Hydrology of the Wolf Branch Sinkhole Basin, Lake County, East-Central Florida

By Donna M. Schiffer

U.S. GEOLOGICAL SURVEY

Open-File Report 96-143

Prepared in cooperation with the
LAKE COUNTY WATER AUTHORITY

Tallahassee, Florida
1996

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Gordon P. Eaton, Director

For addtional information write to:

District Chief
U.S. Geological Survey, WRD
Suite 3015
227 North Bronough Street
Tallahassee, FL 32301

Copies of this report can be purchased from:

U.S. Geological Survey
Information Services
Box 25286, Mail Stop 417
Denver Federal Center
Denver, CO 80225-0046

CONTENTS

FIGURES

TABLES

CONVERSION FACTORS, VERTICAL DATUM, ABBREVIATIONS, AND ACRONYMS

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	12.590	square kilometer
	Volume	
acre-foot (acre-ft)	1,233	cubic meter
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot per second (ft/s)	0.3048	meter per second
foot per hour (ft/h)	0.3048	meter per hour
foot per day(ft/d)	0.3048	meter per day
	Mass	
pound (lb)	0.4536	kilogram

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

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.

Acronyms and abbreviations used in report

LCWA	Lake County Water Authority
NOAA	National Oceanic and Atmospheric Administration
USGS	United States Geological Survey

Hydrology of the Wolf Branch Sinkhole Basin, Lake County, East-Central Florida

By Donna M. Schiffer

ABSTRACT

A 4-year study of the hydrology of the Wolf Branch sinkhole basin in Lake County, Florida, was conducted from 1991-95 by the U.S. Geological Survey to provide information about the hydrologic characteristics of the drainage basin in the vicinity of Wolf Sink. Wolf Branch drains a 4.94 square-mile area and directly recharges the Upper Floridan aquifer through Wolf Sink. Because of the direct connection of the sinkhole with the aquifer, a contaminant spill in the basin could pose a threat to the aquifer.

The Wolf Branch drainage basin varies in hydrologic characteristics from its headwaters to its terminus at Wolf Sink. Ground-water seepage provides base flow to the stream north of Wolf Branch Road, but the stream south of State Road 46 is intermittent and the stream can remain dry for months. A single culvert under a railroad crossing conducts flow from wetlands just south of State Road 46 to a well-defined channel which leads to Wolf Sink. The basin morphology is characterized by karst terrain, with many closed depressions which provide surface-water storage. Wetlands in the lower third of the basin (south of State Road 46) also provide surface water storage. The presence of numerous water-control structures (impoundments, canals, and culverts), and the surface-water storage capacity throughout the basin affects the flow characteristics of Wolf Branch. Streamflow records for two stations (one upstream and one downstream from major wetlands in the basin) indicate the flow above State Road 46 is characterized by rapid runoff and continuous base flow, whereas peak discharges downstream from State Road 46 are much lower but of longer duration than at the upstream station.

Rainfall, discharge, ground-water level, and surface-water level data were collected at selected sites in the basin. Hydrologic conditions during the study ranged from long dry periods when there was no inflow to Wolf Sink, to very wet periods, as when nearly 7 inches of rain fell in a 2-day period in November 1994, following an extended wet season. A comparison to long-term rainfall record (40 years) indicates that this range in hydrologic conditions during the 4-year study is representative of the range of conditions expected during a much longer time period. Two dye-trace studies conducted during the study indicated no direct connections between the sink and local wells. The path of a constituent entering the aquifer through Wolf Sink generally would be to the east, following the gradient of the regional ground-water flow system.

The conductance of Wolf Sink (the rate at which the sink conducts water to the underlying aquifer) was estimated from streamflow data, ground-water levels, and water levels in Wolf Sink. The range of hydrologic conditions during the study provided a basis for the determination of a representative conductance value. The regression of streamflow as a function of head difference between the sink water level and the potentiometric surface at an observation well (an approximation of the potentiometric level beneath Wolf Sink) resulted in a significant relation ($r^2 = 0.91$, mean square error = 1.60 cubic feet per second); and the slope of the regression line, rep-

resenting sink conductance, was 1.48 cubic feet per second per foot of head difference.

Flow and storm-volume frequency curves for selected time periods (1 day, 7 days, 14 days, 21 days, and 30 days) were generated based on streamflow data from January 10, 1992, to September 30, 1995. These curves indicate that, based on the available record, the volume of water that would have to be stored (in the event that streamflow had to be diverted from Wolf Sink) during a 30-day period would be equal to or less than about 11 acre-feet 30 percent of the time and 161 acre-feet 80 percent of the time. The maximum volume that would be generated during a 30-day period, based on this study, would be about 570 acre-feet.

INTRODUCTION

Wolf Branch is a small stream that drains 4.94 mi^2 of pasture, residential, and some industrial areas near the intersection of State Road 46 and U.S. Highway 441 in Lake County, Florida (fig. 1). The downstream terminus of Wolf Branch is a sinkhole named Wolf Sink. This sink is thought to be directly connected to the Upper Floridan aquifer, the primary source of drinking water in central Florida. Because the aquifer is the principal source of water for the region, the potential for degradation of the aquifer has significant health and economic implications.

Land use within the Wolf Branch basin presents a number of potential water-quality hazards to the surface water and receiving ground water at the sink. Though much of the Wolf Branch basin is undeveloped, it is zoned for medium to heavy industry and presently includes an agricultural-chemical warehouse and distribution facility and some other light industries along State Road (SR) 46. Train, truck, and automobile traffic in the basin offers the potential for a spill of toxic materials. A railroad crosses Wolf Branch less than 1/3 mi upstream from Wolf Branch Sink, and parallels the stream, less than 100 ft away, for a distance of 1,000 ft. Because of the direct connection of Wolf Sink with the Upper Floridan aquifer, further development within the basin will increase the potential for contamination of the aquifer from accidental spills or nonpoint-source runoff.

The potential for contamination of the aquifer through surface-water inflow to the sink has created interest within Lake County to control or minimize contamination hazards. Two courses of action have been considered: (1) construction of detention ponds which could retain or delay the movement of contaminants, allowing time for containment and cleanup of the contaminant spills before reaching the sinkhole; or (2) partial or complete plugging of the sinkhole. A partial plug of sand could act as a filter for contaminants reaching the sinkhole and could also delay the entry of contaminants to the aquifer and allow time for cleanup in the event of a spill. However, the plugging of the sinkhole would also change the natural drainage of the area and probably would cause flooding in the vicinity of the sinkhole as well as in the lower third of the drainage basin. The degree of flooding is a function of the topography of the Wolf Branch basin, the rate at which water naturally infiltrates and percolates to the Floridan aquifer throughout the basin, the rate of inflow through Wolf Sink, and the rate and frequency of runoff in the basin.

Prior to this investigation, insufficient information existed to provide the understanding of the hydrology of the Wolf Branch drainage basin that is necessary to make decisions about drainage modifications in the basin or to evaluate the effects of partial or total plugging of Wolf Sink. Also, no information was available on the range of streamflow to Wolf Sink. To better understand the hydrology of Wolf Sink and thus provide a body of knowledge upon which future management decisions can be based, the U.S. Geological Survey (USGS) began a 2 1/2-year study of the Wolf Sink basin in October 1991 in cooperation with the Lake County Water Authority (LCWA). The study was extended 1 year to April 1995 because of abnormally dry conditions during the first year of the study.

Purpose and Scope

This report provides information about the hydraulic characteristics of the connection between Wolf Sink and the Upper Floridan aquifer. Surface-water and ground-water hydrology are evaluated on the basis of hydrologic data collected during the study and on information from previous studies. The general relation of the sinkhole to the ground-water hydrology of the area is described.

Data presented in this report include rainfall at one site, stream discharge at two sites, water levels in

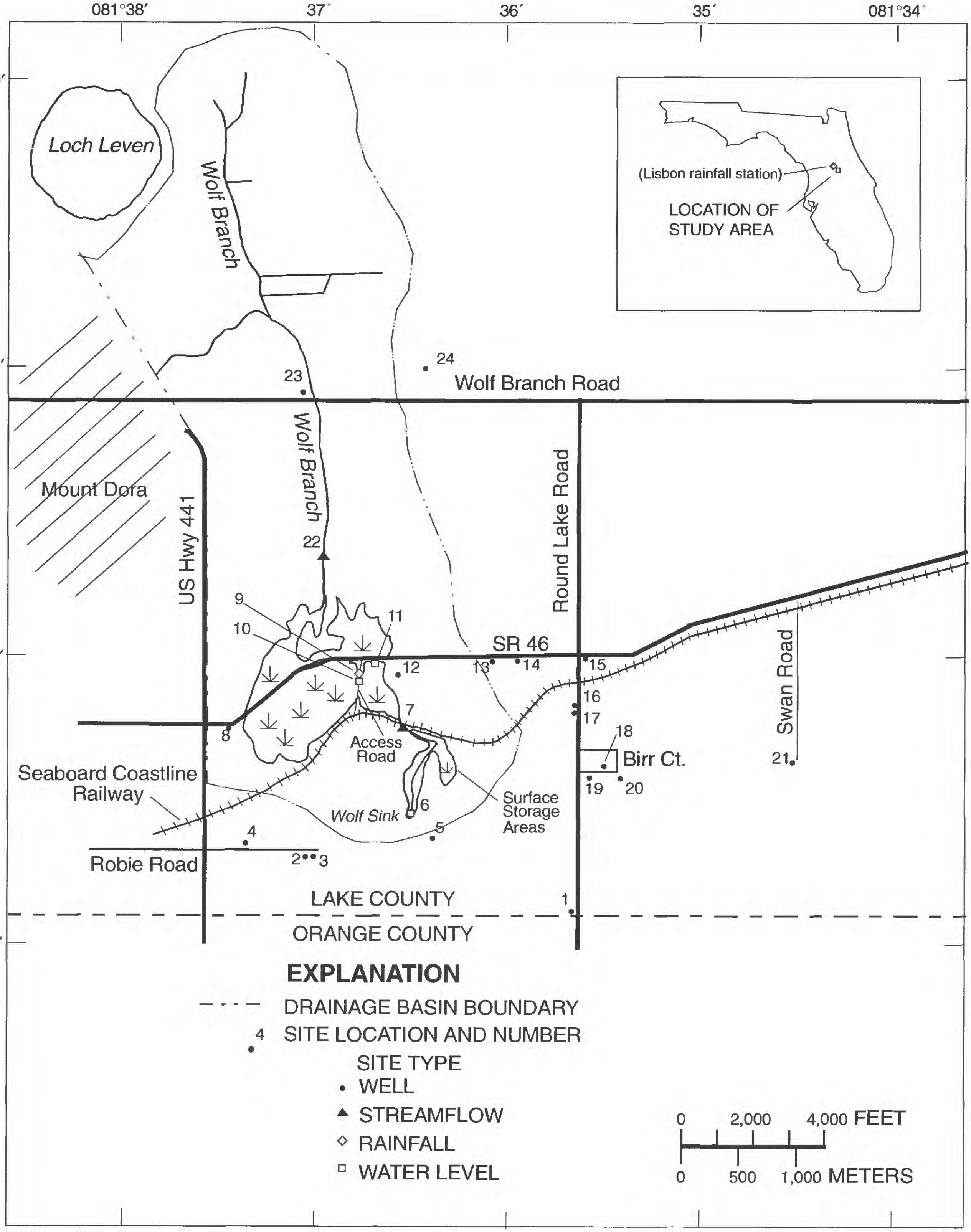

Figure 1. Wolf Branch and data-collection sites.

two wetland areas in the basin and in Wolf Sink, and ground-water levels at 11 sites. Also described in this report are the results of two dye studies conducted to determine if any direct connections exist between Wolf Sink and local wells. Hydrologic conditions during the study are described and the relations between streamflow, sink water level, and ground-water levels are described.

Previous Studies

Several reports are available that describe the general hydrology of Lake County, but specific data and information on the Wolf Branch basin are limited. The general hydrology of Lake County is described by Knochenmus and Hughes (1976) and the hydrology of the Floridan aquifer system in the area is described in Tibbals (1990).

Sinclair (1991) conducted a preliminary study of the potential for ground-water contamination at Wolf Sink. Sinclair indicated that heavy sustained rainfall is necessary for surface runoff to reach Wolf Sink because of the permeable soils in the basin. Sinclair estimated that Wolf Sink could drain as much as 50 ft^3/s to the Floridan aquifer system when flooded to a depth of 40 ft.

Acknowledgments

The author wishes to acknowledge the assistance provided by the residents living in the Wolf Branch drainage basin in collecting water samples from their private wells for the dye studies. The author also acknowledges the assistance provided by Robert Taylor, technician with the LCWA, for collecting water-level data and observing water levels at Wolf Sink; Nancy Coon of LCWA, who provided GIS coverages of the Wolf Branch area, and Will Davis, Director, LCWA, for his support and insight into the hydrology of Wolf Branch, rainfall data collected at his home in the Wolf Branch basin, which was used to corroborate data collected for the study, and for his participation in the dye studies.

DESCRIPTION OF THE STUDY AREA

The study area is northwest of Orlando in central Florida, north of the Orange County line and east of the city of Mount Dora in Lake County (fig. 1). The Wolf Branch drainage basin is within the Mount Dora Ridge of the Central Highlands topographic division described by White (1970) and is characterized by features typical of karstic terrain. Altitudes in the basin range from 47 ft at the floor of Wolf Sink to 184 ft in the northeast part of the basin, north of Wolf Branch Road.

Land uses in the basin are residential, agricultural, sand-mining, commercial, and industrial. Sand-mining activities in the lower basin have periodically affected the flow in Wolf Branch because of the alteration of natural drainage and the occasional failure of berms constructed to contain runoff water from mined areas. The potential for contamination of the ground-water resource exists because of some of the land uses in the basin. For example, the railroad and highways in the basin are avenues for chemical spills that can be introduced into the aquifer through Wolf Sink.

Soils in the basin are of the Astatula-Lake series, which are characterized as well-drained and typically are present on high ridges and upland areas, with the water table several feet below land surface. In some parts of the basin, soils are of the Myakka-Swamp series, which are poorly drained soils on broad lowlands, with the water table located within 30 in. of the land surface (Knochenmus and Hughes, 1976, p. 22-25).

