Hydrology, Water Quality, and Surface- and Ground-Water Interactions in the Upper Hillsborough River Watershed, West-Central Florida

By J.T. Trommer, L.A. Sacks, and E.L. Kuniansky

Prepared in cooperation with the
Southwest Florida Water Management District

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Conversion Factors, Acronyms, and Abbreviations

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow rate	
foot per second (ft/s)	0.3048	meter per second (m/s)
foot per day (ft/d)	0.3048	meter per day (m/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per day (ft^3/d)	0.02832	cubic meter per day (m^3/d)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)
pound per year (lb/yr)	0.4536	kilogram per year (kg/yr)
pound per square mile (lb/mi^2)	0.1751	kilogram per square kilometer (kg/km^2)
ton, short (2,000 lb)	0.9072	megagram (Mg)
ton per year (ton/yr)	0.9072	megagram per year (Mg/yr)

Multiply	By	To obtain
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Transmissivity*	
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)
	Temperature	
degrees Celsius (˚C)	˚F = (1.8 × ˚C) + 32	degrees Fahrenheit (˚F)
degrees Fahrenheit (˚F)	˚C = (˚F – 32) / 1.8	degrees Celsius (˚C)

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD of 1929).

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

Altitude, as used in this report, refers to distance above the vertical datum.

*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.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at ˚25 C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Acronyms and Additional Abbreviations

AMO	Atlantic Multidecadal Oscillation
APHA	American Public Health Association
DO	dissolved oxygen
DOC	dissolved organic carbon
FC	fecal coliform
FS	fecal streptococci
HRSP	Hillsborough River State Park
LOWESS	locally weighted regression and smoothing of scatter plots
MVUE	minimum variance unbiased estimator
NOAA	National Oceanographic and Atmospheric Administration
NWIS	National Water Information System
ROMP	Regional Observation and Monitoring Program
SWFWMD	Southwest Florida Water Management District
SA	surficial aquifer
TBW	Tampa Bay Water
TC	total coliform
UFA	Upper Floridan aquifer
USGS	U.S. Geological Survey

Hydrology, Water Quality, and Surface- and Ground-Water Interactions in the Upper Hillsborough River Watershed, West-Central Florida

By J.T. Trommer, L.A. Sacks, and E.L. Kuniansky

Abstract

A study of the Hillsborough River watershed was conducted between October 1999 through September 2003 to characterize the hydrology, water quality, and interaction between the surface and ground water in the highly karstic uppermost part of the watershed. Information such as locations of ground-water recharge and discharge, depth of the flow system interacting with the stream, and water quality in the watershed can aid in prudent water-management decisions.

The upper Hillsborough River watershed covers a 220-square-mile area upstream from Hillsborough River State Park where the watershed is relatively undeveloped. The watershed contains a second order magnitude spring, many karst features, poorly drained swamps, marshes, upland flatwoods, and ridge areas. The upper Hillsborough River watershed is subdivided into two major subbasins, namely, the upper Hillsborough River subbasin, and the Blackwater Creek subbasin. The Blackwater Creek subbasin includes the Itchepackesassa Creek subbasin, which in turn includes the East Canal subbasin.

The upper Hillsborough River watershed is underlain by thick sequences of carbonate rock that are covered by thin surficial deposits of unconsolidated sand and sandy clay. The clay layer is breached in many places because of the karst nature of the underlying limestone, and the highly variable degree of confinement between the Upper Floridan and surficial aquifers throughout the watershed. Potentiometric-surface maps indicate good hydraulic connection between the Upper Floridan aquifer and the Hillsborough River, and a poorer connection with Blackwater and Itchepackesassa Creeks. Similar water level elevations and fluctuations in the Upper Floridan and surficial aquifers at paired wells also indicate good hydraulic connection.

Calcium was the dominant ion in ground water from all wells sampled in the watershed. Nitrate concentrations were near or below the detection limit in all except two wells that may have been affected by fertilizer or animal waste. Wells at the Blackwater Creek and Hillsborough River at State Road 39 transects showed little seasonal variation in dissolved organic carbon. Dissolved organic carbon concentrations, however, were greater during the wet season than during the dry season at the Hillsborough River Tract transect, indicating some influence from surface-water sources.

During dry periods, streamflow in the upper Hillsborough River was sustained by ground water from the underlying Upper Floridan aquifer. During wet periods, streamflow had additional contributions from runoff, and release of water from extensive riverine wetlands, and by overflow from the Withlacoochee River. In contrast, streamflow in Blackwater and Itchepackesassa Creeks was less constant, with many no-flow days occurring during dry periods. During wet season storm events, streamflow peaks occur more rapidly because there is greater confinement between the surficial deposits and the Upper Floridan aquifer, and these creeks have been highly channelized, leaving less of the adjacent wetlands intact. During dry periods, Blackwater Creek is dry upstream from its confluence with Itchepackesassa Creek, and all downstream flow is from Itchepackesassa Creek. Much of the dry season flow in Itchepackesassa Creek originates from a treated wastewater effluent outfall located on East Canal. Long-term streamflow at the Hillsborough River and Blackwater Creek stations was greater than the discharge observed during the study period.

Water quality in the upper Hillsborough River is influenced by ground-water discharge. The chemical composition of water from Blackwater Creek, Itchepackesassa Creek, and East Canal was more variable because there was less ground-water discharge to these creeks than to the upper Hillsborough River, and because of the influence of wastewater effluent. Strontium isotope data indicated that the source of the water at all Hillsborough River sites during the dry season was the Oligocene-age Suwannee Limestone, and that water from Blackwater and Itchepackesassa Creeks as well as East Canal was from shallower zones in the Upper Floridan aquifer. Bacteria samples indicated that the most likely sources of bacteria are cattle and native animals. Thirty-eight organic wastewater and pesticides compounds were detected at five sites; however, concentrations were typically less than 1 microgram per liter. Nitrogen species varied at the Hillsborough River sampling sites seasonally and in a down-gradient direction. The dominant species of nitrogen in water at the three upstream sites was total Kjeldahl nitrogen, and is probably from riverine wetlands and cattle grazing activities. Inorganic nitrogen was the dominant species at the three downstream sites, and is probably from ground-water sources. Nitrogen isotope data indicate the nitrogen is from mixed sources. The dominant species of nitrogen in water from Blackwater and Itchepackesassa Creeks was total Kjeldahl nitrogen, similar to the upstream Hillsborough River sites.

Estimates of streamflow gains and losses were made along the main channel of the upper Hillsborough River, Blackwater Creek, Itchepackesassa Creek, and East Canal. During May 2001, losing and gaining stream reaches were observed in all subbasins. During November, the only losing stream reaches observed were in the East Canal and Itchepackesassa Creek subbasins near their confluence.

Ground-water contributions to the streams were estimated at continuous record stations using hydrograph separation methods. Average mean annual base flow ranged from about 4 to 9 inches per year. This method probably overestimates base flow because of flat gradients and extensive wetlands located in the watershed. Ground-water discharge to the streams was simulated using a two-dimensional cross-sectional model at three transect sites along the Hillsborough River and Blackwater Creek, and ranged from about 0.05 to 1.6 inches per year.

Introduction

Population growth has resulted in extensive development of the water resources in the Tampa Bay area, and anticipated future growth will place increasing stress on these resources. The Hillsborough River watershed is a valuable natural resource located in the northern Tampa Bay area (fig. 1). The watershed extends from the Green Swamp area in eastern Pasco County, to downtown Tampa, covering about 690 square miles (mi^2).

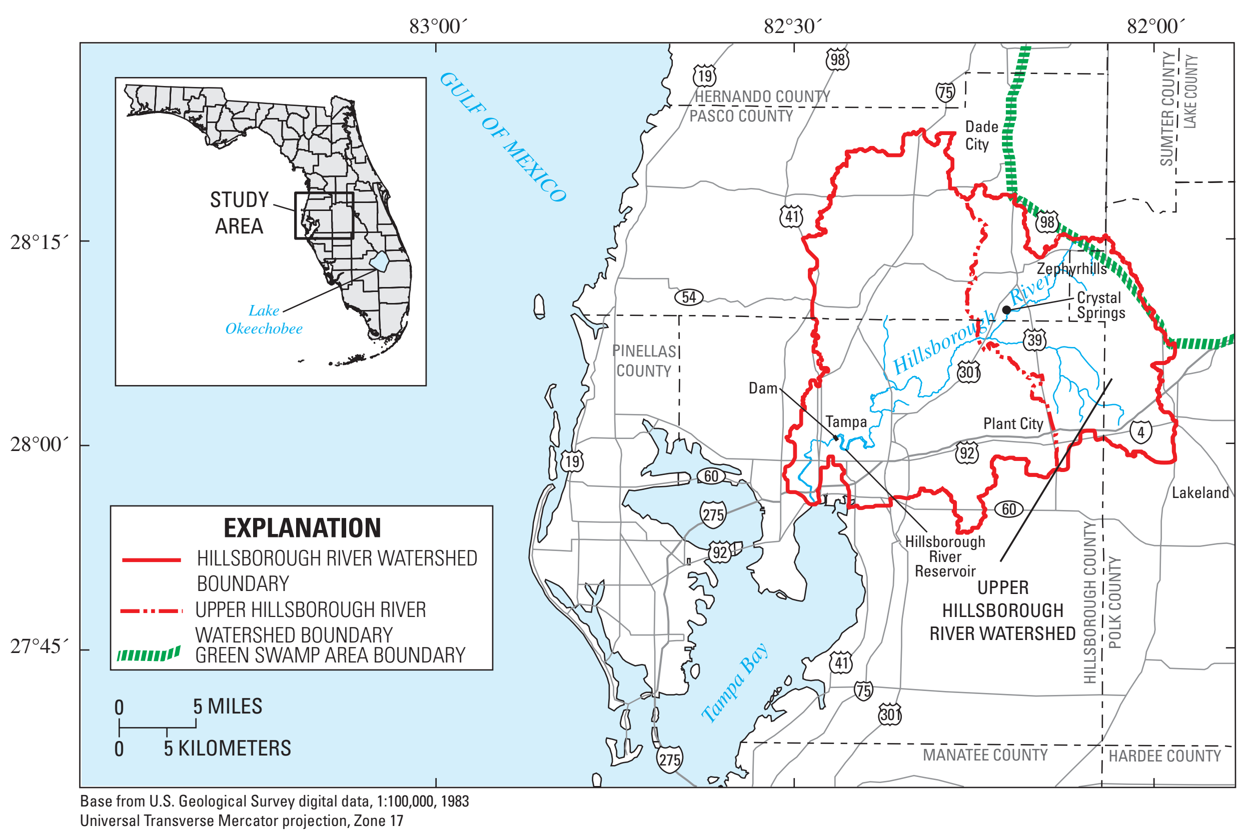


Figure 1. Location of the Hillsborough River watershed and the upper Hillsborough River watershed, west-central Florida.

The river has been an important source of public supply for the city of Tampa since 1926. In 1945, a water-supply reservoir was created by damming the river about 10 miles (mi) upstream from the bay. Currently, most of the 71 million gallons per day (Mgal/d) demand necessary to supply about 450,000 people is from the Hillsborough River Reservoir (Tampa Water Department, 2001). Downstream from the reservoir, the river is tidal and the watershed is highly developed and urban. Upstream from the reservoir, the watershed is primarily suburban with varying densities of residential and commercial development, and agricultural areas. Development is less dense in the uppermost part of the watershed, which is the focus of this study.

Ground water is withdrawn from within the Hillsborough River watershed and used as a source of public and private supply. Three well fields provide ground water to a regional water-supply authority, and ground water also is withdrawn from distributed wells that provide public supply for Dade City, Zephyrhills, Plant City, and Lakeland (fig. 1). In the upper part of the watershed, 300,000 gallons of water per day (gal/d) is withdrawn for commercial use from Crystal Springs, a second order magnitude spring. Ground water also is withdrawn for agricultural, industrial, and domestic purposes.

The interconnection between the surface- and ground-water systems in the upper part of the Hillsborough River watershed is not fully understood. The karst nature of the study area further complicates the surface-water and ground-water relation. Information such as location of ground-water discharge, depth of the flow system interacting with the stream, and pumping effects can aid in prudent water-management decisions. The hydraulic connection between surface and ground water can influence the water quality of either resource.

Water managers are required to set minimum flows and levels for the water bodies throughout the State, including the Hillsborough River and its major tributaries (fig. 2). “Minimum flows and levels” is a flow or level below which significant harm occurs to the water resources or ecology of the area (Southwest Florida Water Management District, 2001). Assessments of the hydrologic system, water quality, and the interaction between surface water and ground water are necessary to document current conditions and to provide information that can be used to evaluate the susceptibility and sustainability of water resources in this relatively undeveloped part of the watershed. In 1999, the U S Geological Survey (USGS) began a cooperative study with the Southwest Florida Water Management District (SWFWMD) to characterize the hydrology, water quality, and interaction between surface and ground water in the uppermost part of the Hillsborough River watershed. Studies that include surface- and ground-water interaction, water-supply watersheds, and source-water protection information are a high priority of the USGS Federal and State Cooperative program, and the results of this study have transfer value to other watersheds located in karst areas.

Purpose and Scope

This report describes the hydrology, surface- and ground-water quality, and the interaction between the surface- and ground-water systems in the upper part of the Hillsborough River watershed. Hydrologic and geologic data collected in the watershed during the study period (October 1999—September 2003), historical data from the files of the USGS and the SWFWMD, and data from previously published reports were examined and analyzed. Data were collected at six continuous streamflow monitoring stations during the study. Detailed potentiometric surface maps were constructed and synoptic streamflow measurements were made to determine the direction of flow in the aquifer system, and to assess the interconnection of the surface- and ground-water systems. Numerical simulation and hydrograph separation analysis at three transect sites were made to determine the ground-water contribution to the streams. Areas of hydraulic connection between the river and the aquifers were identified. Water-quality trends and constituent loading at the four continuous streamflow monitoring stations were determined. Surface- and ground-water quality data were compared to assess sources and interconnection between the hydrologic systems. Annual data included in this report was presented by water year (a 12-month period from October 1 through September 30). All continuously recorded streamflow and water-quality data are stored in the USGS National Water Information System (NWIS) databases.

Previous Investigations

Previous ground- and surface-water investigations by the USGS and State of Florida agencies have included the Hillsborough River watershed. However, most have been larger regional studies or studies that focused on the watershed downstream from the Hillsborough River State Park (fig. 2). Menke and others (1961) studied the water resources of Hillsborough County and noted that flow in the river was sustained by ground-water discharge from Crystal Springs. Cherry and others (1970) described the hydrogeology of the middle gulf area of Florida, which includes part of the Hillsborough River watershed. Turner (1974) completed flood profiles for the lower Hillsborough River. Stewart (1977) analyzed the hydrologic effects of pumping from a large sinkhole near the Hillsborough River, and Stewart and others (1978) described the hydrogeology of the Temple Terrace area adjacent to the river. The water-supply potential for the lower Hillsborough River was evaluated by Goetz and others in 1978. Murphy (1978) completed flood profiles for Cypress Creek, a tributary of the Hillsborough River. Fernandez and others (1984) completed a water-quality model of low flow for the Hillsborough River. Knutilla and Corral (1984) studied the hydrologic effects of the Tampa Bypass Canal near the lower Hillsborough River. Wolansky and Thompson (1987)

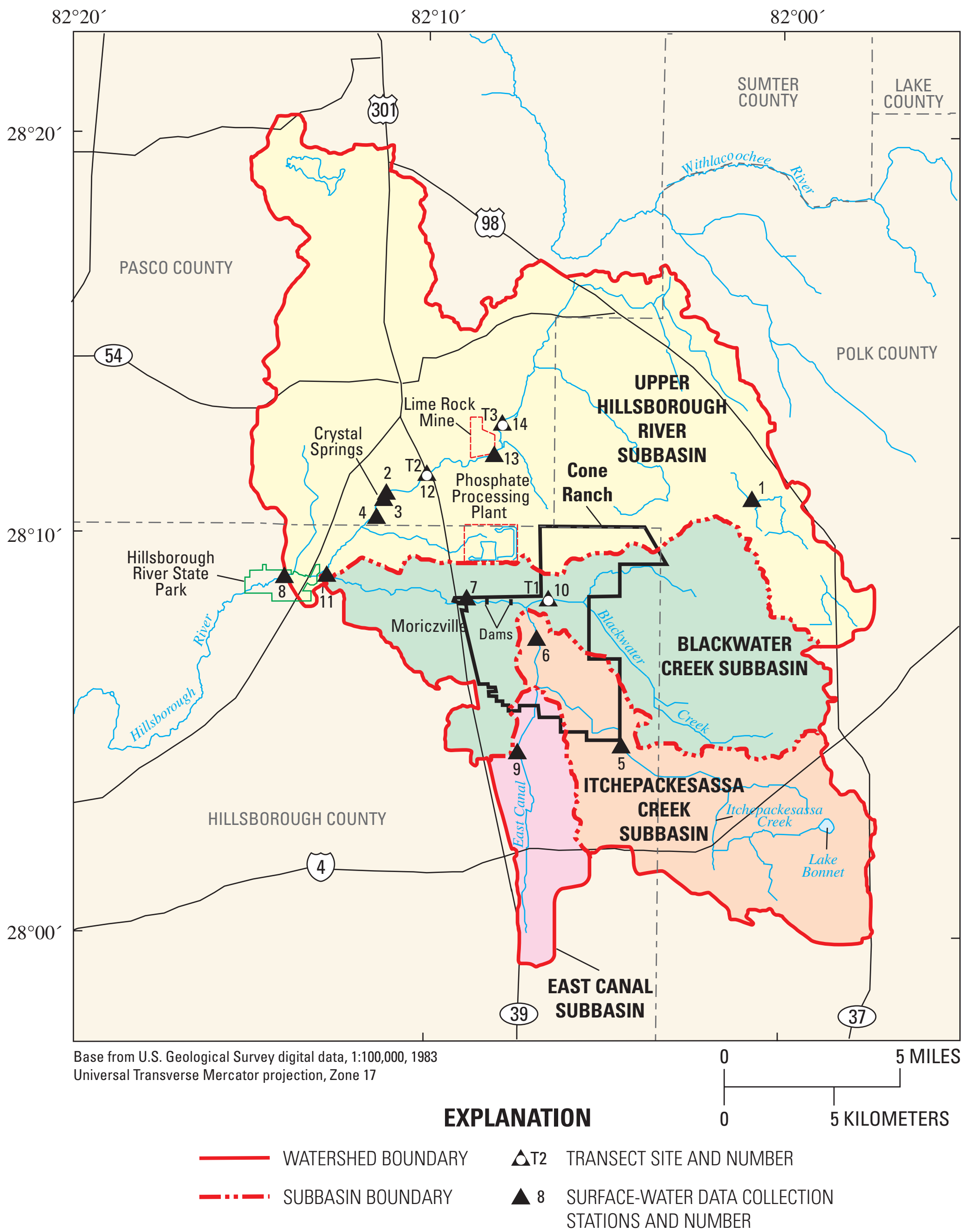


Figure 2. Location of the upper Hillsborough River watershed and the surface-water data-collection network.

studied the relation between ground and surface water in the Hillsborough River below the Hillsborough River State Park. The hydrogeology of the northern Tampa Bay area was described by Hancock and Smith (1996). The hydrogeology of the Crystal Springs area and origins of nitrate discharging from the springs was investigated by Champion and DeWitt (2000). Weber and Perry (2001) studied the impacts of ground-water withdrawals in the Hillsborough River watershed.

Acknowledgments

The authors gratefully acknowledge the cooperation and assistance of personnel with the Southwest Florida Water Management District, Tampa Bay Water, and Hillsborough River State Park. Special thanks are given to Dwain Williams, General Manager with Plaza Materials Corporation, for access to the Hillsborough River at the Yonkers Limerock mine, and for providing water-level data for monitoring wells at the mine.

Description of Study Area

The 220-mi^2 study area, referred to as the upper Hillsborough River watershed in this report, is northeast of the city of Tampa, and encompasses parts of Hillsborough, Pasco, and Polk Counties. The study concentrates on the upper Hillsborough River watershed, from Hillsborough River State Park to the overflow between the Withlacoochee and Hillsborough Rivers in eastern Pasco County (fig. 2). The watershed is subdivided into two major subbasins, the upper Hillsborough River subbasin and the Blackwater Creek subbasin. The Blackwater Creek subbasin contains the Itchepackesassa Creek subbasin, which in turn contains the East Canal subbasin.

The upper Hillsborough River subbasin is located in the northern part of the upper Hillsborough River watershed and drains an area of about 107 mi^2. The river originates in the Green Swamp area (fig. 1) and flows southward from the Withlacoochee-Hillsborough Overflow at U.S. Highway 98, exiting the study area at Hillsborough River State Park. Crystal Springs, a second order magnitude spring, is located next to the river about 2 mi upstream from the State Park. During dry periods, Crystal Springs is a major source of water to the river. A large limerock mine also is located next to the river, about 2.5 mi upstream from State Road 39 (fig. 2). Most of the river channel above the limerock mine lies within a broad, heavily forested floodplain with extensive riverine wetlands and low topographic relief. The channel in that area is poorly defined or nonexistent; downstream from the mine, the channel is moderately incised (Lewelling, 2004).

The Blackwater Creek subbasin is located in the southern part of the Upper Hillsborough River watershed, and drains an area of about 113 mi^2. The creek flows westward from the base of the Lakeland Ridge to the river just upstream from Hillsborough River State Park (fig. 3). Most of the channel upstream from State Road 39 has been extensively ditched to improve drainage. Two small dams, originally built to support agricultural activities, are located about 0.5 and 1.5 mi upstream from State Road 39. Most of the stream channel downstream from State Road 39 remains natural.

Itchepackesassa Creek is a tributary to Blackwater Creek and drains an area of about 57 mi^2. The creek flows northwestward from its headwaters at Lake Bonnet, west of the City of Lakeland, to the confluence with Blackwater Creek. Similar to Blackwater Creek, most of the stream channel has been extensively ditched. The Itchepackesassa Creek subbasin has a larger drainage area than the upgradient part of Blackwater Creek and contributes most of the water in the Blackwater Creek subbasin (Lewelling, 2004).

East Canal is a tributary to Itchepackesassa Creek, and drains an area of about 13 mi^2. The creek flows northward from Plant City to the confluence with Itchepackesassa Creek. A treated wastewater outfall is located on the creek at Stae Road (SR) 582. During low-flow conditions, the treated wastewater is the predominant source of water to the creek.

With the exception of the city of Zephyrhills and parts of the cities of Lakeland and Plant City, the upper Hillsborough River watershed has not been developed extensively and consists primarily of heavily forested floodplains, upland forests, open grazing and rangeland, riverine wetlands, isolated wetlands and prairies, and some agricultural lands. Some rural communities and low density residential areas exist outside of the three cities. Thirty-five percent of the entire upper Hillsborough River watershed is agricultural land (most of which is pasture and rangeland), 23 percent is urban, 19 percent is wetlands, and 21 percent is a variety of uplands that are not developed (1999 land-use cover from the SWFWMD). Although land-use percentages in the four subbasins were similar, the Itchepackesassa and East Canal subbasins had the most urbanized land use, the Blackwater Creek subbasin had the most agricultural land use, and the Upper Hillsborough River and the Blackwater Creek subbasins had the most wetlands (table 1). Hillsborough County owns a parcel of land in the north-central part of the Blackwater Creek subbasin, commonly referred to as the Cone Ranch, that is the proposed site of a well field. The land currently is being leased for agricultural uses. In addition to the limerock mine located in the upper Hillsborough subbasin, a large phosphate processing facility is located about 0.5 mi north of Blackwater Creek (fig. 2).

Land-surface altitudes in the upper Hillsborough River watershed range from about 40 feet (ft) to greater than 200 ft above NGVD of 1929 (fig. 3). Parts of four physiographic provinces are located in the watershed: the Western Valley, the Brooksville Ridge, the Lakeland Ridge, and the Polk Uplands (White, 1970). The upper Hillsborough River flows southwesterly through the Western Valley toward the coast. Land-surface altitudes in the Western Valley range from about 40 ft to about 100 ft above NGVD of 1929. Much of the Hillsborough River flows through the part of the Western Valley referred to as the Zephyrhills Gap. This area contains karst features, poorly drained swamps and marshes in low areas, and flatwoods at the higher altitudes (Southwest Florida Water Management District, 1996). The Brooksville Ridge lies to the north and west of the Western Valley. Altitudes on the ridge range from 70 ft to greater than 200 ft. The topography is hilly due to karst features (Vernon, 1951), with land-surface altitudes varying over short distances. Depressional features and sinkholes are common. The smaller Lakeland Ridge lies to the southeast, with land-surfaces altitudes ranging from about 130 ft to greater than 200 ft above NGVD of 1929. The Polk Uplands borders the Western Valley on the south and east, with altitudes ranging from about 100 to 130 ft above NGVD of 1929 (fig. 3).

Climate in the area is subtropical and humid with an average annual temperature of 72 ^{o}F. The mean annual rainfall for the 30-year period from 1973 to 2002 was between 51.86 and 54.31 inches per year (in/yr), averaging about 53.00 in/yr for the entire watershed (data were compiled from the records of the National Oceanic and Atmospheric Administration (NOAA)). About 60 percent of all rainfall occurs during the

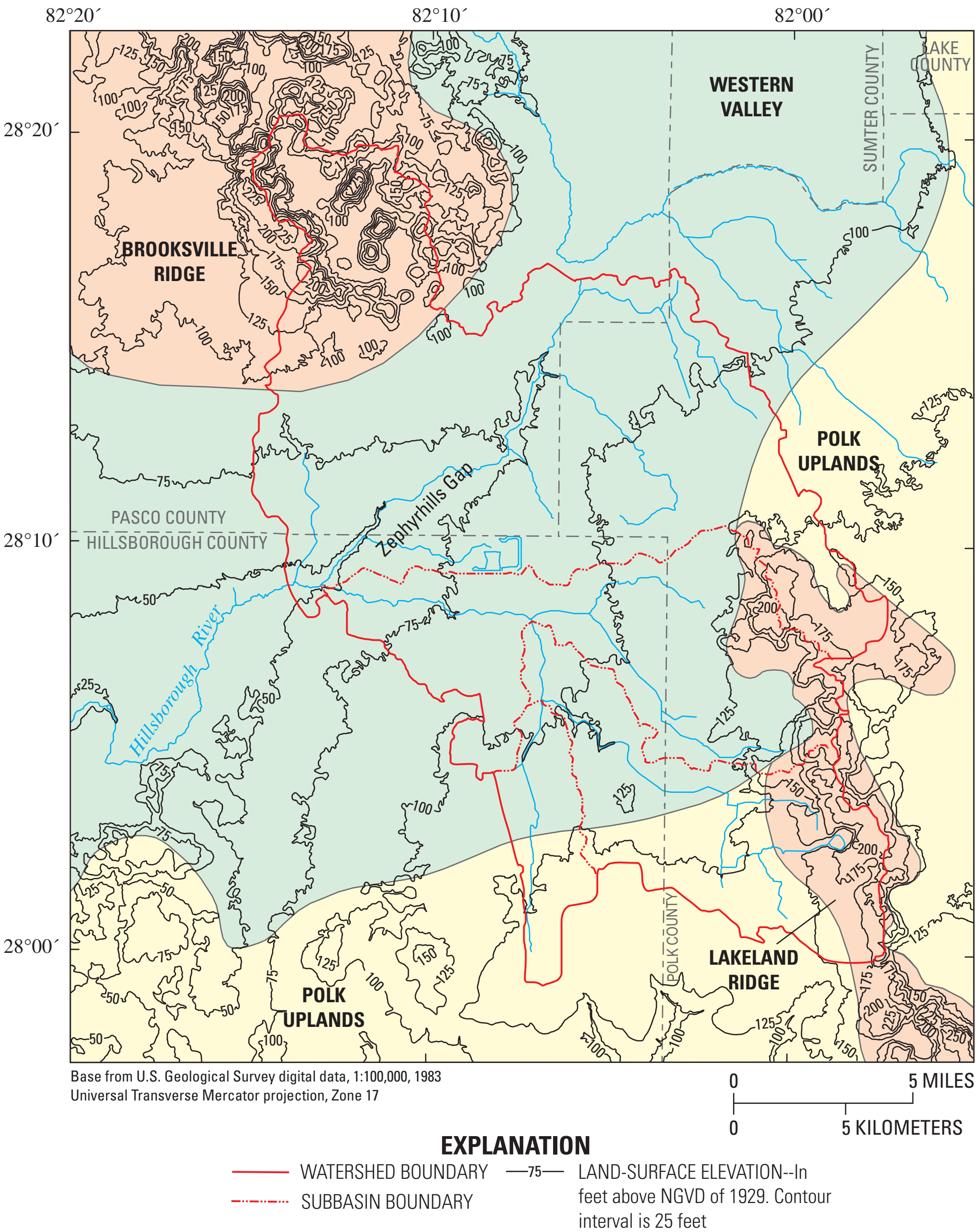


Figure 3. Physiography and topography in the upper Hillsborough River watershed (physiography from White, 1970).

Table 1. Land use in the upper Hillsborough River watershed and its subbasins.

[Percent land use, from digital orthophoto quarter quadrangles interpreted by the Southwest Florida Water Management District]

Basin	Percent land use (1999)				
	Urban	Agricultural	Uplands	Wetlands	Surface water
Upper Hillsborough River watershed	23	35	21	19	1
Itchepackesassa Creek subbasin	33	38	14	12	3
East Canal subbasin	32	39	15	12	2
Blackwater Creek subbasin	19	42	17	22	1
Upper Hillsborough River subbasin	21	30	26	22	1

wet season from June through September during intense, localized thunderstorms, as well as occasional tropical storms and hurricanes. Winter frontal storms account for most of the rainfall from December through March. Rainfall across the watershed for the 2000 water year (October 1, 1999 through September 30, 2000) averaged 42.50 inches (in.), 10.50 in. below the 30-year mean annual of 53.00 in. (table 2). For the 2001 water year, the rainfall average was 55.71 in., almost 3 in. above the 30-year mean annual, and for the 2002 water year, the rainfall average was 50.09 in., about 3 in. below the 30-year mean annual (table 2).

Dry season rainfall (October through May) was below average for each of the 3 water years. Dry season deficits ranged from 8 to 11 in. less than the 30-year mean for those months. The most severe deficit occurred during the 2000 dry season, and the least severe deficit occurred during the 2002 dry season. Wet season rainfall (June through September) was about normal for 2000, and above average for the 2001 and 2002 water years. Surpluses for the 2001 and 2002 wet seasons were about 12 and 5 in. above the 30-year mean for those months, respectively (fig. 4).

Table 2. Annual rainfall at NOAA stations in or near the upper Hillsborough River watershed, the annual watershed average for the 2000–2002 water years, and the 30-year mean annual.

[Rainfall values, in inches]

Water year[1]	Hillsborough River State Park	Plant City	Lakeland	Saint Leo	Watershed average
2000	36.91	47.11	40.52	45.47	42.50
2001	64.46	55.20	57.30	45.90	55.71
2002	46.36	48.88	50.82	54.31	50.09
30-year mean annual	53.91	51.93	51.86	54.30	53.00

[1] Water year is a 12-month period from October 1 through September 30.

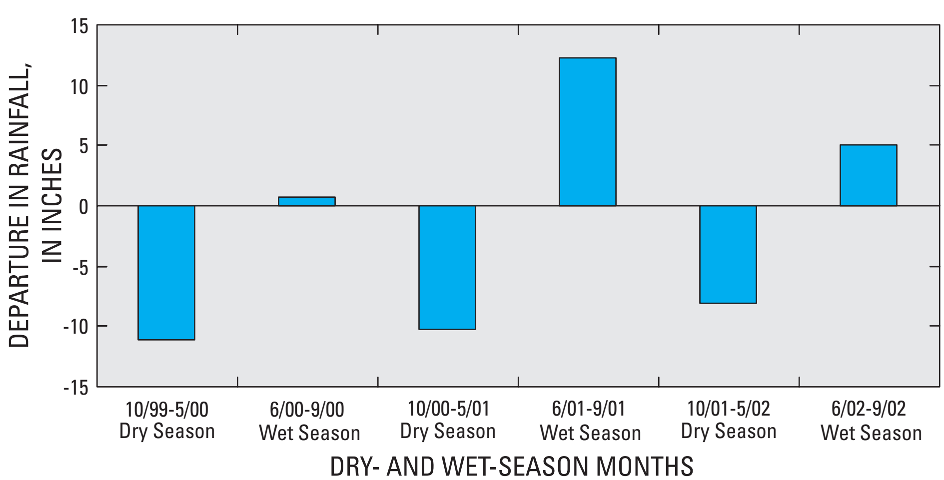


Figure 4. Departure from the 30-year mean annual rainfall for the dry (October through March) and wet (June through September) seasons in the upper Hillsborough River watershed, water years 2000–2002.

Data Collection and Methodology

Major components of data collection for the study included streamflow and ground-water level measurements, and surface- and ground-water sampling for water-quality analysis. Synoptic streamflow measurements during low-flow conditions, hydrograph separation, and numerical simulations were conducted to assess ground-water seepage to the river and its tributaries. Trends in ground-water levels and nutrients also were evaluated. Water-quality samples were collected and discharge was measured at numerous locations along the main stem of each stream.

Surface Water

Six continuous streamflow stations were operated in the watershed during the study (table 3 and fig. 2). Five of these sites were established prior to the study, and thus have historical data. The station at Itchepackesassa Creek near Moriczville (site 6, fig. 2) was established for this study to quantify streamflow to Blackwater Creek. Peak water-level altitudes and streamflow events were measured at one previously established partial record station (site 5, fig. 2). Miscellaneous streamflow measurements were made at six additional sites (fig. 2, table 3). Streamflow data from site 1 (table 3, fig. 2) was only used to estimate ground-water recharge using hydrograph separation methods. Data from sites 2, 7, and 8 (table 3, fig. 2) also were used for the hydrograph separation analysis. Discharge from Crystal Springs (site 3, fig. 2) to the Hillsborough River has been calculated since 1934, by subtracting measured streamflow in the river at locations upstream and downstream from the spring. Spring discharge cannot be calculated during high riverflow events when the Hillsborough River below Crystal Springs station (site 4, fig. 2) overflows shallow banks and inundates wide areas of the floodplain, thus eliminating an adequate measuring section. Because discharge records for Crystal

Table 3. Surface-water data-collection network used for this study.

[N/A, not applicable]

Map number (fig. 2)	USGS site identification number	Station name	Type of record	Period of record (water years [1])	Drainage area (square miles)	Water quality site number (fig. 6)
1	02301900	Fox Branch near Socrum	continuous [2]	1964-current	9.5	N/A
2	02301990	Hillsborough River above Crystal Springs near Zephyrhills	continuous [2]	1964-current	82	HR4
3	02302000	Crystal Springs at Crystal Springs	miscellaneous [3]	1933-current	N/A	N/A
4	02302010	Hillsborough River below Crystal Springs near Zephyrhills	continuous [2]	1994-current	undetermined	HR5
5	02302260	Itchepackesassa Creek at S-582 near Knights	partial [4]	1982-current	34	IC1
6	02302280	Itchepackesassa Creek near Moriczville	continuous [5]	2000-2002	57	IC2
7	02302500	Blackwater Creek near Knights	continuous [5]	1951-current	113	BWC2
8	02303000	Hillsborough River Near Zephyrhills	continuous [5,6]	1963-current	220	HR6
9	280430082071800	East Canal near Knights	miscellaneous [7]	2001-2002	13	EC1
10	280828082062900	Blackwater Creek transect trans near Knights	miscellaneous [7]	2001-2002	undetermined	BWC3
11	280858082124800	Blackwater Creek upstream of mouth near Zephyrhills	miscellaneous [7]	2001-2002	undetermined	BWC1
12	281135082095500	Hillsborough River at U.S. Hwy 39 transect site near Crystal Springs	miscellaneous [7]	2001-2002	undetermined	HR3
13	281205082080200	Hillsborough River at limerock mine near Zephyrhills	miscellaneous [7]	2001-2002	undetermined	HR2
14	281251082074900	Upper Hillsborough River tract transect site near Zephyrhills	miscellaneous [7]	2001-2002	undetermined	HR1

[1] Water year is a 12-month period from October 1 through September 30.

[2] Daily discharge station.

[3] Discharge is calculated from measured river discharge above and below the spring.

[4] Crest stage indicator station—discharge measured during periods of high flow.

[5] Daily discharge station; satellite telemetry site.

[6] Nonrecording gage prior to 1963.

[7] Miscellaneous water-quality samples and streamflow measurements collected at these sites.

Springs are periodic and lack flood stage data, comparing discharge data to continuous data from other springs can yield inaccurate results unless caution is used.

Ground Water

Water-level data from a network of 72 wells tapping the Upper Floridan aquifer were used to map the potentiometric surface of the Upper Floridan aquifer for dry (May) and wet (September) season conditions (fig. 5, and appendix 1). The network also included any transect wells drilled during this study (table 4). The potentiometric-surface maps developed for this study are more detailed than the regional potentiometric-surface maps produced for the same time periods.

