THE EFFECT OF DISCHARGE AND WATER QUALITY OF THE ALAFIA RIVER, HILLSBOROUGH RIVER, AND THE TAMPA BYPASS CANAL ON NUTRIENT LOADING TO HILLSBOROUGH BAY, FLORIDA

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CONVERSION FACTORS, VERTICAL DATUM, AND ADDITIONAL ABBREVIATIONS

Multiply	By	To obtain
billion gallons (Bgal)	0.003785	billion cubic meters
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per year [(ft^3/s)/yr]	0.02832	cubic meter per second per year
foot (ft)	0.3048	meter
foot per second (ft/s)	0.3048	meter per second
inch (in.)	25.40	millimeter
mile (mi)	1.609	kilometer
million gallons per day (Mgal/d)	0.04381	cubic meter per second
square foot (ft^2)	0.0929	square meter
square mile (mi^2)	2.590	square kilometer
ton per day (ton/d)	0.9072	megagram per day
ton per square mile per year [(ton/mi^2)/yr]	0.3503	megagram per square kilometer per year
ton per year (ton/yr)	0.9072	megagram per year
ton, short	0.9072	megagram

Degree Fahrenheit (°F) may be converted to degree Celsius (°C) by using the following equation:

$$°C = 5/9\ (°F - 32).$$

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

Abbreviated water-quality units:

mg/L	milligram per liter
µg/L	microgram per liter
µS/cm	microsiemens per centimeter at 25 degrees Celsius

Additional abbreviations:

BBADCP	broad-band acoustic doppler current profiler
cBOD	5-day carbonaceous biological oxygen demand
FWPCA	Federal Water Pollution Control Administration
HDPE	high density polyethylene
QA	quality assurance
R^2	coefficient of determination
SWFWMD	Southwest Florida Water Management District
SWIM	Surface Water Improvement and Management
USGS	U.S. Geological Survey
WCRWSA	West Coast Regional Water Supply Authority

The Effect of Discharge and Water Quality of the Alafia River, Hillsborough River, and the Tampa Bypass Canal on Nutrient Loading to Hillsborough Bay, Florida

By Yvonne E. Stoker, Victor A. Levesque, *and* William M. Woodham

Abstract

Techniques to measure discharge and nutrient loads in the tidally affected portions of two major rivers tributary to Tampa Bay, the Alafia River and the Hillsborough River, were developed and tested. Discharge, water quality, and total phosphorus and total nitrogen loads for the period April 1, 1991, through March 31, 1992, were evaluated and compared with discharge, water quality, and loads at long-term, nontidal gages in the basins.

Long-term discharge and water-quality characteristics at selected sites in the Alafia River and Hillsborough River basins were evaluated. A long-term, decreasing trend in annual-mean discharge was observed for discharges at the Alafia River, Sulphur Springs, and Hillsborough River. Low-flow and high-flow characteristics in the Alafia River and Hillsborough River have changed as well. The decreasing trend in the Alafia River discharges is not due to deficient rainfall but probably is due to decreased ground-water inflow to the river because of long-term declines in the potentiometric surface of the Upper Floridan aquifer.

Daily-mean discharges at the mouth of the Alafia River were more variable than discharges at the long-term gage upstream. Daily-mean discharge near the mouth of the river was negative at times, indicating a net loss of water from the river. Daily-mean discharge from the Hillsborough River was minimal from April to May 1991, and from late September 1991 to March 1992. During these periods, discharge from Sulphur Springs was a major source of freshwater to the tidally affected reach of the river.

Concentrations of total phosphorus and orthophosphorus in the Alafia River above Lithia Springs were the greatest in the 1960's and have generally declined since then. Total nitrogen concentrations have been declining since about 1981. However, increases in nitrate plus nitrite nitrogen concentrations are occurring in Lithia Springs, a second-magnitude spring that flows into the Alafia River. Specific conductance of water discharging from Sulphur Springs to the Hillsborough River has increased from about 124 to more than 2,000 microsiemens per centimeter since 1945.

Water quality at the mouth of the Alafia River and Hillsborough River is the result of mixing of freshwater and estuarine water from Hillsborough Bay. Large daily variations in water quality occur at these sites because of tidal currents, and vertical stratification of specific conductance is a common feature. Concentrations of phosphorus, nitrate plus nitrite nitrogen, organic carbon, and silica are inversely related to specific conductance at the mouth of the Alafia River.

Constituent concentration and discharge data were used to compute loads during the study period. Average daily phosphorus loads were 2.4 tons per day at the mouth of the Alafia River; 0.35 ton per day at the mouth of the Hillsborough River; and 0.06 ton per day at the Tampa Bypass Canal. Average daily nitrogen loads were 1.7 tons per day at the mouth of the Alafia River; 0.86 ton per day at the mouth of the Hillsborough River; and 0.26 ton per day at the Tampa Bypass Canal. The greatest annual loads of phosphorus and nitrogen from the major tributaries to Hillsborough Bay are from the Alafia River, with the greatest loads at the river mouth. Total phosphorus load from the Alafia River was about 894 tons during April 1991 through March 1992, more than six times greater than phosphorus loads from the Hillsborough River. Annual total nitrogen load at the mouth of the Alafia River was about 630 tons, two times greater than at the mouth of the Hillsborough River and more than six times greater than loads from the Tampa Bypass Canal.

Basinwide yields of total phosphorus during April 1991 through March 1992 were about 2 tons per square mile at the mouth of the Alafia River basin and were about 0.2 ton per square mile at the mouth of the Hillsborough River. Total nitrogen yield was about 1.5 tons per square mile at the mouth of the Alafia River and about 0.5 ton per square mile at the mouth of the Hillsborough River.

Phosphorus and nitrogen yields from the part of the basin draining the tidal reach of the Alafia and Hillsborough Rivers were much different than yields from the rest of the basin. In the Alafia River, phosphorus yields in the lower part of the basin were 2.9 tons per square mile and were greater than they were upstream. Nitrogen yields were 2.4 tons per square mile, about twice the yield upstream. In the Hillsborough River, phosphorus yields from the part of the basin draining the tidal reach were 0.9 ton per square mile and were more than four times greater than they were in the nontidal basin area. Nitrogen yields were 1.1 tons per square mile and were more than two times greater than they were in the nontidal basin.

INTRODUCTION

The effects of land-use changes and other human activities on the water quality and ecology of estuaries and other coastal waters is a national concern that is being addressed in many areas of the country. Agricultural, commercial, industrial, and residential land uses within a basin and areas adjacent to bodies of water commonly result in nutrient enrichment of those waters.

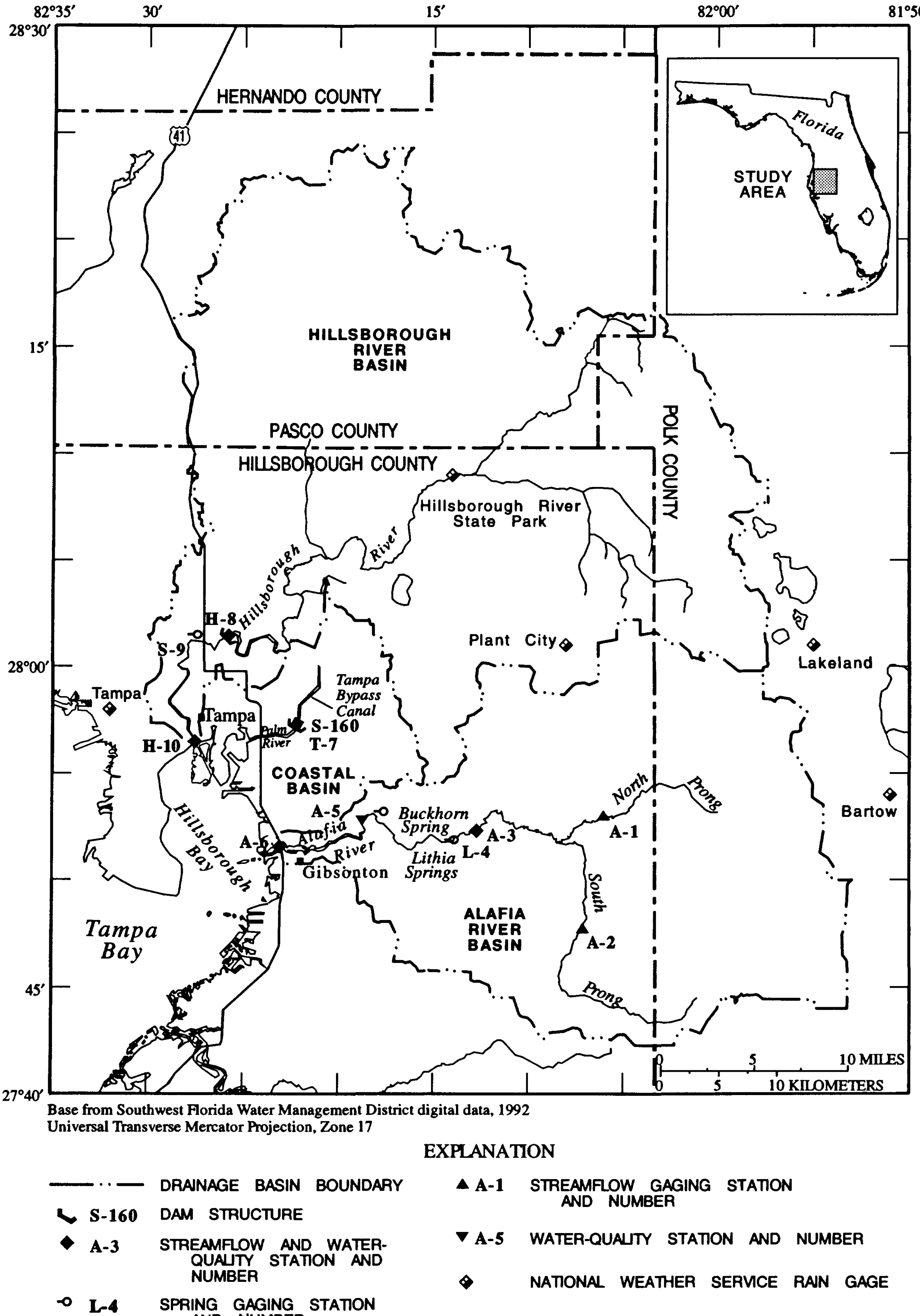
Scientists have long recognized that excessive nutrients in Tampa Bay (fig. 1), particularly in Hillsborough Bay, have resulted directly and indirectly in a decline in water quality and the natural resources of the area. Odum (1953) may have been the first to recognize the negative effects of nutrient enrichment on the surface waters of Florida. He expressed concern that the high phosphorus concentrations in the Alafia River basin would increase "fertility" in the river and receiving estuary.

The Federal Water Pollution Control Administration (FWPCA) (1969) concluded that contributions of excessive nutrients and organic wastes to Hillsborough Bay were the cause of obnoxious odors in the area. Results of their study indicated that nitrogen was the nutrient that limited plant growth because phosphorus was present in excess quantities. The FWPCA recommended control of nitrogen and phosphorus inputs to Hillsborough Bay to limit growth of algae in the bay. A specific recommendation was that the city of Tampa sewage treatment plant, a source of about 28 Mgal/d of primary treated sewage to Hillsborough Bay at the time of the study, be upgraded to a secondary treatment plant. The plant was upgraded in 1979 to an advanced wastewater treatment plant with a 60-Mgal/d capacity (Johansson, 1991). Output from the plant is 5 mg/L 5-day biological oxygen demand, 5 mg/L total suspended solids, and 3 mg/L total nitrogen. The 1-mg/L total phosphorus level for advanced wastewater treatment was waived for the city of Tampa sewage treatment plant because nitrogen is considered the limiting nutrient in Hillsborough Bay.

Excessive nutrients historically have caused frequent algae blooms in Hillsborough Bay, which resulted in decreased light levels in the bay. Decreased light levels probably caused 80 percent loss of seagrass meadows in Tampa Bay from 1879 to 1982 (Lewis and others, 1985).

Long-term monitoring has indicated that water-quality conditions in Tampa Bay have improved between 1981 and 1991 (Boler, 1992), and seagrass coverage has increased slightly between 1982 and 1988 (Lewis and others, 1991). However, excessive nutrients in Tampa Bay remain a problem. This issue is now (1995) being addressed by the Surface Water Improvement and Management (SWIM) department of the Southwest Florida Water Management District (SWFWMD) and the U.S. Environmental Protection Agency's Tampa Bay National Estuary Program.

Several recent studies have estimated total nitrogen and phosphorus loads to Tampa Bay. Dames and Moore, Inc. (1990) estimated nonpoint-source loads to Tampa Bay using literature-based land-use loading for each basin. Johansson (1991) compared total nitrogen loads to Hillsborough Bay during two periods, 1967 to 1968, and 1987 to 1990. Johansson (1991) reported that the Alafia River was the largest source of nitrogen to Hillsborough Bay for the period 1987 to 1990, when compared to the city of Tampa wastewater treatment plant at Hooker's Point and various fertilizer plants along Tampa Bay and in nearby basins. Nitrogen loadings from the river currently are less that those computed for 1967–68 (Federal Water Pollution Control Administration, 1969), and Johansson (1991) attributes the decrease in nitrogen loading from the river to changes in fertilizer industry practices in the basin. Morrison (1992) determined a nutrient budget for Tampa Bay that estimated inputs from atmospheric deposition, fugitive industrial releases (such as product losses during handling and shipping), tributaries, point sources, and stormwater runoff. Estimated inputs were compiled from existing data from various sources.



Base from Southwest Florida Water Management District digital data, 1992
Universal Transverse Mercator Projection, Zone 17

EXPLANATION

Figure 1. Study area.

Nutrient-loading estimates for the tidally affected sections of rivers traditionally have been estimated from nutrient loading at upstream, nontidal sites on a river, or estimated from similar basins. Because urbanization in the Tampa Bay area is concentrated around the bay and the river mouths, nutrient loading from the ungaged, tidal portion of a river can be significantly different from loading from the gaged, nontidal portion. The magnitude of phosphorus and nitrogen loading from the tidal reaches of the major rivers discharging to Hillsborough Bay was not known, largely because discharge data needed to compute loads were not available for these tidal reaches. The U.S. Geological Survey (USGS), in cooperation with the SWFWMD, conducted a study from August 1990 to April 1993 to develop techniques to measure discharge and water quality in the tidal reaches of the Alafia and Hillsborough Rivers and to compute nutrient loads from these data.

Purpose and Scope

This report presents the results of the study to develop techniques for the measurement of discharge and water quality in tidally affected reaches of rivers and to provide empirical estimates of nonpoint-source nutrient loads from the major tributaries to Hillsborough Bay. The study area included the Alafia River, Hillsborough River, and the Tampa Bypass Canal. Reconnaissance data collection began in August 1990. Discharge computations and water-quality sampling began in April 1991 and ended in April 1992. Nitrogen and phosphorus loads for the period April 1, 1991, through March 31, 1992, were computed from data collected during the study. The techniques used to measure and to compute tidal discharge, to collect water-quality samples, and to compute nutrient loads from the tributaries are described, and the results of those computations are presented. Discharge, water quality, and loading characteristics at upstream nontidal sites in the Alafia and Hillsborough River basins are evaluated and compared to characteristics at downstream tidal sites. Daily and seasonal loads in the tidal rivers are evaluated and compared with loads computed at nontidal, upstream sites.

Description of Study Area

Surface drainage of the Alafia River is shown in the basin map in figure 1. Two tributaries form the headwaters of the river: the North Prong Alafia River and the South Prong Alafia River. The branches converge in eastern Hillsborough County to form the Alafia River. The river meanders generally westward and empties into the southeastern part of Hillsborough Bay. Lithia Springs, a second-magnitude spring, flows into the Alafia River about 13.8 river miles upstream of U.S. Highway 41. A second-magnitude spring has an average flow of between 10 and 100 ft^3/s (Rosenau and others, 1977). A smaller spring, Buckhorn Spring, flows into the river about 6.6 river miles upstream from U.S. Highway 41. Several other small springs and seeps contribute flow to the Alafia River. The drainage basin is 418 mi^2 in area upstream of U.S. Highway 41 near the mouth of the river.

The mouth of the Alafia River was modified extensively by dredge and fill activities completed by 1930 (Fehring, 1985). A deep-water channel was dredged from the main ship channel in Tampa Bay, through uplands north of the river mouth, to the river upstream of the mouth. This channel was dredged to provide shipping access to a fertilizer-processing plant. The former river mouth was partially filled with the excavated material, effectively changing the location of the river mouth. Over the years, sediment from a spoil area has accumulated in the historic river mouth, reducing the former river mouth to a small tidal creek with little or no connection to the river.

The Tampa Bypass Canal is a series of canals and control structures that were constructed to relieve flooding in the Hillsborough River basin (fig. 1). Construction of the bypass canal began in 1966 and was completed in 1981. Water flows from structure S-160, the most downstream control structure in the bypass canal, into the Palm River, which discharges to the northeastern part of Hillsborough Bay.

Excavation of the bypass canal breached the confining bed that separates the surficial aquifer from the Upper Floridan aquifer, resulting in discharge to the canal, lowered potentiometric levels in the aquifer, and lower spring discharges in the area (Knutilla and Corral, 1984). The resulting large base flows in the canal have become a source of water supply for the city of Tampa. Sometimes, water is pumped from the Tampa Bypass Canal to the Hillsborough River to augment flow in the river. Pumpage generally occurs during the dry season.

Surface drainage of the Hillsborough River is shown in figure 1. Natural flow in the lower Hillsborough River was altered in the 1920's by a hydroelectric dam that was built about 10 river miles upstream from the mouth. The dam failed during a flood in 1933, and the river flowed unregulated until 1945, when a new dam was completed to create a water-supply reservoir for the city of Tampa (Pride, 1962). Discharge from the dam is regulated, and the structure acts as a salinity barrier. The city of Tampa currently (1993) withdraws about 60 Mgal/d from the river upstream of the dam (Sheila Bradley, city of Tampa Water Treatment Plant, oral commun., 1993). At times, minimal leakage is the only source of flow from the reservoir to the tidal reach of the river.

Drainage in the lower Hillsborough River basin is affected by the Tampa Bypass Canal. Prior to construction of the bypass canal, the basin was about 690 mi^2 in area. Because of pumpage from the bypass canal to the Hillsborough River, the effective drainage basin area sometimes increases. Operation of the control structures that divert water from the Hillsborough River to the bypass canal during floods also changes the effective drainage area.

Sulphur Springs flows into the tidally-affected reach of the Hillsborough River about 8 river miles upstream from the river mouth (fig. 1). Spring flow is regulated by a control structure at the spring boil and by a structure near the river. The city of Tampa periodically diverts water by pumping from the spring to the Hillsborough River Reservoir to augment the Tampa water supply.

Discharge characteristics near the mouth of the Alafia and Hillsborough Rivers are affected by tide. Tide is defined as the periodic rise and fall of water resulting from gravitational interactions between the Sun, Moon, and Earth. Meteorological conditions, such as wind and barometric pressure, also can influence the tide (National Oceanographic and Atmospheric Administration, 1991). Tides along the west coast of Florida are typically mixed tides in which two high waters and two low waters of unequal height occur in one tidal cycle of approximately 25 hours duration. The mean range in tide in Hillsborough Bay is 2.8 ft (National Oceanographic and Atmospheric Administration, 1991).

The climate in the study area is subtropical and humid. Rainfall records for Bartow, Hillsborough River State Park, Lakeland, Plant City, and Tampa (fig. 1) were combined to describe conditions in the study area. Averaged normal annual rainfall (1951–80) for these sites was 51.5 in., with about 55 percent of the rainfall occurring from June to September. Rainfall during the wet season is from frequent thunderstorms that can result in intense rainfall for short periods over localized areas. Rainfall during the remainder of the year typically is due to large frontal systems that are distributed throughout the area. Average annual temperature for the above stations, excluding Hillsborough River State Park, was about 72°F, with average monthly temperatures ranging from 61°F in January to 82°F in August (National Oceanic and Atmospheric Administration, 1988).

Monthly rainfall during this study is shown in figure 2. Maximum rainfall occurred in July 1991 and minimum rainfall occurred in November 1991. The average annual rainfall during this study was 50.6 in. Total rainfall in July 1991 accounted for about 25 percent of the total rainfall for the study period (National Oceanic and Atmospheric Administration, 1992).

Acknowledgments

The authors express appreciation to the Hillsborough County Parks and Recreation Department and the Florida Department of Transportation for allowing the installation and maintenance of gages on their properties and to the CSX Transportation, Inc., bridge tenders at U.S. Highway 41 for their cooperation and occasional loans of boat drain plugs. Special thanks go to Brant Hutchinson who volunteered hours of his time to assist in water-quality sampling. The Hillsborough County Environmental Protection Commission, West Coast Water Supply Authority, Florida Department of Environmental Protection, and the SWFWMD all contributed data in support of this study.

METHODS OF STUDY

Discharge and water-quality data were collected at selected tidal and nontidal sites. Sites in the tidally affected reaches of the Alafia and Hillsborough Rivers were established in 1991 near the river mouths for water quality and discharge data collection. A long-term data-collection network that includes water quality and discharge data at nontidal sites in the Alafia and Hillsborough River basins is operated by the USGS. Locations of study sites are shown in figure 1, and site information is listed in table 1. The following section describes the data-collection and interpretation methods used in this study.

Discharge

In a river that drains to a coastal area, the river eventually becomes influenced by tides as the river nears the receiving body of water. At nontidally affected sites on the river, the flow or discharge of the river can be related to stage (water-surface elevation) if a stable control element exists for the river (Rantz and others, 1982a; 1982b). A simple discharge rating that relates stage to discharge can be developed by observing or recording the stage of the pool immediately upstream from the control, and periodically measuring the total discharge over a range of stage that is expected

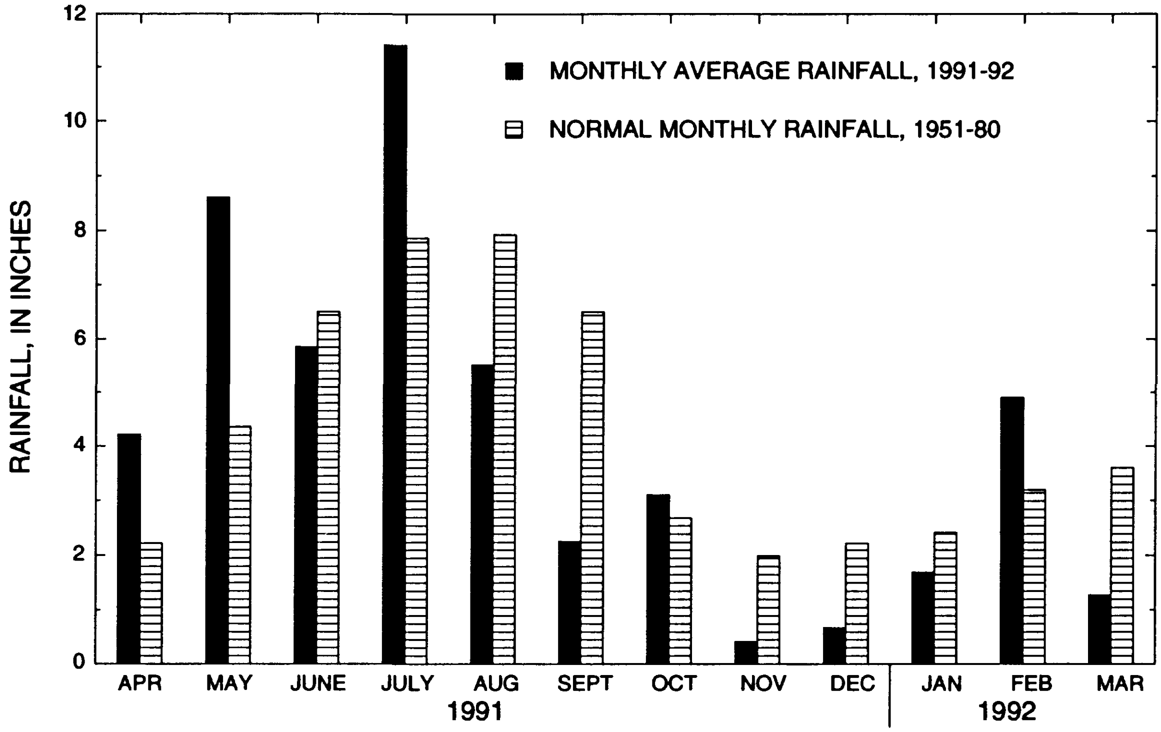


Figure 2. Average monthly rainfall at selected rainfall gages, April 1991 through March 1992, and normal monthly rainfall, 1951 to 1980.

Table 1. Site numbers, station numbers, site names, and type of data collected at selected sites in the Alafia River, Hillsborough River, and the Tampa Bypass Canal basins

Site number (fig. 1)	Station number	Site name	Type of data	Affected by tide
A-1	02301000	North Prong Alafia River at Keysville	Continuous discharge	No
A-2	02301300	South Prong Alafia River near Lithia	Continuous discharge	No
A-3	02301500	Alafia River at Lithia	Water quality, continuous discharge	No
L-4	02301600	Lithia Springs near Lithia	Water quality, periodic discharge	No
A-5	02301706	Alafia River near Riverview	Continuous specific conductance and temperature	Yes
A-6	02301721	Alafia River at Gibsonton	Water quality, continuous discharge, specific conductance, and temperature	Yes
H-8	02304500	Hillsborough River near Tampa	Water quality, continuous discharge	No
S-9	02306000	Sulphur Springs at Sulphur Springs	Water quality, continuous discharge	No
H-10	02306028	Hillsborough River at Platt Street at Tampa	Water quality, periodic discharge, continuous specific conductance, and tide	Yes
T-7	02301802	Tampa Bypass Canal at structure S-160 at Tampa	Water quality, continuous discharge[1]	No

[1]Discharge provided by the Southwest Florida Water Management District.

for the river (Rantz and others, 1982a; 1982b). This measurement technique was used to compute continuous discharge at the nontidally affected gages on the Alafia and Hillsborough Rivers and at the Tampa Bypass Canal.

At tidally affected sites on a river, a simple stage-discharge relation does not exist; however, discharge can be determined if the cross-sectional area and mean velocity are known (discharge = area × velocity). Cross-sectional area can be related to stage (stage-area rating), and mean velocity can be related to an index velocity (velocity in a portion of the cross section). Discharge measurements must be made at different flow and tide conditions. This measurement technique was used to compute continuous discharge at the mouth of the Alafia River.

Discharge measurements at the mouths of the Alafia (site A-6) and Hillsborough (site H-10) Rivers were made using both the standard point velocity-discharge technique (Rantz and others, 1982a) and a moving boat method that uses a broad-band acoustic doppler current profiler (BBADCP). The BBADCP, a recently developed instrument used to measure velocity, allows the direct measurement of three-dimensional water velocities and net discharge in a minimal amount of time. The BBADCP uses acoustic pulses to measure water velocities at multiple discrete depths and vessel velocity over the channel bottom in the measurement section. The BBADCP also measures and records vessel compass headings and water depths during the river measurement. This information is then used to compute river discharge at the time of measurement. Detailed descriptions of the BBADCP used in this study and how it measures discharge are discussed in a report by RD Instruments (1989).

The measurement of discharge at tidally affected sites is difficult using conventional current meter techniques because of continuously changing flow characteristics, complex vertical velocity profiles, and reversal of flows during the measurement. These techniques also can be labor intensive. For example, conventional discharge measurement at the Alafia River at site A-6 using two crews of two people each typically required 45 minutes to complete. Two point-velocity measurements were made in each vertical, and approximately 26 vertical measurements were made in the cross section. In contrast, a discharge measurement using the BBADCP typically required two people and about 4 minutes to complete, and a much higher density of data collection was achieved. A point-velocity measurement was made at every 1.5 ft of depth, and more than 100 vertical measurements were made in the cross section.

The discharge-measurement data collected using standard point-velocity measurements are subject to the errors inherent in making velocity measurements in tidally affected rivers. Velocity changes as the tide varies, and variation in the direction of water movement limits the accuracy of discharge measurements. Because measurements made with the BBADCP can be made within a relatively short period of time, the errors associated with rapidly changing water velocities and flow direction are reduced.

Discharges in tidal rivers have a high frequency variation that dominates the discharge patterns. This variation is characterized by frequent reversals in flow and changes in flow magnitude and is caused by the upstream and downstream movements of water as a result of tidal currents. The amount of discharge caused by freshwater inflow can be small relative to the amount of discharge caused by tidal currents. The freshwater inflow, however, is the significant factor in this study. Tidal variations in time-series data, such as tidal discharge, can be removed using a mathematical filter. The filtered data can then be examined to determine variations in the data that are the result of nontidal processes, such as freshwater inflow. The Godin filter, a low-pass, digital filter (Walters and Heston, 1982), was used to remove tidal variations in the discharge data. Once tidal variations were removed, daily-mean discharges were then computed.

The stage at all study sites was measured by a float-type water-level indicator installed in a stilling well and connected to an automatic paper punch-type recorder. The stage recorders measure stage within ±0.01 ft. The stage data and bathymetric profiles at the measurement section at site A-6 at the Alafia River were used to develop the stage-area rating.

Two types of velocity indices were used for the gages at the mouths of the Alafia (site A-6) and Hillsborough (site H-10) Rivers: a point index and a section index. The terms point-velocity index and section-velocity index indicate the relative area of water measured by the velocity measurement device. The point-velocity index typically measures a small section of the total river cross-section length (< 1 ft), whereas the section-velocity index typically measures a larger section of the total cross-section length. A point-velocity index was used at the Hillsborough River at site H-10, and both a point-velocity index and a section-velocity index were used at the Alafia River at site A-6. The point-velocity indices were measured by electromagnetic velocity meters, and the section-velocity index was measured by an acoustic velocity meter. The use of acoustic velocity meters for the measurement of discharge is described by Laenen and Smith (1983), and the application of this technique in this study is described by Woodham and Stoker (1991).

The Tampa Bypass Canal structure S-160 (site T-7) is a concrete structure with six 28-ft wide, hydraulically operated lift gates. Five of the lift gates each have five manually operated weir gates, or skimmers, that control discharge, except during periodic lift gate openings. The elevation of each skimmer can be adjusted. Stop logs are installed across a gate during maintenance to prevent discharge from that gate. Total discharge from the structure is a combination of skimmer discharge, skimmer leakage, lift-gate discharge, lift-gate leakage, and stop-log leakage. The structure is maintained and operated by the SWFWMD.

Daily-mean discharges at the Tampa Bypass Canal at site T-7 were provided by the SWFWMD and were based on skimmer discharge. The assumption was made that each skimmer gate was set to the same elevation and that this elevation was not changed during the study. Discharges as a result of leakage, periodic gate operations, and variations in individual skimmer elevations were not accounted for in the SWFWMD data.

Water Quality

Water quality at any point in the tidally affected reach of a river is constantly changing due to physical, biological, and chemical processes. Physical processes include tide, interaction with the atmosphere, mixing of freshwater and saltwater, and flow patterns. Biological and chemical processes include absorption to or adsorption from sediments, photolysis, interaction with suspended material, uptake or release by plants, temperature effects, and bacterial interactions. Water-quality techniques that are appropriate for sampling in nontidal systems must be modified when applied to sites in tidally affected rivers because of vertical and horizontal variability that complicates sampling procedures.

Reconnaissance water-quality samples were collected in September 1990 at the mouth of the Alafia River (site A-6) to provide data needed to determine appropriate sampling procedures for the remainder of the study. The samples were collected near the end of the wet season when vertical variability in water quality was most likely to occur because of increased freshwater inflow.

A cross section in the Alafia River on the downstream side of the U.S. Highway 41 bridge was chosen for the reconnaissance study because the bottom was firm, depths were less than 15 ft, and the bridge pilings allowed accurate reference points for sampling sites. Samples were collected at three points in the cross section: at two depths (near-surface and near-bottom) at two of the sites and at three depths at one site (a mid-depth sample was added) (fig. 3). Site selection was designed to define vertical and horizontal variability in water quality. Samples were collected at 2-hour intervals for one 25-hour tidal cycle to determine tidal variability in water quality. Each sample was analyzed for total and dissolved nitrate plus nitrite nitrogen, nitrite nitrogen, ammonia nitrogen, ammonia plus organic nitrogen, phosphorus, orthophosphorus, and organic carbon; dissolved silica and chloride; total suspended solids; 5-day carbonaceous biological oxygen demand (cBOD); and chlorophylls *a* and *b*. In addition to the point samples, a depth-integrated sample was collected at one of the sampling locations on the bridge.

Samples for all constituents were collected with a brass point sampler and, except for organic carbon, were placed in a precleaned polyethylene churn splitter. Samples for organic carbon were placed in a precleaned glass bottle with a Teflon-lined cap. Sampling times were coordinated so that all samples in the cross section were collected at approximately the same time. Churns were transported back to shore for further processing. Samples from the churn and glass bottle were split into appropriate sample bottles and preserved. Sample volumes, bottle types, preservation techniques, and holding times are presented in table 2. Sample splitting and filtration techniques are described by Ward and Harr (1990).

All reconnaissance samples were analyzed in USGS laboratories. Samples for nutrients (nitrogen and phosphorus), suspended solids, chloride, silica, and specific conductance were analyzed using methods described by Fishman and Friedman (1989); methods used for organic carbon analyses are described by Wershaw and others (1987); the method used for biological oxygen demand analysis is described in a report by the American Public Health Association (1989); and the methods used for chlorophylls *a* and *b* analyses are described by Britton and Greeson (1987).

