Water Quality in Big Cypress National Preserve and Everglades National Park—Trends and Spatial Characteristics of Selected Constituents

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Conversion Factors, Acronyms, Abbreviations, and Datums

Multiply	By	To obtain
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.59	square kilometer (km^2)
foot per day (ft/d)	0.3048	meter per day (m/d)
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)
cubic foot per day (ft^3/d)	0.028317	cubic meter per day (m^3/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
foot per year (ft/yr)	0.3048	meter per year (m/yr)

Acronyms and Abbreviations

BICY	Big Cypress National Preserve
DOM	Dissolved organic matter
EVER	Everglades National Park
μg/kg	micrograms per kilogram
μg/L	micrograms per liter
μS/cm	microsiemens per centimeter
mg/L	milligrams per liter
NPS	National Park Service
OFW	Outstanding Florida Waters
ONRW	Outstanding Natural Resource Waters
SOFIA	South Florida Information Exchange
SFWMD	South Florida Water Management District
TSB	Taylor Slough bridge
TN	Total nitrogen
TP	Total phosphorus
USGS	U.S. Geological Survey

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD29); horizontal coordinate information is referenced to the North American Datum of 1927 (NAD27).

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Abstract

Seasonal changes in water levels and flows in Big Cypress National Preserve (BICY) and Everglades National Park (EVER) affect water quality. As water levels and flows decline during the dry season, physical, geochemical and biological processes increase the breakdown of organic materials and the build-up of organic waste, nutrients, and other constituents in the remaining surface water. For example, concentrations of total phosphorus in the marsh are less than 0.01 milligram per liter (mg/L) during much of the year. Concentrations can rise briefly above this value during the dry season and occasionally exceed 0.1 mg/L under drought conditions.

Long-term changes in water levels, flows, water management, and upstream land use also affect water quality in BICY and EVER, based on analysis of available data (1959-2000). During the 1980's and early 1990's, specific conductance and concentrations of chloride increased in the Taylor Slough and Shark River Slough. Chloride concentrations more than doubled from 1960 to 1990, primarily due to greater canal transport of high dissolved solids into the sloughs. Some apparent long-term trends in sulfate and total phosphorus were likely attributable, at least in part, to high percentages of less-than and zero values and to changes in reporting levels over the period of record. High values in nutrient concentrations were evident during dry periods of the 1980's and were attributable either to increased canal inflows of nutrient-rich water, increased nutrient releases from breakdown of organic bottom sediment, or increased build-up of nutrient waste from concentrations of aquatic biota and wildlife in remaining ponds. Long-term changes in water quality over the period of record are less pronounced in the western Everglades and the Big Cypress Swamp; however, short-term seasonal and drought-related changes are evident.

Water quality varies spatially across the region because of natural variations in geology, hydrology, and vegetation and because of differences in water management and land use. Nutrient concentrations are relatively low in BICY and EVER compared with concentrations in parts of the northern Everglades that are near agricultural and urban lands. Concentrations of total phosphorus generally are higher in BICY (median values, 1991-2000, were mostly greater than 0.015 mg/L) than in EVER (median values, 1991-2000, less than 0.01 mg/L), probably because of higher phosphorus in natural sources such as shallow soils, rocks, and ground water in the Big Cypress region than in the Everglades region. Conversely, concentrations of chloride and sulfate are higher in EVER (median values in Shark River Slough, 1991-2000, mostly greater than 2 mg/L sulfate and 50 mg/L chloride) than in BICY (median values, 1991-2000, less than 1 mg/L sulfate and at most sites less than 20 mg/L chloride), probably because of the canal transport system, which conveys more water from an agricultural source into EVER than into BICY.

Trace elements and contaminants such as pesticides and other toxic organic compounds are in relatively low concentrations in BICY and EVER compared with concentrations in parts of the northern Everglades near agricultural and urban sources. Concentrations rarely exceeded aquatic life criteria in BICY and EVER. Atrazine was the only pesticide found in water that exceeded the criteria (in 2 out of 304 samples). The pesticides heptachlor expoxide, lindane, and p,p′ -DDE exceeded criteria in canal bed sediments in 1, 2, and 16 percent of the samples, respectively.

Introduction

The extreme southern tip of the Florida peninsula is an extensive subtropical wetland that includes the Everglades, the Big Cypress Swamp, and the coastal mangrove forests (fig. 1). The Everglades is a wide, flat expanse of grassland and tree islands that historically served as the primary drainage path for runoff from water overflowing the southern bank of Lake Okeechobee, as well as from direct rainfall. Water drains south and southwest toward Florida Bay and the Gulf of Mexico. The Big Cypress Swamp, west of the Everglades, is characterized by cypress domes, elongated bands of cypress trees called strands, and meandering marshy areas called sloughs. Water in the Big Cypress Swamp generally drains southwest towards the coast.

South Florida wetlands are dominated by a "sheetflow" flooding regime, thus named because the landscape becomes covered with a shallow (1-3 ft deep) and continuous expanse of water during the wet season (generally during the summer and fall) that flows at a slow velocity towards the coast. Land surface differences of less than 3 ft determine the distribution and abundance of plant communities (sawgrass prairie, marsh, pinelands, cypress, hardwood hammocks), and influence the volume, timing, and duration of surface-water flows. Drainage basins are often difficult to define because of the relative flatness of the south Florida landscape and the redirection of water with gates and pumps.

Major physical alteration of the landscape and associated water management practices, including canal and levee

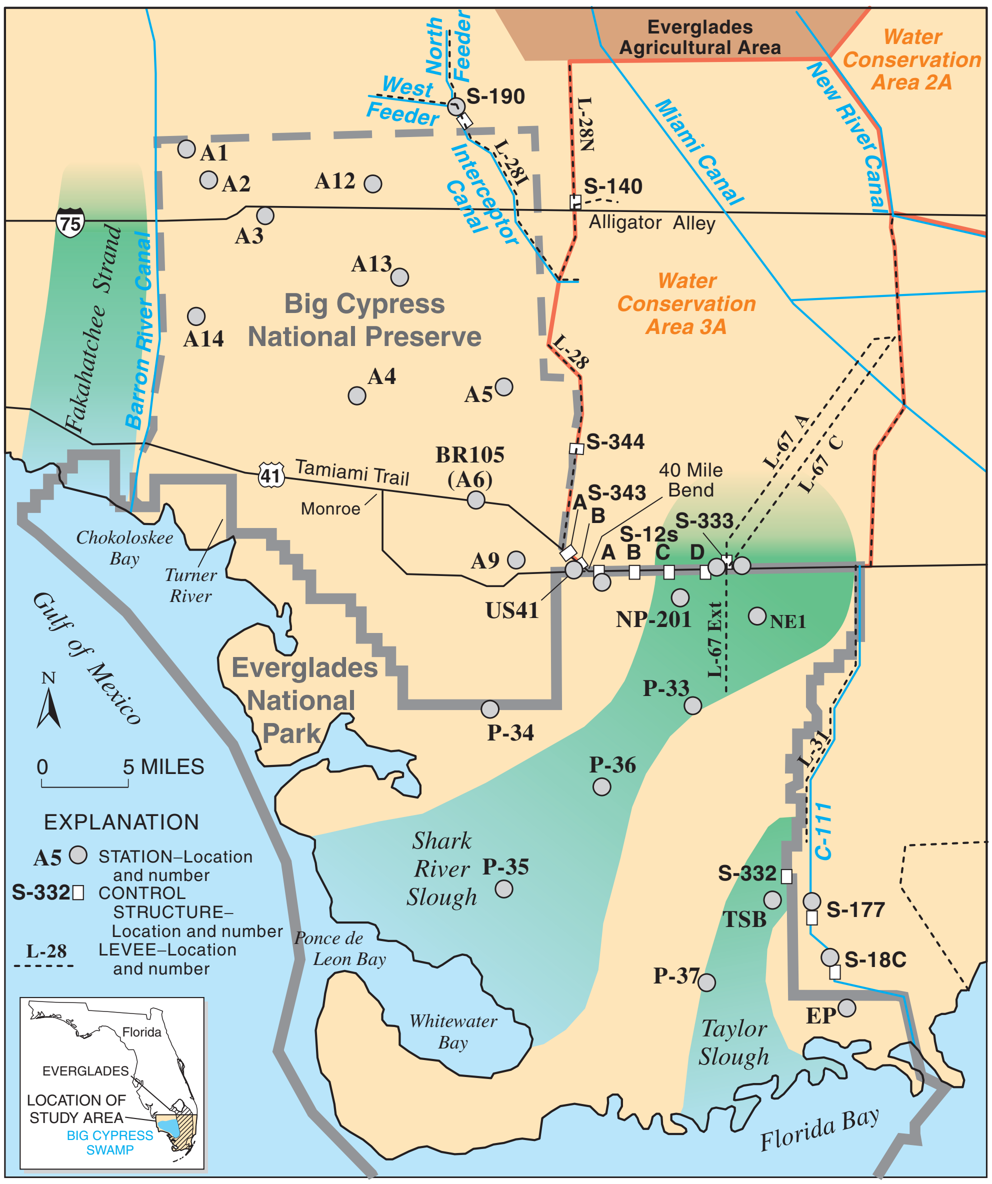


Figure 1. Map showing Big Cypress National Preserve and Everglades National Park and major features and sampling sites.

