surficial aquifer system through the intermediate confining unit. In actuality, leakage from the Lower Floridan aquifer through the middle semiconfining unit also contributes water to the pumped wells. As a result, values derived from aquifer tests represent the combined or resultant leakances of both the intermediate confining and middle semiconfining units, providing an upper bound for model calibration purposes. Field-derived values also can be used to distinguish between general areas of relatively high and low leakance.

Floridan Aquifer System

The Floridan aquifer system is composed of a sequence of highly permeable, Tertiary limestone and dolomitic limestone that thickens from about 2,000 ft in the northwest part of the study area to more than 2,600 ft near the southeast part of the study area (Tibbals, 1990, fig. 10). From bottom to top, the geologic units of the aquifer system are of Eocene age and include the Oldsmar Formation, the Avon Park Formation, and the Ocala Limestone (fig. 4). The base of the system is marked by the first occurrence of relatively impermeable, vertically persistent beds of anhydrite generally found in the upper third of the Paleocene-age Cedar Keys Formation.

The Floridan aquifer system consists of two major permeable zones separated by a less permeable zone of highly variable water-transmitting characteristics. Water-level and water-quality data and flow-meter logs indicate that this less permeable zone acts as a semiconfining unit that hydraulically separates the more permeable zones above and below it (Miller, 1986, p. 56). Based on this information, the Floridan aquifer system has been divided into the Upper Floridan aquifer, the middle semiconfining unit, and the Lower Floridan aquifer (Tibbals, 1981; Miller, 1986).

Lithology and Structure

The Upper Floridan aquifer consists of the Ocala Limestone and the dolomite and dolomitic limestones of the upper one-third of the Avon Park Formation. The Ocala limestone generally is soft, porous, white-to-cream colored, and contains numerous caverns, fissures, and other features of secondary porosity. The Ocala Limestone has been removed by erosion in south-central Orange and north-central Osceola Counties and in a small area of southwest Seminole County. The top of the Upper Floridan aquifer in these areas is defined by the dolomitic limestones of the Avon Park Formation. The top of the aquifer generally dips from northwest-to-southeast across the study area, with altitudes ranging from 0 to 50 ft above sea level in Lake County to more than 300 ft below sea level in southeast Orange and northeast Osceola Counties (fig. 6). The contours shown in figure 6 are for generalized conditions and were compiled from work by Lichtler and others (1968), Knochenmus (1976), Tibbals and Frazee (1976), Rutledge (1985), Schiner (1993), and Boniol (1994). The altitude of the top of the Upper Floridan aquifer at any particular site may differ from that indicated in figure 6 because of local irregularities caused by erosion and solution of the limestone or by collapse of sinkholes.

Wide variations in the altitude of the top of the Upper Floridan aquifer near the St. Johns River have

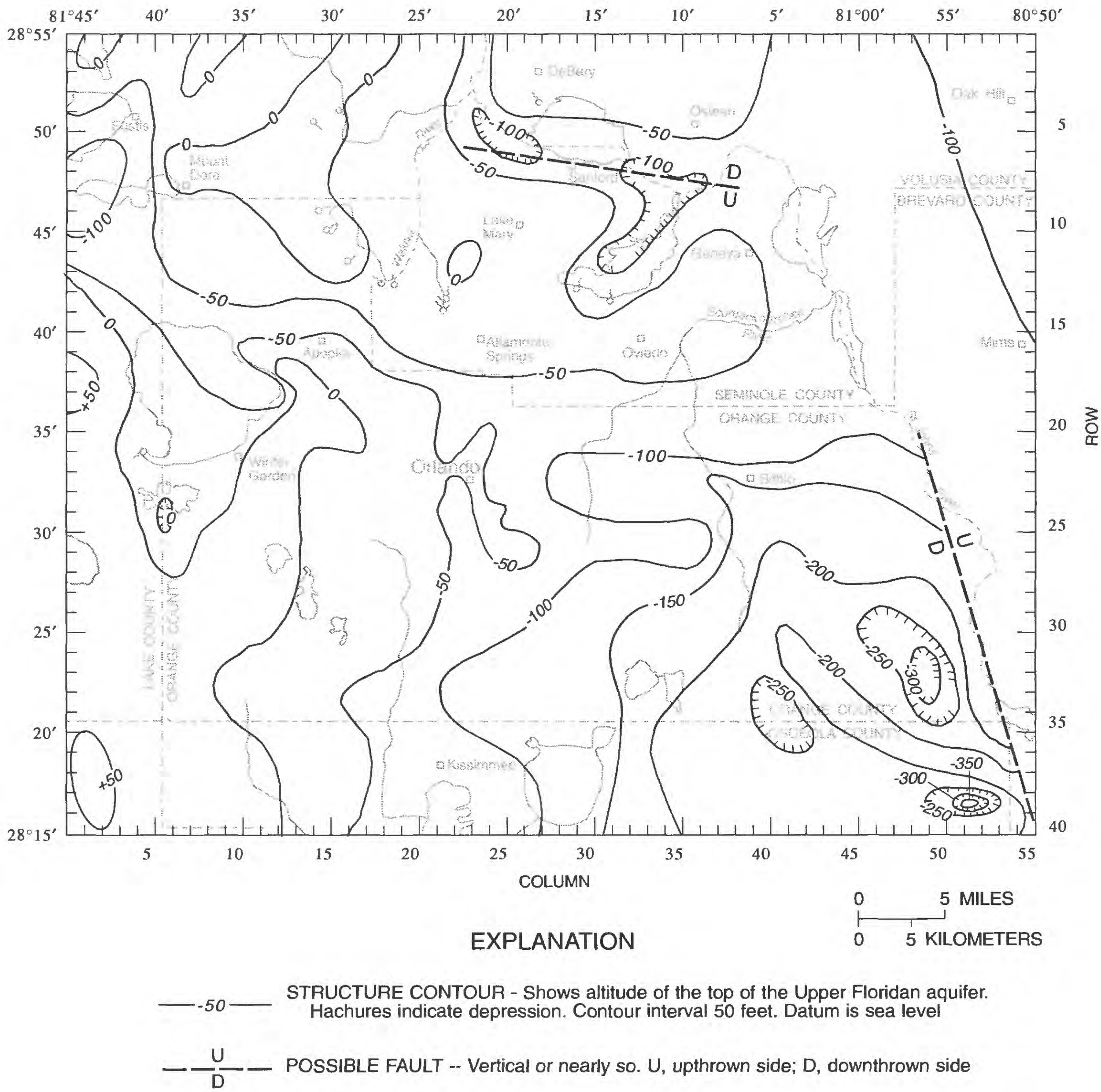


Figure 6. Altitude of the top of the Upper Floridan aquifer (compiled from Boniol (1994); Knochenmus (1976); Lichtler (1968); Rutledge (1984); Schiner (1993); and Tibbals (1976)).

been attributed by some investigators to a system of faults aligned with the river. The offset course of the St. Johns River northwest of Lake Harney could be indicative of subsurface faulting (Pirkle, 1971). Two inferred faults mapped by previous investigators and shown in figure 6 include an east-west oriented fault through north Seminole County (Barraclough, 1962) and a north-south oriented fault through west Brevard County (Brown and others, 1962). The inferred fault in west Brevard County would explain the unusually large difference (about 200 ft) in the altitude of the top of the Upper Floridan aquifer over a relatively short (2 mi) distance. Other investigators believe the inferred faults are based on sparse, limited well data and that offsets may be due to steeper-than-average dipping of the rock surface. Spechler (1994) showed that structures thought to be faults in the Jacksonville area could also be collapse features of a regional scale.

The middle semiconfining unit consists of less permeable, soft micritic limestone and dense dolomitic limestone in the middle one-third of the Avon Park Formation (fig. 4). The unit underlies the entire study area and thickens from about 200 ft in Lake County to about 800 ft in southeast Orange and northeast Osceola Counties (Tibbals, 1990, fig. 13). The lithologic character of the limestone and dolomite varies considerably, both with depth and areally across the unit. Lichtler (1972, p. 13) noted the presence of interconnected solution channels in this unit, but added that in areas where the dolomitic layers do not contain solution channels or fractures, they probably inhibit vertical movement of water.

The Lower Floridan aquifer includes the bottom one-third to one-half of the Avon Park Formation and all of the Oldsmar Formation. Aquifer lithology is limestone and fractured dolomite. The top of the Lower Floridan aquifer dips from northwest-to-southeast across the study area, with altitudes from about 600 ft to more than 1,200 ft below sea level (Miller, 1986). Thickness of the aquifer averages about 1,500 ft across the study area.

Aquifer Recharge and Discharge

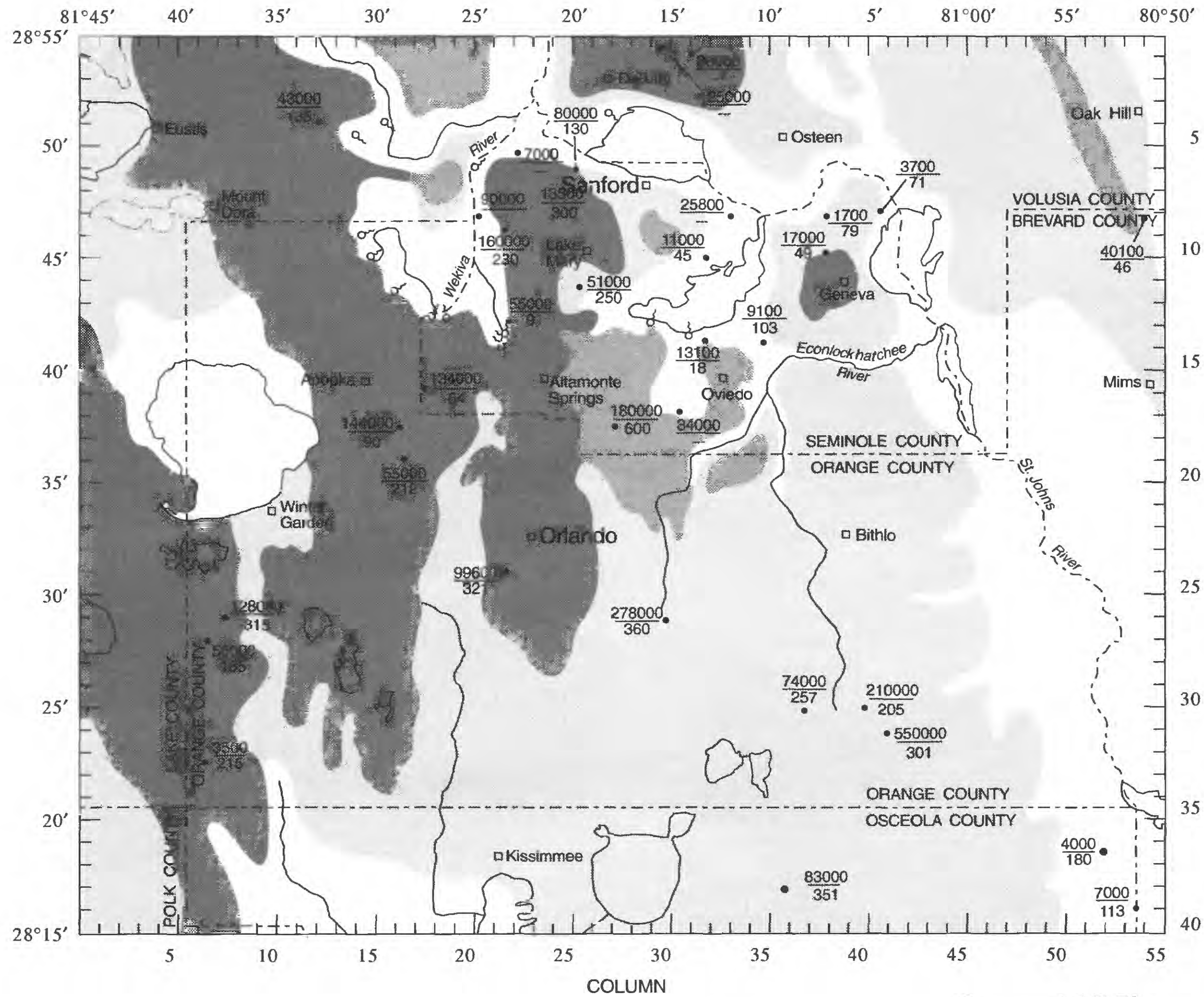
The Upper Floridan aquifer is recharged by downward leakage from the surficial aquifer system; by lateral inflow across the study area boundaries; and, for developed conditions, through drainage wells in the Orlando area and from the land application of reclaimed water. Estimated rates of recharge to the Upper Floridan aquifer from the surficial aquifer system range from less than 3 in/yr (low-rate recharge areas) to greater than 10 in/yr (high-rate recharge areas) (fig. 7). High-rate recharge areas in west Orange, east Lake, and southwest Volusia Counties are characterized by karstic sand ridges with relatively deep water tables. Rainfall in these recharge areas infiltrates rapidly into the thick, permeable surficial sands, reducing losses from surface runoff and evapotranspiration. The highest rates of recharge occur locally within closed sinkhole basins where the intermediate confining unit is breached and surface runoff is negligible. High recharge rates in west Seminole County can be attributed to a relatively thin intermediate confining unit. Low-rate recharge areas include the topographically low areas of the Kissimmee River basin in south-central Orange and north Osceola Counties, and the Coastal basin of east Volusia and north Brevard Counties. The water table in these areas typically is within a few feet of land surface, limiting storage capacity in the unsaturated zone and enhancing evapotranspiration and surface runoff.

The generalized areas of recharge and discharge shown in figure 7 are composited from separate county-wide maps constructed by previous investigators from basin-wide water budgets, soil-drainage properties, and other hydrogeologic data. The actual recharge rate at any particular site may vary considerably from that shown in figure 7. However, this generalized map distinguishes between broad areas of varying recharge potential.

Anthropogenic structural features also provide recharge to the Floridan aquifer system. Numerous drainage wells constructed in and around the city of Orlando between the early 1900's and mid-1960's convey water directly into the confined Floridan aquifer system. The USGS has inventoried 377 of these wells (Kimrey, 1978), half of which were designed to dispose of stormwater runoff in areas where natural drainage is poorly developed. A third of the wells were constructed for lake-level control, and the remainder were constructed to dispose of various types of industrial and municipal wastewater. Recharge to the aquifer from these wells has been estimated at about 30 Mgal/d (Tibbals, 1990, p. 28), but may be considerably more or less.

Recharge rates through individual drainage wells are largely undocumented and vary with the size of the respective drainage basin, the amounts of impervious area within the basin, soil conditions, and the condition of the well. Drainage-basin areas and associated recharge rates are larger for lake-level control wells that continuously receive water (such as those at Lake Underhill and Lake Killarney (fig. 2)) than for wells that dispose of stormwater runoff during discrete rainfall events. Recharge rates measured at the Lake Underhill well in 1988 averaged about 2.1 Mgal/d (Bradner, 1991); rates measured at the Lake Killarney well in 1993 averaged about 2.5 Mgal/d (Anne Bradner, USGS, oral commun., September 1994). Past inspections indicate that some of the wells have either been plugged with debris or destroyed and no longer recharge the aquifer (Kimrey, 1978; Bradner, 1991; and Taylor, 1993).

Reclaimed water from municipal treatment facilities operated by the city of Orlando and by Orange County is disposed of by land application to rapid-infiltration basins (RIBS) and by citrus irrigation in southwest Orange and east Lake Counties. In 1988, about 12.5 Mgal/d of reclaimed water was used to irri-



EXPLANATION

DISTRIBUTION OF RECHARGE TO AND DISCHARGE FROM THE UPPER FLORIDAN AQUIFER, IN INCHES PER YEAR

less than 0 (area of discharge)

0-3 (low recharge)

3-10 (moderate recharge)

greater than 10 (high recharge)

83,000• 351 — TRANSMISSIVITY DETERMINED FROM MULTI-WELL AQUIFER TEST -- Top number is transmissivity, in feet squared per day. Bottom number is thickness of aquifer penetrated by pumped well, in feet; ---, data not available

Figure 7. Generalized distribution of recharge to and discharge from the Upper Floridan aquifer and results of selected aquifer tests (compiled from Frazee (1980); Knochenmus (1976); Lichtler (1968; 1972); Szell (1993); Tibbals (1977); and Vecchioli and others (1990)).

gate 2,000 acres of citrus, 9.5 Mgal/d was applied to RIBS, and 1 Mgal/d was applied to alternate application (sinkhole) sites (Metcalf & Eddy, Inc., written commun., 1993). Most of the reclaimed water eventually recharges the Upper Floridan aquifer because no streams exist to transport water away from the disposal area and because flow in the surficial aquifer system is intercepted by numerous sinkholes that act as vertical conduits to the Upper Floridan aquifer.

Natural discharge from the Upper Floridan aquifer occurs primarily by spring flow. During 1988, 15 springs within the study area collectively discharged about 306 ft^3/s of water from the aquifer, slightly less than the 356 ft^3/s of water pumped from the aquifer by wells. Discharge rates measured at individual springs, which are subject to errors of up to 10 percent or greater, ranged from about 69 ft^3/s at Wekiva Springs to about 1 ft^3/s at Lake Jesup, Sulphur, and Witherington Springs (table 1). The discharge rates shown in table 1 for Wekiva, Rock, Sanlando, Palm, Starbuck, and Miami Springs were averaged from measurements made in May and September 1988, months that generally provide seasonal low and high values, respectively. Discharge rates shown for Seminole and Messant Springs represent May 1988 measured values only (September 1988 measurements were not made at these springs); discharge rates indicated for Apopka, Island, Gemini, Witherington, Clifton, Sulphur, and Lake Jesup Springs were estimated from measurements made prior to or after 1988 because no measurements were made at these springs in 1988. Differences between actual 1988 discharge rates and those indicated for the smaller springs (less than 2 ft^3/s) can be neglected because their collective discharge represents less than 3 percent of the total and these springs exert little influence on the ground-water flow system.

Flow at undocumented springs also may account for appreciable quantities of water discharged from the Upper Floridan aquifer. One area where undocumented spring flow likely occurs is along the St. Johns River from just below Lake Harney downstream to the

Table 1. Discharge from selected Upper Floridan aquifer springs in the Orlando metropolitan area for 1988 and predevelopment steady-state conditions

[R, spring locations published by Rosenau and Faulkner (1977); U, spring and flowing well locations estimated from U.S. Geological Survey (USGS) quadrangle maps; T, spring location published by Tibbals (1990); RT, revised from Tibbals (1990), based on inspection of additional or more current data; C, estimate from data collected during current study and not included in Tibbals (1990) report; spring discharge is in cubic feet per second; --, not applicable]

Name of spring	Spring location		Spring location source	Model		1988 average discharge[a]	Estimated predevelopment discharge	Source of estimates
	Latitude	Longitude		Row	Column			
Wekiva	284243	0812736	R	13	18	69	80	RT
Apopka	283400	0814051	R	21	5	61	70	RT
Rock	284520	0812958	R	10	15	58	70	T
Sanlando	284119	0812344	R	14	22	20	--	T
Palm	284127	0812334	R	14	22	6	50[b]	T
Starbuck	284148	0812328	R	14	22	15	--	T
Seminole	285044	0813122	R	5	14	39	40	RT
Messant	285121	0812956	R	4	16	14	20	T
Island	284922	0812503	T	6	20	6	10	RT
Gemini	285144	0811839	R	4	27	8	10	T
Miami	284236	0812634	R	13	19	5	6	RT
Witherington	284353	0812922	R	12	16	1	2	RT
Clifton	284156	0811414	R	14	31	2	2	T
Sulphur	284610	0813035	U	9	15	1	2	C
Lake Jesup	284236	0811605	R	13	29	1	1	T
TOTAL:						306	360[c]	

[a] Spring-discharge measurements typically are subject to ± 10 percent error, except for submerged Apopka and Island Springs, which are subject to measurement errors of 25 percent or greater.

[b] Collective total for Sanlando, Palm, and Starbuck Springs.

[c] Rounded to two significant figures.

Wekiva River. The intermediate confining unit in this area is relatively thin (less than 50 ft). Barraclough (1962, p. 35) described two areas, one near Lake Jesup and one near the Wekiva River, where relatively shallow excavations produced small spring flow. Tibbals (1981, p. 17) simulated 54 ft^3/s of Upper Floridan aquifer discharge from beneath the St. Johns River between Lakes Harney and Jesup. The Upper Floridan aquifer probably does not discharge much water to the St. Johns River between the confluence of the Econlockhatchee River south to Lake Poinsett, where streamflow measurements indicate little or no increase in baseflow (Tibbals, 1990, p. 29).

Abandoned flowing wells, constructed during the early 1900's to the 1970's to irrigate vegetable crops, also discharge water from the Upper Floridan aquifer. As of 1990, nearly 500 such wells were located in the study area by the SJRWMD (Steele, 1991). The majority of these wells are in Seminole County, just north and southeast of Lake Jesup. The total discharge from these wells is unknown because flow has been measured from only a relatively small number of wells. However, a rough estimate of 12 Mgal/d was made by extrapolating flows measured at wells of known diameter to unmeasured wells of the same diameter.

Hydraulic Characteristics

The transmissivity of an aquifer characterizes its ability to transmit water and is defined as "the rate of flow under unit hydraulic gradient through a cross section of unit width over the whole saturated thickness of the aquifer" (Bear, 1979). Transmissivity is calculated as the product of the aquifer's horizontal hydraulic conductivity and its saturated thickness.

Transmissivity of the Floridan aquifer system reported from aquifer tests varies widely across the study area (fig. 7). Variations from one test to another can be attributed to the heterogeneity of the system and to differences in well-penetration intervals and depths. In northwest Seminole County, transmissivity values of 13,500 ft^2/d and 160,000 ft^2/d were reported from two tests conducted relatively close to one another in the Upper Floridan aquifer. The wells used in these tests penetrated similar depths of the aquifer. Tests conducted in three wells that penetrated similar intervals of the Upper Floridan aquifer at the Cocoa well field yielded transmissivities of 74,000 ft^2/d, 210,000 ft^2/d, and 510,000 ft^2/d. The heterogeneous nature of the aquifer limits the extrapolation of field-derived hydraulic characteristic data to accurately estimate the spatial distribution of transmissivity beyond the field-tested areas. Moreover, field-derived values may underestimate actual transmissivity because wells used in aquifer tests seldom penetrate the full thickness of the aquifer. However, these tests do serve as a lower limit for flow-model calibration.

Specific-capacity and normalized well-yield data collected in Seminole County by Tibbals (1977) were used to distinguish between areas of relatively high, moderate, and low transmissivity within the Upper Floridan aquifer. Specific capacity is calculated by dividing the discharge rate at a pumping well by the drawdown measured in the well. Normalized well yield is equal to the well discharge divided by the length of the open hole. Specific capacities and well yields are lower in discharge areas near the St. Johns River and adjoining lakes than in areas further southwest, away from the St. Johns River. The highest specific capacities and well yields were mapped in high-rate recharge areas of west Seminole County from Altamonte Springs northeast to the Seminole-Lake County line.

Aquifer-test data for the Lower Floridan aquifer are sparse. However, three tests performed in Orange County yielded relatively high transmissivities. Values of 574,000 and 668,000 ft^2/d were reported from tests at two water-supply facilities operated by the city of Orlando (Lichtler, 1968). A third test conducted 2 mi south of Apopka yielded a value of 632,000 ft^2/d (Post, Buckley, Schuh, and Jernigan, Inc., 1989).

Few data are available to quantify the hydraulic properties of the middle semiconfining unit. A multi-zoned aquifer test conducted at the Bull Creek Wildlife Management Area in north Osceola County, just outside the boundary of the study area, was used to estimate a range of effective vertical hydraulic conductivity values for a part of this unit described as having relatively low porosity and permeability. Calculated test values ranged from $5x10^{-3}$ to 2 ft/d (Post, Buckley, Schuh and Jernigan, Inc., 1990). Leakance values derived from this test range from $1x10^{-5}$/d to $1x10^{-3}$/d, bracketing the value of $5x10^{-5}$/d used in the RASA model. Recent USGS aquifer tests conducted at the Cocoa well field indicate that the middle semiconfining unit can be highly anisotropic (Phelps and Schiffer, 1996). The vertical hydraulic conductivity of a 6-ft section of the unit was estimated to be no greater than $5x10^{-2}$ ft/d, whereas the horizontal hydraulic conductivity was estimated at 20 ft/d.

Storage coefficients calculated from aquifer tests conducted in both the Upper and Lower Floridan aquifers range from $1x10^{-3}$ to $1x10^{-4}$, typical of confined conditions. The storage coefficient is a measure of the volume of water released by elastic compression of the aquifer and by expansion of water as a result of declining heads. A theoretical lower limit for the storage coefficient can be made by assuming that the aquifer matrix is incompressible and the storage coefficient is attributed soley to the compressibility of water. The equation used to calculate this lower limit is taken from Lohman (1972, eq 20) as:

$$S = \theta\gamma b/E_w , \quad (1)$$

where

S is the storage coefficient,

θ is the volumetric aquifer porosity,

γ is the specific weight of water (62.4 lb/ft^3),

b is the aquifer thickness (ft), and

E_w is the bulk modulus of elasticity of water ($4.5x10^7$ lb/ft^2).

Assuming a porosity of 0.2 and a thickness of 300 ft for the Upper Floridan aquifer, the storage coefficient due to the compressibility of water is $8x10^{-5}$. Similarly, with an assumed porosity of 0.2 and a thickness of 1,000 ft, the storage coefficient due to the compressibility of water for the Lower Floridan aquifer is $3x10^{-4}$. Higher values calculated from aquifer tests can be attributed to the compressibility of the aquifer matrix and from storage effects not considered in the test analysis.

Water Levels and Effects of Pumping

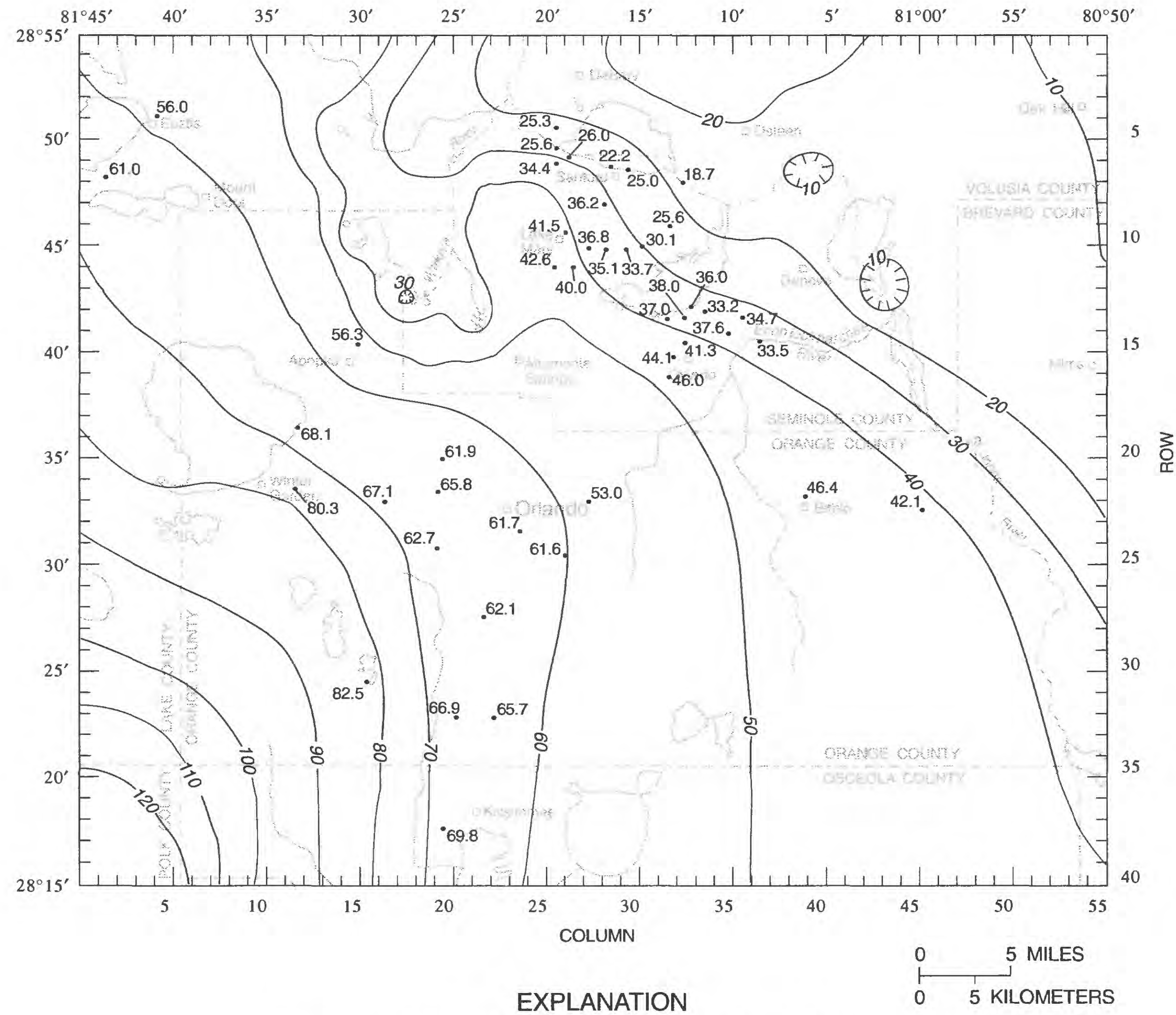
Prior to ground-water development, water levels in the Floridan aquifer system responded seasonally to variations in rainfall. Average long-term, annual predevelopment water levels probably were in a dynamic equilibrium; that is, water-level fluctuations were small with respect to total aquifer thickness and the relative configuration of the potentiometric surface was maintained through seasonal or longer cycles of fluctuations.

The estimated potentiometric surface of the Upper Floridan aquifer prior to extensive ground-water development is shown in figure 8. This map was adapted from a multi-state potentiometric surface map of the entire Tertiary limestone aquifer (Johnston and others, 1980) and is a composite of many other maps including recent potentiometric surface maps in areas only marginally affected by pumping, and older maps or modifications of older maps of areas where ground-water development is extensive. Potentiometric contours were estimated largely from water-level data collected in the 1930's by Stringfield (1936). Water levels measured in 45 of these wells are shown in figure 8.

Ground water in the Upper Floridan aquifer moves regionally in a southwest-to-northeast direction across the study area, from altitudes of more than 120 ft in north Polk County to less than 10 ft in east Seminole County. Depressed contours around Lake Harney in east Seminole County indicate significant Upper Floridan aquifer discharge beneath the St. Johns River in this area. Upper Floridan aquifer discharge also occurs laterally across the north-central boundary in Volusia County, along the east boundary into Brevard County, and across the northwest part of the study-area boundary in Lake County. Lateral recharge to the Upper Floridan aquifer occurs along the west boundary of the study area in Lake County and from the north in Volusia County, northeast of Lake Monroe.

Prior to extensive ground-water development, discharge from the 15 documented Upper Floridan aquifer springs was estimated at about 360 ft^3/s (table 1). Predevelopment discharge rates for Rock, Sanlando, Palm, Starbuck, Messant, Gemini, Clifton, and Lake Jesup Springs were obtained from the RASA report (Tibbals, 1981, p. 16) and rounded to the nearest single significant figure to reflect the error inherent in the estimates. Discharge estimates for Wekiva, Apopka, Seminole, Island, Miami, and Witherington Springs were revised from previous RASA estimates, based on additional data and recent measurements. At Apopka Spring, for example, the RASA-estimated discharge rate of 30 ft^3/s was based on a single field measurement. Subsequent measurements made by the USGS indicate that about 70 ft^3/s may have discharged from Apopka Spring prior to development.

Extensive ground-water development of the Floridan aquifer system has affected both Upper Floridan aquifer water levels and spring discharge (fig. 9). From 1950 to 1992, pumpage from Orlando and Winter Park well fields alone increased from about 10 to about 90 Mgal/d. Increased withdrawals have lowered the potentiometric surface of the Upper Floridan aqui-



EXPLANATION

—20— POTENTIOMETRIC CONTOUR -- Shows altitude at which water level would have stood in tightly cased wells tapping the Upper Floridan aquifer in the 1930's. Hachures indicate depressions. Contour interval is 10 feet. Datum is sea level

69.8 • WELL USED TO MEASURE UPPER FLORIDAN AQUIFER HEAD -- Top number is head, in feet above mean sea level. Well locations and descriptions are arranged by model row and column number in Appendix A.

Figure 8. Potentiometric surface of the Upper Floridan aquifer prior to extensive ground-water development (adapted from Johnston, 1980) and water levels measured at selected Upper Floridan aquifer monitoring wells in the early 1930's (from Stringfield, 1936).

fer, as shown by the water-level record at monitoring well OR-47 (fig. 9), thus reducing the hydraulic gradients that move water toward the springs. As a result, discharge from Wekiva Springs has declined over the years (fig. 9), as have the discharges from the other springs. Total spring flow measured in 1988 (306 ft^3/s) was about 15 percent less than estimated predevelopment spring flow (360 ft^3/s).

The average 1988 Upper Floridan aquifer potentiometric surface and the areal distribution of water-level declines (drawdowns) that have occurred since the early 1930's are shown in figure 10. Pumpage

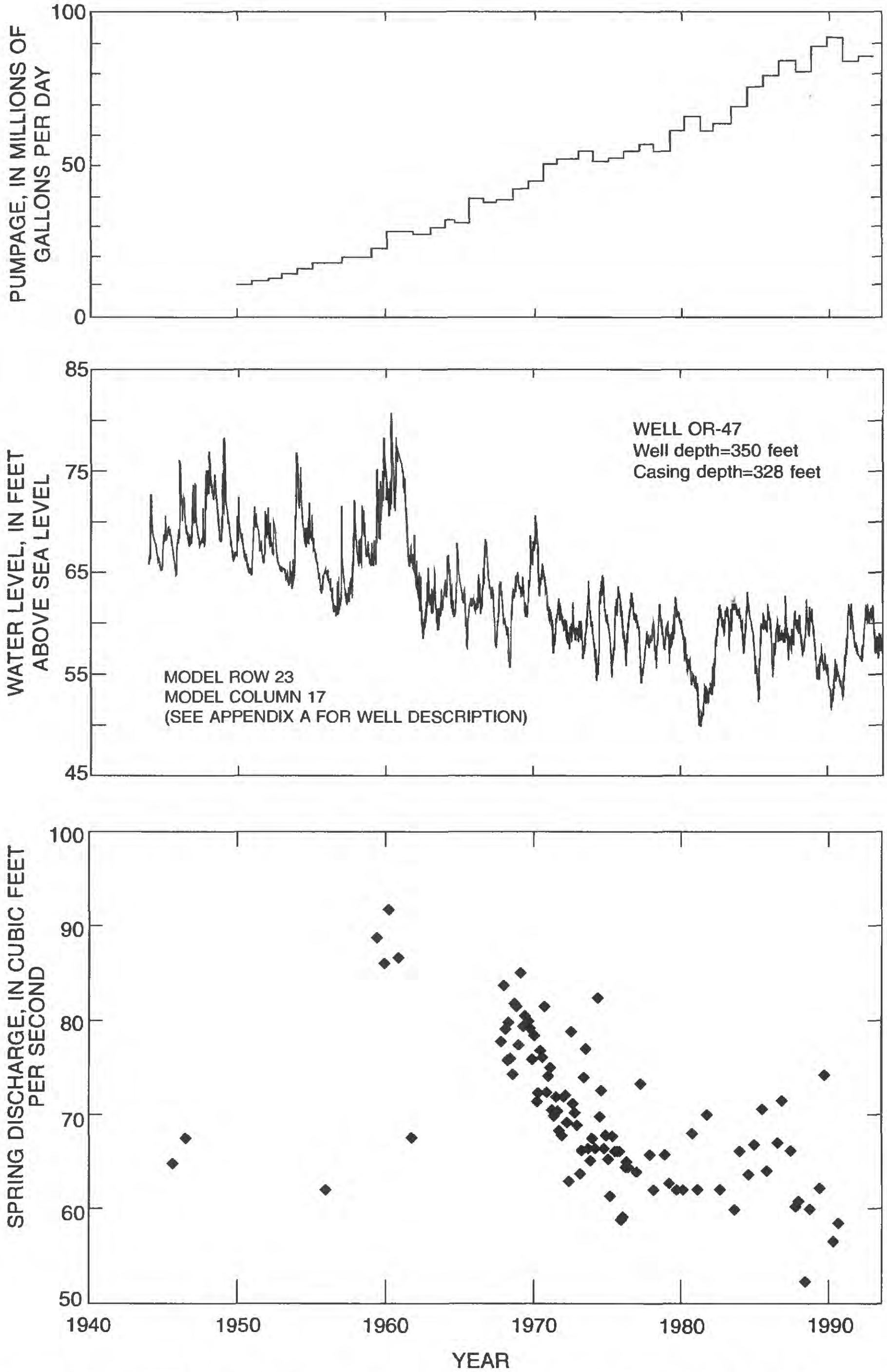
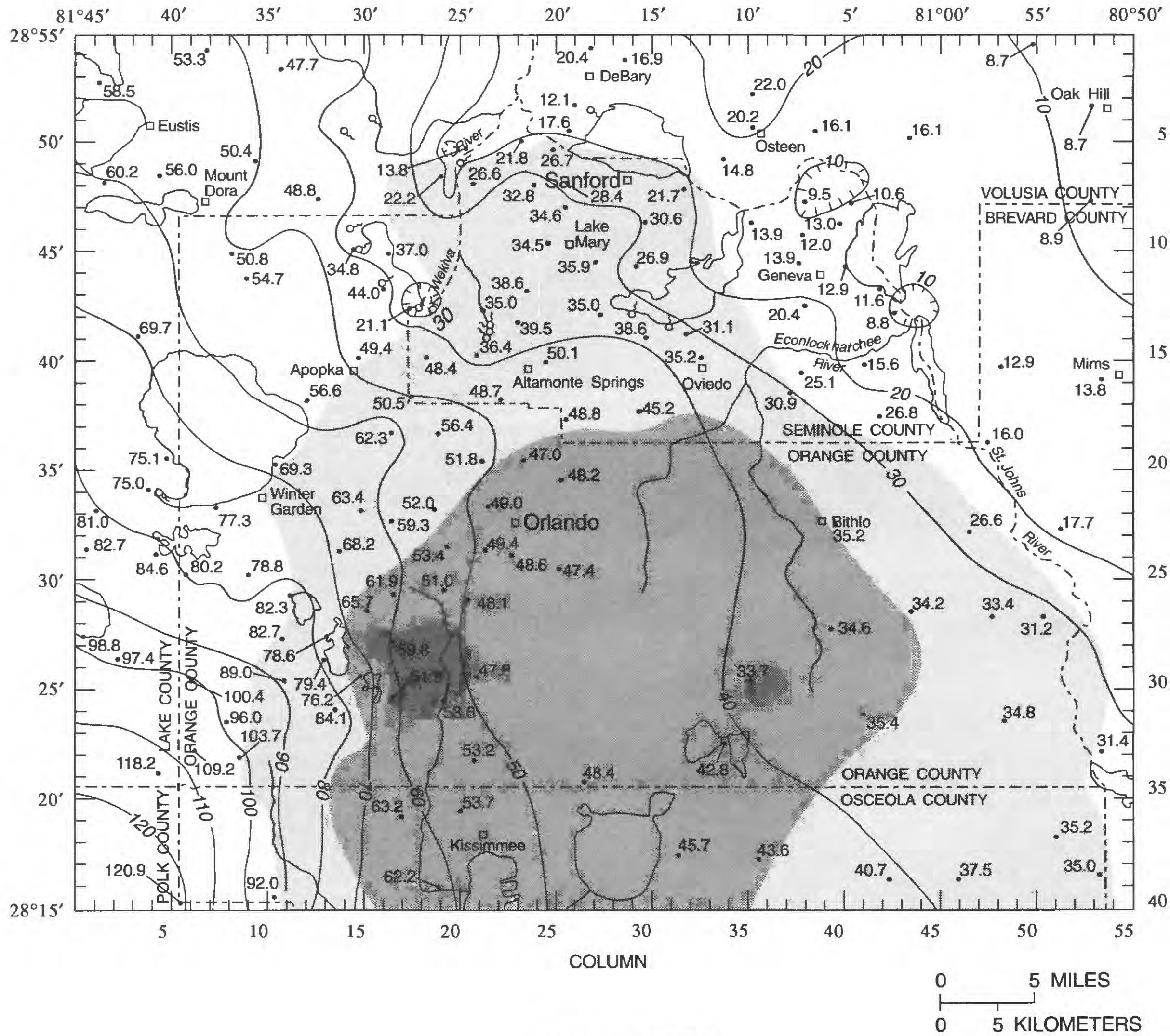


Figure 9. Pumpage from Floridan aquifer system by Orlando and Winter Park (1951-93), water levels in Upper Floridan aquifer monitoring well OR-47 (1944-93), and discharge of water from Wekiva Springs (1944-91).

from the Floridan aquifer system in 1988 was estimated at 305 Mgal/d within the study area, 230 Mgal/d of which was pumped from the Upper Floridan aquifer. Although the general configurations of the predevelopment and the average 1988 potentiometric surfaces are similar, water levels in the more highly developed parts of the study area are significantly lower than respective predevelopment levels. Drawdowns across central and east Orange County range from 10 to 20 ft, with declines of 5 to 10 ft across Seminole County. In east Lake, south Volusia, east Seminole, north Brevard, and northeast Polk Counties,



EXPLANATION

DRAWDOWN IN UPPER FLORIDAN AQUIFER FROM PREDEVELOPMENT TO AVERAGE 1988 CONDITIONS, IN FEET

0-5

5-10

10-15

15-20

—60— POTENTIOMETRIC CONTOUR -- Shows the altitude at which water level would have stood in tightly cased wells tapping the Upper Floridan aquifer in 1988. Hachures indicate depressions. Contour interval is 10 feet. Datum is sea level

43.6. WELL USED TO CONSTRUCT AVERAGE 1988 UPPER FLORIDAN AQUIFER POTENTIOMETRIC SURFACE MAP -- Number is head, in feet above mean sea level, as calculated from Eq. (2). Well located by column and row and described in Appendix A

Figure 10. Average 1988 Upper Floridan aquifer potentiometric surface and drawdowns relative to predevelopment conditions.

where relatively little development has occurred, water levels have declined by less than 5 ft.

The average potentiometric surface shown in figure 10 was constructed from water levels measured in 142 monitoring wells in May and September 1988. To evaluate average conditions for all of 1988, a multiple linear regression was applied to define the relation between the mean annual water levels and representative May and September water levels in 14 wells equipped with continuous water-level recorders. The regression result (eq 2) was then used to calculate the average 1988 Upper Floridan aquifer head (in feet above mean sea level) at each of the 128 wells where only periodic measurements were available as:

$$h = 0.36h_m + 0.65h_s - 0.08 , \qquad (2)$$

where

h is the average 1988 Upper Floridan aquifer head (feet above sea level),

h_m is the head measured in May 1988 (feet above sea level), and

h_s is the head measured in September 1988 (feet above sea level).

The correlation coefficient r^2 calculated for equation 2 is 0.99. The heads calculated by equation 2 and shown in figure 10 are probably more representative of steady-state conditions than either the May or September heads because seasonal variations in pumping and recharge affect the heads. In this case, however, the computed heads were an average of only 0.5 ft higher than the mean of May and September measured water levels, with a maximum difference of 1.3 ft. The 0.5-ft difference is considerably smaller than the range of water-level fluctuations typically observed in Upper Floridan aquifer monitoring wells in 1988 (about 5 ft in well OR-47, fig. 11), indicating that the average of May and September measured heads could have been used as a reasonable estimate of the true annual average.

Water-level data collected from 1980 to 1990 in Upper Floridan aquifer monitoring well OR-47 are typical of data from other wells in the study area and indicate that, for 1988 and the proceeding 2 to 3 years, the potentiometric surface was in a "quasi" steady-state condition (fig. 11); that is, the average annual water level about which seasonal highs and lows fluctuated remained relatively constant at about 59 ft above sea level with little net change in head from the beginning to the end of 1988. Water-level declines in 1981, 1985, 1989, and 1990 reflect drought conditions when rainfall was significantly less than 51 in, the long-term annual average.

