Analysis of Water-Quality Trends at Two Discharge Stations — One within the Big Cypress National Preserve and One near Biscayne Bay — Southern Florida, 1966-94

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 00-4099

Prepared as part of the
U.S. GEOLOGICAL SURVEY PLACE-BASED
STUDIES PROGRAM

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2000

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Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C = (°F - 32)/1.8

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.

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Abstract

An analysis of water-quality trends was made at two U.S. Geological Survey daily discharge stations in southern Florida. The ESTREND computer program was the principal tool used for the determination of water-quality trends at the Miami Canal station west of Biscayne Bay in Miami and the Tamiami Canal station along U.S. Highway 41 in the Big Cypress National Preserve in Collier County. Variability in water quality caused by both seasonality and streamflow was compensated for by applying the nonparametric Seasonal Kendall trend test to unadjusted concentrations or flow-adjusted concentrations (residuals) determined from linear regression analysis.

Concentrations of selected major inorganic constituents and physical characteristics; pH and dissolved oxygen; suspended sediment; nitrogen, phosphorus, and carbon species; trace metals; and bacteriological and biological characteristics were determined at the Miami and Tamiami Canal stations. Median and maximum concentrations of selected constituents were compared to the Florida Class III freshwater standards for recreation, propagation, and maintenance of a healthy, well-balanced population of fish and wildlife. The median concentrations of the water-quality constituents and characteristics generally were higher at the Miami Canal station than at the Tamiami Canal station. The maximum value for specific conductance at the Miami Canal station exceeded the State standard. The median and maximum concentrations for ammonia at the Miami and Tamiami Canal stations exceeded the State standard, whereas median dissolved-oxygen concentrations at both stations were below the State standard.

Trend results were indicative of either improvement or deterioration in water quality with time. Improvement in water quality at the Miami Canal station was reflected by downward trends in suspended sediment (1987-94), turbidity, (1970-78), total ammonia (1971-94), total phosphorus (1987-94), barium (1978-94), iron (1969-94), and fecal coliform (1976-94). Deterioration in water quality at the same station was indicated by upward trends in specific conductance (1966-94), dissolved solids (1966-94, 1976-94, and 1987-94), chloride (1966-94), potassium (1966-94), magnesium (1966-94), sodium (1966-94), sulfate (1966-94), silica (1966-94), suspended sediment (1974-94), total organic carbon (1970-81), and fecal streptococcus (1987-94). The downward trend in pH (1966-94) was indicative of deterioration in water quality at the Miami Canal station.

Improvement in water quality at the Tamiami Canal station was reflected by downward trends in fluoride (1967-93), total ammonia (1970-92), total nitrite plus nitrate (1975-85), and barium (1978-93). Deterioration in water quality at the same station was statistically significant by

upward trends in specific conductance (1967-93), dissolved solids (1967-93), chloride (1967-93), sodium (1967-93), potassium (1967-93), magnesium (1967-93), strontium (1967-93), and suspended sediment (1976-93). The downward trend in dissolved oxygen (1970-93) was indicative of deterioration in water quality.

INTRODUCTION

Because of development and the disruption of natural drainage, the ecosystem of southern Florida has experienced a variety of environmental problems such as loss of soil, nutrient enrichment, contamination by pesticides, mercury buildup in the biota, fragmentation of landscape, loss of wetlands, widespread invasion by exotic species, increased algal blooms in coastal waters, seagrass die-off, and declines in fishing resources (McPherson and Halley, 1996, p. 2). The tremendous population growth from 1.3 million people in 1960 to 3.3 million people in 1990 (South Florida Regional Planning Council, 1995, p. 11) and increased agricultural and urban water use in recent decades have increased the demand for water in southern Florida. This increased demand, together with changes in the hydrologic system, have caused a decrease in water supply and deterioration in water quality (McPherson and Halley, 1996, p. 2).

In southern Florida, water-quality trends may be directly influenced by urban and agricultural activities. Natural phenomena, such as physical and geochemical rock weathering, may result in increasing concentrations of some constituents over time. The implementation of best agricultural management practices or land-use changes in agricultural areas may result in concentrations of some chemical compounds decreasing over time. Additionally, the control of point and nonpoint source contamination in both urban and agricultural areas may also result in downward trends for specific constituents. Many substances found in atmospheric deposition, both wet and dry, can adversely affect water quality with time. Conversely, improvement in the control of toxic substances emitted in atmospheric discharges may result in temporal improvements in water quality.

A consensus was recently reached by governmental agencies and environmental groups for the need to restore the southern Florida and Everglades ecosystems to patterns similar to those of its predevelopment state. In 1996, the U.S. Geological Survey (USGS) conducted a study, as part of the South Florida Place-Based Studies (PBS) Program, to analyze long-term water-quality trends in southern Florida areas critical to ecosystem protection and restoration. The USGS South Florida PBS Program was established for the purpose of providing physical and biological science data and information on which to base ecosystem restoration management decisions impacting the mainland of southern Florida, Florida Bay, and the Florida Keys and reef ecosystems.

Purpose and Scope

The purpose of this report is to describe long-term water-quality trends in selected ecosystem areas of southern Florida. Summary statistics and temporal trends of selected water-quality constituents were determined at two USGS daily discharge stations – one located within the Big Cypress National Preserve and the other located just west of Biscayne Bay along the southeastern coast of Florida. Comparisons between trends and median concentrations for selected constituents are also made based on the difference in land-use characteristics of the two stations. The period of record for constituents is 1966-94 (except for three nitrogen and phosphorus species, which were collected through 1996), with most of the data having been collected under the auspices of the National Stream Quality Accounting Network (NASQAN) program. The objective of the NASQAN program is to determine the quality of the Nation’s streams on a temporal and spatial basis by routinely analyzing chemical constituents in the waters.

Descriptive statistics, including the minimum, maximum, mean, 25th, 50th (median), and 75th percentiles, are presented as well as temporal trends of major inorganic constituents and other related physical characteristics; nitrogen, phosphorus, and carbon species; trace metals; and bacteriological and biological characteristics. The ESTREND computer program was used to determine water-quality trends; it provides for the removal of extraneous variation in water-quality data caused by seasonality and discharge. The effects of seasonality and discharge on water quality and the criteria for selecting censored and uncensored data are addressed in this report. The specific statistical test used to compensate for seasonal variability in water-quality data is the Seasonal Kendall trend test. This nonparametric, distribution-free test compares relative ranks of data values rather than their specific magnitudes. The Seasonal Kendall Slope Estimator is the median slope of all pairwise comparisons from all seasons, and is presented in this report as changes per year, both in original units (depending on the constituent) as well as in percent. Locally Weighted Scatterplot Smoothing (LOWESS) plots are used to delineate local nonlinear variations in water-quality data over time where statistically significant trends exist.

Previous Studies

Previous studies involving water-quality trend analysis are numerous. Smith and others (1982) studied trends in total phosphorus measurements from NASQAN stations. Baldys and others (1995) determined summary statistics and trend analysis on water-quality data in New Mexico and Arizona. Sources of trends in water-quality data for streams in Texas were documented by Schertz and others (1994). Smith and others (1987) analyzed and interpreted water-quality trends in major U.S. rivers from 1974 to 1981. Trends in stream water-quality data in Arkansas between 1975 and 1989 were determined by Peterson (1992). Trends in surface-water quality in Connecticut from 1968 to 1988 were determined by Trench (1996), and associations between water-quality trends in New Jersey streams and basin characteristics from 1975 to 1986 were determined by Robinson and others (1996). Miller and others (1999) documented water-quality trends for selected constituents in the southern Everglades and Big Cypress Swamp.

DESCRIPTION OF STUDY AREA

Southern Florida occupies an area of about 10,000 mi^2 (square miles) and contains a complex hydrologic system of canals, control structures, pumping stations, and land-use areas (fig. 1). The eastern part of southern Florida, including Biscayne National Park and parts of Everglades National Park, represents a highly managed and controlled streamflow system that provides adequate flood protection during the wet season (May-October), water storage and ground-water replenishment during the dry season (November-April), and retardation of saltwater intrusion. The western part of southern Florida is more representative of natural flow, especially through the Big Cypress National Preserve and adjacent parts of Everglades National Park (fig. 1). The Big Cypress National Preserve lies west of the water-conservation areas (fig. 1) and encompasses parts of Collier and Monroe Counties. Most of the preserve consists of swamps, ponds, and sloughs where flow moves slowly southward and southwestward through these broad strands and sloughs.

The climate of southern Florida ranges from tropical to subtropical marine in the west and east coasts to tropical maritime in the Florida Keys; the climate is characterized by long, warm summers with abundant rainfall and mild, dry winters. The average monthly rainfall during the wet season is 6.24 in. (inches) and 1.97 in. during the dry season, and the average annual rainfall ranges from about 40 to 65 in. (South Florida Regional Planning Council, 1995, p. 23). Rainfall comes mostly from local showers, which usually are of short duration and high intensity, and is more abundant along the east coast and in the Florida Keys than on the west coast.

The five distinct physiographic provinces of southern Florida (fig. 2) are the Atlantic Coastal Ridge, Sandy Flatlands, Everglades, Big Cypress Swamp, and the mangrove and coastal glades (Klein and others, 1975, p. 2). The Atlantic Coastal Ridge is densely populated, with an average width of 5 mi and elevations that range from 8 to 24 ft (feet) above sea level (Klein and others, 1975, p. 7). The Sandy Flatlands lie between the Atlantic Coastal Ridge and the Everglades on the east coast (where elevations range from 6 to 20 ft above sea level) and north of the Big Cypress Swamp on the west coast (where elevations range from 5 to 40 ft above sea level). The Everglades extends from Lake Okeechobee southward to the mangrove and coastal glades, with much of the area developed in Miami-Dade and Broward Counties. Vast regions of the Everglades are inundated seasonally during natural conditions, with elevations that range from 14 ft above sea level near Lake Okeechobee to sea level at Florida Bay. Big Cypress Swamp is characterized by flat, poorly drained marshes and tree islands, with elevations usually less than 15 ft above sea level. The mangroves and coastal glades consist of tidal streams, bays, lagoons, and small islands that lie along the gulf coast of Florida.

The two daily discharge stations selected for this study are:

Station 02288600 Miami Canal at N.W. 36th Street, Miami, Fla., and

Station 02288900 Tamiami Canal Outlets, 40-Mile Bend to Monroe, Fla.

Station 02288600 is located in Miami upstream from salinity-control structure S-26 and about 5 mi upstream of Biscayne Bay. Station 02288900 is located on U.S. Highway 41 in the Big Cypress National Preserve in Collier County, 54 mi west of Miami. For identifications purposes only, station 02288600 will be referred to as the Miami Canal station in this report, and station 02288900 will be referred to as the Tamiami Canal station. The station locations are shown in figure 1.

Miami Canal System

The Miami Canal traverses 81 mi through agricultural, water-conservation, and urban areas from Lake Okeechobee southeastward to Biscayne Bay (fig. 1). Flow in Miami Canal is highly regulated with many pump stations, levees, and control structures situated throughout the canal reach. Flow at the northern end of the canal is commonly reversed (into Lake Okeechobee) as a result of pumpage from agricultural

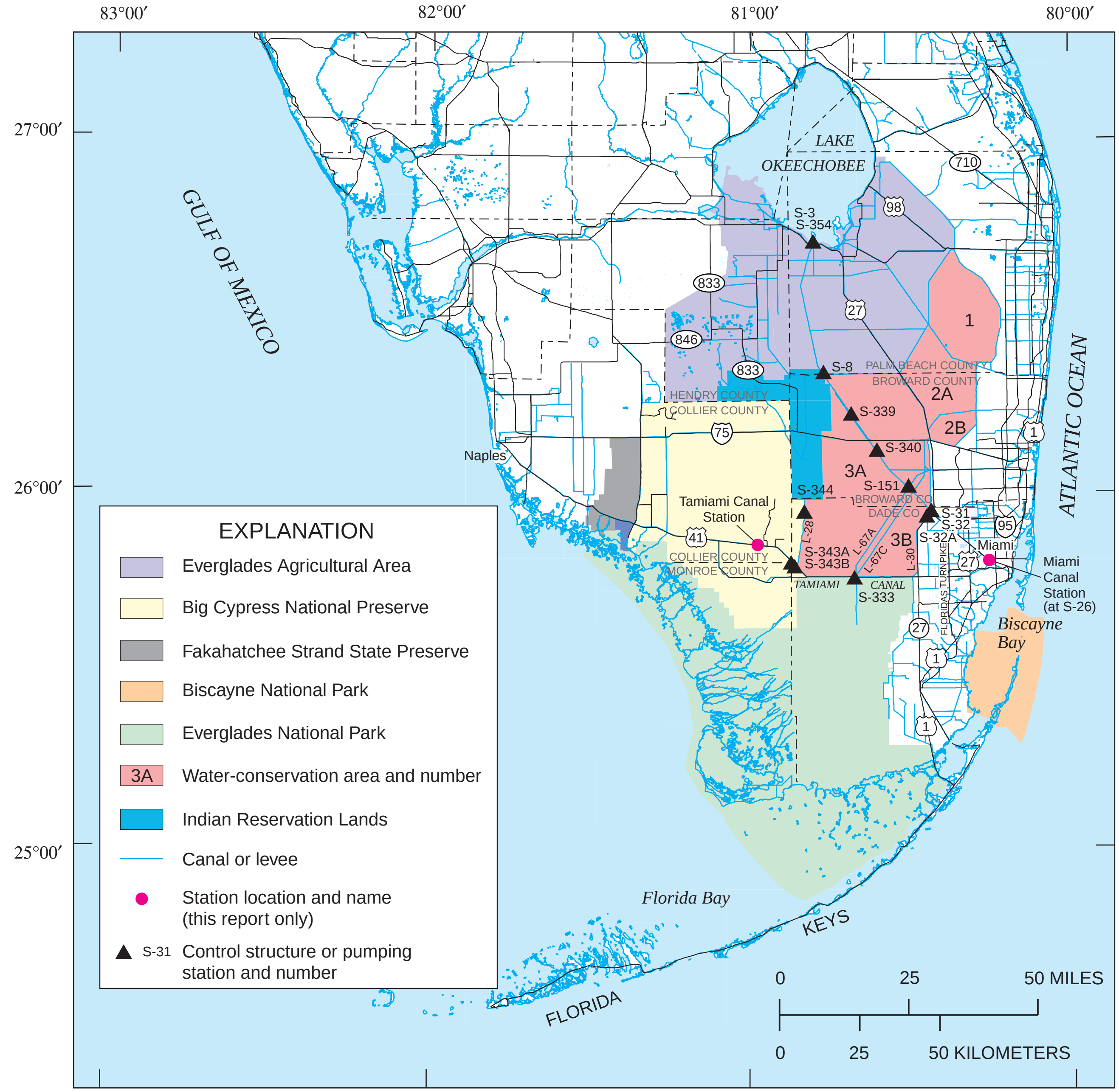


Figure 1. Southern Florida showing location of study sites, major canals, control structures, pumping stations, and land-use areas.