construction, agriculture and residential development, and operation of pumps and flood gates in the 1900's, have substantially altered the volume, timing, distribution, and quality of surface water in this system (fig. 2). Everglades National Park (EVER, established in 1947) and Big Cypress National Preserve (BICY, established in 1974) were both established by Congress to preserve and protect large areas of the south Florida ecosystem that had remained relatively intact and free of agricultural and urban development. Waters in BICY and EVER currently are designated by the State of Florida as Outstanding Florida Waters (OFW) and Outstanding Natural Resource Waters (ONRW), respectively. However, because these waters are located at the downgradient end of the altered system, they are subject to the effects of upstream water management practices. Water flow and water quality in EVER are most affected because the Park receives surface water from canals that drain nutrient-enriched upstream agricultural lands. In comparison, water quality in BICY has remained relatively unaffected by upstream land use because the original BICY boundary encompassed a predominantly self-contained, rain-driven watershed, in which headwater flows were diverted into bypass canals around and downstream of the Preserve. To the east of BICY, headwaters flowed into the northeast corner of Water Conservation Area (WCA) 3A through the L-28 Interceptor (L-28I) canal drainage system, and to the west of BICY, headwaters flowed from agricultural areas in the north down the Barron River Canal into Chokoloskee Bay (fig. 1). The threat posed to the quality of water in the Preserve by these upstream sources has increased recently because: (1) new areas to the northeast and west have been included in the preserve's boundaries by Congressional legislation and include lands that either abut or encompass these bypass canals; (2) future restoration plans include diverting a portion of the canal waters into the preserve that previously had bypassed it; and (3) land-use activities that impair water quality have intensified in the upstream watersheds. Similar concerns are raised for EVER because of its 1989

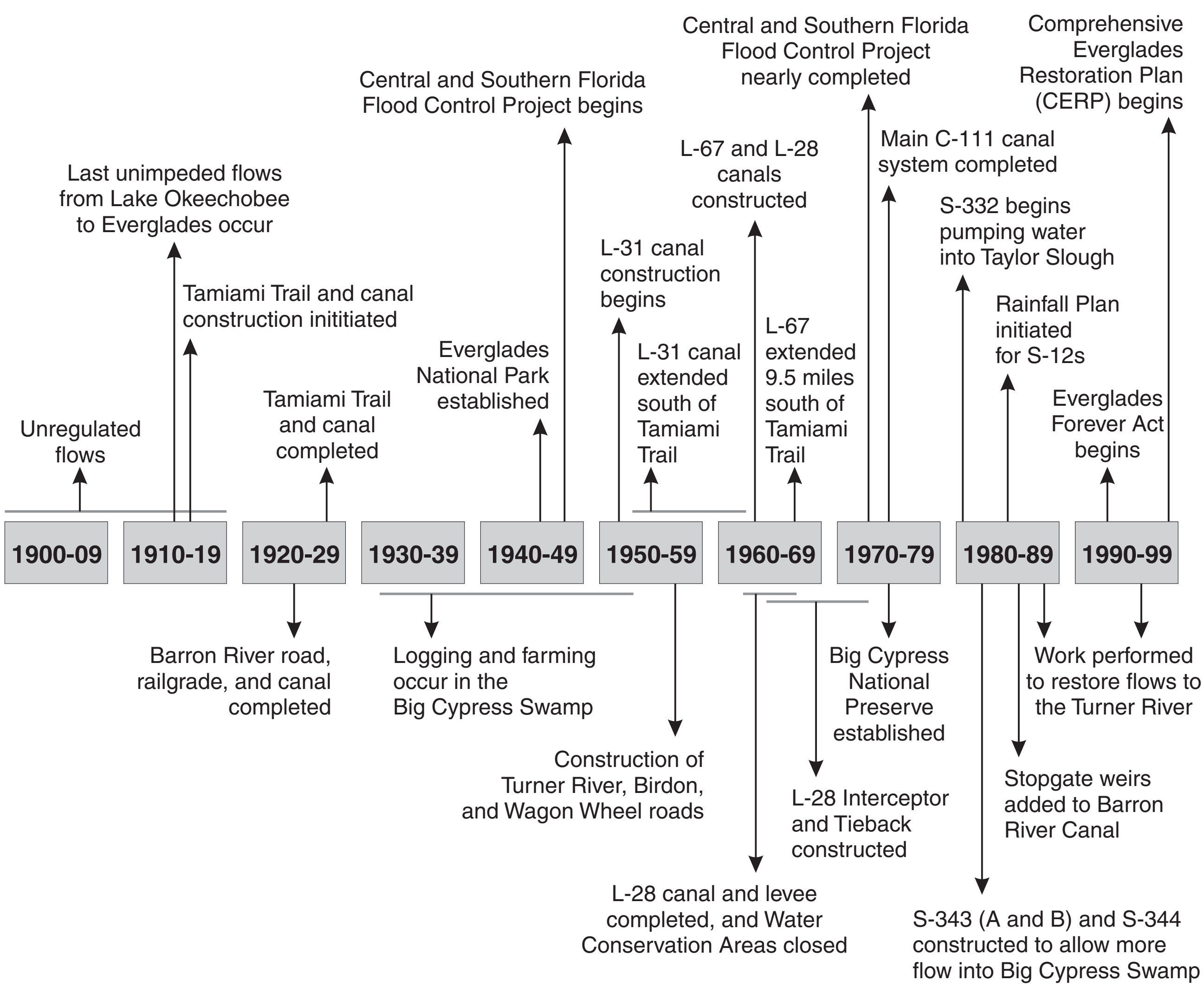


Figure 2. Timeline showing major human and climatic events that might affect water quality.

boundary expansion into the northeastern portion of Shark River Slough where future restoration efforts will increase water levels and flows. As a result, water quality in BICY and EVER will become increasingly vulnerable to degradation as land development (especially conversion to high intensity agricultural activities) along upstream boundaries is coupled with restoration activities that increase surface-water flows into the Park and Preserve.

Data Sources

Water-quality analyses and studies have been conducted in EVER for over four decades and have increased in number and scope in recent years. The most extensive water-quality database is maintained by the South Florida Water Management District (SFWMD) and includes data collected since 1984. SFWMD has recently begun publishing annual summaries of these data (for example, see South Florida Water Management District, 2000), including baseline conditions (October 1, 1987-September 30, 1988) and yearly exceedances from Class III criteria in EVER (Florida Department of Environmental Protection, 1996, Criteria for surface water; Class III: Recreation, propagation and maintenance of a healthy well-balanced population of fish and wildlife). In addition, SFWMD has monitored pesticide residues in water and sediment in canals that are near EVER for more than 10 years and now posts quarterly summaries of the data at http://www.sfwmd.gov/curre/pest/pestindex.htm. Water-quality data collection and studies in BICY have been fewer, but extend back to at least the early 1970's when the proposed Big Cypress "Jetport" triggered a flurry of environmental investigations (Duever and others, 1979; Klein and others, 1970 and 1975; U.S. Department of the Interior, 1969).

Networks of hydrologic monitoring stations (hydrostations) are maintained in BICY and EVER to measure the surface-water level (stage) and monitor water-quality conditions (fig. 1). Data have been collected at these sites since 1984, providing a historical baseline for assessing hydrologic conditions and making a wide range of management decisions. Collection and analysis of water-quality samples at BICY and EVER are performed under cooperative agreements with the SFWMD. Under these agreements, the National Park Service (NPS) collects water samples in the field and the SFWMD provides sampling equipment and laboratory analysis (Germain, 1998). In EVER, water-quality samples have been collected at nine "internal marsh" sites on a monthly basis since 1984. In BICY, water-quality samples have been collected at 10 "internal" sites on a bimonthly basis since 1995. In recent years, the number of sampling sites increased to 14. Additional water-quality data were analyzed by a private laboratory (Thornton Laboratories, Inc., Tampa, Florida) between 1988 and 1994, but not under the agreement with SFWMD. Water-quality data collected at the BICY and EVER stations have been archived at SFWMD, and the data from EVER have been summarized in the SFWMD Everglades Consolidated Report (2000).

In addition to the water-quality data currently being collected in the park and preserve, other agencies and individuals have collected water-quality data and information over the years. Some of these sources extend coverage of water-quality conditions back into the 1960's and 70's (Duever and others, 1979; Kolipinski and Higer, 1969; Kolipinski and others, 1971; Klein and others, 1970; McPherson, 1970; Klein and others, 1975; Waller, 1982). Some of this earlier information is included in this report to provide the longest record possible for water-quality conditions in BICY and EVER.

Objective and Scope

The overall objective of this report is to describe and summarize the results of analyses of surface water-quality data collected in freshwaters in or near EVER and BICY. The analyses include an evaluation of seasonal and long-term trends, and possible effects of hydrologic, climatic, and human-induced perturbations. Included in the report are: (1) an analysis of long-term trends for selected properties, such as specific conductance, chloride, sulfate, total phosphorus (TP), and total nitrogen (TN); (2) an evaluation of baseline water-quality conditions; (3) a comparison of selected water-quality indicators across the landscape; and (4) an evaluation of water-quality network design with regard to frequency of sampling and optimal number of sites and their locations**.** The database developed for this report is available at South Florida Information Exchange (SOFIA) web site at http://sofia.usgs.gov.

Data Analysis

Analysis of water-quality data focused on a comprehensive review of all water-quality data collected in BICY and EVER. Data from 1984 to 2000 were from the South Florida Water Management District (SFWMD) DBHYDRO database. Manual data entry was required for the water-quality data at BICY predating 1995. Other sources of water-quality data, primarily from the USGS, were reviewed and integrated into the analysis. Data related to water quality, such as water levels and flow, also were compiled. Land-use and water management changes in watersheds upstream of BICY and EVER (fig. 2) were evaluated to determine the effects of these changes on water quality. Data collected at selected canal sites near the parks also were included in the study.

We selected specific conductance, chloride, sulfate, TP, and TN for evaluation of long-term trends. Specific conductance and chloride were selected because they are the most chemically and biologically conservative water-quality indicators and tracers, and because they usually have a long and reliable analytical record. Sulfate was selected because concentrations naturally are low in remote freshwater wetlands in south Florida and thus, a good indicator of human activities. Sulfate also is important in mercury methylation, a major environmental concern in south Florida. TP was selected because concentrations naturally are low in freshwater wetlands that have not been affected by agricultural and urban development, and because TP is considered to be the primary growth-limiting nutrient for plants and controlling the ecological balance of the Everglades. TN was selected because nitrogen is an important micronutrient that can influence the ecological balance, and because TN serves as an indicator of ecological conditions, especially in tidal and estuarine waters.

Some water-quality constituents were compared to others using chemical logic checks to assess data quality. Additionally, chemical logic and statistical or graphical checks of the data were used together when feasible, to eliminate erroneous data or outliers that could bias interpretations.