Water levels in the surficial aquifer system, as inferred from lake levels in the study area, have been less affected by development than have water levels in the Upper Floridan aquifer. The differences between historic lake-level altitudes, as shown on USGS quadrangle maps, and those measured at 25 lakes in 1988 are small, generally within 1 to 2 ft (table 2). Many of the lake levels shown on the quadrangle maps were recorded in the mid-to-late 1950's, prior to extensive development. Average 1988 levels measured in 11 of the lakes were higher than respective map-based estimates. Although these data indicate that average 1988 water levels in some lakes were similar to those of the 1950's, this does not imply that all lake levels (and surficial aquifer system heads) across Orange and Seminole Counties were unaffected by ground-water development. Rainfall in 1988 totaled 56 in. (5 in. above the long-term average) and as a result, 1988 lake levels were slightly higher (0 to 1 ft) compared to the average levels during the 1980's and early 1990's (USGS, Orange County, and Seminole County data files).

Detailed potentiometric surface maps cannot be constructed for the Lower Floridan aquifer because few wells penetrate the aquifer within the study area. However, in June 1962 Lichtler and others (1968, p. 99) constructed a potentiometric surface map of the Lower Floridan aquifer in the downtown Orlando area from data collected at 11 public-supply wells. The general configuration of the Lower Floridan potentiometric surface was a subdued reflection of the Upper Floridan potentiometric surface, with Upper Floridan aquifer heads 1 to 3 ft higher than Lower Floridan aquifer heads.

Conceptual Model of Ground-Water Flow

A conceptual model of ground-water flow in the Floridan aquifer system is shown in figure 12. Hydrogeologic section A-A' is aligned along row 10 of the grid used for the digital flow model discussed later in this report.

Water in the Upper Floridan aquifer generally flows east and northeast in the direction of declining head. The Upper Floridan aquifer is recharged by the surficial aquifer system in areas where the water table is higher than the potentiometric surface of the Upper Floridan aquifer. Water in the Floridan aquifer system

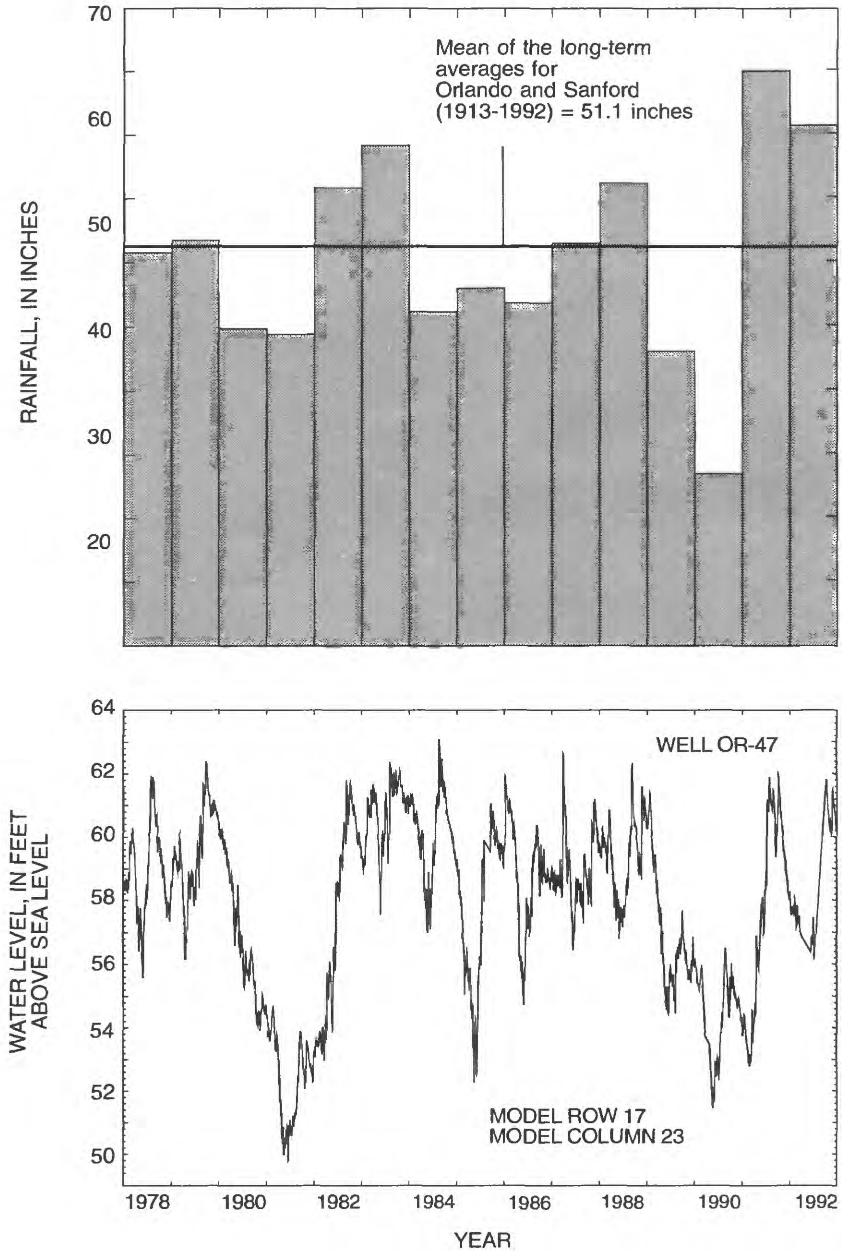


Figure 11. Average rainfall for Orlando and Sanford and water levels in Upper Floridan aquifer monitoring well OR-47, 1978-92.

is eventually discharged at Upper Floridan aquifer springs, by diffuse upward leakage in areas where the water table is below the potentiometric surface of the Upper Floridan aquifer, by undocumented spring flow, and as lateral outflow toward the Atlantic Ocean. Water generally moves laterally within the aquifers and vertically through the confining units. In areas where the potentiometric surface of the Upper Floridan aquifer indicates a ground-water flow divide, water in the aquifer flows laterally in directions opposite and perpendicular to the divide. Ground-water flow divides occur between the Wekiva River and Lake Jesup in Seminole County and in north Brevard County near the Volusia-Brevard County line (fig. 12).

The middle semiconfining unit serves as a leaky base for the Upper Floridan aquifer. In areas near downtown Orlando, where large quantities of water are pumped from the Lower Floridan aquifer, downward leakage from the Upper Floridan aquifer is a major source of recharge to the Lower Floridan. Elsewhere,

Table 2. Average 1988 lake water levels based on monthly observations and lake water levels estimated from USGS quadrangle maps

[Elevation is in feet above sea level. OCPUD, Orange County Public Utilities Department (Stormwater Division) data files; SEMCO, Seminole County data files; USGS, U.S. Geological Survey data files]

Name of lake	Model row	Model column	Average 1988 elevation[a] (1)	Source of lake-level data	USGS quadrangle topographic survey			Difference in lake level, in feet (2) - (1)
					Estimated elevation (2)	Map name	Year	
Prevatt	13	16	55.0	OCPUD	57.0	Forest City	1959	2.0
Barton	22	27	92.7	OCPUD	93.0	Orlando East	1956	0.3
Bay	20	20	90.4	OCPUD	91.0	Orlando West	1956	0.6
Bear	16	19	104.8	SEMCO	104.0	Forest City	1959	-0.8
Black	24	9	94.0	OCPUD	94.0	Winter Garden	1956	0.0
Bosse	17	20	60.4	OCPUD	61.0	Forest City	1959	0.6
Brantley	14	20	46.3	SEMCO	48.0	Forest City	1959	1.7
Butler	26	12	99.7	USGS	98.0	Windermere	1953	-1.7
Charm	15	34	46.3	SEMCO	45.0	Oviedo	1956	-1.3
Clear	24	21	94.6	OCPUD	92.0	Orlando West	1956	-2.6
Conway	27	24	86.7	USGS	86.0	Pine Castle	1953	-0.7
Fairview	20	21	87.7	OCPUD	88.0	Orlando West	1956	0.3
Flat	26	5	85.7	OCPUD	89.0	Lake Louisa	1959	3.3
Formosa	21	23	71.8	OCPUD	73.0	Orlando West	1956	1.2
Geneva	11	39	24.3	SEMCO	27.0	Geneva	1953	2.7
Howell	17	27	53.1	SEMCO	53.0	Casselberry	1962	-0.1
Huckleberry	29	9	96.8	OCPUD	96.0	Windermere	1953	-0.8
Jessamine	27	22	91.4	OCPUD	89.0	Lake Jessamine	1953	-2.4
Kathryn	18	29	50.8	SEMCO	52.0	Casselberry	1962	1.2
Lotta	22	15	87.5	OCPUD	85.0	Winter Garden	1956	-2.5
Mann	23	20	90.8	OCPUD	90.0	Orlando West	1956	-0.8
Mary	11	27	39.0	SEMCO	40.0	Casselberry	1962	1.0
Mirror	16	19	61.3	SEMCO	60.0	Forest City	1959	-1.3
Orienta	16	23	61.2	SEMCO	61.0	Casselberry	1962	-0.2
Sylvan	7	23	38.6	SEMCO	40.0	Sanford SW	1965	1.4

[a] Mean of twelve monthly lake-level measurements.

recharge to the Lower Floridan aquifer from the Upper Floridan aquifer probably occurs beneath the higher topographic areas of east Lake and west Orange Counties. Generally, however, relatively little water is exchanged between the two aquifers (Tibbals, 1981; 1990). The Lower Floridan aquifer is underlain by an impermeable lower confining unit which serves as the base of the freshwater-flow system in much of the study area.

Ground-water flow velocities generally are greater in the Upper Floridan aquifer than in the Lower Floridan aquifer. Shorter flow paths between recharge areas and springs, as well as the increased potential for dissolution of carbonate minerals by shallower circulating recharge water, contribute to this condition (Bush, 1982, p. 17). The highest ground-water velocities in the Upper Floridan aquifer occur in areas close to and upgradient from the springs, where transmissivity is high and converging flow lines induce relatively large local hydraulic gradients. Flow velocities in the Upper Floridan aquifer probably are relatively slow where potentiometric-surface gradients are small and transmissivity is low. Lowest flow velocities probably occur in the aquifer just northeast of Lake Harney and downgradient from Upper Floridan aquifer springs. The reduced circulation of ground water immediately downgradient from the springs limits the potential for formation of secondary porosity and enhanced aquifer transmissivity.

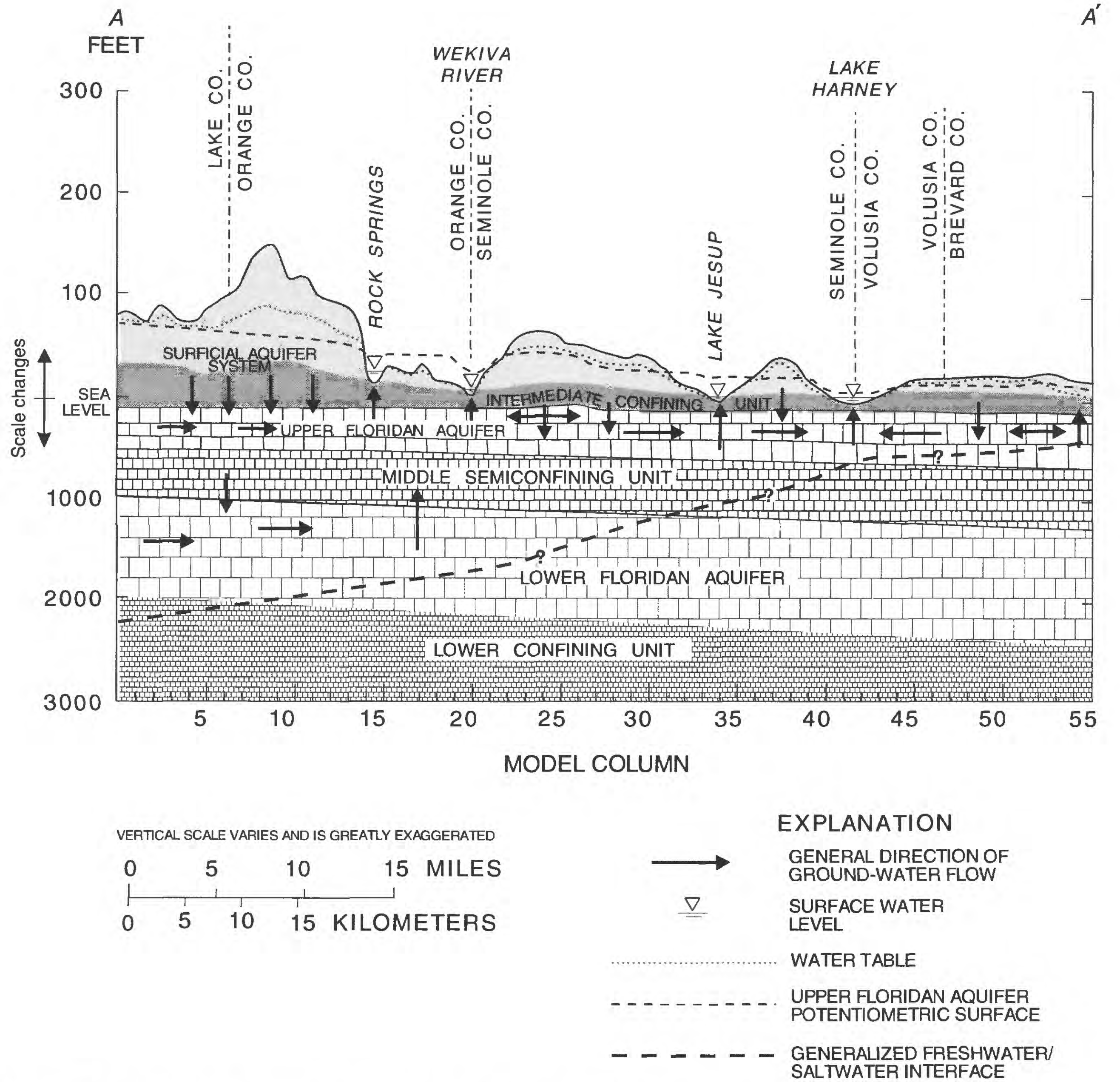


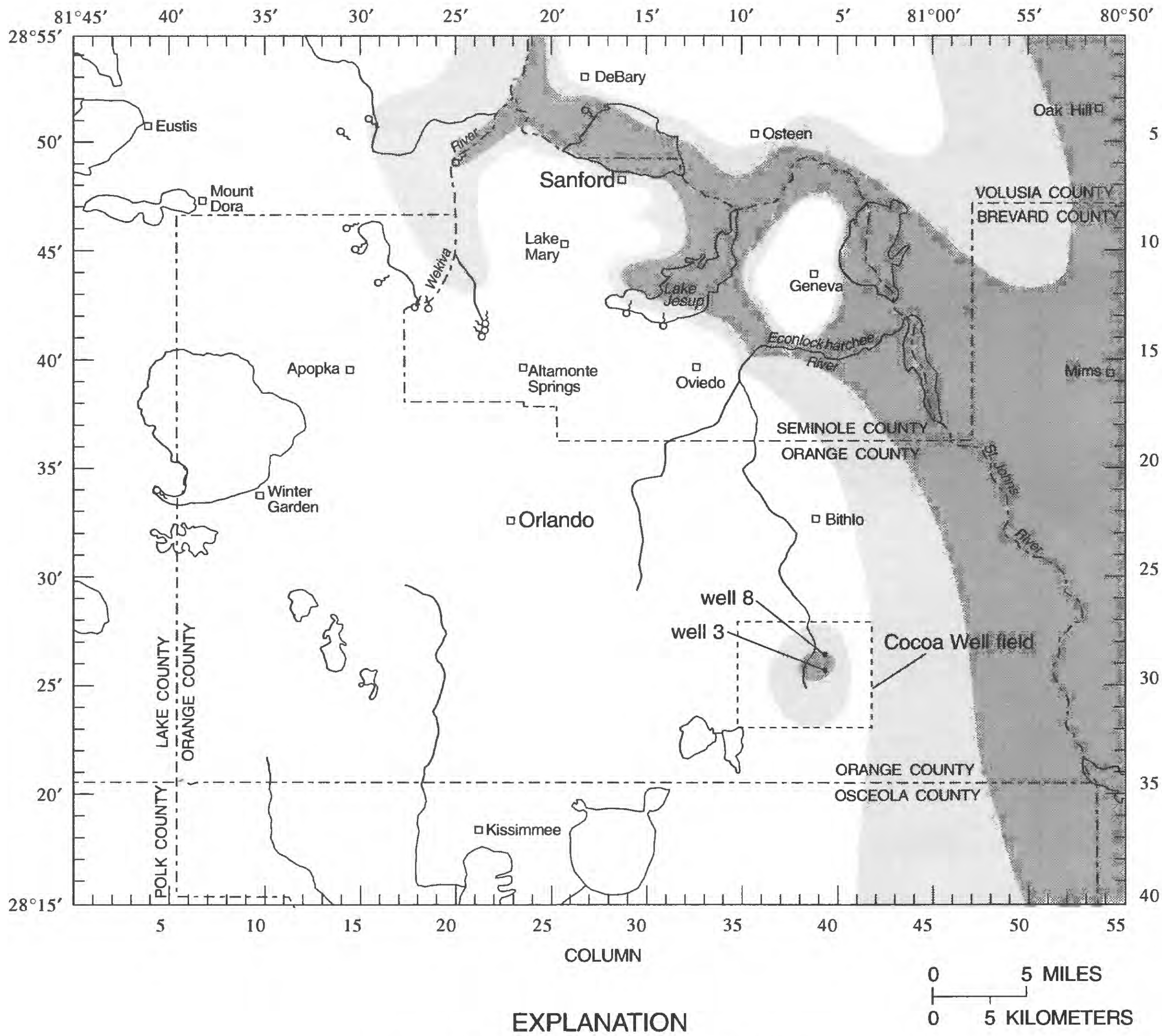
Figure 12. Hydrogeologic section and conceptualized ground-water flow along model row 10, columns 1-55. Trace of section A-A' shown in figure 3.

Water Quality

Water in the Floridan aquifer system generally is of a calcium and magnesium bicarbonate type because of the reaction between the limestone aquifer matrix and the weak carbonic acid characteristic of rainfall as a source of recharge. Water in the Lower Floridan aquifer tends to be more highly mineralized than water in the Upper Floridan aquifer, indicative of longer flow paths and greater contact time with the aquifer matrix. In discharge areas around the St. Johns and Wekiva Rivers, the Upper Floridan aquifer contains highly mineralized relict seawater that entered the aquifer during a higher stand of the sea in past geologic time (Tibbals, 1990). The relict seawater in these areas moves upward in the direction of decreasing hydraulic head and mixes with fresher water in the aquifer that moves laterally toward these rivers.

Concentrations of dissolved solids, chloride, and sulfate vary widely across the study area (figs. 13-15).

Figures 13-15 were adapted from maps published by Tibbals (1990) and modified to include recent and more detailed data collected in the Wekiva River basin by Toth and others (1989), in northeast Seminole County by Phelps and Rohrer (1987), and at the Cocoa well field by the USGS (1993). For the purposes of this report, brackish water is defined by the constituent concentration ranges shown in table 3. Water-quality data used to bracket the fresher range of constituent concentrations were acquired from wells that typically penetrate most, if not all, of the Upper Floridan aquifer. As a result, the indicated ranges are considered to represent average concentrations with respect to the full thickness of the aquifer. Wells drilled within the



EXPLANATION

DISSOLVED SOLIDS CONCENTRATION, IN MILLIGRAMS PER LITER

Less than 500

500-1,000

Greater than 1,000

Figure 13. Dissolved solids concentrations in water in the Upper Floridan aquifer (adopted from Tibbals, 1990).

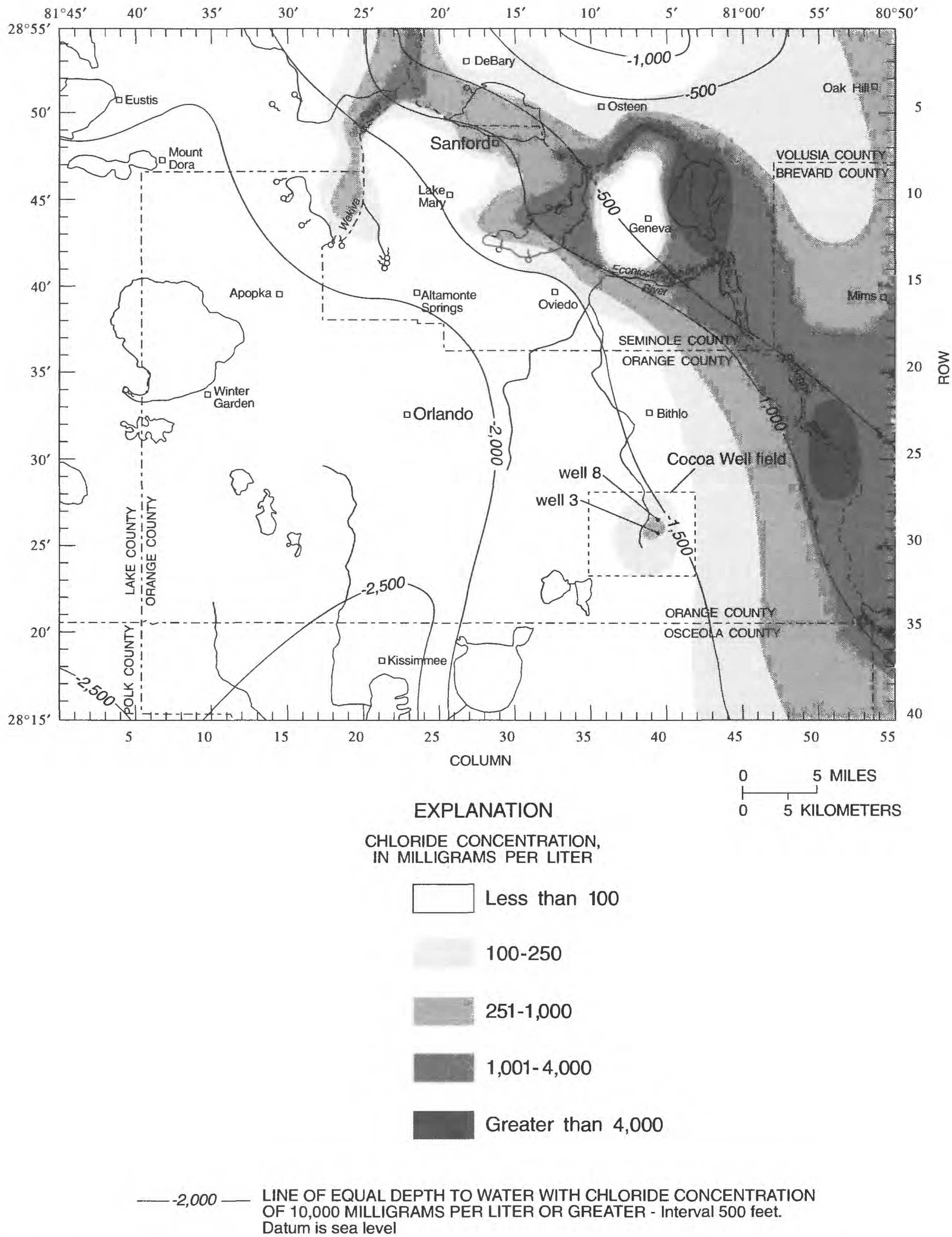


Figure 14. Chloride concentrations in water in the Upper Floridan aquifer and estimated depth to water containing chloride concentrations greater than 10,000 milligrams per liter (adapted from Rutledge (1985); Phelps and Rohrer (1987); Toth and others (1989); Tibbals (1990); and Schiner (1993)).

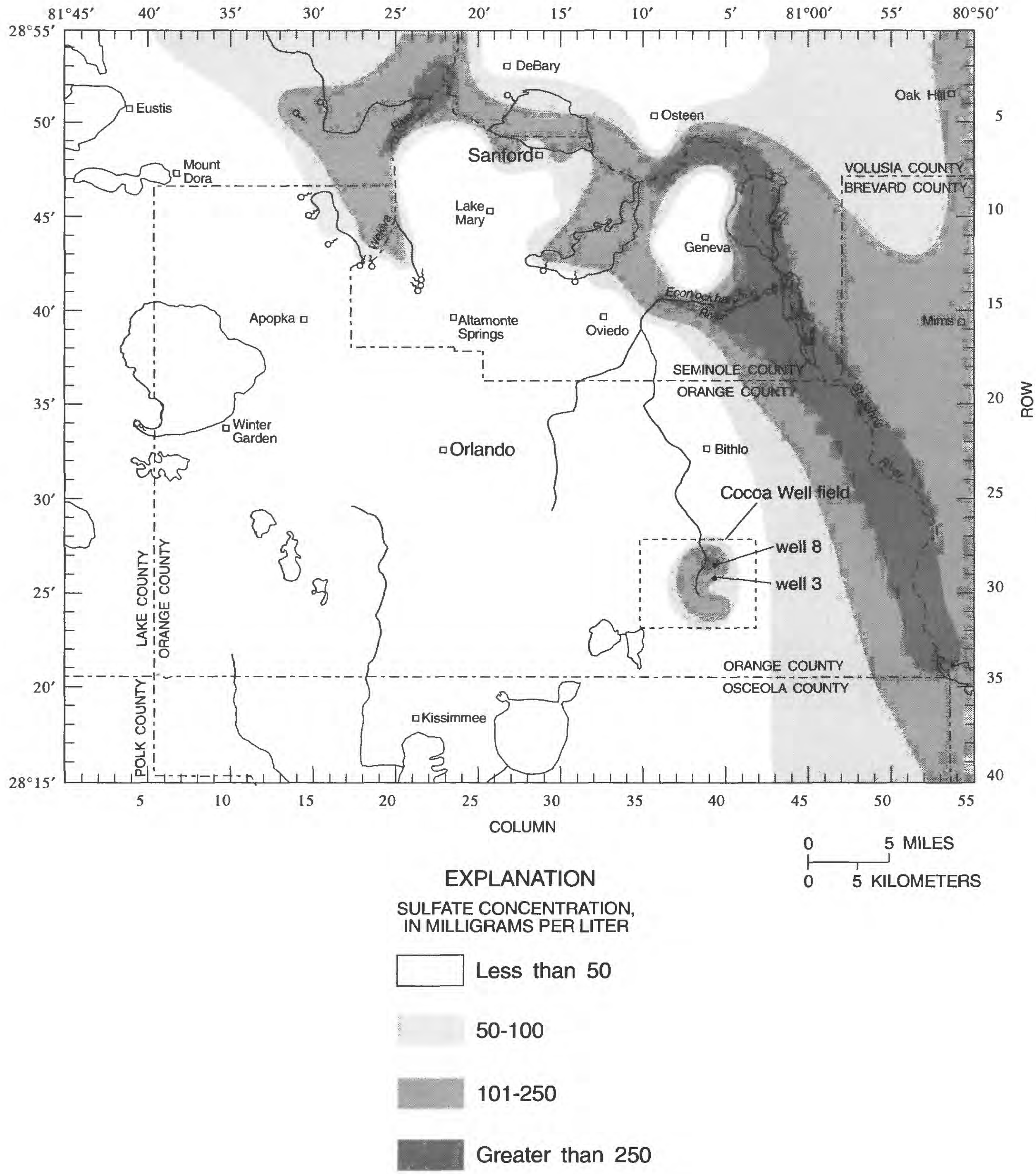


Figure 15. Sulfate concentrations in water in the Upper Floridan aquifer (adapted from Phelps and Rohrer (1987); Toth and others (1989); and Tibbals (1990)).

more brackish areas, however, usually penetrate less of the aquifer and the higher concentrations of the bracketed ranges represent average concentrations for only the top 100 to 200 ft. Constituent concentrations at greater depths may be considerably higher than the upper limit of these ranges.

Table 3. Typical concentrations of dissolved solids, hardness, sulfate, and chloride in freshwater, brackish water, and seawater

[Constituent concentrations in milligrams per liter; <, less than; $CaCO_3$, calcium carbonate]

Constituent	Fresh-water	Brackish water	Sea-water
Dissolved solids	< 1,000	1,000 - 35,000	35,000
Hardness as $CaCO_3$	< 400	400 - 6.600	6.600
Sulfate	< 250	250 - 2,700	2,700
Chloride	< 250	250 - 19,000	19,000

The extent to which water in the Upper Floridan aquifer is mineralized can be described by its concentration of dissolved solids. The freshest water in the study area is characterized by dissolved solids concentrations less than 500 mg/L (the drinking water standard set by the Florida Department of Environmental Regulation, 1982). Water containing the lowest concentrations of dissolved solids occurs in west and central Orange, southwest Seminole, east Lake, and southwest Volusia Counties (fig. 13). In these areas, recharge to the aquifer from rainfall occurs at a relatively high rate through a thin or breached intermediate confining unit. Brackish water (dissolved solids concentration greater than 1,000 mg/L) occurs in discharge areas beneath the St. Johns River and adjoining lakes, beneath the Wekiva River, and near the Atlantic coast. Brackish water beneath the St. Johns and Wekiva Rivers probably results from the mixing of freshwater with relict seawater. Movement of this brackish water is relatively slow, particularly beneath the St. Johns River from Lake Harney northward. The relatively small amounts of water that are discharged from the Upper Floridan aquifer to the St. Johns and Wekiva Rivers by diffuse upward leakage and undocumented spring flow are being replenished by the upward movement of deeper and more saline water. A discussion of the origin and flushing of brackish water in the Floridan aquifer system in east-central Florida is provided by Tibbals (1990).

Brackish water also occurs in two Upper Floridan aquifer wells (Cocoa 3 and Cocoa 8) located in the east part of the Cocoa well field, in east Orange County. The occurrence of this slightly brackish water may be the result of induced upward leakage of more brackish water from depth in the Floridan aquifer (Tibbals and Frazee, 1976). Such leakage could occur through fractures in the aquifer near these wells. Another possible source of this brackish water is a local pocket of entrapped relict seawater that exists near or below pumping wells. Water-quality data collected during recent test drilling at the Cocoa well field indicate that fresh and saltier (relict) water may be layered within the Upper Floridan aquifer, possibly the result of fluctuating sea levels over geologic time (Phelps and Schiffer, 1996). Lateral intrusion of brackish water from the east is also a potential source of brackish water at the well field. However, water sampled from wells located less than a mile north and south of Cocoa 3 and Cocoa 8 is considerably less mineralized, inferring a more localized source of brackish water moving along preferential flow paths. Samples collected from an Upper Floridan aquifer monitoring well constructed 1 to 2 mi east of wells Cocoa 3 and Cocoa 8 could be used to evaluate the likelihood of lateral intrusion. If the sampled water was less mineralized than water in wells Cocoa 3 and Cocoa 8, it would be unlikely that the lateral movement of brackish water from a nonlocal source (east of the well field nearer the St. Johns River) was contributing to the condition at the Cocoa wells.

Chloride is the predominant anion in seawater and is an important indicator of brackish water in the Upper Floridan aquifer. Water containing chloride at concentrations greater than 250 mg/L is considered brackish and unfit for human consumption (Florida Department of Environmental Regulation, 1982). Concentrations of chloride in the Upper Floridan aquifer range from less than 100 mg/L in west and central Orange, southwest Seminole, east Lake, and southwest Volusia Counties, to greater than 4,000 mg/L along the course of the St. Johns River in east-central Orange and east Seminole Counties and along the Wekiva River in northwest Seminole County (fig. 14). Concentrations of less than 30 mg/L are common in recharge areas where fresh percolating rainfall more easily infiltrates the aquifer.

The lateral transition from freshwater to brackish water within the Upper Floridan aquifer is particularly abrupt in northeast Seminole County at the Geneva "bubble." This isolated lens of freshwater is about 350 ft thick at its center and is surrounded by brackish water. Chloride concentrations near the edge of the bubble increase from less than 100 mg/L to greater than 4,000 mg/L in less than a mile. The Geneva bubble was originally formed and is now sustained by the local flushing of relict seawater by recharge from rainfall. Recharge rates to the bubble from the surficial aquifer system have been estimated at 10 to 13 in/yr (Phelps and Rohrer, 1987).

The vertical location of the freshwater-saltwater interface defines the vertical extent of the freshwater-flow system. For the purposes of this study, this interface is defined by the 10,000-mg/L isochlor and approximates the midrange of the transition zone between freshwater and saltwater. The depth to the freshwater-saltwater interface is estimated to range from about 2,500 ft below sea level in southwest Orange County to less than 500 ft below sea level in east Seminole County (Tibbals, 1990) (fig. 14).

The isochlors depicted in figure 14 were slightly modified from Tibbals (1990) to include data collected in 1993 and 1994 from two deep monitoring wells drilled in Seminole County near the cities of Oviedo and Altamonte Springs. Chloride concentrations in water sampled from the Oviedo well increased abruptly with depth from less than 1,000 mg/L at 1,380 ft below land surface to nearly 7,000 mg/L at the wells's maximum depth of 1,607 ft below land surface (Yovaish Engineering Sciences, Inc., 1994). A chloride concentration of 11 mg/L was reported for the Altamonte Springs site at the terminal depth of 1,506 ft below land surface (Ardaman and Associates, Inc., 1993).

The areal distribution of sulfate concentrations in the Upper Floridan aquifer is very similar to those of chloride and dissolved solids (fig. 15). Sulfate concentrations of less than 50 mg/L occur across much of the study area, with concentrations of less than 20 mg/L found in high-rate recharge areas. The highest sulfate concentrations (greater than 250 mg/L) are found along the St. Johns River in east Orange and Seminole Counties, and beneath the Wekiva River in northwest Seminole County. Relatively high sulfate concentrations measured near Lake Harney result from the mixing of freshwater with relict seawater and, to a lesser extent, from the dissolution of gypsum (calcium sulfate) within the aquifer matrix (Phelps and Rohrer, 1987, p. 51).

The quality of water discharging from Upper Floridan aquifer springs varies considerably (table 4). Water sampled at Wekiva, Rock, Sanlando, Palm, Starbuck, Miami, and Witherington Springs in May 1993 contained low concentrations of chloride (less than 20 mg/L), sulfate (less than 30 mg/L), and dissolved solids (less than 250 mg/L). Based on an analysis of major cations and anions, water from these seven springs is classified as a calcium-magnesium bicarbonate type that results from dissolution of the calcium carbonate (limestone) aquifer matrix and probably travels along relatively short, lateral flow paths that originate in high-rate recharge areas (fig. 16). Water sampled from Seminole and Messant Springs is more highly mineralized and contains higher concentrations of sulfate (120 mg/L and 240 mg/L, respectively). This calcium sulfate type water results from the dissolution of a calcium sulfate aquifer matrix and probably travels along longer and deeper flow paths than the fresher calcium-magnesium bicarbonate type water discharged by the other

Table 4. Chloride, sulfate, and dissolved solids concentrations in selected Upper Floridan aquifer springs, May 1993, and average values

[Discharge in cubic feet per second; constituent concentrations in milligrams per liter]

Name	1988 average discharge	Chloride			Sulfate			Dissolved solids		
		May 1993	Average	Number of samples	May 1993	Average	Number of samples	May 1993	Average	Number of samples
Wekiva	69	13	10	19	17	12	19	182	148	17
Rock	58	8	7	21	19	17	21	145	132	20
Sanlando	20	15	11	6	12	8	6	192	165	4
Palm	6	14	10	5	21	16	5	211	161	4
Starbuck	15	19	14	5	22	16	5	192	163	4
Miami	5	10	8	3	8	6	3	148	134	2
Seminole	39	8	7	3	120	80	3	286	228	3
Messant	14	10	10	5	240	230	5	503	492	4
Witherington	1	8	7	3	10	11	3	142	139	2
Gemini	8	600	590	2	120	120	2	1,430	1,315	2

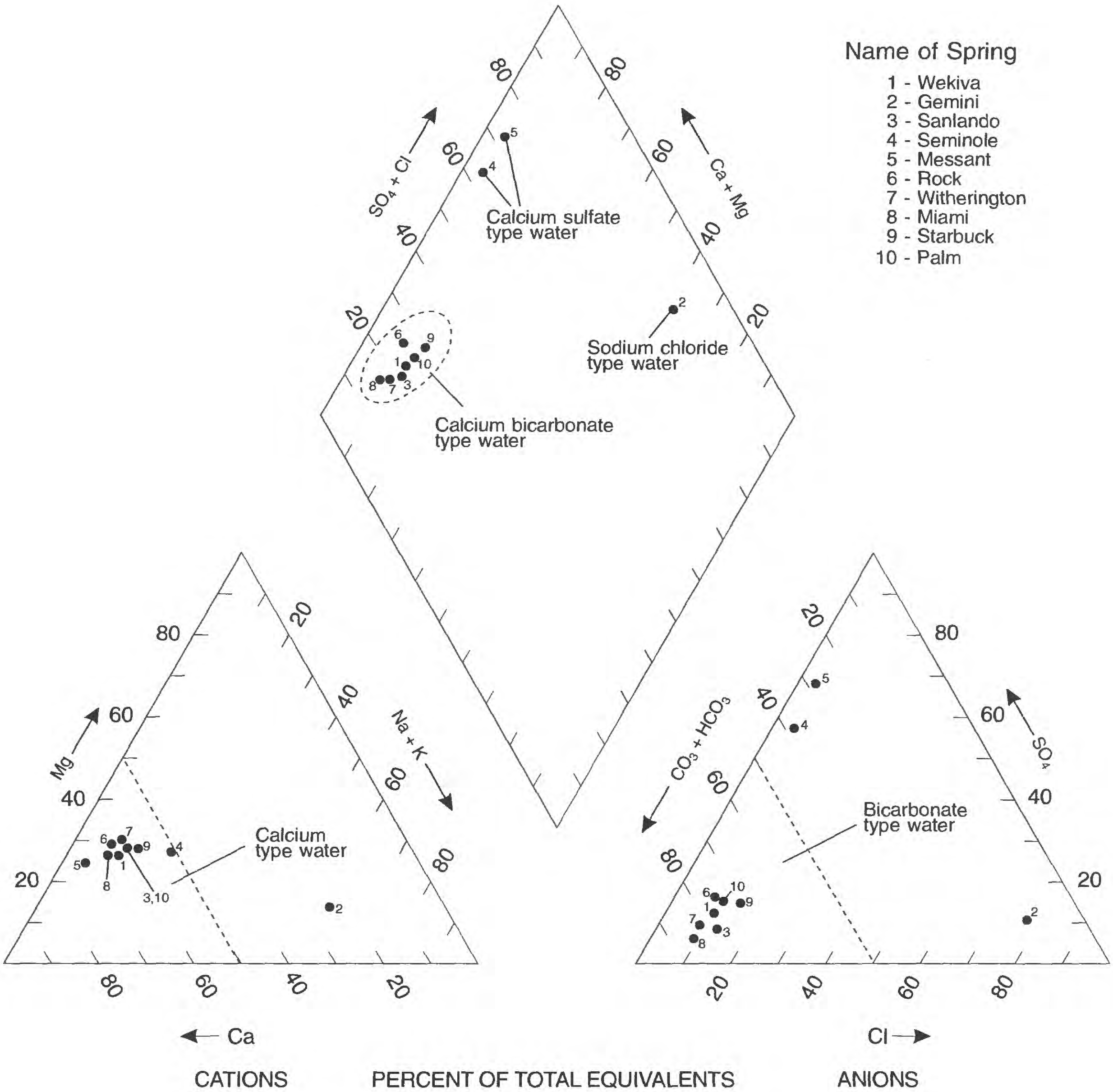


Figure 16. Major cations and anions in water from Upper Floridan aquifer springs.

springs. At Gemini Spring, sampled water contained brackish concentrations of chloride (600 mg/L). This sodium chloride type water probably results from the mixing of freshwater with entrapped relict seawater or from the upwelling of deeper brackish water through fractures.

Water discharged from Upper Floridan aquifer springs has become more mineralized with time. At Wekiva Springs, the specific conductance of discharged water (an indirect measurement of the concentration of dissolved solids) has increased from about 225 µS/cm in 1956 to about 300 µS/cm in 1993 (fig. 17). Moreover, the concentrations of chloride, sulfate, and dissolved solids determined from the most recent (May 1993) USGS sampling of selected springs exceed respective mean concentrations determined from previous sampling events (table 4). Although the increases are relatively small, they do indicate the potential for further degradation of springwater quality. The causes for the observed increases are unknown.

At the Cocoa well field, chloride concentrations measured in the Upper Floridan aquifer at Cocoa C, a multi-zoned monitoring well, have increased from 50 mg/L in 1966 to about 120 mg/L in 1994 (fig. 18). Concentrations measured in the Lower Floridan aquifer at Cocoa C have increased from about 600 mg/L in 1966 to nearly 3,000 mg/L in 1994. It is unlikely that a regional upconing of the freshwater-saltwater interface and the brackish transition zone is contributing to the water-quality changes observed in the Upper Floridan aquifer at Cocoa C because chloride concentrations measured in the intervening zones between the Upper and Lower Floridan aquifers have not changed. Increased chloride concentrations at Cocoa C probably result from the local movement of brackish water laterally from the east part of the well field. A more detailed discussion of water-quality conditions in the Floridan aquifer system at the Cocoa well field is provided by Phelps and Schiffer (1996).

SIMULATION OF GROUND-WATER FLOW

The conceptual model and hydrologic data discussed in the previous section were used to construct a digital computer ground-water flow model of the Floridan aquifer system. The model simulates both predevelopment and post-development (1988) steady-state ground-water flow conditions, as well as the transient declines in Upper Floridan aquifer heads observed during the drought period from January to May 1990. The model also was used to evaluate the response of the flow system to projected ground-water pumpage in the year 2010. Particle-tracking simulations were used to identify potential changes in areas that contribute recharge to selected springs and well fields under proposed 2010 pumping conditions and to delineate the possible flow paths and destinations of surface water that recharges the Upper Floridan aquifer through two high-capacity drainage wells.

Model Description

The USGS three-dimensional finite-difference ground-water flow model MODFLOW (McDonald and Harbaugh, 1988) was used to simulate the flow system. MODFLOW uses a finite-difference method to numerically solve a system of partial differential equations that describe the response of ground-water flow to hydrologic stresses and specified boundary conditions. The hydrologic system described in the previous section was modeled as three aquifer layers with each layer separated by a confining bed (fig. 4). The Upper and Lower Floridan aquifers were each represented as an active model layer in which heads were calculated by the model, not imposed by the user. Flow simulated within aquifer layers is horizontal because calculated heads are assumed constant with depth. The surficial aquifer system was represented by the third, and uppermost, model layer. Heads within this layer were not simulated by the model, but were assigned by the user to provide a constant source or sink of water to or from the Floridan aquifer system. The intermediate confining unit and the middle semi-

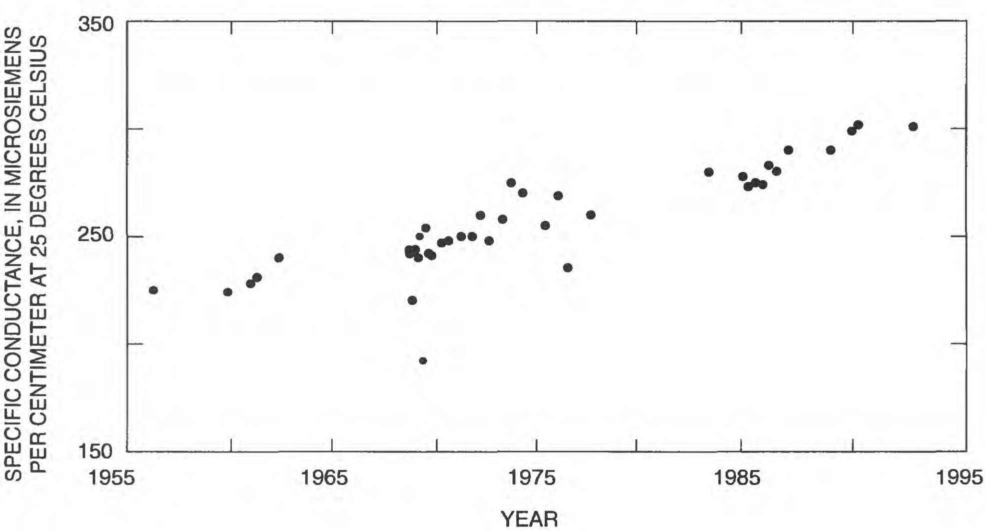


Figure 17. Specific conductance of water discharged from Wekiva Springs, 1956-93.