Reconnaissance results were examined to determine sampling protocols at tidally affected sites for the remainder of the study. These results showed that samples collected near high slacktide and near low slacktide generally represented the maximum daily range in constituent concentration. Averaging these concentrations provided an estimate of daily-mean constituent concentrations. Based on these results, samples generally were collected during several consecutive days, three times a day, at the mouth of the Alafia River (site A-6): near high slacktide, near low slacktide, and once between slacktides. Water-quality samples from four subsections at site A-6 were depth integrated using

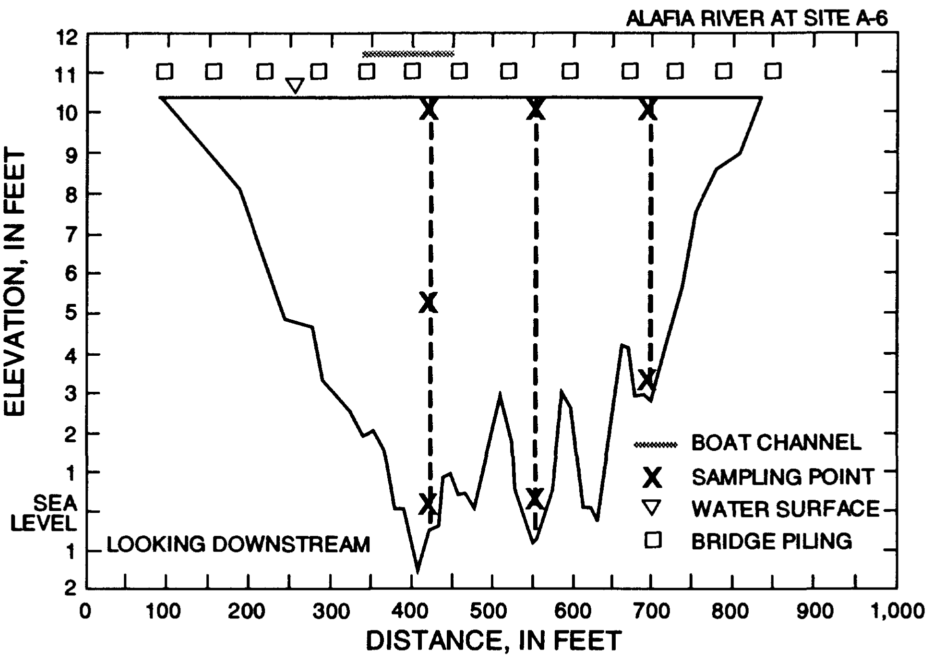


Figure 3. Reconnaissance sampling sites at the Alafia River at cross section A-6.

Table 2. Sample volumes, bottle types, preservatives, and holding times for selected constituents

[HDPE, high density polyethylene; °C, degrees Celsius]

Constituent	Volume (milliliter)	Bottle type	Preservative	Holding time
Nutrients (nitrogen and phosphorus)	250	Amber HDPE	Mercuric chloride, chill to 4°C	7 days
Total suspended solids	500	HDPE	Chill to 4°C	7 days
Specific conductance	250	HDPE	None	7 days
Biological oxygen demand	1,000	HDPE	Chill to 4°C	24 hours
Chlorophylls *a* and *b*	300 to 1,000	Glass fiber filter	Freeze in the dark	14 days
Chloride, silica	250	HDPE	None	28 days
Organic carbon	125	Glass, baked at 350°C, Teflon-lined cap	Chill to 4°C	28 days

a weighted sampler and were composited in a churn splitter. A total of 122 sets of samples were collected during the study at site A-6. Field measurements of dissolved oxygen, pH, temperature, and specific conductance were made at 2-ft intervals at each subsection to define vertical variability in these parameters. Water samples from two generally well-mixed subsections at the mouth of the Hillsborough River (site H-10) were collected and composited in a churn splitter, and field measurements were made as described above.

Samples for water-quality analyses were collected at nontidally affected sites in each basin so nutrient loading upstream of the tidal reach could be compared with nutrient loading at the river mouth. In the Hillsborough River basin (fig. 4), water samples were collected at the upstream side of the dam (site H-8). Water samples at Sulphur Springs (site S-9) were collected from the springwater flowing over the spillway. Water samples were collected from the Tampa Bypass Canal upstream of structure S-160 (site T-7) near the surface. In the Alafia River, depth-integrated water samples were collected at site A-3 (fig. 5). Water samples for Lithia Springs (site L-4) were collected near the major spring boil.

Routine water-quality sample collection began in April 1991 and ended in March 1992. Sample collection dates for each site are shown in figure 6. During the first 3 months of the study, samples were collected during day and night at sites A-6, T-7, and H-10. Examination of these data indicated that diel changes in nutrient concentrations were not significant, so the remainder of the samples were collected only during daylight hours.

Water samples for nutrient analyses were collected at about 1 river-mile intervals, beginning near the mouth of the Alafia River at site A-6 (river mile 0) and ending at the Alafia River at site A-3 (river mile 16) (fig. 5) to describe nutrient concentrations throughout the 16-mile river reach between sites A-3 and A-6. One set of samples was collected during base-flow conditions, and the other was collected after a rain event. The sampling was designed to identify segments of the river where nutrient conditions changed rapidly. Rapid changes in constituent concentrations during base-flow conditions could be caused by contributions from or dilutions by ground water or point sources, and changes during the wet season could be caused by tributary and stormwater runoff, in addition to contributions from or dilutions by ground water and point sources.

All analyses, except those for cBOD, were performed by the SWFWMD laboratory in Brooksville, Fla. Analyses for cBOD demand were performed by a USGS laboratory in Ocala, Fla. Ammonia plus organic nitrogen, nitrate plus nitrite nitrogen, and phosphorus were analyzed using methods described by Koop and McKee (1983); the remainder were analyzed using methods described by the American Public Health Association (1985, 1989).

About 10 to 20 percent of the water samples collected were field quality-assurance (QA) samples. Four types of QA samples were collected: (1) duplicate samples sent to the same laboratory, (2) duplicate samples split between the SWFWMD and USGS laboratories, (3) equipment blanks, and (4) reference samples. Reference samples were sent as "blind" samples (packaged to look like routine samples). Field quality-assurance samples were sent to the laboratory with the regular samples.

Specific conductance and water temperature were measured and recorded at 15-minute intervals at the mouths of the Alafia River (fig. 5, site A-6) and Hillsborough River (fig. 4, site H-10). At site A-6, two sets of probes were installed, one about 1 ft from the bottom and the other set about 5 ft from the bottom. At site H-10, one set of probes was installed about 1 ft above the river bottom. Probes were checked and calibrated during routine maintenance. Adjustments to the recorded specific-conductance measurements were made based on calibrations and independent measurements of specific conductance near the probes. Adjusted values were digitally filtered using the Godin filter prior to the computation of daily-mean specific conductance.

Computation of Nutrient Loads

Instantaneous nitrogen and phosphorus loads were computed as follows:

$$L = C \times Q \times 0.002697 \qquad (1)$$

where

L is the constituent load, in short tons per day;
C is the constituent concentration, in milligrams per liter; and
Q is discharge, in cubic feet per second.

Instantaneous loads are defined for this report as loads that were computed from constituent concentrations and discharge for each sample collected at sites A-3, A-6, T-7, H-8, and S-9 (figs. 4 and 5). For nontidal sites, constituent concentrations determined at discrete times were assumed to be representative of the daily average concentrations so daily-mean discharges were used in load computation. For the tidally affected site on the Alafia River (site A-6), instantaneous loads were computed for each sample. Because sampling

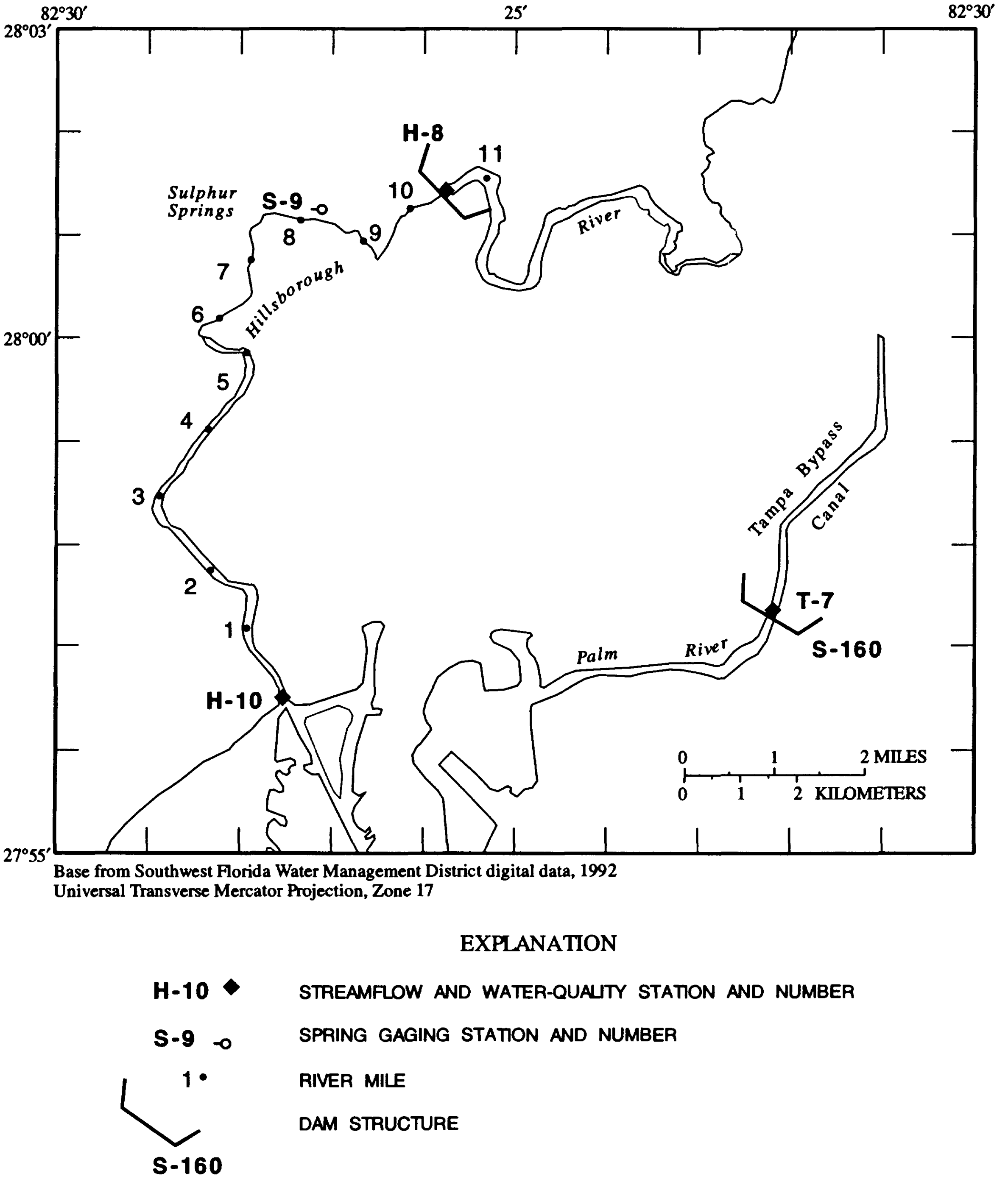


Figure 4. Location of streamflow and water-quality stations in the Hillsborough River and the Tampa Bypass Canal.

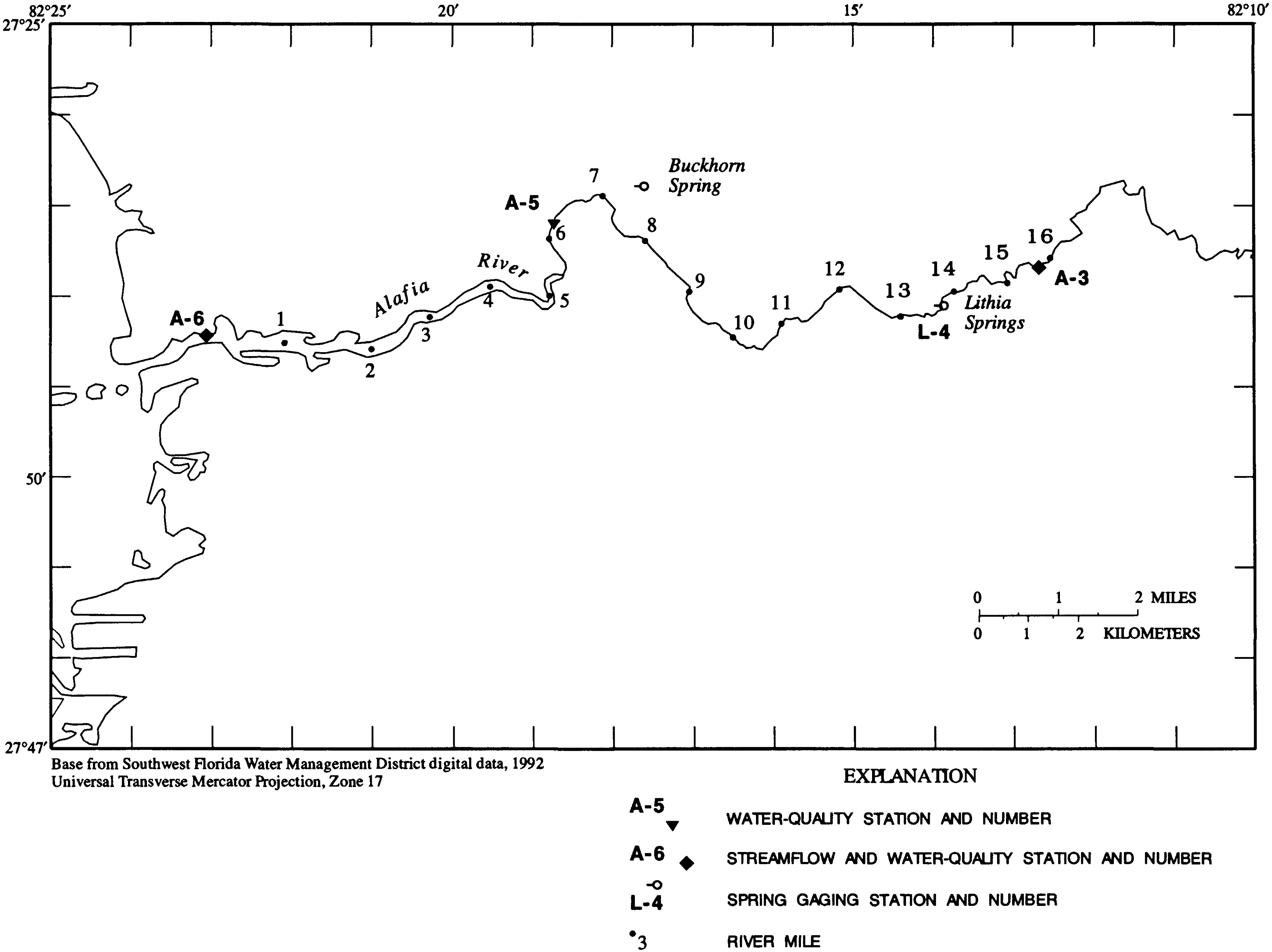


Figure 5. Location of streamflow and water-quality stations in the Alafia River.

SITE NAME	SITE	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR
		1991									1992		
ALAFIA RIVER AT LITHIA	A-3	X	X		XX	X	X X	X X	X	X X	X	X	X X
LITHIA SPRINGS NEAR LITHIA	L-4	X				X		X				X	
ALAFIA RIVER AT GIBSONTON	A-6	18	18	11	5	6 9	8	8	8	6	9	9	7
TAMPA BYPASS CANAL AT STRUCTURE S-160 AT TAMPA	T-7	5	4	X	X	X X	X	X	X	X	X	X	X
HILLSBOROUGH RIVER NEAR TAMPA	H-8			X X	X	X	X X						
SULPHUR SPRINGS AT SULPHUR SPRINGS	S-9			X		X	X X	X	X	X	X	X	X
HILLSBOROUGH RIVER AT PLATT STREET AT TAMPA	H-10		4	2 4	3	7	5 5	5	5	6	5	6	6

EXPLANATION

X INDICATES SINGLE SAMPLE

5 INDICATES TOTAL NUMBER OF SAMPLES COLLECTED OVER MULTIPLE DAYS, WITH 2 TO 3 SAMPLES COLLECTED PER DAY

Figure 6. Dates of water-quality sample collection at selected study sites.

took an average of 30 minutes to complete, discharges for the 15-minute interval before, during, and after the sampling event were averaged to provide a discharge for instantaneous load computations. At the Hillsborough River at site H-10, constituent concentrations for each day of sampling were averaged to represent average concentrations for the day. An estimate of daily-mean discharge for the day was used in load computation.

Computed loads are defined as loads that were estimated from instantaneous loads. For days when water quality was not sampled at the Alafia River at site A-3 and at the Tampa Bypass Canal at site T-7, daily loads were estimated from linear regression equations developed from the instantaneous loads (dependent variable) and daily-mean discharge (independent variable). For days when water-quality data were not available at the Hillsborough River at site H-8 and at Sulphur Springs site S-9, daily loads were estimated from daily-mean discharge and average concentrations of constituents for the study period.

Daily loads at the tidally affected sites could not be estimated in the same way as they were at the nontidally affected sites because concentrations of all constituents measured in the study varied with tide throughout the day. At the Alafia River at site A-6, loads at 15-minute intervals were computed using regression equations developed from instantaneous loads (dependent variable) and instantaneous discharge and near-bottom specific conductance (independent variables). The computed loads were digitally filtered with the Godin filter to remove variations in the 15-minute loads caused by tide. A daily-mean load was then computed from the filtered data. Monthly loads were computed by summing the daily loads for each month, and the annual load was computed by summing the monthly loads. Daily loads at the Hillsborough River at site H-10 were computed using regression equations developed from measured loads (dependent variable) and estimated daily-mean discharge (independent variable).

DISCHARGE TO HILLSBOROUGH BAY

Hillsborough Bay receives more freshwater inflow from surface water than any other segment of Tampa Bay. Discharge from the Alafia River, Hillsborough River, and Tampa Bypass Canal, as well as several smaller tributaries, contribute to the total freshwater input to Hillsborough Bay. This freshwater contains suspended and dissolved constituents that eventually reach Hillsborough Bay. Because constituent loading to an estuary is dependent on a net freshwater inflow, an understanding of the discharge characteristics of the main tributaries to Hillsborough Bay is necessary in the interpretation of constituent loads to Hillsborough Bay.

Analyses of selected streamgaging stations in the nontidally affected reaches of the Alafia and Hillsborough River basins and the Tampa Bypass Canal were done to determine the long-term discharge characteristics of major tributaries to Hillsborough Bay. The period of record, mean-annual discharge, and duration of daily-mean discharges based on complete climatic years (April through March) at selected stations are summarized in table 3.

Annual-mean discharges at site H-8 in the Hillsborough River typically are greater than those of any other gaged sites tributary to Hillsborough Bay. Discharge at the most downstream, nontidally affected Hillsborough River site (H-8) represents drainage from about 94 percent of the historic Hillsborough River drainage area (prior to construction of the Tampa Bypass Canal). Mean-annual discharge at site H-8 was 472 ft^3/s for the period April 1939 through March 1992.

Flow characteristics in the Hillsborough River have changed during the period of record. Trend analyses of annual-mean discharges were computed using the nonparametric Kendall Tau test. This test assumes that the data are independent and identically distributed regardless of the type of distribution. All possible pairs of the data are compared. A minus is scored if a later value is less than a previous value; a plus is scored if the later value is higher. Smith and others (1982) discuss this technique in more detail.

Trend analyses indicate a decrease in annual-mean discharges at site H-8. The trend is significant at the 5-percent level and is -7.7 $(ft^3/s)/yr$ (fig. 7 and table 4). The most dramatic changes in the flow characteristics are changes in the timing and magnitude of high and low flows. From 1939 to 1992, the 7- and 30-day low flows generally have declined and were near zero for many years during the period 1961 through 1992 (fig. 7). The 7- and 30-day high flows have decreased in magnitude as well. Because of alteration of drainage patterns that resulted in an indeterminate contributing drainage basin size during the period of record, no attempt was made to identify the cause of the decline. Deficient rainfall, alteration of drainage patterns, increased water use, and decreased base flows, however, probably have all contributed to the change in flow characteristics.

Discharge at Sulphur Springs (fig. 4, site S-9) is related to the elevation of the potentiometric surface of the Upper Floridan aquifer (Stewart and Mills, 1984). Dye tests have confirmed the hydraulic connection of the spring with several sinkholes in the area, some of

Table 3. Duration analyses for selected streamflow stations in the study area

[ft³/s, cubic feet per second]

Station	Period of record	Mean-annual discharge[1] (ft³/s)	Daily-mean discharge equaled or exceeded for the given percentage of days				
			5	10	50	90	95
Site A-1							
North Prong Alafia River	April 1951-March 1992	155	476	297	94.2	37.0	27.9
Site A-2							
South Prong Alafia River	April 1963-March 1992	97.5	330	210	57.8	17.8	12.6
Site A-3							
Alafia River at Lithia	April 1933-March 1992	342	1,140	746	180	59.1	38.9
Site H-8							
Hillsborough River near Tampa	April 1939-March 1992	472	2,150	1,360	162	0.47	0.08
Site S-9							
Sulphur Springs	April 1960-March 1992	38.9	62.5	54.8	41.3	11.5	6.69
Site T-7							
Tampa Bypass Canal at S-160	April 1975-March 1990	141	342	131	61.0	23.0	10.6

[1]Mean of the annual-mean discharges for the period of record.

Table 4. Trend analyses of annual-mean discharge at selected streamflow stations

Station	Period of record	Kendall Tau	Significance level	Trend slope	
				Cubic feet per second	Percent[1]
Site A-1					
North Prong Alafia	April 1951-March 1992	[2]-0.215	0.05	-1.93	-1.2
Site A-2					
South Prong Alafia	April 1963-March 1992	[2]-.448	.001	-2.67	-2.7
Site A-3					
Alafia River at Lithia	April 1933-March 1992	[3]-.173	.05	-1.37	-.004
Site H-8					
Hillsborough River	April 1939-March 1992	-.331	.0005	-7.74	-1.6
Site S-9					
Sulphur Springs	April 1960-March 1992	-.460	.0002	-.52	-1.3

[1]Percentage of mean-annual discharge.

[2]Discharge data were adjusted for correlation with rainfall at Bartow.

[3]Discharge data were adjusted for correlation with rainfall at Plant City.

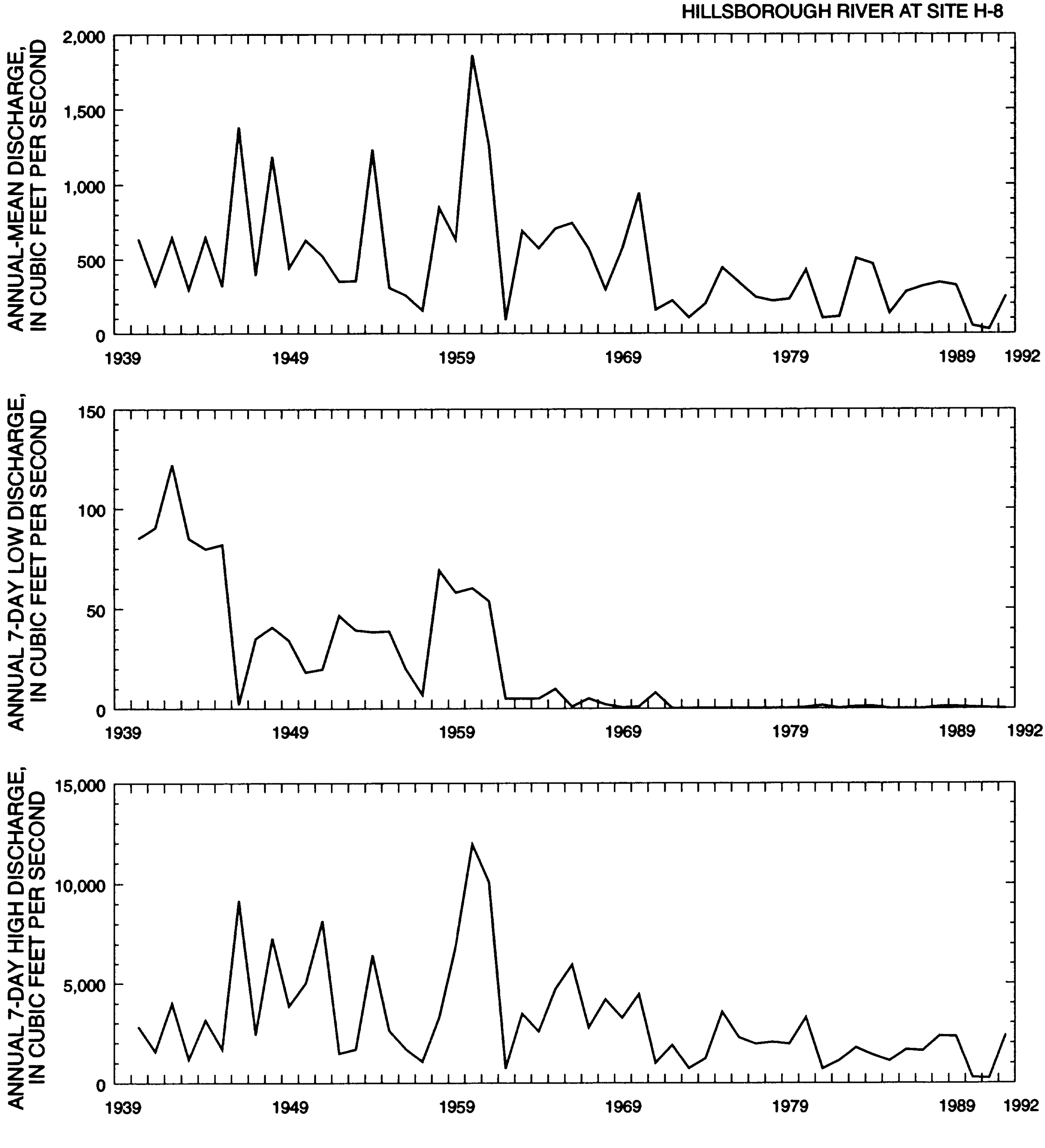


Figure 7. Annual-mean discharges, 7-day low discharges, and 7-day high discharges of the Hillsborough River at site H-8, April 1939 through March 1992. (Annual data are plotted on ending year. Location of site H-8 is shown in figure 4.)

which are used for stormwater retention (Stewart and Mills, 1984). Mean-annual discharge at site S-9 was 38.9 ft^3/s for the period April 1960 through March 1992 (table 3).

Trend analysis indicates a long-term decline in the annual-mean discharge from Sulphur Springs (site S-9). The trend is significant at the 5-percent level and is about -0.5 $(ft^3/s)/yr$ (table 4). Because of diversions of water that affect flow from the spring, the cause of the decline in the discharge was not investigated for this study. Increased water use and decreased ground-water levels most likely have contributed to this decline. Figure 8 shows the annual-mean discharges for the period April 1961 to March 1992.

Annual-mean discharges measured at the most downstream, nontidally affected site in the Alafia River (site A-3) at times have exceeded those measured at site H-8 in the Hillsborough River. Discharge at site A-3 represents drainage from about 80 percent of the total river drainage area. Mean-annual discharge was 342 ft^3/s for the period April 1933 through March 1992 (table 3).

Flow characteristics in the Alafia River also have changed during the period of record April 1933 through March 1992. A general decrease in annual-mean discharge at site A-3 has occurred since about 1963 (fig. 9). Cumulative annual total rainfall at Plant City was plotted against the cumulative annual-mean discharge to evaluate the relation between rainfall and discharge at site A-3 (fig. 10). If the change in streamflow characteristics was due only to a change in rainfall patterns, then the resulting plot would be a straight line. The relation, however, is not linear, and changes in slope occur. The change in slope after about 1980 indicates a decrease in discharge relative to rainfall.

Because discharge in the Alafia River is related to rainfall, annual-mean discharges were adjusted for rainfall before trend analyses were computed. The residuals from a simple linear regression of discharge against rainfall describe the rainfall-adjusted discharge. These residuals were used in the trend analyses. Trend analyses of rainfall-adjusted discharge at sites A-1, A-2, and A-3 in the Alafia River basin indicate a decrease in annual-mean discharges at each site (table 4). Trend analyses of rainfall did not show a significant trend at the 5-percent level. This indicates that the decreasing trends in discharge probably are not solely due to deficient rainfall.

The declines in annual-mean discharge at selected sites in the Alafia River basin are most likely related to a long-term decline in the potentiometric surface of the Upper Floridan aquifer. The decline in the potentiometric surface in the vicinity of the Alafia River basin was 5 to 30 ft between January 1964 and May 1980 (Yobbi, 1983). This decline probably resulted in decreased ground-water inflow to the river. Hammett (1990) demonstrated a similar decreasing trend in annual discharge in the Peace River, attributing the decline to long-term declines in the potentiometric surface of the Upper Floridan aquifer.

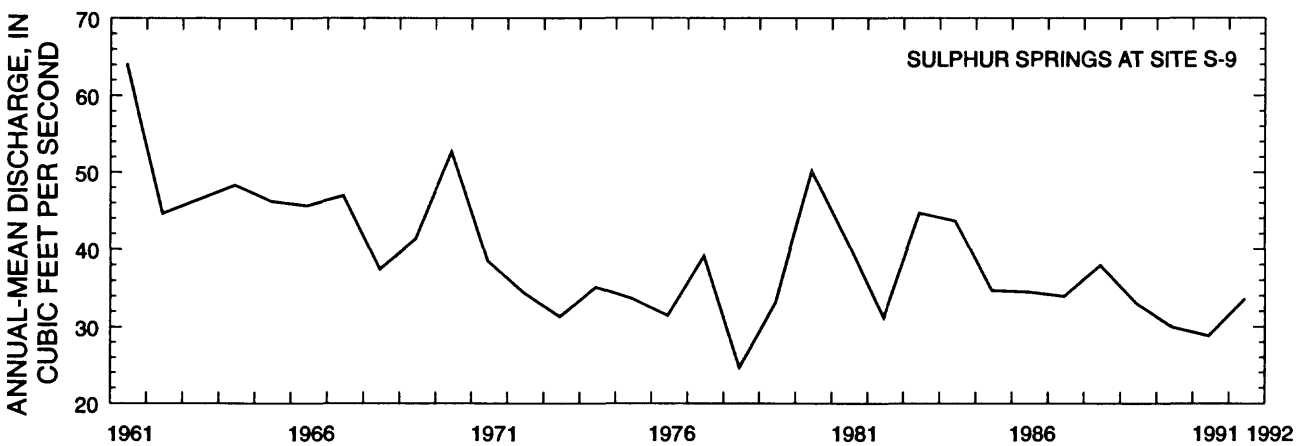


Figure 8. Annual-mean discharges of Sulphur Springs at site S-9, April 1961 through March 1992. (Location of site S-9 is shown in figure 4.)

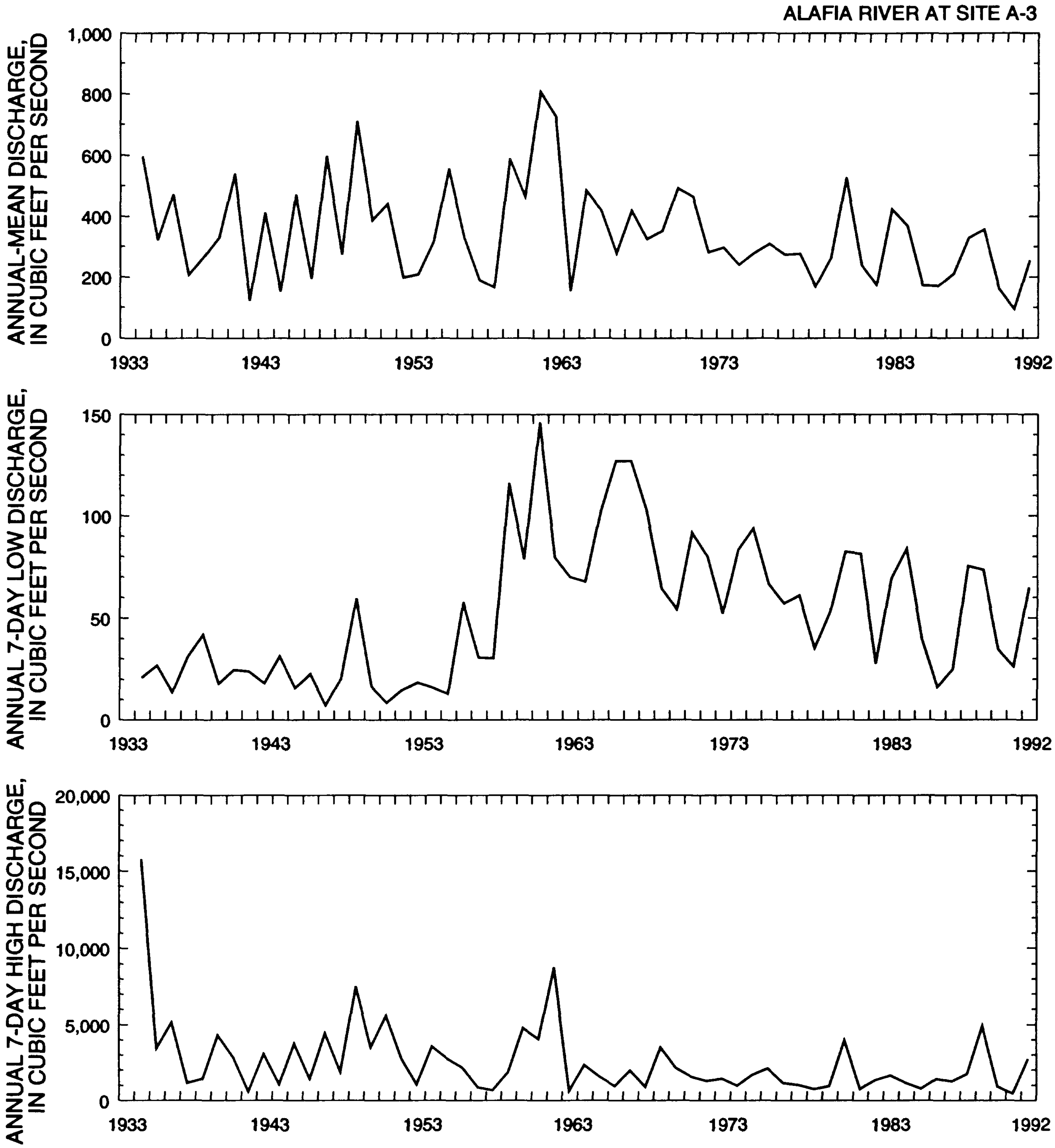


Figure 9. Annual-mean discharges, 7-day low discharges, and 7-day high discharges of the Alafia River at site A-3, April 1933 through March 1992. (Annual data are plotted on ending year. Location of site A-3 is shown in figure 5.)

