Hydrogeology, Water Quality, and Potential for Contamination of the Upper Floridan Aquifer in the Silver Springs Ground-Water Basin, Central Marion County, Florida

By G.G. Phelps

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

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 foot (ft^2)	0.09290	square meter
square mile (mi^2)	2.590	square kilometer
	Volume	
gallon (gal)	3.785	liter
	Mass	
gram (g)	0.03527	ounce, avoidrupois
	Flow	
foot per minute (ft/min)	0.3048	meter per minute
foot per hour (ft/h)	0.3048	meter per hour
cubic foot per second (ft^3/s)	28.32	cubic meter per second
gallon per minute (gal/min)	0.06309	liter per second
gallon per day (gal/d)	0.003785	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
	Transmissivity	
foot squared per day (ft^2/d)	0.0929	meter squared per day
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day
	Specific capacity	
gallon per minute per foot [(gal/min)/ft)]	0.207	liter per second per meter

Equations for temperature conversion between degrees Celsius (°C) and degrees Fahrenheit (°F):

$$°C = 5/9\ (°F - 32)$$
$$°F = 1.8\ (°C) + 32$$

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 the United States and Canada, formerly called Sea Level Datum of 1929.

Altitude, as used in this report, refers to distance above or below sea level.

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.

Additional abbreviations

hp	horsepower
L	liter
MHz	Megahertz
µg/L	micrograms per liter
µm	micrometer
µS/cm	microsiemens per centimeter at 25 degrees Celsius (25 °C)
mg/L	milligrams per liter
mL	milliliter
mm	millimeter
min	minute

Acronyms

EM	Electromagnetic methods
ERM-South	Environmental Resources Management-South, Inc.
GPR	Ground-Penetrating Radar
MCL	Maximum Contaminant Level
PAHs	Polynuclear Aromatic Hydrocarbons
SJRWMD	St. Johns River Water management District
VLF	very low frequency
VISA	very intensely studies area
VOCS	Volatile Organic Compounds

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Abstract

The Upper Floridan aquifer is the principal source of water supply in the Silver Springs ground-water basin of central Marion County, Florida. The karstic nature of the local geology makes the aquifer susceptible to contaminants from the land surface. A thick sequence of very porous limestone and dolomite composes the Upper Floridan aquifer. Secondary porosity is well developed along two regionally significant sets of fractures. The dominant hydrologic feature of the area is Silver Springs, which has an average discharge of about 525 million gallons per day. Withdrawals from wells in the county total about 42 million gallons per day.

A variety of potential contaminants could enter the aquifer through natural pathways such as seepage through surficial materials overlying the aquifer and sinkholes, or through drainage wells. In 1990, permit files of the Florida Department of Environmental Protection indicated Marion County had 165 sites that contained underground storage tanks; 95 sites where waste is buried; about 160 sites where potentially hazardous materials may be handled; about 100 sites where treated wastewater is disposed; and about 475 acres covered by surface-water impoundments. A field check of drainage wells in 1989-90 revealed the presence of 42 active drainage wells.

Detailed investigations of four sites were used to define local hydrologic conditions and their relation to regional hydrologic conditions. Surface geophysical methods were of limited value in predicting the presence of fractures or buried sinkholes which might contribute to the introduction or movement of contaminants. Water-level monitoring at the sites showed that the horizontal hydraulic gradient is very low (on the order of 10^{-4} foot per foot). Ground-water flow velocities determined from dye traces ranged from about 1 foot per hour under natural flow conditions to about 10 feet per hour under pumping conditions, considerably higher than velocities estimated using Darcy's equation for steady-state flow in a porous medium. Additional dye traces over the expected range of hydrologic conditions are needed to refine the estimates of average ground-water flow velocities in the basin.

Based on the results of analyses of water samples collected from 34 wells in 1989 and 1990 and analyses of water entering the Upper Floridan aquifer through drainage wells, widespread degradation of water quality in the study area has not occurred. Water entering the aquifer through drainage wells contained bacteria, somewhat elevated concentrations of nutrients, manganese and zinc, and occasionally, low concentrations of organic compounds. The wells sampled did not seem to be adversely affected by recharge through drainage wells or by contaminants from the

potential sources identified during this study; however, in an area of karst, particularly one where fracture flow is significant, evaluating the distribution of contaminants is difficult. Special care should be used when interpolating hydrogeologic data from regional studies to a specific site.

INTRODUCTION

The Silver Springs ground-water basin in central Marion County, Fla., (fig. 1) is a karstic area where the limestone of the Upper Floridan aquifer is at or near land surface. Thus, the Upper Floridan aquifer could be contaminated by surface water infiltrating the aquifer, by leachate from landfills, and by accidental spills of hazardous materials. A well-developed fracture-flow system in the Upper Floridan aquifer makes prediction of the movement of contaminants more difficult than in a system where porous flow is dominant. Among the effects of rapid development and population growth in the area are increased amounts of surface runoff and solid waste (requiring disposal), and an increased demand for water. Because the Upper Floridan aquifer is the principal (and virtually sole) source of water supply in the Silver Springs basin, a need exists for documentation of the major potential sources of contamination. Also needed is a better understanding of the geohydrologic system on which to base a rapid evaluation of potential effects should contamination occur in the future. To address these needs, the U.S. Geological Survey, in cooperation with the Florida Department of Environmental Protection, the City of Ocala, Marion County, and the St. Johns River Water Management District, conducted a study of the Silver Springs ground-water basin from 1988 to 1991.

Purpose and Scope

This report: (1) describes the geohydrology of the Silver Springs ground-water basin, (2) documents the locations of major potential sources of contamination to the Upper Floridan aquifer in the basin, and (3) provides information needed to help water managers and planners evaluate the potential movement of contaminants which might be introduced into the aquifer. The report also presents information about the quality of water entering the aquifer at selected points and the ambient quality of ground water in the Upper Floridan aquifer. Surface and borehole geophysical data, data from drilling of test wells, and traveltimes determined from dye traces were used to help improve the understanding of fracture systems and thus of the potential movement of contaminants in the aquifer.

This report presents inventories of sinkholes, drainage wells, retention and percolation ponds, landfills, and spray fields; and inventories of wells, particularly public-supply wells near potential contamination sources. The study area includes the Silver Springs ground-water basin with emphasis on central Marion County (fig. 1).

Description of Area

The Silver Springs ground-water basin, as delineated on the basis of the potentiometric surface of the Upper Floridan aquifer (fig. 1), comprises about 1,200 mi^2 in north-central Florida, including parts of Marion, Alachua, Putnam, and Sumter Counties. The area of primary interest in this study consists of about 700 mi^2 in the center of the ground-water basin and centered around the city of Ocala in Marion County.

The climate of the area is humid subtropical. Annual rainfall averages about 54 in/yr and the annual average air temperature is about 71 °F (National Oceanic and Atmospheric Administration, 1988). There are two distinct seasons: the summer rainy season (June-September), during which about 50 percent of the total annual rainfall occurs, and the dry season (October-May). During the rainy season, convection thunderstorms predominate resulting in an uneven distribution of rainfall. During the dry season, rainfall is usually associated with occasional cold fronts and is more evenly distributed areally than wet-season rainfall.

The study area lies within the Central Highlands physiographic division described by Cooke (1939, p. 14), which generally coincides with the "Ocala Uplift," a broad, structural high that formed in middle-to-late Tertiary time (Miller, 1986, p. B11). White (1970) and Brooks (1981) further subdivided the Central Highlands into several hill regions based on altitude and near-surface geology. The gently rolling topography results from the combination of karst depressions caused by dissolution of limestone and hills capped with

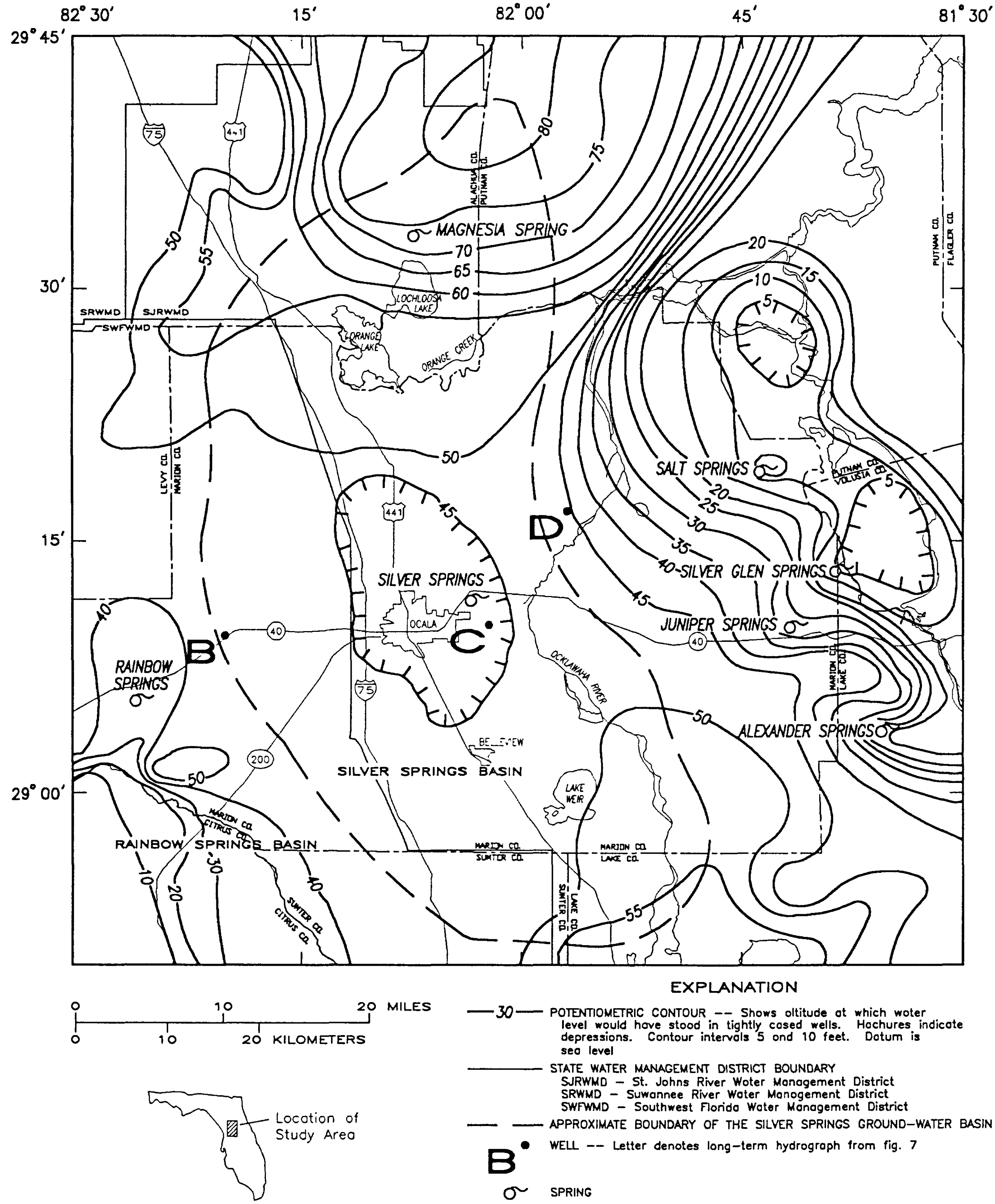


Figure 1. Location of Silver Springs basin and potentiometric surface of the Upper Floridan aquifer, May 1989 (from Schiner, 1989).

Miocene and Pliocene clastic sediments that tend to retard dissolution. Land-surface altitudes range from about 65 to 180 ft above sea level. The dissolution of limestone which occurs at or near land surface has resulted in a subdued karst terrain, characterized by numerous shallow sinkhole depressions.

The area is characterized by an almost complete absence of surface drainage. Most of the drainage is internal, either directly into closed depressions or by seepage directly into the unconfined limestone of the Upper Floridan aquifer. Ground-water basins in the area do not correspond to the boundaries of surface-water drainage divides (Faulkner, 1973, p. 22). The predominant feature of the ground-water drainage system is Silver Springs, which has the largest discharge of any nontidal spring in Florida (Rosenau and others, 1977, p. 7), averaging about 800 ft^3/s (about 525 Mgal/d) for the period 1933 to 1989.

Previous Investigations

Several hydrologic studies of the Silver Springs basin were made in the mid-to-late 1960's and early 1970's in order to study the potential effects of the proposed Cross-Florida Barge Canal (fig. 3). A study by Knochenmus (1967) provided information about ground-water traveltimes and background fluorescence data for ground water in part of the area. Faulkner (1973) provided a detailed report of the stratigraphy, the structural geology, and the ground-water flow system of the proposed Barge Canal right-of-way, with emphasis on the Ocala area. The report by Faulkner also included information about the specific conductance, hardness, and chloride concentration of ground water in the area. Tibbals (1975) conducted aquifer tests of the upper 100 ft of the Floridan aquifer in the Barge Canal right-of-way to provide information about potential exchange of water between the canal and the aquifer. Information about drainage wells in Ocala was collected by Kimrey and Fayard (1984) for a report on drainage wells throughout the State of Florida. A report by Environmental Resources Management-South, Inc. (1988) contained information about contamination of the Floridan aquifer in downtown Ocala. A report by GeoTrans, Inc. (1988) described the analysis of ground-water flow in the adjacent Rainbow Springs basin (fig. 1), which has a similar hydrogeologic setting to that of the Silver Springs basin.

Site Numbering System

The U.S. Geological Survey (USGS) assigns a unique site identification number to each well, surface-water site, or other site inventoried. Surface-water sites that are part of the long-term data-collection network are assigned an 8-digit downstream order number, such as 02239500 for Silver Springs, which designates the major river basin (02) and the order in which the tributary joins the main stream. Wells, surface-water sites where only miscellaneous measurements are made, and other sites of interest are assigned a 15-digit site identification number based on the latitude and longitude of the site location. The first 6 digits denote the degrees, minutes and seconds of latitude, the next 7 digits denote the degrees, minutes and seconds of longitude, and the last 2 digits (assigned sequentially) identify the sites within a 1-second grid of latitude and longitude. Once assigned, a site identification number does not change even though the locations determined by latitude and longitude may be revised later.

Acknowledgments

The author wishes to thank William Ten Broeck and Douglas Harris of the City of Ocala Engineering Department, Larry Varnadore and John Schinfessel, formerly of the Marion County Engineering Department, and Donald Bonoil of the St. Johns River Water Management District, for their assistance with data collection. Geophysical logs of test wells were made by Jeff Davis of the St. Johns River Water Management District. Margaret L. Mitchell of the Florida Department of Environmental Protection (FDEP) provided data from the FDEP data bases. Russell Days, building superintendent of the Appleton Museum of Art, was very helpful during the drilling and testing of wells on museum property. Frank Drago and Angie Noble of the City of Ocala Electric Utility were very helpful in installing power to the test site. G. Matthew Fischer and Jerry Johnson of the Gainesville chapter of the Florida Speleological Society provided sketches of major caves and guided the author on a tour of Briar Cave. The author also is grateful to the many property owners in Marion County who willingly gave permission to access their property for data collection. Finally, the author extends her thanks to the staff of the U.S. Geological Survey Water Quality Service Unit, Ocala, for

assisting with the data collection. Special thanks to Donald Mull (U.S. Geological Survey, Louisville, Ky.), who did the fluorometric analyses for the dye trace at the Appleton Museum.

HYDROGEOLOGY

In the karstic Silver Springs ground-water basin, geologic features, such as sinkholes and fractures, control both the ground- and surface-water hydrology. The location of Silver Springs probably is controlled by geologic and tectonic factors (Faulkner, 1973, p. 43-44).

Geology

The geology of central Marion County was described in detail by Faulkner (1973, p. 24-52). The following sections are a brief summary of the geology of the study area based on Faulkner's work and incorporate updated stratigraphic information from more recent work.

Stratigraphy

The Florida Plateau is a large, tectonically stable platform of carbonate rocks which overlies the post-Paleozoic Coastal Plain Floor. In central Marion County, the sedimentary rocks are about 4,000 ft thick, of which about 1,500 to 2,500 ft are Cretaceous and the remainder Tertiary and younger.

The basal Tertiary unit is the Cedar Keys Formation of Paleocene age (fig. 2). Conformably overlying the Cedar Keys are about 600 ft of the lower Eocene Oldsmar Formation, composed mostly of limestone with some interbedded dolomite and minor amounts of anhydrite.

The Avon Park Formation, a thick sequence of marine limestone and dolomite, conformably overlies the Oldsmar Formation. Miller (1986) determined that the sediments formerly known as the Lake City Limestone could not be differentiated from the Avon Park Formation, so strata designated as Lake City by Faulkner (1973) are now considered a part of the Avon Park. A characteristic of the Avon Park Formation is the alternating layers of hard to very hard dark-brown dolomite and softer, light-brown to tan limestone. The Avon Park Formation in much of Marion County is highly fractured and contains cavities.

An erosional unconformity separates the Avon Park from the overlying upper Eocene Ocala Limestone. The Ocala Limestone has been eroded away entirely in some parts of Marion County and the Avon Park occurs at or near land surface; however, in other parts of the county, the Ocala is at land surface (fig. 3). The Ocala is composed of white to cream or tan limestone which is usually fossiliferous and soft to very soft. Occasionally, the Ocala contains chert either as irregular masses or thin layers. Differential erosion of the limestone surface has caused the formation of pinnacles and a wide variation in the altitude of the surface of the limestone. The presence of limestone at, or near, land surface has resulted in a mature karst type of landform, including rolling hills, and numerous closed sinkhole depressions.

The Hawthorn Formation of Miocene age unconformably overlies the Ocala Limestone, and where present, ranges in thickness from a few to more than 100 ft in the eastern part of Marion County. The sediments of the Hawthorn Formation consist mostly of marine sand interbedded with clay, sandy phosphatic clay, and, occasionally, hard, dense limestone or dolomite. In much of western Marion County the Hawthorn Formation has been eroded away and the remaining Hawthorn deposits commonly form caps on hilltops. East of the outcrop area of the Ocala Limestone (fig. 3), the Hawthorn is present as a continuous layer and the resulting expression at land surface is a change from the rolling karst hills in the western part of the county to a more subdued, often poorly drained, landform.

Overlying the Hawthorn Formation in parts of Marion County are a variety of mostly clastic sediments that have been classified as Pliocene to Holocene in age and range in thickness from 0 to about 100 ft. Undifferentiated upper Miocene to Holocene sediments which overlie the Hawthorn Formation include: nonmarine clayey sands described as the Fort Preston Formation by Faulkner (1973); marine and lacustrine sand, shell marl, and sandy clay; and phosphatic limestone. In most of the basin, the thickness of sediments overlying the limestone ranges from about 10 to 50 ft, with a maximum of about 100 ft in a few areas (fig. 4).

Series	Stratigraphic Unit	Thickness (feet)	Lithology
Pleistocene to Holocene	Undifferentiated post-Miocene deposits	0-100+	Marine quartz sand. Also fluviatile and lacustrine sand, clay, marl, and peat deposits.
Pliocene	Undifferentiated Pliocene deposits	0-100	Nonmarine clayey sands, red and yellow, fine to coarse grained to pebbly, kaolinitic, crossbedded.
			UNCONFORMITY
Upper Miocene to Pliocene(?)	Undifferentiated Upper Miocene-Pliocene deposits	0-100+	Marine sands, argillaceous, carbonaceous; sandy shell marl; some phosphatic limestone. Also terrestrial-deltaic(?) interbedded deposits of clay, sand, and sandy clay. Phosphatic, including a rubble of phosphate rock and silicified limestone residuum in a gray and green phosphatic matrix.
			UNCONFORMITY
Middle and Lower Miocene	Hawthorn Formation	0-140	Marine interbedded sand, cream, white, and gray, phosphatic, often clay, green to gray and white, phosphatic, often sandy; dolomite, cream to white and gray, phosphatic, sandy, clayey; and some limestone, hard, dense in part sandy and phosphatic.
			UNCONFORMITY
Upper Eocene	Ocala Limestone	0-180	Marine limestone, white to cream to tan and brown, granular, soft to firm, porous, highly fossiliferous, cherty in places. Lower part at places is dolomite, gray and brown, crystalline, porous.
			UNCONFORMITY
Middle Eocene	Avon Park Formation	800-1,100	Marine limestone, light brown to brown, finely fragmental, low to high porosity, highly fossiliferous (mostly foraminifers); and dolomite brown to dark brown, firm to very hard, low to moderate porosity, crystalline, saccharoidal; both limestone and dolomite are fractured. Carbonaceous or peaty; gypsum present in small amounts.
Lower Eocene	Oldsmar Formation	500-650	Marine limestone, light brown to chalky white, porous, fossiliferous, with interbedded brown, porous, crystalline dolomite; minor amounts of anhydrite and gypsum.
Paleocene	Cedar Keys Formation	400-700	Marine dolomite, light gray, hard, slightly porous to porous, crystalline, in part fossiliferous, with considerable anhydrite and gypsum, some limestone.

Figure 2. Description of stratigraphic section in Marion County. (Faulkner, 1973, fig. 11, and K. Campbell, Florida Geological Survey, written commun., 1990).

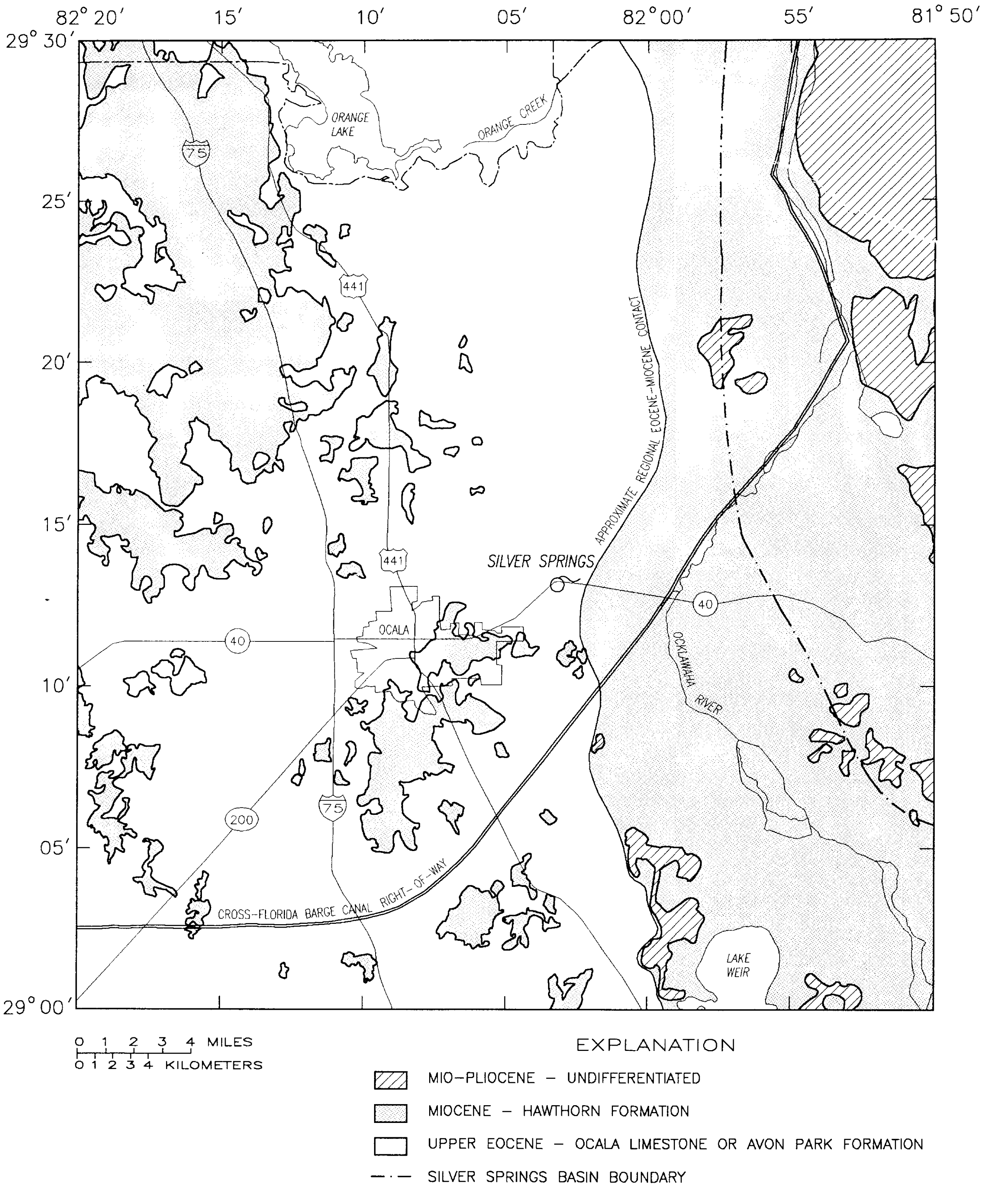


Figure 3. Geologic formations at or near land surface, central Marion County (from Faulkner, 1973, fig. 14).

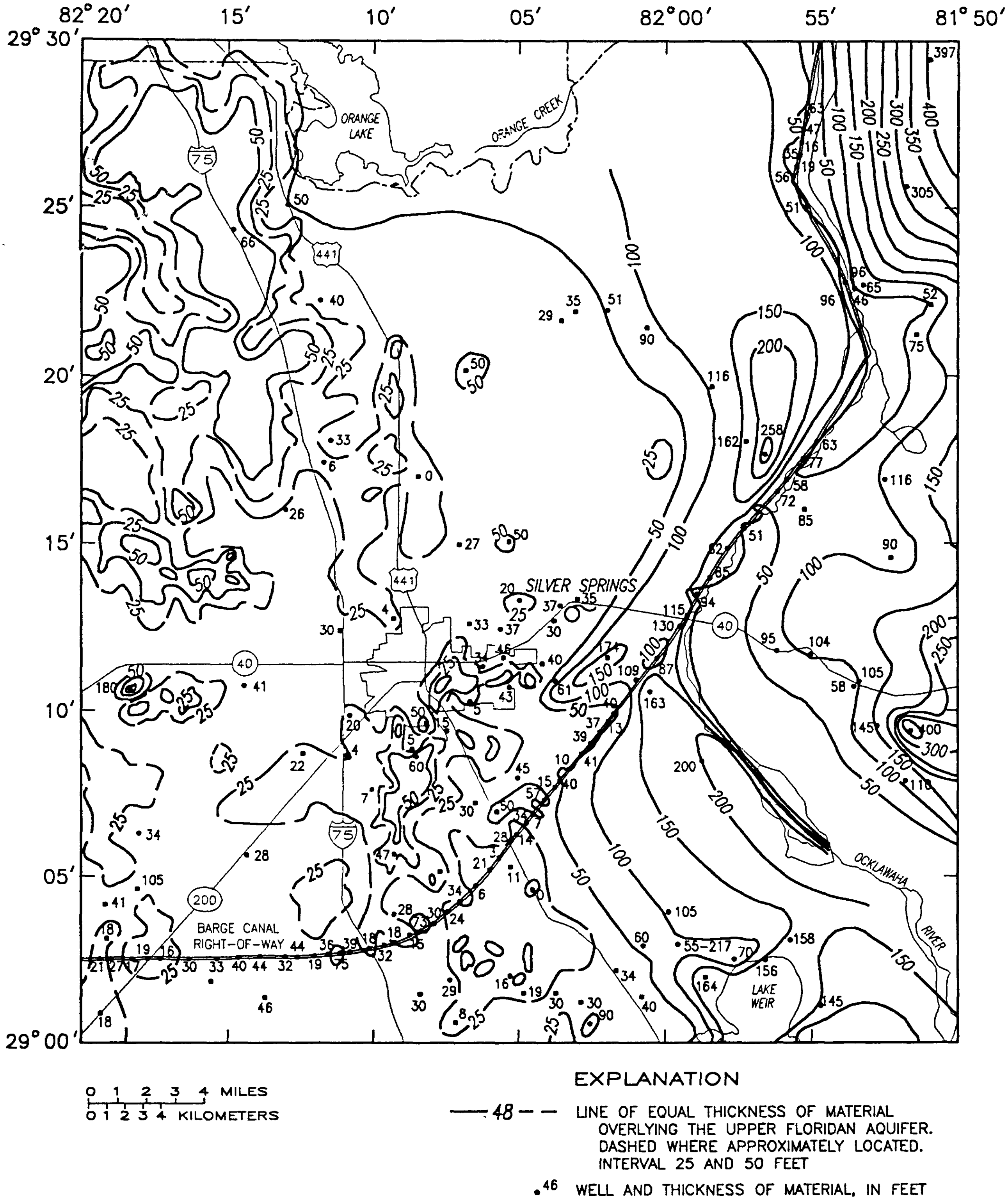


Figure 4. Thickness of sediments overlying the Upper Floridan aquifer, central Marion County (from Faulkner, 1973, fig. 15).

Structure

Two regional physiographic features are significant in Marion County, the Peninsular Arch and the Ocala Uplift. The Peninsular Arch is believed to have been formed in the Mesozoic geologic era by stresses in the Earth's crust which caused gentle upward warping of the floor of the Coastal Plain (Faulkner, 1973, p. 26). The Peninsular Arch is the primary structural control for sedimentary rocks laid down during Cretaceous and early Tertiary time. The axis of the arch runs from northwest to southeast through eastern Marion County. Later in geologic time, another smaller uplift occurred to the west of the Peninsular Arch, causing upwarping of early Tertiary rocks. The axis of this uplift, the Ocala Uplift, occurs in western Marion County and runs roughly parallel to that of the Peninsular Arch.

As the Ocala Uplift developed, probably as a result of sedimentational processes (Miller, 1986, p. B11), tensional stresses in the rock strata at the top and down the sides of the Ocala Uplift caused the formation of fractures and possibly some normal faults in the Tertiary rocks. Vernon (1951, p. 47-52) was the first to map two conjugate sets of fractures which intersect at nearly a right angle. The primary set of fractures parallels the axis of the Ocala Uplift; Vernon concluded that many of the fractures were actually faults with vertical displacements of 100 ft or more (Faulkner, 1973, p. 40). The traces of fractures and possible faults as interpreted by Faulkner from aerial photographs are shown in figure 5.

Numerous cavern systems exist in the Ocala Limestone in Marion County, most of which are oriented along one or the other of the fracture systems (Faulkner 1973, p. 43). This observation was confirmed through analysis of maps of dry-cave systems in the study area. When the water table was higher than at present, the fractures were the easiest path of flow for the ground water. Flow of water (rich in carbon dioxide) through the fracture systems resulted in further dissolution of the rock surrounding the existing fractures and increased the size and innerconnection of the fractures. Extensive fracture systems are apparent in the limestone near land surface and, based on interpretation of well logs, in the rocks at depth. Millions of years ago, extensive cavern systems were formed when the deeper rocks were near land surface. The same processes are still occurring.

The fracture system also influenced the locations of the Oklawaha River and Silver Springs (fig. 1) (Faulkner, 1973, p. 43-44). Faulkner concluded that the river valley and the area to the east of it have been structurally lowered. As a result, low-permeability sediments of the Hawthorn Formation are present east of the river but have been eroded from the higher areas to the west. The apparent down-faulting of the sediments east of the river resulted in these low-permeability beds of the Hawthorn Formation blocking eastward flow of ground water in the underlying limestone. The ground water surfaced in what is now Silver Springs.

Hydrology

The dominant hydrologic feature of Marion County is Silver Springs, one of the largest freshwater springs in Florida. Silver Springs discharges on average about 800 ft^3/s or about 525 Mgal/d from the Upper Floridan aquifer (U.S. Geological Survey, 1989, p. 120). Delineated on the basis of the potentiometric surface of the Upper Floridan aquifer, the Silver Springs ground-water basin comprises about 3,000 mi^2 in north-central Florida and includes a major part of Marion County and small sections in Alachua, Putnam, and Sumter Counties (fig. 1). Generally, ground-water and surface-water basins in the study area do not coincide. Because the delineation of a ground-water basin is made on the basis of the potentiometric surface of the Upper Floridan aquifer, the delineation of the ground-water basin can change seasonally. Locally, Miocene and younger sediments may be thick and permeable enough to form a surficial aquifer, but generally, such aquifers are of very limited extent and importance.