Problems in Long-Term Trend Analyses

Analysis of water-quality data to determine long-term trends is confounded by three basic problems: (1) the variety and complexity of environmental causes of trends; (2) changes over time in the protocols and methods used to collect and analyze water samples; and (3) changes in frequency or timing of sampling. Natural changes in rainfall, water flow, and water level, and changes in water management practices, land use, and water treatment may produce water-quality trends. Hydrologic changes can be partially compensated for by using statistical computer programs, such as S-ESTREND (Slack and others, 2003), that fit a relationship between concentration and flow or between concentration and water level, and use the relationship to minimize effects of wet and dry seasons on concentrations. Consequently, an apparent trend in concentration during a long drought may not produce a statistically valid trend because the stage adjustment compensated adequately for the effects of stage on concentration. Changes in water management, however, may alter the adjustment or relation between water quality and flow over time, and can be evaluated using a residual time plot. Statistical computer programs such as S-ESTREND require sufficient data with suitable distribution throughout the period of interest to meet the requirements of S-ESTREND for reliable statistical analysis.

Analytical laboratory methods and reporting levels for constituents have changed over the years, and these changes can affect the results of some trend analyses; this is especially true if many of the concentrations are near to or less than the minimum reporting level for the analytical methods. For example, the laboratory procedures for some trace elements were changed in early 1994 when BICY switched from using a private laboratory to using the SFWMD laboratory. Consequently, some differences in concentrations before and after 1994 may be due to changes in the analytical method rather than to environmental changes. Minimum reporting levels also have varied over the years within and between agencies. The USGS reported TP concentrations as low as 0.01 mg/L in the 1970's and 1980's; in the mid-1980's, SFWMD began reporting TP concentrations as low as 0.004 mg/L. The TP concentrations, therefore, appear to decrease after 1985 because of the lower minimum reporting level, suggesting an apparent downward trend over time, even though the concentrations may have been the same during both periods. Additionally, trend determinations are more difficult if a large percentage of the data are reported as less-than values (censored data; data reported as less than a minimum reporting level for the method of measurement). Because all measurements have random errors and some have biases associated with them, low concentrations near the reporting levels can be influenced and biased by such errors even though the data are not censored. For example, if the earliest sulfate reporting level is less than 5 mg/L and the variability is +/- 3 mg/L, a "true" concentration of 3 mg/L could be reported as 6 mg/L. If in 1988, the analytical method changed and the reporting level was revised to less than 2 mg/L, a "true" concentration of 3 mg/L could be reported by the laboratory as 3 mg/L. Thus, the latter method could report one half the concentration of the former for the same sample. In addition to less-than data, low concentrations of some constituents were reported as zeroes instead of less-than values in the earliest data available. The factors discussed above are most likely to affect our trend analyses of sulfate and TP data for sites with the lowest concentrations. Data for specific conductance, chloride, and TN were well above the reporting levels, and therefore, were less influenced by changes in analytical methods. We have attempted to recognize and minimize such problems in the data analyses. The S-ESTREND programs have the ability to minimize some of the effects of changes in minimum reporting levels.

Changes in the frequency or timing of sampling can affect results of water-quality analyses. For example, if sampling frequency increases during a year, seasonal trends will be more obvious. An increase in sampling frequency also will increase the chance of collecting samples during extreme rainfall and storms or during droughts, both of which may result in a large range in water quality not evident with fewer samples.

Statistics

We used loess (locally weighted scatter-plot smoothing) plots (Slack and others, 2003) to evaluate long-term data and to show the generalized direction of change in concentration with time. Loess smoothing is especially useful for visualizing trends in data when the data are highly scattered or messy. Loess smoothing also was used for adjusting concentrations for flow or stage changes in order to reduce the normal seasonal changes in concentration due to variations in flow or stage. Without these adjustments, cyclical variations in concentrations due to seasonal or drought-related changes in flow or stage make it difficult to determine if there are real long-term trends in concentration due to other changes within the drainage basin. One of the advantages of using loess smoothing for flow and stage adjustment of water-quality data is that no advanced knowledge is needed about the relation between the two variables. Loess smoothing allows the user to describe a relation between two variables even when simple or commonly used equations do not describe the relation between them. Loess smoothing is accomplished by fitting a linear regression for many small parts of the x-axis (horizontal axis) and piecing together a line. The loess regression weights the close (local) data points more than more distant data points, and is similar to a moving average. When viewing plots of data and loess smooth lines, the reader may perceive a trend in concentration that is not statistically significant especially when the statistical programs adjust for severe wet and dry periods.

The uncensored seasonal Kendall test and Tobit regression procedures, provided with the S-ESTREND program, were used to analyze water-quality data for trends. A 95-percent confidence level ($p = 0.05$) was used for all of the statistical tests. The uncensored seasonal Kendall test requires that a minimum of 5 years of data be available, that censored (less than) data be no more than about 5 percent of the data set, and that there is only one censoring level. In addition, there are requirements for a minimum abundance of data in the first and last fifth of the time span being tested. This test allows water-quality data to be flow or stage adjusted. The uncensored seasonal Kendall test was used to test for trends in specific conductance, chloride, and TN. The uncensored seasonal Kendall test is considered robust; that is, it is not sensitive to outliers in the data (Schertz and others, 1991). The uncensored seasonal Kendall test permits the user to compare only data from the same seasons over the period of record, which reduces the effect of seasonal water-quality changes and improves one's ability to determine long-term trends. Three seasons were used in most cases. Comparisons were made between concentrations in the same seasons in the first year and each following year to count the number of increases and decreases. Then, comparisons were made between concentrations in the same seasons in the second year and each following year, and so on. For each season, a single value was selected for use in the seasonal Kendall test. For seasons with multiple values, the most central value with respect to time, that is also paired with discharge or stage, was selected to represent the season (Schertz and others, 1991). Because of this selection process, some of the data that are visible on a graph and that influence the shape of the loess smooth plots, may not be used by the seasonal Kendall test procedure. Consequently, graphs showing all of the data points over time may appear to show a trend that is not found to be statistically significant using this procedure.

The Tobit regression analysis was used to test for trends in sulfate and TP concentrations. This was necessary because the percentage of censored data was often more than the 5-percent limit suggested for the uncensored seasonal Kendall test, and because the sulfate and TP data sets usually contained more than one censoring level, making the data set unsuitable for the uncensored seasonal Kendall test.

Data requirements for using the S-ESTREND program sometimes prevented the use of the full period of record for statistical analysis. In addition, the S-ESTREND program assumes a monotonic trend (tends to increase, decrease, or have no trend, but not change from an increase to a decrease or vice versa) in concentration, which is not the case for sites where an increase in concentration was followed by a decrease. Consequently, we used loess smooth plots to decide where to break the data sets into shorter periods for trend analysis. Common linear regressions were used to look for trends in stage over time.

Trends in Rainfall, Water Levels, and Flows

Water quality in the BICY and EVER is affected by seasonal and long-term changes in rainfall (fig. 3), water levels, and flows. During the period when water-quality data are available, annual water conditions in the Everglades have been described as being dry in 1974-76 and 1985, and very dry in 1989-91 (Frederick and Ogden, 2001). Low water levels in the marshes and sloughs generally result in ponding and increased major ion and nutrient concentrations because of the enhanced breakdown of organic material and the build-up of wastes from aquatic and terrestrial wildlife that concentrate in and near the remaining surface water. Conversely, high water levels and flowing water may decrease concentrations by dilution or flushing major ions and nutrients out of the marsh, or may increase concentrations by introducing water enriched in major ions and nutrients from agricultural or urban sources. Tropical storms and hurricanes might be expected to affect water quality because of heavy rainfall and high winds, but it appears that such effects are minimal, at least in remote regions of EVER, where little change was seen in water quality after Hurricane Andrew passed over the park on August 24, 1992 (Roman and others, 1994).

Water levels and flows in the eastern Everglades have been altered by development and water management. The eastern Everglades (including the eastern part of Everglades National Park) encompasses a vegetative region know as the southern marl-forming marsh (Davis and others, 1994)—an area of rugged limestone at the surface (Miami Rock Ridge), marl marshes and prairies, mangrove-lined creeks near the coast, and a few deeper water sloughs, including Taylor Slough. Annual fluctuations in water levels were dampened in the 1970's (fig. 4) by changes in water management, primarily the construction of the L-31 canal and later the C-111 canal system.

Shark River Slough, the major drainage feature in the central Everglades, lies to the west of the marl-forming marsh of the eastern Everglades. The Slough originally extended about 100 miles in a southwesterly direction and drained into the mangrove forests and Ponce de Leon Bay of southwest Florida. The Tamiami Trail (US 41), constructed across the Slough in the 1920's, was the first impediment to the Slough's flow. Drainage and impoundment to the north of the Trail in the 1960's and 70's further isolated the Slough from its headwaters in the central Everglades. The L-67 canals, which were dug in the early 1960's, brought water from the northern Everglades to the newly constructed S-12 structures (S-12s), where waters flowed into EVER along the western side of the Slough. In 1966-67, the L-67 canal was extended south from the Tamiami Trail along what was then the eastern boundary of the park and conveyed