Comparisons between heads in the surficial and Upper Floridan aquifers were made to evaluate the spatial and temporal patterns of recharge and discharge. Frequency of measurements varied at the sites: heads at paired wells on the Cone Ranch were monitored with continuous recorders by

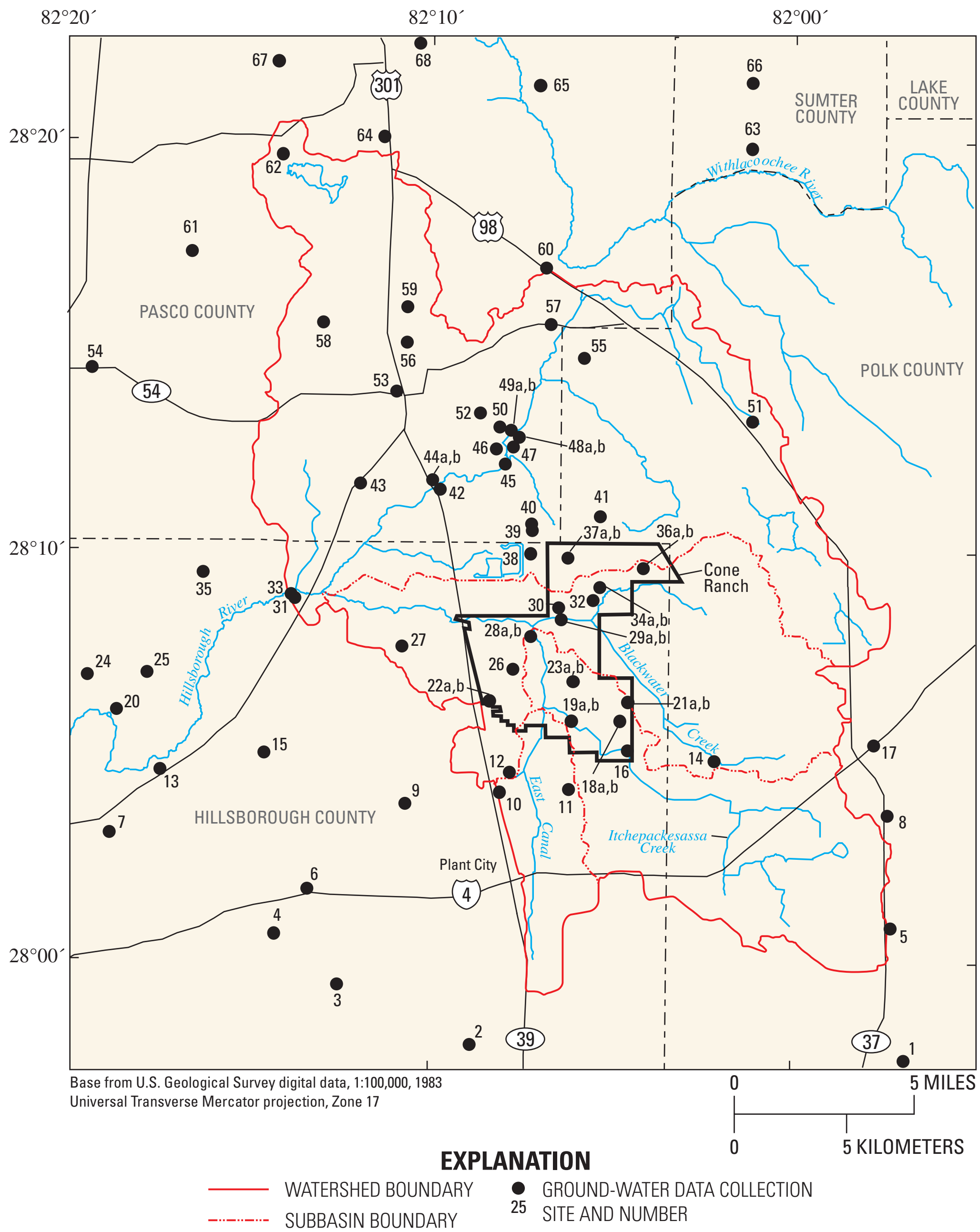


Figure 5. Location of the upper Hillsborough River watershed and the ground-water data-collection network (site identification number and name are given in app. 1).

Table 4. Ground-water transect wells used for this study.

USGS well site identification number	Well name	Depth of well below land surface (feet)	Depth of casing below land surface (feet)
Blackwater Creek Transect (T1)			
280821082062901	BWCT1UFAD (CM-4)	175	100
280821082062902	BWCT1SAS (CM-4)	6.0	1.0
280825082062901	BWCT2UFAS	26	23
280825082062902	BWCT2SAS	5.2	2.2
280828082062901	BWCT3UFAS	10.3	8.6
280828082062902	BWCT3SAS	5.6	4.5
280828082062903	BWCT3CR	2.1	1.0
280834082062901	BWCT4UFAS	8.9	4.9
280835082063101	BWCT5UFAS	16	12
280837082063101	BWCT6UFAD	91	43
Hillsborough River at State Road 39 Transect (T2)			
281130082095101	HRSR391UFAD	112	44
281130082095102	HRSR391UFAS	21	17
281133082095301	HRSR392UFAS	12	8.0
281136082095601	HRSR393So	9.8	5.8
281136082095602	HRSR393No	19	15
281136082095603	HRSR393CR	4.5	2.5
281141082100001	HRSR394UFAS	18	14
281143082100101	HRSR395UFAS	21	17
281144082100402	ROMP 86A Avon Park	560	500
281144082100401	ROMP 86A Suwannee	135	75
Upper Hillsborough River Tract Transect (T3)			
281247082074101	UHRT1UFAD	93	41
281247082074102	UHRT1SAS	5.2	3.2
281249082074501	UHRT2UFAS	19	15
281251082074901	UHRT3UFAS	24	20
281251082074902	UHRT3SAS	6.3	4.3
281251082074903	UHRT3CR	11	7.0
281253082075201	UHRT4UFAS	10	6.0
281257082075401	UHRT5UFAD	93	54
281257082075402	UHRT5SAS	5.2	3.2

Tampa Bay Water; heads at paired wells at three river sites were measured approximately monthly by USGS personnel (the Blackwater Creek transect, the Upper Hillsborough River transect, and Hillsborough River State Park); and at six additional sites, surficial aquifer heads and adjacent Upper Floridan aquifer heads were measured by USGS personnel semi-annually along with the regional potentiometric-surface map wells.

Three well transects were constructed to evaluate the ground-water component of flow in the streams (fig. 2; table 4). The first transect (T1) was located across Blackwater Creek on the Cone Ranch, upstream from the Blackwater Creek near Knights streamflow station (site 7, fig. 2). The second transect (T2) was located across the Hillsborough River at State Road 39, and the third transect (T3) was located across the Hillsborough River about 3.5 mi. upstream from T2, in the vicinity of the limerock mine (fig. 2; table 3). Each transect consisted of 9 or 10 wells arranged in a line perpendicular to the stream. A pair of deep and shallow wells was placed at each end of the transect to monitor head differences with depth. Shallow wells (less than 30 ft deep) were completed into the Tampa Member of the Arcadia

Formation or into the top of the Suwannee Limestone. Deep wells (greater than 90 ft deep) were completed into the lower part of the Suwannee Limestone. Surficial aquifer wells were installed where the aquifer was present or to verify the absence of the surficial aquifer (table 4). Where possible, transects were constructed using existing Upper Floridan aquifer wells. The SWFWMD Regional Observation and Monitoring Program (ROMP) 86.5 CM-4 surficial and Upper Floridan aquifer wells (fig. 2, appendix 1) were used at the T1 transect, and the ROMP 86A Suwannee and Avon Park wells were used at the T2 transect. Because no existing wells were available at the T3 transect site, the SWFWMD constructed two deep Upper Floridan aquifer wells. Additional Upper Floridan aquifer wells also were constructed by the SWFWMD at T1 and T2 to complete the transects. A reference point was established to measure stream stage and a well was installed into the streambed at each of the three transects to determine the gradient between stream stage and ground water beneath the stream. All wells and reference points were leveled to NGVD of 1929. Water-level data from the transect wells were collected monthly and used to construct hydrographs of ground-water heads and stream stage, and provide input to a cross-sectional flow-net model to calculate ground-water discharge to the streams. Hydrogeologic cross sections were constructed using data previously collected by the SWFWMD and from drilling and testing conducted as part of this study.

Ground- and Surface-Water Interaction

Synoptic streamflow measurements (seepage runs) were made along the main stem of the Hillsborough River and the three main tributaries, during 2- to 3-day periods of differing low-flow conditions to quantify streamflow gains or losses, and to evaluate areas of measureable interaction between the surface-water system and the underlying aquifer. An increase in streamflow at the downstream measurement not accounted for by tributary inflow was considered to be ground-water seepage. Likewise, a decrease in streamflow at the downstream measurement site was considered to be a loss from the stream to the ground-water system.

Seepage runs were conducted on May 1-2, 2001, and November 5-7, 2001, to coincide with low base-flow and high base-flow conditions, respectively. Fifty-two sites were evaluated for each of the seepage runs. A total of 42 streamflow measurements were made during the May seepage run, and 50 measurements were made during the November seepage run. Specific conductance also was measured at each site to provide insight into the source of the water. Flow was stable for the majority of the seepage runs, with flow decreasing slightly during the latter part of the November run. The slight change in flow was factored into the interpretation of the data. Because of the inherent potential for error with low-flow measurements, relatively small gains or losses were not always considered to indicate changes. When differences in streamflow between measuring sections were greater than 5 percent (Hortness and Vidmar, 2005), and the streamflow was greater than 0.5 cubic feet per second (ft^3/s), the gain or loss was considered statistically significant.

Hydrograph separation techniques were used to estimate the ground-water contribution to streamflow (base flow) from long-term streamflow stations. Within the upper Hillsborough River watershed, hydrograph separation methods were applied to data from four streamflow stations. The partition methodology documented by Rutledge (1998) was used for this analysis. The 1984-2002 period of record was evaluated because this was the longest period of record for which all streamgages had daily discharge data.

Numerical simulation also was used to estimate ground-water discharge to the streams at the three transect sites (fig. 2). Ground-water heads and stream stage, as well as hydraulic conductivity data from multiple aquifer tests conducted at and in the vicinity of each transect site, were used as input to the simulation models. Models were developed using the finite-difference ground-water flow simulation code MODFLOW (McDonald and Harbaugh, 1988; Harbaugh and McDonald, 1996). A two-dimensional, cross-sectional model was constructed for each transect with one row 10 ft wide to represent the y-direction along the stream, multiple columns representing the x-direction perpendicular to the stream, and multiple layers to represent the z-direction from land surface to depths within the Upper Floridan aquifer. A steady-state simulation was run for each set of water-level measurements taken on the same date if the stream was not dry.

Because hydraulic conductivity data were available for all transect models, the flow-net models were not calibrated. Standard statistics of residual water-level error (observed minus simulated), mean, and standard deviation were computed to evaluate how well the models fit the observed data. The mean and standard deviation were calculated by combining the residual errors for all steady-state simulations for each transect. Thus, if there were five observations and four steady-state simulations, 20 values were used to calculated the statistic reported for the transect.

A sensitivity analysis was conducted for each transect for one of the steady-state flow-net simulations by changing each hydraulic conductivity zone value as well as the riverbed hydraulic conductivity by multipliers of 0.5, 1, and 2, and reporting the change in flux to the stream. The estimated flux to the stream computed by the numerical models is considered most sensitive to the parameter that results in the greatest range of flux. A form of scaled sensitivity also was calculated to indicate the relative sensitivity of the simulated ground-water discharge to each parameter. The scaled sensitivity is computed by calculating the relative range in the change in flux for each parameter and then dividing each relative range by the relative range of the most sensitive parameter. Thus the most sensitive parameter will have a scaled value of 1.

$$RP_i = \left|0.5FluxP_i - 2FluxP_i\right| / (1FluxP_i) \qquad (1)$$

$$ScaledSensitivity = RP_i / RP_{max} \qquad (2)$$

where RP_i is the relative range in flux for one of the parameters, P_i; $0.5FluxP_i$ is the flux of the parameter when the parameter is multiplied by 0.5; $2FluxP_i$ is the flux of the parameter when the parameter is multiplied by 2; $1FluxP_i$ is the flux of the parameter when the parameter is multiplied by 1; and RP_{max} is the relative range of the most sensitive parameter.

Water Quality

Samples for water-quality analysis were collected from 12 surface-water sites, the outfall to Crystal Springs (table 3, fig. 6), and 14 Upper Floridan aquifer wells (appendix 1) in the upper Hillsborough River watershed. With the exception of Crystal Springs and the ROMP 86A Avon Park well, samples were collected at all sites around May and September of 2001 and 2002, corresponding to the dry and wet seasons, respectively. Crystal Springs outfall was sampled only once during the study because access to the spring vent was not allowed by the owner, and only one sample was collected from

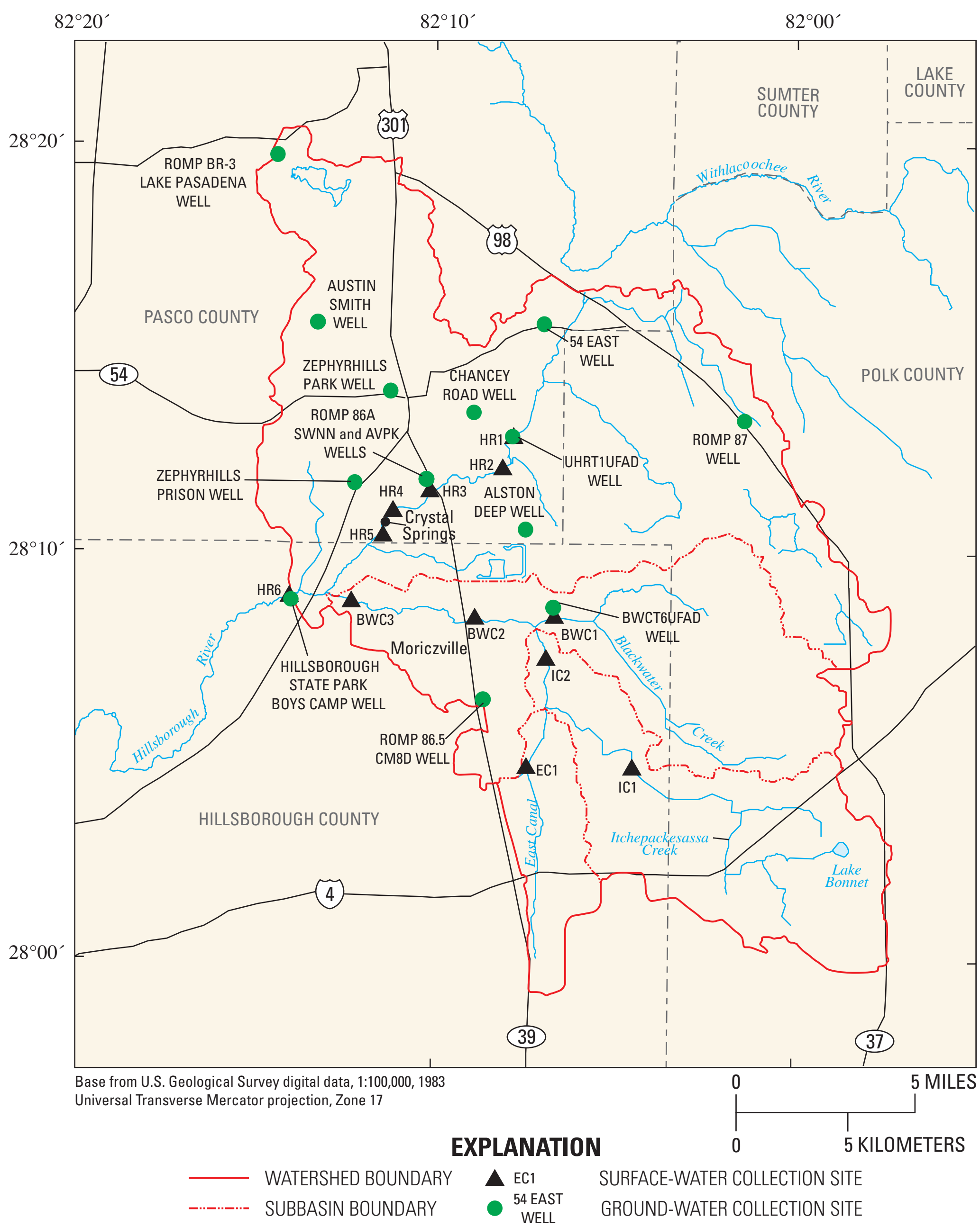


Figure 6. Location of the upper Hillsborough River watershed and the water-quality sampling sites.

the ROMP 86A Avon Park well, which was used to compare water from the deep and shallow parts of the Upper Floridan aquifer. Surface-water samples were collected more frequently at the transect sites and streamflow stations, and ground-water samples were collected more frequently at the three transect sites. All surface-water samples were depth and channel width integrated. Surface- and ground-water samples were collected using methods described in the USGS National Field Manual for the Collection of Water-quality Data (U.S. Geological Survey, variously dated). Specific conductance, temperature, pH, and dissolved oxygen were measured in the field. Samples were analyzed for total nutrients, dissolved major ions and trace metals, dissolved and total organic carbon, and ultraviolet (UV) absorbance at 254 nanometers (an estimate of the aromatic form of organic carbon). Surface-water samples also were analyzed for coliform bacteria by USGS personnel using the membrane filtration method. Selected samples were analyzed for pesticides, wastewater compounds, and stable isotopes of nitrogen, strontium and uranium ($^{15}N/^{14}N$, $^{87}Sr/^{86}Sr$, and $^{234}U/^{238}U$, respectively).

Nitrogen isotope ratios ($\delta^{15}N$) in nitrate were used to indicate the source of nitrogen in the surface and ground water. The $\delta^{15}N$ value is derived by comparing the ratio of ^{14}N to ^{15}N in a water sample against the ratio of a known sample (atmospheric nitrogen). Kreitler (1975) and Kreitler and others (1978) reported that $\delta^{15}N$ values greater than +10 per mil were indicative of animal sources, values ranging from -3 to +2 per mil were indicative of inorganic fertilizer sources, and values ranging from +2 to +8 per mil were indicative of organic soil nitrogen sources.

Strontium isotope ratios ($^{87}Sr/^{86}Sr$) in surface-water samples were compared to ratios from ground-water samples to gain insight about the source of the water in the streams. Strontium isotope ratios were used to identify the age of the rock that the ground water has been in contact with because $^{87}Sr/^{86}Sr$ ratios varied in seawater during the period of deposition for rocks in the study area (DePaolo and Ingram, 1985; Hess and others, 1986; Howarth and McArthur, 1997; Kendall, 1998).

Naturally occurring uranium concentrations and the corresponding activity ratios of uranium isotopes ($^{234}U/^{238}U$) were used to gain insight into the ground-water flow system interacting with the streams. Ground water from deep, slow moving parts of the Upper Floridan aquifer is characterized by uranium concentrations less than 0.1 µg/L and $^{234}U/^{238}U$ activity ratios appreciably greater than 1.0. Ground water from shallower, karst flow systems is characterized by uranium concentrations greater than 0.1 micrograms per liter (µg/L) and $^{234}U/^{238}U$ activity ratios less than 1.0 (Osmund and Cowart, 1976; Cowart and Osmund, 1992).

Nutrient concentration and continuous streamflow data were used to estimate nutrient loads and yields at four streamflow stations (stations 2, 6, 7, and 8; table 3). The load is the mass of a constituent transported by water during a specific time period. Linear regression techniques are commonly used to estimate mean daily loads. This method assumes a linear relation between the log transformed water-quality and streamflow data; however, the method has a bias toward underestimating the loads when transformed back to linear units. To remove this bias, the Minimum Variance Unbiased Estimator (MVUE) model was used. The model combines multiple linear regression techniques and a MVUE (Cohen and others, 1989) to calculate an adjusted daily mean constituent load for each month. Mean daily loads were then summed to calculate monthly and annual constituent loads. Nutrient yields were computed by normalizing previously estimated loads to the drainage area of each subbasin, and are commonly used to compare loading from subbasins of varying sizes. Annual yields were reported in pounds per square mile.

Trends in nutrient concentrations were evaluated at three stations with long-term discharge and water-quality data. Trends in the concentration of many water-quality constituents may be influenced by variables such as seasonality or streamflow. These variables may hide or falsely indicate the presence of a trend. To remove seasonal and streamflow effects from the trend analysis, the seasonal Kendall trend test on residuals calculated from the Locally Weighted Regression and Smoothing of Scatter Plots (LOWESS) technique was used to identify any statistically significant water-quality trends. The seasonal Kendall test accounts for seasonality by computing the Mann-Kendall test on each season separately, then combining the results (Helsel and Hirsch, 1995). For the purpose of this study, significance was based on a two-sided significance test (p value) equal to or less than 0.05, or a 95 percent or greater likelihood that the observed trend is real.

Hydrogeologic Framework

The upper Hillsborough River watershed is underlain by thick sequences of carbonate rock covered by thin surficial deposits of unconsolidated sand and sandy clay. The karst nature of the landscape in the watershed is due to irregular weathering of the limestone surface, illustrated by small, localized sinkholes, sinkhole lakes (primarily on the ridges), isolated circular wetlands, and coalescence of multiple sinkholes in wetlands and lakes. The principal hydrogeologic units within the watershed are the surficial aquifer, the intermediate confining unit, and the Upper Floridan aquifer (fig. 7).

The top of the surficial aquifer is contiguous with land surface, and the aquifer consists of unconsolidated clastic sediments of quartz sand, clayey sand, and organic debris that range in age from Holocene to Pliocene. Commonly this unit is referred to as the surficial aquifer system where more than one permeable unit is present or where the deposits are interbedded (Metz and Sacks, 2002). In this report, these deposits are considered to form a single aquifer referred to as the surficial aquifer, rather than a system. The thickness of the aquifer is variable; generally, surficial deposits are thinnest near the stream channels and thickest to the south and toward the ridges. Surficial deposits at the Cone Ranch are thickest

Series	Stratigraphic unit		General lithology	Hydrogeologic unit	
HOLOCENE TO PLIOCENE	UNDIFFERENTIATED SANDS AND CLAYS		Quartz sand, silty sand, clayey sand	SURFICIAL AQUIFER	
HOLOCENE TO PLIOCENE	HAWTHORN GROUP		Clay, minor quartz sand, phosphate, fine-grained dolomite, residual limestone	INTERMEDIATE CONFINING UNIT	
MIOCENE	HAWTHORN GROUP	TAMPA MEMBER OF THE ARCADIA FORMATION	Limestone, minor quartz sand, phosphate, chert, clay, fine-grained dolomite	UPPER FLORIDAN AQUIFER	TAMPA/SUWANNEE PRODUCING ZONE
OLIGOCENE	SUWANNEE LIMESTONE		Limestone, packstone to grainstone, trace quartz sand, organics, variable dolomite and clay content, highly fossiliferous, vuggy	UPPER FLORIDAN AQUIFER	TAMPA/SUWANNEE PRODUCING ZONE
EOCENE	OCALA LIMESTONE		Limestone, micritic, chalky, very fine- to fine-grained, soft, poorly indurated, trace organics, clays and dolomite, abundant foraminifera	UPPER FLORIDAN AQUIFER	OCALA SEMICONFINING UNIT; OCALA/AVON PARK PRODUCING ZONE
EOCENE	AVON PARK FORMATION		**Limestone, dolomite, and evaporites** Limestone and dolomite interbeds typical in upper part, deeper beds are continuous dolomite with increasing evaporites at base **Limestone** is fine-grained, tan, recrystallized packstone with variable amounts of organic-rich laminations near top **Dolomite** is hard, brown, sucrosic in texture and commonly fractured **Evaporites** occur in dolomite as interstitial gypsum and anhydrite with evaporite filling pore space and as interbeds in the lower part	UPPER FLORIDAN AQUIFER	AVON PARK PRODUCING ZONE
				MIDDLE CONFINING UNIT	

Figure 7. Generalized hydrostratigraphy for the study area (modified from Tihansky, 2005).

along the western and southern boundaries and thinnest near Blackwater Creek (fig. 2) (Thompson and others, 1998). At transect sites, surficial deposits are less than 5 ft thick near the stream channels, and thicken with distance away from the channels. A continuous surficial aquifer does not extend across the entire study area due to the variability of the underlying confining unit, but continuity is most likely to occur along the Brooksville Ridge (fig. 3) where low permeability clays of the Hawthorn Group (Scott, 1988) impede the downward movement of water (Champion and DeWitt, 2000).

Within the surficial aquifer, the occurrence of a water table is influenced by seasonal rainfall and the discontinuity of the underlying confining unit. When present, depth to the water table in the surficial aquifer ranges from land surface in wetland areas to greater than 15 ft below land surface along the Brooksville and Lakeland ridges (Southwest Florida Water Management District, 1996). During the dry season, some of the surficial aquifer wells in the study area were dry. During the wet season, these same wells contained water for only short periods of time following rainfall events, suggesting a direct hydraulic connection with the underlying Upper Floridan aquifer. The surficial aquifer is not a substantial source of supply in the upper Hillsborough River watershed. However, it does provide a source of water that flows to the streams, and recharges the Upper Floridan aquifer either by downward vertical leakage through the confining unit, or directly through breaches in the confining unit. Estimates of hydraulic conductivity for the surficial aquifer determined by the SWFWMD at 10 well sites on the Cone Ranch (fig. 2) ranged from 0.2 to 13 feet per day (ft/d), averaging about 5 ft/d (Thompson and others, 1998). Cherry and others (1970) reported hydraulic conductivity estimates for the surficial aquifer that ranged from 1.34×10^{-4} to about 28 ft/d for an area that includes the current study area. Estimates of hydraulic conductivity determined during this study at the three transect sites ranged from 0.6 to 5.3 ft/d, averaging about 2.8 ft/d.

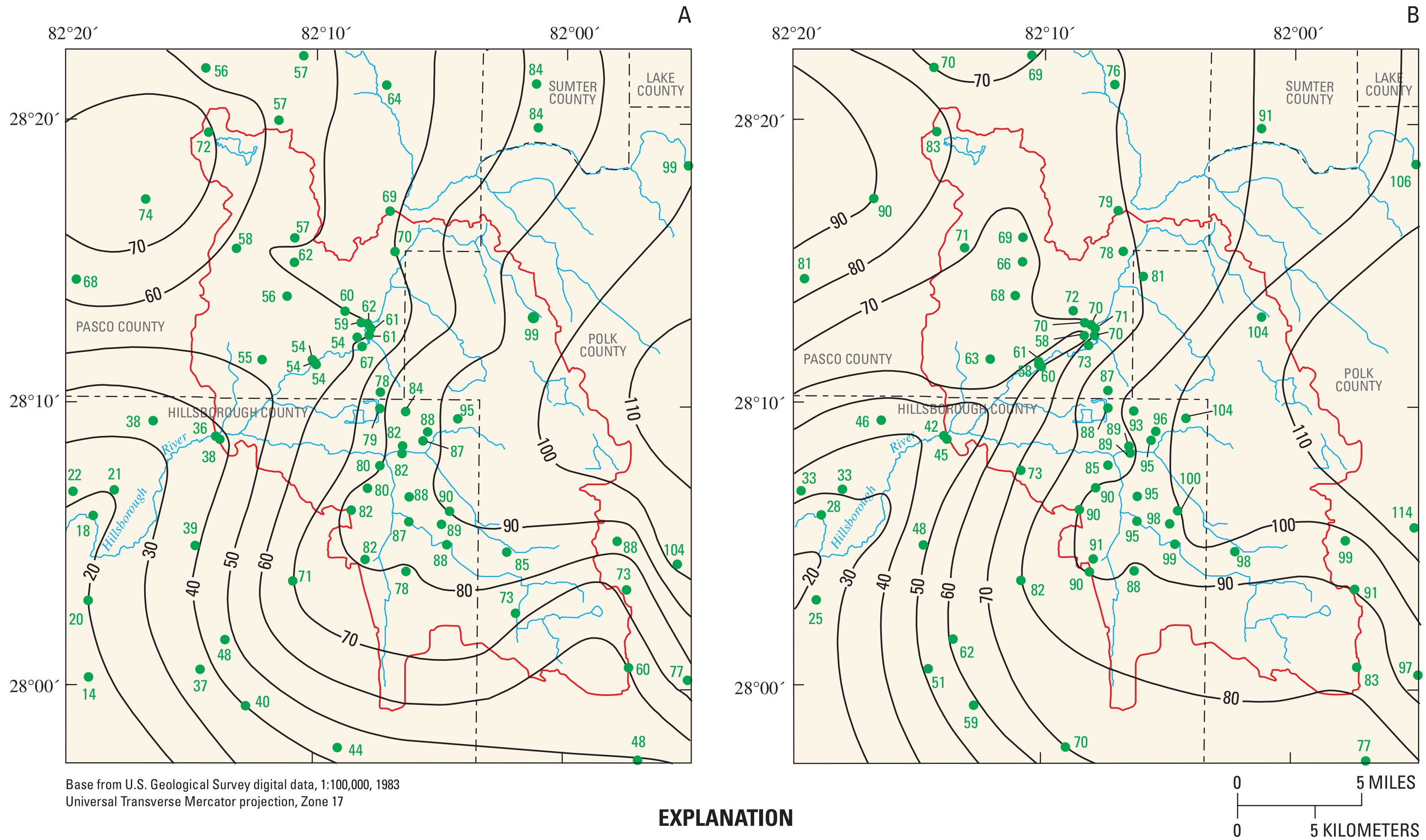
The intermediate confining unit underlies the surficial aquifer. This semiconfining layer consists of undifferentiated deposits of the upper portion of the Hawthorn Group (Scott, 1988), that include clay, chert, and carbonate mud that has been described as a residuum of the limestone in the underlying Tampa Member of the Arcadia Formation (Sinclair, 1974). The confining unit ranges from 0 to greater than 30 ft thick in the study area (Southwest Florida Water Management District, 1996); it is discontinuous near the Hillsborough River channel and along the middle and lower reaches of Blackwater Creek. Pitted and highly eroded limestone outcrops of the Tampa Member of the Arcadia Formation are present in the stream channel along these reaches. Clay outcrops also are present in the stream channel and along the banks. Estimates of vertical hydraulic conductivity of the intermediate confining unit made for this study ranged from 0.05 to 1.6 ft/d. The effective vertical hydraulic connection, however, between the surficial and Upper Floridan aquifers can be substantially greater due to many localized karst features.

The Upper Floridan aquifer underlies the intermediate confining unit. It is semiconfined throughout most of the study area due to the karst nature of the watershed, and is unconfined in the stream valleys where the intermediate confining unit is absent. The Upper Floridan aquifer is a regional aquifer consisting of multiple layers of continuous limestone and dolomite that range in age from Miocene to Eocene. The aquifer includes part of the Tampa Member of the Arcadia Formation, the Suwannee Limestone, the Ocala Limestone, and the Avon Park Formation. The limestone of the Tampa Member of the Arcadia Formation is the uppermost carbonate unit encountered in the study area, and is close to or at land surface, cropping out in some stream channels. Geologic logs from wells drilled during this study indicate that the Tampa Member of the Arcadia Formation is not present at all well sites. Observations at the limerock mine indicate the presence of a thin Tampa Member of the Arcadia Formation (Tom Scott, Florida Geological Survey, oral commun., 2002). Evaporites of gypsum and anhydrides infill the pore spaces in the lower part of the Avon Park Formation, reducing permeability and forming the lower boundary of the aquifer. This lower boundary is referred as the middle confining unit and separates the Upper Floridan aquifer from the underlying Lower Floridan aquifer. The Lower Floridan aquifer contains water with high chloride and sulfate concentrations and is not used as a source of water in this area.

Potentiometric-surface maps of the Upper Floridan aquifer were constructed for the dry and wet seasons (May and September, respectively) during the study period (2000-2002): two representative maps are shown in figure 8. The May 2001 map represents the lowest water levels observed during the study period, and the September 2002 map represents the highest observed levels. The pattern of the map contours was similar for all periods. The direction of flow in the Upper Floridan aquifer was generally to the west on the east side of the upper Hillsborough River. West of the river, the direction of ground-water flow was to the south and east toward the river from a potentiometric high (commonly referred to as the East Pasco High) located in the northwestern part of the study area. Aquifer interconnection is indicated by the hydraulic gradient toward streams, and potentiometric contours that bend upstream in the vicinity of the Hillsborough River on both wet and dry season maps. Similar contour patterns were not as evident near Blackwater or Itchepackesassa Creeks, indicating less connection between the Upper Floridan aquifer and these streams. The highest potentiometric heads for all periods were observed in the eastern part of the study area, and were greater than 100 ft above NGVD of 1929. A second potentiometric high (the East Pasco High), had heads ranging from 70 to 90 ft above NGVD of 1929 (fig. 8). The lowest heads were observed in the southwestern part of the study area. Changes in head values between wet and dry seasons at each well ranged from 7 to 29 ft during the study period. The greatest changes were observed in the southeastern part of the study area, along the Lakeland Ridge. The smallest changes were observed in the northeastern part of the study area near the Green Swamp.

Estimated transmissivity for the Upper Floridan aquifer at the ROMP 86.5 well sites on the Cone Ranch (fig. 2), ranged from 204 to 13,000 square feet per day (ft^2/d) (Thompson and others, 1998). Hydraulic conductivity at these well sites was estimated to range from 2.7 to 173 ft/d. The thickness of the aquifer tested was about 75 ft, and included the Tampa Member of the Arcadia Formation and the Suwannee and Ocala Limestones. The ROMP 86.5 wells did not penetrate the highly transmissive Avon Park Formation. Transmissivity values ranging from 22,000 to 53,400 ft^2/day were estimated at six additional test wells on the Cone Ranch that penetrated the Avon Park Formation (Thompson and others, 1998). Estimates of hydraulic conductivity determined for wells drilled during this study ranged from 2.0 to 10 ft/d for the Tampa Member of the Arcadia Formation; from 20 to 35 ft/d near the top of the Suwannee Limestone; and from 126 to 135 ft/d for the lower part of the Suwannee Limestone.

Vertical head differences between the surficial and Upper Floridan aquifers were used to evaluate the recharge and discharge potential and degree of confinement in the study area. Water-level altitudes and fluctuations were similar in the surficial and Upper Floridan aquifers at paired wells located at the T1 and T3 transects and at the ROMP 86.5 well sites (fig. 9, appendix 1) on the Cone Ranch, indicating good



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Universal Transverse Mercator projection, Zone 17

EXPLANATION

WATERSHED BOUNDARY

—70— POTENTIOMETRIC CONTOUR--Shows the altitude at which water would have stood in tightly cased wells. Contour is 10 feet. Datum is NGVD of 1929

● 59 OBSERVATION WELL--Number is the altitude of water level, in feet above the NGVD of 1929

Figure 8. Potentiometric surface of the Upper Floridan aquifer in the upper Hillsborough River watershed and adjacent areas, (A) May 2001 (dry) and (B) September 2002 (wet) (modified from Duerr, 2001 and 2003).

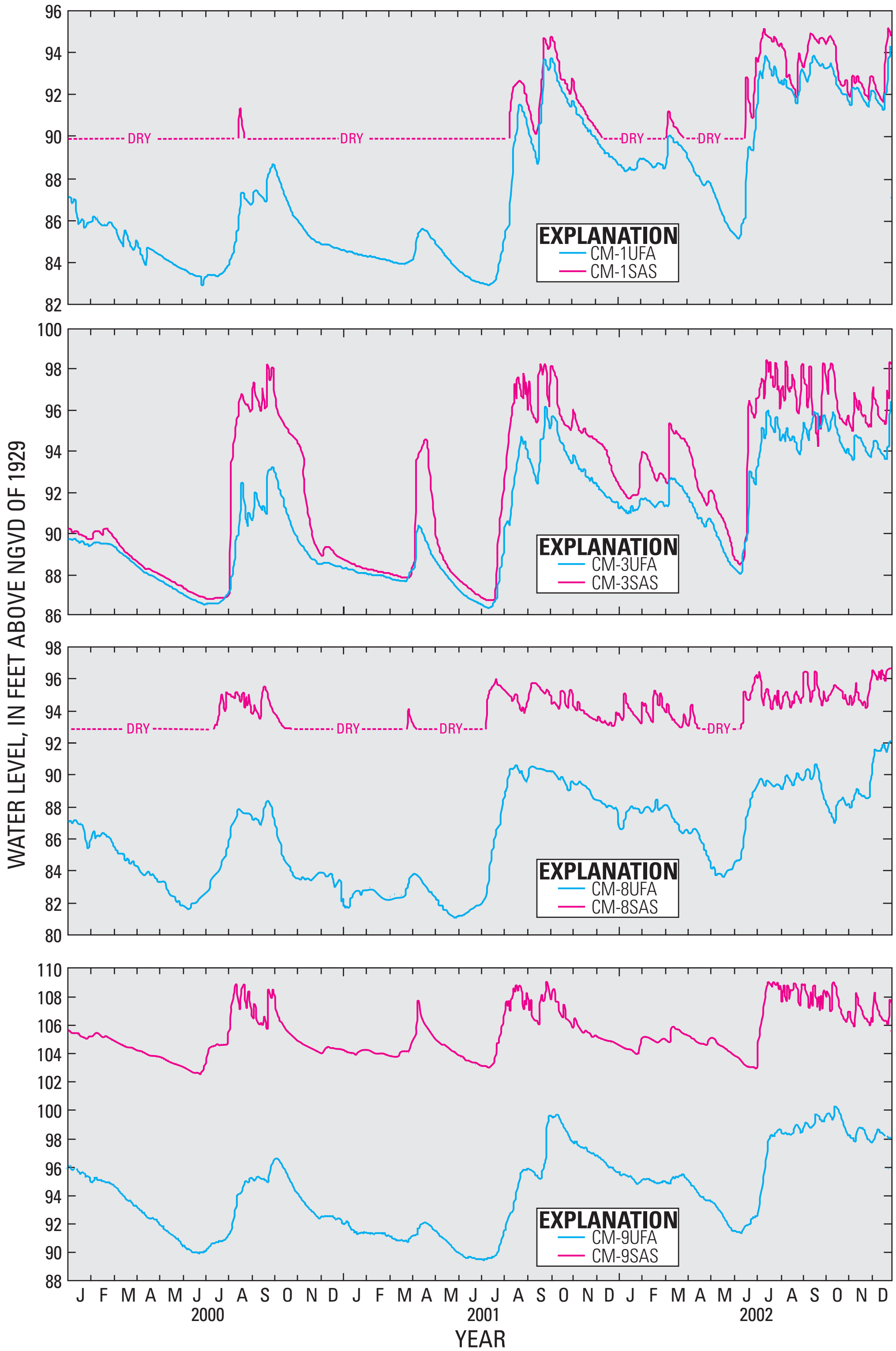


Figure 9. Comparison of water levels in the Upper Floridan and surficial aquifers at selected ROMP 86.5 well sites with continuous data, 2000–2002.

hydraulic connection. There is no surficial aquifer at the T2 transect. Water levels at the T1 and T3 transects and at some ROMP 86.5 well sites fell below the bottom of the surficial aquifer well during the dry season. When a water table was observed in the surficial aquifer, it was generally higher than the potentiometric surface of the Upper Floridan aquifer, indicating a potential for recharge to the underlying aquifer. Greater head differences indicate a greater degree of confinement between aquifers, and were observed at well sites in the southern part of the Cone Ranch and at the ROMP BR-3 well site on the Brooksville Ridge (site 62, fig. 5, appendix 1) where the intermediate confining unit is the thickest. Smaller head differences were observed in the northeastern part of the watershed where the confining unit is thin and discontinuous. Figure 9 illustrates the head differences between the surficial and Upper Floridan aquifers at four ROMP 86.5 well sites at the Cone Ranch. Even within the Cone Ranch, the degree of connection between the surficial and Upper Floridan aquifers varies greatly.