Surface Drainage

Surface drainage in the northern part of the Silver Springs basin differs from that in the southern part. The northern fourth of the basin (about 500 mi^2) is drained by Orange Creek, which has a flow equivalent to about 5 in/yr of runoff (Clark and others, 1964, p. 56-60), whereas in the southern part there is little, if any, surface drainage west of the Oklawaha River. Rather, almost all of the drainage is internal by direct infiltration into the limestone, which is at or near land surface throughout much of the basin. That part of the rainfall that does not recharge

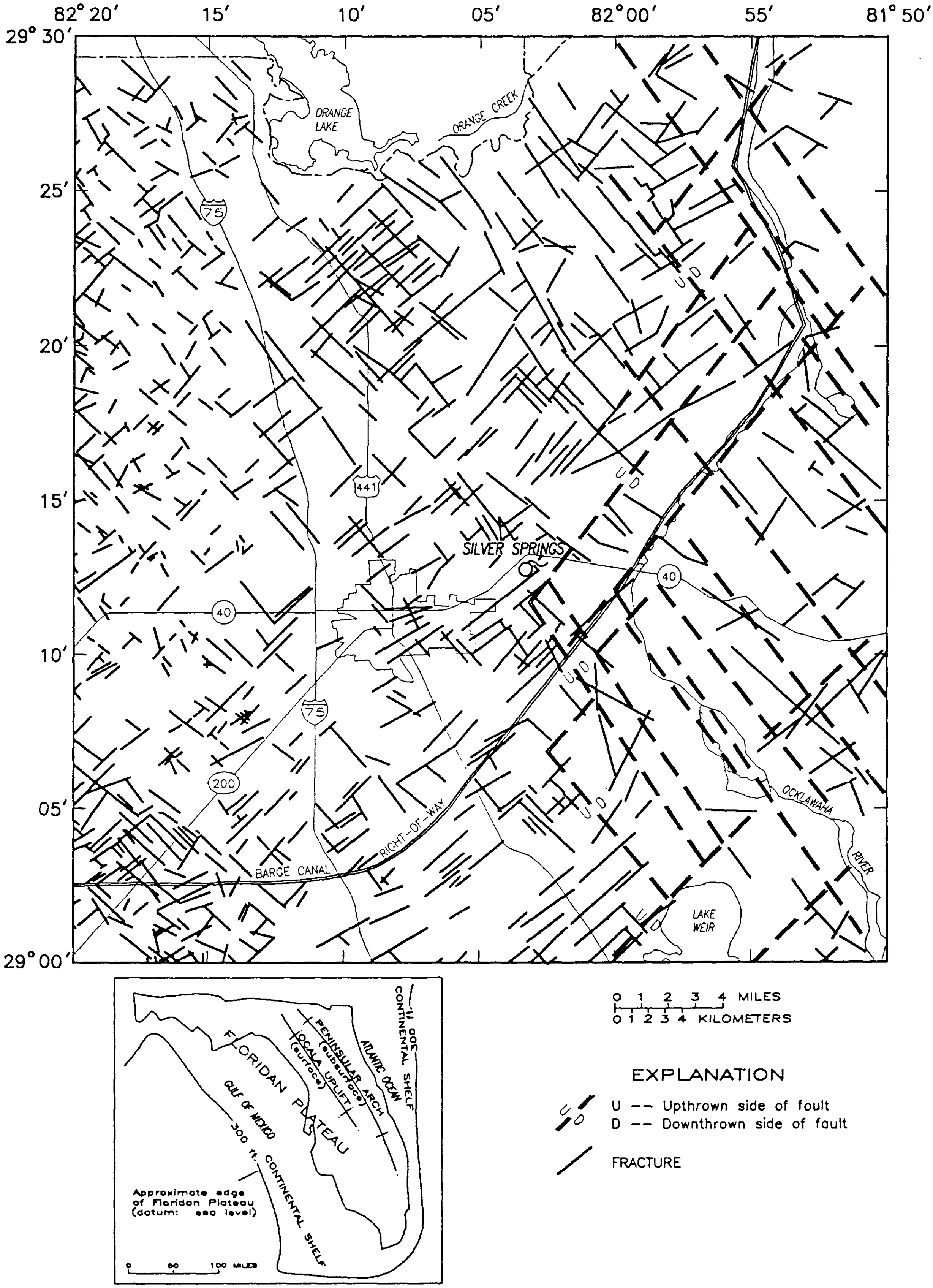


Figure 5. Fracture traces and possible faults as interpreted from aerial photographs, central Marion County (from Faulkner, 1973, figs. 8 and 18).

the limestone aquifers leaves the basin by evapotranspiration.

There are several large lakes (greater than 1,000 acres in area) in the basin, including Lake Weir, Orange Lake, and Lochloosa Lake. Some of the lakes are perched on materials of low permeability overlying the limestone, but others (such as Orange Lake) have a direct connection to the limestone aquifer.

In most of the basin, the mature karst terrane is characterized by numerous closed sinkhole depressions which have permeable bottoms and do not hold water. Sinkholes are actively forming in the basin, especially in areas in which some of the overburden has been excavated from the limestone to create detention or retention areas. Sinkhole activity is much less prevalent east of the Oklawaha River, where the Hawthorn Formation is continuous, than west of the Oklawaha River.

Upper Floridan Aquifer

The Oldsmar and Avon Park Formations and the Ocala Limestone, all of Eocene age, comprise the Upper Floridan aquifer, which in the Silver Springs basin ranges from about 1,000 to 1,500 ft in thickness (Faulkner, 1973, p. 58). Thayer and Miller (1984) determined from thin sections of five samples that the porosity of limestone from the Upper Floridan aquifer in central Florida ranges from 15 to 40 percent. Because of the significant porosity of the limestone, flow in the Upper Floridan aquifer occurs in both the rock matrix and in fractures and conduits, unlike the karst in older limestones elsewhere in the world (where virtually all of the flow occurs in fractures or conduits, rather than in the rock matrix).

Transmissivity of the Upper Floridan aquifer is a function of primary and secondary porosity of the aquifer. Secondary porosity features resulting from solution channels enhance permeability but, because of their irregular distribution, the transmissivity of the aquifer varies widely. Transmissivity values calculated from three aquifer tests of the upper 100 ft of the aquifer ranged from 6,200 to 29,500 ft^2/d. Specific capacities at three test sites in the area ranged from about 30 to 4,750 (gal/min)/ft of drawdown (Tibbals, 1975, p. 27). Vertical hydraulic conductivities calculated for the Ocala Limestone from aquifer tests about 80 mi southeast of Ocala, ranged from about 20 to about 350 ft/d (Tibbals, 1977, fig. 14).

Transmissivity values calculated from flow nets represent the full effective thickness of the aquifer and include the effects of large solution channels, the orientation of which is probably controlled by the regional fracture patterns (fig. 4). Transmissivities calculated from flow nets ranged from 10,700 to 25,500,000 ft^2/d with an average value of 2,000,000 ft^2/d (Faulkner, 1973, p. 95).

In areas where the Hawthorn Formation is present (fig. 3), the Upper Floridan is confined by overlying less permeable sediments and the water levels in wells drilled into the aquifer rise above the top of the aquifer. However, in most of the basin the Hawthorn is very thin or absent and the Upper Floridan is not confined.

Potentiometric surface

Potentiometric surfaces for the Upper Floridan aquifer in May 1989 and September 1990 are shown in figures 1 and 6, respectively. The potentiometric surface of the aquifer is the altitude to which water levels will rise in tightly cased wells, regardless of whether the aquifer is confined or unconfined. Generally, water moves through the aquifer from areas of high potential to areas of low potential and at right angles to the potentiometric contours. The cone of depression caused by the discharge of Silver Springs is the dominant feature of the potentiometric surface in most of the basin. A low gradient on the potentiometric surface throughout most of the area is the result of the high transmissivity of the aquifer.

The potentiometric surface commonly is lower in May than in September because rainfall is relatively sparse from November through early May. Rainfall at Ocala in 1988 and 1989 differed by less than 2 in. from the 30-year average of 53.86 in/yr (National Oceanic and Atmospheric Administration, 1988-90). However, rainfall from May through September 1990 was about 11 in. below average. Thus, the potentiometric surface in September 1990 was lower than that in May 1989 and May 1990. Although the altitude of the potentiometric surface normally fluctuates seasonally about 5 to 6 ft, there does not seem to be a long-term decline in the surface when compared to potentiometric-surface maps constructed by Faulkner (1973, figs. 23-26) in 1968.

The potentiometric surface and water levels in individual wells respond to changes in the amount of rainfall. Hydrographs for three wells with long-term

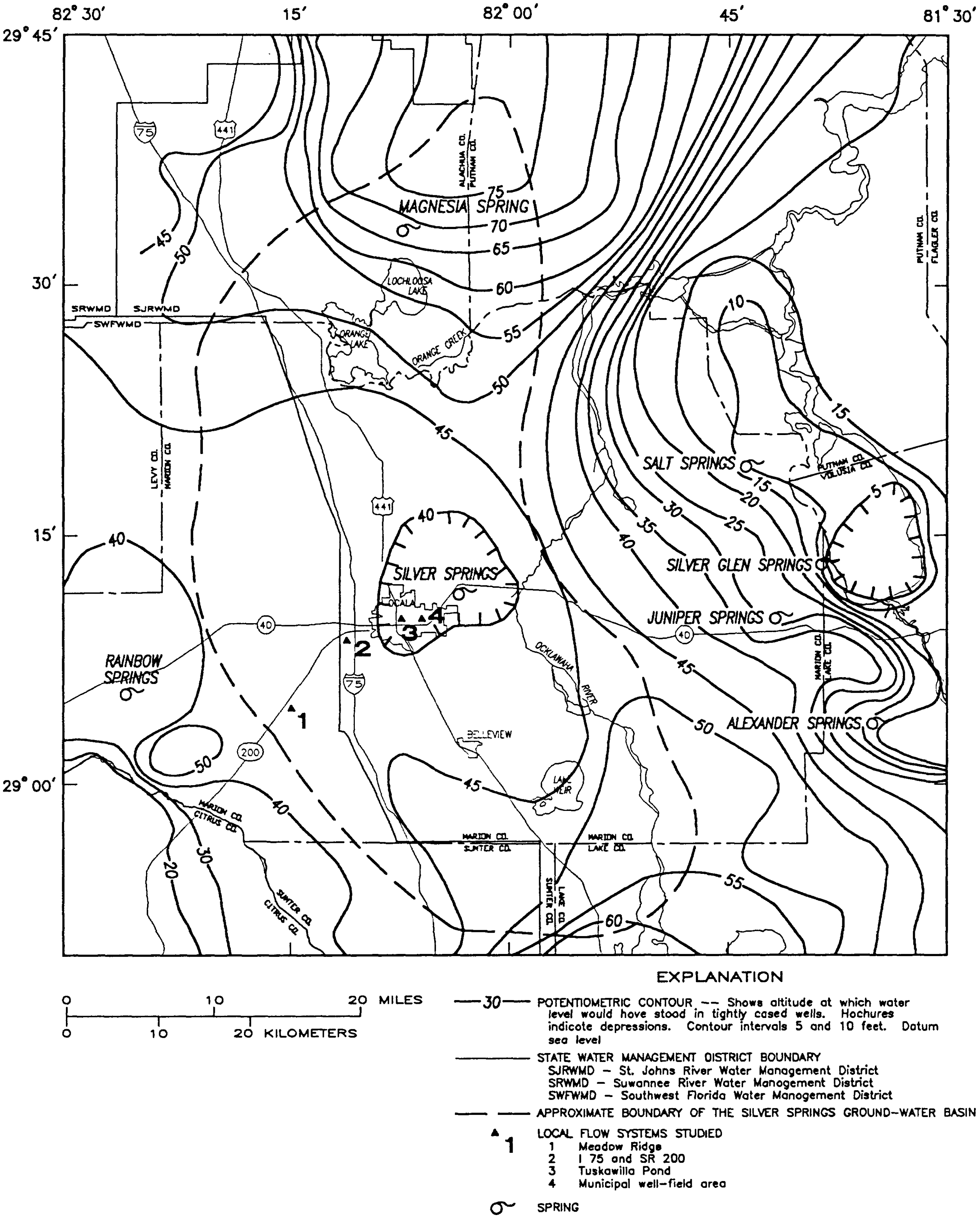


Figure 6. Potentiometric surface of the Upper Floridan aquifer, Marion County and adjacent areas, September 1990 (modified from Spechler and others, 1991),

recorc are shown in figure 7 (well locations are shown in fig. 1). In 1981 and 1982, the years of greatest fluctuation, the water level in well B (near the western edge of the basin) fluctuated the most, about 10 ft, whereas the water levels in wells C (near Silver Springs) and D (near the Oklawaha River) fluctuated about 6 ft. Rainfall at Ocala in 1981 was 46.21 in. (7.65 in. below average), whereas in 1982, rainfall was 74.71 in. (20.85 in. above average).

Discharge

Periodic discharge measurements from Silver Springs have been made since 1906 (Rosenau and Faulkner, 1975, table 2). The average discharge from the spring for 57 years of record is 811 ft^3/s (525 Mgal/d) (U.S. Geological Survey, 1989, p. 120). Minimum discharge for the period is 539 ft^3/s (348 Mgal/d) on May 7, 1957, and the maximum recorded discharge of 1,290 ft^3/s (833 Mgal/d) occurred on each of 7 days in October 1960. The yearly mean discharge of Silver Springs is shown in figure 8. Silver Springs is considered to have a slow response to precipitation compared to springs in other types of geohydrologic settings (White, 1988, p. 187). This may be because of the size of the drainage area, the difference between the primary and secondary porosity of the aquifer, and the large amount of storage in the nonartesian parts of the aquifer in much of the basin.

In addition to Silver Springs, ground water in the basin discharges from Magnesia Spring north of Orange Lake (fig. 1) which is a third-magnitude spring with an average discharge of less than 10 ft^3/s (6.46 Mgal/d). There does not seem to be ground-water outflow from the basin other than that of Magnesia Spring and Silver Springs.

Withdrawals from all wells in Marion County averaged about 42 Mgal/d in 1987, the most recent year for which water-use data have been compiled (Note: all water-use data were supplied by R. Marella, U.S. Geological Survey, written commun., 1991). As of January 1989, the St. Johns River Water Management District had issued permits for about 120 public-supply wells in central Marion County and the Southwest Florida Water Management District had issued permits for about 300 public-supply wells in western Marion County. A public-supply well is defined as a well that serves 5 or more families or more than 25 people. The locations of these public-supply wells are shown on plate 1.

The withdrawals from public-supply wells in 1987 included about 7 Mgal/d from the city of Ocala municipal well field and about 6 Mgal/d from privately owned water utilities. Additionally, about 15 Mgal/d was pumped from private domestic wells in areas not served by public supply and about 14 Mgal/d was used for agricultural and industrial self-supply. In 1987, about 82,500 people in Marion County were served by a utility company, whereas about 92,500 people obtained their water from individual domestic wells.

Water use for public supply and domestic self-supply in Marion County has increased in recent years because of an increase in population. In 1980, water use for public supply and domestic self-supply was about 14 Mgal/d. Water use for that purpose had doubled to about 28 Mgal/d by 1987. According to figures from the U.S. Census (University of Florida, 1991), the population of Marion County increased from about 122,000 in 1980 to about 195,000 in 1990, an increase of about 60 percent. At the same time, ground-water use for agricultural purposes has decreased from about 20 Mgal/d in 1980 to about 13 Mgal/d in 1987. The decrease is probably because of changes in land use from agricultural to urban, decreases in agricultural activities following severely cold winters in the early 1980's, and the use of more efficient irrigation techniques.

The total discharge from the Upper Floridan aquifer in the central part of the Silver Springs basin is about 570 Mgal/d, about 92 percent of which is discharge from the spring. Some of the water withdrawn from wells tapping the aquifer may return to the ground-water system through infiltration of water from treatment plants or drain fields, and through irrigation. Discharge by evapotranspiration is included in the net recharge rate that is estimated in the following discussion.

Recharge

Most of the recharge to the aquifer is by percolation of rainfall into the ground within the basin and by flow into sinkholes connected directly to the aquifer. Flow into a sinkhole in Orange Lake on November 21, 1957, was measured to be 12 Mgal/d (Clark and others, 1964, p. 60). Bush (1982, fig. 5) estimated the annual rate of recharge in the basin to be between 15 and 20 in/yr. If the recharge rate were

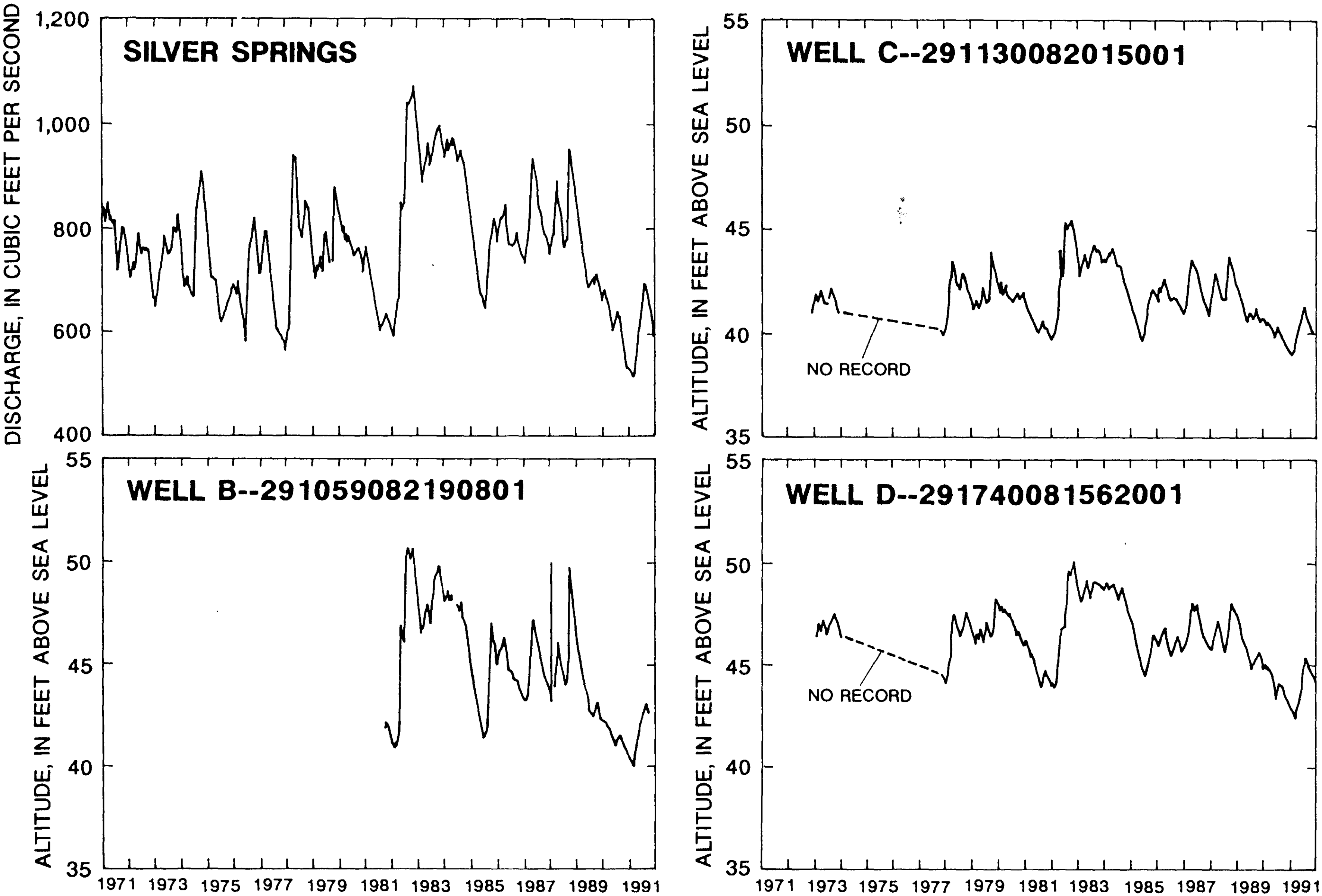


Figure 7. Discharge of Silver Springs and water levels in selected wells, 1971-90. (Well locations are shown in fig. 1.)

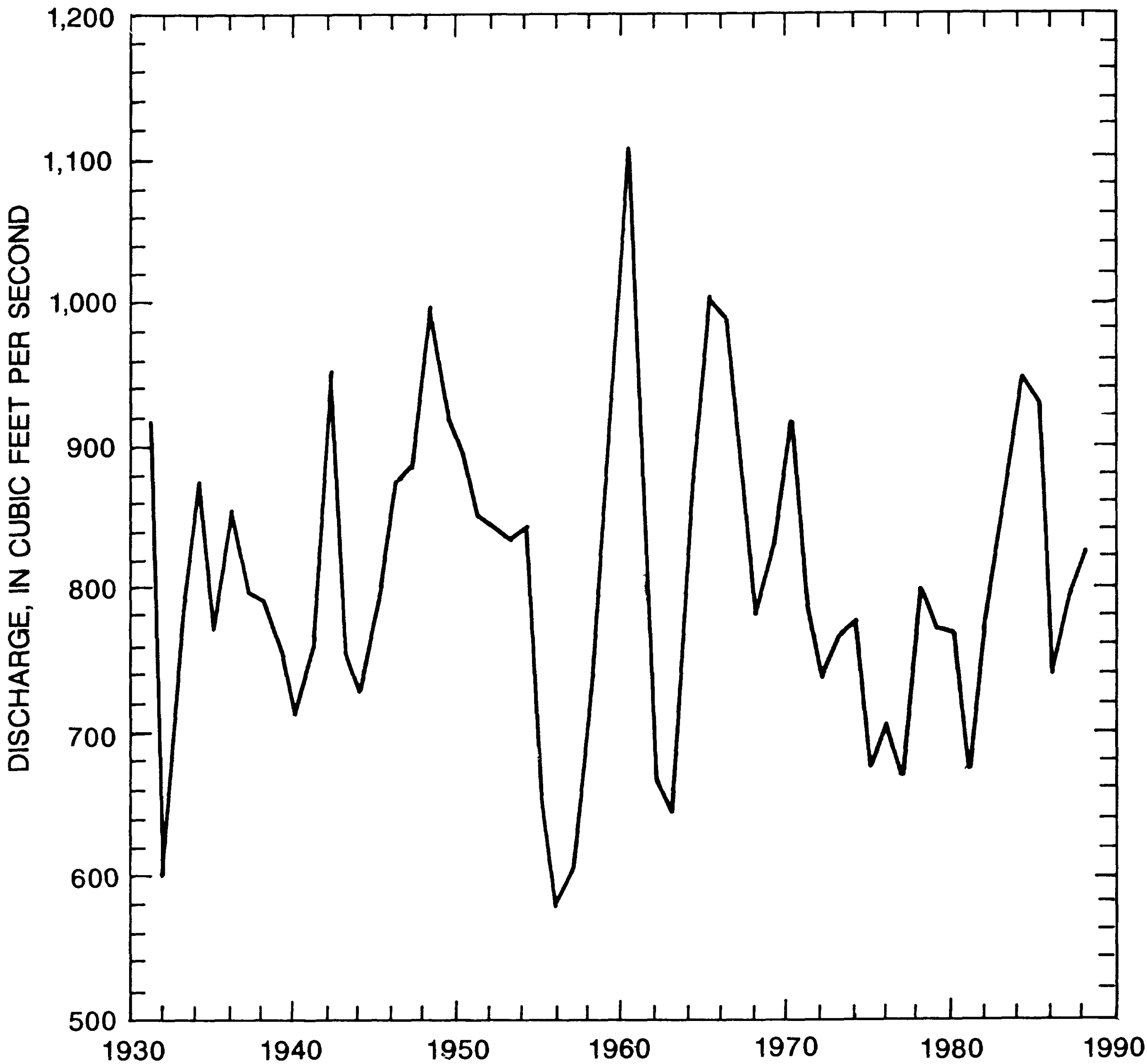


Figure 8. Yearly mean discharge of Silver Springs, 1930-89.

20 in/yr, a recharge area of about 550 mi^2 would be required to provide the average discharge from Silver Springs; if the recharge rate were 15 in/yr, the area required would be about 734 mi^2. Thus, about half the total basin area is able to support the average discharge of Silver Springs.

Additional recharge also occurs through drainage wells drilled into the aquifer to dispose of excess surface water. Records are available for about 40 drainage wells in the Ocala area of central Marion County (fig. 9 and table 1). Estimating the amount of recharge occurring through drainage wells is difficult because most receive water only during or shortly after storms. Kimrey and Fayard (1984, p. 36-43) report that in the Orlando area a total of about 390 drainage wells contributed about 30 to 35 Mgal/d to the aquifer, an average of 80,000 to 90,000 gal/d per well. The result of multiplying the number of active drainage wells by 90,000 gal/d is 4.5 Mgal/d, which probably represents the upper limit of possible recharge through drainage wells in the Ocala area.

POTENTIAL SOURCES OF CONTAMINATION AND PATHWAYS OF ENTRY INTO THE AQUIFER

A variety of potential contaminants can enter the Upper Floridan aquifer through natural and manmade pathways. Some sources of contamination include surface runoff, leaking underground storage tanks, discharges from wastewater treatment plants and drain fields and leachate from landfills. Pathways of entry into the aquifer include seepage through surficial sediments, sinkholes and drainage wells.

Sources

The types of contaminants that enter the aquifer in surface runoff generally depend on land use. In agricultural areas, fertilizer, pesticides, or livestock wastes in runoff are prevalent. In urbanized areas, metals and hydrocarbons in street runoff are likely. In both urban and agricultural runoff, bacteria and viruses probably exist in recharge water.

Commercial activities also may be the source of some contaminants in surface runoff. As of October 1990, FDEP had inventoried about 160 sites in Marion County which potentially contained hazardous materials. These sites are plotted on plate 2. Such materials are often the product or byproduct of manufacturing, or are the result of cleaning or degreasing processes. A few of the inventoried sites are nonhandlers of hazardous materials, but remain in the files because of the activities on the site, such as companies involved in agricultural or transportation activities. Some of these companies are no longer in business and usually it is not known if inactive businesses still have hazardous materials onsite. Many of the sites inventoried by FDEP generate small quantities of materials such as solvents, paints, oil and gasoline wastes, or chemicals. A few of the sites generate, store, treat, or transport larger quantities of hazardous materials and wastes. The site types range from drycleaning and automobile body repair shops to a defunct manufactured-gas plant site.

There also is the possibility of a chemical or hydrocarbon spill (either at a storage or usage site or while in transit) which can be washed into the aquifer along with the runoff. The locations of accidental spills of hazardous materials reported to date to FDEP are also shown on plate 3. Most accidental spills of hazardous materials are related to motor vehicle accidents during transit.

Nearly all underground storage tanks in the study area are used for gasoline or fuel oil. These tanks may pose a significant threat as a potential source of ground-water contamination, despite Protections that require monitoring wells near tanks and improved methods of accounting for fuel as it is delivered and sold. It is estimated that 20 to 40 percent of all underground storage tanks leak and 40 percent of the tanks removed because of leaks have more than five holes (Ten Broeck, 1984, p. 3). Incidents such as the contamination of municipal wells in Belleview in 1982 have raised awareness of the problem in the Silver Springs basin.

In October 1990, permits for 165 sites containing underground storage tanks were on file with the FDEP. These sites are shown on plate 3. The locations of these sites were not field checked.

Free-petroleum product can often be recovered when detected; however, a fraction of the product which has leaked from underground storage tanks is water soluble. The most common water-soluble compounds are benzene, toluene, and xylenes (BTX), which are toxic (Barker and others, 1987, p. 64).

Sites where treated wastewater is either applied to the surface of the land (spray irrigation), or is discharged to surface water, can also be sources of

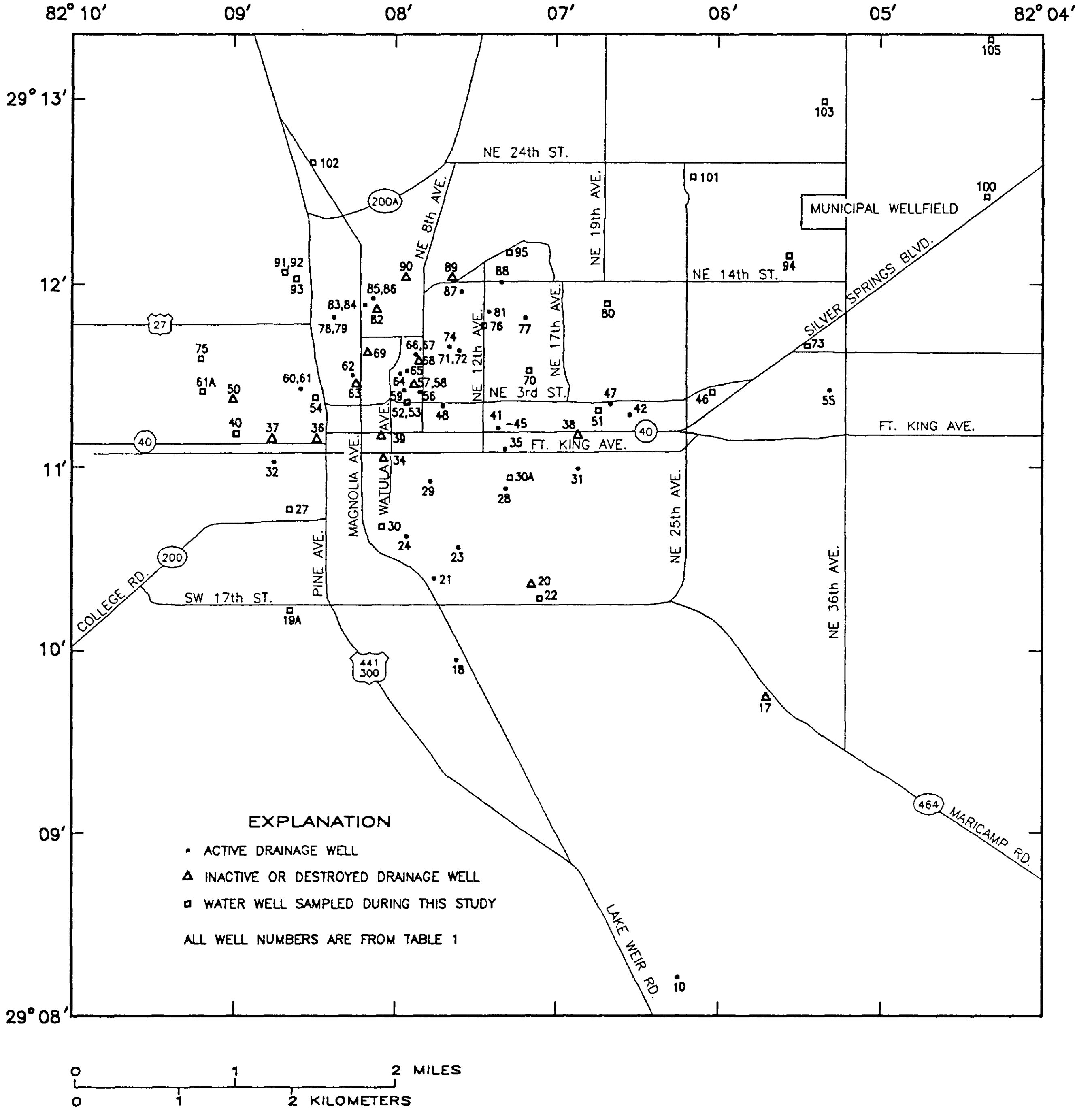


Figure 9. Locations of drainage wells and wells sampled in the Ocala area.