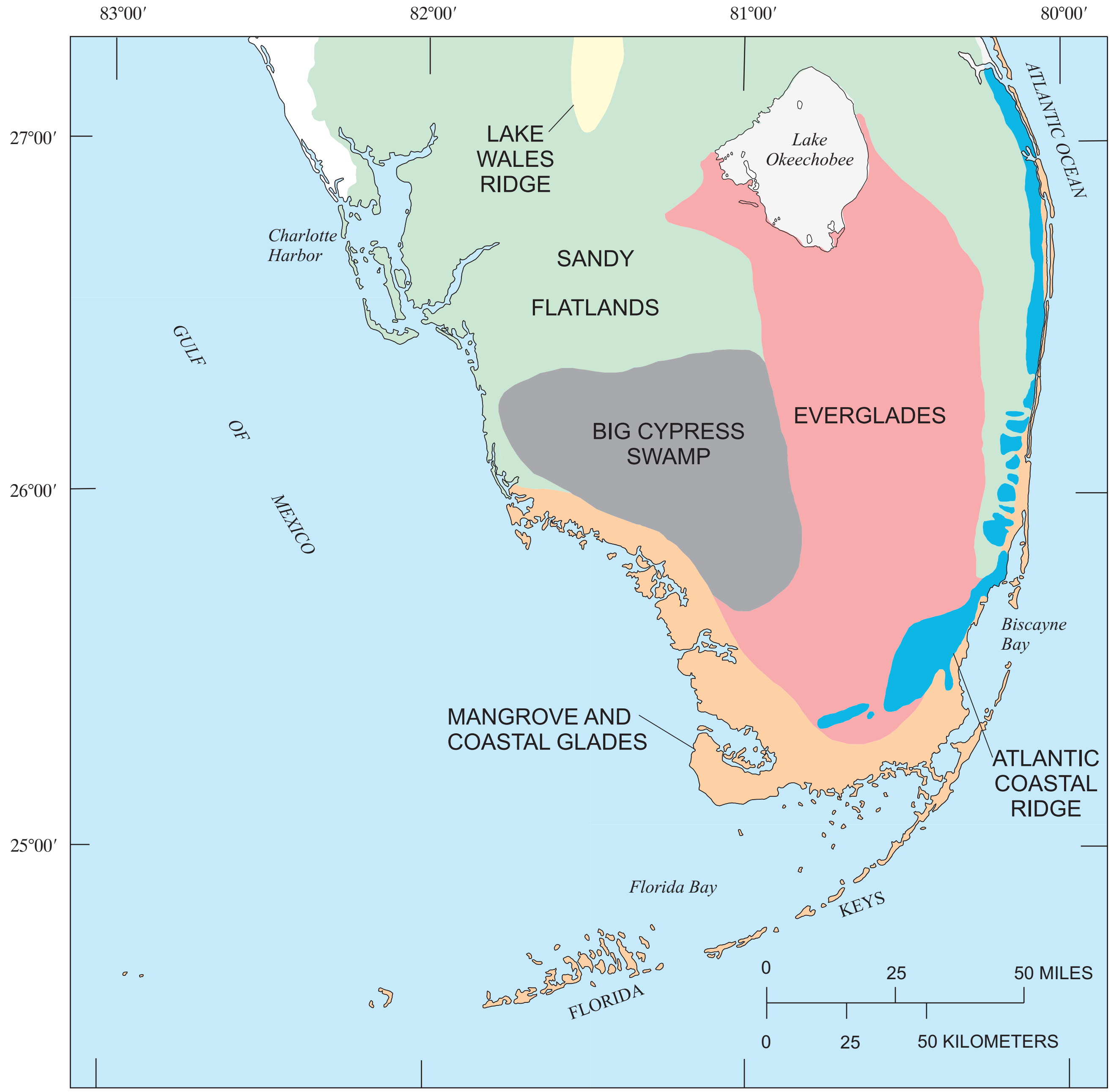


Figure 2. Physiographic provinces of southern Florida (modified from Parker and others, 1955).

lands into the canal after heavy rainfall and operation of pump station S-3 or because of gravity flow at structure S-354 when negative head exists (fig. 1).

Pump stations S-8 and S-151 and structures S-31, S-32, S-32A, S-339, and S-340 are located along Miami Canal near or within Water Conservations Areas 3A and 3B. Pump station S-8, the northernmost station along the middle reach of the canal and just outside of the water-conservation areas, is used to discharge water (to the south) into Water Conservation Areas 3A and 3B for storage. Structures S-339 and S-340, located within Water Conservation Area 3A, are used to prevent overdrainage of the northern part of the water-conservation area by: (1) forcing flows into the marsh when the three manually operated slide gates are closed, and (2) transferring water along Miami Canal to urban areas when the gates are opened. Pump station S-151 discharges water to Levee 67A (L-67A) to convey water southward to structure S-333 for discharge eastward through Tamiami Canal and eventually southward to Everglades National Park through culverts along the reach from Levee 30 (L-30) to L-67A (fig. 1). Water is discharged from L-30 through structures S-31, S-32, or S-32A to Miami Canal (fig. 1) for ground-water replenishment to the Biscayne aquifer (the sole source of potable water for southeastern Florida) during dry periods and for retardation of saltwater intrusion.

Upstream from Biscayne Bay along the lower reach of the Miami Canal is structure S-26 (fig. 1, Miami Canal station). For this study, water samples were collected upstream of this site at the bridge at N.W. 36th Street and N.W. 42nd Avenue. Structure S-26 has two vertical lift gates, which when closed, prevent saltwater intrusion during dry periods, and when opened, discharge excess water during heavy rainfall. The reach from structure S-26 to Biscayne Bay is commonly referred to as the Miami River. Based on a 38-year period of record, summary statistics indicate a mean discharge of 251 ft^3/s (cubic feet per second), a maximum daily mean discharge of 1,570 ft^3/s, and a minimum daily mean discharge of -279 ft^3/s (Price and others, 1998). A flow-duration curve for the Miami Canal station is shown in figure 3. A photograph showing structure S-26 on the Miami Canal is shown in figure 4.

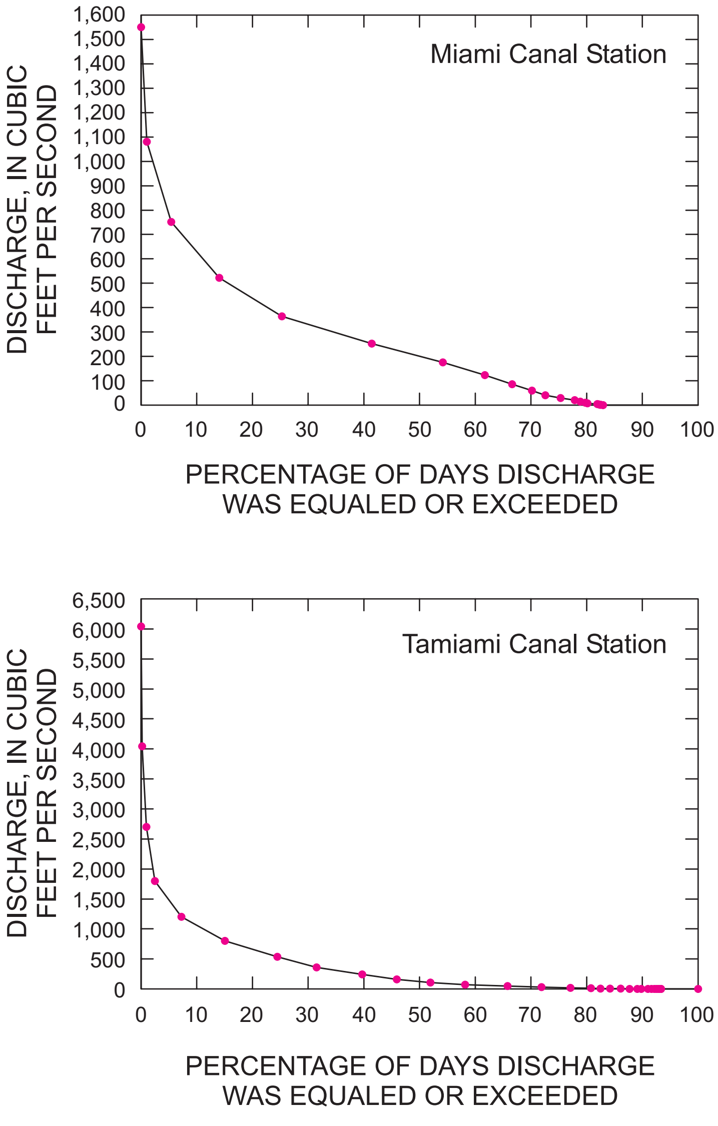


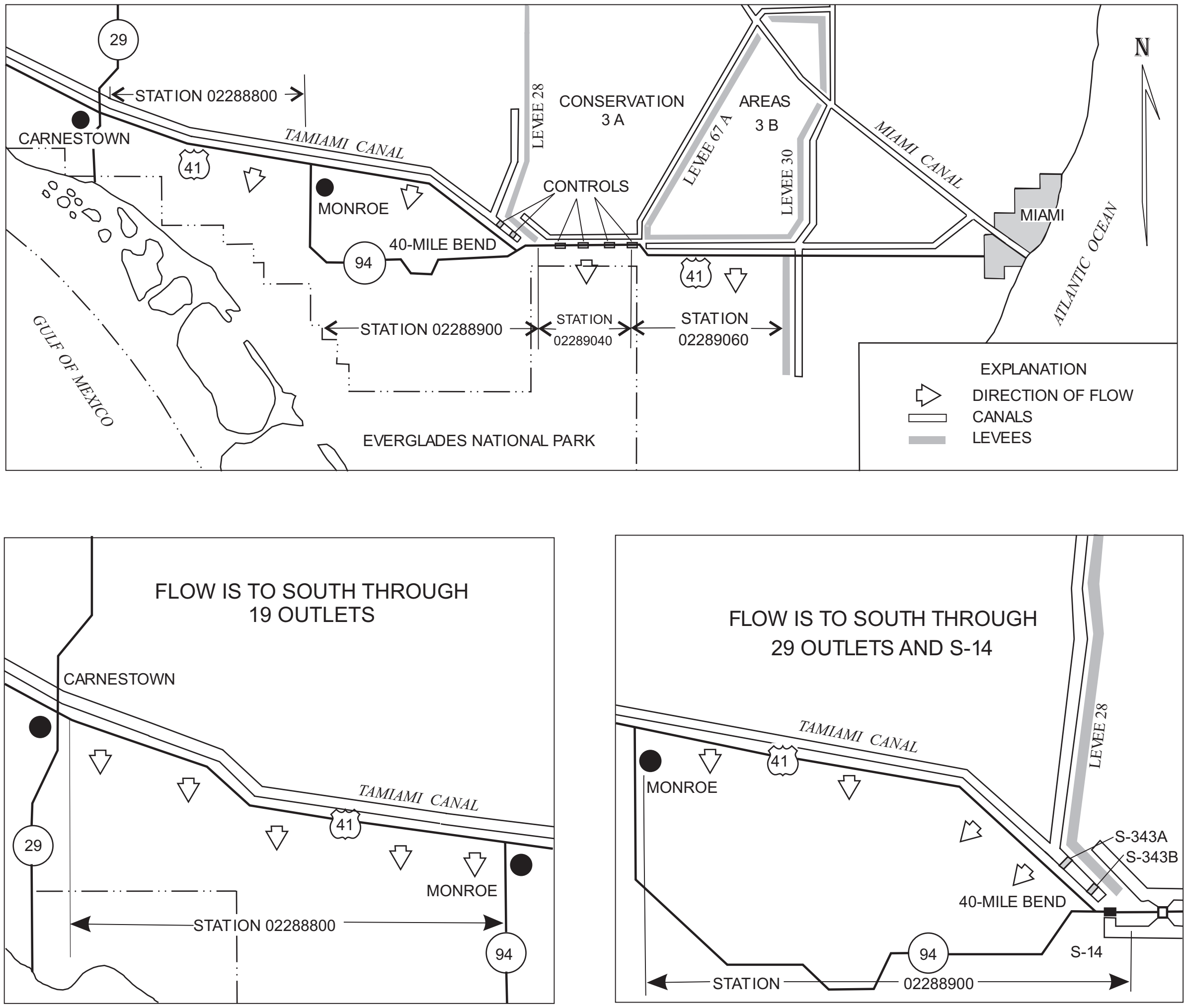
Figure 3. Flow-duration curves for the Miami and Tamiami Canal stations. Valid only for positive discharges.

Tamiami Canal System

The Tamiami Canal traverses in an east-west direction from Miami along the southeastern coast to Naples along the southwestern coast (fig. 1). East of the Big Cypress National Preserve, flow is highly regulated along the reaches of the Tamiami Canal. The direction of flow is to the south through 19 outlets from Monroe to Carnestown, through 29 outlets and structure S-14 from Forty-Mile Bend to Monroe, through 4 control structures (S-12A, B, C, D) from L-67A to Forty-Mile Bend, and through 19 outlets and structure S-12E from L-30 to L-67A (fig. 5). East of Monroe, the Tamiami Canal crosses the highest elevation in its reach (about 8 ft above sea level). Although flow diminishes during the dry season, ground-water seepage occurs until the water table recedes beneath the streambed. The canal water eventually evaporates and stagnant pools of nonflowing water also develop during the dry season.

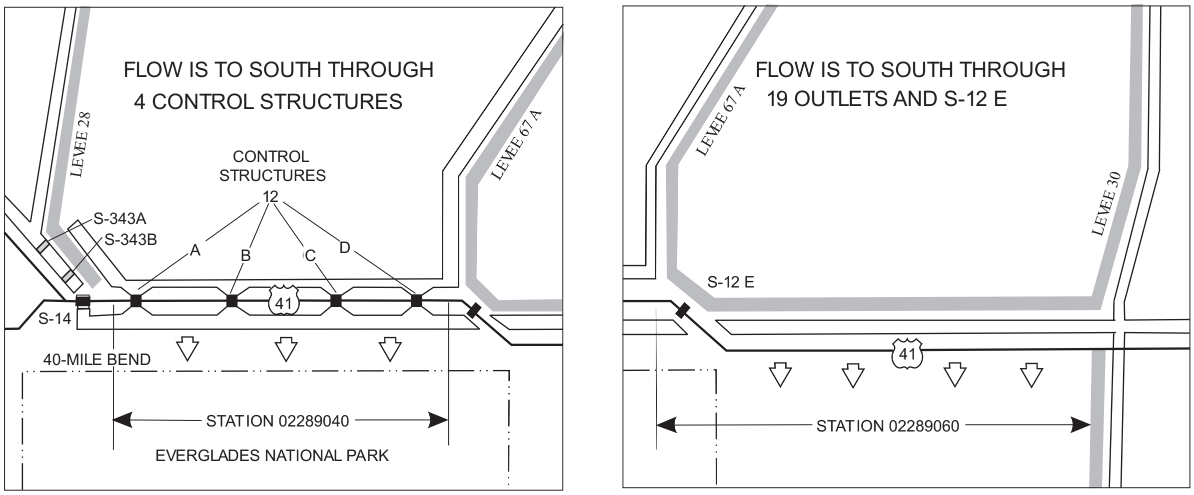
The section of the Tamiami Canal that is of principal interest in this study is Forty-Mile Bend to Monroe, which consists of 29 bridges over a distance of about 15 mi in an east-west direction. For this study, the entire 15-mi reach was considered to be one site (fig. 1, Tamiami Canal station). Discharge at the station is computed from a stage/discharge rating based on a single stage recorder at bridge 105. Two control structures, S-343A and S-343B (figs. 1 and 5), may influence flow in the easternmost part of this section. Generally, the gates of both structures are only operated during high stages in Water Conservation Areas 3A and 3B. Another nearby structure (S-344 along L-28) also may influence flow in the Tamiami Canal from Forty-Mile Bend to Monroe. The gates at structure S-344 are rarely opened. Based on a 35-year period of record, summary statistics for Tamiami Canal from Forty-Mile Bend to Monroe (fig. 1, Tamiami Canal station) indicate a mean discharge of 363 ft^3/s, a maximum daily mean discharge of 6,110 ft^3/s, and a minimum daily mean discharge of 0.0 ft^3/s (Price and others, 1998). A flow-duration curve for the Tamiami Canal station is shown in figure 3. A southerly view of the Tamiami Canal outlet from Forty-Mile Bend to Monroe in the Big Cypress National Preserve is shown in figure 6.

Figure 4. Structure S-26 at the Miami Canal station.



STATION 02288800 MONROE TO CARNESTOWN

STATION 02288900 40-MILE BEND TO MONROE



STATION 02289040 LEVEE 67A TO 40-MILE BEND

STATION 02289060 LEVEE 30 TO LEVEE 67A

Figure 5. Tamiami Canal Outlets (from Price and others, 1998, p. 203).

Figure 6. Southerly view of an outlet of the Tamiami Canal from Forty-Mile Bend to Monroe in the Big Cypress National Preserve.

COLLECTION AND PROCESSING OF WATER SAMPLES

Representative water samples were collected from the Miami and Tamiami Canal stations. Sample processing and preservation techniques were such that chemical and biological contamination and degradation were minimized. The methodology employed for the study was similar to that used throughout the Nation for water-quality sampling under the NASQAN program; minor exceptions were made to accommodate the unique hydrology of southern Florida. Prior to the NASQAN program, sample collection and processing procedures were not well documented. The use of nonstandard procedures for analysis of certain constituents and changes in laboratory analytical procedures during the sampling program may have resulted in variation in water-quality results over time. The water-quality constituents and groups sampled at the Miami and Tamiami Canal stations and the period of frequency of data collection are presented in table 1.

