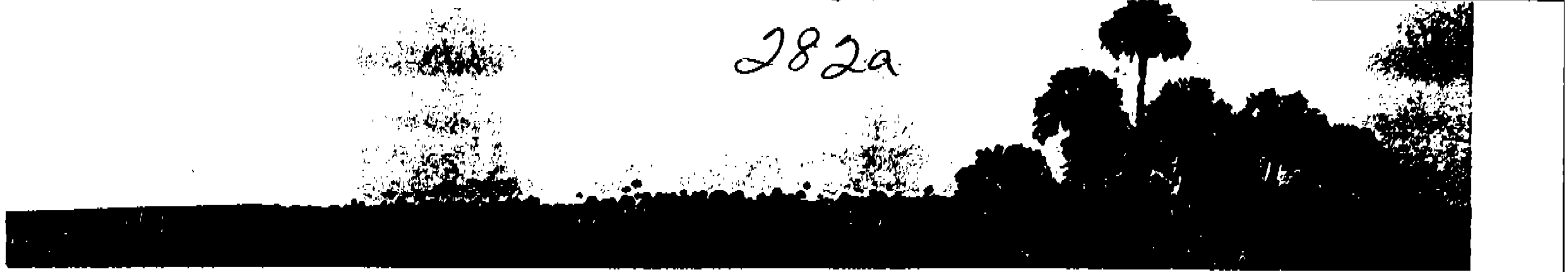


Water Quality in the Southern Everglades and Big Cypress Swamp in the Vicinity of the Tamiami Trail, 1996–97

By Ronald L. Miller, Benjamin F. McPherson, and Kim H. Haag

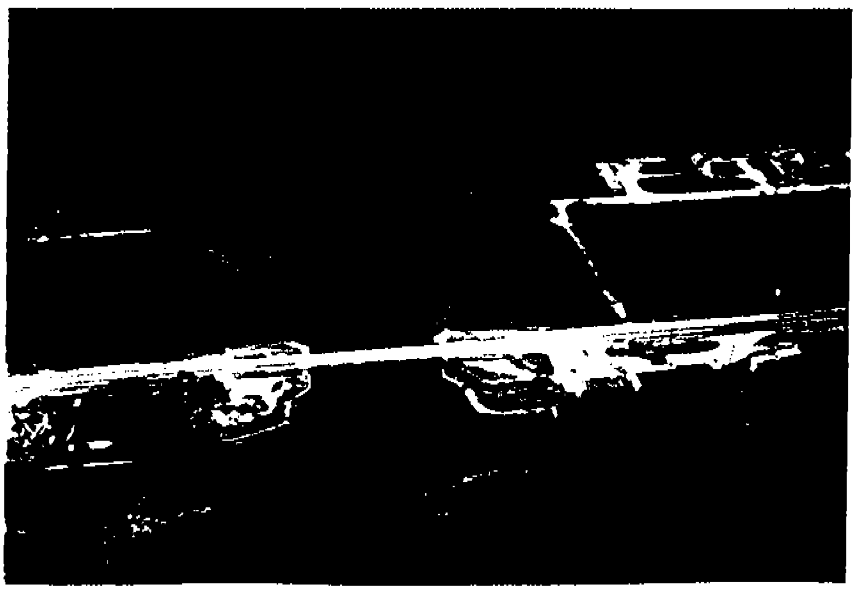
ABSTRACT

The quality of water flowing southward in the Everglades and the Big Cypress Swamp was characterized by three synoptic surveys along an 80-mile section of the Tamiami Trail and along a 24-mile transect down the Shark River Slough, by monthly sampling of a background reference site in the central Big Cypress Swamp, and by sampling of fish tissue for contaminants at several sites near the Trail. The quality of water along the Trail is spatially variable due to natural and human influences. Concentrations of dissolved solids and common ions such as chloride and sulfate were lowest in the central and eastern Big Cypress Swamp and were higher to the west due to the effects of seawater, especially during the dry season, and to the east due to canal drainage from the northern Everglades. Concentrations of total phosphorus tended to decrease from west to east along the 80-mile section of the Trail, and were usually about 0.01 milligram per liter or less in the Everglades. Short-term loads (based on average discharge for 4 days) of total phosphorus and total Kjeldahl nitrogen (ammonia plus organic nitrogen) across four gaged sections of the Tamiami Trail were highest in the Everglades near the S-12 structures primarily due to the relatively greater discharges in that section. Concentrations of dissolved solids and total phosphorus at the central Big Cypress Swamp site increased significantly during the dry season as waters ponded. Effects of nearby, upstream agricultural activities were evident at a site in the western Big Cypress Swamp where relatively high concentrations of total phosphorus, total mercury, and dissolved organic carbon and high periphyton biomass accumulation rates were measured and where several pesticides were detected. The most frequently detected pesticides along the Trail were atrazine (14 detections), tebuthiuron (11 detections), and metolachlor (5 detections), and most concentrations were less than 0.1 microgram per liter. DDT compounds were the only pesticides detected in fish from five sites. Total DDT ranged from 5 to 6 micrograms per kilogram in largemouth bass and from 11 to 17 micrograms per kilogram in Florida gar.

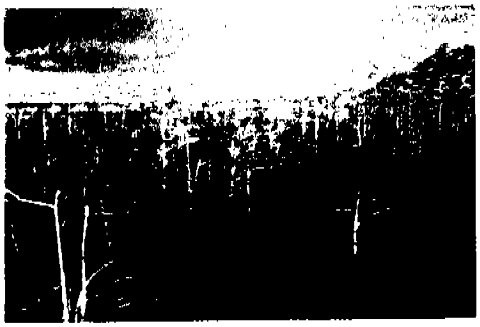
INTRODUCTION

The National Water-Quality Assessment (NAWQA) Program is designed to assess the status and trends in water quality over more than half of the Nation. This significant task is subdivided into about 59 study units to focus more attention on local settings and issues. The work within each study unit is intended to continue for decades as

Below: Southerly view of Tamiami Trail near S-12-B

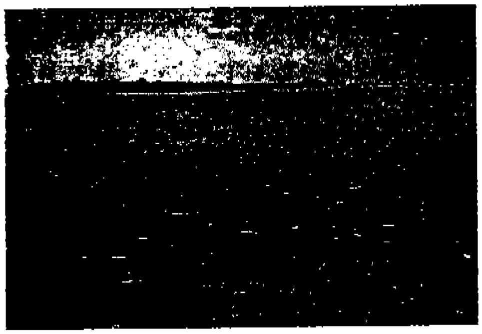


a series of repeated cycles of a few years of intensive sampling and interpretative studies followed by a few years of low-intensity sampling. Study units use fixed sites to gather data on a regular basis, but also use synoptic studies to gain insight into topics of special interest, such as transport of water and water-quality constituents, improvement of spatial resolution of water-quality data, and identification of sources of water-quality constituents (Gilliom and others, 1995). The Southern Florida (SOFL) NAWQA study began a 3-year period of intensive sampling in 1996 (Haag and others, 1998). This report summarizes a synoptic study of water quality near the southern end of the SOFL NAWQA study unit (fig. 1). The movement and quality of water in this area is of great interest because of its importance to State and National parks and preserves and to the ecosystem restoration underway in the region.



At left: Big Cypress Swamp near Loop Road

Below: Shark River Slough in the Everglades (The River of Grass) with tree islands



Surface waters near the southern end of the SOFL study unit are predominantly dispersed over broad wetlands in Everglades National Park (ENP), Big Cypress National Preserve (BCNP), and several other preserves and flow into coastal waters from the Ten Thousand Islands to Florida Bay (figs. 1 and 2). The Tamiami Trail (U.S. 41) spans these wetlands with numerous bridges and culverts and, as the last significant roadway that crosses the mainland before the coast, provides a location from which to sample, measure, and characterize water near the downstream end of the study unit (fig. 2).

Most of the Tamiami Trail between Naples and Miami is within two physiographic provinces—the Big Cypress Swamp and the Everglades (Davis, 1943). The Big Cypress Swamp is characterized by numerous cypress strands, cypress domes, and forested wetlands that grow on limestone with little soil cover (Duever and others, 1979). The Everglades is characterized by a wetland mosaic of tree islands, dense sawgrass, and wet prairies with peat soils and has periods and depths of inundation generally greater than those in the Big Cypress Swamp (Davis and others, 1994). The two physiographic provinces also differ in their land use. Much of the central and southern Big Cypress Swamp is relatively undisturbed by channelization and development. North of BCNP, the land is primarily used for farming and ranching. The Everglades has been more highly modified north of the Tamiami Trail, but is relatively undisturbed to the south.