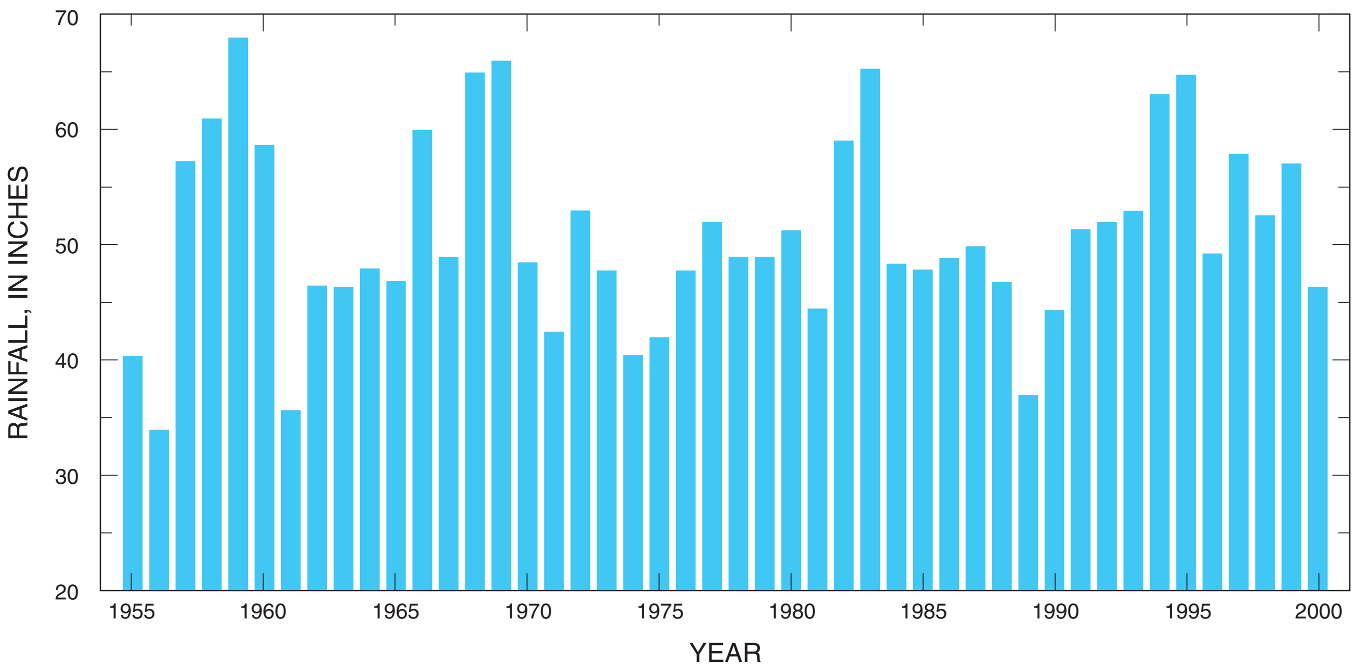


Figure 3. Average annual rainfall at 20 sites in south Florida.

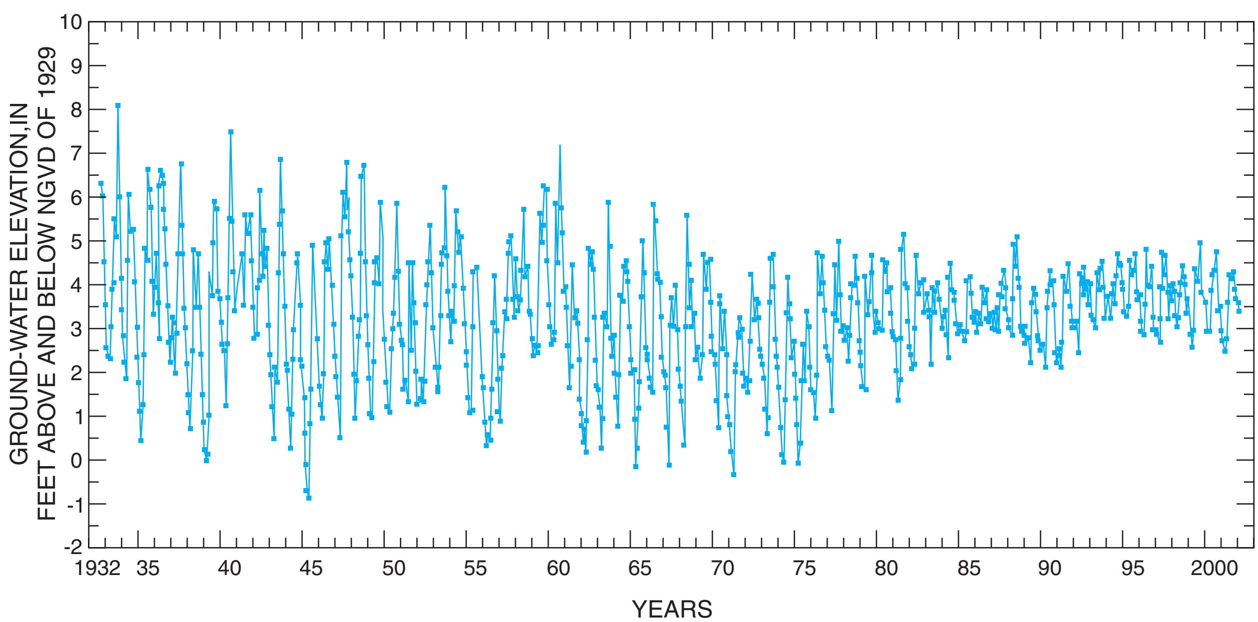


Figure 4. Average monthly water elevation in feet above NGVD 29 at wells S-196 and S-196A near Homestead, FL.

waters into the Slough 9.5 miles south of the Trail. In the early 1980's, the gates of the S-12s were left open, so waters flowed to EVER based on hydraulic gradient. In 1985, a Rainfall Plan was initiated so that water flowed to the park following a more natural pattern that reflected upstream rainfall. Compared to the high rainfall and flows in 1969-70, annual flows to EVER across the Tamiami Trail were low during the 1970's and 1980's (fig. 5). The years 1989 and 1990 were dry with little flow to EVER. Annual flows increased in the 1990's and peaked in 1996 (fig. 5). Also during the 1990's, proportionally more water passed through the eastern section of the Tamiami Trail (L-30 to L-67) into the Shark River Slough than in earlier years. Efforts currently are underway to divert even more water to the eastern part of the Slough to more closely mimic natural (predevelopment) flow patterns.

West of Shark River Slough lies the slightly higher lands of the western Everglades and the Big Cypress Swamp. These lands are a mosaic of cypress strands and sloughs, rocky marshes, and slightly higher pine forests. Disruption of natural flows has been minimal in the Swamp compared with the effects on Shark River Slough and the eastern Everglades. The Tamiami Trail, constructed in the 1920's, is regarded as having less effect on flows in BICY than in EVER. Canals in the Big Cypress Swamp are small and have less effect on hydrology than the larger canals in the Everglades. Water in the Big Cypress Swamp flows under the Trail through numerous culverts and bridges. Flows in the Big Cypress Swamp have been affected by the L-28 Interceptor Canal drainage system (fig. 1), which was constructed in the mid-1960's and blocked flows to the swamp from the Everglades, and by the Barron River Canal (fig. 1), which was completed in 1926 and intercepted flows from the Okaloacoochee Slough and Deep Lake Strand and discharged water to the coast near Everglades City. Structures (S-343A, S-343B, and S-344) were cut in the L-28 levee in 1983-85 to allow water to flow from the western Everglades (WCA 3A) into the eastern Big Cypress Swamp. Flows in the section of Tamiami Trail from 40-Mile Bend to Monroe (fig. 1) increased markedly in the mid-1990's, as a result of abundant rainfall and the construction of the S-343A, S-343B, and S-344 water control structures (fig. 5).

Water Quality in South Florida

Water quality in freshwater marshes and sloughs of BICY and EVER is characterized by low specific conductance (typically in the range of 200-400 microsiemens per centimeter (µS/cm) at 25° C), a predominance of calcium and bicarbonate ions, low nutrient concentrations, and high dissolved organic matter (DOM). Water quality in canals of the region is characterized by specific conductance usually greater than 400 µS/cm at 25° C, relatively more chloride, sodium, and magnesium ions; higher (darker) color, and higher DOM and nutrient concentrations than in marshes and sloughs (McPherson and others, 1976).

Seasonal changes in water quality in the wetlands of BICY and EVER are a result of natural processes, water management, and land-use activities. As water levels and flows decline during the dry season (November to May), ionic concentrations increase due to evaporation and geochemical and biological processes especially in ponded water (Waller, 1982). Drought and fire can cause geochemical changes in Everglades peat that

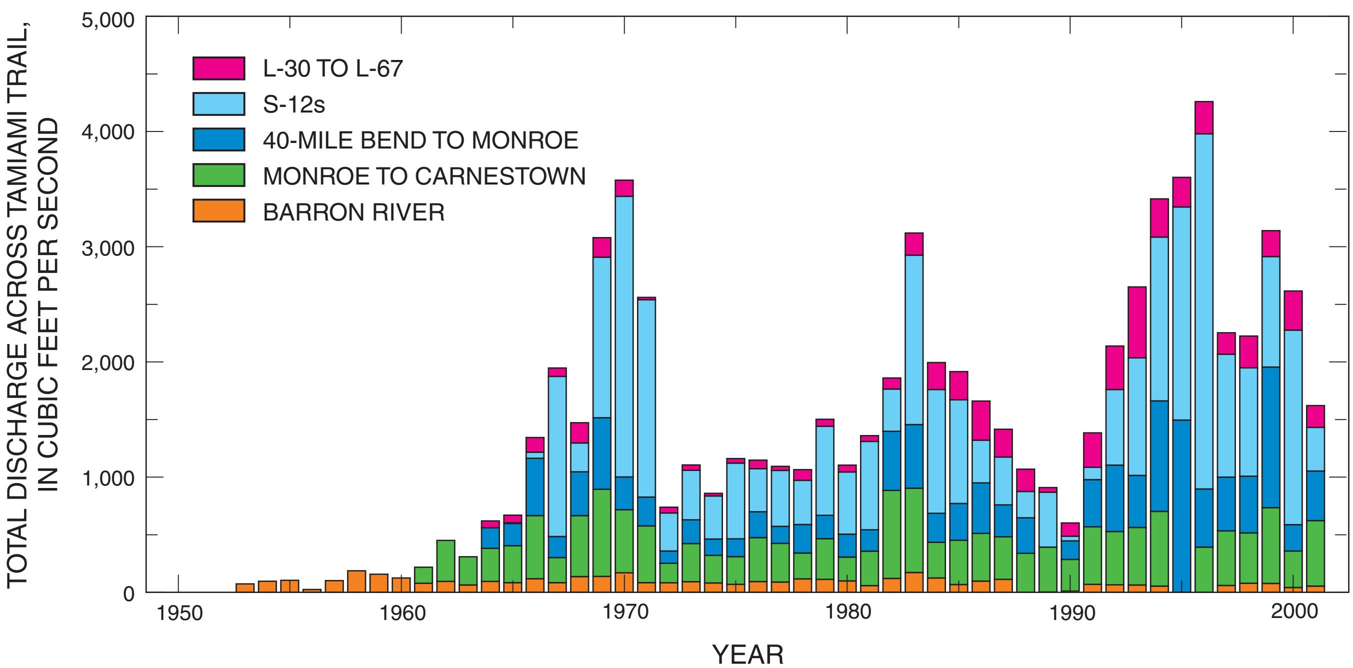


Figure 5. Average annual discharge under the Tamiami Trail. L-30 to L-67A; S-12s, 40-Mile Bend to Monroe, and Monroe to Carnestown, and Barron River. [Discharge measurements started during the 1960's in some sections.]