Depth-integrated samples were collected under the NASQAN program by the equal-width-increment method. This method divides the stream cross section into equally spaced intervals, with sampling verticals established at the middle of each interval. The first sampling vertical is located at half the distance of the first interval from the bank, with subsequent verticals located equidistant from the first vertical at the midsection of each of the remaining intervals. During every sampling event, water samples were collected from at least three verticals in the cross section. Because of the low velocities, less than 2 ft/s (feet per second) that usually predominate in the canals of southern Florida, the weighted-bottle method was used to collect water samples. With this method, a 1-L (liter) open-mouth polyethylene bottle is placed in an epoxy-coated, weighted basket sampler that is raised and lowered through each vertical at a constant transit rate. Thus, the bottle is not overfilled when returned to the surface. During the study, the same transit rate was maintained throughout each of the sampling verticals. Because flow moves through 29 outlets at the Tamiami Canal station and concentration or volume may vary spatially depending on the season and the amount of streamflow present, equal-width-increment sampling was conducted at no less than three bridges in which flow existed in the canal reach for each sampling event and composited as one water sample.

Table 1. Period and frequency of data collection for water-quality constituents and groups at the Miami and Tamiami Canal stations

[Individual major inorganic constituents and other related physical characteristics, except where noted below, are given in tables 3 and 4]

Water-quality constituent or groups	Miami Canal station		Tamiami Canal station	
	Period of data collection	Frequency	Period of data collection	Frequency
Major inorganic constituents and physical characteristics[1,2]	1966-74 1975-80 1981-94	Intermittently Monthly Quarterly	1967-75 1976-80 1981-93	Intermittently Monthly Quarterly
Specific conductance	1966-80 1981-94	Monthly Quarterly	1967-75 1976-80 1981-93	Intermittently Monthly Quarterly
pH and dissolved oxygen	1966-74 1975-80 1981-94	Intermittently Monthly Quarterly	1967-75 1976-80 1981-93	Intermittently Monthly Quarterly
Suspended sediment	1974-80 1981-94	Monthly Quarterly	1975-80 1981-93	Monthly Quarterly
Nitrogen and phosphorus species	1970-74 1975-80 1981-94 1995-96	Intermittently Monthly Quarterly Intermittently	1968-75 1976-80 1981-93	Intermittently Monthly Quarterly
Total organic carbon	1970-74 1975-81	Intermittently Quarterly	1970-75 1976-80 1981-85	Intermittently Monthly Quarterly
Trace metals	1969-74 1975-80 1981-94	Intermittently Monthly Quarterly	1967-75 1976-80 1981-93	Intermittently Monthly Quarterly
Fecal coliform and fecal streptococcus	1976-80 1981-94	Monthly Quarterly	1978-80 1981-93	Monthly Quarterly
Phytoplankton	1974-81	Quarterly	1975-81	Quarterly

[1] Includes all of the individual constituents given in tables 3 and 4, except for specific conductance.

[2] Chloride also sampled from 1966 to 1973.

The equal-width-increment method was used to collect water samples from the Miami Canal station. The water samples were collected from at least three verticals in the cross section per sampling event and composited in a churn splitter for processing and determination of major inorganic constituents and other related physical characteristics, nitrogen and phosphorus species, and trace metals. Water samples for total organic carbon and bacteriological characteristics were collected as grab samples from midstream using a sterilized glass bottle. Before sampling, the churn splitter was washed with a nonphosphate detergent, tap water, and deionized water; the basket sampler was rinsed with native water. When used for trace metal compositing, the churn splitter was soaked with a 5-percent hydrochloric acid solution and rinsed with tap water and deionized water.

The churn splitter was used to withdraw water samples at a churning rate of about 9 in/s (inches per second). This process was carefully executed to ensure that the churn disc did not break the surface, resulting in aeration of the water sample and subsequent changes in water quality. Water samples were initially withdrawn for total (or total recoverable) and suspended determinations. Water samples for all of the dissolved constituents were filtered using 0.45-micron filters. Caution was taken with water samples for filtered constituents; water samples were not withdrawn when the level in the churn splitter was less than 1.5 in. above the spigot intake.

Various methods were used for the preservation of nutrients, trace metals, and bacteriological and biological characteristics during sampling. Water samples for nutrient analysis were collected in amber polyethylene bottles and chilled to 4.0 °C (degrees Celsius). For a period of time, mercuric chloride was used for sample preservation. To prevent cross contamination, the nutrient samples were placed in a separate ice chest that was shipped immediately for laboratory analysis. For trace metals, water samples were collected in acid-rinsed bottles and treated with nitric acid to prevent sample degradation. Water samples for fecal coliform and fecal streptococcus were chilled to 4.0 °C and analyzed at the Miami Subdistrict laboratory within 4 to 6 hours of sample collection. The field and analytical methods that were used to collect and analyze the water samples are described in publications by Guy and Norman (1970), Goerlitz and Brown (1972), Greeson and others (1977), Wershaw and others (1987), and Fishman and Friedman (1989).

DETERMINING TRENDS IN WATER QUALITY

A trend in water quality is defined as a monotonic change in a particular constituent with time. As previously mentioned, the ESTREND program (Schertz and others, 1991) was used in this study to determine trends of water-quality constituents for the Miami and Tamiami Canal stations. This program employs parametric and nonparametric tests that are designed to deal with characteristics unique to water-quality data.

Water-quality data possess unique characteristics that may require specialized approaches to statistical testing. Data sets have a base limit of zero due to positive values only and can contain censored (less than) values, outliers, multiple detection limits, missing values, and serial correlation. These characteristics commonly present problems in the use of conventional parametric statistics based on normally distributed data sets. The presence of censored data, non-negative values, and outliers may lead to an asymmetric or nonnormal distribution instead of a normal, symmetric, or bell-shaped (Gaussian) distribution, which is common for many data sets. These skewed data sets may require use of specific nonparametric statistical procedures for their analysis. The use of nonparametric statistical procedures also is preferred when determining trends of many constituents at multiple stations. Additionally, nonparametric statistical tests are more powerful when applied to non-normally distributed data, and almost as powerful (under certain conditions) as parametric tests when applied to normally distributed data (Helsel and Hirsch, 1992, p. 102).

Two major causes of variation in water-quality data are the effects of seasonality and discharge. Both need to be compensated for in order to discern the specific anthropogenic or natural processes that affect water quality over time. The effects of seasonality and streamflow on water quality, as well as methods of dealing with both censored and non-censored data are addressed in the subsequent sections.

Seasonal Variation

Water-quality data may exhibit seasonal variation (Schertz and others, 1991, p. 12). This variation may be the result of a variety of conditions, including specific agricultural land-use practices, biological activity, or sources of streamflow or sediment. As an example, precipitation-induced discharge may predominate during specific months of the year, whereas base flow (due to ground-water seepage) may be dominant at other times of the year. Another example is the increase in biological activity that occurs during summer months because of warmer temperatures as opposed to decreased activity during winter months, which might cause seasonal variation in nutrient concentrations.

The statistical approach that is used to compensate for seasonal variability in water-quality data is the distribution-free, nonparametric Seasonal Kendall trend test. This test, modified from the Mann-Kendall test (Helsel and Hirsch, 1992, p. 338), compares relative ranks of data values from the same season. For example, January values are compared to January values, February values are compared to February values, and so forth. No comparisons are made across seasonal boundaries. Plus values are recorded if the subsequent value in time is higher, and a minus is recorded if the subsequent value in time is lower. If pluses predominate, a positive trend exists and if minuses predominate a negative trend results. No trend is the result of pluses and minuses being equal. The null hypothesis is that the concentration of the water-quality constituent is independent of time (Smith and others, 1982, p. 5). The test assumes that the data are independent and from the same statistical distribution. The Seasonal Kendall test statistic is the summation of the Mann-Kendall test results from all the seasons. The attained significance level (or p-value) is the probability of incorrectly rejecting the null hypothesis of no trend when actually there is a trend. The Seasonal Kendall slope estimator is computed according to the method of Sen (1968); it is the median slope of all the pairwise comparisons from all of the seasons expressed as rate of change per year in original units (usually in milligrams per liter depending on the constituent) and in percent per year.

Because all data may not have been collected at the same frequency for the duration of a project or monitoring program, specific seasonal definitions are needed to prevent bias in the trend results. For example, data collected under the NASQAN program were collected monthly for the first few years of the program and then quarterly thereafter. Use of a monthly seasonal definition would unduly bias the trend results in favor of the beginning years of the record. The ESTREND program provides a mechanism for determining the appropriate seasonal definitions for specific constituents at each station. The program allows the user to divide the record into 2, 3, 4, 6 or 12 seasons. The specific length and dates of each season are specified by the user. An automated procedure in the ESTREND program determines the degree to which the sampling frequency of a record supports user-defined seasons. This is determined by dividing the record into beginning, middle, and ending periods. The beginning and ending periods each consist of one-fifth of the record, whereas the middle period consists of three-fifths of the record. Seasonal pairwise comparisons are made according to the seasonal definitions with the beginning and ending periods of the record and also with the middle period of the record. For each seasonal definition, the ratio of observed pairwise comparisons to the maximum possible number of pairwise comparisons is computed (Schertz and others, 1991, p. 17) for the beginning and ending, as well as the middle periods of the record for each season. Generally, seasonal selection is based on the lowest sampling frequency for the beginning and ending periods of the record.

Streamflow Variation

Removing unwanted variation in water-quality data caused by extraneous variables is a necessary step in understanding the anthropogenic processes that may have affected water quality over time. These extraneous variables often represent natural processes such as rainfall, temperature, or streamflow (Helsel and Hirsch, 1992, p. 330). Water-quality constituents may be affected by streamflow in various ways. Major inorganic constituents are usually inversely related to streamflow due to the effects of dilution as streamflow increases with time. Nutrients tend to be directly related to discharge through the process of washoff, which results in increases in concentrations of nitrogen and phosphorus species due to runoff from agricultural and urban areas and from streambank erosion. Some constituents may be affected by both dilution and washoff.

The ESTREND program is used to determine water-quality trends by removing flow-related variation based on the development of a time series of flow-adjusted concentrations (residuals) from concentration/discharge regression models. The Seasonal Kendall trend test is then applied to the flow-adjusted residuals. One of the two methods (for using concentration/discharge regression models to reduce flow-related variability) utilizes linear models to regress concentration with various functional forms of flow that include linear, inverse, hyperbolic and log transformations (Schertz and others, 1991, p. 22). The mathematical expression for this method is:

$$C = a + bf(Q) , \qquad (1)$$

where

C is the estimated concentration;
a is the intercept;
b is the slope; and
Q is instantaneous discharge or mean daily discharge.

$f(Q)$ represents functional forms of flow, such as: Q linear, ln (Q) log (natural), $1/(1 + BQ)$ hyperbolic where B is one of eight possible coefficients based on range of discharge, and $1/Q$ inverse.

The above method is used for most conservative water-quality constituents. Selection of the best model is based upon the lowest Prediction Error Sums of Squares (PRESS) statistic. However, for nonconservative constituents (suspended sediment, total organic carbon, nitrogen and phosphorus species, bacteria, turbidity, and phytoplankton), a log-log multiple linear regression model is preferred (Smith and others, 1987). The mathematical expression is:

$$\ln C = a + b_1 \ln Q + b_2 (\ln Q)^2 \text{ exponential.} \qquad (2)$$

The second method of flow adjustment is nonlinear and involves fitting a concentration/discharge or a log concentration/log discharge relation by generation of a locally weighted scatterplot smoothing line, known as LOWESS (Cleveland, 1979). This method uses weighted least squares regressions by weighting observations both as to distance from the fitted line and magnitude of residuals; the method is applicable for many of the nonconservative constituents mentioned above.

Reduction of flow-related variability in water-quality data requires that discharge be unaffected by human influence. If this is not possible, the effect must be constant over the period of record (Helsel and Hirsch, 1992, p. 332). Because discharge at the Miami Canal station is highly influenced by anthropogenic activities and water-management and land-use practices (and because this influence may not have remained constant over the period of record resulting in changes in the probability distribution of the discharge data), only trends on unadjusted concentrations are reported for the Miami Canal station (shown later).

Criteria for Censored and Uncensored Data

Specific guidelines are established by the ESTREND program for the determination of water-quality trends using the Seasonal Kendall trend test on both censored and uncensored data. If less than 5 percent of the record is censored, all censored data values are recoded to half the reporting limit, provided that the required specific criteria are met. These criteria are as follows: (1) at least 5 years of record must exist; (2) the minimum number of observations in the record must be at least three times the designated number of seasons and greater than or equal to 10; and (3) a minimum percentage (recommended 40 percent) of the total number of observations must be present at the beginning and ending periods of the record. Criteria for the selection of statistically significant trends for uncensored data are listed in table 2. The use of this test incorporates flow adjustment on residuals from concentration/discharge regressions and slope estimation.

Table 2. Criteria for selection of statistically significant trends based on uncensored data

[p-value less than 0.10 is statistically significant]

Best trend	Criteria for best trend
Unadjusted concentration (U)	No statistically significant correlation of concentration with discharge, **<u>or</u>** statistically significant correlation of concentration with discharge and statistically significant correlation of flow-adjusted concentration with discharge, **<u>or</u>** statistically significant correlation of concentration with discharge and no statistically significant flow-adjustment model
Flow-adjusted concentration (F)	Statistically significant correlation of concentration with discharge and no statistically significant correlation of flow-adjusted concentration with discharge and a statistically significant flow-adjustment model

The Seasonal Kendall trend test can also be applied when more than 5 percent of the record is censored at a single reporting limit or for multiple-censored data when few values are above the minimum detection limit. The previously mentioned criteria also apply; the exception, at least one observation annually must be present at the beginning and ending fifths of the record. In this case, all detected and nondetected data values below the reporting limit are considered tied. Therefore, the trend is determined only on data that exceed the reporting limit. Use of the Seasonal Kendall trend test on censored data does not result in removal of flow-related variability, and trend slopes may not be reliable and were not reported due to the amount of censored data. For data censored at more than one reporting limit, a parametric censored regression test called Tobit also may be used (Schertz and others, 1991, p. 31). Criteria for use of this test is the same as for the Seasonal Kendall trend test on censored data, except a minimum percentage (recommended 20 percent) of the total observations in the record must be detected values. This test uses a maximum likelihood estimation method based on a linear model and does not incorporate flow adjustment.

ANALYSIS OF WATER-QUALITY TRENDS AT THE MIAMI AND TAMIAMI CANAL STATIONS

Statistical summaries and spatial and temporal trends of selected major inorganic constituents and physical characteristics; pH and dissolved oxygen; suspended sediment; nitrogen, phosphorus, and carbon species; trace metals; and bacteriological and biological characteristics were determined for the Miami and Tamiami Canal stations. Statistical summaries presented in tables 3 and 4 include the number of observations, mean, minimum, maximum, median (50th percentile), and interquartile range (25th and 75th percentiles). A log probability regression of concentration values on normal quartiles is used to predict the magnitude of values for constituents with censored data values. The mean, median, and 25th and 75th percentiles are then estimated from predicted values in place of censored values (Schertz and others, 1991, p. 31). Median concentrations of selected constituents also are compared to the Florida Department of Environmental Protection Class III freshwater standards for recreation, propagation, and maintenance of a healthy, well balanced population of fish and wildlife (Florida Department of Environmental Protection, 1993).