Data-Collection Sites

Hydrologic data were collected at several sites, primarily in the southern third of the basin, near Wolf Sink (table 1, fig. 1). These included both continuous-record sites where data were automatically recorded at 5-minute, 15-minute, or 30-minute intervals, and periodic observation sites which were visited bimonthly and more frequently during periods of high-water. Continuous-data collection sites included one raingage, two streamgaging sites, and one well completed in the Upper Floridan aquifer. Periodic data-collection sites included 11 wells and water-level staff gages in two wetlands and in Wolf Sink.

Streamflow was gaged at one site on Wolf Branch north of SR 46 (site 22, fig. 1) to quantify streamflow from the northern half of the basin and at another site south of SR 46 and the Seaboard Coastline Railway (site 7, fig. 1) to quantify streamflow downstream from two large wetland storage areas. Site 7 (the Railway site) was used to estimate discharge

Table 1. Data-collection sites
[Site number is from figure 1. Data collection types: WL, ground-water level; DS, dye-study collection point; C, continuous record; Q, discharge; GH, gage height; R, rainfall; L, geologic well log]

Map number (from figure 1)	Site number	Site name	Type of data collected
1	284709081353701	Wolf Branch Monitor Well 12 (Sullivan)	WL
2	284720081370001	Wolf Branch - Quinton Well	DS,L
3	284721081365701	Wolf Branch Monitor Well 3 (Robie Ave. East)	WL,DS,L
4	284723081371901	Wolf Branch Monitor Well 2 (Robie Ave. West)	WL,L
5	284725081361901	Wolf Sink Observation Well near. Sorrento	WL,C,L
6	02237736	Wolf Sink Inflow near. Mt. Dora, Fla.	Q, GH
7	02237734	Wolf Branch at Railroad near. Mt. Dora, Fla.	GH,Q,C
8	284747081372401	Wolf Branch Monitor Well 4 (Sunset Pond)	WL
9	284757081364400	Wolf Branch Rain Gage	R, C
10	284758081364200	Wolf Branch West Wetland	GH
11	284801081363700	Wolf Branch East Wetland	GH
12	284757081363101	Wolf Sink Monitor Well 1 (Hacienda Hills)	WL
13	284800081355301	Wolf Branch Monitor Well 5 (Peeler Truck Service)	WL,DS,L
14	284800081355101	Wolf Branch - Helena Well, SR 46	DS
15	284801081353201	Wolf Branch Monitor Well 6 (Wiggins Well Drilling)	WL
16	284750081353602	Wolf Branch - Henderson Well, Round Lake Rd.	DS
17	284750081353601	Wolf Branch Monitor Well 11 (Davis)	WL,DS
18	284738081352701	L-0033	L
19	284737081353301	Wolf Branch - Garton Well, Birr Ct.	DS
20	284737081352201	Wolf Branch - Holm Well, Birr Ct.	DS
21	284734081342801	Wolf Branch Monitor Well 10 (Swan Rd.)	WL
22	02237733	Wolf Branch above SR 46 near. Mt. Dora, Fla.	GH,Q,C
23	284855081370101	Wolf Branch Monitor Well 7 (Robert Rd.)	WL
24	284900081362201	Wolf Branch Monitor Well 8 (Evergreen Ct.)	WL

into Wolf Sink. Electronic dataloggers were used to store data at continuous-record sites. A recording rain-gage was installed in the lower part of the basin near the entrance to a sand mine (site 9, fig. 1). Rainfall data were retrieved remotely by telephone modem and could be queried on demand, such as during storms.

Additional hydrologic sites in the basin included non-recording water-level gages in two wetland areas south of SR 46 (sites 10 and 11), a water-level staff gage and a pressure transducer connected to a datalogger at Wolf Sink (site 6), and a continuous water-level recorder at site 5, an observation well completed in the Upper Floridan aquifer approximately 800 ft east-southeast of the sink. The locations of all sites are shown in figure 1.

A network of wells was used to measure and map the altitude of the potentiometric surface of the Floridan aquifer system in the basin during the study. Water levels in these wells were measured monthly by the LCWA during part of the study and in May (dry season) and September (wet season) by the USGS. A less extensive network of wells was used for the dye studies conducted during the study (fig. 1). Most of these wells were 4-in. in diameter and used for domestic water supply.

Rainfall

Long-term rainfall records are available for a National Oceanic and Atmospheric Administration (NOAA) station at Lisbon, Fla., about 5 mi northwest of the raingage site for this study. Rainfall in central Florida tends to be highly localized, so daily rainfall is not well-correlated between measured locations except during winter months, when the rain often is associated with frontal systems. Monthly rainfall tends to be more comparable than daily rainfall (fig. 2). Most of the monthly totals for the Lisbon and Wolf Branch rainfall stations differed by no more than 1 in. Although there is a lack of correlation in daily rainfall between the two sites, the rainfall record at Lisbon is useful as an indicator of general rainfall volumes and frequencies for the Wolf Branch basin and was used to evaluate long-term rainfall patterns.

The period during which data were collected for this study are representative of a wide range of hydrologic conditions and included extreme dry and wet periods. The cumulative frequency distribution of daily rainfall at Wolf Branch for the 3 years of record is shown with the frequency distribution of rainfall for 40 years (1950-89) at the Lisbon station in figure 3. This figure indicates that the record collected for the 3-year period was representative of the range and frequency that might be expected during a 40-year period. This assumption also is supported by the fact that the maximum daily rainfall recorded at the Wolf Branch site during the study was 5.06 in. (November 16, 1994), which is slightly higher than the 1-day rainfall of 5.03 in. at the Lisbon station, which was exceeded only twice in 40 years, or 0.05 percent of the time.

Hydrogeology

The Floridan aquifer system consists of limestone and dolomitic limestone of the Ocala Limestone, the Avon Park Limestone, and the Lake City Limestone of Eocene Age. The Lake City Limestone of middle Eocene age is the oldest formation of the Floridan aquifer system in Lake County (Knochenmus and Hughes, 1976).

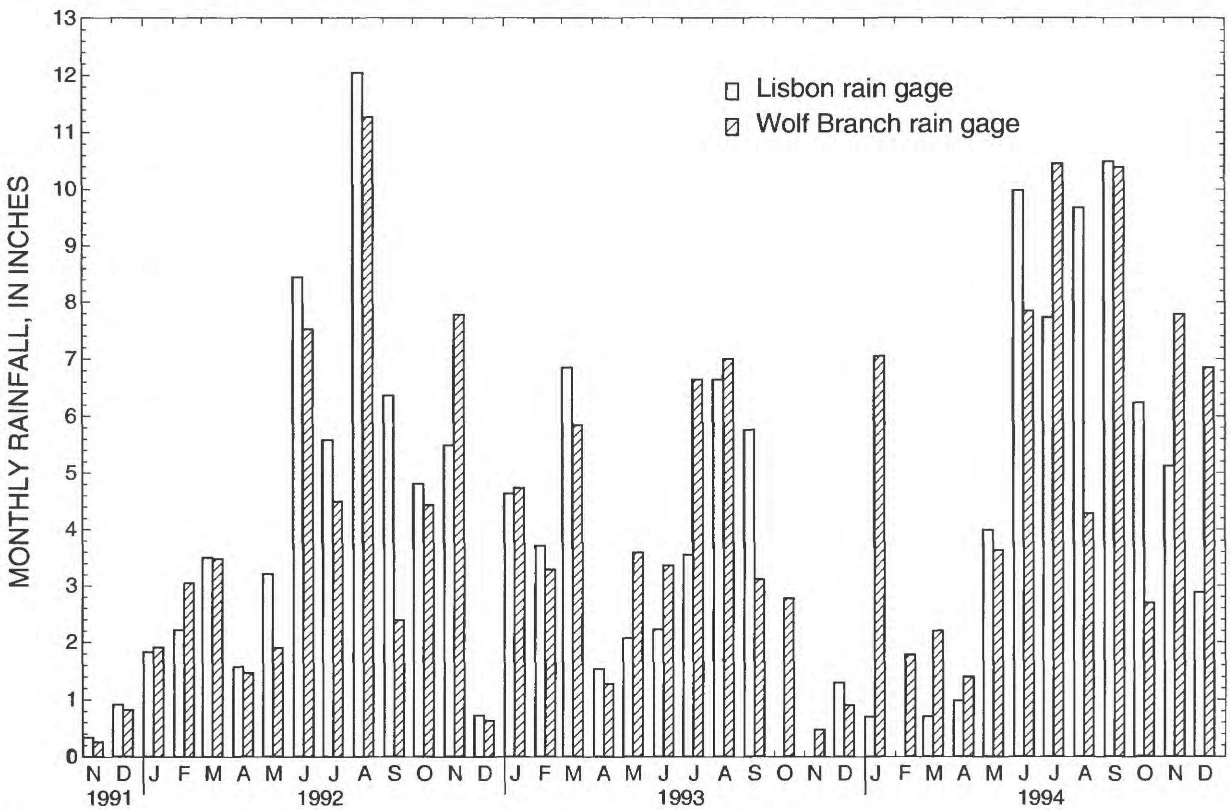

Figure 2. Monthly rainfall at NOAA station at Lisbon, Florida, and at Wolf Branch (site 9).

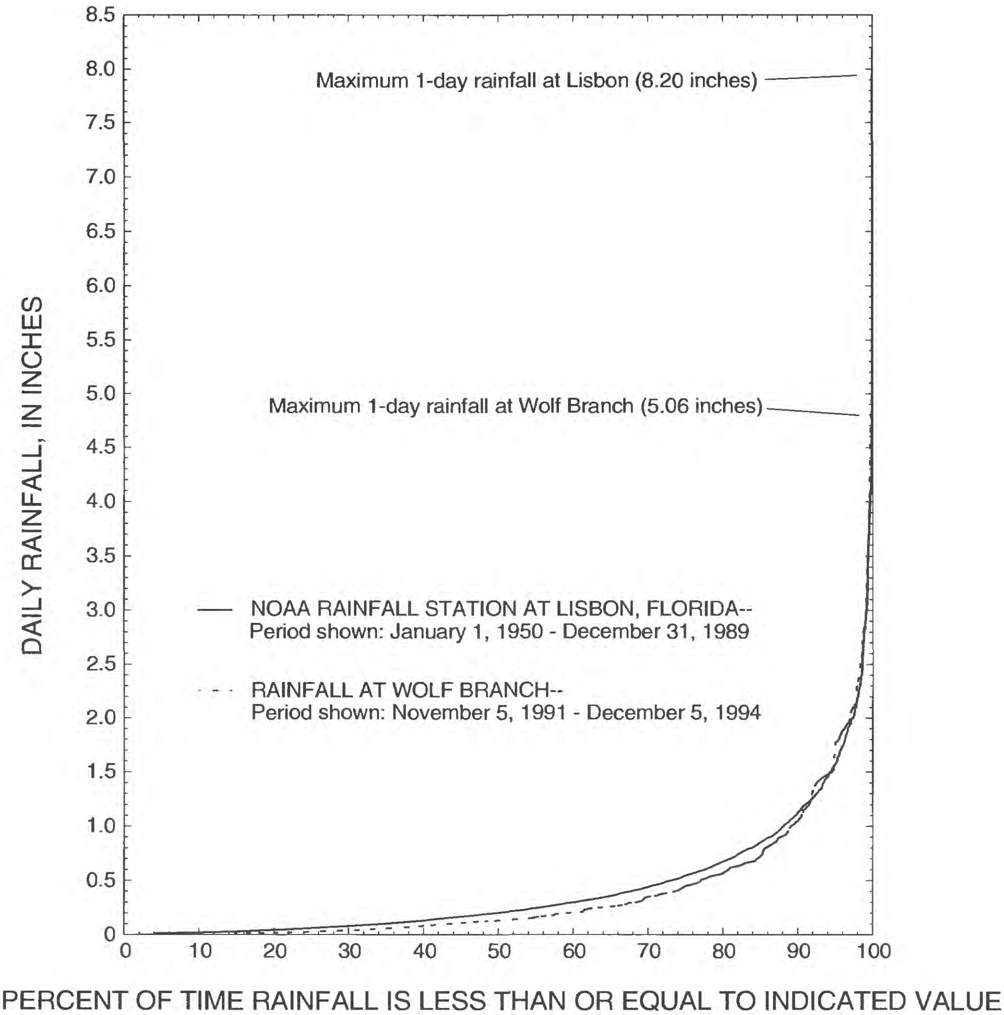

Figure 3. Rainfall cumulative frequency curves for NOAA station at Lisbon, Florida, and for Wolf Branch (site 9).

Overlying the Lake City Limestone is the Avon Park Limestone, which ranges from 400-1,000 ft in thickness. The Ocala Limestone overlies the Avon Park Limestone and varies in thickness from 0-100 ft (Knochenmus and Hughes, 1976, p. 33).

The Hawthorn Formation of Miocene age unconformably overlies the Ocala Limestone and consists primarily of marine sand interbedded with clay, sandy phosphatic clay, and phosphatic limestone. The Hawthorn Formation ranges in thickness from 0-100 ft in Lake County. In the Wolf Branch basin, a highly weathered limestone layer at the base of the Hawthorn Formation rests on and is hydraulically connected to the underlying Ocala Limestone. The Hawthorn Formation in much of the basin is breached or absent, which has allowed the formation of solution and collapse features common to karst terrain. These karst-related features also allow water to move from the surface to the ground water through more direct conduits than would normally occur if the Hawthorn were intact. Above the Hawthorn Formation, and extending to land surface, are unconsolidated sediments of Pleistocene through Miocene age ranging in thickness from 0-200 ft.

The unconsolidated sediments of Pleistocene through Miocene age comprise the surficial aquifer system. The water table of the surficial aquifer system generally is a subdued reflection of the land surface. Beneath the sediments comprising the surficial aquifer system is the intermediate confining unit, also referred to as the intermediate aquifer system, which, in the study area, coincides with the Hawthorn Formation. The intermediate confining unit retards the movement of water from the surficial aquifer system to the underlying Floridan aquifer system. The highly weathered limestone at the base of the Hawthorn Formation is transmissive enough to provide domestic water supply in the Wolf Branch area. The Floridan aquifer system consists of limestone and dolomitic limestone of the Ocala Limestone, the Avon Park Limestone, and the Lake City Limestone, and is the primary source of drinking water for Lake County.