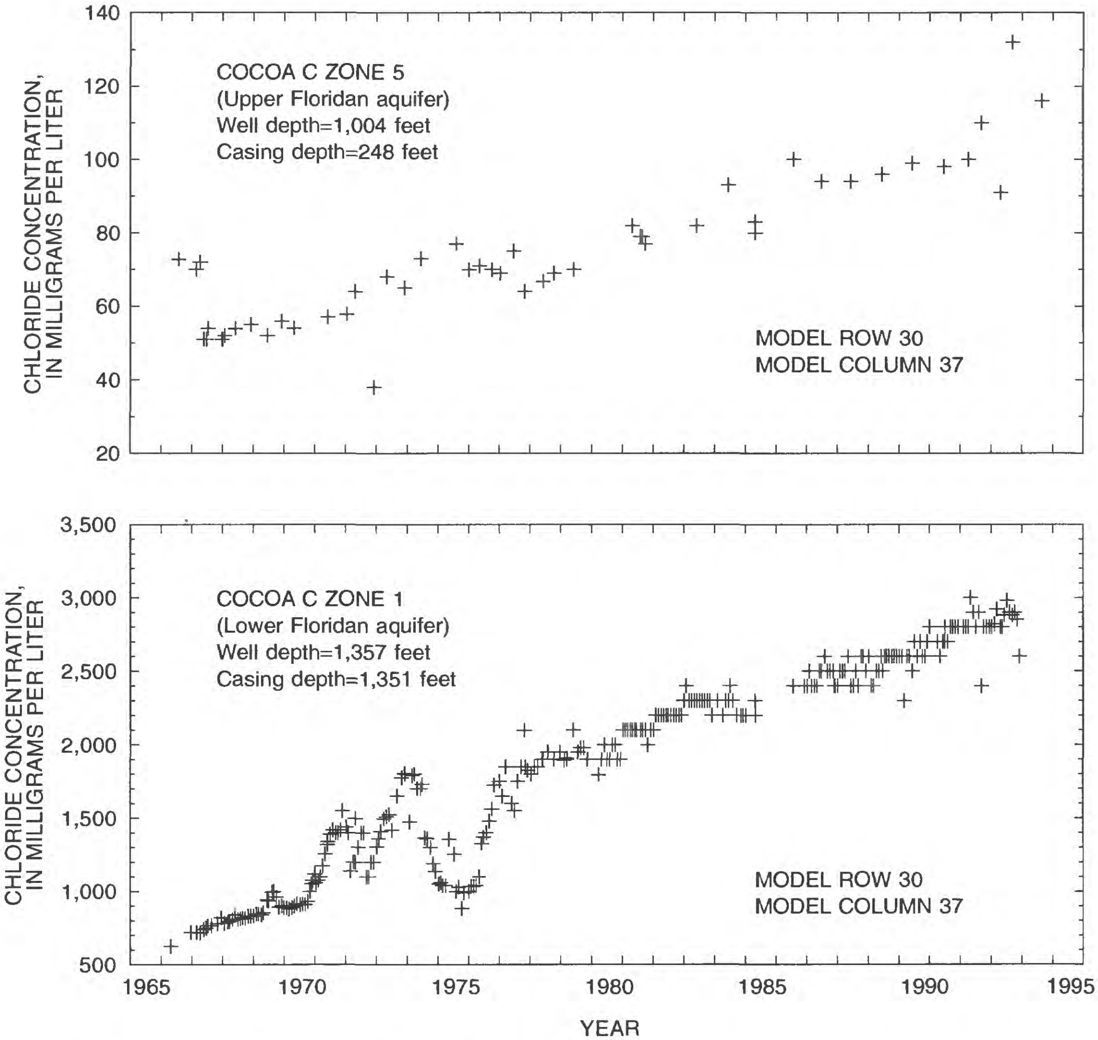
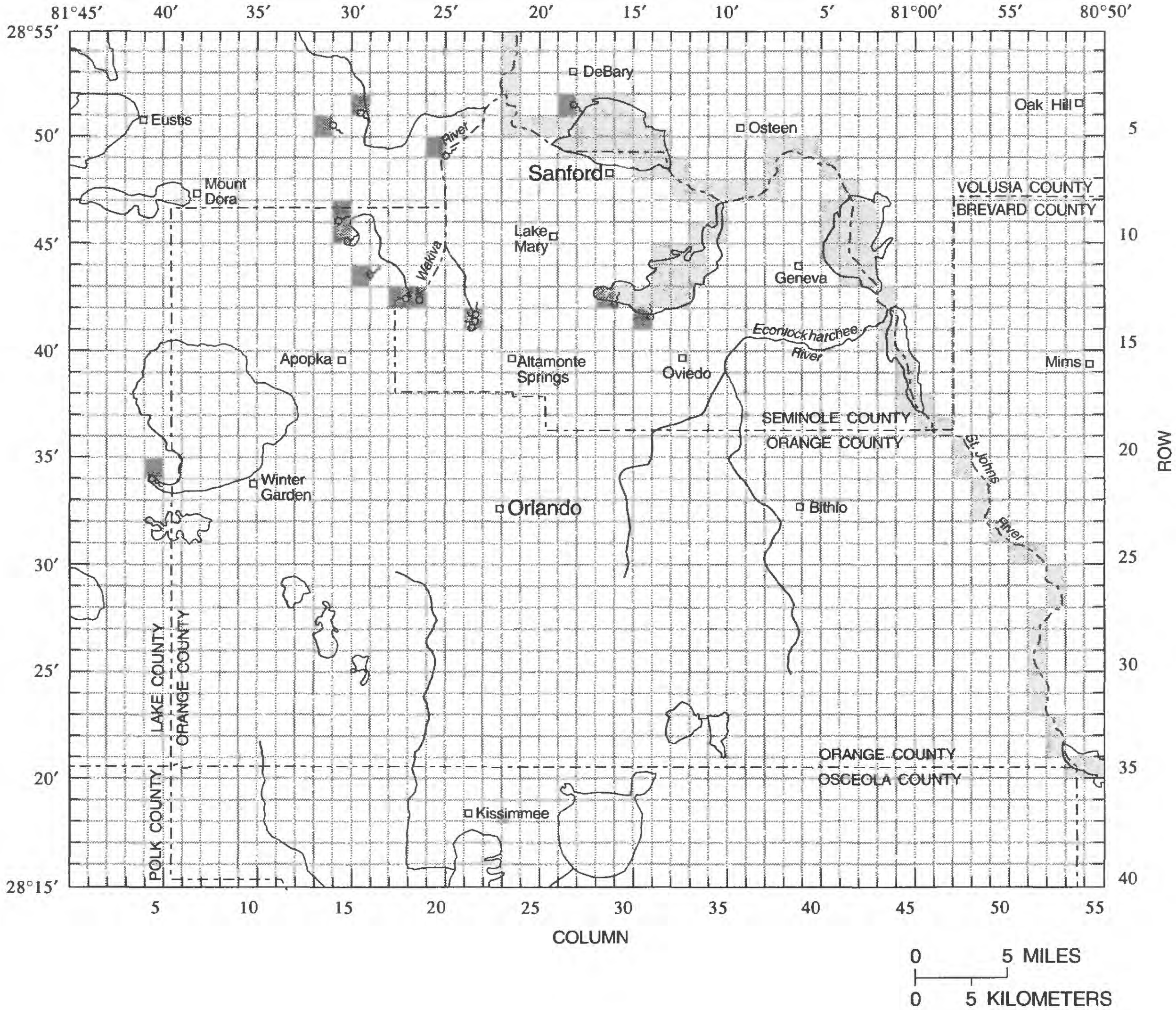


Figure 18. Chloride concentrations in water from zones penetrating the Upper and Lower Floridan aquifers at monitoring well Cocoa C, 1966-94.

confining unit were simulated by arrays of variable leakance (VCONT) values that control the vertical leakage of water between the aquifers. Where the vertical hydraulic conductivity of the aquifer is much greater than that of the adjacent confining unit, leakance is approximately equal to the vertical hydraulic conductivity of the confining unit divided by its thickness. Leakance values can be used to calculate vertical recharge (or discharge) rates from one aquifer to the next by multiplying the head differential between the aquifers by the leakance of the confining unit that separates them. Horizontal flow and changes in storage were not simulated in the confining units.

The study area was subdivided into a finite-difference grid of 40 rows and 55 columns (fig. 19). Each of the 2,200 grid cells was slightly more than 1 mi^2 in area with dimensions of 6,050 ft in the north-south direction and 5,320 ft in the east-west direction. Grid alignment was essentially along lines of longitude and latitude. The total model area is 2,540 mi^2.

Model calibration was performed in an iterative fashion, relying on several historic periods of hydrologic record for independent calibration criteria. The model was initially calibrated to reflect 1988 flow conditions by varying selected hydraulic parameters, mainly intermediate confining unit leakance and Upper Floridan aquifer transmissivity, until simulated heads and spring flow were reasonably close to measured values. Next, pumping stresses were set equal to zero and fixed boundary heads were adjusted to simulate the long-term flow conditions that existed prior to extensive ground-water development. Finally, aquifer



EXPLANATION

Cell in which the vertical flux of water from the Upper Floridan aquifer to the St. Johns River and adjoining lakes is simulated by the RIVER Package


Cell in which the vertical flux of water discharging from Upper Floridan aquifer spring(s) is simulated by the DRAIN Package

Figure 19. Finite-difference grid superimposed on modeled area and locations of Drain and River cells.

storage coefficients were entered, specified surficial aquifer and boundary heads were adjusted, and pumpage was changed during the transient calibration in which Upper Floridan aquifer water-level declines were simulated during a period of deficient rainfall from January to May 1990.

Boundary Conditions

The lateral boundaries of the study area do not coincide with any clearly defined hydrogeologic boundaries. Both the Upper Floridan and the Lower Floridan aquifers are confined and laterally continuous across the study area. For this reason, the General-Head Boundary (GHB) Package was used in both steady-state and transient simulations to calculate the lateral flow rate across each boundary-cell face using the equation (adapted from eq 78, McDonald & Harbaugh, 1988):

$$Q = TW\frac{(HB - HS)}{L} \quad , \qquad (3)$$

where

Q is the lateral flow rate (ft^3/s),
HB is the specified GHB head (ft),
HS is the model-simulated head at the boundary node (ft),
T is the aquifer transmissivity between HS and HB (ft^2/s),
W is the width of the cell face perpendicular to flow (ft), and
L is the distance from HS to HB (ft). The quantity TW/L is equal to the boundary conductance (ft^2/s).

For both predevelopment and average 1988 steady-state simulations, HB for the Upper Floridan aquifer was estimated by superimposing the respective potentiometric surface onto the model grid and identifying the head found at a distance (L) of two cell lengths beyond the gridded area from the adjacent perimeter boundary node. For the transient simulations, HB was estimated from water-level data collected from December 1989 through May 1990 in 14 monitoring wells equipped with continuous water-level recorders and from measurements made in additional monitoring wells in May 1990 (Murray, 1990). Water-level declines measured in wells located near model boundaries ranged from about 1 ft at the Lake Oliver well (near the southwest boundary) to about 3 ft at the Lake Joel well (near the south-central boundary) (fig. 2). Specified GHB-heads for the Lower Floridan aquifer were arbitrarily set 2 ft lower than respective Upper Floridan heads in recharge areas and 2 ft higher than Upper Floridan heads in discharge areas, which is consistent with the limited available data (Tibbals, 1990).

A specified-head, source-sink array was used to represent water-table heads in the surficial aquifer system for steady-state predevelopment and average 1988 conditions. Water-table heads were estimated by superimposing the finite-difference grid on USGS topographic quadrangle maps and, from the many surface-water features, estimating the altitude of the water table at each model node. These data were augmented by surficial aquifer water-level data from published reconnaissance reports (Lichtler and others (1968), Knochenmus and others (1976), and Phelps (1990)); by water-level data collected at 20 surficial aquifer monitoring wells (appendix A); and from data collected at 114 lakes and streams (appendix B). Estimated water-table heads are probably within plus or minus 5 ft (the topographic map contour interval) of long-term average values. The effects of potential errors in specified water-table altitudes on simulated results are evaluated later in this report.

Water-level declines measured in the above-referenced lakes, streams and surficial aquifer wells between 1988 and the middle of each month from January to May 1990 were used to calculate average monthly water-table altitudes used in the transient simulations by subtracting the measured declines from the specified 1988 heads. Estimated water-table declines from 1988 through May 1990 ranged from less than 2 ft in central and east Orange County to about 8 ft beneath the higher karstic sand ridges of west Orange County (fig. 19).

Hydrologic Data Input

Input data required for the ground-water flow model are summarized in table 5. Included are data used to assign starting values for parameters that were adjusted during model calibration. Parameter values obtained by direct field measurements were not adjusted or were only minimally adjusted during model calibration.

Table 5. Model-input data

[X, matrix used in model; --, matrix not used in model]

Model aquifer unit	Data matrices	Matrices required for: Predevelopment steady-state simulations	1988 steady-state simulations	January-May 1990 transient simulations	2010 steady-state simulations
Surficial aquifer system (layer 1)	•Starting head	X	X	X	X
	•Transmissivity [1]	--	--	--	--
	•Storage coefficient [1]	--	--	--	--
Intermediate confining unit (vcont 1)	•Leakance	X	X	X	X
Upper Floridan aquifer (layer 2)	•Starting head	--	--	X	--
	•Transmissivity	X	X	X	X
	•Storage coefficient	--	--	X	--
	•Fixed boundary head (spring pool)	X	X	X	X
	•Boundary conductance (spring pool drain cells)	X	X	X	X
	•Fixed boundary head (river cells)	X	X	X	X
	•Boundary conductance (streambed)	X	X	X	X
	•Fixed general-head boundary head	X	X	X	X
	•General-head boundary conductance	X	X	X	X
	•Direct recharge	--	X	X	X
	•Pumpage	--	X	X	X
Middle semiconfining unit (vcont 2)	•Leakance	X	X	X	X
Lower Floridan aquifer (layer 3)	•Starting head	--	--	X	--
	•Transmissivity	X	X	X	X
	•Storage coefficient	--	--	X	--
	•Fixed general-head boundary head	X	X	X	X
	•General-head boundary conductance	X	X	X	X
	•Pumpage	--	X	X	X

[1] Matrices not required because surficial aquifer system is treated as a constant-head boundary for the Upper Floridan aquifer.

Aquifer and Confining Unit Properties

Starting values for distributed arrays representing Upper Floridan aquifer transmissivity, Lower Floridan aquifer transmissivity, intermediate confining unit leakance, and middle semiconfining unit leakance were taken from Tibbals (1990) and adjusted during model calibration. Storage coefficients assigned to the Upper and Lower Floridan aquifers for the transient simulations ranged from 1×10^{-4} to 1×10^{-3} and are consistent with values reported from aquifer tests.

Spring-Pool Altitude and Conductance

Discharge from the 15 Upper Floridan aquifer springs was simulated with the MODFLOW Drain Package (fig. 20). The Drain package calculates the head-dependent discharge at each spring by the Darcy equation (adapted from eq 69, McDonald & Harbaugh, 1988) as:

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

where

QD is the spring discharge (ft^3/s),
CD is the spring conductance (ft^2/s),
HS is the model-simulated head in the Upper Floridan aquifer at the spring node (ft), and
HD is the spring-pool altitude (ft).

The model-simulated Upper Floridan aquifer head represents the average head across the spring cell and is assumed to prevail at some distance from the spring itself. The spring-pool altitude is localized to the spring itself and is not characteristic of the cell as a whole. Spring-pool altitudes were obtained by direct field measurements or estimated from topographic maps. At Wekiva, Rock, and the Sanlando Spring group, spring-pool altitudes measured in May and September 1988 were 1 to 2 ft lower than predevelopment estimates published by Tibbals (1981) and from

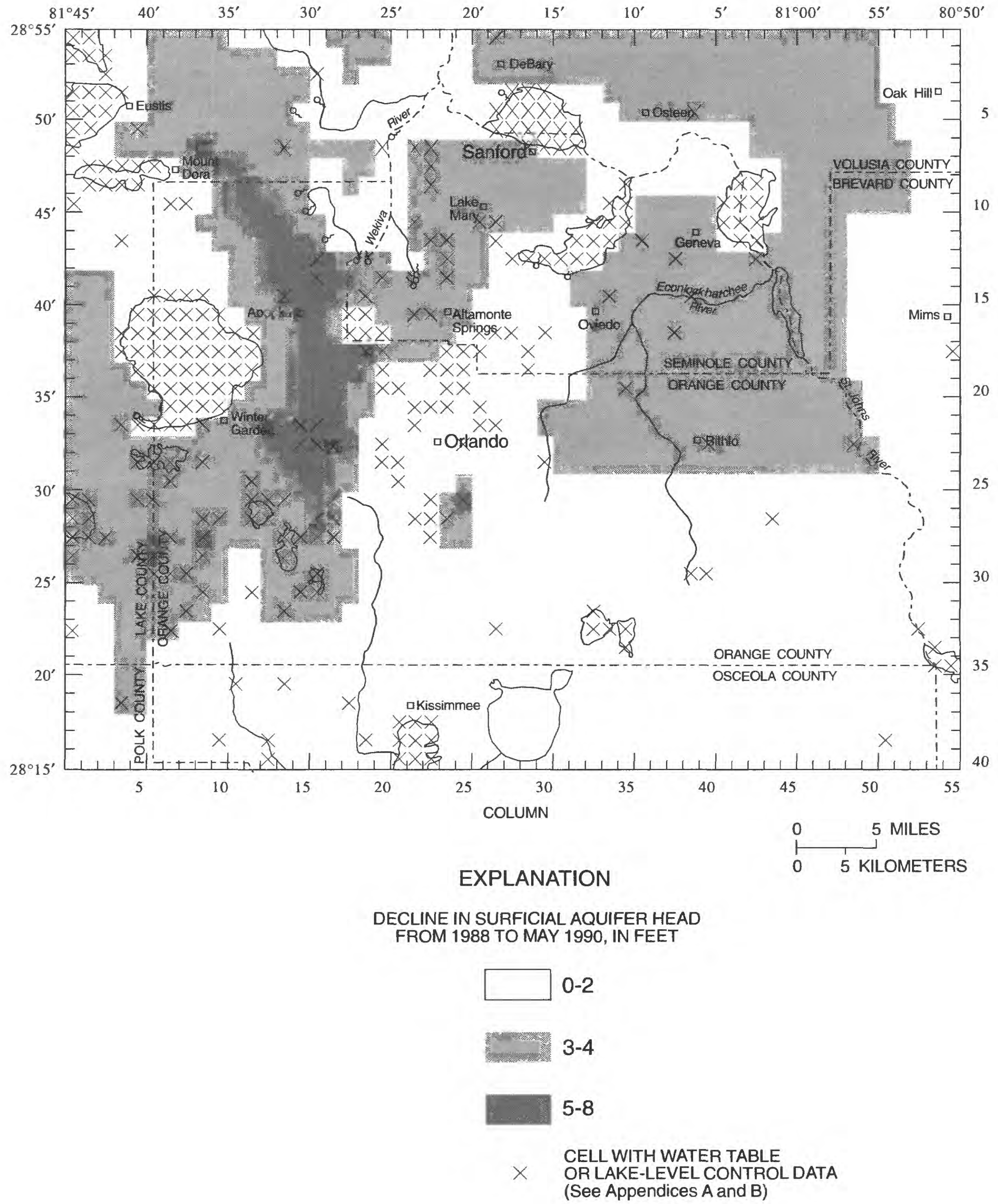


Figure 20. Estimated range of declines in surficial aquifer heads, average 1988 conditions to May 1990.

0.5 to 1.5 ft higher than spring-pool altitudes measured in May 1990. Spring conductance values were calculated by dividing the average 1988 spring discharge by the difference in head between the spring pool and the average 1988 Upper Floridan aquifer head at the spring cell. Average 1988 Upper Floridan aquifer heads were estimated from potentiometric surface maps constructed in May and September 1988

(Schiner, 1988; and Rodis, 1989; respectively). Included in this group are two flowing wells at the Wekiva Falls Resort in Lake County that discharged about 12 Mgal/d in 1988.

Because drain conductance is a function of the cell dimensions, the calculated values apply only to the grid used for this study. In models with smaller grid spacings, the simulated head at the spring node would be lower than that simulated in this model because the head value would be averaged over a smaller cell area, closer to the spring. As a result, the head difference between the Upper Floridan aquifer and the spring pool would be reduced, requiring a greater drain conductance to produce the same discharge rate.

River Stage and Bed Conductance

Discharge from the Upper Floridan aquifer into the St. Johns River system was simulated with the MODFLOW River Package. The St. Johns River discharge area includes 88 model cells that cover the main stem of the river and adjoining lakes (fig. 20). The amount of water discharged from the aquifer into each model cell is computed by the Darcy equation (adapted from eq 63, McDonald & Harbaugh, 1988) as:

$$QRIV = CRIV(HS - HRIV) \qquad (5)$$

where

QRIV is the discharge rate (ft^3/s),

CRIV is the effective vertical conductance between the top of the riverbed and the underlying Upper Floridan aquifer (ft^2/s),

HS is the model-simulated head in the Upper Floridan aquifer at the river node (ft), and

HRIV is the altitude of the river stage (ft).

Data collected from USGS gaging stations (appendix B) were used to specify *HRIV* for both the steady-state and transient simulations. Initial values of *CRIV* were obtained from the RASA model and were adjusted during model calibration. The VCONT term between layers 1 and 2 in the BCF package was set equal to zero at each river cell to avoid redundancy in simulating vertical leakage from the Upper Floridan aquifer to the St. Johns River system.

Ground-Water Withdrawals and Artificial Recharge

About 305 Mgal/d of water was pumped from the Floridan aquifer system in 1988, 247 Mgal/d of which was pumped for municipal, industrial, and commercial purposes; 36 Mgal/d for agricultural irrigation; 10 Mgal/d for golf-course irrigation; and about 12 Mgal/d was discharged from abandoned flowing wells. About 75 percent of this water was withdrawn from the Upper Floridan aquifer (table 6). Pumpage in May 1990 totaled about 439 Mgal/d, nearly 50 percent more than in 1988. The distributions of ground-water

Table 6. Water use during average 1988 conditions, January to May 1990, and projected 2010 conditions

[All values are daily averages, in million gallons per day. Wet, drainage-well recharge rates equal to average 1988 rates; dry, drainage-well recharge rates equal to May 1990 rates]

	Aquifer	Water use category	Average 1988	1990 January	1990 February	1990 March	1990 April	1990 May	2010 Projected pumpage
Ground-water withdrawals	Upper Floridan aquifer	Municipal, industrial and commercial supply [1]	172	174	166	200	194	227	308
		Agricultural–citrus irrigation	14	15	0	15	30	30	14
		Agricultural–non-citrus irrigation	22	23	17	22	30	36	22
		Golf course irrigation	10	6	3	12	15	20	10
		Abandoned flowing wells	12	10	10	10	10	10	12
	Lower Floridan aquifer	Municipal supply	75	81	75	97	97	116	176
		Total	305	309	271	356	376	439	542
Artificial recharge	Upper Floridan aquifer	Orlando drainage wells	30	30	30	30	22	15	30 (wet), 15 (dry)
		Reclaimed water application [2]	18	17	16	17	17	16	18
		Total	48	47	46	47	39	31	48 (wet), 33 (dry)

[1] Includes discharge from flowing wells at Wekiva Falls Resort recreational facility.

[2] Land application rate x 0.8 (irrigation efficiency).

withdrawals in 1988 from the Upper and Lower Floridan aquifers are shown on figures 21 and 22. A listing of individual municipal, industrial, and commercial water users, together with respective withdrawal rates

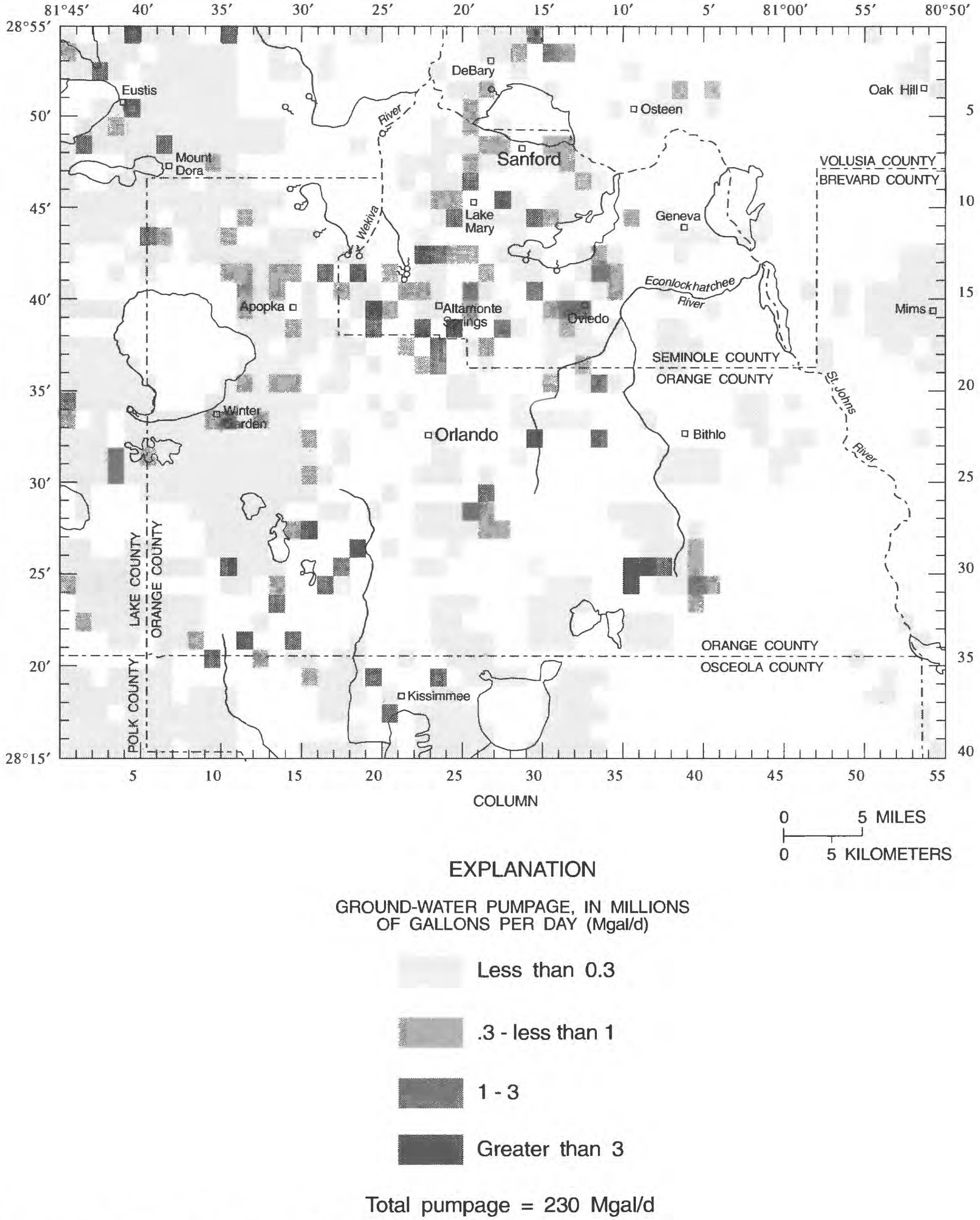


Figure 21. Distribution of average 1988 Upper Floridan aquifer pumpage.

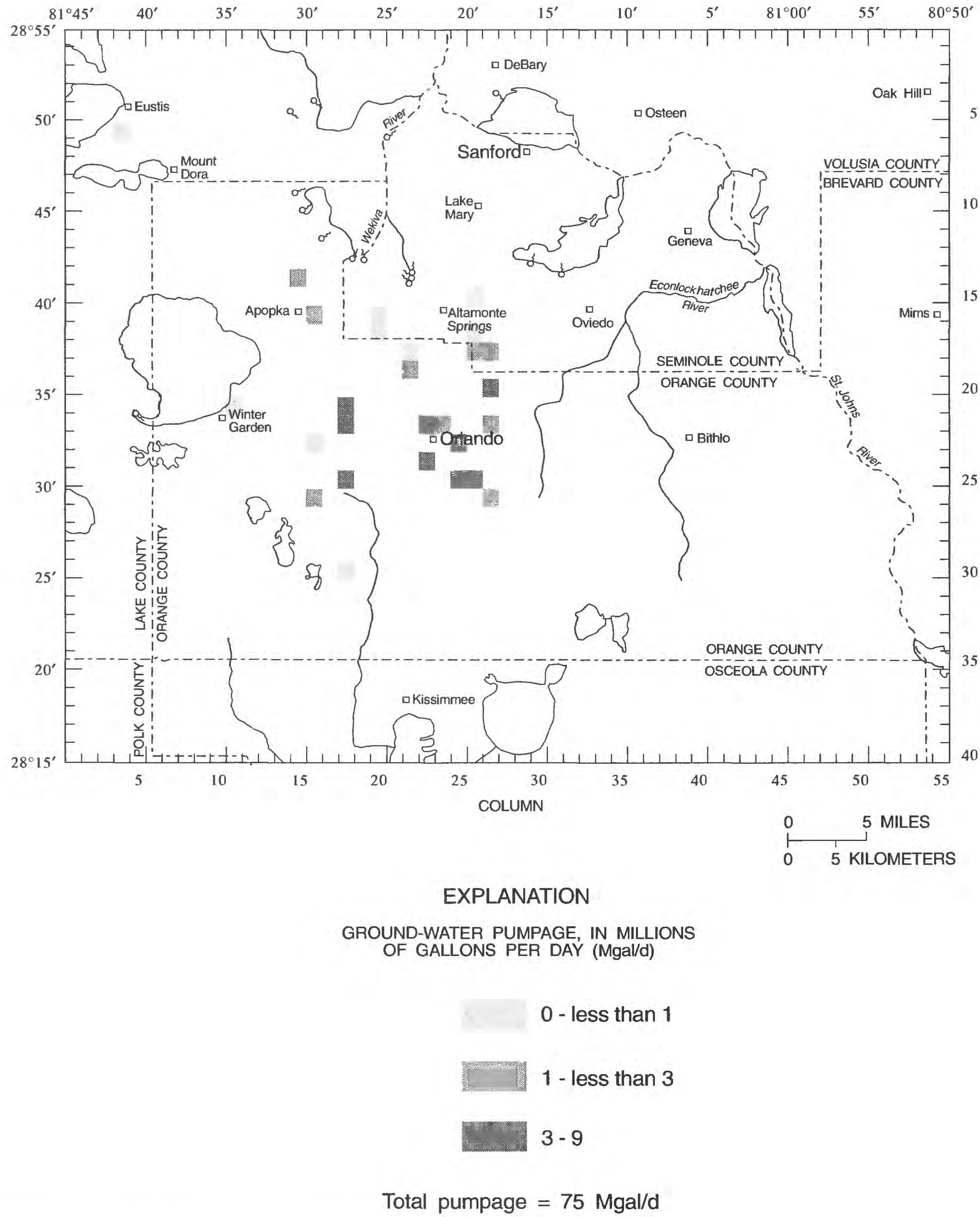


Figure 22. Distribution of average 1988 Lower Floridan aquifer pumpage.

for average 1988, December 1989 to May 1990, and projected 2010 conditions, is provided in appendix C. Pumpage from the Floridan aquifer system was simulated with the MODFLOW Well Package.

Ground-water withdrawal rates for municipal, industrial, and commercial users were obtained from monthly operating reports compiled by SJRWMD and SFWMD. Additional data were obtained from the Reedy Creek Improvement District (RCID), the Orlando Utilities Commission (OUC), the city of Cocoa, the Sanlando Utilities Corporation, and other municipalities. The monthly operating reports are based on metered readings and are considered accurate. Average daily well-field discharge rates were calculated from these data for 1988 and for each of the months from December 1989 to May 1990. Permitted withdrawal rates were assigned to several industrial users where metered data were not available. The locations and penetration depths of individual wells in each well field were provided by FDEP, SJRWMD, SFWMD, and municipalities.

Assumptions were made to apportion total pumpage between individual wells and between the Upper and Lower Floridan aquifers where data were lacking. At well fields containing multiple wells, the average daily well-field discharge rate was divided by the number of wells to obtain an average pumping rate per well. The error associated with this approach probably is negligible because individual wells that comprise most well fields are located in the same model cell. Discharge from wells that penetrate both the Upper and Lower Floridan aquifers was divided equally between the two aquifers.

Ground-water withdrawals required to irrigate citrus, non-citrus crops, and golf courses generally are not metered but, for 1988, were estimated at 14, 22, and 10 Mgal/d, respectively (table 6). These withdrawals increased during the drought period and peaked at about 30, 36, and 20 Mgal/d in May 1990. The pumping rates shown in table 6 were calculated by multiplying the crop or golf-course acreage identified in each cell by an estimated irrigation rate. Citrus-farm locations and acreages were obtained from the Florida Agricultural Statistics Service in Orlando, Florida. Cells with less than 5 acres of citrus or citrus farms irrigated with reclaimed water were not included in these compilations. Acreages for non-citrus crops (vegetables, nurseries, sod, ferns, and improved pasture) were obtained from Consumptive Use Permit (CUP) files provided by SJRWMD and SFWMD. Acreage related to permits issued after April 1988 was omitted from the 1988 compilations; acreage described in permits issued after January 1990 was omitted from the transient period compilations. Permits issued for less than 5 acres were also omitted. Ground-water withdrawals were assumed negligible for users whose permits indicated that ground water was used soley to backup a primary surface-water source. Irrigated acreage was estimated for each of 53 golf courses by multiplying the number of holes at the course by 4.2 acres, the average acreage per hole reported by Duerr and Trommer (1982, p. 40). Ground-water withdrawals were assumed negligible at golf courses irrigated with reclaimed water or surface water.

Irrigation rates estimated for average annual 1988 conditions and monthly from January to May 1990 are listed in table 7. The citrus irrigation rate in 1988 was estimated at 10 in/yr, based on studies in which SJRWMD (Singleton, 1988) and the USGS (Duerr and Trommer, 1982) recorded metered irrigation rates at selected benchmark farms over a period of several years. Irrigation rates estimated for January to May 1990 ranged from 0 in. in February to 2 in. in May (Bruce Florence, SJRWMD, written commun., 1992). For the non-citrus crops and golf courses, irrigation rates for 1988 were obtained from Florence (1990), whereas monthly rates for the January to May 1990 drought period were provided by SJRWMD or taken from benchmark data (Singleton, 1988; Duerr and Trommer, 1982). Irrigation rates for vegetable farms were obtained from CUP files and assumed constant for both simulated periods. The irrigation rates estimated in this study for both citrus and non-citrus crops probably are within plus or minus 50 percent of actual rates.

Table 7. Estimated application rates for agricultural irrigation for average 1988 and January to May 1990

[Application rates are in acre-inches. Estimated application rates for all but vegetables and fruits taken from Florence (1990); Duerr and Trommer (1982); and Singleton (1988)]

Crop	1988 Total for year	1988 Average monthly	1990 January	1990 February	1990 March	1990 April	1990 May
Citrus	10	0.8	1	0	1	2	2
Golf course	40	3.3	2	1	4	5	7
Nursery	90	7.5	7	4	8	12	18
Ferns	60	5.0	6	3	4	4	5
Landscape	30	2.5	2	1	3	4	5
Sod, Turf	30	2.5	2	1	3	4	5
Pasture	6	0.5	1	0	0	1	1
Vegetables & fruits	as permitted[1]			as permitted[1]			

[1] Application rates as permitted for individual crop farms by the St. Johns River or South Florida Water Management District (single rate used for both 1988 and 1990 simulations).

Recharge to the Upper Floridan aquifer from Orlando drainage wells and reclaimed water was simulated with the MODFLOW Recharge package. Recharge rates measured at the Lake Underhill and Lake Killarney drainage wells (2.1 and 2.5 Mgal/d, respectively) were applied to the appropriate cells and were not adjusted during model calibration. The remaining 25.4 Mgal/d of recharge was evenly distributed among the other cells and adjusted during model calibration to better replicate Upper Floridan aquifer heads in the Orlando area. Recharge rates at individual wells are largely unknown and the calibrated rates shown in figure 23 represent the aggregated totals for the wells grouped in respective model cells. Higher

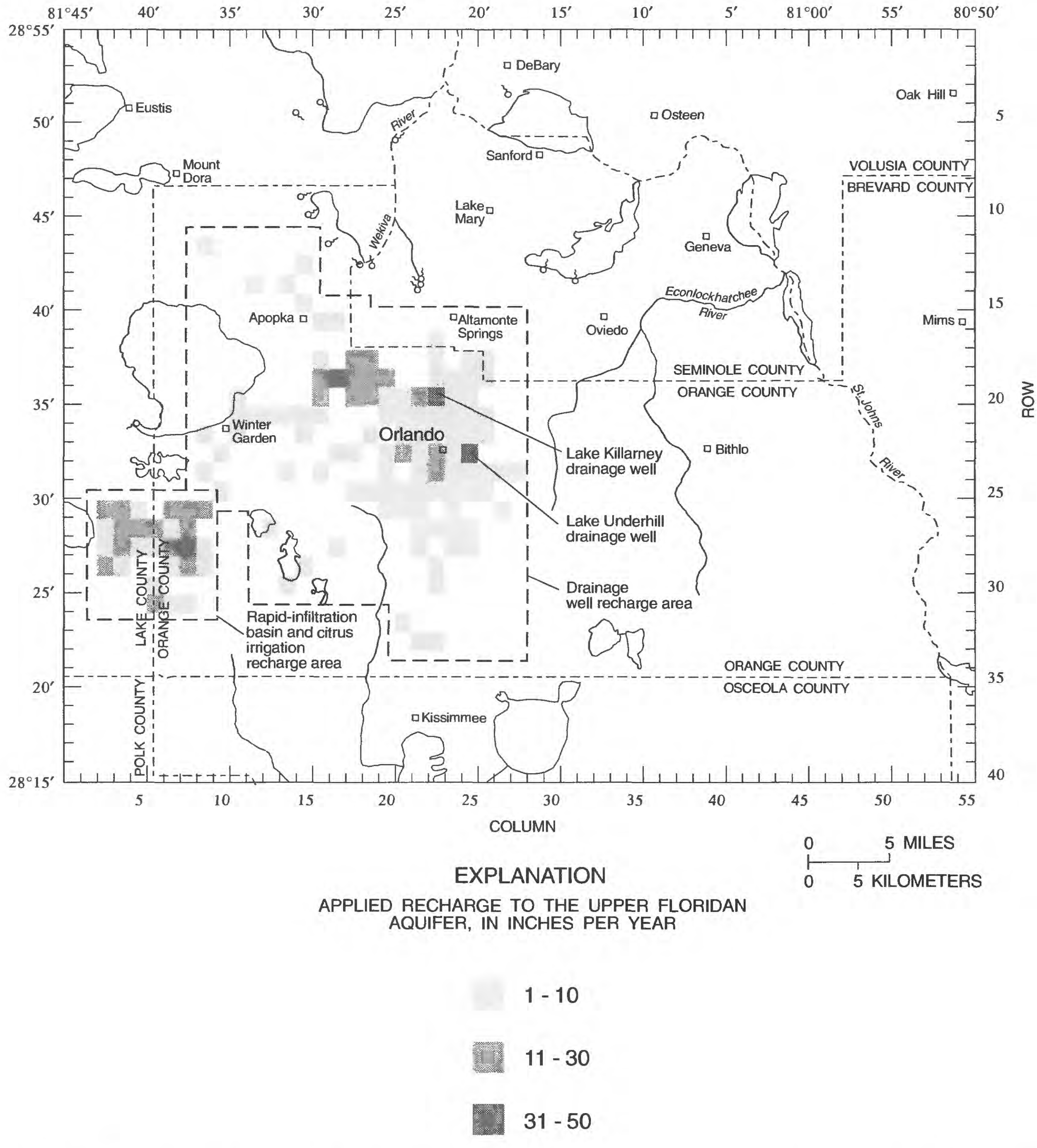


Figure 23. Distribution of recharge to the Upper Floridan aquifer from drainage wells (calibrated) and rapid-infiltration basins (measured) for average 1988 steady-state conditions.

rates of recharge were applied to wells that control lake levels and continuously receive recharge; lower rates were applied to wells that receive intermittent stormwater runoff. Recharge rates applied to the model for the transient simulations were estimated by decreasing the calibrated 1988 recharge rates in proportion to the decreased inflows observed at the Lake Underhill and Lake Killarney drainage wells during this period. Observed inflows to the Lake Underhill and Lake Killarney wells in May 1990 were only about 50 percent of 1988 rates.

The distribution and rates of reclaimed water applied to the Conserv II project areas by land application were provided by Metcalf & Eddy Services, Inc. The actual percentage of applied water that recharges the Upper Floridan aquifer is unknown, but probably exceeds 50 percent of the total. Recharge rates used in this study and shown in figure 23 were calculated by multiplying the land-application rates by 0.8, a factor representative of irrigation efficiencies (Vince Singleton, SJRWMD, oral commun., 1992). Based on these calculations, about 18 Mgal/d of reclaimed water was assumed to recharge the Upper Floridan aquifer in 1988. Assumed recharge rates from January to May 1990 ranged from about 20 to 22 Mgal/d.

Calibration and Results

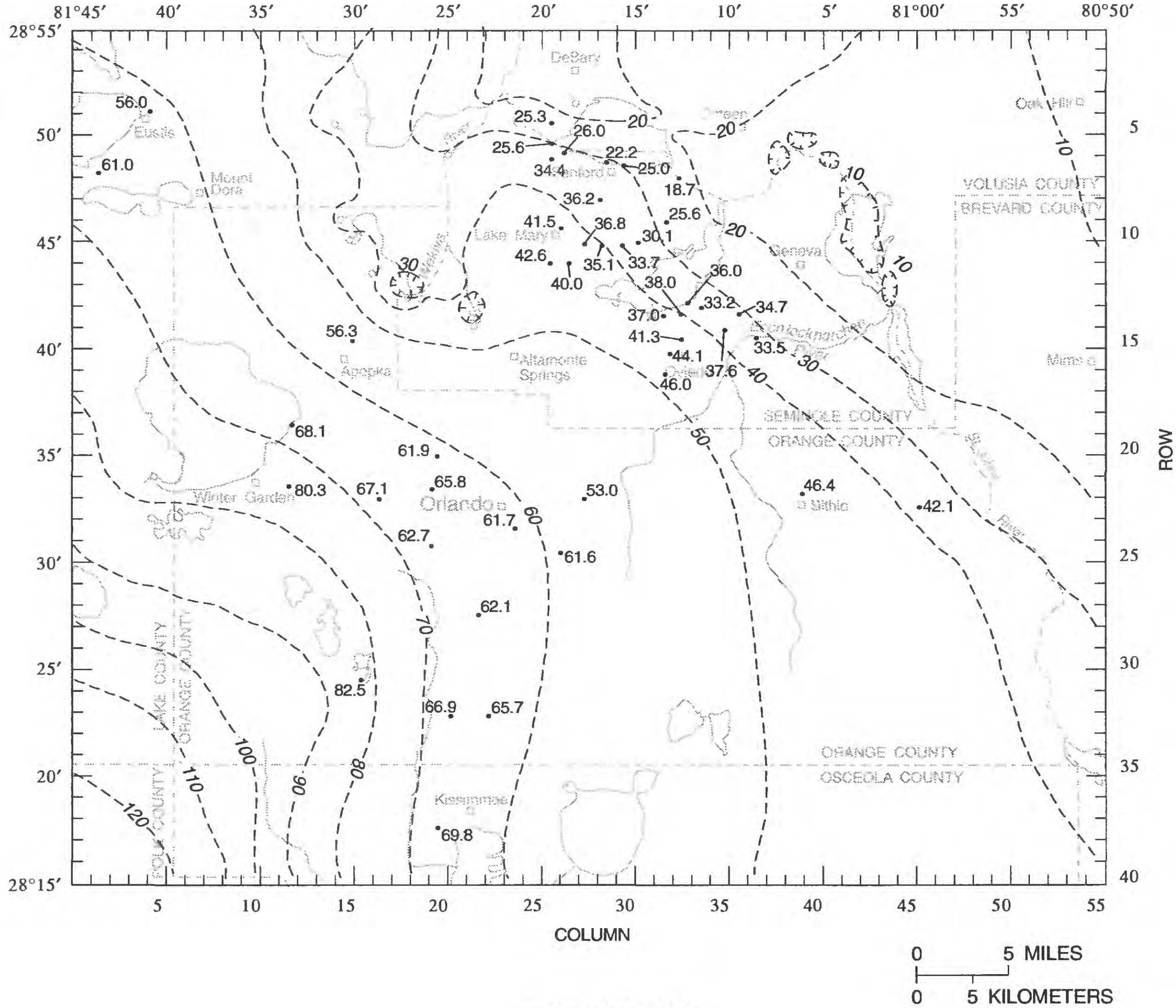
The model was calibrated by adjusting model-parameter values—within reasonable ranges—until an acceptable match was achieved between model-simulated and measured Upper Floridan aquifer heads and spring flow. Specific calibration criteria included the (1) steady-state water levels measured in 142 Upper Floridan aquifer monitoring wells in 1988; (2) the discharge rates measured at 15 Upper Floridan aquifer springs in 1988 and in May 1990; (3) the estimated spring flow and Upper Floridan aquifer potentiometric surface as it existed prior to extensive ground-water development; (4) declines in Upper Floridan aquifer water levels measured in 12 wells equipped with continuous water-level recorders from January to May 1990; and (5) drawdowns measured in 134 Upper Floridan aquifer monitoring wells between 1988 and May 1990. Parameters adjusted during model calibration included both Upper and Lower Floridan aquifer transmissivity, intermediate confining unit leakance, middle semiconfining unit leakance, and drain and river conductances. Drainage-well recharge rates were also adjusted during model calibration.