Table 3. Statistical summary and trends of selected water-quality constituents at the Miami Canal station

[Only trends in unadjusted concentrations reported. N, total number of observations; n, number of observations used for trend determination; mg/L, milligrams per liter; Pt-Co units, platinum-cobalt units; NTU, nephelometric turbidity units; µS/cm, microsiemens per centimeter; t/acre-ft, tons per acre feet; °C, degrees Celsius; µg/L, micrograms per liter; mL, milliliter]

Constituent	Period of record	N	Mean	Minimum	Percentile			Maximum	n	Rate of increase or decrease		p-value[1]
					25	50	75			Units per year	Percent per year	
Major Inorganic Constituents and Physical Characteristics												
Calcium, in mg/L	05-66 to 09-94	158	76.3	45.0	73.0	77.0	81.0	95.0	55	-0.07	-0.09	0.47
Chloride, in mg/L	05-66 to 09-94	249	72.5	12.0	58.0	70.0	82.0	290.0	141	.89	1.23	.00
Fluoride, in mg/L	05-66 to 09-94	156	.3	.0	.2	.3	.3	.5	54	.00	.00	.12
Magnesium, in mg/L	05-66 to 09-94	132	10.4	2.1	8.6	9.9	11.0	26.0	93	.13	1.20	.00
Potassium, in mg/L	05-66 to 09-94	157	2.1	.4	1.6	1.9	2.6	5.2	54	.07	3.35	.00
Silica, in mg/L	05-66 to 09-94	168	6.8	1.0	5.7	6.9	7.8	16.0	54	.06	.82	.03
Sodium, in mg/L	05-66 to 09-94	156	45.5	7.2	38.0	44.5	54.0	86.0	115	.70	1.54	.00
Sulfate, in mg/L	05-66 to 09-94	157	7.7	.0	3.4	5.8	9.8	43.0	54	.37	4.74	.00
Color, in Pt-Co units	05-66 to 05-78	52	53.4	30.0	41.3	50.0	60.0	80.0	19	1.25	2.34	.17
Hardness, as $CaCO_3$, in mg/L	05-66 to 09-94	157	234.0	160.0	220.0	230.0	245.0	300.0	54	.00	.00	.27
Turbidity, in NTU	05-70 to 04-78	91	1.6	.1	.5	1.0	2.0	11.0	72	-.04	-2.37	[2].06
Specific conductance, in µS/cm	05-66 to 09-94	263	649.0	455.0	580.0	640.0	700.0	1,350.0	139	5.70	.88	.00
Dissolved solids, in mg/L	05-66 to 09-94	156	392.0	213.0	369.0	396.0	419.0	520.0	54	1.62	.41	.01
	1976-94	121	398.0	213.0	379.0	398.0	420.0	520.0	89	1.50	.38	.01
	1987-94	33	391.0	213.0	382.0	416.0	427.0	462.0	25	3.25	.83	[2].09
Dissolved solids, in t/acre-ft	05-66 to 09-94	155	.5	.3	.5	.5	.6	.7	54	.00	.45	.01
	12-74 to 09-94	101	219.0	.0	91.8	215.0	315.0	1,020.0	70	-3.70	-1.69	.22
pH, Dissolved Oxygen, and Suspended Sediment												
pH, in standard units	05-66 to 08-94	166	7.6	6.7	7.4	7.6	7.8	8.6	54	-.01	-.17	.05
Dissolved oxygen, in percent saturation	05-68 to 08-94	59	48.6	.0	18.0	47.0	75.0	119.0	50	-.16	-.33	.80
Dissolved oxygen, in mg/L	05-68 to 08-94	147	3.7	.0	1.6	3.0	5.9	10.4	88	.04	1.10	.15
	1987-94	33	3.8	.4	1.5	3.3	6.0	8.4	25	-.13	-3.44	.38
Suspended sediment, in mg/L	12-74 to 09-94	107	6.7	.0	1.0	3.0	6.0	92.0	81	.24	3.56	[2].09
	1976-94	97	7.0	.0	2.0	3.0	6.0	92.0	76	.10	1.42	.25
	1987-94	33	8.6	.0	2.0	3.0	8.5	48.0	25	-1.25	-14.44	[2].09

Table 3. Statistical summary and trends of selected water-quality constituents at the Miami Canal station (Continued)

[Only trends in unadjusted concentrations reported. N, total number of observations; n, number of observations used for trend determination; mg/L, milligrams per liter; Pt-Co units, platinum-cobalt units; NTU, nephelometric turbidity units; µS/cm, microsiemens per centimeter; t/acre-ft, tons per acre feet; °C, degrees Celsius; µg/L, micrograms per liter; mL, milliliter]

Constituent	Period of record	N	Mean	Minimum	Percentile			Maximum	n	Rate of increase or decrease		p-value[1]
					25	50	75			Units per year	Percent per year	
Nitrogen, Phosphorus, and Carbon Species[3]												
Total ammonia, in mg/L	12-71 to 09-94	153	0.3	<0.01	0.1	0.2	0.5	1.2	83	-0.02	-5.63	.01
Total nitrite, in mg/L	12-71 to 12-92	94	.03	<.01	.01	.02	.03	.2	24	.00	.00	.48
Total nitrate, mg/L	12-71 to 12-92	93	.1	.01	.1	.2	.2	.4	23	.00	-.27	.76
Total nitrite plus nitrate, in mg/L	12-74 to 12-92	90	.2	.01	.1	.2	.2	.5	51	.00	.00	.96
Total organic nitrogen, in mg/L	08-70 to 12-96	164	1.2	.2	1.0	1.2	1.4	2.6	70	.00	.00	.41
Total ammonia plus organic nitrogen, in mg/L	11-74 to 11-90	141	1.5	.2	1.2	1.5	1.8	2.7	75	.00	.00	.68
Total organic carbon, in mg/L	08-70 to 10-81	62	21.5	4.0	15.8	20.0	24.0	87.0	49	.61	2.83	.03
Total nitrogen, in mg/L	06-73 to 10-96	127	1.7	.5	1.4	1.7	2.0	3.8	54	.01	.54	.36
	1976-94	104	1.7	.5	1.4	1.7	2.0	3.8	72	.00	-.13	.58
	1987-94	24	1.7	1.0	1.4	1.5	2.0	2.6	16	.08	4.51	.13
Total phosphorus, in mg/L	12-71 to 12-96	162	.02	<.01	.01	.02	.03	.3	85	.00	.00	.95
	1976-94	122	.02	<.01	.01	.02	.03	.3	88	.00	.00	.42
	1987-94	32	.02	<.01	.01	.02	.03	.1	24	.00	-12.94	[2].09
Trace Metals												
Barium, in µg/L	04-78 to 09-94	64	36.1	5.0	29.0	31.0	45.8	66.0	58	-1.39	-3.86	.00
Iron, in µg/L	12-69 to 09-94	93	112.0	.0	41.0	100.0	175.0	300.0	70	-2.71	-2.43	[2].06
Bacteriological and Biological Characteristics												
Fecal coliform, in colonies per 100 mL	12-76 to 09-94	82	1,241.0	2.0	130.0	230.0	470.0	43,000.0	71	-47.70	-3.84	[2].07
	1987-94	28	415.0	5.0	102.0	150.0	290.0	5,700.0	23	26.22	6.32	.32
Fecal streptococcus, in colonies per 100 mL	1987-94	28	188.0	5.0	38.5	125.0	198.0	1,000.0	23	86.19	45.86	[2].08
Phytoplankton, in cells per mL	12-74 to 10-81	36	6,503.0	14.0	400.0	840.0	2,650	160,000	36	163.00	2.50	.72

[1] Attained significance level. Value less than 0.10 is statistically significant as shown in red.

[2] Not statistically significant at an alpha level of 0.05.

[3] Total organic nitrogen, total nitrogen, and total phosphorus at the Miami Canal station were the only constituents sampled through 1996 in this study.

Table 4. Statistical summary and trends of selected water-quality constituents at the Tamiami Canal station

[N, total number of observations; n, number of observations used for trend determination. Best trend: F, flow-adjusted concentrations; U, unadjusted concentrations. Other abbreviations: mg/L, milligrams per liter; mL, milliliter; Pt-Co units, platinum-cobalt units; NTU, nephelometric turbidity units; µS/cm, microsiemens per centimeter; t/d, tons per day; t/acre-ft, tons per acre feet; °C, degrees Celsius; CD, censored data; TS, trend slopes not reliable due to censored data]

Constituent	Period of record	N	Mean	Minimum	Percentile			Maximum	n	Rate of increase or decrease		p-value[1]	Best trend
					25	50	75			Units per year	Percent per year		
Major Inorganic Constituents and Physical Characteristics													
Calcium, in mg/L	05-67 to 09-93	113	58.7	34.0	49.0	58.0	66.0	110.0	42	0.32	0.54	0.18	F
Chloride, in mg/L	05-67 to 09-93	113	20.1	7.8	13.0	17.0	24.0	74.0	42	.21	1.07	.04	F
Fluoride, in mg/L	05-67 to 09-93	113	.1	--	.1	.1	.2	.7	113	TS	TS	.08	U
Magnesium, in mg/L	05-67 to 09-93	112	2.8	.8	1.9	2.5	3.2	12.0	42	.04	1.48	.00	F
Potassium, in mg/L	05-67 to 09-93	112	1.1	.0	.5	.6	.8	18.0	42	.02	1.34	.00	F
Silica, in mg/L	05-68 to 09-93	112	3.3	.2	1.5	2.8	4.4	14.0	42	.07	2.15	.19	F
Sodium, in mg/L	05-67 to 09-93	111	13.6	5.2	8.7	12.0	16.0	63.0	42	.20	1.45	.01	F
Sulfate, in mg/L	05-67 to 09-93	113	2.3	--	.3	1.0	3.3	17.0	113	.00	.00	.63	U
Color, in Pt-Co units	05-67 to 11-85	55	30.8	10.0	20.0	30.0	40.0	100.0	19	.25	.80	.79	F
Hardness, as $CaCO_3$, in mg/L	05-67 to 09-93	113	159.0	90.0	130.0	150.0	180.0	300.0	42	1.00	.63	.23	F
Turbidity, in NTU	03-70 to 04-78	83	1.1	.0	.5	1.0	1.2	4.5	47	-.02	-2.11	.18	U
Specific conductance, in µs/cm	05-67 to 09-93	114	365.0	215.0	302.0	352.0	400.0	821.0	41	4.44	1.22	.00	F
Dissolved solids, in t/d	05-69 to 09-93	93	170.0	.0	30.7	99.1	268	1,030.0	52	.08	.05	.79	F
Dissolved solids, in t/acre-ft	05-67 to 09-93	101	.3	.2	.2	.3	.3	.7	40	.00	.58	.17	F
Dissolved solids, in mg/L	05-67 to 09-93	113	223.0	113.0	176.0	212.0	255.0	540.0	42	1.73	.78	.03	F
	1976-93	99	218.0	113.0	177.0	211.0	248.0	487.0	55	2.08	.95	.17	F
	1987-93	29	220.0	129.0	168.0	210.0	242.0	420.0	27	-3.48	-1.58	.22	F
pH, Dissolved Oxygen, and Suspended Sediment													
pH, in standard units	05-67 to 09-93	115	7.5	6.7	7.3	7.5	7.7	8.8	46	-.01	-.15	.15	U
Dissolved oxygen, percent saturation	05-68 to 09-93	43	35.0	10.0	24.0	30.0	46.0	80.0	28	-.08	-.23	.73	U
Dissolved oxygen, in mg/L	05-67 to 09-93	105	3.1	.5	2.0	2.7	4.0	14.0	41	-.08	-2.59	.02	U
	1976-93	97	2.9	.5	2.0	2.7	3.6	6.3	48	-.02	-.63	.41	U
	1987-93	29	2.7	1.1	2.0	2.4	2.9	6.2	27	-.09	-3.50	.16	F
Suspended sediment, in mg/L	11-75 to 09-93	80	5.9	1.0	2.0	4.0	6.0	44.0	52	.00	.00	.46	U
	1976-93	81	5.9	1.0	2.0	4.0	6.0	44.0	44	.24	4.08	.07	U
	1987-93	29	5.4	1.0	2.0	4.0	7.0	23.0	28	.00	.00	1.00	U

Table 4. Statistical summary and trends of selected water-quality constituents at the Tamiami Canal station (Continued)

[N, total number of observations; n, number of observations used for trend determination. Best trend: F, flow-adjusted concentrations; U, unadjusted concentrations. Other abbreviations: mg/L, milligrams per liter; mL, milliliter; Pt-Co units, platinum-cobalt units; NTU, nephelometric turbidity units; µS/cm, microsiemens per centimeter; t/d, tons per day; t/acre-ft, tons per acre feet; °C, degrees Celsius; CD, censored data; TS, trend slopes not reliable due to censored data]

Constituent	Period of record	N	Mean	Minimum	Percentile			Maximum	n	Rate of increase or decrease		p-value[1]	Best trend
					25	50	75			Units per year	Percent per year		
Nitrogen, Phosphorus, and Carbon Species													
Total ammonia, in mg/L	03-70 to 12-92	112	0.2	<0.01	0.0	0.1	0.1	14.0	65	-0.01	-4.46	0.02	U
Total nitrite, in mg/L[2]	03-70 to 09-92	83	.01	CD	.1	.01	.01	.1	83	.00	.00	.44	U
Total nitrite + nitrate, in mg/L	05-75 to 11-85	73	.04	CD	.1	.02	.04	.3	73	.00	-5.68	.08	U
Total organic nitrogen, in mg/L	03-70 to 09-92	123	1.2	.3	.7	.9	1.1	9.9	42	-.01	-.89	.35	U
Total ammonia plus organic nitrogen, in mg/L	11-75 to 08-93	114	1.2	.2	.8	.9	1.1	10.0	57	.01	.44	.51	F
Total organic carbon, in mg/L	05-70 to 11-85	65	16.5	2.0	10.0	13.0	17.0	160	25	-.46	-2.78	.24	U
Total nitrogen, in mg/L	10-73 to 09-93	81	1.8	.4	.9	1.0	1.2	24.0	29	-.02	-1.17	.54	U
	1976-93	78	1.2	.4	.8	1.0	1.2	8.5	25	.02	1.34	.36	F
Total phosphorus, in mg/L	05-68 to 09-93	128	.1	<.01	.01	.02	.05	1.5	42	.00	1.36	.36	F
	1976-93	115	.1	<.01	.01	.02	.05	1.5	57	.00	-.06	.98	F
	1987-93	29	.0	<.01	.01	.02	.05	.2	28	.00	.00	.27	U
Trace Metals													
Barium, in µg/L	03-78 to 09-93	58	23.4	6.0	13.0	19.5	31.0	53.0	48	-2.00	-8.55	.00	U
Copper, in µg/L	03-70 to 11-90	58	3.6	CD	1.5	3.0	5.0	11.0	58	TS	TS	.33	U
Iron, in µg/L	05-67 to 09-93	73	57.2	5.0	30.0	50.0	77.0	200.0	42	.00	.00	.90	U
Manganese, in µg/L	05-70 to 05-91	60	11.0	CD	3.0	6.0	9.5	190.0	60	-.11	-.98	.62	U
Nickel, in µg/L[2]	10-77 to 09-93	52	2.3	CD	.7	1.5	2.8	23.0	52	TS	TS	.80	U
Strontium, in µg/L	05-67 to 05-93	79	26.0	58.0	180.0	230.0	310.0	830.0	33	2.82	1.08	.09	U
Zinc, in µg/L	03-70 to 11-89	54	15.1	CD	6.0	10.0	18.5	60.0	54	TS	TS	.40	U
Bacteriological and Biological Characteristics													
Fecal coliform, in colonies per 100 mL	01-78 to 07-93	65	620.0	2.0	30.8	60.0	125.0	28,000	39	16.54	2.67	.30	U
	1987-93	25	80.6	6.0	43.5	60.0	105.0	300.0	17	-4.99	-6.19	.67	U
Fecal streptococcus, in colonies per 100 mL	01-78 to 07-93	54	200.0	2.0	47.5	100.0	222.0	1,300	38	3.75	1.88	.76	U
	1987-93	25	80.6	6.0	43.5	60.0	105.0	300.0	17	-4.99	-6.19	.67	U
Phytoplankton, in cells per mL	11-75 to 11-81	40	8,832	65.0	842.5	1,800	3,050	110,000	17	-1.227	-13.89	.22	U

[1] Attained significance level. Value less than 0.10 is statistically significant as shown in red.

[2] At the 25th percentile, constituent is estimated from a log-probability regression procedure.

Water-quality trends were based on the seasonal definition and the resultant flow/concentration pairs or concentration values selected within that seasonal definition. The trend slope is presented as change in original units per year and as percent per year for each constituent. The trend slope in percent per year is expressed as a percentage of the mean concentration by dividing the slope by the mean and then multiplying by 100 (Schertz and others, 1991, p. 19). In tables 3 and 4, statistically significant values (marked in red) are represented by p-values less than 0.10. The p-value is the attained significance level or probability of rejecting the null hypothesis of no trend when there actually is a trend. ESTREND allows for the use of high p-values (0.10 or higher) when removing flow-related variability (Schertz and others, 1991, p. 24). However, even though no flow adjustment was performed for trends at the Miami Canal station due to the human influence on discharge, a p-value of 0.10 also was used for consistency. Those trends that would not be statistically significant at a p-value of 0.05 are mentioned in the text and noted in tables 3 and 4. The best trends also are represented as to whether they are based on unadjusted or flow-adjusted concentrations (table 2).