Table 1. Inventory of selected water wells and drainage wells

[CR, county road; DW, drainage well; VISA, very intensely studied area; SR, state road; --, no data]

Well no.	Site identification number	Local identifier	Land surface altitude (feet)	Well diameter (inch)	Well depth (feet)	Casing depth (feet)	Field checked (year)	Comments
1	290238082131101	CPTI Pilot hole	75.4	13	236	34	1990	
2	290325082140701	Abandoned well 4" well nr 109th St, Ocala	86	4	--	--	1990	
3	290340082131001	16S21E32 SCE-106, R.F. Crane	87.7	4	77	--	1990	
4	290352082134901	Well at 10831 SW 67th Ave. Ocala, Oak Manor	67	4	90	--	1990	
5	290358082140201	Meadow Ridge well no.1 SW 108th St, Ocala	67.08	2	28	28	1990	
6	290358082140202	Meadow Ridge well no.2 SW 108th St, Ocala	67.91	2	33	33	1990	
7	290358082140203	Meadow Ridge well no.3 SW 108th St, Ocala	66.97	2	28	28	1990	
8	290405082140501	Well at 10650 SW69 Terrace, Ocala	70	4	90	--	1990	
9	290809082102901	Hilltop barn well CR 475A nr Ocala	122.85	4	--	--	1990	
10	290811082061701	Drain well SE corner of old Vitrafied plant	--	--	--	--	1989	
11	290813082105701	Race track well CR 475C nr Ocala	77.88	6	125	--	1989	
12	290832082105201	Main barn well CR 475C nr Ocala	101	4	--	--	1989	
13	290835082102701	6" well CR475A nr Ocala	77.57	6	--	--	1989	
14	290835082102702	4" backup well CR 475A nr Ocala	77.57	4	--	--	1989	
15	290838082103501	Yearling barn well CR 475C nr Ocala	76	4	--	--	1989	
16	290930082104501	Well at 2918 SW 34th Ave, Ocala	62	2	90	--	1990	
17	290944082054301	Dayco Rubber Co. A/C well (2 wells on site)	--	--	--	--	1990	(plugged)
18	290956082073901	DW N side of Fischer Park in manhole	--	4	27	--	1989	
19	291002082104901	CFCC 2" well at Fire Station	77	2	--	--	1989	
19A	291015082084001	Well at Rinker plant	65	--	--	--	1989	
20	291022082071001	DW 21 W side pond NE of SE 16th St & 14th Av	70.8	16	149	--	1989	(not found)
21	291024082074601	DW 41 E of pond E of Magnolia ext. at SE 3rd Av	110	--	--	--	1989	
22	291025082070401	VISA monitoring well M-0217 Clyatt Park	90	4	60	--	1989	
23	291034082073701	DW 40 SE 10th Ave at SE 12th Pl	135	--	--	--	1989	
24	291038082075601	DW 38 E end of pond at SE 11th St and 12th St N	95	8	78	62	1989	
25	291039082081901	DW N Side of NW 8th St N of cemetery in pond	--	--	--	--	1989	
26	291043082093201	VISA Monitoring well M-0205 SW 20th Ave, Ocala	70	4	40	--	1990	
27	291049082084701	VISA Monitoring well M-0208 SW 7th St, Ocala	70	4	40	--	1990	
28	291053082071901	DW 22 E side SE 13th Ave nr SE 7th St	125.3	10	129	--	1989	
29	291056082074701	DW 20 Manhole on 5th St W of SE 8th Av (Wenona)	133.5	10/6	135	129	1989	
30	291057082080201	VISA Monitoring well M-0209 SE 4th Av	115	4	35	--	1989	
30A	291058082071701	Bay well	145	--	--	--	1989	
31	291059082065201	DW 39 depression behind Forrest High Sch	115	14	340	130	1989	
32	291102082084501	DW 1 N side of SW 3rd St, manhole in pond	60.8	8	129	48	1989	
33	291102082084502	DW 1A (2nd well in manhole with DW-1)	60.8	--	--	--	1989	
34	291103082080501	DW 25 SE 2nd St (Police Station might be paved over)	103.6	12	84	--	1989	(not found)
35	291107082071901	DW 24 Manhole in sidewalk at pole, SE 13th	125.3	8	70	--	1989	
36	291110082082901	DW 2 W of Pine St, N of SW 1st St, S of Hwy 40	65	--	65	--	1989	(destroyed)
37	291110082084601	DW 5 75 ft E of SW 9th Ave (2 wells)	68.4	--	112	--	1989	(destroyed)
38	291111082065201	A/C well Mt Vernon Motel on SR 40	--	--	--	--	1989	(destroyed)
39	291111082080501	DW 42 In alley behind United Telephone	80	10	--	--	1989	(not found)
40	291111082085801	VISA Monitoring well M-0200 NW 12th Av	75	4	40	--	1989	
41	291113082072301	DW W side of NE 12th St just N of Silver Sp. Blvd.	--	--	--	--	1989	
42	291117082063301	DW 23 Adams St pond	90	18	609	106	1989	
43	291117082063302	DW 34 Adams St pond	97	18	185	41	1989	
44	291117082063303	DW 35 Adams St pond	97	4	47	--	1989	
45	291117082063304	DW 36 Adams St pond	97	4	46	--	1989	
46	291120082060001	Forestry Service well, Ocala	95	4	140	55	1989	
47	291120082064001	DW 27 S end pier in ret pond 1900 NE 3rd St(Wyomia)	90	18	154	69	1989	
48	291120082074201	DW 19 Center line NE 9th Ave 15 ft S of NE 3rd St.	82.3	8	80	--	1989	
49	291120082074202	DW 43 intersection eastbound NE 3rd St. & NE 9th Av	82	10	--	--	1989	
50	291122082090001	DW 37 W end of pond at NW 4th and 12th Av	70	10	26	12	1989	(not found)
51	291123082065001	VISA monitoring well M-0216 NE 18th Av and NE 3rd St	90	4	57	--	1989	
52	291123082075401	VISA monitoring well M-0211, Tuskawilla	80	4	30	--	1989	
53	291123082075402	VISA monitoring well M-0212, Tuskawilla	80	4	70	--	1989	

Table 1. Inventory of selected water wells and drainage wells--Continued

[CR, county road; DW, drainage well; VISA, very intensely studied area; SR, state road; --, no data]

Well No.	Site identification number	Local identifier	Land surface altitude (feet)	Well diameter (inch)	Well depth (feet)	Casing depth (feet)	Field checked (year)	Comments
54	291123082082901	VISA montoriing well M-0210 NW 4th Av	65	4	35	--	1989	
55	291124082051901	DW Ocala Municipal Golf Course S. side pond nr trees	--	--	--	--	1989	
56	291125082075201	DW pond N of City nursery on NE 3rd St	92	18	83	68	1989	
57	291125082075301	DW 12 SE corner NE 7th Av & NE 4th St (manhole)	78.8	8	49	--	1989	(not found)
58	291125082075302	DW 45 W side Sanchez (NE 7th Av) at NE 4th St.	79	8	--	--	1989	(not found)
59	291125082075701	DW 31 S end E side Tuskawilla Park under slab	70	16	214	65	1989	
60	291126082083501	DW 3 pond at NW 4th Av & 6th St	63.5	10	58	50	1989	
61	291126082083502	DW 4 pond at NW 4th Av & 6th St	64	8	73	52	1989	
61A	291126082091101	Cunningham Funeral Home well	80	4	--	--	1989	
62	291129082081501	DW 10 N side of fence on NW 6th St at 1st Av	70.1	12	95	--	1989	
63	291129082081502	DW 44 W side of fence on NW 1st Av at 6th St	70	8	88	30	1989	(not found)
64	291130082075801	DW N side old May St NE side of pond, corrugated pipe	--	--	--	--	1989	
65	291131082075501	DW 32 N end of E side of Tuskawilla Park under slab	70	12	66	42	1989	
66	291136082075201	DW 28 E of Tusk. Pk N of NW corner ball field fence	70	8	111	--	1989	
67	291136082075202	DW 29 E of Tusk. Pk W of NW corner ball field fence	70	10	--	--	1989	
68	291136082075203	DW 30 E of Tusk. Pk, manhole inside ball field	70	10	--	--	1989	(plugged)
69	291138082081001	DW 11 SE corner Magnolia at NE 8th St.	61.9	6	129	--	1989	(not found)
70	291139082070801	Highland Cemetary well	130	--	--	--	1989	
71	291139082073601	DW 14 SE end Chazel Park NE of NE 7th St & 10th Av	69.1	15	220	--	1989	
72	291139082073602	DW 13 Chazel Park	70	12	--	--	1989	
73	291140082052701	USGS well CE80 at Ocala	77.4	4	90	61	1989	
74	291140082074001	DW 14A N side Chazel Park NE of NE 7th St & 10th Av	80	3	--	--	1989	
75	291140082091401	VISA monitoring well M-0243 NW 7th St & NW 16 Ct	70	4	35	25	1989	
76	291148082072702	VISA monitoring well M-0239 NE 10th St & NE 12th Av	100	4	75	65	1989	
77	291149082071201	DW 17 250 ft S of NE 10th St,100 ft E of NE 14th Av	96	6	235	160	1989	
78	291150082082301	DW 6A pond NE of NW 10th St & NW 4th Av S side	57.2	10	123	70	1989	
79	291150082082302	DW 6B pond NE of NW 10th St & NW 4th Av S side	57.3	8	121	--	1989	
80	291151082064201	VISA monitoring well M-0215 NE 20th Av & NE 10th St	88	4	55	45	1989	
81	291151082072501	DW 16 pond N of 10th St at NE 12th Ter	85.9	8	83	68	1989	
82	291152082080601	DW 9 NE 11th Pl at Osceola	68.4	6	125	63	1989	(destroyed)
83	291154082081101	DW 7 E side Magnolia at NE 12th St in manhole	60	6	78	--	1989	
84	291154082081102	DW 7A W side Magnolia at NE 12th St under grate	60	--	--	--	1989	
85	291156082080801	DW 8 S side of NE 13th St at NE 1st St, manhole	58.3	6	181	78	1989	
86	291156082080802	DW 8A S side of NE 13th St at NE 1st St, road drain	58	6	--	--	1989	
87	291158082073501	DW 15 SW of intersection of NE 13th St & NE 11th Av	85.5	8	64	44	1989	
88	291200082072001	DW 18 Eastbound NE 14th St under pavement	78.1	3	105	--	1989	
89	291202082074001	A/C well Kerrs Grocery Store	--	--	--	--	1989	(destroyed)
90	291203082075601	Old Swift Meat Co. drainage well, basement	--	--	--	--	1989	(modified)
91	291204082083601	VISA monitoring well M-0244 NW 6th Av, Ocala	60	4	54	--	1989	
92	291204082083602	VISA monitoring well M-0194 NW 6th Av, Ocala	60	2	25	15	1989	
93	291206082084401	VISA monitoring well M-0248 STP no.1 well 4	58	2	66	66	1989	
94	291210082053301	Construction well 1530 NE 32nd Av, Ocala	70	2	--	--	1989	
95	291214082072501	VISA monitoring well M-0213 NE 16th St	65	4	25	15	1989	
96	291225082042801	AM-1 Appleton Museum test well near Ocala	65	6	178	75	1990	
97	291225082042802	AM-2 Appleton Museum test well near Ocala	65	6	180	89	1990	
98	291225082042803	AM-3 Appleton Museum test well near Ocala	65	6	150	75	1990	
99	291225082042804	AM-4 Appleton Museum test well near Ocala	65	6	180	75	1990	
100	291226082042001	Well SR40 AND NE48th Ave. Ocala	60	4	--	--	1989	
101	291235082061001	Irrigation well NE 25th Av and 24th St, Ocala	82	4	--	--	1989	
102	291239082082702	VISA monitoring well M-0177 NW Magnolia	50	4	40	--	1989	
103	291255082051701	Booster Stadium well NE 36th Av, Ocala	60	4	--	--	1989	
104	291310082045001	USGS well CE45 at Silver Springs, Fla.	51.9	4	40	20	1989	
105	291320082042301	Warehouse well 4690 NE 35th St, Ocala	70	4	100	--	1990	
106	291704082111501	Livestock market well	95	4	180	84	1990	

contaminants. There are about 50 land-application sites, ranging from about 100 ft^2 to more than 1,500 acres, and about 50 surface-discharge sites (pl. 2). As with most sites where treated wastewater is released, there is some risk of increased concentrations of nitrogen, phosphorus, bacteria, and viruses in the ground water at these sites.

Plate 4 shows nine major septic tank drain fields permitted by FDEP. These range from about 1,200 ft^2 to slightly more than 1 acre and receive drainage from septic tanks or small sewage-treatment plants. The wastewater applied to these drain fields commonly is rich in nitrogen and phosphorus and may contain bacteria and viruses.

The locations of 95 sites in Marion County containing buried wastes are shown on plate 3. Included in this listing are municipal and private landfills (both active and closed) and some construction sites where building materials were buried. Most landfills which are currently operating are designed to minimize the possibility of ground-water contamination. Old landfills, especially those whose operators are out of business, can pose a threat to ground-water quality.

Pathways

Throughout most of the central part of the Silver Springs basin, the limestone comprising the Upper Floridan aquifer is overlain by only a thin (20 ft or less) veneer of sediments. The formation of sinkholes, solution pipes, or other karst features provide numerous direct pathways for water (and contaminants) to enter the Upper Floridan aquifer.

In order to portray the spatial distribution of sinkholes in the central part of the basin, six topographic quadrangles in central Marion County were examined (Ocala East, Ocala West, Shady, Belleview, Reddick, and Anthony). The locations of topographic features which seemed to be sinkholes were digitized and replotted on the county highway map base (pl. 5).

Regional trends in the density and alignment of sinkholes are not readily apparent, but the density of sinkholes does seem to be greater to the west of U.S. Highway 441-301 than to the east. This is probably because of the distribution of the Hawthorn Formation, which has been eroded in much of the area west of U.S. Highway 441-301 (fig. 3). The thickness of sediments overlying the Upper Floridan aquifer is only about 25 ft west of U.S. Highway 441-301 and increases from 25 to 50 ft or more to the east (fig. 4).

Not all natural sinkholes provide direct conduits to the Upper Floridan aquifer. Sinkholes can become plugged with debris for long periods of time. However, loss of support from underlying rock and sediment can unplug sinkholes without warning and reactivate them as direct points of entry into the aquifer. Eventually, the bottoms of many sinkholes become filled with sediments of low permeability, reducing the potential for downward movement of contaminants.

Urbanization can accelerate the development of sinkholes if grading operations or the construction of surface impoundments removes much of the overburden covering the limestone. Also, the need to provide for drainage has prompted the clearing of plugged sinkholes in some areas.

Current practices require the construction of detention or retention ponds to receive stormwater runoff in urbanized areas. Permits for construction of these ponds are issued by the FDEP. In Marion County, about 475 acres have been developed as surface impoundments. Most of the permits are for stormwater detention or retention ponds, but a few are holding ponds at sewage-treatment plants. Distribution of surface impoundments in Marion County, based on data from FDEP permit files as of October 1990, is shown on plate 4. The data were not field checked during this study. Surface impoundments in Marion County range from less than 2,000 ft^3 to 200 acres. Surface impoundments can fail due to the development of sinkholes. These sinkholes usually are small (less than 20 ft in diameter) and generally do not appear on topographic maps.

Surface impoundments probably do not change the total amount of recharge that enters the Upper Floridan aquifer in the Silver Springs basin, but can cause the recharge to be concentrated in a smaller area than would occur under natural conditions and thus cause a local reduction in evapotranspiration. Surface impoundments constructed to receive stormwater should detain stormwater and allow it to seep slowly into the ground, thereby allowing potential contaminants to settle or to chemically break down. However, in a karst area, construction of impoundments often removes a significant amount of overburden and can accelerate the natural process of sinkhole formation, thus negating any natural cleaning of runoff which might occur in an impoundment. Also, depending on the type and concentrations of constituents in the runoff, an impoundment may not remove all of the contaminants before they enter the receiving ground water.

Drainage wells, another major pathway of contaminant entry, were drilled throughout central Florida in the early- to mid-20th century as a means of disposing excess surface water that can be a serious problem in the flat topographic conditions in most of Florida. It has long been recognized that stormwater entering the drainage wells could pose a threat to the quality of water in the aquifer. The city of Ocala is implementing a plan to reduce dependence on drainage wells by replacing them with stormwater treatment and disposal systems.

Sources of data about drainage wells include permit files from the FDEP dating back to the mid-1960's, lists compiled for the city of Ocala at various times in the past, and data from the U.S. Geological Survey files. Kimrey and Fayard (1984) made a reconnaissance of drainage wells throughout Florida, including the Ocala area. At present (1991), there are 42 active drainage wells in the central part of the Silver Springs basin.

Discrepancies noted among the various lists of drainage wells include locations and the number of drainage wells at some sites. A field inventory of drainage wells was compiled in 1988-89 to reconcile the information from the various sources. The locations of 42 active drainage wells identified during the inventory are shown in figure 9. Eleven drainage wells that had been identified in past inventories were verified as being plugged, destroyed, or modified for use other than drainage. Nine wells could not be found and apparently have been destroyed (table 1).

Rates of recharge through drainage wells are difficult to estimate because many wells receive drainage water only after heavy rains. Some of the wells at Tuskawilla Park in Ocala normally receive water at about 2 to 3 ft^3/s, but after heavy rains, the recharge rate is higher. Because of the shallow depth to the underlying limestone in the Silver Springs basin and the lack of integrated surface drainage, it has generally been assumed that any precipitation not lost to evapotranspiration recharges the Upper Floridan aquifer. Thus, the recharge through drainage wells probably does not significantly increase total recharge to the Upper Floridan aquifer, as it does in areas where a relatively thick confining layer overlies the aquifer. Instead, the effect of drainage wells is to concentrate the recharge at point locations whereas natural recharge takes place over a larger area. This effect might result in a slight lowering of the water table in areas where runoff is routed to remote drainage wells, and subsequently, in a slightly reduced rate of evapotranspiration.

HYDROGEOLOGY OF SELECTED LOCAL FLOW SYSTEMS

As discussed in the previous section, there are many potential sources of ground-water contamination within the Silver Springs basin. Understanding the movement of such materials, if and when they enter the aquifer, requires study of the flow system in the basin. Because of the importance of subsurface karst features such as solution channels and pipes, the methods used for analyzing flow in homogeneous porous media may not be applicable to the Silver Springs basin, or if used, the user must be aware that the results may only be an approximation.

The regional potentiometric-surface maps, which have contour intervals of 5 ft (figs. 1 and 6), show a low gradient in the Silver Springs basin, indicative of a uniform flow system that discharges at Silver Springs. However, a more complex flow pattern is indicated by a potentiometric-surface map for May 1968 (fig. 10) which has 1-ft contour intervals (Faulkner, 1973, fig. 25). This map shows that the cone of depression is irregularly shaped and not centered around Silver Springs, probably as a result of transmissivity variations caused by flow through well-developed conduits. Because water-level measurements made in 1990 and 1991 indicate no long-term change in the altitude of the potentiometric surface, the shape of the cone of depression mapped by Faulkner is probably representative of present conditions.

To help increase understanding of the ground-water flow system in the basin, four local flow systems within the main study area were studied in detail. The locations of these sites are shown in figure 6. The methods of investigation used at each site varied depending on such factors as site geology and degree of urbanization, the number and accessibility of nearby wells, and the type and

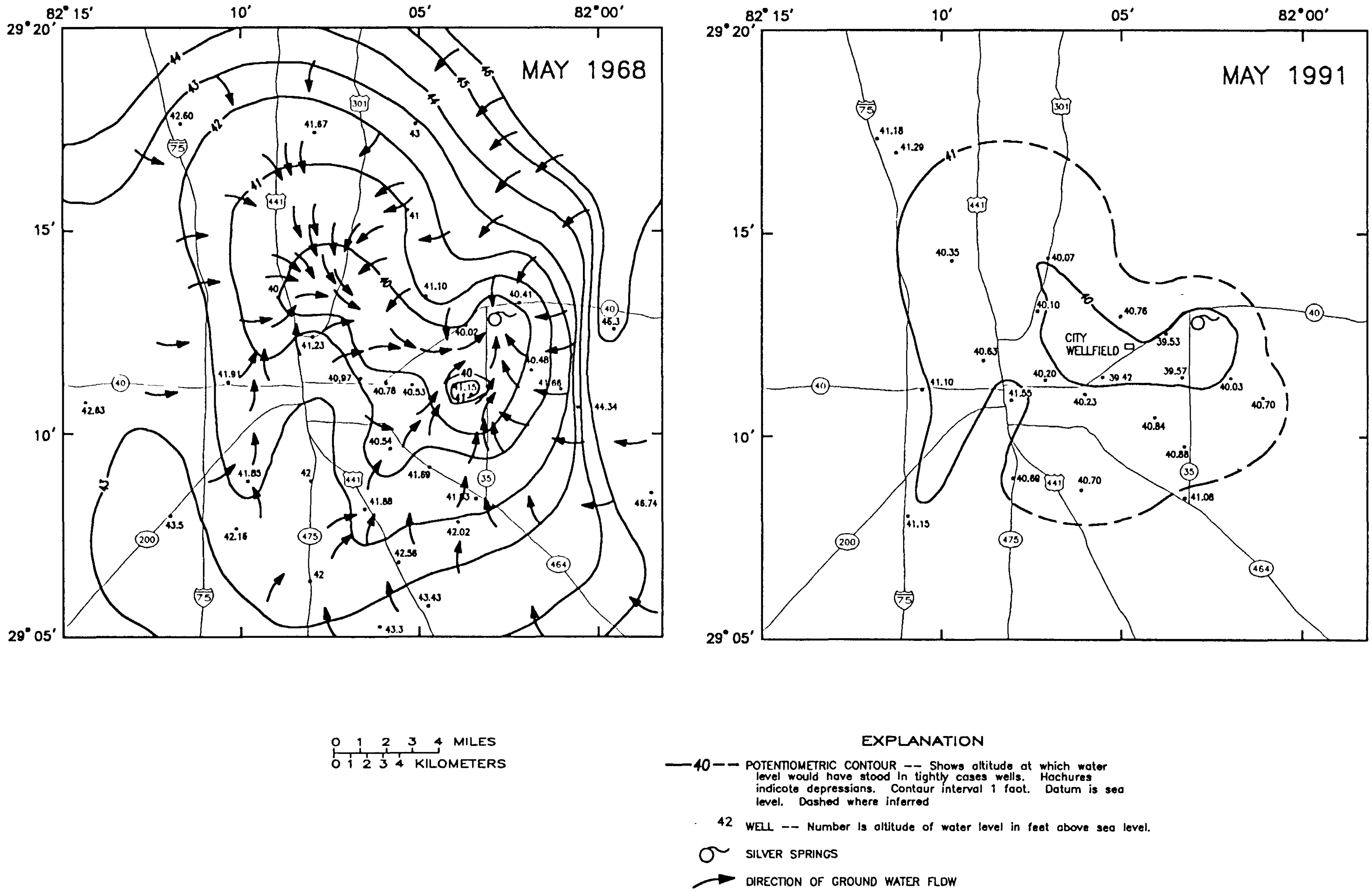


Figure 10. Flow patterns in the Upper Floridan aquifer and potentiometric surfaces of 1968 and 1991 (modified from Faulkner, 1973, fig. 25).

proximity of potential contamination sources. Several different surface geophysical methods were used at some sites to ascertain their suitability in mapping fractures or conduits. At other sites, interference from cultural features precluded the use of surface geophysics. Well inventories and, where possible, test drilling provided a network of wells from which to obtain samples for chemical analysis. Finally, analytical models of capture zones and dye traces were used to calculate ground-water flow velocities and directions for some local flow systems.

Surface Geophysical Methods

Surface geophysical methods can be used to map anomalies or changes in the properties of subsurface materials from which the subsurface hydrogeology can sometimes be inferred. Commonly measured properties include the velocities of sound (seismic) or electromagnetic (radar) waves through the earth, or variations in the earth's electrical, magnetic or gravitational fields. Ground-penetrating radar (GPR) and two electromagnetic (EM) methods were used in this study.

GPR uses a beam of radio waves. The beam is transmitted through the earth by an apparatus which also contains an antenna that receives waves reflected from the subsurface materials. The velocities of the reflected waves depend on the type of material present and whether or not it is saturated with water (Ulriksen, 1982, p. 22). The water table, changes in rock types, and voids in the rock appear as reflectors on a strip chart. The electrical signals are recorded so that electronic filtering can be used to aid in the analysis of the data. The frequencies of GPR waves range from 80 to 300 Megahertz (MHz), depending on the depth of penetration desired. The maximum depth to which GPR can be utilized, under ideal geologic conditions, is about 100 ft. The GPR antenna can be pulled by hand across a site, but for large sites it is usually pulled by a vehicle. Two people are needed to conduct a GPR survey. An SIR System 8 unit, manufactured by Geophysical Survey Systems, Inc., Hudson, N.H., was used in this survey.

Electromagnetic methods measure variations in induced electromagnetic fields that can be interpreted to infer variations in electrical conductivity of subsurface materials. For this study, electromagnetic surveys were run using EM-34 and EM-16 equipment manufactured by Geonics Limited, Mississauga, Ontario, Canada. The EM-34 has two coils, one of which transmits electromagnetic signals which induce magnetic fields in the underlying earth that are proportional to the conductivity of the earth materials. The other coil acts as a receiver. By varying the spacing and orientation of the coils, the conductivity of the materials at depths up to about 120 ft can be inferred. Two people are needed to conduct EM-34 surveys.

The EM-16 makes use of the very low frequency (VLF) radio waves used to transmit signals to submarines. At distances greater than 500 mi from the transmitter, the radio waves are plane waves perpendicular to the surface of the earth. The radio waves induce electromagnetic fields in the earth, the orientation of which are influenced by variations in the electrical conductivity of the subsurface materials. The EM-16 apparatus allows the orientation (tilt angle) of the induced field to be measured. When the measurements are made over several lines of survey, changes in subsurface conductivity can be inferred. The greater the contrast in conductivity between the target and the surrounding materials, the more successful are the interpretations of both the EM-34 and the EM-16. The EM-16 apparatus is smaller than the EM-34 and can be used by one person. Both methods are subject to interference from buried utility lines, chain-link fences, and overhead power lines.

Meadow Ridge Subdivision

The Meadow Ridge subdivision is south of Ocala and west of State Road (SR) 200 (fig. 6). Faulkner (1973) concluded that the divide between the Silver Springs and Rainbow Springs basins migrates seasonally, so the Meadow Ridge area was investigated to delineate the western boundary of the basin. Also, the site provided a potential opportunity to monitor direct recharge of surface runoff into the aquifer through a sinkhole. A surface impoundment in the area failed because of a sinkhole in the bottom of the impoundment. GPR, test drilling, and a dye trace were used to investigate the local flow system.

GPR was used at the site to determine the depth to the top of limestone and to evaluate the potential for using the technique to provide information about subsurface fractures or potential sinkholes. The technique was useful in determining depth to the top of limestone, but did not provide any information about fractures or sinkholes, either because these features were not present or because they were not large enough to be detected. The lines of GPR profiles near the Meadow Ridge sinkhole are shown in figure 11 and the profiles along these lines are shown in figure 12.

An inventory was made of wells in the area. Water supply to homes in the Meadow Ridge subdivision is provided by a utility company, but homes in subdivisions to the west and north of the area are supplied by individual wells. The area to the south and southwest is mostly undeveloped.

Three 2-in. diameter monitoring wells, ranging from 28 to 33 ft deep, were drilled near the sinkhole in April 1990. Records at Ocala indicate no rainfall recharge to the ground-water system for several days before the measurements were made. Water levels in these wells in May and September 1990 and February 1991 were:

Date	Altitude of water level (ft)		
	Well 5	Well 6	Well 7
5-01-90	42.38	42.34	42.47
9-10-90	42.15	42.11	42.12
2-20-91	40.48	40.41	40.45

The gradient is very low (about 3×10^{-4}) and water-level differences of only a few hundredths of a foot from one well to another could be within the range of error for the measurements. However, based on water levels, the direction of flow seemed to be to the southwest or south, away from Silver Springs.

A dye trace was run at the site in February 1991 using fifty mL of Rhodamine WT diluted in 30 gal of water. The dye was poured into the sinkhole, followed by a flow of water through a 2-in. diameter hose for 12 min (about 200 gal). Because the dye was expected to move to the southwest, a sampling pump was placed in well 6 (fig. 11) and pumped at 1 gal/min for 3 hours after the dye was poured into the sinkhole. Samples were collected at 10- to 15-minute intervals from the pumped well and samples were bailed from wells 5 and 7 at the same intervals. One bailer was dedicated to each of the wells so there would be no possibility of cross contamination. The samples were analyzed in the field using a fluorometer.

When it became apparent that the flow velocity was low, the sampling intervals were lengthened. Qualitative, rather than quantitative, measurements were made (that is, the presence of dye above background level was measured, but actual dye concentrations and the dye-recovery curve were not calculated).

Twenty-two hours after the dye was introduced, the leading edge was detected in well 7, seemingly "upgradient" of the point of introduction. The dye concentration in well 7 peaked about 5 hrs later. Although the time from injection to peak concentration is not the true mean traveltime, it does provide a reasonable indicator of ground-water velocity (Smart, 1988, p. 448). The distance from the sinkhole to well 7 is about 38 ft, which indicates that the ground-water flow velocity was about 1.4 ft/hr. No dye was detected in wells 5 and 6.

The detection of the dye "upgradient" is probably explained by movement through fractures. The direction of ground-water flow was deduced from water levels in the three monitor wells; these water levels differed from each other by only a few hundredths of a foot. The actual heads in the aquifer (and thus the direction of the gradient) depend on a complex system of vertical and lateral heads that are related to individual fractures and conduits. The water level measured at the wellhead in a particular well is an average of all the individual heads penetrated by the well. Thus, the gradient through a particular conduit penetrated by a well can differ from the gradient estimated from the average heads at the site.

In addition to the geometry of the fracture system at a site, the direction of flow through fractures also can be related to the altitude of the water table in the aquifer. In the simplified example shown in figure 13a, if the water table is at level 1, both fractures A and B are part of the flow system. However, if the water table is at level 2, only fracture B is active in the flow system. White (1988, p. 83 and 155) compares low-gradient conduit systems to a swamp which may have numerous channels, pools, islands, and embayments. Water may flow through different channels depending on the water level in the swamp. By analogy, in a low-gradient fractured aquifer, the head in the aquifer may control which fractures the water flows through as much as does the gradient, and thus, where the tracer moves.

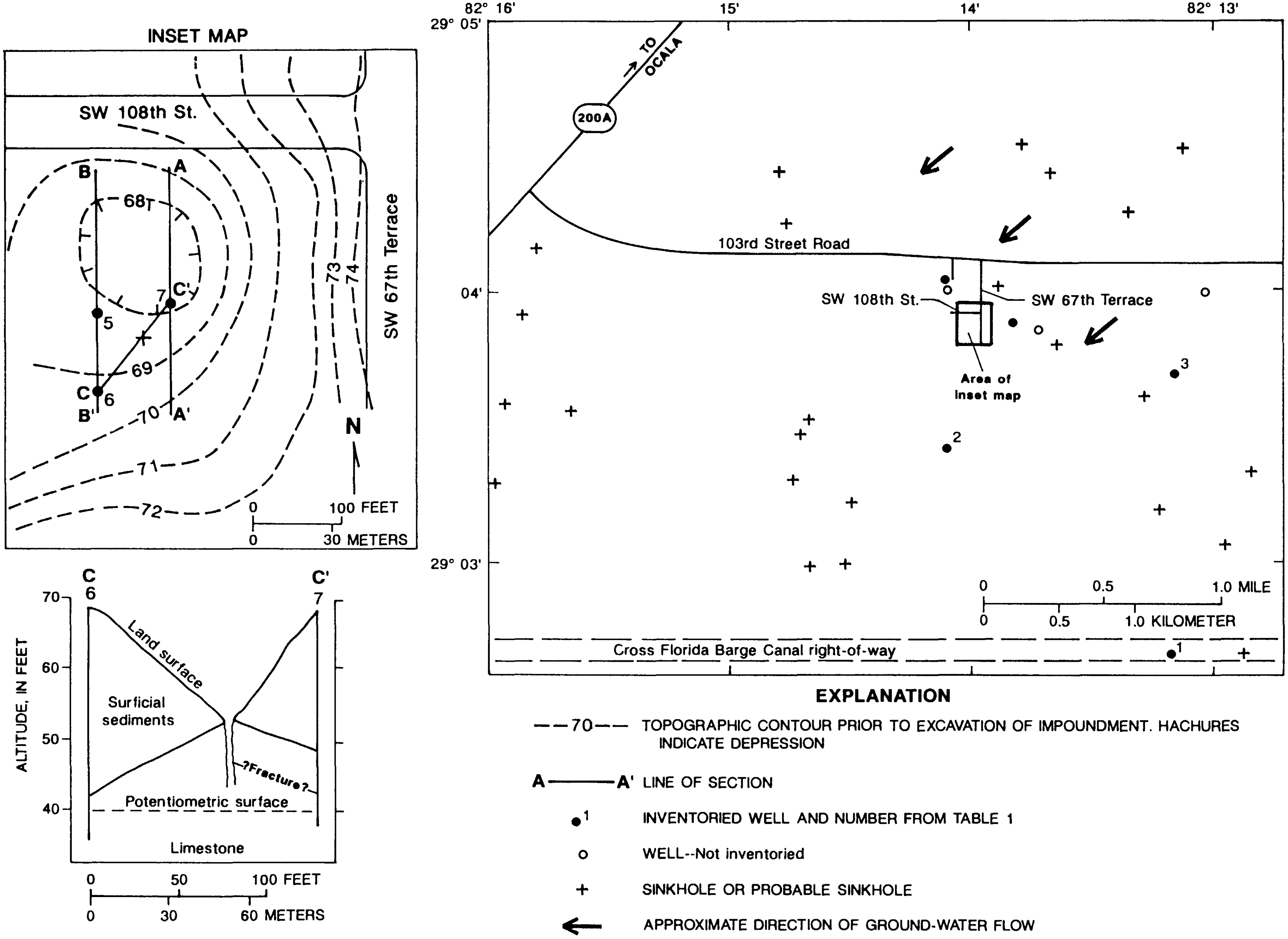


Figure 11. Meadow Ridge area and locations of wells, sinkholes, and traces of hydrogeologic sections (site location shown in fig. 6).