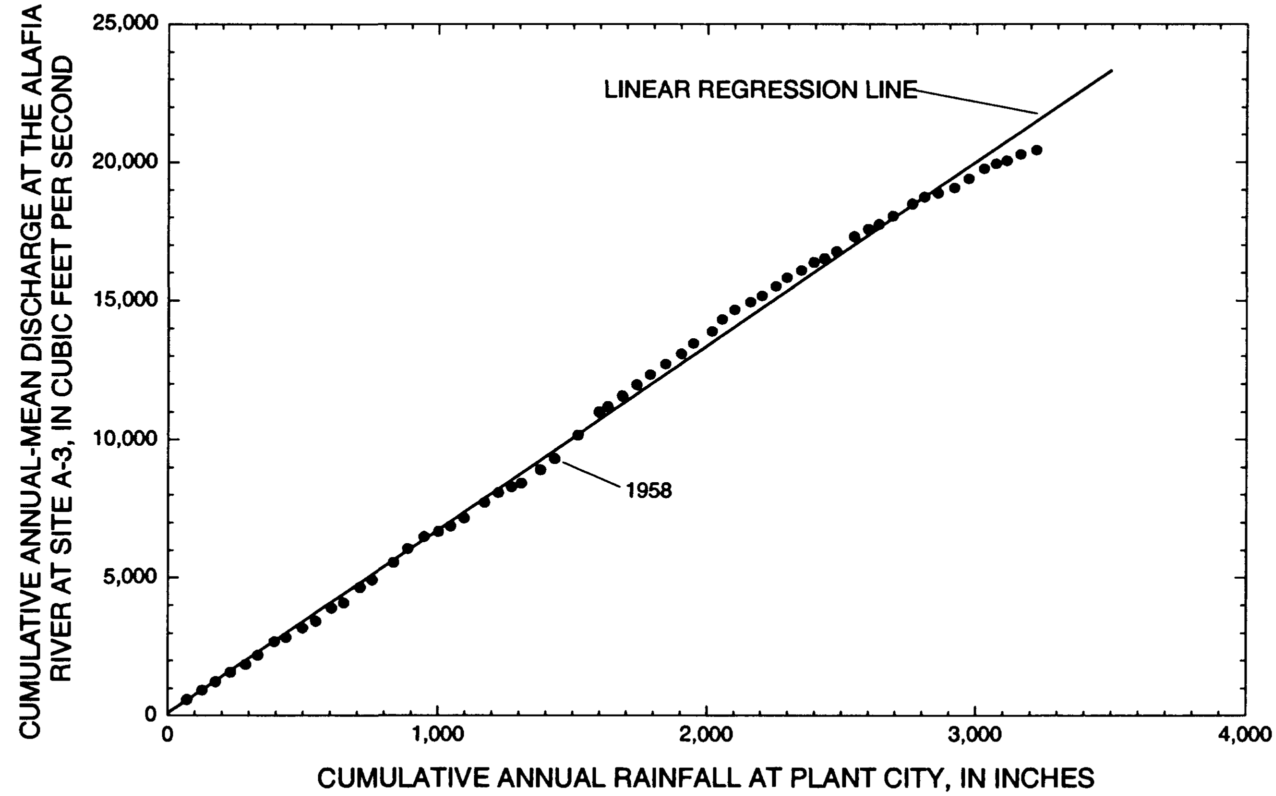


Figure 10. Accumulated annual-mean discharge of the Alafia River at site A-3 as a function of accumulated annual rainfall at Plant City, 1933–92. (Location of site A-3 is shown in figure 5.)

Low-flow characteristics in the Alafia River were examined for the period of record. The results of an analysis of 7- and 30-day low flows at site A-3 showed that low flows in the Alafia River increased from about 1957 to 1966, and generally have decreased from about 1967 through 1992, whereas 7- and 30-day high flows have generally decreased during the period of record (fig. 9).

The analyses of long-term discharge characteristics at selected tributaries to Hillsborough Bay indicate that (1) annual flows to the bay vary considerably from year to year, and (2) the long-term flow characteristics are changing in the Hillsborough and Alafia Rivers. In both basins, annual-mean flows are decreasing, and both low- and high-flow characteristics have changed. These changes in the discharge characteristics impact the magnitude and timing of constituent loads to Hillsborough Bay. The effect of discharge on loading is discussed in more detail in the report section "Nutrient loads to Hillsborough Bay."

Discharge at selected sites in the Alafia River basin, Hillsborough River basin, and the Tampa Bypass Canal were measured during the study for subsequent use in loading computations. The following sections discuss discharge characteristics at these sites during the study.

Alafia River

Daily-mean discharge at the Alafia River at site A-3 during the study is shown in figure 11. Annual-mean discharge for the study period April 1991 to March 1992 was 254 ft^3/s, 26 percent less than the long-term average. The maximum daily-mean discharge, 4,120 ft^3/s, occurred on July 15, 1991. An annual maximum daily-mean discharge of this magnitude is expected to be equaled or exceeded about once every 3 years. Extended periods of low flow occurred in April and May 1991 and from November 1991 through mid-February 1992.

Discharge from Lithia Springs (site L-4) is measured periodically by the USGS and by the West Coast Regional Water Supply Authority (WCRWSA). Mea-

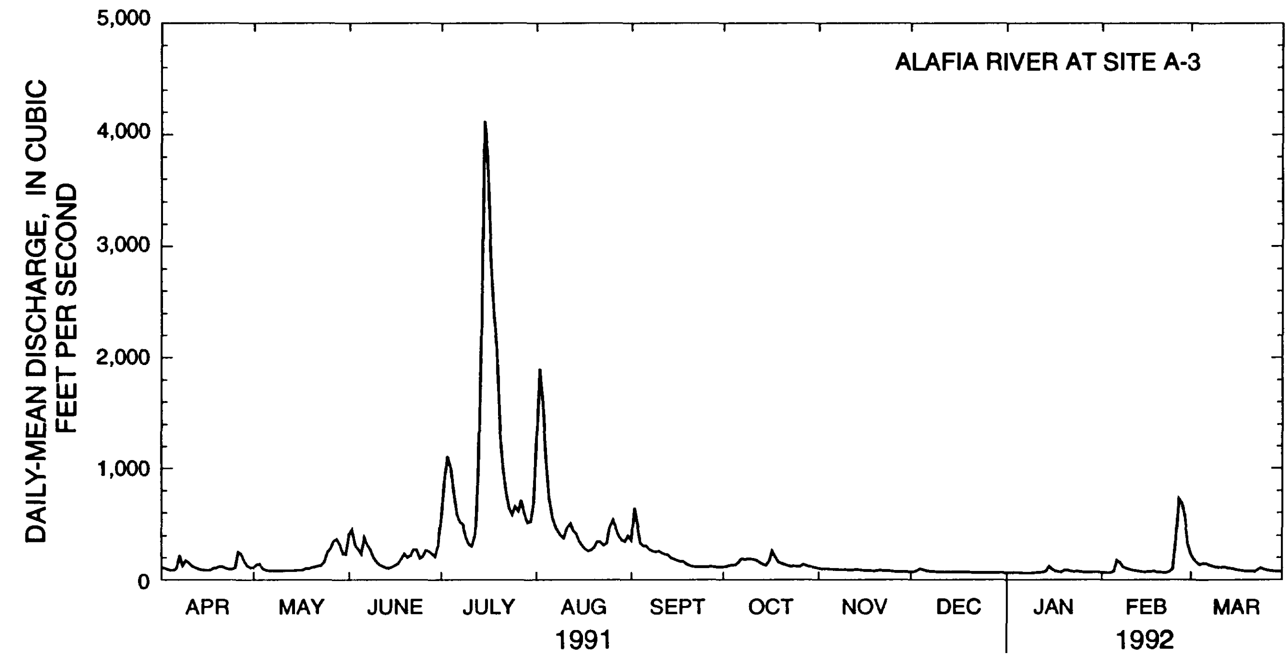


Figure 11. Daily-mean discharge of the Alafia River at site A-3, April 1991 through March 1992. (Location of site A-3 is shown in figure 5.)

sured discharge at Lithia Springs during the study ranged from 24.0 to 61.5 ft^3/s, and all measurements were affected by withdrawals from the spring for industrial use. Total withdrawal during the study was 1.4 Bgal and averaged about 3.8 Mgal/d (5.9 ft^3/s) (John Hilbert, Southwest Florida Water Management District, written commun., 1992).

Discharge in the tidally affected reach of the Alafia River is constantly varying due to the effects of tide. Although large volumes of water move upstream and downstream each day, the net downstream movement of water may be very small. This net discharge is of interest in this study because it (with the associated constituents) constitutes loading to Hillsborough Bay.

There are several difficulties in determining the net flow of water at a tidally affected site on the Alafia River. One difficulty is the effect of tide. Because the tidal period is about 25 hours, computation of daily discharge based on a 24-hour day does not accurately reflect the true net flow from a tidally affected site. However, mean discharges for longer periods of time, such as monthly and annual means, eliminates most of the problem with tidal-discharge computations.

Two types of discharge measurements were made at the mouth of the Alafia River at site A-6. Ten conventional current-meter measurements and 42 BBADCP measurements were made. Conventional current-meter measurements were made on the downstream side of U.S. Highway 41, and BBADCP measurements were made upstream of the U.S. Highway 41 bridge and the CSX railroad bridge. Measured discharges ranged from -5,370 to +6,570 ft^3/s (negative values denote upstream flow), and stage during discharge measurements ranged from -0.33 to +3.0 ft above sea level.

Continuous discharge (discharges computed at 15-minute intervals) was computed from ratings developed from the measured discharges. Continuous discharges ranged from about -11,000 to +11,000 ft^3/s during the study period. The continuous discharge was digitally filtered with the Godin filter to remove variations caused by tide. An example of the effects of the filtering process is shown in figure 12. The filtered data were then used to compute the daily-mean discharge at site A-6.

Daily-mean discharge at site A-6 ranged from -453 to 4,070 ft^3/s and averaged 384 ft^3/s during the study (fig. 13). Daily-mean discharge at the mouth of the Alafia River (site A-6) followed the same general pattern as discharge at site A-3, but the discharges at the mouth (site A-6) vary more during periods of low discharge than discharge upstream (site A-3). The variation in discharge at site A-6 is expected because of

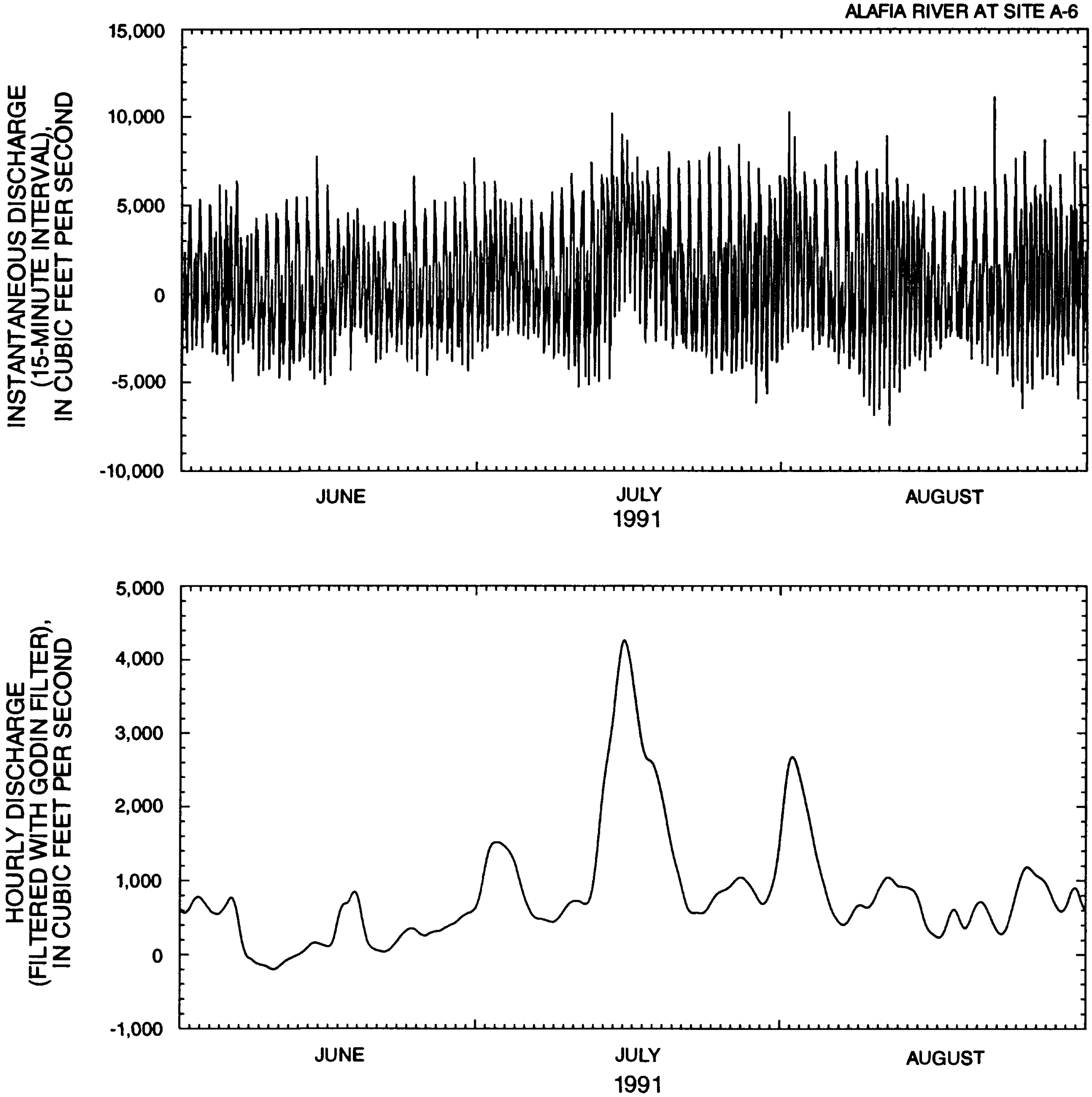


Figure 12. Instantaneous discharge and filtered discharge of the Alafia River at site A-6, June 1991 through August 1991. (Location of site A-6 is shown in figure 5.)

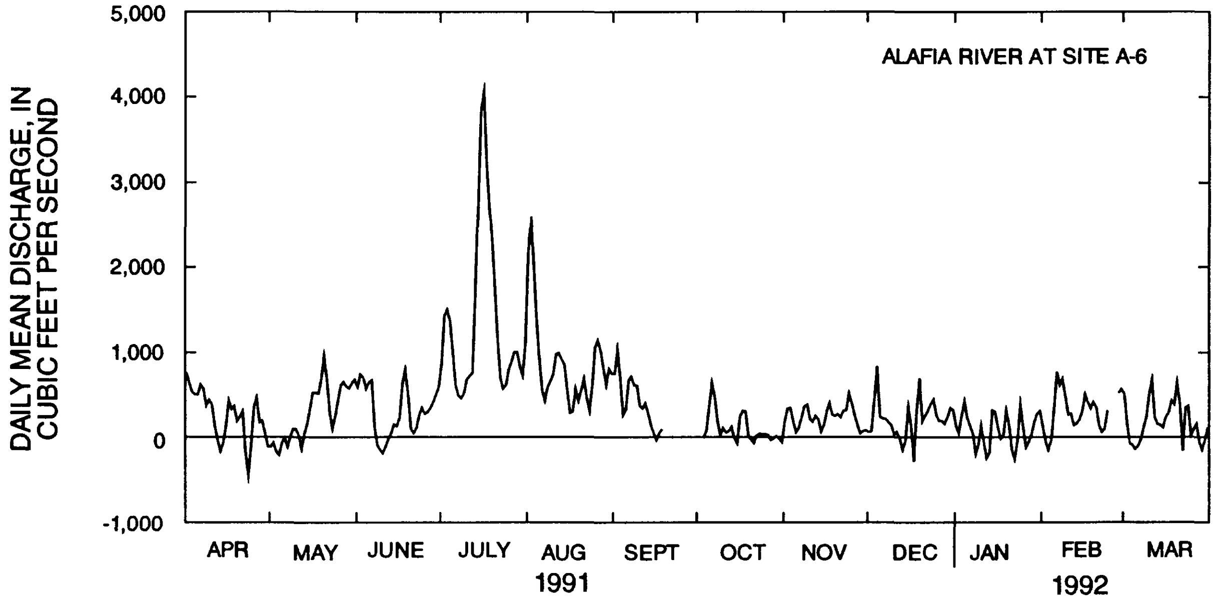


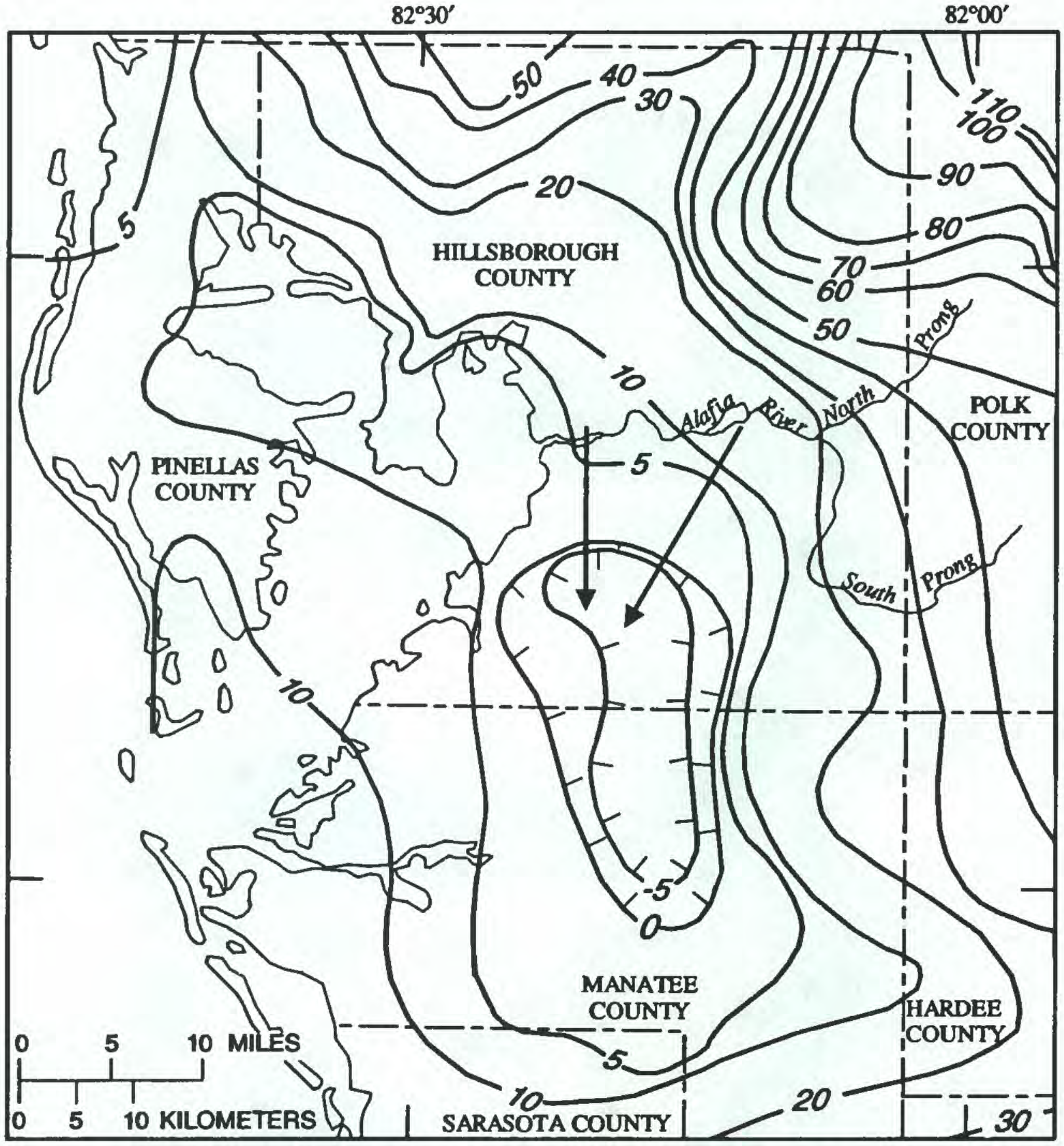
Figure 13. Daily-mean discharge of the Alafia River at site A-6, April 1991 through March 1992. (Location of site A-6 is shown in figure 5.)

the variability of runoff events, basin characteristics, wind effects, and the effects of tide. Daily-mean discharge at site A-6 was sometimes negative (upstream), indicating a net loss of water from the river (fig. 13). This loss occurred during extended periods of low flow in the Alafia River at site A-3 (fig. 11). This loss of water could be due to errors in the measurement and computation of discharge. However, it is possible that losses of river water might be occurring. A potentiometric-surface map of the Upper Floridan aquifer for May 1991 shows a cone of depression south of the tidal reach of the Alafia River (fig. 14). During these conditions, water in the aquifer would be moving away from the river in the general direction shown by arrows in figure 14, and the potential exists for the seepage of river water to the aquifer.

The maximum daily-mean discharge at the mouth of the Alafia River at site A-6 (fig. 13), 4,070 ft^3/s, occurred 1 day after the peak at site A-3 (fig. 11), 16 mi upstream. The 1-day lag represents the traveltime of peak floodwater during this time. The mean stream velocity of the peak discharge in the 16-mi reach between sites A-3 and A-6 was about 1 ft/s.

Velocity profiles were examined to determine flow characteristics at site A-6. Three "snapshots" of velocity profiles at site A-6 during a floodtide, a slacktide, and an ebbtide are shown in figure 15. These are copies of screen displays taken from a BBADCP data-processing program developed by RD Instruments. All profiles are viewed looking downstream, and vertical-velocity profiles were averaged in 19-ft-wide blocks and include about 30 individual measurements in each block. Positive values are shown in red, orange, and yellow hues and denote downstream (seaward) flows, and negative numbers are shown in blue hues and denote upstream flows. The depth scale on the left side of the display indicates the depth at which a point velocity was measured. During floodtide, velocity in the shallower part of the cross section is affected by the bridges. During slacktide, velocities are low and variable; both upstream and downstream velocities were detected. During ebbtide, velocities were all seaward with maximum velocities near the center of the cross section. Cross-sectional mean velocity was estimated from the point-velocity index. Mean velocity ranged from about -2.0 to +2.2 ft/s and averaged 0.09 ft/s. Ebbtide velocities were greater in magnitude than floodtide velocities and averaged 0.57 ft/s. Floodtide velocities averaged -0.38 ft/s.

There are several potential sources of error associated with the measurement and computation of discharge at tidally affected sites. The resolution of the index-velocity meter is one critical factor in the accuracy of discharge computations and is a function of the equipment limitations. For example, the point-velocity



Base from Southwest Florida Water Management District digital data, 1:500,000, 1992
Universal Transverse Mercator Projection, Zone 17

EXPLANATION

— 10 — POTENTIOMETRIC CONTOUR — Shows altitude at which water level would have stood in tightly cased wells, May 1991. Contour interval 5 and 10 feet. Datum is sea level. Hachures indicate depressions

← GENERAL DIRECTION OF GROUND-WATER FLOW

Figure 14. The potentiometric surface of the Upper Floridan aquifer, May 1991. (Modified from Mularoni, 1991.)

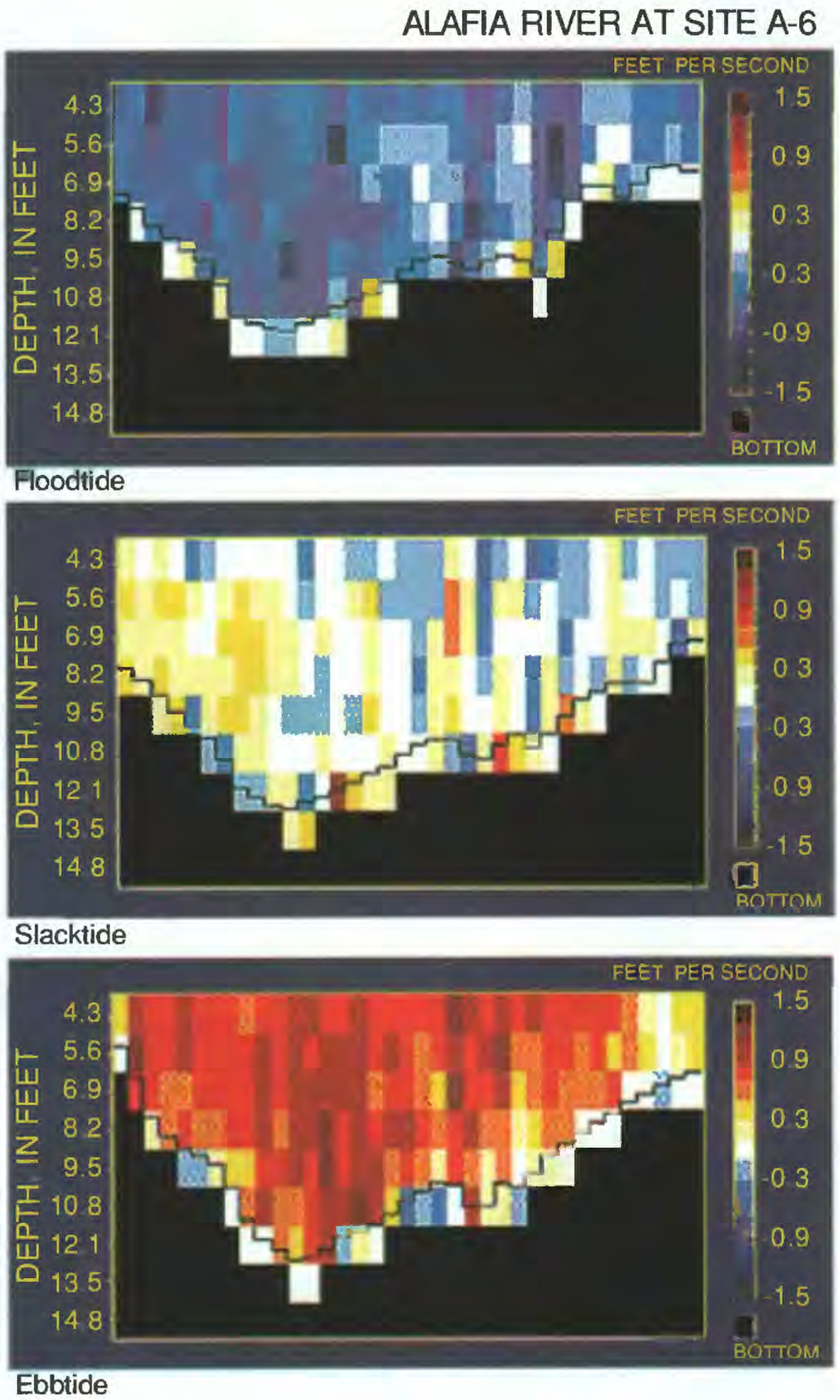


Figure 15. Velocity profiles for the Alafia River at site A-6. (Location of site A-6 is shown in figure 5.)

index at site A-6 has a resolution of about 0.06 ft/s, and the average cross-sectional area is 2,500 ft^2. Multiplying the two values yields 150 ft^3/s, the resolution of the discharge rating at site A-6. The frequency of measurements, the measurement of a representative range of freshwater inflow and tide conditions, and the stability of the cross section affect the accuracy of discharge computations. Measurements made during the study indicated that the cross section at the Alafia River at site A-6 was stable; that is, the cross-sectional area did not change during the study. Because of this stability, only one stage-area rating and one index-velocity/mean-velocity rating were developed for this site.

Another potential source of error in the computation of discharge occurs during stratified flow. In stratified flow, an upper layer of freshwater or less saline water can move downstream while the saltwater wedge near the bottom is moving upstream. When this occurs, errors in the computation of discharge by conventional techniques can occur because conventional meters do not detect the change in direction of flow with depth in tidal rivers. However, the BBADCP does distinguish flow direction.

The velocity measured using the BBADCP was compared to the velocity measured using conventional current meters at discrete depths. Discharge computed using data from the BBADCP also was compared to discharge ratings developed from conventional discharge measurement techniques. These comparisons indicated that the BBADCP, if used correctly, will accurately measure discharges when mean velocities are greater than 0.5 ft/s. At lower velocities (<0.5 ft/s), which are typical during periods around slacktides, the variability of the BBADCP discharge measurements can be as much as 20 percent of the rated discharge. If discharge measurement errors of the BBADCP techniques are random, the errors theoretically can be reduced by increasing the number of measurements. Even with these limitations, the BBADCP can make more accurate discharge measurements in tidal rivers than is possible using the conventional current-meter method.

Hillsborough River

Discharge from the Hillsborough River at site H-8 was minimal (less than or equal to 0.5 ft^3/s) from April 1 to May 22, 1991, and from September 23, 1991, to March 31, 1992 (fig. 16). These time periods represent about 66 percent of the year. During the study, most of the total annual discharge occurred from late May to mid-September, with about 50 percent of the total occurring in July. Annual-mean discharge for the study period was 249 ft^3/s, 47 percent less than the long-term average. The maximum discharge was 2,590 ft^3/s on July 20.

Daily-mean discharge at Sulphur Springs at site S-9 during the study ranged from 27 to 48 ft^3/s and averaged 34.4 ft^3/s during the study (fig. 17). Discharge was greatest in August 1991 and least in January 1992. During periods of low flows in the Hillsborough River at site H-8, ground water from Sulphur Springs is a major source of freshwater to the tidally affected reach of the Hillsborough River.

Six conventional current-meter measurements and more than 60 BBADCP discharge measurements were made near the mouth of the Hillsborough River at site H-10. Conventional current-meter measurements were made at the gage, and the BBADCP measurements were made about 200 ft upstream from the gage.

Measured discharges ranged from about -1,200 to +2,000 ft^3/s, and measured cross-sectional mean velocities ranged from about -3 to +3 ft/s. Velocity profiles for a floodtide, a slacktide, and an ebbtide at site H-10 are shown in figure 18. All profiles are viewed looking downstream. Velocity profiles during floodtide show bidirectional flow, although most of the flow direction is upstream, a small section is flowing downstream on the floodtide. This velocity distribution becomes even more complex near slacktide. Flow reversals during slacktide occur horizontally and vertically throughout the cross section. Velocities during ebbtide become more uniform than during floodtide. These figures demonstrate the difficulties in accurately representing vertical and horizontal velocity distributions in tidal rivers, especially during periods of flow reversal (slacktide).

The point-velocity index meter at site H-10 was affected by local conditions that prevented the proper operation of the equipment. The interference problems were initially thought to be equipment problems, but frequent replacement of various components did not resolve the problem. The meter was installed on a bridge with a metal drawbridge that could have generated an intermittent electromagnetic field that interfered with velocity readings. Hand-held water-quality field equipment also occasionally malfunctioned when used at this bridge. As a result of this interference, continuous discharge data could not be computed for this site. Discharge at site H-10 was estimated by summing the discharges from the gaging station on the Hillsborough River (site H-8) and those from the gaging station at Sulphur Springs (site S-9). During rainfall events, the total discharge at site H-10 was underestimated because the watershed below the two gaged freshwater sources was not considered. Therefore, the discharge at site H-10 used in load computations is a conservative estimate of actual discharge.