Statistically significant and nonsignificant trends are reported at the Miami and Tamiami Canal stations for each constituent during its entire period of record. For most constituents, the time period is 1966-94 for the Miami Canal station or 1967-93 for the Tamiami Canal station (tables 3 and 4). However, because trends are dependent on the period of record for which they originally were determined, trends of selected water-quality constituents (dissolved solids, dissolved oxygen, suspended sediment, total nitrogen, total phosphorus, fecal coliform, and fecal streptococcus) are presented for two or three time periods each at the Miami and Tamiami Canal stations. The additional data sets for the above constituents help provide further understanding of trends at these stations during different time periods (tables 3 and 4). Because of changes in program emphasis over time, some constituents span shorter time periods; whereas others, such as the major inorganic constituents and nutrients, span longer time periods. This accounts for the fact that some trends are for shorter periods than others. Additionally, for constituents spanning the entire period of record, trends are determined for various time periods, but always compared to water-quality data existing at the end of the program.

Water-quality trend analysis is defined as estimating the change in water quality over time (Schertz and others, 1994, p. 1). The trends presented here for a particular constituent over a specific time period represent the overall trend that has occurred during that period. However, trend slopes present the rate of change in original units per year and as a percentage of the mean, but give no indication of how a particular trend has occurred. Trends may have occurred as gradual changes over time, abrupt changes, step changes, or reversals over the period of record. Therefore, those constituents where a statistically significant (p-value less than 0.10) trend has occurred, plots of LOWESS lines have been generated to illustrate the nonlinear variations in the data for the specific period of record. Table 5 provides the number of statistically significant trends for selected constituents at the Miami and Tamiami Canal stations. Table 6 summarizes temporal trends as indicators of improvement or deterioration in water quality over time.

Table 5. Number of statistically significant trends for selected constituents at the Miami and Tamiami Canal stations over time

[MC, Miami Canal station; TC, Tamiami Canal station]

Station	Time period	Number of upward trends	Number of downward trends
MC	1966-94	13	8
TC	1966-93	8	5

Relation of Selected Water-Quality Constituents to Discharge

Plots were generated to depict the LOWESS lines of concentration as a function of discharge for dissolved solids, suspended sediment, total nitrogen, and total phosphorus at the Miami and Tamiami Canal stations. LOWESS minimizes the influence of outliers on the smoothed line. A smoothness factor (F) of 0.5 was used for the plots shown in figures 7 and 8. The smoothness factor is the fraction of observations used in fitting the data to the line, and usually ranges from 0.3 to 0.7 (Schertz and others, 1991, p. 24).

The concentration of dissolved solids as a function of discharge at the Miami Canal station (fig. 7) shows no substantial changes with increasing discharge, indicating there is no dilution effect or increase in concentration due to washoff. The dissolved-solids

Table 6. Summary of water-quality indicators showing improvement or deterioration at the Miami and Tamiami Canal stations over time

[Based on trends determined at a p-value of 0.10]

Water-quality constituent	Time period	Trend	Effect on water quality
Miami Canal Station			
Chloride	1966-94	Upward	Deterioration
Magnesium	1966-94	Upward	Deterioration
Potassium	1966-94	Upward	Deterioration
Silica	1966-94	Upward	Deterioration
Sodium	1966-94	Upward	Deterioration
Sulfate	1966-94	Upward	Deterioration
Turbidity	1970-78	Downward	Improvement
Specific conductance	1966-94	Upward	Deterioration
Dissolved Solids	1966-94	Upward	Deterioration
	1976-94	Upward	Deterioration
	1987-94	Upward	Deterioration
pH	1966-94	Downward	Deterioration
Suspended sediment	1974-94	Upward	Deterioration
	1987-94	Downward	Improvement
Total ammonia	1971-94	Downward	Improvement
Total organic carbon	1970-81	Upward	Deterioration
Total phosphorus	1987-94	Downward	Improvement
Barium	1978-94	Downward	Improvement
Iron	1969-94	Downward	Improvement
Fecal coliform	1976-94	Downward	Improvement
Fecal streptococcus	1987-94	Upward	Deterioration
Tamiami Canal Station			
Chloride	1967-93	Upward	Deterioration
Fluoride	1967-93	Downward	Improvement
Magnesium	1967-93	Upward	Deterioration
Potassium	1967-93	Upward	Deterioration
Sodium	1967-93	Upward	Deterioration
Specific conductance	1967-93	Upward	Deterioration
Dissolved solids	1967-93	Upward	Deterioration
Dissolved oxygen	1967-93	Downward	Deterioration
Suspended sediment	1976-93	Upward	Deterioration
Total ammonia	1970-92	Downward	Improvement
Total nitrite plus nitrate	1975-85	Downward	Improvement
Barium	1978-93	Downward	Improvement
Strontium	1967-93	Upward	Deterioration

concentration plot for the Tamiami Canal station (fig. 8) illustrates the effect of constituent dilution with increasing discharge. The concentration of suspended sediment as a function of discharge at the Miami Canal station (fig. 7) indicates a slight increase with increasing discharge. A similar suspended-sediment concentration plot for the Tamiami Canal (fig. 8) shows slight dilution followed by an increase in sediment with increased discharge. An initial decrease in suspended sediment concentration with increasing discharge, followed by an increase in constituent concentration with increasing discharge, might reflect initial dilution of a point source followed by washoff of nonpoint source contaminants. The concentrations of total nitrogen and total phosphorus as a function of discharge at the Miami Canal station indicate the effects of dilution and washoff (fig. 7). The total nitrogen and total phosphorus plots (fig. 8) for the Tamiami Canal station show only initial dilution at lower discharges.

Major Inorganic Constituents and Physical Characteristics

Major inorganic constituents and physical characteristics were analyzed to determine water-quality trends at the Miami and Tamiami Canal stations during the period of record (1966-94) or other selected time periods. Upward trends of some major dissolved ions (chloride, magnesium, potassium, and sodium), specific conductance, and dissolved solids were detected at both stations; upward trends of silica and sulfate also were detected at the Miami Canal station. Downward trends of turbidity and fluoride were detected at the Miami and Tamiami Canal stations, respectively. Plots were generated to show the LOWESS lines of selected major inorganic constituents and other characteristics as a function of time at the Miami and Tamiami Canal stations (figs. 9 and 10).

Major inorganic constituents, as discussed in this report, include those cations (positively charged ions) and anions (negatively charged ions) that constitute the bulk of the dissolved solids and that commonly occur in concentrations exceeding 1.0 mg/L (milligram per liter). The major dissolved cations generally are calcium, magnesium, sodium, and potassium; the major anions are sulfate, chloride, fluoride, and those constituents contributing to alkalinity, which primarily are carbonate and bicarbonate (Hem, 1985). These charged species in solution contribute to the water's specific conductance, defined as the ability to conduct an electric current. Both dissolved solids and specific conductance are dependent on the degree of mineralization of the water and generally are indicators of inorganic water quality. Silicon, which is nonionic, contributes to the dissolved solids and is usually reported as silica.

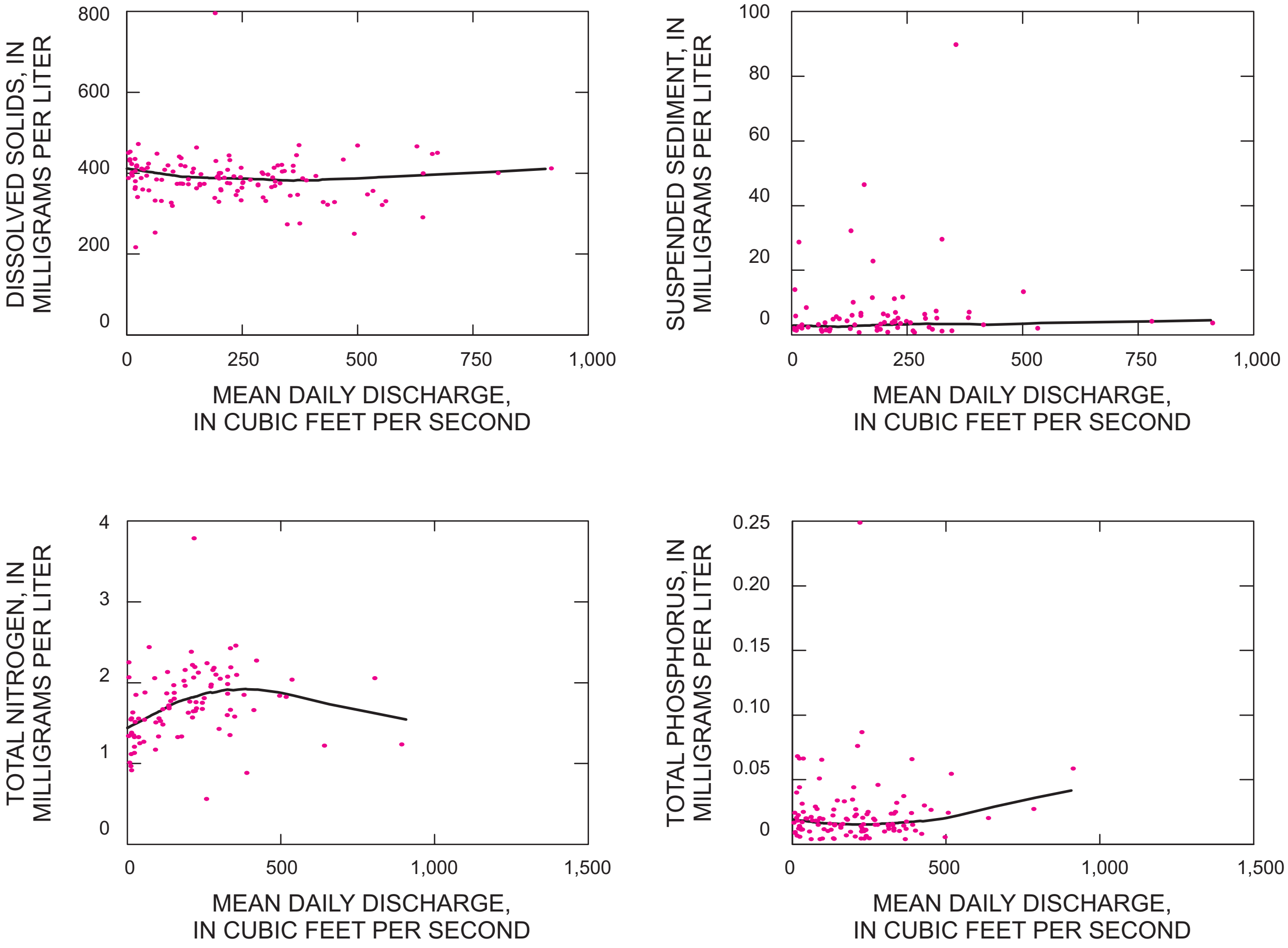


Figure 7. LOWESS lines of concentration as a function of discharge for dissolved solids, suspended sediment, total nitrogen, and total phosphorus at the Miami Canal station. Smoothness factor is 0.5.

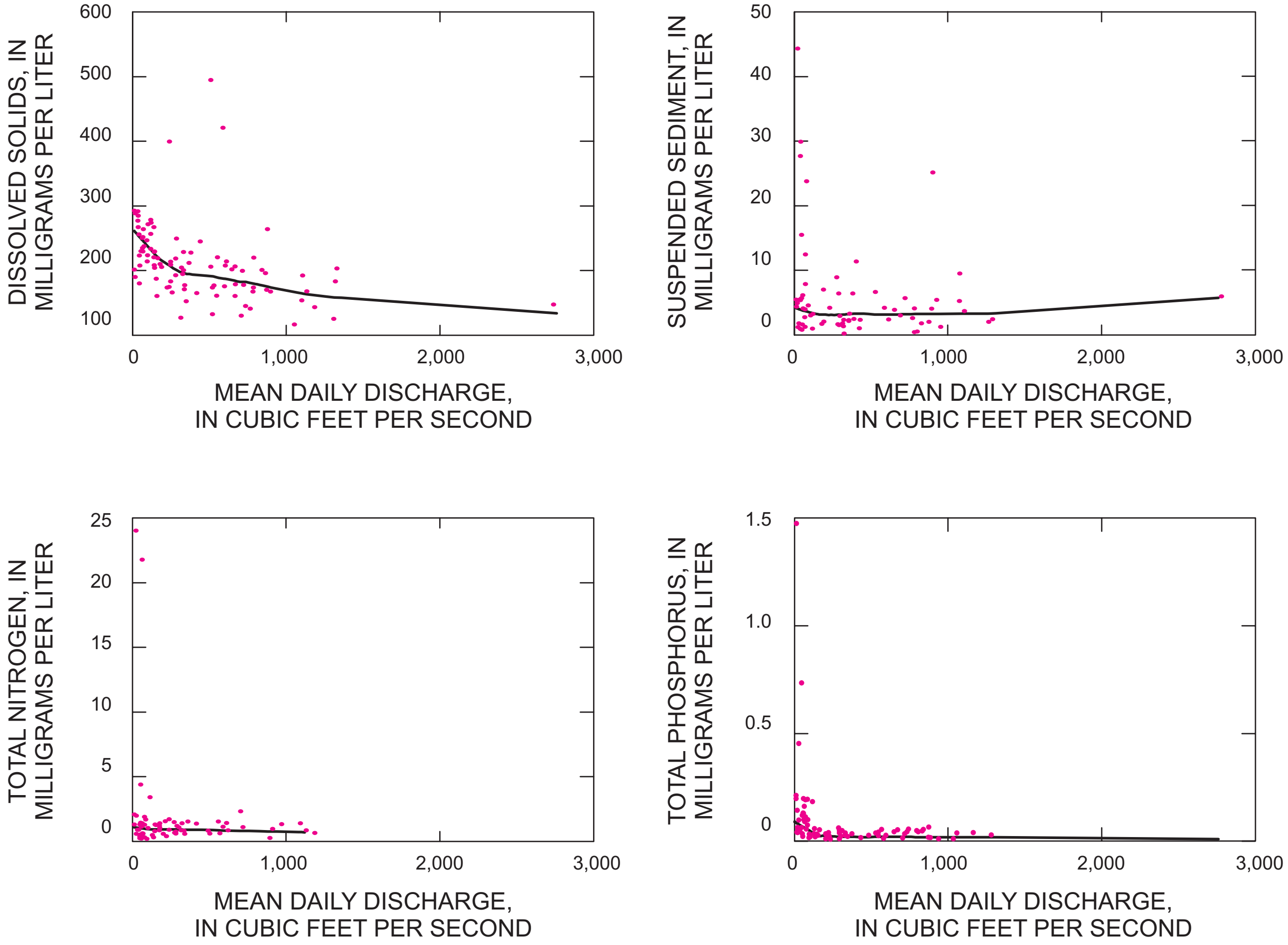


Figure 8. LOWESS lines of concentration as a function of discharge for dissolved solids, suspended sediment, total nitrogen, and total phosphorus at the Tamiami Canal station. Smoothness factor is 0.5.