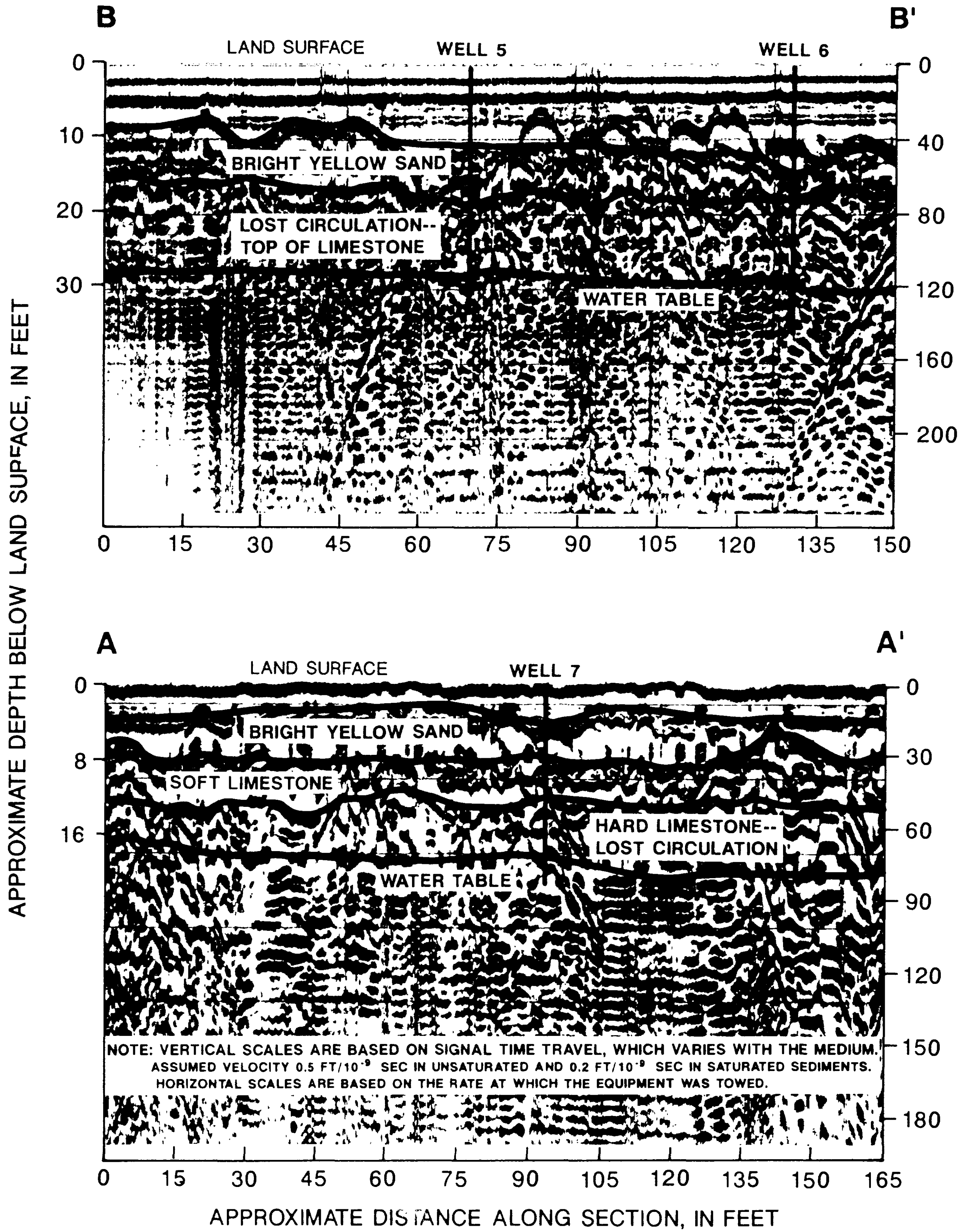


Figure 12. Hydrogeologic sections at Meadow Ridge interpreted from ground-penetrating radar records (locations of sections shown in fig. 11).

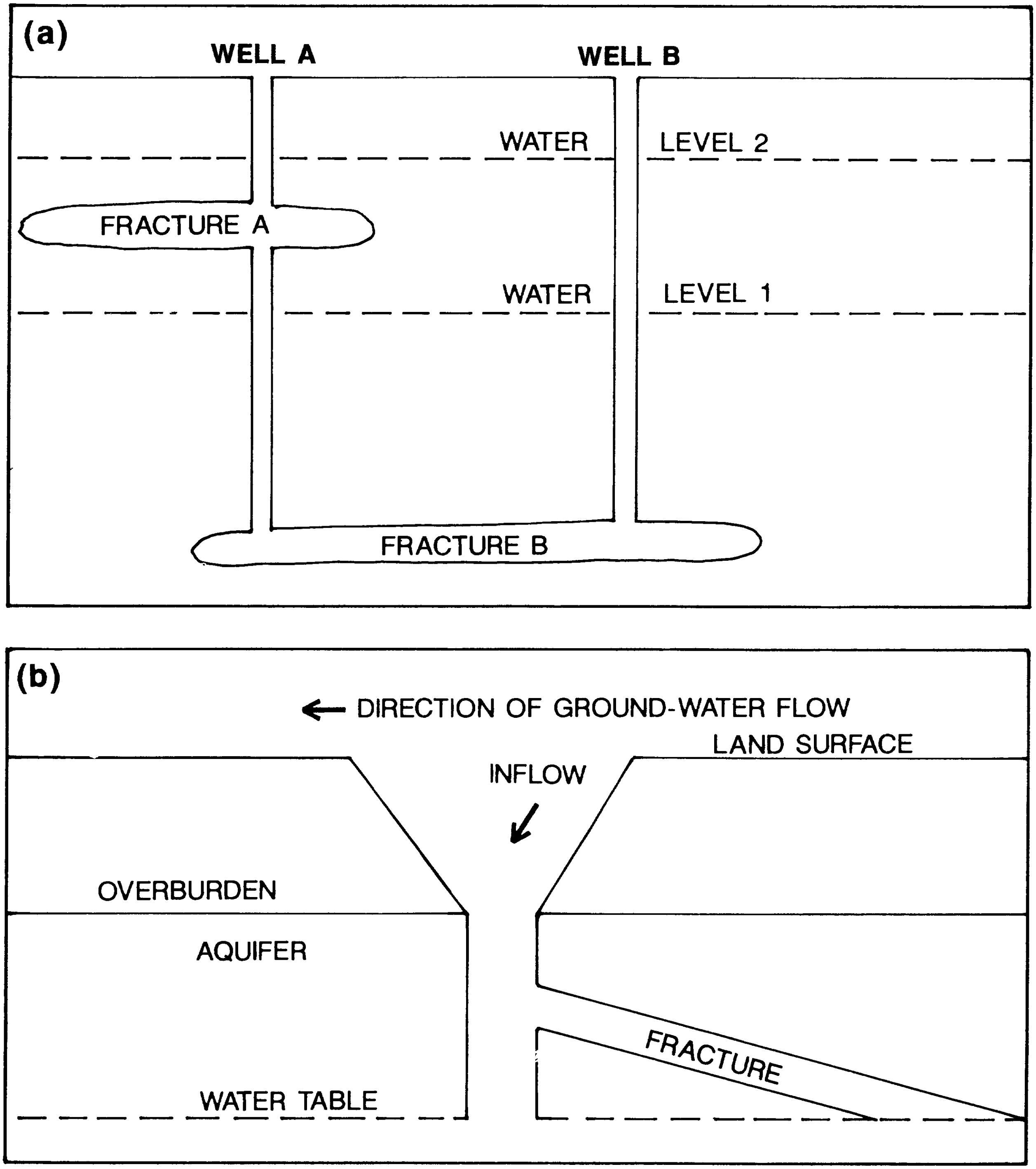


Figure 13. Fracture flow affected by (a) water table altitude or (b) rate of inflow.

Finally, the rate of inflow can affect the direction of movement in the aquifer in a purely mechanical sense. If water flows slowly into a sinkhole, the fracture shown in figure 13b receives little, if any, water. But if inflow to the sinkhole occurs at a faster rate than does outflow into the aquifer, the backup of water in the throat of the sinkhole allows water to flow through the fracture, even though this flow is in the opposite direction to the local gradient.

To summarize, the gradient of the local flow system is very low at Meadow Ridge near the southwest boundary of the Silver Springs ground-water basin. Ground-water flow probably is to the southwest but movement of dye in a dye trace was to a well upgradient from the sinkhole at a rate of 1 ft/hr. This probably occurred because of the influence of fractures in the local flow system.

Interstate-75 and State Road 200 Area

The area near the intersection of I-75 and State Road 200, southwest of Ocala (fig. 14), contains numerous sinkholes and detention ponds, as well as Briar Cave, a large, partly air-filled cave (fig. 15). The area was investigated (1) to inventory wells for potential sampling to see if the sinkholes and surface impoundments have any effect on water quality; (2) to attempt a measurement of the ground-water flow velocity; and (3) to determine which, if any, surface geophysical methods might be useful in locating caves or fractures. If a surface technique could be used to map a known subsurface feature, then the method might prove useful at sites where the subsurface features are unknown.

Both EM-34 and EM-16 surveys were made in a pasture above Briar Cave to determine if these techniques could be used to detect the location of the cave in the subsurface. Apparently there was not enough contrast between the conductivity of the air-filled cave passages and the surrounding limestone (both having low conductivity) to map the entire cave from the surface. However, EM-16 was used successfully in mapping the cave in areas where the passages are large.

Briar Cave is a "loose-maze" cave, a type that tends to form in low-gradient flow systems. White (1988, p. 84) believes that the loops of such a maze result from the superposition of conduits formed by water from the same source at different times. A generalized sketch of Briar Cave, shown in figure 15, is based on a rope-and-compass survey by members of the Florida Speleological Society. Lines of an EM-16 survey, conducted at land surface above the cave, are superimposed on the sketch of the cave (fig. 15). The orientation of cave passages corresponds to Faulkner's map of fracture traces (fig. 4). The depth of the cave varies from less than 20 to about 45 ft below land surface. The cave consists of a series of large rooms with high ceilings, some partly water filled, connected by narrower passages (in some areas these passages contain jagged vertical fractures about 2-ft wide and 20- or more ft deep), as well as several rooms with low ceilings, called breakdown rooms.

The EM-16 survey lines (fig. 15) show the tilt angle of the induced magnetic field measured at intervals across a pasture above the cave. The actual value of the angle is not as significant as the point at which the angle crosses over from positive to negative or negative to positive, which indicates that the sensor has passed over an area of change in earth conductivity. Starting at the cave entrance (not shown in fig. 15), survey lines labeled A through M were set up by using a tape and compass. In the western part of the survey, the tilt-angle crossover points closely correspond to the locations of cave passages except on line H, on which the crossover is offset from the passage. This could be the result of discrepancies between the actual passage location and that estimated from the cave survey. The offset might also be caused by the fact that the passage, called the Lake Room, is partly filled with water. The survey for the eastern part of the cave was not as successful, probably because the cave is honey-combed with smaller passages in that area.

Water levels in area wells indicate that the regional direction of ground-water flow is to the north and northeast. The gradient is very low, about 1×10^{-4}, similar to that in the Meadow Ridge area. The water levels measured in the wells shown in figure 14 are:

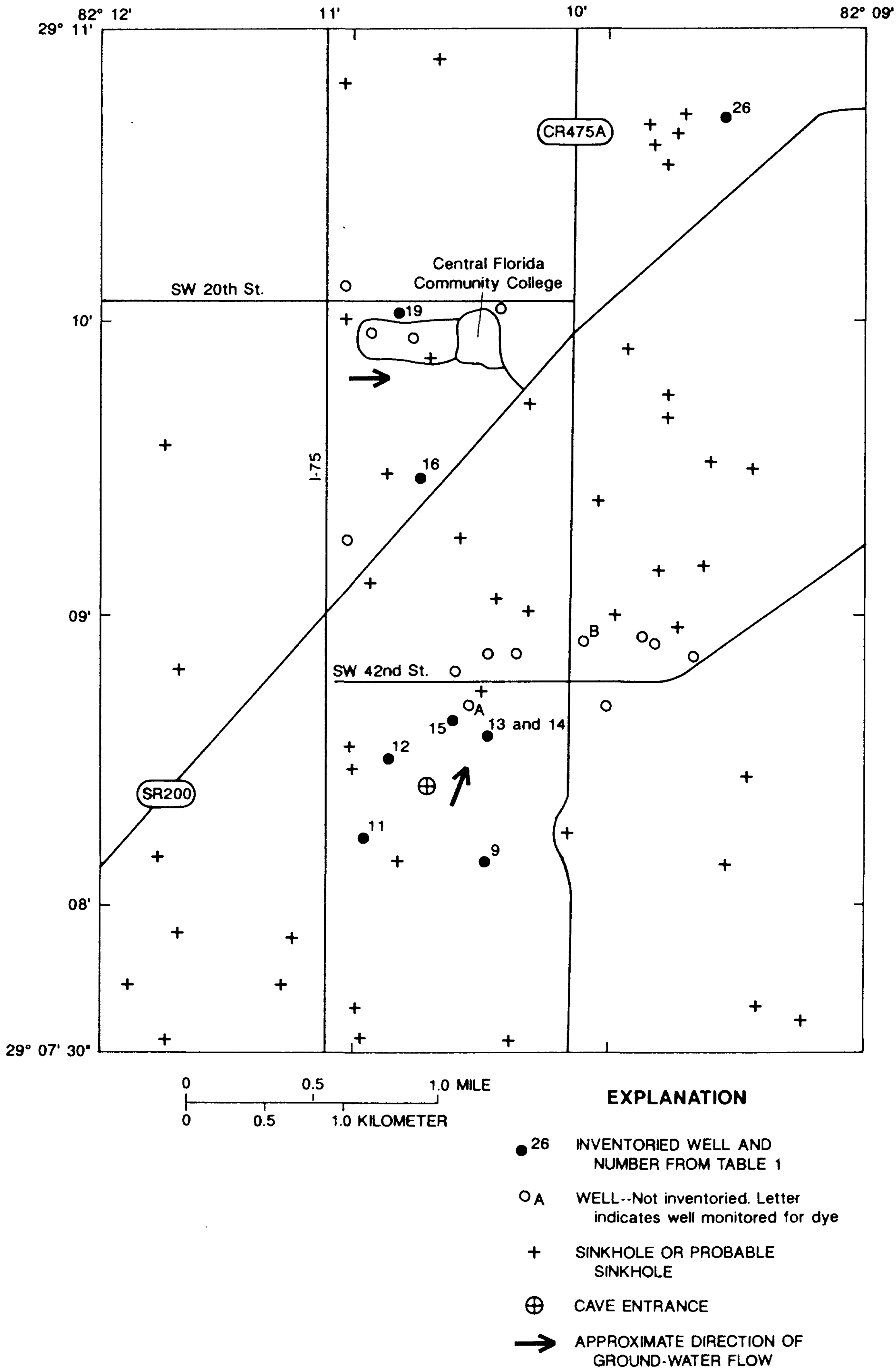


Figure 14. Area near intersection of Interstate 75 and State Road 200 and locations of wells, sinkholes and cave entrance (site location shown in fig. 6).

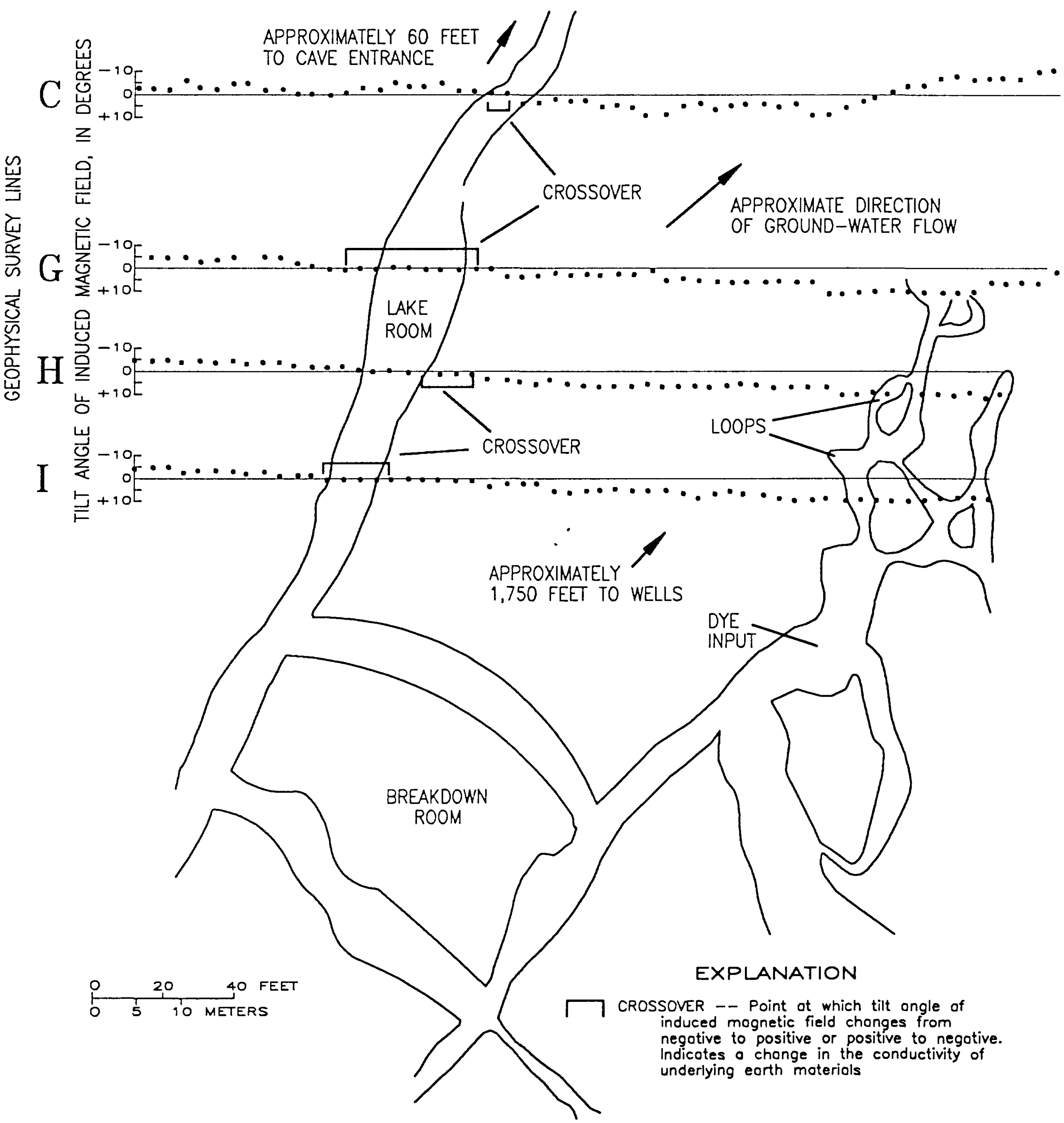


Figure 15. Briar Cave showing geophysical survey lines and dye input point.

Altitude of water level (ft)
[---, indicates no data available]

Date	Well 9	Well 11	Well 12	Well 14	Well 15	Well B
11-02-89	---	42.92	---	---	42.78	---
11-06-89	43.01	---	---	42.6	---	---
11-29-89	---	---	---	---	---	42.46
01-24-90	42.63	---	42.36	42.14	---	---
01-25-90	---	42.47	---	---	42.16	42.05

A dye trace was made in December 1990 to estimate the ground-water flow velocity under natural conditions. Because this was the first dye trace undertaken during this study, an initial estimate of ground-water flow velocity of about 0.8 ft/min was made based on work by Knochenmus (1967, p. 23). The natural-gradient trace reported by Knochenmus was made from a cave to a sinkhole south of Ocala. In that area the regional gradient is similar to that at Meadow Ridge and Briar Cave, about 3×10^{-4}. A volume of 30 mL of Rhodamine WT was released and mixed with the water in a cave passage (fig. 14). If the estimated velocity of 0.8 ft/min were correct, the dye would be expected to arrive at wells about 1,750 ft away in about 36 hours.

Water samples from wells 11, 12, 13, 14, 15 and A, collected at various time intervals beginning 24 hours after the dye release (fig. 14), were analyzed by fluorometer. Sampling continued for 1 month, and included the collection of daily samples from well B (except for two 2-day periods when the pipes in the plumbing system were frozen). No dye was detected in any water sample. A negative result in a dye trace can be attributed to the use of too little dye, sampling for an inadequate period of time, movement of the dye away from the wells sampled, or a combination of these factors.

Based on results of the Meadow Ridge dye trace, which was run about a year after the Briar Cave dye trace, and assuming that the ground-water flow velocities were the same at both sites, the dye would have reached well B about 52 days after release. Thus, the sampling time may have been too short. However, the possibility exists that the wells did not penetrate the fractures into which the dye was released. The movement of tracers in a fractured aquifer will be discussed in more detail in a later section of this report.

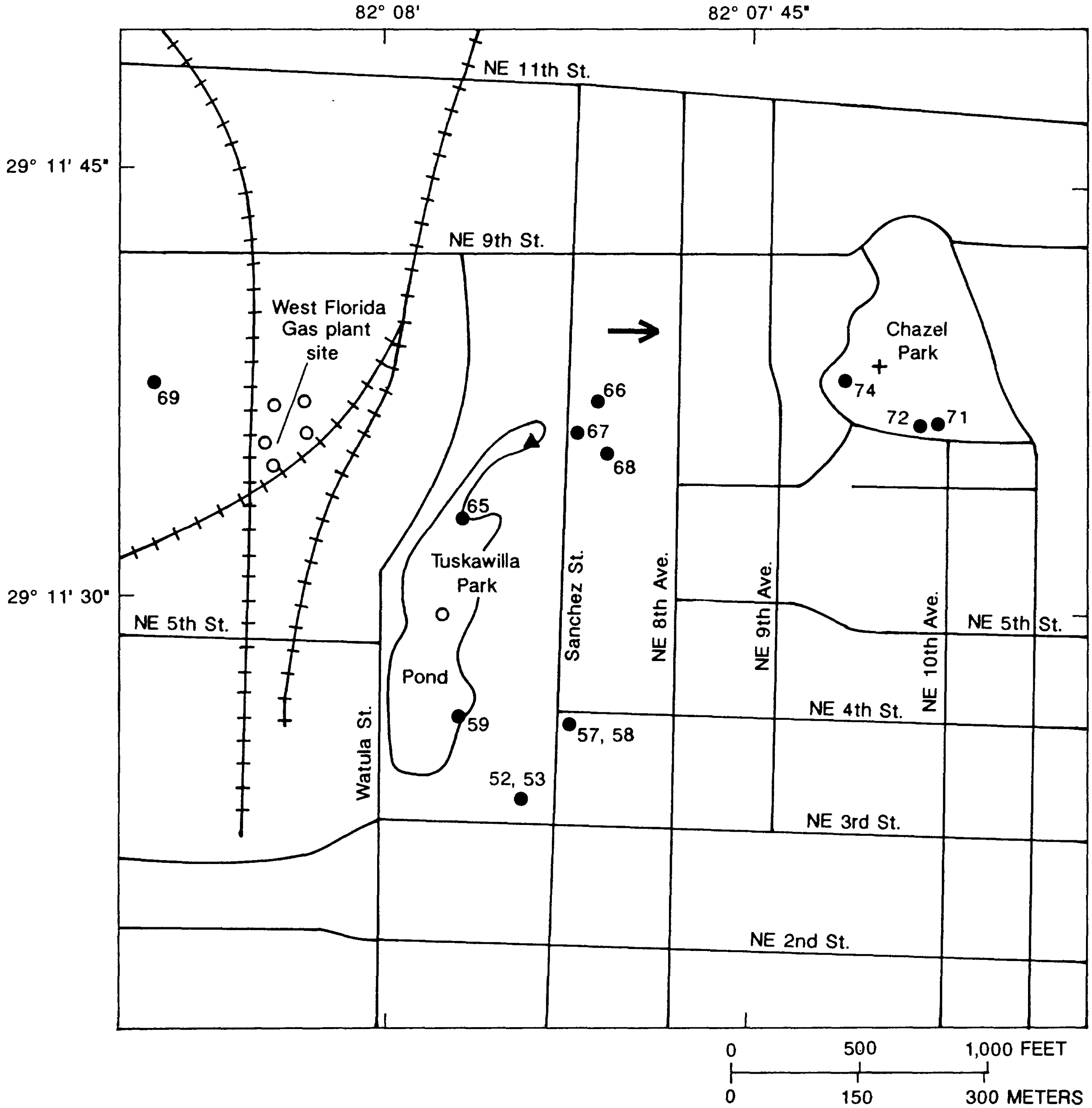
About 1.5 mi north of the Briar Cave area, geophysical surveys were run on the campus of Central Florida Community College (fig. 14) to determine if surface geophysical methods could provide information about the locations of subsurface fracture or conduit systems. GPR, run in a large field at the south end of the campus, did not indicate the presence of discernible fracture features. EM-16 was run in the central part of the campus near one of the active sinkhole areas, but interference from underground utilities and chain-link fences masked any possible response from subsurface features. Such interference is a major drawback when attempting to use electrical detection methods in an urbanized area. Because the surface geophysical surveys did not strongly indicate the presence of subsurface fractures which might be studied to advantage, no further studies were done on the campus.

To summarize, the area near the intersection of I-75 and State Road 200 was studied to determine if any surface geophysical method could be used to locate caves or fractures. EM-16 was useful in mapping large passages at Briar Cave but was not useful for detecting smaller passages. Neither GPR nor EM-16 were useful in a subsurface analysis of the Central Florida Community College campus. Also, the results of a dye trace from Briar Cave to wells 1,750 ft away were inconclusive because the dye was not detected at any of the wells sampled.

Tuskawilla Pond Area

In downtown Ocala (fig. 16), street runoff flows into Tuskawilla Pond and then into drainage wells which are completed in the Upper Floridan aquifer. The area was studied to understand the chemical quality of urban runoff entering the aquifer through drainage wells. In addition to collecting water samples from the pond, well inventories were made to locate drainage wells and potential observation wells from which to collect ground-water-quality data. Surface geophysical surveys were also conducted.

Tuskawilla Pond has been developed as a park and recreation area. The pond drains an area of about 400 acres. The area is a naturally low topographic point and there was a sinkhole into which runoff flowed in what is now the northern part of the pond (Hardy Croom, local resident, oral commun, 1991).



EXPLANATION

- ● 71 INVENTORIED WELL AND NUMBER FROM TABLE 1--All are drainage wells except 52 and 53
- ○ WELL--Not inventoried
- + SINKHOLE
- ▲ INTAKE FOR WELLS 66-68
- → APPROXIMATE DIRECTION OF GROUND-WATER FLOW

Figure 16. Tuskawilla Park area and locations of wells and sinkhole (site location shown in fig. 6).

The area around the sinkhole was marshy, indicating that the sinkhole was not always capable of accepting all inflow. In about 1910-12, dikes were constructed to create two ponds. Stormwater was held in the southern pond and fed into the northern one, which contained the sinkhole. As the town and the amount of impervious area grew, the sinkhole could not drain enough water to prevent flooding of the pond. Probably sometime in the mid-1900's, drainage wells were drilled near the two ponds to reduce surface-water levels. Sometime in the late 1960's or early 1970's, a short section of N.E. 5th Street, which previously divided the two ponds, was removed and the two ponds were combined.

Chazel Park, east of Tuskawilla Park, has a similar drainage feature: a sinkhole that provided sufficient drainage under natural conditions. However, the Chazel Park sinkhole basin was much smaller with steeper sides than that at Tuskawilla Pond. Because this sinkhole configuration did not lend itself to enlargement, drainage wells have been drilled to augment the natural drainage.

Field observations in 1989 and 1990 indicate that there are four active drainage wells receiving water from Tuskawilla Pond (wells 59, 65, 66, and 67) (fig. 16 and table 1). Two other drainage wells in the area (wells 57 and 58, figs. 9 and 16) are presumed to be destroyed. Well 68 has been plugged. The active wells range from 66 to 214 ft deep, with casing depths ranging from 42 to 65 ft, indicating that the top of the limestone is about 40 to 60 ft below land surface. During drilling of monitoring well 53 in 1989, limestone was encountered at 60 ft.

The water level in the pond fluctuates between 55 and 60 ft above sea level; the potentiometric surface of the Upper Floridan in the area is about 45 ft above sea level. This head difference indicates that the permeability of the materials overlying the Upper Floridan is sufficiently low to retard downward seepage. Cuttings from test wells drilled at the nearby West Florida Gas plant site indicate that the sediments which overlie the Upper Floridan are primarily sand, sandy clay, clayey sand, and silt, which together effectively retard downward movement of water from the pond to the Upper Floridan. Data from wells at the gas plant also indicate the presence of a perched water table in the sediments overlying the Upper Floridan (Environmental Resources Management-South, Inc., 1988, figs. 4-3 through 4-7 and p. 5-8).

The West Florida Gas plant, where natural gas was made from coal, was one of many such plants operating in Florida from about the late 1800's until about 1950. The waste products from the process were disposed onsite in either open or covered pits. In addition to the pits, there was also a drainage well on the plant site which could provide an avenue for contamination to enter the Upper Floridan aquifer. A 1988 assessment of the site by Environmental Resources Management-South, Inc., (ERM-South) determined that ground water at the site contained elevated levels of volatile organic compounds (VOCs) and polynuclear aromatic hydrocarbons (PAHs). The highest levels of these compounds were present in water from a well used to monitor the unsaturated zone, just above the top of the Upper Floridan aquifer. The unsaturated zone at the site is composed primarily of clayey sediments. ERM-South also reported that if the contaminated water were to move to surface-water bodies, the most likely receiving water would be Tuskawilla Pond. Thus, if contaminated water from the surficial sediments entered Tuskawilla Pond, it could then enter the Upper Floridan aquifer either through the drainage wells at Tuskawilla or through downward seepage through the pond bottom sediments.

Some sinkhole activity had been reported south of Tuskawilla Pond near N.E. 3rd Street. A GPR survey of the area was made, including a transect north on Sanchez Street to N.E. 9th Avenue, but a pattern of fracture or sinkhole activity could not be determined from the data. As in other urbanized areas, underground pipes and other structures produced interference and masked response of subsurface features in the survey.

Data files of the St. Johns River Water Management District (SJRWMD) and the U.S. Geological Survey were searched for evidence of wells in the area which might be used to collect water samples or provide geologic information. Because the area is in downtown Ocala and city water has been available for many years, no private wells close to Tuskawilla Pond could be found. A well located about 1,500 ft east of Chazel Park could not be used because the pump was broken. Only one nearby observation well (well 53) could be used to sample the water in the aquifer. Therefore, multiple samples of the surface water in the pond were collected and analyzed to determine the types and concentrations of chemical constituents entering the drainage wells. The results of these analyses are discussed in the "Water Quality" section of this report.

Municipal Well-Field Area

Another area studied in detail is in the northeastern part of Ocala, which includes the city of Ocala's municipal well field (fig. 17). The objectives of studying the area included: (1) evaluating the applicability of standard wellhead protection schemes to a system where regional and fracture flow are important; (2) determining the prevalence of fracture flow in the area of the field; and (3) locating wells for the collection of water samples for chemical analysis. Techniques used to investigate the area included analytical methods of ground-water flow analysis, surface geophysical surveys, well inventories, test drilling, and a dye trace.

Five wells at the new municipal well field were drilled in 1969 to replace abandoned wells in downtown Ocala. The 24-in. diameter wells range from 187 to 265 ft deep, with casing depths from 85 to 140 ft. The minimum depth to the top of limestone at the wells is 35 ft below land surface. More than half of the public-supply water distributed in Marion County in 1987 was pumped from the Ocala municipal well field (R. Marella, U.S. Geological Survey, written commun., 1991).

Testing of the wells after drilling indicated that well yields ranged from 4,250 gal/min with 0.66 ft of drawdown to 4,650 gal/min with 12 ft of drawdown (specific capacities ranged from 388 to 6,440 (gal/min)/ft). Using a method described by Meyer (1963, fig. 100) for estimating transmissivity from specific capacity, the transmissivity corresponding to the lower value of specific capacity is about 143,000 ft^2/d. Numerous sinkholes formed in the immediate area of the well field during initial testing of the supply wells (C.H. Tibbals, U.S. Geological Survey, oral commum., 1991.)

Also located in the area are several drainage wells (wells 31, 36, and 42 through 45, table 1), test wells drilled as part of the investigation for the Cross Florida Barge Canal (Faulkner, 1973), and more recently drilled monitoring wells (wells 51 and 81).

Wellhead Protection Zone

Concern about protecting public-supply wells from sources of contamination has resulted in guidelines for establishing wellhead protection zones being issued by FDEP (Vecchioli and others, 1989, p. 1). For wells in unconfined or semiconfined aquifers, the wellhead protection zone is designed to encompass an area containing the volume of water that can be pumped from the well field in a defined period of time, usually 5 or 10 years. Factors influencing the susceptibility of a well field to contamination include: the number, types, and locations of potential sources of contaminants; the geology of the area, which determines whether an aquifer is confined or unconfined; and the influence of geologic and structural controls on flow rates and patterns in the aquifer.

The methodology described by Vecchioli and others (1989, p. 17), was used to delimit the area that would contribute water to the municipal well field within a specific time period. The appropriate equation is:

$$r = \left(\frac{Q\,t}{\pi\, hn}\right)^{1/2} \qquad (1)$$

where

- r is radius of the protection zone, in feet;
- t is a specified horizontal traveltime to the well head (1,825 days (5 years) or 3,650 days (10 years));
- n is effective porosity of the Upper Floridan aquifer, assumed to be 0.05 as specified by FDEP regulation;
- π is 3.14;
- Q is average withdrawal rate, in cubic feet per day; and
- h is average thickness of the Upper Floridan aquifer penetrated by the well, in feet.

To simplify the calculation, the total withdrawal from the Ocala municipal well field (7 Mgal/d) was assumed to be made from a single well located at the center of the well field. The thickness of the Upper Floridan aquifer was estimated to be 200 ft, the maximum depth penetrated by the wells in the well field. The radii of contributing areas calculated using equation 1 for 5 and 10 years are about 3,700 and 5,200 ft, respectively (fig. 17).