Parameter adjustments were guided by several criteria. The results from numerous aquifer tests were used as minima to bracket a range of values for the transmissivity of the Upper and Lower Floridan aquifers. The assigned leakance of the intermediate confining unit and, to a lesser extent, of the middle semiconfining unit, were also based on aquifer-test results. Highest intermediate confining unit leakance generally was assigned to cells where the confining unit is thin or where the topography is characterized by numerous karst features. Lowest leakances correspond to areas where the confining unit is thickest. Calibrated leakance and Upper Floridan aquifer transmissivity arrays were further evaluated by comparing, for general consistency, simulated recharge rates to the Upper Floridan aquifer from the surficial aquifer system to the recharge rates mapped in figure 7.

Calibrated recharge rates for 1988 were not allowed to exceed 21 in/yr, the difference between long-term average annual precipitation and an assumed minimum ET of 30 in/yr (Tibbals, 1990). Additional adjustments were made to the Upper Floridan aquifer transmissivity and intermediate confining unit leakance arrays during the transient simulations to better simulate declines in Upper Floridan aquifer heads measured in monitoring wells.

Steady-State Simulations

The Upper Floridan aquifer potentiometric surface simulated by the calibrated model prior to development compares favorably with water levels measured in the early 1930's (fig. 24). Similarly, the simulated 1988 steady-state surface is consistent with average 1988 water levels measured in 142 monitoring wells (fig. 25). For predevelopment conditions, water levels measured near the city of Orlando are higher than simulated heads, probably because the predevelopment model did not account for recharge to the Upper Floridan aquifer from numerous Orlando drainage wells. As many as 100 to 200 of these wells had been constructed in the Orlando area by the early 1940's (Unklesbay, 1944). In north-central Seminole County, simulated predevelopment heads were higher than observed heads, possibly because the model did not account for Upper Floridan aquifer discharge from numerous flowing wells used to irrigate crops in the 1930's.



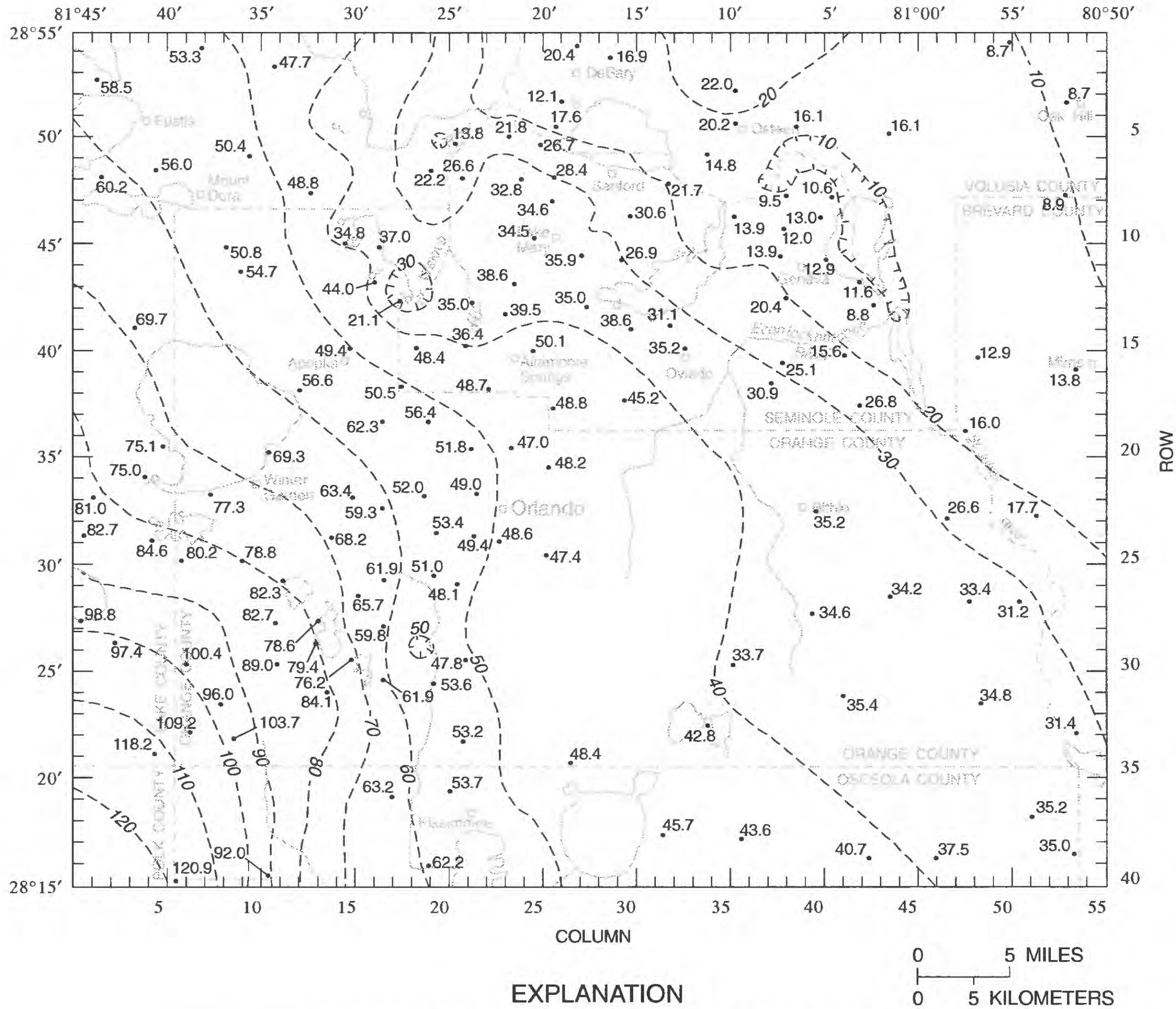
EXPLANATION

--- 40 --- POTENTIOMETRIC CONTOUR OF UPPER FLORIDAN AQUIFER--
Derived from computer model simulation of predevelopment heads. Shows altitude of potentiometric surface. Hachures indicate depressions. Contour interval 10 feet. Datum is sea level

69.8. WELL USED TO MEASURE UPPER FLORIDAN AQUIFER HEAD --
Number is head, in feet above mean sea level (from figure 8). Well locations and descriptions are arranged by model row and column number in Appendix A

Figure 24. Simulated Upper Floridan aquifer potentiometric surface for predevelopment steady-state conditions and water levels measured at selected Upper Floridan aquifer monitoring wells in the early 1930's.

The simulated 1988 Lower Floridan aquifer potentiometric surface is a subdued reflection of the Upper Floridan aquifer potentiometric surface (fig. 26). Water levels measured in five Lower Floridan aquifer monitoring wells in the late 1980's and early 1990's generally are consistent with simulated contours. Simulated Lower Floridan aquifer heads generally are lower than Upper Floridan aquifer heads in recharge areas and higher than Upper Floridan aquifer heads in discharge areas. These results are consistent with the conceptualized model discussed in the previous section. Simulated Lower Floridan aquifer heads



EXPLANATION

--- 60 --- POTENTIOMETRIC CONTOUR OF UPPER FLORIDAN AQUIFER-- Derived from computer model simulation of average 1988 heads. Shows altitude of potentiometric surface. Hachures indicate depressions. Contour interval 10 feet. Datum is sea level

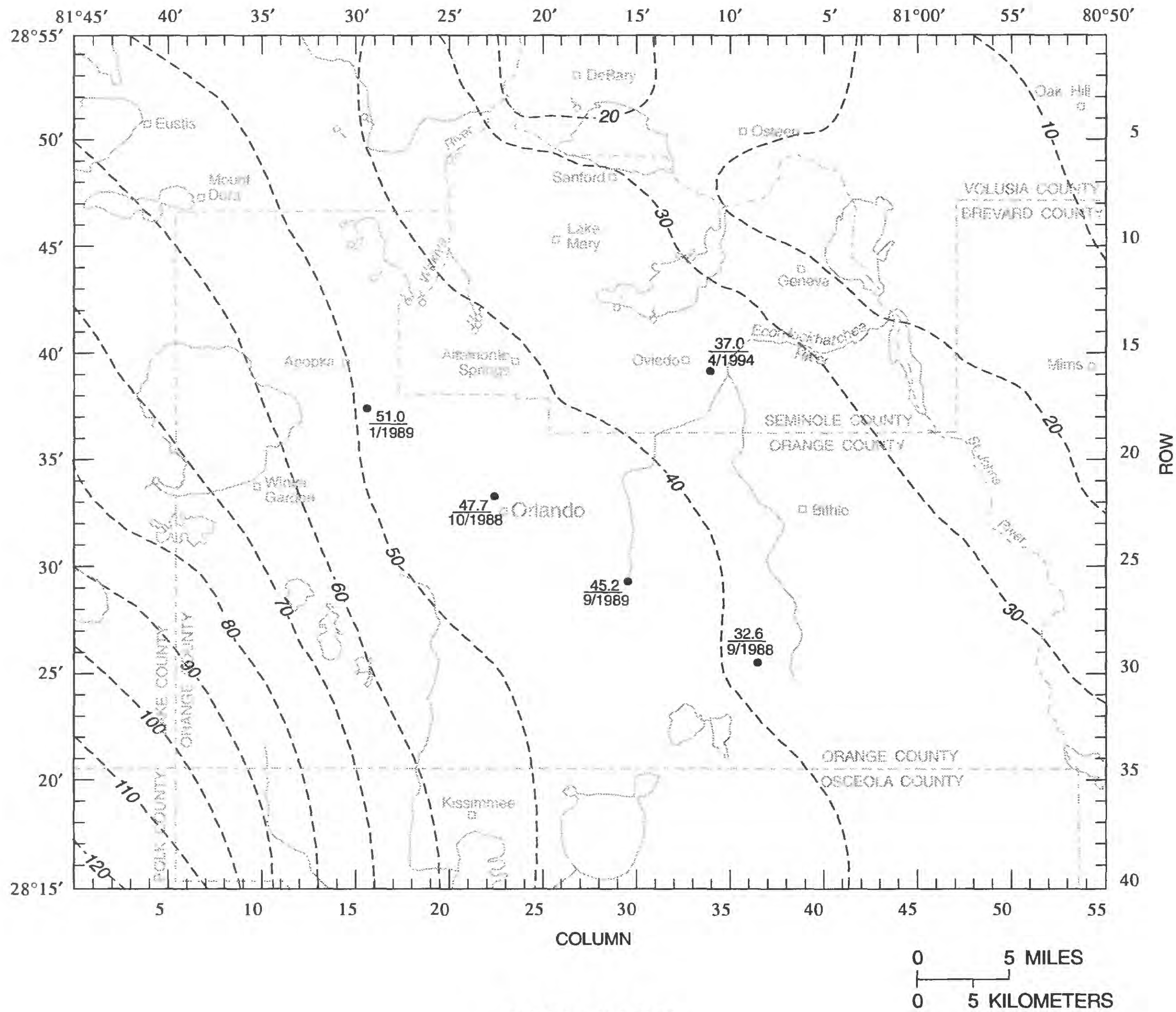
•43.6 WELL USED TO MEASURE AVERAGE 1988 UPPER FLORIDAN AQUIFER HEAD -- Number is head, in feet above mean sea level (from figure 10). Well located by column and row and described in Appendix A

Figure 25. Simulated Upper Floridan aquifer potentiometric surface for average 1988 steady-state conditions and water levels measured at Upper Floridan aquifer monitoring wells.

in central Orange County are 1 to 3 ft lower than simulated Upper Floridan aquifer heads.

Upper Floridan aquifer heads simulated in 1988 are within 2 ft of measured heads in 101 of 142 monitoring wells (fig. 27). The average absolute error, calculated as the average of the absolute values of the differences between measured and simulated water levels, is 1.8 ft. The average error (algebraic sum of the differences divided by the number of observations) is 0.12 ft, indicating little bias in simulated results.

Simulated and observed spring flow for both predevelopment and average 1988 steady-state conditions are listed in table 8. Predevelopment discharge rates simulated by the model totaled 356 ft^3/s com-



EXPLANATION

--50-- POTENTIOMETRIC CONTOUR -- Contours derived from computer-model simulation of Lower Floridan aquifer heads, average 1988 conditions. Contour interval is 10 feet. Datum is sea level

45.2 • 9/1989 WELL USED TO MEASURE LOWER FLORIDAN AQUIFER HEAD -- Top number is head, in feet above mean sea level. Bottom number is month and year in which measurement was recorded. Well locations and descriptions are arranged by model row and column

Figure 26. Simulated Lower Floridan aquifer potentiometric surface for average 1988 steady-state conditions and water levels measured at selected Lower Floridan aquifer monitoring wells.

pared to an independently estimated rate of about 360 ft^3/s. Simulated discharge rates in 1988 totaled 306 ft^3/s, equal to that measured in 1988. Discharge rates simulated at the largest springs (Wekiva, Apopka, Rock, the Sanlando group, and Seminole) were within 3 percent of measured values. The simulated reduction in spring discharge between predevelopment and 1988 conditions totaled 50 ft^3/s compared to a difference of 54 ft^3/s between the estimated predevelopment and the measured 1988 spring discharges.

Water budgets simulated by the model and shown in figure 28 indicate that recharge from the surficial aquifer system was the single largest contributor of water to the Upper Floridan aquifer during pre-

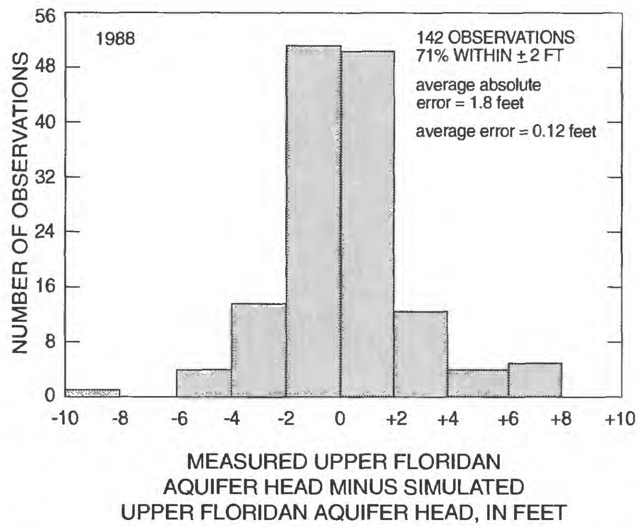


Figure 27. Differences between simulated and measured water levels in the Upper Floridan aquifer for average 1988 steady-state conditions.

development and 1988 conditions (540 and 771 ft^3/s, respectively). Smaller amounts of water were contributed by lateral (boundary) inflow (69 and 79 ft^3/s, respectively). Discharge from the aquifer by spring flow totaled 356 and 306 ft^3/s for predevelopment and average 1988 conditions, respectively. Smaller amounts of discharge occurred by diffuse upward leakage to the surficial aquifer system (108 and 64 ft^3/s, respectively) and St. Johns River (96 and 78 ft^3/s, respectively), and by lateral outflow across model boundaries (65 and 55 ft^3/s, respectively). Well discharge in 1988 totaled 356 ft^3/s.

About half (231 ft^3/s) of the 473 ft^3/s of water discharged by wells from the Floridan aquifer system in 1988 was accounted for by increased recharge from the surficial aquifer system. The possible sources of this increased recharge include excess 1988 rainfall (56 in. as compared to 51 in., the long-term annual average assumed for predevelopment conditions), captured evapotranspiration, and reduced surface runoff. Much of the increased surficial-aquifer recharge occurred across areas of west Orange, east Lake, west Seminole, and southwest Volusia Counties, where the intermediate confining unit is thin or is breached by numerous sinkholes. The balance of pumpage was accounted for by recharge from drainage wells and reclaimed water (75 ft^3/s) and by reductions in spring flow (50 ft^3/s), diffuse upward leakage (44 ft^3/s), lat-

Table 8. Measured or estimated discharge and simulated discharge from selected Upper Floridan aquifer springs during predevelopment, average 1988, and May 25, 1990 conditions

[All discharge values in cubic feet per second. --, spring discharge not measured in May 1990]

Name of spring	Predevelopment steady-state conditions		1988 average steady-state conditions		End of transient drought period May 25, 1990	
	Estimated	Simulated	Measured[a]	Simulated	Measured[a]	Simulated
Wekiva	80	80	69	69	52	56
Apopka	70	69	61	62	--	51
Rock	70	63	58	58	46	51
Sanlando, Palm, and Starbuck	50	53	41	40	28	29
Seminole	40	45	39	38	34	30
Messant	20	17	14	16	12	14
Island	10	9.1	6	7.2	--	6.5
Gemini	10	8.1	8	6.7	--	5.7
Miami	6	6.5	5	4.8	4	3.6
Witherington	2	1.2	1	1.0	--	0.8
Clifton	2	1.9	2	1.5	--	1.2
Sulphur	2	1.3	1	1.1	--	0.9
Lake Jesup	1	1.0	1	0.8	--	0.7
TOTAL:	360 [d]	356	306	306	--	250
					(176) [b]	(184) [c]

[a] Spring-discharge measurements typically are subject to ± 10 percent error, except for submerged Apopka and Island Springs, which are subject to measurement errors of 25 percent or greater.

[b] Total discharge measured from the eight springs in May 1990.

[c] Total discharge simulated from the eight measured springs in May 1990.

[d] Rounded to two significant figures.

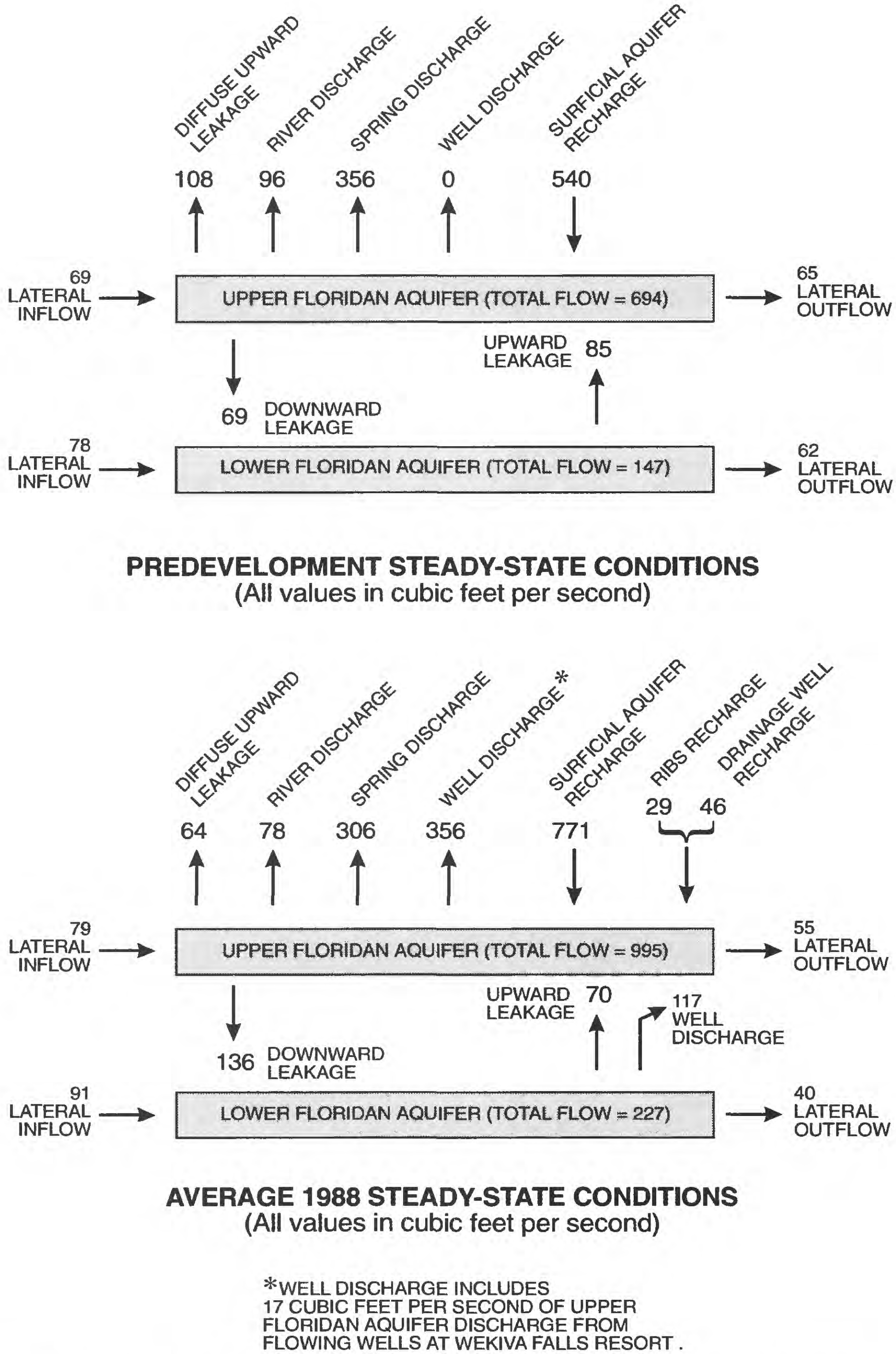


Figure 28. Simulated hydrologic budgets for steady-state predevelopment and average 1988 conditions.

eral outflow (32 ft^3/s for both aquifers) and river discharge (18 ft^3/s). A relatively small increase in lateral inflow (23 ft^3/s total for both aquifers) was induced by 1988 pumpage (fig. 28).

The net flow rate of water exchanged between the Upper and Lower Floridan aquifers prior to development was relatively small (16 ft^3/s) and moved upward from the Lower to the Upper Floridan aquifer. In 1988, the net flow rate increased to 66 ft^3/s and moved from the Upper Floridan aquifer to the Lower Floridan aquifer. The reversal and increase in the net flow rate can be attributed to the drawdowns induced in the Lower Floridan aquifer by 1988 pumpage and from mounding of the Upper Floridan potentiometric surface by recharge from the Orlando drainage wells.

Transient Simulation

For the transient simulation, the January to May 1990 drought period was divided into five stress periods, each corresponding to a month. Each stress period was further subdivided into 60 time steps to improve the temporal resolution of the simulated heads. Starting heads for the Upper and Lower Floridan aquifers were determined from a steady-state simulation of the flow system using December 1989 pumping rates. Specified GHB heads, surficial aquifer heads, and pumping rates for each of the five stress periods were assigned as previously discussed. Surficial aquifer heads were recalculated for each time step by linear interpolation between heads specified at the middle of respective stress periods. The interpolation scheme developed by Leake and others (1994) was used for these calculations. Simulations were completed for each of three storage coefficients ($1x10^{-4}$, $5x10^{-4}$, and $1x10^{-3}$) that bracket the range of values referenced in previous aquifer tests (Szell, 1993). The lowest of these three values approximates the theoretical minimum storage coefficient of $8x10^{-5}$ calculated for the Upper Floridan aquifer using equation 1, whereas the median value of $5x10^{-4}$ equals the theoretical minimum value calculated for the Lower Floridan aquifer.

Water-level declines measured in the Upper Floridan aquifer from January to May 1990 generally are well simulated by the model (figs. 29-32). At well OR-47 (fig. 30), where the simulated drawdown is appreciably higher than the observed drawdown, recharge through numerous drainage wells in the area may not have been entirely accounted for by the recharge rates assigned to the model for the final stress period. The short-term fluctuations induced by variations in daily pumpage from nearby well fields could not be simulated by the model since the applied pumpage was constant across each stress period (only average monthly pumping rates were available for most users). The abrupt change in head simulated at the beginning of each stress period is attributed to the corresponding change in pumpage imposed at the beginning of each period.

Simulated water levels generally were insensitive to changes in storage coefficient for most of the transient period. In May 1990, however, when changes in pumpage, direct recharge, and surficial aquifer heads were greatest, simulated water-level declines were more sensitive to changes in storage coefficient, particularly at the Cocoa A, Cocoa P, Bithlo, OR-47, and Sea World monitoring wells that are located near high-capacity well fields. Water released from storage accounted for less than 5 percent of the total simulated inflow to the aquifer system during the first 10 days of the May stress period (using the median storage coefficient of $5x10^{-4}$) but represented about 80 percent of the change in inflow during this 10-day period.

A storage coefficient of $1x10^{-3}$ provided the best match between simulated and measured water-level declines. These results are similar to those reported by Tibbals (1990) and may account for the combined effects of water released from storage in both the Upper Floridan aquifer and the overlying intermediate confining unit. Because changes in Upper Floridan aquifer heads are generally insensitive to the storage coefficient, the model was not areally calibrated for this parameter. Additionally, the high transmissivity and low storativity of the Floridan aquifer system result in a large diffusivity (T/S). Thus, the aquifer probably equilibrates rapidly to changes in stress or stress distribution, further minimizing the importance of transient analyses.

The Upper Floridan aquifer potentiometric surface simulated by the model at the end of the transient period (May 25, 1990) is consistent with water levels measured in 145 monitoring wells during the third week in May (fig. 33). Relative to 1988 conditions, the simulated May 1990 potentiometric surface is affected by a 40 percent increase in pumpage from the Floridan aquifer system and by declines in surficial aquifer heads (fig. 19). The average absolute error calculated between measured and simulated water levels is 1.7 ft, with an average error of 0.13 ft. Drawdowns measured in 134 monitoring wells common to both 1988 and May 1990 data-collection periods ranged from 6 to 10 ft in central Orange, southwest Seminole, and north-central Osceola Counties, and were less than 4 ft across the rest of the study area (fig. 33). Drawdowns simulated by the model are within plus or minus 25 percent of measured drawdowns at 78 of the 134 monitoring wells, and within plus or minus 50 percent of drawdowns measured in 128 of the 134 wells (fig. 34).

Drawdowns simulated in the less populated areas of northwest Orange and east Lake Counties generally were less than measured drawdowns. Differences between simulated and measured drawdowns in

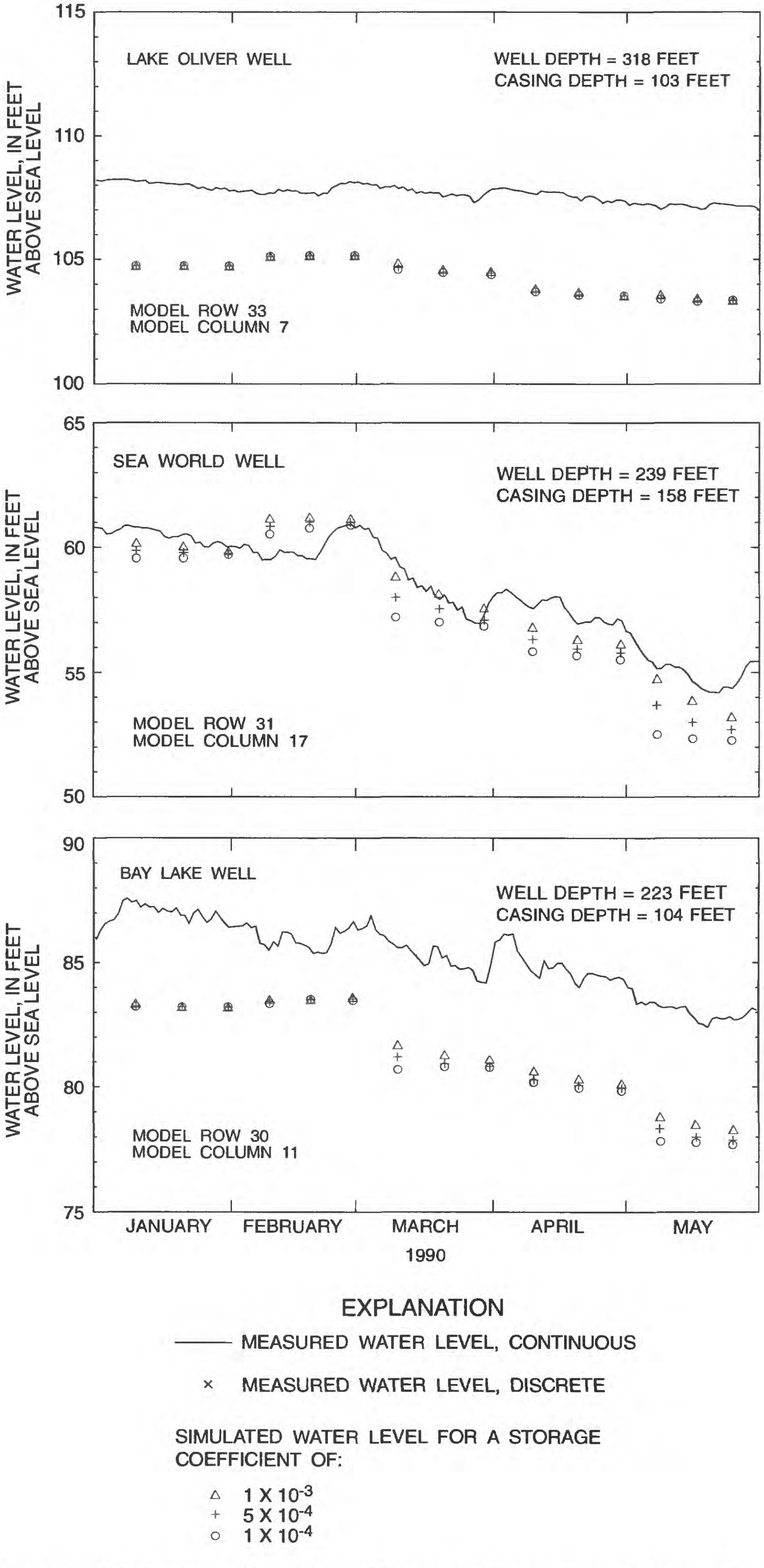


Figure 29. Observed and simulated water levels in selected Upper Floridan aquifer monitoring wells, January 1 to May 25, 1990.

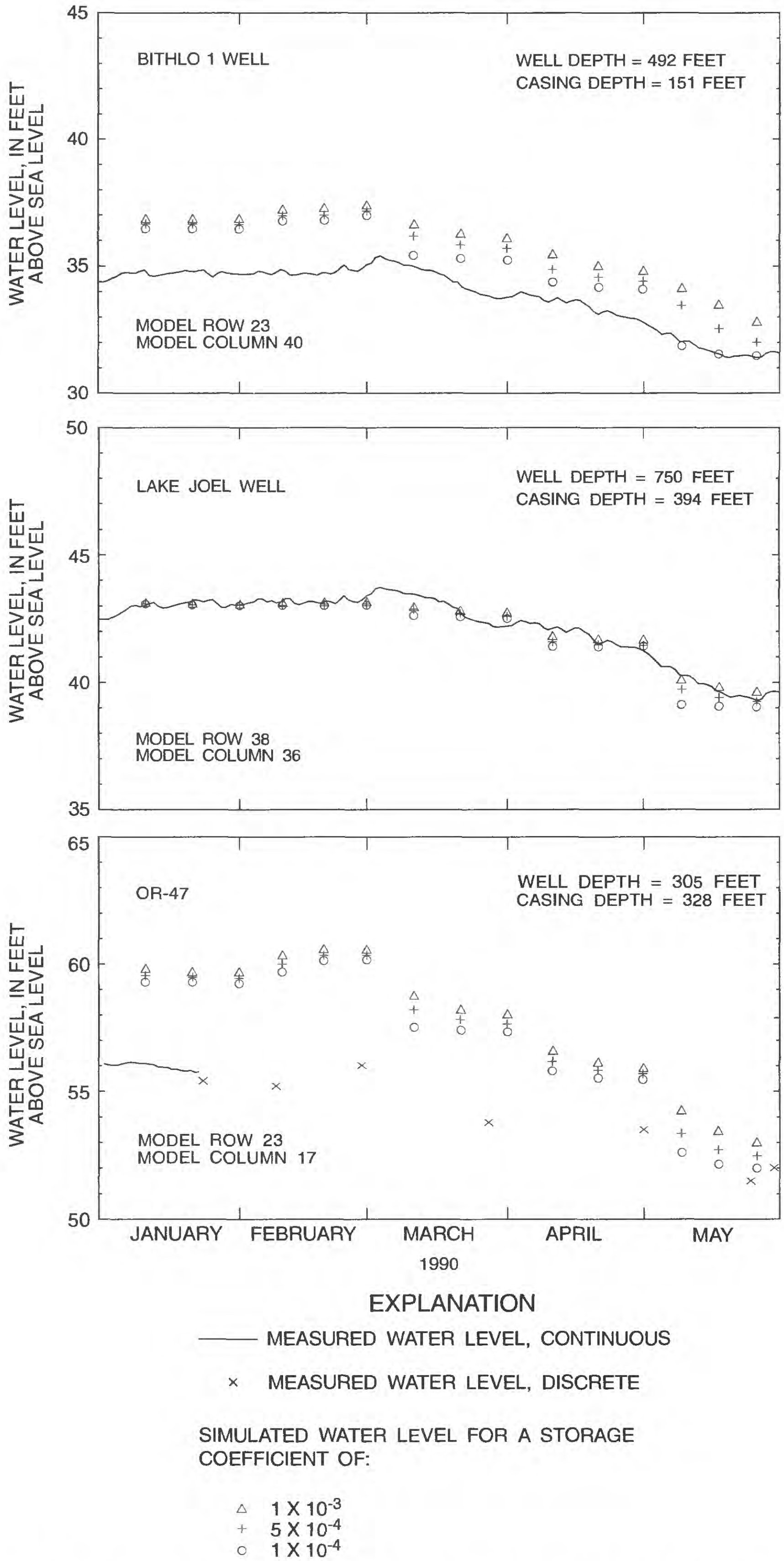


Figure 30. Observed and simulated water levels in Upper Floridan aquifer monitoring wells, January 1 to May 25, 1990.

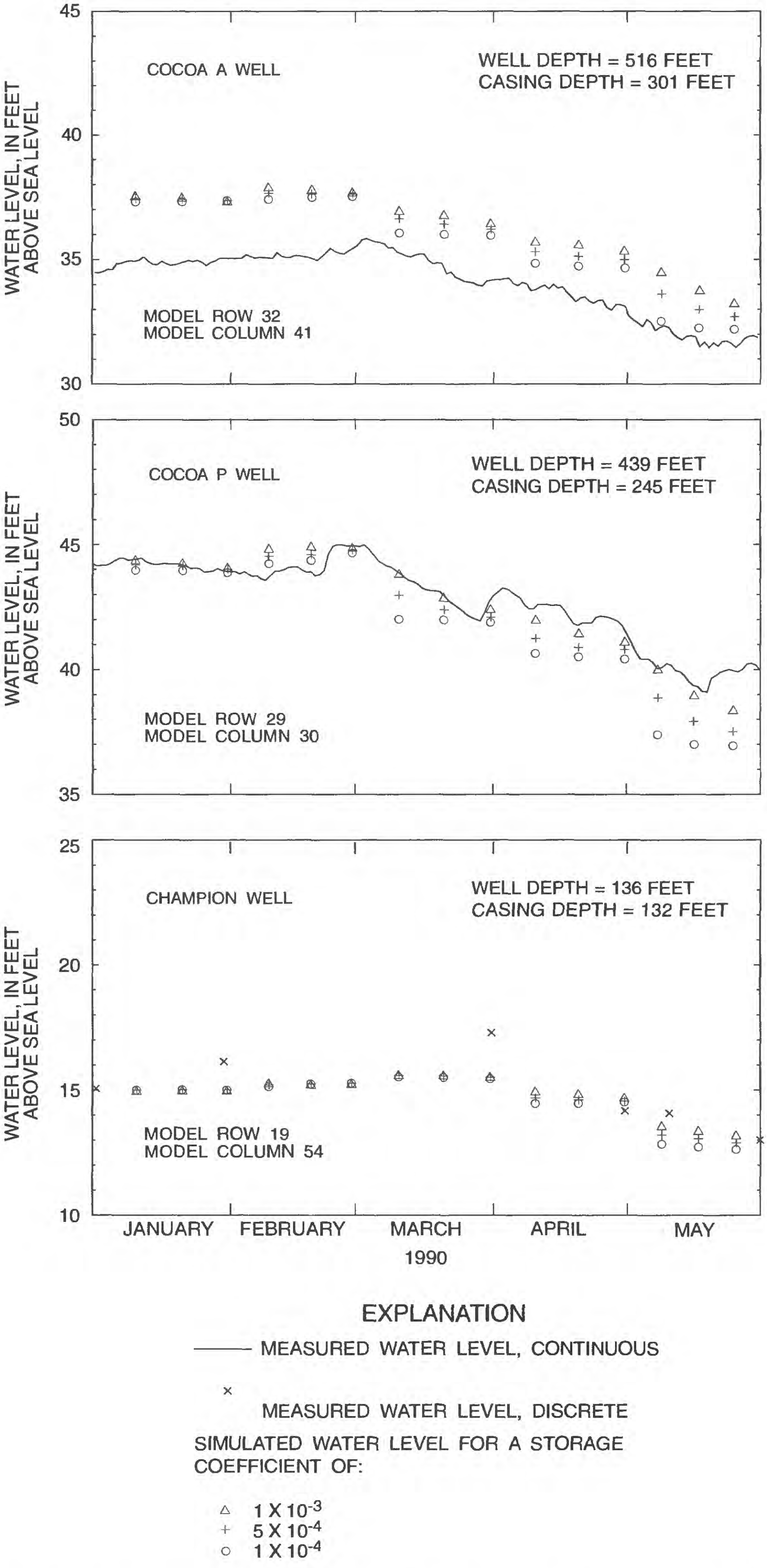


Figure 31. Observed and simulated water levels in Upper Floridan aquifer monitoring wells, January 1 to May 25, 1990.

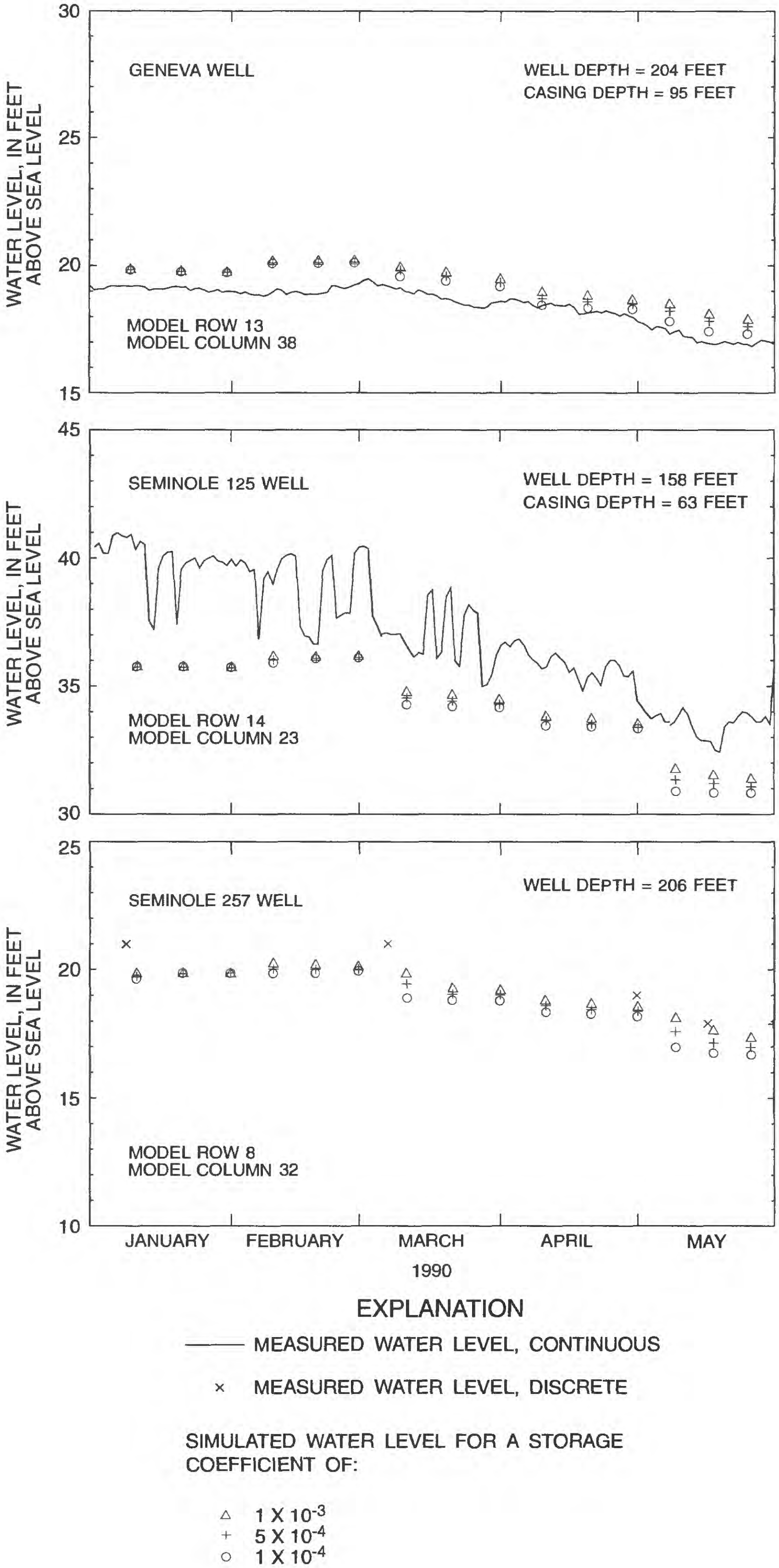


Figure 32. Observed and simulated water levels in Upper Floridan aquifer monitoring wells, January 1 to May 25, 1990.

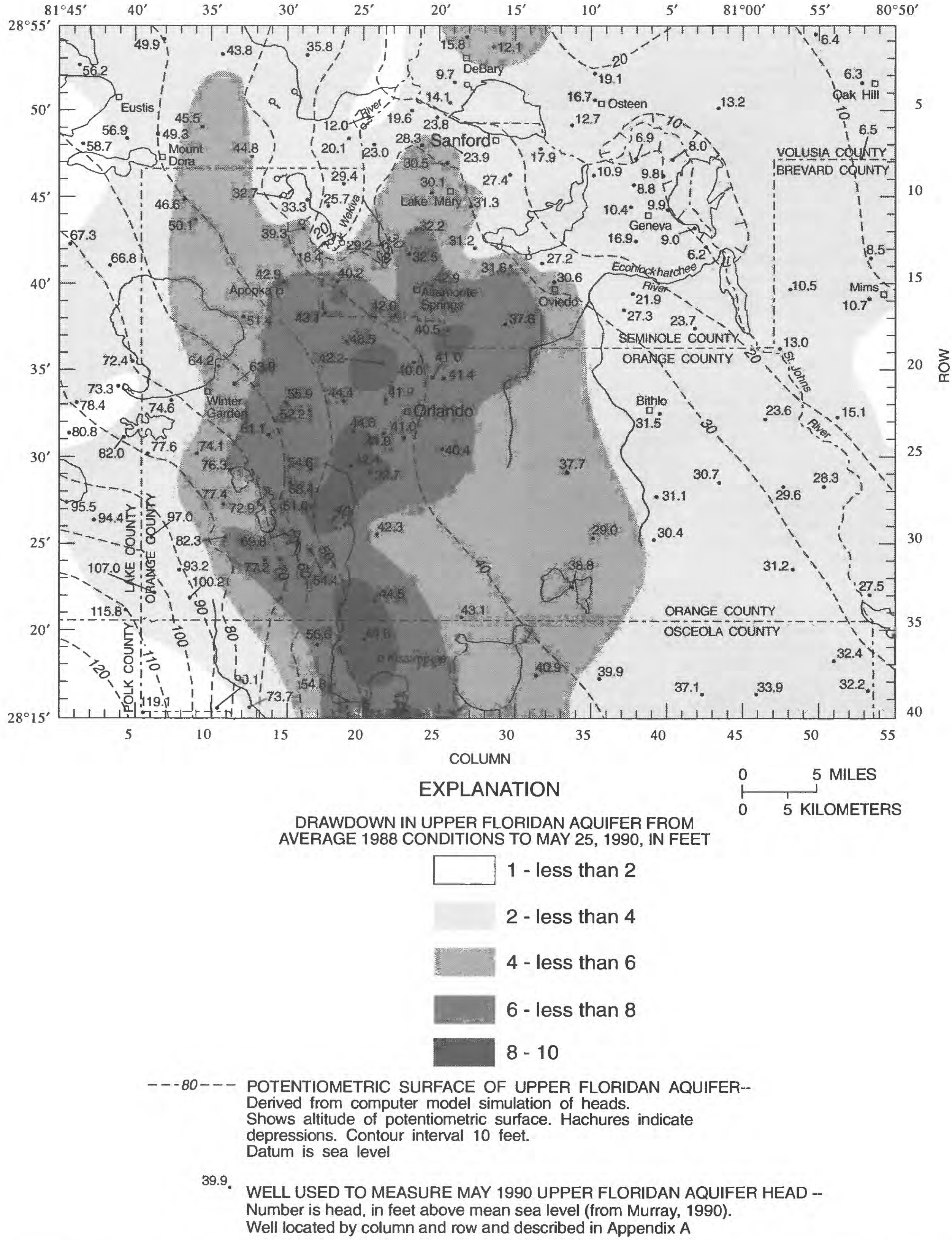


Figure 33. Simulated Upper Floridan aquifer potentiometric surface (May 25, 1990), water levels measured at Upper Floridan aquifer monitoring wells, and observed drawdowns relative to average 1988 conditions.