stimulates release of constituents such as sulfate and nutrients to surface waters after the peat is reflooded (Krabbenhoft and Fink, 2000). A decline in water level in these wetlands can result in greater inflows from the canals, changing wetland water quality (Waller, 1982; McPherson and others, 1970; Walker, 1997). Land-use activities in the urban and agricultural areas affect water quality in canals and in wetlands that receive the canal inflows. Concentrations of phosphorus at inflows to EVER (S-12 structures; S-12s) increased in the late 1970's and the 1980's (Walker, 1997). Walker attributed the increases to the expansion of agricultural land use, changes in water management, and long-term nutrient enrichment in the WCAs. In water years (October to September) 1985 and 1986, water managers kept the S-12s structures open and water levels in WCA-3A were low, which resulted in the increased transport of phosphorus–rich canal flow to EVER. After about 1991, concentrations of phosphorus at the S-12s decreased. Walker speculated that this decrease may reflect post-1991 changes in water management and water treatment, and shifts in agricultural crops away from vegetables. Rice and others (2002) estimated that implementation of best management practices in the Everglades Agricultural Area (EAA) reduced farm phosphorus loads an average of 55 percent between water years 1996-98.

Water-quality conditions in EVER sometimes exceed Class III water-quality criteria established by the State. The SFWMD (2000, p. 4-63–4-64) summarized baseline and yearly water-quality exceedances of Class III criteria for inflow and interior sites of EVER. An exceedance is a concentration or other water-quality value that is outside of the acceptable range specified in a criterion. Highest percentages of exceedance of the criteria were for dissolved oxygen (from about 24 to 82 percent), followed by total iron at interior sites (from about 4 to 20 percent). Small percentages of exceedances occurred for pH, specific conductance, total cadmium, total lead, total zinc, turbidity, and unionized ammonia.

Water Quality Changes Over Time

To address the questions, "Has water quality changed over time in BICY and EVER?" and "If changes have occurred, then have they been similar across the region?" selected sites in different regions that had long-term water-quality records were evaluated. These regions include Taylor Slough in the eastern Everglades (along the eastern boundary of EVER), Shark River Slough, and the western Everglades and Big Cypress Swamp.

Eastern Everglades

Taylor Slough Bridge

Taylor Slough bridge (TSB), located near the headwaters of the Taylor Slough, serves as a long-term (1960-2000) water-quality reference site for the eastern Everglades. Water discharged from S-332 (1980-2000) into the Slough several miles north of TSB increased in the mid-1990's (fig. 6). Waller (1982), using regression analysis, reported that there were no long-term changes in ionic concentrations in the Taylor Slough drainage from 1960 to 1977, but his analysis preceeded the large increase in discharge at S-332.

We evaluated trends in stage and water-quality constituents at TSB both graphically (fig. 7) and statistically for the period of record, 1960-2000. Statistically, stage, specific conductance, and chloride increased significantly (fig. 7A, B, C). Chloride concentrations ranged from less than 5 to 25 mg/L during most of the 1960's and 70's, except for a few higher values in the early 1960's, and increased significantly in the mid 1980's through early 1990's, with several values greater than 50 mg/L (fig. 7C). The loess smooth line for chloride concentrations decreased in the 1990's, but the decline is not yet statistically significant.

Sulfate concentrations at TSB ranged from about 1 to 62 mg/L, with most concentrations less than 20 mg/L. Statistical tests on sulfate indicate that concentrations increased significantly in the late 1980's and decreased significantly in the 1990's (fig. 7D). However, 28 percent of the sulfate data were less-than or zero values and there were changes in the reporting levels (0.0, <0.1, <5.0, < 2.0, <1.0 mg/L), indicating that the trend could be false.

Concentrations of TP at TSB generally were less than 0.02 mg/L, except in the late 1980's when values were sometimes higher. There was a significant downward trend from about 1988 to 2000 (fig. 7E). Like sulfate, the high percentage

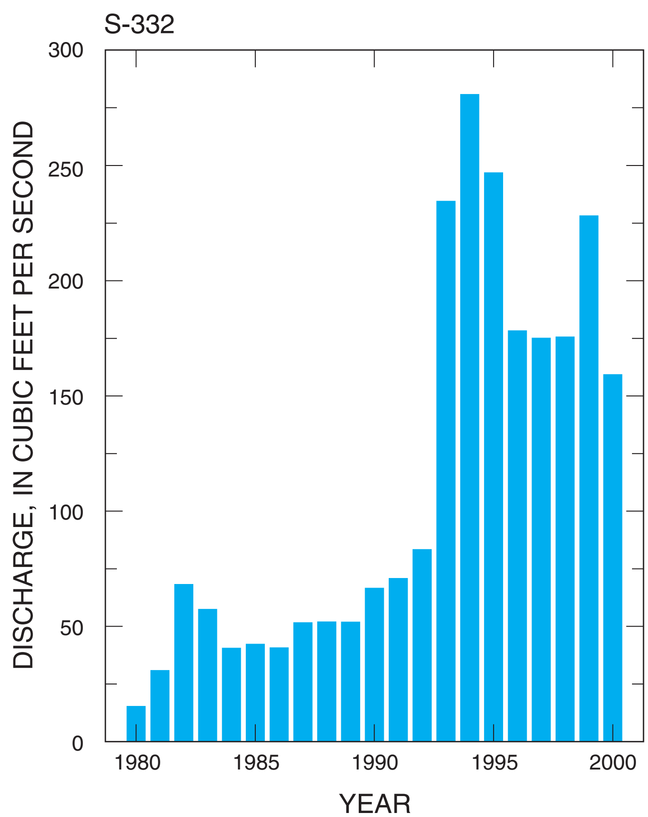


Figure 6. Average annual discharge at S-332.