Ground-water development has affected ground-water levels in the watershed; however, natural variation in rainfall must also be considered in evaluating water-level trends. Ground-water level data were examined at three Upper Floridan aquifer wells in or near the study area that had about 40 years of continous record. Declining trends were observed at all three sites (site 6, 25 and 40, fig. 5 and 10, and appendix 1). Site 6 is located near Plant City and is likely affected by large agricultural withdrawals. Site 25 is located in the middle of a wellfield where pumping affects ground-water levels in the area. The remaining site (site 40) was located within the watershed, and showed only a slight declining trend, which was probably related to local conditions. Double mass analysis (Searcy and Hardison, 1960) of cumulative water level data did not indicate any changes to the slope, thus, the trends appear consistent over the entire period of record. Data from 11 of 12 monitoring wells in the upper Hillsborough River watershed recently analyzed by the SWFWMD staff, however, did not indicate statistically significant declining trends between 1975 and 2005 (Ron Basso, Southwest Florida Water Management District, written commun., 2007). Using data from three long-term rainfall stations in the Hillsborough River watershed, Weber and Perry (2001) determined that no statistically significant equivalent trend in rainfall had occurred over the period of record, and attribute declining ground-water levels to anthropogenic factors. Major increases in ground-water withdrawals for public supply within the Hillsborough River watershed occurred between 1970 and 1980, from about 3 (Mgal/d) to about 65 Mgal/d. Ground-water withdrawals for public supply within the Hillsborough River watershed have remained about the same, averaging about 71 Mgal/d between 2001 and 2005 (Ron Basso, Southwest Florida Water Management District, written commun., 2007).

Subsequent analysis of rainfall by the SWFWMD staff also indicated there has been no statistically significant change in annual rainfall over the last century. When the record was partitioned into shorter intervals, however, several cycles of above and below average rainfall were evident

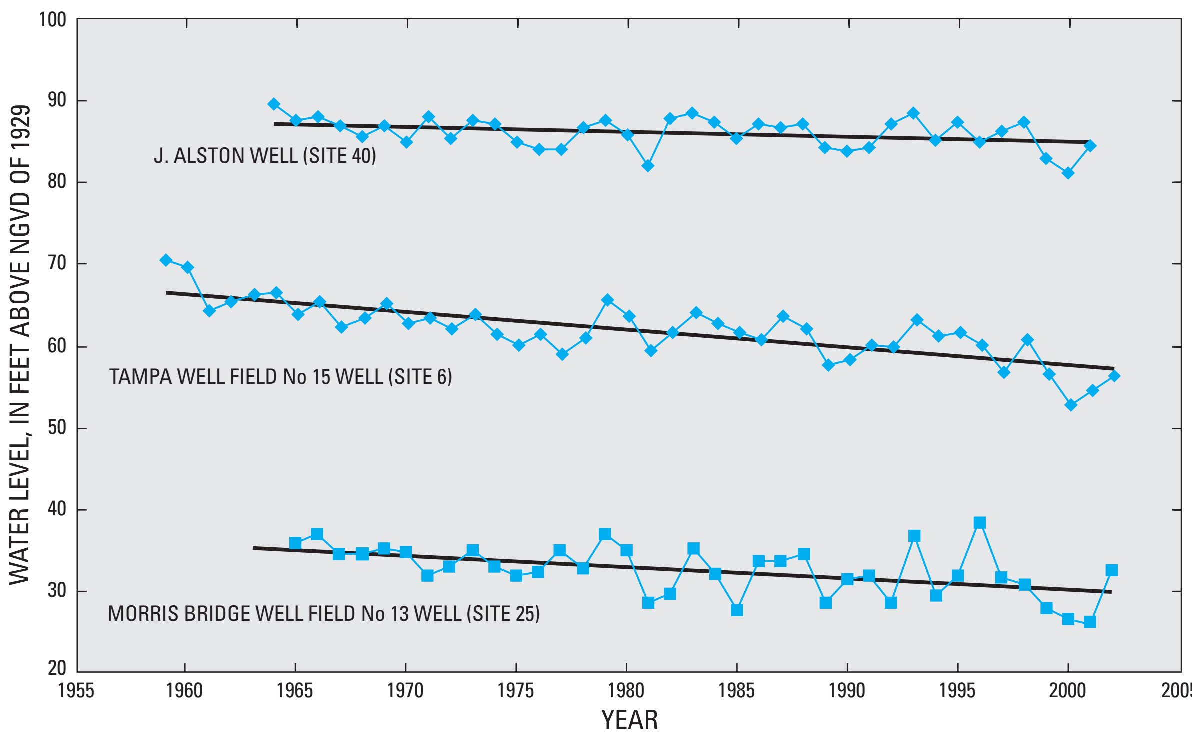


Figure 10. Trends in mean annual ground-water levels at three well sites with long-term data (site locations are shown in fig. 5 and described in app. 1)

(Basso and Shultz, 2003). The period between 1940 and 1969 was wetter than the period between 1970 and 1999. A study by Enfield and others (2001) also found differences in pre- and post-1970 rainfall. This time period is similar to the natural variation in North Atlantic sea surface temperature cycles that occurs every 20 to 50 years, referred to by Kerr (2000) as the Atlantic Multidecadal Oscillation (AMO). Kelley (2004) examined rainfall in relation to the AMO and river flows, and determined that some trends previously assumed to be anthropogenic may be explained more easily as natural step trends related to the AMO.

Ground-Water Geochemistry

Fifty-three ground-water samples were collected from the 13 Upper Floridan aquifer wells (fig. 6) completed into the Suwannee Limestone. An additional sample was collected from a well completed into the Avon Park Formation well (ROMP 86A Avon Park) to compare deep Upper Floridan aquifer water to water from the shallower part of the aquifer. Wells sampled during this study are listed in appendix 1.

Water from all Upper Floridan aquifer wells was a calcium-bicarbonate type, with calcium (Ca) being the dominant cation. Although the general ground-water composition was similar among wells, specific conductance values ranged from about 300 to 600 microSiemens per centimeter (µS/cm), with a median value of 413 µS/cm. Differences in specific conductance partly reflect differences in calcium concentrations, which varied from 48 to 110 milligrams per liter (mg/L).

Nitrate (NO_3) concentrations were near or below the detection limit of 0.01 mg/L as N in all ground water sampled for this study, except for samples from the Zephyrhills Park and Austin Smith wells (fig. 6). Nitrate concentrations in samples from the Zephyrhills Park well were about 2 mg/L as N, and dissolved oxygen (DO) concentrations were greater than 4 mg/L (aerobic), which is higher than DO concentrations in samples from other wells. A nitrogen isotope analysis ($\delta^{15}N$ of 8.8 per mil) of water from this well indicates the source of the nitrate is a mix between organic and inorganic nitrogen (Kreitler, 1975). Water from the Austin Smith well had a median nitrate concentration of 0.48 mg/L as N. Median wet and dry season concentrations were about 0.32 and 0.68 mg/L as N, respectively. The nitrogen isotope analysis indicates the nitrate concentration in water from this well is from an animal source ($\delta^{15}N$ of 42.6 per mil). This well is adjacent to agricultural operations that may be the source of the organic nitrogen. Potassium, sulfate, and chloride concentrations were elevated in the ground water at this site, which also suggests the influence of a waste source.

Deep and shallow ground waters have different chemical and isotopic characteristics because of different residence times and types of rock the water interacts with. The depth of most wells sampled ranged from 74 to 246 ft, corresponding to the Suwannee Limestone. The ROMP 86A Avon Park well is 560 ft deep and is completed in the Avon Park Formation. Water from this deeper well had greater concentrations of sulfate, strontium, and magnesium than water from the shallower Upper Floridan aquifer wells sampled, characteristic of deeper ground water that has dissolved dolomite and trace evaporites (Jones and others, 1993; Sacks and Tihansky, 1996).

Water from the ROMP 86A Avon Park well had a $^{87}Sr/^{86}Sr$ ratio of 0.70778, which is within with the range of values for Eocene-age seawater (Hess and others, 1986; Howarth and McArthur, 1997), and consistent with the age of the Avon Park Formation. In contrast, the ROMP 86A Suwannee well had a $^{87}Sr/^{86}Sr$ ratio of 0.70811, which is within the range of values for Oligocene-age seawater, and consistent with the age of the Suwannee Limestone. Strontium isotope ratios in samples from the remaining wells were all within the range of values for Oligocene-age seawater. The BWCT6UFAD transect well and the UHRT1UFAD transect well had higher strontium and magnesium concentrations, and lower $^{87}Sr/^{86}Sr$ ratios than would be expected for their depth. Although both wells are less than 100 ft deep, the shallow ground water in the area of these wells may be influenced by the upward movement of deeper water. Both wells are adjacent to streams where upward head gradients have been measured between shallow and deep parts of the Upper Floridan aquifer.

Seasonal variation in water chemistry in the transect wells was examined to evaluate whether ground water at the sites was influenced by stream water. Dissolved organic carbon (DOC) is a good indicator of the influence of surface water on ground water (Katz and others, 1998) because DOC concentrations can be more than an order of magnitude greater in streams than in ground water. At the Blackwater Creek (T1) and the Hillsborough River at State Road 39 (T2) transects, ground-water DOC concentrations showed little seasonal variation. At the Upper Hillsborough River Tract transect (T3), however, DOC concentrations were greater than 5 mg/L during the wet season and less than 3 mg/L during the dry season. Calcium concentrations and alkalinity increased along with DOC in the ground water during the wet season. If ground water mixing with the river water occurred, it would be expected that calcium concentrations would decrease when DOC increased because calcium concentrations in river water were lower during runoff periods. The higher calcium concentrations in the ground water indicate greater limestone dissolution. The higher DOC concentrations in ground water during the wet season are likely a result of local recharge through the extensive wetlands in the upper part of the upper Hillsborough River watershed rather than flow from the river. Water levels in the surficial deposits and in the river are higher than heads in the Upper Floridan aquifer during much of the wet season at this site, increasing the probability of local recharge. During the dry season, ground-water levels are lower and the wetlands and surficial deposits are dry, making the influence of regional ground water on water quality more apparent.

Samples from the Suwannee and Avon Park wells at ROMP 86A were analyzed for uranium isotopes to characterize ground water in various parts of the watershed and to compare with surface-water isotope ratios. Ground water from the ROMP 86A Suwannee and Avon Park wells had $^{234}U/^{238}U$ activity ratios of 1.82. and 0.94, respectively. Samples from both wells contained low uranium concentrations that were less than 0.10 μg/L, although the sample from the shallower well contained a higher concentration (0.093 μg/L) than the sample from the deeper well (0.038 μg/L). The low uranium concentration and the high isotope activity ratio for the shallow ground water is consistent with deep, anoxic, slow moving ground water. Water from the deep well, however, had a slightly lower uranium activity ratio, implying that it may intersect a faster moving flow zone. The deep Avon Park well is probably completed into a fractured zone. Many high-yielding production wells in west-central Florida are completed into fractured dolomite in the Avon Park Formation (Ryder, 1985; Tihansky, 2005).

Surface-Water Hydrology

Continuous stage data were collected at five gaging stations in the upper Hillsborough River watershed during the study period to estimate streamflow. An additional station located at Fox Branch (station 1; fig 2) was used only for the hydrograph separation analysis. Fox Branch is a tributary of the Hillsborough River, and streamflow from this station was included in downstream estimates. Three continuous stations were located on the upper Hillsborough River (stations 2, 4, and 8; fig. 2), one on Blackwater Creek (station 7; fig. 2), and one on Itchepackesassa Creek (station 6; fig. 2).

Streamflow

Streamflow was observed at the Hillsborough River stations during the entire study period. During dry periods, streamflow was sustained by ground water from the underlying Upper Floridan aquifer (fig. 11). During wet periods, streamflow was influenced by runoff, storage and release of water from the extensive riverine wetlands in the headwater area, and by overflow from the Withlacoochee River (fig. 2).

In contrast, streamflow in Blackwater and Itchepackesassa Creeks was less constant than at the upper Hillsborough River stations, with many no-flow days occurring during dry periods (fig. 11). During wet periods, water flowed from swampy areas along the base of the Lakeland Ridge to the main channel of Blackwater Creek through many small intermittent ditches and tributaries. Itckepackesassa Creek originates at the outfall from Lake Bonnet, which is located at the base of the Lakeland Ridge (figs. 2 and 3). Streamflow peaks occur more rapidly than those observed at the Hillsborough River stations because of greater confinement between surficial deposits and the Upper Floridan aquifer, and because surficial deposits in the area have a fairly low hydraulic conductivity, about 5 ft/d (Thompson and others, 1998). Additionally, Blackwater and Itchepackesassa Creeks have been highly channelized, leaving less of the adjacent wetlands intact. During much of the dry season, Blackwater Creek is dry upstream from the confluence with Itchepackesassa Creek, and all downstream flow in Blackwater Creek is from Itchepackesassa Creek. Much of the dry season flow in Itchepackesassa Creek originates from a treated wastewater effluent outfall located on East Canal—a tributary to Itchepackesassa Creek (fig. 2).

During the dry season, flow at the downstream Blackwater Creek station is often less than at the Itchepackesassa Creek station, indicating a loss of streamflow to underlying sediments. Between February 2000 and September 2002, a total of 91 no-flow days was recorded at the Blackwater Creek station and only 36 no-flow days were recorded at the Itchepackesassa Creek station. The longest consecutive period of no flow recorded at the Blackwater Creek station was 43 days, occurring during the extended drought in May and June 2000. Only 8 no-flow days were recorded at the Itchepackesassa Creek station during 2000. The longest consecutive period of no flow recorded at the Itchepackesassa Creek station was 27 days, occurring the following year during May and June 2001. A total of 32 no-flow days was recorded at the Blackwater Creek station during 2001. Rainfall was below normal during the 2000 and 2001 dry seasons.

Streamflow at the Hillsborough River above Crystal Springs and Hillsborough River below Crystal Springs stations (fig. 2; stations 2 and 4) and the Blackwater and Itchepackesassa Creek stations (fig. 2; stations 7 and 6) was compared with streamflow at the downstream Hillsborough River near Zephyrhills station (fig. 2; station 8) for the 2000 to 2002 water years (fig. 11). The Zephyrhills station is located at Hillsborough River State Park, where the river exits the study area. Hydrographs showing flow at the two upstream stations generally were subdued reflections of the hydrograph at the downstream station, with the exception of the very wet periods (fig. 11). Increase in streamflow at the Hillsborough River stations was minimal in response to individual storm events during the dry season, because much of the precipitation was stored in riverine and isolated wetlands. Streamflow at the Hillsborough River below Crystal Springs station (station 4) was even less responsive to storm events during the dry season because streamflow is dominated by discharge from Crystal Springs (fig. 11a). During dry periods, discharge from Crystal Springs and other adjacent smaller springs constituted between 85 and 100 percent of the downstream river flow, illustrating the importance of ground-water discharge in sustaining Hillsborough River flow. During the wet seasons, river flow at the downstream station was dominated by runoff and flow from wetland areas and Blackwater and Itchepackesassa Creeks.

In contrast, the hydrographs for the Blackwater and Itchepackesassa Creek stations did not reflect of the hydrograph for the downstream Hillsborough River at Zephyrhills station. Peaks and recessions were more rapid and extreme (fig. 11b). During the wet season, peaks were not as great and recession periods were longer at the upper Hillsborough River

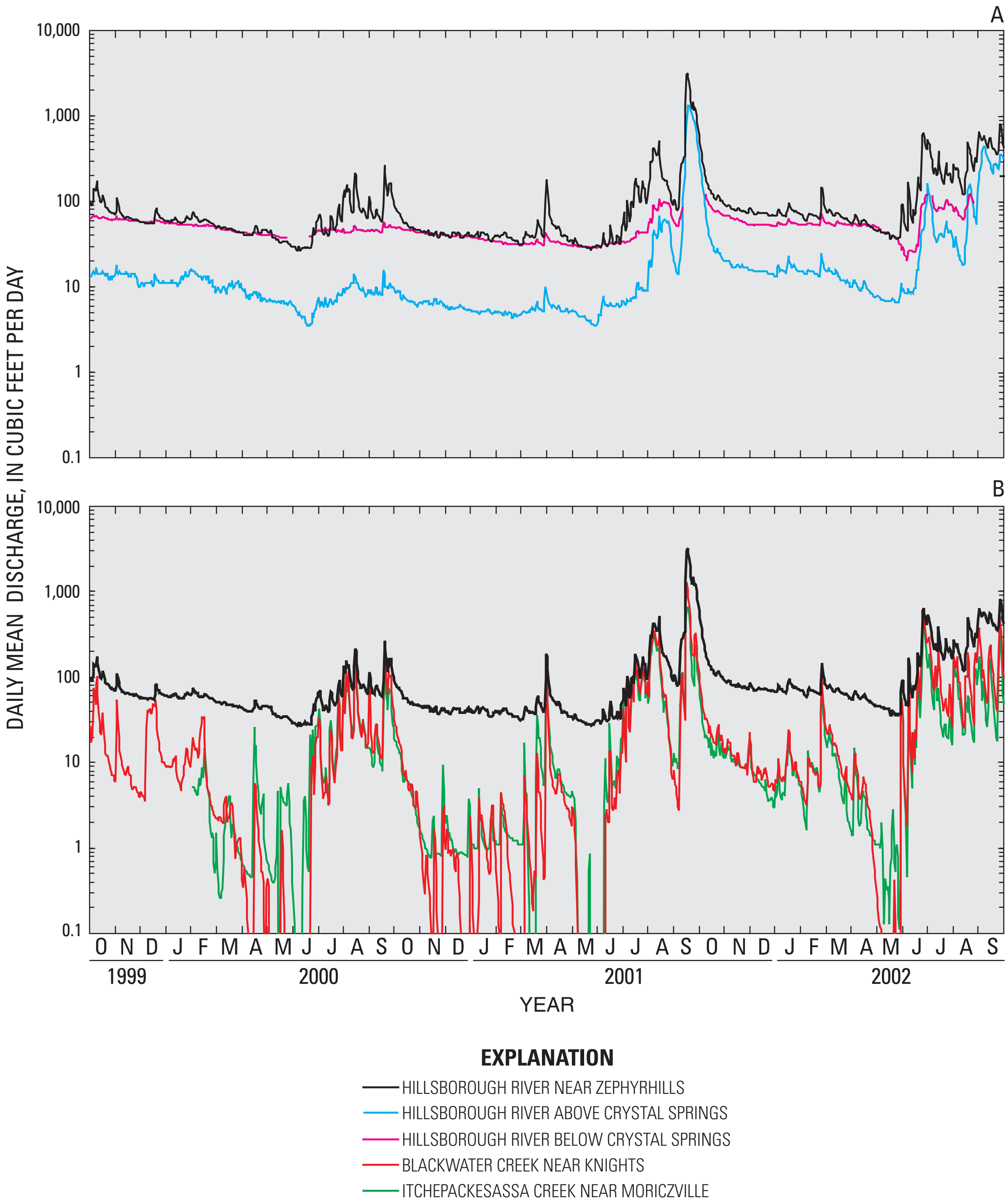


Figure 11. Daily mean discharge at the (A) Hillsborough River stations and at the (B) Blackwater and Itchepackesassa Creek stations, water years 2000–2002 (site locations are shown on fig. 2 and described in table 3).

stations than at the Blackwater and Itchepackesassa Creek stations because of the storage and subsequent release of water from the adjacent wetlands.

Differences in streamflow at the five continuous-record stations in response to a large storm event are illustrated by the observed streamflow resulting from the passage of tropical storm Gabrielle in mid September 2001. Maximum peak flow at the Hillsborough River above Crystal Springs station (station 2) was 1,340 ft^3/s on September 17, 2001. The duration of the high streamflow event lasted about 18 days. In contrast, the peak flows at the Blackwater (station 7) and Itchepackesassa (station 6) Creek stations were 1,320 and 664 ft^3/s, respectively. Peaks occurred on September 16, 2001, at station 6 and on September 15, 2001, at station 7. The duration of the streamflow event at these stations was 11 days—about 7 days shorter than at the Hillsborough River above Crystal Springs station. Streamflow at the Hillsborough River near Zephyrhills station was a composite of all the stations, peaking at 3,200 ft^3/s on September 16, 2001, with a duration of 18 days.

Flow Duration

Discharge-duration curves are cumulative frequency curves that show the percentage of time that the daily mean discharge of a stream equals or exceeds a given value during a specific time period. The shape of the curve reflects the characteristics of the watershed upstream from the station. A flatter slope indicates flood plain storage, whereas a steeper slope indicates less storage (Searcy, 1959). Duration curves were developed for the period of record at the Hillsborough River near Zephyrhills (1940–2002), Hillsborough River above Crystal Springs station (1952–2002), and the Blackwater Creek near Knights station (1984–2002) (fig. 12a). Duration curves also were calculated for the study period at these stations (fig. 12b) to compare current and long-term historical flow characteristics.

Duration curves developed for the period of record are flatter for the Hillsborough River sites than for Blackwater Creek (fig 12a). The low end of the curve also is flat, never reaching zero flow. Ground-water discharge, and the storage and release of water from many riverine wetlands in the headwaters and along the flood plain, have a stabilizing effect on flow in the Hillsborough River. The curve for Blackwater Creek is steeper at its lower end, indicating less ground-water and storage influence on streamflow at this station, which also is demonstrated by no-flow days that occur throughout the record. Duration curves developed for the Hillsborough River sites for the study period (2000 to 2002) are similar in shape and slope to duration curves calculated for the period of record, also indicating stable and constant flow at the Hillsborough River stations. The slope of the curve for the Blackwater Creek station for the study period is steeper, declining more rapidly at its lower end than for the entire period of record. Conditions in the watershed during the study period were drier than normal, resulting in relatively low ground-water levels and many no-flow days at the station.

Long-term discharge rates at a given exceedance level for the Hillsborough River near Zephyrhills station were about double the discharge rates for the same exceedance level during the study period, across the range of exceedance levels, with the exception of extreme low-flow conditions (near the 100 percent equaled or exceeded level), which were similar for both periods (fig. 12). Similarly, long-term discharge rates at the Hillsborough River above Crystal Springs station were about 40 to 60 percent greater than discharge rates for the same exceedance level during the study period, again with the exception of extreme low-flow conditions. Long-term discharge rates at the Blackwater Creek station were between 40 and 100 percent greater than study-period discharge rates across the entire range of exceedance levels.

Analysis of the mean daily streamflow data over time also was performed using the double-mass curve technique. Cumulative daily streamflow data were plotted against cumulative time data. A resulting straight line indicates that data are proportional, and that the slope represents the proportionality of the variables. A change in slope of the resulting line indicates a change in the proportionality of the variables, and the time at which the change occurred (Searcy and Hardison, 1960). Data were examined at the Hillsborough River near Zephyrhills, Blackwater Creek near Knights, and Crystal Springs stations. A change in slope is evident around 1969 for the Hillsborough River near Zephyrhills station. Analysis of data from Crystal Springs indicated multiple changes in the slope of the line occur over the period of record. The first change occurs around 1945 and may be attributable to the dynamiting of the spring vent and subsequent damming of the spring run to create a recreational area (Weber and Perry, 2001). The second change coincides with the 1969 change observed in the Hillsborough River at Zephyrhills station data, and a third change occurs around 1991. Similar slope changes at 1945 and 1991 were not evident on the plot for the Hillsborough River at Zephyrhills station. Weber and Perry (2001) attributed the declining trends in streamflow and spring discharge to anthropogenic factors. The 1969 slope change coincides with the wetter pre- and drier post-1970 rainfall cycles related to the AMO (Enfield and others, 2001).

Enfield and others (2001), Basso and Schultz (2003), and Kelley (2004) have examined rainfall and streamflow in Florida rivers in relation to the AMO and found them to be directly correlated. Kelley's (2004) analysis of river flow throughout Florida determined that some trends that had been assumed to be anthropogenic were more easily explained as a natural step trend related to the AMO. Recent analysis of discharge from Crystal Springs by the SWFWMD indicates a smaller anthropogenic effect than determined by previous analyses (Ron Basso, Southwest Florida Water Management District, written commun., 2007). Anthropogenic factors probably affected the hydrologic system in the watershed; however, natural variation in rainfall must also be considered when evaluating long-term streamflow trends.

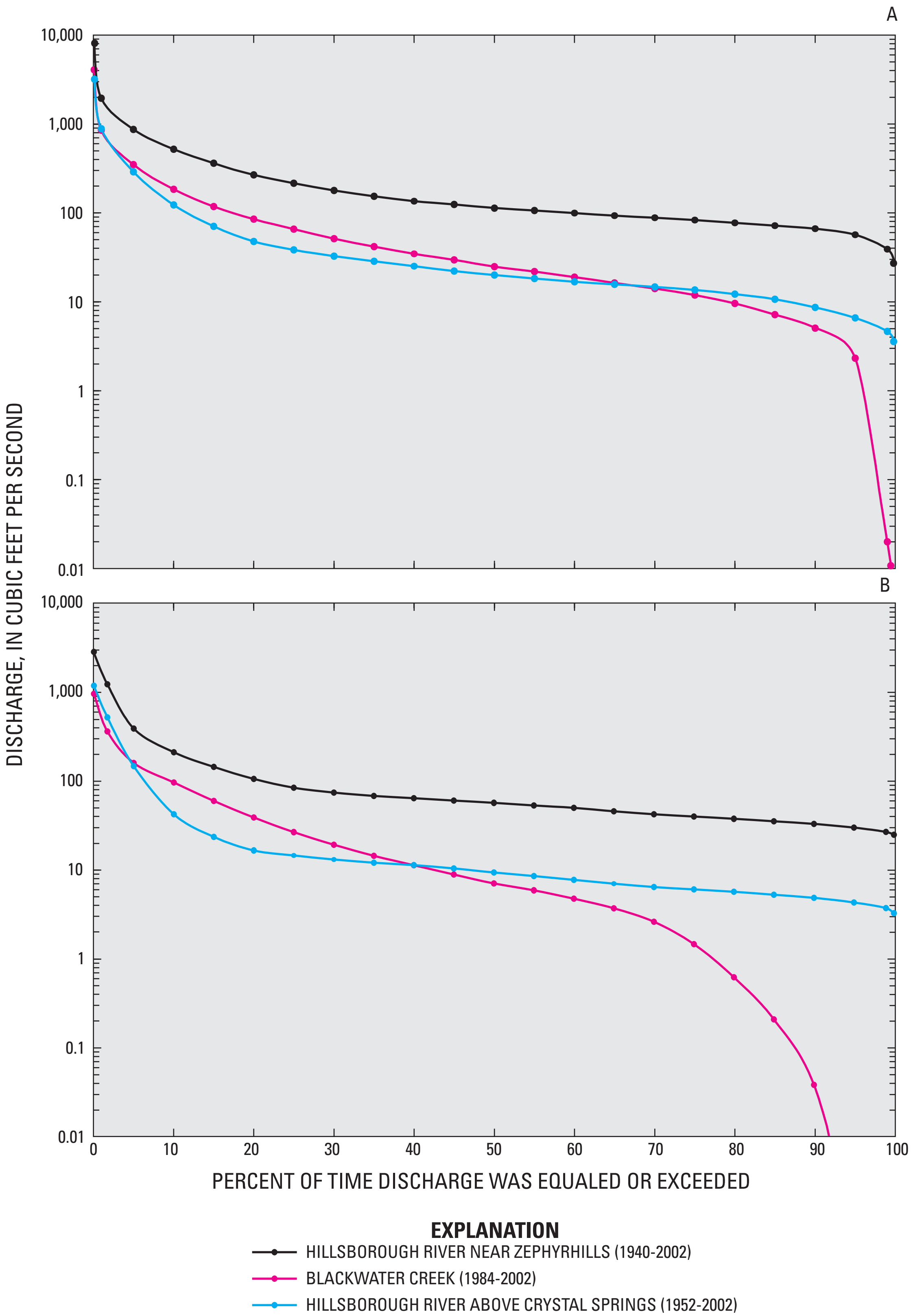


Figure 12. Duration curves of the daily mean discharge at the Hillsborough River near Zephyrhills, Hillsborough River above Crystal Springs, and Blackwater Creek near Knights, stations for (A) the period of record and (B) study period (2000–2002).

Surface-Water Quality

Samples were collected to characterize the water quality in the upper Hillsborough River watershed and to evaluate the spatial and temporal factors influencing streamflow such as ground-water discharge and runoff. Isotope data were used to gain insight into the ground-water flow system and the sources of nutrients. Nutrient data from long-term gaging stations were used to determine trends over time and to compute loads from the subbasins. Streams also were sampled to evaluate the presence of compounds that currently are being considered as emerging contaminants or wastewater components. Appendix 2 presents a summary of selected water-quality data collected at the surface-water sites during the study period. These data, as well as historical data from the long-term stations, have been published in the annual Water-Data Reports for the year the samples were collected and are stored in the USGS NWIS database. Data can be accessed from the Internet at *http://waterdata.usgs.gov/nwis*.

The water quality of streams in the study area is influenced by ground-water discharge. Calcium was the dominant ion in samples collected at six sites along the upper Hillsborough River (fig. 6), indicative of ground-water discharge. Calcium concentrations ranged from 18 to 88 mg/L, with a median concentration of 61 mg/L. Lower concentrations of calcium were observed during the wet season, when stormwater runoff is the larger component of streamflow. Higher concentrations were observed during the dry season when ground water is the larger component of streamflow. The median calcium concentrations for wet and dry seasons were 40 and 64 mg/L, respectively. Samples from the ROMP 86A Suwannee well (located at the T2 transect site) were used to compare the chemical signature of Upper Floridan aquifer water near the river to samples collected from the river. The median concentration of calcium of samples collected from the well was 75 mg/L, similar to dry season river water. The similarity of the water chemistry of the samples from the river and the well is shown in figure 13.

In contrast, the chemical composition of water from Blackwater Creek, Itchepackesassa Creek, and East Canal was more variable. Specific conductance and concentrations of major ions, most notably sodium, potassium, chloride, and sulfate, were greater compared to the upper Hillsborough River. The effect of wastewater from East Canal was apparent on the downstream water quality in Itchepackesassa and Blackwater Creeks, which had elevated concentrations of these constituents compared to the upstream reaches that were not affected by flow from East Canal (site IC1 and BWC1, fig. 6; fig. 14). Similar to the Hillsborough River, water in the unaffected reaches of Itchepackesassa and Blackwater Creeks also was dominated by calcium. Median concentration of calcium in samples from Blackwater Creek was 33 mg/L for the wet season, and 56 mg/L for the dry season. Similarly, median concentrations of calcium in samples from Itchepackesassa Creek was 29 mg/L for the wet season, and 56 mg/L for the dry season. Seeps and small Upper Floridan aquifer springs were observed during this study at the lower edge of the creek banks along Blackwater Creek. Similar seeps or springs probably exist along the banks of Itchepackesassa Creek, but were not observed during the study period, and are probably the reason that calcium concentrations were similar in both creeks. Calcium concentrations in samples from these creeks were less than in water from the Hillsborough River sites, indicating less ground-water discharge.

At most sites, specific conductance and calcium, magnesium, alkalinity, and silica concentrations were negatively correlated with streamflow. These constituents are all chemical indicators of ground-water discharge. The only site that did not have significant correlations between streamflow and these ground-water indicators was the IC2 site (fig. 6), probably because of the strong influence of the wastewater on stream chemistry during periods of low flow. Chloride, sodium, and potassium concentrations were greater at the IC1 site than at the BWC1 and Hillsborough River sites (fig. 14), and silica concentrations were less, indicating less ground-water discharge and more runoff occurs at this site.

Organic carbon concentrations (total and dissolved) were greater in samples collected during the wet season than the dry season for all sites because of runoff from adjacent wetland areas. A greater seasonal fluctuation in DOC was observed in water from the Hillsborough River sites than from the Blackwater and Itchepackesassa Creek sites (fig. 15). The median concentration for the six Hillsborough River sites was about 30 mg/L for the wet season, and 2 mg/L for the dry season. During the wet season, inundated areas adjacent to the streams are considerably larger in the upper Hillsborough River subbasin than in the Blackwater and Itchepackesassa Creek subbasins (Lewelling, 2004), resulting in higher DOC concentrations in river water. DOC concentrations in the upper Hillsborough River declined substantially as wetland runoff ceased and streamflow approached base-flow conditions, indicating that the majority of base flow was from ground-water source with a low DOC concentration. DOC concentrations decreased in a downstream direction from median values of about 31 to 13 mg/L for the wet season, and from about 3 to 1 mg/L for the dry season between site HR1 and HR5 (fig. 6), a further indication of ground-water inflow. An increase in both wet and dry season median DOC concentrations (to about 20 and 2.2 mg/L, respectively) occurred between site HR5 and HR6 (fig. 6). This increase is a result of surface-water inflow from Blackwater and Itchepackesassa Creeks. The median DOC concentrations for the Blackwater and Itchepackesassa Creek sites were about 24 and 19 mg/L, respectively, for the wet season, and about 9 and 11 mg/L, respectively, for the dry season. Greater dry season DOC concentrations in water from Blackwater and Itchepackesassa Creeks, compared with the upper Hillsborough River sites, was probably due to upstream surface water (Bonnet Lake) and wastewater from East Canal.

Concentrations of many trace metals were greater in water from Blackwater and Itchepackesassa Creeks than in water from the upper Hillsborough River, particularly during

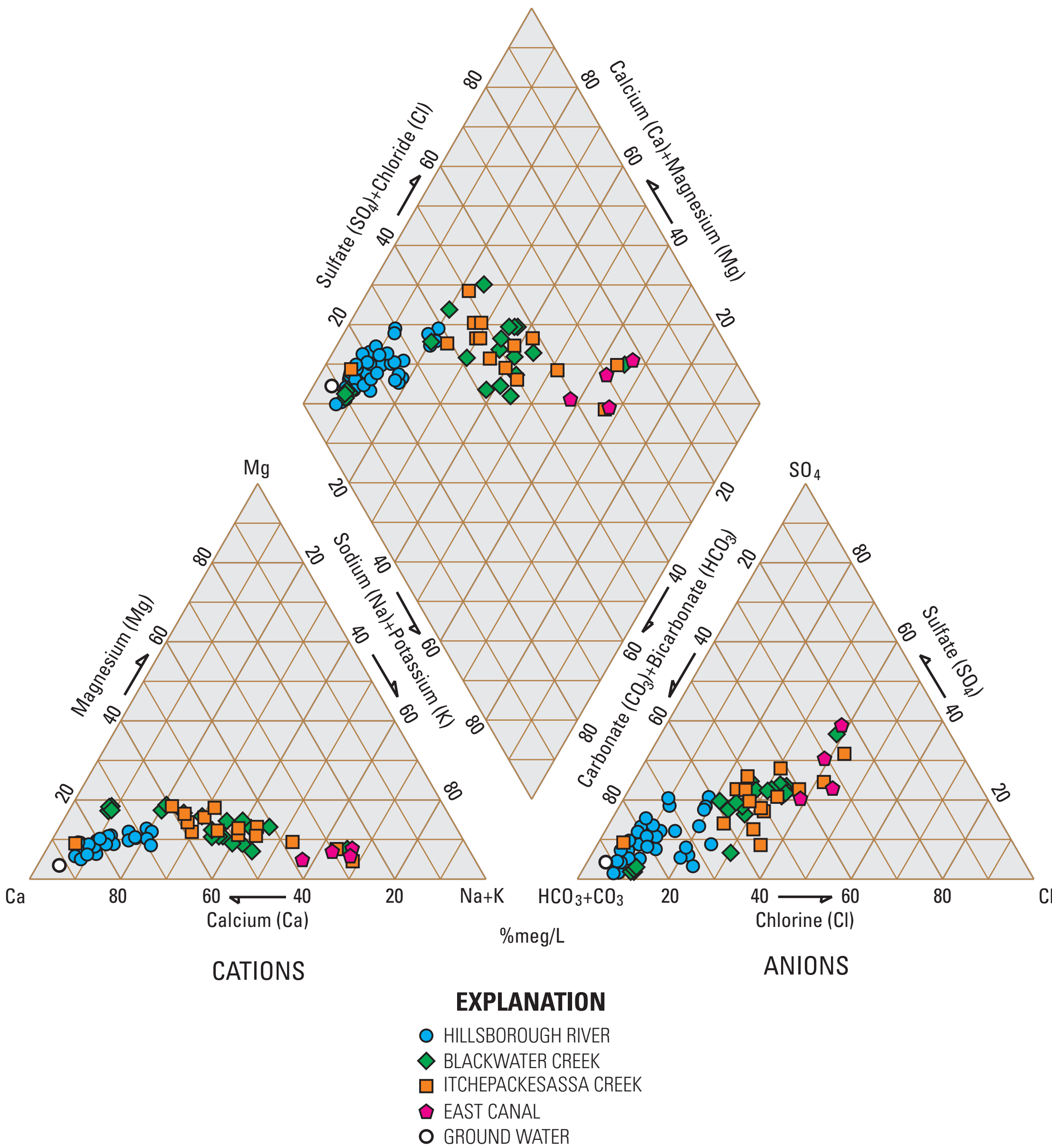


Figure 13. Water chemistry at the twelve surface-water sites, and one Upper Floridan aquifer ground-water reference sample in the upper Hillsborough River watershed, 2000 -2002.

the dry season when DOC concentrations were higher in the creeks than in the river (fig. 15). Many trace metals had distinct seasonal fluctuations in the river, with lower concentrations occurring in the dry season when DOC concentrations also were lower. The trace metals aluminum (Al), copper (Cu), iron (Fe), lead (Pb), and zinc (Zn) were positively correlated with DOC, and are likely mobilized by complexing with the organic acids. Aluminum, iron, and lead concentrations were positively correlated with streamflow, indicating a surface or shallow source for these metals.