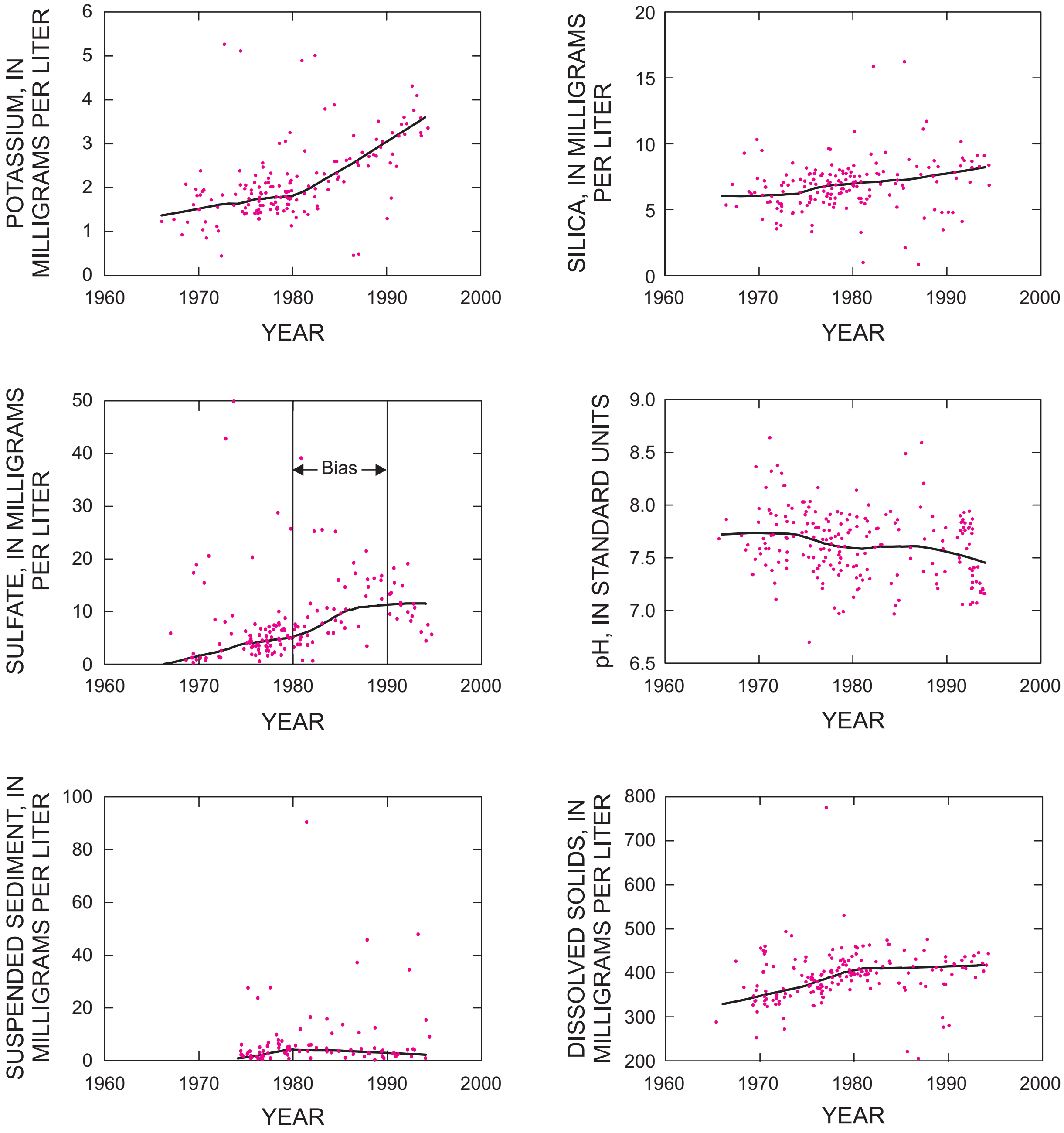


Figure 9. LOWESS lines of selected major inorganic constituents and other characteristics as a function of time at the Miami Canal station. Smoothness factor is 0.5.

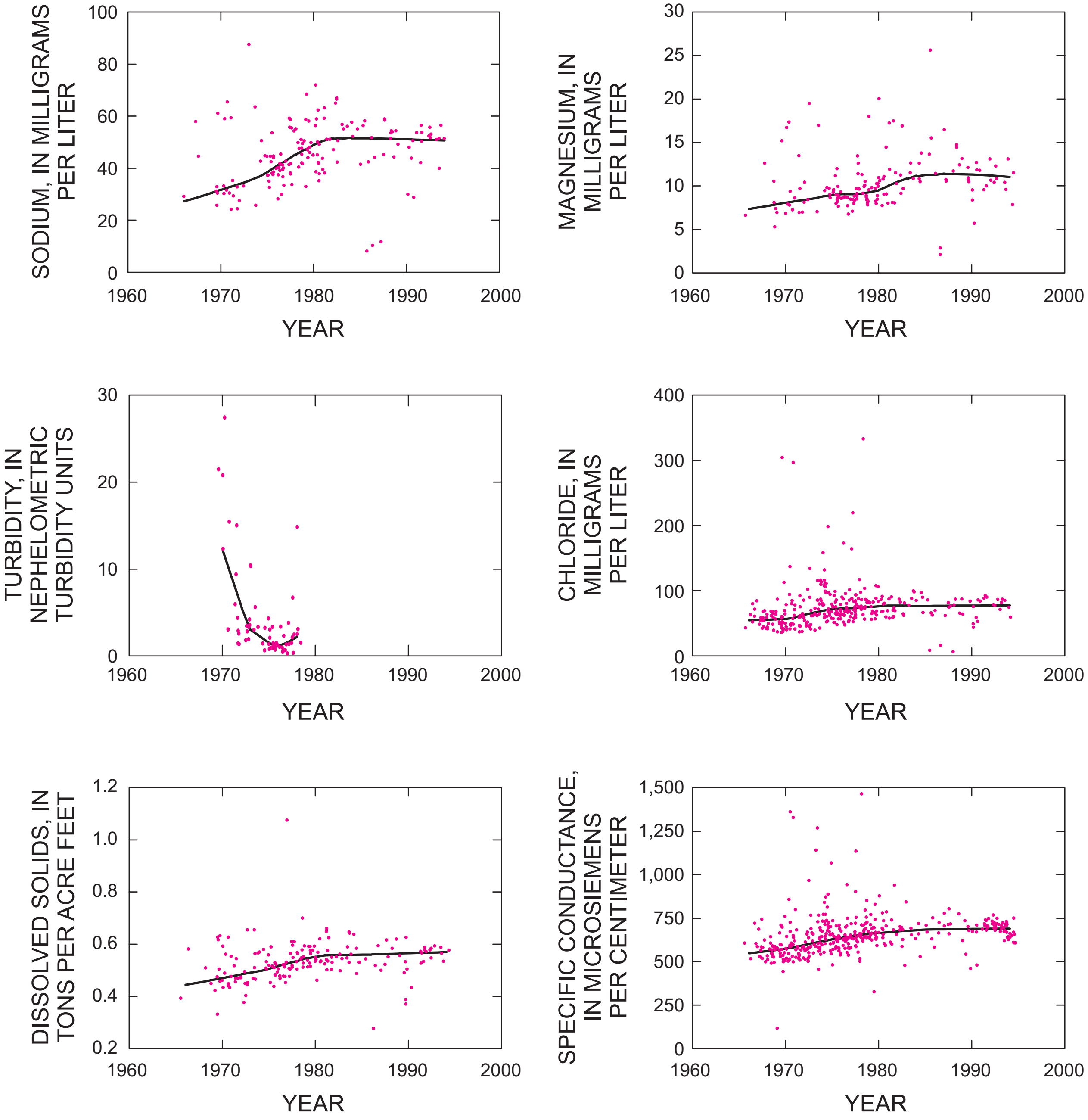


Figure 9. LOWESS lines of selected major inorganic constituents and other characteristics as a function of time at the Miami Canal station (continued). Smoothness factor is 0.5.

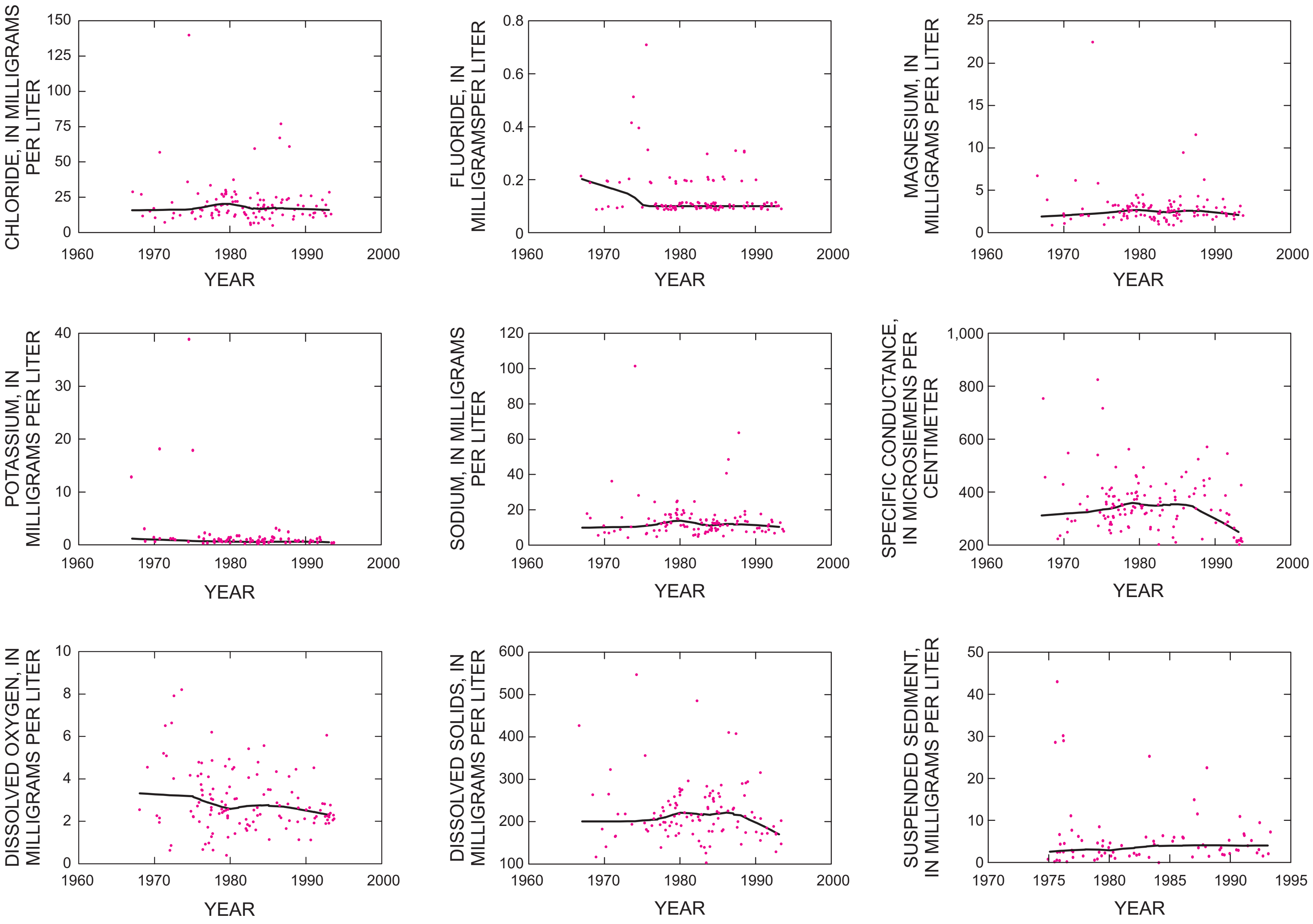


Figure 10. LOWESS lines of selected major inorganic constituents and other characteristics as a function of time at the Tamiami Canal station.

The highest rate of increase for the cations was determined for potassium (3.35 percent per year) at the Miami Canal station during 1966-94. The LOWESS line of potassium shows an overall increase during the period of record, with a rather abrupt rate of increase beginning in about 1980 (fig. 9). The rate of increase for potassium was 1.34 percent per year at the Tamiami Canal station (table 4). The rates of increase for sodium were 1.54 percent per year at the Miami Canal station (1966-94) and 1.45 percent per year at the Tamiami Canal station (1967-93); the rates for magnesium were 1.20 percent per year at the Miami Canal station (1966-94) and 1.48 percent per year at the Tamiami Canal station (1967-93). However, the LOWESS lines for sodium and magnesium at the Miami Canal station shows decreasing trends for the last several years of record (fig. 9). The cations potassium, sodium, and magnesium occur in fertilizers, and upward trends of these constituents may be related to fertilizer usage. Median concentrations of potassium, sodium, magnesium, and other cations were determined at the Miami and Tamiami Canal stations. Median concentrations of all these cations were higher at the Miami Canal station than at the Tamiami Canal station (tables 3 and 4).

The highest rate of increase for anions was determined for sulfate (4.74 percent per year) at the Miami Canal station in 1966-94 (table 3). Results also indicate rates of increase for chloride at the Miami Canal station (1.23 percent per year) and the Tamiami Canal station (1.07 percent per year) as presented in tables 3 and 4, respectively. However, trends for chloride at both stations are relatively flat for the last few years of record. An upward trend in chloride at the Miami Canal station (fig. 9) might be due to increased urban or agricultural activities, whereas the upward trend for this anion at the Tamiami Canal station might be due to discharge of more highly mineralized water from Water Conservation Areas 3A and 3B through structures S-343A, S-343B, and S-344 (fig. 1). An upward trend in sulfate at the Miami Canal station might be due to increased urban or agricultural activities, as well as sulfur-emitting discharges in atmospheric deposition. Smith and others (1987, p. 8), however, concluded that sources of sulfate in NASQAN stations across the Nation were more likely to be terrestial (rather than atmospheric) in origin because of the higher frequency of trends in basins where the statistical association between the ratio of atmospheric deposition to aquatic yield of sulfur is low. The LOWESS lines for sulfate and chloride at the Miami Canal station and for chloride at the Tamiami Canal station are shown in figures 9 and 10. The fluoride trend for the Tamiami Canal station shows an overall downward trend; however, there seems to be no trend for about the last 15 years of record (fig. 10).

Median concentrations of chloride, sulfate, and other anions were determined at the Miami and Tamiami Canal stations. Median chloride concentrations were higher at the Miami Canal station (70 mg/L) than at the Tamiami Canal station (17 mg/L). During periods of backpumping in the northern Everglades, highly mineralized connate ground water is drawn into the canals, which might account for the higher chloride concentrations (Parker and others, 1955, p. 733).

Median concentrations of sulfate were 5.8 mg/L at the Miami Canal station and 1.0 mg/L at the Tamiami Canal station. Caution is in order in the interpretation of the sulfate trend at the Miami Canal station (fig. 9); a known positive bias in sulfate concentrations was discovered in 1989 based on a turbidimetric method in laboratory use since 1982 (Schertz and others, 1994, p. 35). This bias was generally evident in water samples where sulfate concentrations were less than 75 mg/L and median concentrations were less than 20 mg/L, which correlated with the data from the Miami and Tamiami Canal stations (tables 3 and 4). Additionally, color values greater than 20 Pt-Co units (platinum-cobalt units) may also have contributed to the positive bias (tables 3 and 4). The LOWESS line for sulfate indicates an overall upward trend in sulfate over time (fig. 9), which coincides with the upward trends for other ions. What effect this bias may have had on the overall trend remains unknown.

Results indicate upward trends for silica and dissolved solids at the Miami Canal station (fig. 9), and a general upward trend for dissolved solids at the Tamiami Canal station (fig. 10). The rate of increase for silica was 0.82 percent per year at the Miami Canal station during 1966-94. The rates of increase for dissolved solids were 0.41 percent per year at the Miami Canal station during 1966-94 (table 3), and 0.78 percent per year at the Tamiami Canal station during 1967-93 (table 4). A slightly downward trend for dissolved solids occurred at the Tamiami Canal station during the last few years of record (fig. 10). There also were upward trends at the Miami Canal station during 1976-94 (0.38 percent per year) and 1987-94 (0.83 percent per year). The trend for dissolved solids in 1987-94 would not have been statistically significant at an alpha level of 0.05 as noted in table 3. Median concentrations of silica and dissolved solids were higher at the Miami Canal station than at the

Tamiami Canal station (tables 3 and 4), indicating greater mineralization. Upward trends in silica and dissolved solids tend to indicate an overall deterioration in water quality. High concentrations also can be detrimental to aquatic organisms.