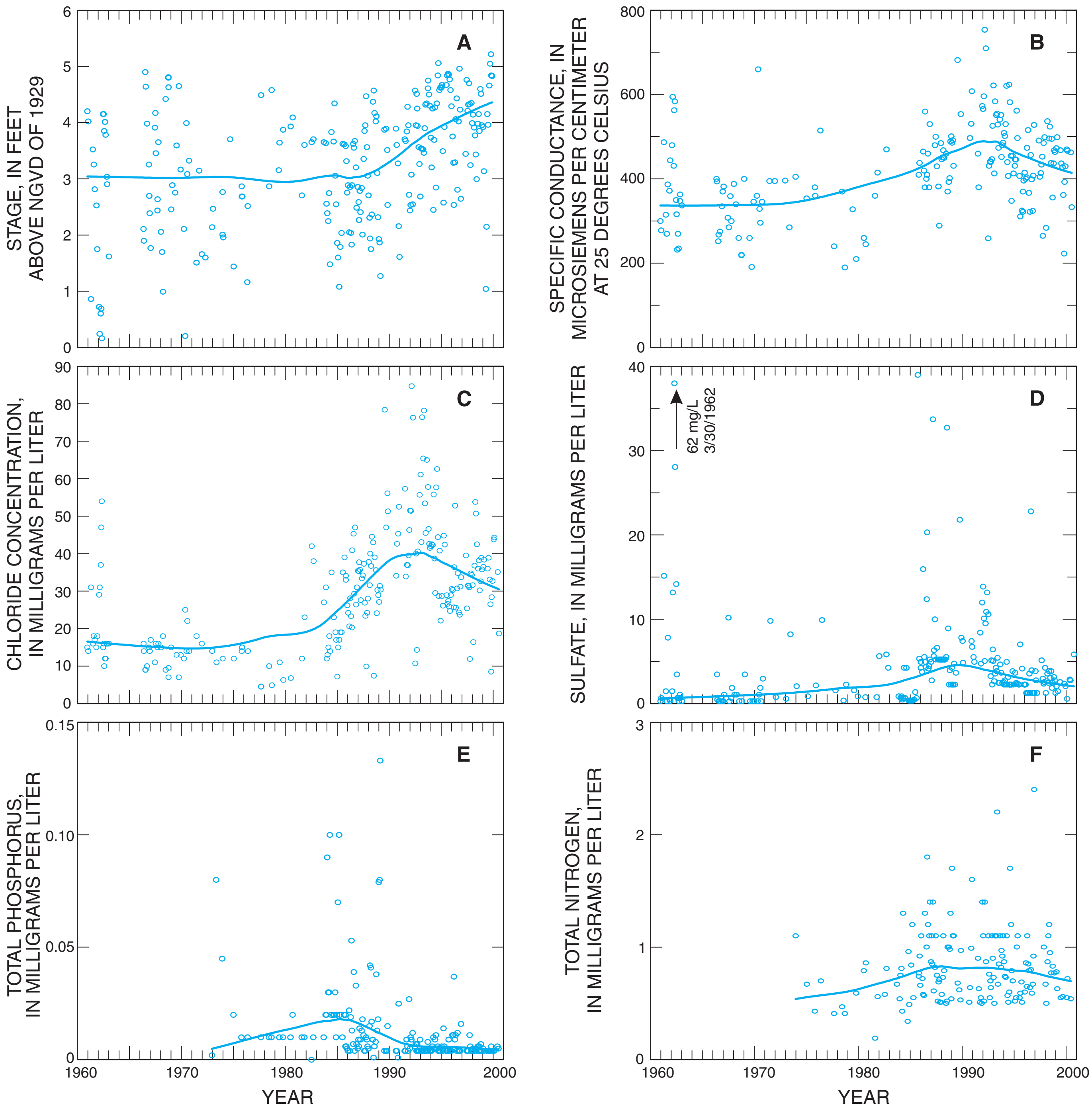


Figure 7. Stage (water level) and water-quality data with loess smooth lines for period of record at Taylor Slough Bridge. [Trends or lack of trends at the 95-percent confidence level follows. (a) Linear regression for stage gave a significant upward trend for 1960-2000. (b) Uncensored seasonal Kendall test for specific conductance using stage adjustment gave significant upward trends for 1966-1992 and 1966-2000 and no significant trends for 1993-2000. (c) Uncensored seasonal Kendall test for chloride with stage adjustment gave significant upward trends for 1966-2000, 1966-1993, and 1983-1993 and no significant trend for 1993-2000 and 1966-1983. (d) Tobit regression for sulfate gave a significant downward trend for 1989-1999; a significant upward trend for 1983-1990; and no significant trends for 1984-1998, 1981-1989, and 1981-1999. The trends may be influenced by changes in reporting levels for sulfate and may not be valid. (e) Tobit regression for total phosphorus gave a significant downward trend for 1978-2000; and no significant trends for 1986-1999; 1978-1985; 1978-1986; 1978-1987, and 1985-2000. The trends may be influenced by changes in reporting levels for total phosphorus and may not be valid. The clusters of data at the reporting levels are visible on the graph. (f) Uncensored seasonal Kendall test for total nitrogen with stage adjustment gave significant upward trends for 1980-2000 and 1984-1996 and no significant trends for 1982-1988, 1988-2000, 1980-1990, and 1990-2000.]

(27 percent) of less-than or zero values and changes in reporting levels (<0.01, < 0.02, 0.004, and 0.00 mg/L) may mean that the trend is not valid. Effects of the reporting levels can be seen by the clusters of data points at 0.01, 0.02, and 0.004 mg/L (fig. 7E). The higher concentrations of TP during the late 1980's were associated with low water levels (fig. 8A) and low flows in the Slough (fig. 8B). Higher phosphorus concentrations also could be related to increased nutrient inputs from upstream canal sources. Walker (1991) reported an increasing trend of over 20 percent per year in TP at S-332 (which discharges into the headwaters of the Slough) for the period 1983-89.

Concentrations of TN at TSB ranged from less than 0.5 mg/L to nearly 2.5 mg/L. TN increased significantly over the period 1980-2000 (fig. 7F), but not during other time periods that were tested (fig. 7F).

Shark River Slough

Water-quality records in Shark River Slough go back to at least 1959. Flora and Rosendahl (1981) reported that before construction of levee L-29 (in 1962) along the Tamiami Trail, water in the Slough was dominated by calcium and bicarbonate ions with a mean specific conductance of 272 µS/cm at 25° C, and a sodium-to-calcium ratio of 0.34; after 1962, mean specific conductance increased to 653 µS/cm at 25° C, and the sodium-to-calcium ratio changed to 0.88 in the late 1970's. Waller (1982) also described changes in water quality in the Slough during 1959-77; he attributed the increases in ionic concentrations and changes in water color to channelization that allowed more mineralized and darker colored water to flow from L-67A directly into Shark River Slough.

Several long-term water-level and water-quality sites (P-sites) are located along the length of the Shark River Slough south of Tamiami Trail. Trends for stage and water-quality constituents at one of these sites, P-33, were evaluated for the period of record, 1959-2000 (fig. 9). Stage increased significantly during the period; the increase was most noticeable in the 1990's (fig. 9A). Both specific conductance and chloride concentrations also increased significantly during the period (fig. 9B, C); however, chloride concentrations decreased significantly from 1993-2000 (fig. 9C). Increases in chloride from 1960 to the mid-1990's were due primarily to increased canal transport of high dissolved-solids water from the north by the L-67 Canals, which were constructed in 1962-63 (Waller, 1982; Walker, 1997). In 1966-67, the L-67 Canal extension was dug 9.5 miles south of the Tamiami Trail and delivered canal water to within 3 miles of site P-33. Dry periods in the 1960-90 time span also probably contributed to the high chloride values. During dry periods, the inflow of canal water probably increases relative to sheetflow from the interior of WCAs and surrounding marshes. The decrease in chloride concentrations in the 1990's probably is due to increased marsh inflow, fewer droughts, higher water levels, and changes in upstream water management and treatment.

Most concentrations of sulfate at site P-33 were less than 20 mg/L for the period of record, 1960-2000 (fig. 9D), except for a few high concentrations at low-water periods (fig. 10B). Sulfate tended to increase when flow through the L-30 to 40-Mile Bend reach of the Tamiami Trail increased (fig. 10A). Although sulfate concentrations graphically appeared to increase until the early 1990's, and then decrease until the end of 2000, trends were not statistically significant. Concentrations of sulfate increased with increasing flows under the Tamiami Trail (fig. 10A). Stober and others (2001) showed high concentrations of sulfate in the vicinity of P-33 during both wet and dry seasons of 1995 and 1996 (presumably transported to the vicinity by the L-67 Canal extension), but lower sulfate concentrations in 1999, when the L-67 Canal extension no longer transported water. Our data at P-33 (fig. 10B and 10C) have a few relatively high concentrations of sulfate (10-25 mg/L) in 1999; however, these data were collected at different times and a different location and are not directly comparable to those of Stober and others (2001).

Concentrations of TP at site P-33 showed a significant downward trend from 1972 to 2000; this trend probably is related to a decrease in the laboratory reporting level (from <0.01 to <0.004 mg/L) in the mid-1980's and a high percentage (19 percent) of less-than or zero values (fig. 9E). The effect of changes in reporting level is visible, with numerous values at 0.01 and 0.004 mg/L (fig. 9E). Concentrations remained low (less than 0.05 mg/L), other than a few high values (spikes) associated with sharp drops in water level (fig. 10C), over the entire period of record, even though the concentrations of TP increased at the S-12 inflows to EVER during 1977-89 (Walker, 1991). Site P-33 is about 3 miles from the nearest canal (L-67 Canal extension), and much of the phosphorus transported by the canal is probably taken up in the marsh before reaching P-33 (McPherson and others, 1976). The few high spikes of phosphorus concentrations associated with a sharp decline in water level (fig. 10C) may result from a combination of the following:

1. large phosphorus loading from canals that reaches P-33 during droughts;
2. breakdown of organic matter and the accumulation of biological waste in the marsh at low water levels when ponding may occur;
3. contamination of samples because of difficulty in collecting water samples in shallow water without disturbing phosphorus-rich bottom sediments.

It is also possible that increased sampling frequency (particularly at low stage) might result in more high-phosphorus concentrations by increasing the likelihood of sampling very high concentrations.

Western Everglades and Big Cypress Swamp

The two sites with the longest water-quality records in these regions are P-34 (in EVER just south of the BICY boundary) and the 40-Mile-Bend-to-Monroe section of the Tamiami

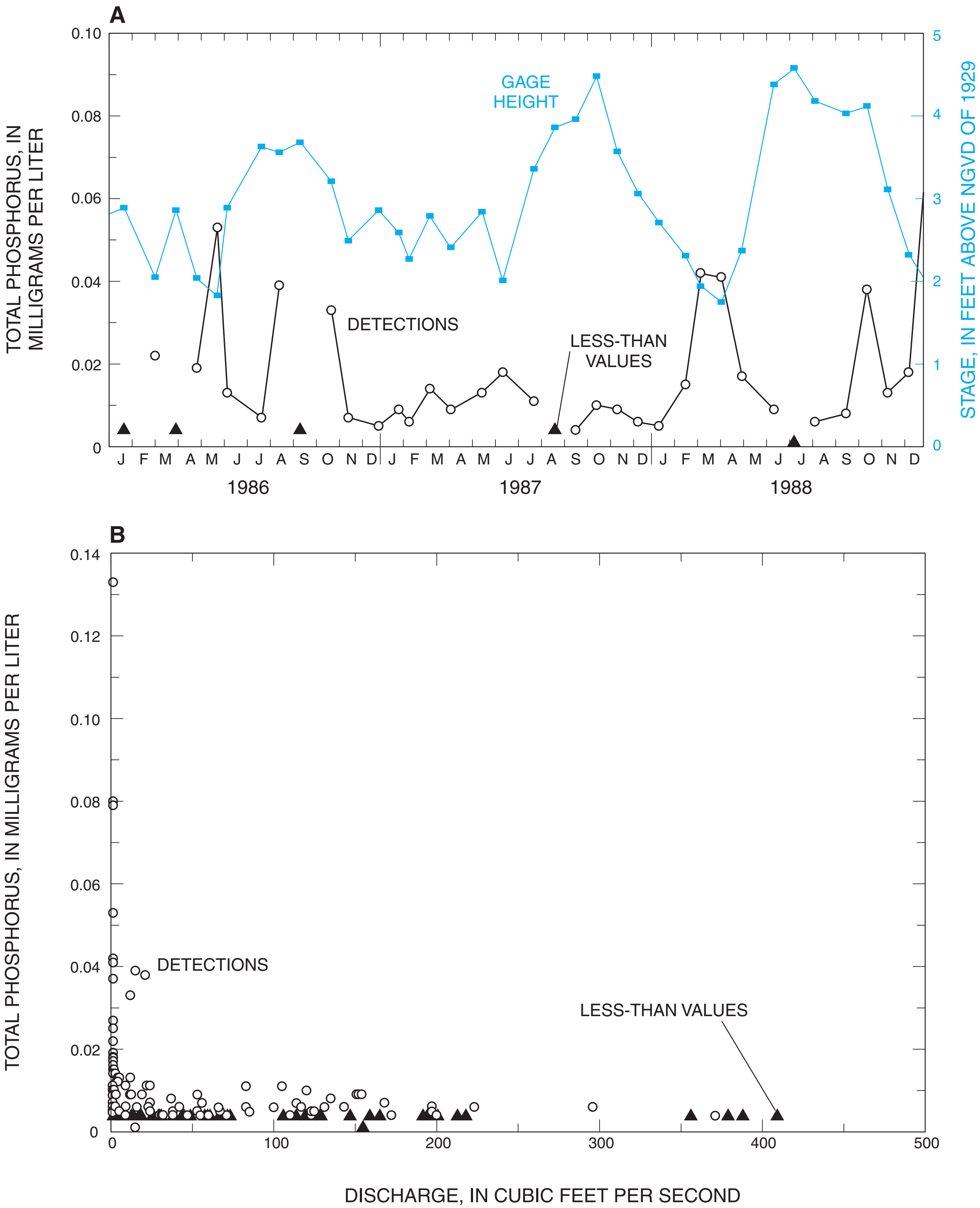


Figure 8. (A) Variation in stage and concentration of total phosphorus with time, and (B) variation of concentration of total phosphorus with discharge at Taylor Slough Bridge.