Strontium concentrations in surface water are highly correlated with ground-water sources and are inversely correlated with streamflow. In contrast to other trace metals, strontium concentrations in the streams were greater in the dry season than in the wet season (fig. 15). During base-flow conditions, strontium concentrations increased in the Hillsborough River in the downstream direction, ranging from about 150 µg/L at HR1 to more than 300 µg/L at HR6, further indicating that ground-water discharge to the river is the primary source of water (fig. 16). Strontium also increased

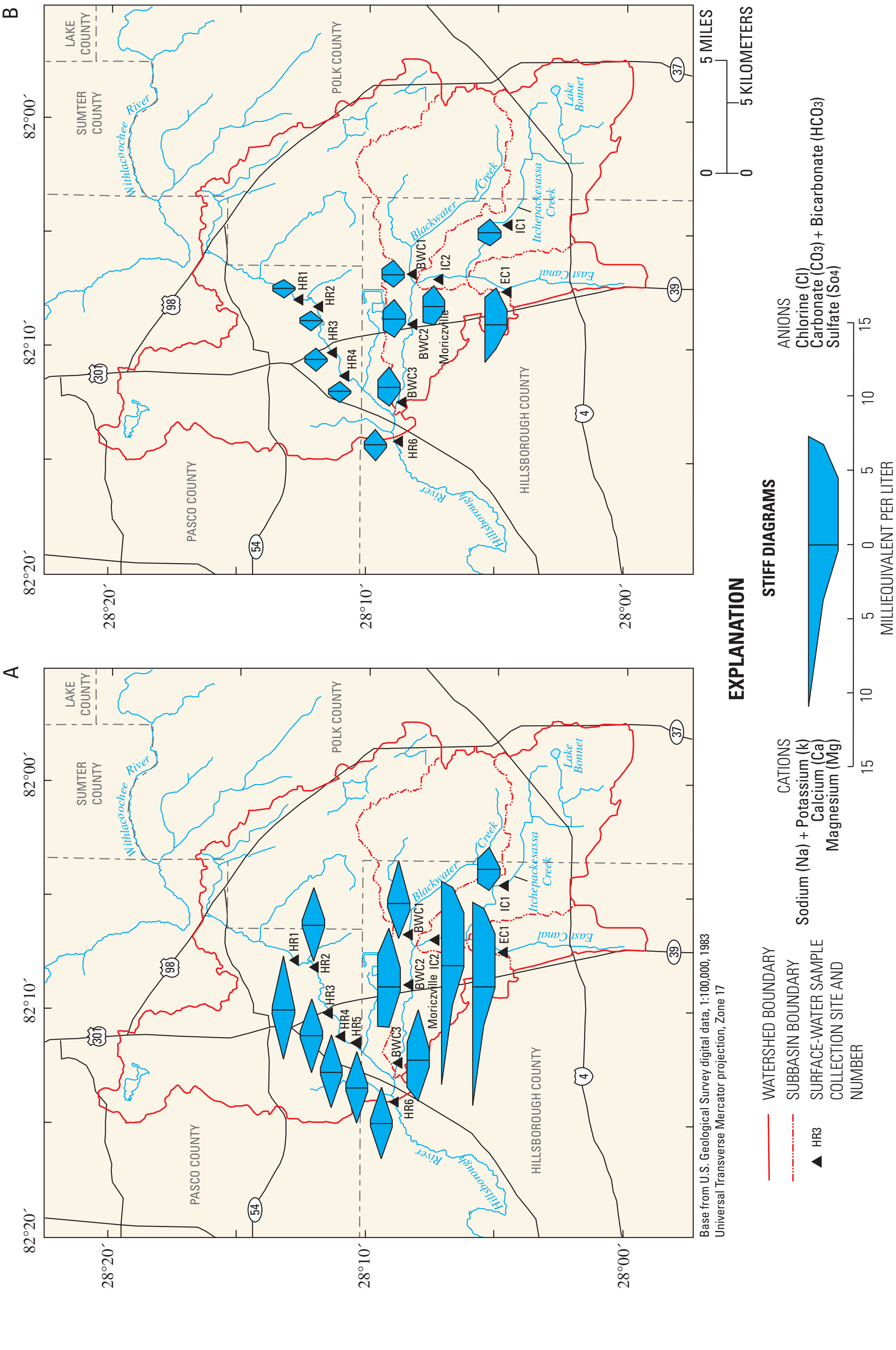


Figure 14. Distribution of water chemistry at the twelve surface-water sites in the upper Hillsborough River watershed, (A) May and (B) September 2002.

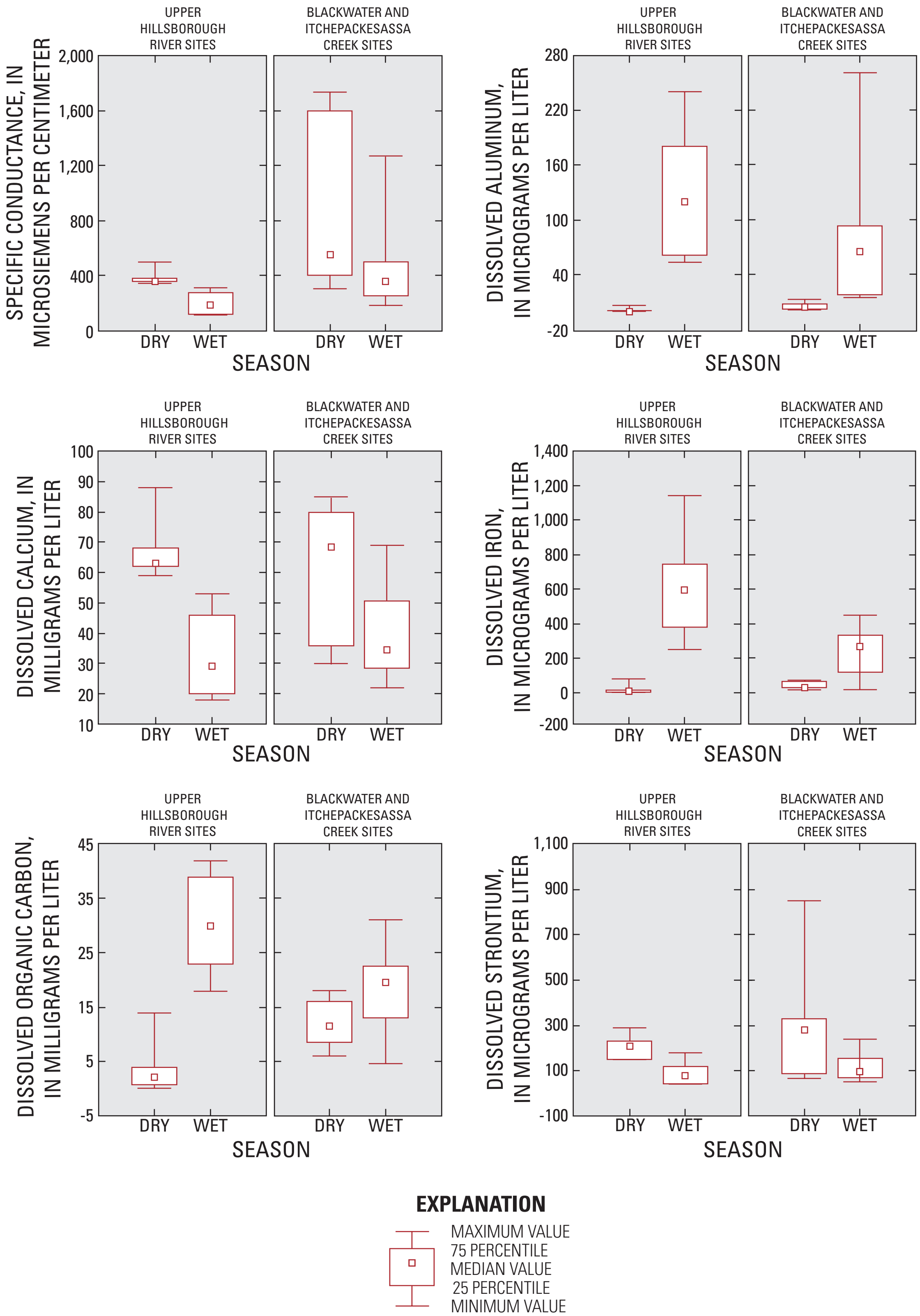


Figure 15. Selected constituent concentrations in water at the upper Hillsborough River sites and at the Blackwater and Itchepackesassa Creek sites during the dry and wet seasons, 2001–2002.

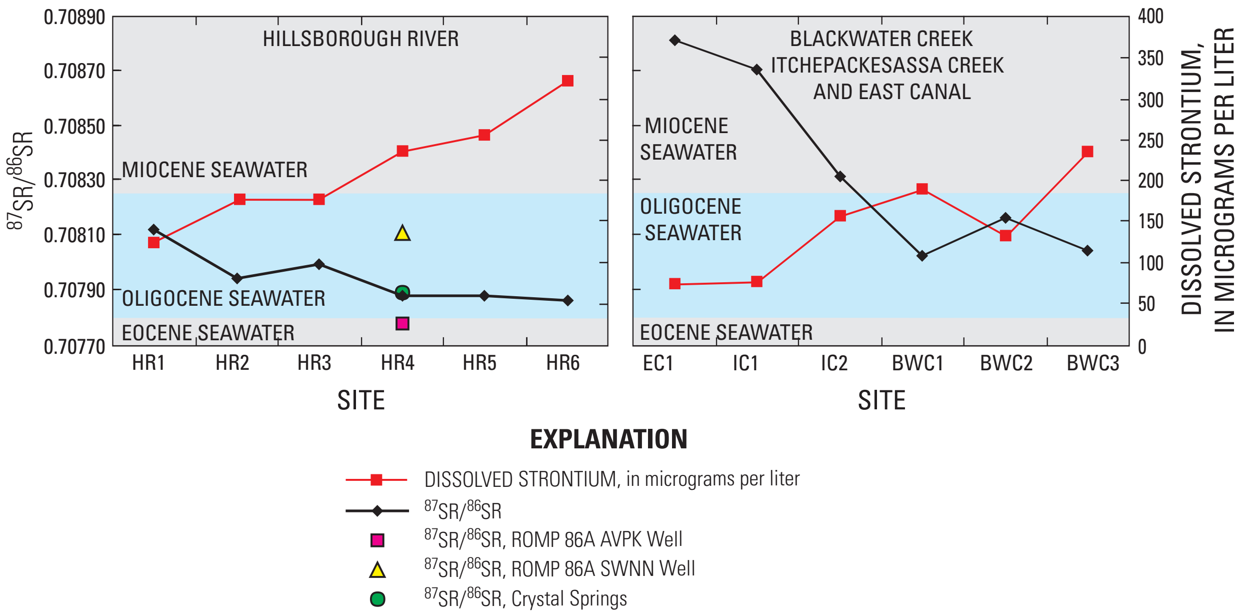


Figure 16. Strontium concentrations and $^{87}Sr/^{86}Sr$ ratios of water at the upper Hillsborough River sites and at the Blackwater and Itchepackesassa Creek and East Canal sites for dry season conditions (seawater boundaries from Howarth and McArthur, 1997).

in a downstream direction in Blackwater and Itchepackesassa Creeks in the dry season. Itchepackesassa Creek upstream from East Canal (IC1) had the lowest dry season strontium concentration, averaging about 70 µg/L. This is consistent with lower amounts of ground-water discharge at this site. The high concentration of strontium in East Canal (averaging about 245 µg/L) is likely a result of wastewater discharge.

The strontium isotope ratio ($^{87}Sr/^{86}Sr$) can be used to indicate the age of the rock that the ground water has been in contact with because $^{87}Sr/^{86}Sr$ ratios varied in seawater during the time the rocks in the study area were deposited (DePaolo and Ingram, 1985; Hess and others, 1986; Howarth and McArthur, 1997; Kendall, 1998). In the Hillsborough River subbasin, $^{87}Sr/^{86}Sr$ ratios in river water decreased from 0.70812 to 0.70786 in the downstream direction, indicating that the source of the ground water flowing to the river increased in depth farther downstream (fig. 16). The $^{87}Sr/^{86}Sr$ ratios were greater at the HR1, HR2, and HR3 sites (0.70799 to 0.70812) than at the HR4, HR5, and HR6 sites (0.70786 to 0.70788) (sites are shown in fig. 6). The sharp decrease observed at the HR4 site indicates a deeper source of water to the river. This reach of the river corresponds to the area near Crystal Springs where springs and seeps have been documented in and near the river (Champion and DeWitt, 2000). Water from Crystal Springs had a similar $^{87}Sr/^{86}Sr$ ratio to the lower river samples (0.70789). During base-flow conditions, most streamflow in the upper Hillsborough River downstream from Crystal Springs originates from the spring complex. Comparison samples from wells completed into the Oligocene-age Suwannee Limestone and the Eocene-age Avon Park Formation at the ROMP 86A site had $^{87}Sr/^{86}Sr$ ratios of 0.70811 and 0.70778, respectively (fig. 16). The $^{87}Sr/^{86}Sr$ signature of the river and Crystal Springs is not as low as that from the deep Avon Park well (fig 16), indicating the source of the water at all sites was the Oligocene-age Suwannee Limestone. However, $^{87}Sr/^{86}Sr$ ratios at these sites are near the boundary between Eocene and Oligocene seawater, and could be a mixture of shallow and deep ground-water sources.

Strontium isotope data indicate a shallower source of ground water in the Blackwater and Itchepackesassa subbasins than in the upper Hillsborough River subbasin. The $^{87}Sr/^{86}Sr$ ratios in water at the East Canal and Itchepackesassa Creek sites ranged from 0.70832 to 0.70882, similar to Miocene-age seawater (fig. 16) indicating that the source was the Hawthorn Formation, and most likely the carbonate Tampa Member of the Arcadia Formation. Most of the water in East Canal was from a wastewater source, so the $^{87}Sr/^{86}Sr$ ratio probably reflects the source of the municipal water supply. The $^{87}Sr/^{86}Sr$ ratios in water at the Blackwater Creek sites ranged from 0.70803 to 0.70817, similar to Oligocene seawater, indicating the source was most likely the Suwannee Limestone. The $^{87}Sr/^{86}Sr$ ratios, however, indicate the source of ground water to Blackwater Creek is shallower than in the upper Hillsborough River subbasin (fig. 16).

Uranium isotope data were collected from selected streams to give insight into the ground-water flow system interaction with the streams (Osmund and Cowart, 1976; Cowart and Osmund, 1992). For most samples from the

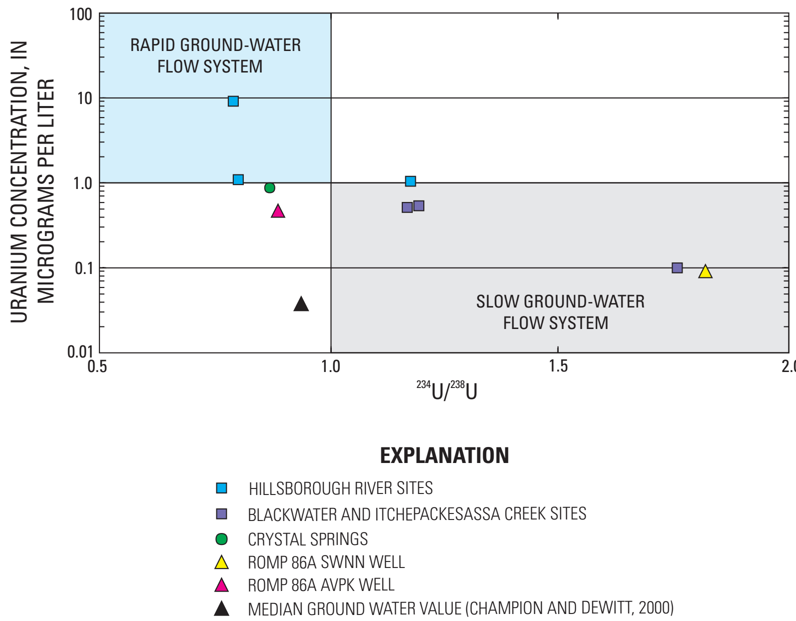


Figure 17. Uranium concentration and $^{234}U/^{238}U$ ratios of water at the upper Hillsborough River sites and at the Blackwater and Itchepackesassa Creek sites for dry season conditions.

Hillsborough River, $^{234}U/^{238}U$ activity ratios were less than 1.0 and concentrations were greater than 1.0 µg/L (fig. 17), indicating a rapid flow system. The $^{234}U/^{238}U$ activity ratio and concentration for water from Crystal Springs was similar to nearby Hillsborough River water, indicating water discharging to the river from the spring also is from a rapid ground-water flow system. In contrast, water from Blackwater Creek at the BWC1 site had a $^{234}U/^{238}U$ activity ratio greater than 1.0 and a concentration of less than 1.0 µg/L, indicating a slower ground-water flow system than in the upper Hillsborough River subbasin. Uranium concentrations were greater in samples from the streams than in samples from the two comparison wells completed into the Suwannee Limestone and the Avon Park Formation at the ROMP 86A site. Uranium isotope data from both wells indicate a deep, slow moving ground-water flow system. Water from the Suwannee well also is isotopically similar to water from the BWC1 site. In contrast, most of the 24 wells sampled as part of a SWFWMD study of Crystal Springs (Champion and DeWitt, 2000) had uranium activity ratios less than 1.0 and uranium concentrations greater than 1.0 µg/L, similar to Crystal Springs and the Hillsborough River. Those wells are located north of the river in an area defined by Champion and DeWitt (2000) as the ground-water basin to Crystal Springs.

Although uranium data suggest a rapid ground-water flow system discharging to the Hillsborough River, strontium isotope data indicate this water may circulate deeper than water discharging to Blackwater and Itchepackesassa Creeks (fig. 17). The area discharging to the river appears to have a well-developed karst (conduit) flow system, exhibited by the springs located in the subbasin. Conduits may intercept the Eocene-age Ocala or Avon Park Limestones. Strontium isotope data for Blackwater and Itchepackesassa Creeks indicate the source of ground water is from the Miocene-age Tampa Member of the Arcadia Formation and from the upper parts of the Oligocene-age Suwannee Limestone. Ground water discharging to these creeks apparently is shallower with a less developed karst flow system than the ground-water flow system discharging to the upper Hillsborough River.

Bacteria samples were collected at 10 sites (HR2, HR3, HR4, HR5, HR6, BWC1, BWC2, BWC3, IC1, and IC2; fig. 6) and analyzed for total coliform (TC), fecal coliform (FC), and fecal streptococci (FS) bacteria. Samples were collected at least four times at each site, and more often at the five sites where daily streamflow was computed. TC and FS bacteria were positively correlated to streamflow at the HR4, HR6, and BWC2 sites, and were highest during the wet season and lowest during the dry season. For most samples, FC bacteria were not as seasonal; however, a significant positive correlation between streamflow and FC was observed in the data for the BWC2 site.

At the fiive upper Hillsborough River sites, the median TC concentration was 530 coliforms per 100 mililiters (cols/100 mLs) during the dry season, and 1,980 cols/100 mls during the wet season. The median FC concentration was 83 cols/100 mls during the dry season, and 109 cols/100 mls during the wet season. The median FS concentration was 76 cols/100 mls during the dry season, and 440 cols/100 mls during the wet season.

At the Blackwater and Itchepackesassa Creek sites, median TC concentration was 950 cols/100 mls during the dry season, and 3,950 cols/100 mls during the wet season. The median FC concentration at these sites was 223 cols/100 mls during the dry season, and 370 cols/100 mls during the wet season. The median FS concentration was 195 cols/100 mls during the dry season, and 670 cols/100 mls during the wet season.

Specific sources of bacteria could not be identified with the standard methods used during this study because of the wide range of species that fall into the general categories of the indicator bacteria. The ratio of fecal coliform to fecal streptococcus (FC/FS), has been used to indicate possible sources (Geldreich 1966; Elder, 1986). Only one sample collected at HR6, the farthest downstream site in the study area, had a FC/FS ratio indicating a possible human source. All other samples collected indicate the most likely sources of bacteria in the study area are cattle and native animals in this riverine ecosystem. Use of the FC/FS ratio has limitations because the ratio changes over time and distance from the source as a result of unequal die-off rates for the indicator bacteria. As a result, the American Public Health Association (APHA) has suggested this method not be used to identify sources (American Public Health Association, 1998). East Canal (EC1) was sampled once, and indicator bacteria were low because wastewater discharging into East Canal is chlorinated, effectively killing bacteria.

Five surface-water sites (HR4, HR6, BWC2, IC2, and EC1; fig. 6) were sampled in September 2001 for 131 organic wastewater compounds and pesticides. Many of these compounds have been detected in streams throughout North America and include industrial, agricultural, and household products; pharmaceuticals and antibiotics; and sterols and hormones (Kolpin and others, 2002; Lee and others, 2004). Thirty-eight of these compounds were detected, however, concentrations were typically less than 1 μg/L. Analysis of some of these compounds demonstrate poor or variable method performance; therefore detected values for those compounds are considered to be estimated. Although multiple compounds were detected at all 5 sites, more compounds were detected at sites along Blackwater and Itchepackesassa Creeks and East Canal than at sites along the Hillsborough River sites. The EC1 and IC2 sites had the greatest number of compounds detected (22 and 25, respectively). It is not known if these compounds, or multiples of these compounds, are a risk to humans and wildlife at the levels detected during this study. Some of these compounds are known endocrine disrupters and in small concentrations can mimic natural hormones, potentially affecting reproductive health in animals (Kolpin and others, 2002).

The most commonly detected compounds at all five sites were DEET, an insect repellent; phenol, a disinfectant; and cholesterol, an animal waste by-product (table 5). Atrazine,

Table 5. Organic wastewater compounds and pesticides detected in surface-water samples, September 2001.

Compound name	Sampling site				
	HR4	HR6	BWC2	IC2	EC1
Pesticide					
CIAT					x
Atrazine		x	x	x	x
Bromacil			x	x	
Carbaryl			x	x	
DEET	x	x	x	x	x
Diazinon			x		
Metachlor				x	
Prometon			x	x	x
Simazine					x
Tebuthiuron			x	x	
Detergent Metabolite					
4-tert-octylphenol				x	
Para-nonylphenol	x	x		x	
Nonylphenol diethoxylate (NPEO2)	x			x	
Fragrance					
Acetophenone				x	x
AHT Napthalene				x	x
HHHMCP benzo-pyran			x	x	x
Plasticizer					
Bisphenol A	x				x
Ethanol-2-butoxy-phosphate			x	x	x
Tributylphosphate			x	x	x
Triphenylphosphate					x
Fire retardant					
Tri(2-chloroethyl) phosphate			x	x	x
Tri(dichloroisopropyl) phosphate			x	x	x
Polycyclic Aromatic Hydrocarbon (fossil fuel indicator)					
Flouranthene	x				
Phenanthrene	x				
Pyrene	x				
Sterol					
3-beta-coprostanol	x			x	
Beta-sitosterol	x			x	
Cholesterol	x	x	x	x	x
Stigmastanol	x			x	
Other					
Antraquinone					x
Benzophenone			x	x	x
Bromoform				x	x
Carbazole					x
Caffeine			x	x	x
Phenol	x	x	x	x	x
Triclosan					x

a herbicide, was found at four sites. Pesticides were the most commonly detected category of compounds. Ten different pesticides were detected and at least one was detected in all stream samples. Other compounds detected include fire retardants, sterols, disinfectants, fragrances, detergent metabolites, plasticizers, and polycyclic aromatic hydrocarbons (a fossil fuel indicator). Plant and animal sterols (hormones) were detected that can occur naturally or as an indicator of wastewater. Caffeine was the only "human drug" detected, and was found at the EC1, IC2, and BWC2 sites, all of which are downstream from the wastewater outfall on East Canal.

Compounds detected during this study were among the seven most commonly detected compounds in a national reconnaissance study of 139 streams (Koplin and others, 2004), and were among six of the most common compounds detected in a Minnesota study of 32 surface-water bodies (Lee and others, 2002). The IC2 site was sampled previously in August 1999 as part of the national reconnaissance study. Seven of the compounds detected for the current study also were detected in the 1999 sample.

Nutrients

Nutrient data from streams were evaluated temporally and spatially to characterize concentration ranges and the effects of ground water and runoff on nutrient concentrations. In addition, loads and yields were computed for the 2001 and 2002 water years at sites with continuous streamflow data. Trends were evaluated for sites with long-term data.

Nitrogen species varied at the upper Hillsborough River sampling sites both seasonally and in a downgradient direction. Total Kjeldahl nitrogen (ammonia plus organic nitrogen), was the dominant nitrogen species in water at the HR1, HR2, and HR3 sites (fig. 6). Total Kjeldahl nitrogen was positively correlated with streamflow and can be indicative of a shallow ground-water or surface-water source. The large riverine wetlands located in this part of the watershed and nearby cattle grazing activities are the probable source of the nitrogen. During the study period, the concentration of total Kjeldahl nitrogen at these three sites ranged from 0.56 to 1.7 mg/L during the wet season, and from below detection levels to 0.41 mg/L during the dry season. The median concentrations of total Kjeldahl nitrogen at these sites were about 1.5 and 0.28 mg/L for wet and dry seasons, respectively. The organic nitrogen concentration was the larger component of the total Kjeldahl nitrogen in all samples except one. The ammonia concentration was higher than expected (1.2 mg/L) in the sample collected at the HR1 site during May 2002. Ammonia concentrations in all other samples ranged from below detection levels to 0.32 mg/L. Inorganic nitrogen (nitrate plus nitrite) concentrations at the HR1, HR2, and HR3 sites ranged from below detection levels to about 0.34 mg/L during the wet season, and from below detection levels to about 0.15 mg/L during the dry season. The median concentrations of inorganic nitrogen at these sites were 0.03 and 0.04 mg/L for wet and dry seasons, respectively.

Inorganic nitrogen was the dominant nitrogen species in the river at the HR4, HR5, and HR6 sites (fig. 6). Inorganic nitrogen was negatively correlated with streamflow, which can be indicative of a ground-water source. The median concentration of nitrate in the river increased from about 0.10 to 0.54 mg/L between sites HR3 and HR4 during the wet season, and from 0.20 to 1.5 mg/L during the dry season. Median nitrate concentrations further increased between HR4 and HR5 during both wet and dry seasons, to about 1.2 mg/L and about 2.0 mg/L, respectively. Springs (including Crystal Springs) are located in and near the river along this subreach. A water-quality sample collected from the outfall from Crystal Springs to the river during this study contained 2.3 mg/L of inorganic nitrogen and 0.29 mg/L of total Kjeldahl nitrogen, indicating inorganic nitrogen was the dominant species in water discharging from Crystal Springs. Champion and DeWitt (2000) identified a 20-mi^2 ground-water basin as the probable water source for Crystal Springs. The change in the dominant nitrogen species and the large increase in inorganic nitrogen concentration in the river indicates that ground water contributes substantial amounts of inorganic nitrogen to the river. Between HR5 and HR6, median inorganic nitrogen concentrations in the river decreased from 1.2 mg/L to about 0.76 mg/L during the wet season, and from about 2.0 mg/L to about 1.7 mg/L, during the dry season because of inflow of water from Blackwater Creek that contained lower concentrations of inorganic nitrogen.

As with the uppermost Hillsborough River sites (HR1, HR2, and HR3), the dominant species of nitrogen in water at all the Blackwater and Itchepackesassa Creek sites and from East Canal was total Kjeldahl nitrogen. With the exception of the East Canal (EC1) and the BWC1 sites (fig. 6), sample concentrations were greater during the wet season. Much of the Blackwater and Itchepackesassa Creek subbasins are rural or agricultural and contain wetland areas. Samples collected from East Canal reflect the influence of treated effluent. Dry season samples could not be collected from the BWC1 site because the stream was dry. Samples collected at the BWC3 site were composites of all the waters from the upstream tributaries, and reflect the quality of water discharging into the Hillsborough River (fig. 6). The concentration of total Kjeldahl nitrogen at BWC3 ranged from 0.80 mg/L to 1.4 mg/L during the wet season, and from 0.52 to 0.70 mg/L during the dry season. The median concentrations of total Kjeldahl nitrogen were 1.1 and 0.61 mg/L for wet and dry seasons, respectively. Inorganic nitrogen concentrations at BWC3 were 0.29 and 0.50 mg/L for the two wet season samples, and were both 0.16 mg/L for the two dry season samples. The median concentrations of inorganic nitrogen were 0.39 and 0.16 mg/L for wet and dry seasons, respectively.

Nitrogen isotope samples were collected at 11 sites during the study, mostly during the dry season. Delta nitrogen-15 ($\delta^{15}N$) for most sites on the Hillsborough River

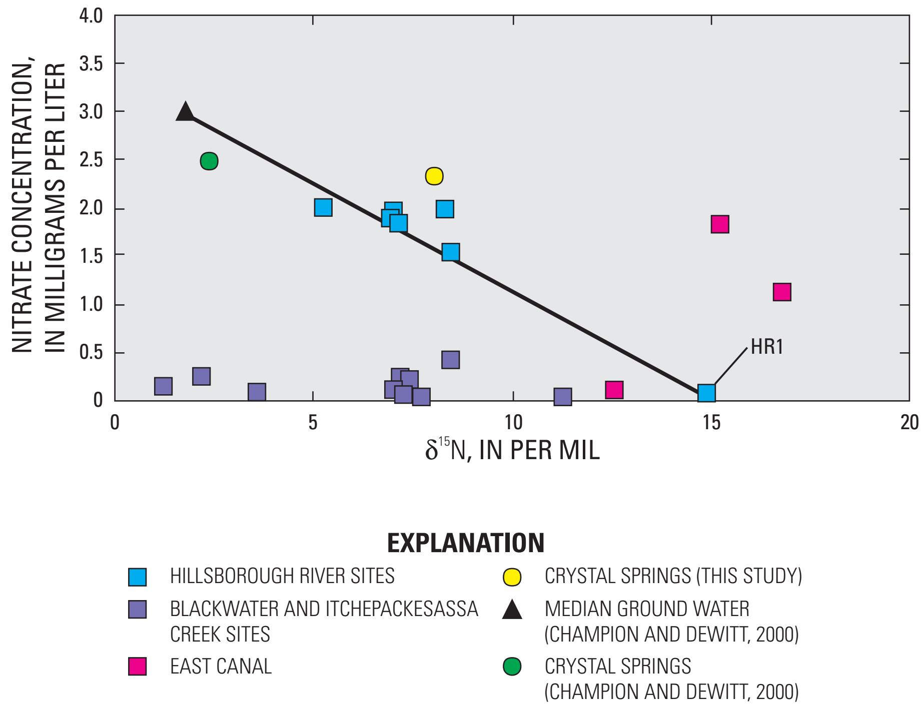


Figure 18. Nitrate concentration and $\delta^{15}N$ data at selected sites in the upper Hillsborough River watershed, 2001–2002.

ranged from 5.5 to 8.3 per mil, indicating a mixture of inorganic and organic nitrogen (fig. 18) or, alternatively, inorganic nitrogen that has undergone denitrification. The only exception was at the farthest upstream site, HR1, where nitrate concentrations were consistently low (0.02 mg/L) and the $\delta^{15}N$ value was +14.9 per mil, within the range for organic nitrogen from animal sources. The $\delta^{15}N$ value from a sample collected at the Crystal Springs outfall during this study was +8 per mil, which was higher than the sample collected during the Champion and DeWitt (2000) study. The $\delta^{15}N$ value of that sample was +2.4 per mil, well within the range of inorganic fertilizers. The sample with the lower $\delta^{15}N$ value was from the main spring vent, whereas the sample from this study was collected at the outfall to the river, which could have affected results. Ground water sampled by Champion and Dewitt (2000) in the contributing area to Crystal Springs had high nitrate concentrations and low $\delta^{15}N$ values indicating inorganic fertilizer as the source of elevated nitrate. The median $\delta^{15}N$ value and nitrate concentrations of the ground-water samples from that study can be used to form one end member of a mixing line, with the $\delta^{15}N$ value and nitrate concentrations of low nitrate river water from the upstream site (HR1) forming the other end member (fig. 18). The Hillsborough River and Crystal Springs samples from this study generally plot along this mixing line, implying that the elevated nitrate in the river is from an inorganic (fertilizer) source.

Orthophosphate, the inorganic bioavailable form of phosphorous, was the dominant species in all surface-water samples collected for this study. Orthophosphate concentrations in the upper Hillsborough River were greater during the wet season than in the dry season. Median concentrations ranged from about 0.15 to 0.40 mg/L during the wet season, and from below detection limits to about 0.06 mg/L during the dry season. Greater phosphorus concentrations during the wet season probably were due to storage and subsequent drainage from riverine wetlands in the upper Hillsborough River subbasin. The sample collected from Crystal Springs during May 2002 had an orthophosphate concentration of 0.03 mg/L. Ground water in the study area also had low phosphorus concentrations and was similar to dry season concentrations in river water. The low phosphorous concentrations in the river are indicative of ground-water, which constitutes most of the total streamflow during the dry season. The median concentration of orthophosphate in water from the Blackwater Creek, Itchepackesassa Creek, and East Canal sites ranged from 0.22 to 0.68 mg/L during the wet season, and from 0.13 to 0.48 mg/L during the dry season. Blackwater Creek, Itchepackesassa Creek, and East Canal receive less ground-water discharge than the upper Hillsborough Rivers, resulting in higher orthophosphate concentrations and less seasonal variation.

Loads, Yields, and Trends

Nutrient loads, yields, and trends were estimated for the sites with continuous streamflow data (HR4, HR6, BWC2, and IC2) for the 2001 and 2002 water years (fig. 6, appendix 3). Inorganic nitrogen trends also were calculated for Crystal Springs.

The farthest downstream site, HR6, was used to characterize nutrient loads exported from the entire upper Hillsborough River watershed. Nutrient loads generally increased as streamflow increased. Greater than 90 percent of the nitrogen loading during the 2001 water year (574 tons), and about 70 percent during the 2002 water year (213 tons) occurred during the wet season. About 85 percent of the nitrogen load exported from the watershed during the 2001 water year and about 60 percent during the 2002 water year was organic nitrogen. Nitrogen loads were greater during the 2001 water year than during the 2002 water year, probably because of greater wet season flushing of organic nutrients from the wetlands that had accumulated during the preceding dry season; the dry season was drier and the wet season wetter during the 2001 water year than during the 2002 water year (fig. 4). About 13 and 39 percent of the respective total nitrogen loads for 2001 and 2002 were inorganic nitrogen (nitrite plus nitrate). Kjeldahl nitrogen (ammonia plus organic nitrogen) loading varied by more than an order of magnitude between wet and dry seasons. Seasonal loading of inorganic nitrogen was less variable, however, probably because a large part of the nitrate nitrogen is from ground water, which is relatively constant compared to runoff. Most of the nitrogen exported during the study was total Kjeldahl nitrogen. Nutrient loads and yields were greater during the 2001 water year than during the 2002 water year. Phosphorous loads at the HR6 site also were greater during the wet season than during the dry season, but were not as variable as nitrogen loads between the 2001 and 2002 water years. The annual load of orthophosphate was estimated to be 48 tons for the 2001 water year and 43 tons for the 2002 water year (appendix 3).

Loads were estimated at the BWC2 and HR4 sites (fig. 6) because these sites are the farthest downstream in the upper Hillsborough River and Blackwater Creek subbasins, and are above the confluence of the two streams. Comparisons were made to gain insight into the loading from each major subbasin. Nitrogen and phosphorus loads were considerably greater at the BWC2 site than at the HR4 site for both water years (appendix 3). Organic nitrogen was the dominant species at the BWC2 site, averaging about 73 percent of the nitrogen load for the 2001 and 2002 water years. At the HR4 site, however, the nitrogen load was dominated by inorganic species, averaging greater than 90 percent for each water year. Although inorganic nitrogen was the dominant form of nitrogen at the HR4 site (fig. 6), annual loading was less (12 and 18 tons during the 2001 and 2002 water years) than at the BWC2 site (21 and 35 tons during the 2001 and 2002 water years). This was due to greater nitrate concentrations in Blackwater Creek during the wet season when streamflow was greatest, whereas nitrate concentrations were lowest during the wet season in the Hillsborough River. The annual loads of orthophosphate were estimated to be 45 and 34 tons for the 2001 and 2002 water years at the BWC2 site, and about 14 and 15 tons at the HR4 site for the same periods, respectively.

Comparing the sum of the nutrient loads at the BWC2 and HR4 sites with loads estimated downstream at the HR6 site indicates substantial differences in nitrogen loads. The total nitrogen load at the HR6 site for the 2 water years is about four times greater than the sum of the loads estimated at the BWC2 and HR4 sites. Most of this nitrogen consisted of the organic species added to the streams below the BWC2 and HR4 sites during the wet season by runoff from riverine wetlands and small, unnamed, seasonal tributaries. Loading of inorganic nitrogen (mostly nitrate) was also greater at HR6 than the sum of the upstream sites, and the difference was greater during the dry season. Streamflow increases below the HR4 site because of inflow to the river from Crystal Springs. Much of the nitrate comes from Crystal Springs and ground-water discharge to the river downstream from HR4. Nitrate concentrations in water from Crystal Springs and in ground water in the vicinity are about 2 mg/L (this study, and Champion and Dewitt, 2000). Annual phosphorus loads estimated at the HR6 site were similar to the sum of the HR4 and BWC2 sites, indicating no additional sources of phosphorous between the sites (appendix 3).