This method, however, does not take into consideration the effects of regional flow, which are important in the Ocala area. The discharge from Silver Springs is about 525 Mgal/d, whereas the discharge from the well field is about 7 Mgal/d, or about 1 percent of the discharge from the spring. As determined from a natural gradient dye trace, the

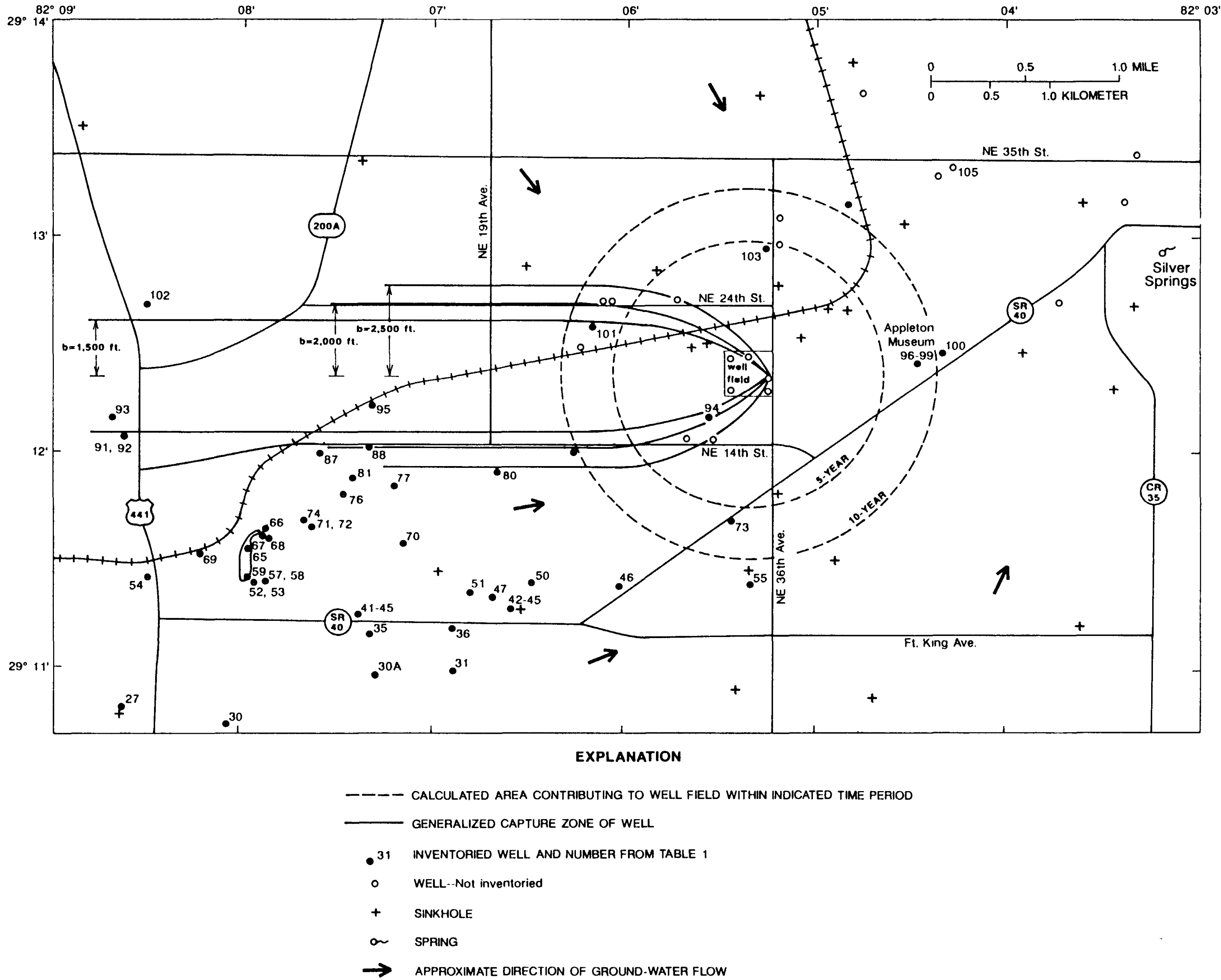


Figure 17. Municipal well-field area, calculated contributing areas to well field, generalized capture zones, and locations of wells and sinkholes.

regional flow velocity ranges from about 33 to 200 ft/d (Knochenmus, 1967, p.23). The method also does not account for the effects of flow through conduits.

The effects of regional flow can be taken into consideration using a method described by Javandel and Tsang (1986, p. 617). The method yields equations for calculating the capture zone of a well located in a homogeneous, isotropic aquifer in which a steady regional flow has a Darcy velocity designated U. The point of stagnation, s, (the point downgradient from the well at which particles of water will cease to be drawn toward the well and instead be captured by the regional flow) can be calculated by the equation:

$$s = \frac{Q}{2\pi BU} \qquad (2)$$

where

Q is discharge from the well, in cubic feet per day;
B is aquifer thickness, in feet; and
U is regional flow velocity, in feet per day.

In this analysis, the capture zone of the well will be shaped, in two dimensions, like an elliptic parabola rather than a circle, as it was in the previous contributing area model in which regional flow was not considered (fig. 17). Near the Ocala well field, depending on the velocity assumed for regional ground-water flow ranging from 33 to 200 ft/d, the point of stagnation ranges from 23 to 4 ft downgradient from the well; therefore, the assumption is made that the point of stagnation occurs approximately at the boundary of the well field and that the entire parabola extends upgradient from the well field. The area of the parabola is estimated using the equation for determining the area of an ellipse.

The length of the minor axis of the elliptic parabola depends on the direction and velocity of the regional ground-water flow. As seen in figure 10, the regional flow paths do not uniformly flow from west to east toward Silver Springs, but in some areas the flow turns toward the well field for some distance. Available potentiometric-surface maps of the area are not detailed enough to show the direction of flow to the north of the well field. Therefore, calculations were made for a range of possible values of the minor axis for a part of the aquifer containing the volume of water that could be pumped in 5 years.

Once the length of the minor axis is estimated, the major axis of the elliptic parabola (or the extent upgradient of the capture zone) can be estimated based on the volume of aquifer to be protected (calculated in equation (1) for 5 or 10 years). Note that because the porosity of the aquifer was considered in the calculation of the well-head protection zone in equation (1), it is not included in the calculation of the length of the major axis of the elliptic parabola.

Minor axis lengths and corresponding major axis lengths for the contributing part of the aquifer containing the volume of water that could be pumped in 5 years are:

Minor axis (b) (in feet)	Major axis (a) (in feet)
200	67,500
400	34,000
600	22,000
800	17,000
1,000	13,500
1,500	9,000
2,000	6,800
2,500	5,400

Values of (b) less than about 1,500 ft and the corresponding values of (a) are probably not meaningful based on potentiometric maps of the Ocala area. Thus the elliptic parabolas defined by the values of (b), ranging from 1,500 to 2,500 ft, define potential capture zones for the well field during 5 years of pumping (fig. 17). The upgradient extent of the capture zone is influenced by the direction and velocity of regional flow and the capture zone extends well beyond the wellhead protection zone calculated using equation 1. Thus, analytical methods that take regional flow into account are more useful for delineating wellhead protection zones in the Ocala area than are those that do not.

Appleton Museum Area

Both methods used in the previous section to estimate ground-water flow (and thus, capture or protection zones) are based on the assumptions of aquifer isotropy and homogeneity. A factor to be considered in the Ocala area is the effect of fracture flow in the aquifer. Test wells were drilled in the well-field area to study the effect of fractures. Factors considered in choosing a site for test wells included the absence of cultural features that would interfere with surface geophysical surveys, accessibility for the drill rig, and the land owner's permission to drill. GPR and EM-16 were used at several sites within the well-field area to help determine their usefulness in locating fractures in the limestone. The techniques did not indicate the presence of fractures in the limestone, probably because none were present at a shallow enough depth to be detected. A site for test drilling was chosen near the Appleton Museum of Art (about three-fourths of a mile east of the well field), where four wells were drilled in August 1990 (wells 96-99, table 1 and figs. 17 and 18).

Test wells

Prior to drilling at the museum site, a detailed GPR survey was conducted. The lines of survey and locations of test wells are shown in figure 18. A test boring, drilled near the location of well 97 prior to the GPR survey, provided information about the surficial materials that was used to analyze the GPR data. An anomaly thought to be a cavity was located and well 98 was drilled near, but not directly above, the suspected cavity. As the drill rig was being set up for the last hole about 30 ft southeast of well 96, a small sinkhole caused by a soil void (or a small cavity) developed under the rig. The rig was then moved and well 99 was located southwest of the planned location at the site of the small sinkhole (fig. 18). The void was not detected in the GPR survey, either because it was small in comparison to the larger feature detected, or because the void formed after the survey as a result of the movement of surficial materials disturbed by drilling wells 96, 97, and 98.

A 6-in. bit was used to drill to the top of the limestone using an air rotary drill rig and 6-in. diameter steel casings were driven to depths of 75 to 89 ft. The wells were then drilled through the limestone to a depth of 180 ft and finished as open hole (uncased). During drilling the bit penetrated numerous small cavities in the surficial material and hit soft limestone at depths ranging from 46 to about 60 ft below land surface. Caliper, natural gamma, and geologic logs of well 96 (the first well drilled at the site) are shown in figure 19. Well 96 penetrated a large cavity just below the bottom of the casing and also encountered numerous fractures and cavities in the lower Ocala Limestone and upper Avon Park Formation. Caliper logs for wells 96-99 (fig. 20) indicate the presence of numerous cavities, many of them large, in the aquifer. Well 98 could be logged to a depth of only about 150 ft. At a later time, the drill stem was run down the well to a depth of 180 ft, so the inability to log the well probably was because the logging tool was stuck on a ledge, not because of the collapse of the hole.

The test wells were developed with air during drilling. Well 96 was later pumped at a rate of 370 gal/min with a 10 hp pump. After 30 minutes of pumping, drawdown in well 97 (25 ft away) was 0.04 ft and in well 98 (also 25 ft from the pumped well) was 0.02 ft. The water level in the pumped well was not measured during pumping.

Forced-Gradient Dye Trace

The effects of conduits or fractures in the aquifer on tracer breakthrough can be evaluated by comparing the actual time it takes for a tracer to move from one well to another under pumping stress to the theoretical time of travel calculated using the assumptions of evenly distributed porous flow. Arrival times for a conservative tracer injected into wells located 25 and 40 ft from a pumped well (assuming a homogeneous porous medium and neglecting dispersion and diffusion) were calculated based on the radial form of Darcy's equation suggested by C.B. Hutchinson (U.S. Geological Survey, written commun. 1990):

$$t = \frac{(7.48)\ \pi\,(r^2)\ (d-c)\ (\sigma)}{Q} \qquad (3)$$

where

- t is arrival time, in days;
- r is distance to the pumped well, in feet;
- d is total well depth, in feet;
- c is depth of casing, in feet;
- σ is aquifer porosity, assumed to be 0.25; and
- Q is pumping rate, in gallons per day.

Based on this equation and an estimated pumping rate of 350,000 gal/d (250 gal/min), the dye from wells 40 ft from the pumping well would be expected to arrive about 63 hours after the start of pumping, and the dye from wells 25 ft away would be expected to arrive about 24 hours after pumping began.

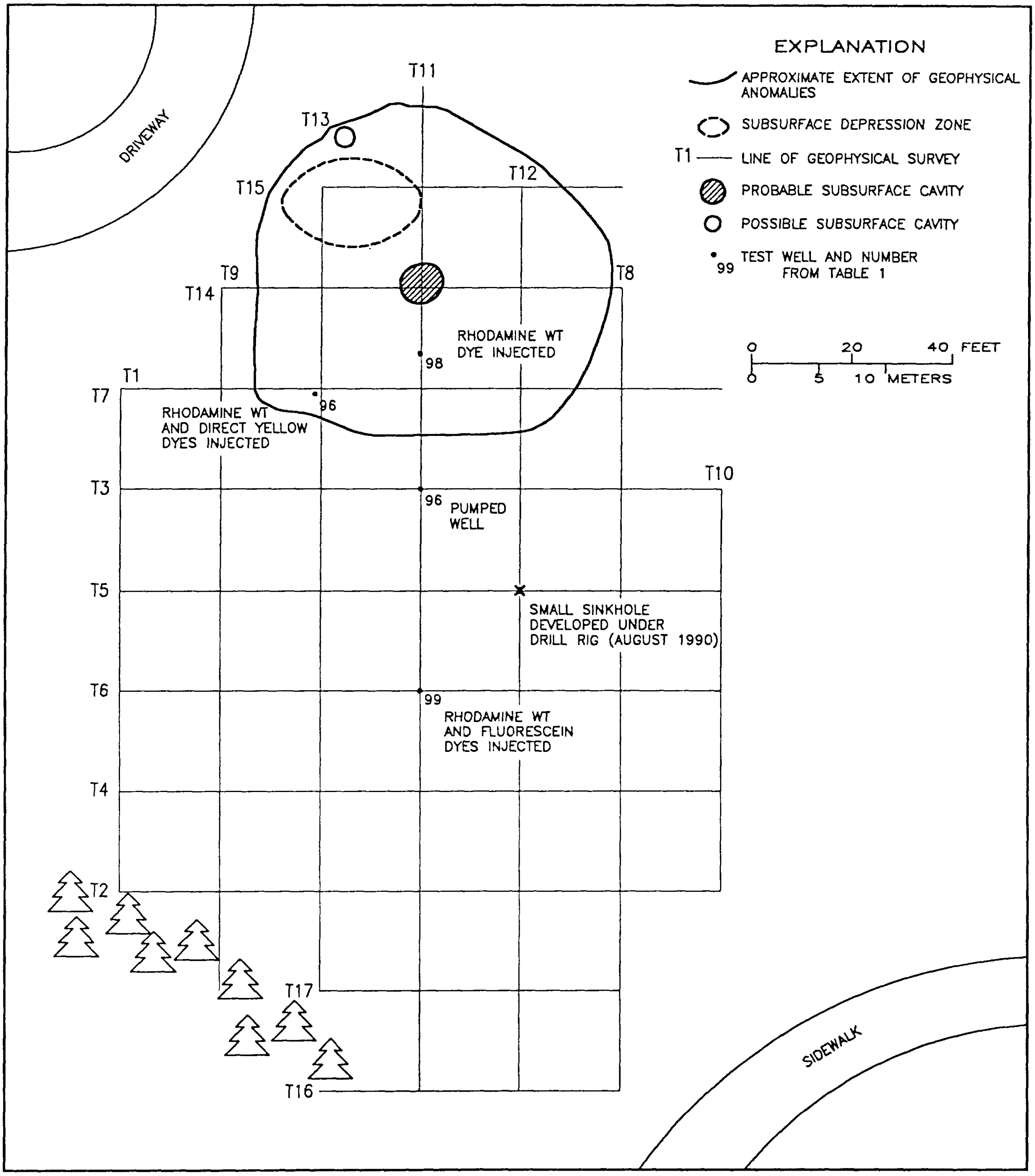


Figure 18. Appleton Museum test well locations and geophysical survey lines.

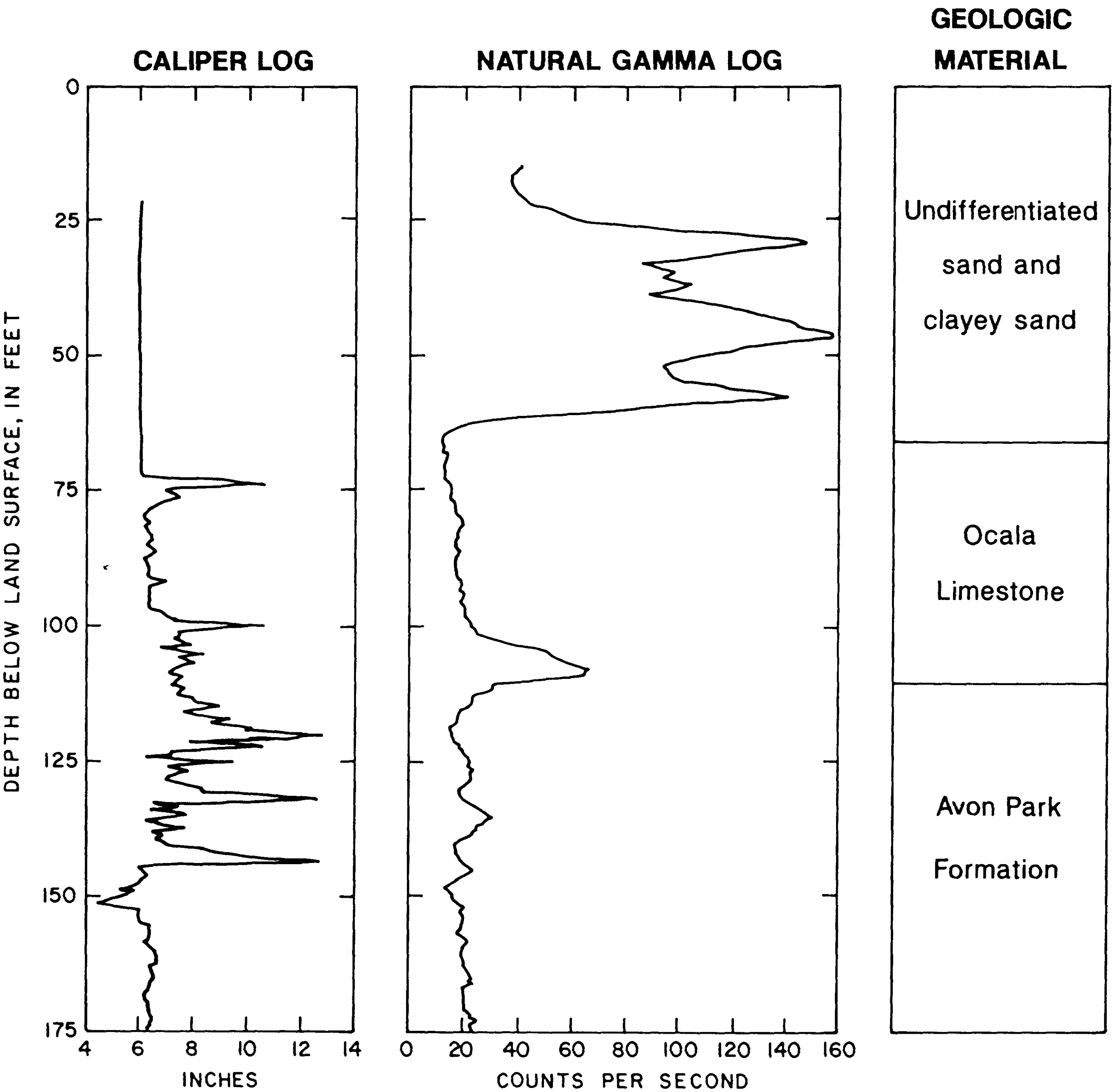


Figure 19. Geologic and geophysical logs of test well 96 at Appleton Museum (well number is from table 1).

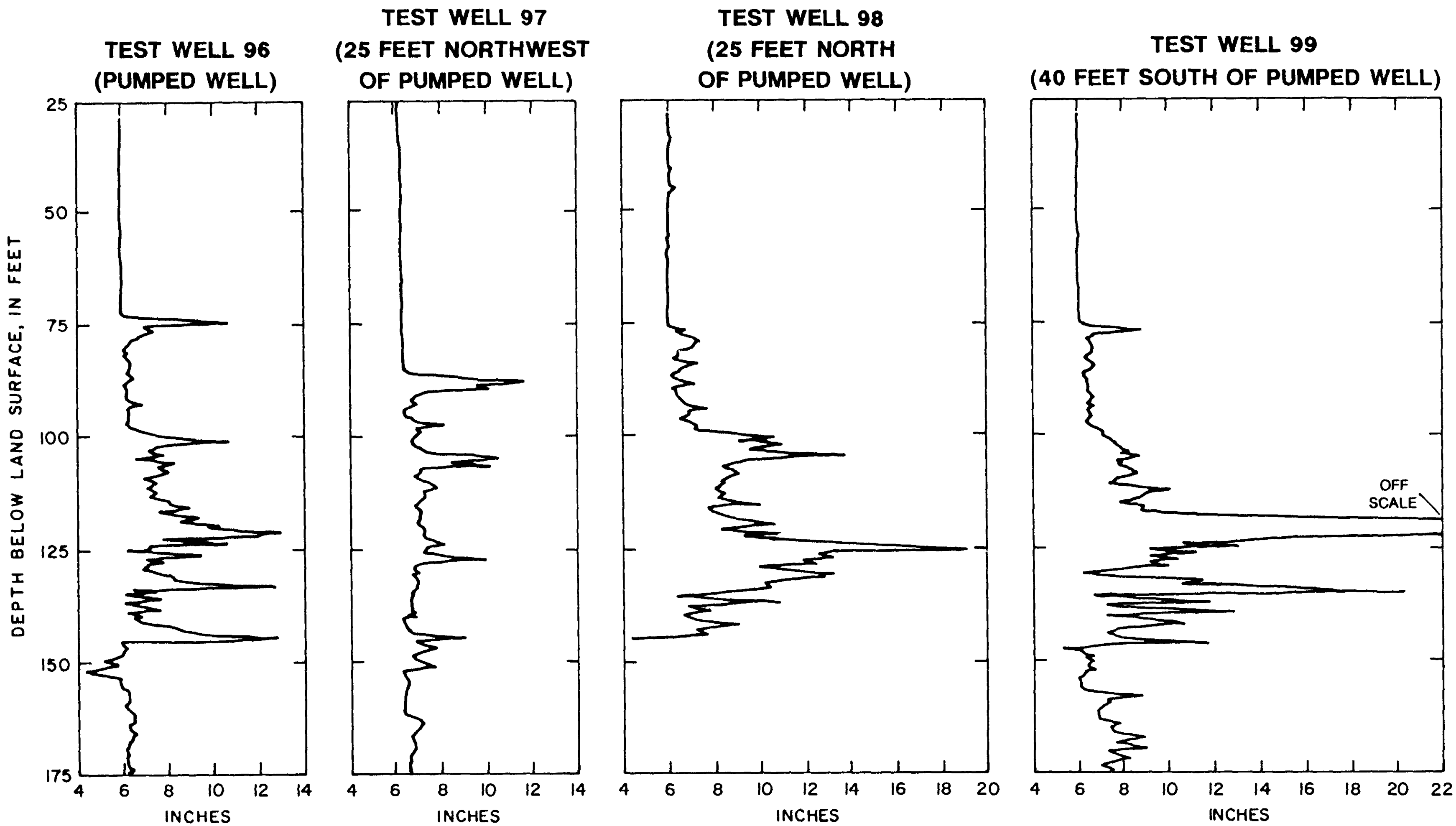


Figure 20. Caliper logs of test wells at Appleton Museum (well numbers are from table 1).

Three fluorescent dyes were used as tracers: Rhodamine WT, Fluorescein, and Direct Yellow 96. Rhodamine WT and Fluorescein can be detected in low concentrations using a fluorometer, whereas Direct Yellow 96 can be detected with an ultraviolet light. Thus Rhodamine WT and Fluorescein can be used quantitatively, but Direct Yellow 96 can only be used qualitatively. Because only one fluorometer was available for use in the field and it was not known which dye would arrive first, Rhodamine WT was added to all three injection wells. One well received only Rhodamine WT, one well received Rhodamine WT and Fluorescein, and the other well received Rhodamine WT and Direct Yellow 96. Then, using the fluorometer in the field, frequently collected samples were tested to determine the arrival time of dye from the wells. Sample bottles were then filled for later quantitative analysis in the laboratory.

The chemical quality of water from the test wells can affect the concentration of fluorescent dyes determined using a fluorometer. For example, Fluorescein loses its fluorescence in water having a pH lower than 5.5 (Mull and others, 1988, p. 26). This was not a problem at the site because the pH of the water from the pumped well was 7.3. A sample from the pumped well also was collected prior to the test to determine background fluorescence.

To mix the dye as thoroughly as possible through the entire open borehole of each injection well, a 1.25-in. diameter polyvinyl chloride (PVC) drop pipe was designed with 80 ft of slotted screen at the bottom and 100 ft of solid pipe at the top so that dye could be pumped to the bottom of the well. Water was withdrawn from the top of the borehole at the rate of about 50 gal/min, mixed with dye in a 30-gal container, and then pumped down the drop pipe. When dye was detected in the water withdrawn from the top of the well, it was assumed that the dye had been thoroughly mixed throughout the borehole. The drop pipe was used to inject dye into well 99 (fig. 18). During the process of lowering the drop pipe into well 97, it broke and was lost down the well. The dye was then pumped to the bottom of wells 97 and 98 using a weighted garden hose while pumping from the top the well, a method which was not as certain as the drop pipe to produce a thoroughly mixed dye mass.

Various types and quantities of dye were injected in wells 96, 97, and 99. A mixture of 0.5 L Rhodamine WT, 20 percent solution (119 g), and 400 g Flourescein dissolved in deionized water, was pumped into well 99. A mixture of 0.5 L Rhodamine WT, mixed with 400 g Direct Yellow 96 dissolved in deionized water, was injected into well 97, and 0.5 L of Rhodamine WT was pumped to the bottom of well 98. The dye was injected into wells 97 and 98 using the weighted garden hose method. The process of injecting dye into all three wells took about 3 hours.

After all the dye was injected, well 96 was pumped at a rate of 260 gal/min. Within 15 seconds after the pump was turned on, discharge water contained visible amounts of Rhodamine WT. Later analysis of the water samples collected showed that all samples also contained Direct Yellow 96, indicating a direct connection between wells 97 and 96. The highest concentration of Rhodamine WT detected was in a sample collected 5 minutes after pumping started (fig. 21). A peak concentration of Fluorescein also occurred in that sample and probably resulted from a direct connection of wells 99 and 96 by a small fracture. The highest Fluorescein concentration, however, occurred about 4.5 h after pumping started. A second, smaller peak of Rhodamine WT, which occurred after about 2 hrs of pumping, probably came from well 98 through a series of interconnected fractures. The second Rhodamine peak was a broad peak probably because of the arrival of the main plume of the Rhodamine WT and Fluorescein mixture from well 99. Smaller peaks of Fluorescein and Rhodamine WT also arrived after about 16.5 and 21.5 hrs, indicating breakthrough from a series of smaller fractures.

Pumping continued for 208 h. At the end of the pumping, the concentration of Rhodamine WT in the discharge water was 1.12 μg/L and that of Fluorescein was 0.86 μg/L. The mass of dye recovered or left in injection-well casings totaled 190 g (53 percent) for Rhodamine WT and 63 g (21 percent) for Fluorescein.

To summarize the Appleton test, dye from well 97 arrived almost immediately, indicating a direct connection between well 97 and the pumped well, probably at or near the well bottoms. Traveltimes for the peak dye concentration from well 98 (a distance of 25 ft) was 2 h and from well 99 (a distance of 40 ft) was 4.5 h, compared to traveltimes calculated from Darcy's equation of 24 and 63 h, respectively.

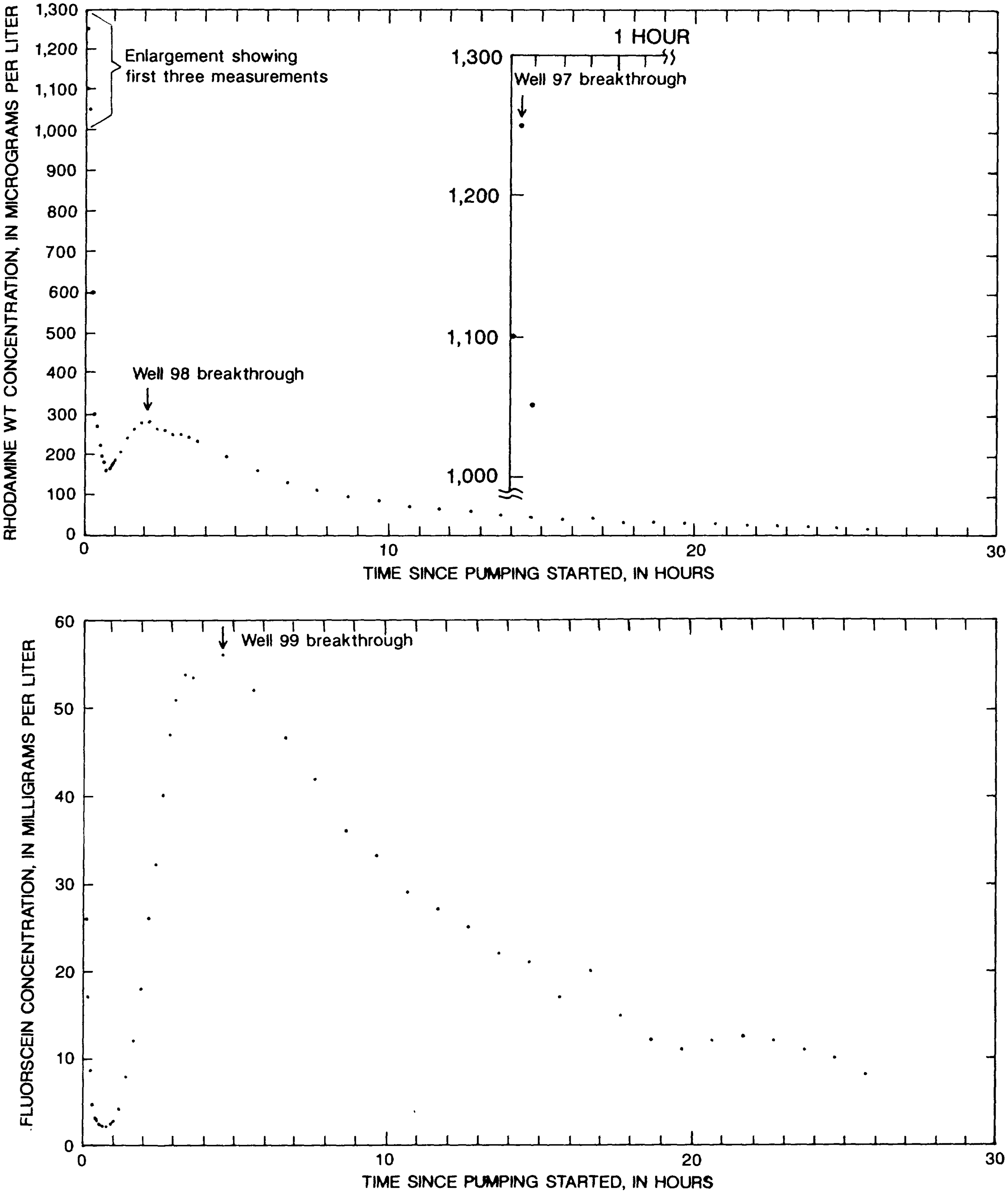


Figure 21. Concentrations of Rhodamine WT and Fluorescein in water from well 96 as functions of time.

Rapid flow through fractures has serious implications for evaluating wellhead protection schemes. It is unlikely that networks of fractures could allow a contaminant to move throughout the entire wellhead protection zone at a constant rate similar to the rapid rates observed at the Appleton site. However, the existence of fracture flow limits the usefulness of the 5- or 10-yr protection zones determined using equations 1 and 2. More detailed study of the area immediately surrounding the well field, especially with regard to the presence of fractures, would facilitate more accurate estimates of traveltime for contaminants to reach the well field.

FACTORS AFFECTING THE MOVEMENT OF POTENTIAL CONTAMINANTS

In a karst area such as central Marion County, evaluating the movement and the potential effect of contaminants on ground-water quality is a complex task. The factors that control these effects can be grouped into these categories: surface hydrogeologic, subsurface hydrogeologic and hydrologic factors (all of which are interrelated), and the rate of introduction and type of contaminant involved.

By necessity, hydrogeologic information available for only a few individual sites has been used to describe the regional ground-water flow system and the potential for contamination of that system. Although this approach provides an improved understanding of the system, caution should be used when evaluating the hydrologic characteristics at other specific sites based on these regional characterizations. In the event of a site-specific, local threat to ground-water quality, it would be prudent to collect data from the particular site for analysis rather than to make judgements or draw conclusions based solely on data from a regional study.

Surficial Hydrogeologic Factors

Surficial hydrogeologic factors that influence the potential for contamination of ground-water in the Upper Floridan aquifer in the study area include the thickness and hydraulic conductivity of the sediments overlying the aquifer, and the presence or absence of sinkholes or drainage wells. As discussed in previous sections, much of Marion County west of the Ocklawaha River has limestone of the Upper Floridan aquifer at or near land surface (figs. 3 and 5). The permeability of sediments overlying the limestone depends on lithology. Generally, the Hawthorn Formation is less permeable than the late Miocene and younger sediments. However, sinkholes can breach the Hawthorn as well as form in areas where the Hawthorn is absent. Also, because the surface of the Upper Floridan aquifer has been eroded, its depth below land surface can vary widely over a short horizontal distance. Because of the heterogeneity of the surficial geology in central Marion County, site-specific information about the thickness and lithology of materials that overlie the Upper Floridan aquifer and information about the presence of sinkholes are needed when evaluating sites suspected of being potential sources of contamination.

The surficial geology of the area also has an effect on the discharge of ground water at Silver Springs. Faulkner (1973, p. 43-46) concluded that Silver Springs results from the near-surface juxtaposition of the much less permeable Hawthorn Formation with the very permeable Ocala Limestone of the Upper Floridan aquifer at the contact of the outcrop areas of the two formations.