The altitude of the top of the Ocala Limestone is highly irregular in the Wolf Branch area. Attempts to drill an observation well northeast of Wolf Sink, adjacent to an area of surface collapse features (just east of Wolf Branch and south of the railway) were abandoned because drilling 200 ft below land surface failed to reach limestone. A second attempt to drill an observation well adjacent to Wolf Sink (about 100 ft east of the sinkhole) was abandoned after breaching the roof of a large cavity apparently in the clay confining bed about 20 ft below land surface. The observation well (site 5) used for this study was drilled about 800 ft east of Wolf Sink; the top of the Floridan aquifer system at this well was 140 ft below land surface.

Geophysical logs are valuable in the investigation of subsurface geology. Natural gamma logs can indicate where changes in lithology occur (Keys and MacCary, 1971). High gamma counts generally indicate either clays or phosphatic materials in the strata and commonly are used to identify the extent of confining beds. Low gamma counts usually are associated with limestone and can indicate the top of the Floridan aquifer system.

Natural gamma logs of selected wells in the Wolf Branch basin obtained from the St. Johns River Water Management District are shown in figure 4. The top of the Hawthorn Formation can be identified in each well, but the top of the Ocala Limestone is identified in only two of the wells (site 5 and site 18). The signature of the natural gamma logs at sites 5 and 18 indicate that the other wells shown (sites 2, 3, 4, and 13) are not completed in the Ocala Limestone (limestone of the Upper Floridan aquifer). If these domestic wells are typical of others in the Wolf Branch basin, it is possible that many of the domestic supply wells are not completed in the Upper Floridan aquifer. These wells provide sufficient water supply and probably derive some water from the underlying Upper Floridan aquifer because of the hydraulic connection between the lower Hawthorn Formation and the upper layer of the Ocala Limestone; however, these wells may also be more susceptible to contamination from surface water that is percolating through the soils.

Some general observations about the geology of the Wolf Branch basin can be made based on the gamma logs shown in figure 4. For comparison, all logs presented in figure 4 are referenced to sea-level datum. In all the wells shown, a zone of non-phosphatic (low gamma count) material was detected between the altitudes of 30-50 ft, and may indicate a layer of sand. Also indicated by the gamma logs for site 5 and site 18 is the variability that exists in the thickness of the intermediate confining unit which overlies the rock of the Floridan aquifer system. At the observation well (site 5), the thickness of this zone is about 65 ft, but at site 18, this same zone is about 90 ft thick. The variability in thickness corresponds to the difference in the altitude of the rock of the Upper Floridan aquifer (located at about 4 ft above sea level at site 5, and about 20 ft below sea level at site 18). The variability in the top of the rock of the Upper Floridan aquifer is characteristic of karstic terrain.

GROUND WATER

Wolf Branch is in a recharge area to the Floridan aquifer system. The prevailing direction of regional ground-water flow in the Wolf Branch basin generally is from west to east, or west to east-northeast. However, ground-water flow paths can be locally affected by the geology of the basin and by the presence of fractures. For example, Wolf Sink acts as a point of recharge to the aquifer and affects the nearby ground-water flow paths; mounding of the potentiometric surface creates a localized area where flow is moving radially outward, away from the focused point of recharge. Because of this concentrated point of recharge, ground water near the sink may be moving in a direction which is opposite the prevailing regional ground-water flow direction. Because of the highly localized nature of the mounding, a map of the mounding of the potentiometric surface is not possible. Also, well drilling in the area near Wolf Sink was problematic, so no observation wells were available on which to base a map of the ground-water mound around the sink.

Reports from local residents of color in their well water caused concern that surface water might be

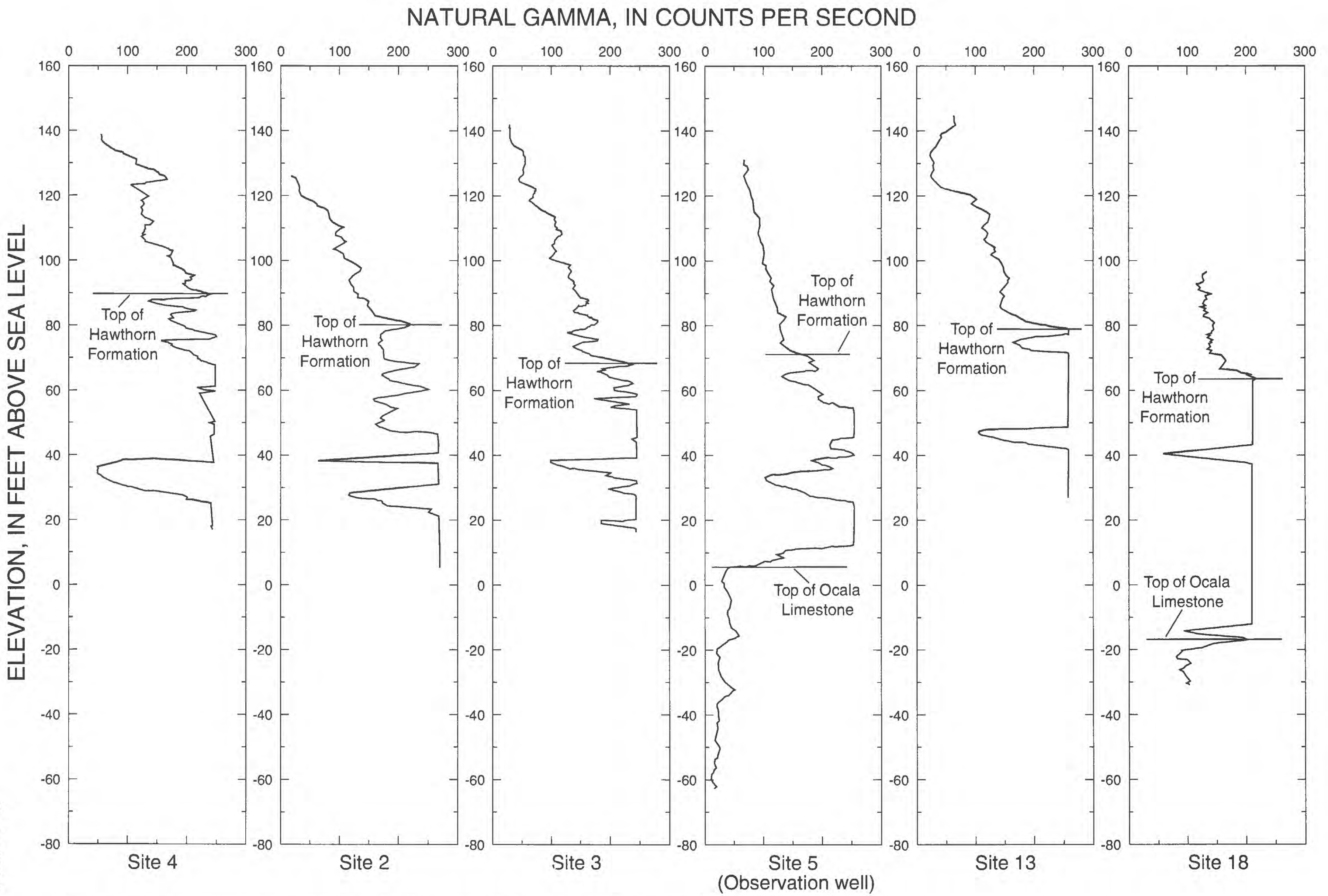

Figure 4. Natural gamma logs for selected wells in the Wolf Branch area. (See figure 1 for well locations.)

contaminating the aquifer through the connection at Wolf Sink. However, the water problems that have been reported (tea-colored water in wells, Will Davis, Lake County Water Authority, written commun., 1991) cannot be definitively associated with the inflow at Wolf Sink. Many of the wells in the Wolf Branch basin are completed into the limestones of the lower Hawthorn Formation (refer to earlier discussion of wells in the basin and fig. 4) and do not penetrate the Ocala Limestone. Thus, the water in these wells is from the intermediate aquifer system and not the Upper Floridan aquifer. A significant difference in the hardness of the rock between the lower Hawthorn Formation and the Ocala Limestone has been noted during well drilling operations; because the highly weathered limestone of the lower part of the Hawthorn Formation yields adequate water and because the drilling becomes very difficult and slow after the Ocala Limestone is reached, it is likely that many wells in the Wolf Branch basin are not completed in the rock of the Upper Floridan aquifer.

The Wolf Branch basin is riddled with depressions, typical of karstic terrain, and there are likely many breaches through the confining materials of the Hawthorn Formation through which water from the land surface can travel through surficial materials and leach through to the limestones of the lower Hawthorn. During periods of heavy and intense rainfall, recharge water to the lower part of the Hawthorn Formation may reach domestic supply wells; the color that is reported in water from domestic wells could be the result of this recharge. Well construction also may contribute to the color in water, because of the degradation of casing materials and poor or decaying seals around the well casing which could allow water to flow downward in the annular space around the well casing into the pumped zone of the well.

Wolf Sink is a sinkhole that is actively draining and it is highly probably that it is connected to the Upper Floridan aquifer. Water that enters the sink probably is entering the Upper Floridan aquifer but, as indicated previously, many of the domestic wells are not completed in the Upper Floridan aquifer. The source of the colored water reported in these wells may be the result of one or both of the processes previously described.

Water Levels

Water levels were measured by the USGS in a network of wells in the basin (see fig. 1 for location of wells, and table 1) every May and September during the study to document the annual lows and highs associated with the dry and wet seasons. Water levels in these wells also were measured periodically by personnel from the Lake County Water Authority. Water levels measured during an extremely dry period (May 1992) and during a wet period (November 1994) are shown in figure 5. No water level is shown for May 1992 for the observation well southeast of the sink because the well had not been drilled at that time. Water levels in some wells fluctuated more than 10 ft during the study. Generally, water levels nearest the sink had the greatest differences from wet-season to dry-season. This probably was caused by the large volume of localized recharge through the sink during the wet season.

Water levels measured in domestic wells in the Wolf Branch basin (fig. 5) may not represent the potentiometric surface of the Upper Floridan aquifer. The gamma logs shown in figure 4 indicate that only the wells at sites 5 and 18 are completed into the rock of the Upper Floridan aquifer. Wells at sites 2, 3, 4, and 13 appear to be completed in the lower part of the Hawthorn Formation, which can be highly productive and suitable for water supply. Because the Wolf Branch basin is located in a ground-water recharge area, water levels in the Hawthorn Formation probably are slightly higher than water levels in the Upper Floridan aquifer.

The potentiometric surface of the Upper Floridan aquifer near Wolf Sink was continuously monitored at site 5 (fig. 6). The response to rainfall can be seen in figure 6; for example, the large rainfall amounts during the summer of 1994 caused water levels to rise nearly 10 ft above the levels monitored in October 1992. This range in water levels is similar to the range noted in the domestic wells during the study.

Wolf Sink and Domestic Water Supply

Reports of colored water in local domestic wells (The Lake Sentinel, July 27, 1991) raised concerns that the water entering Wolf Sink might be contaminating local water-supply wells. Two dye studies were conducted during the study to investigate the possibility that colored water in wells might be related to the

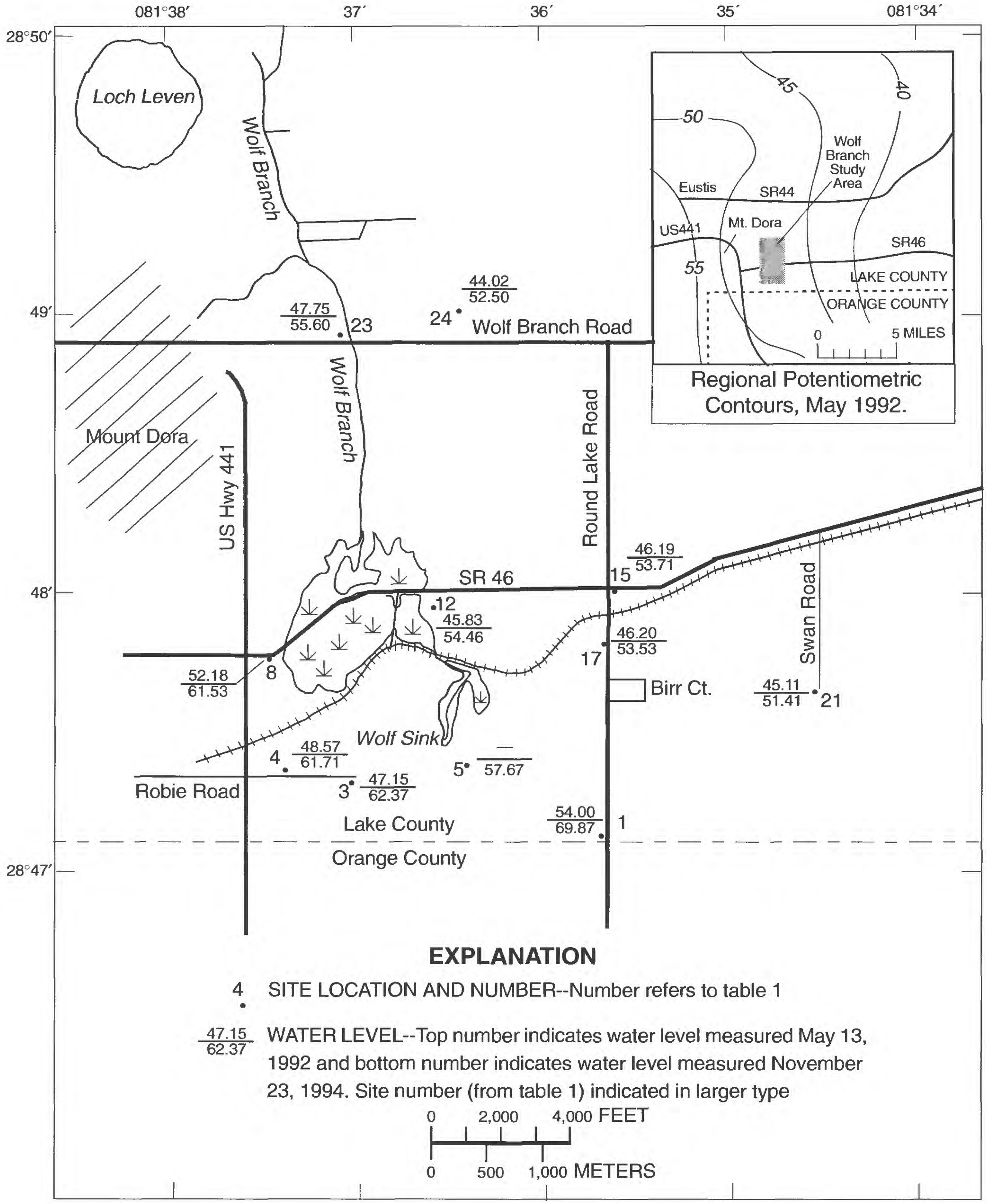

Figure 5. Water levels in wells in the Wolf Branch basin, May 13, 1992 and November 23, 1994.