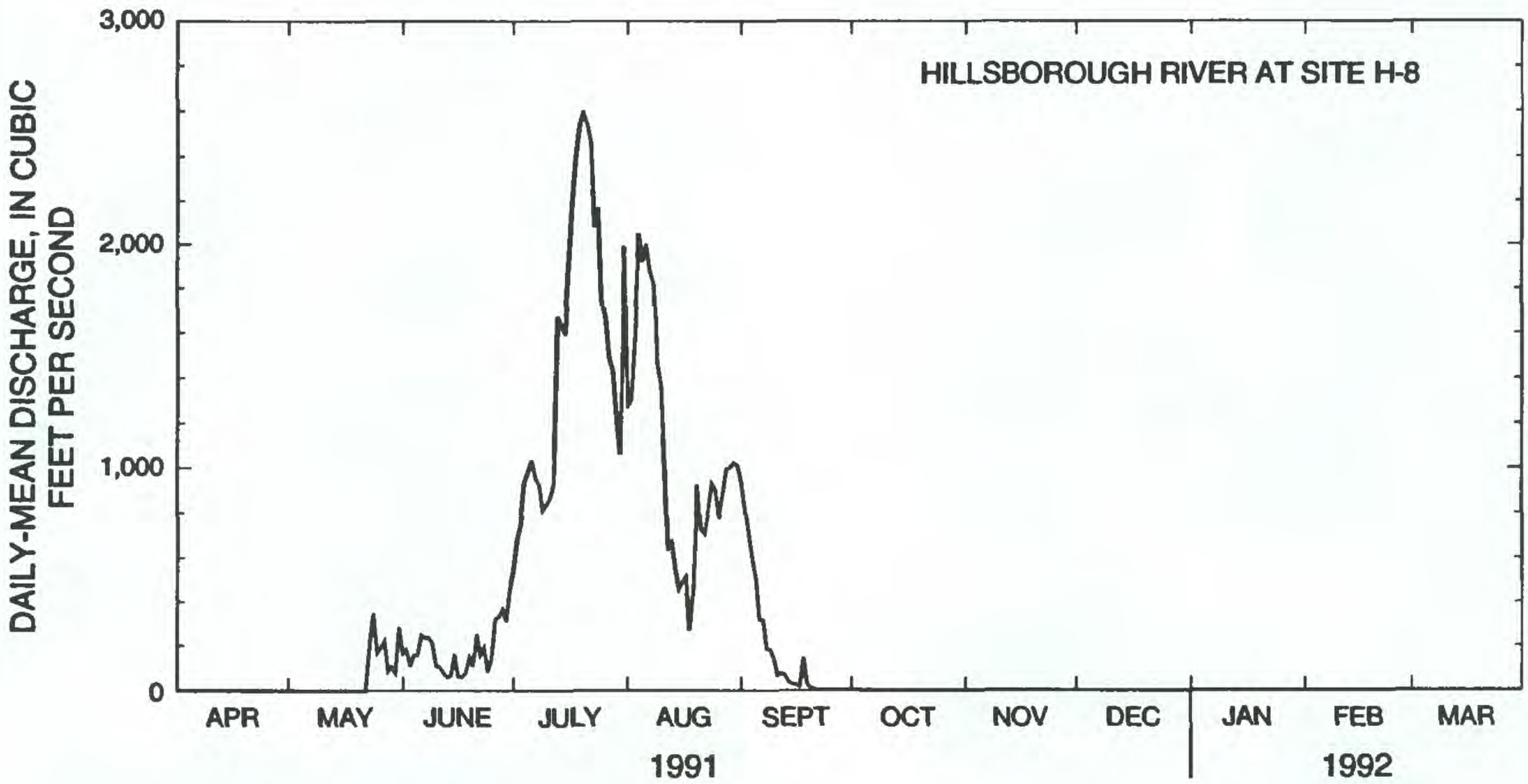


Figure 16. Daily-mean discharge of the Hillsborough River at site H-8, April 1991 through March 1992. (Location of site H-8 is shown in figure 4.)

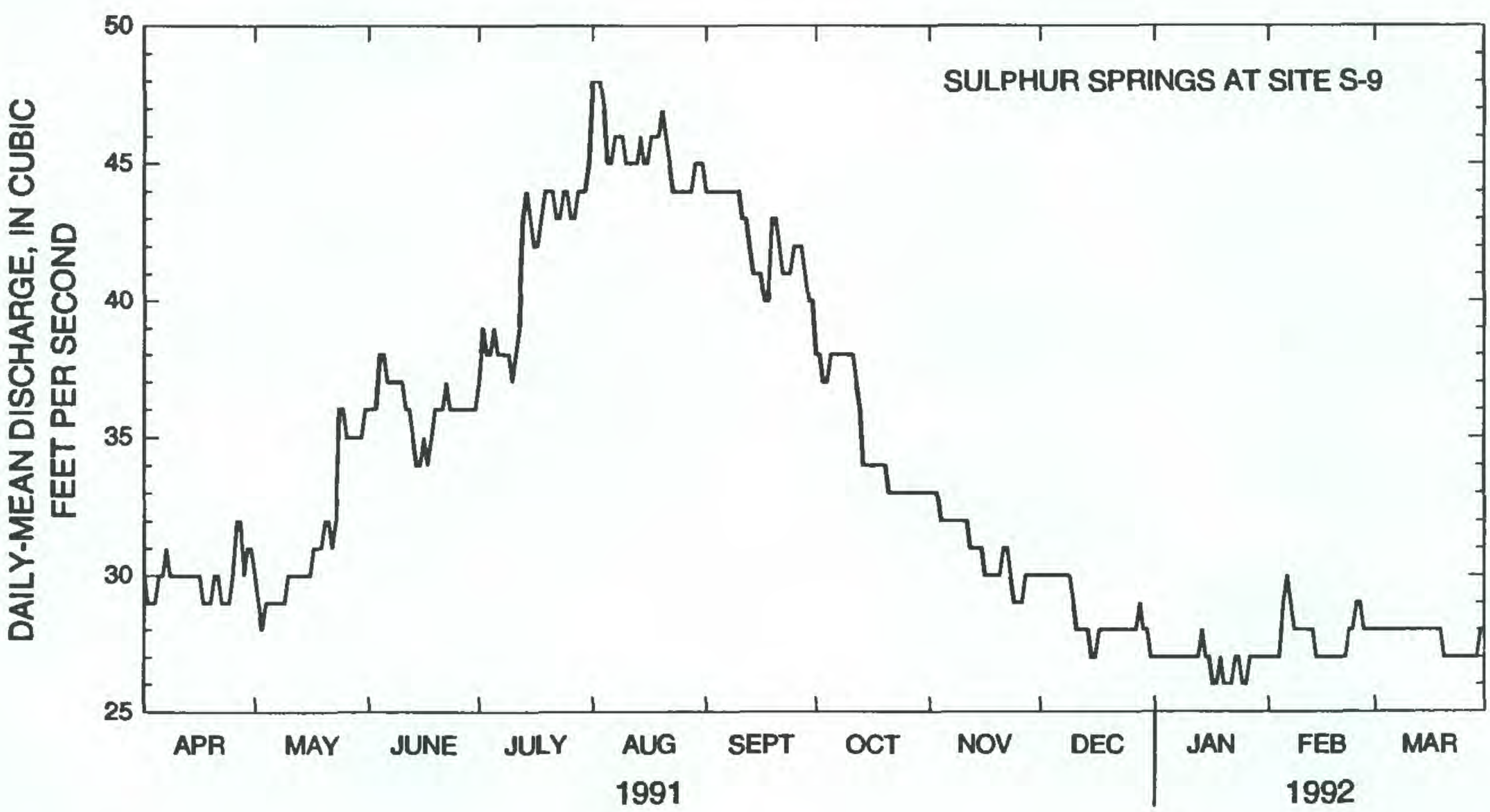


Figure 17. Daily-mean discharge of Sulphur Springs at site S-9, April 1991 through March 1992. (Location of site S-9 is shown in figure 4.)

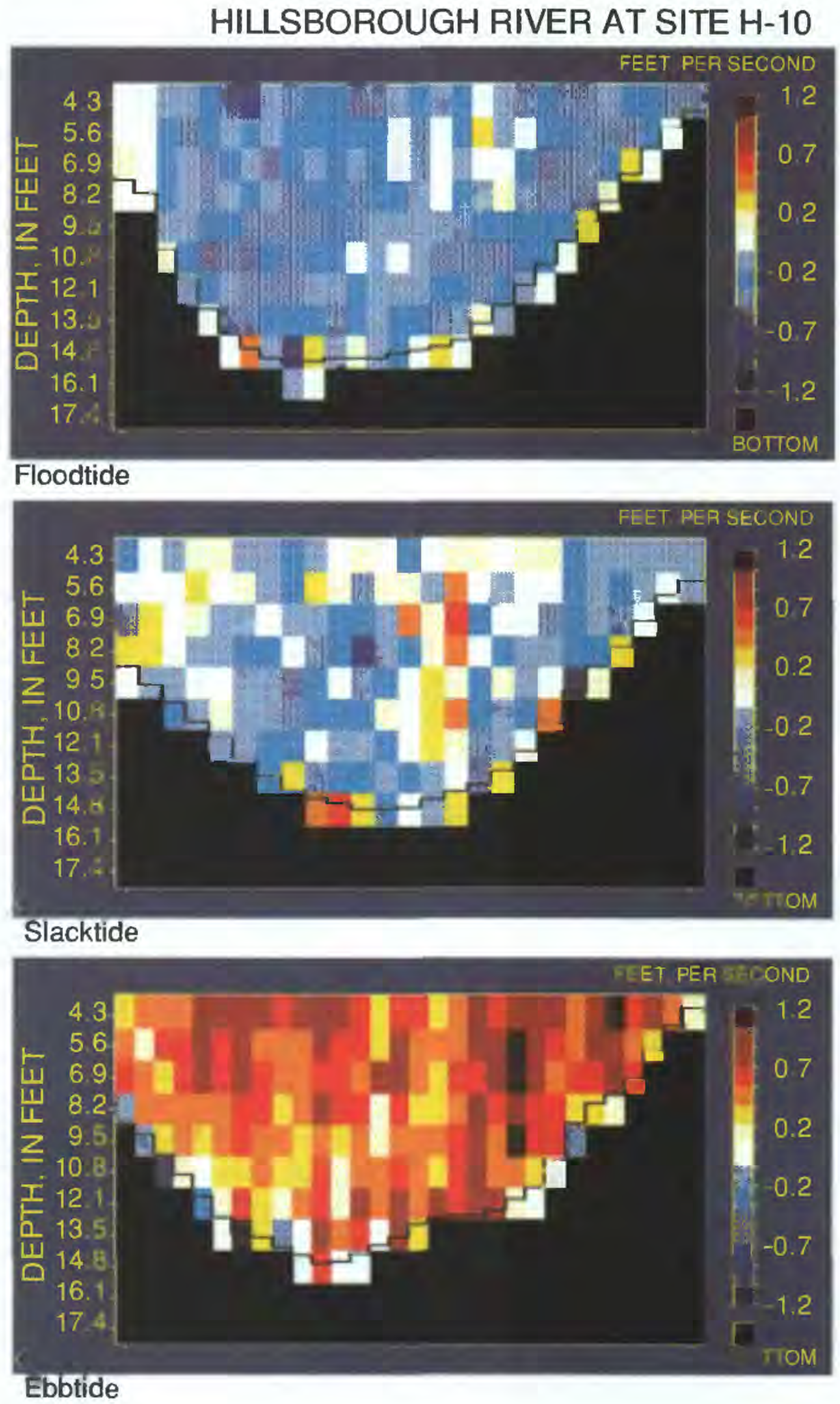


Figure 18. Velocity profiles for the Hillsborough River at site H-10. (Location of site H-10 is shown in figure 4.)

Tampa Bypass Canal

Discharge from the Tampa Bypass Canal at site T-7 is affected by rainfall and evaporation, gate operations in the upstream bypass canal structures, ground-water flow, and pumpage from the canal. No pumpage from the canal occurred from May to October 1991, but monthly averages ranged from 16.1 to 45.2 ft^3/s for the remaining months of the study (table 5) (Michael Coates, West Coast Regional Water Supply Authority, written commun., 1992). Control structures in the bypass canal were not operated for flood control during the study; however, gates were operated periodically for maintenance (Richard Lee, Southwest Florida Water Management District, oral commun., 1992).

Table 5. Monthly average pumpage from the Tampa Bypass Canal to the Hillsborough River, April 1991 through March 1992

[ft^3/s, cubic feet per second]

Year/month	Average pumpage (ft^3/s)
1991	
April	17.8
May	0
June	0
July	0
August	0
September	0
October	0
November	15.9
December	45.2
1992	
January	40.7
February	35.4
March	16.1

Daily-mean skimmer discharges at site T-7 were provided by the SWFWMD and are shown in figure 19. Discharges from skimmer leakage, lift-gate operations, lift-gate leakage, or stop-log leakage, if any, were not included. Computations do not account for variations in individual skimmer elevations. The daily-mean skimmer discharges, therefore, generally represent minimum discharges from the Tampa Bypass Canal. For example, reported skimmer discharges for December 3, 1991, were 0 ft^3/s, whereas, during an inspection, discharge was about 17 ft^3/s based on elevations of individual skimmers and upstream gage height determined on that date.

WATER-QUALITY CHARACTERISTICS IN THE ALAFIA RIVER, HILLSBOROUGH RIVER, AND THE TAMPA BYPASS CANAL

The magnitude of a constituent load from a river is dependent on the constituent concentration as well as the discharge. Although discharge generally has a greater influence on the magnitude of a constituent load, an evaluation of water-quality characteristics can provide insight into constituent-load characteristics. Long-term water-quality characteristics at selected sites in the Alafia River, Hillsborough River, and the Tampa Bypass Canal were evaluated for the period of record.

Long-Term Trends

Water quality in the Alafia River basin is affected by residential, agricultural, and industrial land uses. Phosphate mining in the basin began over 100 years ago and remains a major land-use activity. Industrial waste from mining operations in west-central Florida was the greatest single source of orthophosphate to the river in the mid-1970's, and the highest phosphorus concentrations and loads in the State were observed in the Alafia River (Kaufman, 1975). Water-quality characteristics of the river before mining operations began are unknown.

Orthophosphorus concentrations in the Alafia River generally have been declining since the mid-1960's (fig. 20). Because phosphate mining has occurred in the basin during the period of record, total and dissolved orthophosphorus concentrations were compared with the 7-day low flows at site A-3. Orthophosphorus data were selected instead of total phosphorus, because the data record for orthophosphorus was more extensive. Orthophosphorus concentrations were greatest in the 1960's and have generally declined from that time to 1992, coinciding with the period when the annual low flows also generally declined (fig. 9). The high orthophosphorus concentrations found in the Alafia River during the 1960's probably were caused by releases of water from mining operations. These releases may explain the increase in annual low flows during the 1960's.

Although orthophosphorus concentrations in the Alafia River have decreased, periodic spills from mining operations occur and can result in a large increase in total phosphorus concentration and load in the river. For example, total phosphorus concentration during one sampling event at the Alafia River at site A-3 in February 1983 was 42 mg/L; orthophosphorus concentration was 3.4 mg/L; and suspended sediment concentration was 822 mg/L. The high total phosphorus and

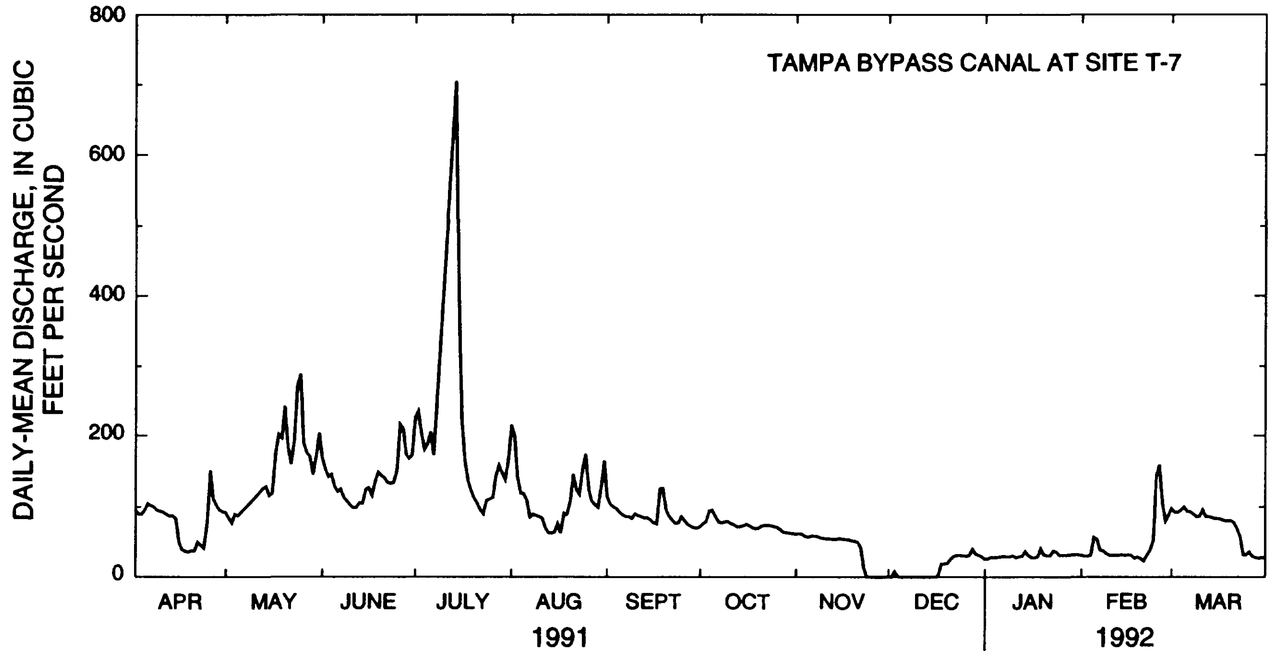


Figure 19. Daily-mean skimmer discharge of the Tampa Bypass Canal at site T-7, April 1991 through March 1992. (Location of site T-7 is shown in figure 4. Data were furnished by the Southwest Florida Water Management District.)

sediment concentrations indicate a probable release of phosphatic clays upstream.

About 93 percent of the total phosphorus in the Alafia River at site A-3 is dissolved, primarily dissolved orthophosphorus. The percentage of dissolved orthophosphorus contributing to the total phosphorus concentrations in the river averaged about 90 percent from 1971 to 1992. Although the total concentration of phosphorus has declined during this period, the ratio of total phosphorus to orthophosphorus generally has not changed.

Nitrogen concentrations in the Alafia River at site A-3 generally have declined since 1981 (fig. 20). About 93 percent of the total nitrogen in the Alafia River at site A-3 is dissolved. About 58 percent of the total nitrogen is the highly soluble nitrate plus nitrite form of nitrogen and about 38 percent is organic nitrogen. Whereas nitrogen concentrations in the river generally are declining, nitrogen concentrations in the ground water of the Alafia River basin are increasing. These increases are evident at Lithia Springs (site L-4) where nitrate plus nitrite nitrogen concentrations in the spring have increased from about 0.16 mg/L in 1946 (Ferguson and others, 1947) to about 3 mg/L in 1992. Jones and Upchurch (1993) have attributed that increase in nitrogen concentrations in water in Lithia and Buckhorn Springs to fertilizer inputs to the ground water when citrus groves covered a large portion of the south basin. Many of these groves have been replaced by residential developments, many of which use septic tanks for sewage disposal. Septic tanks most likely will affect future nitrogen concentrations in the springs (Jones and Upchurch, 1993).

Concentrations of selected major ions in the Alafia River at site A-3 also are decreasing concurrently with the decreasing concentrations of nitrogen and phosphorus (fig. 21). Dissolved silica, fluoride, chloride, sulfate, calcium, and sodium concentrations peaked during the late 1960's and have decreased since that time. The decreasing trends in concentrations of these constituents probably are due to changes in mining and other land-use practices in the basin.

Because of the long-term trends in concentrations of many constituents in the Alafia River, average seasonal concentrations were not evaluated for the entire period of record. The period from April 1982 to March 1992 was selected for analysis because long-term trends in the constituent concentrations during this period are not apparent. Therefore, variations in seasonal water-quality concentrations that are independent of long-term trends in the data could be evaluated. Constituent-concentration data for February 25, 1983, were excluded to avoid bias in the calculation of winter summaries. Water samples collected as part of this study are included in the seasonal analyses.

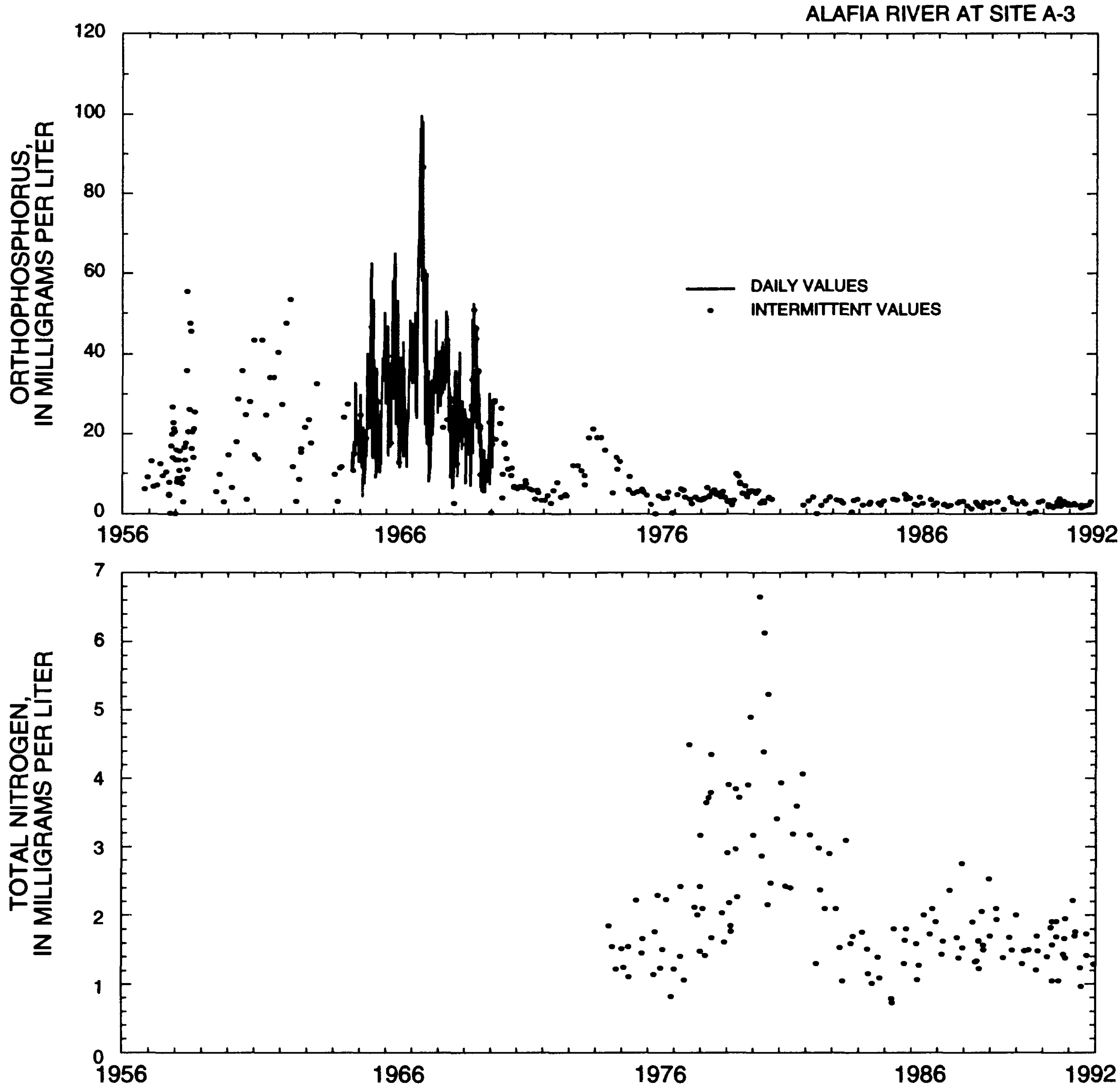


Figure 20. Orthophosphorus and nitrogen concentrations in the Alafia River at site A-3. (Location of site A-3 is shown in figure 5.)

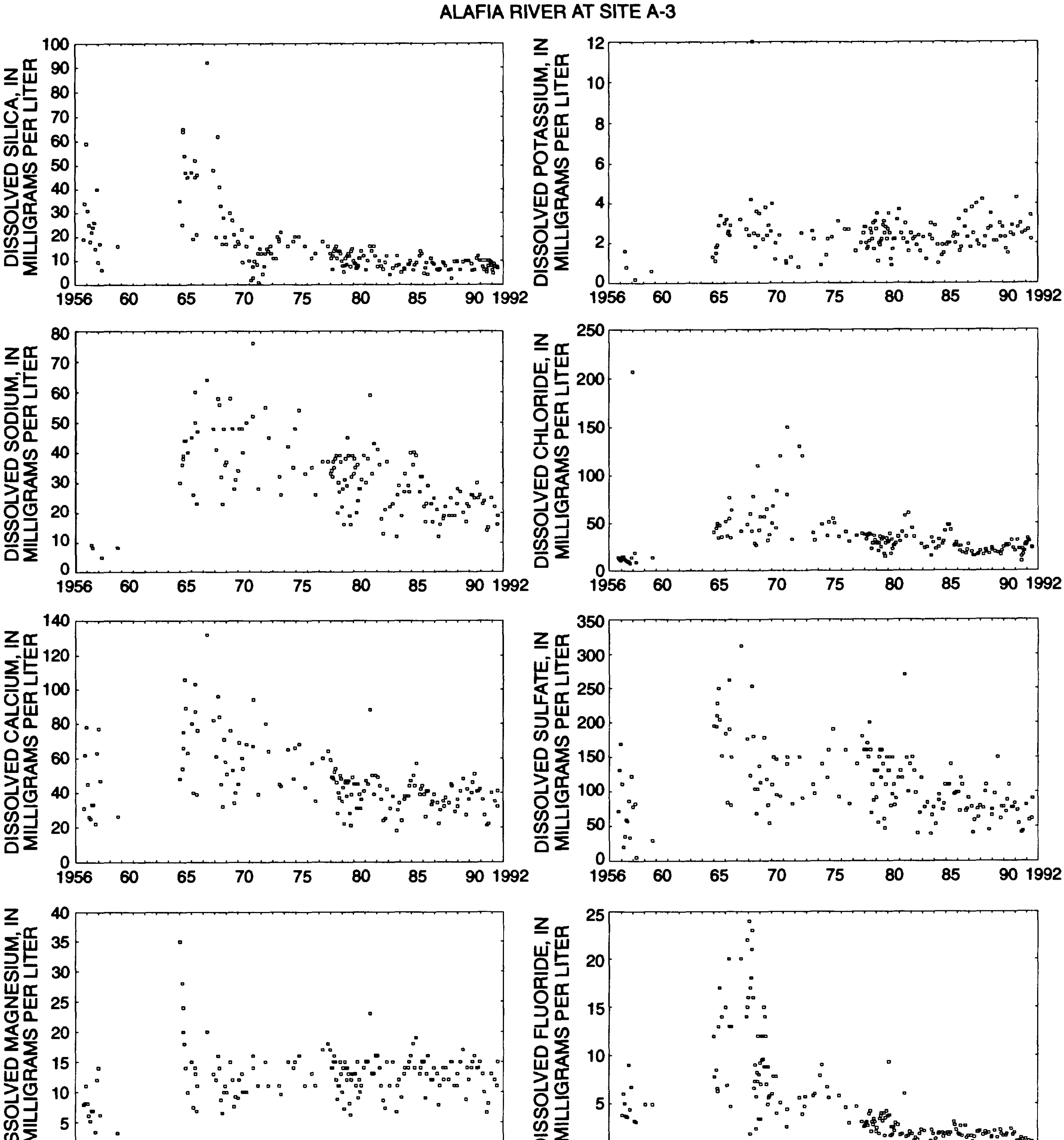


Figure 21. Concentrations of selected major ions in the Alafia River at site A-3, 1956–92. (Location of site A-3 is shown in figure 5.)

Average seasonal concentrations of selected constituents in the Alafia River at site A-3 are shown in figure 22. The months of the year were grouped to approximate the four seasons: January through March represents winter, April through June represents spring, July through September represents summer, and October through December represents fall. Total concentrations of nitrogen in the Alafia River at site A-3 remain relatively constant throughout the year (fig. 22). However, nitrate plus nitrite nitrogen concentrations are much less during the summer than during the remainder of the year; probably the result of dilution of nitrate-rich base flow (ground-water discharge) during summer runoff. A decrease in specific conductance in the river during the summer also is an indication of this dilution. Total organic carbon and organic plus ammonia nitrogen concentrations peaked during the summer, coinciding with the wet season discharges. The associated increase in organic plus ammonia nitrogen and total organic carbon concentrations indicate that biological activity also might contribute to the decrease in nitrate plus nitrite nitrogen concentration. Total phosphorus concentrations in the Alafia River at site A-3 increased slightly in summer and fall. Dissolved silica also was higher during these seasons, with highest concentrations during the fall.

Water quality in the Hillsborough River basin also is affected by residential, agricultural, and industrial land uses. Phosphate mining historically has not been a major land use in the basin, but mining activities are planned in small portions of the southeastern basin (Long and Orne, 1990). The quality of water entering the tidal portion of the Hillsborough River at the Tampa Dam is most likely affected by storage in the reservoir upstream from the dam. The effects of storage on water quality typically include a reduction in suspended sediments and a decrease in the constituent concentrations that are associated with the suspended sediments. Sediment losses are due to reduced velocities in the reservoir that allow sediments to settle in the deep parts of the reservoir. For this study, the quality of water flowing over the dam was of interest because that is the water that contributes to the tidal part of the Hillsborough River. The quality of water in the reservoir upstream from the dam was not evaluated.

Few long-term water-quality data are available for the Hillsborough River at site H-8. The city of Tampa measures the concentrations of selected constituents in water samples collected at an intake pipe that withdraws water from the reservoir for public water supply (Jim Giannatasio, City of Tampa Water Treatment Plant, oral commun., 1993). An evaluation of this water-quality data was not made because it was unknown if the water in the intake pipe was representative of the quality of water flowing over the dam.

Water discharging from Sulphur Springs (site S-9) is primarily a sodium-chloride type water, based on samples collected from 1964 to 1977. The primary source of water to the spring probably is the deep zones of the Upper Floridan aquifer (Stewart and Mills, 1984). The interconnection of the spring with nearby sinkholes that are used as stormwater detention areas sometimes results in stormwater runoff mixing with spring discharges. Prior to 1986, the spring had been used as a recreational swimming area but has since been closed due to excessive coliform bacteria in the water. The bacteria levels in the spring are correlated with rainfall in the basin (Cardinale, 1993).

Long-term data on concentrations of total nitrogen and phosphorus in Sulphur Springs are sparse. Based on samples collected during the study and intermittently between 1968 and 1981, total phosphorus concentrations ranged from 0.08 to 0.46 mg/L. Excluding the maximum value, concentrations were between 0.08 and 0.18 mg/L. Total nitrogen ranged from 0.47 to 1.4 mg/L. Specific conductance of water discharging from Sulphur Springs has increased from 124 µS/cm in 1945 to current levels of more than 2,000 µS/cm (fig. 23). This increase in specific conductance combined with the decreasing trend in spring discharge has resulted in a major change in the hydrologic characteristics of Sulphur Springs.

The quality of water in the Tampa Bypass Canal is affected by the quality of ground water discharging to the canal, by the quality of water in tributaries that flow into the canal, and by the quality of effluent that enters the canal from industrial and domestic point sources. During floods, water from the Hillsborough River can be diverted through the bypass canal, which might result in changes in the water quality of the canal.

Water flowing from the Tampa Bypass Canal at site T-7 is primarily a calcium-bicarbonate type water with a mean specific conductance of about 480 µS/cm. Total phosphorus and nitrogen concentrations for the period 1974 to present (1992) are shown in figure 24. Concentrations of total phosphorus and nitrogen ranged from 0.06 to 1.3 mg/L and 0.2 to 5.8 mg/L, respectively. Long-term trends in specific conductance, total phosphorus, and total nitrogen are not apparent for the period of record.

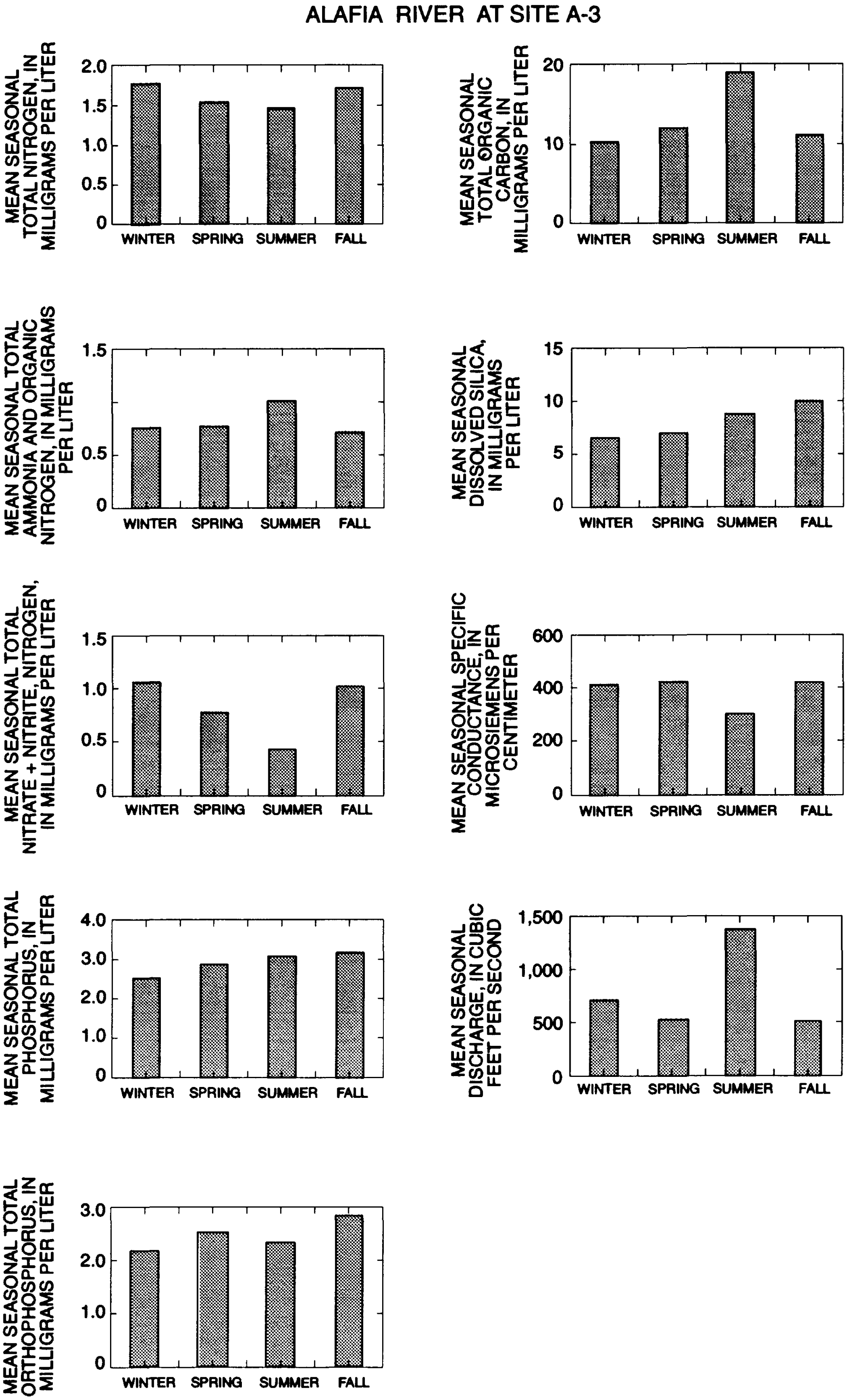


Figure 22. Seasonally averaged concentrations of selected water-quality constituents in the Alafia River at site A-3, April 1982 through March 1992. (Location of site A-3 is shown in figure 5.)