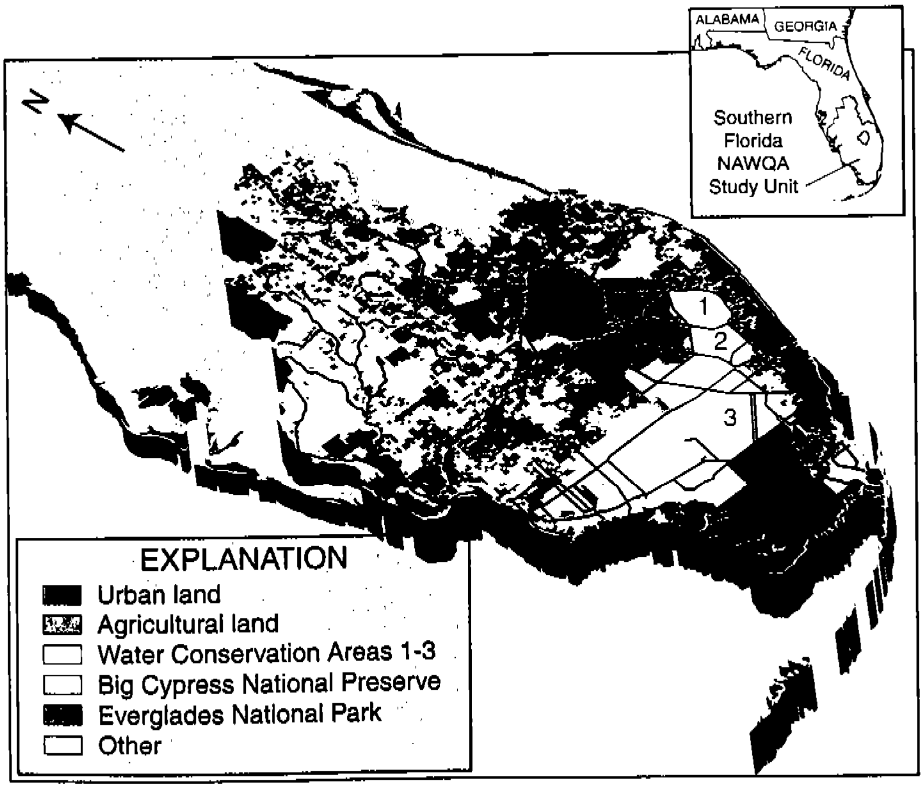


Figure 1. Selected land use and physical features in southern Florida.

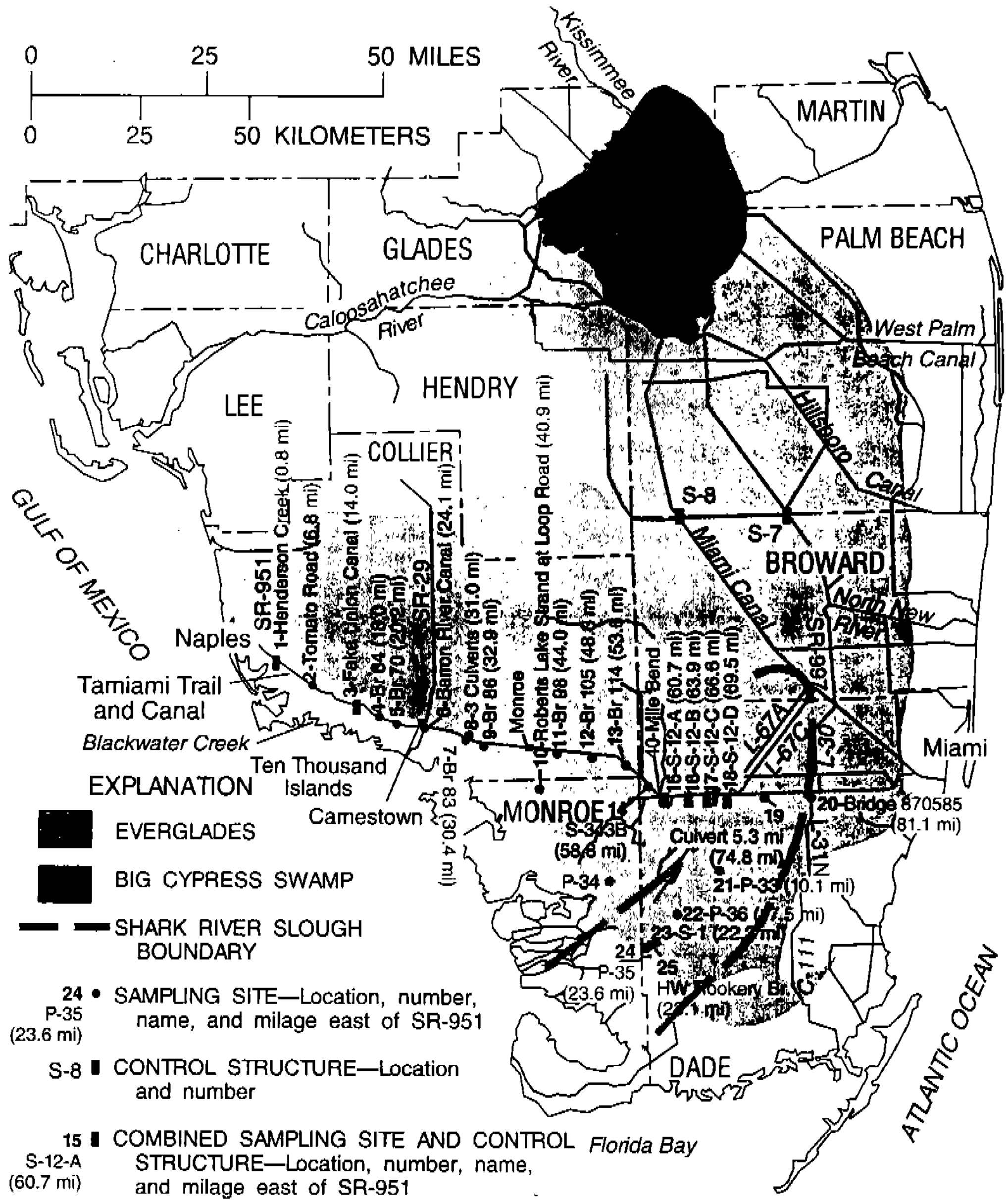


Figure 2. Sampling sites along and south of the Tamiami Trail (U.S. 41) between Naples and Miami.

Hydrologic Changes

Major modification of southern Florida's natural drainage system began in 1882 with the construction of small drainage canals in the Kissimmee and Caloosahatchee basins and gained momentum in 1905 when the Florida Legislature passed the first drainage law creating the Everglades Drainage District (Klein and others, 1975). In subsequent years, major modifications were made to the hydrologic system through construction of large canals and levees (earthen embankments), by establishment of water conservation areas (WCAs), and through land-use changes that continued throughout the century. Development and hydrologic modifications have been most intense in the northern Everglades (which has been drained for farming) and along the east coast (which has been urbanized). The central and southern Everglades and the Big Cypress Swamp have remained mostly wilderness, but the effects of drainage to the north were already affecting water levels and flows in some parts of the Everglades early in the century. Construction of the Tamiami Trail, which crosses the southern Everglades and Big Cypress Swamp and connects Miami with Naples, began in the 1920's and was completed in 1928 (Klein and others, 1975). The Tamiami Canal was dug on the north side of the Tamiami Trail during construction of the road and served as a source of limestone road base. Water from canals, rivers, and sheetflow from wetlands collects in the canal and flows southward under the Tamiami Trail through more than 100 culverts and bridges. The Tamiami Trail was widened in the 1950's and 1960's by adding limerock fill from nearby excavations to the old road bed; however, the number and length of the bridges was unaltered (Duever and others, 1979; p. 705-748). The western part of the Big Cypress Swamp was drained by the Barron River Canal (completed in 1926, fig. 2) and the Faka Union Canal System (competed in the 1970's, fig. 2). The central and southern Big Cypress Swamp has remained relatively undisturbed by drainage and development; however, much of the southern Everglades, though protected as wetlands in the ENP, has been affected by water management activities to the north (Klein and others, 1975).

Predevelopmental hydrology in south Florida is largely inferred from vegetation and soils and from historical documents. Actual measurements of water levels, water flows, and water quality only began around midcentury, after substantial hydrologic modifications had been made. Parker and others (1955) described hydrologic conditions in the southern Everglades during the 1940's and 50's. U.S. Geological Survey (USGS) records continued after that report and provide information on water levels and flows near the Tamiami Trail during the last half of the 20th century. These records include the southerly discharge of water between State Road (SR) 29 and SR 997 (Krome Avenue) through five east-west sections (fig. 2) of the Trail for which discharge through bridges, culverts, and water-control structures are continuously gaged.

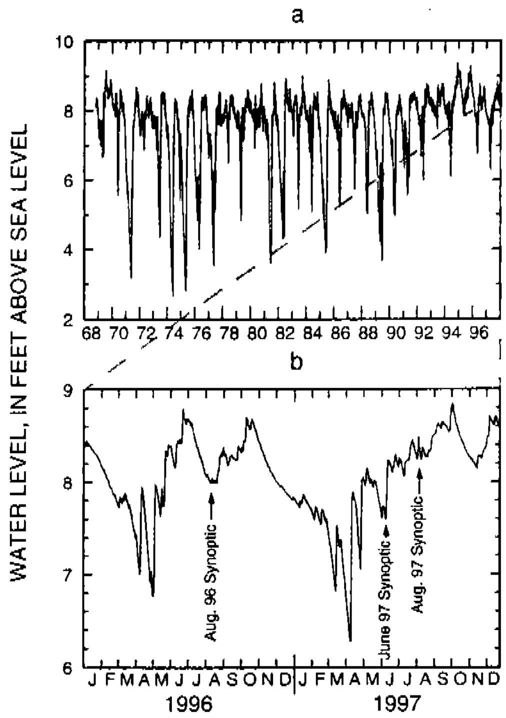


Figure 3. Water-level fluctuations at Bridge 105 on the Tamiami Trail in the Big Cypress Swamp, (a) 1968–97 and (b) 1996–97.

Annual water-level fluctuations at a central location along the Trail (Bridge 105 in the Big Cypress Swamp, fig. 3a) illustrate changes during the last 30 years in a region that has been least modified by drainage and land development. Reduced fluctuations and higher water levels occurred after about 1990 at this site. Similar changes are also evident at other locations in the southern Everglades.