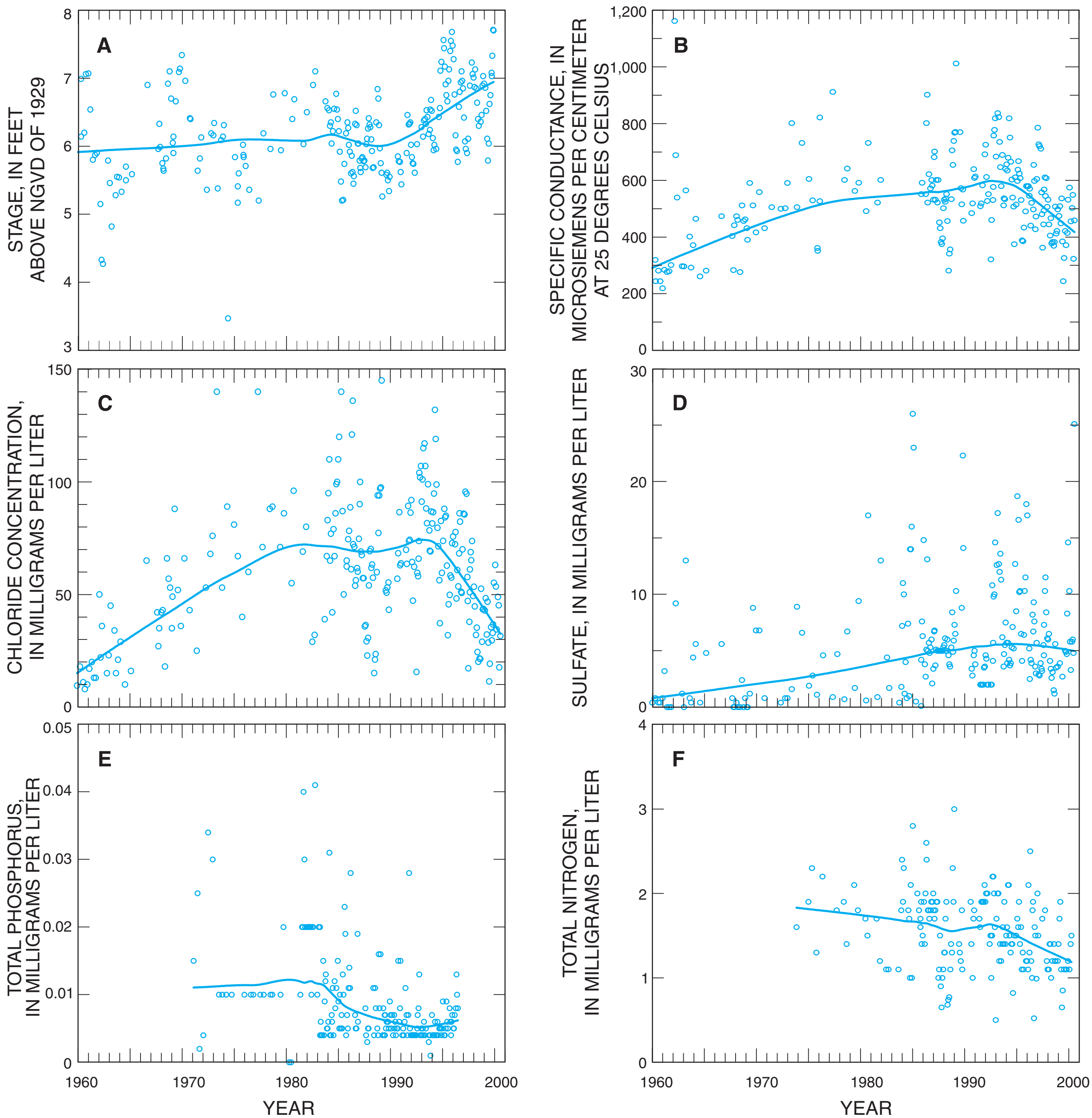


Figure 9. Stage (water level) and water-quality data with loess smooth lines for the period of record at P-33.

[Trends or lack of trends at the 95-percent confidence level follows. (a) Linear regression for stage gave a significant upward trend for 1959-2000. (b) Uncensored seasonal Kendall test for specific conductance with stage adjustment gave significant upward trends for 1959-1975, 1959-1995 and 1959-2000 and no significant trends for 1980-1993 and 1994-2000. (c) Uncensored seasonal Kendall test with stage adjustment for chloride gave significant upward trends for 1959-2000 and 1959-1982, no significant trend for 1982-1993, and significant downward trend for 1993-2000. (d) Tobit regression for sulfate gave no significant trend for 1977-2000. (e) Tobit regression for total phosphorus gave a significant downward trend for 1972-2000 and no significant trends for 1986-2000 and 1972-1986. The clusters of data points at the reporting level of 0.01 mg/L before 1985 and 0.004 mg/L after 1985, when lower reporting levels began, make the influence of the reporting levels on less-than and reported values visible on the graph. Although 19-percent of the data were less-than or zero values, the influence of the change in reporting levels also appears to have influenced many of the reported (not less than or zero) values and the trend is appears to be false. (f) Uncensored seasonal Kendall test for total nitrogen with stage adjustment gave no significant trend for 1975-2000.]

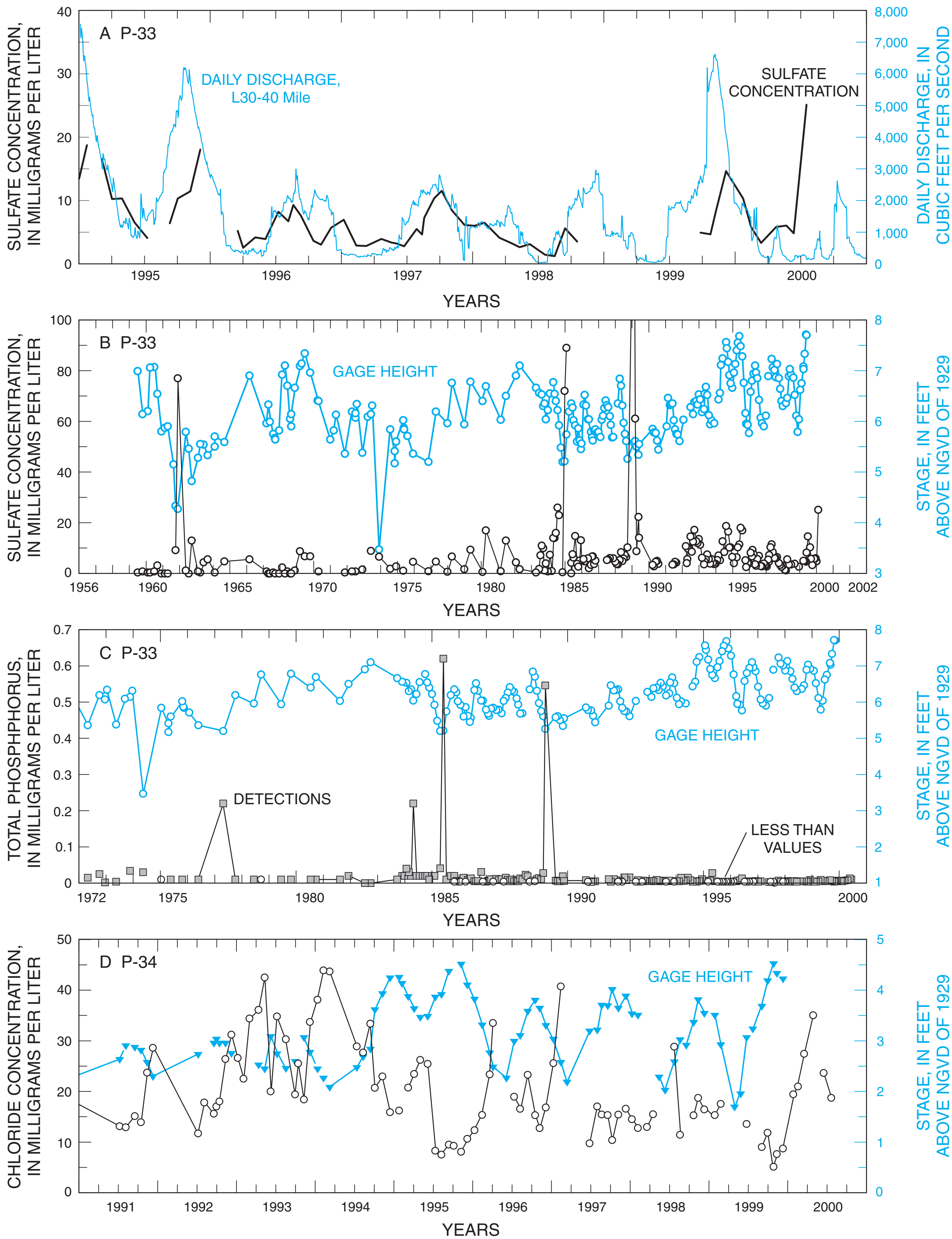


Figure 10. (A) Concentration of sulfate at P-33 and discharge under Tamiami Trail (L-30-40-Mile Bend); (B) sulfate at P-33 and stage; (C) total phosphorus at P-33 and stage; (D) chloride concentration at P-34 and stage.

Trail, which includes Bridge 105 and is referred to as Bridge 105.