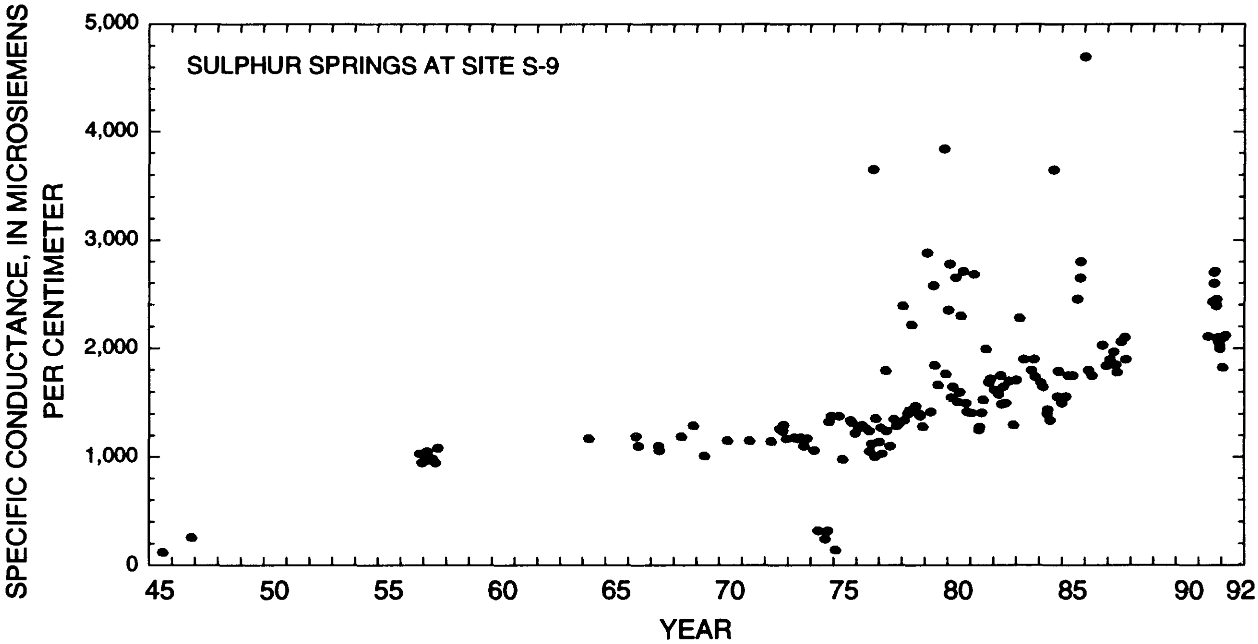


Figure 23. Specific conductance of water at Sulphur Springs at site S-9, 1945–92. (Location of site S-9 is shown in figure 4.)

Water-Quality Characteristics During the Study

Samples collected during the study at sites in the Alafia River and Hillsborough River basins and the Tampa Bypass Canal were evaluated to determine the water-quality characteristics during the period of constituent-load computations.

Water samples collected at the tidally affected sites during the study represent a wide range of freshwater inflow and specific-conductance conditions. Samples collected at different times during the same day represent variations in water quality caused by tide. These data were evaluated to determine which variations in water quality were caused by tide conditions and which were caused by freshwater inflow conditions.

Results of analyses of quality-assurance samples submitted to the SWFWMD laboratory during the study indicated that the accuracy of analyses for silica, ammonia nitrogen, nitrite nitrogen, nitrate plus nitrite nitrogen, phosphorus, and orthophosphorus was acceptable when samples were analyzed within recommended holding times. Chloride concentrations were biased about 3 to 10 percent below concentrations in submitted reference samples (samples with a known constituent concentration). Ammonia plus organic nitrogen analyses were biased about 15 to 60 percent higher than submitted reference samples when samples were analyzed within recommended holding times. Reference samples were not submitted for organic carbon and suspended-solids determinations.

Recommended holding times for nutrients (table 2) were exceeded for samples collected August 13–16, September 3–4, and September 17–19, 1991. Reference samples indicated a negative bias in concentrations of ammonia plus organic nitrogen and nitrate plus nitrite nitrogen, which means that reported concentrations probably were less than actual concentrations. Concentration data and loads from these periods must be considered estimates because of the unknown amount of error in the data.

Alafia River

Time series concentrations of selected constituents in the water samples collected from the Alafia River during the study are shown in figure 25 and are summarized in tables 6 and 7. Constituent concentrations in the Alafia River at the nontidally affected site A-3 are for discrete sampling events, whereas concentrations in the Alafia River at the tidally affected site A-6 were averaged for each day of sampling. Plotted points (fig. 25) are connected by lines on the graph only to improve clarity and to indicate general trends and do not imply continuity.

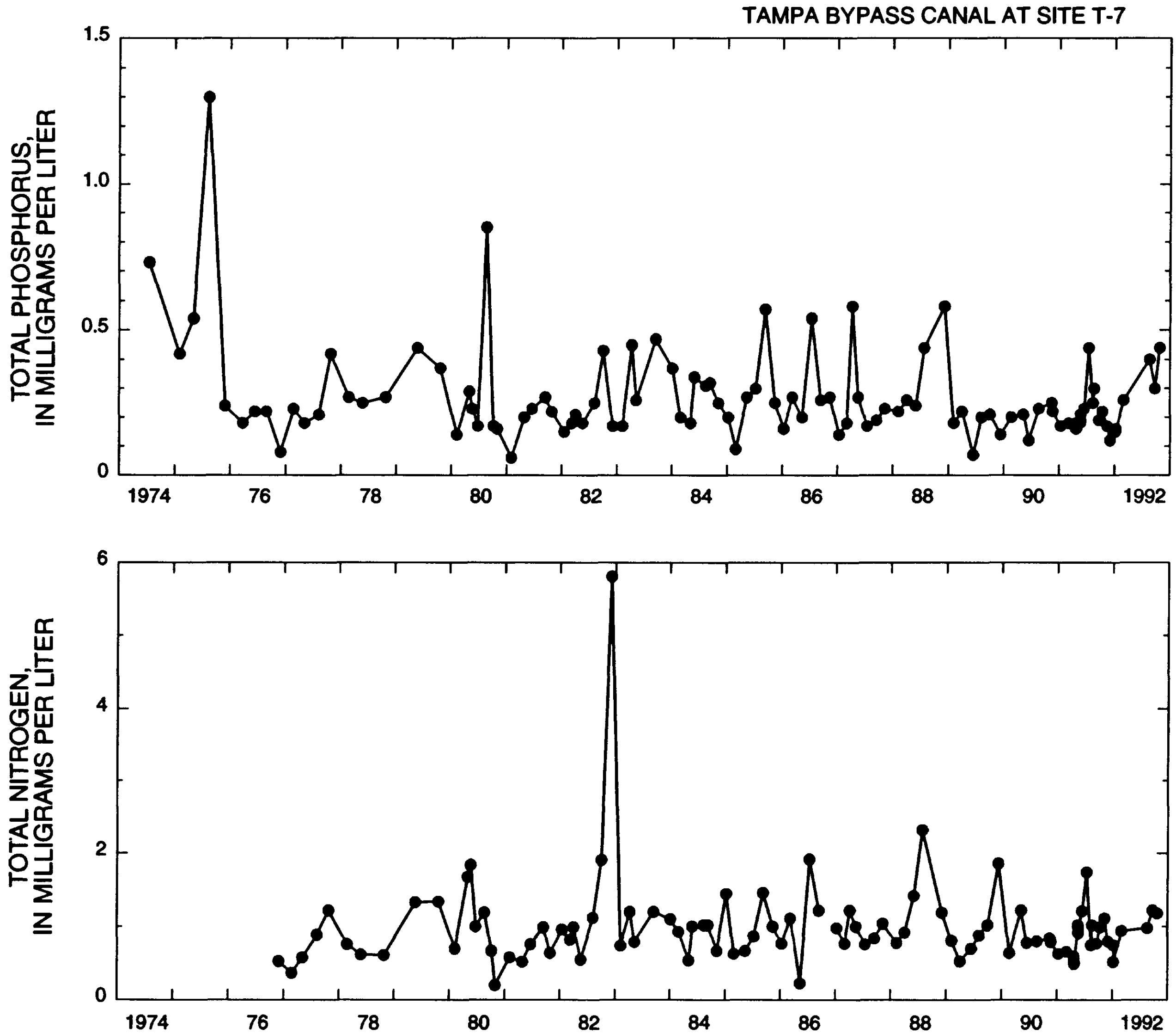


Figure 24. Total concentrations of phosphorus and nitrogen in the Tampa Bypass Canal at site T-7, 1974–92. (Location of site T-7 is shown in figure 4.)

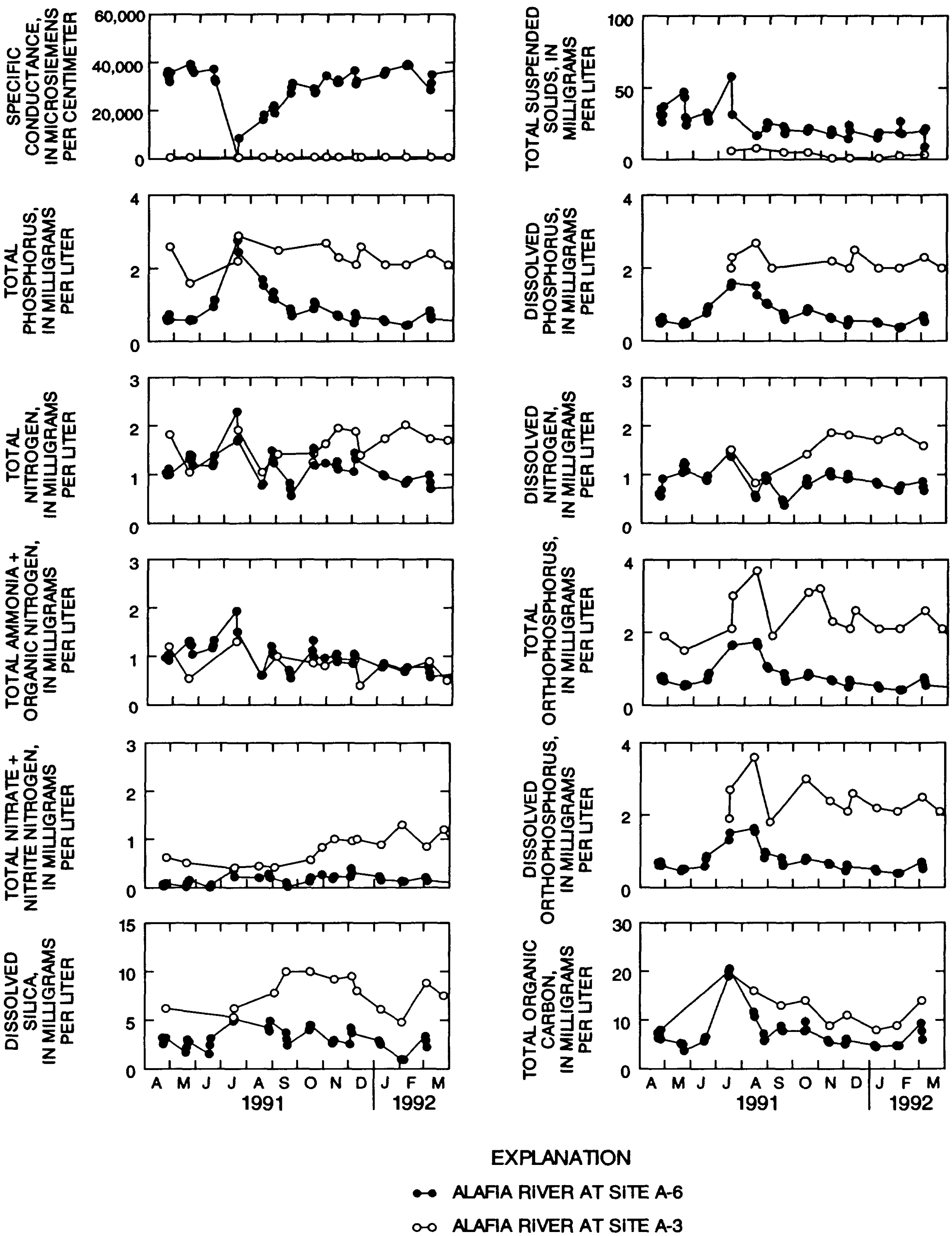


Figure 25. Concentrations of selected water-quality constituents in the Alafia River basin. (Locations of sites A-3 and A-6 are shown in figure 5.)

Table 6. Summary of selected water-quality constituents at the study sites, April 1991 through March 1992

[Concentrations are in milligrams per liter unless otherwise noted. µS/cm, microsiemens per centimeter at 25 degrees Celsius; µg/L, micrograms per liter; <, less than; N, number of samples]

	Laboratory specific conductance (µS/cm)	Total suspended solids	Total organic carbon	Dissolved organic carbon	Dissolved silica	Dissolved chloride	Chlorophyll *a* (µg/L)	Biological oxygen demand
			Alafia River at site A-3					
Mean	373	[1]4	12	13	7.6	24	2.1	0.8
Maximum	480	8	20	21	10	34	3.1	2.1
Minimum	178	<1	8.0	7.7	4.8	10	.7	.2
N	15	9	10	9	13	15	9	9
			Alafia River at site A-6					
Mean	31,000	26	7.0	6.5	3.0	11,000	21	2.1
Maximum	43,200	80	21	21	7.8	16,000	90	7.8
Minimum	238	3	2.3	1.5	.3	33	2.0	.6
N	123	120	121	121	116	122	120	115
			Hillsborough River at site H-8					
Mean	233	2	21	21	7.4	15	8.7	1.4
Maximum	314	5	28	28	8.3	25	17	1.6
Minimum	167	1	12	10	6.3	9	1.6	1.0
N	6	6	6	6	5	6	6	6
			Sulphur Springs at site S-9					
Mean	2,270	[1]2	3.1	3.2	9.7	515	1.4	0.5
Maximum	2,710	8	4.7	6.0	11	640	6.6	.8
Minimum	1,830	<1	1.9	2.1	8.2	390	.2	.1
N	11	10	11	10	9	10	9	10
			Hillsborough River at site H-10					
Mean	32,900	20	7.9	7.5	1.9	11,700	11	1.6
Maximum	42,500	151	23	23	6.6	15,000	34	5.2
Minimum	2,370	4	2.9	2.3	.4	640	2.3	.7
N	63	63	63	63	56	63	62	62
			Tampa Bypass Canal at site T-7					
Mean	513	6	6.2	5.6	9.0	36	31	2.0
Maximum	647	13	12	12	12	66	72	4.2
Minimum	326	4	3.7	3.9	5.8	15	12	.5
N	19	18	19	17	18	19	18	18

[1]The value is estimated by using a log-probability regression to predict the values of data below the detection limit (Helsel, 1990).

Table 7. Summary of nitrogen and phosphorus concentrations at the study sites, April 1991 through March 1992

[Concentrations are in milligrams per liter. <, less than; N, number of samples]

	Total ammonia nitrogen	Dissolved ammonia nitrogen	Total ammonia plus organic nitrogen	Dissolved ammonia plus organic nitrogen	Total nitrate plus nitrite nitrogen	Dissolved nitrate plus nitrite nitrogen	Total nitrite nitrogen	Dissolved nitrite nitrogen	Total phosphorus	Dissolved phosphorus	Total orthophosphorus	Dissolved orthophosphorus
Alafia River at site A-3												
Mean	[1]0.04	[1]0.03	0.87	0.81	0.77	0.78	[1]0.01	<0.01	2.3	2.2	2.4	2.4
Maximum	.12	.12	1.5	1.1	1.5	1.3	.03	< .01	2.9	[3]2.7	[3]3.7	[3]3.6
Minimum	< .01	< .01	.40	[3].41	.39	.39	< .01	< .01	1.6	2.0	1.5	1.8
N	14	12	14	9	14	12	14	12	12	11	14	12
Alafia River at site A-6												
Mean	[1]0.06	[1]0.05	1.0	0.72	[1]0.15	[1]0.15	[1]0.01	[1]0.01	0.87	0.72	0.77	0.70
Maximum	.24	.22	2.2	1.3	.60	.60	.04	.02	3.3	1.9	2.0	[3]1.9
Minimum	< .02	< .02	[3].39	[3].25	< .01	< .01	< .01	< .01	.32	.26	.31	.28
N	122	120	120	121	122	121	122	121	120	121	120	121
Hillsborough River at site H-8												
Mean	0.04	0.04	1.0	0.93	[1]0.06	[1]0.06	<0.01	<0.01	0.38	0.36	0.36	0.35
Maximum	[3].06	[3].06	1.7	1.5	.12	.11	.02	.02	[3].53	[3].46	[3].50	[3].50
Minimum	.01	.02	[3].69	.72	< .01	< .01	< .01	< .01	.28	.25	.23	.23
N	6	6	6	6	6	6	6	6	6	6	6	6
Sulphur Springs at site S-9												
Mean	[1]0.01	[1]0.01	0.32	0.27	0.49	0.53	0.05	0.05	0.11	0.10	0.10	0.10
Maximum	.01	.01	.57	.54	.70	.68	.08	.09	.13	.12	.12	.12
Minimum	< .01	< .01	[3].01	[3].01	.14	.27	.01	.01	.09	.09	[3].08	.08
N	11	10	11	10	10	9	11	10	11	9	11	10
Hillsborough River at site H-10												
Mean	[1]0.05	[1]0.04	0.80	0.60	[1]0.05	[1]0.05	[1]0.02	[1]0.02	0.41	0.36	0.35	0.33
Maximum	.14	.14	1.8	1.2	[3].22	[3].22	.09	[3].14	.79	[3].66	[3].50	[3].48
Minimum	< .01	< .01	[3].35	[3].01	< .01	< .01	< .01	< .01	.29	.26	.28	.26
N	63	63	62	62	63	63	63	63	62	62	63	63
Tampa Bypass Canal at site T-7												
Mean	[1]0.02	[2]--	0.85	0.56	[1]0.02	[1]0.02	[1]0.01	<0.01	0.20	0.15	0.16	0.14
Maximum	.24	0.24	1.6	2.1	.14	.14	[3].02	.02	.44	.37	.36	.34
Minimum	< .01	< .01	.48	.20	< .01	< .01	< .01	< .01	.12	.06	.04	.03
N	20	18	20	18	20	18	20	20	20	18	20	18

[1]The value is estimated by using a log-probability regression to predict the values of data below the detection limit (Helsel, 1990).

[2]Mean value could not be computed because too many data values were below the detection limit.

[3]Value is considered an estimate because analyses were performed after the recommended holding times were exceeded.

Water quality at the mouth of the Alafia River (site A-6) during most of the study was the result of a mixing of water from the river and estuarine water from Hillsborough Bay. During July 16–17, 1991, however, high discharges resulted in freshwater conditions for a short time at the mouth of the river. Samples collected during this period of high discharge had the lowest specific conductance and chloride and the highest suspended solids; total nitrogen, phosphorus, orthophosphorus, and organic carbon; and dissolved nitrogen, phosphorus, orthophosphorus, organic carbon, and silica concentrations measured during the study.

Water-quality characteristics in the Alafia River varied with location in the river reach and with time. Total nitrogen concentrations at site A-6 were similar to concentrations at the nontidal site A-3 from May to October 1991, but nitrogen concentrations at site A-6 decreased from November 1991 to March 1992, when concentrations at site A-3 increased. Maximum total nitrogen concentrations in the downstream site (site A-6) occurred in February 1992 during low-flow conditions (table 7 and fig. 25). Concentrations of total nitrogen at the upstream site (site A-3) increased during this time as a result of an increase in concentrations of dissolved nitrate plus nitrite nitrogen. Phosphorus concentrations, both dissolved and total, were consistently higher upstream (table 7 and fig. 25), except on July 16–17, 1991, when high flows resulted in freshwater flushing all the way to the mouth and produced similar total phosphorus concentrations. Suspended solids, specific conductance and cBOD were higher at the downstream site, whereas organic carbon and silica were higher at the upstream site.

The largest differences in water quality between the nontidal and tidal parts of a river are found in specific conductance (or salinity). Vertical stratification, where specific conductance at the surface is less than specific conductance at the bottom, is common in the tidally affected reach of the Alafia River. Differences in specific conductances in the vertical during sampling events ranged from well-mixed conditions to differences of up to 35,000 μS/cm. Field measurements of specific conductance indicated that large differences in the vertical can occur over a very small range of depths (fig. 26). During every field measurement of specific conductance, near-surface values were equal to or less than near-bottom values. The average vertical gradients measured by the fixed specific-conductance probes at the mouth of the Alafia River (site A-6) was 3,760 μS/cm (table 8).

Daily-mean specific conductance at 2 depths, digitally filtered to remove short-term variations caused by tide, are shown in figure 27. At times, the near-bottom (1 ft above the bottom) specific conductance recorded at the gage appears to be less than near-surface (5 ft from the bottom) values. Because this condition never was observed in the field, and because the accuracy of the recorded value is about 10 percent, the specific-conductance values near the bottom most likely were not less than near-surface values. Vertical stratification generally was greatest when freshwater discharge increased during the wet season and was least during the dry season (figs. 13 and 27).

Large daily variations in specific conductance are caused by tidal currents (figs. 28 and 29). Daily variation in near-bottom specific conductance at the mouth of the Alafia River at site A-6 during the study ranged from 1,530 to 42,200 μS/cm per day (table 8). The magnitude of daily variation in specific conductance generally increases with increased freshwater discharge (figs. 28 and 29).

The location of the saltwater-freshwater interface in any tidal river moves upstream and downstream in response to freshwater discharge and tides. Giovannelli (1981) examined this relation for the Alafia River and observed that flushing and large movements of saltwater are controlled by large fluctuations in streamflow, and that small, frequent saltwater movements occur as a function of tide. At a stage of 0.64 ft above sea level at site A-6, the saltwater-freshwater interface was near river mile 4 about 70 percent of the time and near river mile 8 about 10 percent of the time. The maximum upstream encroachment of saltwater is determined by the streambed elevation and maximum tide. Giovannelli (1981) estimated that the maximum location of the interface during zero freshwater discharge and average tide would be around river mile 10.5.

Concentrations of total phosphorus and nitrogen in the tidal parts of a river are affected by the mixing of saltwater and freshwater, as well as inputs from tributaries and ground water, and biological and physical processes that affect concentrations of constituents.

To determine the effects of tide on nutrient concentrations, the estimated daily ranges in concentrations of total nitrogen and phosphorus, based on samples collected during this study, were examined (fig. 30). The daily range in total phosphorus concentrations at the mouth of the Alafia River (site A-6) indicates a seasonal pattern that is the result of variations in freshwater inflow (figs. 13 and 30). As freshwater inflow increased in July and August 1991, the daily range in the concentration of phosphorus increased. The daily range in nitrogen concentration at site A-6, however, did not indicate a trend related to freshwater inflow.

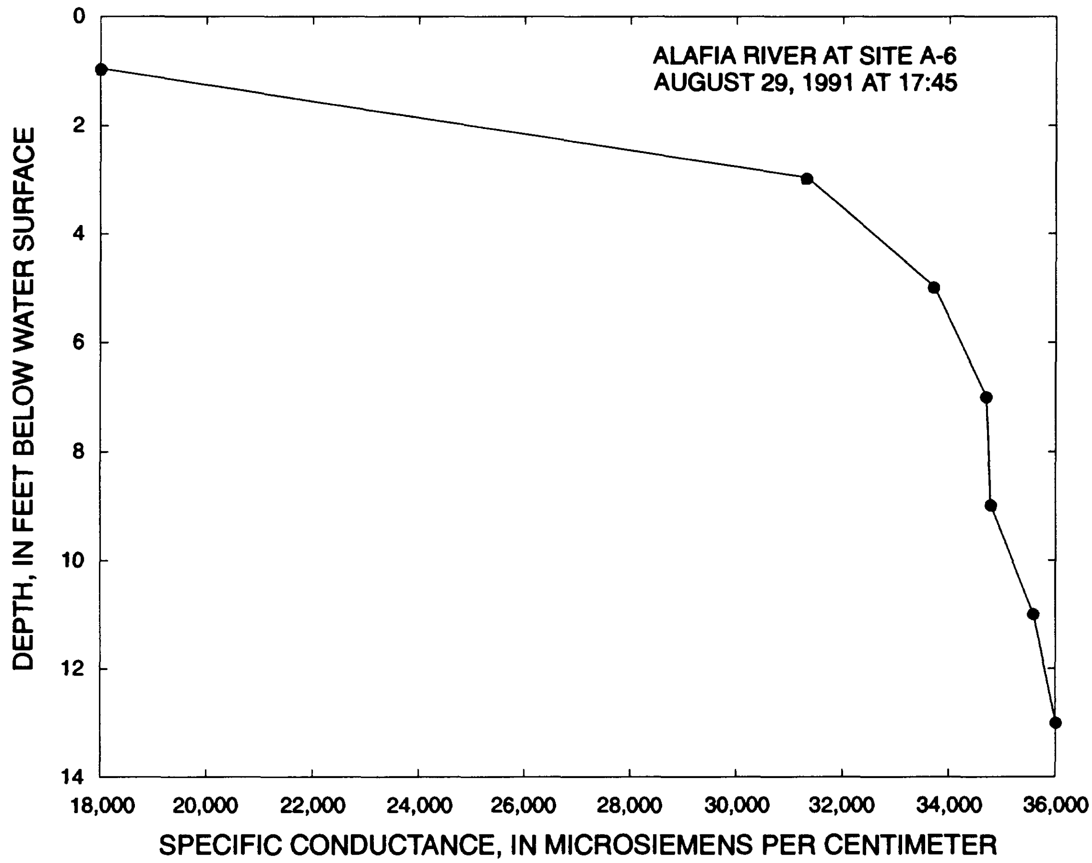


Figure 26. Field measurements of specific conductance at one site in the Alafia River at site A-6. (Location of site A-6 is shown in figure 5.)

Table 8. Summary of specific conductance at the mouth of the Alafia River at site A-6

[All values are in microsiemens per centimeter at 25 degrees Celsius; --, not computed]

	Specific conductance		
	Minimum	**Maximum**	**Mean**
Near-bottom	193	47,800	35,400
Near-surface	193	48,000	32,200
(Near-bottom)-(near-surface)	--	--	3,760
Daily range in bottom conductance	1,530	42,200	12,500
Daily range in top conductance	3,400	45,600	21,200

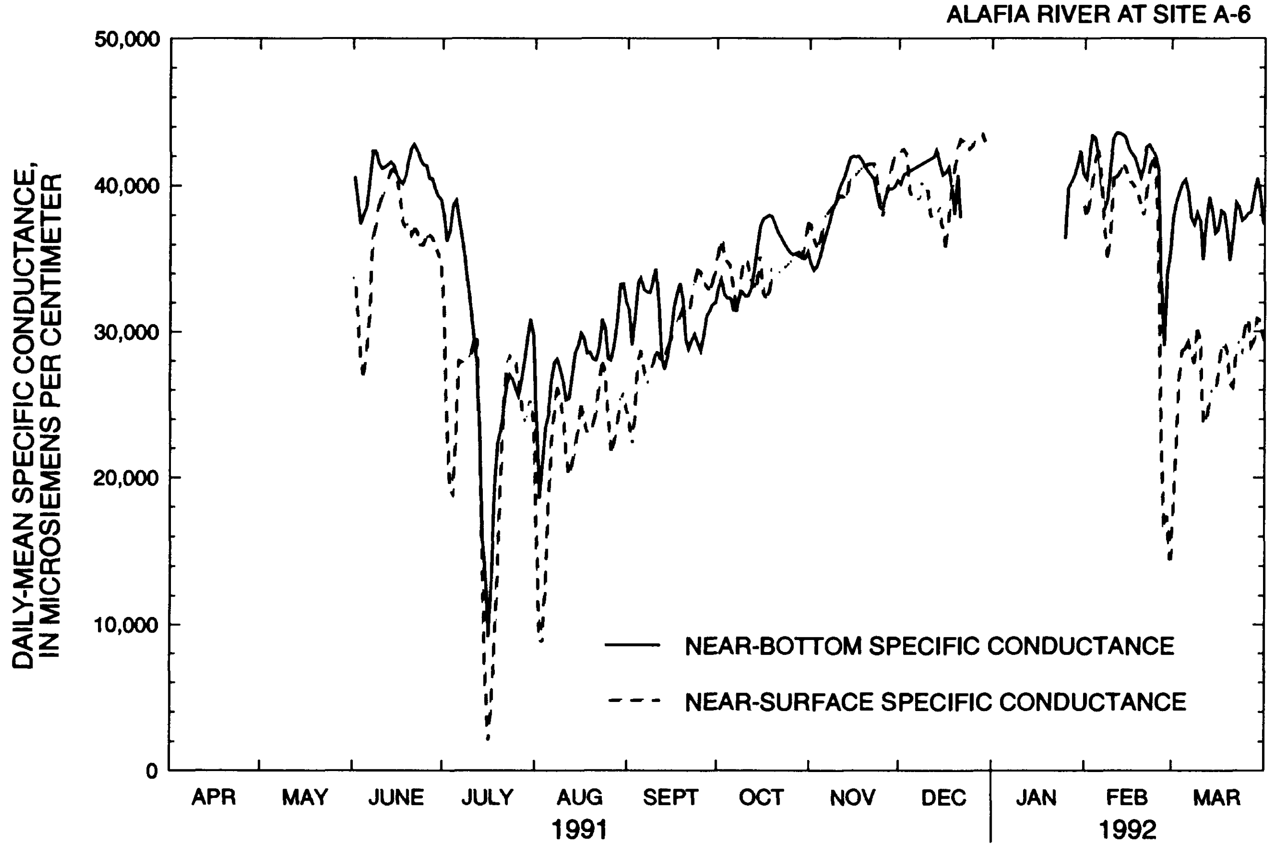


Figure 27. Daily-mean specific conductance (near-bottom and near-surface) in the Alafia River at site A-6. (Location of site A-6 is shown in figure 5.)

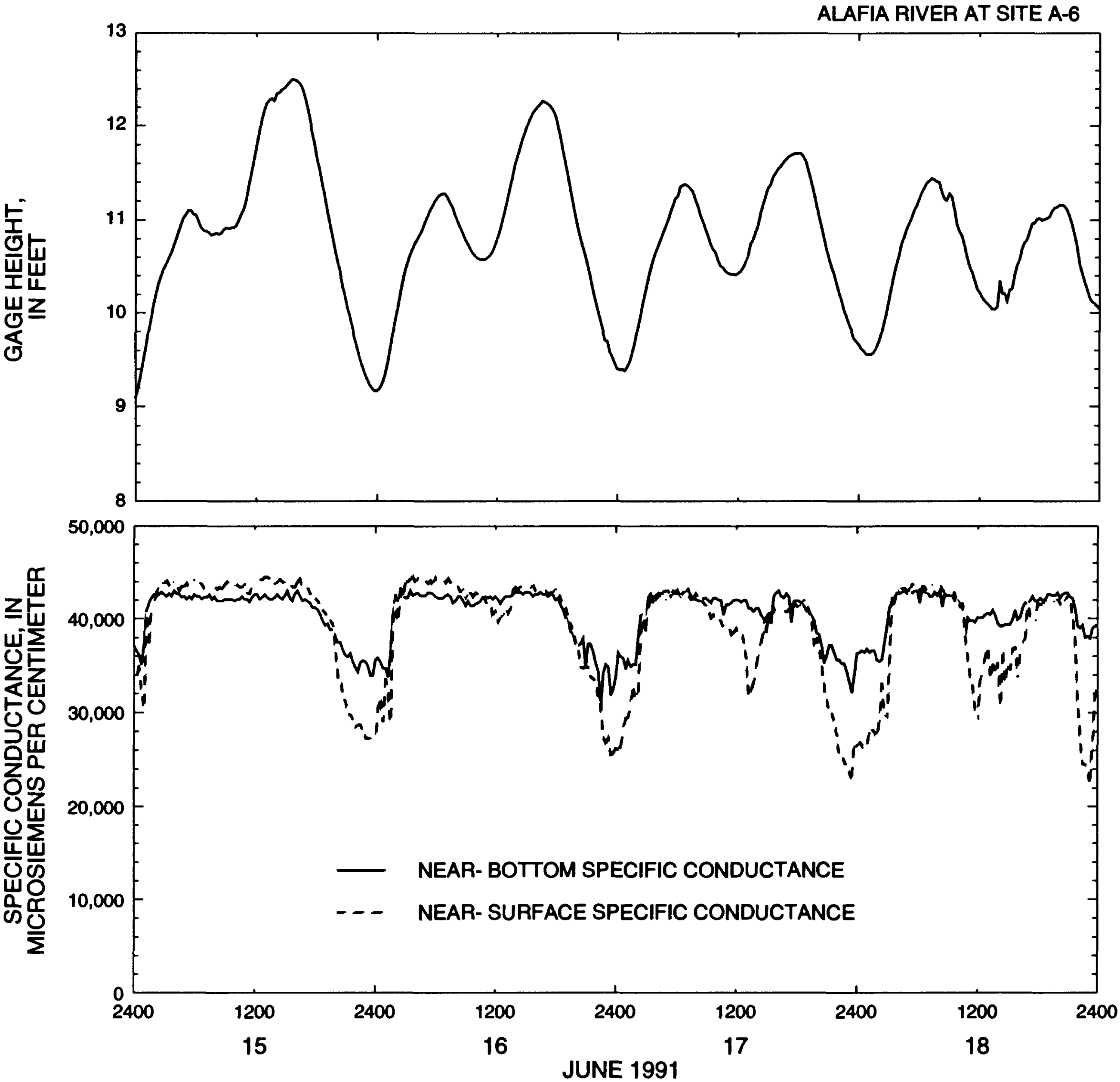


Figure 28. Gage height and specific conductance in the Alafia River at site A-6, June 15–18, 1991. (Location of site A-6 is shown in figure 5.)