Water-quality measurements across the Tamiami Trail have been unevenly distributed. Extensive monitoring has been done in recent years by the South Florida Water Management District (SFWMD) in the Everglades section of the Trail, but relatively few data have been collected in the Big Cypress Swamp section. However, between 1978 and 1993, the 40-Mile Bend to Monroe section (fig. 2) of the Trail was sampled as a USGS National Stream Quality Assessment Network (NASQAN) site. According to A. Clint Lietz (U.S. Geological Survey, oral commun., 1998), water-quality samples for the NASQAN program were composites of water from one to three bridges that had flow.

Changes in water quality have been extensive in some regions of south Florida; nutrients and pesticides are in higher concentrations in agricultural and urban lands of the northern Everglades than in remote areas of the Big Cypress Swamp and southern Everglades (McPherson and Halley, 1996). However, even some remote parts of the southern Everglades have undergone water-quality changes during the last 30 years, as shown by the significant increase in chloride concentrations at P-33 (fig. 4; shown as site 21 on fig. 2). No comparable change in the concentration of chloride is evident in the central Big Cypress Swamp at Bridge 105 (fig. 4; shown as site 12 on fig. 2) during the same period. The increase in chloride concentration at P-33 is attributable to the construction of the L-67A Canal (fig. 2) about 1962 and its extension in 1967. The L-67A Canal and its extension transport large amounts of dissolved chloride from developed lands in the northern Everglades into the southern Everglades (McPherson and others, 1976).

In recent years, a consensus has developed among governmental officials and environmentalists that undeveloped parts of the Everglades should be protected and restored. Restoration of the Everglades will require large-scale changes in surface-water flow patterns to recreate predevelopment hydrologic conditions. These changes will include the diversion of more water from the WCAs southward under the Tamiami Trail to restore historic drainage pathways, such as the Shark River Slough, and to approximate predevelopment hydropatterns. Both an understanding of historic and current water quality and a sustained monitoring program are required to ensure that water quality is suitable for successful restoration.

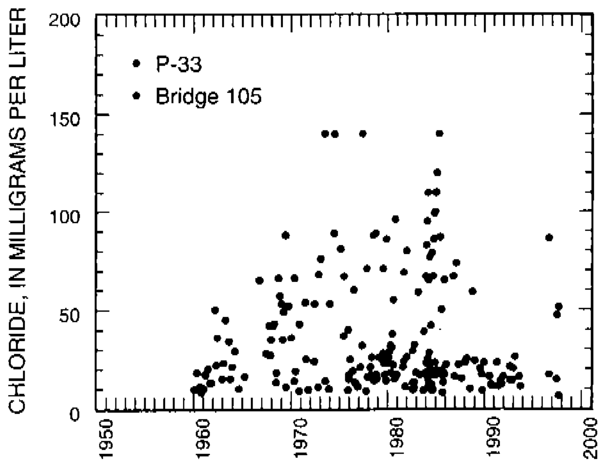


Figure 4. Long-term concentrations of chloride at P-33 in the Everglades and at Bridge 105 in the Big Cypress Swamp.

Purpose and Scope

Water-quality data have been collected extensively in some parts of the Everglades; however, broad-scale sampling across the southern end of the Florida Peninsula is less common (Haag and others, 1996). The purpose of this report is to provide a broad synoptic or "snap-shot" view of selected water-quality characteristics and short-term mass transport of nutrients at selected sites across the southern Everglades and Big Cypress Swamp near the southern end of the SOFL study unit. The synoptic view identifies high concentrations of and notable patterns in selected water-quality constituents that will be helpful in understanding regional variations in water quality and in selecting future sampling locations for monitoring or refining mass transport estimates.

Table 2. Synoptic sampling sites with estimated distances down the Shark River Slough transect starting at S-12-D

[Map numbers shown on fig. 2; mileages were computed from latitudes and longitudes]

Map number	Distance southwest of S-12-D, in miles	USGS station identification numbers	Short name	Physiographic province
21	10.1	02290815	P-33	Everglades
22	17.5	02290828	P-36	Everglades
23	22.3	252818080504200	S-1	Everglades
24	23.6	02290830	P-35	Everglades
25	23.1	252756080512900	Headwaters Rookery Branch	Everglades

This report presents water-quality data collected from 20 sites along an 80-mile section of the Tamiami Trail (table 1) between SR 951 in the west and SR 997 (Krome Avenue) in the east and from five sites along a 24-mile transect through the Shark River Slough (table 2) starting near S-12-D on the Trail and running southwesterly to the headwaters of Rookery Branch (fig. 2). Approximately 20 of the 115 bridges, culverts, and flood-control gates along the 80-mile section of the Trail (table 3) were sampled during three synoptic sampling periods (fig. 3b) that represent both high summer runoff (August 19–22, 1996, and August 11–14, 1997) and low late-spring runoff (June 2–5, 1997). Historical water-quality information in the vicinity of the Trail is also included to show time trends or make comparisons.

Table 1. Synoptic sampling sites with estimated distance along the Tamiami Trail transect starting at State Road 951

[Map numbers shown on fig. 2; mileages are approximations from odometer readings along the Tamiami Trail; SR, State Road; Br, bridge; L, lake]

Map number	Estimated distance east of SR 951, in miles	USGS station identification number	Short name	Physiographic province
1	0.8	260326081412200	Henderson Creek	Big Cypress Swamp
2	6.8	260020081363300	Tomato Road	Big Cypress Swamp
3	14.0	255734081303400	Faka Union	Big Cypress Swamp
4	18.0	255615081273600	Br 64	Big Cypress Swamp
5	20.2	255531081252000	Br 70	Big Cypress Swamp
6	24.1	255511081213000	Barron River	Big Cypress Swamp
7	30.4	255327081161300	Turner River (Br 83)	Big Cypress Swamp
8	31.0	255401081154100	Turner R. Rd. 3 Culverts	Big Cypress Swamp
9	32.9	02290975	Br 86	Big Cypress Swamp
10	40.9	254714081055700	Roberts L. Strand at Loop Rd.	Big Cypress Swamp
11	44.0	255133081033400	Gannet Strand (Br98)	Big Cypress Swamp
12	48.3	02288798	Br 105	Big Cypress Swamp
13	53.6	254957080541600	Br 114	Big Cypress Swamp
14	58.8	254716080511900	Culvert below S-343B	Big Cypress Swamp
15	60.7	254543080491100	S-12-A	Everglades
16	63.9	02289018	S-12-B	Everglades
17	66.6	02289041	S-12-C	Everglades
18	69.5	254543080405400	S-12-D	Everglades
19	74.8	254539080354800	Culvert 5.3 mile east of S-12-D	Everglades
20	81.1	254540080295500	Br 870585	Everglades

METHODS

Sampling sites were categorized as either primary or secondary sites. Primary sites were sampled for more constituents than secondary sites and required more time for sample processing in the field. At most primary sites, water samples were collected by the equal-width-increment or multiple-vertical method in which sample water is collected continuously (depth integrated) from the water surface to near the bottom at several places (verticals) across a canal (Shelton, 1994). If aquatic plants were abundant, verticals were made in the deepest areas that were clear of plants. All bottles and equipment that were used to collect and process samples were rinsed at least three times with native water prior to sample collection. At the primary sites, sample water from all verticals was passed through a cone splitter according to NAWQA

Table 3. Historical mean annual discharges and numbers of water-conveyance features within sections of the Tamiami Trail
[$ft^3 s^{-1}$, cubic feet per second; SR, State Road]

Station identification number	Discharge sections	Flow under Tamiami Trail is through	Annual mean discharge, ($ft^3 s^{-1}$)[1]	Averaging period, water years
Not applicable	Carnestown to SR 951	41 bridges and culverts[1]	Ungaged, most are tidally influenced	Not applicable
02288800	Monroe to Carnestown	19 bridges and 1 culvert[2]	393[3]	1960–1996
02288900	40-Mile Bend to Monroe	29 bridges[3]	361[3]	1964–1996
02289040	Levee 67A to 40-Mile Bend	4 flood control structures (S-12A, B, C, and D)[3]	805[3]	1964–1996
02289060	Levee 30 to Levee 67A	19 culverts and S-12–E[2]	157[3]	1964–1996
02290767	Bridge 870585	Flow under Trail is at Bridge 870585. Discharge is measured at Levee 31 North Extension at 1 mile.	243[3] (median)	1992–1996
	Sum for all six reaches	115 water-conveyance features under the Tamiami Trail between SR 951 and Krome Avenue (SR 997)		

[1]Richard Semple, DOT, Tampa, Fla., written comm., 1998; [2]Ernesto Mangual, USGS, Miami, Fla., written comm., 1998; [3]Price and others, 1997.

parts-per-billion protocols (Shelton, 1994) to ensure that each sample bottle received a representative mix of water (Capel and others, 1995; Capel and Larson, 1996). At secondary sites, water was collected at a single point approximately 6 inches below the water surface. In June and August 1997, extra water was collected at secondary sites and filtered for dissolved nutrient and anion determinations. All water samples for mercury were collected at a single point. All water samples were shipped to the laboratories on ice, with the exception of mercury which was preserved with hydrochloric acid and shipped at ambient temperatures. After each use, equipment that contacted sample water was cleaned with laboratory detergent, rinsed with deionized water and then methanol, and stored in closed containers to prevent contamination of the next sample.