The source of much of the nutrient loading estimated at the BWC2 site is from Itchepackesassa Creek. Because Itchepackesassa Creek is a tributary to Blackwater Creek, loads were compared to those at the downstream BWC2 site. Nitrogen loading at the IC2 site (fig. 6) for the 2001 and 2002 water years was estimated to be 156 tons, which was about 75 percent of the nitrogen load estimated at the downstream BWC2 site. Loads of inorganic and organic nitrogen for both water years were 31 and 133 tons, which was about 55 and 88 percent of the load estimated at the BWC2 site. Orthophosphate loads totaled 49 tons for both water years, about 62 percent of the phosphorous load estimated at the BWC2 site (appendix 3).

Loads estimated at the four sites were normalized to subbasin surface area to calculate yields that can be used to compare loading from subbasins of varying sizes. Yields were calculated in pounds per square mile and are shown in appendix 4. Yields calculated at the HR6 site reflect the entire upper Hillsborough River watershed. Nutrient yields were greater during the wet season, consistent with runoff, and inorganic nitrogen was greater during the dry season, consistent with ground-water discharge. The HR4 site had the lowest nutrient yields of those calculated, and had little seasonal variability in inorganic nitrogen, consistent with discharge from ground water. Yields at the BWC2 site reflect the loading from the entire Blackwater Creek subbasin, including the Itchepackesassa Creek and East Canal subbasins. Monthly yields of all nutrients from Blackwater Creek were greater during the wet season (appendix 4). The drainage area for the IC2 site is 52 mi^2 and is the smallest for which yields were calculated. Nitrogen yields are almost as high as those calculated for the HR6 site, which reflects the entire upper Hillsborough River watershed. Phosphorous yields at the IC2 site were greater than those calculated at the other three sites. Itchepackesassa Creek also receives treated wastewater from East Canal, which has an effect on nutrient loads and yields.

Flow-corrected trends in nutrient concentrations were computed for the HR6, HR4, and BWC2 sites. Nutrient concentrations have been measured at these sites for at least 15 years. A statistically significant increasing trend of 0.03 mg/L/yr ($p = < 0.01$) was observed in the inorganic nitrogen concentration data at the HR6 site, and statistically significant decreasing trends of 0.01 and 0.06 mg/L/yr, respectively, ($p = < 0.01$) were observed in the organic nitrogen and orthophosphate concentration data from the site. At the HR4 site, only the orthophosphate concentration data showed a statistically significant trend ($p = 0.04$), which was a decreasing trend of 0.04 mg/L/yr. Atthe BWC2 site, a statistically significant decreasing trend of 0.13 mg/L/yr ($p =< 0.01$) was observed in orthophosphate concentration.

Nitrate concentrations in Crystal Springs have increased over time (Champion and DeWitt, 2000); however, the rate of increase was greater prior to 1990 (fig. 19). The trend for median annual nitrate concentration was statistically significant for the period prior to 1990 ($p = < 0.01$), but was not significant for the period from 1990 to 2002 ($p = 0.26$). Data from the SWFWMD for 1998 and 1999 were included in the analysis. Only one sample was collected from the springs after 1999, so additional samples would be necessary to better understand more recent trends. Sources of nitrate for Crystal Springs have been discussed in detail by Champion and DeWitt (2000).

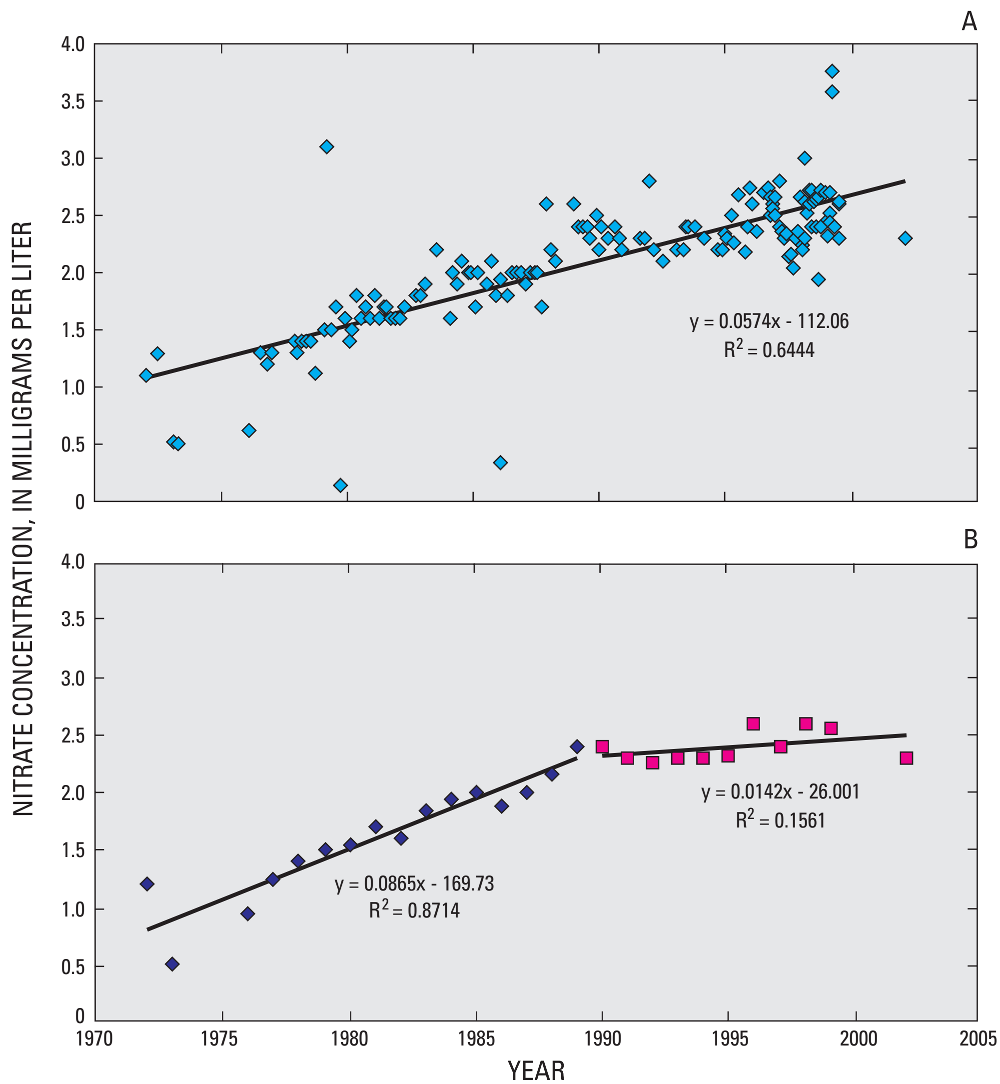


Figure 19. Nitrate trends at Crystal Springs between 1972 and 2002 from (A) individual samples, and (B) median annual data. Includes data from the U.S. Geological Survey and the South Florida Water Management District.

Interaction Between Surface- and Ground-Water Systems

Examination of surface-water altitude data, surficial aquifer and Upper Floridan aquifer water-level data, and water-quality data for the upper Hillsborough River watershed indicates that a good hydraulic connection exists between the shallow and deep ground-water systems and the surface-water system. Depending on the location and the seasonal conditions, water can discharge from the aquifers to the streams, or from the streams to the underlying aquifer. Four techniques were used to gain an understanding of the exchange of surface and ground water in the watershed: (1) seepage runs were conducted to determine the quantity of water being received or lost from the surface-water system, (2) base-flow separation analysis was conducted to characterize ground-water discharge to the streams, (3) hydraulic analysis of the ground-water system at selected cross sections was conducted to characterize the linkage between ground water and surface water, and (4) water-quality analysis was used to establish the linkage between the streams and the ground-water flow system.

Streamflow Gains and Losses

Synoptic streamflow measurements (seepage runs) were made along the main channel of the upper Hillsborough River, Blackwater Creek, Itchepackesassa Creek, and East Canal. Measurements were made from the farthest upstream point where streamflow was observed to the confluence with the downstream larger stream, or, in the case of the Hillsborough River, where the river exits the study area. Data were collected at 6 gaged and 52 previously determined, ungaged sites in the four subbasins. Each site was visited, and if streamflow was observed, a streamflow and specific conductance measurement was made (fig. 20). Seepage runs were made during base flow conditions in May and November 2001. Successive downstream streamflow measurements were compared to determine if the stream reaches were gaining or losing flow.

Data were collected during both seepage runs at 10 ungaged sites on East Canal, a small tributary that drains from Plant City (fig.1) to Itchepackesassa Creek (fig. 20, table 6). During the May seepage run, streamflow was zero at sites E1 and E2, and ranged from 0.02 to 0.07 ft^3/s at sites E3 through E6. The measured streamflow was below the accuracy range of the current meters and, therefore, downstream differences were not considered meaningful. A small amount of ground water, however, was observed seeping to the stream channel along this reach, so it was considered a gaining reach. Specific conductance values measured at these sites averaged about 330 μS/cm. The specific conductance values were higher than expected for surficial aquifer water, but may be a result of seepage from surficial deposits in areas irrigated with water from the Upper Floridan aquifer. Streamflow and specific conductance increased to 5.1 ft^3/s and 1,604 μS/cm, respectively, at the E7 site. The increase in streamflow and specific conductance is a result of surface-water inflow from a treated wastewater outfall located just upstream from the site and not from ground-water seepage between sites E6 and E7. A loss of about 3 ft^3/s to the ground-water system was calculated between sites E7 and the confluence of East Canal with Itchepackesassa Creek (site E10). Specific conductance values were about 1,600 μS/cm throughout this subreach (table 6).

During the November seepage run, flow was observed at all sites and streamflow patterns were similar to the previous seepage run. Streamflow at sites E1 through E6 increased in the downstream direction, ranging from 0.09 to 0.45 ft^3/s (table 6). Specific conductance values were lower, averaging about 240 μS/cm, indicating that rainfall had a greater influence on the water in the surficial deposits than during the May seepage run. Wastewater discharge to East Canal was considerably less in November than in May. Just downstream from the wastewater outfall, streamflow and specific conductance at the E7 site increased to 1.9 ft^3/s and 1,076 μS/cm, respectively, due to the wastewater inflow. A loss of 0.49 ft^3/s was calculated between E7 and E8, and specific conductance remained about the same. A gain of about 0.60 ft^3/s was calculated between E8 and E10. Specific conductance values decreased slightly from 1,073 to 985 μS/cm between these sites, indicating some ground water with lower specific conductance was seeping into the stream along this subreach (fig. 20, table 6).

Data were collected at 2 gaged and 18 ungaged sites during both seepage runs along Itchepackesassa Creek (fig. 20, table 7). Bonnet Lake outfall (site I1) is the headwater for Itchepackesassa Creek. During the May seepage run, discharge at the lake outfall was 0.02 ft^3/s. Specific conductance measured at the site was 185 μS/cm, indicating the source of the water was probably surficial ground water seeping into the lake. Streamflow increased to 0.47 ft^3/s between the lake outfall and site I3. Farther downstream, a small tributary (I4) contributed an additional 0.23 ft^3/s to the creek. Specific conductance at the tributary was 396 μS/cm, indicating the water is from upstream wetlands or from irrigation or other releases of water with Upper Floridan aquifer sources. Streamflow along Itchepackesassa Creek increased 0.91 ft^3/s between I3 and I5: the streamflow at I5 is almost twice the combined streamflow of the Creek at I3 and the tributary at I4. Specific conductance measured at I5 was 276 μS/cm, indicating the higher conductance water from the tributary did not affect conductance substantially along the stream. Streamflow increased to 1.49 ft^3/s between site I5 and I6, a gain of 0.11 ft^3/s. The stream reach between sites I1 and I6 can be considered as a gaining reach (fig. 20, table 7). Streamflow remained essentially unchanged between I6 and I8; the tributary at I7 was dry. Streamflow decreased 0.51 ft^3/s between sites I8 and I12, and fluctuated between 0.95 to 1.14 ft^3/s from I12 to I17, maintaining a flow of about 1.0 ft^3/s along this reach. The measurement differences along this reach were below the accuracy range for the current meter and were not considered meaningful. Streamflow at site I18 was 3.13 ft^3/s,

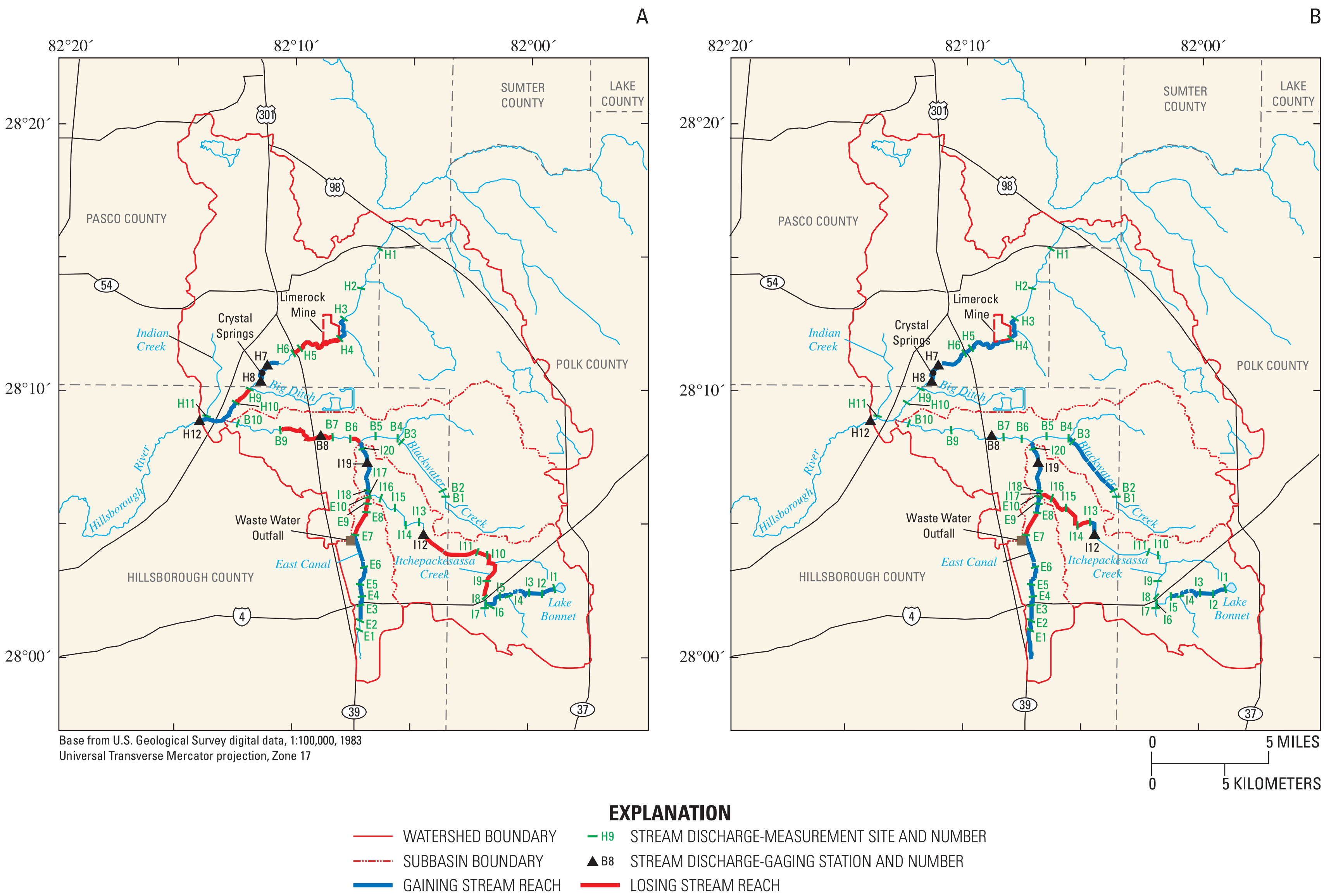


Figure 20. Location of streamflow measurement sites and gaining and losing stream reaches for the (A) May and (B) November 2001 seepage runs.

Table 6. Summary of streamflow and specific conductance data for East Canal during the May and November, 2001 seepage runs.

[ft^3/s, cubic feet per second; μS/cm, microsiemens per centimeter; --, no data]

Site number (fig. 20)	Site location	May 2001		November 2001	
		Streamflow (ft^3/s)	Specific conductance (μS/cm)	Streamflow (ft^3/s)	Specific conductance (μS/cm)
E1	East Canal at Gilchrist Park	0.00	--	0.09	240
E2	East Canal at Cherry Street	.00	--	.15	238
E3	East Canal at South Frontage Road	.05	295	.38	240
E4	East Canal at Terrace Road	.05	330	.39	242
E5	East Canal at Sam Allen Road	.02	360	.42	249
E6	East Canal at mobile home park	.07	353	.45	152
E7	East Canal near waste-water outfall	5.12	1,604	1.90	1,076
E8	East Canal at boundary of Cone Ranch	3.62	1,611	1.41	1,073
E9	East Canal at TBW gage	2.59	1,600	1.85	989
E10	East Canal upstream from Itchepackesassa Creek	2.03	1,590	2.03	985

Table 7. Summary of streamflow and specific conductance data for Itchepackesassa Creek and its tributaries during the May and November, 2001 seepage runs.

[ft^3/s, cubic feet per second; μS/cm, microsiemens per centimeter; --, no data]

Site number (fig. 20)	Site location	May 2001		November 2001	
		Streamflow (ft^3/s)	Specific conductance (μS/cm)	Streamflow (ft^3/s)	Specific conductance (μS/cm)
I1	Bonnet Lake outfall	0.02	185	2.18	150
I2	Itchepackesassa Creek at Wabash Ave.	.33	246	2.46	189
I3	Itchepackesassa Creek at Lone Pine Golf and Country Club	.47	251	2.71	188
I4	Unnamed tributary to Itchepackesassa Creek	.23	396	3.95	238
I5	Itchepackesassa Creek at Galloway Road	1.38	276	10.2	233
I6	Itchepackesassa Creek at Kraft Road	1.49	288	9.34	236
I7	Unnamed tributary to Itchepackesassa Creek	.00	--	.05	280
I8	Itchepackesassa Creek at North Frontage Road	1.50	249	9.84	224
I9	Itchepackesassa Creek at Wilkes Road	1.42	261	11.0	241
I10	Itchepackesassa Creek at Walker Road	1.33	250	10.9	247
I11	Itchepackesassa Creek near power line	1.37	246	11.5	274
I12	Itchepackesassa Creek at Knights-Griffin Road (CSI gage)	.99	266	10.4	269
I13	Itchepackesassa Creek at TBW gage	1.14	258	14.9	266
I14	Itchepackesassa Creek on Cone Ranch near eastern tributary	.95	256	14.2	268
I15	Itchepackesassa Creek on Cone Ranch near middle tributary	1.09	252	12.6	268
I16	Itchepackesassa Creek on Cone Ranch near west tributary	1.06	250	13.2	270
I17	Itchepackesassa Creek upstream of East Canal	1.09	256	11.8	274
I18	Itchepackesassa Creek downstream of East Canal	3.13	1,372	13.8	412
I19	Itchepackesassa Creek on Cone Ranch at USGS gage	4.54	1,274	14.7	413
I20	Itchepackesassa Creek near Blackwater Creek	4.62	1,293	15.2	410

an increase of 2.0 ft^3/s over I17. The increase in streamflow between I17 and I18 is not from ground-water seepage, but inflow from East Canal. Specific conductance increased to 1,372 µS/cm at I18 as a result of the wastewater from East Canal. Streamflow increased to 4.62 ft^3/s between site I18 and I20, a gain of 1.49 ft^3/s. Site I20 is located near the confluence with Blackwater Creek. Specific conductance measured at I20 was 1,293 µS/cm (table 7).

Although the streamflow was greater during the November seepage run, patterns of gains and losses along Itchepackesassa Creek were similar to the previous seepage run. Streamflow at sites I1 through I3 increased from 2.18 to 2.71 ft^3/s, indicating a 0.53 ft^3/s gain from ground water. Specific conductance values increased from 150 µS/cm at the lake outfall (I1) to 189 µS/cm at I3, indicating higher conductance ground water was seeping to the stream. The tributary at site I4 was flowing, adding 3.95 ft^3/s to the stream for a total of 6.66 ft^3/s. Specific conductance of water from the tributary was 238 µS/cm. Streamflow at site I5 was 10.2 ft^3/s, a gain of 3.54 ft^3/s between the tributary (site I4) and I5. Between sites I1 and I5, the stream can be considered a gaining stream (fig. 20, table 7). Itchepackesassa Creek streamflow fluctuated between 9.34 and 11.5 ft^3/s between sites I5 and I12, averaging about 10 ft^3/s, with no substantial net gain or loss along the reach. A gain of about 4.5 ft^3/s was calculated between site I12 and site I13. Streamflow decreased from 14.9 to 11.8 ft^3/s between sites I13 and I17, indicating a loss of 3.1 ft^3/s. Streamflow at site I18 was 13.8 ft^3/s, an increase of about 2.0 ft^3/s due to flow from East Canal. Specific conductance at this site increased to 412 µS/cm, again indicating the influence of the wastewater from East Canal. Streamflow continued to increase to 15.2 ft^3/s between sites I18 and I20, with a gain of about 1.40 ft^3/s calculated along this subreach (fig. 20; table 7).

Data were collected at one gaged and nine ungaged sites during both seepage runs along Blackwater Creek (fig. 20, table 8). During the May seepage run, the creek was dry above the confluence with Itchepackesassa Creek (sites B1 through B5), and the only water in the downstream reaches was from Itchepackesassa Creek. Between site I20 on Itchepackesassa Creek and site B6 near the easternmost dam on Blackwater Creek (fig. 2), a loss of 0.77 ft^3/s was calculated (tables 7 and 8). The specific conductance value measured at site B6 was 940 µS/cm, indicating the influence of wastewater. A small increase in streamflow (0.19 ft^3/s) was measured at the B7 site, but was within the measurement error and not considered meaningful. The specific conductance value measured at the site, however, was 255 µS/cm, indicating the source of the water in the stream was probably from the shallow ground-water system, which had not been influenced by wastewater. Site B7 is located downstream from the westernmost dam on Blackwater Creek (figs. 2 and 20). The dams may impede the movement of wastewater downstream during low streamflow conditions. Streamflow decreased 0.62 ft^3/s between site B7 and B8, and 1.44 ft^3/s between sites B8 and B9. Specific conductance values at B8 and B9 were 260 and 281 µS/cm, respectively, and the increase may indicate a greater influence of Upper Floridan aquifer water on stream water. Streamflow at site B10 was essentially unchanged from site B9; however, specific conductance at site B10 increased to 354 µS/cm, similar to water from the Upper Floridan aquifer.

All Blackwater Creek sites had measurable discharge during the November seepage run. Discharge at site B1, a small tributary, was 0.27 ft^3/s (fig. 20, table 8). Streamflow at site B2, located on the main channel of Blackwater Creek, downstream of the tributary, also was 0.27 ft^3/s, indicating all water in the main channel of the creek was from the tributary. Specific conductance values at both sites were 245 µS/cm. Streamflow increased fourfold between site B2 and B3 (from 0.27 to 1.39 ft^3/s), a gain of 1.12 ft^3/s. Specific conductance measured at site B3 was 390 µS/cm, indicating higher conductance water, probably from the Upper Floridan aquifer, was seeping into the stream. Small seeps and springs were observed along the lower bank of the creek near this site. A gain of 0.86 ft^3/s was calculated between sites B3 and B4, and specific conductance increased slightly to 400 µS/cm; streamflow was not observed in the tributary upstream from the B4 site. Streamflow remained essentially unchanged between sites B4 and B5 (2.25 and 2.22 ft^3/s), and specific conductance again increased slightly to 413 µS/cm. Downstream from the confluence with Itchepackesassa Creek, streamflow increased to 17.4 ft^3/s at site B6, the result of combined streamflow from Itchepackesassa Creek and upstream Blackwater Creek rather than ground-water seepage. Specific conductance at B6 was 418 µS/cm. There was no meaningful change in streamflow between sites B7 and B10, with values ranging from 17.6 to 18.3 ft^3/s. Specific conductance values also remained essentially unchanged, ranging from 413 to 422 µS/cm.

Data were collected at three gaged and nine ungaged sites during both seepage runs along the upper Hillsborough River (fig. 20, table 9). During the May seepage run, the river was dry from sites H1 through H3. Streamflow at the H4 site, near the limerock mine, was 1.54 ft^3/s. The gain represents ground-water seepage; however, stable isotope (deuterium and oxygen-18) samples indicated the river water was isotopically similar to water that was removed from the active mine area and stored in a holding pit near to and at a higher altitude than the river. During extreme low streamflow periods, the limerock mine appears to be the first source of water to the river. Streamflow decreased to 0.68 ft^3/s in the downstream direction between the limerock mine (H4) and the T2 transect (H6), a loss of 0.86 ft^3/s. A substantial gain of 4.53 ft^3/s was calculated between sites H6 and H7 above Crystal Springs. The gain is a result of discharge from a series of small springs located in the river channel and flood plain upstream of site H7. Figure 20A shows the approximate location of the gaining reach. The most substantial gain occurs between sites H7 and H8 due to inflow from Crystal Springs (fig. 20). Streamflow at the H8 site was 31.3 ft^3/s, a gain of 26.1 ft^3/s. Streamflow measured below Big Ditch (H9), a tributary to the river, was essentially unchanged because Big Ditch was dry.

Table 8. Summary of streamflow and specific conductance data for Blackwater Creek during the May and November 2001 seepage runs.

[ft3/s, cubic feet per second; µS/cm, microsiemens per centimeter; --, no data]

Site number (fig. 20)	Site location	May 2001		November 2001	
		Discharge (ft^3/s)	Specific conductance (µS/cm)	Discharge (ft^3/s)	Specific conductance (µS/cm)
B1	Unnamed tributary to Blackwater Creek	0.00	--	0.27	245
B2	Blackwater Creek near trailer park	.00	--	.27	245
B3	Blackwater Creek at eastern boundary of Cone Ranch	.00	--	1.39	390
B4	Blackwater Creek near unnamed tributary	.00	--	2.25	400
B5	Blackwater Creek at TBW gage	.00	--	2.22	413
B6	Blackwater Creek downstream of Itchepackesassa Creek	3.85	940	17.4	418
B7	Blackwater Creek near western dam	4.04	255	17.6	422
B8	Blackwater Creek at State Road 39 (USGS gage)	3.42	260	18.2	422
B9	Blackwater Creek at eastern boundary of Two Rivers Ranch	1.98	281	18.3	413
B10	Blackwater Creek near confluence with the Hillsborough River	2.00	354	18.3	419

Table 9. Summary of streamflow and specific conductance data for the upper Hillsborough River during the May and November 2001 seepage runs.

[ft3/s, cubic feet per second; µS/cm, microsiemens per centimeter; --, no data]

Site number (fig. 20)	Site location	May 2001		November 2001	
		Streamflow (ft^3/s)	Specific conductance (µS/cm)	Streamflow (ft^3/s)	Specific conductance (µS/cm)
H1	Hillsborough River at State Road 54	0.00	--	0.00	--
H2	Hillsborough River at railroad crossing	.00	--	3.53	238
H3	Hillsborough River at the UHRT transect	.00	--	4.64	240
H4	Hillsborough River at the limerock mine	1.54	349	8.94	420
H5	Hillsborough River at railroad crossing near State Road 39	.91	353	10.4	417
H6	Hillsborough River at State Road 39 (T2 transect)	.68	356	11.3	423
H7	Hillsborough River above Crystal Springs (USGS gage)	5.21	360	18.4	421
H8	Hillsborough River below Crystal Springs (USGS gage)	31.3	359	67.6	420
H9	Hillsborough River below Big Ditch	31.0	360	66.9	417
H10	Hillsborough River near cattle crossing	28.8	360	66.2	421
H11	Indian Creek	.00	--	.00	--
H12	Hillsborough River at the State Park (USGS gage)	33.3	361	86.2	420

A loss of 2.2 ft^3/s was calculated for the subreach between Big Ditch and the cattle crossing site (H10). Indian Creek (site H11), a tributary to the river, also was dry. Streamflow at Hillsborough River State Park (H12), the farthest downstream site in the study area, was 33.3 ft^3/s. Blackwater Creek flows into the Hillsborough River between sites H10 and H11, and 2.0 ft^3/s of the 4.5 ft^3/s gain in streamflow calculated at H12 is from Blackwater Creek. Specific conductance values for all the sites along the river ranged from 349 to 361 μS/cm (table 9), similar to specific conductance values of water samples from some Upper Floridan aquifer wells in the study area.

Water was present at all the upper Hillsborough River sites during the November seepage run; however, the river at site H1 was not flowing (fig. 20, table 9). At H1, water was ponded in the extensive cypress swamps and marshes located in the area. Streamflow at site H2 was measured at 3.53 ft^3/s, with most of the flow originating from a tributary located about 0.25 mi upstream from the site. Streamflow further increased to 4.64 ft^3/s at the H3 site; the increasing flow from H1 to H3 was probably a result of surface drainage from upstream wetlands rather than seepage from the ground-water system. Specific conductance measured at both sites was about 240 μS/cm, also indicating surface drainage. A gain of 4.3 ft^3/s was calculated between sites H3 and H4. Specific conductance measured at H4 was 420 μS/cm, indicating a deeper ground-water source for the increased streamflow. Site H4 is adjacent to the limerock mine where streamflow to the Hillsborough River originated during the May seepage run. Substantial gains were calculated at all sites between H4 and H8, with the largest at site H8 (49.2 ft^3/s) reflecting the discharge from Crystal Springs. As with the May seepage run, a loss was calculated between H8 and H10. Because of the higher flows, however, the losses were within the measurement error and not considered meaningful. As with the May seepage run, the Indian Creek tributary was dry. Streamflow measured at Hillsborough River State Park (H12) was 86.2 ft^3/s. About 1.7 ft^3/s of the 20 ft^3/s gain between sites H10 and H12 was from ground-water seepage, while the remainder was inflow from Blackwater Creek. Specific conductance for the entire subreach between sites H4 and H12 ranged from 417 to 423 μS/cm, similar to specific conductance values observed in Upper Floridan aquifer wells.

During low base-flow conditions when ground-water levels were low, one losing and one gaining stream reach in the East Canal subbasin, one losing and two gaining stream reaches in the Itchepackesassa Creek subbasin, two losing reaches in the Blackwater Creek subbasin, and two losing and four gaining stream reaches in the upper Hillsborough River subbasin were identified. These results indicate both recharge and discharge conditions were occurring throughout the upper Hillsborough River watershed (fig. 20). During high base-flow conditions when ground-water levels were higher, all stream reaches were gaining with the exception of one stream reach in the East Canal subbasin and one stream reach in the Itchepackesassa Creek subbasin. The losing stream reaches are in the area near the confluence of East Canal and Itchepackesassa Creek where losing stream reaches also were observed during the May 2001 seepage run.

Hydrograph Separation

Base flow is that part of streamflow usually attributed to ground-water discharge (U.S. Geological Survey, 1989). The standard assumptions are that base flow equals ground-water discharge, and that ground-water discharge is about equal to ground-water recharge. During periods of little or no rainfall, streamflow is assumed to be composed entirely of ground water (base flow), allowing the amount of streamflow contributed by ground water to be estimated. According to

Table 10. Base flow estimated by hydrograph separation methods for 1984–2002.

[mi^2, square miles; ft^3/s, cubic feet per second; in/yr, inches per year]

Station number	Station description	Drainage area (mi^2)	Mean stream flow		Mean base flow		Base-flow index (percent)
			(ft^3/s)	(in/yr)	(ft^3/s)	(in/yr)	
2301900	Fox Branch near Socrum	9.5	10.0	14.3	4.84	6.92	48.3
2301990	Hillsborough River above Crystal Springs near Zephyrhills	82.0	66.9	11.1	54.2	8.98	81.1
2302500	Blackwater Creek near Knights	110	71.1	8.77	36.0	4.44	50.7
2303000	Hillsborough River near Zephyrhills	220	203	12.5	150	9.26	74.1

Kinzelbach and others (2002), recharge estimates using hydrograph separation may be accurate within a factor of 2, and this can be one of the best methods for estimating long-term average regional recharge.

The estimated range of mean annual base flow at the streamflow stations with long-term continuous record (table 10) was between 4.44 to 9.26 in/yr. The percentage of total streamflow that was estimated as base flow (the base-flow index) ranged from about 50 to 80 percent. The base-flow index for Fox Branch and Blackwater Creek was about 50 percent. The base-flow index for the two Hillsborough River sites was about 74 and 81 percent, respectively, and is due to a greater degree of karstification in the upper Hillsborough River subbasin than in the Fox Branch and Blackwater Creek subbasins. The smallest mean annual base-flow estimate was for Fox Branch (6.92 in/yr), a small tributary to the Hillsborough River with a drainage area of 9.5 mi^2 located upstream from major ground-water discharge features, such as Crystal Springs. The largest mean annual base-flow estimate is for the Hillsborough River near Zephyrhills station (9.26 in/yr), located downstream from Crystal Springs, with a drainage area of 220 mi^2 (table 10).

Using a specific conductance mass-balance method, base flow to the river at Hillsborough River State Park was estimated to be about half that estimated using the partition method (Stewart and others, 2007). Using a moving minimum value variation of the hydrograph separation methods, consultants for the Southwest Florida Water Management District calculated mean streamflow to Blackwater Creek for the 20-year period from 1975 to 1995 of about 8 in/yr and base flow of 1.5 in/year. The base flow indicator was about 20 percent (Thompson and others, 1998), which also is less than the volume estimated using the partition method. The higher estimates from this study are a result of using the standard assumptions applied to this method. Halford and Mayer (2000) identify factors that may affect the assumption that all base flow is ground-water discharge. Two main factors may affect the accuracy of the recharge estimates: relatively low topographic relief and potentially slow drainage of surface water from wetlands. Both of these factors exist in the upper Hillsborough River watershed, thus the hydrograph separation base-flow estimate probably overestimates ground-water discharge to the streams.

Ground-Water Levels and Flow Direction

To better illustrate ground-water flow near the stream channels in the upper Hillsborough River watershed, hydrogeologic cross sections were constructed for each of the three well transects. Ground-water flow also was mapped for the wet and dry seasons corresponding to the potentiometric surface maps presented in figure 8. Hydrographs were used to compare ground-water heads to the stream stage during the study period to determine potential flow direction. Ground-water discharge to the streams was simulated using finite-difference ground-water flow models of each transect.

Hydrogeologic Cross Sections

Near the T1 transect, Blackwater Creek has been extensively ditched and is incised through the surficial deposits. Limestone outcrops are visible in the streambed near the transect site. The semiconfining unit at the Blackwater Creek transect is thinnest at the creek and thickens with distance away from the creek. The creek flows intermittently during the dry season; however, water remains ponded in the creek at the transect site (except during extreme dry periods) due to backwater from Itchepackesassa Creek.

Two types of water-level patterns corresponding to the wet and dry seasons were observed at the T1 transect. During wet conditions, head gradients in the Upper Floridan and surficial aquifers were toward the stream, and stream stage was lower than ground-water heads. This type of flow pattern is consistent with ground-water discharge and was usually observed during the wet season. The surficial aquifer contained water only during the wet season and gradients were relatively steep toward the creek (figs. 21; fig. 22a). During the dry season, when backwater conditions from Itchepackesassa Creek existed, the stream stage was higher than heads adjacent to the stream, causing localized recharge to the aquifer (fig. 22b). The surficial aquifer was dry during these periods, and there was an upward gradient in the Upper Floridan aquifer toward the creek along the remainder of the transect.

Of the three transects in the upper Hillsborough River subbasin, the Hillsborough River at State Road 39 transect (T2) is the farthest downstream, but it is still upstream fromf the Hillsborough River above Crystal Springs station. The river flowed continuously at this site during the study, even during prolonged dry periods. Head gradients in the Upper Floridan aquifer were consistently upward and toward the river during both wet and dry seasons (fig. 23 and 24), and were steeper than at the T1 transect, indicating greater potential for ground-water discharge. Surficial deposits did not contain water except after very wet periods and were not a significant source of water discharging to the river.

The Upper Hillsborough River Tract transect (T3) is the farthest upstream transect site in the upper Hillsborough River subbasin (fig. 2). The river was dry during all observations between November 2000 and July 2001, corresponding to a period of below normal rainfall (table 2; fig. 4). Streamflow was observed after July 2001 (fig. 25), except during one site visit in May 2002 when some ponding was evident but no flow was observed. During dry periods, the surficial aquifer wells did not contain water. During wet periods, the water table in the surficial aquifer was higher than Upper Floridan aquifer heads, and gradients were toward the river, indicating

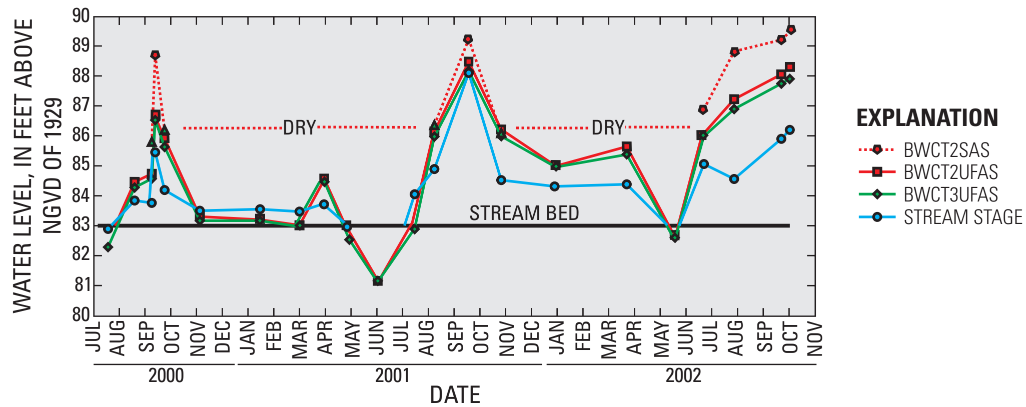


Figure 21. Water levels in selected wells and stream stage at the Blackwater Creek transect (T1), 2000–2002.