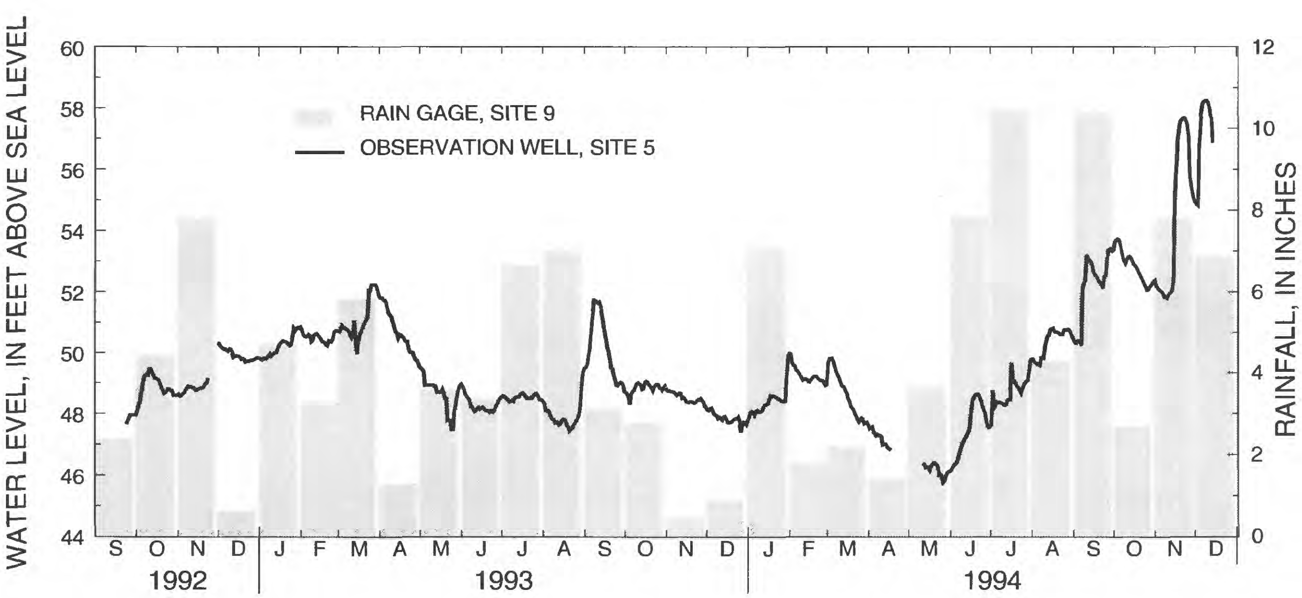

Figure 6. Ground-water levels at site 5 and monthly rainfall at site 9 during the study.

inflow of surface water through Wolf Sink and to investigate possible connections between Wolf Sink and local wells through aquifer conduits. The traveltime and path of constituents entering the Floridan aquifer system at Wolf Sink depends on the characteristics of the rock forming the aquifer. Flow through a uniform porous medium will tend to be slow (on the order of 2 to 3 months to travel less than 1,000 ft—see later calculations of traveltime). The length of time involved in flow through porous media provides time for dilution, dispersion, and sorptive processes to occur. Because constituents tend to move slowly and be sorbed in a uniform porous medium, the presence of tannic acids in well water would suggest the existence of fractures or conduits through which ground water could move preferentially and rapidly toward areas of withdrawal (such as wells). It is unlikely that highly colored water entering the Floridan aquifer system through Wolf Sink would appear in local well water unless fracture or conduit flow is occurring; however, the karst terrain of the Wolf Branch basin would indicate that some fracture or conduit flow is possible.

In a study of the potential for contamination of the Upper Floridan aquifer in the Silver Springs ground-water basin in Marion county, Phelps (1994) observed that although regional flow can be approximated as flow through a porous medium, fracture or conduit flow can have a significant effect on local systems. Dye-trace studies conducted in karstic areas in Florida have resulted in the calculation of apparent velocities (so noted because they are observed from dye studies rather than computed from ground-water flow equations) of 1.2 ft/h (Phelps, 1994, for the Silver Springs area), 26-107 ft/h (Wilson and Skiles, 1989, for an area in Gilchrist County), and 48 ft/h (Knochenmus, 1967, p. 23, for Wolf Sink in Marion County).

If the ground water in the vicinity of Wolf Sink is assumed to be flowing through a uniform porous medium, the traveltime of a constituent entering the aquifer at Wolf Sink can be estimated from an equation based on Darcy's law:

$$t = (bL^2n) / (T\Delta h) \qquad (1)$$

where

t is traveltime, in days,
b is the aquifer thickness, in feet,
L is the length of the flow path, in feet,
n is the porosity, dimensionless,
T is the transmissivity, in feet-squared per day, and
Δh is the difference in head between the sink water level at time of entry and the ground water level at the point of interest, in feet.

For the Wolf Branch area, the transmissivity (T) was assumed to be between 100,000 and 200,000 ft^2/d

(Tibbals, 1990), the thickness of the Upper Floridan aquifer (b) was estimated to be 325 ft (Tibbals, 1990), and the porosity of the aquifer (n) was assumed to be 0.2 (Thayer and Miller, 1984). A flow-path length (L) of 800 ft, which represents the distance from Wolf Sink to the nearest well (site 5), was used in equation 1. The difference in head (Δh) between Wolf Sink and site 5 was determined to be 3.8 ft in April 1993. Given these values, the traveltime (t) from Wolf Sink to the nearest well through a uniform porous medium would be from 55 to 110 days. This equates to a flow velocity of 7.3 to 14.6 ft/d. If ground-water flow in the Wolf Sink area is predominantly Darcian, it is unlikely that any dye placed in the sink would appear at any sampling sites because the dye would have been diluted and adsorbed within the length of time it took to travel to the sampling site.

If ground water is moving in preferential paths from Wolf Sink through fracture or conduit flow, the traveltime would be less than that computed for Darcian flow through a uniform porous medium. The path of a contaminant entering the Floridan aquifer system through Wolf Sink initially could be in any radial direction around the recharge mound beneath the sink. Gradually, the water would move to the east or east-northeast, in the direction of regional flow. If the wells sampled for the dye study are directly connected hydraulically with Wolf Sink, then dye placed in the sink should appear within a time frame governed by fracture or conduit flow rather than a timeframe determined by Darcy's law.

The presence of fractures in the aquifer in the Wolf Sink area would be indicated by the movement of dye from Wolf Sink to domestic wells over some time period shorter than that predicted for a uniform porous medium. Wells selected for sampling in the dye studies ranged in distance from about 800 ft (site 5) to about 5,600 ft (site 20) from Wolf Sink (fig. 1). Because fracture or conduit flow was suspected, an apparent velocity was assumed from earlier dye studies in karst areas in Florida to estimate the possible traveltime under fracture flow. Assuming an apparent velocity of 26 ft/d (the lowest estimate from the study by Wilson and Skiles, 1989), the traveltime of dye to sites 5 and 20 would be 1.3 to 9 days, respectively. Based on this estimate of traveltime for fracture or conduit flow, samples were collected for a period of 10 days following the placement of dye at Wolf Sink for both dye studies. This length of time for the dye studies is similar to the time allowed for other dye studies in karst areas reported in the literature. Though a slower apparent velocity might require longer travel times to reach sampled wells, it is impractical to sample wells over a longer period of time because of the natural attenuation of the dye. Traveltimes much greater than 10 days would suggest limited conduit flow and a tendency for increased adsorption of the dye on aquifer materials.

CI Direct Yellow 96 dye was used as a tracer. This dye typically is used for general detection of flow direction and traveltime. Direct Yellow 96 is detectable with an ultraviolet light and provides qualitative rather than quantitative data (Wilson, 1968). The dye was premixed in a bucket, then placed into the stream at Wolf Sink. Residents with domestic wells in the Wolf Branch basin and one business were asked to collect samples. The wells included for the study provided areal coverage of the basin near the sink, including one location upgradient from the sink (site 2). All participants were given whirl-pak bags with sterile cotton pads for sample collection. One cotton pad was placed in each whirl-pak bag and the bag was filled with water from the well. The date and time of the sample collection were noted on the bag with a waterproof pen. Samples were collected at the conclusion of the 10-day sampling period and examined in the office with a fluorescent lamp. If the dye had reached an area within the pumping zone of any of the wells included in the study, the dye would adhere to the cotton fibers and concentrate there. The dye would be visible on the cotton, even in small concentrations, under an ultraviolet light.

The first release of dye was on October 5, 1992, following an extended period of dry weather. There had been no flow at the gaging station (site 7) from November 1991 until September 5, 1992. On October 3, 1992, 2.36 in. of rain was recorded at the rain gage at site 7, and continuous streamflow to Wolf Sink began sometime during the day on October 4, 1992. Dye was placed in the sink on October 5, and sample bags and supplies were distributed to participants in the study. Initial samples were collected when the supplies were distributed, and sampling continued daily for 10 days following the day the dye was released.

The second release of dye was on April 5, 1993, following a wet period, when Wolf Sink had been receiving inflow continuously for several months, and following a total rainfall of 5.84 in. for the month of March. The amount of dye (15 lb) placed in the throat of the sink was nearly double the mass that had been used in the first dye study. More dye was released for the second study because of the failure to detect dye from the initial study. The observation well east of the sink (site 5) was sampled in the second dye study by suspending a cotton pad in the well continuously for a total of 52 days following the introduction of the dye. Should dye pass through the location of the well, some dye would be sorbed onto the cotton. Although the observation well is the nearest well tapping the Upper Floridan aquifer in the vicinity of Wolf Sink, it is possible that dye in ground water flowing near the well may have been missed, particularly if the dye were moving through fractures and conduits. Domestic wells sampled by residents in the basin should be more representative because ground water is pumped from the wells, drawing in water from the surrounding rock. Thus, if dye were present in ground water in a fracture or conduit within the cone of depression caused by pumping a domestic well, then the dye would be drawn into the domestic supply.

No dye was recovered from any of the sampled wells in either dye study. The lack of any detection of dye may be attributed to one or more of the following causes: (1) the zone tapped by the domestic wells used in the studies was not the same as the zone in which the dye was traveling, based on the geologic logs shown in figure 4 and on the assumption that the sink collapse extends to the Upper Floridan; (2) there are likely many pathways (fractures, conduits) through which the dye could have traveled, and none of the sites where samples were collected were directly in the paths in which the dye traveled; (3) although the dye used for the study is more resistant to adsorption by organic matter than other dyes used for similar purposes (Wilson and others, 1986, p. 7), some of the dye could have been sorbed onto the organic debris which has settled in the throat of the sink over the years, reducing the amount of dye that reached the aquifer; (4) the dilution effects are such that there was no detectable dye left by the time it reached any of the wells included in the studies; or (5) ground-water flow in the Wolf Sink area is predominantly through a uniform porous medium, and governed by Darcy's law. The dye also could have adsorbed partially to the matrix of limestone and dolomite which make up the aquifer, although the available literature on the dye indicate it is more resistant to adsorption on mineral sediments than other dyes. As indicated in an earlier section of the report, the colored water reported in some domestic wells may be the result of the wells not being completed into the limestone of the Upper Floridan. Thus, these wells are more susceptible to contamination from water infiltrating through the unconsolidated materials which carry organic matter that can contribute to color in water, or the water may be entering from the surface along the casing.

SURFACE WATER

The headwaters of Wolf Branch are in a golf course (The Country Club of Mount Dora). Canals, dikes, and culverts have altered the natural drainage patterns in the upper basin, north of Wolf Branch Road. As the stream flows southward toward Wolf Sink, the stream alternates from wetlands to narrow, well-defined channels. Several wetlands in the basin south of SR 46 provide surface-water storage.

The Wolf Branch drainage basin consists of several sub-basins. Within each of the sub-basins are areas which provide for some storage of surface water. Streamflow in the basin upstream from Wolf Branch Road is controlled by a broad-crested concrete weir and two small (15-in.) bleed-down pipes. Just south of the concrete weir are two box culverts that convey the water south under Wolf Branch Road. Ground-water seepage from the steep hillsides east and west of the stream enters concrete drainage channels adjacent to Wolf Branch Road, and enters the stream through a drop inlet at the lowest point in the road (at the stream crossing). This ground-water seepage provides base flow for the stream south of Wolf Branch Road. Upstream from Wolf Branch Road, the impoundment of the stream by the concrete weir (built about 1985) has caused a wetland to form where the original stream was.

South of Wolf Branch Road, the stream has a well-defined channel and winds through a heavily wooded area, then through pastureland until just north of SR 46, where the stream broadens into a marsh. Several culverts conduct flow from north to south beneath SR 46, but the principal conveyance structure is a set of three 36-in. reinforced concrete pipes. The culverts act as controls on the flow from the northern part of the basin to the southern part of the basin south of SR 46. The wetland east of Wolf Branch and north of SR 46 is not connected to the wetland south of SR 46, but overflows to the west when water levels are high. South of SR 46 there is no visible stream channel and Wolf Branch becomes a large wetland area which is divided into two sections by a small isthmus. The eastern and western sections of the wetlands are connected through a single concrete pipe that leads under a dirt access road for a local sand-mining operation. Water flows from west to east through this single culvert and exits the eastern wetland through an arch culvert that conducts flow from north to south under the Seaboard Coastline Railway. The presence of these wetlands south of SR 46 indicates the presence of some confining materials that probably prevents the infiltration of water. Downstream from the culvert, Wolf Branch again becomes a well-defined channel and the stream bed turns sharply to the east. Site 7 is downstream from where the stream turns eastward.