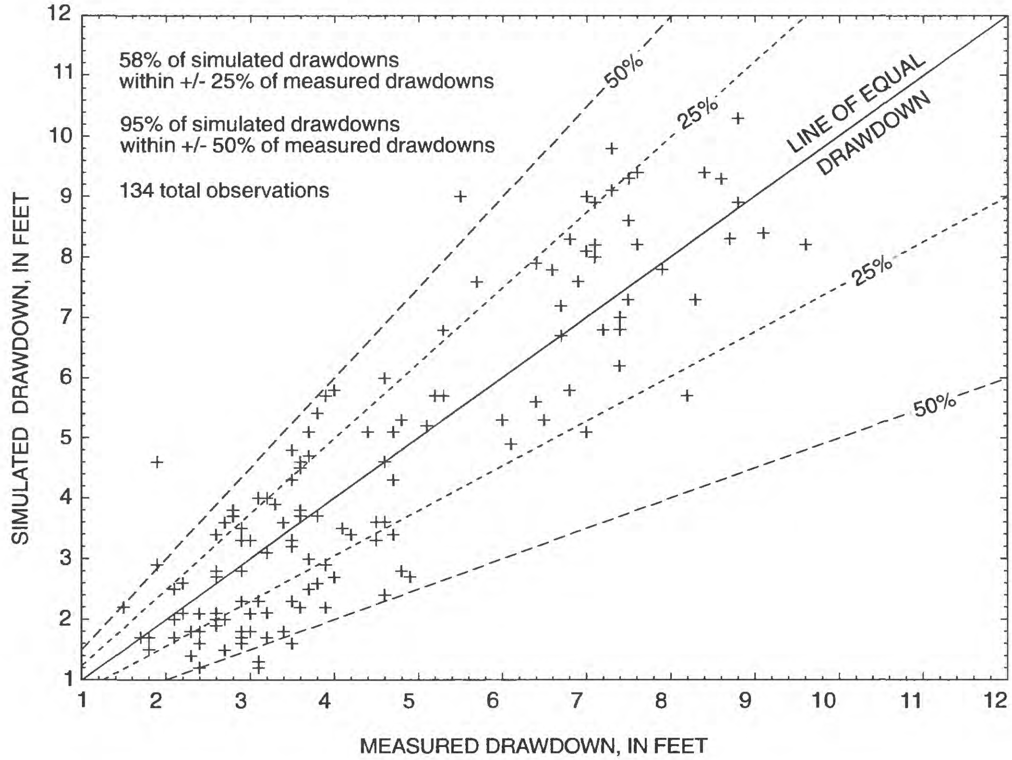


Figure 34. Measured and simulated drawdowns in Upper Floridan aquifer monitoring wells, average 1988 conditions to May 25, 1990.

these areas may be attributed to any or all of several model deficiencies:

(1) Rural-domestic pumpage was not included in the model simulations. Under typical rainfall conditions, the stress imposed by rural-domestic pumpage over the study area is relatively small because the vast majority of the population is served by municipal well fields. In the more rural areas of northwest Orange and east Lake Counties, however, where self-supplied domestic users are concentrated, increased pumpage for lawn irrigation during drought periods could have significantly affected heads in the Upper Floridan aquifer.

(2) Declines of heads in the surficial aquifer system may have been underestimated. Many of these estimates were based on lake-level declines, which may be smaller than actual water-table declines beneath the sandy ridges; thus, heads assigned to the source/sink array may have been too high, resulting in excessive simulated leakage to the Upper Floridan aquifer.

(3) The actual amount of water pumped from the Upper Floridan aquifer to irrigate nurseries in east Lake and northwest Orange Counties may have been underestimated for May 1990. During periods of drought, farmers occasionally exceed permitted withdrawal rates and differences between estimated and actual pumping rates may have been large enough to affect the heads in these areas.

Discharge simulated from Upper Floridan aquifer springs in May 1990 totaled 250 ft^3/s, about 56 ft^3/s less than spring flow simulated in 1988 (table 8). This reduction in discharge is greater than the reduction of 50 ft^3/s simulated between predevelopment and average 1988 conditions and illustrates the sensitivity of spring flow to periods of deficit rainfall. Discharge simulated at Wekiva, Rock, Sanlando, Palm, Starbuck, Seminole, Messant, and Miami Springs in May 1990 totaled 184 ft^3/s compared to the measured total of 176 ft^3/s (table 8). Simulated spring flow is greater than measured spring flow because drawdowns simulated by the model in northwest Orange County, upgradient from Wekiva and Rock Springs, were less than measured values. Possible explanations for insufficient drawdowns in this area were discussed previously.

Calibrated Aquifer and Confining-Unit Hydraulic Characteristics

The calibrated leakance array that represents the intermediate confining unit is shown in figure 35. Calibrated values range from $1x10^{-5}$/d to $4x10^{-3}$/d. Values are highest where the confining unit is thinnest or is breached by numerous sinkholes. These areas include northeast Polk and east Lake Counties; west Seminole

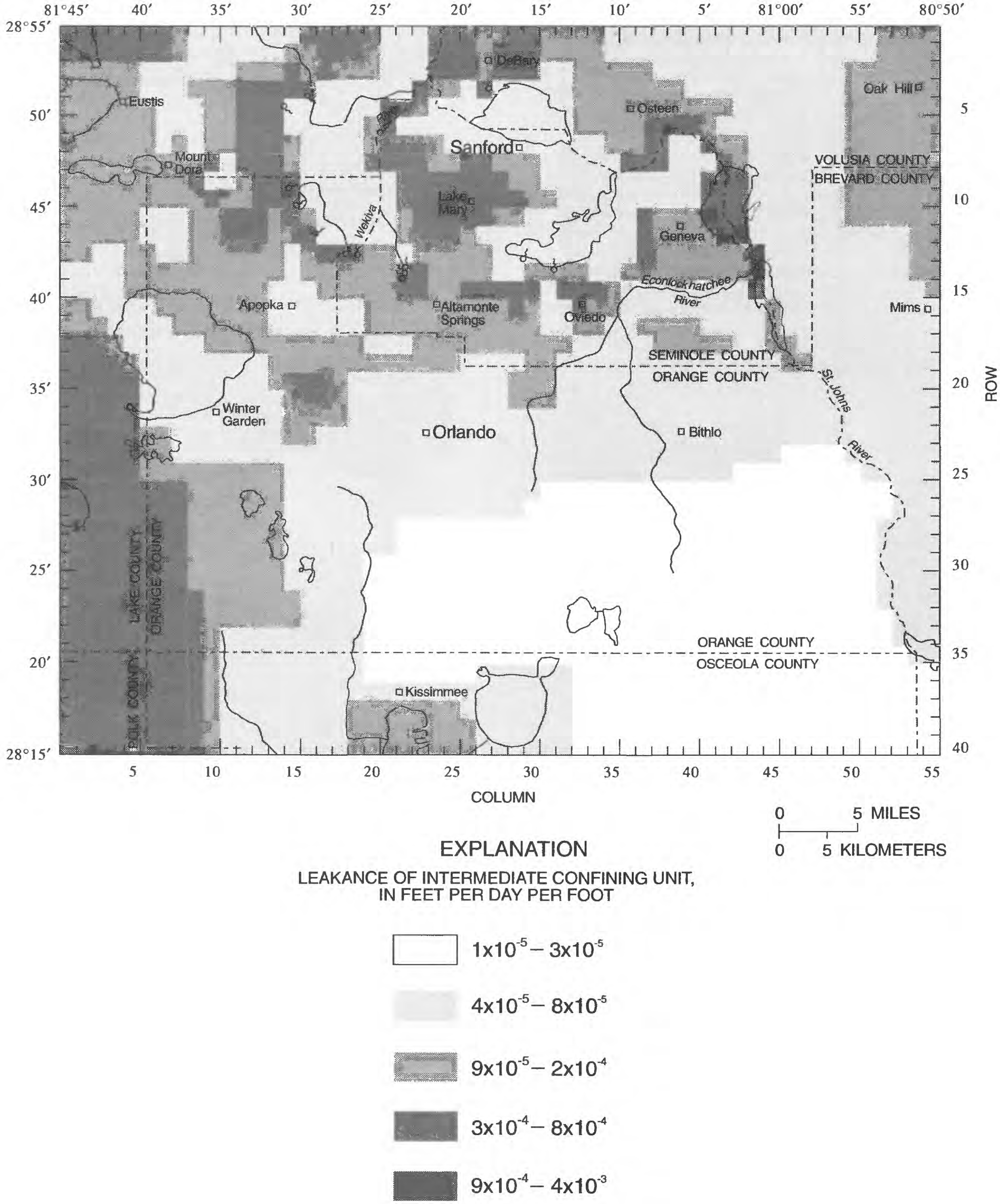


Figure 35. Calibrated leakance of the intermediate confining unit.

County around the city of Lake Mary and northwest to the Wekiva River; east Seminole County along the St. Johns River; northwest Orange County upgradient from Upper Floridan aquifer springs; and southwest Volusia County north of Lake Monroe. Leakance values are lowest in southeast Orange and northeast Osceola Counties where the confining unit is thickest. The higher leakance values simulated beneath the St. Johns River at the Orange-Osceola County boundary reflect the abrupt decrease in confining unit thickness observed east of the river in Brevard County (fig. 5). Subsurface faulting may exist at or near the river in this area. Model-calibrated leakance values were consistently lower than those derived from aquifer tests, indicating that field-derived values probably include the effects of leakage from below the pumped aquifer; that is, from the Lower Floridan aquifer through the middle semiconfining unit. Generally, model-calibrated leakance values are greatest in areas where aquifer tests have yielded relatively high values and are lowest where aquifer tests have yielded relatively low values.

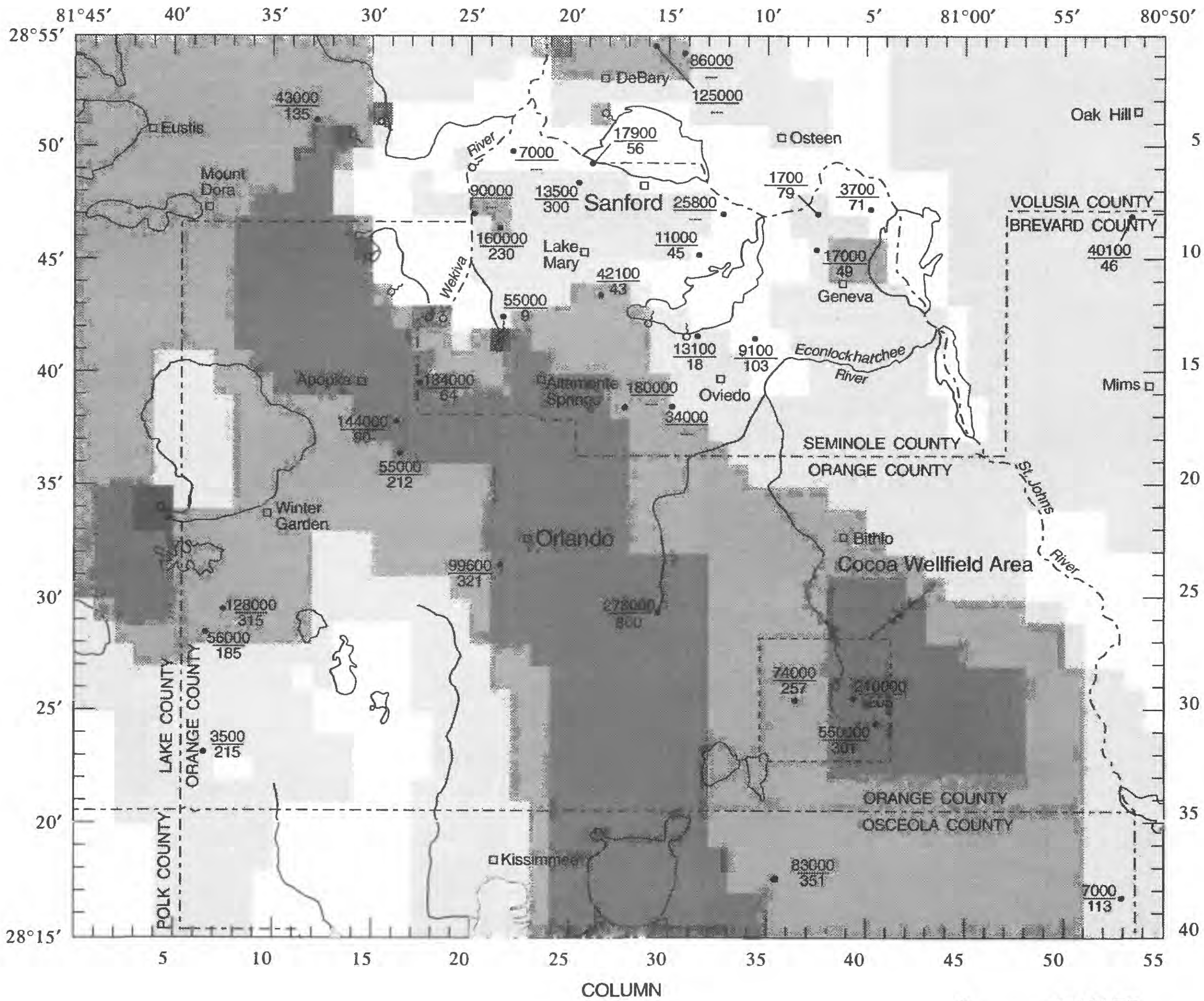
Leakance values shown at the river cells were calculated by dividing the calibrated CRIV values by the area of the cells. This conversion assumes that the river stage specified in the River package is representative of the average water-table altitude across the cell. This assumption seems reasonable since the topography within the river cells is flat and swampy and observed differences between river stage and the nearby water table are small.

Upper Floridan aquifer transmissivity values derived by model calibration range from 10,000 to more than 400,000 ft^2/d (fig. 36). Calibrated transmissivities for a given area usually exceed transmissivities determined by aquifer tests. However, areas where calibrated transmissivities are high generally correspond to areas where aquifer tests have yielded relatively high values. Similarly, areas of low simulated transmissivities generally correspond to areas where transmissivities based on aquifer tests also are low. The highest calibrated transmissivities (greater than 400,000 ft^2/d) occur locally at several of the larger Upper Floridan aquifer springs where cavernous conditions are known to exist. Broader areas of high calibrated transmissivity (200,000 to 400,000 ft^2/d) occur in northwest, central, and east Orange County, and in east-central Lake County. The highly transmissive areas in northwest Orange and east-central Lake Counties are close to and upgradient from Upper Floridan aquifer springs, where the flow fields of the springs capture nearly all of the recharging water. The highly transmissive area in east Orange County covers the east part of the Cocoa well field and is consistent with aquifer-test results. Moderate calibrated transmissivity values (100,000 to 200,000 ft^2/d) occur in east Lake, southwest Seminole, northeast Osceola, and parts of Orange Counties. Tranmissivity determined by aquifer-test analyses in the west part of the Cocoa well field is lower than calibrated values in the east half, consistent with aquifer and specific-capacity test differences measured at production wells in these two areas (Tibbals and Frazee, 1976).

The lowest calibrated transmissivities (10,000 to 40,000 ft^2/d) occur in northeast Polk County and in areas that discharge water from the Upper Floridan aquifer. These discharge areas include the St. Johns River system and adjoining lakes in north and east Seminole County, where measured specific capacities and well yields are low (Tibbals, 1977); the area downgradient from Upper Floridan aquifer springs near the Wekiva River where ground-water velocities are relatively slow; and the area around Reedy Creek where closely spaced potentiometric contours indicate low transmissivity in the Upper Floridan aquifer (fig. 25). In northeast Polk County, transmissivity is reduced by the clayey limestone beds present in the top 100 ft of the Upper Floridan aquifer (Grubb, 1978).

A leakance value of 5×10^{-5}/d, obtained from the calibrated RASA model (Tibbals, 1990), was assigned to the middle semiconfining unit array and was adjusted in only a few areas during model calibration (fig. 37). Leakance was increased in central Orange County to 1×10^{-3}/d to more closely simulate the 1- to 3-ft head differences observed between the Upper and Lower Floridan aquifers in the Orlando area.

Calibrated transmissivity of the Lower Floridan aquifer is greatest (600,000 ft^2/d) in central Orange County where aquifer-test results range from 576,000 to 668,000 ft^2/d (fig. 38). Calibrated transmissivities are lowest (5,000 to 10,000 ft^2/d) in north and east Seminole, north Brevard, and southwest Volusia Counties. The freshwater-saltwater interface beneath these areas probably is close to the top of the Lower Floridan aquifer, limiting the movement of freshwater to only a thin part of the aquifer. Ground-water flow velocities within the Lower Floridan aquifer are relatively slow, if not stagnant, in these areas. The singular



EXPLANATION

TRANSMISSIVITY, IN FEET SQUARED PER DAY

- 10,000 - 39,999
- 40,000 - 99,999
- 100,000 - 199,999
- 200,000 - 399,999
- Greater than 400,000

99600/321 • TRANSMISSIVITY DETERMINED FROM MULTI-WELL AQUIFER TEST -- Top number is transmissivity, in feet squared per day. Bottom number is thickness of aquifer penetrated by pumped well, in feet; ---, data not available

Figure 36. Calibrated transmissivity of the Upper Floridan aquifer and results of selected aquifer tests.

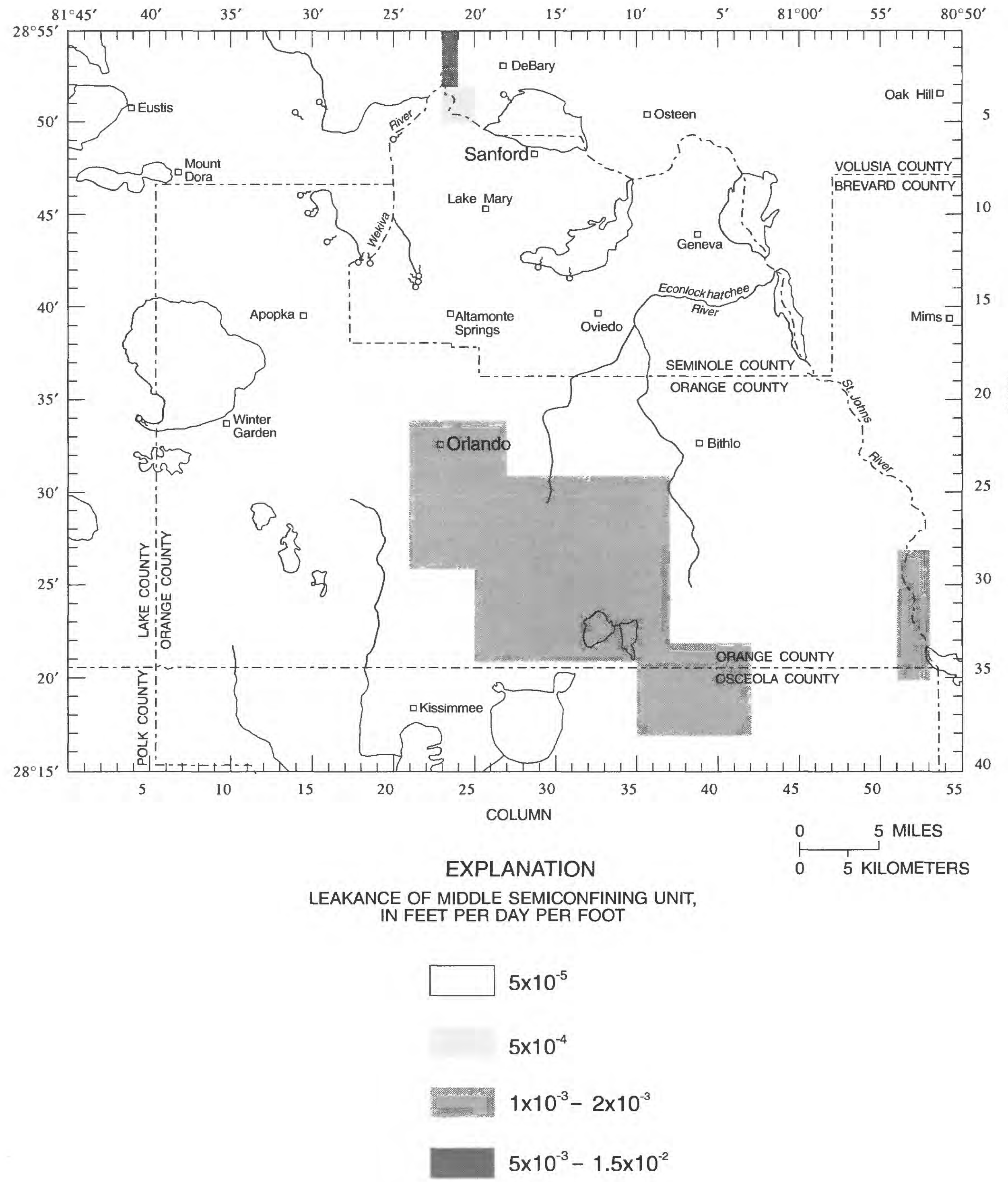


Figure 37. Calibrated leakance of the middle semiconfining unit of the Floridan aquifer system.

distribution of intermediate transmissivities (60,000 and 130,000 ft^2/d) shown in figure 38 was taken from Tibbals (1981) and was not changed during model calibration.

Recharge and Discharge Rates

Simulated recharge from the surficial aquifer system to the Upper Floridan aquifer occurs across

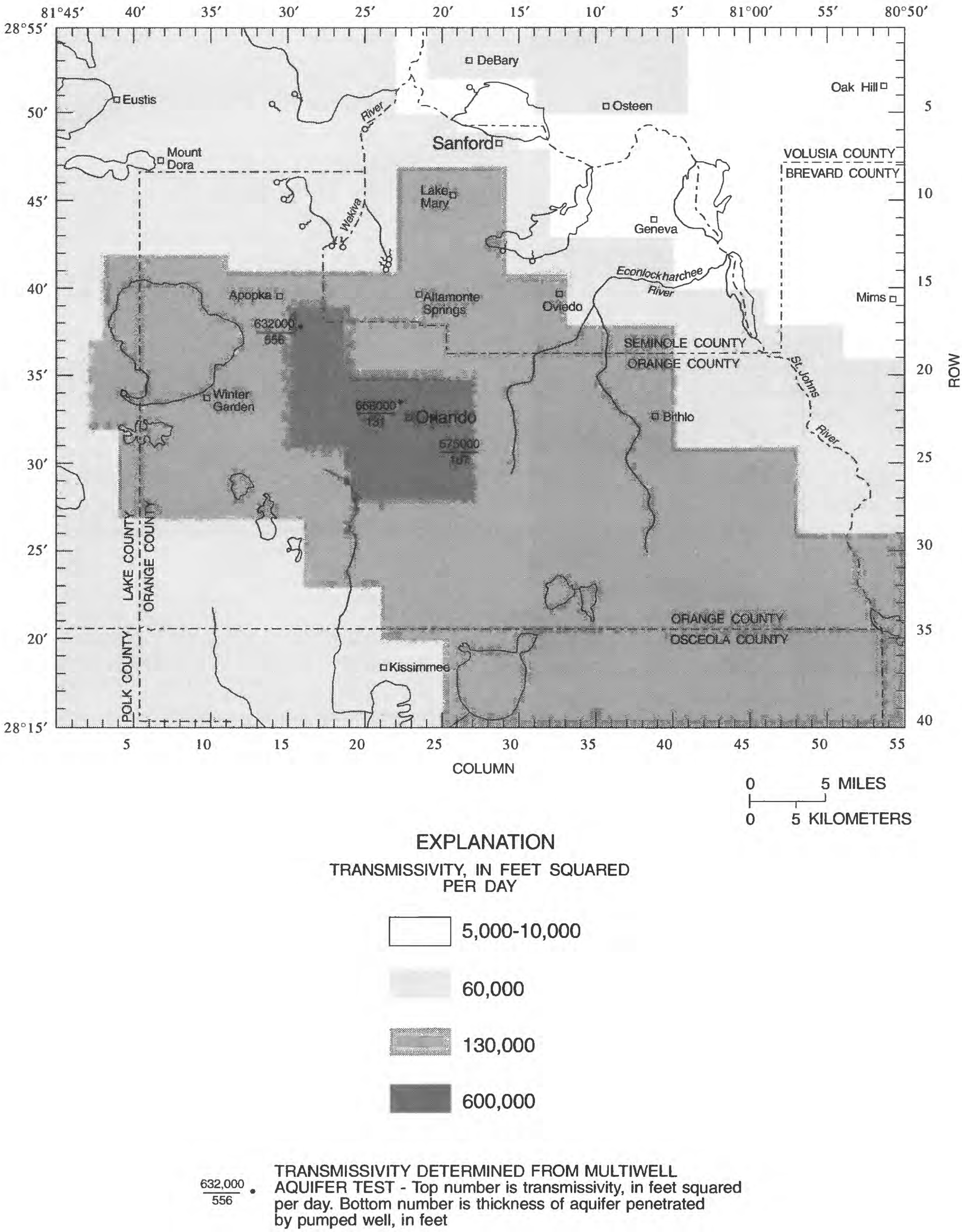


Figure 38. Calibrated transmissivity of the Lower Floridan aquifer and results of selected aquifer tests.

75 percent of the study area. Simulated 1988 recharge rates range from less than 1 to 21 in/yr, with an average of 4.2 in/yr over the study area (fig. 39). Recharge rates were calculated for each model cell by multiplying the calibrated leakance by the difference in head between the surficial and Upper Floridan aquifers. The distribution of recharge and discharge areas shown in figure 39 generally are consistent with those mapped by previous investigators (fig. 7). Highest recharge rates (10-21 in/yr) cover about 16 percent of the study area and occur in east Lake, west Orange, west Seminole, and southwest Volusia Counties. Areas of high recharge (fig. 39) generally correspond with areas of relatively high intermediate confining unit leakance (fig. 35) and are characterized by either karstic topography or a relatively thin intermediate confining unit. Areas with low simulated recharge rates (0-3 in/yr) occur across central Orange, north Osceola, and south Volusia Counties where the water table is closer to land surface and surface runoff and evapotranspiration rates are relatively high.

Lateral recharge to the Upper Floridan aquifer occurs primarily across the west model boundary in Lake County (fig. 39). The highest rates of simulated inflow occur across the west-central part of the boundary, to the west of Lake Apopka and Apopka Spring. Relatively little water moves laterally across the southwest boundary in Polk County, where calibrated transmissivities are relatively low. Simulated outflow rates are highest along the northwest boundary (north of the city of Eustis) and along the north-central boundary (toward Blue Springs, about 2 mi north of the boundary). Water is also discharged across the east model boundary toward the Atlantic Ocean.

Discharge from the Upper Floridan aquifer to the surficial aquifer system and to the St. Johns River system by diffuse upward leakage occurs across 25 percent of the study area. Simulated rates range from 1 to 4 in/yr and occur beneath the St. Johns River and adjacent topographically low areas, downgradient from Upper Floridan aquifer springs and beneath the Wekiva River, beneath Reedy Creek and the western half of Lake Apopka, and in low-lying areas of south Volusia County. Substantially higher discharge rates were simulated beneath the St. Johns River just upstream from and in the southwest part of Lake Harney (24 ft^3/s or 282 in/yr), between Lake Harney and Lake Jesup (11 ft^3/s or 129 in/yr), and at the confluence of the St. Johns and Wekiva Rivers (9 ft^3/s or 106 in/yr, fig. 39). Undocumented Upper Floridan aquifer springs may exist in these areas.

Sensitivity Analyses

A sensitivity analysis was performed to determine the degree to which the calibrated model results are affected by changes in model parameters and aquifer stresses. These parameters include Upper and Lower Floridan aquifer transmissivity, intermediate confining unit leakance, middle semiconfining unit leakance, drain and river conductances, specified GHB heads, and fixed surficial aquifer heads. Tested stresses include drainage-well recharge, agricultural and golf course pumpage, and abandoned flowing-well discharge. The parameters and stresses were varied uniformly, one at a time, over a range judged equal to or greater than the estimated error related to the calibrated parameter or assigned stress. Subsequent changes in the average absolute error computed for the 1988 calibration (1.8 ft) and Upper Floridan aquifer spring flow (306 ft^3/s) were calculated and plotted (fig. 40). Those parameters or stresses that produce the greatest change in calibrated heads or spring flow are better estimated by the model than are parameters or stresses that produce smaller changes. Sensitivity-test results for the aquifer stresses are not plotted in figure 40, but are discussed below.

Simulated Upper Floridan aquifer heads were most sensitive to changes in intermediate confining unit leakance, moderately sensitive to changes in Upper Floridan aquifer transmissivity, and relatively insensitive to changes in river and drain conductances, middle semiconfining unit leakance, and Lower Floridan aquifer transmissivity (fig. 40). Simulated spring flow was highly sensitive to changes in both Upper Floridan aquifer transmissivity and intermediate confining unit leakance, moderately sensitive to drain conductance, and insensitive to river conductance, middle semiconfining unit leakance, and Lower Floridan aquifer transmissivity.

Simulated Upper Floridan aquifer heads and spring flow were moderately sensitive to potential errors in specified surficial aquifer heads (fig. 40). Changes to specified heads of plus or minus 5 ft increased the average absolute error from 1.8 to 4.0 ft and reduced (or increased) spring flow by about 50 ft^3/s. Upper Floridan aquifer heads were most sensitive to changes in surficial aquifer heads where intermediate confining unit leakances are high and head differences between these aquifers are small. Upper

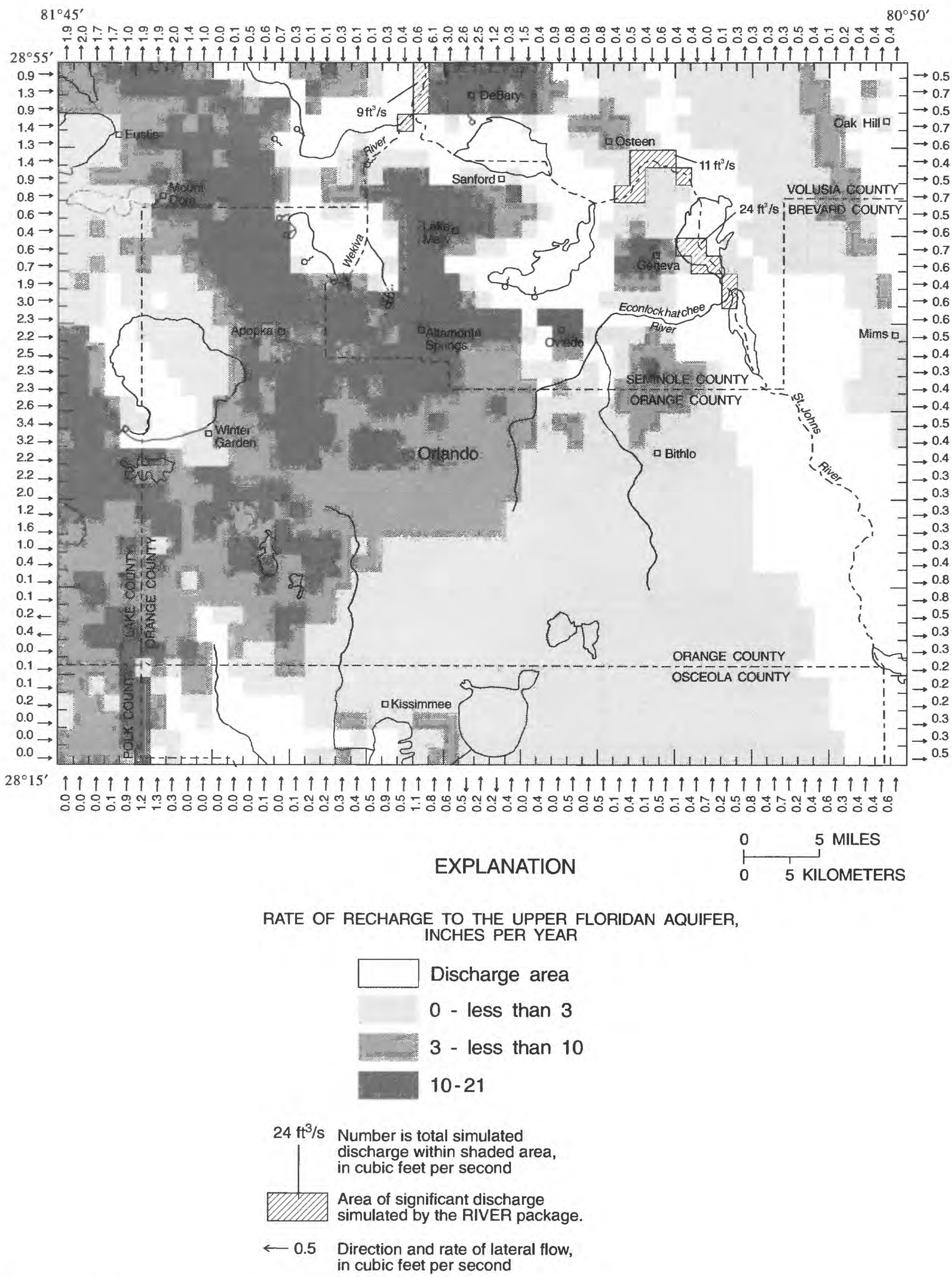


Figure 39. Simulated rates of recharge to and discharge from the Upper Floridan aquifer through the intermediate confining unit and lateral flow to and from the Upper Floridan aquifer across model boundaries, average 1988 steady-state conditions.

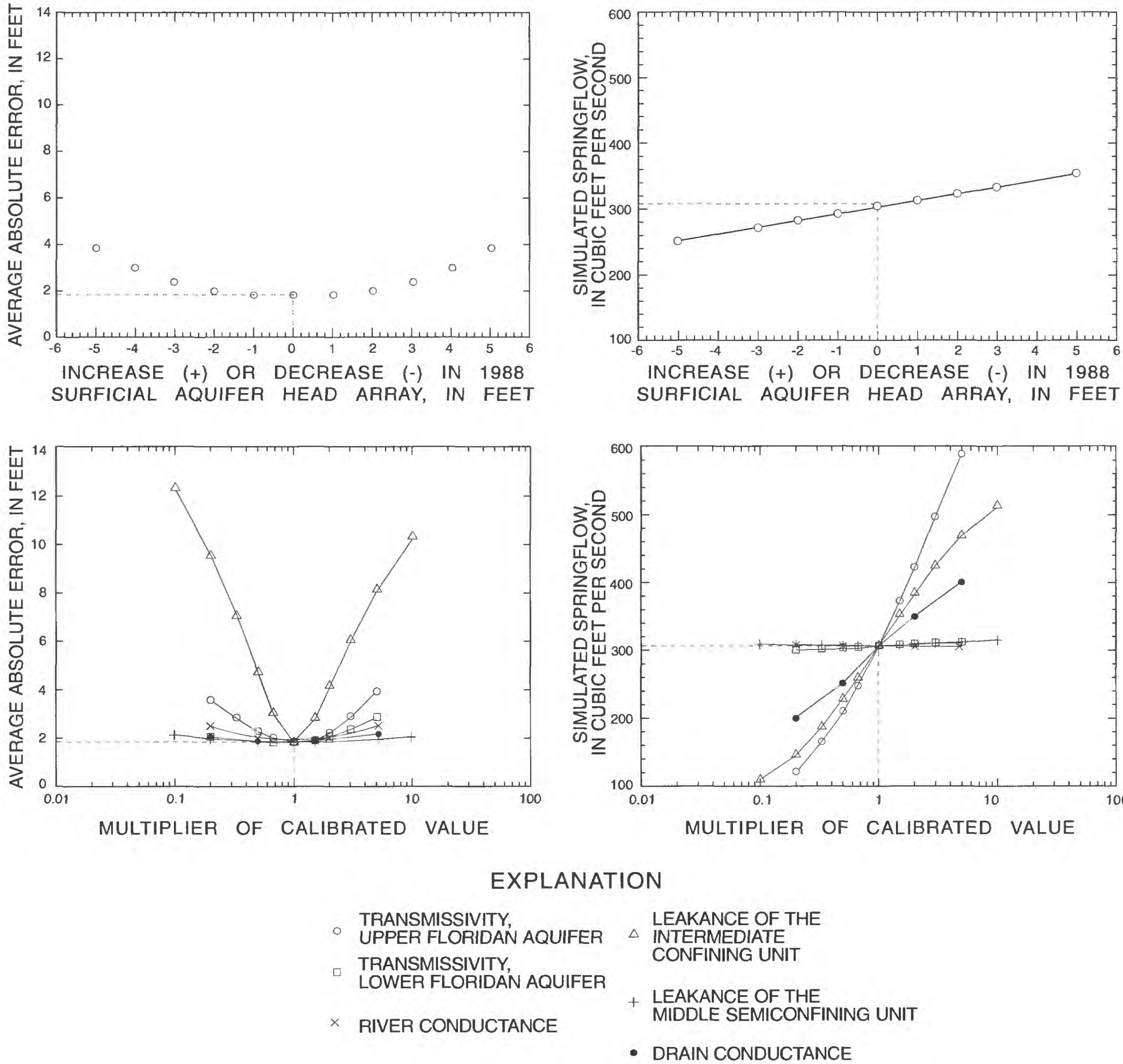


Figure 40. Sensitivity of Upper Floridan aquifer heads and spring flow to variations in calibrated model parameters and in specified surficial aquifer heads.

Floridan aquifer heads were less affected by changes in surficial aquifer heads where the leakances are low and differences in head between the aquifers are large. These results indicate that additional monitoring of surficial aquifer water levels is needed to better predict the response of Upper Floridan aquifer heads to changes in stressed conditions. Additional monitoring is particularly necessary in areas like west Seminole, southwest Volusia, and parts of northwest Orange County where confining unit leakances are high and pumping rates are projected to increase.

Simulated Upper Floridan aquifer heads and spring flow were relatively insensitive to changes in drainage-well recharge. Doubling the applied 1988 recharge rate (to 60 Mgal/d) increased the average absolute error from 1.8 to 2.1 ft and spring flow from 306 to only 314 ft^3/s; reducing the discharge by one-half (to 15 Mgal/d) produced similarly small changes. In a separate simulation, drainage-well recharge was set equal to zero to simulate the effects of plugging all the drainage wells in the study area. Declines in Upper Floridan aquifer heads ranged from

1 to 3 ft in parts of central and north-central Orange County, where drainage wells are most concentrated. The greatest declines in head were simulated at the Lake Underhill and Lake Killarney drainage wells. Cumulative spring flow was reduced by 3 percent (from 306 to 298 ft^3/s) and discharge from the Sanlando Springs group was reduced by 8 percent (from 40 to 37 ft^3/s).

Simulated Upper Floridan aquifer heads were relatively insensitive to changes in agricultural and golf course pumpage and to flowing-well discharge rates. Doubling of agricultural and golf course pumping rates increased the average absolute error from 1.8 to 1.9 ft and decreased simulated spring flow from 306 to 298 ft^3/s. Reducing these withdrawals by one-half increased the average absolute error to 2.0 ft and increased simulated spring flow to 314 ft^3/s. Doubling of flowing-well discharge rates increased the average absolute error to 2.0 ft and reduced simulated spring flow to 304 ft^3/s. Reducing discharge rates by one-half had virtually no effect on the average absolute error and increased simulated spring flow to 307 ft^3/s.

The sensitivity of simulated 1988 heads and spring flow to changes in specified GHB heads was tested by simulating 1988 conditions in which specified 1988 GHB head array was replaced by the predevelopment GHB head array. Predevelopment GHB heads were about 10 ft higher than 1988 GHB heads at the south-central boundary and less than 5 ft higher than 1988 GHB heads at the east, north, and west boundaries. Spring flow was relatively insensitive to these changes, increasing from 306 to 313 ft^3/s. Apparently, the springs are located far enough away from model boundaries to be relatively unaffected by potential errors in specified GHB heads. The average absolute error computed from this simulation increased from 1.8 to 2.7 ft. Water levels simulated in north-central Osceola County were up to 5 ft greater than those simulated by the model using 1988 GHB heads. Water levels in Seminole, east Lake, northeast Polk, west Orange, and in southwest Volusia Counties generally were within 1 ft of those simulated by the model using 1988 GHB heads. Lateral inflow to the Upper Floridan aquifer increased by 45 ft^3/s when predevelopment GHB heads were used in place of 1988 GHB heads to simulate 1988 conditions. This increase is relatively small when compared with the 1988 volumetric budget of 995 ft^3/s (fig. 28). Most of the water discharged by Upper Floridan aquifer wells is not derived from lateral inflow across model boundaries, but from vertical recharge of water from the surficial aquifer system within model boundaries.

Effects of Projected 2010 Ground-Water Withdrawals

The ground-water flow model described in this report reasonably simulates measured historic Upper Floridan aquifer heads and spring flow and the effects of modern-day (1988) ground-water development on the system. The calibrated model can now be used to evaluate the potential effects of projected year 2010 ground-water withdrawals on steady-state Upper Floridan aquifer water levels, spring flow, and areas that contribute recharge to selected springs and well fields.

Projected Water Use

Pumpage from the Floridan aquifer system in 2010 is estimated at 542 Mgal/d (839 ft^3/s), nearly an 80 percent increase from 1988 rates. This increase is attributed soley to additional pumpage from municipal and commercial well fields. Pumping rates for industrial, agricultural, and golf course demands in 2010 were assumed equal to 1988 rates because relatively little growth is anticipated in these demands. Discharge from the aquifer by flowing wells and recharge to the system by drainage wells and by land application of reclaimed water also were assumed constant at 1988 rates.

Pumping rates estimated for municipal and commercial users in 2010 were provided by SJRWMD. Withdrawals from Upper Floridan aquifer well fields were projected to be 366 Mgal/d (567 ft^3/s) compared to 230 Mgal/d pumped in 1988; pumpage from the Lower Floridan aquifer was projected to be 176 Mgal/d (272 ft^3/s), compared to 75 Mgal/d in 1988. Several new well fields are expected to be operating by 2010. The most significant new Upper Floridan aquifer well field is the Orange County eastern regional well field (OCERW), which is projected to withdraw about 20 Mgal/d in 2010 (fig. 41). The estimated distribution of pumpage from the Lower Floridan aquifer in 2010 is shown in figure 42. Projected 2010 pumping rates for municipal, commercial, and industrial users are listed in appendix C.