Water samples from primary sites were analyzed for nutrients, major ions, pesticides, dissolved organic carbon (DOC), and UV absorbance at 254 nanometers (nm). Most samples from secondary sites were analyzed for sulfate, chloride, nutrients (only total phosphorus, TP, and total Kjeldahl nitrogen, TKN, were determined in August 1996), DOC, and UV absorbance at 254 nm. Nutrient concentrations are all reported as the elements nitrogen (N) and phosphorus (P). Water samples for total mercury were collected in August 1996 and June 1997 at selected sites. Field determinations of dissolved oxygen (DO), specific conductance, temperature, and pH were made at most sites close to the time of sample collection. For quality assurance, eight organic or inorganic field blanks of high-quality blank water (11 percent of environmental samples) and seven replicates (9 percent of environmental samples) were collected during the synoptic sampling trips, and additional field blanks were collected at some other sampling sites near the time of the synoptic sampling.

Biomass (ash-free dry mass, AFDM) and chlorophyll–*a* (an indicator of the algal component of the periphyton) accumulation rates were determined for periphyton from glass slides deployed near the Tamiami Trail in June and August 1997. Periphyton samplers were floated just below the water surface starting the week that water samples were collected for the synoptic surveys. The slides were collected 2 to 3 weeks later and processed for laboratory analysis. The rate of periphyton growth can be computed from accumulated mass, surface area, and the length of time that slides are exposed to water.

The USGS National Water-Quality Laboratory in Arvada, Colorado, analyzed the samples with a few exceptions. Sulfate and chloride samples collected at secondary sites in August 1996 were analyzed at the USGS Quality Water Service Unit in Ocala, Florida. The DOC and UV absorbance at 254 nm were determined by Dr. George Aiken, USGS, Boulder, Colorado, and total mercury in water was determined by Dr. David Krabbenhoft, USGS, Middleton, Wisconsin.

Water-Quality Characteristics Along the Tamiami Trail and the Shark River Slough

Total Dissolved Solids, Specific Conductance, and Major Ions

Chloride, sulfate, other major ions, DOC, and silica contribute to total dissolved solids (TDS). Specific conductance is a measure of the electrical conductivity of dissolved ions in water and, when multiplied by 0.65, provides a rough and inexpensive estimate of the TDS. Sources of TDS that contribute to specific conductance include agricultural and urban drainage, seawater, dissolution of rocks and soils, and wastes from wildlife.

Specific conductance varied widely along the 80-mile section of the Tamiami Trail, depending on location, season, upstream land use, and proximity to the coast (fig. 5a-c). Specific conductance values were generally higher along the western Big Cypress Swamp (approximately miles 0–30) and the Everglades (approximately miles 66–81) sections of the Trail than in the central section (miles 30–66). Higher values in the west, where the Trail is within a few miles of the coast, are attributed to effects of seawater, particularly during dry periods when marine waters extend farthest inland. Higher specific conductance values in the Everglades (miles 66–81) are attributed to canal transport of mineralized water from the northern Everglades. The sources of the mineralized water include Lake Okeechobee; the Everglades Agricultural Area south of Lake Okeechobee; and naturally occurring, shallow, mineralized water beneath the northern Everglades (Parker and others, 1955, p. 764). Water from the northern Everglades flows under the Trail through culverts and the S-12 water-control structures into ENP and then south and southwest down the Shark River Slough toward the coast. Specific conductance values in the Shark River Slough tended to decline slightly downstream of the S-12 structures (fig. 5d-f).

Specific conductance values vary seasonally at locations that are relatively unaffected by canal drainage or coastal waters. This seasonal variation is illustrated for a 22-month period at Bridge 105 in the central Big Cypress Swamp by comparing specific conductance and selected ion concentrations with discharge (figs. 6a-f). Specific conductance increased from a minimum of 207 microsiemens per centimeter at 25 degrees Celsius ($\mu S\ cm^{-1}$) on October 8, 1996, near the end of the rainy season when the daily mean discharge was 1,230 cubic feet per second ($ft^3\ s^{-1}$) to a maximum of 535 $\mu S\ cm^{-1}$ on March 25, 1997, near the end of the dry season when discharge was only 30 $ft^3\ s^{-1}$. Approximately 91 percent of the increase in specific conductance between these two sampling times was due to increases in concentrations of calcium and bicarbonate (shown as alkalinity) ions. Magnesium (not shown), sodium, and chloride

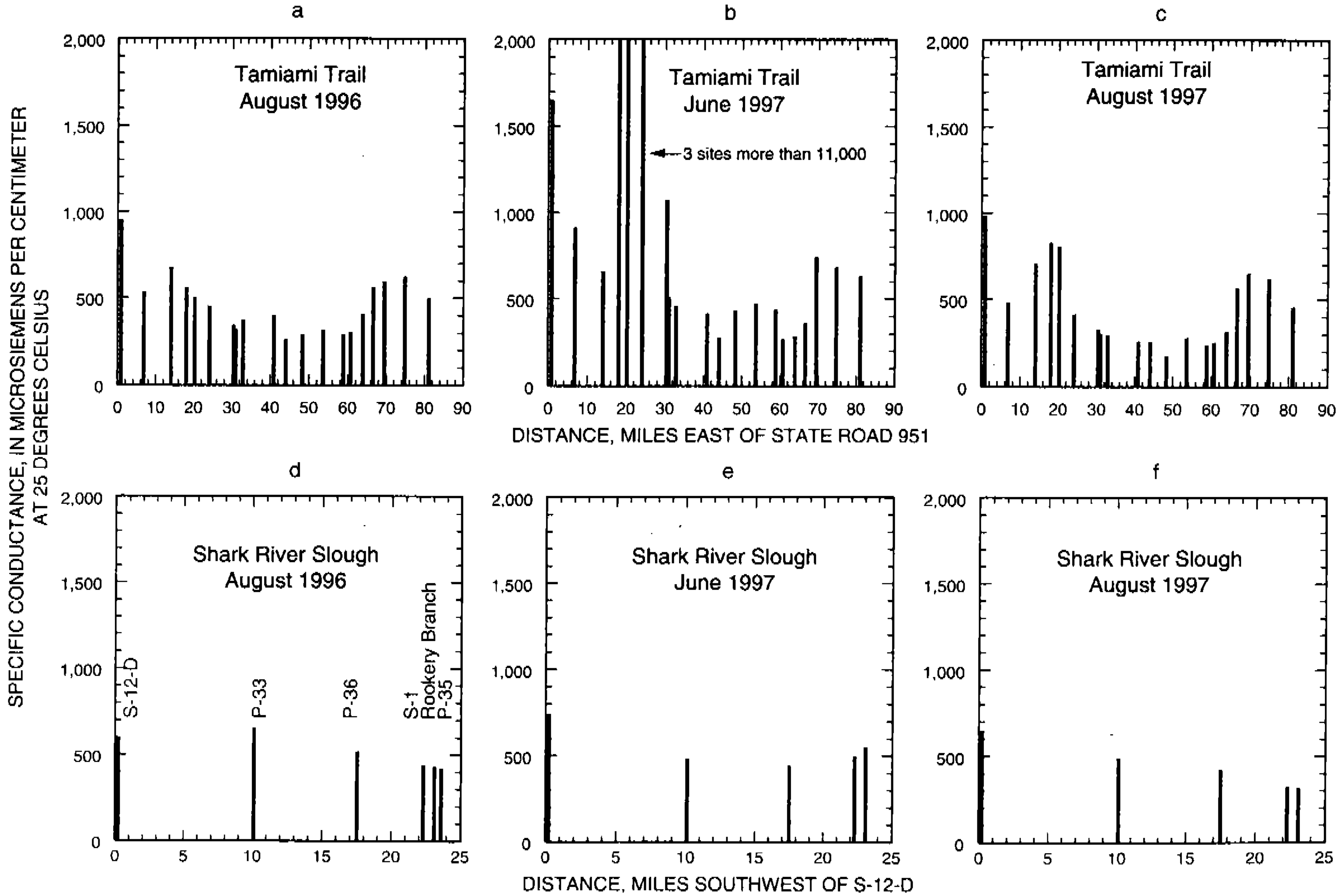


Figure 5. Specific conductance along the Tamiami Trail and down the Shark River Slough, August 1996 and June and August 1997.