Downstream from the gaging station, the stream meanders through heavy palmetto underbrush and in many places widens to form small marshy areas. Approximately 1,000 ft east of site 7, the stream bed changes directions from southeast to southwest in nearly a 90-degree turn (fig. 1). East of this southward bend in the stream channel and south of the railroad is an open field that contains several collapse features (identified in fig. 1 as surface storage areas). As the stage rises in Wolf Branch, water overflows the stream bank and is diverted into the open field where the water is retained until it can evaporate or infiltrate the soil. The main channel of Wolf Branch continues generally to the southwest through a wooded area and is generally contained within a well-defined channel for most of the remainder of the distance to Wolf Sink. Approximately 200 ft east of the sinkhole, the stream bed drops off sharply from an elevation of about 64 ft above sea level to an elevation of about 54 ft above sea level, creating a small waterfall. From the low point at the base of this waterfall, the channel continues westward to the sink. During most of the study, when there was flow in Wolf Branch that was continuous to Wolf Sink, there was not enough backwater from the sink to affect the presence of the waterfall. The channel from the waterfall to the sink is ravine-like, with a width of only about 4 ft and steep side slopes rising 20-30 ft above the stream bottom. The slope of the channel bed in this section is steep, dropping 4 ft in 160 ft (25 ft per 1,000 ft, or 0.025), and velocities in this part of the stream can exceed 3 ft/s. The sinkhole has steep side slopes that level off about 40 ft above the sink floor (one location on the sink floor surveyed in 1991 was 49.75 ft above sea level, and elevations along the west rim ranged from 78.48 to 91.83 ft above sea level). The throat of the sink is filled with sand, debris, and leaves, but the debris does not appear to impede the movement of water through the sink.

Flow in the stream south of the railroad to the sink is intermittent during much of the year and is highly dependent on cumulative rainfall and the availability of surface storage. During the study, the stream was dry from November 1991 through early September 1992, May 1993 to late July, most of August 1993, and mid-May through early June 1994. There are seepage losses along the stream bed between site 7 and the sink, so that many times there is measurable flow at site 7 but the flow terminates before reaching the sink. As the stream recedes, flow at the sink ceases first, and the flow in the stream gradually recedes until the channel is completely dry, often throughout the entire length of the channel from the wetlands north of the railroad (just north of site 7) to the sink. When flow at the sink first begins following a long period of dry conditions (so that the ground-water levels also have receded), the sounds of water can be heard as it cascades downward into an unseen cavity under the visible floor of the sink, indicating the presence of large openings under the sink floor. Although the opening to the sink often is not visible because of the debris and sand that collects there, there is sufficient conductivity through the material on the surface for 2-3 ft^3/s to flow through without creating a backwater.

The relation between cumulative rainfall at site 9 and discharge at site 7 is indicated in figure 7. The long period of dry conditions early in the study created conditions under which the basin had a large capacity for storage of runoff. No flow was recorded at site 7 until early September 1992, although 35 in. of rainfall had been recorded from January through August 1992. The slope of the cumulative rainfall curve indicates the volume of rainfall per unit time; steeper slopes indicate a greater volume of rainfall in a given time period. Periods when the cumulative rainfall curve is flatter correspond to periods of decreasing discharge in Wolf Branch.

The wetlands located south of SR 46 provide surface-water storage and reduce peak flows in the lower reaches of Wolf Branch. Also affecting flow in the basin south of SR 46 are the culverts which convey the water to the south. To determine the effects of the wetlands and culverts on discharge at site 7 (and thus to Wolf Sink), a gaging station was installed at site 22 in early December 1992. Although streamflow at site 7 was intermittent during the study, flow at site 22 was continuous, probably because of ground-water seep-

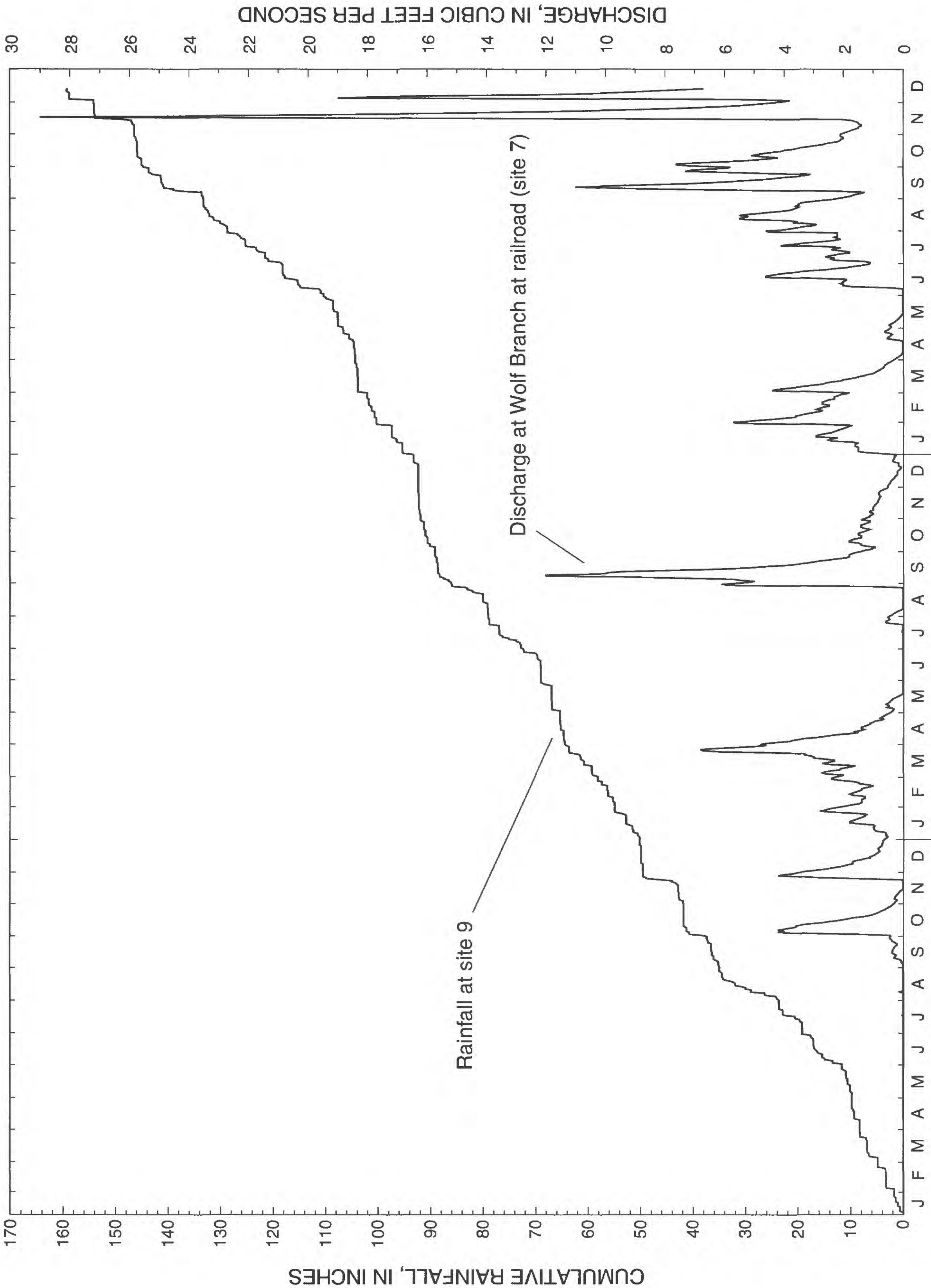

Figure 7. Cumulative rainfall at site 9 and discharge at site 7 (Wolf Branch at railroad).

age from the upper reaches of the basin and the lack of surface storage between Wolf Branch Road (where ground-water seepage enters the stream) and site 22. Discharge at sites 7 and 22 and monthly rainfall during the study are shown in figure 8. The difference in discharge characteristics of the two sites is evident from examination of this figure. Discharge at site 22 is continuous and more flashy than at site 7; the difference between these curves indicates the volume of water retained in storage areas (wetlands) between these two sites. Figures 9 and 10 show the discharge at both sites and rainfall for two storm periods and illustrate the storage effect of the basin wetlands. The storage potential of the Wolf Branch basin is a critical element when evaluating the potential effect of a contaminant spill in the drainage basin. The delay in peak flow and flow volume caused by wetlands in the basin are, in effect, mimicking a detention facility and may allow for some mitigation of the impact of a contaminant spill.

Seepage Studies

During the study discharge was measured along the stream from the most upstream station (site 22, Wolf Branch above SR 46) to the sink to evaluate the potential for seepage losses in the channel. The first seepage study was done October 13, 1992, and included discharge measurements at site 7 (Wolf Branch at railroad), three sites downstream from the site at the railroad, and inflow to the sink. The second study was done on September 27, 1994; discharge measurements were made at site 22 (Wolf Branch above SR 46), Site 7 (Wolf Branch at railroad), and two sites downstream from site 7 and above Wolf Sink.

Prior to the seepage study performed on October 13, 1992, there had been an extended dry period of 7 months during which time there was no flow in Wolf Branch downstream from the wetlands south of SR 46. Beginning in early September, streamflow was recorded at site 7; in early October, following a 2-day rainfall of 3.25 in., flow in Wolf Branch at site 7 increased gradually and peaked on October 5 (4.2 ft^3/s). Sites at which discharge was measured for the seepage studies are shown in figure 11. The first site downstream from site 7 is just upstream from a fork in the stream channel. At this fork, some water overflows to the north into a wetland storage area. The second site is just downstream from the sharp bend in the channel at the easternmost point of Wolf Branch before the stream turns to the southwest. This site is downstream from the point at which water can overflow into wetland storage areas east of the stream channel and south of the railroad; however, all flow was contained in the channel during the seepage studies. The third site is several hundred feet further downstream from the second, in a section where the flow also was within the stream banks and upstream from the sink waterfall. The inflow to the sink was measured downstream from the waterfall, within the steep-walled channel, and approximately 100 ft upstream from the sink opening.

Discharge measured on October 13, 1992, at selected sites in the stream is shown in figure 11. There was no significant difference in the total discharge between site 7 (3.48 ft^3/s at Wolf Branch at railroad) and the third site downstream from the sink (3.16 ft^3/s). However, some loss was noted between this third measuring site downstream from site 7 and the site just upstream from the sink (2.23 ft^3/s, sink inflow). It is likely that the loss between these two measuring sites is due in part to seepage loss but is primarily the result of storage in a wetland area between the two sites.

Hydrologic conditions in central Florida during the summer of 1994 were extremely wet and many lakes and streams were approaching 20-year record water levels. Inflow to the sink was continuous throughout the summer. Discharge was measured at four locations: site 22 (Wolf Branch above SR 46), site 7 (Wolf Branch at railroad), and two sites downstream from site 7 (fig. 11). The first downstream site is just upstream from a bridge across the stream where three culverts were installed in 1993; the second site is just upstream from an old jeep trail crossing approximately 30 ft upstream from the waterfall at Wolf Sink. The difference between discharge at sites 22 and 7, upstream and downstream, respectively, from the wetlands south of SR 46 is similar to the differences indicated in the graphs in figures 9-10. There was little difference between the discharge at site 7 and the first downstream site measured during the seepage run in September 1994; however, between the first downstream site and the second downstream site, the discharge increased by 1.5 ft^3/s. During the seepage study conducted in October 1992, there was a net loss in the lower reaches of Wolf Branch, which was attributed to storage in wetland areas in the system. In the September 1994 seepage study, the increase in flow in the

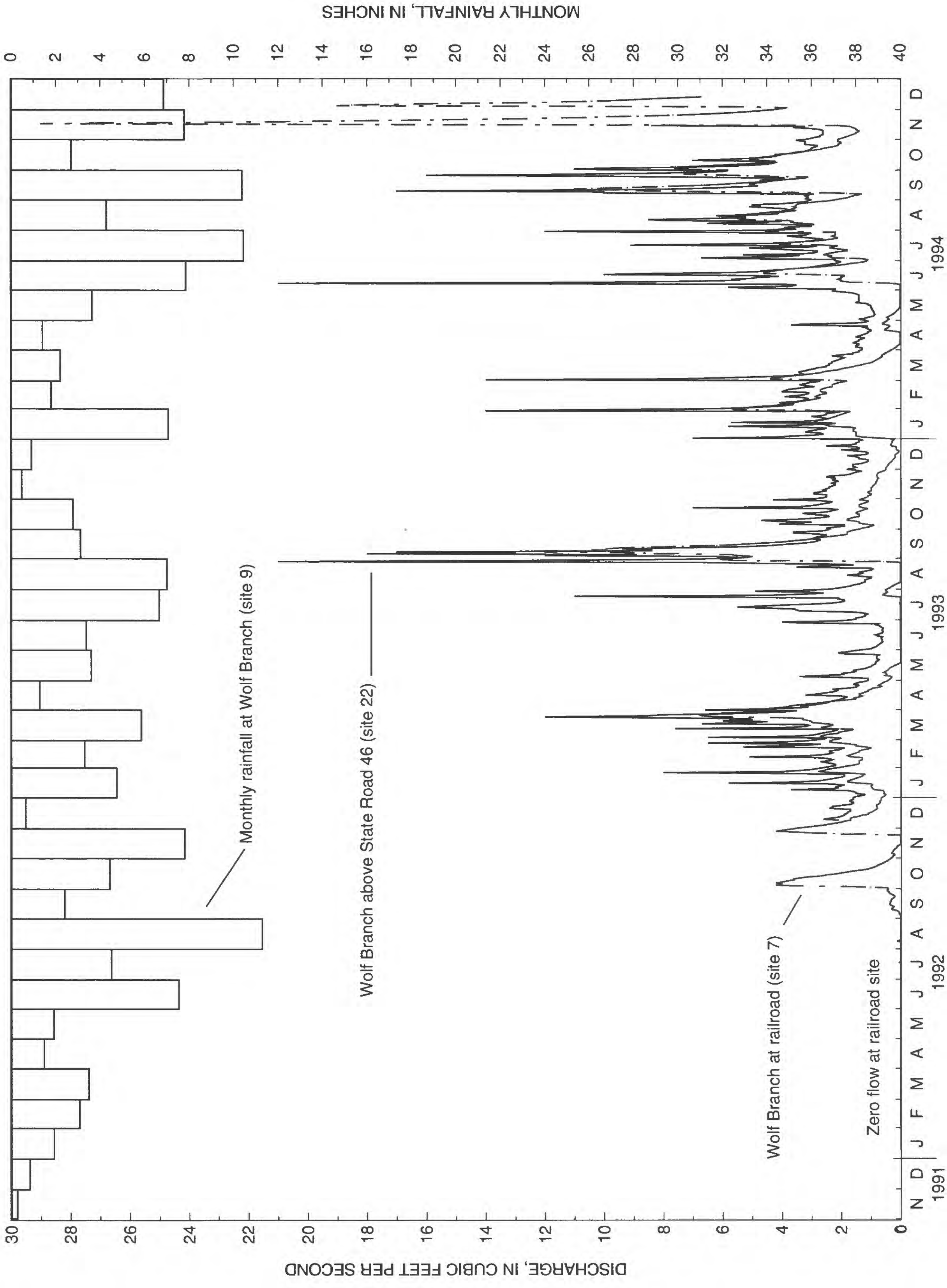

Figure 8. Discharge at sites 7 and site 22 and monthly rainfall at site 9 during the study.