Subsurface Hydrogeologic Factors

Subsurface hydrogeologic factors that are of considerable significance when evaluating the potential movement of contaminants at specific sites in central Marion County include the porosity and permeability of the limestone of the Upper Floridan aquifer and the presence of fractures or conduits in the limestone. Unlike the karst in many other parts of the world, where virtually all of the flow occurs in fractures or conduits rather than in the rock matrix, flow in the Upper Floridan aquifer occurs in both the rock matrix and in fractures and conduits. The Upper Floridan aquifer is therefore a dual porosity flow system. On a regional scale and over a long period of time, flow in the Upper Floridan aquifer commonly can be approximated as flow through a porous medium. Under such conditions, the effective hydraulic conductivity of the aquifer is actually a lumped parameter including the influence of both flow through the porous matrix and flow through the fractures or conduits. In other situations, such as in local systems or short timeframes, flow through the fractures or conduits can be of primary importance.

However, the threshold delineating which of the two models is most appropriate to a particular situation is not well understood (GeoTrans, Inc., 1988, p. 3-56 through 3-58). Thus, sites of interest must be evaluated individually to determine which conceptual flow model is best suited to the particular hydrogeologic situation.

In addition to the importance of a dual porosity system, the size and interconnection of the fractures or conduits are important. In a series of dye-trace tests in a controlled set of fractures, Moreno and others (1990, p. 2390) concluded that tracer traveltimes were determined primarily by the spatial variability in fracture apertures and by the location of the injection point within the aperture. This effect will be even more noticeable in field studies of natural systems where the fractures or conduits are neither parallel nor of constant aperture. Thus, if dye-trace results are to be used to predict the transport of conservative contaminants, several dye traces must be made over the range of hydraulic conditions which might exist at the site; and furthermore, extrapolation of the predictions beyond the range of observed conditions should be done with extreme care (Mull and others, 1988, p. 66). Commonly, in karst terranes where most flow is through fractures or conduits rather than through the matrix of the aquifer, the most significant hydraulic variable is spring discharge, which typically fluctuates through a greater range than does the discharge from Silver Springs. In central Marion County, hydraulic head in the aquifer is probably as significant a hydraulic variable as spring discharge. This affects the interpretation of dye traces because head altitude determines which fracture system tracers will move through.

Locating and determining size and orientation of fracture or conduit features is difficult. Although surface geophysical methods are somewhat successful in some geologic and cultural situations, in others they may provide little information. Mapping fractures on a regional scale (fig. 4) is useful, but may not be useful at the scale of a site-specific study. The size of fractures also has a significant influence on the velocity of ground-water flow, but size is not easily determined from the information available at land surface.

Two distinct regimes of nonporous flow are defined: fracture flow and conduit flow. The boundary between fracture and conduit flow occurs at an aperture of about 5 to 10 mm (less than 0.5 in.) (White, 1988, p. 287). The implications of interpretation as to whether Darcian flow or fracture-conduit flow predominates at a particular site are significant because laminar flow occurs in porous media. Turbulent flow begins in fractures or conduits larger than about 5 to 50 mm (less than 0.25 to about 2 in.) (White, 1988, p. 291) and the hydraulics of transport in turbulent flow vary considerably from those of laminar flow. The growth of conduit features is related to the amount of water available to flow through the system. White's "constant head case" (1988, p. 293), assumes that the conduit is fed by water entering at a constant altitude difference with respect to the outlet, so that the developing conduits are always flooded, which generally is the case in the Silver Springs basin. In this situation, the discharge and velocity through the conduit increase as the passage diameter increases.

The dye traces conducted during this investigation allowed the direction and rate of ground-water flow at the study sites to be estimated. Additional dye-trace studies would refine those estimates, but some comparisons can be made that indicate the importance of fracture flow in the aquifer. If simple flow through a porous medium is assumed, the apparent velocity of ground-water flow can be estimated using Darcy's equation in the form (Walton, 1985, p. 88):

$$Q = T\,I\,L, \qquad (4)$$

where

- Q is the flow rate through a unit cross section of aquifer in cubic feet per day;
- T is transmissivity in foot squared per day;
- I is the hydraulic gradient in feet; and
- L is 1 foot.

To obtain velocity, the flow rate is divided by a unit area of aquifer 1 ft wide and 100 ft thick (the estimated thickness of the aquifer in the area). The estimated velocities calculated using reported transmissivity values range from 0.03 to 60 ft/d or 0.00125 to 2.5 ft/hr (table 2). Velocities estimated from dye-trace studies for natural gradient (nonpumping) conditions ranged from 1.2 ft/hr at Meadow Ridge to 48 ft/hr at Wolf Sink (Knochenmus, 1967, p. 23). For forced gradient (pumping) conditions, the velocities ranged from 9 to 13 ft/hr at the Appleton Museum test site. Thus, the

Table 2. Ground-water flow velocities computed using Darcy's equation, and apparent velocities based on dye studies

[ft^2/d, feet squared per day; ft/ft, feet per foot; ft/hr, feet per hour]

Flow velocity based on steady-state porous flow (Darcy's equation)			Apparent velocity based on dye study		
Transmissivity (ft^2/d)	Hydraulic gradient (ft/ft)	Calculated velocity (ft/hr)	Location (reference)	Gradient type	Apparent velocity (ft/hr)
10,000	3×10^{-4}	1.25×10^{-3}	Meadow Ridge	Natural	1.2
	3×10^{-3}	1.25×10^{-2}	Wolf Sink, Marion County (Knochenmus, 1967, p. 23)	Natural	48
30,000	3×10^{-4}	3.75×10^{-3}	Ginnie Springs, Gilchrist County (Wilson and Skiles, 1989, p. 1)	Natural	26-107
	3×10^{-3}	3.75×10^{-2}	Appleton Museum	Forced	9-13
300,000	3×10^{-4}	3×10^{-4}			
	3×10^{-3}	3.75×10^{-1}			
2,000,000	3×10^{-4}	2.5×10^{-1}			
	3×10^{-3}	2.5			

lowest velocity observed from a dye trace is about the same order of magnitude as the velocity calculated assuming a very high value of transmissivity from which it can be concluded that fracture flow, not porous flow, is dominant, at least on a local scale.

Hydrologic Factors

Hydrologic factors, such as heads (water levels) and the hydraulic gradient in the Upper Floridan aquifer, control the movement of contaminants in the ground water. Heads, which fluctuate about 5 to 6 ft from wet to dry seasons, can influence which systems of fractures or conduits may be active in receiving substances introduced into the aquifer. As mentioned previously, a relatively low hydraulic gradient tends to increase the development of maze-type caves and conduits (White, 1988, p. 84). Also, a low gradient makes determination of the exact direction of ground-water movement more difficult. In an area with a low hydraulic gradient, the altitude of measuring points of all wells used for water-level measurements must be accurately surveyed relative to accurate benchmarks which increases the time and expense of constructing site-specific potentiometric-surface maps. Small amounts of localized recharge or discharge, which have little influence on regional ground-water flow, can significantly influence flow on a site-specific scale; this may have caused the apparent "upgradient" movement of dye during the test at Meadow Ridge. Under a low-gradient condition, both minuscule differences in hydrostatic pressure and the presence of a network of fractures can interact to form a "probabilistic space in which water has a finite chance of flowing in one of multiple outlets" (Wilson and Skiles, 1989, p. 19).

Substance Type and Rate of Introduction

The type of substance or contaminant introduced and its physical characteristics have a significant influence on its movement within an aquifer. Some of the attributes of importance include: density and specific gravity (compared to water), miscibility or solubility in water, temperature, pH, ability to adsorb onto various minerals found in the aquifer and particles in the water, and chemical reactivity. For example, although gasoline is less dense than water (and thus will float on water) and a part of the free product spilled can usually be recovered, some constituents of gasoline are soluble in water and can be transported in ground water. Thus, some types of contaminants can present a greater threat to water quality than others, depending on their physical and chemical attributes.

The rate of introduction of substances into the ground water can also play a role in their movement through the aquifer. Moreno and others (1990, p. 2390) concluded that the injection flow rate may strongly modify the breakthrough curves obtained in tracer tests. High injection rates can cause some of the dye tracer to be forced into fractures which are poorly connected to the major fracture system; as a result, the dye moves through longer, more complex flow paths, and thus breaks through at the detection point at a later time than would dye traveling along paths with more direct interconnections. Under other conditions, such as in the Meadow Ridge test, if the tracer is moving into a sinkhole faster than it can move out into the aquifer, the backup can cause the tracer to move through fractures in an unexpected direction. Thus, during dye tracing experiments, it is important to inject the dye at a rate that might be similar to the expected rate of introduction of potential contaminants into the aquifer. In the Meadow Ridge test, a 30-gal dye solution flowed by gravity into the sinkhole and was followed by a flow of water through a 2-in. diameter hose for about 12 min, approximating the flow into the detention pond after a rain shower. At the Appleton test site, problems in mixing the dye solution throughout the entire open well bore may have allowed the slug of dye to be pumped directly into a conduit at a faster rate than would be expected under the conditions of an accidental spill or leakage from a burial site; however, the injection rate was similar to that at Meadow Ridge.

WATER QUALITY

The Upper Floridan aquifer is the source of nearly all water supply in the Silver Springs basin and local geologic conditions do little to retard the entry of potential contaminants into the aquifer. As discussed in previous sections of this report, numerous potential sources of contamination are present in the basin. In this section, the chemistry of possible contaminants and the quality of water samples collected from the aquifer are discussed. Chemical analyses of water entering the aquifer through drainage wells are also described. Primary and secondary drinking-water standards established by the Florida Department of Environmental Protection (1989) and the maximum contaminant levels (MCL) for regulated constituents analyzed in samples collected during this study are listed in table 3.

Relation of Water Quality to Human Activity

Human activities, which include agriculture, manufacturing, disposal of sewage and other waste products, and the accidental release of harmful substances, can affect the chemical quality of water in the areas where such activities occur. Work by Rutledge (1987) and E.R. German (U.S. Geological Survey, written commun., 1991) indicates a relation between type of land use and ground-water quality. The chemical character of stormwater runoff may vary with urban land use, but typically the water contains elevated levels of lead, zinc, and other trace metals, as well as organic compounds (Rutledge, 1987, p. 6). Agricultural practices (including applications of fertilizers and pesticides) and the presence of animal wastes on the land surface often result in increased concentrations of nutrients and organic compounds in ground water. Surface and subsurface disposal of treated sewage can result in increased chloride concentrations (Phelps, 1987, table 6) and, sometimes, nutrient concentrations. Characteristic constituents, particularly organic compounds, are associated with manufacturing

Table 3. Primary and secondary drinking water standards established by the Florida Department of Environmental Protection, 1989

[All concentrations are in milligrams per liter unless otherwise indicated]

Constituent	Maximum contaminant level
Primary standards	
Arsenic	0.05
Barium	1.0
Cadmium	.010
Chromium	.05
Fluoride	4.0
Lead	.05
Mercury	.002
Nitrate (as N)	10
Selenium	.01
Silver	.05
Sodium	160
Endrin	.0002
Lindane	.004
Methoxychlor	.1
Toxaphene	.005
2,4-D	.1
2,4,5-TP (Silvex)	.01
Total trihalomethanes	.10
Trichloroethene	.003
Tetrachloroethene	.003
Carbon tetrachloride	.003
Vinyl chloride	.001
1,1,1-trichloroethane	.2
1,2-dichloroethane	.003
Benzene	.001
Ethylene dibromide	.00002
p-dichlorobenzene	.075
1,1-dichloroethene	.007
Secondary standards	
Chloride	250
Color	15 color units
Copper	1.0
Iron	.3
Manganese	.05
pH	6.5-8.5 units
Sulfate	250
Total dissolved solids	500
Zinc	5.0

processes (Walton, 1985, table 3.15). Nearly all human activities alter the bacteriological quality of water. For example, Mattraw and Miller (1981, table 2) reported that total coliform counts for 62 samples of urban runoff ranged from 24,000 to 1,770,000 colonies per 100 mL of sample, with a mean of 274,000 colonies per 100 mL.

A summary of specific conductance and selected constituents in urban runoff, surface water, and shallow ground water from several agricultural areas in Florida is presented in table 4. The summary includes data for various types and concentrations of constituents that can enter the Upper Floridan aquifer through sinkholes and drainage wells. In addition to the constituents listed in table 4, bacteria and organic compounds may also serve as indicators of ground-water contamination.

Water Entering Drainage Wells

In March and April 1989 and May 1990, samples of water flowing into three drainage wells that receive water from Tuskawilla Pond were collected. Samples from the center of the pond were also collected on two occasions. Results of the analyses of these samples (table 5) indicate their chemical character is typical of water entering the Upper Floridan aquifer through drainage wells. The specific conductance of the samples ranged from 280 to 360 µS/cm, with a median of 286 µS/cm, whereas total nitrate nitrogen ranged from 0.230 to 0.310 mg/L, with a median of 0.285 mg/L. High densities of coliform, fecal coliform, and fecal streptococci bacteria were present in some samples.

Concentrations of metals were low (less than 10 µg/ L), with the exception of iron, manganese, and zinc. Iron concentrations probably result from dissolution of iron minerals in the surficial sand, but the concentrations of zinc could be related to fertilizer use or other sources associated with urban development. The median manganese concentration was 80 µg/L and the median zinc concentration was 30 µg/L. Manganese likewise may be related to fertilizer use or may be leached from vegetative debris in pond sediments.

Schiner and German (1983, table 8) reported median manganese concentrations of 20 µg/L in water from drainage wells and 10 µg/L in public-supply wells in Orlando; median zinc concentrations of

Table 4. Summary of selected physical and chemical characteristics in urban runoff and in surface water and shallow ground water in an agricultural area

[All constituents are total, measured in micrograms per liter, unless otherwise noted. μS/cm, microsiemens per centimeter at 25 °C; mg/L, milligrams per liter; S.D., standard deviation; S, surface water; --, not determined; n.d., not detected; G, ground water; <, less than. Urban runoff data from Mattraw and Miller, 1981; ground-water data from Rutledge, 1987; and surface-water data from D.M. Schiffer, U.S. Geological Survey, written commun., 1990]

	Urban Runoff									Surface and ground water		
	Residential area			Highway			Commercial area			Agricultural area		
Property or constituent	Range	Mean	S.D.	Range	Mean	S.D.	Range	Mean	S.D.	Range	Mean	S.D.
Specific conductance (μS/cm)	34-350	96	56	25-450	104	72	32-6,200	131	330	290-630 S	438	--
Nitrogen, (mg/L)	0.29-11	2.0	1.8	0.09-6.5	.96	1.0	0.07-11	1.1	.96	0.91-11 S	5.5	--
Organic nitrogen, (mg/L)	0.14-9.4	1.2	1.1	0.05-3.3	.53	.53	0.00-11	.81	.91	0.87-7.8 S	4.5	--
Ammonia nitrogen, (mg/L)	0.00-2.6	.33	.50	0.00-2.7	.13	.36	0.00-0.34	.03	.04	n.d.-0.93 S	.10	--
Nitrite nitrogen, (mg/L)	0.00-1.5	.05	.12	0.00-0.41	.02	.03	0.00-0.40	.02	.03	n.d.-0.12 S	.02	--
Nitrate nitrogen, (mg/L)	0.00-2.1	.46	.34	0.00-1.6	.28	.24	0.00-1.3	.21	.17	0.00-4.3 S	.91	--
Phosphorus, (mg/L)	0.06-2.4	.31	.28	0.00-0.80	.08	.09	0.01-1.0	.10	.10	0.10-1.8 S	.42	--
Orthophosphate, (mg/L)	0.03-1.8	.21	.21	0.00-0.31	.04	.03	0.00-0.73	.05	.07	0.01-1.6 S	.24	--
Organic carbon (mg/L)	0-104	14	14	0-149	6.3	4.8	0-99	5.8	4.8	19-59 S	31	--
Chloride, dissolved (mg/L)	1-48	8.8	6.6	1-62	12	7.8	4-118	32	27	24-44 S	36	--
Arsenic	--	--	--	--	--	--	--	--	--	4 G	--	--
Barium	--	--	--	--	--	--	--	--	--	100 G	--	--
Cadmium	0-6	.8	1.0	0-8	.7	.1	0-7	.9	1.2	1-2 G	--	--
Chromium	<10-20	--	--	<10-70	--	--	<10-2,300	--	--	10-20 G	--	--
Copper	0-41	8.0	6.0	0-51	6.5	6.1	0-500	15	32	1-51 G	--	--
Iron	0-5,300	298	405	0-3,100	207	294	0-8,400	334	607	20-2,300 G	--	--
Lead	30-1,100	167	158	18-2,700	282	258	6-7,000	387	603	1-18 G	--	--
Manganese	--	--	--	--	--	--	--	--	--	20-280 G	--	--
Mercury	--	--	--	--	--	--	--	--	--	.1- .6 G	--	--
Selenium	--	--	--	--	--	--	--	--	--	1-10 G	--	--
Silver	--	--	--	--	--	--	--	--	--	n.d.	--	--
Zinc	10-560	86	72	0-1,000	90	117	0-1,900	128	170	10-4,000 G	--	--

Table 5. Selected physical and chemical characteristics of water from Tuskawilla Pond entering drainage wells in Ocala

[µS/cm, microsiemens per centimeter at 25 °C; mg/L, milligrams per liter; immed., immediate incubation; cols, colonies; mL, milliliter; µm, micrometer; MF, membrane filter; µg/L, micrograms per liter; --, not analyzed; less than; K, nonideal count]

Site identification	Date	Specific conductance (µS/cm)	pH (standard units)	Hardness total (mg/L as $CaCO_3$)	Calcium dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate dissolved (mg/L as as SO_4)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Coliform, total, (immed. cols/ 100 mL)	Coliform, fecal, 0.7 µm MF (cols/ 100 mL)	Streptococci fecal, KF agar (cols/ 100 mL)
291126082075700	03-13-89	283	9.6	--	39	4.8	12	7.3	22	24	0.4	<0.1	6,000	1,000	<1
	05-15-90	300	9.7	120	39	5.1	12	5.3	20	24	.3	5.4	K12	--	K28
291130082075800	03-13-89	280	9.6	--	40	4.9	12	7.4	22	23	.5	< .1	7,000	<1	<1
	04-05-89	360	9.1	130	42	6.6	18	8.3	30	29	.4	2.0	--	--	--
291132082075600	03-13-89	280	9.6	--	44	5.3	12	7.5	25	24	.6	< .1	4,000	<1	1,000
291137082075300	03-13-89	289	8.0	--	39	4.5	11	6.9	20	22	.7	< .1	16,000	1,000	7,000

Site identification	Date	Nitrogen, total (mg/L as N)	Nitrogen, organic total (mg/L as N)	Nitrogen, ammonia total (mg/L as N)	Nitrogen, nitrite total (mg/L as N)	Nitrogen, nitrate total (mg/L as N)	Nitrogen, ammonia + organic total (mg/L as N)	Nitrogen, NO_2+NO_3 total (mg/L as N)	Phosphate, ortho, dissolved (mg/L as PO_4)	Carbon, organic total (mg/L as C)	Phosphorus, ortho total (mg/L as P)
291126082075700	03-13-89	3.7	--	<0.01	0.07	0.31	3.3	0.38	0.09	7.5	0.04
	05-15-90	--	2.9	.02	<.01	--	2.9	<.02	.64	9.4	.48
291130082075800	03-13-89	3.6	3.3	.03	.07	.27	3.3	.34	.06	6.7	.05
291132082075600	03-13-89	3.7	--	<.01	.07	.30	3.3	.37	.06	6.6	.03
291137082075300	03-13-89	3.2	2.4	.50	.05	.23	2.9	.28	.58	8.2	.30

Site identification	Date	Arsenic total (µg/L as As)	Cadmium total recoverable (µg/L as Cd)	Chromium, total recoverable (µg/L as Cr)	Copper, total recoverable (µg/L as Cu)	Iron, total recoverable (µg/L as Fe)	Lead, total recoverable (µg/L as Pb)	Manganese, total recoverable (µg/L as Mn)	Zinc, total recoverable (µg/L as Zn)	Selenium total (µg/L as Se)
291126082075700	03-13-89	<1	<1	<10	5	230	<5	80	60	<1
	05-15-90	2	<1	<10	4	120	1	70	40	<1
291130082075800	03-13-89	<1	<1	<10	6	250	<5	80	30	<1
291132082075600	03-13-89	<1	<1	<10	5	310	<5	80	20	<1
291137082075300	03-13-89	<1	<1	<10	4	420	<5	170	30	<1

10 µg/L were reported in water from both drainage and public-supply wells. Rutledge (1987, tables 5 and 7) reported manganese concentrations ranging from 10 to 560 µg/L and zinc concentrations ranging from 10 to 50 µg/L in water from a pond in an agricultural area; manganese concentrations ranging from 10 to 60 µg/L and zinc concentrations ranging from 10 to 360 µg/L were reported in stormwater runoff samples collected in Orlando.

The chemical characteristics of water entering the Upper Floridan aquifer through drainage wells at other detention ponds in the Ocala area is assumed to be similar to that entering through the drainage wells at Tuskawilla Pond. This conclusion can be tested by comparing the ranges of constituents in urban runoff from table 4 to those for samples of water entering drainage-well intakes (table 5). For example, comparing runoff from a commercial area to the Tuskawilla Pond water, the specific conductance is higher in Tuskawilla Pond; most nutrients are similar in concentration; and concentrations of metals have a much narrower range in the pond than in the urban runoff. Water entering the aquifer through sinkholes usually flows directly into the ground rather than flowing into a pond; so water entering through sinkholes could be assumed to be similar in chemical quality to urban runoff summarized in table 4.

Water flowing into the three drainage-wells and water from the center of Tuskawilla Pond were analyzed for the pesticides and volatile compounds listed in table 6. The samples were also screened for the presence of other organic compounds using a gas chromatograph with a flame ionization detector (FID scan). Quantitative analysis with a gas chromatograph/mass spectrometer (GC/MS) was performed if the FID scan indicated the presence of organic compounds.

In one sample from March 1989, lindane was detected in a concentration of 0.010 µg/L, well below the 4 µg/L MCL (table 3). The FID scans did not indicate the presence of other organic compounds in detectable amounts except in the sample from the center of the pond. This sample contained Chrysene, 0.14 µg/L; Fluoranthene, 1.04 µg/L; and Pyrene, 0.86 µg/L.

FID scans of water samples collected at the drainage-well inflow sites in April 1989 did not detect the presence of organic compounds, but a sample collected near one drainage well in May 1990 had a toxaphene concentration of 1 µg/L (MCL 5 µg/L) and a 2,4-D concentration of 0.46 µg/L (MCL 100 µg/L). During this study, organic compounds were not a consistent problem in water entering the drainage wells at Tuskawilla Pond.

Water Sampled From Drainage Wells

Drainage wells in Ocala were not sampled during this study, but data are available for water pumped from six drainage wells in the area (Kimrey and Fayard, 1984, table 2). Two of the drainage wells were receiving water at the time of sampling. The other four wells were not receiving water, but probably had received water within a few days preceding sampling (Kimrey and Fayard, 1984, p. 24). Concentrations of selected constituents in water from the six wells sampled in the Ocala area are presented in table 7; locations of the wells are shown in figure 9. Because so few data were available for the Ocala area, water-quality data for drainage wells in Orlando (Schiner and German, 1983, tables 6-8) were also evaluated. The median specific conductance values and nitrate concentrations in drainage-well water samples from Ocala and Orlando were similar (about 300 µS/cm and less than 0.1 mg/L, respectively). Drainage wells in Orlando had water with higher chloride concentrations, whereas water from drainage wells in Ocala had somewhat higher total organic carbon concentrations and much higher total ammonia and total orthophosphorus concentrations.

The median pH of water from Ocala drainage wells was 7.1, very similar to the median of 7.3 determined for samples from Orlando drainage wells. All of the Ocala drainage-well samples contained coliform bacteria (table 7). Bacteria were present in most, but not all, of the 21 drainage wells sampled by Schiner and German (1983, table 7). The water samples collected by Kimrey and Fayard (1984) were analyzed for the organic compounds 2,4-D, 2,4,5-T, and Silvex; however, none were detected in any of the water samples from the six Ocala drainage wells sampled.

Samples from two drainage wells in Ocala had manganese concentrations of 100 and 170 µg/L, whereas the median manganese concentration in water from Orlando drainage wells was 20 µg/L. Similarly, five samples from Ocala drainage wells had zinc concentrations ranging from 10 to 50 µg/L,

Table 6. Organic compounds analyzed in water entering drainage wells and in ground water

[μg/L , micrograms per liter. Detection limit for all volatiles, 0.20 μg/L]

Volatile organic compounds	Pesticides	
	Compound	Detection limit (μg/L)
Benzene	Aldrin	0.01
Bromoform	Chlordane	.1
Carbon Tetrachloride	DDD	.01
Chlorobenzene	DDE	.01
Chlorodibromomethane	DDT	.01
Chloroethane	Diazinon	.08
Chloroform	Dieldrin	.01
Chloromethane	Endosulfan	.01
Cis 1, 3-dichloropropene	Endrin	.01
Dichlorobromomethane	Ethion	.01
Dichlorodifluoromethane	Gross polychlorinated biphenyls	.1
Ethylbenzene	Gross polychlorinated naphthalenes	.1
Methylbromide	Heptachlor epoxide	.01
Methylchloride	Heptachlor	.01
Methylene chloride	Lindane	.01
Styrene	Malathion	.01
Tetrachloroethylene	Methoxychlor	.01
Toluene	Methylparathion	.01
Trans-1, 3-dichloropropene	Methyltrithion	.01
Trichloroethylene	Mirex	.01
Trichlorofluoromethane	Parathion	.01
Vinyl chloride	Perthane	.1
Xylene	Toxaphene	1.0
1, 1-Dichlorethylene	Trithion	.01
1, 1-Dichlorethane	Silvex	.01
1, 1, 1-Trichloroethane	2, 4-D	.05
1, 1, 2-Trichloroethane	2, 4, 5-T	.01
1, 1, 1, 2-Tetrchloroethane		
1, 2-Dibromoethane		
1, 2-Dichlorobenzene		
1, 2-Dichloroethane		
1, 2-Dichloropropane		
1, 3-Dichlorobenzene		
1, 3-Dichloropropene		
1, 4-Dichlorobenzene		
1, 2-Transdichloroethylene		
2-Chloroethylvinyl ether		
1, 2-Transdichloroethene		

Table 7. Selected physical and chemical characteristics of water from drainage wells in Ocala

[µS/cm, microsiemens per centimeter at 25 °C; mg/L, milligrams per liter; immed., immediate incubation; cols, colonies; mL, milliliter; µg/L, micrograms per liter; E, nonideal sample; --, not analyzed. Data from Kimrey and Fayard, 1984, table 2; Well numbers are from table 1; locations are shown in plate 3]

Well number	Site identification	Date	Specific conductance (µS/cm)	pH (standard units)	Calcium dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L) as Cl)	Sulfate dissolved (mg/L as as SO_4)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Coliform, total, (immed. cols/ 100 mL)
42	291117082063301	07-24-80	203	7.0	37	1.3	3.1	1.4	6.2	8.1	0.3	1.9	5,600
47	291120082064001	07-28-80	330	7.6	57	4.0	3.3	1.3	3.6	36	.3	4.7	410
59	291125082075701	07-25-80	299	7.0	31	4.0	12	9.4	39	24	.4	5.4	E56,000
60	291126082083501	07-28-80	194	7.5	30	2.4	4.5	1.5	4.4	15	.5	4.4	2,700
65	291131082075501	07-29-80	330	7.2	35	4.0	12	9.6	23	13	.4	5.8	21,000
81	291151082072501	07-23-80	452	6.9	68	8.0	6.9	1.8	9.0	46	.7	8.5	2,900

Well number	Site identification	Date	Arsenic total (µg/L as As)	Cadmium total recoverable (µg/L as Cd)	Chromium, total recoverable (µg/L as Cr)	Copper, total recoverable (µg/L as Cu)	Iron, total recoverable (µg/L as Fe)	Lead, total recoverable (µg/L as Pb)	Manganese, total recoverable (µg/L as Mn)	Strontium, dissolved (µg/L as Sr)	Zinc, total recoverable total (µg/L as Zn)	Selenium total (mg/L as Se)
42	291117082063301	07-24-80	4	0	20	0	840	0	170	80	30	0
47	291120082064001	07-28-80	--	0	--	--	--	2	--	450	10	--
59	291125082075701	07-25-80	5	0	20	20	280	0	100	270	50	0
60	291126082083501	07-28-80	2	0	20	--	--	0	--	150	30	0
65	291131082075501	07-29-80	--	0	--	--	--	1	--	250	10	--
81	291151082072501	07-23-80	--	--	--	--	--	--	--	790	--	--

Well number	Site identification	Date	Nitrogen, total (mg/L as N)	Nitrogen, organic total (mg/L as N)	Nitrogen, ammonia total (mg/L as N)	Nitrogen, nitrite total (mg/L as N)	Nitrogen, nitrate total (mg/L as N)	Nitrogen, ammonia + organic total (mg/L as N)	Nitrogen, NO_2+NO_3 total (mg/L as N)	Carbon, orbanic total (mg/L as C)	Phosphorus, ortho total (mg/L as P)
42	291117082063301	07-24-80	0.80	0.52	0.26	0.01	0.01	0.78	0.02	9.1	0.24
47	291120082064001	07-28-80	.39	.14	.03	.00	.22	.17	.22	5.7	.09
59	291125082075701	07-25-80	8.0	1.8	3.10	.58	2.5	4.9	3.1	26	.78
60	291126082083501	07-28-80	.70	.48	.19	.01	.02	.67	.03	9.0	.28
65	291131082075501	07-29-80	4.3	1.1	3.20	.01	.00	4.3	.01	13	1.30
81	291151082072501	07-23-80	.86	.25	.60	.00	.01	.85	.01	4.9	.58

with a median of 30 µg/L; the median zinc concentration for the Orlando drainage-well water was 10 µg/L. The higher manganese and zinc concentrations in the Ocala area are probably related to fertilizer runoff.

Ground-Water Quality

Sampling-Well Network

During 1989-90, 34 wells were sampled to obtain an overview of ground-water quality in central Marion County. The locations of wells sampled are shown on plate 1 and the results of the analyses are listed in table 8. Some of the sampling and analyses were done by FDEP.

Wells sampled by FDEP were drilled and sampled under the direction of the St. Johns River Water Management District as part of FDEP's statewide Very Intensely Studied Areas (VISA) program. In 1989, 17 wells were drilled at 13 sites, chosen because of proximity to, but not necessarily downgradient of, potential sources of contamination. All wells were drilled on property owned by a government entity rather than on private property. The wells were drilled using a hollow-stem auger (thus water-quality variations do not reflect residual drilling mud) and water samples were collected from the top of the Upper Floridan aquifer. Some of the wells penetrated only the surficial sediments that overlie the Upper Floridan aquifer. At two sites, two wells of different depths were drilled. The wells were all completed with 10 ft of slotted PVC screen. Well bores around the screen were packed with sand and sealed with 1 ft of bentonite clay.

Results of Analyses

The VISA wells were sampled in May 1990 for major ions, metals, selected nutrients, and organic constituents. The organic constituents included purgeables (volatiles), base neutrals, acid extractables, pesticides, PCBs, and carbamates. Organic constituents were analyzed using GC/MS.

During 1989-90, the USGS sampled 17 wells in central Marion County and analyzed the water using techniques described by Skougstad and others (1979) and Wood (1976). The samples were analyzed for major ions, metals, nutrients, and bacteria. FID scans for organic contaminants were also run and selected samples were analyzed for volatile organics. Some of the wells were selected because they were near two or more of the sites identified in earlier sections of this report as potential sources of contamination (wells 16, 94, 105, 106). Other wells were selected, primarily on the basis of accessibility, to provide background data. The depth of some of the wells was not known, but all wells of unknown depth were drilled either by rotary or cable-tool method and are assumed to be completed into the limestone of the Upper Floridan aquifer.

Analyses of water samples from the 17 wells sampled during this study or sampled as part of FDEP's VISA program indicated traces of organic compounds in water from 6 of the wells. Samples from some of the VISA wells, analyzed by GC/MS, had traces of 1,2 dichloropropane, chloroform, and tetrachloroethene; however, none of the organics were detected in significant quantities. Of the wells sampled by the USGS, chloroform was detected in three wells, toluene in one well and tetrachloroethylene in one well.

Wells deeper than 40 ft were assumed to be completed in the Upper Floridan aquifer (25 wells), whereas wells less than 40 ft deep (9 wells) were considered to be completed in the surficial aquifer. The chemistry of water samples from the two groups was compared using the logarithmic distributions of selected constituents in water samples (fig. 22). The concentrations are plotted on a logarithmic scale to make the scale suitable for the various constituents. Generally, the plots do not indicate major water-chemistry differences between the two groups.

A statistical test (Kruskal-Wallis) was applied to the data to determine whether any significant differences exist in water chemistry between samples from the surficial aquifer and those from the Upper Floridan. This nonparametric test performs an analysis of variance on the ranks of the data (German and Schiffer, 1988, p. 25-27). Data for the following constituents were analyzed: iron, specific conductance, calcium, magnesium, sodium, potassium, chloride, sulfate, ammonia, nitrate, total orthophosphorus, pH, and total organic carbon.