The simulated results discussed in this section are unique to a particular set of pumping locations and rates. If actual 2010 rates or locations differ from those

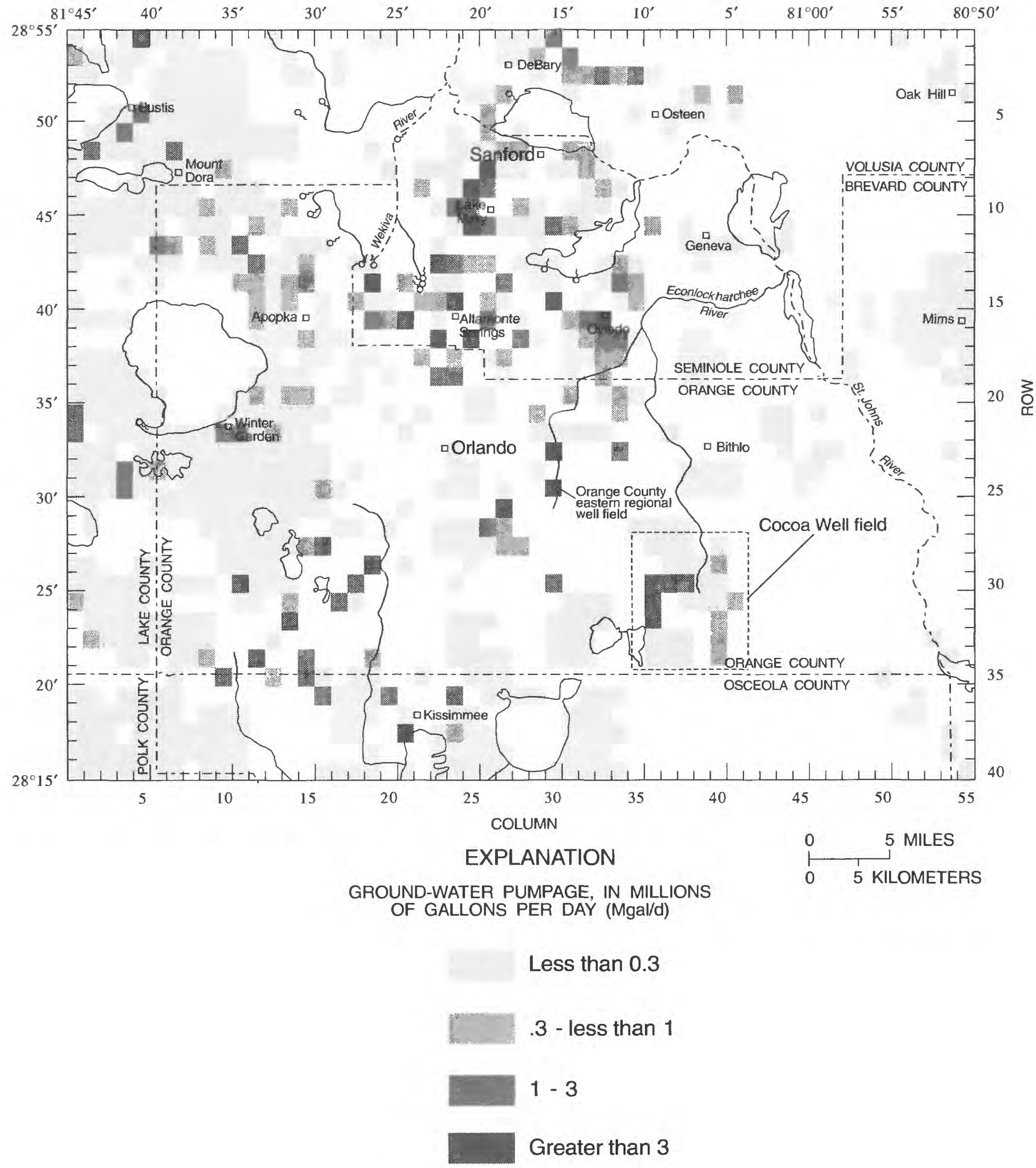


Figure 41. Distribution of projected 2010 Upper Floridan aquifer pumpage and location of new well field.

referenced above, then corresponding simulations would be required to evaluate the respective 2010 conditions.

Projected Boundary Heads

Specified heads assigned at model boundaries for the predevelopment, 1988, and January to May

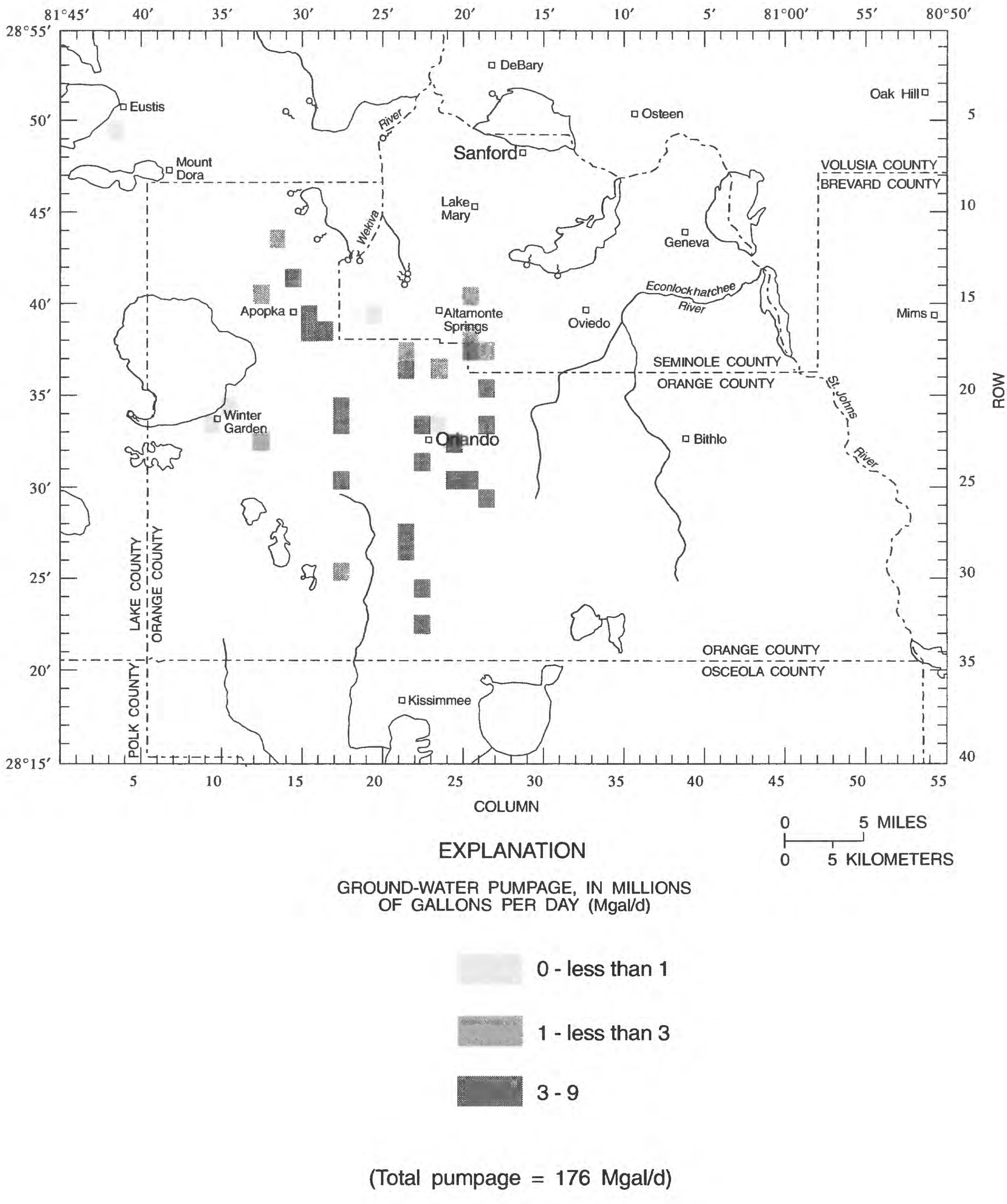


Figure 42. Distribution of projected 2010 Lower Floridan aquifer pumpage.

1990 simulations were estimated from available hydrologic data. For the 2010 simulations, distributed heads at the source/sink array and other fixed-head values are not known but, for the purposes of this study, are assumed to fall within an estimated range of values represented by average 1988 and May 1990 conditions. Under average rainfall conditions, future 2010 surficial aquifer system heads probably would be lower than those used to represent 1988 conditions because of increased 2010 pumpage. However, average 2010 surficial aquifer heads probably would be higher than those observed in May 1990. May 1990 heads were affected by both a 40 percent increase in Floridan aquifer pumpage (as compared to 1988) and an extended period of deficient rainfall. Similarly, actual 2010 fixed spring-pool heads, river heads, and drainage-well recharge rates, under average rainfall conditions, would likely fall somewhere between the values used in respective 1988 and May 1990 arrays. Accordingly, the model was run once with 2010 pumping rates and 1988 fixed-head arrays (representing wet 2010 conditions) and once with 2010 pumping rates and May 1990 fixed-head arrays (representing dry 2010 conditions). Drawdowns and reductions in spring flow projected for wet and dry conditions provide estimates of the range of potential effects of 2010 pumping rates on the Floridan aquifer system under average rainfall conditions.

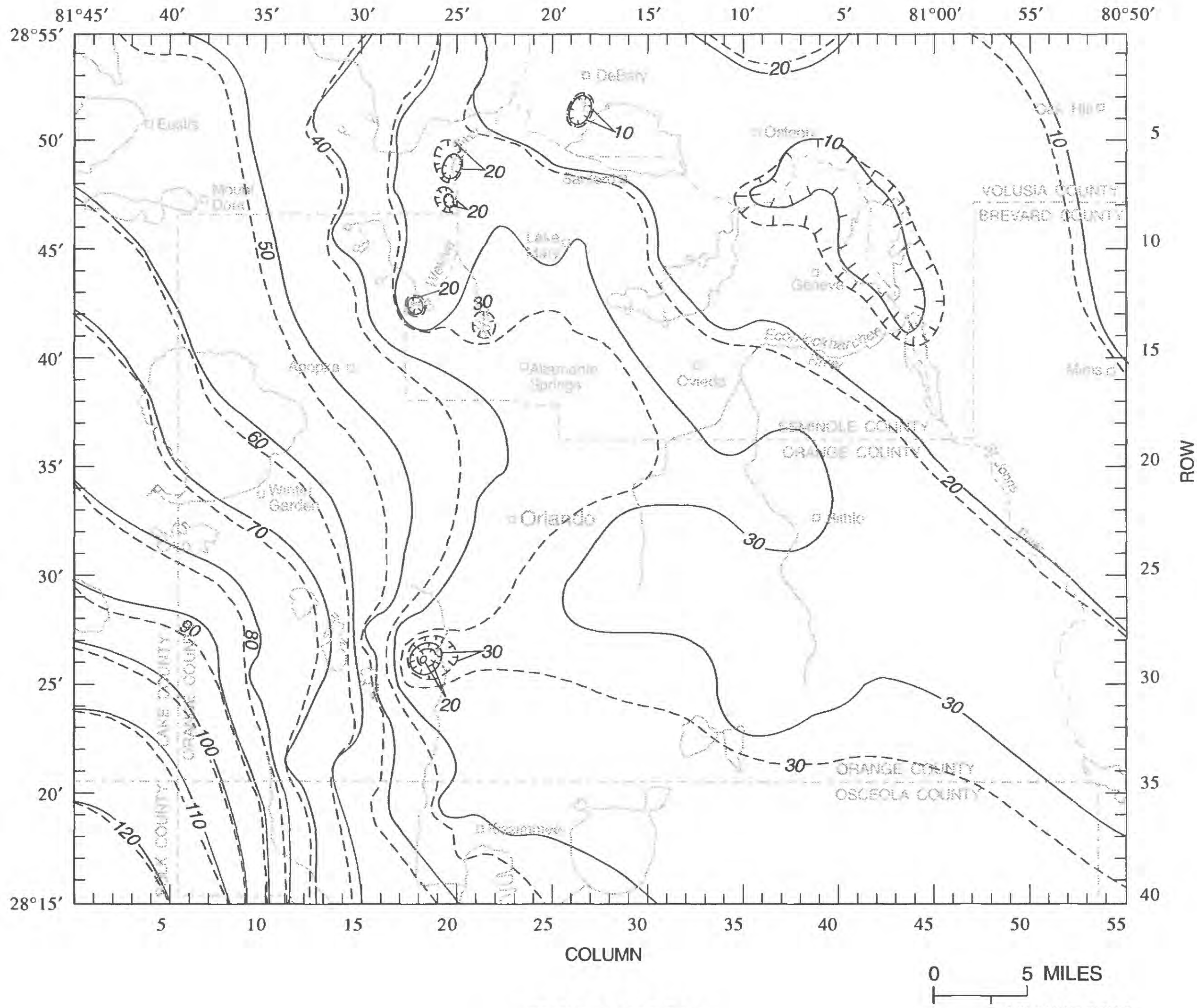
Unlike the previous simulations, the boundary heads specified in the GHB package are unknowns for projected 2010 conditions and could not be interpolated from water-level measurements. Boundary heads in 1988 were lowered by as much as 10 ft from predevelopment levels by 305 Mgal/d of pumpage, and increased 2010 pumpage would be expected to further lower these heads. Instead, the regional RASA model (Tibbals, 1990) was used to estimate the change in specified GHB heads due to increased 2010 pumpage. In doing so, the RASA model was run twice to generate two sets of projected GHB head changes, one each for projected wet and dry conditions. In the first simulation, the differences between 1988 and projected 2010 pumping rates were input to the RASA model. Then the change in heads simulated by the RASA model at locations coincident with the GHB heads in the Orlando model were identified. These "drawdowns" were then subtracted from the 1988 GHB array to produce the GHB array used in the Orlando model for simulating 2010 wet conditions. In the second simulation, differences between May 1990 and 2010 pumping rates were input into the RASA model to simulate drawdowns that were subtracted from the May 1990 GHB array. This resultant GHB array was used in the Orlando model for simulating 2010 dry conditions.

Water Levels and Spring Flow

The steady-state Upper Floridan aquifer potentiometric surfaces simulated for wet and dry conditions in 2010 are shown in figure 43. Compared to the average 1988 surface (fig. 10), the 2010 surfaces are most affected in central and southwest Orange County, where increased Floridan aquifer withdrawals are greatest. Drawdowns in these areas range from 10 to 20 ft, with a local maximum of about 30 ft at the OUC Martin well field (model row 29, column 19) (fig. 44). In Seminole County, projected drawdowns for both wet and dry conditions range from greater than 10 ft in the south-central part of the county to less than 2 ft in the northeast part of the county. Drawdowns of less than 2 ft were simulated in parts of northeast Polk, east Lake, south Volusia, and north Brevard Counties. The differences in drawdown between projected 2010 wet and dry conditions were generally less than 1 ft in these less populated areas, whereas differences of up to 3 ft were simulated in parts of central and southwest Orange County. The larger differences simulated near Orlando are due primarily to differences in applied drainage-well recharge rates. For projected 2010 wet conditions, 30 Mgal/d of recharge were applied, twice the rate applied for projected 2010 dry conditions.

Projected drawdowns in the Upper Floridan aquifer caused by increased Lower Floridan aquifer withdrawals in 2010 ranged from about 4 to greater than 8 ft in central Orange County (fig. 45), where Lower Floridan aquifer pumpage is concentrated (fig. 42). Drawdowns were calculated by subtracting the heads simulated for 2010 wet conditions from the heads simulated in a separate model run in which Lower Floridan aquifer pumping rates were held constant at 1988 levels. The drawdowns contoured in figure 45 are considered gross estimates because model-calibrated values for middle semiconfining unit leakance and Lower Floridan aquifer transmissivity are subject to error. If leakance of the middle semiconfining unit in central Orange County is greater than model-calibrated values, then the maximum drawdown may be greater than that shown in figure 45. If leakances are less than calibrated values, then the maximum drawdown may be less.

Relative to 1988 conditions, simulated spring flow from the Upper Floridan aquifer was reduced by 43 ft^3/s (14 percent) for wet conditions and by 67 ft^3/s (22 percent) for dry conditions (table 9). The largest reduction (32 and 37 percent for wet and dry conditions, respectively) occurred at the Sanlando Springs group, which is located near several large-capacity well fields. Smaller decreases were simulated at Wekiva Springs (13 and 23 percent), Apopka Spring (13 and 22 percent), Rock Springs (12 and 16 percent),



EXPLANATION

POTENTIOMETRIC SURFACE OF UPPER FLORIDAN AQUIFER
Shows altitude of potentiometric surface. Hachures indicate depressions. Contour interval 10 feet. Datum is sea level

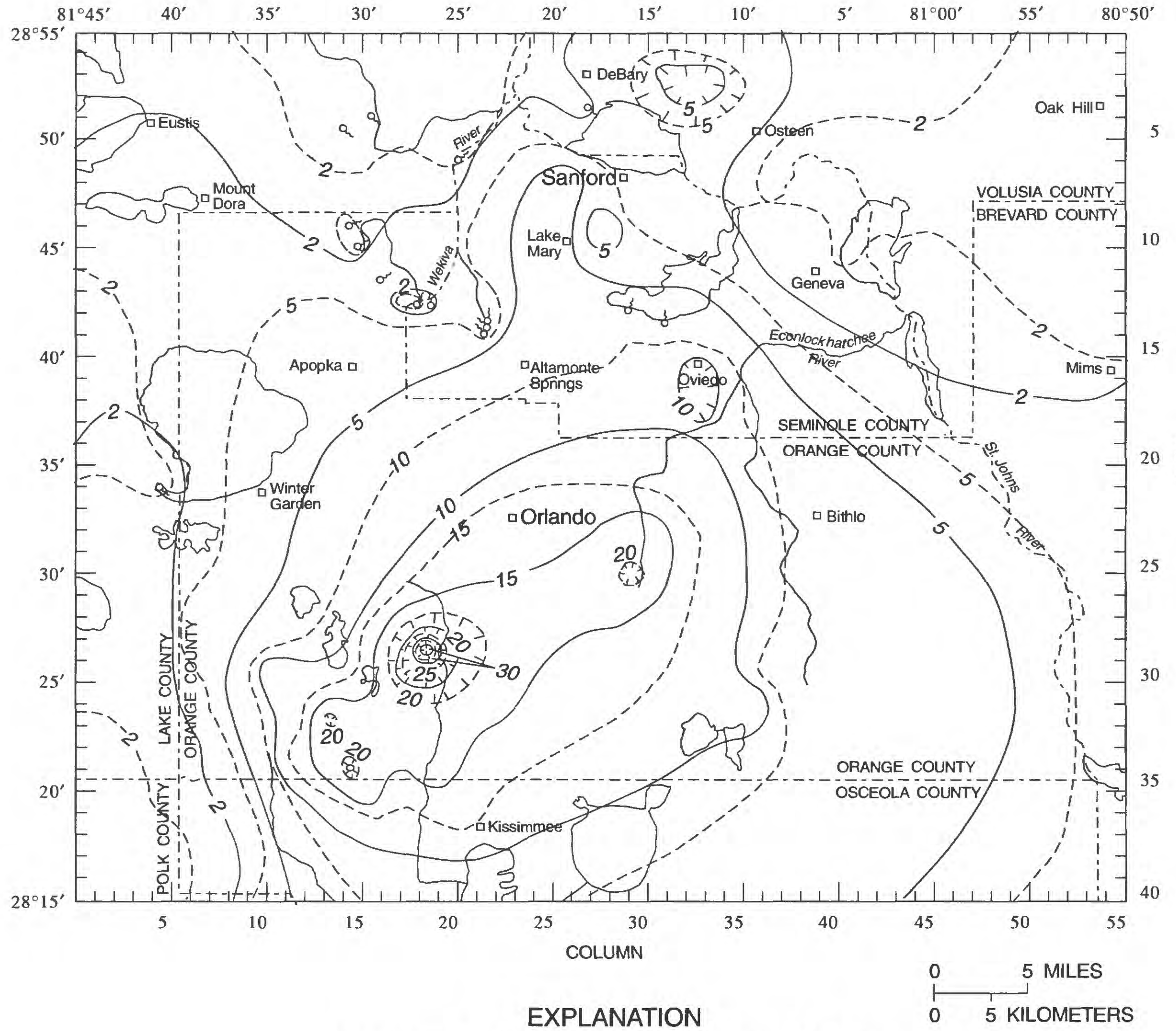
——70—— Derived from computer model simulation of projected 2010 heads, using 1988 surficial aquifer heads (wet conditions)

- - -70- - - Derived from computer model simulation of projected 2010 heads, using May 1990 surficial aquifer heads (dry conditions)

Figure 43. Simulated Upper Floridan aquifer potentiometric surfaces for projected 2010 wet and dry conditions.

Seminole Spring (10 and 24 percent), and Messant Spring (6 and 12 percent). For both 2010 wet and dry conditions, increased pumpage from the Lower Floridan aquifer contributed to about 17 ft^3/s (40 and 25 percent, respectively) of the reduced spring flow.

Simulated hydrologic budgets shown in table 10 document the changes induced by 2010 pumpage on the 1988 ground water-flow conditions in the Floridan aquifer system. Increased pumpage from the Floridan aquifer system in 2010 (366 ft^3/s) is derived primarily



EXPLANATION

DRAWDOWN IN THE UPPER FLORIDAN AQUIFER FROM AVERAGE 1988 CONDITIONS TO THE YEAR 2010
Hachures indicate depressions. Datum is in feet.

——10—— Derived from computer model simulation of projected 2010 drawdowns, using 1988 surficial aquifer heads (wet conditions)

- - -10- - - Derived from computer model simulation of projected 2010 drawdowns, using May 1990 surficial aquifer heads (dry conditions)

Figure 44. Simulated Upper Floridan aquifer drawdowns from 1988 to the year 2010 for projected wet and dry conditions.

from increased rates of surficial aquifer recharge (244 and 218 ft^3/s for wet and dry conditions, respectively); by reduced rates of Upper Floridan aquifer spring flow (43 and 67 ft^3/s), diffuse upward leakage (21 and 20 ft^3/s), and river discharge (9 and 14 ft^3/s); and by increased rates of lateral inflow (39 and 58 ft^3/s). The ultimate source of increased surficial aquifer recharge under long-term average rainfall conditions is captured evapotranspiration and reduced surface runoff.

Relatively high rates of water are discharged from the Upper Floridan aquifer to the Lower Floridan aquifer to compensate for 155 ft^3/s of increased Lower Floridan aquifer pumpage. In 2010, the Lower Floridan aquifer was recharged by the Upper Floridan aqui-

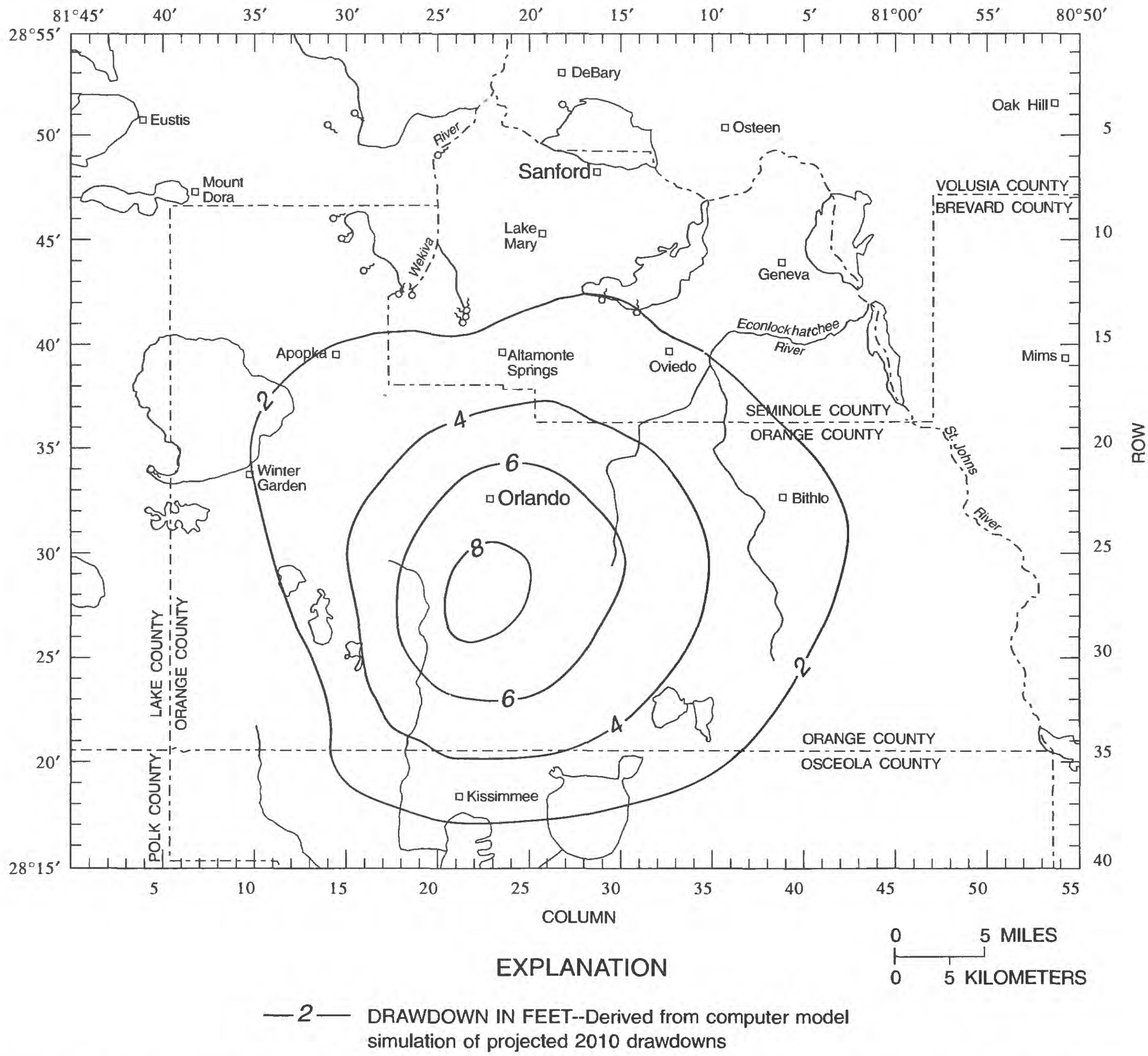


Figure 45. Simulated drawdown in the Upper Floridan aquifer attributed to the increase in Lower Floridan aquifer pumpage from 1988 to 2010 (wet and dry conditions).

fer at a net rate 192 ft^3/s for wet conditions and 177 ft^3/s for dry conditions, or nearly three times the net rate (66 ft^3/s) simulated in 1988. The simulated effects of diverting water from the Upper Floridan aquifer to the Lower Floridan aquifer on Upper Floridan aquifer drawdowns and spring flow have been documented in this section.

Spring and Well-Field Capture Zones

Particle-tracking techniques can be used to delineate the areas of aquifers that contribute recharge to wells and springs, and to define the paths along which injected water moves in an aquifer. MODPATH (Pollock, 1989), a USGS particle-tracking program, commonly is used in these types of analyses and was selected for this study. The program tracks “particles” of water toward or away from specified locations, based on the output from steady-state model simulations. Particle-tracking is based on advective transport and cannot be used to compute solute concentrations in ground water because the method does not account for dispersion, degradation, or retardation processes.

MODPATH was used in this study to delineate 1988 and projected 2010 recharge areas for: (1) eight

Table 9. Simulated discharge from selected Upper Floridan aquifer springs for average 1988 and projected 2010 steady-state wet and dry conditions

[All discharge values in cubic feet per second]

Name of spring	Simulated discharge, 1988 average conditions	Wet conditions[1] Simulated discharge, 2010 steady-state	Wet conditions[1] Percent change, 1988-2010	Dry conditions[2] Simulated discharge, 2010 steady-state	Dry conditions[2] Percent change, 1988-2010
Wekiva	69	61	-13	56	-23
Apopka	62	54	-13	48	-22
Rock	58	51	-12	49	-16
Sanlando, Palm, and Starbuck	40	27	-32	25	-37
Seminole	38	35	-10	29	-24
Messant	16	15	-6	14	-12
Island	7.2	6.6	-8	6.2	-14
Gemini	6.7	5.6	-16	5.0	-25
Miami	4.8	3.9	-19	3.5	-27
Witherington	1.0	0.9	-10	0.8	-20
Clifton	1.5	1.1	-27	1.0	-33
Sulphur	1.1	1.0	-9	0.9	-18
Lake Jesup	0.8	0.7	-12	0.6	-25
TOTAL:	306	263	-14	239	-22

Table 10. Simulated water budgets for the Upper and Lower Floridan aquifers during average 1988 and projected 2010 steady-state wet and dry conditions

[All discharge values in cubic feet per second]

Water budget component		Simulated 1988 steady-state conditions (from fig. 28) (1)	Wet conditions[1] Simulated 2010 steady-state (2)	Wet conditions[1] Change (2) - (1)	Wet conditions[1] Percent change	Dry conditions[2] Simulated 2010 steady-state (3)	Dry conditions[2] Change (3) - (1)	Dry conditions[2] Percent change
Recharge to the Upper Floridan aquifer from:	Surficial aquifer	771	1,015	244	32	989	218	28
	Lateral inflow	79	97	18	23	107	28	35
	Drain well; reclaimed water	75	75	0	0	48	-27	-36
	Lower Floridan aquifer	70	50	-20	-29	52	-18	-26
Discharge from the Upper Floridan aquifer to:	Wells[3]	356	567	211	59	567	211	59
	Springs	306	263	-43	-14	239	-67	-22
	Lower Floridan aquifer	136	242	106	78	229	93	68
	River	78	69	-9	-12	64	-14	-18
	Diffuse upward leakage	64	43	-21	-33	44	-20	-31
	Lateral outflow	55	53	-2	-4	53	-2	-4
Recharge to the Lower Floridan aquifer from:	Upper Floridan aquifer	136	242	106	78	230	94	69
	Lateral inflow	91	112	21	23	121	30	33
Discharge from Lower Floridan aquifer to:	Wells	117	272	155	132	272	155	132
	Upper Floridan aquifer	70	50	-20	-29	52	-18	-26
	Lateral outflow	40	32	-8	-20	27	-13	-33

[1] Simulated with 1988 surficial aquifer head array; 1988 drainage-well recharge distribution; and 1988 specified river and spring-pool heads.

[2] Simulated with May 1990 surficial aquifer head array; May 1990 drainage-well recharge distribution; and May 1990 specified river and spring-pool heads.

[3] Includes discharge from flowing wells at Wekiva Falls Resort.

of the larger Upper Floridan aquifer springs (Messant, Seminole, Rock, Wekiva, Miami, Sanlando, Palm, and Starbuck); (2) the Cocoa well field; and (3) the proposed Orange County Eastern Regional well field (projected 2010 conditions only). MODPATH also was used to show changes caused by 2010 pumpage in the possible routes and destinations of surface water that recharges the Upper Floridan aquifer through the Lake Underhill and Lake Killarney drainage wells.

Recharge areas for selected well fields and springs were delineated by evenly distributing particles about the lateral faces of respective grid cells and then running MODPATH in the backward-tracking mode to delineate the track of simulated ground-water flow paths. Backward-tracked particle pathlines terminate at the source of the spring or well-field water. A total of 10,000 particles was distributed among appropriate cells representing Seminole, Messant, Rock, Wekiva, Miami, and the Sanlando Springs group; and 25,000 particles were distributed among the pumping wells at the Cocoa well field. The number of particles assigned to each spring and pumping well was proportional to its flow rate and sufficient to clearly delineate recharge areas. Because lateral flow was not simulated within the surficial aquifer system, the shaded areas do not include the surficial aquifer system itself but, instead, include the top of the intermediate confining unit. However, differences between recharge areas described in this report and those that would be simulated using an active surficial aquifer system probably are relatively small considering the scale of the model grid and the fact that the hydraulic conductivity of the surficial aquifer system is much smaller than the hydraulic conductivity of the Upper Floridan aquifer.

Areas contributing recharge to the Cocoa well field and the eight Upper Floridan aquifer springs in 1988 are delineated in figure 46. The contributing area shown for the Cocoa well field accounts for about 85 percent of the water discharged at the well field in 1988 and extends across south-central Orange, north-central Osceola and, to a smaller extent, northeast Polk Counties. The remaining 15 percent was contributed from areas in north Osceola and northeast Polk Counties, outside the southern model boundary. Virtually no water is shown to be captured east of the well field where water in the Upper Floridan aquifer is brackish. However, if the aquifer transmissivity east of the well field is appreciably higher than that represented by the model, then a greater potential exists for brackish water to be captured by the eastern-most supply wells. The contributing area delineated in 1988 for the eight springs accounts for about 95 percent of the total spring discharge, covers about 320 mi^2, and extends into northwest Orange, east Lake, and southwest Seminole Counties where water in the Upper Floridan aquifer is fresh. However, it is possible that a relatively small amount of the brackish water that exists downgradient from the springs (figs. 13-15) is being captured and contributes to the gradual increase in dissolved solids concentrations (fig. 17). The grid used for this model is too coarse to simulate accurately the directions and magnitudes of the hydraulic gradients close to the springs and, thus, to draw conclusions about the sources of brackish water.

The contributing areas delineated for the Cocoa well field and Upper Floridan aquifer springs are roughly equal in size, even though the spring discharge rate in 1988 was about six times that of the Cocoa well field. This difference in contributing area per unit of aquifer discharge can be attributed to the differences in Upper Floridan aquifer recharge rates simulated in the respective contributing areas. Recharge rates in south-central Orange County are low (0-3 in/yr, fig. 39), so the contributing area must extend further from the well field to capture enough water to meet the demand. In northwest Orange and east Lake Counties, recharge rates are high (10-21 in/yr) and the capture area required per unit of spring discharge is relatively small.

Increased pumping rates in 2010 reduced the size of the area contributing recharge to the eight springs (fig. 46). As pumping rates increase, the hydraulic gradients between the springs and contributing areas are reduced as water is diverted away from the springs and toward well fields. As a result, spring flow decreases. The 2010 recharge area shown in figure 46 was simulated for wet conditions and was nearly identical to that simulated for dry conditions (not shown). This similarity indicates that the recharge area is more sensitive to changes in ground-water pumpage than to changes in surficial-aquifer head declines, at least for the range of conditions examined in this study.

The proposed OCERW is projected in 2010 to capture water from central Orange County that contributed to the Cocoa well field in 1988 (fig. 47). As a result, the projected Cocoa well field contributing area is displaced to the south and is projected to capture more water from north Osceola County and less water from central Orange County than it did in 1988. About

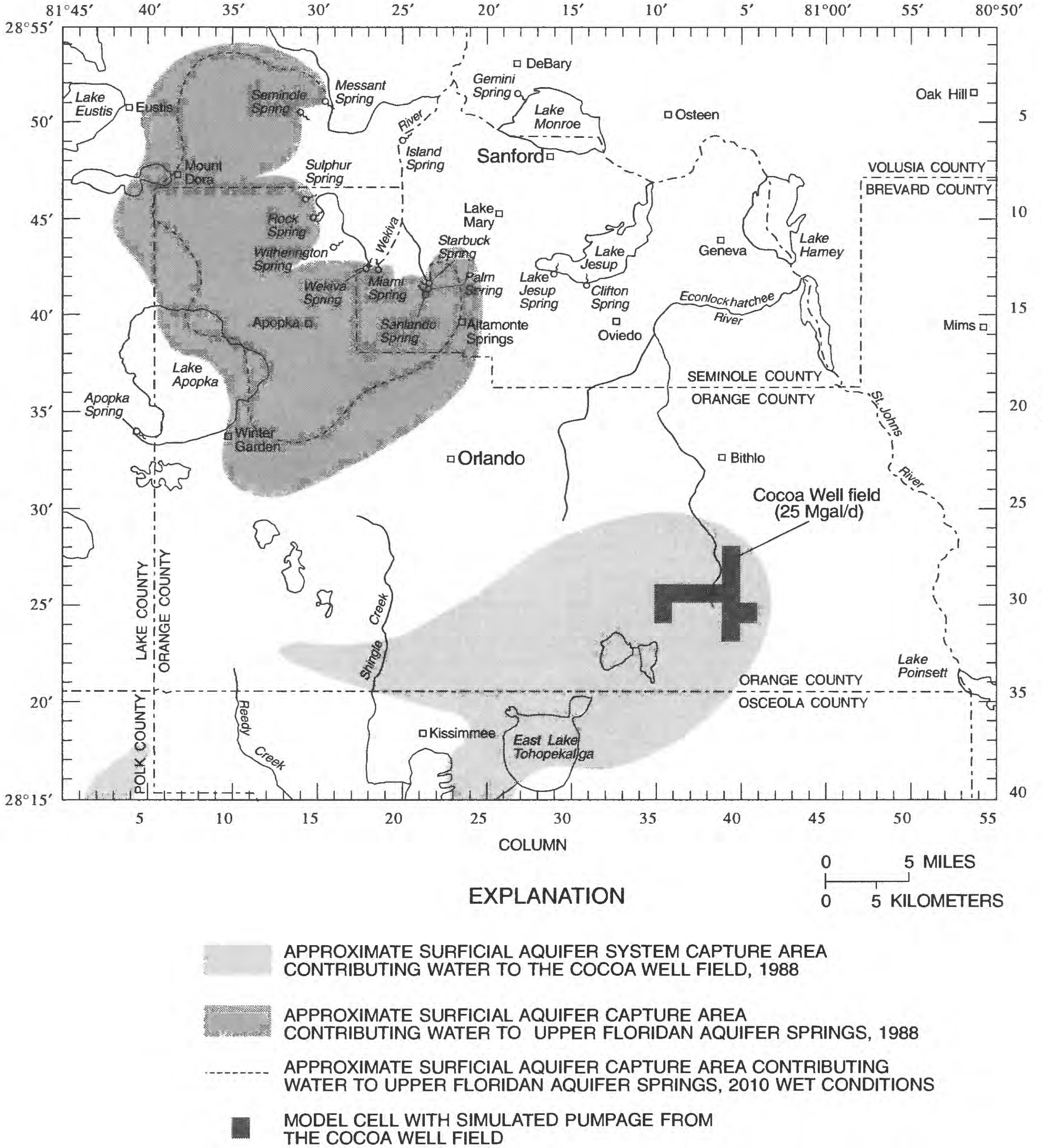


Figure 46. Approximate areas contributing water to the Cocoa well field in 1988 and to Upper Floridan aquifer springs from the base of the surficial aquifer system, average 1988 and projected 2010 wet conditions.

95 percent of the water contributing to the projected discharge rate at the OCERW is captured from the recharge area shown in figure 47. The contributing area depicted for the Cocoa well field accounts for about 65 percent of the projected discharge rate. The remaining 35 percent is captured from areas in Osceola County south of the model boundary. Displacement of the 2010 Cocoa contributing area also may be influenced, to a smaller degree, by a shift in the center of pumpage at the well field to the south and west, by the regional effects of increased pumpage across the study area, and by errors in projected GHB heads. However, several experiments performed with various GHB head changes and distributions along the south-central

boundary all yielded contributing areas of very similar shape and displacement. Contributing areas delineated for both 2010 wet and dry conditions at the Cocoa well field and the OCERW were nearly identical because wet and dry recharge rates in these areas are very similar.

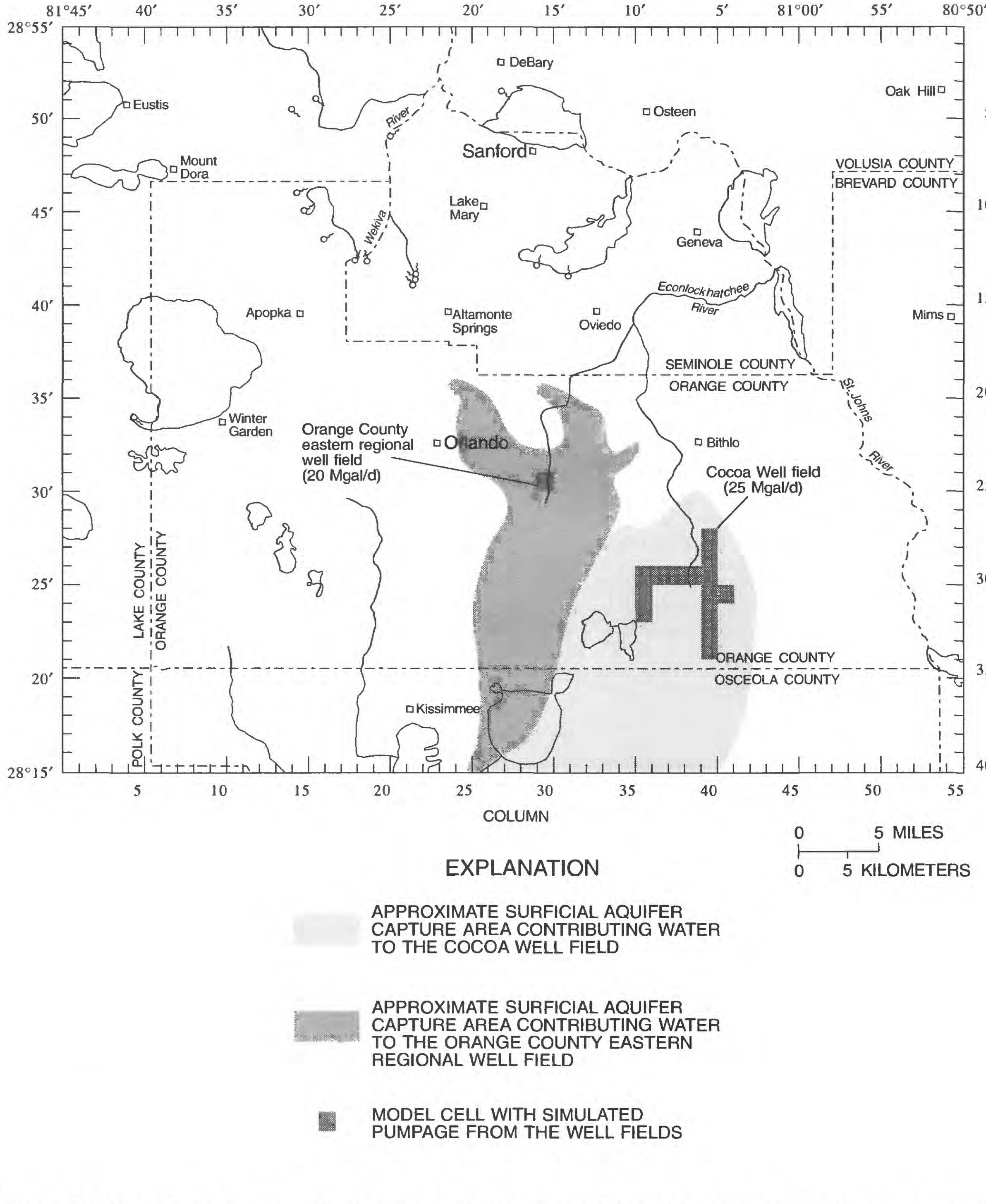


Figure 47. Approximate areas contributing water to the Cocoa well field and the Orange County eastern regional well field from the base of the surficial aquifer system, projected 2010 wet conditions.

Drainage-Well Pathlines

The routes and destinations of surface water that recharges the Upper Floridan aquifer through the Lake Underhill and Lake Killarney drainage wells were determined by analyses of forward-tracked particles. The Lake Killarney and Lake Underhill wells were selected for analysis because of their high capacities, well-documented recharge rates (2.1 and 2.5 Mgal/d, respectively), and their close proximity to several large municipal well fields. Between the two wells, 25,000 particles were apportioned and evenly applied to the four cell faces. The percentage of particles applied to each well that terminates at a given cell and aquifer layer can be used as an estimate of the percentage of drainage-well inflow that is discharged at that particular cell and aquifer layer. Of the inflow (particles) applied to the Lake Killarney and Lake Underhill drainage wells in 1988, about 60 percent (1.5 Mgal/d) and 76 percent (1.6 Mgal/d), respectively, moved toward the northeast and were discharged either to the surficial aquifer system or beneath the St. Johns River in east Seminole County (fig. 48). The remaining 40 percent (1.0 Mgal/d) of inflow to the Lake Killarney well was discharged by the Sanlando Springs group. The remaining 24 percent (0.50 Mgal/d) of inflow to the Lake Underhill well was discharged by an OUC Lower Floridan aquifer well field at model row 23, column 25. The pathlines shown in figure 48 represent a composite of simulated paths in both the Upper and Lower Floridan aquifers.