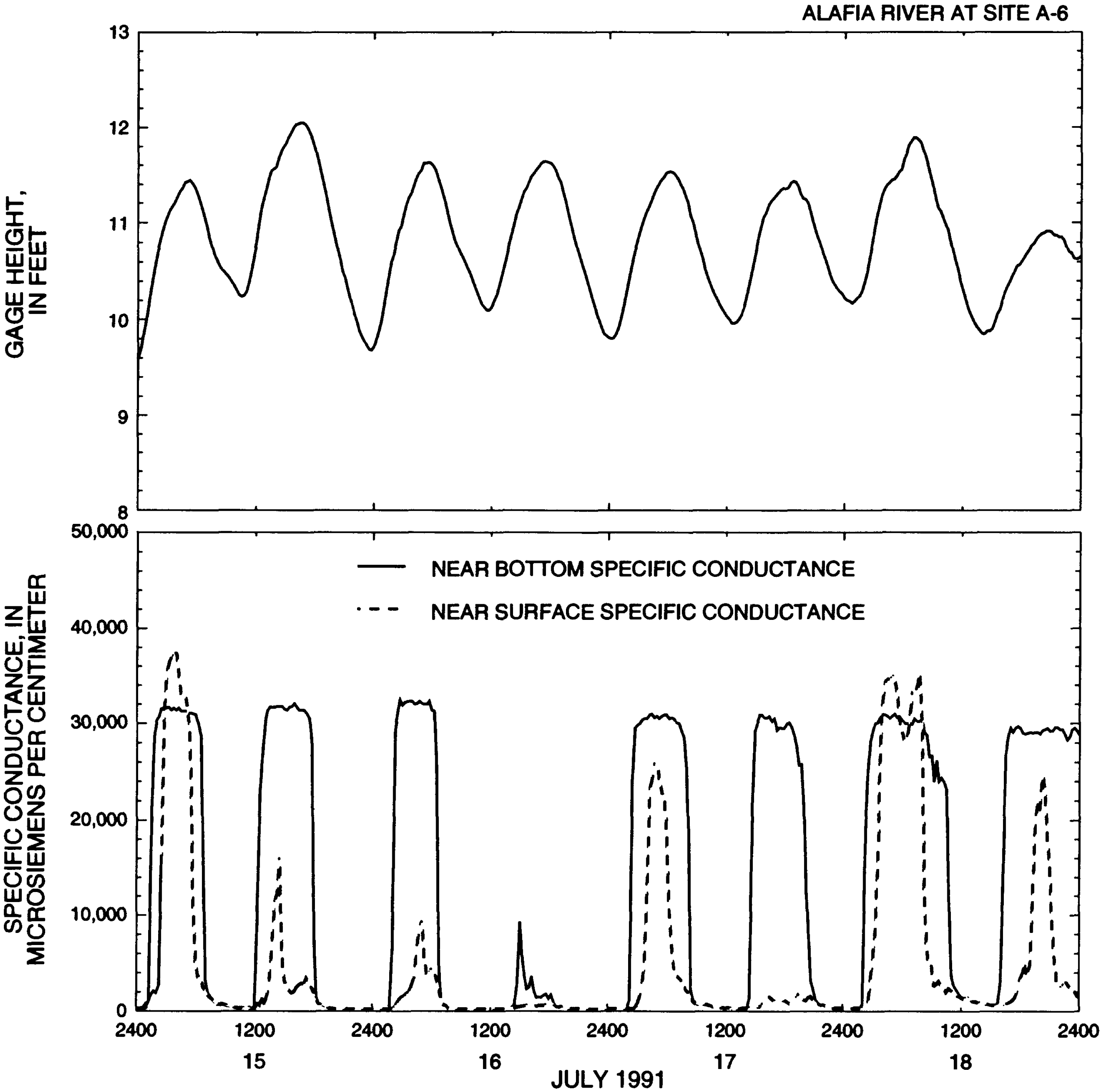


Figure 29. Gage height and specific conductance in the Alafia River at site A-6, July 15–18, 1991. (Location of site A-6 is shown in figure 5.)

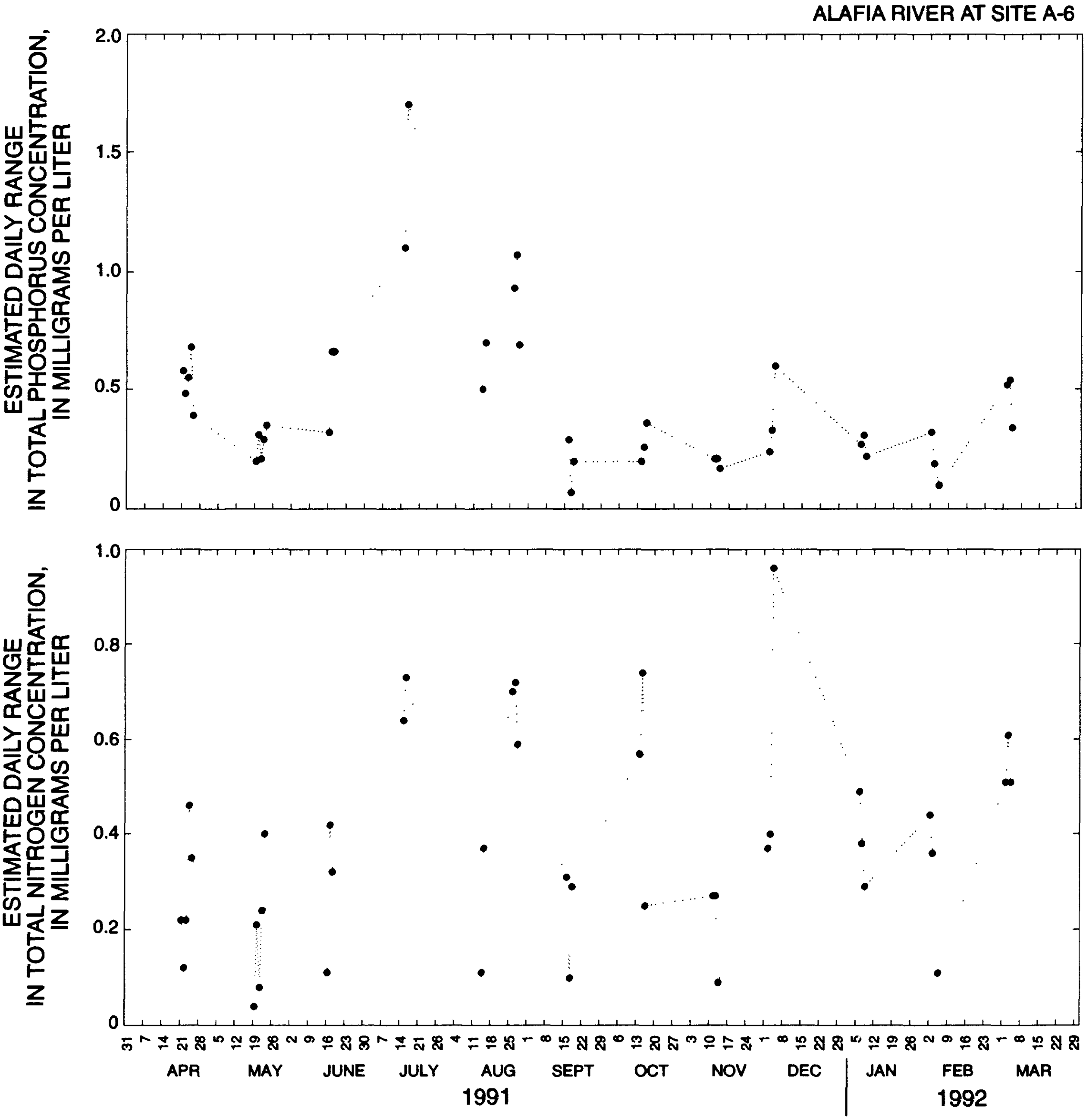


Figure 30. Estimated daily range in total phosphorus and total nitrogen of the Alafia River at site A-6. (Location of site A-6 is shown in figure 5.)

Laboratory specific conductance represents the depth and cross-sectionally averaged specific conductance during the time of sampling and provides an indication of the amount of freshwater in the tidal river at the time of sampling. The relation between laboratory specific conductance and selected water-quality constituents was examined to evaluate the effects of freshwater on water quality.

Concentrations of phosphorus, nitrate plus nitrite nitrogen, organic carbon, and silica at the Alafia River at site A-6 are inversely related to laboratory specific conductance (fig. 31). The concentrations of these constituents at site A-6 result primarily from simple conservative mixing of river water with estuarine water. This conservative mixing is indicated by the nearly linear relation between specific conductance and all the above constituents except nitrate plus nitrite nitrogen. Nitrate plus nitrite nitrogen concentrations are affected by processes other than simple mixing near the mouth of the Alafia River. Biological activity probably has a significant effect on nitrogen dynamics in the lower tidal river. The inverse relation of concentrations of phosphorus, nitrate plus nitrite nitrogen, organic carbon, and silica to specific conductance indicates that concentrations of these constituents are higher in the Alafia River than in Hillsborough Bay.

Concentrations of total nitrogen, suspended solids, ammonia plus organic nitrogen, biological oxygen demand, and chlorophylls *a* and *b* at the mouth of the Alafia River at site A-6 are unrelated to laboratory specific conductance, which indicates that concentrations of the above constituents are independent of the amount of freshwater in the tidal river.

Chloride concentrations at the mouth of the Alafia River are directly related to specific conductance (fig. 31). Sodium chloride is a major constituent in seawater, and Hillsborough Bay is the source of chloride in the tidal reaches of the Alafia River.

To determine nutrient characteristics in the tidal reach of the Alafia River, samples were collected at intervals of approximately 1 river mile during baseflow and higher runoff conditions. Sample results are presented in table 9.

Water samples were collected on October 30, 1991, during base-flow conditions and were analyzed for specific conductance and for concentrations of total phosphorus, orthophosphorus, ammonia nitrogen, nitrate plus nitrite nitrogen, and ammonia plus organic nitrogen. Specific conductance in the river generally decreased from the mouth (river mile 0) until the river water became fresh at river mile 8. Specific conductance at river mile 5, however, was greater than expected. This may have been caused by poor mixing of fresh and saline water in this part of the river during low flows.

Lithia Springs (site L-4) is a major source of nitrogen-rich water to the Alafia River. Daily-mean discharge in the river upstream of the spring was 134 ft^3/s on October 30, 1991, and spring flow was estimated at about 50 ft^3/s. Spring flow therefore increased discharge in the river by about 37 percent. Total nitrogen concentrations increased from 1.6 mg/L at river mile 16 to 2.4 mg/L at river mile 10.5, primarily because of input of nitrate plus nitrite nitrogen from Lithia Springs (table 9). About 90 percent of the nitrogen in the spring water was as nitrate plus nitrite nitrogen, an inorganic form readily available to plants. Nitrate plus nitrite nitrogen concentrations in the river also increased downstream of Lithia Springs between river miles 10.5 and 9, possibly because of nitrogen-rich ground-water seepage to the river. A section of the river called Bell Shoals (river mile 10) has exposed rock and clay deposits and is a likely location for increased ground-water discharge. A small seep enriched with excessive nitrate nitrogen also enters the river near this point (Gregg Jones, Southwest Florida Water Management District, oral commun., 1992).

Nitrate plus nitrite nitrogen concentrations and percent of total nitrogen generally decreased from about river mile 7 to the river mouth on October 30, 1991, whereas ammonia plus organic nitrogen concentrations and percent of total nitrogen generally increased toward the mouth. Total nitrogen concentrations, however, varied little from river mile 7 to the river mouth, indicating that the change in concentrations of individual species of nitrogen may be caused by biological activity (photosynthesis) that converts inorganic nitrogen to organic nitrogen. Total nitrogen concentrations were lowest near the mouth where the river water was diluted by saline water from Hillsborough Bay.

Sampling at 1 river mile intervals was repeated during higher runoff conditions on April 22, 1992. Specific conductance decreased from the mouth (river mile 0) until freshwater conditions occurred at river mile 6.

Although nitrate plus nitrite nitrogen concentrations in Lithia Springs were much higher than in the Alafia River during higher runoff conditions on April 22, 1992, a marked increase in the concentration of total nitrogen in the river did not occur downstream of the spring (table 9). However, a small increase in nitrate plus nitrite nitrogen concentrations and nitrate plus nitrite percent of total nitrogen did occur. Discharge in the river upstream of Lithia Springs was 285 ft^3/s on April 22, 1992, and discharge of Lithia

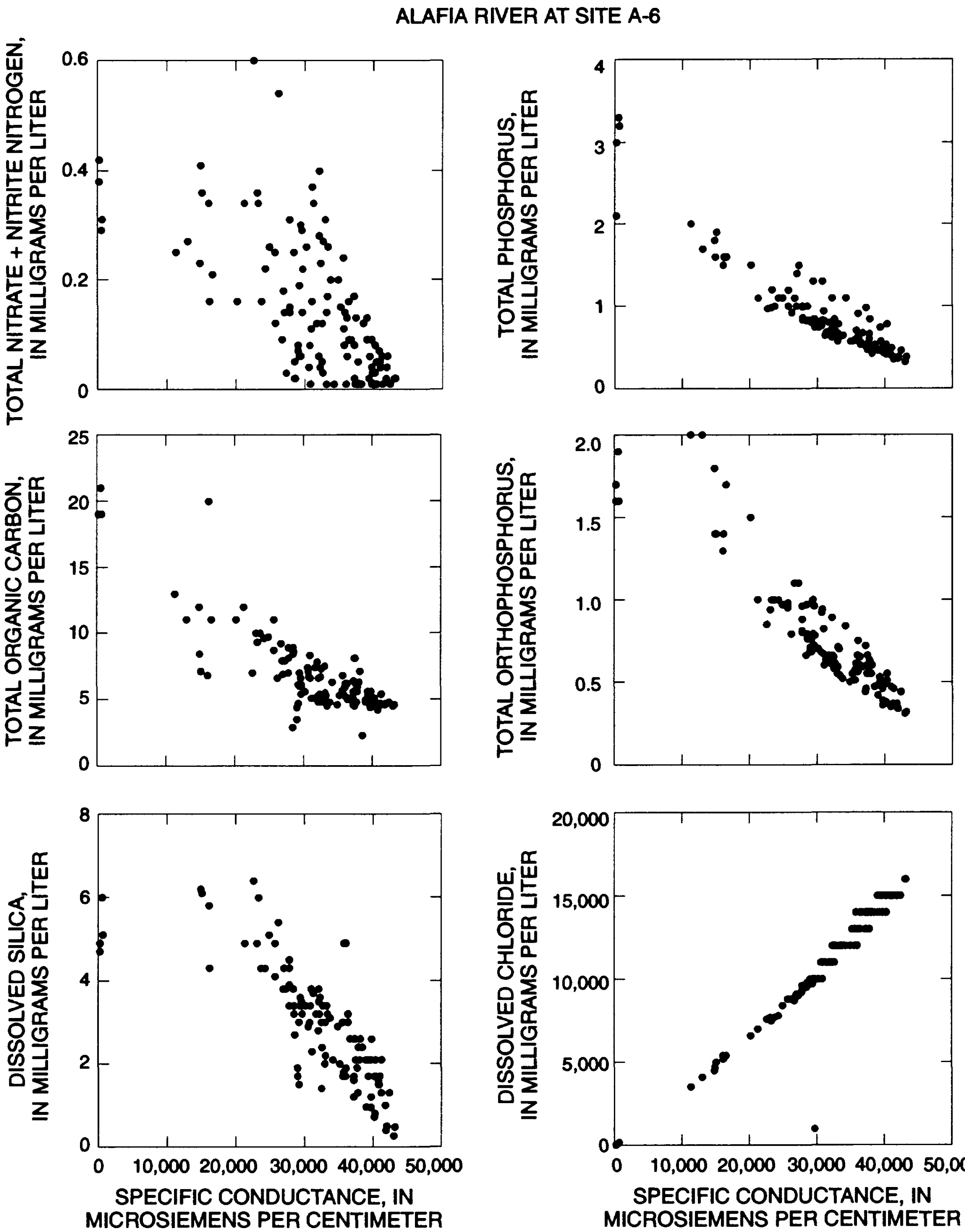


Figure 31. Relation between specific conductance and selected water-quality constituents of the Alafia River at site A-6. (Location of site A-6 is shown in figure 5.)

Table 9. Total nutrient concentrations in the Alafia River from near the mouth (river mile 0) to Lithia (river mile 16)

[Daily-mean discharge at river mile 16 was 134 cubic feet per second on October 30, 1991, and 285 cubic feet per second on April 22, 1992. µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; --, no data; <, less than]

River mile	Specific conductance (µS/cm)		Total phosphorus (mg/L)		Total orthophosphorus (mg/L)		Total ammonia nitrogen (mg/L)	
	10-30-91	4-22-92	10-30-91	4-22-92	10-30-91	4-22-92	10-30-91	4-22-92
0	34,500	38,000	--	0.53	--	0.45	0.07	0.10
1	35,400	28,600	0.91	.84	0.64	.74	.12	.20
2	26,800	14,600	1.2	1.1	.98	1.0	.04	.23
3	18,900	13,800	1.3	1.1	1.2	1.1	.01	.22
4	12,800	9,110	1.4	1.3	1.4	1.2	<.01	.18
5	19,200	2,300	1.3	1.4	1.2	1.3	.04	.09
6	11,400	510	1.6	1.5	1.5	1.4	.05	.05
Buckhorn Spring								
(6.6)	--	390	--	.08	--	.06	--	<.01
7	1,980	360	2.1	1.3	2.0	1.2	.02	.04
8	440	295	1.6	1.2	[1]2.0	1.1	<.01	.03
9	425	275	2.0	1.2	2.0	1.1	<.01	.03
9.1	--	285	--	1.3	--	1.1	--	.03
9.5	430	--	2.0	--	2.0	--	<.01	--
10	--	295	--	1.6	--	1.2	--	.04
10.5	435	--	2.1	--	2.1	--	<.01	--
Lithia Springs								
(13.8)	470	410	.06	.06	[1].07	.05	<.01	<.01
14	--	280	--	1.9	--	1.4	--	.03
16	480	285	2.7	2.0	[1]3.2	1.4	<.01	.04

River mile	Total ammonia plus organic nitrogen (mg/L)		Total nitrogen (mg/L)		Total nitrate plus nitrite nitrogen (mg/L)	
	10-31-91	4-22-92	10-31-91	4-22-92	10-31-91	4-22-92
0	0.97	0.68	1.2	0.77	0.27	0.09
1	1.3	1.0	1.5	1.2	.19	.20
2	1.7	.90	2.0	1.3	.34	.38
3	1.6	.86	2.2	1.2	.59	.39
4	1.6	.91	2.5	1.4	.94	.47
5	1.6	.84	2.4	1.4	.75	.61
6	1.0	.93	2.0	1.6	1.0	.69
Buckhorn Spring						
(6.6)	--	.49	--	1.3	--	.83
7	1.0	.86	2.6	1.6	1.6	.70
8	.83	.88	2.3	1.5	1.5	.64
9	.96	.87	3.4	1.4	2.4	.56
9.1	--	.84	--	1.5	--	.67
9.5	1.0	--	2.7	--	1.7	--
10	--	1.0	--	1.6	--	.59
10.5	1.0	--	2.4	--	1.4	--
Lithia Springs						
(13.8)	.41	.04	3.8	2.7	3.4	2.7
14	--	1.1	--	1.5	--	.36
16	.80	1.1	1.6	1.5	.83	.36

[1]Reported orthophosphorus value is greater than total phosphorus value.

Springs was about 30 ft^3/s, increasing river discharge by only 10 percent.

The percent of nitrate plus nitrite nitrogen in the total nitrogen concentrations in the Alafia River decreased downstream during higher runoff conditions, whereas ammonia plus organic nitrogen increased. Total nitrogen throughout the Alafia River remained about the same concentration. One notable difference in water quality between base flow and higher runoff conditions was an increase in ammonia nitrogen concentrations between river miles 4 and 1 during higher runoff conditions in April 1992.

Total phosphorus concentrations were high throughout the Alafia River and generally decreased from river mile 16 to the mouth (table 9). This pattern occurred during both the base-flow and the higher runoff sampling events. Orthophosphorus constituted 92 to 100 percent of the total phosphorus concentration in the river upstream of river mile 3 during base-flow conditions. The concentration of phosphorus was significantly lower in Lithia Springs than in the Alafia River, which resulted in a dilution of phosphorus concentrations in the river downstream of the spring.

Hillsborough River

Concentrations of selected constituents in water samples collected from the Hillsborough River and Sulphur Springs during the study are shown in figure 32 and are summarized in tables 6 and 7. Concentrations in the Hillsborough River at site H-8 (nontidal) and Sulphur Springs at site S-9 (nontidal) are for discrete sampling events, whereas concentrations in the Hillsborough River at site H-10 (tidal) were averaged for each day of sampling. Data points are connected by lines on the graph only to improve clarity and to show general trends. Water-quality sampling at the Hillsborough River at site H-8 was done only in June, July, August, and September 1991 during periods of discharge from the Tampa Dam. Seasonal trends in concentrations of nitrogen and phosphorus at this site, therefore, could not be evaluated. Because of uncertainty in the accuracy of summer nutrient concentration data, water quality at site H-8 was not compared with discharge or seasonal trends for the study period at sites S-9 and H-10.

Water-quality characteristics of the Hillsborough River differed from those of Sulphur Springs. Concentrations of total and dissolved phosphorus, orthophosphorus, ammonia nitrogen, organic nitrogen, and organic carbon are less in Sulphur Springs than in the Hillsborough River. Because of the lower concentrations of organic nitrogen and organic carbon in Sulphur Springs, concentrations of these constituents in the tidal Hillsborough River are reduced as a result of dilution. The effects of these dilutions can be seen in figure 32; concentrations of organic nitrogen and organic carbon at the mouth of the river at site H-10 are less than at site H-8 but are greater than in the spring. Concentrations of nitrate plus nitrite nitrogen and silica were greater in the spring than at either Hillsborough River site, indicating that springwater is enriched with these constituents relative to the concentrations found in the river.

Water-quality characteristics at the mouth of the Hillsborough River (site H-10) are affected by water-quality characteristics of Hillsborough Bay. Suspended solids, specific conductance, ammonia nitrogen, phosphorus, and chloride were greater at site H-10 than at the nontidal Hillsborough River (site H-8) or at Sulphur Springs (site S-9). The effects of dilution on concentrations of phosphorus and ammonia nitrogen from Sulphur Springs were not apparent because of the greater concentration of phosphorus and, at times, ammonia nitrogen in Hillsborough Bay relative to Sulphur Springs and the nontidal Hillsborough River.

Concentrations of total nitrate plus nitrite nitrogen, total organic carbon, and dissolved silica at the mouth of the Hillsborough River (site H-10) are inversely related to specific conductance (fig. 33), which indicates that concentrations of these constituents are higher in the Hillsborough River than in Hillsborough Bay. Unlike the Alafia River, phosphorus is not related to specific conductance at the mouth of the Hillsborough River.

Tampa Bypass Canal

Concentrations of selected constituents in water samples collected from the Tampa Bypass Canal at structure S-160 (site T-7) are shown in figure 34 and summarized in tables 6 and 7. Minimum specific conductance and concentrations of dissolved chloride and chlorophyll *a* occurred in July, coinciding with peak discharges. Ammonia nitrogen, ammonia plus organic nitrogen, nitrate plus nitrite nitrogen, phosphorus, and orthophosphorus reached maximum concentrations in July. Variations in total suspended solids were unrelated to season or discharge.

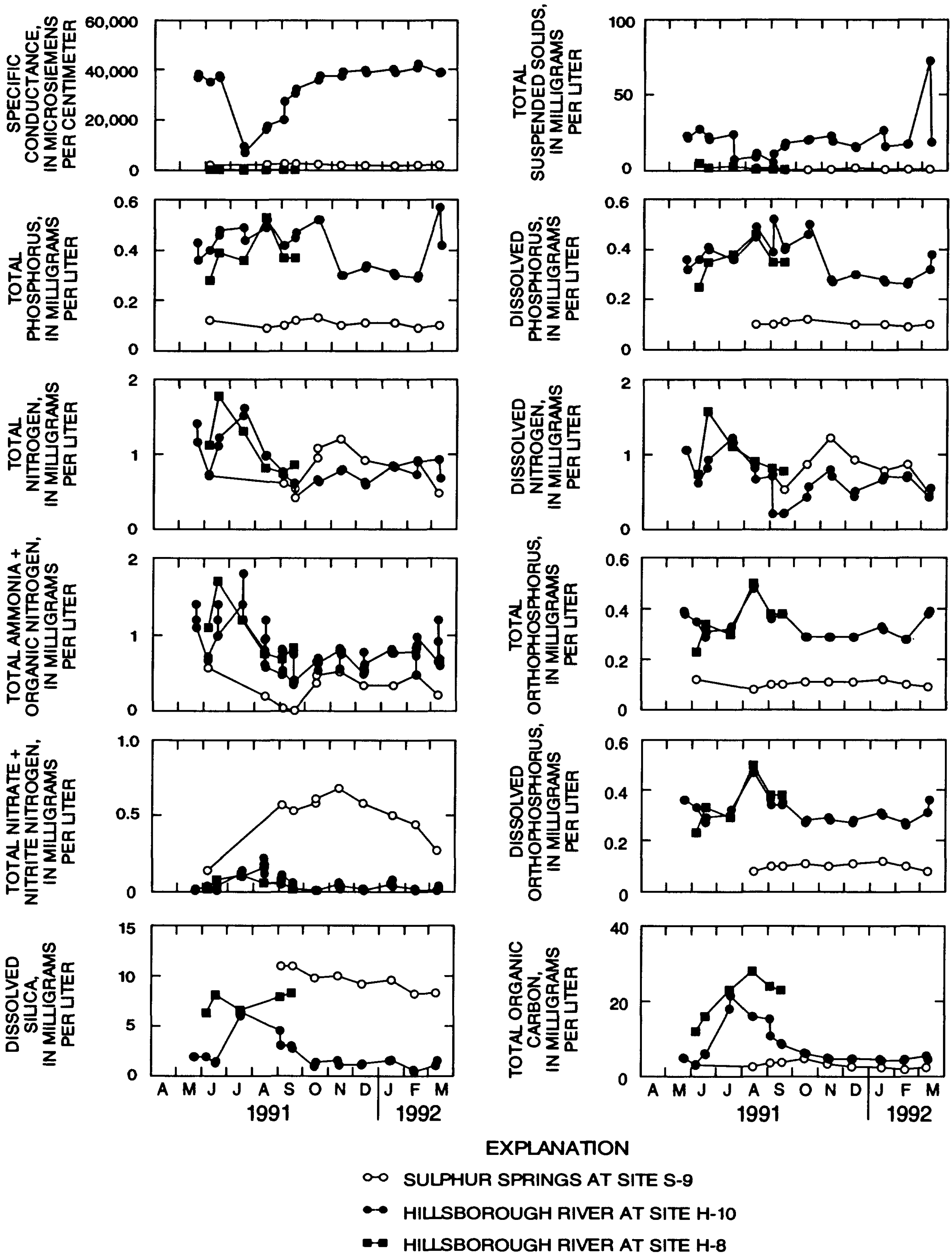


Figure 32. Concentrations of selected water-quality constituents in the Hillsborough River and Sulphur Springs. (Location of sites H-8, S-9, and H-10 are shown in figure 4.)

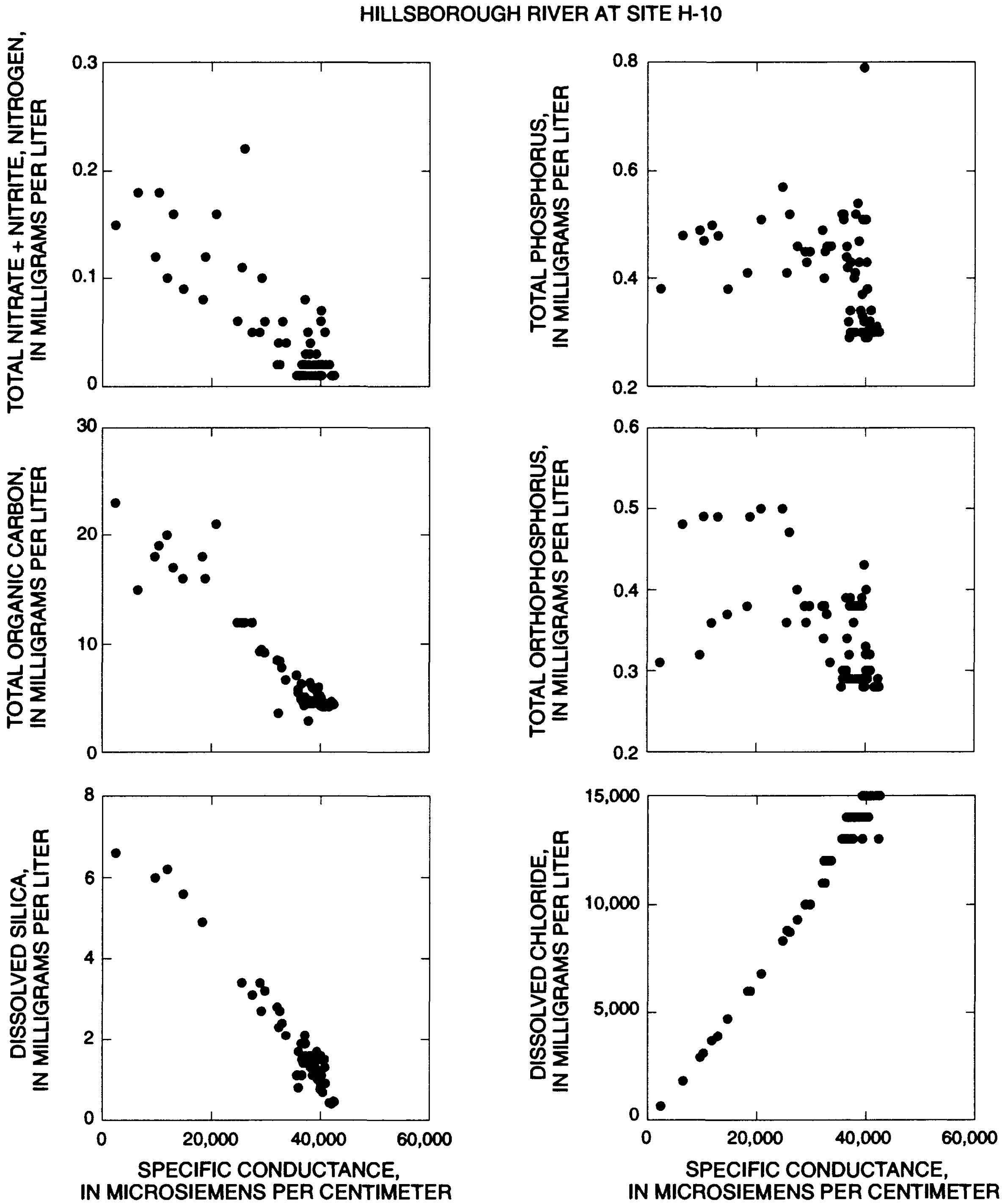


Figure 33. Relation between specific conductance and selected water-quality constituents of the Hillsborough River at site H-10. (Location of site H-10 is shown in figure 4.)