The results of the Kruskal-Wallis test indicate no significant difference between the two groups of samples for iron, specific conductance, calcium, sodium, potassium, chloride, nitrate, and total organic carbon. At a 95 percent confidence level, the test results indicate that pH and concentrations of magnesium, sulfate, ammonia, and total

Table 8. Selected physical and chemical characteristics of water from wells in central Marion County

[Agency analyzing sample: USGS, U.S. Geological Survey; FDEP, Florida Department of Environmental Protection. Aquifer: S, surficial; F, Upper Floridan. µS/cm, microsiemens per centimeter at 25 °C; mg/L, milligrams per liter; µg/L, micrograms per liter; --, not analyzed; <, less than; ND, not detected. Well numbers are from table 1; locations are shown in figures 9, 11, or 14, and on plate 1]

Well No.	Site identification	Date	Aquifer	Agency analyzing sample	Specific conductance (µS/cm)	pH (standard units)	Hardness total mg/L as ($CaCO_3$)	Calcium total[1] (mg/L as Mg)	Magnesium total[1] (mg/L as Mg)	Sodium total[1] (mg/L as Na)	Potassium total[1] (mg/L as K)	Chloride total[1] (mg/L as Cl)	Sulfate total[1] (mg/L as SO_4)	Fluoride total[1] (mg/L as F)	Silica, dissolved (mg/L as SiO_2)
8	290405082140501	08-30-89	F	USGS	270	7.3	140	54	0.80	2.5	0.20	4.1	0.90	0.10	5.8
13	290835082102701	06-27-90	F	USGS	580	7.5	300	100	12	5.9	.80	9.4	140	.20	9.6
15	290838082103501	06-27-90	F	USGS	550	7.5	300	100	11	6.6	.70	11	120	.20	9.6
16	290930082104501	06-28-90	F	USGS	650	7.3	--	120	16	8.5	.90	13	210	.20	9.8
19	291002082104901	08-22-89	F	USGS	280	7.7	150	56	2.0	4.2	.20	11	12	.10	7.9
19A	291015082084001	08-04-89	F	USGS	400	7.6	180	62	5.7	4.8	3.0	6.2	61	--	--
22	291025082070401	08-04-89	F	USGS	452	7.3	190	69	5.1	16	1.2	17	25	--	--
		05-24-90		FDEP	469	7.1	--	80	4.1	9.9	.8	14	<.10	<.10	--
26	291043082093201	05-22-90	S	FDEP	897	6.5	--	182	4.7	9.1	.2	17	9.4	<.10	--
27	291049082084701	05-22-90	S	FDEP	290	7.2	--	54	1.5	2.8	.1	3.9	<5.0	<.10	--
		FDEP		FDEP	290	7.2	--	54	1.5	2.8	.1	3.4	<5.0	<.10	--
30	291057082080201	05-24-90	S	FDEP	190	5.49	--	18	2.7	8.0	1.0	14	36	<.10	--
30A	291058082071701	08-02-89	F	USGS	--	--	260	82	14	10	.90	11	100	--	--
40	291111082085801	05-22-90	S	FDEP	548	6.8	--	120	4.1	3.6	.4	4.2	18	.20	--
46	291120082060001	08-03-89	F	USGS	565	7.2	290	100	8.7	6.0	.60	7.5	62	--	--
51	291123082065001	05-23-90	F	FDEP	544	6.9	--	100	5.1	7.6	1.0	6.4	36	.13	--
52	291123082075401	05-23-90	F	FDEP	296	5.5	--	21	5.8	23	.6	43	32	.18	--
53	291123081075402	05-23-90	S	FDEP	407	6.3	--	66	10	15	1.9	19	41	.30	--
54	291123082082901	05-22-90	S	FDEP	51	6.9	--	98	4.5	6.6	2.8	4.3	15	.26	--
61A	291126082091101	08-03-89	F	USGS	532	7.3	260	96	5.1	9.1	.50	12	47	--	--
70	291139082070801	08-04-99	F	USGS	430	7.5	200	60	13	7.8	.90	12	48	--	--
73	291140082052701	05-04-89	F	USGS	320	7.6	--	--	--	--	--	3.1	--	--	--
		09-20-89		USGS	304	7.5	--	--	--	--	2.3	2.3	--	--	--
75	291140082091401	05-23-90	S	FDEP	286	7.2	--	54	1.1	0.8	1.2	<2.0	5.6	.24	--
76	291148082072702	05-24-90	F	FDEP	792	6.7	--	101	24	32	.6	34	22	.35	--
80	291151082064201	05-23-90	F	FDEP	609	6.7	--	124	2.0	3.9	2.0	2.5	10	<.10	--
91	291204082083601	08-03-89	F	USGS	361	7.6	170	60	5.5	5.0	.40	8.0	42	--	--
92	291204082083602	05-21-90	S	FDEP	185	7.6	--	35	2.1	1.3	.3	2.7	9.0	<.10	--
93	291206082084401	05-21-90	F	FDEP	56	6.8	--	93	11	8.6	.8	14	99	.11	--
94	291210082053301	06-28-90	F	USGS	595	6.9	310	120	2.7	5.1	.20	7.1	11	.10	8.6
95	291214082072501	05-23-90	S	FDEP	198	7.1	--	34	1.6	2.9	.9	2.3	<5.0	.40	--
100	291226082042001	06-21-89	F	USGS	550	7.4	270	87	13	7.7	.80	13	100	<.10	10
101	291235082061001	06-21-89	F	USGS	500	7.4	240	78	10	7.0	1.0	12	45	.20	11
102	291239082082702	05-21-90	F	FDEP	820	6.5	--	192	2.7	3.6	.1	2.9	84	<.10	--
103	291255082051701	06-27-90	F	USGS	475	7.2	240	79	10	5.9	.60	9.0	29	.30	12
105	291320082042301	06-28-90	F	USGS	225	7.8	110	38	2.9	3.0	.20	5.2	1.9	.10	9.6
106	291704082111501	06-28-90	F	USGS	390	7.1	200	72	5.9	4.9	.40	7.6	6.4	.20	11

Table 8. Selected physical and chemical characteristics of water from wells in central Marion County--Continued

[Agency analyzing sample: USGS, U.S. Geological Survey; FDEP, Florida Department of Environmental Protection. Aquifer: S, surficial; F, Upper Floridan. μS/cm, microsiemens per centimeter at 25 °C; mg/L, milligrams per liter; μg/L, micrograms per liter; --, not analyzed; <, less than; ND, not detected. Well numbers are from table 1; locations are shown in figures 9, 11, or 14, and on plate 1]

Well No.	Site identification	Date	Aquifer	Agency analyzing sample	Arsenic total (mg/L as As)	Cadmium total recoverable (μg/L as Cr)	Chromium, total recoverable (μg/L as Cr)	Iron, total recoverable (μg/L as Fe)	Iron, total recoverable (μg/L as Fe)	Iron, dissolved (μg/L as Fe)	Lead, total recoverable (μg/L as Pb)	Manganese, dissolved (μg/L as Mn)	Manganese, dissolved (μg/L as Mn)	Manganese, dissolved (μg/L as Mn)	Strontium, dis, solved (μg/L as Sr)	Selenium total (μg/L as Se)
8	290405082140501	08-30-89	F	USGS	<1	<1	<10	20	40	--	<1	<10	--	--	90	<1
13	290835082102701	06-27-90	F	USGS	<1	<1	4	4	220	<10	8	<10	<10	--	20	<1
15	290838082103501	06-27-90	F	USGS	<1	<1	2	1	120	<10	<1	20	<10	--	30	<1
16	290930082104501	06-28-90	F	USGS	<1	<1	1	1	30	<10	<1	<10	<10	--	320	<1
19	291002082104901	08-22-89	F	USGS	<1	<1	<10	3	30	--	2	10	--	--	230	<1
22	291025082070401	05-24-90	F	FDEP	ND	0	ND	ND	ND	--	ND	3	--	--	3	ND
26	291043082093201	05-22-90	S	FDEP	ND	0	ND	ND	ND	--	ND	120	--	--	2	ND
27	291049082084701	05-22-90	S	FDEP	ND	0	ND	ND	ND	--	ND	ND	--	--	ND	ND
		05-22-90		FDEP	ND	0	ND	ND	3	--	ND	ND	--	--	ND	ND
30	291057082080201	05-24-90	S	FDEP	ND	<1	ND	ND	9	--	ND	8	--	--	10	ND
40	291111082085801	05-22-90	S	FDEP	ND	0	ND	ND	ND	--	ND	25	--	--	1	ND
51	291123082065001	05-23-90	F	FDEP	ND	0	ND	ND	ND	--	ND	3	--	--	ND	ND
52	291123082075401	05-23-90	F	FDEP	ND	0	ND	ND	10	--	ND	11	--	--	5	ND
53	291123082075402	05-23-90	S	FDEP	ND	0	ND	ND	30	--	ND	78	--	--	2	ND
54	291123082082901	05-22-90	S	FDEP	ND	0	ND	ND	20	--	ND	ND	--	--	ND	ND
75	291140082091401	05-23-90	S	FDEP	ND	0	ND	ND	8	--	ND	8	--	--	ND	ND
76	291148082072702	05-24-90	F	FDEP	ND	0	ND	ND	5	--	ND	38	--	--	3	ND
80	291151082064201	05-23-90	F	FDEP	ND	0	ND	ND	8	--	ND	3	--	--	4	ND
92	291204082083602	05-21-90	S	FDEP	ND	0	ND	ND	ND	--	ND	ND	--	--	ND	ND
93	291206082084401	05-21-90	F	FDEP	ND	0	ND	ND	ND	--	ND	ND	--	--	ND	ND
94	291210082053301	06-28-90	F	USGS	<1	<1	3	2	40	<10	4	10	<10	--	140	<1
95	291214082072501	05-23-90	S	FDEP	ND	0	ND	ND	10	--	ND	11	--	--	ND	ND
100	291226082042001	06-21-89	F	USGS	<1	<1	<10	1	150	--	<5	<10	--	--	90	<1
101	291235082061001	06-21-89	F	USGS	<1	<1	<10	2	50	--	<5	<10	--	--	160	<1
102	291239082082702	05-21-90	F	FDEP	<4	0	ND	ND	9800	--	ND	200	--	--	5	ND
103	291255082051701	06-27-90	F	USGS	<1	<1	1	4	20	<10	1	<10	<10	600	30	<1
105	291320082042301	06-28-90	F	USGS	2	<1	6	<1	120	<10	<1	10	<10	--	40	3
106	291704082111501	06-28-90	F	USGS	5	<1	1	1	380	80	3	10	<10	--	120	<1

[Agency analyzing sample: USGS, U.S. Geological Survey; FDEP, Florida Department of Environmental Protection. Aquifer: S, surficial; F, Upper Floridan. µS/cm, microsiements per centimeter at 25 °C; mg/L, milligrams per liter; µg/L, micrograms per liter; --, not analyzed; <, less than; ND, not detected. Well numbers are from table 1; locations are shown in figures 9, 11, or 14, and on plate 1]

Well No.	Site identification	Date	Aquifer	Agency analyzing sample	Nitrogen total (mg/L as N)	Nitrogen, organic total (mg/L as N)	Nitrogen, ammonia total (mg/L as N)	Nitrogen, nitrite total (mg/L as N)	Nitrogen, nitrate total (mg/L as N)	Nitrogen, ammonia + organic total (mg/L as N)	Nitrogen NO_2+N_3 total (mg/L as N)	Nitrogen, NO_2+N_3 dissolved (mg/L as N)	Phosphate total (mg/L as PO_4)	Phosphorus total (mg/L as P)	Phosphorus ortho, dissolved (mg/L as P)	Phosphorus ortho total (mg/L as P)	Carbon, organic total (mg/L as C)
8	290405082140501	08-30-89	F	USGS	--	--	0.010	<0.01	--	<0.20	0.24	--	0.03	0.02	--	0.01	<0.1
13	290835082102701	06-27-90	F	USGS	--	--	<.010	<.01	--	<.20	1.4	1.50	.12	.03	0.04	.04	32
15	290838082103501	05-27-90	F	USGS	3.0	--	<.010	<.01	--	.32	2.7	--	.09	.04	--	.03	33
	06-27-90	USGS	--	--	--	--	--	--	--	2.50	--	--	.03	--	--		
16	290930082104501	06-28-90	F	USGS	--	--	<.010	<.01	--	<.20	.89	.910	--	.03	--	.01	.3
19	291002082104901	08-22-89	F	USGS	--	--	<.010	<.01	--	<.20	3.6	--	.06	.02	--	.02	.4
19A	291015082084001	08-04-89	F	USGS	.36	0.19	.150	<.01	--	.34	.02	--	.15	.08	--	.05	2.0
22	291025082070401	08-04-89	F	USGS	--	--	<.010	<.01	--	<.20	1.4	--	.25	.08	--	.08	.6
		05-24-90		USGS	--	--	--	--	1.46	--	--	--	.22	--	--	.073	<1.0
		08-04-89		GSUS	--	--	<.010	<.01	--	<.20	1.4	--	.25	.08	--	.08	.6
		05-24-90		USGS	--	--	.081	--	1.46	--	--	--	.22	--	--	.073	<1.0
26	291043082093201	05-22-90	S	FDEP	--	--	.044	--	2.54	--	--	--	.47	--	--	.152	<1.0
27	291049082084701	05-22-90	S	FDEP	--	--	.029	--	1.17	--	--	--	.36	--	--	.119	3.0
	05-22-90	FDEP	--	--	<.020	--	1.16	--	--	--	--	--	--	ND	ND		
30	291057082080201	05-24-90	S	FDEP	--	--	.068	--	1.20	--	--	--	3.10	--	--	1.01	<1.0
30A	291058082071701	08-02-89	F	USGS	--	--	<.010	<.01	--	<.20	.47	--	.03	<.02	--	.01	.5
40	291111082085801	05-22-90	S	FDEP	--	--	.070	--	1.10	--	--	--	.21	--	--	.069	3.0
46	291120082060001	08-03-89	F	USGS	--	--	<.010	<.01	--	<.20	1.2	--	.12	.05	--	.04	.3
51	291123082065001	05-23-90	F	FDEP	--	--	.069	--	.524	--	--	--	.47	--	--	.152	ND
52	291123082075401	05-23-90	F	FDEP	--	--	.029	--	.843	--	--	--	3.83	--	--	1.25	ND
53	291123082075402	05-23-90	S	FDEP	--	--	.043	--	.422	--	--	--	1.86	--	--	.606	3.0
54	291123082082901	05-22-90	S	FDEP	--	--	.047	--	1.89	--	--	--	.47	--	--	.152	2.0
61A	291126082091101	08-03-89	F	USGS	--	--	<.010	<.01	--	<.20	3.2	--	.12	.05	--	.04	.4
70	291139082070801	08-04-89	F	USGS	--	--	<.010	<.01	--	<.20	.43	--	.37	.12	--	.12	.4
	08-04-89	USGS	--	--	<.010	<.01	--	<.20	.41	--	.40	.12	--	.13	.5		
73	291140082052701	05-04-89	F	USGS	--	--	<.010	<.01	--	<.20	.15	--	.12	.22	--	.04	.3
		09-20-89		USGS	--	--	<.010	<.01	--	.15	.15	--	.14	.14	--	.04	.4
75	291140082091401	05-23-90	S	FDEP	--	--	.093	--	.129	--	--	--	.48	--	--	.156	ND
76	291148082072702	05-24-90	F	FDEP	--	--	.026	--	.598	--	--	--	.67	--	--	.217	2.0
80	291151082064201	05-23-90	F	FDEP	--	--	.068	--	.212	--	--	--	.56	--	--	.182	ND
91	291204082083601	08-03-89	F	USGS	--	--	<.010	<.01	--	<.20	1.4	--	.31	.15	--	.10	.2
92	291204082083602	05-21-90	S	FDEP	--	--	.078	--	.125	--	--	--	.65	--	--	.212	ND
93	291206082084401	05-21-90	F	FDEP	--	--	ND	--	1.41	--	--	--	.26	--	--	.086	ND
94	291210082053301	06-28-90	F	USGS	--	--	<.010	<.01	--	<.20	1.7	1.70	.21	.05	.06	.07	66
95	291214082072501	05-23-90	S	FDEP	--	--	.069	--	.068	--	--	--	1.59	--	--	.519	ND
100	291226082042001	06-21-89	F	USGS	--	--	<.010	<.01	--	<.20	1.2	--	.15	.04	--	.05	1.0
101	291235082061001	06-21-89	F	USGS	--	--	.040	.01	3.49	<.20	3.5	--	.18	.06	--	.06	.6
102	291239082082702	05-21-90	F	FDEP	--	--	.141	--	<.020	--	--	--	--	--	--	<.05	2.0
103	291255082051701	06-27-90	F	USGS	3.4	--	<.010	<.01	--	.35	3.0	2.00	.15	.05	.05	.05	42
105	291320082042301	06-28-90	F	USGS	.38	--	<.010	<.01	--	.25	.13	.150	.06	.02	.01	.02	24
106	291704082111501	06-28-90	F	USGS	.53	.24	.010	<.01	--	.25	.28	.310	.06	.02	.03	.02	1.1

[1]Samples analyzed by the USGS are dissolved; FDEP samples are total. In ground water, dissolved and total constituents are comparable if particulate matter is negligible. Recent studies indicate that dissolved-phase concentrations of trace elelents (such as arsenic, cadmium, chromium, copper, lead, and zinc) higher than a few tenths of a microgram per liter may actually represent elevated environmental concentration, or could reflect contamination introduced by processing or analysis (D.A. Ricket, U.S. Geological Survey, Reston, Va., written commun., 1992).

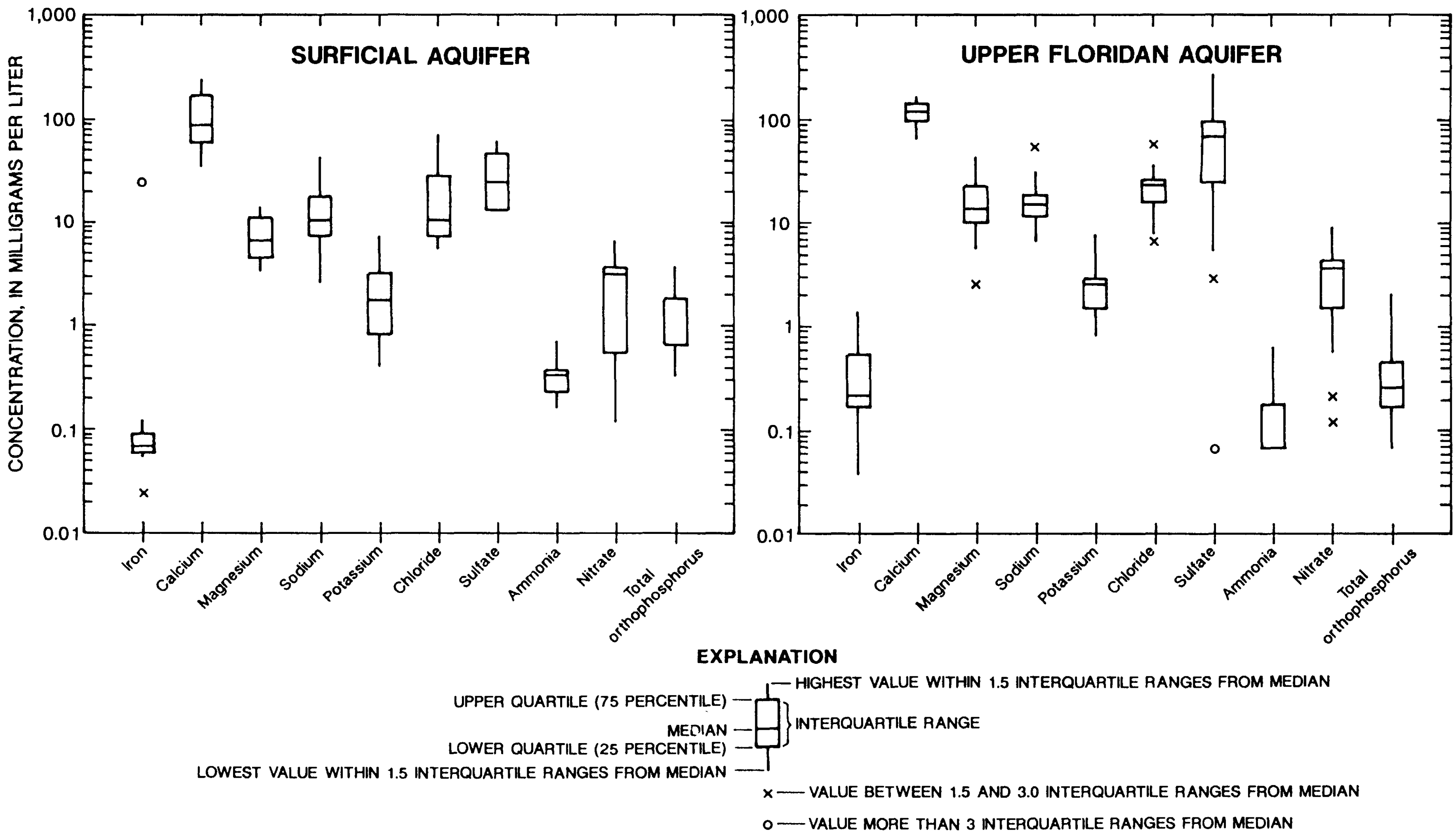


Figure 22. Logarithmic distribution of selected constituents in water from sampled wells.

orthophosphate are significantly different in water from Upper Floridan aquifer wells than in water from the surficial aquifer wells. The differences in magnesium and sulfate probably are related to the dissolution of gypsum and dolomite from the Upper Floridan aquifer. These minerals generally are not present in the surficial aquifer. The difference in ammonia and total orthophosphate may be the result of recharge water containing significant concentrations of these constituents seeping down through the surficial sediments. These constituents are diluted and dispersed when the recharge water reaches the Upper Floridan aquifer.

Comparison of Water Quality from Various Sources

As an aid to the interpretation of observed concentrations of constituents in ground water in the Ocala area, comparisons were made with runoff from various sources (table 4) and with water entering the drainage wells in Ocala (table 5). If recharge through sinkholes and drainage wells is affecting the chemistry of water in the aquifer, higher than background concentrations of some constituents would be expected. Comparisons were also made with data from a study of the Orlando area where 65 public-supply wells and 21 drainage wells were sampled (Schiner and German, 1983). Mean concentrations of major ions in water samples are shown in figure 23. Mean concentrations, rather than medians, were used because Mattraw and Miller (1981, table 4) reported mean rather than median concentrations for runoff from highways and residential and commercial areas.

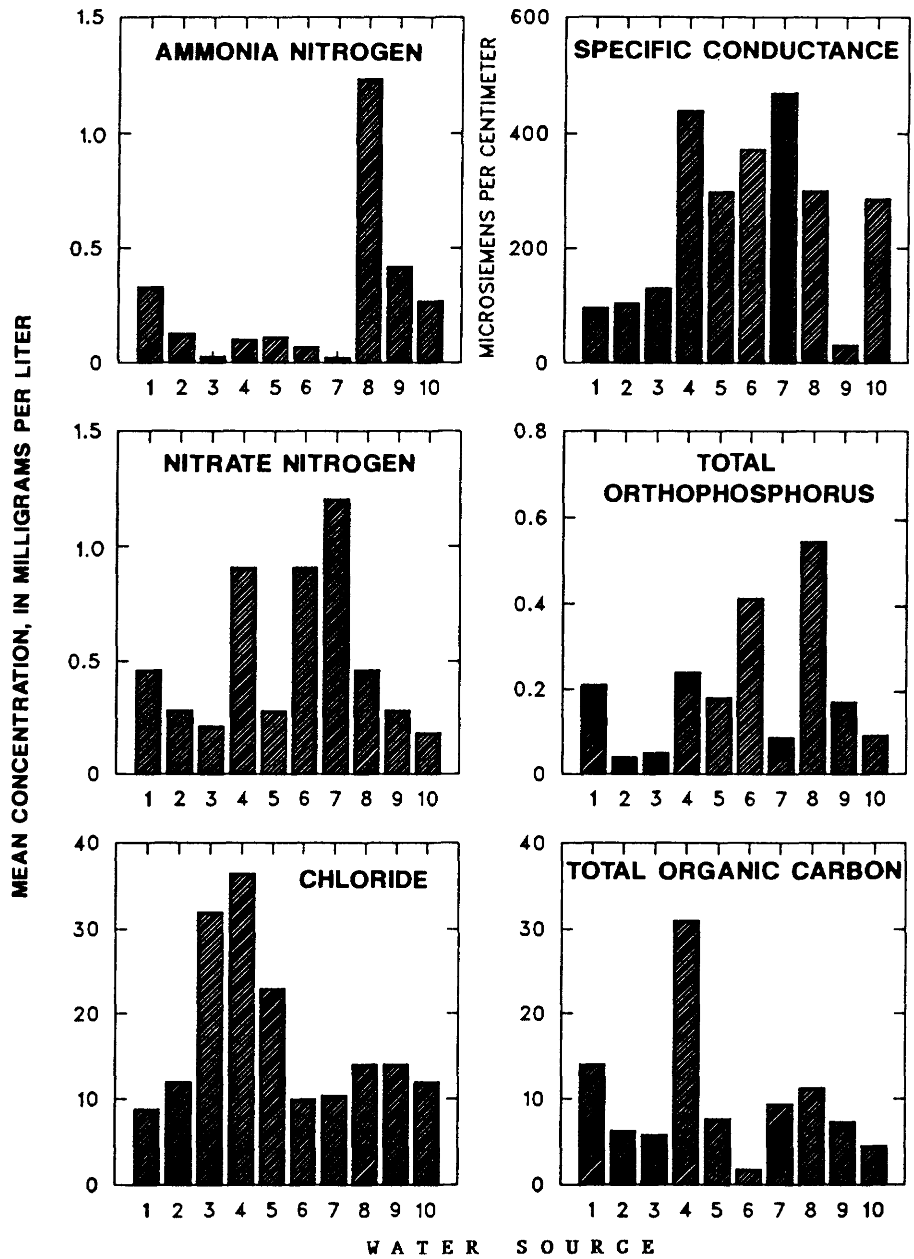
The specific conductance of urban runoff (bars 1-3 in fig. 23) is lower than that of all ground-water samples except water from Orlando area drainage wells (bar 9). The specific conductance of agricultural surface water is more than double that of urban runoff. Water from drainage wells in Ocala had nearly the same specific conductance as water in Tuskwilla Pond, whereas water from drainage wells in Orlando had a much lower specific conductance, probably reflecting the direct inflow of surface runoff into the Orlando drainage wells. The highest mean specific conductance was in water from Ocala-area Upper Floridan aquifer wells. Thus it seems that the specific conductance of water from the Upper Floridan aquifer in Ocala relates to dissolution of minerals in the aquifer, rather than to the influence of recharge through drainage wells or sinkholes.

The highest mean concentration of ammonia nitrogen was in water from drainage wells in the Ocala area. Water from wells tapping both the surficial and Upper Floridan aquifers in Ocala had lower mean concentration of ammonia than water from either drainage wells or public-supply wells in Orlando. Mean nitrate concentrations were higher in water samples from both the surficial and Upper Floridan aquifers in Ocala than in water from Ocala drainage wells or Orlando drainage or public-supply wells. In the Orlando area, there seems to be little difference in the mean concentrations of ammonia and nitrate in water from drainage and public-supply wells. The nitrogen speciation of ground water in the Ocala area might be due to nitrification of ammonia nitrogen in water recharging the surficial and Upper Floridan aquifers by seepage through the soil zone, resulting in a decrease in ammonia concentration and an increase in nitrate concentration. Water rapidly recharged through drainage wells has no opportunity to undergo nitrification by bacteria in the soil and could have relatively high concentrations of ammonia. Also, the leaching of nitrogen from fertilizers in the soil zone could have more effect on the nitrogen speciation in the Ocala area (where the sediments overlying the aquifer are thin) than in the Orlando area (where the unconsolidated sediments can be 200 ft thick or more).

Both chloride and total organic carbon were high in agricultural surface water but low in water from wells tapping the Upper Floridan aquifer in the Ocala area. This indicates that contamination from agricultural waste does not seem to affect the ground-water chemistry in the Ocala area.

The chemical composition of water in the Ocala drainage wells seems to be influenced by a wide variation in the quality of urban runoff in the area. Analysis of additional water samples from each source would provide more data with which to understand the chemical composition of the water from Ocala-area drainage wells and how that water influences the chemical composition of Upper Floridan aquifer water.

To summarize, water entering the aquifer through drainage wells and sinkholes commonly contains bacteria and may contain significant concentrations of nutrients and metals (table 7). Low



EXPLANATION

Bar number	Water source	Reference
1	Residential runoff	Table 2
2	Highway runoff	Table 2
3	Commercial runoff	Table 2
4	Agricultural surface water	Table 2
5	Tuskawilla pond	Table 3
6	Surficial aquifer water wells, Ocala	Table 6
7	Upper Floridan aquifer water wells, Ocala	Table 6
8	Drainage wells, Ocala	Table 5
9	Drainage wells, Orlando	Schiner and German (1983, table 7)
10	Public-supply wells, Orlando	Schiner and German (1983, table 7)

Figure 23. Mean concentrations of selected constituents (Schiner and German, 1988, table 9), surface runoff, surface water, and ground water.

concentrations of some organic compounds were occasionally detected in water entering the aquifer through drainage wells. However, analyses of water samples collected from 34 wells in Marion County in 1989-90 do not indicate widespread degradation of water quality.

SUMMARY AND CONCLUSIONS

This report presents the results of a study conducted in 1988-90 to document sites of potential sources of contamination to the Upper Floridan aquifer in the Silver Springs ground-water basin in central Marion County and to improve understanding of the hydrogeology of the system, especially as related to the potential movement of contaminants in ground water. The Upper Floridan aquifer is the principal source of water supply for the area. The karstic nature of the local geology makes the ground water susceptible to contaminants from the land surface. The limestone of which the aquifer is comprised is covered by a thin veneer of generally permeable sediments and contains numerous fractures and conduits that can transmit water at a much faster rate than if diffuse porous flow alone were dominant.

The Silver Springs ground-water basin is characterized by an almost complete absence of surface drainage. Instead, nearly all precipitation not lost to evapotranspiration recharges the aquifer. The dominant hydrologic feature of the system is Silver Springs, which has an average discharge of about 525 Mgal/d. The discharge from the spring is supported by approximately 15 to 20 in/yr of rainfall that recharges the aquifer over the approximately 1,200 mi^2 drainage basin.

Withdrawals from wells completed in the Upper Floridan aquifer in Marion County average about 42 Mgal/d. The transmissivity of the Upper Floridan ranges from about 6,200 to 29,500 ft^2/d for the upper 100 ft of the aquifer and from about 10,700 to 25,500,000 ft^2/d for the full thickness of the aquifer.

An inventory of natural and manmade potential sources of contamination to the Upper Floridan was made during the study. The types of contaminants that can enter the aquifer are related to the land use of the area and the types of substances used or stored at various sites. Possible contaminants include organic compounds, metals, nutrients, bacteria, and viruses.

Sinkholes provide a natural pathway for the entry of contaminants into the aquifer. The density of sinkholes in the center of the basin was plotted. Sinkholes exist throughout the area, but they seem to be more numerous in the areas where the Hawthorn Formation has been eroded away. Urbanization can accelerate the development of sinkholes if grading removes most or all of the overburden that covers the limestone of the Upper Floridan aquifer.

Drainage wells, constructed as a means of disposing of unwanted surface water, can also provide entry for contaminants into the aquifer. The use of such wells is being phased out; but as of 1990, there were 42 known active drainage wells in central Marion County. The wells may drain as much as 4.5 Mgal/d of surface runoff to the aquifer.

Seepage from surface impoundments and wastewater discharges can also introduce contaminants into the aquifer. Surface impoundments cover about 475 acres in Marion County. Contaminants in these impoundments can seep into the aquifer and have sometimes drained directly into the aquifer when a sinkhole developed within the impoundment. Seepage from nine major septic-tank drain fields in the county also can introduce bacteria, viruses, and nutrients into the aquifer. Sites where treated wastewater is either impounded, applied to the land surface as spray irrigation, or discharged to surface-water bodies are also potential sources of contamination. About 50 land-application sites and 50 surface-discharge sites for treated wastewater exist in Marion County.

Other potential sources of contamination include underground storage tanks, chemicals used in manufacturing, and buried wastes. As of October 1990, FDEP had permits for about 165 sites containing underground storage tanks (primarily gasoline tanks). These sites pose a threat to ground-water quality because it is estimated that 20 to 40 percent of all storage tanks leak and the most common water-soluble compounds in gasoline and other organic compounds are toxic. Other chemicals that are used in manufacturing, are manufacturing byproducts, or are used in cleaning or degreasing processes can also become sources of ground-water contamination. About 160 sites in Marion County have been identified as potentially containing toxic substances. There are also about 95 sites where wastes have been buried in the county, ranging from active landfills where management and ground-water monitoring are designed to minimize the effects on ground-water quality, to abandoned landfills containing unknown materials.