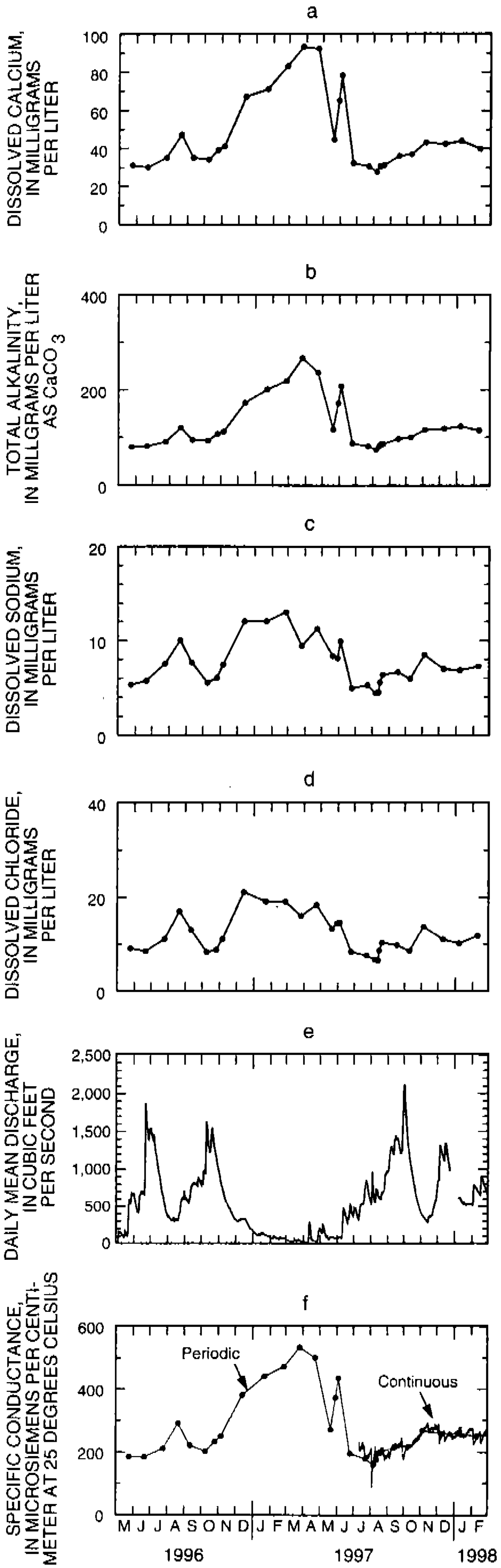


Figure 6. Concentrations of calcium, alkalinity, sodium, and chloride; discharge; and specific conductance at Bridge 105 in the Big Cypress Swamp from May 1996 to February 1998.

ions were responsible for approximately 9 percent of the increase in specific conductance, whereas potassium, sulfate, and fluoride ions had only a minor effect on specific conductance. The percentage increases in calcium (174 percent), and bicarbonate (189 percent) ion concentrations were greater than for the sodium (71 percent), potassium (33 percent), and chloride (95 percent) ions. Processes that could contribute to increased TDS and specific conductance in surface waters during the dry season are evapotranspiration, increased density of animal populations in and around dwindling surface waters, and relatively greater ground-water contributions to the remaining surface waters (as surface water flows and rainfall decline). If evaporation of ponded surface water were the only process occurring during the dry season, the concentration of ions such as sodium, chloride, calcium, and bicarbonate would all increase by similar percentages. The relatively greater increase in calcium and bicarbonate ion concentrations at Bridge 105 cannot be explained by evaporation alone. Increased ground-water inflow from the limestone surficial aquifer, relative to surface-water inflow and rainfall, is likely the cause of much of the relatively greater increase in the calcium and bicarbonate ions, compared with the increases in the sodium, chloride, and magnesium ions.

The plot of chloride concentration along the Tamiami Trail is U-shaped (fig. 7a) with the highest concentrations occurring near the west and east ends of the study area. Concentrations in the central section of the Tamiami Trail (approximately miles 30–66) were typically about 10 to 30 milligrams per liter (mg L^{-1}) and increased to 40 mg L^{-1} or more in the western Big Cypress Swamp and the Everglades from about S-12-C and eastward (miles 66–81). The highest concentrations were in western Big Cypress Swamp in June 1997, when seawater moved inland from the nearby coast during the low runoff period. The higher concentrations of chloride in the Everglades east of S-12-C, compared with concentrations in the central section, are due to the canal transport of mineralized water from the northern Everglades (Parker and others, 1955).

Like chloride, the plot of sulfate concentration across the Tamiami Trail is U-shaped (fig. 7b). The higher concentrations in the western Big Cypress Swamp are due to the effects of seawater, and the higher concentrations in the Everglades are due to the effects of mineralized water from the north. In the central section of the Tamiami Trail (approximately miles 30–66), most sulfate concentrations were quite low (30 out of 31 concentrations were from less than 0.1 to 2.0 mg L^{-1}) during the three synoptic sampling periods and during monthly sampling at Bridge 105 between May 1996 and January 1998 (25 out of 27 concentrations were less than 0.8 mg L^{-1}). These low background concentrations make sulfate ion a sensitive indicator of human impacts on water quality in the central Big Cypress Swamp.

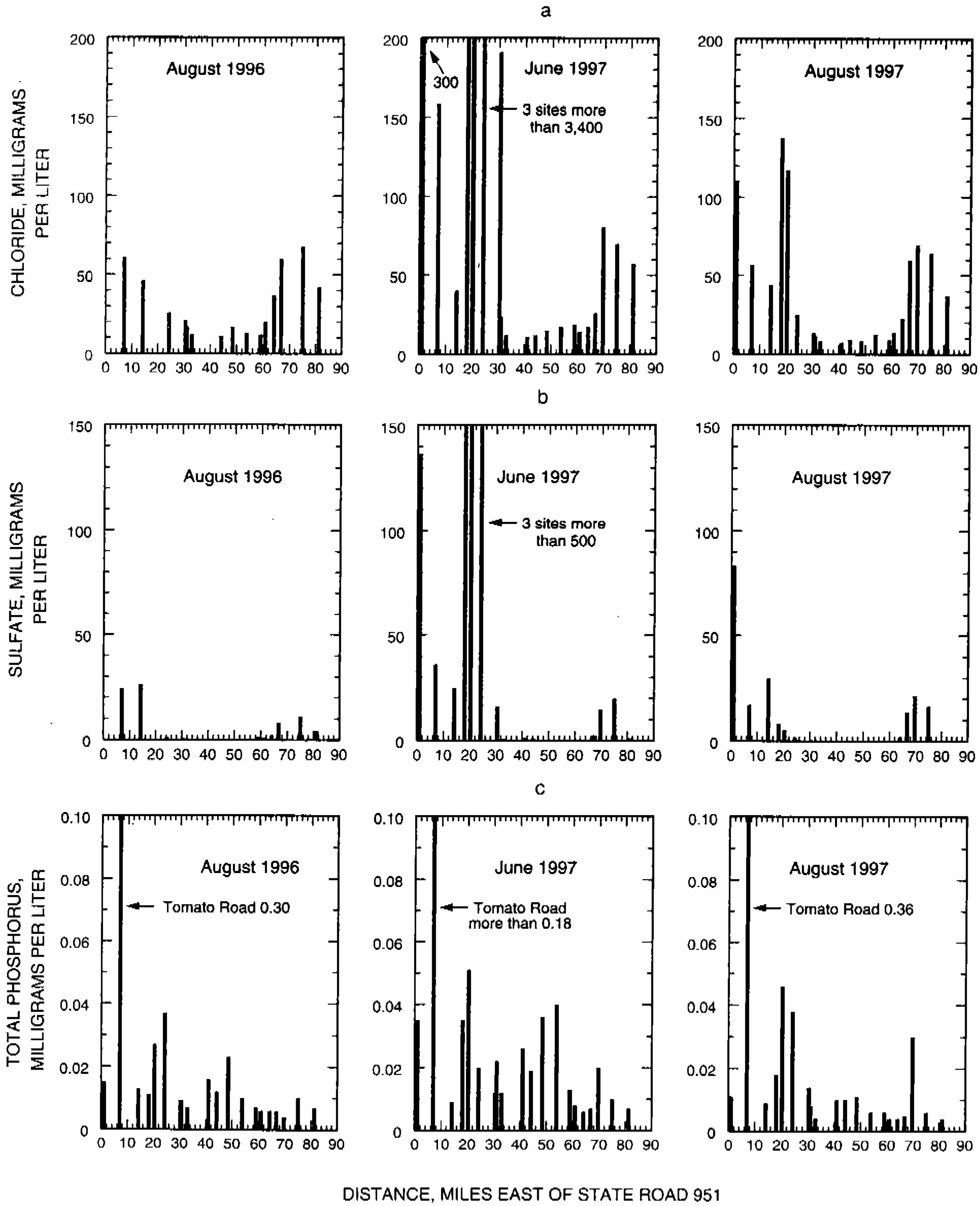


Figure 7. Concentrations of chloride, sulfate, and total phosphorus along the Tamiami Trail in August 1996 and June and August 1997.

Nutrient Concentrations and Periphyton Growth

Phosphorus and nitrogen are the most common nutrients that limit the growth of aquatic plants. Phosphorus is usually growth-limiting in freshwater and even small increases in concentrations and loadings can have significant ecological impacts. Phosphorus generally occurs at quite low concentrations (less than 0.01 mg L^{-1}) in unimpacted wetlands of southern Florida and at higher concentrations (median concentrations of 0.060 mg L^{-1} at S-7 and 0.067 mg L^{-1} at S-8 for 1984–93, data from SFWMD) in parts of the northern Everglades. The high concentrations in the northern parts of the Everglades have been implicated in changes in wetland communities, such as the shift from sawgrass to cattails and the change from calcareous periphyton mats of cyanobacteria and diatoms to periphyton dominated by filamentous green algae (McCormick and O'Dell, 1996).

Unlike chloride and sulfate, the plot of TP concentration along the Tamiami Trail was not U-shaped, but generally decreased from west to east (fig. 7c). The highest concentrations (0.30, greater than 0.18, and 0.36 mg L^{-1}) during our three sampling events were at the Tomato Road site (mile 6.8) and were probably caused by agricultural activities just north and upgradient of the site. Water from these agricultural lands may also contribute to the high phosphorus concentrations in Blackwater Creek (0.016 to 0.095 mg L^{-1}; Joseph Boyer, written commun., Florida International University, 1998) a few miles downstream of Tomato Road and in the Ten Thousand Islands (Florida International University, 1998). East of Tomato Road, concentrations of TP tended to decrease across the Big Cypress Swamp from about 0.05 to 0.01 mg L^{-1} (fig. 7c). During the synoptic sampling, concentrations of TP along the Everglades section of the Tamiami Trail (miles 60–81) and at sites in Shark River Slough were generally less than 0.01 mg L^{-1}, except for higher concentrations at S-12-D (mile 69.5 in August 1997; 0.030 mg L^{-1}) and at the headwaters of Rookery Branch (0.027 mg L^{-1}; fig. 2, site 25) in the Shark River Slough. Concentrations of TP less than 0.01 mg L^{-1} are consistent with long-term (1984–93) patterns in phosphorus concentrations for these areas (fig. 8, data from SFWMD).