TAMPA BYPASS CANAL AT SITE T-7

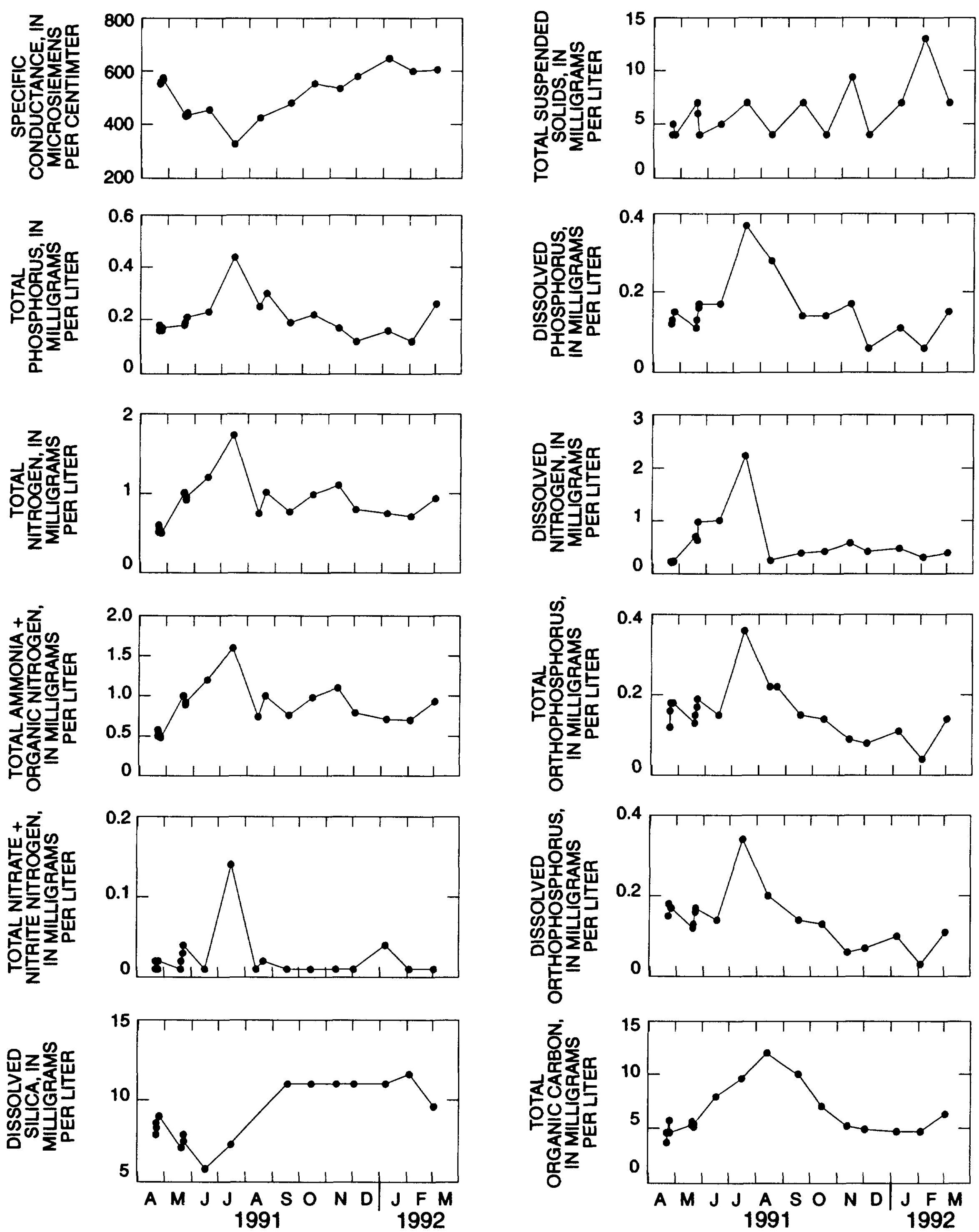


Figure 34. Concentrations of selected water-quality constituents in the Tampa Bypass Canal at site T-7. (Location of site T-7 is shown in figure 4.)

NUTRIENT LOADS TO HILLSBOROUGH BAY

Constituent loads to Hillsborough Bay from the Alafia and Hillsborough Rivers change in response to changes in the constituent concentrations and the river discharges. Because of long-term trends in discharge and constituent concentrations, long-term trends in nutrient loads also have occurred. Nutrient loads from the Alafia and Hillsborough Rivers that are presented in the following section of this report represent conditions that occurred during April 1991 through March 1992. Therefore, prediction of future loads based on analyses presented in this report would most likely be in error if trends in the constituent concentrations and discharges continue.

Net daily constituent loads from a tidally affected reach of a river are difficult to determine because of the complexity of the flow patterns that drive the loading. When river reaches are affected by tide, flows often are either vertically or horizontally stratified or both. Vertical flow stratification occurs when the surface layer of water moves in an opposite direction from the bottom layer. Horizontal stratification occurs during the period of reversal in tide direction. During horizontal stratification, flows can be seaward (downstream) near one bank of the tidal river and upstream at the opposite bank. With stratified flows such as these, constituent loading could be occurring at one point in the cross section and net or average loads could be negative, or upstream. In this study, the sample-collection methods were not designed to determine the variation of the loads in vertical layers in the water. Sampling methods were designed to collect a sample that represented cross-sectionally averaged concentrations. Therefore, loads in this study represent the average load at the cross section for a given time interval.

Daily Loads

Daily total phosphorus and total nitrogen loads were computed for the Alafia River at site A-3 based on equations developed using regression analyses. Water quality and discharge data for the period April 1982 through March 1992 were used in the regression analyses. Data prior to April 1982 were not used to develop the regression equations because of the trends in phosphorus and nitrogen concentrations over time. Also excluded were data for February 25, 1983, when phosphorus concentrations were elevated due to an apparent spill from a phosphate mining area. Because discharges during the study were less than 5,000 ft^3/s, discharges greater than 5,000 ft^3/s also were excluded. A strong correlation between daily load, in tons per day, and daily-mean discharge was observed (table 10).

Regression equations were used to estimate daily total phosphorus and nitrogen loads from the Alafia River at site A-3 for the 1-year period April 1991 to March 1992. Average daily phosphorus load was 1.8 ton/d, and average daily nitrogen load was 1.2 ton/d. Maximum daily loads at the Alafia River at site A-3 occurred on July 15, 1991, when daily-mean discharge was 4,120 ft^3/s, the maximum discharge during the study (fig. 35). Total phosphorus load was 29.1 tons, and total nitrogen load was 19.2 tons on that

Table 10. Results of regression analyses for the Alafia River at site A-3

[ton/d, tons per day; ft^3/s, cubic feet per second; R^2, coefficient of determination; mg/L, milligrams per liter; N, number of measurements; Q, daily-mean discharge]

Dependent variable (ton/d)	Independent variable (ft^3/s)	Adjusted R^2	Standard error (ton)	N	Equation
Total nitrogen load[1]	[2]Q	0.99	0.42	39	Load = 0.004650 × Q
Total phosphorus load[1]	[2]Q	.96	1.0	71	Load = 0.007062 × Q
Phosphorus load for February 25, 1983:					
Total phosphorus, 42 mg/L; daily-mean discharge, 422 ft^3/s:					
Load = 42 mg/L × 422 ft^3/s × 0.002697 = 47.8 ton/d.					

[1]Water-quality and discharge data collected from April 1982 to March 1992 were used in the regression analyses. Data collected on February 25, 1983, are excluded from the analysis.

[2]Discharge is daily-mean discharge; discharges greater than 5,000 ft^3/s are excluded from the analysis.

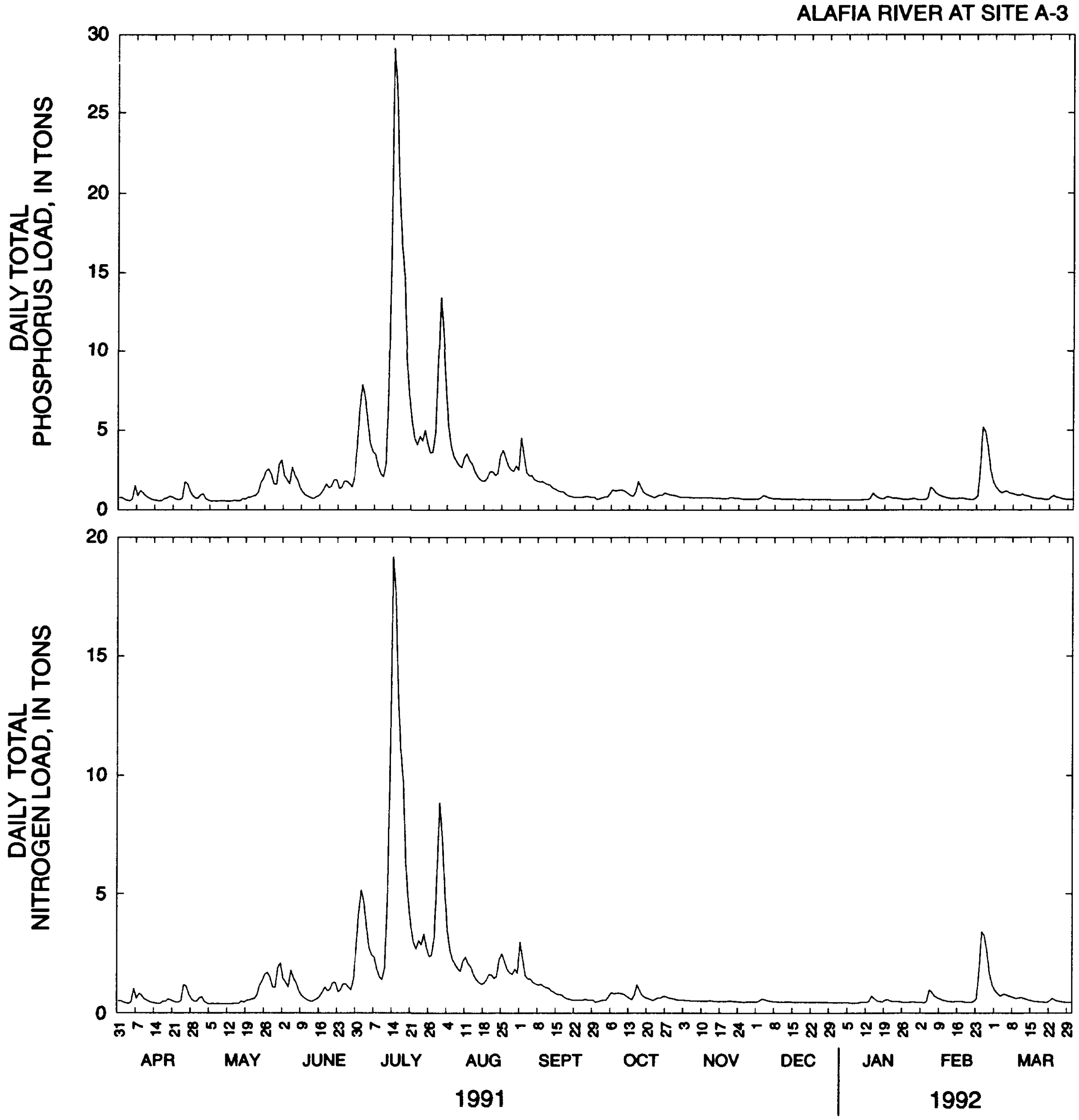


Figure 35. Daily loads of total phosphorus and total nitrogen in the Alafia River at site A-3. (Location of site A-3 is shown in figure 5.)

day. Minimum loads occurred during November to mid-February, an extended period of low flow.

Daily loads at the mouth of the Alafia River (at site A-6) were computed in two steps. The first step was to develop regression equations from the data collected for discrete sampling events. Plots of instantaneous loads and instantaneous discharge were evaluated before regression analyses were done (fig. 36). Inspection of the plots indicated that the slope of the relation between load and discharge increased at discharges above about 4,000 ft^3/s. Samples collected during these higher discharges were collected during ebb currents in July and August 1991, the period with the highest freshwater runoff. Two sets of regression equations were then developed to estimate nutrient loads at this site: one for discharges less than or equal to 4,000 ft^3/s, and one for discharges greater than 4,000 ft^3/s.

Near-bottom specific conductance was tested in the regression analyses for the Alafia River at site A-6 and was determined to be a significant variable when discharges were greater than 4,000 ft^3/s. Specific conductance is strongly influenced by freshwater inflow. Tidal flow usually is very large relative to freshwater discharge. By including specific conductance in the regression equation, differentiation could be made between large discharges caused by tidal processes alone and large discharges caused by tidal processes plus large freshwater inflows.

Regression equations developed for the Alafia River at site A-6 are shown in table 11. The loads for discharges greater than 4,000 ft^3/s are positively related to discharge and are negatively related to near-bottom specific conductance. Phosphorus and nitrogen loads for discharges less than or equal to 4,000 ft^3/s are positively related to discharge. Specific conductance, however, was not a significant variable at the 95-percent level. The regression equations were used to compute loads at 15-minute intervals for the study period.

The second step in determining daily loads at site A-6 was to average the instantaneous loads (at 15-minute intervals) for each day. The data were digitally filtered using the Godin filter to remove tidal variations in the instantaneous loads prior to averaging for each day.

Daily loads of total phosphorus and total nitrogen at the mouth of the Alafia River at site A-6 are shown in figure 37. Daily loads were highest during late June to early September 1991, coinciding with the wet season discharges. Average daily phosphorus load was 2.4 ton/d, and average daily nitrogen load was 1.7 ton/d. Maximum daily phosphorus and nitrogen loads at site A-6 occurred on July 16, 1991, and were 27.1 and 21.0 tons. Maximum loads at site A-6 occurred 1 day after maximum loads at site A-3, 16 mi upstream.

Daily loads of total phosphorus and total nitrogen at the mouth of the Alafia River at site A-6 sometimes were negative because discharges were negative (upstream). Negative loads indicate a net loss of phosphorus and nitrogen loads. Negative loads, however, could be the result of errors in discharge computations for periods of low flow, as discussed in the discharge section. However, these negative loads coincided with periods when specific conductance in the tidal reach of the river was increasing because of a net upstream movement of the saltwater-freshwater interface. A net upstream movement of other constituents such as nitrogen and phosphorus also would occur at such times.

Estimated daily loads of phosphorus in the Alafia River represent minimum loads because the regression analyses are based on "normal" conditions; that is, when a temporary point source of phosphorus is not present. Frequent episodic loading from phosphate mining-related spills in the Alafia River basin has occurred. These spills can contribute large amounts of phosphorus and suspended sediments to the river. For example, the measured phosphorus load at site A-3 on February 25, 1983, was 48 tons, whereas the load predicted from the regression equation is 3.0 tons. There were no documented phosphate mining-related spills reported for the Alafia River during the study (Vishwas Sathe, Florida Department of Environmental Regulation, oral commun., 1992), but undocumented spills have been known to occur.

During the study, daily loads from the Hillsborough River at site H-8 and from Sulphur Springs at site S-9 were computed using daily-mean discharge and the average constituent concentrations during the study for each site. Average constituent concentrations were used instead of regression equations because the relation between load and discharge at these sites was poor and because of the uncertainty of the accuracy of the August and September nutrient concentration data. Daily phosphorus and nitrogen loads at the Hillsborough River at site H-8 are shown in figure 38. Average daily phosphorus load was 0.26 ton/d, and average daily nitrogen load was 0.74 ton/d. Maximum daily loads occurred in July 1991, and minimum daily loads occurred from April 1 to May 22, 1991, and from September 23, 1991, to March 1, 1992. Daily phosphorus and nitrogen loads at Sulphur Springs (site S-9) are shown in figure 39. Average daily phosphorus load was 0.01 ton/d, and average daily nitrogen load was 0.07 ton/d. Maximum daily loads occurred during July and August 1991.

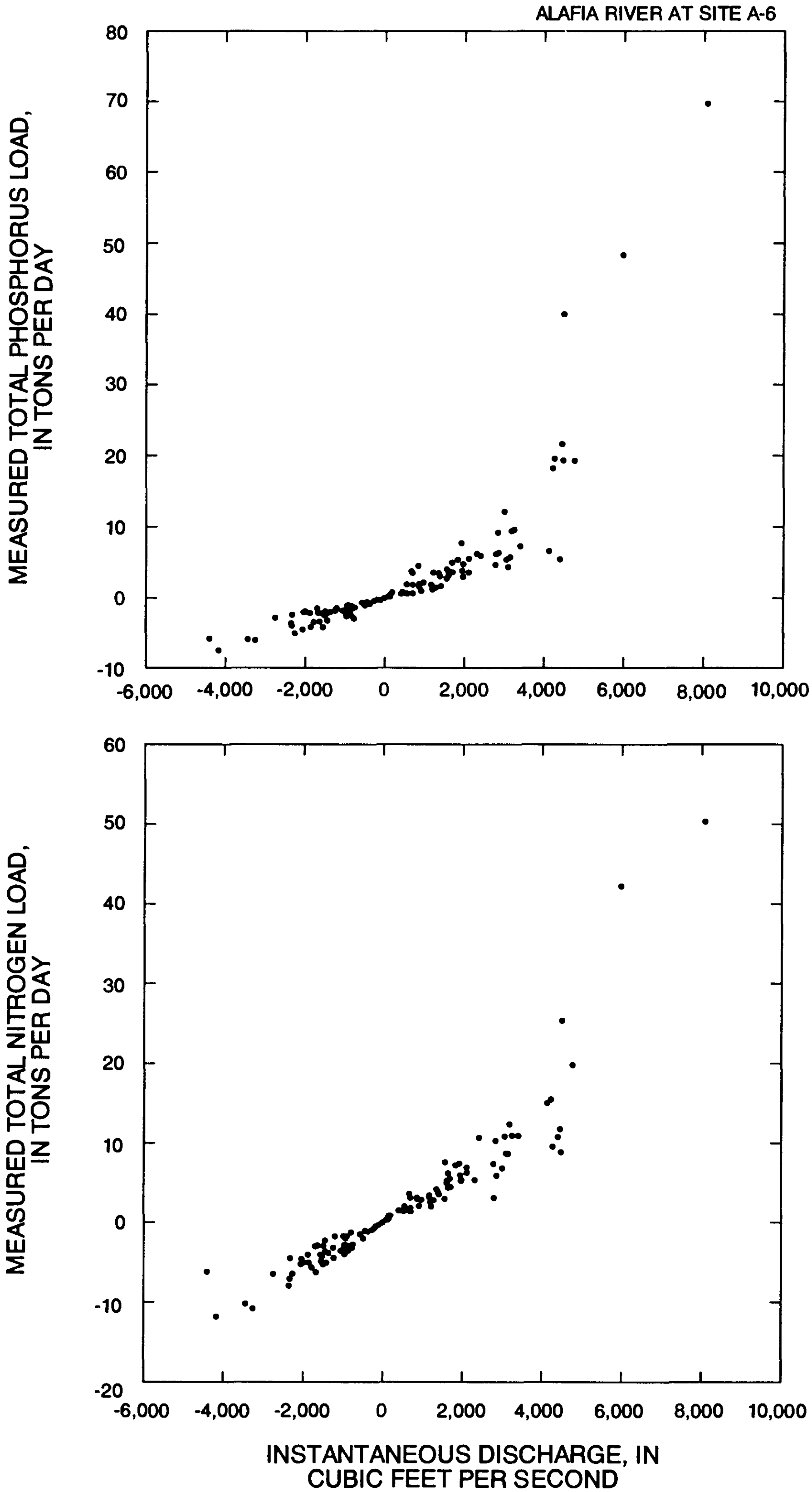


Figure 36. Instantaneous loads of total phosphorus and total nitrogen in the Alafia River at site A-6. (Location of site A-6 is shown in figure 5.)

Table 11. Results of regression analyses for the Alafia River at site A-6

[ton/d, tons per day; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; R^2, coefficient of determination; N, number of measurements; Q, instantaneous discharge; C, instantaneous near-bottom specific conductance]

Dependent variable (ton/d)	Independent variable (Q, ft^3/s) (C, µS/cm)	Adjusted R^2	Standard error (ton)	N	Equation
		For discharges less than or equal to 4,000 ft^3/s			
Total nitrogen load	Q	0.94	1.3	109	Load = $[(2.8045 \times 10^{-3}) \times Q] + [(8.1 \times 10^{-8}) \times Q^2]$
Total phosphorus load	Q	.91	1.2	110	Load = $[(2.0062 \times 10^{-3}) \times Q] + [(1.4 \times 10^{-7}) \times Q^2]$
		For discharges greater than 4,000 ft^3/s			
Total nitrogen load	Q,C	.92	4.4	9	Load = $[(7.3411 \times 10^{-3}) \times Q] - [(4.4322 \times 10^{-4}) \times C] - 6.4770$
Total phosphorus load	Q,C	.98	3.1	9	Load = $[(7.9359 \times 10^{-3}) \times Q] - [(7.6192 \times 10^{-4}) \times C] + 4.3463$

Daily loads of phosphorus and nitrogen at the mouth of the Hillsborough River at site H-10 were computed in two steps. First, loads for days when water-quality samples were collected were computed using estimated daily-mean discharge and measured concentrations of total phosphorus and nitrogen. Results from analyses of water samples collected at different times of the day (and different parts of the tide cycle) were averaged for each day of water-quality sampling. The assumption was made that this average concentration was representative of average conditions for the day. Plots of measured phosphorus and nitrogen loads and estimated daily-mean discharge were then examined. Based on visual inspection of the plots, linear or second order polynomial regression analyses were run relating load to estimated daily-mean discharge (table 12). The relation between load and discharge was very good partly because much of the variability in the data was removed by using average concentrations and estimated discharges.

The regression equations were used to compute daily-total phosphorus and total nitrogen loads at the mouth of the Hillsborough River (site H-10). Daily loads for the period April 1991 to March 1992 are shown in figure 40. Average daily total phosphorus load was 0.35 ton/d, and average daily nitrogen load was 0.86 ton/d. Maximum loads occurred on July 20, 1991, when estimated discharge at site H-10 was 2,630 ft^3/s. Minimum loads occurred during periods when discharge at the Tampa dam (site H-8) upstream was less than 0.5 ft^3/s.

Daily phosphorus and nitrogen loads from the Tampa Bypass Canal at structure S-160 (site T-7) were computed based on equations developed using regression analyses relating measured load and daily-mean skimmer discharge. The coefficient of determination for the regression was 0.86 for total phosphorus load and 0.91 for total nitrogen load (table 13). Computed daily phosphorus and nitrogen loads are shown in figure 41.

Average daily phosphorus and nitrogen loads at the Tampa Bypass Canal at (site T-7) for the period April 1991 to March 1992 were 0.06 and 0.26 ton/d, respectively. Maximum loads occurred on July 14, 1991, and minimum loads occurred in late November to early December 1991. Because daily-mean skimmer discharge did not include all sources of discharge from the structure, estimated daily nitrogen and phosphorus loads most likely are less than actual loads.

Seasonal Loads

Monthly total phosphorus and nitrogen loads at the Alafia River, Hillsborough River, Sulphur Springs, and Tampa Bypass Canal are shown in tables 14 and 15. Monthly loads were computed by summing the daily-mean loads. For months with missing daily-mean loads, an average daily load for the month was computed and used to estimate total monthly load.

Monthly phosphorus loads in the Alafia River ranged from 15.9 to 245 tons at site A-3 and from 23.4 to 259 tons at site A-6 (table 14). Maximum monthly phosphorus loads occurred in July 1991 at both sites. Except during June 1991, monthly phosphorus loads at the mouth of the Alafia River at site A-6 exceeded upstream loads. Monthly phosphorus loads were about 6 to 123 percent higher at site A-6 than at site A-3.

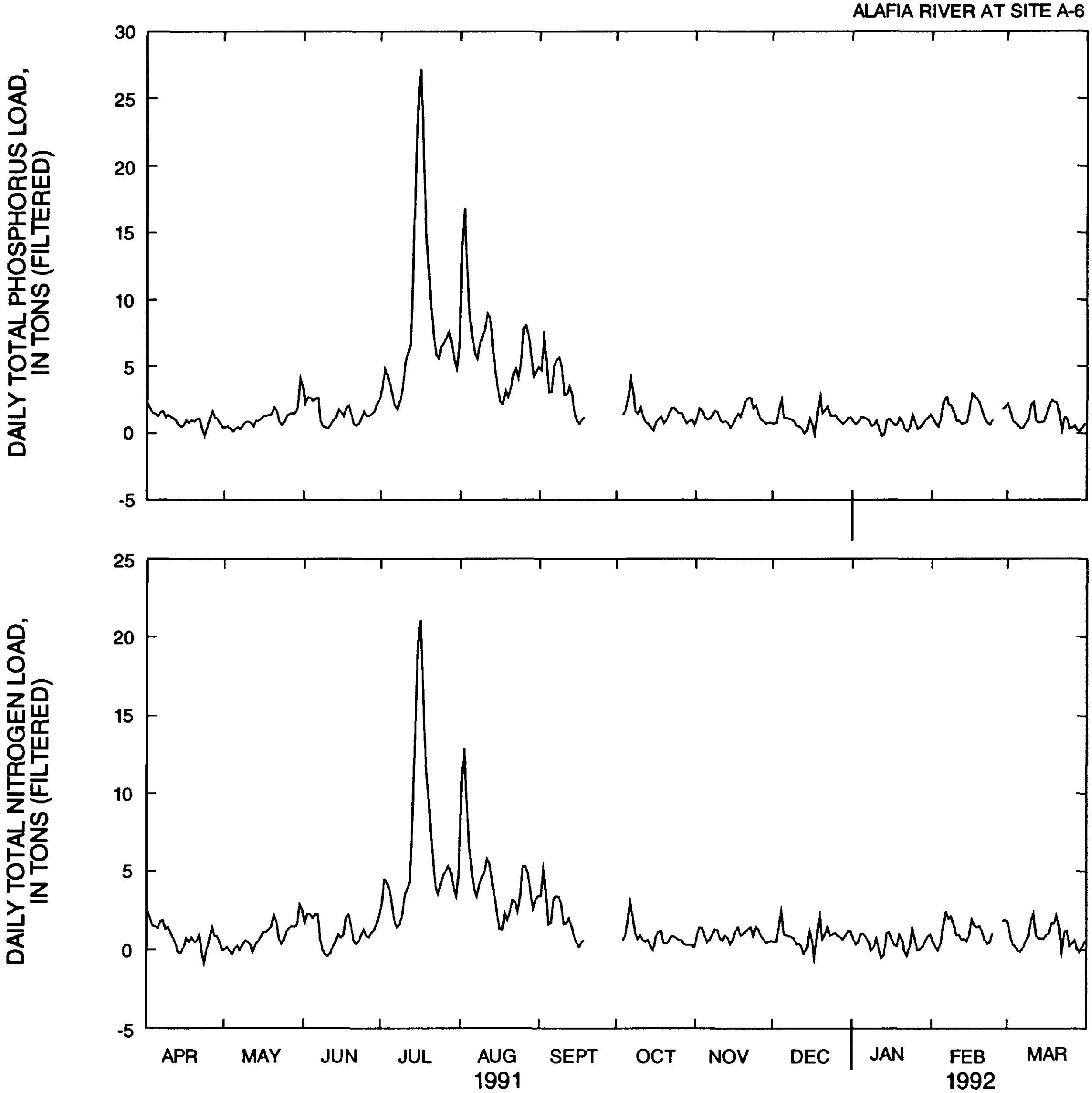


Figure 37. Daily loads of total phosphorus and total nitrogen in the Alafia River at site A-6. (Location of site A-6 is shown in figure 5.)

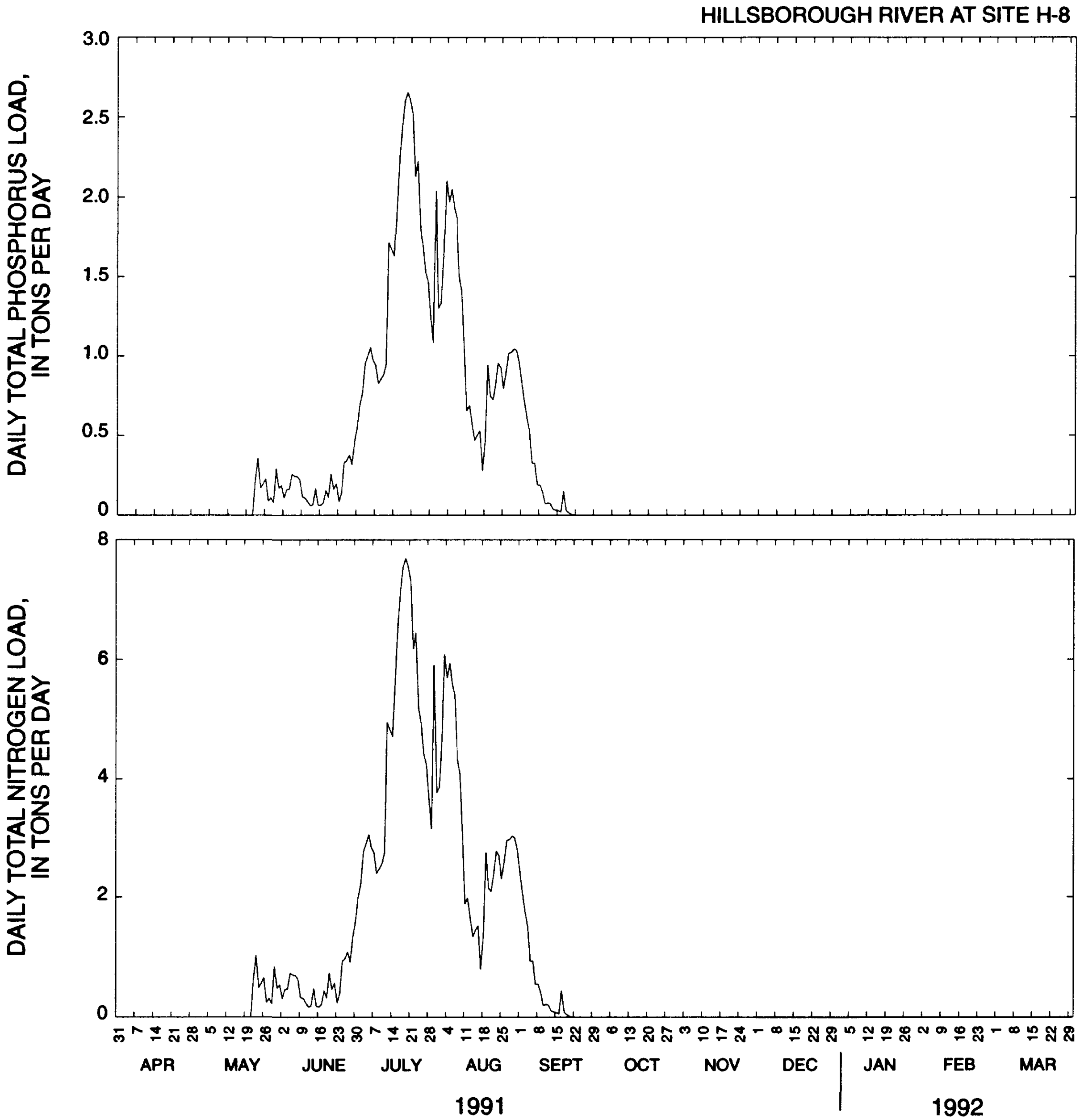


Figure 38. Daily loads of total phosphorus and total nitrogen in the Hillsborough River at site H-8. (Location of site H-8 is shown in figure 4.)

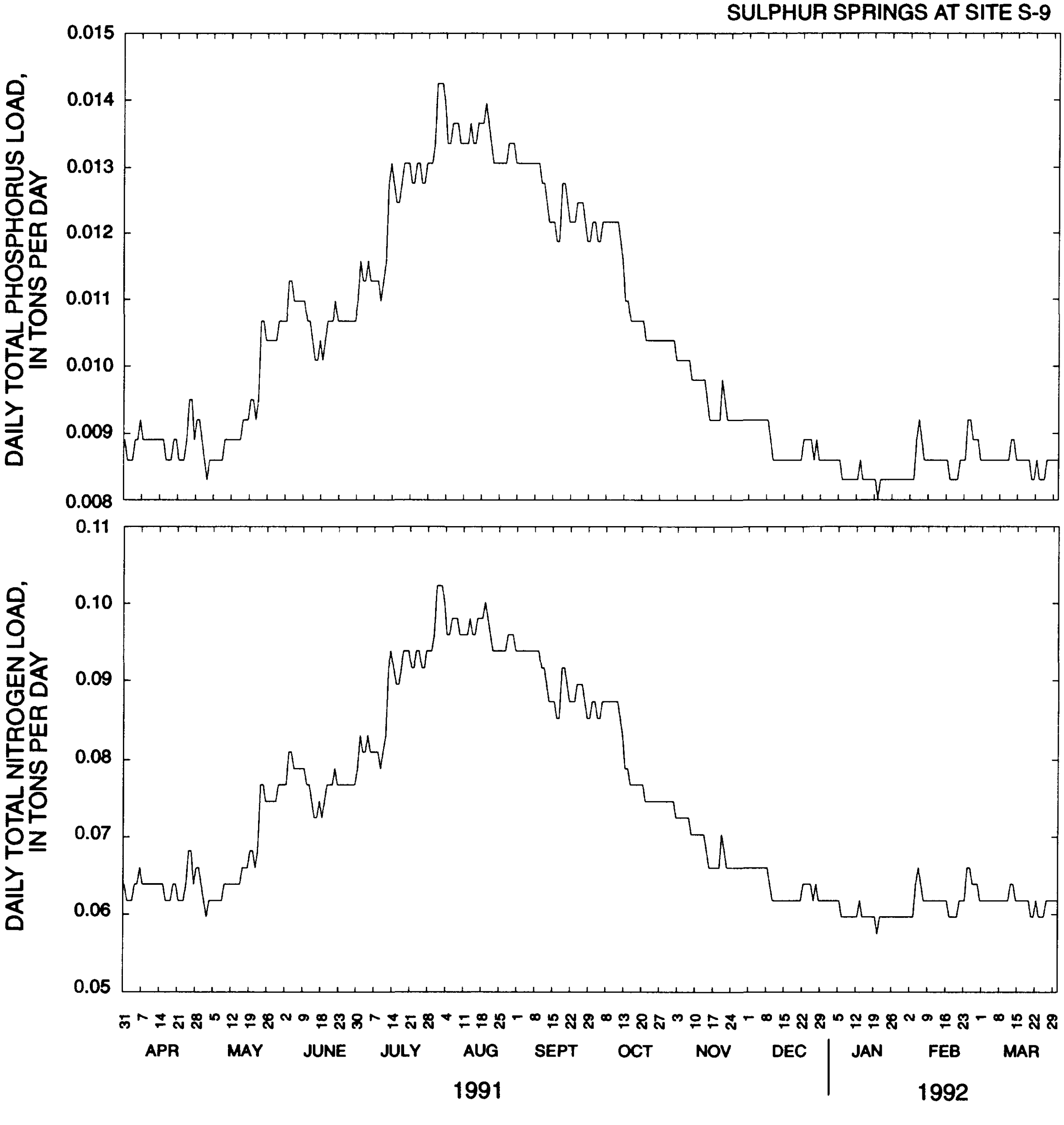


Figure 39. Daily loads of total phosphorus and total nitrogen in Sulphur Springs at site S-9. (Location of site S-9 is shown in figure 4.)