Detailed investigation of four sites in the basin provided insight into the relation between the regional hydrogeology and the hydrogeology of local systems. Surface geophysical methods were of limited success in predicting the presence of fractures or buried sinkholes (which might be significant to the introduction or movement of contaminants); but, under some geologic conditions, these methods may be useful. A major drawback to the use of some geophysical methods was interference from cultural features, including metal fences and buried cables and pipes. Water-level monitoring showed that the horizontal hydraulic gradient in the Silver Springs basin is very low, on the order of 10^{-4}. Ground-water flow velocities calculated from dye traces were on the order of 1-2 ft/hr under natural-flow conditions and up to about 10 ft/hr under pumping conditions. These velocities were considerably higher, under all conditions except the highest estimated transmissivity and horizontal hydraulic gradients, than those estimated for steady-state flow in a porous medium. If apparent ground-water flow velocities determined from dye-trace studies are to be useful, several traces over the expected range of hydrologic conditions are needed. The effects of regional flow can be significant, especially near Silver Springs, and can affect the delineation of wellhead protection zones.

Evaluating the potential effects of contaminants is difficult in a karstic area where fracture flow dominates; caution must be used when evaluating a specific site based on hydrogeologic data obtained from regional studies. Movement of contaminants through surficial deposits can be affected by surface hydrogeologic factors, such as the thickness and hydraulic conductivity of shallow, unconsolidated sediments, and the presence of sinkholes. Movement of contaminants through the Upper Floridan aquifer is controlled by subsurface hydrogeologic factors, such as porosity and permeability of the Upper Floridan aquifer and the presence and size of fractures and conduits. Hydrologic factors, such as head and horizontal hydraulic gradient, are also important. The physical and chemical characteristics of the potential contaminant, as well as the rate of introduction into the aquifer, can affect the movement of a contaminant through the aquifer.

Analysis of water from 34 wells sampled in 1989-90 and of several samples collected from water entering the Upper Floridan aquifer through drainage wells indicates no widespread degradation of water quality in the ground-water basin. Water entering the aquifer through drainage wells contained bacteria, slightly elevated concentrations of nutrients, manganese, zinc, and in places, low concentrations of organic compounds. At present, water from sampled wells does not seem to be adversely affected by the recharge through drainage wells and sinkholes. Compared to public-supply wells in Orlando, water from wells in central Marion County had lower concentrations of ammonia, orthophosphate, and total organic carbon; higher concentrations of nitrate; and about equal concentrations of chloride. Organic compounds were detected in low concentrations in water from a few wells in central Marion County.

SELECTED REFERENCES

Aldous, P.J., and Smart, P.L., 1988, Tracing ground-water movement in abandoned coal mine aquifers using fluorescent dyes: Ground Water, v. 26, no. 2, p. 172-178.

Barker, J.F., Patrick, G.C., and Major, D., 1987, Natural attenuation of aromatic hydrocarbonds in a shallow sand aquifer: Ground Water Monitoring Review, v. 7, no. 1, p. 64-71.

Brooks, H.K., 1981, Physiographic divisions of Florida: Cooperative Extension Service, Gainesville, Institute of Food and Agricultural Science, University of Florida, 1 sheet.

Brown, R.H., 1963, Estimating the transmissibility of an artesian aquifer from the specific capacity of a well, *in* Bentall, Ray, compiler, Methods of determining permeability, transmissibility, and drawdown: U.S. Geological Survey Water-Supply Paper 1536-I, p. 324-330.

Bush, P.W., 1982, Predevelopment flow in the Tertiary limestone aquifer, Southeastern United States: A regional analysis from digital modeling: U.S. Geological Survey Water-Resources Investigations Report 82-905, 41 p.

Clark, W.E., Musgrove, R.H., Menke, C.G., and Cagle, J.W., Jr., 1964, Water resources of Alachua, Bradford, Clay, and Union Counties, Florida: Florida Geological Survey Report of Investigations No. 35, 170 p.

Cooke, C.W., 1939, Scenery of Florida interpreted by a geologist: Florida Geological Survey Bulletin 17, 118 p.

Davis, S.N., Campbell, D.J., Bentley, H.W., and Flynn, T.J., 1985, Ground water tracers: Worthington, Ohio, National Water Well Association, 200 p.

Environmental Resources Management-South, Inc., 1988, Final contamination assessment report for West Florida Natural Gas Company, Ocala, Florida: Tampa, Fla.

Faulkner, G.L., 1973, Geohydrology of the cross-Florida Barge Canal area with special reference to the Ocala vicinity: U.S. Geological Survey Water-Resources Investigations 1-73, 117 p.

Florida Department of Environmental Protection, 1989, Drinking water standards, monitoring and reporting *in* Florida Administrative Code: chap. 17-550.

Fraser, D.C., 1969, Contouring of VLF-EM data: Geophysics, v. 34, no. 6. Geonics Ltd., 1979, EM-16 and EM-16R operating manuals: Mississauga, Canada, Geonics Ltd.

Geotrans, Inc., 1988, Hydrologic investigation of the northern portion of the Southwest Florida Water Management District: Herndon, Va.

German, E.R., and Schiffer, D.M., 1988, Application of national stream quality accounting network (NASQAN) station data for assessing water quality in the Peace River Basin, Florida: U.S. Geological Survey Water-Resources Investigations Report 87-4167, 73 p.

Greenfield, R.J., 1979, Review of geophysical approaches to the detection of karst: Association of Engineering Geologists Bulletin, v. 16, no. 3, p. 393-408.

Hem, John D., 1985, Study and interpretation of the chemical characteristics of natural water (3d ed.): U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Hickey, J.J., 1984, Field testing the hypothesis of Darcian flow through a carbonate aquifer: Ground Water, v. 22, no. 5, p. 544-547.

Jansen, John, and Taylor, Robert, 1989, Geophysical methods for groundwater exploration or groundwater contamination studies in fracture controlled aquifers, *in* Proceedings of the Third National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring and Geophysical Methods, Orlando, Fla., May 1989: National Water Well Association, 855-869 p.

Javandel, Iraj, and Tsang, Chin-Fu, 1986, Capture-zone type curves: A tool for aquifer cleanup; Ground Water, v. 24, no. 5, p. 616-625.

Kimrey, J.O., and Fayard, L.D., 1984, Geohydrologic reconnaissance of drainage wells in Florida: U.S. Geological Survey Water-Resources Investigations Report 84-4021, 67 p.

Knochenmus, D.W., 1967, Tracer studies and background fluorescence of ground water in the Ocala, Florida, area: U.S. Geological Survey Open-File Report 67004, 35 p.

Lohman, S.W., 1972, Ground-Water Hydraulics: Geological Survey Professional Paper 708, 70 p.

Magner, J.A., Book, P.R., and Alexander, E.C., Jr., 1986, A waste treatment/disposal site evaluation process for areas underlain by carbonate aquifers: Ground Water Monitoring Review, v. 6, no. 2, p. 117-121.

Mattraw, H.C., Jr., and Miller, R.A., 1981, Stormwater processes for three land-use areas in Broward County, Florida: U.S. Geological Survey Water-Resources Investigations 81-23, 56 p.

Meyer, R.R., 1963, A chart relating well diameter, specific capacity, and the coefficients of transmissibility and storage, *in* Bentall, Ray, compiler, Methods of determining permeability, transmissibility and drawdown: U.S. Geological Survey Water-Supply Paper 1536-I, p. 338-340.

Miller, J.A., 1986, Hydrogeologic framework of the Floridan aquifer system in Florida and in parts of Georgia, Alabama, and South Carolina: U.S. Geological Survey Professional Paper 1403-B, 91 p., 33 pl.

Moreno, Luis, Tsang, Chin-Fu, Tsang, Yvonne, and Neretnieks, Ivars, 1990, Some anomalous features of flow and solute transport arising from fracture aperture variability: Water Resources Research, v. 26, no. 10, p. 2377-2391.

Mull, D.S., Liebermann, T.D., Smoot, J.L., and Woosley, L.H., 1988, Application of dye-tracing techniques for determining solute-transport characteristics of ground water in karst terranes: U.S. Environmental Protection Agency EPA 904/6-88-001, 103 p.

NOAA, 1988, Climatological data, annual summary for Florida, 1988: v. 92, no. 13.

----- 1989, Climatological data, annual summary for Florida, 1989, v. 93, no. 13.

----- 1990, Climatological data, annual summary for Florida, 1990, v. 94, no. 13.

Phelps, G.G., 1987, Effects of surface runoff and treated wastewater recharge on quality of water in the Floridan aquifer system, Gainesville area, Alachua County, Florida: U.S. Geological Survey Water-Resources Investigations Report 87-4099, 57 p.

Rosenau, J.C., Faulkner, G.L., 1975, An index to springs of Florida, (2d ed.): Florida Bureau of Geology Map Series 63.

Rosenau, J.C., Faulkner, G.L., Hendry, C.W., Jr., and Hull, R.W., 1977, Springs of Florida (revised): Florida Bureau of Geology Bulletin 31, 461 p.

Rutledge, A.T., 1987, Effects of land use on ground-water quality in central Florida--preliminary results: U.S. Geological Survey Toxic Waste--Ground-Water Contamination Program: U.S. Geological Survey Water-Resources Investigations Report 86-4163, 49 p.

Schiffer, D.M., 1989, Effects of three highway-runoff detention methods on water quality of the surficial aquifer system in central Florida: U.S. Geological Survey Water-Resources Investigations Report 88-4170, 79 p.

Schiner, G.R., 1989, Potentiometric surface of the Upper Floridan aquifer in the St. Johns River Water Management District and vicinity, Florida, May 1989: U.S. Geological Survey Open-File Report 89-417, 1 sheet.

Schiner, G.R., and German, E.R., 1983, Effects of recharge from drainage wells on quality of water in the Floridan aquifer in the Orlando area, entral Florida: U.S. Geological Survey Water-Resources Investigations 82-4094, 124 p.

Skougstad, M.W., Fishman, M.J., Friedman, L.C., Erdmann, D.E., and Duncan, S.S., eds., 1979, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1, 626 p.

Smart, C.C., 1988, Artificial tracer techniques for the determination of the structure of conduit aquifers: Ground Water, v. 26, no. 4, p. 445-453.

Smart, C.C., and Ford, D.C., 1986, Structure and function of a conduit aquifer: Canadian Journal of Earth Science, v. 23, p. 919-929.

Spechler, R.M., Murray, L.C., Bradner, L.A., and Phelps, G.G., 1991, Potentiometric surface of the Upper Floridan aquifer in the St Johns River Water Management District and vicinity, September 1990: U.S. Geological Survey Water-Resources Investigations 91-190, 1 sheet.

Ten Broeck, B.W., 1984, Leaking underground storage tanks: Report to the Board of County Commissioners, Marion County, Fla., 62 p.

Thayer, P.A., and Miller, J.A., 1984, Petrology of lower and middle Eocene carbonate rocks, Floridan aquifer, central Florida: Transactions, Gulf Coast Association of Geological Societies, v. 34, p. 421-434.

Thrailkill, J., 1988, Drawdown interval analysis: A method of determining the parameters of shallow conduit flow carbonate aquifers from pumping tests: Water Resources Research, v. 24, no. 8, p. 1423-1428 p.

Tibbals, C.H., 1975, Aquifer tests in the Summit reach of the proposed Cross-Florida Barge Canal near Ocala, Florida: U.S. Geological Survey Water-Resources Investigations 28-75, 42 p.

----- 1977, Availability of ground water in Seminole County and vicinity, Florida: U.S. Geological Survey Water-Resources Investigations 76-87, 15 p., 4 sheets.

Ulriksen, C.P.F., 1982, Application of impulse radar to civil engineering: Sweden, Lund University of Technology, (published in the United States by Geophysical Survey Systems, Inc., Hudson, N.H.), 175 p.

U.S. Environmental Protection Agency, 1988a, Maximum contaminant levels (subpart B of 141, National interim primary drinking-water regulations) (revised July 1, 1988): U.S. Code of Federal Regulations, title 40, parts 100 to 149, p. 530-533.

----- 1988b, National revised primary drinking water regulations, Maximum contaminant levels, (subpart G of 141, National interim primary drinking-water regulations) (revised July 1, 1988): U.S. Code of Federal Regulations, title 40, parts 100 to 149, p. 586-587.

----- 1988c, Secondary maximum contaminant levels (section 143.3 of part 143, National secondary drinking-water regulations) (revised July 1, 1988): U.S. Code of Federal Regulations, title 40, parts 100 to 149, p. 608.

U.S. Geological Survey, 1989, Water resources data for Florida, water year 1989, v. 1A, northeast Florida surface water: U.S. Geological Survey Water-Data Report FL-89-1A, 440 p.

University of Florida, 1991, Florida population: census summary 1990: Gainesville, University of Florida, Bureau of Economic and Business Research, College of Business Administration, 55 p.

Vecchioli, John, Hunn, J.D., and Aucott, W.R., 1989, Evaluation of methodology for delineation of protection zones around public-supply wells in west-central Florida: U.S. Geological Survey Water-Resources Investigations Report 88-4051, 36 p.

Vernon, Robert O., 1951, Geology of Citrus and Levy Counties, Florida: Florida Geological Survey Bulletin 33, 255 p.

Walton, W.C., 1985, Practical aspects of ground water modeling, Worthington, Ohio: National Water Well Association, 587 p.

White, R.B., and Gainer, R.B., 1985, Control of ground water contamination at an active uranium mill, *in* Dublin, Ohio, Ground Water Monitoring Review, v. 5, no. 2, p. 75-82.

White, W.A., 1970, The Geomorphology of the Florida Peninsula: Florida Geological Survey Bulletin 51, 164 p.

White, W.B., 1988, Geomorphology and hydrology of karst terrains: Oxford University Press, 464 p.

Wilson, W.L., and Skiles, W.C., 1989, Aquifer characterization by quantitative dye tracing at Ginnie Spring, Northern Florida, *in* Proceedings of the 2nd Conference on Environmental Problems in Karst Terranes and Their Solutions, Nashville, Tenn., Nov. 1988, National Water Well Association, p. 121-141.

Wood, W.W., 1976, Guidelines for collection and field analysis of ground-water samples for selected unstable constituents: U.S. Geological Survey Techniques of Water-Resources Investigations, book 1, chap. D2, 24 p.

APPENDIX

Appendix. Wells inventoried by the U.S. Geological Survey in central Marion County

[--, no data]

Site identification number	Local identifier	Altitude of land surface (feet)	Depth of well (feet)	Depth to bottom of casing (feet)	Diameter of casing (inch)	Date well constructed
290057082064401	900206 17S22E16 Lloyd Monroe	70.0	132	81	8	01-01-52
290103082104501	90121001 17S21E14 Marion Oaks no. 2	82.7	--	--	8	--
290130082082001	90120801 USGS ob well CE35 nr Pedro, FL	78.6	70	40	4	01-01-66
290132082133001	90121301 17S21E08 USGS ob well CE78 nr Pedro, FL	89.1	82	61	4	01-01-68
290133082140901	ROMP 119 near Ocala, FL	71.85	--	--	--	--
290156082092301	90120901 17S21E12 wl devel	81.8	187	53	8	01-01-55
290213082142001	90221401 17S21E06 SCE 167 Syd Herlong	80	192	--	8	01-01-65
290215082023301	CBPT2-pilot hole	--	258	--	--	--
290215082152401	902215431 obser well CE74 near Ocala, FL	77.0	51	--	2	--
290216082023201	CBPT2-pumped well bottomed at +26 ft msl	--	44	--	--	--
290238082120901	90221201 17S21E03 SCE 168 Corps of Engineers	65	65	--	3	01-01-33
290238082131101	90221301 17S21E05 CPTI pilot hole	75.5	238	35	13	10-01-74
290238082131102	90221302 17S21E05 CPTI bottom at 28+msl	75.5	48	337	13	10-01-74
290238082131103	90221303 17S21E05 CPTI bottom at 9+msl	5.5	67	37	13	10-01-74
290238082141801	90221402 17S21E06 SCE 169 Corps of Engineers	65	73	--	3	01-01-33
290250082091001	16S22E31 CE34 333	74.2	83	60	2	01-01-66
290250082091002	902209 16S22E31 CE34S	74.2	29	26	2	01-01-67
290325082140701	Abandoned 4in. well on Chanrai prop.nr 109th St Oca	--	--	--	--	--
290339082032001	90320302 city of Belleview well no. 2	85	300	--	8	--
290340082032201	90320301 city of Belleview well no. 1	75	300	--	8	--
290340082131001	90321301 16S21E32 SCE 106 R.F.Crane	87.7	77	--	4	--
290340082151001	90321501 16S20E36 SCE 107 R.F.Crane	76.6	68	--	2	--
290352082134901	Well at no.10831 SW 67th Ave. Ocala, Oak Manor	67	90	--	--	--
290358082140201	Meadow Ridge mon.well no.1 SW 108th St, Ocala	67.08	28	--	--	04-17-90
290358082140202	Meadow Ridge mon.well no.2 SW 108th St. Ocala	67.91	33	--	--	04-17-90
290358082140203	Meadow Ridge mon.well no.3 SW 108th St. Ocala	66.97	28	--	--	04-17-90
290400082091001	90420901 USGS ob well CE33 nr Ocala Fl	78.2	80	29	4	01-01-66
290405082140501	Well at 10650 SW69 Terrace, Ocala	70	90	--	--	--
290510082061001	90520601 SCE 109 Corps of Engineers	65.3	28	13	3	01-01-36
290552082044701	90520401 USGS well CE81 Wolf Sink nr Santos, FL	66.7	40	--	--	--
290620082080001	90620801 SCE 111 Junie Counts SR475 & SR328	65.1	30	--	3	--
290643082045001	90620401 16S22E11 George Perry well (used384)	69.6	78	--	3	01-01-35
290650082053001	90620501 SCE 143 Vernon D. Lowder nr Santos	65.1	110	40	6	01-01-57
290650082053002	906205121 16S22E10 SCE 143A nr Ocala	66.3	62	50	4	01-01-56
290700082015001	16S23E08 CE41 122	91.2	157	124	2	01-01-66
290740082100001	90721001 16S21E02 CE32	105.6	82	62	2	01-01-66
290745082153501	90721501 16S20E01 SCE 113 Norris cattle	96.9	78	--	4	--
290750082035001	SCE115 16S22E01	66.9	37	--	2	--
290752082121401	College Rd church well	70	210	--	--	--
290800082115001	90821101 16S21E03 SCE 117 Bonnie Heath	79.5	133	--	4	01-01-47
290809082102901	Hilltop barn well os no.3 CR475A nr Ocala	122.85	--	--	--	--
290810082025001	90820201 USGS obser well CE40 nr Ocala, FL	87.0	110	85	6	01-01-66
290810082063001	908206 15S2E33 Ellis Savage	80	75	--	3	01-01-54
290810082063002	908206 15S22E33 SCE 144	82.1	75	--	4	--
290813082105701	Race track CR475C nr Ocala	77.88	125	--	--	--
290815082025701	CE40 replacement well nr Ocala, FL	91	105	16	4	03-12-86
do	do	do	do	47	3	do
290820082031301	908203440 15S23E31 Tilton Boutwell	89.3	87	38	2	01-01-53
290820082032001	90820301 USGS ob well CE39 nr Ocala, FL	79.3	72	51	4	01-01-66
290832082105201	Main barn well RO no.1 CR475C nr Ocala	--	--	--	--	--
290835082102701	6 in. well CR475A nr Ocala	77.57	--	--	--	--
290835082102702	4 in. backup well os no.2 CR475A nr Ocala	77.57	--	--	--	--
290837082030701	908203 15S23E31	96.0	240	45	13	01-01-75
290838082030601	908203 15S23E31	88.5	62	48	13	01-01-75
290838082030602	908203 15S23E31 Corps of Engrs	88.5	82	48	13	01-01-75
290838082103501	Yearling barn well CR475C nr Ocala	--	--	--	--	--
290843082053801	908205 15S22E34 Paul Meadows	125	172	--	4	01-01-69
290850082065101	15S22E22 908206140 123	115	325	192	8	01-01-35
290850082080001	908208 15S22E32 SCE 45	140	170	100	6	01-01-27
290850082094001	908209 15S21E36 SCE 146A	105.2	--	--	4	--
290850082100001	90821001 15S21E36 SCE 146 Reverie Knoll Farm	114.0	86	--	3	--

Appendix. Wells inventoried by the U.S. Geological Survey in central Marion County--continued

[--, no data]

Site identification number	Local identifier	Altitude of land surface (feet)	Depth of well (feet)	Depth to bottom of casing (feet)	Diameter of casing (inch)	Date well constructed
290900082070001	909207 15S22E28	127.7	145	--	4	--
290910082045001	909204 15S22E26	68.5	45	26	2	01-01-66
290915082023301	909202 15S23E30 CBPT 2 ph a	67.30	258	46	13	11-01-74
290916082023201	909202 15S23E30 CBPT 2	67.5	41	35	24	12-05-74
290916082023202	90920201 15S23E30 CBPT 2	67.3	49	35	24	12-01-74
290930082055001	909205 15S22E27 SCE 148	71.2	35	--	2	--
290930082104501	Well at 2918 SW 34th Ave, Ocala	62	--	--	--	--
290942082045702	Ocala WWTP well 5	--	--	--	--	--
290953082031301	90920301 USGS ob well CE79 nr Silver Springs, FL	79.5	86	60	4	01-01-68
290956082073901	909207 15S22E20 DW 26	66.7	27	--	--	--
291002082104901	CFCC 2in. well fire station	77	--	--	--	--
291015082084001	Rinker Plant Floridan well at Ocala, FL	65	--	--	--	--
291021082073901	91020708 sinkhole b s of 16 St, Ocala	100	--	--	--	--
291022082071001	910207 15S22E21 DW 21	70.8	149	--	--	--
291022082131101	Ocala Airport well	85	--	--	--	--
291024082074601	91020707 drainage well 41 Ocala	110	--	--	--	--
291025082064301	910206 15S22E21 K.A.Mackichen	120	--	--	2	--
291025082070401	Clyatt Park monitoring well at Ocala, FL	90	60	--	--	--
291030082003001	910200 15S23E21	59.4	183	116	2	01-01-66
291030082035001	910203 15S22E24 SCE 49	88.0	210	101	4	01-01-67
291034082073701	91020706 drainage well 40 Laurel St, Ocala	135	--	--	--	--
291038082075601	91020705 drainage well 38 Anderson Lake, Ocala	95	--	--	8	--
291040082083801	91020804 sinkhole e s of SW 10 St, Ocala	50	--	--	--	--
291040082142001	91021401 SCE 122 arthopod control W of Ocala	90.5	100	52	4	01-01-62
291043082093201	VISA monitoring well M-0205	70	40	--	--	05-12-89
291049082081101	910208 15S22E17	115.0	385	164	20	01-01-57
291049082084701	VISA monitoring well M-0208	70	40	--	--	05-15-89
291050082142301	91021401 15S21E18 arthopod control	88.00	100	--	--	--
291052082045001	91020401 15S22E14 R.A.Musgrove	130	128	105	3	01-01-61
291053082071901	910207 15S22E17 City of Ocala	125.3	129	--	--	--
291055082052501	91020501 sinkhole c w of 34 Ave, Ocala	90	--	--	--	--
291056082074701	910207 15S22E17 DW 20	133.5	135	20	10	--
do	do	do	do	129	6	do
291056082080501	15S22E17 911208444 314	115	381	--	10	01-01-16
291057082033401	910203 15S22E13 SCE 171	92.9	115	63	4	01-01-67
291057082080201	VISA monitoring well M-0209	115	35	--	--	05-16-89
291057082080401	15S22E17 SCE162 314	116.2	350	100	12	01-01-26
291058082071701	Bay well at Ocala, FL	145	--	--	--	--
291059082065201	91020602 drainage well 39 forest hs, Ocala	115	440	130	14	--
291100082010001	911120101 15S23E16	65	177	150	4	10-01-65
291100082010002	91120102 15S23E16	64.1	92	42	2	01-01-65
291100082010003	USGS obser well CE76 near Ocala, FL	64.5	153	124	6	01-29-68
291100082080601	911208 15S22E17	110	455	119	20	01-01-45
291102082084501	911208 15S22E18	60.8	129	48	8	--
291103082080501	911208 15S22E17	103.6	70	--	--	--
291106082040401	91120403 15S22E13	100	90	--	4	01-01-60
291107082071901	911207 15S22E17 DW 24	125.3	84	--	--	--
291109082133501	91121301 15S21E17 All Farm, Inc	85	266	63	6	01-01-70
291110082052001	911205 15S22E15 SCE 50	132.2	166	--	--	--
291110082060001	USGS obser well CE44 at Ocala, FL	102.7	91	34	6	01-01-66
291110082082901	911208 15S22E18 DW2 City of Ocala	65	65	--	--	--
291110082084601	911208 15S22E18	68.4	112	--	--	--
291111082080501	91120815 drainage well 42 Fla. Tele Ocala	80	--	--	10	--
291111082085801	VISA monitoring well M-0200	75	40	--	--	05-11-89
291115082102901	CE31 replacement well nr Ocala, FL	73	55	27	4	02-20-86
291117082063301	Drainage well no. 23 Ocala, FL	90	500	106	18	--
291117082063302	91120605 drainage well 34 DOT, Ocala	97	185	--	18	--
291117082063303	91120606 drainage well 35 DOT, Ocala	97	47	--	4	--
291117082063304	91120607 drainage well 36 DOT, Ocala	97	47	--	4	--
291120082060001	91120603 15S22E15	95	140	55	4	01-01-50
291120082064001	Drainage well no. 27 Ocala, FL	90.0	154	--	18	01-01-60

Appendix. Wells inventoried by the U.S. Geological Survey in central Marion County--continued

[--, no data]

Site identification number	Local identifier	Altitude of land surface (feet)	Depth of well (feet)	Depth to bottom of casing (feet)	Diameter of casing (inch)	Date well constructed
291120082074201	911207 15S22E17	82.3	80	--	--	--
291120082074202	91120716 drainage well 43 NE 3 St, Ocala	82	--	--	10	--
291120082102501	91021001 USGS obser well CE31 at Ocala, FL	74.6	106	--	4	--
291121082044001	911204 15S22E14	115	117	78	4	01-01-58
291121082044002	911204 15S22E14	115	240	222	4	01-01-61
291122082090001	91120901 drainage well 37 NW 4 St, Ocala	70	--	12	10	--
291123082065001	VISA monitoring well M-0216	90	57	--	--	06-01-89
291123082075401	VISA monitoring well M-0211	80	30	--	--	05-19-89
291123082075402	VISA monitoring well M-0212	80	70	--	--	05-23-89
291123082082901	VISA monitoring well M-0210	65	35	--	--	05-17-89
291125082075201	91120715 drainage well 33 City Nursery, Ocala	92	--	--	18	--
291125082075301	911207 15S22E17	78.8	49	--	--	--
291125082075302	91120717 drainage well 45 Tuscawilla Park, Ocala	79	--	--	8	--
291125082075701	Drainage well no. 31 Ocala, FL	70	214	65	16	--
291126082065801	91120608 sinkhole a w of NE 17 St, Ocala	70	--	--	--	--
291126082083501	Drainage well no. 3 Ocala, FL	63.5	58	50	10	--
291126082083502	91120808 drainage well 4 NW 6 Ave, Ocala	64	73	52	8	--
291126082091101	Cunningham Funeral Home well at Ocala, FL	80	--	--	--	--
291129082081501	911208 15S22E18	70.1	95	--	12	--
291129082081502	91120814 drainage well 44 NW 1 Ave, Ocala	70	88	--	8	--
291130082015001	USGS obser well CE47 near Ocala, FL	53.9	192	174	6	04-04-66
291130082015002	91120105 15S23E17 CE47S	53.9	21	18	2	05-18-66
291131082075501	Drainage well no. 32, Ocala, FL	70	66	--	12	--
291136082075201	91120710 drainage well 28 Tuscawilla Park, Ocala	70	111	--	8	--
291136082075202	91120711 drainage well 29 Tuscawilla Park, Ocala	70	--	--	10	--
291136082075203	91120712 drainage well 30 Tuscawilla Park, Ocala	70	--	--	10	--
291138082081001	911208 15S22E08	61.9	129	--	--	--
291139082070801	Highland Cemetary well at Ocala, FL	130	--	--	--	--
291139082073601	911207 15S22E08	69.1	220	--	--	--
291139082073602	91120709 drainage well 13 Chazal Park, Ocala	70	--	--	12	--
291140082052701	91120501 USGS ob well CE80 at Ocala, FL	77.4	90	61	4	08-09-68
291140082074001	Chazel Pk 3in. drainage well 14-A, Ocala	80	--	--	--	--
291140082091401	VISA monitoring well M-0196	70	35	--	--	05-10-89
291141082091001	91120902 sinkhole d NW 16 Ave, Ocala	70	--	--	--	--
291148082072702	VISA monitoring well M-0239	100	75	--	--	09-01-89
291149082071201	911207 15S22E09	96.0	208	160	6	--
291150082082301	911208 15S22E07	57.2	123	--	10	--
291150082082302	911208 15S22E07	57.3	121	--	--	--
291151082064201	VISA monitoring well M-0215	90	55	--	--	05-30-89
291151082072501	Drainage well no. 16 Ocala, FL	85.9	243	68	8	--
291152082080601	911208 15S22E08	64.8	125	--	--	--
291154082081101	911208 15S22E08	60	78	--	--	--
291155082052001	91120501 15S22E10	70	68	23	2	02-01-59
291156082080801	911208 15S22E08	58.3	181	78	6	--
291158082073501	911207 15S22E08 DW 15	85.5	76	--	8	--
291200082072001	912207 15S22E08	78.1	105	--	--	--
291201082075501	912207 15S22E08	73.3	1,080	850	26	01-23-52
291204082083601	NW 6th Ave monitor well at Ocala, FL	60	54	--	--	--
291204082083602	VISA monitoring well M-0194	60	25	--	--	05-09-89
291206082084401	VISA monitoring well no.4 STP no.1	60	66	--	--	03-18-83
291210082053301	Const.co well 1530 NE 32nd Ave, Ocala	70	--	--	--	--
291214082072501	VISA monitoring well M-0213	65	25	--	--	05-24-89
291215082051401	912205 15S22E10 NF 02	78.5	265	85	24	11-20-69
291215082052701	912205 15S22E10 NF 03	64.8	187	140	24	11-27-69
291220082080001	912208 15S22E08	60.0	62	--	4	--
291221082051401	912205 15S22E10 NF 01	75.7	240	85	24	01-01-69
291225082042801	AM-1 Appleton Museum test well nr Ocala	65	180	--	--	08-21-90
291225082042802	AM-2 Appleton Museum test well nr Ocala	65	180	--	--	08-23-90
291225082042803	AM-3 Appleton Museum test well nr Ocala	65	180	--	--	08-28-90
291225082042804	AM-4 Appleton Museum test well	65	180	--	--	09-07-90

Appendix. Wells inventoried by the U.S. Geological Survey in central Marion County--continued

[--, no data]

Site identification number	Local identifier	Altitude of land surface (feet)	Depth of well (feet)	Depth to bottom of casing (feet)	Diameter of casing (inch)	Date well constructed
291226082042001	Well SR40 and NE 48th Ave. Ocala	60	--	--	--	--
291227082052101	912205 15S22E10 NF 05	76.9	230	104	24	01-01-69
291227082052701	912205 15S22E10 NF 04	76.3	198	110	24	01-01-69
291233082082201	91220801 15S22E06	50	90	65	2	01-01-63
291235082061001	Irr.well NE 25th Ave and 24th St, Ocala	82	--	--	--	--
291239082082701	VISA monitoring well M-0086	50	15	--	--	05-08-89
291239082082702	Magnolia Ave. well at Ocala, FL	50	40	--	--	--
291239082082702	VISA monitoring well M-0177	50	40	--	--	05-09-89
291240082034001	91220301 15S22E01 SCE 124	55.9	104	--	6	--
291255082051701	Booster Stadium well NE 36th Ave, Ocala	60	--	--	--	--
291310082022001	913202 15S12E06 SCE 127	60.8	100	--	--	--
291310082045001	91320401 USGS ob well CE45 at Silver Springs, FL	51.9	40	20	4	01-01-66
291320082042301	Warehouse well 4690 NE 35th St. Ocala	70	100	--	--	01-02-12
291320082090001	913209 15S22E06 SCE 55	65	81	63	4	01-01-62
291330082004001	913200 14S23E33 Ocala Ice & Mag	50.00	150	--	3	--
291340082145001	91321401 14S21E31 SCE 128	158.1	175	150	6	01-01-58
291354082160801	91321601 14S20E35 P.W.Reed	150	171	108	4	--
291400082070001	914207 14S22E33	75	70	40	3	01-01-25
291416082140801	91421401 USGS test hole near Golden Hills	75	--	--	--	03-11-82
291418082150801	91421501 14S20E25 Golden Hills unused well	160.3	--	--	10	--
291420082151201	91421502 14S20E25 Golden Hills irrigation	170	268	83	8	04-01-74
291422082151201	91421503 14S20E25 Golden Hills irrigation	175	157	84	6	02-03-72
291441082070501	91420701 Sara Jones old US 301 north of Ocala	70	44	28	2	01-01-62
291445082071201	91420702 Marvin Spinks old US 301 north of Ocala	70	75	35	2	01-01-59
291510082082001	915208 14S22E07 SCE 30	110	69	--	4	01-01-50
291520082052001	915205 14S22E22 SCE 29	95	80	--	4	01-01-30