At Bridge 105 in the central Big Cypress Swamp, concentrations of TP ranged from 0.005 to 0.086 mg L^{-1} over a 22-month period from May 1996 to February 1998 (fig. 9a). Highest concentrations were associated with low discharge and low water levels. TP concentrations had a pattern quite similar to that of specific conductance (fig. 6f); whereas, concentrations of total nitrogen (TN; fig. 9b) had no apparent relation with seasonal changes in discharge. TP increased 760 percent from a minimum of 0.01 mg L^{-1} on October 8, 1996, near the end of the rainy season when the daily mean discharge was 1,230 ft^3 s^{-1}, to a maximum of 0.086 mg L^{-1} on March 25, 1997, near the end of the dry season when discharge was only 30 ft^3 s^{-1}. As a basis of comparison, dissolved nitrogen, total Kjeldahl nitrogen (TKN is total organic nitrogen plus ammonia), ammonia, and orthophosphate increased by 225, 29, 17, and more than 700 percent, respectively, whereas dissolved Kjeldahl nitrogen and nitrate decreased by 33 and 21 percent, respectively, between the same sampling dates.

Biomass and growth rate of periphyton (biological communities living on submerged surfaces such as rocks and aquatic plants) can serve as indicators of the availability of nutrients and of the potential of water to support plant growth. A number of studies in the Everglades have addressed the

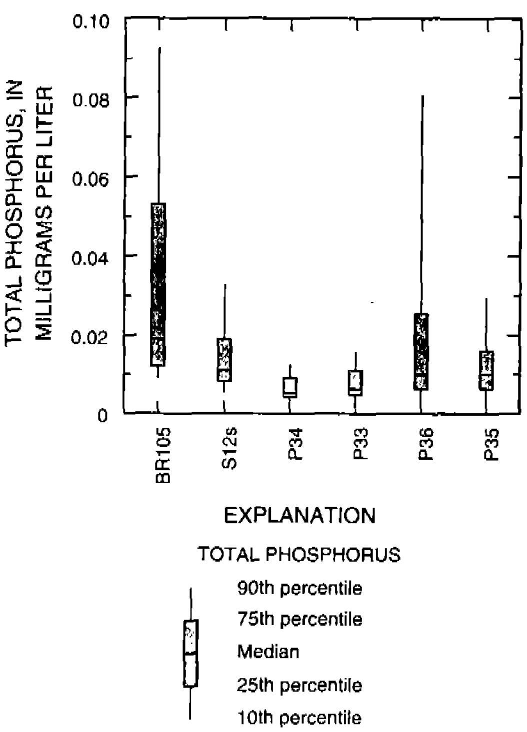


Figure 8. Median and percentiles of concentrations of total phosphorus at Bridge 105, the S-12 Structures, and Shark River Slough sites, 1984–93. (S12s means S-12-A, S-12-B, S-12-C, and S-12-D combined.)

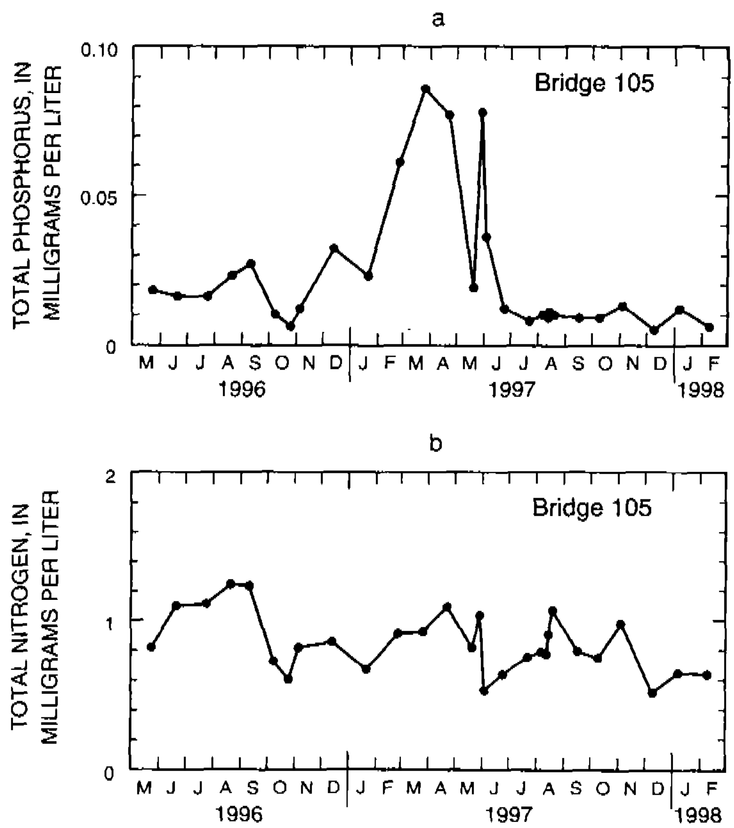


Figure 9. Monthly concentrations of total phosphorus and total nitrogen at Bridge 105 in the Big Cypress Swamp, 1996–98.

influence of water-column phosphorus on the biomass and growth rate of periphyton communities. Generally, periphyton biomass and growth rates in the Everglades are significantly changed by nutrient enrichment (Swift, 1981; Swift and Nicholas, 1987; Hall and Rice, 1990; Browder and others, 1994; McCormick and O'Dell, 1996). Other studies have focused on the influence of phosphorus enrichment on periphyton community composition (Scheidt and others, 1987; McCormick and O'Dell, 1996; McCormick and others, 1999). Changes in community composition of periphyton have important implications for the Everglades food web.

We evaluated periphyton growth (as accumulation of AFDM and of chlorophyll-*a*) along the Tamiami Trail using artificial substrates that allow sample collection in a standardized way and facilitate comparisons between water bodies. Periphyton biomass accumulated at sites along the Trail at rates of 0.09 to 0.9 grams per square meter per day (g m^{-2} d^{-1}) as AFDM and 0.05 to 1.0 milligrams per square meter per day (mg m^{-2} d^{-1}) as chlorophyll-*a* with no obvious spatial patterns, although the highest rate for AFDM was at the Tomato Road site (fig. 10a) just downgradient of agricultural land. The absence of obvious spatial patterns of chlorophyll-*a* and AFDM accumulation rates may be due to the limited number of samples collected and the inherent variability of the methods. Chlorophyll-*a* accumulation rates measured during this study in June and August 1997 were comparable with rates reported by Swift and Nichols (1987; 0.04 to 0.07 mg m^{-2} d^{-1} as chlorophyll-*a* for June through August was computed from data in fig. 3) at a low-nutrient (average TP of 0.011 mg L^{-1}) marsh site in the northern Everglades.

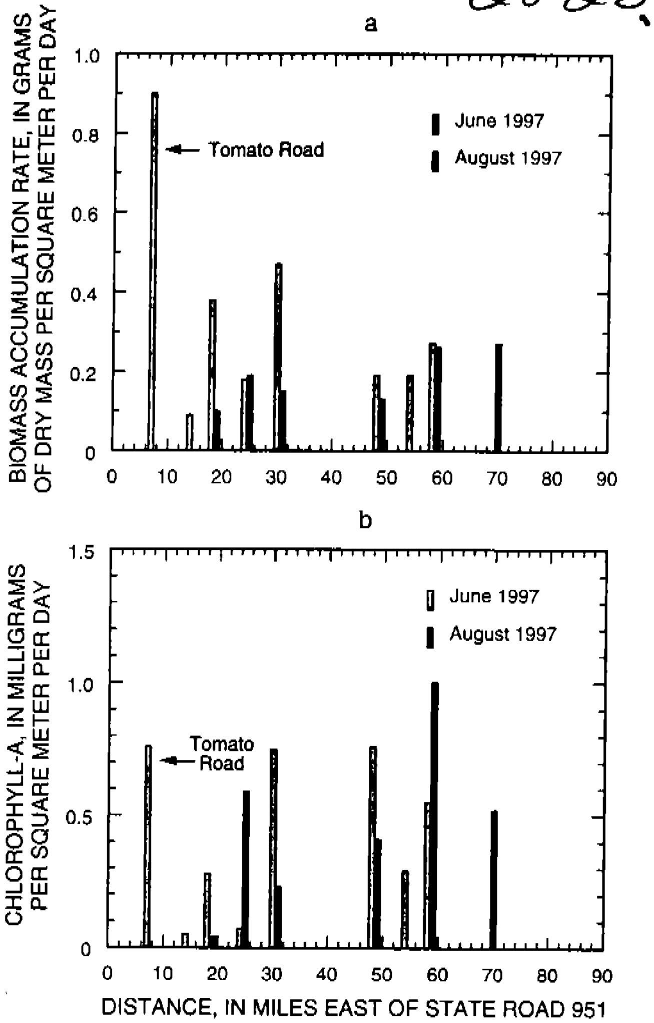


Figure 10. Biomass (as ash-free dry mass, AFDM) and chlorophyll-*a* accumulation rates across the Tamiami Trail, June and August 1997.