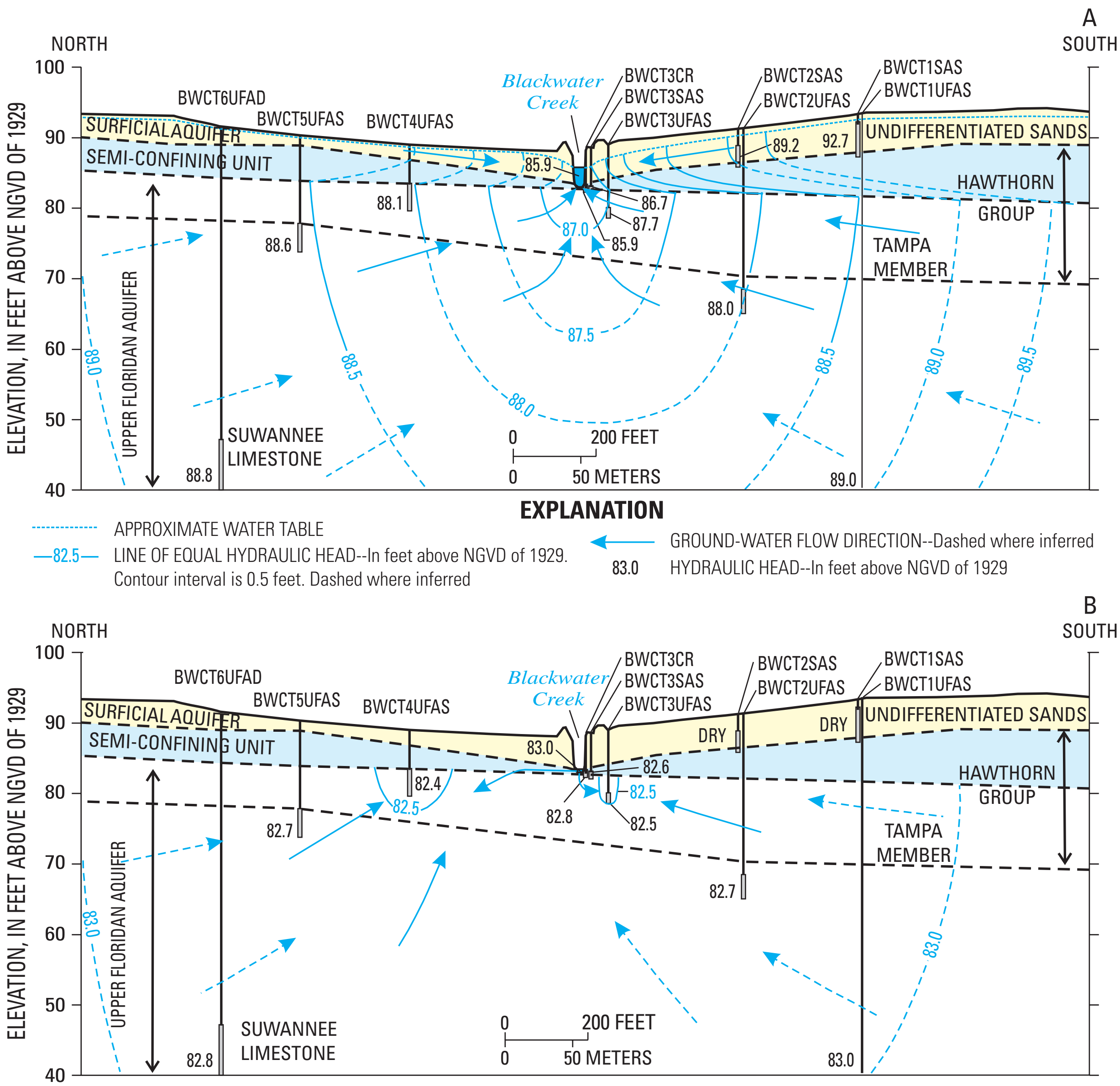


Figure 22. Ground-water flow at the Blackwater Creek transect (T1), during the (A) wet season, September 17, 2002, and the (B) dry season, May 2, 2001.

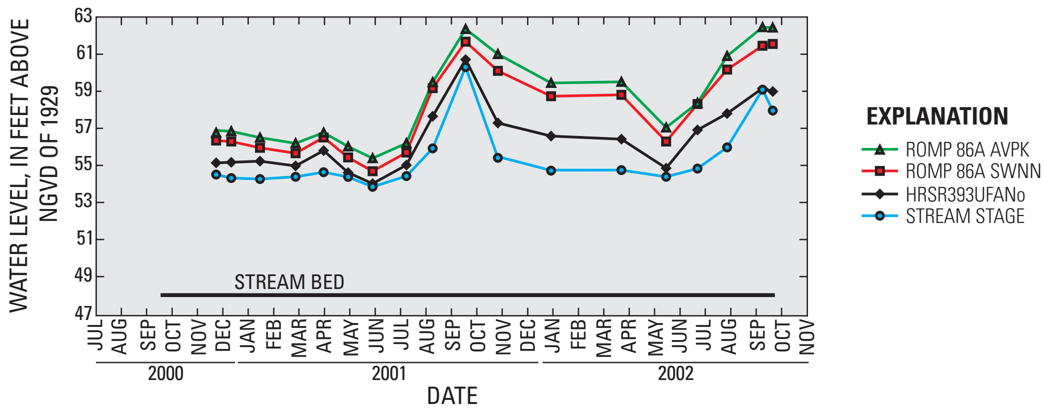


Figure 23. Water levels in selected wells and stream stage at the Hillsborough River at State Road 39 transect (T2), 2000–2002.

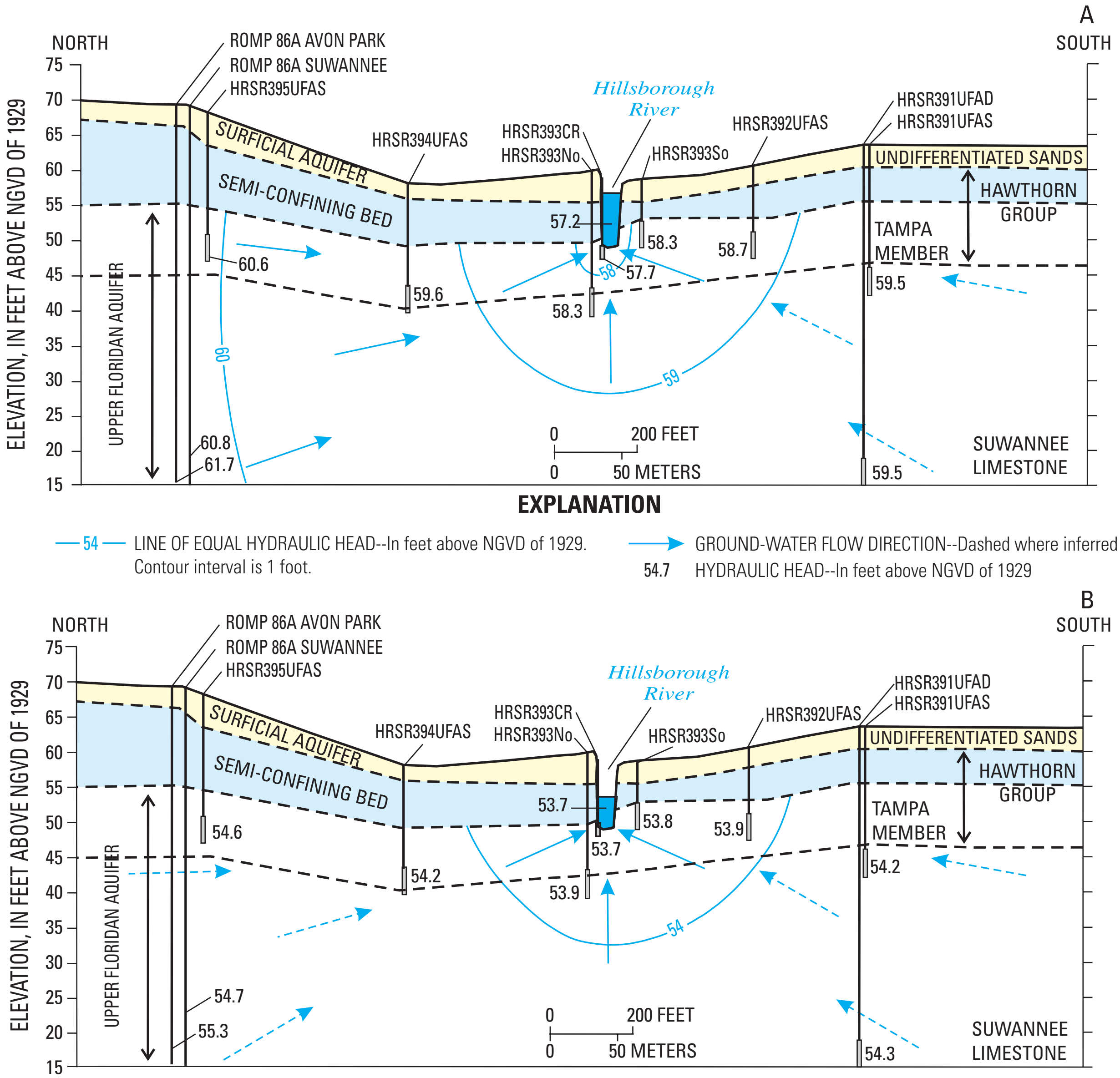


Figure 24. Ground-water flow at the Hillsborough River at State Road 39 transect (T2), during the (A) wet season, September 16, 2002, and the (B) dry season, May 2, 2001.

ground-water discharge to the river from the surficial aquifer as well as recharge from the surficial aquifer to the Upper Floridan aquifer. Consistent head gradients from the southeast to the northwest existed in the Upper Floridan aquifer during wet and dry periods at this transect that appear to be minimally influenced by the river. Heads in the Upper Floridan aquifer wells at the river (UHRT3UFAS) and at the northwest end of the transect (UHRT5UFAD) were lower than the river stage, indicating the potential for recharge to the underlying aquifer. Heads in the Upper Floridan aquifer well at the opposite end of the transect (UHRT1UFAD), however, were consistently higher than the river stage, indicating the potential for discharge from the deeper aquifer. The river may receive some ground-water inflow from the southeast but may lose water to the northwest. This transect appears to be less influenced by ground-water exchange than the other transect sites (fig. 25 and 26).

Simulated Ground-Water Discharge

Two dimensional, cross-sectional models were developed using the finite-difference ground-water flow simulation code MODFLOW (McDonald and Harbaugh, 1988: Harbaugh and McDonald, 1996) to quantify ground-water discharge to the streams. A simulation model was developed for each of the three transects (fig. 2). Boundary conditions for each steady-state simulation were identical, consisting of a head-dependent flux condition at the cells representing the stream and a constant head at the open interval of the wells aligned with the vertical sides of the cross sections (figs. 27-29). The MODFLOW River package (Harbaugh and McDonald, 1996) was used for the head-dependent conditions representing the stream. Recharge and evaporation were not simulated because preliminary simulations indicated that there was less than a 10-percent difference in simulated ground-water discharge to the stream if these boundary conditions were incorporated. Additionally, recharge and evaporation data corresponding to the water-level measurements were not available at each transect.

The model developed for the Blackwater Creek transect (T1; fig. 2) is shown in figure 27. Ground- and surface-water level data used for the simulations are shown in appendix 5. The Blackwater Creek transect grid consisted of 1 row and 200 columns of 10-ft by 10-ft cells and 40 layers 5 ft thick. The altitude of the top of the model (layer 1) and the base of the model (layer 40) are 100 ft above and 100 ft below NGVD of 1929, respectively. The creek is in the center of layer 4, in columns 99 to 102 (40 ft wide at the transect). A head-dependent flux boundary condition (stage) was applied at these cells. The creek bottom is at an altitude of 83 ft above NGVD of 1929. The thickness of the riverbed sediments was assumed to be 1 ft and the hydraulic conductivity was assumed to be similar to the surficial aquifer, which is 5 ft/d. The area of the river is assumed to be the entire cell, thus the riverbed conductance applied to the head-dependent flux term is 500 ft^2/d. A constant-head boundary condition (measured ground-water level) was assigned to the open interval of each well as follows: for well BWCT5UFAS, to column 1, layer 5; for well BWCT6UFAD, to column 1, layers 12 to 40; for well, BWCT1SAS to column 200, layers 2 and 3; and for well BWCT1UFAD, to column 200, layers 20 to 40. Stage and ground-water levels were varied for each steady-state simulation using the data in appendix 5. Hydraulic conductivity was assigned to the hydrologic units as follows: surficial aquifer, 5 ft/d; Tampa Member of the Arcadia Formation, 5 ft/d; semiconfining unit, 1 ft/d; and Suwannee Limestone, 130 ft/d. Hydraulic conductivities used for the hydrogeologic units are averages of previously published tests (Thompson and others, 1998) and values from tests conducted as part of this study.

Simulated ground-water discharge to the creek at the T1 transect ranged from 0.52 to 1.78 in/yr (table 11) for nine simulations during the months when the creek flowed. The average ground-water discharge simulated was about 1.0 in/yr; however, because the creek does not flow year round, the annual ground-water discharge to the creek should be less than 1.0 in/yr. The average residual error was -0.38 ft and the standard deviation was 0.56 ft for 45 observations. Sensitivity analysis using data from September 17, 2002, for each simulated multiplier is shown in table 12. Simulated ground-water discharge is most sensitive to the hydraulic conductivity of the semiconfining unit and relatively insensitive to the hydraulic conductivity of the riverbed.

The model developed for the Hillsborough River at State Road 39 transect (T2) is shown in figure 28. Ground- and surface-water level data used for the simulations are shown in appendix 5. The Hillsborough River at State Road 39 transect grid consists of 1 row and 164 columns of 10-ft by 10-ft cells and 30 layers. This model extends deeper into the formations than the other transect grids, because ground-water level data were available for the Avon Park Formation. The altitude of the top of the model (layer 1) and the base of the model (layer 30) are 70 ft above and 240 ft below NGVD of 1929, respectively; layers 1 to 16 are 5 ft thick; layers 17 to 21 are 10 ft thick; and layers 22 to 30 are 20 ft thick. The river is simulated in layer 5, columns 98 to 102 (50 ft wide at the transect). The head-dependent flux boundary condition (stage) was applied at these cells. The riverbed hydraulic conductivity is 1 ft/d and the bed is at an altitude of 48 ft above NGVD of 1929. The constant-head boundary was assigned to the open interval of each well as follows: for the HRSR395UFAS well, column 1, layer 5; for the ROMP 86A SWNN well, column 1, layers 17 to 21; for the ROMP 86A AVPK well, column 1, layer 30; for the HRSR391UFAS well, column 164, layer 6; and for the HRSR391UFAD well, column 164, layers 13 to 20. Stage and ground-water levels were varied for each steady-state simulation using the data in appendix 5. Hydraulic conductivity was assigned to the hydrologic units as follows: surficial aquifer, 3 ft/d; Tampa Member of the Arcadia Formation, 5 ft/d; semiconfining unit, 0.5 ft/d; semiconfining unit and Tampa Member of the Arcadia Formation mixed, 1 ft/d; the upper part of the Suwannee Limestone, 50 ft/d; the

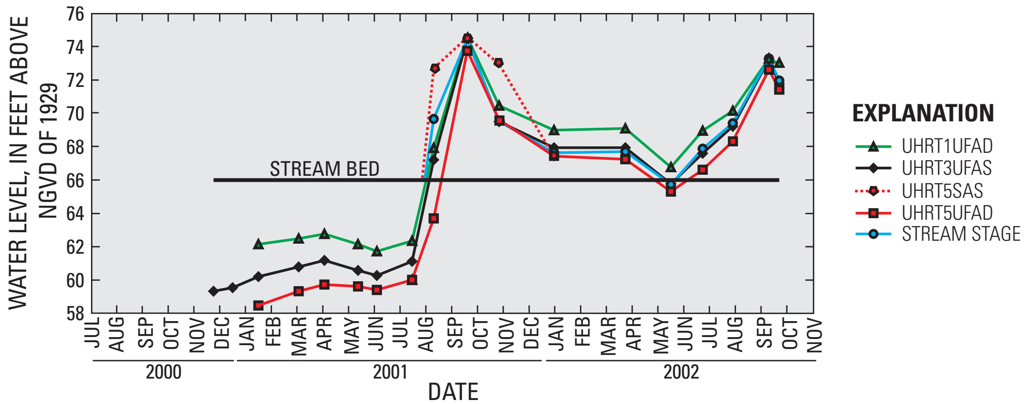


Figure 25. Water levels in selected wells and stream stage at the upper Hillsborough River Tract transect (T3), 2000–2002.

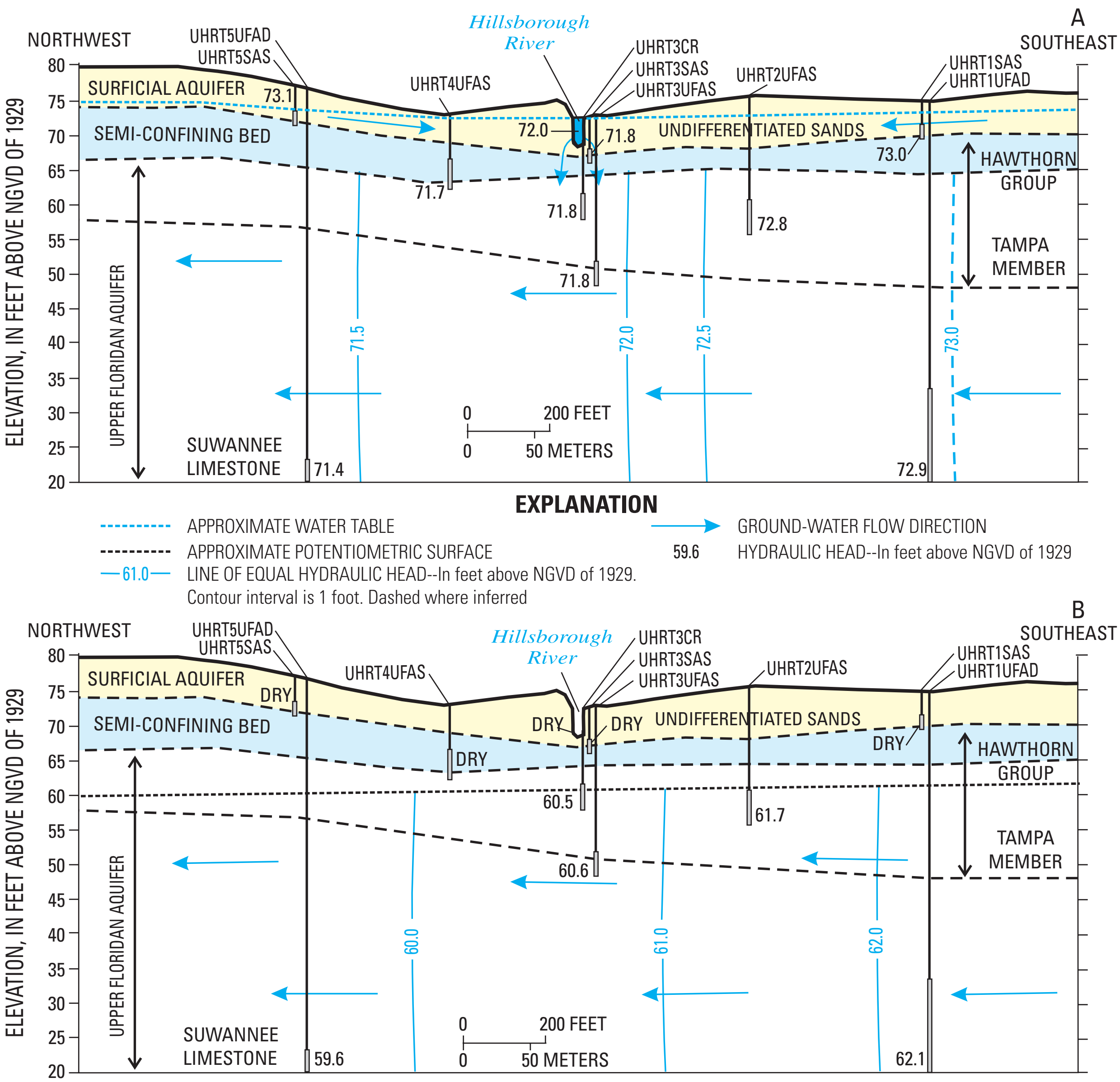


Figure 26. Ground-water flow at the upper Hillsborough River Tract transect (T3), during the (A) wet season, September 16, 2002, and the (B) dry season, May 14, 2001.

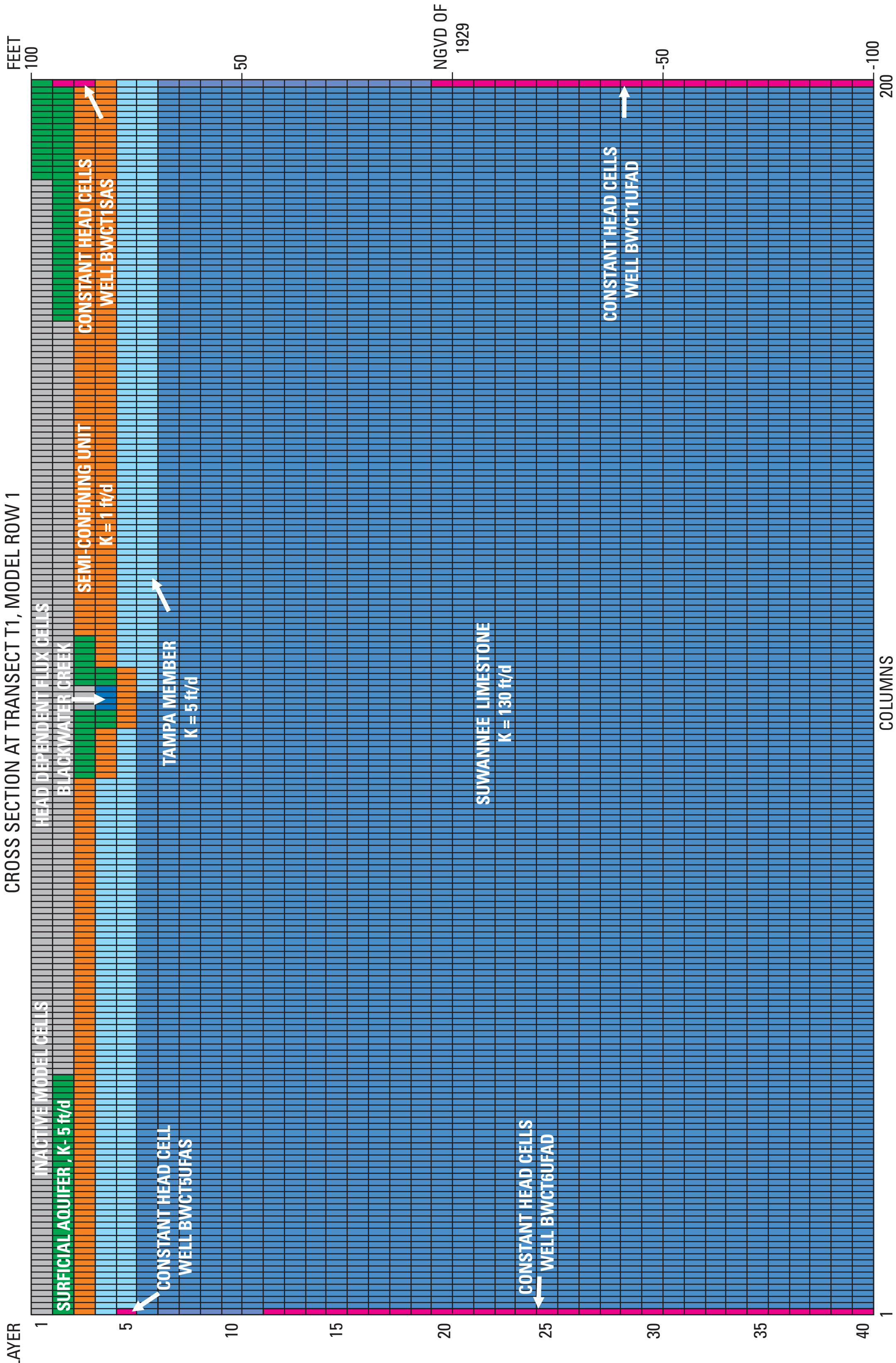


Figure 27. Cross-sectional model grid for the Blackwater Creek transect (T1).

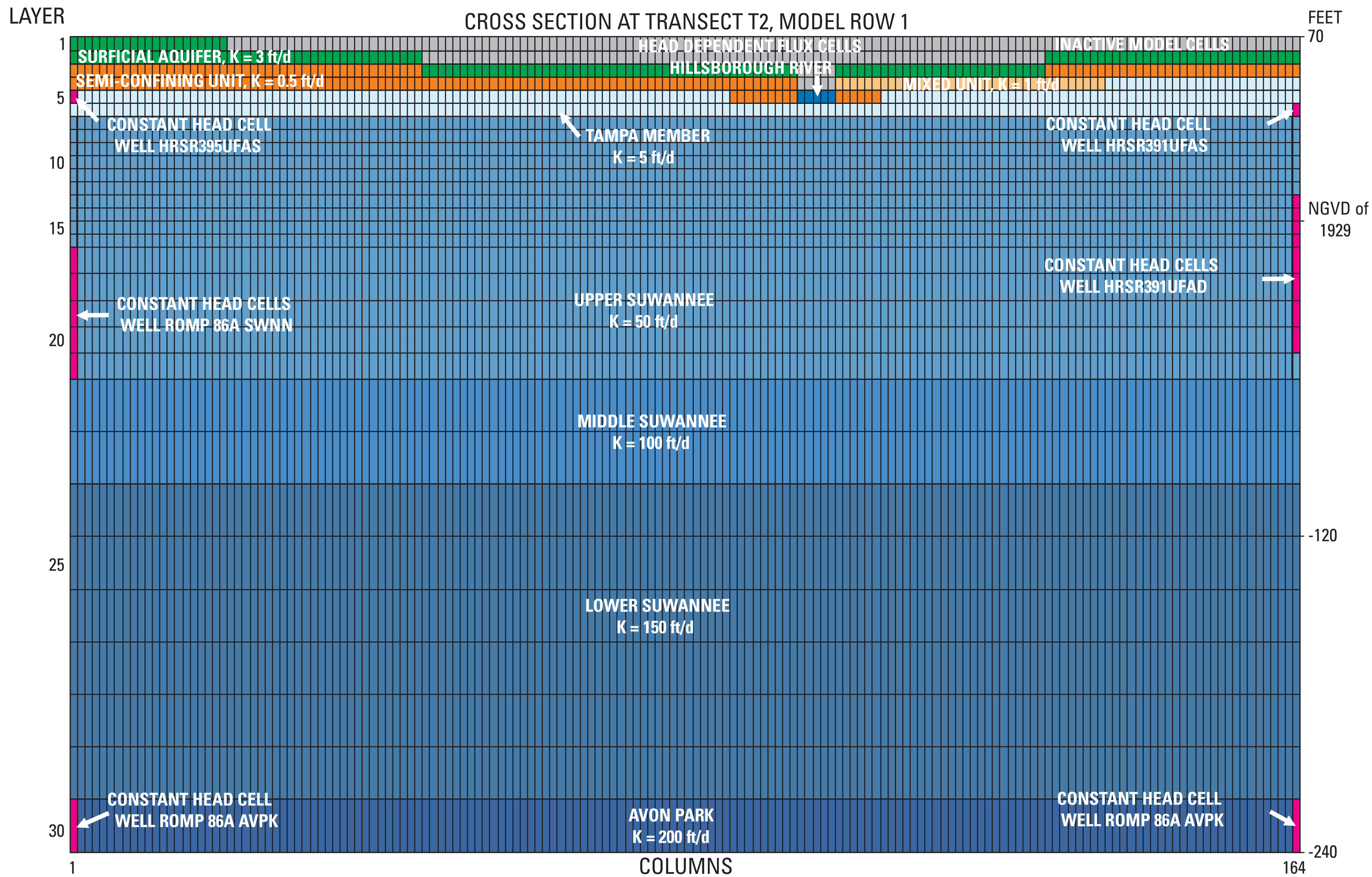


Figure 28. Cross-sectional model grid for the Hillsborough River at State Road 39 transect (T2).

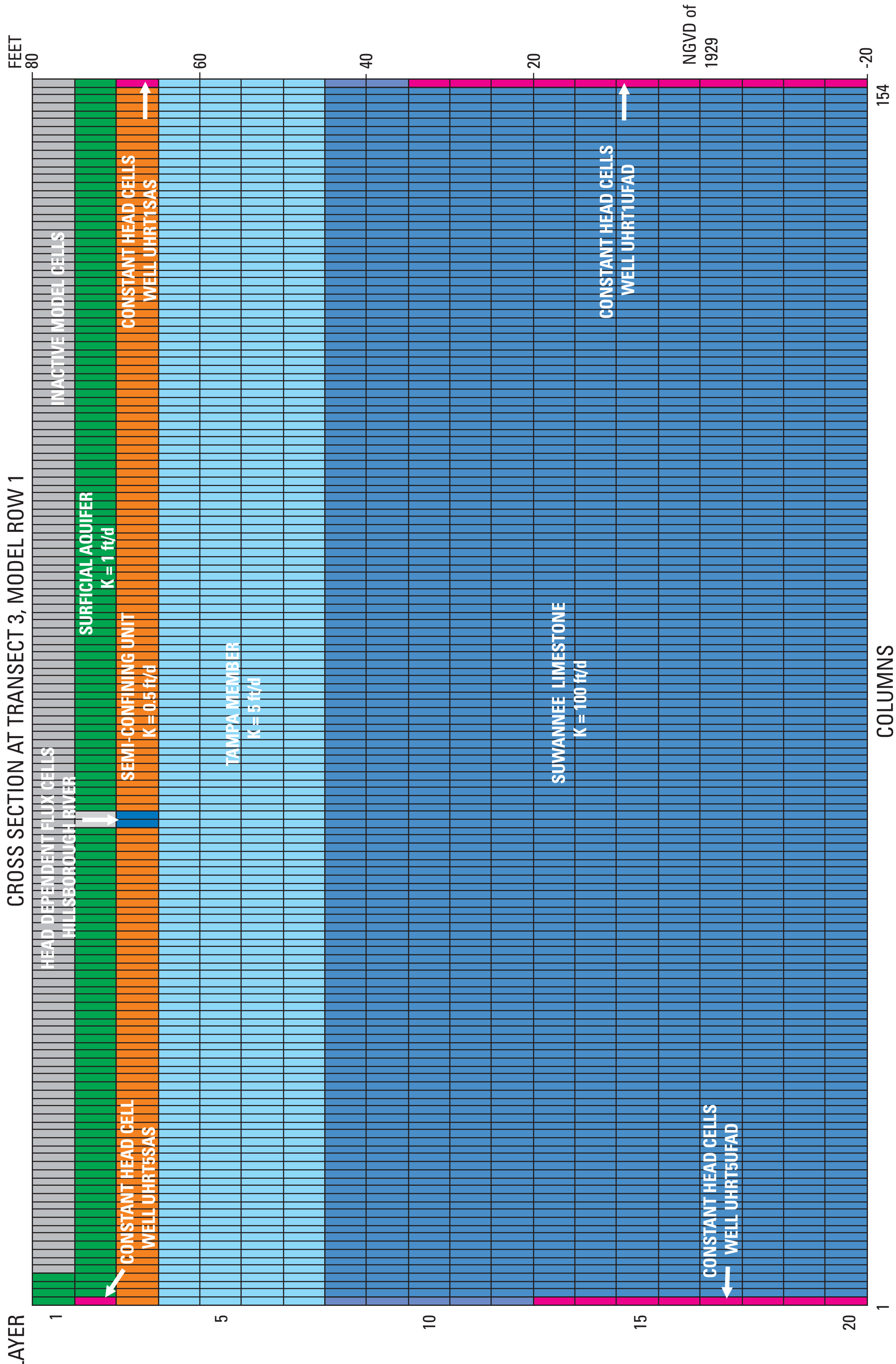


Figure 29. Cross-sectional model grid for the upper Hillsborough River Tract transect (T3).

Table 11. Simulated ground-water discharge at the Blackwater Creek transect site (T1).

Date	Cubic feet per day	Cubic feet per second	Cubic feet per second per square mile	Cubic feet per basin	Inches per year
8/9/2001	120	1.39×10^{-3}	0.73	5.87	0.79
9/18/2001	79.6	9.21×10^{-4}	.49	3.89	.52
10/26/2001	19.1	2.21×10^{-3}	1.17	9.34	1.26
12/27/2001	87.7	1.01×10^{-3}	.54	4.29	.58
3/21/2002	119	1.38×10^{-3}	.73	5.82	.78
6/19/2002	108	1.24×10^{-3}	.66	5.26	.71
7/24/2002	271	3.13×10^{-3}	1.65	11.3	1.78
9/17/2002	229	2.65×10^{-3}	1.40	11.2	1.50
9/27/2002	233	2.70×10^{-3}	1.43	11.4	1.53
Average	141	1.85×10^{-3}	0.98	7.60	1.05

Table 12. Simulated ground-water discharge, in cubic feet per day, for each formation for sensitivity analysis at the Blackwater Creek transect site (T1).

Multiplier	Suwannee Limestone	Tampa Member of the Arcadia Formation and surficial aquifer	Semiconfining unit	Riverbed
0.5	192	193	155	220
1	229	229	229	229
2	253	268	322	234
Scaled	0.37	0.45	1	0.08

middle Suwannee Limestone, 100 ft/d; the lower part of the Suwannee Limestone, 150 ft/d; and the Avon Park Formation, 200 ft/d. Hydraulic conductivities used for the hydrogeologic units are averages of previously published tests (Thompson and others, 1998) and values from tests conducted as part of this study.

Ground-water discharge to the river at the T2 transect ranged from 0.62 to 2.83 in/yr (table 13). The average ground-water discharge for all simulations was about 1.6 in/yr. Because the river flows continuously at T2, the average ground-water discharge represents an estimate of the annual ground-water discharge. The average residual error was -1.28 ft and the standard deviation was 0.64 ft for 85 observations. Sensitivity analysis using data from September 16, 2002, indicates that, similar to the Blackwater Creek model, the simulated ground-water discharge is most sensitive to the hydraulic conductivity of the semiconfining unit and relatively insensitive to the hydraulic conductivity of the surficial aquifer, the small zone of mixed semiconfining unit and Tampa Member of the Arcadia Formation, and the middle and upper Suwannee Limestone (table 14).

The model developed for the Upper Hillsborough River Tract transect (T3; fig. 2) is shown in figure 29. Ground- and surface-water level data used for the simulations are shown

Table 13. Simulated ground-water discharge at the Hillsborough River at State Road 39 transect site (T2).

Date	Cubic feet per day	Cubic feet per second	Cubic feet per second per square mile	Cubic feet per basin	Inches per year
12/15/2000	131	1.52 x10^{-3}	0.80	6.57	1.22
1/18/2001	116	1.35 x10^{-3}	.719	5.83	1.09
3/1/2001	91.4	1.06 x10^{-3}	.56	4.58	.85
4/3/2001	118	1.36 x10^{-3}	.72	1.10	1.10
5/2/2001	78.7	9.11 x10^{-4}	.48	5.90	.73
5/31/2001	66.8	7.73 x10^{-4}	.41	3.94	.62
7/10/2001	89.8	1.04 x10^{-3}	.55	3.35	.84
8/10/2001	210	2.49 x10^{-3}	1.32	10.8	2.01
9/18/2001	108	1.25 x10^{-3}	.66	5.41	1.01
10/26/2001	304	3.52 x10^{-3}	1.86	15.2	2.83
12/28/2001	261	3.02 x10^{-3}	1.60	13.1	2.44
3/21/2002	259	3.00 x10^{-3}	1.58	13.0	2.42
5/13/2002	132	1.53 x10^{-3}	.81	6.63	1.23
6/19/2002	209	2.42 x10^{-3}	1.28	10.5	1.95
7/24/2002	272	3.15 x10^{-3}	1.66	13.6	2.54
9/4/2002	163	1.89 x10^{-3}	1.00	8.17	1.52
9/16/2002	233	2.70 x10^{-3}	1.43	11.7	2.18
Average	167	1.94 x10^{-3}	1.02	8.20	1.56

Table 14. Simulated ground-water discharge, in cubic feet per day, for each formation for sensitivity analysis at the Hillsborough River at State Road 39 transect site (T2).

Multiplier	Avon Park Formation	Lower Suwannee Limestone	Middle Suwannee Limestone	Upper Suwannee Limestone	Tampa Member of the Arcadia Formation	Mixed Tampa Member of the Arcadia Formation and semiconfing unit	Semiconfining unit	Surficial aquifer	Riverbed
0.5	223	219	235	224	210	233	146	233	207
1	233	233	233	233	233	233	233	233	233
2	244	248	232	233	247	233	332	233	249
Scaled	0.112	0.155	0.013	0.052	0.196	0.0004	1	0.0009	0.222

in appendix 5. The Upper Hillsborough River Tract transect grid consists of 1 row and 154 columns of 10-ft by 10-ft cells, and 20 layers that are 5 ft thick. The altitude of the top of the model (layer 1) and the base of the model (layer 20) are 80 ft above and 20 ft below NGVD of 1929, respectively. The river is left of center, simulated in layer 3, columns 65 to 66 (20 ft wide at the transect). The upper part of the Hillsborough River was dry during most of 2001. Boundary conditions were applied to this cross-sectional model in the same way as the previous models. The riverbed hydraulic conductivity is 1 ft/d and the bed is at an altitude of 67 ft above NGVD of 1929. The constant-head boundarywas assigned to the open interval of each well as follows: for well UHRT5SAS, to column 1, layer 2; for well UHRT5UFAD, column 1, layers

13 to 20; for well, UHRT1SAS column 154, layer 3; for well UHRT1UFAD, column 154, layers 10 to 20. Stage and ground-water levels were varied for each steady-state simulation using the data in appendix 5. Hydraulic conductivity was assigned to the hydrologic units as follows: surficial aquifer, 1 ft/d; Tampa Member of the Arcadia Formation, 5 ft/d; semiconfining unit, 0.5 ft/d; and Suwannee Limestone, 100 ft/d.