Trends were determined for physical characteristics that include color, turbidity, and specific conductance. No upward or downward trends were determined for color; however, median values were 50 Pt-Co units at the Miami Canal station (table 3) and 30 Pt-Co units at the Tamiami Canal station (table 4), indicating higher concentrations of organic material in the Miami Canal water. This might be due to the organic peat soils found in the water-conservation and agricultural areas through which water in the Miami Canal flows as compared to the marls or sands prevalent in the Big Cypress National Preserve. A statistically significant downward trend for turbidity was detected at the Miami Canal station (fig. 9), with a rate of decrease of -2.37 percent per year during 1970-78 (table 3). This trend would not have been statistically significant at an alpha level of 0.05 as noted in table 3. The median turbidity value of 1.0 NTU (nephelometric turbidity unit) was the same at both stations (tables 3 and 4) and was well below the State freshwater standard (Florida Department of Environmental Protection, 1993) of less than or equal to 29 NTU above natural background conditions. The maximum turbidity values for the Miami and Tamiami Canal stations were 11 and 4.5 NTU, respectively. As for specific conductance, an upward trend was detected at both the Miami and Tamiami Canal stations during the period of record, with rates of increase of 0.88 and 1.22 percent per year, respectively, (tables 3 and 4). A downward trend for specific conductance was apparent at the Tamiami Canal station, but only during the last few years of record (fig. 10). Whereas median specific conductance values of 640 µS/cm (microsiemens per centimeter) at the Miami Canal station and 352 µS/cm at the Tamiami Canal station were below the State freshwater standard of 1,275 µS/cm (Florida Department of Environmental Protection, 1993), a maximum specific conductance of 1,350 µS/cm detected at the Miami Canal station did exceed the State standard. The upward trend in specific conductance indicates that an increase in dissolved solids occurred in both canals over time, which might be a result of natural phenomena or anthropogenic activities.

Water hardness is reported as an equivalent amount of calcium carbonate ($CaCO_3$) and is dependent primarily on calcium and magnesium. No Federal or State standards exist for hardness, but waters are classified as soft from 0-60 mg/L, moderately hard from 61-120 mg/L, hard from 121-180 mg/L, and very hard at greater than 180 mg/L (Hem, 1985, p. 159). Based on median concentrations, water is very hard (230 mg/L) at the Miami Canal station and is hard (150 mg/L) at the Tamiami Canal station (tables 3 and 4). Limestone present in the surficial aquifer system and Big Cypress National Preserve, where the stations are situated, is a natural source of calcium and magnesium, which affect hardness.

pH and Dissolved Oxygen

Trend determinations were made for the time-dependent constituents pH and dissolved oxygen. The characteristics of pH and dissolved oxygen are related through the process of photosynthesis, which results in the uptake of carbon dioxide and the manufacture of dissolved oxygen by aquatic plants. Both pH and dissolved oxygen may exhibit diel variations, and together may be positively correlated to be higher during daylight hours because of photosynthetic activity and lower during night-time hours because of plant respiration. For this study, dissolved-oxygen concentrations were determined only in the daytime, and thus, represent concentrations that occurred during photosynthetic activity. However, the downward trends in pH at the Miami Canal station (fig. 9) and dissolved oxygen at the Tamiami Canal station (fig. 10) did not correlate with an accompanying statistically significant trend in either dissolved oxygen at the Miami Canal station (table 3) nor pH at the Tamiami Canal station (table 4), which would be expected if the trends were dependent on photosynthetic activity alone.

Results indicate downward trends in pH (-0.17 percent per year) at the Miami Canal station during 1966-94 (fig. 9 and table 3) and in dissolved oxygen (-2.59 percent per year) at the Tamiami Canal station during 1967-93 (figs. 9 and 10; tables 4 and 5). There were, however, no statistically significant trends in dissolved oxygen at the Tamiami Canal station for the 1976-93 and 1987-93 periods. A downward trend in dissolved oxygen usually results from an increase in oxygen-demanding materials (most likely organic) in water, and generally is indicative of increased anthropogenic activities and deteriorating water-quality conditions. Median pH values were 7.6 at the Miami Canal station during 1966-94 and 7.5 at the Tamiami Canal station during 1967-93, which were well within the range (6.0-8.5) established by the Florida Department of Environmental Protection (1993) for freshwater standards. The median concentrations of dissolved oxygen were 3.3 mg/L (1987-94) and 2.7 mg/L (1967-93) at the Miami and Tamiami Canal stations, respectively, which were below the FDEP standard.

Suspended Sediment

Suspended sediment is material that is maintained in suspension in a water column due to the upward components of turbulent currents or material that exists in suspension as a colloid. This solid material may result from the disintegration of rocks and may include chemical and biochemical precipitates, as well as decomposed organic material. The concentration of suspended sediment in a stream is closely related to environmental and land-use factors (both urban and agricultural), intensity and volume of precipitation, geology and soil types, and physical characteristics of the stream. Suspended-sediment concentrations in southern Florida streams tend to be lower than those in other areas across the Nation, especially the western areas, which probably is due to the abundant vegetative cover that limits soil bank erosion. High suspended-sediment concentrations may adversely affect stream water quality by increasing turbidity, and thus, inhibiting photosynthetic activity. Suspended material, highly organic in nature, may increase the water column oxygen demand, resulting in hypoxic conditions. Additionally, high concentrations of suspended sediment may adversely affect aquatic life. Smith and others (1987, p. 13) found a close association between increasing trends in suspended sediment and basins in which land use results in high rates of soil erosion.

Results indicate a statistically significant upward trend (3.56 percent per year) in suspended sediment at the Miami Canal station during 1974-94, a statistically significant upward trend (4.08 percent per year) at the Tamiami Canal station during 1976-93 (but no detectable trend during 1987-93), and a statistically significant downward trend (-14.44 percent per year) at the Miami Canal station during 1987-94 (tables 3 and 4). The upward trends indicate some deterioration of water quality. At the Miami Canal station, the downward trend is an indication of improvement in water quality over the last few years of the period of record. Median concentrations of suspended sediment at the Miami and Tamiami Canal stations were 3.0 and 4.0 mg/L, respectively. The suspended sediment trends at the Miami Canal station during 1974-94 and 1987-94 were not statistically significant at an alpha level of 0.05 as noted in table 3.

Nitrogen, Phosphorus, and Carbon Species

Nitrogen, phosphorus, and carbon species are needed for the growth and maintenance of all organisms, especially plants. Water bodies that receive increased concentrations of nitrogen and phosphorus tend to have dense plant growth or algal blooms and usually become eutrophic (Hem, 1985, p. 128). Elevated concentrations of nitrogen and phosphorus can be attributed to municipal wastewater, industrial wastewater, or agricultural and urban runoff. Nitrogen occurs in natural waters in the form of organic nitrogen, ammonia, nitrite, and nitrate. Phosphorus also may exist in both organic and inorganic states. Organic carbon can be contributed to a water body through plant and animal waste. Total organic carbon is a measure of the dissolved and suspended organic carbon in a water sample.

Trends were determined for selected nitrogen, phosphorus, and carbon species at the Miami and Tamiami Canal stations. Statistically significant downward trends in total ammonia were detected at both stations (figs. 11 and 12). The rates of decrease for ammonia were -5.63 percent per year at the Miami Canal station during 1971-94, and -4.46 percent per year at the Tamiami Canal station during 1970-92 (tables 4 and 5). The median concentration of total ammonia was 0.1 mg/L at the Tamiami Canal station and 0.2 mg/L at the Miami Canal station, both exceeding the FDEP freshwater standard of 0.02 mg/L (Florida Department of Environmental Protection (1993).

According to Schertz and others (1994, p. 38), a known positive analytical bias occurred between 1980 and 1986 in the analysis of total ammonia and total ammonia plus organic nitrogen (Kjeldahl nitrogen). This bias was introduced by the mercuric chloride tablets used for field preservation of nutrient samples, and was caused by an additional positive matrix effect introduced by the sodium chloride carrier in the tablets. In 1986, the preservation of nutrient samples using the tablets was discontinued, and mercuric chloride ampoules were substituted. This bias, however, did not seem to affect the overall trends of total ammonia at the Miami and Tamiami Canal stations (figs. 11 and 12).

Total nitrite plus nitrate and total phosphorus were the only other species that demonstrated statistically significant downward trends. The rates of decrease were -12.94 percent per year for total phosphorus at the Miami Canal station during 1987-94 (fig. 11 and table 3) and -5.68 percent per year for total nitrite plus nitrate at the Tamiami Canal station during 1975-85 (fig. 12 and table 4). The statistically significant downward trend for total phosphorus (-12.94 percent per year) at the Miami Canal station coincides with the statistically significant downward trend for suspended sediment (-14.44 percent per year) over the same time period (table 3). However, the total phosphorus trend was not statistically significant at an alpha level of 0.05 as noted in table 3. A strong statistical association (p-value less than 0.001) exists between trends in total phosphorus and suspended sediment at NASQAN stations across the Nation (Smith and others, 1987, p. 13). The coexisting downward trends in total phosphorus and suspended sediment may also suggest that the source of total phosphorus was primarily nonpoint in origin over this time period. These decreasing trends indicate a general improvement in water quality, perhaps due to a reduction in agricultural or urban runoff. Median concentrations of the nitrogen species were higher at the Miami Canal station, which may be attributed to flow through the highly urbanized and agricultural areas. Median concentrations of total phosphorus (0.02 mg/L) were the same at both the Miami and Tamiami Canal stations during all time periods.

The only statistically significant upward trend (2.83 percent per year) was reported for total organic carbon at the Miami Canal station during 1970-81 (fig. 11 and table 3). Median concentrations of total organic carbon were 20 mg/L at the Miami Canal station (table 3) and 13 mg/L at the Tamiami Canal station (table 4). The higher concentration at the Miami Canal station probably reflects the influence of the highly organic soils prevalent in the agricultural and water-conservation areas.

Trace Metals

Trace metals commonly occur in concentrations less than 1.0 mg/L (Hem, 1985, p. 129), and in small amounts, some may be toxic to plants, animals, and humans. Many trace metals occur naturally in the environment, but some may be present

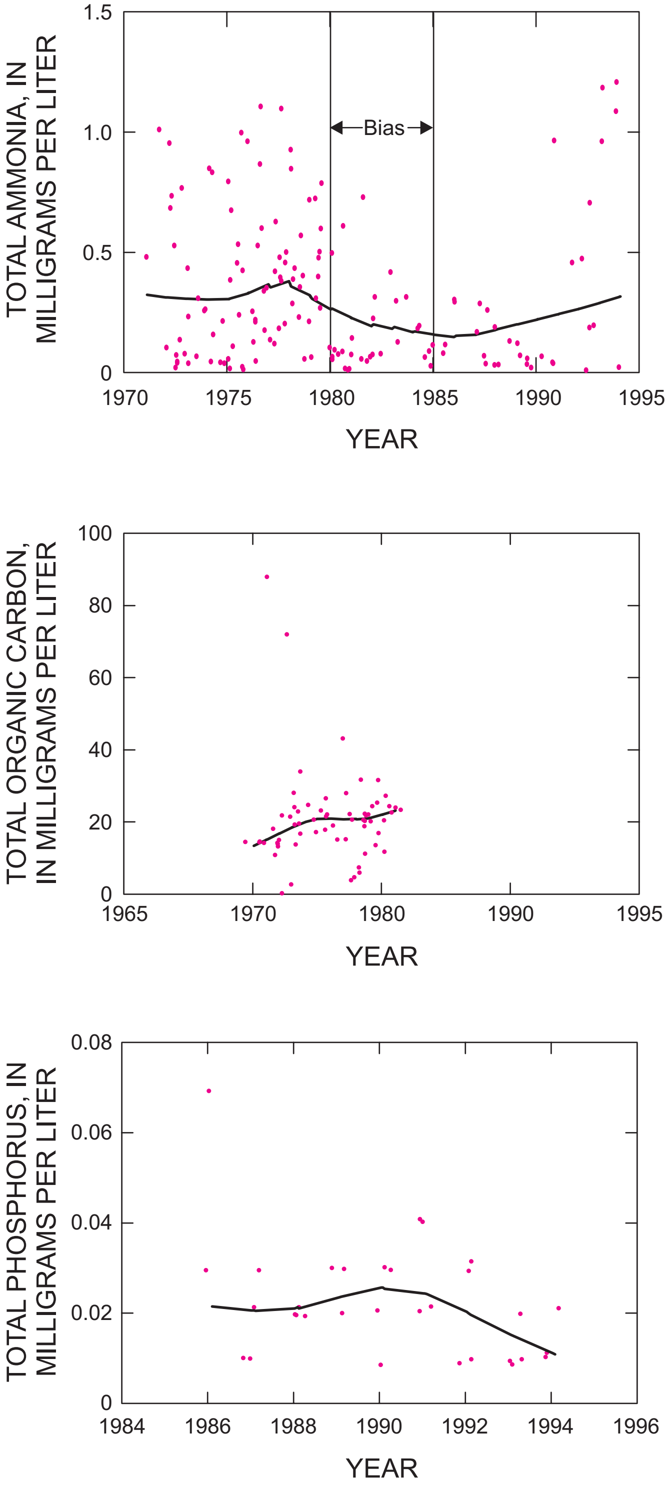


Figure 11. LOWESS lines of total ammonia, total organic carbon, and total phosphorus as a function of time at the Miami Canal station. Smoothness factor is 0.5.

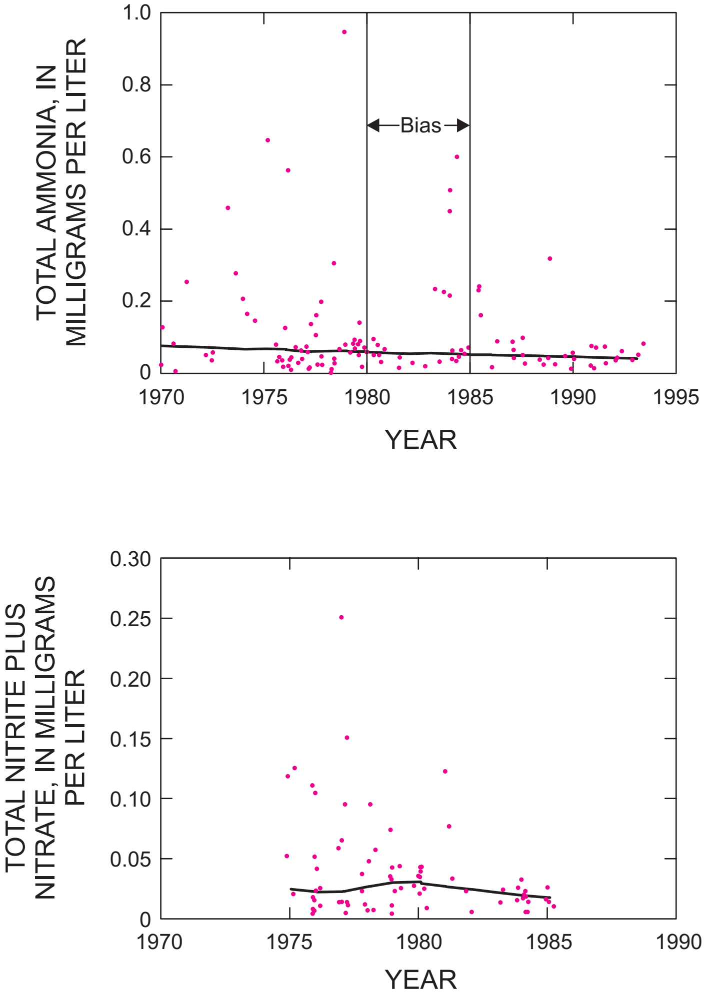


Figure 12. LOWESS lines of total ammonia and total nitrite plus nitrate as a function of time at the Tamiami Canal station. Smoothness factor is 0.5.

as a result of urban, agricultural, or atmospheric sources. Trace metals can adsorb to the bottom sediments and reenter the water column due to changes in the oxidation/reduction potential. Trend determinations were made for dissolved barium, copper, iron, manganese, nickel, strontium, and zinc. Most samples were analyzed using the Seasonal Kendall censored procedure, which does not provide for removal of flow-related variability. Where censored data consist of greater than 5 percent of the total data values for a specific trace metal, the trend slopes might not be reliable, thus, the results were not recorded. Data sets for many of the water samples were too highly censored to make definitive trend analyses for the trace metals at the Miami and Tamiami Canal stations.

Results indicated statistically significant downward trends in barium and iron at the Miami Canal station (fig. 13 and table 3) and in barium at the Tamiami Canal station (fig. 14 and table 4). The downward trend in iron at the Miami Canal station was not statistically significant at an alpha level of 0.05 as noted in table 3. A weak trend also was detected for strontium at the Tamiami Canal station (fig. 14 and table 4), with a median concentration of 230 μg/L (micrograms per liter). The rates of decrease for barium were -3.86 percent per year at the Miami Canal station and -8.55 percent per year at the Tamiami Canal station. The concentration of barium in natural water is controlled by barium sulfate solubility, which usually limits the concentration of barium to a narrow range. Median concentrations of barium were 31 and 19.5 μg/L at the Miami and Tamiami Canal stations, respectively; these concentrations are not considered to be toxic to aquatic life.