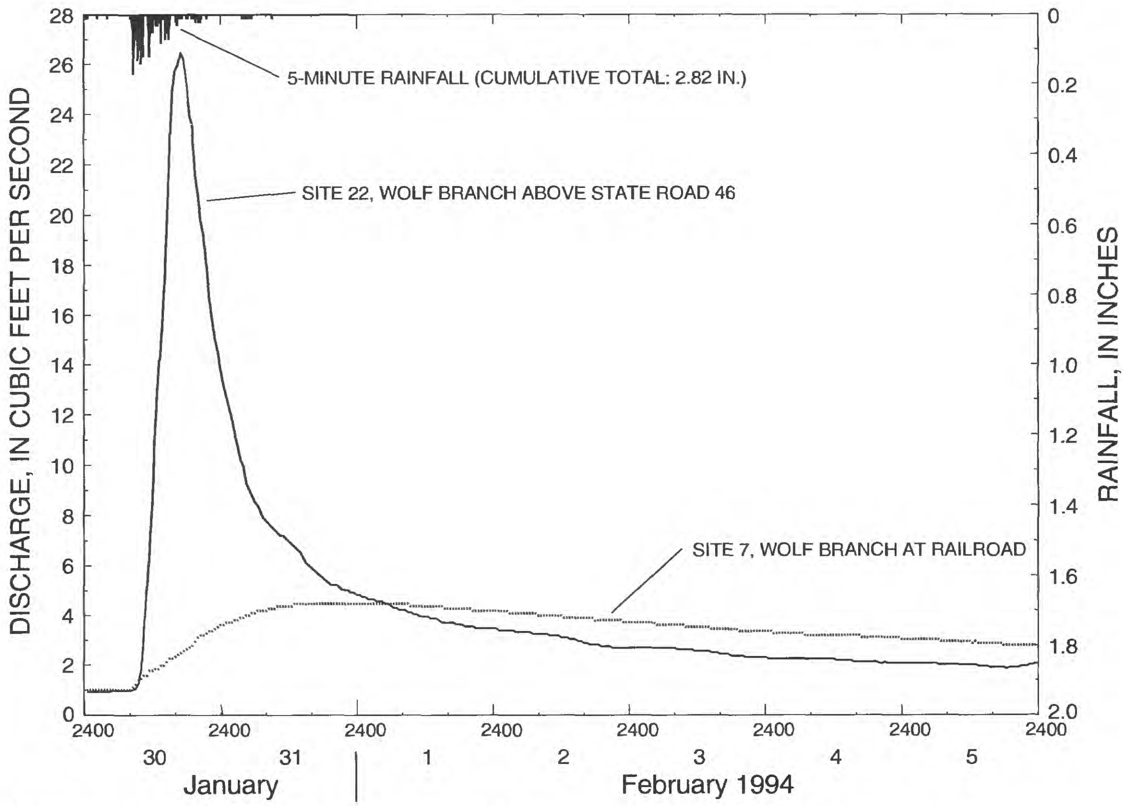

Figure 9. Discharge at sites 7 and 22 and rainfall at site 9, January 30-February 5, 1994.

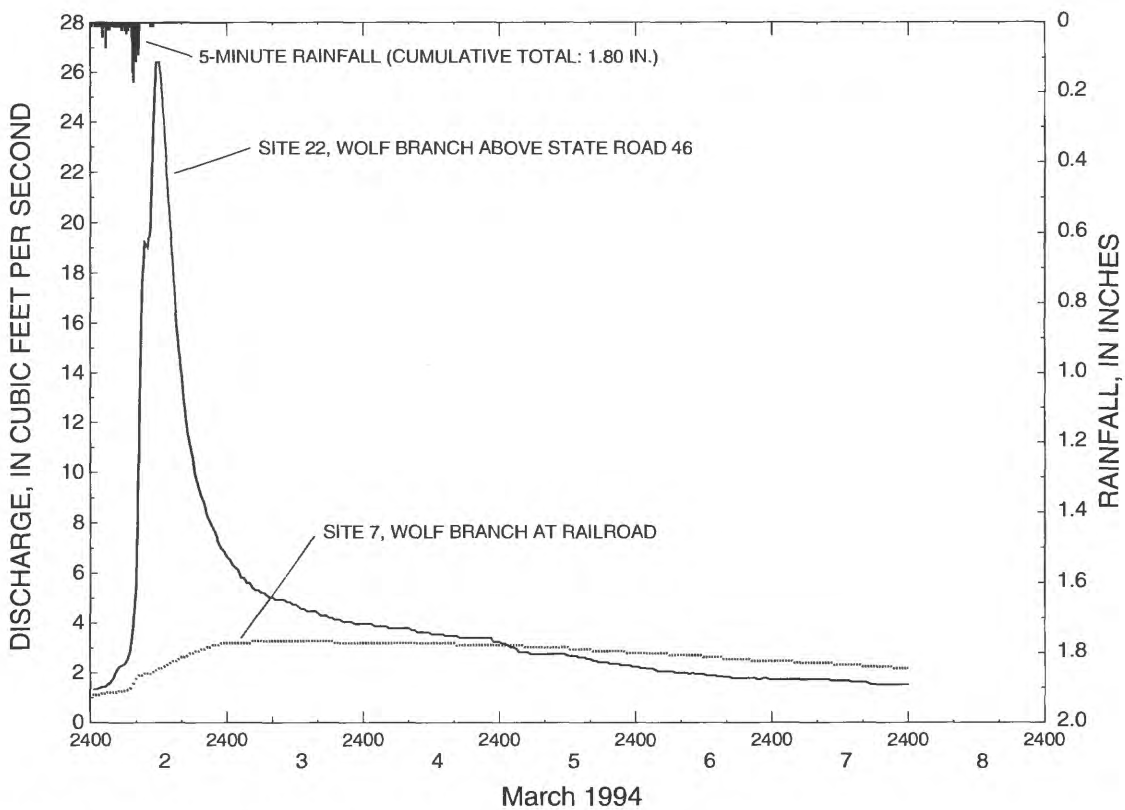

Figure 10. Discharge at sites 7 and 22 and rainfall at site 9, March 2-8, 1994.

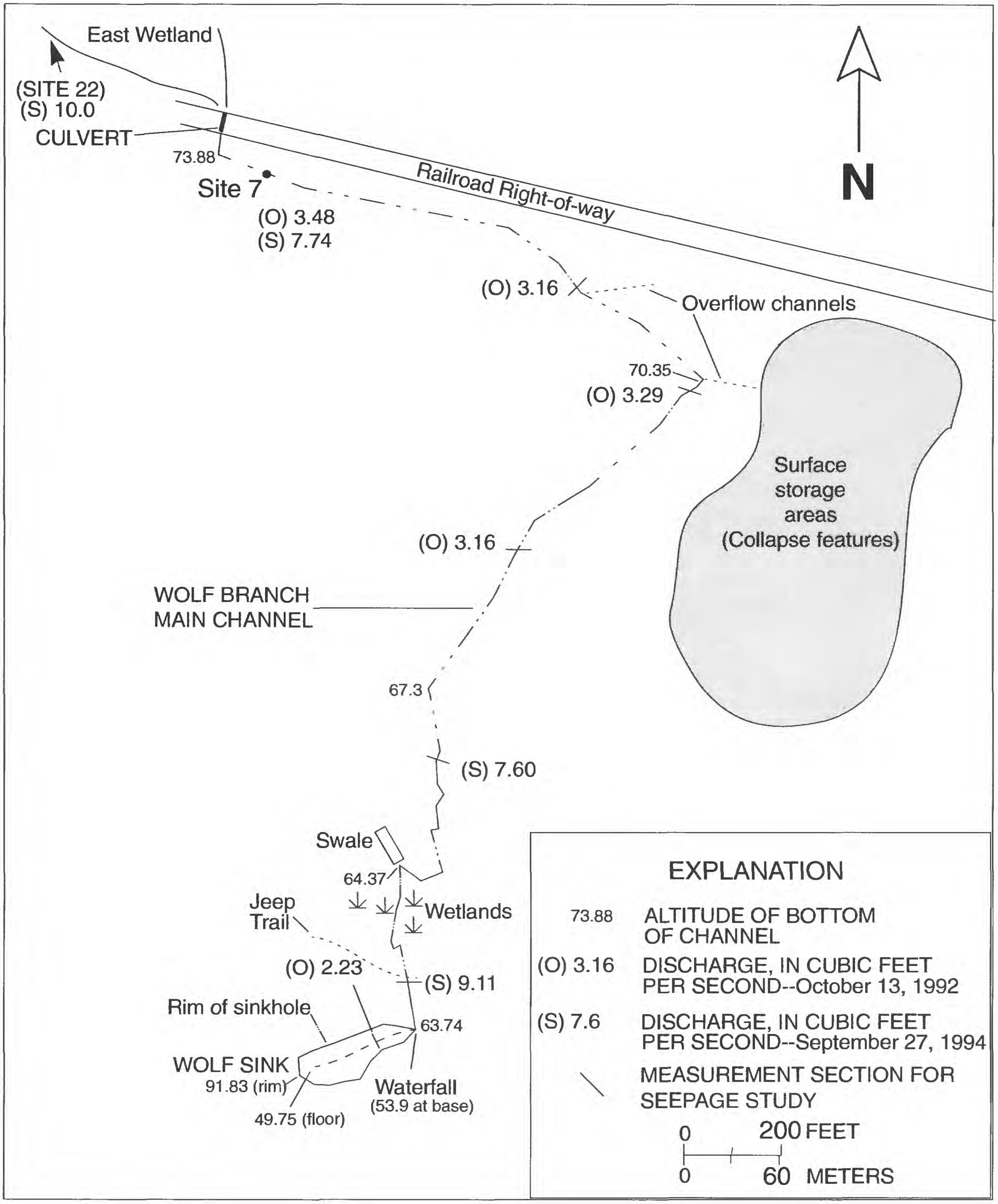

Figure 11. Discharge measurement site locations used for seepage studies. (Altitude of stream channel surveyed on September 26, 1991, by Hall, Farner, & Associates, Inc., Leesburg, Florida.)

lower reaches of Wolf Branch probably is the result of release of water from storage in the wetlands. The difference in results between the two seepage runs reflects the antecedent hydrologic conditions—in October 1992, there was storage available in the soil column because of a long period of dry conditions, but in September 1994, the ground was saturated and provided no storage. Also in September 1994, some flow was probably being released from surface storage in the wetlands in the lower reaches of the basin.

Hydraulic Conductance of Wolf Sink

One of the objectives of the study of the hydrology of Wolf Branch was to determine the rate at which surface water is conducted through Wolf Sink to the underlying aquifer. Based on this information and the hydrologic characteristics of the lower basin described in this report, management decisions can be made regarding protection of the ground-water resources in the area. Several options available include the diversion of flow into the wetland east of Wolf Branch and south of the railroad in the event of a contaminant spill, or the installation of a fabric filter at the sink, which would significantly reduce the rate of inflow. To provide the basis on which these management decisions can be made, the sink conductance (the rate of inflow per unit of head difference between the sink water level and the potentiometric surface of the Upper Floridan aquifer) and probabilities of flow volumes at site 7 were estimated from hydrologic data collected during the study.

The conductance of Wolf Sink was estimated using regression analysis of discharge at site 7, the water level in the sink, and the altitude of the potentiometric surface of the underlying Upper Floridan aquifer during the study. These data represent a wide range of hydrologic conditions, from extremely dry to extremely wet periods. The conductance estimate assumes that the inflow is governed by Darcy's law and is equal to the slope of the regression line for the relation between discharge and head difference (the difference between the water level in the sink and the water level in the Upper Floridan aquifer beneath the sink).

There are some possible errors in the estimation of conductance of Wolf Sink that should be noted. The water level at site 5 was assumed to be an approximation of the altitude of the potentiometric surface beneath the sink. However, the sink serves as a concentrated point of recharge to the aquifer and mounding of the potentiometric surface is highly probable; therefore, the water level at site 5 (800 ft downgradient) probably is lower than the water level directly beneath the sink and the head difference used in the regression is overestimated. The discharge at site 7 probably is an overestimation of the inflow to the Upper Floridan aquifer through Wolf Sink based on the seepage study of October 13, 1992, and other measurements made at sites 6 and 7. Given that the relation being determined through regression is the discharge per unit head, the overestimated discharge would result in an overestimation of the conductance and the overestimated head difference would result in an underestimation of the conductance, so the effects of these errors tend to cancel each other. The effects of these errors on the estimate of conductance cannot be quantified because of the inability to measure the potentiometric surface directly below the Wolf Sink. However, the regression analysis may give some indication of the sensitivity of the conductance value to both variables (discharge and head difference).

A data set was created for regression analysis using observed water levels in the sink obtained from site visits when the staff gage at Wolf Sink was read and from high water marks that were later surveyed to determine the peak elevation of the water surface at the sink for individual storm events. Each observation in the data set included discharge at site 7, the ground-water level at site 5, and the sink water level. High-water marks were used at times when the staff gage in the sink was under water (indicating the depth of water was greater than 12 ft, the top of the staff gage).

The data used for regression analysis represent a wide range of hydrologic conditions during the study; however, some conditions are not represented. The condition of low flow following a dry period could not be accurately represented because of the difficulty in monitoring a water level in Wolf Sink. The staff gage and transducer used to monitor the water level were installed in the channel about 10-ft upstream from the circular bowl of the sink. Water levels could not be monitored until sufficient ponding had occurred at the sink to cause the altitude of the water surface to form a pool around the staff gage. Although this condition could not be represented, extreme wet conditions and associated high water levels are of greater interest because of flooding potential, and the data collected during November and December 1994 are representative of wet conditions.

The response of the hydrologic system to rainfall is indicated in graphs of the water level in Wolf Sink, the ground-water level at site 5, and the discharge at site 7 for several time periods (fig. 12). Several "spikes" in the graph of water level in Wolf Sink indicate rapid runoff to the sink which caused the water level to rise and fall quickly, probably in response to short-duration, high-intensity storms. The ground-water response is a subdued reflection of the sink water level. Of particular note is the "spike" which occurred on March 2, 1994. The 2-ft rise in stage in Wolf Sink caused a noticeable (nearly 0.5 ft) rise in the water level in the observation well at site 5.