Ground-water discharge to the river ranged from 0.01 to 0.07 in/yr (table 15). The average ground-water discharge for the months that the river flowed was about 0.05 in/yr. Because the river did not flow year-round, annual ground-water discharge was less than 0.05 in/yr (table 15). The average residual error was -0.06 ft and the standard deviation was 0.41 ft for 20 observations. Sensitivity analysis using data from September 16, 2002, indicates that similar to the other cross-sectional models, simulated ground-water discharge to the river was most sensitive to the hydraulic conductivity of the semiconfining unit and relatively insensitive to the hydraulic conductivity of the surficial aquifer (table 16).

The estimates of ground-water discharge to the streams from the numerical simulation are based on the assumption that the hydrogeologic framework and gradients are uniform for the watershed above each transect. However, the models were constructed with site-specific data. Although the three transects have similar hydrogeology, it is not known whether the entire watershed has similar properties. The sensitivity analyses indicate that the estimate of ground-water discharge to the stream is most affected by the hydraulic conductivity of the semiconfining unit present in all three transects. Elsewhere in the watershed where this unit is absent or higher hydraulic conductivity sediments are present, greater ground-water discharge to the stream than indicated by the flow-net analyses should occur. The models presented herein do not account for breaches in the semiconfining unit, or for conduit flow features such as springs. All three transects are located upstream from Crystal Springs, an area of focused ground-water discharge. Model results indicate that the upper reaches of the river in the upper Hillsborough River subbasin contribute less of the base flow than the lower reaches. Estimates also are less than the long-term estimates using hydrograph separation methods.

Table 15. Simulated ground-water discharge at the upper Hillsborough River Tract transect site (T3).

[Data are not shown for October 5 and December 28, 2001; and May 13, June 19, July 24, and September 4, 2002, because T3 was within a losing reach of the Hillsborough River during these periods]

Date	Cubic feet per day	Cubic feet per second	Cubic feet per second per square mile	Cubic feet per basin	Inches per year
10/25/2001	$1.05 \times 10^{+1}$	1.22×10^{-4}	0.06	0.30	0.07
12/28/2001	9.91	1.15×10^{-4}	0.06	0.28	0.07
3/21/2002	6.88	7.97×10^{-5}	0.045	0.20	0.05
9/16/2002	1.85	2.15×10^{-5}	0.01	0.05	0.01
Average	4.92	8.45×10^{-5}	0.04	0.21	0.05

Table 16. Simulated ground-water discharge, in cubic feet per day, for each formation for sensitivity analysis at the upper Hillsborough River Tract transect site (T3).

Multiplier	Suwannee Limestone	Tampa Member of the Arcadia Formation	Semiconfining unit	Surficial aquifer	Riverbed
0.5	1.72	1.50	1.20	1.84	1.66
1	1.85	1.85	1.85	1.85	1.85
2	1.93	2.12	2.56	1.87	1.97
Scaled	0.16	0.46	1	0.03	0.22

Summary

The upper Hillsborough River watershed covers a 220 mi^2 area upstream from Hillsborough River State Park where the watershed is relatively undeveloped. The watershed contains many karst features and can be subdivided into two major subbasins, namely, the upper Hillsborough River subbasin and the Blackwater Creek subbasin. The Blackwater Creek subbasin includes the Itchepackesassa Creek subbasin, which in turn includes the East Canal subbasin.

Major components of the data collection effort included streamflow and ground-water level measurements, and surface- and ground-water samples for water-quality analysis. Seepage runs, hydrograph separation, and numerical modeling were conducted to assess ground-water seepage to the river. Streamflow data were collected at six continuous gaging stations and six miscellaneous measurement sites. Detailed potentiometric-surface maps were produced using ground-water data collected from a network of 72 Upper Floridan aquifer wells. Water-quality samples were collected from 12 surface-water sites and 13 Upper Floridan aquifer wells. Crystal Springs was sampled at the outfall once during the study. Nutrient loads, yields, and trends were estimated at four daily streamflow stations that have long-term data.

The principal hydrogeologic units within the watershed include the surficial aquifer, the intermediate confining unit, and the Upper Floridan aquifer. Surficial deposits are thinnest near the stream channels and thickest toward the ridges. A continuous surficial aquifer does not extend across the entire study area. The confining unit is discontinuous near the Hillsborough River channel and along the middle and lower reaches of Blackwater Creek, but can be up to 30 ft thick on the Brooksville Ridge. Because of the karst nature of the underlying limestone, the confining unit is breached in many places and the degree of confinement between the Upper Florida aquifer and the surficial aquifer is highly variable.

Potentiometric-surface contours indicate good aquifer interconnection near the Hillsborough River, and less near Blackwater and Itchepackesassa Creeks. Water-level altitudes and fluctuations in the paired surficial and Upper Floridan aquifer wells at the T1 and T3 transects and at the ROMP 86.5 well sites also indicate good aquifer interconnection. Most of the surficial aquifer wells contained water only during the wet season, or only after substantial rainfall events. When a water table was observed in the surficial aquifer, it was generally higher than the potentiometric surface of the Upper Floridan aquifer, indicating recharge potential to the underlying aquifer.

Anthropogenic factors have affected ground-water levels in the watershed; however, natural variation in rainfall must also be considered in evaluations of water-level trends. Long-term, mean annual ground-water data for two Upper Floridan aquifer wells affected by large ground-water withdrawals indicated a declining trend. Data from a third long-term well located within the watershed and affected only by local conditions showed a lesser declining trend.

Water from all Upper Floridan aquifer wells was a calcium-bicarbonate type, with calcium (Ca) being the dominant cation. Dissolved oxygen (DO) was low, less than 2 mg/L, in most ground-water samples. Some samples with high dissolved organic carbon concentrations (DOC) had correspondingly high aromatics (high UV254 absorbance), indicating possible recharge through wetlands. Nitrate (NO_3) concentrations were near or below the detection limit in all wells sampled, except for samples from the Zephyrhills Park and Austin Smith wells. Nitrogen isotope data indicate the source of the elevated nitrogen concentrations was a mix between organic and inorganic nitrogen at the Zephyrhills Park well, and from an animal source at the Austin Smith well. Strontium isotope ratios indicate water samples from most wells were from the Suwannee Limestone. Uranium isotope activity ratios indicate the deeper ROMP 86A well may intersect a fracture zone in the Avon Park Formation.

Streamflow at the gaging stations along the upper Hillsborough River was sustained by ground water from the Upper Floridan aquifer during dry periods. Discharge from Crystal Springs consistuted between 85 and 100 percent of the river flow during dry periods. Runoff to the river during wet periods was moderated by the storage and release of water from riverine wetlands and by overflow from the Withlacoochee River. Streamflow in Blackwater and Itchepackesassa Creeks was less constant. During much of the dry season, Blackwater Creek is dry upstream from the confluence with Itchepackesassa Creek. Much of the dry season flow in Itchepackesassa Creek originates from the treated wastewater effluent outfall along East Canal. There is often less flow at the downstream Blackwater Creek station than at the Itchepackesassa Creek station, indicating surface water recharge to the underlying aquifer.

Duration curves for the Hillsborough River sites for the study period are similar in shape and slope to duration curves for the period of record, indicating stable and constant flow in the Hillsborough River over time. In contrast, the slope of the curve for the Blackwater Creek station for the study period is steeper, declining more rapidly at its lower end, than for the period of record. Conditions in the watershed during the study period were drier than normal, resulting in less streamflow and lower ground-water levels.

Double mass curve analysis of daily streamflow indicates a change in slope around 1969 for the Hillsborough River near Zephyrhills station. At Crystal Springs, multiple changes in the slope of the line occur over the period of record. The first occurs about 1945 and may be attributable to the dynamiting of the spring vent and subsequent damming of the spring run. The 1969 slope change coincides with the wetter pre- and drier post-1970 rainfall cycles related to the Atlantic Multidecadal Oscillation (AMO). Previous studies have examined rainfall and streamflow in Florida rivers with relation to the AMO and found them to be directly correlated.

The water quality of streams in the study area is influenced by ground-water discharge. As with ground-water samples, calcium was the dominant ion in samples from the upper Hillsborough River. Wastewater effluent from the outfall influenced water quality and quantity in East Canal and in downstream Itchepackesassa and Blackwater Creeks, resulting in higher variability than in the Hillsborough River. Calcium also was the dominant ion in water from the unaffected reaches of Itchepackesassa and Blackwater Creeks; however, calcium concentrations were less than those of water from the Hillsborough River sites, indicating less ground-water discharge to the creeks.

Organic carbon concentrations were higher in surface-water samples collected during the wet season than the dry season due to runoff from adjacent wetland areas. Greater seasonal fluctuation in DOC was observed in water from the Hillsborough River than from Blackwater and Itchepackesassa Creeks. During the wet season, the inundated areas adjacent to the Hillsborough River are larger than the areas adjacent to Blackwater and Itchepackesassa Creeks, resulting in higher DOC concentrations in river water. The DOC concentrations in the Hillsborough River declined as wetland runoff ceased. Concentrations of many trace metals were greater in water from Blackwater and Itchepackesassa Creeks than in the Hillsborough River, particularly during the dry season when organic carbon concentrations were higher in the creeks than the river. Many trace metals had distinct seasonal fluctuations in the river, with lower concentrations occurring in the dry season when DOC concentrations also were much lower. Aluminum, copper, iron, lead, and zinc were positively correlated with DOC, and probably are mobilized by complexing with the organic acids. Aluminum, iron, and lead concentrations also were positively correlated with streamflow, indicating a surface or shallow source.

During base-flow conditions, strontium concentrations increased in the upper Hillsborough River in the downstream direction, indicating increased ground-water discharge. Strontium isotope ratios were greater at the three upstream river sites than at the three downstream sites, indicating a deeper water source at the downstream sites near Crystal Springs. Strontium isotope ratios at the East Canal and Itchepackesassa Creek sites indicate Miocene-age seawater, most likely from the carbonate Tampa Member of the Arcadia Formation. Ratios at the Blackwater Creek sites indicate Oligocene-age seawater, most likely from the Suwannee Limestone; however, the source appears shallower than in the upper Hillsborough River subbasin. Uranium isotope data for the Hillsborough River sites and Crystal Springs indicate the source of the water is from a rapid ground-water flow system, whereas data from Blackwater Creek indicate a slower ground-water flow system. Water from the ROMP 86A Suwannee well was isotopically similar to water from Blackwater Creek. In contrast, water from 24 wells sampled as part of a previous study were similar to Crystal Springs and the Hillsborough River. Those 24 wells were located north of the river in an area previously defined as the ground-water basin to Crystal Springs. Uranium data suggest a rapid ground-water flow system discharging to the Hillsborough River; however, strontium data indicate this water may circulate deeper than water discharging to Blackwater and Itchepackesassa Creeks. The area discharging to the river appears to have a well-developed karst flow system that may intercept the Eocene-age Ocala or Avon Park Limestones. The ground-water system discharging to Blackwater and Itchepackesassa Creeks apparently is shallower, with a less developed karst flow system.

Bacteria samples were collected from the upper Hillsborough River, Blackwater Creek, and Itchepackesassa Creek. Most samples indicate the probable sources of the bacteria are cattle and native animals in this riverine ecosystem.

Five surface-water sites were sampled for organic wastewater compounds and pesticides that included industrial, agricultural, and household products; pharmaceuticals and antibiotics; and sterols and hormones. Thirty-eight of these compounds were detected; however, concentrations were typically less than 1 μg/L. The most commonly detected compounds were DEET, a topical insect repellent; phenol, a disinfectant; cholesterol, an animal waste by-product; and atrazine, a herbicide. Other compounds detected include fire retardants, sterols, disinfectants, fragrances, detergent metabolites, and polycyclic aromatic hydrocarbons. Plant and animal sterols (hormones) were detected; these can occur naturally or be an indicator of wastewater. Caffeine was the only "human drug" detected, and was found at three sites downstream from the wastewater outfall on East Canal.

Nitrogen species varied in the upper Hillsborough River both seasonally and in a downgradient direction. The dominant species of nitrogen in water at the three upstream sites was total Kjeldahl nitrogen. The large riverine wetlands and cattle grazing activities are the probable source of this form of nitrogen. Inorganic nitrogen was the dominant species in the river at the three downstream sites. Inorganic nitrogen was negatively correlated with streamflow, indicative of a ground-water source. Springs, including Crystal Springs, are located in and near the river along this subreach. The change in the dominant nitrogen species, and the large increase in inorganic nitrogen concentration in an area of known ground-water discharge, indicates ground-water contributes substantial amounts of inorganic nitrogen to the river. The dominant species of nitrogen in water at all the Blackwater and Itchepackesassa Creek sites and from East Canal was total Kjeldahl nitrogen. Much of the Blackwater and Itchepackesassa Creek subbasins are rural or agricultural and contain wetland areas. The chemical composition of samples collected downstream from the East Canal outfall site reflects the influence of treated effluent.

Nitrogen isotope ratios for sites on the upper Hillsborough River indicated a mixture of inorganic and organic nitrogen. The only exception was at the farthest upstream site, where nitrate concentrations were consistently very low and the $\delta^{15}N$ value was in the range of organic nitrogen from animal sources. Ground water sampled during a previous study had high nitrate concentrations and low $\delta^{15}N$ values, indicating inorganic fertilizer is the source of elevated nitrate. The Hillsborough River and Crystal Springs samples from this study generally plot along a mixing line formed by the median ground-water $\delta^{15}N$ value from a previous study, and the value from the upstream Hillsborough River site, implying that the elevated nitrate in the river and from Crystal Springs is from fertilizer.

Orthophosphate concentrations in surface water from the upper Hillsborough River were higher in the wet season than in the dry season. Ground-water samples and a sample collected from Crystal Springs had low orthophosphate concentrations and were similar to dry season concentrations in river water. The Blackwater Creek, Itchepackesassa Creek, and East Canal sites receive less ground-water discharge than the upper Hillsborough River sites, resulting in higher orthophosphate concentrations and less seasonal variation.

Nutrient loads, yields, and trends were estimated for the sites with continuous streamflow data for the 2001 and 2002 water years. The inorganic nitrogen trend for a longer period also was calculated for Crystal Springs. The gaging station at Hillsborough River State Park was used to characterize nutrient loads and yields exported from the entire upper Hillsborough River watershed. Nutrient loads and yields generally increased as streamflow increased. Most of the nitrogen exported during the study was total Kjeldahl nitrogen, which varied by more than an order of magnitude between wet and dry seasons. Seasonal loading of inorganic nitrogen was less variable because a large part of the nitrate nitrogen is from ground water. Phosphorous loads and yields also were greater during the wet season than during the dry season, but were not as variable as nitrogen. Nutrient loads and yields were considerably greater from Blackwater Creek than from the upper Hillsborough River. Total Kjeldahl nitrogen was the dominant species from Blackwater Creek, whereas inorganic nitrogen was the dominant species from the upper Hillsborough River. About 75 percent of the nitrogen load and about 62 percent of the phosphorous load from Blackwater Creek was from Itchepackesassa Creek. Nutrient loads and yields were greater during the 2001 water year than during the 2002 water year.

A statistically significant increasing trend in inorganic nitrogen, and decreasing trends in organic nitrogen and orthophosphate were observed in data from the gaging station at Hillsborough River State Park. A decreasing trend in orthophosphate was observed in data from the gaging station at Hillsborough River above Crystal Springs, and at Blackwater Creek. The increasing trend for median annual nitrate concentration in samples from Crystal Springs was statistically significant for the period of record prior to 1990, but was not significant for the period from 1990 to 2002.

Synoptic streamflow measurements were made along the main channel of the upper Hillsborough River, Blackwater Creek, Itchepackesassa Creek, and East Canal to estimate ground-water discharge to the streams. Measurements were made during base-flow conditions in May and November 2001. During low base-flow conditions when ground-water levels also were low, six losing stream reaches and seven gaining stream reaches were identified, indicating both recharge and discharge was occurring throughout the upper Hillsborough River watershed. During high base-flow conditions when ground-water levels were higher, all stream reaches were gaining except near the confluence of East Canal and Itchepackesassa Creek, where losing stream reaches were observed in the same areas as the low base-flow seepage run.

Mean annual base flow estimated using the partition method during this study ranged from about 4 to 9 in/yr. Ground-water recharge to the river at the Hillsborough River State Park, estimated in other studies using specific conductance mass-balance and a moving minimum value modification of the hydrograph separation method was about half the amount calculated for this study using the partition method. Lower base-flow volume also was estimated in another study. Two factors may affect the accuracy of the recharge estimates: relatively small topographic relief and potentially slow drainage of surface water from wetlands. Both factors exist in the study area and probably caused the overestimation.

Ground-water flow was mapped and discharge simulated at three well transects to better understand and quantify ground-water flow near the streams. During wet conditions at the Blackwater Creek transect (T1), stream stage was lower than ground-water heads and head gradients were toward the stream. The surficial aquifer contained water only during the wet season and gradients were relatively steep toward the creek. During the dry season when backwater from Itchepackesassa Creek occurred, the stream stage was higher than heads adjacent to the stream, causing localized recharge to the aquifer. The surficial aquifer was dry during these periods, and there was an upward gradient in the Upper Floridan aquifer toward the creek along the remainder of the transect. The river continuously flowed at the Hillsborough River at State Road 39 transect (T2) during the study. Head gradients in the Upper Floridan aquifer were consistently upward and toward the river for both wet and dry seasons and were steeper than at the T1 transect, indicating greater potential for ground-water discharge. The river at the Upper Hillsborough River Tract transect (T3) was dry during all observations between November 2000 and July 2001. During dry periods, the surficial aquifer did not contain water. During wet periods, the water table in the surficial aquifer was higher than Upper Floridan aquifer heads, and gradients were toward the river, indicating ground-water discharge to the river, as well as potential recharge to the Upper Floridan aquifer. Consistent head gradients from the southeast to the northwest existed in the Upper Floridan aquifer during both wet and dry periods at transect T3. Heads in the Upper Floridan aquifer wells at the river and at the northwest end of the transect were lower than the river stage, indicating the potential for recharge to the underlying aquifer. Heads in the Upper Floridan aquifer well at the opposite end of the transect, however, were consistently higher than the river stage, indicating the potential for discharge to the river from the deeper aquifer. The river may receive some ground-water inflow from the southeast. This transect is less influenced by ground-water exchange than the other transect sites.

Two dimensional, cross-sectional numerical models were developed for each transect. Simulated ground-water discharge to the creek at the T1 transect averaged about 1.0 in/yr; however, because the creek does not flow year round, the annual ground-water discharge to the creek should be less than 1.0 in/yr. The simulated ground-water discharge at the Hillsborough River at State Road 39 transect (T2) averaged about 1.6 in/yr. Because the river flows continuously at this site, the average simulated ground-water discharge represents an estimate of the annual ground-water discharge. Simulated ground-water discharge to the river at the Upper Hillsborough River Tract transect (T3) averaged about 0.05 in/yr. Because the river did not flow year round annual ground-water discharge is less than 0.05 in/yr. The estimates of ground-water discharge to the streams are based on the assumption that the hydrogeologic framework and gradients are uniform for the watershed above each transect. The models were constructed with site-specific data and it is not known whether these data are applicable for the entire watershed. Sensitivity analysis indicated that the estimate of ground-water discharge to the stream is most affected by the hydraulic conductivity of the semiconfining unit. Elsewhere in the watershed, this unit is absent or higher hydraulic conductivity sediments are present. The Hillsborough River watershed contains karst features that create areas of focused ground-water discharge, such as Crystal Springs. The models do not account for breaches in the semiconfining unit, or for conduit flow features such as springs. The numerical simulations indicate the upper reaches of the river in the upper Hillsborough River subbasin contribute less of the base flow than the lower reaches. Simulation-based estimates also are less than the long-term estimates based on hydrograph separation methods.

Selected References

American Public Health Association, 1998, Standard methods for the examination of water and wastewater (20th ed.), Clesceri, L.S., Greenberg, A.E., and Eato, A.D. (eds.): Washington, D.C. American Public Health Association, American Water Works Association, and Water Environmental Federation.

Basso, R.J., and Schultz, R.W., 2003, Long-term variation in rainfall and its effects on Peace River flow in west-central Florida: Brooksville, Southwest Florida Water Management District.

Bouwer, H., and Rice, R.C., 1976, A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells: Water Resources Research, v. 12, no. 3, p. 423-428.

Cherry, R.N., Stewart, J.W., and Mann, J.A., 1970, General hydrology of the middle gulf area, Florida: Tallahassee, Florida Bureau of Geology Report of Investigations 56, 96 p.

Champion, K.M., and DeWitt, D.J., 2000, Origin of nitrate in ground water discharging from Crystal Springs, Pasco County, Florida: Brooksville, Southwest Florida Water Management District, 192 p.

Cohen, T.A., DeLong, L.L., Gilroy, E.J., Hirsch, R.M., and Wells, D.K., 1989, Estimating constituent loads: Water Resources Research, v. 25, no. 5, p. 937-942.

Cowart, J.B., and Osmund, J.K.,1992, Uranium isotopes as indicators of ground-water susceptibility to nitrate pollution: Report to the Southwest Florida Water Management District, Brooksville, Fla.

Daniel, C.C., and Harned, D.A., 1998, Ground-water recharge to and storage in the regolith-fractured crystalline rock aquifer system, Guilford County, North Carolina: U.S. Geological Survey Water-Resources Investigations Report 97-4140, 65 p.

Depaolo, D.J., and Ingram, B.L., 1985, High-resolution stratigraphy with strontium isotopes: Science, v. 227, p. 938–941

Duerr, A.D., 2001, Potentiometric surfaces of the Upper Floridan aquifer, west-central Florida, May 2001: U.S. Geological Survey Open-File Report 01-310, 1 sheet.

Duerr, A.D., 2003, Potentiometric surfaces of the Upper Floridan aquifer, west-central Florida, September 2002: U.S. Geological Survey Open-File Report 03-223, 1 sheet.

Elder, J.F., 1986, Transport and variability of indicator bacteria in the Apalachicola River and estuary, Florida, 1983-84: U.S. Geological Survey Water-Resources Investigations Report 85-4285, 29 p.

Enfield, D.B., Mestas-Nunez, A.M., Trimble, P.J., 2001, The Atlantic Multidecadal Oscillation and its relation to rainfall and river flows in the continental U.S.: Geophysical Research Letters, v. 28, no. 10, p. 2077–2080.

Fernandez, Mario, Jr., Goetz, C.L., and Miller, J.E., 1984, Evaluation of future base-flow water-quality conditions in the Hillsborough river, Florida: U.S. Geological Survey Water-Resources Investigations Report 84-4182, 47 p.

Geldreich, E.E., 1966, Sanitary significance of fecal coliforms in the environment: U.S. Department of the Interior Water Pollution Control Administration WP-20-3, 101 p.

Goetz, C.L., Reichenbaugh, R.C., and Ogle, J.K., 1978, Water-supply potential of the lower Hillsborough River, Florida: U.S. Geological Survey Water-Resources Investigations Report 78-29, 25 p.

Halford, K.J. and Mayer, G.C., 2000, Problems associated with estimating ground water discharge and recharge from stream-discharge records: Ground Water, v. 38, no. 3 p. 331-342.

Hancock, M.C., and Smith, D.A., 1996, Northern Tampa Bay water resources assessment project, Vol. 1: Surface-water/ground-water interrelations: Brooksville, Southwest Florida Water Management District.

Harbaugh, A.W., and McDonald, M.G., 1996, User's documentation for MODFLOW-96, an update to the U.S. Geological Survey modular finite difference ground-water flow model: U.S. Geological Survey Open-File Report 96-485, 56 p.

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

Helsel and Hirsch, 1995, Statistical Methods in Water Resources: Amsterdam, Elsevier Science, 529 p.

Hess, J., Bender, M.L., and Schilling, J.G., 1986, Seawater $^{87}Sr/^{86}Sr$ evolution from Cretaceous to present: Science v. 231, p. 979–984.

Hirsch, R.M., Alexander, R.B., and Smith, R.A., 1991, Selection of methods for the detection and estimation of trends in water-quality data: Water Resources Research, v. 27, no. 5, p. 803-813.

Hortness, J.E., and Vidmar, Peter, 2005, Surface-water/ground-water interaction along reaches of the Snake River and Henrys Fork, Idaho: U.S. Geological Survey Scientific Investigations Report 2004-5115, 18 p.

Howarth, R.J., and McArthur, J.M., 1997, Statistics for strontium isotope stratigraphy: A robust LOWESS fit to the marine Sr-isotope curve for 0–206 Ma, with look-up table for the derivation of numerical age: Journal of Geology, v. 105, p. 441-456.

Jones, G.W., Upchurch, S.B., Champion, K.M., and Dewitt, D.J., 1997, Water-quality and hydrology of the Homosassa, Chassahowitzka, Weeki Wachee, and Aripeaka Spring complexes, Citrus and Hernando Counties, Florida—Origin of increasing nitrate concentrations: Brooksville, Southwest Florida Water Management District, 165 p.

Jones, I.C., Vacher, H.L., and Budd, D.A., 1993, Transport of calcium, magnesium, and SO_4 in the Floridan aquifer, west-central Florida: implications to cementation rates: Journal of Hydrology, v. 143, p. 455-480.

Katz, B.G., Catches, J.S., Bullen, T.D., Michel, R.L., 1998, Changes in isotopic and chemical composition of ground water resulting from a recharge pulse from a sinking stream: Journal of Hydrology, v. 211, p. 178-207.

Kelley, M., 2004, Florida river flow patterns and the Atlantic multidecadal oscillation (draft): Brooksville, Southwest Florida Water Management District.

Kendall, Carroll, 1998, Tracing nitrogen sources and cycles in catchments, *in* Kendall, C., and McDonnell, J.J., eds., Isotope tracers in catchment hydrology: Amsterdam, Elesevier, p. 519-576.

Kerr, R.A., 2000, A North Atlantic climate pacemaker for the centuries: Science, v. 288, no. 5473, 1984-1986.

Kinzelbach, W., Aeschbach, W., Alberich, C., Goni, I.B., Beyerle, U., Brunner, P., Chiang, W-H., Rueedi, J., and Zoellmann, K., 2002, A survey of methods for groundwater recharge in arid and semi-arid regions: Early warning and assessment report series, Nairobi, Kenya, United Nations Environmental Program, UNEP/DEWA/RS.02-2, 101 p.

Knutilla, R.L., Corral, M.A., Jr., 1984, Impacts of the Tampa Bypass Canal system on the areal hydrology, Hillsborough County, Florida: U.S. Geological Survey Water-Resources Investigations Report 84-4222, 65 p.

Kolpin, D.W, Furlong, E.T., Meyer, M.T, Thurman, E.M., Zaugg, S.D., Barber, L.B., and Buxton, H.T, 2002, Pharmaceuticals, hormones, and other organic wastewater contaminants in U.S. streams, 1999–2000: A national reconnaissance: Environmental Science and Technology, v. 36, no. 6, p. 1202-1211.

Kreitler, C.W., 1975, Determining the source of nitrogen in ground water by nitrogen isotope studies: University of Texas, Austin, Bureau of Economic Geology, Report of Investigation 83, 57 p.

Kreitler, C.W., Ragone, S.F., and Katz, B.G., 1978, $^{14}N/^{15}N$ ratios of ground water nitrate, Long Island, New York: Ground Water, v. 16, no. 6, p. 404-409.

Lee, K.E., Barber, L.B., Furlong, E.T., Cahill, J.D., Kolpin, D.W., Meyer, M.T., and Zaugg, S.W., 2004, Presence and distribution of wastewater compounds in wastewater, surface, ground, and drinking waters, Minnesota, 2000-02: U.S. Geological Survey Scientific Investigations Report 2004-5138, 47 p.

Lewelling, B.R., 2004, Extent of areal inundation along five river systems in the upper Hillsborough River watershed, west-central Florida: U.S. Geological Survey Water-Resources Investigations Report 04-5133, 60 p.

McDonald, M.G., and Harbaugh, A.W., 1988, A modular three dimensional finite difference ground-water flow model: U.S. Geological Survey Techniques of Water-Resources Investigations, book 6, chap. A1, 586 p.

Menke, C.G., Meridith, E.W., and Wetterhall, W.S., 1961, Water resources of Hillsborough County, Florida: Tallahassee, Florida Geological Survey, Report of Investigations 25, 101 p.

Metz, P.A., and Sacks, L.A., 2002, Comparison of the hydrology and water quality of a ground-water augmented lake with non-augmented lakes in northwest Hillsborough County, Florida: U.S. Geological Survey Water-Resources Investigations Report 02-4032, 74 p.

Murphy, W.R., Jr., 1978, Flood profiles for Cypress Creek, west-central Florida: U.S. Geological Survey Water-Resources Investigations Report 78-8, 29 p.

Osmund, J.K., and Cowart, J.B., 1976, The theory and uses of uranium isotopes in hydrology: Atomic Energy, Rev. 14.

Pettyjohn, W.A., and Henning, Roger, 1979, Preliminary estimate of ground-water recharge rates related to streamflow and water quality in Ohio: Ohio State University, Water Resources Center, Project Completion Report 552, 323 p.

Plummer, L.N., 1977, Defining reactions and mass transfer in part of the Floridan aquifer: Water Resources Research, v. 13, no. 5, p. 801-812.

Rutledge, A.T., 1998, Computer programs for describing the recession of ground-water discharge and for estimating mean ground-water recharge and discharge from streamflow data-Update: U.S. Geological Survey Water-Resources Investigations Report 98-4148, 43 p.

Ryder, P.D., 1985, Hydrology of the Floridan aquifer system in west-central Florida: U.S. Geological Survey Professional Paper 1403-F, 63 p.

Sacks, L.A., and Tihansky, A.B., 1996, Geochemical and isotopic composition of ground water, with emphasis on sources of sulfate in the upper Floridan aquifer and intermediate aquifer system in southwest Florida: U.S. Geological Survey Water-Resources Investigations Report 96-4146, 54 p.

Scott, T.M., 19881, The lithostratigraphy of the Hawthorne Group (Miocene) of Florida: Tallahassee, Florida Geological Survey, Bulletin 59, 148 p.

Searcy, J.K., 1959, Flow duration curves: Manual of Hydrology, pt. 2 *of* Low-flow techniques: U.S. Geological Survey Water-Supply Paper 1542-A, 33 p.

Searcy, J.K., and Hardison, C.H., 1960, Double-mass curves: Manual of Hydrology, pt. 1 *of* General surface-water techniques: U.S. Geological Survey Water-Supply Paper 1541-B, 65 p.

Sinclair, W.C., 1974, Hydrologic characteristics of the surficial aquifer in northwest Hillsborough County, Florida: Tallahassee, Florida Bureau of Geology, Information Circular 86, 98 p.

Sloto, R.A., and Crouse, M.Y., 1996, HYSEP: A computer program for streamflow hydrograph separation and analysis: U.S. Geological Survey Water-Resources Investigations Report 96-4040. 46 p.

Southwest Florida Water Management District, 1996, Northern Tampa Bay Water Resources Assessment Project: Vol. 1, Surface-water/ground-water interrelationships: Brooksville, 427 p.

Southwest Florida Water Management District, 2001, Regional water supply plan: Brooksville, 266 p.

Southeastern Geological Society, Ad Hoc committee, cds., 1986, Hydrogeologic units of Florida: Tallahassee, Florida Geological Survey, Special Publication 28, 9 p.

Stewart, J.W., 1977, Hydrologic effects of pumping a deep limestone sink near Tampa, Florida, U.S.A., *in* Proceedings of the 12th International Congress on Karst Hydrology, Huntsville, Alabama: p. 125-211.

Stewart, J.W., Goetz, C.L., Mills, L.R., 1978, Hydrogeologic factors affecting the availability and quality of ground-water in the Temple Terrace area, Hillsborough County, Florida: U.S. Geological Survey Water-Resources Investigations Report 78-4, 38 p.

Stewart, Mark, Cimino, Joseph, Ross, Mark, 2007, Calibration of base flow seperation methods with streamflow conductivity: Ground Water, v. 45, no. 1, p. 17-27.

Tampa Water Department, 2001, Water quality report for the year 2001: Tampa, Florida, Water Department Brochure, accessed May 15, 2001, at *http://www.TampaGov.net/water/*

Thompson, D., Basso, R., and Albury, C., 1998, Drilling and testing report, Romp 86.5, Cone Ranch, Hillsborough County, Florida: Brooksville, Southwest Florida Water Management District, p. 47.

Tihansky, A.B., 2005, Effects of aquifer heterogeneity on ground-water flow and chloride concentrations in the Upper Floridan aquifer near and within an active pumping well field, west-central Florida: U.S. Geological Survey Scientific Investigations Report 2004-5268, 75 p.

Turner, J.F., Jr., 1974, Flood profiles of the lower Hillsborough River, Florida: U.S. Geological Survey Open File Report FL-74003, 29 p.

U.S. Geological Survey, variously dated, National field manual for the collection of water quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A1-A9, accessed February 15, 2007, at *http://pubs.water.usgs.gov/twri9a*

U.S. Geological Survey, 1935, Surface water supply of the United States 1935, pt. 2 *of* South Atlantic Slope and Eastern Gulf of Mexico Basins: U.S. Geological Survey Water-Supply Paper 782, 233 p.

U.S. Geological Survey, 1989, Federal glossary of selected terms—Subsurface-water flow and solute transport: USGS, Office of Water Data Coordination, Ground Water Subcommittee of the Federal Interagency Advisory Committee on Water Data, 38 p.

Vernon, R.O., 1951, Geology of Citrus and Levy Counties, Florida: Tallahassee, Florida Geological Survey Bulletin 33, 256 p.

Weber, K., and Perry R.G., 2001, Impacts of ground-water withdrawals in the Hillsborough River region, Hillsborough, Pasco, and Polk Counties: Brooksville, Southwest Florida Water Management District, Report 99-2, 29 p.

White, W.A., 1970, The geomorphology of the Florida Peninsular, Tallahassee, Florida Geological Survey, Bulletin 51, 164 p.

Wolansky, R.M., and Thompson,T.H., 1987, Relation between the ground water and surface water in the Hillsborough River basin, west-central Florida: U.S. Geological Survey Water-Resources Investigations Report 87-4010, 58 p.

Appendixes 1-5

Appendix 1. Ground-water data-collection sites.

[UFA, Upper Floridan aquifer; SA, Surficial aquifer; --, no value, or value was not known]

Site number (fig. 6)	USGS station identifier	Station name	County	Total depth (feet)	Casing depth (feet)	Aquifer	Number of water quality samples
1	275728081570001	ROMP 60X	Polk	806	212	UFA	--
2	275759082085402	ROMP DV-2 Howthorn/Tampa Well	Hillsborough	130	--	UFA	--
3	275926082123404	ROMP DV-2 Avon Park Well	Hillsborough	850	--	UFA	--
4	280042082142301	Griffen Well	Hillsborough	590	100	UFA	--
5	280053081572301	Orleans Street Well	Polk	773	219	UFA	--
6	280145082132501	Tampa Well Field No. 15	Hillsborough	315	300	UFA	--
7	280305082185101	Morris FLRD Well near Thonontosassa	Hillsborough	162	74	UFA	--
8	280338081572901	North Florida Avenue Well	Polk	865	203	UFA	--
9	280350082104401	Fisher FLRD Well	Hillsborough	2	2	UFA	--
10	280408082080801	Mcintosh ELAPP UFA Well	Hillsborough	155	99	UFA	--
11	280413082061401	Quagliani FLRD Well	Hillsborough	216	80	UFA	--
12	280438082075301	Martin Griffin FLRD Well	Hillsborough	469	127	UFA	--
13	280438082172901	Upper Hillsborough FDA Well #22	Hillsborough	152	68	UFA	--
14	280455082021501	JB Sergeant FLRD Well	Hillsborough	144	96	UFA	--
15	280503082143702	ROMP 68-2 TPA/SWNN Well	Hillsborough	220	120	UFA	--
16	280510082043801	T-2 DP Well - CNR	Hillsborough	585	130	UFA	--
17	280520081575201	Cresent Street Well	Polk	827	224	UFA	--
18a	280553082045101	ROMP 86.5 CM-10UFA	Hillsborough	195	120	UFA	--
18b	280553082045102	ROMP 86.5 CM-10SAS	Hillsborough	12	2	SA	--
19a	280558082060901	ROMP 86.5 CM-7UFA	Hillsborough	195	120	UFA	--
19b	280558082060902	ROMP 86.5 CM-7SAS	Hillsborough	24	2	SA	--
20	280605082184101	Moris Bridge FLRD Well 12	Hillsborough	520	238	UFA	--
21a	280621082043201	ROMP 86.5 CM-9UFA	Hillsborough	195	120	UFA	--
21b	280621082043202	ROMP 86.5 CM-9SAS	Hillsborough	12	2	SA	--
22a	280622082082701	ROMP 86.5 CM-8UFA	Hillsborough	177	102	UFA	3
22b	280622082082702	ROMP 86.5 CM-8SAS	Hillsborough	6	1	SA	--
23a	280650082060901	ROMP 86.5 CM-6UFA	Hillsborough	174	99	UFA	--
23b	280650082060902	ROMP 86.5 CM-6SAS	Hillsborough	7	2	SA	--
24	280655082193001	Morris Bridge FLRD Well 3A	Hillsborough	600	95	UFA	--
25	280659082175201	Morris Bridge FLRD Well 13	Hillsborough	593	50	UFA	--
26	280708082074801	T-1 DP Well - CNR	Hillsborough	579	140	UFA	--
27	280740082105201	Blackwater Creek ELAPP UFA Well	Hillsborough	154	94	UFA	--
28a	280756082071901	ROMP 86.5 CM-5UFA	Hillsborough	175	100	UFA	--
28b	280756082071902	ROMP 86.5 CM-5SAS	Hillsborough	6	1	SA	--
29a	280821082062901	ROMP 86.5 CM-4UFA	Hillsborough	175	100	UFA	--
29b	280821082062902	ROMP 86.5 CM-4SAS	Hillsborough	6	1	SA	--
30	280837082063101	BWC Transect Well 6UFAD	Hillsborough	91	43	UFA	6
31	280846082134601	Hillsborough River State Park Boys Camp Deep Well	Hillsborough	74	62	UFA	2
32	280849082053701	T-3 DP Well - CNR	Hillsborough	700	144	UFA	--
33	280852082135601	Hillsborough River State Park Parking Lot Deep Well	Hillsborough	50	37	UFA	--
34a	280908082052601	ROMP 86.5 CM-3UFA	Hillsborough	195	118	UFA	--
34b	280908082052602	ROMP 86.5 CM-3SAS	Hillsborough	12	2	SA	--
35	280926082162101	USGS Tampa Well 532	Hillsborough	46	44	UFA	--
36a	280936082041501	ROMP 86.5 CM-2UFA	Hillsborough	195	120	UFA	--
36b	280936082041502	ROMP 86.5 CM-2SAS	Hillsborough	12	2	SA	--
37a	280951082061901	ROMP 86.5 CM-1UFA	Hillsborough	195	120	UFA	--

Appendix 1. (Continued) Ground-water data-collection sites.