Table 12. Results of regression analyses for the Hillsborough River at site H-10

[ton/d, tons per day; ft^3/s, cubic feet per second; R^2, coefficient of determination; N, number of measurements; Q, estimated daily-mean discharge]

Dependent variable (ton/d)	Independent variable (ft^3/s)	Adjusted R^2	Standard error (ton)	N	Equation
Total nitrogen load	Q	0.998	0.14	25	Load = $[(1.185 \times 10^{-6}) \times Q^2] + [(1.477 \times 10^{-3}) \times Q]$
Total phosphorus load	Q	.996	.06	25	Load = $(1.244 \times 10^{-3}) \times Q$

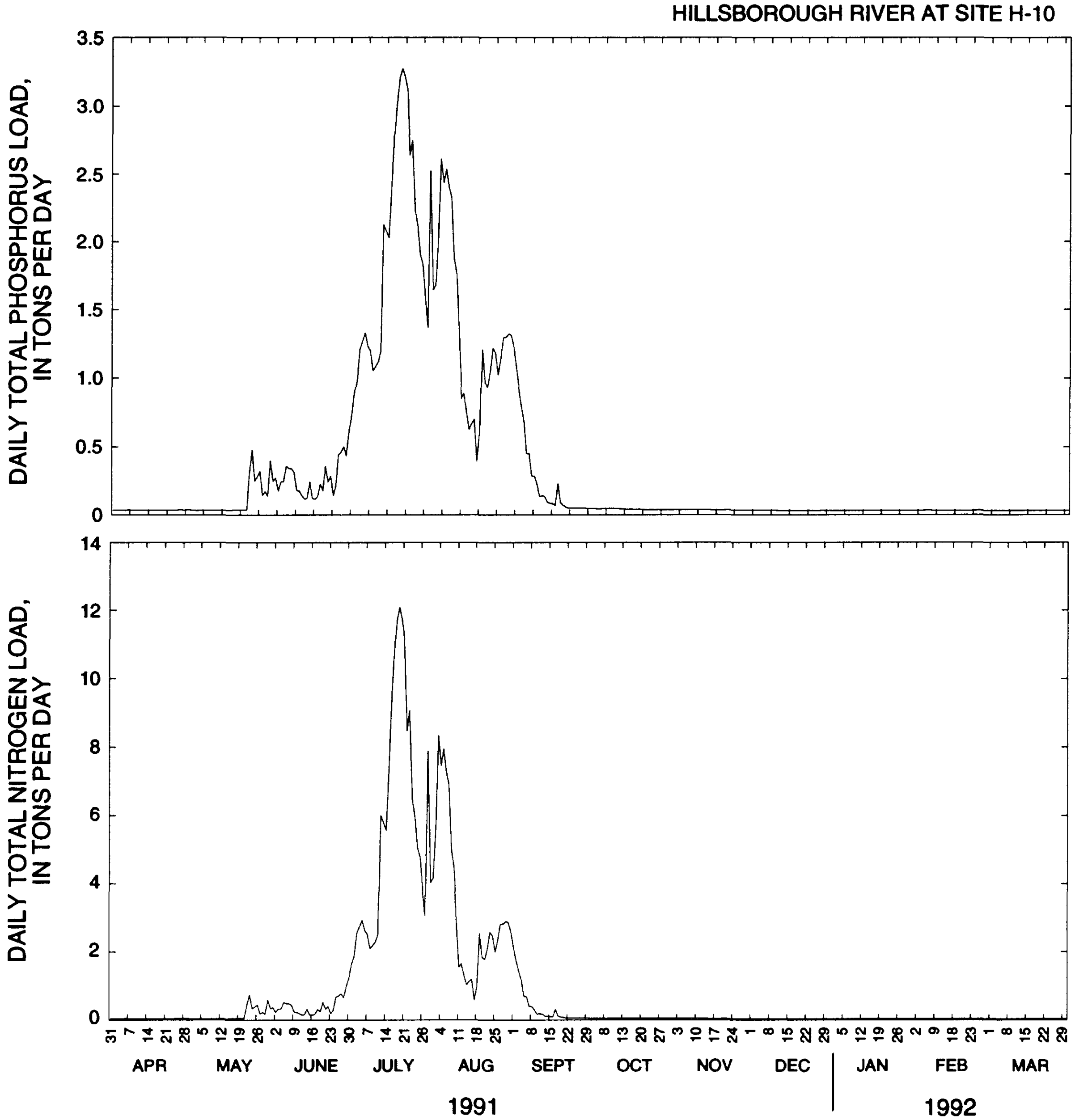


Figure 40. Daily loads of total phosphorus and total nitrogen in the Hillsborough River at site H-10. (Location of site H-10 is shown in figure 4.)

Table 13. Results of regression analyses for the Tampa Bypass Canal at site T-7

[ton/d, tons per day; ft^3/s, cubic feet per second; R^2, coefficient of determination; N, number of measurements; Q, daily-mean skimmer discharge]

Dependent variable (ton/d)	Independent variable (ft^3/s)	Adjusted R^2	Standard error (ton)	N	Equation
Total nitrogen load	Q	0.91	0.11	16	Load = $(3.001 \times 10^{-3}) \times Q$
Total phosphorus load	Q	.86	.03	16	Load = $(6.753 \times 10^{-4}) \times Q$

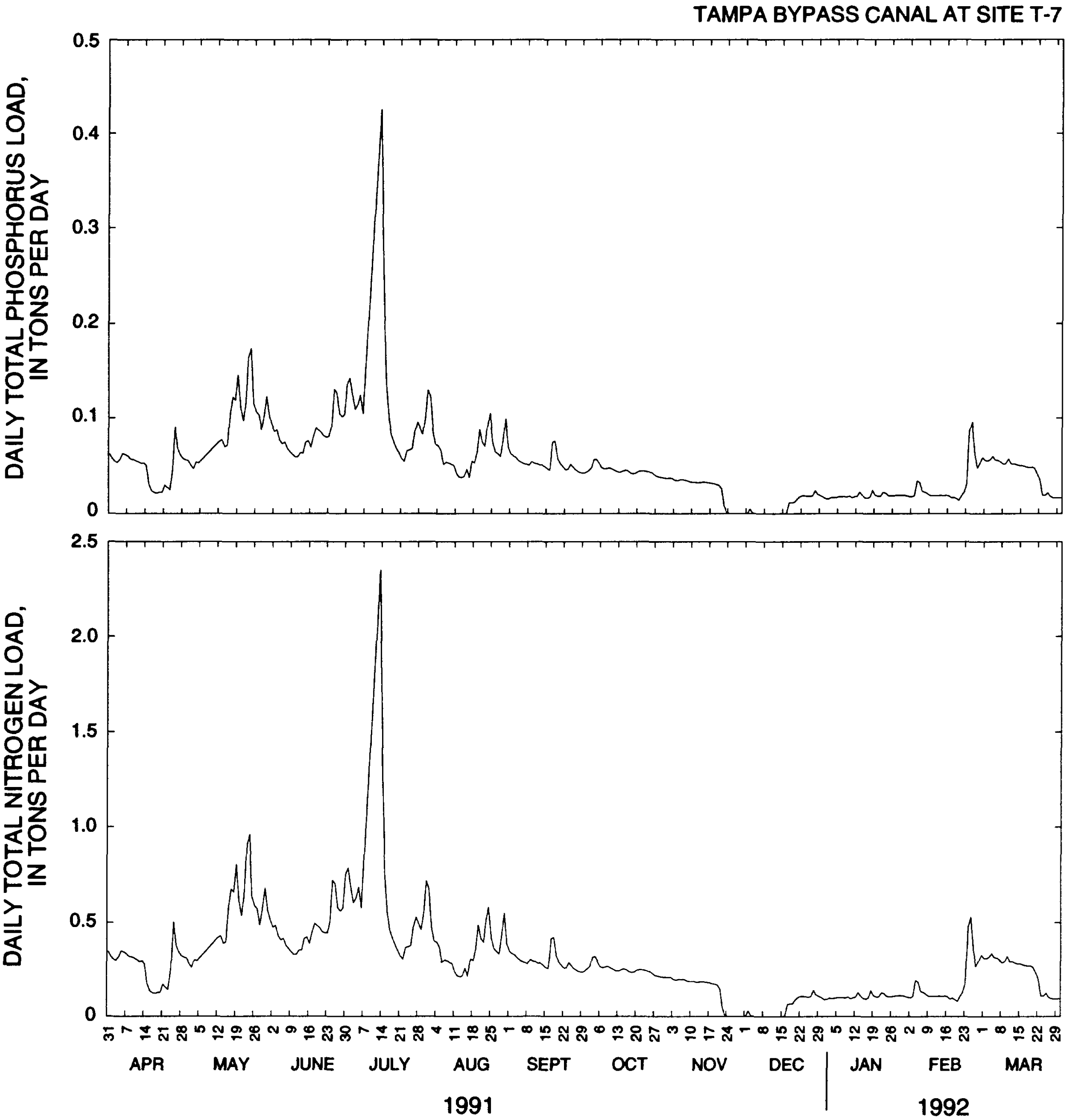


Figure 41. Daily loads of total phosphorus and total nitrogen in the Tampa Bypass Canal at site T-7. (Location of site T-7 is shown in figure 4.)

Table 14. Monthly phosphorus loads to Hillsborough Bay, April 1991 through March 1992

[All values are in tons; --, trace]

Year/month	Alafia River at Lithia (site A-3)	Alafia River at Gibsonton (site A-6)	Hillsborough River near Tampa (site H-8)	Sulphur Springs at Sulphur Springs (site S-9)	Hillsborough River at Platt Street (site H-10)	Tampa Bypass Canal at structure S-160 (site T-7)	Total load to Hillsborough Bay[1]
1991							
April	26.3	31.9	0.006	0.27	1.1	1.6	34.6
May	31.7	36.0	1.7	.29	3.3	3.4	42.7
June	49.0	45.6	5.5	.32	8.0	2.8	56.4
July	245	259	47.7	.38	59.5	3.9	322
August	118	199	33.2	.42	42.0	2.3	243
September	46.2	103	5.3	.38	8.1	1.8	113
October	32.8	42.9	.006	.32	1.4	1.6	45.9
November	18.5	40.4	.003	.28	1.2	.84	42.4
December	15.9	34.1	.001	.26	1.1	.28	35.5
1992							
January	16.1	23.4	--	.25	1.0	.65	25.0
February	33.4	44.6	--	.24	1.0	.95	46.6
March	24.1	34.0	--	.25	1.1	1.5	36.6

[1]Loads from sites A-6, H-10, and T-7 were summed to compute the load to Hillsborough Bay.

Table 15. Monthly nitrogen loads to Hillsborough Bay, April 1991 through March 1992

[All values are in tons]

Year/month	Alafia River at Lithia (site A-3)	Alafia River at Gibsonton (site A-6)	Hillsborough River near Tampa (site H-8)	Sulphur Springs at Sulphur Springs (site S-9)	Hillsborough River at Platt Street (site H-10)	Tampa Bypass Canal at structure S-160 (site T-7)	Total load to Hillsborough Bay[1]
1991							
April	17.3	24.0	0.02	1.9	1.4	7.3	32.7
May	20.9	26.5	5.0	2.1	4.6	15.1	46.2
June	32.3	32.8	15.8	2.3	11.5	12.4	56.7
July	161	197	138	2.7	173	17.3	387
August	78.0	137	96.1	3.0	103	10.4	250
September	30.4	63.1	15.5	2.7	13.7	7.9	84.7
October	21.6	23.8	.02	2.3	1.6	6.9	32.3
November	12.2	28.4	.009	2.0	1.4	3.7	33.5
December	10.5	26.4	.005	1.9	1.3	1.3	29.0
1992							
January	10.6	14.3	.002	1.8	1.2	2.9	18.4
February	22.0	32.9	.002	1.7	1.2	4.2	38.3
March	15.9	24.2	.002	1.8	1.3	6.7	32.2

[1]Loads from sites A-6, H-10, and T-7 were summed to compute the load to Hillsborough Bay.

Monthly nitrogen loads in the Alafia River ranged from 10.5 to 161 tons at site A-3 and from 14.3 to 197 tons at site A-6 (table 15). Maximum monthly nitrogen loads occurred in July 1991 at both sites. Minimum monthly nitrogen loads occurred in December 1991 at site A-3 and in January 1992 at site A-6. Monthly nitrogen loads at the mouth of the Alafia River at site A-6 exceeded upstream loads during the study. Nitrogen loads were about 2 to 151 percent higher at site A-6 than at site A-3.

Monthly phosphorus loads in the Hillsborough River basin ranged from trace amounts to 47.7 tons at the Tampa dam (site H-8); from 0.24 to 0.42 tons at Sulphur Springs (site S-9); and from 1.0 to 59.5 tons at the mouth of the Hillsborough River (site H-10). Maximum monthly phosphorus loads occurred during July 1991 in the river and during August 1991 in Sulphur Springs. Minimal monthly phosphorus loads occurred in April 1991 and from October 1991 to March 1992 at sites H-8 and H-10. Minimal loads were the result of low discharges from the dam during these periods. Monthly phosphorus loads from site S-9 were relatively constant throughout the year.

Monthly nitrogen loads in the Hillsborough River basin ranged from trace amounts to 138 tons at site H-8; from 1.7 to 3.0 tons at site S-9; and from 1.2 to 173 tons at site H-10. Maximum monthly nitrogen loads occurred during July 1991 in the river and during August 1991 in Sulphur Springs. Minimal monthly nitrogen loads occurred during the same periods as minimal monthly phosphorus loads. Monthly nitrogen loads were less at the mouth of the Hillsborough River than at the mouth of the Alafia River. Monthly nitrogen loads from Sulphur Springs were relatively constant throughout the year.

Monthly phosphorus loads in the Tampa Bypass Canal (site T-7) ranged from 0.28 to 3.9 tons, and monthly nitrogen loads ranged from 1.3 to 17.3 tons. Maximum monthly loads occurred during July 1991, and minimum loads occurred during December 1991.

Annual total loads of phosphorus and nitrogen and basin yields (load per unit of area) for the period April 1991 to March 1992 are listed in table 16. Annual loads were computed by summing the monthly loads. Basin yields for Sulphur Springs and the Tampa Bypass Canal were not reported because the main source of discharge is ground water and the contributing drainage area could not be determined.

The greatest annual loads of phosphorus and nitrogen to Hillsborough Bay measured during this study were from the Alafia River, with the greatest loads at the river mouth. Total phosphorus load in the Alafia River was much greater than at any other study site, and was more than six times greater at site A-6 than at the mouth of the Hillsborough River at site H-10. Annual total nitrogen load at site A-6 was about two times greater than at the mouth of the Hillsborough River and more than six times greater than the nitrogen load from the Tampa Bypass Canal. The least annual loads to Hillsborough Bay were from the Tampa Bypass Canal.

Annual loads from the Alafia River, Hillsborough River, and the Tampa Bypass Canal were summed to estimate total loads to Hillsborough Bay (table 16). Total phosphorus load from these major freshwater inflow sources was 1,045 tons during April 1991 through March 1992. Total nitrogen load was 1,041 tons during the same period.

Because of long-term decreases in discharges from the Alafia River and the Hillsborough River, long-term decreases in nutrient loading to Hillsborough Bay have occurred. In the Alafia River, the long-term decreases in nitrogen and phosphorus concentrations also have resulted in reduced nutrient loading as compared to historic loading levels. For example, average annual total nitrogen load for the period 1967–68 was about 1,300 tons per year (Johansson, 1991), whereas the annual total nitrogen load during April 1991 through March 1992 was 630 tons. Because both discharge and water-quality characteristics of the Alafia River have changed, the relation between load and discharge has changed during the period of record. If water quality in the rivers does not change and declines in annual-mean discharge continue, then phosphorus and nitrogen loads to Hillsborough Bay will decrease from current levels. However, if increasing trends in nitrate nitrogen concentrations in Lithia Springs continue, nitrogen loads from the Alafia River could remain at current levels or increase.

The drainage areas of the upstream, nontidal gages in the Alafia River (site A-3) and the Hillsborough River (site H-8) are about 80 and 94 percent, respectively, of the total basin drainage areas. The phosphorus loads at site A-3 are about 73 percent of the total basin load, but the nitrogen loads are about 69 percent. Phosphorus and nitrogen loads at the Hillsborough River at site H-8 represent only 72 and 86 percent, respectively, of the total basin loads. Nutrient loading from the basin that drains the tidal reaches of the Alafia River and Hillsborough River, therefore, contributes a significant part of the total nutrient load to the rivers.

Expressing the load of a constituent as a basin yield allows relative comparison between river basins of different sizes, or between parts of the same river basin. The yield is related to land use in the basin but also is affected by other basin characteristics, such as

Table 16. Annual loads of total phosphorus and total nitrogen and basin yields, April 1991 through March 1992

[mi^2, square mile; ton/mi^2, tons per square mile; --, no data]

Station	Drainage area (mi^2)	Annual total phosphorus load (tons)	Annual total phosphorus yield (ton/mi^2)	Annual total nitrogen load (tons)	Annual total nitrogen yield (ton/mi^2)
Site A-3					
Alafia River at Lithia	335	657	2.0	433	1.3
Site A-6					
Alafia River at Gibsonton	418	894	2.1	630	1.5
Site H-8					
Hillsborough River near Tampa	[1]650	93.4	.14	270	.42
Site S-9					
Sulphur Springs at Sulphur Springs	--	3.7	--	26.2	--
Site H-10					
Hillsborough River at Platt Street	[1]690	129	.19	315	.46
Site T-7					
Tampa Bypass Canal at structure S-160	--	21.6	--	96.1	--
Total loads to Hillsborough Bay	--	1,045	--	1,041	--

[1]Drainage area excludes the Tampa Bypass Canal.

topography, vegetation, and soil types. Basin yields were used to evaluate loads from the Alafia River and Hillsborough River.

Basin yields of total phosphorus were greater in the Alafia River basin than in the Hillsborough River basin (table 16). The basin yield of phosphorus was about 2 (ton/mi^2)/yr at both sites in the Alafia River, more than 10 times greater than the yield of the Hillsborough River basin. Basin yields of nitrogen were greatest at the Alafia River at site A-6 (1.5 (ton/mi^2)/yr) and least at the Hillsborough River at site H-8 (0.4 (ton/mi^2)/yr). Yields of nitrogen in the Alafia River basin were about three times the yield in the Hillsborough River basin. This difference in yields indicates that land use in the Alafia River basin is a significant source of nutrients to the river compared to the Hillsborough River. Low yields at the Hillsborough River at site H-8 could be partially due to storage of nutrients in the sediments upstream of the reservoir.

When yields at the two sites in the Alafia River basin were compared, basinwide nitrogen yield was slightly more at the mouth of the Alafia River at site A-6 than at site A-3, while phosphorus yields were approximately equal (table 16). In the Hillsborough River basin, basinwide yields of phosphorus and nitrogen at the mouth at site H-10 were slightly greater than yields at site H-8.

The phosphorus and nitrogen yields from the part of the drainage basin downstream of the nontidal gages were examined to determine the relative yield from that part of the basin. Yields from the Alafia River and Hillsborough River basins downstream from sites A-3 and H-8, respectively, were much different than the basinwide yields and yields at the upstream sites. In the Alafia River, phosphorus yield for the 83 mi^2 of basin unaccounted for at the nontidal gage was 2.9 (ton/mi^2)/yr, greater than the yield at site A-3. The nitrogen yield for this 83 mi^2 was 2.4 (ton/mi^2)/yr, about twice the yield at site A-3. In the Hillsborough River, phosphorus yield in the 40 mi^2 of basin that drains the tidal reach of the river was 0.9 (ton/mi^2)/yr, more than four times greater than the yield at the nontidal gage. The nitrogen yield for this part of the basin was 1.1 (ton/mi^2)/yr, more than twice the yield at the nontidal gage.

Comparison of Load-Estimation Techniques

Estimates of nitrogen and phosphorus loads from ungaged parts of a river basin often are made by projecting loads from the gaged part for the basin. For example, if 80 mi^2 of a 100-mi^2 river basin were gaged and if adequate water-quality data were available to compute loads, then total basin loads could be estimated by multiplying loads at the gaged site by 1.25. This technique is equivalent to using the basin yield (load per unit area) for the gaged site to compute total basin load by multiplying the yield by the total basin area. This technique assumes that the basin yield of a constituent is uniform throughout a basin. This assumption often is not valid because land use in the basin usually is not uniform.

To test the hypothesis that loads at ungaged sites on a river can be accurately estimated from data at gaged sites, nitrogen and phosphorus loads for site A-6 were estimated from loads computed for site A-3. These estimated loads were then compared with loads at site A-6 that were computed from the regression equations developed from data at site A-6. Annual phosphorus loads at the mouth of the Alafia River (site A-6) that were estimated by adjustments of loads at site A-3 were about 8 percent less than loads at site A-6 that were computed from regression equations. Estimated annual nitrogen loads are about 14 percent less than loads based on the regression equations. Annual phosphorus loads at the mouth of the Hillsborough River (site H-10) that were estimated by adjustments of loads at site H-8 are underestimated by about 23 percent, whereas annual nitrogen loads are underestimated by about 9 percent. This analysis shows that loads that are estimated for an ungaged site on a river by projecting loads at a gaged site can be in error, even if the gage accounts for a large part of the total basin.

Measuring loads at both an upstream, nontidally affected site and at the mouth of a river allows for evaluation of effects of land use in the tidally affected reach of a river. This area often is the part of the basin most affected by human activities. In the Hillsborough River basin, the lower basin is heavily urbanized and contributes more nitrogen and phosphorus per unit area than the basin upstream of site H-8. In the Alafia River basin, residential, agricultural, and industrial uses predominate in the lower basin, while phosphate mining is a major land use activity upstream of site A-3. These differences in land uses are reflected in the load patterns at sites A-3 and A-6.

SUMMARY AND CONCLUSIONS

A study was undertaken to develop techniques for the measurement of discharge in tidally affected reaches of rivers and to provide estimates of nutrient loading to Hillsborough Bay from the Alafia River, Hillsborough River, and Tampa Bypass Canal. The study was conducted by the USGS in cooperation with the SWFWMD. Data collection began in August 1990 and concluded in April 1992. The discharge, water-quality, and loading characteristics of the Alafia River, Hillsborough River, and the Tampa Bypass Canal were evaluated.

The evaluation of long-term discharge characteristics indicated the following:

- Annual flows to Hillsborough Bay vary considerably from year to year.
- Flow characteristics in the Hillsborough River have changed during the period April 1939 through March 1992. A statistically significant decreasing trend in annual-mean discharge, 7- and 30-day annual low flows, and 7- and 30-day annual high flows has occurred.
- A decreasing trend in annual-mean discharge from Sulphur Springs has occurred during the period April 1961 through March 1992.
- Flow characteristics in the Alafia River have changed at three long-term gages in the basin. Statistically significant decreasing trends in annual-mean discharge have occurred at all three sites. At site A-3, the most downstream, nontidally affected site, 7- and 30-day annual high flows have a decreasing trend as well. Although annual-mean and annual high flows have decreased, the 7- and 30-day low flows increased from about 1957 to 1966 and then decreased from about 1967 to 1992.

Techniques for the measurement of tidally affected discharge were developed for a site near the mouth of the Alafia River. Continuous index velocity and stage gages were established. Periodic discharge measurements were made using both the standard point velocity-discharge technique and a moving boat method using a BBADCP. An index velocity-mean velocity rating was developed from the discharge measurements, and a stage-area rating was developed from bathymetric profiles. Continuous discharges were computed for the period April 1991 through March 1992.

Evaluation of discharge characteristics at sites in the Alafia River, Hillsborough River, and the Tampa Bypass Canal during the study period was made. This evaluation indicated the following:

- Annual-mean discharge at the long-term, upstream gage on the Alafia River was 26 percent less during the study than the long-term average. Extended periods of low flow occurred in April and May 1991, and from November 1991 through mid-February 1992. The maximum daily-mean discharge was 4,120 ft^3/s on July 15, 1991, a high-flow event with an estimated 3-year recurrence interval.

- Discharge at the mouth of the Alafia River is affected by tide. The application of a digital filter (the Godin filter) removed much of the variation in the data caused by tide so that daily-mean discharges at this site could be computed.

- Daily-mean discharges in the Alafia River at site A-3 (upstream) and at site A-6 (at the mouth) generally followed the same pattern, but discharges at the mouth were more variable. Maximum daily-mean discharge at the mouth of the river occurred 1 day after the maximum upstream.

- Daily-mean discharges at the mouth of the Alafia River at times were negative or upstream. Negative discharges occurred during extended periods of low flow in the upstream reaches of the Alafia River and indicate that water may have been lost from the downstream reach of the river, possibly from seepage to the underlying aquifer.

- Daily-mean discharge from the Hillsborough River at the Tampa Dam (site H-8) was less than or equal to 0.5 ft^3/s from April 1 to May 22, 1991, and from September 23, 1991, to March 31, 1992, representing about 66 percent of the year. During these periods, discharge from Sulphur Springs was a major source of freshwater to the tidally affected reach of the river. About half of the total annual discharge from the dam during the study occurred in July 1992. Annual-mean discharge during the study was 47 percent less than the long-term average.

- Because of equipment malfunctions of the index velocity gage, discharge at the mouth of the Hillsborough River could not be determined. Daily-mean discharge at the mouth was estimated by summing daily-mean discharge at the upstream gage on the Hillsborough River and the discharge at Sulphur Springs.

Long-term water-quality characteristics at selected sites in the Alafia River, Hillsborough River, and the Tampa Bypass Canal were evaluated. This evaluation indicated the following:

- Phosphorus concentrations in the Alafia River have been affected by phosphate-mining practices in the basin. Orthophosphorus concentrations were greatest in the 1960's and have generally decreased since then. High orthophosphorus concentrations in the 1960's probably were caused by releases of water from mining operations. These releases may explain the increase in annual low flows that occurred during the same period. The general decrease in orthophosphorus concentration from the mid-1960's to 1992 coincides with decreases in annual-mean low flows in the river.

- In the Alafia River, concentrations of nitrogen have decreased since about 1981, and concentrations of selected major ions have generally decreased since the mid-1960's. The decrease in concentrations of dissolved silica, fluoride, chloride, sulfate, calcium, and sodium probably are due to changes in mining practices in the basin.

- In contrast to the Alafia River, nitrogen concentrations in the ground water of the Alafia River basin are increasing. Nitrate plus nitrite nitrogen concentrations in Lithia Springs have increased from 0.16 mg/L in 1946, to about 3 mg/L in 1992.

- Long-term water-quality characteristics of the Hillsborough River at the Tampa Dam could not be evaluated because data were not available.

- Specific conductance in water discharging from Sulphur Springs to the Hillsborough River has increased from 124 μS/cm in 1945 to more than 2,000 μS/cm in 1992.

Evaluation of water-quality characteristics at sites in the Alafia River, Hillsborough River, and the Tampa Bypass Canal during the study period was made. This evaluation indicated the following:

- Water-quality at the mouth of the Alafia River during most of the study was the result of a mixing of freshwater and estuarine water from Hillsborough Bay.

- High discharges in July 1991 resulted in freshwater conditions at the mouth of the Alafia River. During this period, the lowest measured specific conductance and concentration of chloride occurred and the highest measured concentrations of suspended solids, nitrogen, phosphorus, orthophosphorus, organic carbon, and silica occurred.

- Vertical stratification of specific conductance is a common feature in the tidally affected reach of the Alafia River. The difference between specific conductance near the surface and near the bottom ranged from about <10 to 35,000 μS/cm during sampling events.
- Large daily variations in water quality at the mouth of the Alafia River are caused by tidal currents. The magnitude of the daily variation, as indicated by variation in specific conductance and concentration of phosphorus, generally increases with increased freshwater discharge. Daily variations in nitrogen concentration, however, were unrelated to variations in freshwater discharge.
- Concentrations of phosphorus, nitrate plus nitrite nitrogen, organic carbon, and silica at the mouth of the Alafia River are inversely related to specific conductance. Except for concentrations of nitrate plus nitrite nitrogen, the relation is linear indicating a simple conservative mixing of freshwater and saltwater.
- Lithia Springs is a major source of nitrogen-rich water to the Alafia River.
- Total phosphorus concentrations in the Alafia River generally decrease from the upstream, freshwater reaches to the river mouth. Total nitrogen concentrations generally are about the same from upstream at river mile 16 to the mouth at river mile 0.
- Concentrations of phosphorus, orthophosphorus, ammonia nitrogen, organic nitrogen, and organic carbon are less in Sulphur Springs than in the Hillsborough River, whereas concentrations of nitrate plus nitrite nitrogen and silica are greater in the spring.
- Concentrations of nitrate plus nitrite nitrogen, organic carbon, and silica at the mouth of the Hillsborough River are inversely related to specific conductance.

Discharge and concentrations of nitrogen and phosphorus measured during the study were used to compute nutrient loads from the Alafia River, Hillsborough River, and the Tampa Bypass Canal. Daily, monthly, and annual loads were computed and evaluated. Analyses of loads indicated the following:

- Average daily phosphorus load for the study period was 1.8 ton/d at the upstream site on the Alafia River (site A-3) and was 2.4 ton/d at the river mouth (site A-6). Average daily nitrogen load was 1.2 ton/d at site A-3 and was 1.7 ton/d at site A-6.
- Because discharges at the mouth of the Alafia River were negative at times, daily phosphorus and nitrogen loads sometimes were negative.
- Average daily phosphorus load for the study period was 0.26 ton/d at the upstream site on the Hillsborough River (site H-8) and was 0.35 ton/d at the river mouth (site H-10). Average daily nitrogen load was 0.74 ton/d at site H-8 and was 0.86 ton/d at site H-10.
- Average daily phosphorus load was 0.06 ton/d at the Tampa Bypass Canal, and average daily nitrogen load was 0.26 ton/d.
- Maximum daily phosphorus and nitrogen loads at all study sites coincided with maximum discharge.
- Monthly phosphorus loads at the mouth of the Alafia River ranged from 23.4 to 259 tons and exceeded upstream loads except during June 1991. Monthly nitrogen loads at the mouth ranged from 14.3 to 197 tons and exceeded upstream loads.
- Monthly phosphorus loads at the mouth of the Hillsborough River ranged from 1.0 to 59.5 tons, and monthly nitrogen loads ranged from 1.2 to 173 tons.
- Monthly phosphorus loads at the Tampa Bypass Canal ranged from 0.28 to 3.9 tons, and monthly nitrogen loads ranged from 1.3 to 17.3 tons.
- The greatest annual loads of phosphorus and nitrogen to Hillsborough Bay were from the Alafia River, and the least loads were from the Tampa Bypass Canal.

Long-term annual nitrogen and phosphorus loads from the Alafia River and Hillsborough River have generally decreased because of the long-term decreases in annual-mean discharge. In the Alafia River, nitrogen and phosphorus concentrations have decreased as well, resulting in a change in the relation between load and discharge.

Evaluation of basin yields of nitrogen and phosphorus indicated the following:

- Basin yields of phosphorus in the Alafia River were about 2 (ton/mi^2)/yr, and were about 10 times greater in the Alafia River basin than in the Hillsborough River basin. Basin yields of nitrogen in the Alafia River were about 1.5 (ton/mi^2)/yr and were about 3 times greater in the Alafia River basin than in the Hillsborough River basin.
- Phosphorus and nitrogen yields from the tidally affected reaches of the Alafia River and Hillsborough River generally were much different than the yields from the upstream, nontidally affected reaches of the rivers. Phosphorus yield at the mouth of the Alafia River was 2.9 (ton/mi^2/yr), about 1.5 times greater than upstream yield and nitrogen yield at the mouth was 2.4 (ton/mi^2)/yr, about twice the upstream yield. Phosphorus yield at the mouth of the Hillsborough River was 0.9 (ton/mi^2)/day; more than 4 times greater than upstream yield. Nitrogen yield at the mouth of the Hillsborough River was about twice the upstream yield.
- The differences between yields at the mouth of the Alafia River and the Hillsborough River and the upstream gages are due to differences in land use in those parts of the basin.
- Comparison of basin and subbasin yields shows that loads that are estimated for an upgaged site by projecting loads at a gaged site can be in error, even if the gage represents a large part of the total basin.

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