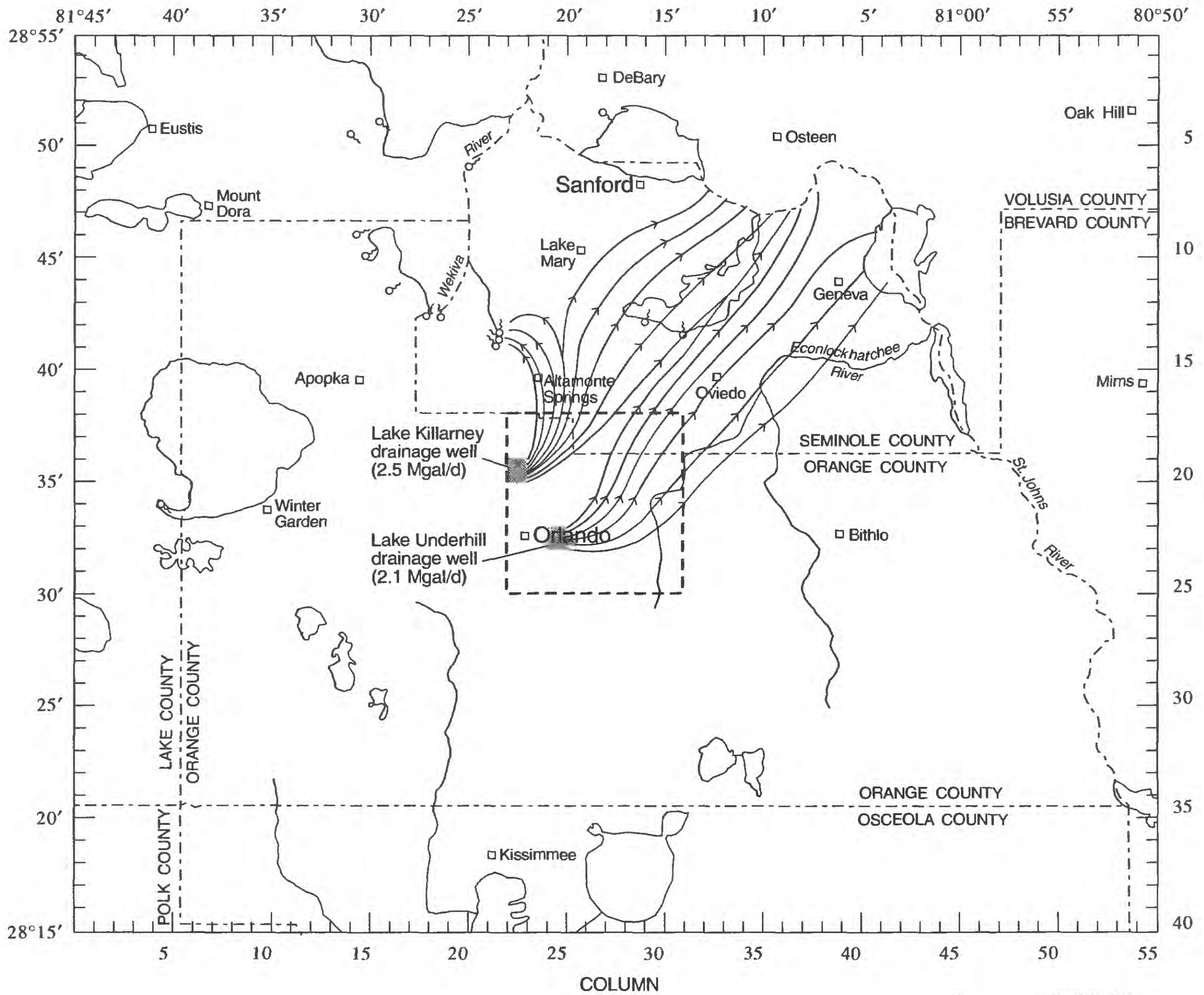
Increased pumpage from the Lower Floridan aquifer in 2010 significantly affected the simulated flow paths and destinations of drainage-well inflow. Under 2010 wet conditions, 100 percent of the inflow applied at these two wells (4.6 Mgal/d) was captured and discharged by well fields in north-central Orange County (fig. 48). Ninety-five percent of the inflow (4.4 Mgal/d) was captured by Lower Floridan aquifer well fields and 5 percent (0.2 Mgal/d) was captured by Upper Floridan aquifer well fields. Individually, 84 percent (about 2.1 Mgal/d) of the inflow to the Lake Killarney drainage well was captured by a Lower Floridan aquifer well field operated by the city of Winter Park (model row 20, column 27); 12 percent (0.3 Mgal/d) was captured by a second Lower Floridan aquifer well field operated by Winter Park (model row 18, column 26); and the remaining 4 percent (0.1 Mgal/d) was captured by an Upper Floridan aquifer well field operated by Orange County (model row 23, column 30). At Lake Underhill, 57 percent (about 1.2 Mgal/d) of the surface-water inflow was captured by the same Lower Floridan aquifer well field in Winter Park that captured most of the inflow from the Lake Killarney well (model row 20, column 27); 38 percent (0.8 Mgal/d) was captured by a Lower Floridan aquifer well field operated by the city of Orlando (model row 26, column 27); and 5 percent (0.1 Mgal/d) was captured in the Upper Floridan aquifer by the proposed OCERW (model row 25, column 30).

The particle-capture percentages referenced above are approximate and depend on the hydrologic assumptions made during the simulations. The percentage of particles discharged to the St. Johns River and surficial aquifer system, for example, represents potential maximum amounts because the particles applied at the drainage wells were allowed to pass through cells where pumpage did not capture all of the flow entering the cell. However, these results suggest that significant increases in pumpage from the Lower Floridan aquifer probably will affect the Upper Floridan aquifer flow system in central Orange County.

Limits of Model Application

Uncertainty and possible error are inherent in the various approaches and methods used to characterize and evaluate ground-water flow systems and may ultimately be reflected in the results of model simulations. The sources of uncertainty most critical to this study are those related to (1) the spatial variation of hydrogeologic characteristics such as transmissivity and leakance; (2) conceptual model development such as defining boundary conditions and the conceptual framework; and (3) knowledge of future states of nature, such as the occurrence of droughts, and future pumpage.

The model described in this report was constructed based on a conceptually simplified flow system. In reality, flow within the Floridan aquifer system is highly complex. Vertical-flow components that exist in the aquifers and lateral-flow components in the confining units were not simulated by the model. Vertical flow within an aquifer indicates that head in the aquifer varies with depth. As a result, heads measured in monitoring wells that penetrate less than the full thickness of the aquifer may not represent the average head computed by the model. Storage changes that occur within confining units and may result in substantial local recharge to the Upper Floridan aquifer were not



EXPLANATION

MODEL CELL WITH SIMULATED RECHARGE TO THE UPPER FLORIDAN AQUIFER FROM INDICATED DRAINAGE WELL

PATHLINE -- delineates ground-water flow path from drainage well for average 1988 conditions

Generalized area within which all drainage-well particles were captured and discharged by Upper and Lower Floridan aquifer municipal-supply wells, steady-state 2010 wet conditions

Figure 48. Simulated pathlines of ground-water flow in the Floridan aquifer system from the Lake Killarney and Lake Underhill drainage wells during average 1988 steady-state conditions, and generalized capture area for particles for projected 2010 wet conditions.

accounted for in the transient simulations. Model results are also based on the assumption that flow in the aquifers can be described by the Darcy equation. This assumption probably is valid for the grid scale used in this model. For smaller grids, however, turbulent conduit or cavernous flow in the aquifer near the springs may violate this assumption.

Comparisons of measured and simulated drawdowns are affected by the proximity of pumping and monitoring wells to one another within the same model cell. Differences increase with the coarseness of the model grid and are more pronounced in areas with steep hydraulic gradients, like those close to the larger springs and municipal-supply wells. Differences between measured and simulated drawdowns may also result from totaling the pumpage from several wells located within the same model cell and assigning the total to pumpage from one well at the center of the cell. In addition, the model does not account for drawdown caused by pumping-well inefficiencies or for partially penetrating pumping wells. Model simulations may underestimate drawdowns at and near these wells. Hydraulic characteristics assigned to each model cell are uniform throughout the cell and represent the average of characteristic values within the cell. These properties are actually spatially heterogeneous and can vary considerably through the 1-mi^2 area represented by a model cell. As a result, two pumping wells located at opposite ends of the same grid cell and pumping at the same rate can produce significantly different drawdowns.

Inaccuracies in assigned stresses and fixed heads also can affect simulated results. Municipal pumping rates used in these simulations were obtained from recorded well-field data and are considered to be reasonably accurate. Estimated agricultural and golf course withdrawals may be in error by as much as 50 percent. Even greater errors may characterize the estimates of drainage-well recharge rates and the abandoned flowing-well discharge rates used in this study. Errors in assigned water-table altitudes would affect model results, particularly in areas of west Seminole and northwest Orange Counties where the intermediate confining unit is thin and ground-water pumpage is substantial. Simulating the surficial aquifer system as an active layer would increase the reliability of predicted drawdowns in the Upper Floridan aquifer, as well as the effects of pumpage on the water table. Future modeling studies that include an active surficial aquifer system will require additional data to better define the configuration of the water table and the thickness and hydraulic properties of the system.

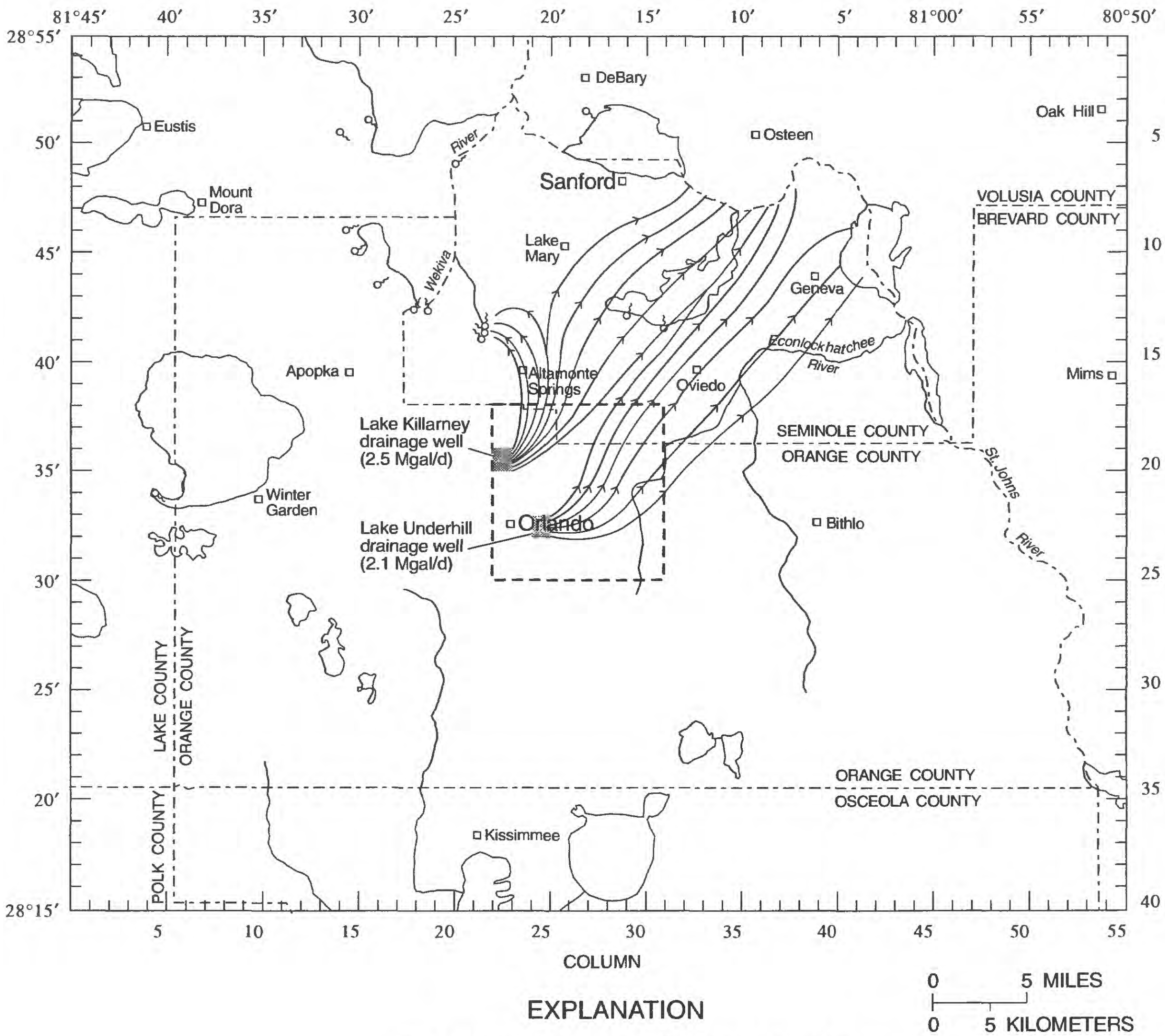
SUMMARY AND CONCLUSIONS

The greater Orlando metropolitan area covers about 2,500 square miles of east-central Florida and includes all of Orange and Seminole Counties and parts of Lake, Volusia, Brevard, Osceola, and Polk Counties. The area is characterized by numerous hydrologic features such as sinkholes, well-drained sandy ridges, swamps, closed-basin lakes, artesian springs, small streams, and the St. Johns River. The population in the study area has increased by more than 50 percent since 1980 and was estimated at about 1.3 million people in 1994.

The hydrogeology of the study area is characterized by a thin, surficial-sand aquifer underlain by the thick, highly productive carbonate rocks of the Floridan aquifer system. The Floridan aquifer system is subdivided into two major permeable zones, the Upper and Lower Floridan aquifers, separated by a less permeable zone, the middle semiconfining unit. The top of the Upper Floridan aquifer dips from about 50 feet above sea level in east Lake County to more than 300 ft below sea level in southeast Orange County. The Upper Floridan aquifer is overlain and confined throughout the study area by the intermediate confining unit, a less permeable and unconsolidated sequence of interbedded sands, silts, and clays. The thickness of the intermediate confining unit ranges from 250 ft in southeast Orange County to less than 50 ft in parts of Polk, Seminole, Lake, and Volusia Counties.

The Upper Floridan aquifer is primarily recharged by leakage from the surficial aquifer system. Smaller amounts of recharge occur by lateral inflow across study-area boundaries and, for developed conditions, by direct recharge from Orlando drainage wells and by the land application of reclaimed water. Primary discharge from the aquifer is by spring flow and, for developed conditions, by pumpage. Smaller quantities of water are discharged through diffuse upward leakage, leakage to the St. Johns River, lateral outflow to the Atlantic Ocean and, for developed conditions, through abandoned flowing wells. Springs identified in the study area include Wekiva, Apopka, Rock, Seminole, Messant, Sanlando, Palm, Starbuck, Gemini, Island, Miami, Witherington, Sulphur, Clifton, and Lake Jesup. These springs collectively discharged nearly as much water in 1988 (306 cubic feet per second (ft^3/s)) as was pumped from the aquifer (356 ft^3/s) for municipal, commercial, industrial, and agricultural purposes.

Ground water in the Upper Floridan aquifer moves regionally from the southwest to the northeast across the study area. Potentiometric-surface altitudes range from greater than 120 ft in north Polk County to less than 10 ft near Lake Harney in east Seminole County. Depressed contours around the St. Johns River in east Seminole County indicate appreciable aquifer discharge, possibly from undocumented springs. Ground-water flow velocities generally are higher in the Upper Floridan aquifer than in the Lower



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Ground water in the Upper Floridan aquifer moves regionally from the southwest to the northeast across the study area. Potentiometric-surface altitudes range from greater than 120 ft in north Polk County to less than 10 ft near Lake Harney in east Seminole County. Depressed contours around the St. Johns River in east Seminole County indicate appreciable aquifer discharge, possibly from undocumented springs. Ground-water flow velocities generally are higher in the Upper Floridan aquifer than in the Lower

Floridan aquifer, particularly in areas of northwest Orange and east Lake Counties where recharge to the Upper Floridan aquifer moves along relatively short flow paths and is captured by springs. Velocities are relatively low in areas of east Seminole County around Lake Harney where hydraulic gradients are small and aquifer transmissivity is low.

Upper Floridan aquifer water levels and spring flow have been affected by extensive ground-water development. Relative to the 1930's, drawdowns induced by 1988 pumpage (305 million gallons per day (Mgal/d) from the Floridan aquifer system) ranged from less than 5 ft in the more rurally populated areas of east Lake, south Volusia, east Seminole, north Brevard, and northeast Polk Counties, to about 10 to 20 ft across central Orange and north Osceola Counties. Spring flow was reduced from about 360 to 306 ft^3/s.

Water in the Floridan aquifer system generally is of a calcium-magnesium bicarbonate type. The chemical quality of water in the Upper Floridan aquifer generally varies with proximity to recharge and discharge areas. Low concentrations of dissolved solids (less than 500 milligrams per liter (mg/L)), chloride (less than 100 mg/L), and sulfate (less than 50 mg/L) generally occur in recharge areas that are infiltrated by fresh rainwater. The most highly mineralized water occurs in discharge areas beneath the St. Johns River where concentrations of dissolved solids, chloride, and sulfate exceed 1,000, 4,000, and 250 mg/L, respectively.

Based on ionic composition, water sampled in May 1993 from 10 Upper Floridan aquifer springs was categorized as one of 3 types. Water from Wekiva, Rock, Sanlando, Palm, Starbuck, Miami, and Witherington Springs is a calcium bicarbonate type water, low in dissolved solids, that results from the dissolution of calcium carbonate (limestone). Water sampled from Seminole and Messant Springs is a more highly mineralized, calcium sulfate type water that results from dissolution of a calcium sulfate aquifer matrix. The sodium chloride type water discharged at Gemini Springs results less from aquifer-matrix dissolution, but more from mixing with entrapped relict seawater or from upwelling of brackish water through fractures.

Water discharged from Upper Floridan aquifer springs has become more mineralized with time. From 1956 to 1993, the specific conductance of water discharged at Wekiva Springs has steadily increased from about 225 to 300 microsiemens per centimeter. The concentrations of dissolved solids, chloride, and sulfate in water sampled in May 1993 at each of the 10 springs all exceeded respective mean concentrations that were calculated from previous sampling events.

The U.S. Geological Survey three-dimensional finite-difference ground-water flow model MODFLOW was used to simulate flow in the Floridan aquifer system within the study area. The uniform model grid consists of 40 rows and 55 columns, with cell dimensions of 5,320 by 6,050 ft. The model was vertically discretized into three layers—the surficial aquifer, the Upper Floridan aquifer, and the Lower Floridan aquifer. The surficial aquifer system was represented by an inactive specified-head array that provides recharge to, and receives discharge from, the Upper Floridan aquifer. The Upper and Lower Floridan aquifers were each represented by a single active layer. Each of the two confining units were represented by an array of variable leakance values. Several MODFLOW packages were used to provide volumetric budgets for different components of the flow system. Pumpage from the aquifer was simulated by the well package; lateral flow across model boundaries by the General-Head Boundary package; discharge from Upper Floridan aquifer springs by the Drain package; discharge from the Upper Floridan aquifer to the St. Johns River system by the River package; and recharge to the aquifer from Orlando drainage wells and reclaimed water by the Recharge package.

The calibrated model simulated the (a) steady-state configuration of the Upper Floridan aquifer potentiometric surface as estimated prior to extensive ground-water development, (b) steady-state water levels measured in 142 Upper Floridan aquifer monitoring wells in 1988 (average absolute error of 1.8 ft), (c) steady-state spring flow measured at 15 Upper Floridan aquifer springs in 1988 (306 ft^3/s simulated and measured), (d) water-level declines measured in the Upper Floridan aquifer from January to May 1990 at 12 monitoring wells equipped with continuous water-level recorders and (e) drawdowns measured in 134 Upper Floridan aquifer monitoring wells between 1988 and May 1990 (58 percent of simulated drawdowns were within plus or minus 25 percent of measured drawdowns).

Relative to predevelopment conditions, about half of the water pumped from the Floridan aquifer system in 1988 (473 ft^3/s) was accounted for by increased recharge from the surficial aquifer system (231 ft^3/s). The balance of pumpage was accounted for by recharge from the Orlando drainage wells and reclaimed water (75 ft^3/s) and by reductions in spring flow (50 ft^3/s), diffuse upward leakage (44 ft^3/s), lateral outflow (32 ft^3/s), and river discharge (18 ft^3/s). A relatively small increase in lateral inflow (23 ft^3/s) was induced by 1988 pumpage. Prior to development, the net flow rate of water exchanged between the Upper and Lower Floridan aquifers was relatively small (about 16 ft^3/s) and flow was upward from the Lower to the Upper Floridan aquifer. The net flow rate increased to 66 ft^3/s in 1988 and flow was from the Upper to the Lower Floridan aquifer. The reversal and increase in the net flow rate can be attributed to the drawdowns induced in the Lower Floridan aquifer by 1988 pumpage and from mounding of the Upper Floridan aquifer potentiometric surface by recharge from the Orlando drainage wells.

A storage coefficient of $1x10^{-3}$ provided the best match of water-level declines measured in the Upper Floridan aquifer between January and May 1990 at the 12 monitoring wells equipped with continuous water-level recorders. This storage value probably accounts for the combined effects of water released from storage in both the Upper Floridan aquifer and the intermediate confining unit. The high transmissivity and low storativity of the Floridan aquifer system result in a large diffusivity (transmissivity divided by the storage coefficient), suggesting that the system can be expected to equilibrate rapidly to changes in stress. Discharge simulated at Wekiva, Rock, Sanlando, Palm, Starbuck, Seminole, Messant, and Miami Springs in May 1990 totaled 184 ft^3/s compared to the measured total of 176 ft^3/s. It is possible that declines in surficial aquifer heads, estimated largely from lake-level data, were underestimated for the transient period. Also, pumpage from nursery farms concentrated in northwest Orange and east Lake Counties may have been underestimated. Finally, rural-domestic pumpage was not included in the model.

Calibrated transmissivity values ranged from 10,000 to greater than 400,000 feet squared per day (ft^2/d) for the Upper Floridan aquifer, and from 5,000 to 600,000 ft^2/d for the Lower Floridan aquifer. Calibrated values for a given area usually exceeded transmissivities determined by aquifer tests. Lowest Upper Floridan aquifer transmissivities occur in northeast Polk County and in discharge areas beneath the St.Johns River and Reedy Creek. Highest calibrated transmissivities occur in northwest, central, and east Orange County and in east-central Lake County.

Transmissivity of the Lower Floridan aquifer is less well known, but smallest calibrated values occur in north and east Seminole, north Brevard, and southwest Volusia Counties where the freshwater-saltwater interface is nearer the top of the aquifer. The highest calibrated transmissivity occurs in central Orange County, where aquifer-test analyses have yielded similarly high values. Calibrated intermediate confining unit leakance values ranged from $1x10^{-5}/d$ to $4x10^{-3}/d$ and were consistently lower than values yielded from aquifer tests. Leakance values are highest in northeast Polk, east Lake, and parts of west Orange, west Seminole, and southwest Volusia Counties. The confining unit in these areas is thin or riddled with sinkholes. Lowest leakance values occur in southeast Orange and northeast Osceola Counties where the confining unit is thickest. A leakance value of $5x10^{-5}/d$ was specified for the middle semiconfining unit across most of the study area.

Recharge from the surficial aquifer system to the Upper Floridan aquifer occurs over about 75 percent of the study area. Simulated recharge rates in 1988 ranged from less than 1 to about 21 inches per year (in/yr), with an average of 4.2 in/yr over the study area. Recharge rates of 10 in/yr or greater occur over about 16 percent of the study area, including parts of east Lake, west Orange, west Seminole, and southwest Volusia Counties. These areas are characterized by either karstic topography or by a relatively thin intermediate confining unit. Low rates of recharge (less than 3 in/yr) occur across central Orange, north Osceola, and south Volusia Counties where the intermediate confining unit is thick or where the water table is relatively close to land surface (increasing losses to evapotranspiration). Discharge from the Upper Floridan aquifer to the surficial aquifer system by diffuse upward leakage was simulated beneath the St. Johns River and adjacent low-lying areas, downgradient from Upper Floridan aquifer springs and beneath the Wekiva River, beneath Reedy Creek and the western half of Lake Apopka, and in low-lying areas of south Volusia County. Simulated discharge rates typically ranged from 1 to 4 in/yr, but were substantially higher in areas beneath the St. Johns River just upstream from and in the southwest part of Lake Harney (24 ft^3/s or 282 in/yr), between Lake Harney and Lake Jesup (11 ft^3/s or 129 in/yr), and at the confluence of the St. Johns and Wekiva Rivers (9 ft^3/s or 106 in/yr). Undocumented Upper Floridan aquifer springs may exist in these areas.

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APPENDIXES

Appendix A. Index to wells used in this study

[Aquifer codes: s, surficial aquifer; u, Upper Floridan aquifer; m. middle semiconfining unit; l, Lower Floridan aquifer; um, Upper Floridan aquifer and middle semiconfining unit; uml, Upper Floridan Aquifer, middle semiconfining unit, and Lower Floridan aquifer. Source of data: B, Barraclough (1961); J, Jammal & Associates (1990); LCES, Lake County Environmental Services; PBS&J, Post, Buckley, Schuh, and Jernigan (1989); S, Stringfield, (1936); SJRWMD, St. Johns River Water Management District; U, Unklesbay (1944); USEO, U.S. Engineers Office (1946); USGS, U.S. Geological Survey; YES, Yovaish Engineering Sciences (1994). ---, no data. Well depths and cased depths are referenced to land-surface datum]

Model row	Model column	Identification number	Local name and/or other well identification number	Total depth (feet)	Cased depth (feet)	Aquifer code	Source of data
40	6	281511081393101	815-139-342 USGS well	447	358	u	USGS
40	11	281532081345001	Loughman deep well	247	85	u	USGS
40	19	281559081260701	Shingle Creek well at SR 531A	200	---	u	USGS
39	43	281630081024401	TH-9 Nova Rd 532 West	405	228	u	USGS
39	46	281630080591001	TH-3 Lake Poinsett SW	377	245	u	USGS
39	54	281632080515001	DSR-38 Lake Poinsett	253	---	u	USGS
38	51	281722080543001	OS-171 shallow well nr Deer Park	19	13	s	USGS
38	32	281719081134001	South Eagle Road E. Narcoossee	480	245	u	USGS
38	36	281714081093001	[1]Lake Joel well	750	394	u	USGS
38	20	Well #3		---	---	u	U
37	51	281820080540501	K6-Tilt Lake Poinsett SW	603	108	u	USGS
36	17	281931081280301	KOA Campground well nr Kissimmee	378	---	u	USGS
36	21	281937081245901	819-124-01 Kissimmee well	1,200	280	uml	USGS
35	27	282051081183401	USGS well at Boggy Creek Road	400	199	u	USGS
34	5	282126081403901	Lake County well 821-140-01	---	---	u	USGS
34	9	282145081365601	Britt Groves trailer park	---	---	u	USGS
34	21	282141081241701	USGS well-US441 at phone relay	435	317	u	USGS
33	1	2822410814439	SJRWMD L-0050 Sand mine shallow	35	25	s	SJRWMD
33	7	282202081384601	[1]Lake Oliver deep well	318	103	u	USGS
33	7	282202081384602	Lake Oliver shallow well	38	---	s	USGS
33	21	Orange 63		300	---	u	S
33	23	Orange 64		300	---	u	S
33	34	282241081112801	USGS well at Moss Park	460	240	u	USGS
33	34	282241081112802	USGS shallow well at Moss Park	---	---	s	USGS
33	54	282204080514301	USGS 822-051-001 SR520	553	---	u	USGS
33	10	282210081352601	Disney shallow well at Tree Farm	18	18	s	USGS
32	8	282331081370801	USGS well at Hartzog Road	166	68	u	USGS
32	14	282354081313001	RCID observation well # 1	281	145	u	USGS
32	40	282344081054201	Cocoa # 11	580	323	u	USGS
32	41	282341081040101	[1]Cocoa A	516	301	u	USGS
32	49	282348080564701	82305601 24S34E18 442 Palmetto	390	244	u	USGS
31	16	Orange 62		484	---	u	S
31	17	282434081283101	[1]USGS well at I-4 and Sea World Dr	235	158	u	USGS
31	19	282434081260301	USGS well at Shingle Creek	203	131	u	USGS
31	40	282416081054101	Cocoa #4	524	252	u	USGS
30	7	282543081385801	82513801; Hickory Nut Lake well	---	---	u	USGS
30	11	282528081340901	[1]Bay Lake deep well	223	104	u	USGS
30	15	282556081302404	Dr. Phillips deep well	230	50	u	USGS
30	21	282545081240901	825-124-01; Turnpike Orlando South 30	450	212	u	USGS
30	36	282530081094001	Cocoa #17	600	252	u	USGS
30	37	282531081082201	Cocoa #14	761	252	u	USGS
30	38	282529081073201	Cocoa #7A	710	237	u	USGS
30	40	282548081054201	Cocoa # 3	496	266	u	USGS
30	40	282530081054201	Cocoa #7	490	285	u	USGS
30	40	282510081054502	Cocoa-M nr Bithlo	10	10	s	USGS
30	40	282510081054501	Cocoa 1 nr Bithlo	710	316	u	USGS
30	37	282533081082202	Cocoa C (zone 1) monitor well	1,357	1,351	l	USGS
30	37	28253308108220	Cocoa C (zone 5) aquifer well	1,004	248	u	USGS
29	3	282633081425601	Bradshaw Windmill	---	---	u	USGS

Appendix A. Index to wells used in this study--Continued

[Aquifer codes: s, surficial aquifer; u, Upper Floridan aquifer; m, middle semiconfining unit; l, Lower Floridan aquifer; um, Upper Floridan aquifer and middle semiconfining unit; uml, Upper Floridan Aquifer, middle semiconfining unit, and Lower Floridan aquifer. Source of data: B, Barraclough (1961); J, Jammal & Associates (1990); LCES, Lake County Environmental Services; PBS&J, Post, Buckley, Schuh, and Jernigan (1989); S, Stringfield, (1936); SJRWMD, St. Johns River Water Management District; U, Unklesbay (1944); USEO, U.S. Engineers Office (1946); USGS, U.S. Geological Survey; YES, Yovaish Engineering Sciences (1994). ---, no data. Well depths and cased depths are referenced to land-surface datum]

Model row	Model column	Identification number	Local name and/or other well identification number	Total depth (feet)	Cased depth (feet)	Aquifer code	Source of data
29	13	282611081320501	82613201; USGS well on Sunset Dr	180	95	u	USGS
29	30	282623081153801	[1]Cocoa P	439	245	u	USGS
29	40	283632081054501	Cocoa # 8	640	255	u	USGS
29	40	282650081054201	Cocoa #9	525	230	u	USGS
28	17	282709081283001	USGS well nr I-4 and SR528A	205	68	u	USGS
28	1	282729081443301	Lake Louisa State Park well	85	---	u	USGS
28	11	282738081341401	USGS well at Lake Sawyer	178	103	u	USGS
28	14	282749081315801	82713101LK; Butler Groves supply	347	120	u	USGS
28	22	Orange 37		375	272	u	S
28	40	282739081054501	Cocoa F	375	200	u	USGS
28	40	282716081054501	Cocoa #10	506	229	u	USGS
27	16	282835081305201	USGS well Palm Lake Dr	235	161	u	USGS
27	44	282847081013701	Cocoa-H nr Bithlo	495	252	u	USGS
27	44	282847081013702	Cocoa-K nr Bithlo	8	8	s	USGS
27	48	282838080572401	Turkey Camp	---	---	u	USGS
27	51	282848080544501	Tosohatchee Game Preserve	335	152	u	USGS
11	280	282936081340201	32913405; Ross home well Lk Butler 26	180	u		USGS
26	17	282923081282801	Iveys Nursery at Turkey Lake Rd	337	168	u	USGS
26	20	282945081255001	829-125-01; Orange 39 on I-4	168	---	u	USGS
26	21	282911081243601	Americana Apts at Texas Ave	---	---	u	USGS
26	30		Orange Cnty eastern regional LFEW				J
25	6	283017081391301	Davenport Road 4-inch well	---	---	u	USGS
25	9	283011081360002	West Orange Country Club well	260	100	u	USGS
25	20	Orange 44		463	105	u	S
25	26	283017081195201	83011901; Lk Margaret & Conway Rd	427	169	u	USGS
25	27	Orange 46		422	137	u	S
24	1	283116081442301	76 Pot Map well	---	---	u	USGS
24	5	283128081404701	Johns Lake well nr Clermont	155	--	u	USGS
24	14	283121081311601	O-197 Lake Olivia drain well	498	344	u	USGS
24	20	283144081254201	831-125-04; Lake Mann drain well	400	137	u	USGS
24	22	283135081234301	831-123-19; Layne-Atlantic deep	460	145	u	USGS
24	23	283105081222201	831-122-03; Delaney & Harding Str	438	153	u	USGS
24	24	Orange 52		435	113	u	S
23	17	283253081283401	[1]OR-47 well at Orlo Vista	350	328	u	USGS
23	17	283253081283404	OR-47B replacement well at Orlo	35	33	s	USGS
23	25	283219081195701	Lake Underhill drain well	399	270	u	USGS
23	28	Well #242		--	--	u	U
23	40	283249081053201	[1]Bithlo-1 at Bithlo	492	151	u	USGS
23	40	283249081053203	Bithlo-3 at Bithlo	15	12	s	USGS
23	46	Orange 66		200	--	u	S
23	47	283214080583501	83205801; DOT East HWY50	200	---	u	USGS
23	52	283236080535101	Old SR50 well	247	---	u	USGS
22	2	283307081435301	76 Pot Map; Jacks Lake well	---	---	u	USGS
22	4	2833530814117	SJRWMD L-0044	---	---	s	SJRWMD
22	4	283359081411501	833-141-01; Well FDAWPC	132	107	u	USGS
22	5	2833330814028	SJRWMD L-0276	45	40	s	SJRWMD
22	8	2833490813715	SJRWMD OR0085	---	---	s	SJRWMD
22	8	283325081374001	833-137-03; City of Oakland #2	370	148	u	USGS
22	12	Orange 61		500	--	u	S
22	15	283307081300801	833-130-01; Lk Sherwood drain well 22	450	118	u	USGS

Appendix A. Index to wells used in this study--Continued

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Model row	Model column	Identification number	Local name and/or other well identification number	Total depth (feet)	Cased depth (feet)	Aquifer code	Source of data
22	19	283326081262101	833-126-02; Lake Lawne drain well	109	84	u	USGS
22	20	Orange 48		123	75	u	S
22	22	283333081233501	Lake Adair deep well	1,281	601	ml	USGS
22	22	283333081233502	[1]Lake Adair shallow well	400	105	u	USGS
22	39	Orange 65		211	205	u	S
21	20	Orange 51		199	100	u	S
21	26	283436081194501	Lake Speir drain well	---	---	u	USGS
20	5	283540081402401	77 Pot Map	180	---	u	USGS
20	11	283524081344701	835-134-01; Lake Apopka test well	202	133	u	USGS
20	22	283528081235201	835-123-02; Lk Fairview drain well 20	745	176	um	USGS
20	23	283548081224601	Lake Killarney drain well	400	200	u	USGS
20	24	283530081214301	835-121-07; Lk Midget drain well	372	170	u	USGS
19	54	283627080512001	Champion Rd well at Titusville	136	132	u	USGS
19	12	Orange 57		465	--	u	S
19	17	283655081283401	Long Lake drain well	301	144	u	USGS
19	19	283654081260801	836-126-04; Lk Davis drain well	365	250	u	USGS
19	48	283644080574901	Silver Lake Hatbill Park well	247	---	u	USGS
18	16		Orange Cnty western regional WF TP-2	1,455	1,040		PBS&J
18	26	283717081194202	837-119-04; W C Phillips well	290	85	u	USGS
18	30	283754081154301	837-115-02; R O Woods well	131	---	u	USGS
18	55	2837320805059	SJRWMD BR0584 Astronaut High	40	32	s	SJRWMD
18	42	283740081031401	C S Lee well #879 nr pumphouse	273	84	u	USGS
17	12	2838020813301	SJRWMD OR0086	27	25	s	SJRWMD
17	13	283813081325701	83813204; State Foliage Research	1,200	---	--	USGS
17	18	283849081273401	838-127-02; Ecolog Utility well	105	---	u	USGS
17	23	283816081225501	Lake Charity well nr Maitland	374	325	u	USGS
17	32	Seminole 14		126	---	u	S
17	38	283843081075501	838-107-06; W H Green well	107	95	u	USGS
16	25	283958081203401	840-120-02	101	---	u	USGS
16	32	839-113-01		200	100	u	B
16	34	---	City of Oviedo LFTW	1,290	1,230		YES
16	38	283945081071901	83910702 21S32E16 411 C Brown	190	---	u	USGS
16	41	283956081040201	839-104-02; Yardborough well	71	---	u	USGS
16	49	283955080565701	PB Plastic well	97	---	u	USGS
16	54	283906080514501	Parrish & Holder Rds Titusville	137	---	u	USGS
15	15	284025081301701	84013002; Apopka drain well	423	124	u	USGS
15	19	284012081264601	840-126-03; C Benton Inc well	---	---	u	USGS
15	21	284023081241001	840-124-04; USGS well	140	---	u	USGS
15	33	284025081123001	84011201 21S31E10 313	282	85	u	USGS
15	33	Seminole 4		225	80	u	S
15	35	Seminole 12		125	80	u	S
15	37	840-108-01		105	70	u	B
14	4	284129081414201	77 Pot Map	69	---	u	USGS
14	23	284147081220201	[1]Seminole 125 at Longwood	158	63	u	USGS
14	30	284120081152201	841-115-01; Ed Bouillon well	185	---	u	USGS
14	32	284125081131701	841-113-01; Curtis Mann well	90	80	u	USGS
14	32	Seminole 10		100	---	u	S
14	33	Seminole 5		100	---	u	S
14	34	841-111-01		---	---	u	B
14	36	Seminole 11		103	---	u	S

Appendix A. Index to wells used in this study--Continued

[Aquifer codes: s, surficial aquifer; u, Upper Floridan aquifer; m, middle semiconfining unit; l, Lower Floridan aquifer; um, Upper Floridan aquifer and middle semiconfining unit; uml, Upper Floridan Aquifer, middle semiconfining unit, and Lower Floridan aquifer. Source of data: B, Barraclough (1961); J, Jammal & Associates (1990); LCES, Lake County Environmental Services; PBS&J, Post, Buckley, Schuh, and Jernigan (1989); S, Stringfield, (1936); SJRWMD, St. Johns River Water Management District; U, Unklesbay (1944); USEO, U.S. Engineers Office (1946); USGS, U.S. Geological Survey; YES, Yovaish Engineering Sciences (1994). ---, no data. Well depths and cased depths are referenced to land-surface datum]

Model row	Model column	Identification number	Local name and/or other well identification number	Total depth (feet)	Cased depth (feet)	Aquifer code	Source of data
13	18	284234081273901	84212702; Wekiva State Park well	---	---	u	USGS
13	22	284244081234901	842-123-02; Quartel well	118	---	u	USGS
13	28	284207081174401	842-117-03; Neely well	90	---	u	USGS
13	33	Seminole 6		100	70	u	S
13	38	284247081070801	[1]Geneva S-0001	204	95	u	USGS
13	38	284247081070802	Geneva S-0002	50	45	s	USGS
13	43	284217081023001	Kilbee #3 test well nr Geneva	154	58	u	USGS
12	9	284330081360501	84313603; Jewell Foliage well	403	127	u	USGS
12	17	284326081283601	Mill Creek cabin	200	---	u	USGS
12	24	284317081213401	Gilbert Principe	---	---	u	USGS
12	26	Seminole 1		100	---	u	S
12	27	843-118-02		104	80	u	B
12	36	284325081092702	Cochran Forest shallow well	37	---	s	USGS
12	42	284331081031001	84310302 20S33E30 241 Pecor	117	---	u	USGS
11	9	284453081365101	Sadler Road nr Lake Ola	325	---	u	USGS
11	17	284453081284401	84412801; Wekiva Park fireplace	40(?)	--	u	USGS
11	28	284440081175901	844-117-22; Seminole County well	250	75	u	USGS
11	28	844-117-02		67	61	u	B
11	29	844-116-01		150	88	u	B
11	30	284428081155201	Largent well Sanford Ave.	---	---	u	USGS
11	30	844-115-08		122	91	u	B
11	31	844-114-01		150	100	u	B
11	38	284428081072602	USGS Avenue C deep zone at Geneva	393	388	u	USGS
11	40	284434081050101	844-105-03; Lake Harney well	60	---	u	USGS
10	1	Astatula 3A		---	--	s	LCES
10	15	284529081301001	84513001; Rock Springs deep well	365	143	u	USGS
10	25	284533081204801	845-120-05; The Forest well	471	97	u	USGS
10	27	845-118-01		135	96	u	B
10	32	845-113-01		145	100	u	B
10	38	284550081071501	845-107-03; Cameron Brothers well	126	77	u	USGS
9	26	284651081193301	846-119-02; Southward Fort well	69	---	u	USGS
9	29	846-116-11		104	---	u	B
9	30	284645081152401	846-115-15; U S Navy well	185	108	u	USGS
9	36	284618081095401	846-109-02; W H Wight well	63	---	u	USGS
9	40	284626081051801	Osceola Road test well nr Geneva	200	83	u	USGS
8	13	284728081322201	Central Florida Academy well	400	63	u	USGS
8	32	284750081132301	Seminole 257 nr Sanford	206	---	u	USGS
8	33	Well#478		---	---	u	USEO
8	38	284706081070801	847-107-03; S C Thrasher well	178	99	u	USGS
8	40	2847150810518	SJRWMD S-0201	25	15	s	SJRWMD
8	41	284712081044301	847-104-01; Seminole County well	141	70	u	USGS
8	53	284743080520101	W L Cantrell well	197	---	u	USGS
7	2	Lake 8		185	---	u	S
7	2	284808081432801	Tavares well	417	226	u	USGS
7	5	284827081403501	848-140-01; D Bartholow well	271	192	u	USGS
7	20	284826081254601	848-125-02; S Hardin well	400	200	u	USGS
7	21	284802081242101	Via Hermosa well	---	---	u	USGS
7	24	284802081211101	Hartstock Wilson Ave. well	147	81	u	USGS
7	26	284802081192701	Jordan Baptist well Upsala Rd	120	70	u	USGS
7	26	848-119-04		168	90	u	B

Appendix A. Index to wells used in this study--Continued

[Aquifer codes: s, surficial aquifer; u, Upper Floridan aquifer; m, middle semiconfining unit; l, Lower Floridan aquifer; um, Upper Floridan aquifer and middle semiconfining unit; uml, Upper Floridan Aquifer, middle semiconfining unit, and Lower Floridan aquifer. Source of data: B, Barraclough (1961); J, Jammal & Associates (1990); LCES, Lake County Environmental Services; PBS&J, Post, Buckley, Schuh, and Jernigan (1989); S, Stringfield, (1936); SJRWMD, St. Johns River Water Management District; U, Unklesbay (1944); USEO, U.S. Engineers Office (1946); USGS, U.S. Geological Survey; YES, Yovaish Engineering Sciences (1994). ---, no data. Well depths and cased depths are referenced to land-surface datum]

Model row	Model column	Identification number	Local name and/or other well identification number	Total depth (feet)	Cased depth (feet)	Aquifer code	Source of data
7	29	848-116-02		150	125	u	B
7	30	Seminole 24		100	---	u	S
6	10	284917081353701	849-135-01; Rickey & Reed well	---	---	u	USGS
6	21	284945081244201	849-124-07; C Fernandez well	41	---	u	USGS
6	25	284954081201101	Anderson well Missouri Street	228	128	u	USGS
6	26	849-119-03		120	100	u	B
6	27	849-118-05		200	144	u	B
6	34	284902081112001	849-111-01; B R Beck well	---	---	u	USGS
5	24	285002081215101	Cain well	---	---	u	USGS
5	26	285040081192101	Stewart well S of DeBary	143	140	u	USGS
5	36	285044081094901	Osteen convenience store well	220	---	u	USGS
5	39	285045081063501	850-106-03; Turner Farms well	280	---	u	USGS
5	39	2850310810623	SJRWMD V-0166 Winston Took farm	35	25	s	SJRWMD
5	54	285016081014101	850101; Cow Creek well nr Maytown	107	102	u	USGS
4	5	Lake 10		180	---	u	S
4	26	285156081190302	851-119-02; Florida Power well	---	---	u	USGS
4	53	285143080521401	Loomis Nursery W of Oak Hill	120	---	u	USGS
3	2	285257081434201	J. Eichelburger well	297	108	u	USGS
3	36	285221081095002	852-109-01; USGS well	92	74	u	USGS
2	11	285318081340601	Sand mine well	350	---	u	USGS
2	29	285359081161701	Deltona Corp Diamond St Deltona	250	76	u	USGS
1	7	285426081380901	A B Marshall well	125	---	u	USGS
1	27	2854420811814	SJRWMD V-0197 Orange City tower	30	20	s	SJRWMD
1	27	285437081181401	SJRWMD test well nr Orange City	230	---	u	USGS
1	41	2854190810410	SJRWMD V-0199 Lake Ashby shallow	86	86	u	SJRWMD
1	50	285452080551801	N. of Volco Road near Ariel	148	---	u	USGS

[1] Well with continuous hydrograph record.