Phosphorus and Nitrogen Loads

Nutrient loads are measures of "new" nutrient matter moving into an ecosystem from a source such as a stream or the atmosphere. Increased annual nutrient loading can change an ecosystem from oligotrophic to eutrophic. Nutrient loads in surface water are computed by multiplying the concentration of a nutrient by the discharge of water (the volume of water flowing past a cross section of the stream or other water course per unit of time). Usually, the product of the concentration and discharge of water must be multiplied by a conversion factor to make the concentration and flow units compatible and to produce a number that is neither too large nor too small to use conveniently. Long-term (annual or multi-annual) nutrient loads average seasonal variations and are more representative of the inputs to an ecosystem than are daily loads. Daily loads, such as those given below, can provide insight into seasonal variations and the relative magnitude of various nutrient sources.

We computed daily loads of TP and TKN for each of the three synoptic sampling periods. Loads were determined for each of the five gaged sections (see table 3) of the Trail from the mean daily discharge for the 4-day sampling period and the average concentration of selected nutrients within each section. Loads for TKN are reasonable estimates of loads of TN along the Trail because TN is composed predominantly of TKN. TKN concentrations for 59 samples averaged 98 percent and ranged from 82 to 100 percent of the TN concentrations during this study.

Across the gaged sections of the Trail, daily loads of TP and TKN were usually highest in the Everglades section through the S-12 structures (fig. 11a and b, miles 60.7–69.5). This was due more to the large flows from the northern Everglades than to high concentrations at the S-12 structures. The maximum daily loads for TP (57 kilograms (kg)) and TKN (6,300 kg) occurred at the S-12 structures during the rainy season in August 1997. A relatively high daily TP load (35 kg) also occurred in the Monroe to Carnestown section during August 1997.

Dissolved Organic Carbon and Ultraviolet Absorbance

DOC can originate from natural sources such as living plants and decaying plant matter or from human sources. DOC is of ecological significance because it can (1) contribute to water color which absorbs light in the photosynthetically active wavelength region and thus reduce the amount of light available for the growth of submerged aquatic plants, (2) serve as a source of carbon for bacterial growth, and (3) form complexes with trace elements (such as mercury) and make them more soluble and mobile in water. DOC concentrations near the Tamiami Trail ranged from 4.8 to 26.9 mg L^{-1} and had a U-shaped plot (fig. 12a) similar to chloride and sulfate ions. Lowest concentrations of DOC occurred in the central section of the Tamiami Trail (approximately miles 30–60), and highest concentrations were at bridges 64 and 70 (miles 18.0 and 20.2) in the west and between S-12-B and culverts 5.3 miles east of S-12-D (miles 63.9–74.8) in the east.

Aromatic (containing conjugated double bonds like those in benzene) DOC compounds that contain carboxylic acid, hydroxyl, and amino functional groups (parts of a molecule) form complexes with trace elements (Stumm and Morgan, 1981, p. 375). One of the simplest and most inexpensive means of comparing the relative abundance of aromatic carbon in DOC is to measure the ultraviolet absorbance at 254 nanometers (UV_{254}) and compute the ratio UV_{254}/DOC (specific ultraviolet absorbance) as an indicator of the relative abundance. A higher ratio indicates a greater potential for complexing and transporting trace elements.

The UV_{254}/DOC ratio ranged from 0.017 to 0.060 along the Tamiami Trail during the three synoptic sampling periods, and tended to decrease from west to east (fig. 12b). The highest ratios (indicative of a relatively high fraction of aromatic carbons in DOC) occurred at bridges 64 and 70 (miles 18.0-20.2) during low flow in June 1997. These bridges are within 5 miles of the Gulf of Mexico and were affected by marine water during this low-flow period, as evident from specific conductance values greater than 11,000 µS cm^{-1} and by the presence of marine organisms such as blue crabs *(Callinectes sapidus)*. Thus, coastal marshes or mangrove forests may be the source of the high ratios.

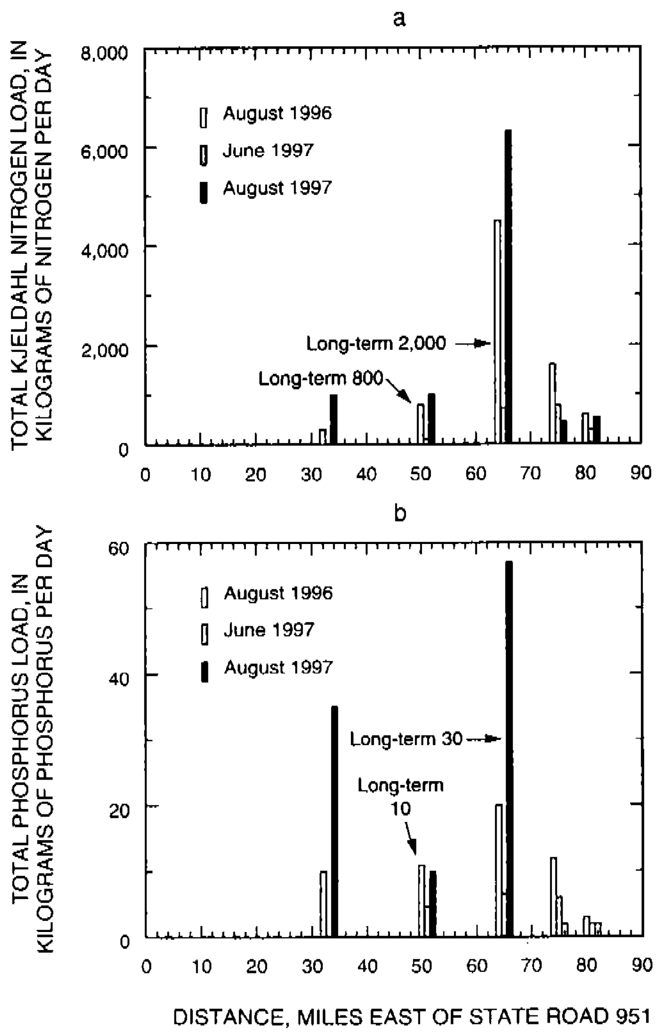


Figure 11. Short-term loads of total phosphorus and total Kjeldahl nitrogen (ammonia plus organic nitrogen) along sections of the Tamiami Trail, August 1996 and June and August 1997 with long-term loads for two of the sections (from Haag and others, 1996).

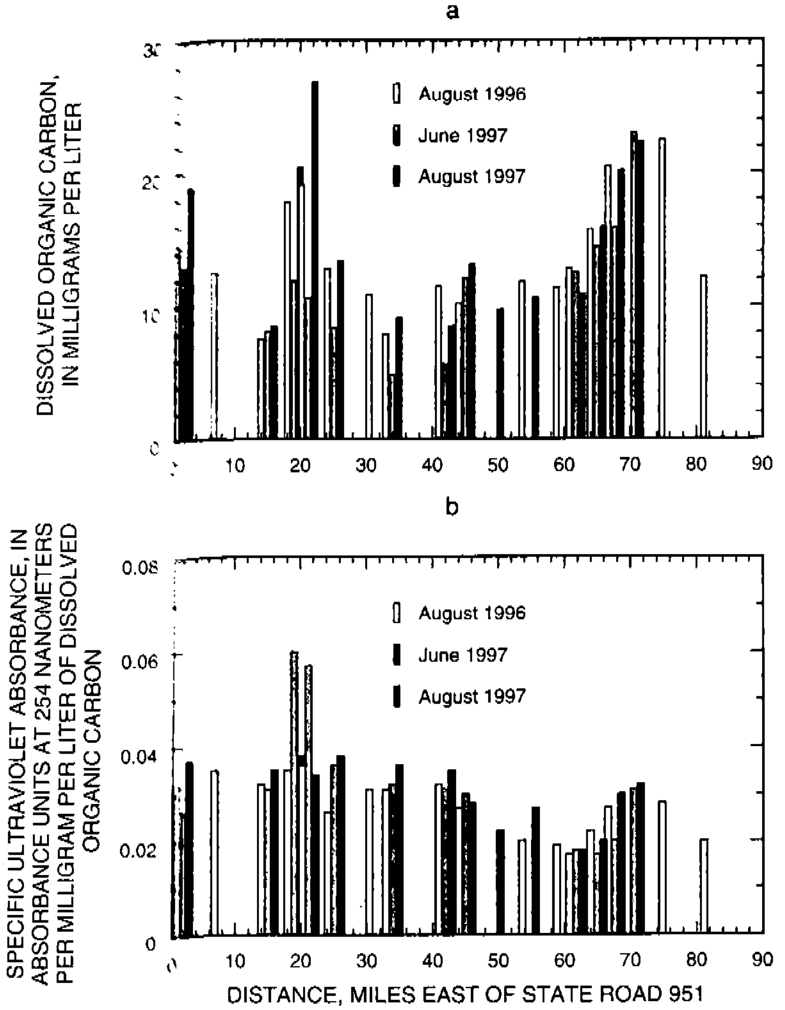


Figure 12. Dissolved organic carbon and specific ultraviolet absorbance (ratio of ultraviolet absorbance at 254 nanometers to the concentration of dissolved organic carbon) along the Tamiami Trail, August 1996 and June and August 1997. (Analyses were done by Dr. George Aiken, USGS, Boulder, Colorado.)

Mercury

The Florida Department of Health and Rehabilitative Services (1993) issued a health advisory recommending that, because of high mercury concentrations, fish consumption be restricted in some parts of Florida and completely avoided in other areas, such as the Everglades. The high concentrations of mercury in the biota are related to processes in the water and sediment that favor methylation of mercury and concentration of mercury in the Everglades food chain. USGS researchers and others are currently studying the sources and cycling of mercury and the relation of these processes to the high concentrations reported in fish and other wildlife.