The relation between discharge and head difference, and between discharge and sink water level were examined. Linear regression was used to determine the best-fit equation for the data and the conductance of Wolf Sink (slope of the linear regression line). Data used in the regression analysis to determine the conductance of Wolf Sink are shown in figure 13. Errors in the regression (scatter of the data about the regression line) are partly the result of using the discharge at site 7 (upstream from the sink) and ground-water levels 800 ft from the sink in the regression analysis. The conductance of Wolf Sink, based on the regression of discharge and head difference, is 1.48 ft^3/s discharge per foot of head difference. Of note is that the intercept of the regression equation is below zero; this reflects the overestimation of the head difference because of the use of water levels 800 ft from the sink and indicates that the error in the estimate of the head difference has more effect on the regression than does the error in the flow estimate (which would have been indicated by a positive intercept).

The discharge and head-difference data were log-transformed and regressed because discharge characteristically is log-normally distributed. The regression equation tends to fit the log-transformed data better than the non-transformed data (fig. 13). The slightly smaller values for standard error indicate the better fit to the data, and the errors are more homeoscedastic (equal variance). The log regression equation is useful for prediction of the inflow into Wolf Sink for a given head difference, but the linear regression is necessary to estimate the actual conductance value if Darcy's law governs inflow at Wolf Sink.

Surface-Water Inflow to Wolf Sink

Discharge data collected at site 7 provided valuable information about the hydrologic characteristics of flow in the lower Wolf Sink basin because of the extremes which occurred during the study. From these data, probabilities of specific flow volumes that might be expected at Wolf Sink can be computed. Additionally, the extremely wet conditions observed during the study indicated the extent of the flooding that might be expected in the lower Wolf Sink basin.

The highest values of discharge at site 7 and water level in Wolf Sink during the study were observed in November and December 1994 and represent an extremely wet hydrologic condition (as noted in the earlier discussion of rainfall). The maximum observed water level during the study was the result of a combination of wet antecedent conditions in the basin (including saturated soils and surface-water storage near capacity) and the 6.96 in. of rainfall on November 15-16, 1994 (fig. 14). No discharge data were recorded after November 16 at site 22 because the water level in Wolf Branch exceeded the maximum range of the recording equipment at the site. Data collection at Wolf Sink had ended in September 1994, so no continuous water-level data were available for Wolf Sink for this event. The ground-water level at site 5 responded quickly to the recharge through Wolf Sink, as indicated in figure 14.

The flooding in the vicinity of Wolf Sink which occurred as a result of the November rainfall was not enough to cause surface overflow from the Wolf Sink drainage basin southward, but the wetlands and additional storage areas in the lower basin were at or near capacity. A contaminant spill under these extreme conditions could not easily be contained because of the lack of available surface-water storage. Further, should a filter be installed in Wolf Sink, reducing the sink conductance, the amount of flooding would be greater than that observed during November 1994. The estimated overflow altitude for Wolf Sink is 85.3 ft, based on the topographic contours of the area (1967 photogrammetric 1-ft contours from Continental Aerial Surveys, Inc.). The maximum water level of Wolf Sink during the study was 72.46 ft above sea level, so theoretically the water level could rise an additional 13 ft before outflow to the south from the Wolf Branch basin would occur. However, much of the basin north of Wolf Sink would be flooded at this water level.

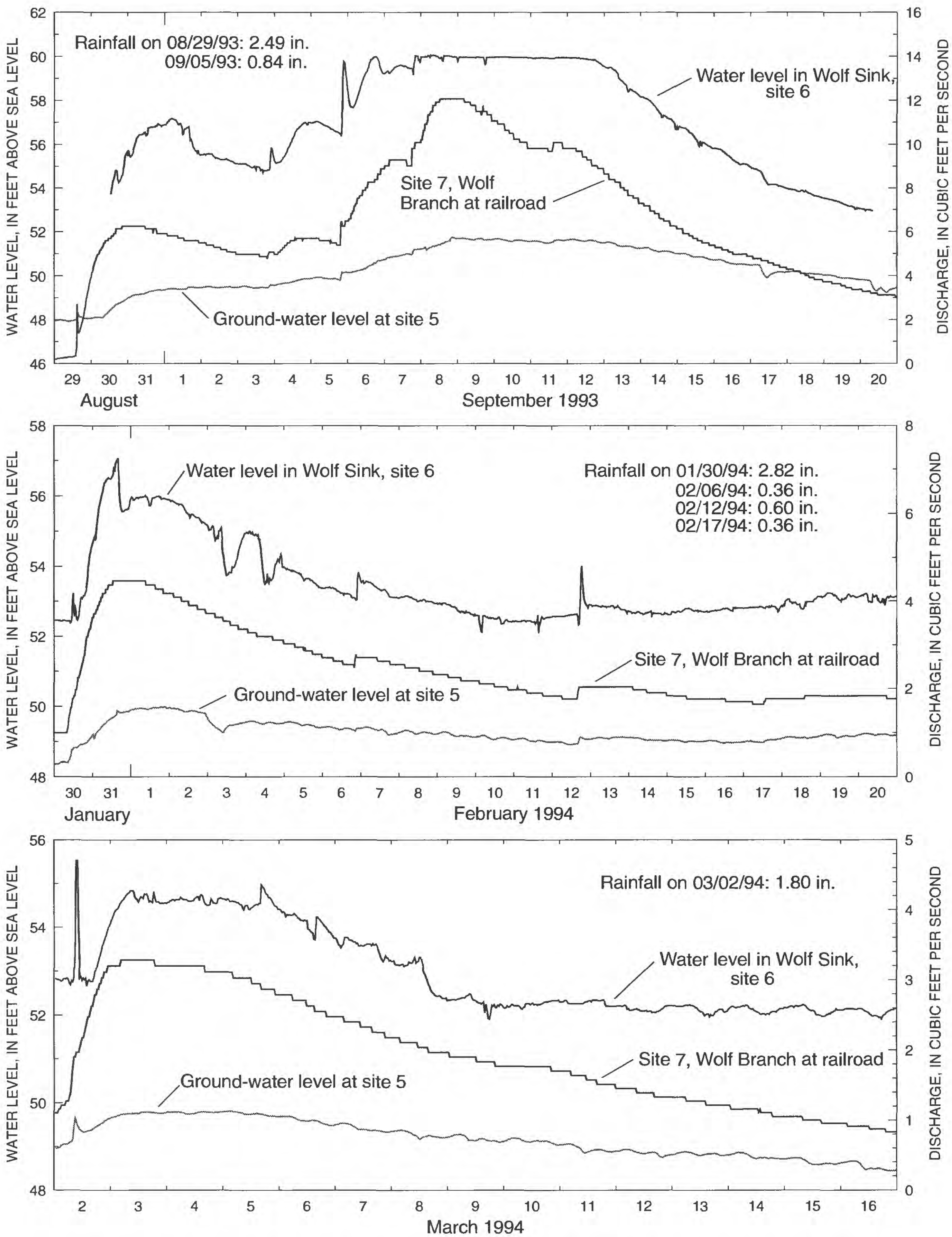

Figure 12. Water level in Wolf Sink, ground-water level at site 5, east of Wolf Sink, and discharge at site 7 for three time periods.

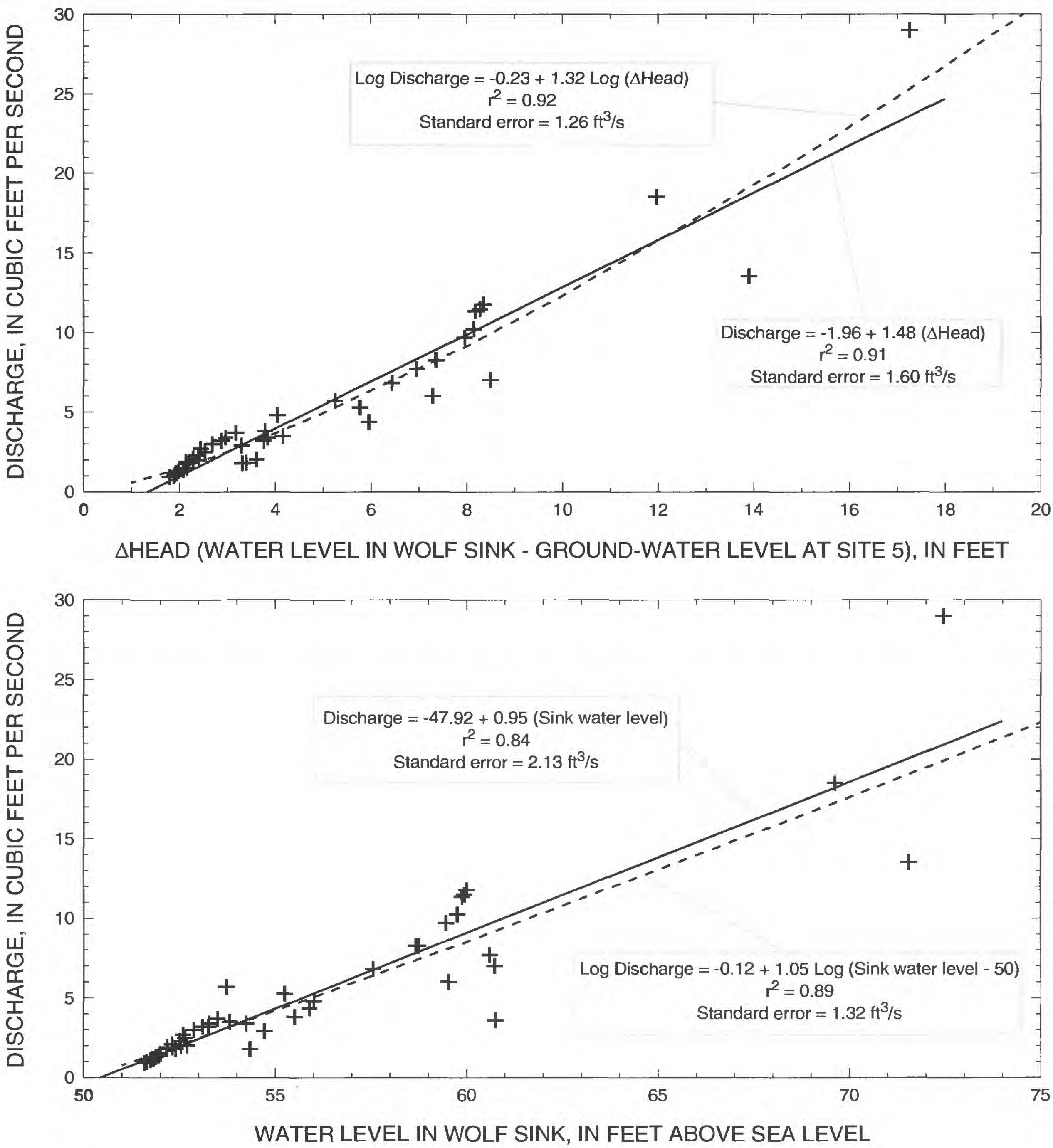

Figure 13. Discharge at site 7 as a function of head (difference between water level in Wolf Sink and ground-water level) and as a function of sink water level.

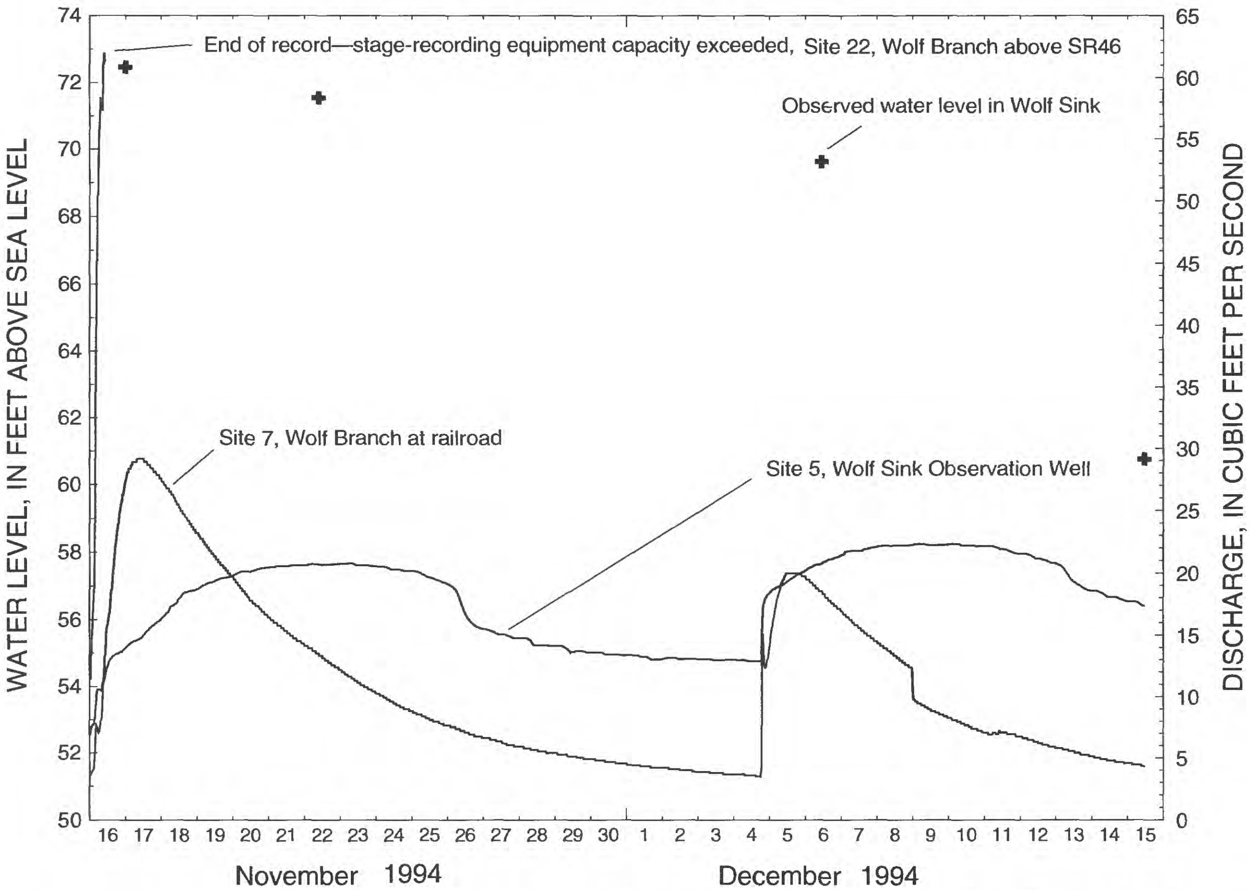

Figure 14. Discharge at sites 7 and 22, ground-water levels at site 5, and water levels in Wolf Sink resulting from rainfall on November 15 (1.90 in.) and November 16 (5.06 in.), 1994.