Appendix B. Names and locations of lakes and streams used in this study

[USGS, U.S. Geological Survey; SEMCO, Seminole County; OCPUD, Orange County Public Utilities Department; do., same; ---, no data]

Model row	Model column	Local name or number	Source of water-level data	USGS identification number
1	1	Lake Yale	USGS	02238200
1	2	do.	do.	do.
2	1	do.	do.	do.
2	2	do.	do.	do.
2	3	do.	do.	do.
3	3	do.	do.	do.
3	16	Blackwater Creek near Cassia	do.	02235200
4	1	Lake Eustis	do.	02237900
4	2	do.	do.	do.
4	3	do.	do.	do.
4	4	do.	do.	do.
5	1	do.	do.	do.
5	2	do.	do.	do.
5	3	do.	do.	do.
6	1	do.	do.	do.
6	2	do.	do.	do.
7	1	do.	do.	do.
4	28	Lake Monroe	do.	02234499
4	29	do.	do.	do.
4	30	do.	do.	do.
5	27	do.	do.	do.
5	28	do.	do.	do.
5	29	do.	do.	do.
5	30	do.	do.	do.
5	31	do.	do.	do.
6	27	do.	do.	do.
6	28	do.	do.	do.
6	29	do.	do.	do.
6	30	do.	do.	do.
6	31	do.	do.	do.
6	32	do.	do.	do.
7	29	do.	do.	do.
7	30	do.	do.	do.
7	31	do.	do.	do.
7	32	do.	do.	do.
6	5	West Crooked Lake	do.	02237753
7	14	Mt. Plymouth Lake	do.	02235260
7	20	Wekiva River near Sanford	do.	02235000
7	22	Lake Sylvan	SEMCO	---
7	23	do.	do.	---
8	23	do.	do.	---
8	2	Lake Dora	USGS	02237800
8	3	do.	do.	do.
8	4	do.	do.	do.
8	5	do.	do.	do.
8	6	do.	do.	do.
9	2	do.	do.	do.
9	3	do.	do.	do.
9	4	do.	do.	do.
9	5	do.	do.	do.

Appendix B. Names and locations of lakes and streams used in this study--Continued

[USGS, U.S. Geological Survey; SEMCO, Seminole County; OCPUD, Orange County Public Utilities Department; do., same; ---, no data]

Model row	Model column	Local name or number	Source of water-level data	USGS identification number
9	23	Island Lake	SEMCO	---
9	35	Lake Jessup	USGS	02234434
10	34	do.	do.	do.
10	35	do.	do.	do.
11	33	do.	do.	do.
11	34	do.	do.	do.
11	35	do.	do.	do.
12	32	do.	do.	do.
12	33	do.	do.	do.
12	34	do.	do.	do.
13	29	do.	do.	do.
13	30	do.	do.	do.
13	31	do.	do.	do.
13	32	do.	do.	do.
13	33	do.	do.	do.
10	7	Lake Ola	OCPUD	---
10	8	do.	do.	---
11	22	Lake Linden	SEMCO	---
11	26	Lake Mary	USGS/SEMCO	02234414
11	27	do.	do.	do.
12	4	Apopka-Beauclaire canal	USGS	02237700
12	23	Lake Myrtle	SEMCO	---
12	24	do.	do.	---
12	27	Soldier Creek near Longwood	USGS	02234384
13	16	Lake Prevatt	OCPUD	---
13	24	West Lake	SEMCO	---
13	28	Gee Creek near Longwood	USGS	02234400
13	43	St. Johns River above Lake Harney	USGS	02234000
12	42	do.	do.	do.
12	43	do.	do.	do.
11	41	do.	do.	do.
11	42	do.	do.	do.
11	43	do.	do.	do.
10	41	do.	do.	do.
10	42	do.	do.	do.
10	43	do.	do.	do.
9	42	do.	do.	do.
9	43	do.	do.	do.
14	16	Lake McCoy	OCPUD	---
14	20	Lake Brantley	USGS/SEMCO	02234638
14	23	11th-hole pond	do.	---
15	14	Lake Marshall	OCPUD	---
15	19	Mirror Lake	SEMCO	---
15	34	Lake Charm	USGS	02234428
15	39	Econlockhatchee River near Chuluota	USGS	02233500
15	6	Lake Apopka	USGS	02237600
15	7	do.	do.	do.
15	8	do.	do.	do.
15	9	do.	do.	do.
16	5	do.	do.	do.

Appendix B. Names and locations of lakes and streams used in this study--Continued

[USGS, U.S. Geological Survey; SEMCO, Seminole County; OCPUD, Orange County Public Utilities Department; do., same; ---, no data]

Model row	Model column	Local name or number	Source of water-level data	USGS identification number
16	6	do.	do.	do.
16	7	do.	do.	do.
16	8	do.	do.	do.
16	9	do.	do.	do.
16	10	do.	do.	do.
17	4	do.	do.	do.
17	5	do.	do.	do.
17	6	do.	do.	do.
17	7	do.	do.	do.
17	8	do.	do.	do.
17	9	Lake Apopka	USGS	02237600
17	10	do.	do.	do.
17	11	do.	do.	do.
18	4	do.	do.	do.
18	5	do.	do.	do.
18	6	do.	do.	do.
18	7	do.	do.	do.
18	8	do.	do.	do.
18	9	do.	do.	do.
18	10	do.	do.	do.
18	11	do.	do.	do.
18	12	do.	do.	do.
19	5	do.	do.	do.
19	6	do.	do.	do.
19	7	do.	do.	do.
19	8	do.	do.	do.
19	9	do.	do.	do.
19	10	do.	do.	do.
19	11	do.	do.	do.
19	12	do.	do.	do.
20	6	do.	do.	do.
20	7	do.	do.	do.
20	8	do.	do.	do.
20	9	do.	do.	do.
20	10	do.	do.	do.
20	11	do.	do.	do.
21	7	do.	do.	do.
21	8	do.	do.	do.
21	9	do.	do.	do.
21	10	do.	do.	do.
22	5	do.	do.	do.
22	6	do.	do.	do.
22	7	do.	do.	do.
22	8	do.	do.	do.
22	9	do.	do.	do.
16	18	Bear Lake	USGS/SEMCO	02234942
16	19	do.	do.	do.
17	18	do.	do.	do.
17	19	do.	do.	do.
16	22	Crane's Roost	SEMCO	---

Appendix B. Names and locations of lakes and streams used in this study--Continued

[USGS, U.S. Geological Survey; SEMCO, Seminole County; OCPUD, Orange County Public Utilities Department; do., same; ---, no data]

Model row	Model column	Local name or number	Source of water-level data	USGS identification number
16	23	Lake Oreinta	USGS/SEMCO	02234943
17	20	Lake Bosse	OCPUD	---
17	26	Lake Howell	SEMCO	---
17	27	do.	do.	---
17	28	do.	do.	---
17	30	Howell Creek near Slavia	USGS	02234324
17	38	Lake Catherine	SEMCO	---
18	18	Long Lake	OCPUD	---
18	19	Lake Lockhart	do.	---
18	23	Lake Sybelia	do.	---
18	24	Lake Maitland	USGS/OCPUD	02234300
18	25	do.	OCPUD	---
19	24	do.	do.	---
19	25	do.	do.	---
18	26	Howell Branch Creek	SEMCO	---
18	29	Bear Gully Lake	do.	---
19	20	Lake Wekiva near Maitland	USGS	02234814
19	23	Park & Gem	OCPUD	---
19	29	Lake Wannata	do.	---
20	20	Bay Lake	do.	---
20	21	Lake Fairview	do.	---
20	24	Lake Virginia	do.	---
20	25	Lake Mizell	do.	---
20	35	Lake Price	do.	---
21	22	Lake Silver	do.	---
21	23	Lake Formosa	do.	---
21	24	Lake Sue	do.	---
21	26	Lake Baldwin	do.	---
22	15	Lake Lotta	do.	---
22	16	Lake Sherwood	do.	---
23	16	do.	do.	---
22	22	Spring Lake (NOBT)	do.	---
22	26	Lake Savannah	do.	---
22	27	Lake Barton	do.	---
23	15	Lake Rose	do.	---
23	20	Lake Mann	do.	---
24	20	do.	do,	---
23	25	Lake Underhill	do.	---
23	49	St. Johns River near Christmas	USGS	02232500
24	5	Johns Lake	do.	02237540
24	6	do.	do.	do.
24	7	do.	do.	do.
24	9	Black Lake	OCPUD	---
24	21	Clear Lake	do.	---
24	30	Little Econ near Union Park	USGS	02236820
25	7	Lake Avalon	OCPUD	---
25	12	Crescent Lake	do.	---
25	21	Lake Tyler	do.	---
26	1	Lake Louisa	USGS	02236820
26	2	do.	do.	do.

Appendix B. Names and locations of lakes and streams used in this study--Continued

[USGS, U.S. Geological Survey; SEMCO, Seminole County; OCPUD, Orange County Public Utilities Department; do., same; ---, no data]

Model row	Model column	Local name or number	Source of water-level data	USGS identification number
27	1	do.	do.	do.
27	2	do.	do.	do.
28	1	do.	do.	do.
28	2	do.	do.	do.
26	5	Flat Lake	OCPUD	---
26	12	Lake Butler	USGS	02263900
26	13	do.	do.	do.
27	12	do.	do.	do.
27	13	do.	do.	do.
26	14	Lake Down	OCPUD	---
26	17	Lake Cain	do.	---
26	23	Lake Jennie Jewell	do.	---
26	25	Lake Anderson	do.	---
27	9	Lake Speer	do.	---
27	10	do.	do.	---
27	16	Palm Lake	do.	---
27	17	Lake Marsha	do.	---
27	22	Lake Jessamine	do.	---
27	23	Lake Mary Jess	do.	---
27	24	Lake Conway	USGS	02262800
28	3	Trout Lake	do.	02266239
28	7	Lake Ingram	OCPUD	---
28	9	Lake Hancock	do.	---
28	14	Lake Tibet	do.	---
28	15	do.	do.	---
28	16	Spring Lake	do.	---
28	17	do.	do.	---
28	23	Bearhead Lake	do.	---
29	1	Big Creek near Clermont	USGS	02236500
29	5	Sawgrass Lake	OCPUD	---
30	5	do.	do.	---
30	6	do.	do.	---
29	6	Lake Needham	do.	---
29	9	Lake Huckleberry	do.	---
30	6	Hickory Nut Lake	do.	---
30	7	do.	do.	---
30	16	Big Sand Lake	do.	---
31	16	do.	do.	---
30	39	Econlockhatchee River at Magnolia Ranch	USGS	02233001
31	9	Reedy Creek at SR46	do.	02266025
31	12	Bay Lake	do.	02263850
31	15	Fish Lake	OCPUD	---
32	8	Whittenhorse Creek near Vineland	USGS	02266200
32	14	Cypress Creek at Vineland	do.	02264000
32	33	Lake Mary Jane/Lake Hart	do.	02261900
33	33	do.	do.	do.
33	34	do.	do.	do.
33	35	do.	do.	do.
34	35	do.	do.	do.
33	27	Boggy Creek near Taft	do.	02262900

Appendix B. Names and locations of lakes and streams used in this study--Continued

[USGS, U.S. Geological Survey; SEMCO, Seminole County; OCPUD, Orange County Public Utilities Department; do., same; ---, no data]

Model row	Model column	Local name or number	Source of water-level data	USGS identification number
33	53	St. Johns River near Cocoa	do.	02232400
34	54	Lake Poinsett	do.	02232300
35	54	do.	do.	do.
35	55	do.	do.	do.
36	11	Reedy Creek near Vineland	do.	02266300
36	14	Bonnett Creek near Vineland	do.	02264100
37	4	Green Swamp run near Eva	do.	02236350
37	18	Shingle Creek at airport	do.	0263800
38	21	Lake Tohopekaliga	USGS	02264495
38	22	do.	do.	do.
38	23	do.	do.	do.
39	21	do.	do.	do.
39	22	do.	do.	do.
39	23	do.	do.	do.
40	21	do.	do.	do.
40	22	do.	do.	do.
40	23	do.	do.	do.
39	10	Davenport Creek near Loughman	do.	02266480
39	13	Reedy Creek at SR40	do.	02266495
39	19	Shingle Creek near Campbell	do.	02264495
40	13	Reedy Creek near Loughman	do.	02266500

Appendix C. Locations of and average daily withdrawal rates from Floridan aquifer municipal/industrial/commercial well fields used in ground-water flow model for 1988, December 1989 through May 1990, and projected 2010 simulations

[All values in cubic feet per second. OCPUD, Orange County Public Utilities Department; OUC, Orlando Utilities Commission]

Well field/well owner name	Model Row	Model Column	1988	December 1989	January 1990	February 1990	March 1990	April 1990	May 1990	2010[a]
Source Aquifer: Upper Floridan										
ORANGE COUNTY										
All Gator Carrot Company	15	12	0.178	0.178	0.178	0.178	0.178	0.178	0.178	0.186
Amcon Products, Inc.	21	11	.040	.040	.040	.040	.040	.040	.040	.040
Apopka (Grossenbacher)	14	15	1.070	1.151	1.175	1.070	1.417	1.427	1.742	3.842
Aquacult. Food Farms, Inc.	14	11	.172	.172	.172	.172	.172	.172	.172	.186
Bruce C. Goren	32	5	0	0	0	0	0	0	0	.387
E. Carroll-RV Park	14	11	.025	.025	.025	.025	.025	.025	.025	.031
Central Florida Research Pk	21	34	0	0	0	0	0	0	0	1.547
Cocoa (well 10)	28	40	.364	.447	.464	.465	.455	.468	.460	.232
Cocoa (wells 1, 2)	29	40	.138	.059	.059	.048	.525	.234	.600	.603
Cocoa (wells 8, 9)	29	40	.601	.751	.778	.603	.910	.791	.855	.742
Cocoa (wells 16,17)	30	36	10.840	9.630	9.980	9.989	9.880	9.980	10.190	5.415
Cocoa (wells 14,15)	30	37	10.310	4.561	4.731	4.983	5.070	5.150	5.120	5.291
Cocoa (well 13)	30	38	2.940	.428	.444	2.339	3.400	2.210	3.150	.928
Cocoa (well 7A)	30	39	.426	.279	.289	1.244	1.385	1.430	1.490	.402
Cocoa (wells 3,7)	30	40	1.025	.936	.969	.874	1.110	1.253	1.415	.371
Cocoa (wells 18,19)	31	36	7.030	4.401	4.565	8.881	10.640	10.850	10.850	5.786
Cocoa (wells 4, 4A1, 5, 12B)	31	40	3.213	4.869	5.051	1.477	3.085	4.970	3.970	1.484
Cocoa (well 12A)	31	41	.497	.769	.798	.171	0	.228	.730	.371
Cocoa (well 11)	32	40	1.440	.957	.993	.708	1.090	1.120	.955	.371
Cocoa (well 20)	31	36	0	0	0	0	0	0	0	2.893
Cocoa (well 21)	31	36	0	0	0	0	0	0	0	2.893
Cocoa (well 22)	32	36	0	0	0	0	0	0	0	2.893
Cocoa (well 31)	32	36	0	0	0	0	0	0	0	2.893
Cocoa (well 32)	32	36	0	0	0	0	0	0	0	2.893
Cocoa (well 33)	32	36	0	0	0	0	0	0	0	2.893
Cocoa (well 38)	32	40	0	0	0	0	0	0	0	.371
Cocoa (well 39)	32	40	0	0	0	0	0	0	0	.371
Cocoa (well 40)	33	40	0	0	0	0	0	0	0	.371
Cocoa (well 41)	33	40	0	0	0	0	0	0	0	.371
Cocoa (well 42)	33	40	0	0	0	0	0	0	0	.371
Cocoa (well 43)	34	40	0	0	0	0	0	0	0	.371
Cocoa (well 44)	34	40	0	0	0	0	0	0	0	.371
Cocoa Cola (Plymouth Plant)	14	12	.163	.267	.241	.128	.180	.188	.167	.170
Spencer G. Douglas	12	9	.053	.053	.053	.053	.053	.053	.053	.077
Eatonville, City of	19	23	.936	.998	1.020	.993	1.100	1.010	1.230	2.181
Econ Util (Wedgefield)	25	41	.206	.219	.219	.214	.260	.265	.260	.248
Fla Dept of Correction	28	36	.340	0	0	0	0	0	0	.372
Fla Mining & Materials	19	27	.020	.020	.020	.020	.020	.020	.020	.030
Fla Mining & Materials	8	28	.045	.045	.045	.045	.045	.045	.045	.046
Frito-Lay, Inc.	21	20	0	0	0	0	0	0	0	.232
G G Products	14	6	.027	.027	.027	.027	.027	.027	.027	.045
Hydro Conduit Corp	17	17	.165	.165	.165	.165	.165	.165	.165	.170
Robert E. Lee	14	13	.097	.097	.097	.097	.097	.097	.097	.139
Maitland, City of (Thistle)	17	25	1.270	.734	.720	.628	.970	.890	1.280	1.083
Maitland, City of (Wymore5)	18	22	.635	.862	.845	.792	.835	.840	.935	.727
Maitland, City of (Swoope)	18	24	.635	0	0	0	0	0	0	0
Maitland, City of (Minnehaha)	18	24	.635	.142	.139	.148	.282	.289	.552	.170
Maitland, City of (Adios)	18	24	.635	0	0	0	0	0	0	0
Maitland, City of (Wymore5A)	18	22	.318	.431	.423	.396	.417	.420	.468	.364
Oakland, City of	22	8	.228	.153	.153	.173	.188	.168	.219	.232

Appendix C. Locations of and average daily withdrawal rates from Floridan aquifer municipal/industrial/commercial well fields used in ground-water flow model for 1988, December 1989 through May 1990, and projected 2010 simulations--Continued

[All values in cubic feet per second. OCPUD, Orange County Public Utilities Department; OUC, Orlando Utilities Commission]

Well field/well owner name	Model Row	Model Column	1988	December 1989	January 1990	February 1990	March 1990	April 1990	May 1990	2010[a]
Ocoee, City of (Hackney)	20	14	.886	.722	.590	.596	.740	.545	1.140	1.052
Ocoee, City of (Kissimmee St)	22	13	1.030	.953	1.120	.999	1.560	1.560	1.890	1.439
Ocoee, City of (Wurst Rd.)	20	15	1.382	1.164	1.680	1.680	2.250	2.260	2.610	1.439
OCPUD (Bent Oaks)	14	17	2.040	1.936	2.240	2.340	2.720	2.540	3.520	0
OCPUD (Bonneville)	20	34	1.150	3.314	3.510	3.170	3.470	3.350	4.090	0
OCPUD (Conway)	26	27	3.440	3.330	3.360	2.754	4.044	2.469	2.271	9.699
OCPUD (Corrine Terrace)	21	27	.310	.434	0	0	0	0	0	0
OCPUD (Cypress Walk)	32	14	.880	1.051	1.250	1.210	1.440	1.400	1.640	3.867
OCPUD (Eastern Regional)	25	30	0	0	0	0	0	0	0	31.250
OCPUD (Econ)	23	30	5.530	5.296	5.460	5.520	6.620	8.348	12.200	12.376
OCPUD (Hidden Springs)	26	16	.365	.448	.613	.582	.771	.757	1.014	0
OCPUD (Hunters Creek)	34	19	.184	.921	.977	.764	1.690	1.790	2.420	.774
OCPUD (Kelso)	26	11	.025	.031	.036	.025	.036	.031	.051	0
OCPUD (Lake John Shores)	23	8	0	0	0	0	0	0	0	.046
OCPUD (Lake Nona)	30	30	.052	.087	.092	.087	.122	.132	.163	3.094
OCPUD (Magnolia Woods)	20	11	.059	.051	.056	.056	.076	.071	.117	.046
OCPUD (Meadow Woods)	33	24	.118	.179	.199	.209	.244	.244	.458	.309
OCPUD (Mt. Plymouth Lakes)	10	14	.295	.260	.283	.250	.434	.420	.581	1.392
OCPUD (Oak Meadows)	23	16	1.500	1.982	2.120	1.850	1.760	2.885	2.770	0
OCPUD (Orange Village)	17	15	.031	.031	.031	.020	.020	.025	.025	.046
OCPUD (Orange Wood)	30	18	1.830	1.661	1.889	1.842	1.963	2.164	2.171	7.426
OCPUD (Plymouth)	13	12	0	0	0	0	0	0	0	2.321
OCPUD (Plymouth Central)	14	12	0	.239	.239	.219	.280	.316	.326	0
OCPUD (Plymouth Hills)	14	12	.164	.285	.285	.280	.433	.305	.580	0
OCPUD (Riverside)	17	20	3.000	3.534	3.122	2.760	4.663	4.623	6.130	0
OCPUD (Vistana)	34	15	1.620	1.598	1.720	1.570	1.760	1.790	1.910	6.188
OCPUD (Wauseon Ridge)	25	13	.045	0	0	0	0	0	0	0
OCPUD (Windermere)	26	13	.022	0	0	0	0	0	0	0
OCPUD (Windermere Downs)	24	14	.344	0	0	0	0	0	0	0
Omer A. Schrock	10	1	0	0	0	0	0	0	0	.325
Orange Villa	25	8	.057	.057	.057	.057	.057	.057	.057	.062
OUC (Dr. Phillips)	28	16	8.250	6.660	7.720	6.760	10.030	9.640	12.000	9.592
OUC (Martin)	29	19	14.190	13.572	14.751	14.100	17.100	16.899	18.000	31.233
OUC (Stanton Energy Center)	27	35	.309	.332	.298	.267	.346	.196	.295	.309
OUC (Stanton Energy Center)	27	36	.309	.332	.297	.267	.346	.196	.295	.309
Park Manor Water Works	22	32	.347	.347	.347	.347	.347	.347	.347	.309
Park Manor Water Works	22	31	.348	.348	.348	.348	.348	.348	.348	.309
Ralston Purina (Zellwood Fms)	15	12	0	0	0	0	0	0	.0	.232
Reedy Creek (Station B)	34	12	6.500	8.304	8.030	7.430	9.090	8.980	10.100	14.341
Reedy Creek (Station A)	30	11	6.910	6.637	6.590	7.200	8.850	8.640	9.670	20.653
Reedy Creek (Station C)	32	14	1.620	1.412	2.780	2.680	3.260	3.250	3.330	9.901
Rinker Materials Corp	19	20	.032	.032	.032	.032	.032	.032	.032	.032
Rock Springs MHP	13	15	.305	.405	.366	.361	.478	.433	.540	.433
Sea World of Florida	31	17	2.420	2.440	2.440	2.180	2.390	2.390	2.430	2.011
Shadow Hills MHP	22	29	.301	0	0	0	0	0	0	.309
Southern Fruit Distributors	25	23	.205	.046	.046	0	0	0	0	.217
Southern Gold Citrus Prod	21	20	.018	.018	.018	.018	.018	.018	.018	0
So.States Util (Dartwyler)	28	25	.082	.092	.092	.087	.102	.112	.122	.124
So.States Util (Dol Ray)	18	15	.067	.067	.067	.067	.072	.072	.085	.062
So.States Util (Lk.Conway Pk)	28	25	.040	.036	.036	.036	.046	.041	.056	.062
So.States Util (Suncrest)	21	29	.206	.494	.494	.382	.550	.550	.687	1.083
So.States Util (Univ.Shores)	20	31	.812	.774	.774	.718	.830	.769	1.040	1.300
Starlight Ranch MHP	26	27	.256	.265	.265	.244	.316	.285	.372	.356
Sun Resorts (Yogi Bear)	17	15	.266	.489	.544	.196	.283	.280	.281	.232
Taft Water Association	30	23	.361	.422	.422	.356	.443	.422	.534	0

Appendix C. Locations of and average daily withdrawal rates from Floridan aquifer municipal/industrial/commercial well fields used in ground-water flow model for 1988, December 1989 through May 1990, and projected 2010 simulations--Continued

[All values in cubic feet per second. OCPUD, Orange County Public Utilities Department; OUC, Orlando Utilities Commission]

Well field/well owner name	Model Row	Model Column	1988	December 1989	January 1990	February 1990	March 1990	April 1990	May 1990	2010[a]
Tangerine, Town of	10	8	.208	.193	.193	.183	.265	.229	.285	0
Turkey Lake Park	25	16	0	0	0	0	0	0	0	.093
University Central Florida	19	33	1.120	1.032	.838	.809	.923	1.040	1.310	.556
University Central Florida	20	34	.390	.120	.295	.285	.325	.365	.460	.834
University Central Florida	20	33	.065	.020	.047	.046	.052	.055	.070	.278
Uniwes, Inc.	19	15	.106	.106	.106	.106	.106	.106	.106	.108
Util of Fla (Crescent Hghts)	23	18	.149	.117	.117	.153	.153	.148	.173	0
Util of Fla (Davis Shores)	25	13	.020	.020	.020	.020	.030	.030	.036	.031
H.J. White	17	18	.066	.066	.066	.066	.066	.066	.066	.093
Winter Garden (Boyd Street)	22	10	.870	1.230	1.270	1.250	1.610	1.520	1.740	.975
Winter Garden (Fuller Cross)	22	10	0	0	0	0	0	0	0	.975
Winter Garden Citrus Products	22	11	2.890	9.180	9.180	7.530	6.340	4.590	2.320	2.893
Winter Park, City of (NY Ave.)	19	24	3.740	2.446	2.920	2.940	3.600	2.250	3.580	3.496
Zellwood Farms	10	9	.234	.255	.255	.232	.205	.205	.289	.495
Zellwood Station	12	10	.092	.165	.165	.158	.200	.201	.222	.248
Zellwood Station	12	11	.552	.990	.990	.942	1.200	1.206	1.326	1.484
Zellwood Station	13	10	.092	.165	.165	.158	.200	.202	.221	.248
Zellwood Water Assoc.	12	9	.254	.229	.229	.229	.397	.346	.463	.572
Zellwood MHP	12	11	0	0	0	0	0	0	0	.990
SEMINOLE COUNTY										
Altamonte Spgs, City (WTP#1)	16	24	.145	.591	.819	.387	.626	.387	.060	0
Altamonte Spgs, City (WTP#2)	17	23	4.840	5.349	2.400	5.000	5.850	6.020	6.690	4.672
Altamonte Spgs, City (WPT#3)	15	23	1.080	.139	1.370	0	0	0	0	0
Altamonte Spgs, City (WTP#4))	16	21	.529	.573	1.090	1.270	1.700	1.240	2.120	4.672
Altamonte Spgs, City (WTP#5)	16	20	6.460	4.816	6.030	3.790	5.210	5.380	6.920	0
Altamonte Spgs, City (Chrlt)	15	24	0	0	0	0	0	0	0	6.420
Margaret C. Cammack	8	24	.070	.070	.070	.070	.070	.070	.070	0
Casselberry (South #1)	18	27	.963	.605	.560	.573	.793	.743	.940	.789
Casselberry (Howell Park)	16	26	.800	1.649	1.527	1.087	1.370	1.440	2.230	1.578
Casselberry, City (North)	15	26	2.260	1.318	1.220	2.030	2.460	2.150	2.360	.742
Casselberry Elementary	16	26	.043	.043	.043	.043	.043	.043	.043	.043
Central V Util (Hunters Field)	17	25	.817	.588	.550	.521	.724	.670	.900	0
Central V Util (Derbyshire)	17	25	.867	1.086	1.060	.979	1.110	.980	1.540	0
Deep South Products	16	20	.244	.229	.229	.217	.239	.204	.181	.317
Indian Creek, Inc.	13	29	.072	.051	.066	.071	.107	.127	.168	.045
Inland Materials, Inc.	15	34	.056	.056	.056	.056	.056	.056	.056	.062
B. Jaffe & B. Tresser	7	24	.076	.076	.076	.076	.076	.076	.076	.092
Keith Elementary	14	29	.065	.065	.065	.065	.065	.065	.065	.065
Lake Brantley High School	15	20	.066	.066	.066	.066	.066	.066	.066	.066
Lake Harney Water Assoc.	12	40	.046	.052	.046	.046	.060	.046	.060	.062
Lake Howell High School	17	29	.030	.030	.030	.030	.030	.030	.030	.030
Lake Mary, City of	10	25	.774	1.594	1.640	1.220	1.990	1.740	2.700	2.476
Lake Mary, City of	9	25	0	0	0	0	0	0	0	6.190
Longwood, City of (Plant #1)	13	25	1.180	.481	.575	.422	.453	.799	.921	1.346
Longwood, City of (Plant #2)	13	24	1.960	2.704	2.470	2.700	3.650	2.840	3.730	3.527
Lutheran Haven	17	32	.061	.056	.056	.051	.076	.071	.087	0
Mullet Lake Water Assoc.	11	38	.057	.056	.056	.056	.076	.066	.092	.093
Oviedo (Alafaya Woods)	16	33	.580	.945	.855	.850	1.270	1.230	1.820	5.693
Oviedo (Alafaya Woods)	17	34	0	0	0	0	0	0	0	2.274
Oviedo, City of (Old)	16	33	1.209	1.461	1.650	1.560	2.220	2.000	2.679	4.671
Oviedo-Prop. well Lake Gem	17	33	0	0	0	0	0	0	0	2.274
Oviedo High School	15	32	.032	.032	.032	.032	.032	.032	.032	.032
Palm Ventures MHP	18	31	.242	.254	.239	.229	.326	.234	.484	.356
L.D. Plante, Inc.	14	30	.100	.100	.100	.100	.100	.100	.100	.108
Sanford, City (Wellfield #1)	10	28	4.970	3.681	3.920	3.690	4.410	4.730	4.990	1.485

Appendix C. Locations of and average daily withdrawal rates from Floridan aquifer municipal/industrial/commercial well fields used in ground-water flow model for 1988, December 1989 through May 1990, and projected 2010 simulations--Continued

[All values in cubic feet per second. OCPUD, Orange County Public Utilities Department; OUC, Orlando Utilities Commission]

Well field/well owner name	Model Row	Model Column	1988	December 1989	January 1990	February 1990	March 1990	April 1990	May 1990	2010[a]
Sanford, City (Wellfield #2)	9	26	2.810	3.440	.324	.462	1.080	.444	.603	2.537
Sanford, City (Wellfield #3)	8	26	1.280	1.767	4.130	3.450	3.800	3.740	4.970	5.028
Sanlando (Despinar)	13	23	5.110	4.756	5.270	5.040	7.100	6.990	9.350	5.444
Sanlando (Knollwood)	14	23	.138	0.290	.158	.153	.300	.290	.590	.139
Sanlando (Wekiva)	14	19	8.835	8.225	8.780	8.210	10.470	10.890	13.050	11.060
Seminole Co. (Consumer)	17	28	4.140	5.020	5.280	4.690	6.310	6.310	7.840	9.050
Seminole Co. (Country Club Hghts)	11	26	.022	.014	.033	.006	.051	.061	.076	2.043
Seminole Co. (Greenwood Lakes)	11	25	1.940	1.975	2.160	2.190	2.910	2.870	3.630	5.461
Seminole Co. (Hanover Woods)	9	22	.221	.349	.349	.338	.570	.614	.890	.928
Seminole Co. (Heathrow)	10	24	.484	.674	.704	.578	.701	.586	.837	2.878
Seminole Co. (Indian Hills)	17	25	1.960	2.376	2.300	2.180	2.970	2.910	3.730	4.796
Seminole Co. (Lake Hayes)	18	33	.132	.098	.174	.172	.373	.408	.620	.606
Seminole Co. (Lake Hayes)	18	34	.198	.147	.263	.256	.558	.612	.920	.909
Seminole Co. (Lynwood/Belaire)	15	18	.779	.857	.867	.850	1.220	1.160	1.470	.170
Seminole Co. (Lynwood)	16	19	0	0	0	0	0	0	0	1.516
Seminole Co. (I-4 Industrial Pk)	7	25	.202	.224	.224	.229	.249	.260	.265	.464
Seminole Co. School Board	15	20	.112	.116	.116	.120	.119	.106	.199	0
Seminole Soccer Club	8	22	.140	.140	.140	.140	.140	.140	.140	.140
Seminole Woods Assoc., Inc.	12	38	.090	.090	.090	.090	.090	.090	.090	.124
So. States Util (Apple Valley)	15	22	.680	.649	.713	.631	.881	.819	1.140	.789
So. States Util (Bretton)	17	23	.212	.200	.214	.199	.290	.270	.377	.278
So. States Util (Chuluota)	17	38	.304	.320	.305	.295	.387	.372	.489	.386
So. States Util (Fern Park)	15	24	.102	.100	.092	.087	.112	.102	.127	.093
So. States Util (Harmony Hms)	15	24	0	0	0	0	0	0	0	.093
So. States Util (Lk Brantley)	14	19	.028	.040	.041	.031	.046	.051	.056	.031
So. States Util(Lk Harriet)	15	20	.126	.150	.143	.127	.173	.163	.209	.139
So. States Util(Meredith)	14	21	.402	.349	.356	.321	.433	.428	.534	.418
Town & Country	7	23	0	0	0	0	0	0	0	.031
Twelve Oaks	6	24	0	0	0	0	0	0	0	.046
United Technology, Inc.	9	24	.125	.125	.125	.125	.125	.125	.125	.124
Util of Fla (Bear Lake Manor)	16	19	.097	.092	.097	.092	.122	.117	.143	.124
Util of Fla (Jansen)	17	18	.104	.095	.102	.095	.126	.121	.178	.124
Util of Fla (Little Wekiva)	15	20	.037	.024	.025	.022	.028	.027	.040	.046
Util of Fla (Oakland Shores)	17	23	.209	.138	.173	.162	.201	.176	.219	.248
Util of Fla (Phillips/Cryst) (9,26)	9	26	.094	.086	.084	.092	.122	.117	.152	.031
Util of Fla (Ravenna Park)	8	27	.186	.167	.157	.143	.178	.168	.208	.186
Util of Fla (Weathersfield)	16	21	.625	.604	.602	.598	.720	.722	.890	.650
Winter Springs (WTP #1)	15	30	2.730	2.621	3.130	2.780	3.950	3.760	4.780	5.229
Winter Springs (WTP #2)	13	26	.906	1.047	1.080	.916	1.150	1.200	1.230	1.114
Winter Springs (WPT #3)	14	27	.962	.851	.876	.931	1.170	1.120	1.630	2.970
LAKE COUNTY										
Clermont (Grandview Highway)	22	1	.741	.611	.637	.720	.926	.850	1.010	2.429
Clermont (Seminole Ave.)	21	1	.693	.730	.717	.522	.910	.841	1.010	.696
Clermont (4th St.)	21	1	.803	.716	.718	.759	.900	.886	.952	.696
Eustis (Ardice Place)	6	4	1.425	1.282	1.290	1.260	1.943	1.740	2.440	2.915
Eustis (CR44A)	5	5	.528	2.086	1.910	1.650	1.660	1.480	1.820	4.208
Eustis (Hazelton Ave.)	5	5	2.020	.249	.377	.351	.667	.677	.764	.835
Eustis Sand Mine	1	11	3.550	3.550	3.550	3.550	3.550	3.550	3.550	0
Florida Crushed Stone	24	4	3.380	2.046	2.700	2.920	2.990	2.440	2.530	3.372
Florida Food Products	3	3	2.510	2.510	2.510	2.510	2.510	2.510	2.510	0
Golden Gem	1	5	6.152	6.522	11.600	8.080	3.310	2.790	2.650	7.317
Lake Hills Utilities	22	4	0	0	0	0	0	0	0	.278
Minneola, City of	21	1	.295	.290	.290	.326	.397	.412	.448	.696
Montverde, City of	19	5	.187	.148	.148	.163	.224	.188	.265	.340
Mount Dora, City of	7	7	3.700	3.756	3.890	3.610	5.140	4.620	5.350	6.900

Appendix C. Locations of and average daily withdrawal rates from Floridan aquifer municipal/industrial/commercial well fields used in ground-water flow model for 1988, December 1989 through May 1990, and projected 2010 simulations--Continued

[All values in cubic feet per second. OCPUD, Orange County Public Utilities Department; OUC, Orlando Utilities Commission]

Well field/well owner name	Model Row	Model Column	1988	December 1989	January 1990	February 1990	March 1990	April 1990	May 1990	2010[a]
Silver Sand Co. (Clermont)	25	4	1.910	2.060	2.200	2.070	2.170	2.090	1.950	1.918
Sundor Brands, Inc.	8	7	.032	.030	.030	.020	.030	.020	.020	.031
Tavares, City of	7	2	1.790	2.117	2.080	2.140	2.700	2.150	2.600	5.200
Utilities,Inc. (Amber Hill)	24	1	.148	.165	.204	.163	.239	.229	.316	.294
Utilities,Inc. of Fla	26	2	.280	.280	.280	.280	.280	.280	.280	.278
Vacation Village	26	2	0	.094	.094	.094	.094	.094	.094	.170
Wekiva Falls (Resort)	8	20	0	0	0	0	0	0	0	.340
VOLUSIA COUNTY										
Howard S. Dorr	5	37	.028	.028	.028	.028	.028	.028	.028	.031
Florida Power (Lake Monroe)	3	29	.147	.131	.132	.122	.132	.132	.137	.232
FP&L (Sanford Power Plant)	5	26	.490	.534	.534	.438	.443	.473	.662	.928
Lemon Bluff	6	37	.044	.044	.044	.044	.044	.044	.044	.092
Kove Assn	5	35	.024	.024	.024	.024	.024	.024	.024	.062
Volusia Co. (Glen Abbey)	1	28	.374	.374	.374	.374	.374	.374	.374	1.176
Volusia Co. (Golden Bay Colony)	3	54	.130	.130	.130	.130	.130	.130	.130	.124
Volusia Co.(Highland Ctry Est)	1	27	.164	.261	.261	.428	.465	.453	.445	.712
Volusia Co. (Indian Harbour)	2	54	.040	.040	.040	.050	.050	.040	.060	.062
Volusia Co. (Lake Marie)	2	27	.216	.193	.193	.188	.239	.214	.280	.402
Volusia Co. (Terra Alta)	1	27	.056	.050	.050	.050	.070	.060	.020	.077
Deltona	1	30	2.253	2.139	2.211	2.163	3.120	3.000	3.840	3.711
Deltona	2	29	.751	.713	.737	.721	1.040	1.000	1.280	1.237
Deltona	2	31	3.004	2.852	2.948	2.884	4.160	4.000	5.120	4.948
Deltona	2	32	.751	.713	.737	.721	1.040	1.000	1.280	0
Deltona	1	30	0	0	0	0	0	0	0	2.474
Deltona	1	29	0	0	0	0	0	0	0	1.237
Deltona	2	31	0	0	0	0	0	0	0	1.237
Deltona	3	33	0	0	0	0	0	0	0	3.711
Deltona	3	31	0	0	0	0	0	0	0	1.237
Deltona	3	34	0	0	0	0	0	0	0	1.237
Deltona	3	35	0	0	0	0	0	0	0	2.474
Deltona	3	32	0	0	0	0	0	0	0	1.237
OSCEOLA COUNTY										
Kissimmee (Camelot West)	36	16	1.408	1.930	1.880	1.820	2.050	2.010	2.090	3.342
Kissimmee (Parkway East)	38	25	.175	.204	.212	.226	.302	.307	.316	.356
Kissimmee (Parkway East)	38	24	.350	.408	.424	.451	.604	.614	.631	.712
Kissimmee (Fountain Park)	36	16	.122	.202	.076	.310	.239	.229	.260	.278
Floribra USA, Inc.	35	15	.050	.050	.050	.050	.050	.050	.050	2.444
Hyatt House Orlando	35	13	.470	.534	.534	.550	.545	.550	.575	1.114
Kissimmee, City (Bermuda)	36	20	3.180	3.802	3.930	2.640	4.190	4.310	5.510	7.580
Kissimmee, City (Ruby St)	38	21	2.750	2.896	2.030	3.440	3.850	3.670	4.110	6.528
Kissimmee Good Samaritan	40	16	.324	.366	.366	.326	.387	.366	.417	.789
Orange/Osceola Mgmt	36	24	.603	.603	.603	.603	.603	.603	.603	1.439
Orange/Osceola (Beunavn. Lks)	36	24	1.766	1.718	1.830	1.730	2.140	2.100	2.520	4.208
Kissimmee NW (Osceola Serv.)	35	10	3.160	1.640	1.640	1.880	1.930	2.110	2.330	3.527
So. States Util (Tropical Pk)	35	22	.129	.143	.143	.137	.153	.158	.199	.310
Source Aquifer: Lower Floridan										
ORANGE AND SEMINOLE COUNTIES										
Apopka (Sheelor Oaks)	16	16	3.210	3.453	3.525	3.210	4.250	4.280	5.225	5.105
Apopka (Grossenbacher)	14	15	2.140	2.300	2.350	2.140	2.833	2.853	3.483	11.371
Apopka (NW wellfield)	12	14	0	0	0	0	0	0	0	3.249
Apopka (SW wellfield)	15	13	0	0	0	0	0	0	0	2.692
Casselberry (South)	18	27	1.926	1.210	1.120	1.146	1.586	1.486	1.880	2.955
Casselberry (N2400)	15	26	1.130	.658	.609	1.020	1.230	2.150	1.180	1.562

Appendix C. Locations of and average daily withdrawal rates from Floridan aquifer municipal/industrial/commercial well fields used in ground-water flow model for 1988, December 1989 through May 1990, and projected 2010 simulations--Continued

[All values in cubic feet per second. OCPUD, Orange County Public Utilities Department; OUC, Orlando Utilities Commission]

Well field/well owner name	Model Row	Model Column	1988	December 1989	January 1990	February 1990	March 1990	April 1990	May 1990	2010[a]
Casselberry (FP2400)	17	26	.400	.824	.763	.542	.686	.719	1.120	2.166
Deep South Products	16	20	.243	.229	.229	.216	.239	.203	.180	.317
Eustis (Ardice Place-Lk.Co.)	6	4	.475	.427	.430	.420	.647	.580	.955	.975
Maitland, City of (Keller)	18	22	0	1.661	1.628	1.940	1.970	2.000	2.290	2.769
Maitland, City of (Wymore5A)	18	22	.318	.431	.422	.396	.417	.420	.467	.364
Ocoee, City of (South Plant)	23	13	0	0	0	0	0	0	0	4.548
OCPUD (Conway)	26	27	1.570	1.495	1.510	1.237	1.817	1.110	1.020	5.368
OCPUD (Hidden Springs)	26	16	2.190	2.754	3.767	3.577	4.739	4.653	6.226	0
OCPUD (Oak Meadows)	23	16	1.500	1.982	2.120	1.850	1.760	2.885	2.770	0
OCPUD (Orangewood)	30	18	.913	.818	.931	.908	.967	1.066	1.069	2.599
OCPUD (Riverside)	17	20	1.499	1.741	1.538	1.360	2.297	2.277	3.020	0
OCPUD (South Regional)	33	23	0	0	0	0	0	0	0	15.470
OCPUD (West Regional)	17	16	0	0	0	0	0	0	0	24.752
OCPUD (West Regional)	17	17	0	0	0	0	0	0	0	6.188
OUC (Conway)	25	26	10.300	11.588	11.820	10.654	13.040	13.086	14.134	9.498
OUC (Conway)	25	25	5.150	5.794	5.910	5.326	6.520	6.544	7.066	4.749
OUC (Highland)	22	23	10.700	11.022	9.798	11.442	13.344	13.104	17.256	11.232
OUC (Highland)	22	24	1.790	1.837	1.633	1.907	2.224	2.184	2.876	1.129
OUC (Kirkman)	25	18	9.690	11.739	11.750	12.750	14.919	15.760	17.800	17.034
OUC (Kuhl)	24	23	12.990	12.279	11.799	11.760	14.590	14.160	17.520	17.496
OUC (Navy)	22	27	2.160	1.366	5.050	5.340	5.260	5.890	6.210	9.901
OUC (Pine Hills)	21	18	8.660	8.510	8.680	5.980	10.180	9.860	11.650	12.128
OUC (Pine Hills)	22	18	8.660	8.510	8.680	5.980	10.180	9.860	11.650	18.192
OUC (Primrose)	23	25	12.420	10.974	9.430	8.580	11.250	10.810	14.200	10.953
OUC (Sky Lake)	28	22	0	0	0	0	0	0	0	11.834
OUC (Sky Lake)	29	22	0	0	0	0	0	0	0	11.834
OUC (Orange)	31	23	0	0	0	0	0	0	0	11.139
OUC (Pershing)	26	27	0	0	0	0	0	0	0	10.829
Winter Garden (Palmetto St.)	21	11	1.360	1.481	1.530	1.470	1.750	1.560	1.890	.975
Winter Garden (Proposed #4)	22	10	0	0	0	0	0	0	0	.975
Winter Park (Magnolia)	18	26	2.810	2.758	2.950	3.010	3.430	3.410	4.230	5.012
Winter Park (Swoope)	19	24	0	0	0	0	0	0	0	2.228
Winter Park (Wymore Rd.)	19	22	4.560	4.581	4.660	4.340	5.460	5.600	6.440	4.827
Winter Park (University Blvd)	20	27	7.870	8.628	8.700	6.830	9.620	10.160	12.700	8.076

[a] projected 2010 pumpages provided by the St. Johns River Water Management District; all other pumpage values compiled from USGS, St. Johns River Water Management District, South Florida Water Management District, and from various city and county records.