The rate of decrease for iron was -2.43 percent per year at the Miami Canal station (table 3). The median iron concentration was 100 μg/L, which is well below

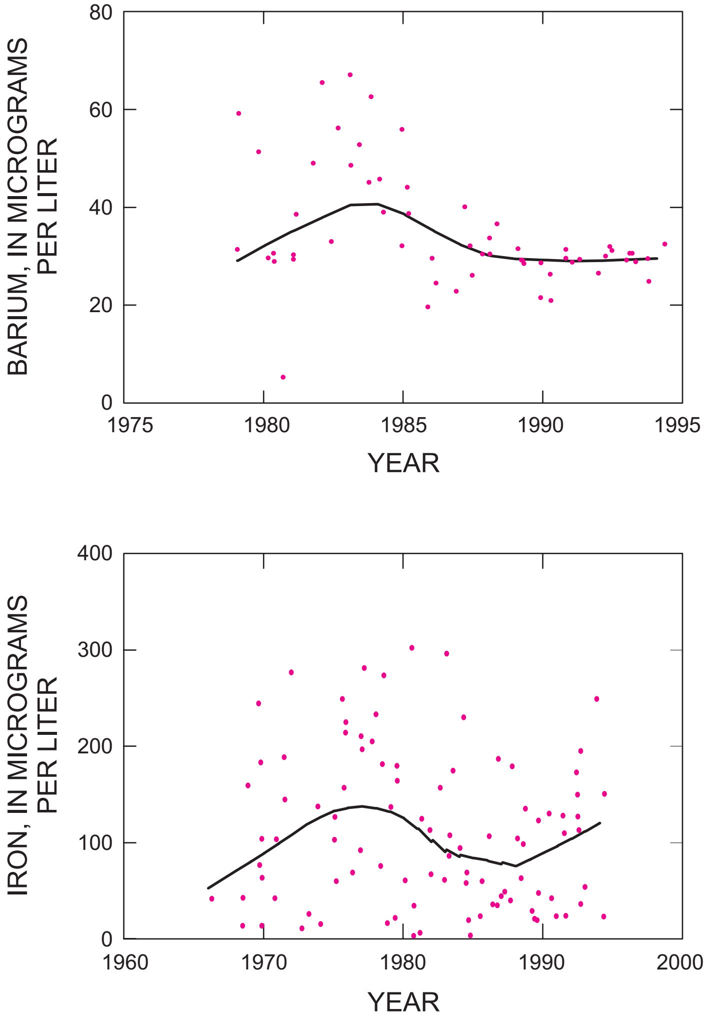


Figure 13. LOWESS lines of barium and iron as a function of time at the Miami Canal station. Smoothness factor is 0.5.

the FDEP freshwater standard of 1,000 µg/L (Florida Department of Environmental Protection, 1993). The solubility of iron in water depends on several factors including the oxidation/reduction potential and the pH of the natural system (Hem, 1985, p. 76).

Bacteriological and Biological Characteristics

Bacteriological determinations were made for two types of indicator bacteria, fecal coliform and fecal streptococcus, at the Miami and Tamiami Canal stations. The presence of these bacteria might be a signal that pathogenic disease-producing bacteria or viruses exist in the specific water body. There is a close association between fecal coliform density and Salmonella contamination, with a sharp increase in Salmonella detection when fecal coliform colonies exceed 200 colonies per 100 mL (milliliters) according to the U.S. Environmental Protection Agency (1976). Contamination with both types of bacteria may come from industrial/municipal and urban/agricultural runoff.

At the Miami Canal station, results indicate a statistically significant downward trend in fecal coliform (-3.84 percent per year) during 1976-94, but no detectable trend during 1987-94. A statistically significant upward trend in fecal streptococcus (45.86 percent per year) also was found at the Miami Canal station during 1987-94 (table 3). The downward trend in fecal coliform may indicate an improvement in water quality over time (1976-94), whereas the upward trend in fecal streptococcus may indicate a deterioration in water quality during the last few years of the period of record (fig. 15). Additionally, the trends for fecal coliform during 1976-94 and for fecal streptococcus during 1987-94 are not statistically significant at an alpha level of 0.05 as noted in table 3. The deterioration in

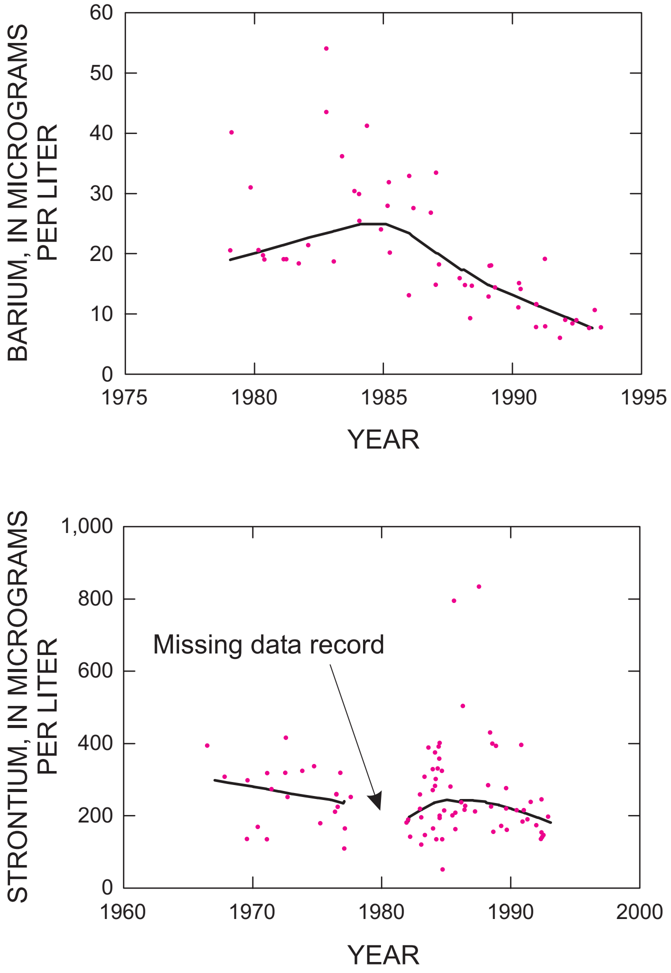


Figure 14. LOWESS lines of barium and strontium as a function of the Tamiami Canal station. Smoothness factor is 0.5.

water quality may be due to inadequately treated sewage or runoff from urban or agricultural areas. There were no statistically significant upward or downward trends in bacteriological characteristics at the Tamiami Canal station (table 4). Median concentrations of fecal coliform and fecal streptococcus were higher at the Miami Canal station than at the Tamiami Canal station (tables 3 and 4). This probably is because the Miami Canal traverses areas that are influenced more by urban and agricultural activities.

Biological determinations were made for phytoplankton at the Miami and Tamiami Canal stations. Phytoplankton consist of microscopic free-floating plants that are mostly blue-green algae, diatoms, or green algae. Their movements are dependent on the prevailing current within the water column, and their growth is dependent on solar radiation and nutrient concentrations within the water body. Heavy nutrient loads (especially phosphorus) to a stream, lake, or estuary may cause the water body to become eutrophic, with an increase in phytoplankton growth or algal blooms and the development of hypoxic or anoxic conditions, resulting in fish kills. Heavy phytoplankton growth might also result in undesirable aesthetic effects, manifested in unpleasant color and odor problems. Conversely, low phytoplankton growth might be an indication that a water body is oligotrophic or poorly nourished with respect to nutrients. Results indicate no statistically significant upward or downward trends in phytoplankton at the Miami and Tamiami Canal stations for the period of record (tables 3 and 4). Median concentrations of phytoplankton were 840 and 1,800 cells/mL (cells per milliliter) at the Miami and Tamiami Canal stations, respectively.

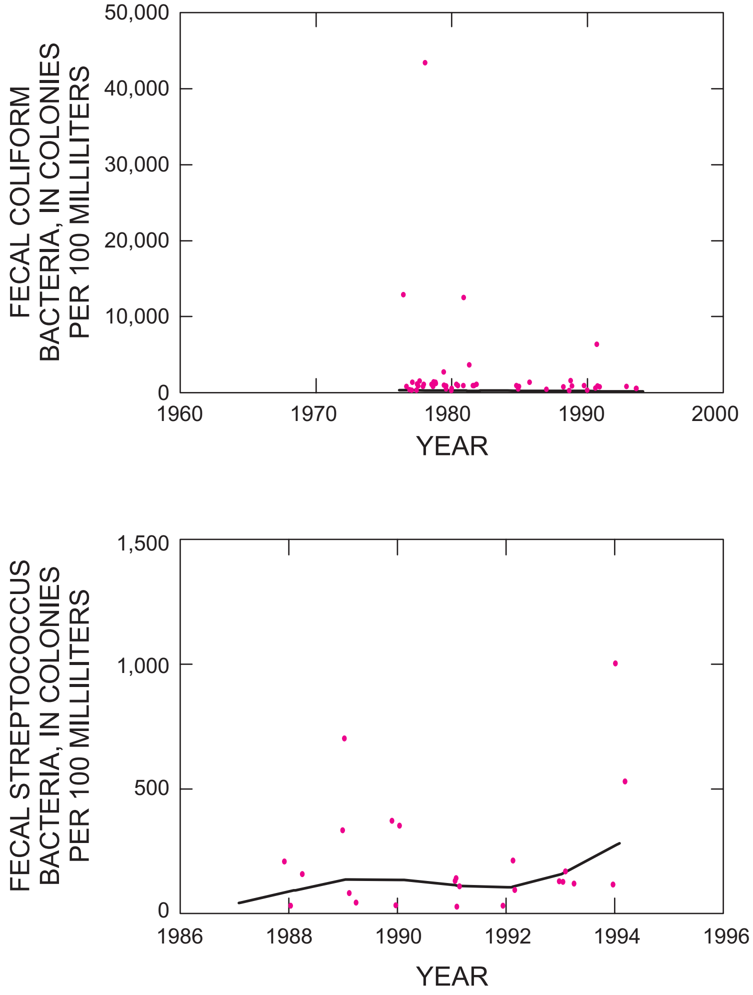


Figure 15. LOWESS lines of fecal coliform and fecal streptococcus bacteria as a function of time at the Miami Canal station. Smoothness factor is 0.5.

SUMMARY

A study was conducted by the USGS to analyze water-quality trends in two areas of southern Florida. Selected major inorganic constituents and physical characteristics; pH and dissolved oxygen; suspended sediment; nitrogen, phosphorus, and carbon species; trace metals; and bacteriological and biological characteristics were determined at two USGS daily discharge stations over a long-term period (1966-94). The stations used in this study are the Miami Canal station west of Biscayne Bay in Miami and the Tamiami Canal station along U.S. Highway 41 in the Big Cypress National Preserve in Collier County.

The principal tool used in this study was the computer program ESTREND, which utilizes the Seasonal Kendall trend test – a nonparametric, distribution-free test for monotonic change in water quality with time. The null hypothesis for this test assumes that the probability distribution of the random variable is independent of time. It is also assumed that the data values come from the same statistical distribution. This test allows for removal of extraneous variation in water-quality data caused by both seasonality and discharge. The test is a modification of the Mann-Kendall test and compares subsequent data values from the same seasons. The p-value, or probability of rejecting the null hypothesis of no trend, when there is in fact a statistically significant trend (p-value less than 0.10), is determined from a standard normal distribution. The test allows for the removal of flow-related variability for a water-quality record by applying the Seasonal Kendall trend test on a time series of residuals developed from concentration/discharge regression models or on unadjusted concentrations. The Seasonal Kendall slope estimator, which presents the rate of change in original units per year and percent per year is the median of all the pairwise comparisons from all the seasons. The ESTREND program also employs a Seasonal Kendall trend test for censored data and a maximum likelihood estimator for multiple censored data values.

Upward trends in the cations sodium, potassium, and magnesium were detected at the Miami and Tamiami Canal stations. Additionally, the anions chloride and sulfate showed upward trends at the Miami Canal station, whereas only chloride showed an upward trend at the Tamiami Canal station. Fluoride exhibited a downward trend at the Tamiami Canal station. The rate of increase for sulfate (4.74 percent per year) at the Miami Canal station was the highest rate of increase for any cation or anion demonstrating statistically significant trends. However, a known bias may have affected the analytical results for sulfate based on a turbidimetric method in laboratory use at the time. No trends in hardness were detected at either station.

A statistically significant downward trend for turbidity was detected at the Miami Canal station; however, the record spans only the 1970-78 period. No statistically significant trend for turbidity was detected at the Tamiami Canal station, nor for color at either station. Upward trends in specific conductance were detected at the Miami Canal station (1966-94) and the Tamiami Canal station (1967-93), which correlated with upward trends in dissolved solids at both stations during the same time periods. The Miami Canal station also showed upward trends in dissolved solids for the 1976-94 and 1987-94 periods. Median values for specific conductance at the Miami and Tamiami Canal stations were 640 and 352 µS/cm, respectively, which are below the FDEP standard of 1,275 µS/cm.

Results indicate a downward trend in pH at the Miami Canal during 1966-94. A similar downward trend in dissolved oxygen occurred at the Tamiami Canal station during 1967-93. Median pH values from the Miami Canal and Tamiami Canal stations were 7.6 and 7.5, respectively, both within the FDEP freshwater Class III standard range of between 6.0 and 8.5 for freshwater. The median concentrations of dissolved oxygen were 3.3 and 2.7 at the Miami and Tamiami Canal stations, respectively, which are below the FDEP standard.

Temporal trends in suspended sediment indicate a statistically significant upward trend at the Miami Canal station during 1974-94, a statistically significant downward trend at the same station during 1987-94, and a statistically significant upward trend at the Tamiami Canal station during 1976-93 period. Median concentrations of suspended sediment at the Miami and Tamiami Canal stations were 3.0 and 4.0 mg/L, respectively.

Nitrogen, phosphorus, and carbon species results indicate downward trends in total ammonia at both stations; however, a known bias occurred in ammonia analysis from the early to mid-1980's as a result of mercuric chloride tablets used for nutrient preservation. This bias, however, did not seem to have affected the overall trends. Median and maximum concentrations of total ammonia at the Miami and Tamiami Canal stations exceeded the FDEP standard of 0.02 mg/L. The only other statistically significant downward trend was for total phosphorus at the Miami Canal station during 1987-94. A statistically significant upward trend in total organic carbon was indicated at the Miami Canal station during 1970-81.

For the analysis of trace metals, statistically significant downward trends were indicated for iron and barium at the Miami Canal station during 1969-94 and 1978-94, respectively, and for barium (1978-93) at the Tamiami Canal station. There was a weak upward trend for strontium during 1967-93 at the Tamiami Canal station. The median concentration of iron at the Miami Canal station was 100 µg/L, which is below the FDEP standard of 1,000 µg/L.

Bacteriological analyses indicate a statistically significant downward trend for fecal coliform and a statistically significant upward trend in fecal streptococcus at the Miami Canal station. There were no statistically significant trends in either bacteria type at the Tamiami Canal station. Biological characteristics at both stations consisted of phytoplankton analyses, with no statistically significant trends in phytoplankton found at either station. Median concentrations of phytoplankton at the Miami and Tamiami Canal stations were 840 and 1,800 cells/mL, respectively.

A summary of temporal trends was done at the Miami and Tamiami Canal stations as indicators of either improvement or deterioration in water quality. At the Miami Canal station, improvement in water quality was indicated by 7 downward trends, and deterioration was reflected by 13 upward trends and 1 downward trend; at the Tamiami Canal station, improvement in water quality was reflected by 4 downward trends and deterioration in water quality was reflected by 8 upward trends and 1 downward trend. Most downward trends indicate improvement in water quality over time. However, the downward trend in pH indicates deterioration in water quality over time and the potential for harmful effects on aquatic life. Trends at the Miami Canal station were flow adjusted, however, a p-value of 0.10 was still used. Trends for turbidity, dissolved solids, suspended sediment, total phosphorus, iron, fecal coliform, and fecal streptococcus were determined not to be statistically significant at an alpha level of 0.05 at the Miami Canal station.

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