Flow and volume cumulative-frequency curves were generated based on streamflow data for site 7 collected during the study and additional data collected through September 30, 1995. Because of the possibility of contamination of the Upper Floridan aquifer through Wolf Sink, water managers may need to divert flow from the sink to other areas for storage in the event of a contaminant spill in the basin. The cumulative-frequency curves in figure 15 present the probability of a given discharge or storm volume for time periods ranging from 1 day to 30 days. From these data, the volume of water that must be stored for any period can be estimated. The additional flow data for site 7 were included so that a longer time period would be represented (January 10, 1992 - September 30, 1995, nearly 4 years of record). The discharge record was divided into time segments beginning January 10, 1992, and the mean discharge for each segment was computed. The beginning of the period was incremented by one day, the time segments were recomputed, and means were computed for each new time segment. This process was repeated up to the number of days in the time segment under consideration. Thus, means were computed for any possible time segment (1-day, 7-day, 14-day, 21-day, and 30-day periods) within the period of record. The mean discharge for each time segment was ranked and the probability of each mean discharge computed. Because of the extremes in hydrologic conditions which occurred during the study, and the similarity in the distribution of rainfall at Wolf Branch during the study to the long-term (40 years) rainfall at Lisbon (fig. 3), the frequency probabilities presented in figure 15 probably are representative of a much longer time period. Also incorporated in these curves is the variability in antecedent conditions which significantly affects the flow in Wolf Branch and, thus, the flow to Wolf Sink.

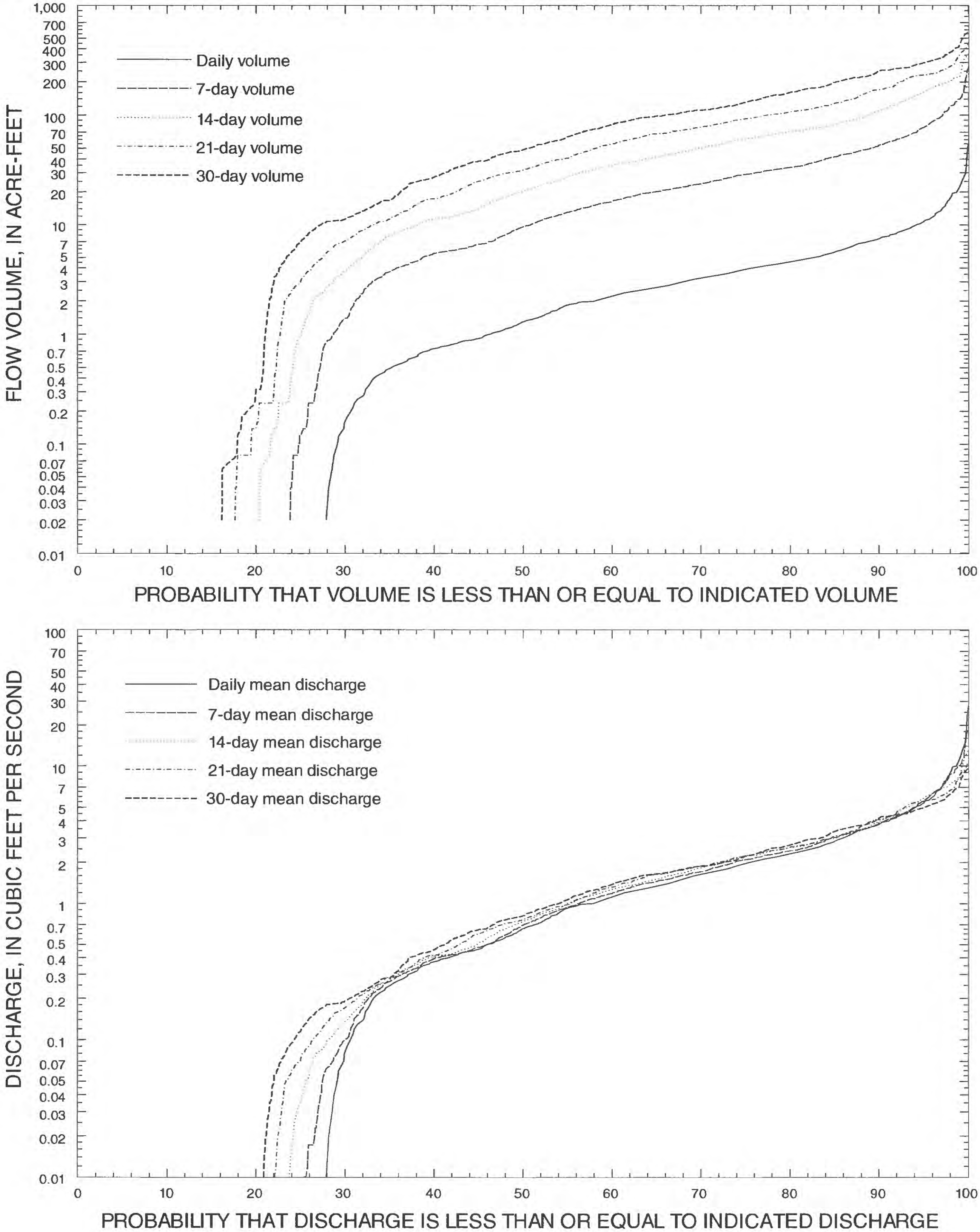

Figure 15. Flow and volume cumulative frequency curves for site 7.

The lower graph in figure 15 indicates the probability that the mean discharge for the indicated time period would be equal to or less than the indicated discharge. For example, the mean flow for a single day will be about 1 ft^3/s 60 percent of the time and, thus, greater than 1 ft^3/s for 40 percent of the time. The similarity in the shape and magnitude of the curves reflect the sustained nature of flow at site 7, as indicated in figures 9-10. All of the curves begin at a probability greater than 20 percent, indicating that 20 percent of the time (or more), there is no flow at this site for any of the time periods presented.

The upper graph in figure 15 indicates the probability of the volume of water that would be generated within the indicated time period. For example, 80 percent of the time the total volume of water expected at site 7 in one day (that would need to be diverted from Wolf Sink in the event of a contaminant spill) is less than or equal to 4.7 acre-ft; 34 acre-ft for a 7-day period; 72 acre-ft for a 14-day period; 108 acre-ft for a 21-day period; and 161 acre-ft for a 30-day period. During any 30-day period, 30 percent of the time a total flow volume of 11 acre-ft or less would be expected at site 7 and 90 percent of the time, 248 acre-ft (or less) of flow volume would be expected. The maximum storage volume that would be required during any 30-day period, based on data from this study, would be about 570 acre-ft. The volumes shown in figure 15 (upper graph) can be used to evaluate the frequency with which the available storage capacity of Wolf Sink will be exceeded. For example, if available storage volume in Wolf Sink is 10 acre-ft, this volume will be exceeded about 4 percent of the time for 1-day time periods, and 73 percent of the time during any 30-day period (based on the graph). The amount of water exceeding the capacity of the sink must either flow through the sink to the Upper Floridan aquifer, or be diverted to another location to prevent potential flooding of the lower Wolf Sink basin.

SUMMARY AND CONCLUSIONS

The potential exists for contamination of the Floridan aquifer system through the surface-water inflow at Wolf Sink in Lake County, Florida. The topography of the Wolf Branch basin is characterized by features typical of karstic terrain, with many closed-depressions and internal drainage. Wetlands in the basin provide surface-water storage, and the well-drained soils on the high ridges and upland areas provide recharge to the underlying aquifers.

Hydrologic conditions during the study ranged from very dry, when there was no streamflow in Wolf Branch for 8 months or more, to very wet, during November and December 1994, when many areas in the basin south of State Road 46 were flooded. The rainfall record for Wolf Branch during the study was compared to long-term rainfall at Lisbon, about 5 miles northwest of the study area. A one-day rainfall of 5.06 inches in the Wolf Branch area on November 16, 1994, corresponded to a one-day rainfall at the Lisbon rainfall site of 5.03 inches, which was exceeded only twice in 40 years, or 0.05 percent of the time. Thus, the hydrologic conditions during data collection for the study are representative of extreme conditions which can be expected during a much longer time period.

Concerns about contamination of local domestic wells by water entering through Wolf Sink were investigated using dye studies and through examination of well logs. The two dye studies were conducted under dissimilar conditions, one following an extended dry period, and one following a wet period. No dye was recovered from any of the sampled wells in the basin for either study. Examination of natural gamma logs of wells in the area indicated that many of the wells do not penetrate the Upper Floridan aquifer, but are open to a highly transmissive zone of the lower Hawthorn Formation. The numerous closed sinkhole depressions throughout the Wolf Branch drainage basin and the fact that many of the wells in the basin are not in the Upper Floridan indicate that some discoloration of water in these wells may be the result of recharge water entering the tapped zone of the aquifer through these depressions (without sufficient filtering to remove color), rather than from water moving laterally from Wolf Sink. Further, it is unknown to what depth the collapse at Wolf Sink extends. The flow path for a constituent entering Wolf Sink generally would be to the east, in the direction of the regional ground-water flow.

The Wolf Branch drainage basin is composed of several sub-basins. Within each of the sub-basins are areas which provide surface-water storage. Ground-water seepage in the upper reaches of Wolf Branch, upstream from Wolf Branch Road, provide base flow to the stream. The wetlands south of State Road 46 provide surface-water storage and reduce peak flows in the lower reaches of Wolf Branch. South of these wetlands, the stream is intermittent and can be dry for many months during the year. Streamflow in Wolf Branch south of State Road 46 is a function of cumulative rainfall and surface- and ground-water storage in the basin.

To evaluate the potential for seepage loss along the stream channel, discharge was measured at several sites from the most upstream gaging site above State Road 46 to Wolf Sink. During the first study on October 13, 1992, some loss in discharge was noted in the lower part of the basin, above Wolf Sink, which was attributed to storage in wetlands near the sink rather than seepage loss. Discharge in Wolf Branch was greater during the second study, which was conducted September 27, 1994. An increase in discharge was noted in the lower part of the basin, above Wolf Sink, which probably was a reflection of the release of water from storage in the wetlands above Wolf Sink.

The conductance of Wolf Sink (the rate at which the sink conducts water to the underlying aquifer) was estimated from streamflow data, ground-water levels, and water levels in Wolf Sink. The range of hydrologic conditions during the study provided a basis for the determination of a representative conductance value. The regression of streamflow as a function of head difference between the sink water level and the potentiometric surface at an observation well (an approximation of the potentiometric level beneath Wolf Sink) resulted in a significant relation ($r^2 = 0.91$, mean square error = 1.60 cubic feet per second); and the slope of the regression line, representing sink conductance, was 1.48 cubic feet per second per foot of head difference.

Under wet conditions, such as occurred in November 1994, a contaminant spill in the Wolf Sink area could not have been easily contained because of the lack of any available surface-water storage. If a filter is installed in Wolf Sink, effectively reducing the sink conductance, the amount of flooding would be greater than that observed during November 1994. The maximum water level of Wolf Sink during the study was 72.46 feet above sea level and the estimated overflow altitude for Wolf Sink is 85.3 feet, so theoretically the water level could rise an additional 13 feet before any outflow from the Wolf Branch basin would occur. However, this level of flooding would have a significant impact on the basin upstream from Wolf Sink.

Flow and storm-volume frequency curves for selected time intervals were generated based on streamflow data from January 10, 1992, to September 30, 1995. These curves indicate that the volume of water that would have to be stored (in the event that streamflow had to be diverted from Wolf Sink) during a 30-day period would be equal to or less than about 11 acre-feet 30 percent of the time and 161 acre-feet 80 percent of the time. The maximum volume that would be generated during a 30-day period, based on this study, would be about 570 acre-feet.

SELECTED REFERENCES

Bush, P.W., 1974, Hydrology of the Oklawaha Lakes area of Florida: Florida Bureau of Geology Map Series 69.

Katz, B.G., 1992, Hydrochemistry of the Upper Floridan aquifer, Florida: U.S. Geological Survey Water-Resources Investigation Report 91-2196, 37 p., 10 pls.

Keys, W.S., and MacCary, L.M., 1971, Application of borehole geophysics to water-resources investigations: U.S. Geological Survey Techniques of Water-Resources Investigations, book 2, chap. E1, 126 p.

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

———1971, Ground water in Lake County, Florida: Florida Bureau of Geology Map Series 44.

Knochenmus, D.D., and Hughes, G.H., 1976, Hydrology of Lake County, Florida: U.S. Geological Survey Water-Resources Investigations 76-72, 100 p.

Phelps, G.G., 1994, Hydrogeology, water quality, and potential for contamination of the Upper Floridan aquifer in the Silver Springs ground-water basin, central Marion County, Florida: U.S. Geological Survey Water-Resources Investigations Report 92-4159, 69 p., 5 pls.

Sinclair, W.C., 1991, Preliminary study of the potential for ground water contamination at Wolf Branch Sink, Lake County, Florida: Consulting report prepared by William C. Sinclair, P.O. Box 1683, Tampa, Florida, 33601, 27 p.

Taylor, G.F., 1984, Distribution and occurrence of total coliform bacteria in Floridan aquifer wells, western Lake County, Florida: U.S. Geological Survey Water-Resources Investigations Report 84-4130, 28 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.

Tibbals, C.H., 1990, Hydrology of the Floridan aquifer system in East-Central Florida: U.S. Geological Survey Professional Paper 1403-E, 98 p.

White, W.W., 1970, The geomorphology of the Florida peninsula: Florida Bureau of Geology Bulletin no. 51, 164 p., 7 pls.

Wilson, J.F., Jr., 1968, Fluorometric procedures for dye tracing: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A12, 31 p.

Wilson, J.F., Jr., Cobb, E.D., and Kilpatrick, F.A., 1986, Fluorometric Procedures for dye tracing: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A12, Revised 1986, 34 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 Karst Terranes and Their Solutions, Nashville, Tenn., Nov. 1988: National Water Well Association, p. 121-141.