[UFA, Upper Floridan aquifer; SA, Surficial aquifer; --, no value, or value was not known]

Site number (fig. 6)	USGS station identifier	Station name	County	Total depth (feet)	Casing depth (feet)	Aquifer	Number of water quality samples
37b	280951082061902	ROMP 86.5 CM-1SAS	Hillsborough	6	1	SA	--
38	280957082072001	LS-01 Deep Well	Hillsborough	65	40	UFA	--
39	281031082071801	Alston Deep Well	Pasco	98	59	UFA	4
40	281037082071801	J Alston Well	Pasco	55	47	UFA	--
41	281052082052601	Alston 1 Deep (UFA) Well	Pasco	112	50	UFA	--
42	281130082095101	HRSR39 Transect Well-1UFAD	Pasco	112	44	UFA	--
43	281138082120201	Zephyrhills Prison FLRD	Pasco	99	42	UFA	4
44a	281144082100401	ROMP 86A AVPK Well	Pasco	560	500	UFA	1
44b	281144082100402	ROMP 86A SWNN Well	Pasco	135	75	UFA	6
45	281208082080401	Yonkers Mine - MW3	Pasco	48	33	UFA	--
46	281230082081901	Yonkers Mine - MW5	Pasco	110	55	UFA	--
47	281232082075001	Yonkers Mine - MW4	Pasco	50	35	UFA	--
48a	281247082074101	UHRT TRANSECT Well-1UFAD	Pasco	93	41	UFA	6
48b	281247082074102	UHRT TRANSECT Well-1SAS	Pasco	5.2	3.2	SA	--
49a	281257082075401	UHRT TRANSECT Well-5UFAD	Pasco	93	54	UFA	--
49b	281257082075402	UHRT TRANSECT Well-5SAS	Pasco	5.2	3.2	SA	--
50	281301082081301	SWFWMD UFA Well near Yonkers Mine	Pasco	137	71	UFA	--
51	281312082011601	ROMP 87 FLRD Well	Polk	380	300	UFA	2
52	281322082084501	Chancey Rd FLRD Well	Pasco	87	50	UFA	4
53	281353082110401	Zephyrhills Park FLRD Well	Pasco	100	55	UFA	4
54	281424082192702	ROMP 85	Pasco	300	160	UFA	--
55	281443082055501	Howard Blvd UFA Well	Pasco	172	134	UFA	--
56	281504082104801	ROMP 86 Avon Park Well	Pasco	434	425	UFA	--
57	281532082065001	54-East FLRD Well	Pasco	98	45	UFA	4
58	281533082130601	Austin Smith RD FLRD Well	Pasco	102	68	UFA	4
59	281556082104701	Wire Road FLRD Well	Pasco	139	92	UFA	--
60	281654082065901	US HWY 98 Well	Pasco	200	41	UFA	--
61	281715082164401	SR 577 DP Well	Pasco	150	57	UFA	--
62	281938082141501	ROMP BR-3 Lake Pasadena Deep	Pasco	246	133	UFA	4
63	281951082012001	Green Swamp Well L11MD	Sumter			UFA	--
64	282005082112801	Stearns Well	Pasco			UFA	--
65	282121082071101	Cummer Office Well	Pasco			UFA	--
66	282127082012001	ROMP 89 - Compressco Ranch	Sumter			UFA	--
67	282154082142401	Haycraft Well	Pasco			UFA	--
68	282221082103001	Collura Well	Pasco			UFA	--

Appendix 2. Statistical summary of selected water-quality data from surface-water sites in the upper Hillsborough River watershed, water years 2000–2002.

[Units are in milligrams per liter except as noted; µS/cm, microsiemens per centimeter; µg/L, micrograms per liter; cols/100mls, colonies per 100 milliliters; --, no value, or value was below detection limit]

Property or constituent	Number of samples	Hillsborough River at T2 Transect (281135082095500)			Number of samples	Hillsborough River at limerock Mine (281205082080200)			Number of samples	Hillsborough River at T3 Transect (281251082074900)		
		Maximum	Minimum	Median		Maximum	Minimum	Median		Maximum	Minimum	Median
Specific conductance (µS/cm)	8	406	136	354	4	380	114	328	6	499	115	330
pH, field	8	8.3	7.2	7.6	4	8.0	7.0	7.6	6	8.2	6.9	7.4
Oxygen, dissolved	3	5.3	2.8	4.0	4	3.9	3.7	3.8	4	4.8	3.5	4.2
Total dissolved solids	8	246	167	215	4	243	158	212	6	302	147	234
Alkalinity, ANC (as $CaCO_3$)	8	179	50	148	4	159	40	133	6	241	37	145
Calcium, dissolved (as Ca)	8	71	22	61	4	68	19	56	6	88	18	58
Magnesium, dissolved (as Mg)	8	3.9	2.2	3.7	4	3.7	2.01	3.5	6	4.3	1.8	4.0
Sodium, dissolved (as Na)	8	7.1	4.6	6.6	4	6.9	4.2	6.5	6	7.7	3.9	6.8
Potassium, dissolved (as K)	8	2.3	.50	.70	4	2.1	.40	1.2	6	2.7	1.0	1.7
Chloride, dissolved (as Cl)	8	10	7.9	9.9	4	10	7.0	9.8	6	14	6.4	11
Sulfate, dissolved (as SO_4)	8	20	2.5	17	4	22	11	18	6	5.5	2.6	3.7
Flouride, dissolved (as F)	8	.22	.19	.20	4	.20	.20	.20	6	.20	.20	.20
Silica, dissolved (as SIO_2)	8	10	3.2	6.8	4	9.2	5.5	6.5	6	12	4.2	6.8
Organic Carbon, total (as C)	8	38	3.1	8.1	4	43	2.8	14	6	45	8.9	20
Organic Carbon, dissolved (as C)	8	35	2.5	5.9	4	39	2.7	13	6	42	8.8	18
Nitrogen, total (as N)	8	1.7	.35	.45	4	1.8	.32	1.1	6	3.1	.70	2.0
Nitrogen, ammonia,total (as N)	8	.08	.02	.04	4	.28	--	.20	6	1.2	.02	.10
Nitrogen, ammonia plus organic, total (as N)	8	1.7	--	.41	4	1.7	.26	1.0	6	2.9	.50	1.9
Nitrogen, Nitrite, total (as N)	8	.01	--	--	4	.03	--	--	6	.06	--	.01
Nitrogen, $NO_2 + NO_3$, total (as N)	8	.34	.02	.15	4	.22	.03	.10	6	.24	.02	.14
Phosphorus, total(as P)	8	.39	.06	.09	4	.37	.02	.14	6	.61	.08	.18
Orthophosphorus, total(as P)	8	.35	.04	.07	4	.33	.03	.16	6	.56	.07	.12
Total Coliform (cols/100mls)	7	7,083	260	1,000	4	6,133	130	440	4	8,000	530	1,183
Fecal Coliform (cols/100mls)	7	570	40	100	4	117	3	57	4	330	42	92
Fecal Strep (cols/100mls)	7	4,200	30	97	4	540	56	200	4	470	140	290

Appendix 2. (Continued) Statistical summary of selected water-quality data from surface-water sites in the upper Hillsborough River watershed, water years 2000–2002.

[Units are in milligrams per liter except as noted; µS/cm, microsiemens per centimeter; µg/L, micrograms per liter; cols/100mls, colonies per 100 milliliters; --, no value, or value was below detection limit]

Property or constituent	Number of samples	Hillsborough River above Crystal Springs (02301990)			Number of samples	Hillsborough River below Crystal Springs (02302010)			Number of samples	Hillsborough River near Zephyrhills (024303000)		
		Maximum	Minimum	Median		Maximum	Minimum	Median		Maximum	Minimum	Median
Specific conductance (µS/cm)	17	399	119	360	10	385	234	357	12	403	184	369
pH, field	17	8.3	6.3	7.3	10	8.3	7.7	7.8	12	8.7	6.2	7.6
Oxygen, dissolved	17	5.5	3.4	4.1	5	5.9	4.9	5.8	12	8.0	4.8	6.3
Total dissolved solids	11	239	150	213	10	253	176	211	11	234	169	219
Alkalinity, ANC (as $CaCO_3$)	11	174	44	151	10	160	94	151	11	169	67	154
Calcium, dissolved (as Ca)	11	70	20	62	10	63	37	62	11	64	29	62
Magnesium, dissolved (as Mg)	11	4.0	2.0	3.8	10	7.1	3.0	4.0	11	4.7	2.7	4.4
Sodium, dissolved (as Na)	11	6.7	4.0	5.9	10	29	4.6	5.7	11	16	5.4	9.5
Potassium, dissolved (as K)	11	2.3	.04	.70	10	8.1	.30	.60	11	4.8	.40	2.0
Chloride, dissolved (as Cl)	11	12	6.6	10	10	39	8.0	11	11	20	9.6	14
Sulfate, dissolved (as SO_4)	11	21	1.5	12	10	32	8.3	9.7	11	26	4.7	16
Flouride, dissolved (as F)	11	.20	.10	.14	10	.40	.10	.11	11	.30	.10	.20
Silica, dissolved (as SIO_2)	11	11	5.6	8.9	10	11	5.5	10	11	10	7.4	9.3
Organic Carbon, total (as C)	11	28	.05	5.1	10	21	.30	1.7	11	34	1.2	4.0
Organic Carbon, dissolved (as C)	11	37	.04	4.5	10	20	.15	1.4	11	30	.80	3.9
Nitrogen, total (as N)	12	2.1	1.3	1.7	10	2.3	1.6	2.0	12	2.1	1.5	1.8
Nitrogen, ammonia,total (as N)	12	.06	--	.02	10	.32	--	.02	12	.08	--	.02
Nitrogen, ammonia plus organic, total (as N)	12	1.6	.20	.20	10	1.1	.20	.70	12	1.5	.20	.40
Nitrogen, Nitrite, total (as N)	12	--	--	--	10	--	--	--	12	.02	--	--
Nitrogen, NO_2 + NO_3, total (as N)	12	2.0	.07	1.3	10	2.1	.73	1.9	12	1.9	.31	1.6
Phosphorus, total(as P)	12	.30	.02	.05	10	.47	.02	.05	12	.96	.05	.08
Orthophosphorus, total(as P)	12	.31	.02	.04	10	.46	.03	.04	12	.76	.04	.08
Total Coliform (cols/100mls)	10	5,900	250	1,100	7	1,367	631	810	10	9,200	310	375
Fecal Coliform (cols/100mls)	10	1,300	20	112	7	120	40	92	10	290	18	40
Fecal Strep (cols/100mls)	10	616	81	160	7	420	46	76	10	480	26	55

Appendix 2. (Continued) Statistical summary of selected water-quality data from surface-water sites in the upper Hillsborough River watershed, water years 2000–2002.

[Units are in milligrams per liter except as noted; µS/cm, microsiemens per centimeter; µg/L, micrograms per liter; cols/100mls, colonies per 100 milliliters; --, no value, or value was below detection limit]

Property or constituent	Number of samples	Blackwater Creek at T1 Transect (280828082062900)			Number of samples	Blackwater Creek near Knights (02302500)			Number of samples	Blackwater Creek upstream of mouth (280858082124800)		
		Maximum	Minimum	Median		Maximum	Minimum	Median		Maximum	Minimum	Median
Specific conductance (µS/cm)	7	413	127	394	12	1,230	211	412	4	694	301	502
pH, field	7	8.4	7.1	7.8	12	8.4	6.9	7.6	4	7.3	8.3	8.0
Oxygen, dissolved	4	6.9	4.9	5.5	10	7.0	4.0	6.0	4	6.7	6.5	6.6
Total dissolved solids	7	248	170	228	11	745	126	259	4	401	215	310
Alkalinity, ANC (as $CaCO_3$)	7	193	28	179	11	247	46	118	4	223	40	135
Calcium, dissolved (as Ca)	7	65	15	62	11	80	21	43	4	74	34	50
Magnesium, dissolved (as Mg)	7	8.1	2.7	7.6	11	10	3.1	8.1	4	8.2	4.9	7.2
Sodium, dissolved (as Na)	7	8.4	6.2	7.7	11	150	9.0	25	4	50	18	36
Potassium, dissolved (as K)	7	3.9	.70	1.3	11	46	4.7	6.2	4	14	5.4	9.2
Chloride, dissolved (as Cl)	7	17	8.1	12	11	150	9.2	3.2	4	57	24	42
Sulfate, dissolved (as SO_4)	7	12	2.3	7.7	11	190	13	25	4	61	16	37
Flouride, dissolved (as F)	7	.30	.20	.30	11	.52	.10	.40	4	.40	.40	.40
Silica, dissolved (as SIO_2)	7	17	8.1	13	11	12	1.3	7.0	4	13	2.9	9.0
Organic Carbon, total (as C)	7	29	4.0	5.9	11	28	8.4	13	4	23	9.3	12
Organic Carbon, dissolved (as C)	7	31	4.1	6.1	11	26	8.5	13	4	21	7.0	12
Nitrogen, total (as N)	7	2.4	.20	.51	11	2.2	.67	1.5	4	1.7	.68	1.1
Nitrogen, ammonia,total (as N)	7	.11	.01	.04	11	.12	.01	.06	4	.04	.01	.03
Nitrogen, ammonia plus organic, total (as N)	7	2.3	.02	.50	11	1.7	.50	.90	4	1.4	.52	.86
Nitrogen, Nitrite, total (as N)	7	.02	--	--	11	.04	--	--	4	--	--	--
Nitrogen, NO_2 + NO_3, total (as N)	7	.11	--	.05	11	1.3	.02	.29	4	.50	.16	.22
Phosphorus, total(as P)	7	1.4	.14	.16	11	1.1	.28	.53	4	.52	.43	.49
Orthophosphorus, total(as P)	7	1.4	.11	.17	11	1.0	.26	.48	4	.48	.47	.48
Total Coliform (cols/100mls)	6	6,000	1,233	1,733	9	9,300	60	851	4	8,300	280	2,735
Fecal Coliform (cols/100mls)	6	733	36	445	9	7,900	26	100	4	127	32	61
Fecal Strep (cols/100mls)	6	663	150	395	9	3,533	47	102	4	650	50	235

Appendix 2. (Continued) Statistical summary of selected water-quality data from surface-water sites in the upper Hillsborough River watershed, water years 2000–2002.

[Units are in milligrams per liter except as noted; µS/cm, microsiemens per centimeter; µg/L, micrograms per liter; cols/100mls, colonies per 100 milliliters; --, no value, or value was below detection limit]

Property or constituent	Number of samples	Itchepackesassa Creek near Knights (02302260)			Number of samples	Itchepackesassa Creek near Moriczville (02302280)			Number of samples	East Canal of Itchepackesassa Creek (280430082071800)		
		Maximum	Minimum	Median		Maximum	Minimum	Median		Maximum	Minimum	Median
Specific conductance (µS/cm)	4	353	200	255	14	1,764	191	405	4	1,734	677	1,435
pH, field	4	8.0	7.6	7.6	14	8.4	6.5	7.5	4	8.4	7.4	8.1
Oxygen, dissolved	4	6.3	5.1	5.7	10	9.5	4.41	6.2	4	7.9	5.5	6.7
Total dissolved solids	4	210	156	181	12	1,040	156	245	4	1,060	421	890
Alkalinity, ANC (as $CaCO_3$)	4	103	49	76	12	311	48	98	4	312	156	207
Calcium, dissolved (as Ca)	4	36	22	27	12	72	22	35	4	85	47	74
Magnesium, dissolved (as Mg)	4	6.6	4.0	5.2	12	11	3.4	5.4	4	12	6.1	11
Sodium, dissolved (as Na)	4	21	8.1	14	12	240	5.7	28	4	230	71	175
Potassium, dissolved (as K)	4	6.1	4.6	5.0	12	55	.40	8.1	4	65	18	47
Chloride, dissolved (as Cl)	4	38	13	22	12	240	12	35	4	240	80	175
Sulfate, dissolved (as SO_4)	4	20	10	13	12	190	9.6	28	4	280	58	185
Flouride, dissolved (as F)	4	.60	.40	.43	12	.60	.10	.40	4	.60	.48	.50
Silica, dissolved (as SIO_2)	4	8.3	.38	4.3	12	11	2.1	9.0	4	16	8.0	13
Organic Carbon, total (as C)	4	24	15	18	12	25	3.7	15	4	14	6.8	11
Organic Carbon, dissolved (as C)	4	23	15	18	12	25	2.9	15	4	18	6.6	12
Nitrogen, total (as N)	4	2.2	1.3	1.7	13	3.3	.91	1.7	4	2.5	1.2	1.8
Nitrogen, ammonia,total (as N)	4	.18	.04	.11	13	.21	.01	.08	4	.06	.02	.04
Nitrogen, ammonia plus organic, total (as N)	4	1.9	1.1	1.4	13	2.6	.02	1.1	4	1.2	.70	1.0
Nitrogen, Nitrite, total (as N)	4	.03	--	--	13	.05	--	--	4	.04	--	--
Nitrogen, $NO_2 + NO_3$, total (as N)	4	.51	.18	.27	13	1.8	.14	.33	4	1.8	.06	.67
Phosphorus, total(as P)	4	.82	.56	.68	13	1.1	.03	.54	4	.30	.03	.15
Orthophosphorus, total(as P)	4	.74	.49	.65	13	.91	.06	.49	4	.41	.03	.13
Total Coliform (cols/100mls)	4	5,700	960	1,184	11	10,333	700	2,500	1	--	--	--
Fecal Coliform (cols/100mls)	4	1,620	18	118	11	3,933	33	608	1	--	--	--
Fecal Strep (cols/100mls)	4	2,700	155	310	11	5,567	240	967	1	--	--	--

Appendix 3. Nutrient loads at the HR6, HR4, BWC2 and IC2 sites in the upper Hillsborough River watershed, water years 2001 and 2002.

[All units in tons]

	Total nitrogen	Inorganic nitrogen	Organic nitrogen	Total phos-phorous	Ortho-phos-phorous	Total nitrogen	Inorganic nitrogen	Organic nitrogen	Total phos-phorous	Ortho-phos-phorous
HR6 Site	Water Year 2001					Water Year 2002				
October	8.6	7.4	1.2	0.81	0.65	24	12	13	7.1	6.7
November	6.4	5.8	.60	.35	.26	11	8.9	2.2	1.3	1.1
December	6.4	5.8	.57	.33	.24	19	8.6	1.8	.98	.85
January	6.2	5.7	.55	.32	.23	11	8.9	1.9	1.0	.91
February	5.3	4.9	.44	.24	.17	9.8	7.9	1.9	.91	.85
March	7.3	6.2	1.1	.73	.59	10	8.4	1.6	.71	.65
April	7.8	6.5	1.2	.88	.10	8.3	7.2	1.0	.39	.36
May	4.8	4.5	3.4	.15	.16	6.9	6.2	.66	.21	.19
June	5.4	5.0	.43	.22	.16	33	11	22	5.8	5.1
July	15	10	4.5	3.3	2.9	39	14	25	7.8	6.7
August	36	13	24	14	13	43	14	29	7.7	6.4
September	518	11	507	35	29	98	15	83	16	13
Annual Load	627	81	545	56	48	313	122	183	50	43
HR4 Site	Water Year 2001					Water Year 2002				
October	1.1	1.1	0.01	0.02	0.02	2.1	1.9	0.17	1.1	1.1
November	1.0	1.0	.01	.02	.02	1.5	1.5	.03	.12	.11
December	.90	.90	.01	.02	.02	1.4	1.4	.03	.09	.09
January	.79	.80	.01	.02	.02	1.4	1.4	.03	.11	.10
February	.65	.66	.01	.02	.01	1.2	1.2	.03	.10	.09
March	.79	.77	.01	.02	.02	1.2	1.2	.02	.08	.08
April	.77	.75	.01	.02	.02	1.0	1.0	.01	.05	.05
May	.65	.65	.01	.01	.01	.90	.90	.01	.03	.03
June	.83	.81	.01	.02	.02	1.4	1.3	.05	.31	.29
July	1.0	1.0	.01	.03	.03	2.1	2.0	.13	.87	.82
August	2.0	1.9	.12	.48	.42	2.2	2.0	.15	1.2	1.2
September	2.0	1.5	.48	13	13	2.7	2.1	.61	8.6	11
Annual Load	12	12	1.0	14	14	19	18	1.3	13	15

Appendix 3. (Continued) Nutrient loads at the HR6, HR4, BWC2 and IC2 sites in the upper Hillsborough River watershed, water years 2001 and 2002.

[All units in tons]

	Total nitrogen	Inorganic nitrogen	Organic nitrogen	Total phos-phorous	Ortho-phos-phorous	Total nitrogen	Inorganic nitrogen	Organic nitrogen	Total phos-phorous	Ortho-phos-phorous
BWC2 Site	Water Year 2001					Water Year 2002				
November	0.05	0.01	0.04	0.02	0.02	1.4	0.32	1.1	0.50	0.44
December	.05	.01	.05	.03	.02	.74	.15	.02	.28	.25
January	.10	.02	.08	.05	.04	1.0	.23	.79	.37	.33
February	.08	.01	.06	.03	.03	2.2	.62	1.6	.81	.71
March	1.6	.44	1.2	.07	.59	1.5	.40	1.1	.55	.48
April	1.5	.38	1.1	.06	.51	.41	.09	.32	.16	.13
May	.03	.01	.03	.48	.43	.42	.14	.28	.14	.12
June	.46	.1	.37	.18	.16	25	7.6	18	10	9.3
July	13	3.5	9.9	5.1	4.6	19	6.5	12	6.7	5.9
August	27	6.3	20	11	10	20	7.5	12	6.9	6.1
September	59	10	51	30	28	27	10	16	10	8.6
Annual Load	104	21	85	47	45	103	35	66	38	34
IC2 Site	Water Year 2001					Water Year 2002				
October	0.83	0.38	0.49	0.32	0.24	2.8	0.89	2.0	0.92	0.76
November	.16	.07	.10	.06	.05	1.4	.45	.93	.43	.35
December	.13	.05	.08	.05	.04	.74	.24	.51	.23	.19
January	.14	.06	.09	.05	.04	.95	.31	.66	.29	.24
February	.14	.06	.09	.05	.04	2.1	.54	1.6	.65	.61
March	1.8	.72	1.6	..88	.72	1.3	.36	.90	.37	.31
April	1.8	.62	1.2	.65	.53	.35	.10	.25	.10	.09
May	.07	.03	.05	.03	.02	.55	.13	.43	.17	.14
June	.90	.33	.60	.31	.25	20	3.0	19	7.0	6.1
July	13	3.6	10	4.9	4.1	11	2.1	9.1	3.4	3.0
August	24	5.2	20	10	8.2	12	2.3	10	3.8	3.3
September	42	7.0	38	18	15	18	2.9	16	5.7	5.0
Annual Load	85	18	72	35	29	71	13	61	23	20

Appendix 4. Nutrient yields at the HR6, HR4, BWC2 and IC2 sites in the upper Hillsborough River watershed, water years 2001 and 2002.

{All units in pounds per square mile]

	Total nitrogen	Inorganic nitrogen	Organic nitrogen	Total phos-phorous	Ortho-phos-phorous	Total nitrogen	Inorganic nitrogen	Organic nitrogen	Total phos-phorous	Ortho-phos-phorous
HR6 Site	Water Year 2001					Water Year 2002				
October	78	67	11	7.4	5.9	218	106	116	65	61
November	58	53	5.5	3.2	2.4	100	81	20	12	10
December	58	52	5.2	3.0	2.2	173	78	16	8.9	7.7
January	56	52	5.0	2.9	2.1	98	81	18	9.3	8.3
February	48	44	4.0	2.2	1.6	89	72	17	8.3	7.7
March	66	56	10	6.6	5.4	91	77	14	6.4	5.9
April	71	59	11	8.0	6.6	75	66	9.3	3.6	3.2
May	44	41	31	1.3	0.9	62	56	6.0	1.9	1.7
June	49	45	3.9	2.0	1.5	300	97	203	52	4.6
July	136	92	41	30	2.6	354	129	225	71	61
August	327	117	215	123	116	390	129	261	70	58
September	4,709	98	4,612	316	263	888	133	754	141	114
Annual Load	5,700	777	4,955	506	434	2,858	1,105	1,659	449	385
HR4 Site	Water Year 2001					Water Year 2002				
October	28	28	0.30	0.59	0.59	51	47	4.2	27	26
November	24	24	.24	.49	.50	36	36	0.84	2.9	2.6
December	22	22	.19	..40	.43	34	33	.66	2.3	2.1
January	19	19	.16	.38	.38	34	33	.76	2.8	2.5
February	16	16	.13	.32	.31	28	28	.61	2.3	2.1
March	19	19	.18	.43	.42	29	29	.854	2.0	1.9
April	19	18	.18	.42	.42	25	24	.32	1.2	1.2
May	16	16	.11	.33	.32	22	22	.20	.78	.81
June	20	20	.19	.51	.50	34	33	1.3	7.6	7.1
July	25	25	.31	.85	.84	52	49	3.2	21	20
August	50	47	2.9	12	10	53	49	3.7	30	30
September	48	37	12	315	305	66	51	15	211	264
Annual Load	306	291	17	332	320	464	434	31	311	360

Appendix 4. (Continued) Nutrient yields at the HR6, HR4, BWC2 and IC2 sites in the upper Hillsborough River watershed, water years 2001 and 2002.

{All units in pounds per square mile}

	Total nitrogen	Inorganic nitrogen	Organic nitrogen	Total phos-phorous	Ortho-phos-phorous	Total nitrogen	Inorganic nitrogen	Organic nitrogen	Total phos-phorous	Ortho-phos-phorous
BWC2 Site	Water Year 2001					Water Year 2002				
October	20	6.7	13	7.5	6.6	74	18	55	27	24
November	1.0	.16	.76	.45	.40	25	5.8	19	9.2	8.1
December	.93	.15	.83	.48	.43	14	2.8	.35	5.1	4.5
January	1.8	.31	1.5	.83	.74	18	4.2	14	6.8	5.9
February	1.4	.25	1.2	.63	.56	40	11	29	15	13
March	30	8.1	22	12	11	28	7.3	21	10	8.7
April	26	6.8	20	10	9.2	7.5	1.7	5.8	2.8	2.4
May	.64	.09	.54	8.8	7.8	7.6	2.5	5.1	2.6	2.3
June	8.4	1.7	6.7	3.3	2.9	457	139	319	188	169
July	243	63	179	94	84	339	119	220	121	108
August	483	114	369	205	186	360	136	225	126	111
September	1,079	182	927	552	512	483	184	299	175	156
Annual Load	1,895	383	1,541	895	822	1,853	631	1,212	689	613
IC2 Site	Water Year 2001					Water Year 2002				
October	201	76	132	86	66	107	34	76	35	29
November	32	15	19	12	9.4	52	17	36	16	14
December	6.1	2.6	3.8	2.3	1.8	28	9	19	9	7
January	4.9	2.0	3.1	1.8	1.5	37	12	25	11	9
February	5.5	2.2	3.5	2.0	1.7	79	21	60	25	24
March	5.5	2.2	3.5	2.0	1.6	48	14	34	14	12
April	67	24	46	25	20	13	4	10	4	3
May	2.8	1.1	1.8	.97	.80	21	5	16	6	5
June	35	13	23	12	10	773	115	717	270	236
July	498	139	384	187	157	419	81	351	131	114
August	920	200	780	369	315	473	88	398	146	126
September	1,610	268	1,480	688	585	695	110	616	220	191
Annual Load	3,388	745	2,880	1,388	1,170	2,745	510	2,358	887	770

Appendix 5. Ground-water and surface-water levels at the Blackwater Creek, Hillsborough River at State Road 39, and the upper Hillsborough River Tract transect sites.

[SAS, surficial aquifer system; UFAS, Upper Floridan aquifer shallow (UFAS wells are finished into the top of the Upper Floridan aquifer and are less than 30-feet deep); UFAD, Upper Floridan aquifer deep (UFAD wells are greater than 90-feet deep); ND, not drilled yet;. Elevations are shown in feet above NGVD of 1929]

Blackwater Creek Transect (T1)

Date	BWCT1 (CM4)		BWCT2		BWCT3				BWCT4	BWCT5	BWCT6
	SAS	UFAD	SAS	UFAS	SAS	UFAS	CR	Creek	UFAS	UFAS	UFAD
7/13/2000	Dry	81.92	Dry	81.71	Dry	81.58	81.57	Dry	81.50	ND	ND
7/18/2000	Dry	82.14	Dry	81.95	Dry	81.87	82.05	Dry	81.80	ND	ND
7/25/2000	Dry	82.58	Dry	82.38	Dry	82.29	82.87	82.89	82.29	ND	ND
8/25/2000	Dry	84.86	Dry	84.46	83.81	84.28	83.89	83.84	84.17	ND	ND
9/14/2000	88.31	85.09	85.80	84.73	83.95	84.57	83.81	83.76	84.76	84.43	ND
9/18/2000	90.76	87.06	88.69	86.63	86.04	86.53	85.52	85.45	86.21	86.88	ND
9/29/2000	89.93	86.47	86.20	85.91	84.74	85.63	84.23	84.19	85.58	86.11	ND
11/9/2000	Dry	83.57	Dry	83.30	82.80	83.17	83.50	83.50	83.07	83.27	ND
1/18/2001	Dry	83.28	Dry	83.20	83.21	83.17	83.59	83.55	83.10	83.10	83.29
3/5/2001	Dry	83.03	Dry	83.01	82.91	82.97	83.47	83.47	82.76	82.89	82.98
4/3/2001	Dry	84.77	Dry	84.55	84.01	84.47	83.77	83.74	84.67	84.76	84.84
5/2/2001	Dry	82.97	Dry	82.70	82.61	82.53	82.95	83.01	82.43	82.66	82.84
6/4/2001	Dry	81.54	Dry	81.27	Dry	81.12	Dry	Dry	81.10	81.22	81.46
7/17/2001	Dry	82.90	Dry	82.88	83.27	82.91	82.01	84.05	84.631	82.869	82.93
8/9/2001	90.76	86.73	86.36	86.14	85.43	85.98	84.94	84.89	86.371	86.52	86.21
9/18/2001	89.20	89.32	89.23	88.47	87.66	88.17	87.64	88.10	88.33	88.57	88.97
10/26/2001	90.11	86.97	86.09	86.21	85.10	85.99	84.58	84.52	86.55	86.77	87.12
12/27/2001	Dry	85.40	Dry	84.97	84.54	84.96	84.35	84.31	85.251	85.34	85.56
3/21/2002	88.62	85.87	Dry	85.64	84.66	85.388	84.42	84.38	85.68	85.80	86.05
5/16/2002	Dry	82.92	Dry	82.63	82.46	82.52	83.00	83.01	82.40	82.62	82.84
6/19/2002	90.71	86.22	86.89	86.02	85.86	86.01	85.25	85.06	86.57	86.53	86.71
7/24/2002	91.04	88.10	88.82	87.22	85.87	86.90	84.63	84.56	87.61	88.11	88.15
9/17/2002	92.70	89.00	89.21	88.05	86.72	87.75	85.89	85.90	88.13	88.64	88.78
9/27/2002	92.70	89.50	89.46	88.30	86.88	87.90	86.180	86.20	88.30	88.65	89.00

Appendix 5. (Continued) Ground-water and surface-water levels at the Blackwater Creek, Hillsborough River at State Road 39, and the upper Hillsborough River Tract transect sites.

[SAS, surficial aquifer system; UFAS, Upper Floridan aquifer shallow (UFAS wells are finished into the top of the Upper Floridan aquifer and are less than 30-feet deep); UFAD, Upper Floridan aquifer deep (UFAD wells are greater than 90-feet deep); ND, not drilled yet;. Elevations are shown in feet above NGVD of 1929]

Hillsborough River at State Road 39 Transect (T2)

Date	HRSR391		HRSR392	HRSR393				HRSR394	HRSR395	ROMP 86A BWCT6	
	UFAD	UFAS	UFAS	UFASo	UFANo	CR	RIVER	UFAS	UFAS	SWNN	AVPK
9/20/2000	ND	ND	ND	ND	ND	ND	53.72	ND	ND	56.56	57.04
11/27/2000	ND	54.88	54.48	54.22	54.44	54.09	53.81	55.00	55.31	55.64	56.19
12/15/2000	54.94	54.87	54.44	54.32	54.47	53.99	53.62	55.05	55.30	55.59	56.14
1/18/2001	54.80	54.74	54.52	54.32	54.53	54.02	53.57	54.85	54.99	55.25	55.80
3/1/2001	54.58	54.57	54.27	54.14	54.27	53.92	53.69	54.58	54.91	54.96	55.49
4/3/2001	55.34	55.56	55.24	55.07	55.10	54.50	53.94	55.61	55.79	55.81	56.07
5/2/2001	54.27	54.23	53.87	53.77	53.91	53.68	53.68	54.19	54.64	54.73	55.32
5/31/2001	53.35	53.24	53.05	53.07	53.32	53.27	53.15	53.49	53.91	53.99	54.69
7/10/2001	54.59	54.54	54.35	54.21	54.32	53.95	53.73	54.67	54.75	55.00	55.50
8/10/2001	58.68	58.74	57.74	57.04	56.94	56.07	55.22	58.05	58.10	58.46	58.78
9/18/2001	60.92	60.95	60.25	60.00	60.00	60.00	59.60	60.32	60.85	60.96	61.64
10/26/2001	58.23	58.213	57.29	56.65	56.58	55.61	54.71	58.16	59.05	59.39	60.29
12/28/2001	57.25	57.013	56.65	55.92	55.88	54.96	54.02	57.11	57.87	58.03	58.74
3/21/2002	57.06	56.63	56.33	55.80	55.71	54.80	54.05	56.86	57.77	58.10	58.80
5/13/2002	54.83	54.81	54.25	54.00	54.15	53.73	53.69	54.73	55.45	55.59	56.34
6/19/2002	57.04	57.06	56.85	56.27	56.21	55.41	54.13	57.55	57.62	57.61	57.67
7/24/2002	58.62	58.65	57.71	57.12	57.09	56.12	55.27	58.48	59.30	59.46	60.19
9/4/2002	59.53	59.51	58.70	58.60	58.45	58.38	58.38	59.47	60.52	60.74	61.74
9/16/2002	59.53	59.53	58.70	58.26	58.28	57.67	57.25	59.58	60.61	60.84	61.72

Appendix 5. (Continued) Ground-water and surface-water levels at the Blackwater Creek, Hillsborough River at State Road 39, and the upper Hillsborough River Tract transect sites.

[SAS, surficial aquifer system; UFAS, Upper Floridan aquifer shallow (UFAS wells are finished into the top of the Upper Floridan aquifer and are less than 30-feet deep); UFAD, Upper Floridan aquifer deep (UFAD wells are greater than 90-feet deep); ND, not drilled yet;. Elevations are shown in feet above NGVD of 1929]

Upper Hillsborough River Tract Transect (T3)

Date	UHRT1		UHRT2	UHRT3				UHRT4	UHRT5	
	SAS	UFAD	UFAS	SAS	UFAS	Creek	River	UFAS	SAS	UFAD
11/27/2000	Dry	ND	60.85	Dry	59.33	59.32	Dry	Dry	Dry	ND
12/19/2000	Dry	ND	61.00	Dry	59.54	59.55	Dry	Dry	Dry	ND
1/18/2001	Dry	62.14	61.49	Dry	60.20	60.16	Dry	Dry	Dry	58.47
3/6/2001	Dry	62.48	61.87	Dry	60.79	60.77	Dry	Dry	Dry	59.33
4/5/2001	Dry	62.76	62.21	Dry	61.18	61.15	Dry	Dry	Dry	59.73
5/14/2001	Dry	62.14	61.72	Dry	60.58	60.54	Dry	Dry	Dry	59.62
6/5/2001	Dry	61.72	61.20	Dry	60.27	60.29	Dry	Dry	Dry	59.40
7/16/2001	Dry	62.35	61.96	Dry	61.12	61.13	Dry	Dry	Dry	60.01
8/10/2001	Dry	67.93	67.82	67.72	67.22	67.27	69.67	65.27	72.78	63.70
9/18/2001	74.51	74.59	74.528	74.50	74.50	74.50	74.50	74.50	74.46	73.77
10/25/2001	70.88	70.47	71.70	69.39	69.51	69.47	69.53	69.81	73.00	69.63
12/28/2001	Dry	69.00	68.68	67.87	67.95	67.57	67.64	67.58	Dry	67.44
3/21/2002	Dry	69.10	68.77	67.90	67.95	67.92	67.71	67.40	Dry	67.25
5/13/2002	Dry	66.77	66.68	Dry	65.78	65.74	Dry	65.22	Dry	65.32
6/19/2002	Dry	68.96	67.98	67.65	67.61	67.52	67.89	66.94	Dry	66.62
7/24/2002	70.08	70.16	69.74	69.15	69.23	69.27	69.42	68.46	Dry	68.33
9/4/2002	73.40	73.23	73.50	73.20	73.25	73.20	73.31	72.64	73.30	72.64
9/16/2002	73.00	72.90	72.80	71.79	71.800	71.79	71.98	71.66	73.055	71.44