We collected water samples for total mercury analysis at eight and seven sites along the Tamiami Trail in August 1996 and June 1997, respectively. The highest value for total mercury (8.3 ng L^{-1}) occurred at Tomato Road (mile 6.8) in June 1997. All other values were between 1.4 and 3.7 ng L^{-1} (fig. 13). Our data are consistent with those of others sampling for mercury in waters of the northern Everglades (David Krabbenhoft, U.S. Geological Survey, oral commun., 1996). There was no obvious relation between mercury concentrations and DOC and UV_{254} along the Trail based on plots of 13 data pairs (not shown).

Concentrations of mercury in fish provide a better time-integrated sample than concentrations in water. Largemouth bass and Florida gar collected by a NAWQA team at four sites near the Tamiami Trail in August–December 1995 (Haag and McPherson, 1997) were analyzed for mercury in fish livers (composites of 5 to 10 livers). Largemouth bass had mercury concentrations of 25 micrograms per gram (µg g^{-1}) at P-33 and 26 µg g^{-1} at L-67A Canal. Florida gar had concentrations of 110 µg g^{-1} at Bridge 105 and 160 µg g^{-1} at Loop Road.

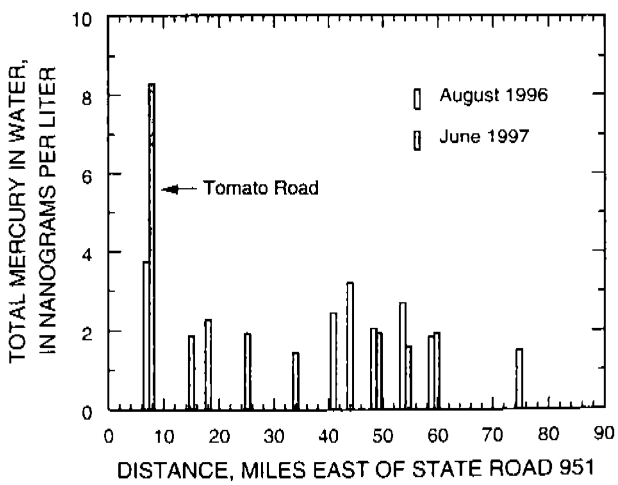


Figure 13. Concentrations of total mercury in water along the Tamiami Trail, August 1996 and June 1997. (Analyses were done by Dr. David Krabbenhoft, USGS, Middleton, Wisconsin.)

Pesticides

Pesticides are applied in agricultural and urban areas and are also sprayed directly into canals to kill nuisance aquatic weeds or onto weeds and shrubs along the roadsides and canal banks. Because pesticides can be transported long distances in air (Majewski and Capel, 1995), they are sometimes detected in areas remote from the point of application.

Water samples were collected at selected sites during the three synoptic sampling periods and analyzed for more than 100 different pesticides. Pesticide concentrations above the minimum reporting level (detections) are listed in table 4 along with criteria recommended for protection of aquatic life (National Academy of Sciences and National Academy of Engineering, 1972; NAWQA NST, 1998). All of the compounds detected were herbicides or a herbicide degradation product (deethylatrazine) except for single detections of the insecticides or nematicides malathion, diazinon, and azinphos-methyl. Atrazine was the most frequently detected pesticide (14 detections), followed by tebuthiuron (11 detections) and metolachlor (5 detections). One or more pesticides were detected at all sites except Bridge 114, and the greatest number of detections were at S-12-D and Tomato Road. In all but five samples, concentrations of pesticides were less than 0.1 µg L^{-1}. A few concentrations exceeded the aquatic life criteria: metolachlor at Tomato Road and S-12-D, malathion at P-33, and azinphos-methyl at Bridge 105 (table 4).

Table 4. Concentrations of pesticides detected in water along the Tamiami Trail and Shark River Slough transects, August 1996 and June and August 1997

[E behind the value means the number is an estimate. Estimated values below the usual reporting level are given for samples in which the compound's presence was verified from spectra. Values above the reporting levels are estimated if there are interferences, values below the lowest standard, or extraction recoveries less than normal. For other pesticides detected only once during the synoptics, the superscripts represent: d, diazinon; m, malathion; n, napropamide; p, propanil; t, triclopyr; z, azinphos-methyl . *Canadian criteria/NAS-NAE recommendations for protection of aquatic life (see text for references).]

Synoptic site and date	Deethyl-atrazine, µg L^{-1}	Atrazine, µg L^{-1}	Tebuthiuron µg L^{-1}	Simazine, µg L^{-1}	Metolachlor, µg L^{-1}	Metribuzin sencor, µg L^{-1}	2,4-D, µg L^{-1}	Other pesticides detected once, µg L^{-1}
Aquatic-Life Criteria *	none/none	2/none	1.6/none	10/10	8/0.005	1/none	4/3	
Tomato Road at gage								
Aug. 1996		0.008	0.14		0.010	0.017		0.004E^{d}, 0.0063^{n}
June 1997			0.02		0.011			
Aug. 1997			0.01		0.023	0.007	0.50E	1.2E^{t}
Faka Union Canal								
June 1997		0.002E						
Bridge 70								
June 1997							0.34	
Barron River								
Aug. 1996		0.004						0.0056^{p}
June 1997		0.003E		0.003E			0.15	
Bridge 105								
Aug. 1996		0.005						
June 1997		0.003E						
Aug. 1997								0.042E^{z}
S-343B at Trail								
Aug. 1996	0.001E	0.004	0.01E					
June 1997		0.004						
S-12D								
Aug. 1996	0.004E	0.036	0.03					
June 1997	0.013E	0.40	0.03	0.022	0.037			
Aug. 1997	0.006E	0.065	0.04E		0.032			
ENP P-33								
Aug. 1996	0.006	0.038	0.02					0.015^{m}
June 1997			0.01					
Aug. 1997	0.005E	0.019	0.03E					
ENP Rookery Branch								
June 1997		0.002E	0.01					
Reporting level	<0.002	<0.001	<0.01	<0.005	<0.002	<0.004	<0.035	

Fish and bottom sediment provide time-integrated samples of pesticide occurrence. Fish and bed-sediment samples were collected during an earlier phase of our study at a number of sites in southern Florida (Haag and others, 1998). In the vicinity of the Tamiami Trail, the fish included largemouth bass and Florida gar collected at the Barron River, Loop Road, Bridge 105, S-12 structures (S-12-A through S-12-D), and in the L-67A Canal in August-December 1995. Composite fish samples (5-10 fish of a species at each site) were analyzed for 25 organochlorine pesticides (Haag and McPherson, 1997). DDT compounds were the only pesticides detected in fish at these five sites near the Trail. Total DDT ranged from 5 to 6 $\mu g\ kg^{-1}$ in largemouth bass and from 11 to 17 $\mu g\ kg^{-1}$ in Florida gar. These DDT concentrations were lower than the concentrations found in largemouth bass and gar samples from six sites in the northern Everglades, where total DDT ranged from about 220 to 1,200 $\mu g\ kg^{-1}$ (Haag and McPherson, 1997). A single bottom sediment sample collected at Bridge 105 in August 1996 contained 41 $\mu g\ kg^{-1}$ of total DDT; concentrations at five other southern Florida sites ranged from 0.7 to 310 $\mu g\ kg^{-1}$ of total DDT.

Conclusions

The quality of surface water flowing southward in the Everglades and Big Cypress Swamp in the vicinity of an 80-mile section of the Tamiami Trail is spatially variable due to natural and human influences. Concentrations of chloride, sulfate, specific conductance, and DOC tended to be relatively low in the undeveloped center of the Tamiami Trail from the Turner River (mile 30.4) to about S-12-C (mile 66.6) and relatively high at the more developed west and east ends, especially during the dry season. These water-quality characteristics suggest that three distinct subsections should be considered as the minimum number required to describe and monitor water quality along the 80-mile study section. Relatively high concentrations of these constituents occurred to the west of the Turner River due to agricultural and marine inputs and to the east of S-12-C due to the inflow of mineralized water from the northern Everglades through a network of canals. Twelve pesticides or pesticide degradation products were detected across the Tamiami Trail, with highest concentrations usually at Tomato Road in the west or S-12-D in the east where agricultural influences were greatest. Total phosphorus tended to decrease from west to east along the Tamiami Trail.

Seasonal variations in water quality are superimposed on spatial variations in the study area. Concentrations of many dissolved constituents and total phosphorus increased during the dry season due to processes such as the inland movement of seawater near the western coast, evapotranspiration, ground-water inflow, or the higher density of wildlife in and around the Tamiami Canal.

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Hydrologic data and other information related to the Southern Florida NAWQA Program can be obtained from:

Project Chief
Southern Florida NAWQA Study
U.S. Geological Survey
4710 Eisenhower Blvd., Suite B5
Tampa, FL 33634

The National Water-Quality Assessment (NAWQA) Program

In 1991, the U.S. Geological Survey began the NAWQA Program to describe the status of and trends in the quality of a large representative part of the Nation's surface- and ground-water resources and to identify the natural and human factors that affect the quality of these resources. The NAWQA Program is designed to produce water-quality information that is useful to policymakers and managers at Federal, State, and local levels. The 60 proposed study units represent 60 to 70 percent of the Nation's water use and population served by public water supplies. The Southern Florida study was begun in 1994.