Both Bridge 105 and P-34 represent relatively unaltered hydrologic conditions, but the Bridge 105 site is affected locally by US Highway 41 and the adjacent borrow canal. Site P-34 is in a location remote from canals and probably best represents long-term undisturbed water-quality conditions in the region. Waller (1982) reported no long-term changes in water quality at site P-34 between 1959 and 1976.

Site P-34

We evaluated trends for stage and selected water-quality constituents at site P-34 for the period of record, 1959-2000 (fig. 11). There was a small but significant increasing trend for stage and stage-adjusted specific conductance, even though the loess plot shows no obvious trend for the unadjusted specific conductance (fig. 11 A, B). Changes in water quality at P-34 were small and may simply be related to changes in rainfall. Concentrations of chloride, which ranged from less than 10 to about 60 mg/L (fig. 11C), appeared to decrease in the 1990's with increasing water levels, but the stage-adjusted seasonal Kendall test did not detect significant trends. This suggests that the apparent decline in chloride concentration in the late 1980's could be due to increasing stage during that period. Higher chloride values typically were associated with lower water levels (fig. 10D).

Most sulfate concentrations at site P-34 were less than 10 mg/L, although a few values (not shown) exceeded 20 mg/L before the early 1970's (fig. 11D). Although the Tobit regression analysis computed a statistically significant downward trend in sulfate, the trend appears to be the result of the high percentage (57 percent) of less-than or zero values and the changes in reporting levels (0 mg/L through 1980, <5 mg/L from 1987 until early 1988, <2 mg/L in 1988 through 1995, <1 mg/L 1995 through 1998, and <0.1 mg/L in 1999) over the period of record. Some of the effect can be seen in the clustering of data at 5, 2, and 1 mg/L and the shape of the loess smooth line.

Concentrations of the nutrients, TP and TN, at P-34 showed no significant trends over the period of record (fig. 11E, F). Ninety percent of TP concentrations were less than 0.03 mg/L. An apparent downward trend in the loess plot for TP (fig. 11D) is probably due to the decrease in reporting levels between 1975 and 1985, and in later years. The change in reporting levels can be seen (fig. 11D) by the clustering of data at 0.01 mg/L from about 1975 to 1983 and at 0.004 and 0.005 mg/L after about 1986.

Bridge 105 Site

The stage and water-quality data used for analysis of the Bridge 105 site (1967-2000) was a mix of samples collected at Bridge 105 and samples composited from flow at Bridge 105 and other bridges between 40-Mile Bend and Monroe along the Tamiami Trail that had flow at the time of sampling (fig. 12). The stage recorder is located at Bridge 105. There was a significant increasing trend for stage (fig. 12A), but no significant trends for specific conductance or chloride (fig. 12 B, C). The increase in stage in the 1990's is related to abundant rainfall during that period and the release of water through the S-343 and S-344 structures into southeastern BICY.

Concentration of sulfate at Bridge 105 showed a significant downward trend from 1970-1999 (fig. 12D). The decline in sulfate possibly is influenced by changes in laboratory reporting levels (0, <1, <0.1, and <0.2 mg/L) and 21 percent less-than or zero values (fig. 12D). High values for sulfate were associated with low water levels (fig. 13).

Concentrations of TP at Bridge 105 showed a significant trend upward for 1970-80, a significant downward trend for 1990-1999, and no trend for 1970-1999 (fig. 12E). Only 6 percent of the TP data were less-than or zero values (most occurred in the 1980's); it is unlikely that either loess plots or Tobit regression trend results would be biased by the less-than values. The statistical analysis of trends is based on Tobit regressions and does not correlate with the loess smooth plot. For example, a few high phosphorus values in the late 1960's and early 1970's cause the loess smooth line to start high and decrease during the 1970's. However, the Tobit regression results in an upward trend between 1970 and 1980 because there are only 3 data values greater than 0.1 mg/L in the first half of that decade and 8 data values greater than 0.1 mg/L in the second half. Higher values for TP concentrations were associated with low water levels (fig. 13), and were probably caused by ponding of water, accumulation of biological waste, and the chemical breakdown of organic material in the water remaining in the Tamiami Canal.

Concentrations of TN at Bridge 105 for the period of record (1975-1999) remained at about 1 mg/L along the loess smooth line with 90 percent of the values ranging between 0.4 and 1.2 mg/L. The uncensored seasonal Kendall tests gave a significant downward trend for 1975 to 1999, but no trend for 1975 to 1985 (fig. 12 F).

Lietz (2000) analyzed trends in water quality at the Tamiami Trail section (40-Mile Bend to Monroe) over the period 1967 to 1993. He used flow-adjusted and unadjusted concentrations and parametric and nonparametric statistics in the analysis, and reported significant increasing or decreasing trends for 13 out of 37 constituents or measurements (Lietz, 2000, pg. 19). He labeled an upward trend as a deterioration in water quality for eight constituents including specific conductance and dissolved solids, and a downward trend as an improvement in water quality for five constituents including ammonia and nitrite plus nitrate. Our analysis differed from that of Lietz, in that we evaluated data extending into 1999 and used stage adjustment for the uncensored seasonal Kendall tests for specific conductance, chloride, and TN. Discharge approaches zero as the stage approaches about 6.9 feet, resulting in ponding near Bridge 105, but the stage ranged from 2.85 to 8.98 feet.

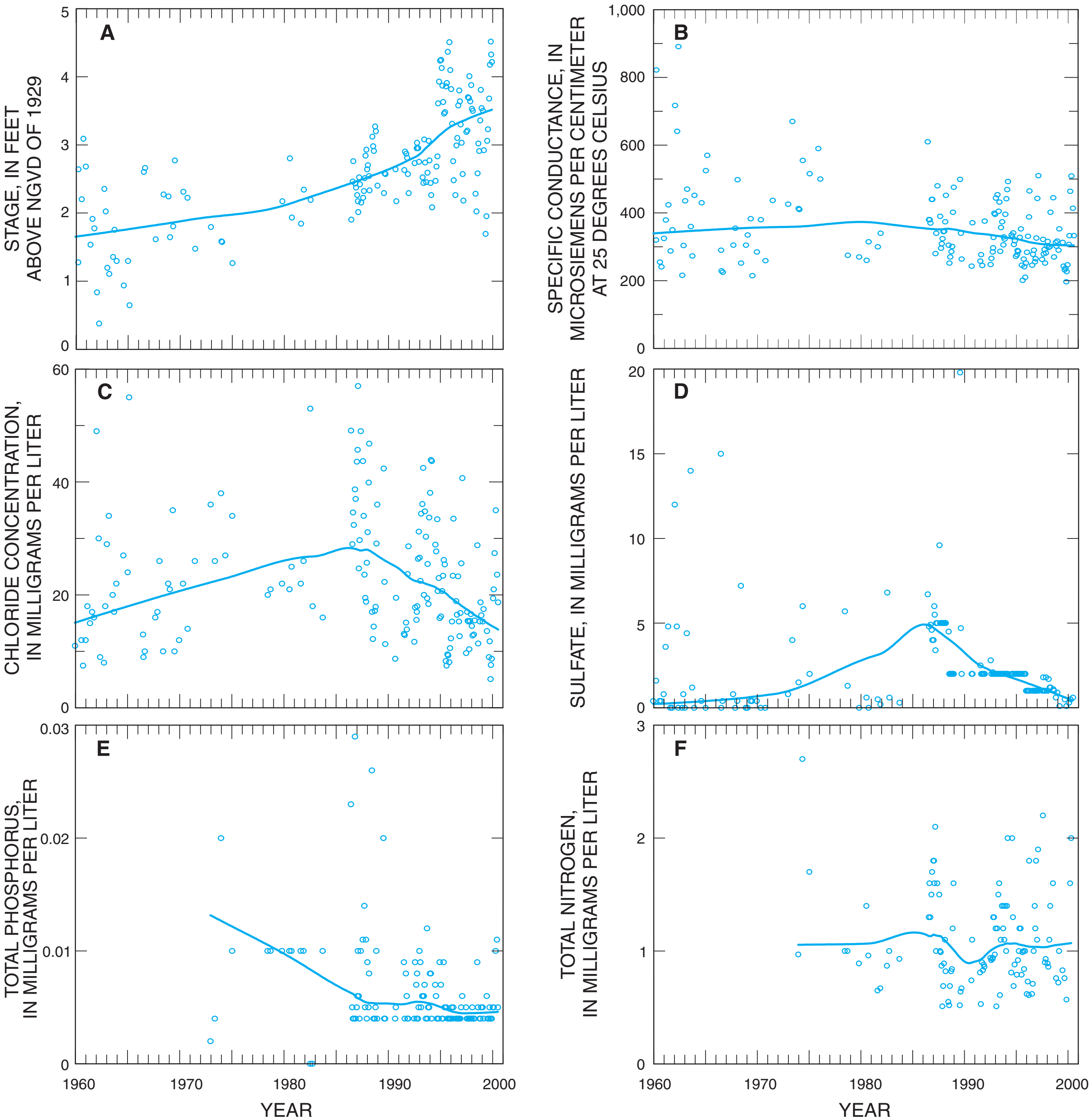


Figure 11. Stage (water level) and water-quality data with loess smooth lines for period of record at P-34. [Trends or lack of trends at the 95-percent confidence level follows. (a) Linear regression for stage gave a significant upward trend for 1959-2000. (b) Uncensored seasonal Kendall test for specific conductance with stage adjustment gave a significant upward trend for 1959-2000 and no trend 1986-2000. (c) Uncensored seasonal Kendall test with stage adjustment for chloride gave no significant trends for 1959-2000 and 1986-2000. (d) Tobit regression for sulfate gave a significant downward trend that is almost certainly a false trend due to changes in laboratory reporting level for 1986-2000. Less-than and zero values comprised 57 percent of the sulfate data and the influence of clusters of data at the reporting levels of 1, 2, and 5 mg/L is visible on the graph. (e) Tobit regression for total phosphorus gave no significant trends for 1986-2000. (f) Uncensored seasonal Kendall test for total nitrogen with stage adjustment gave no significant trend for 1986-2000.]

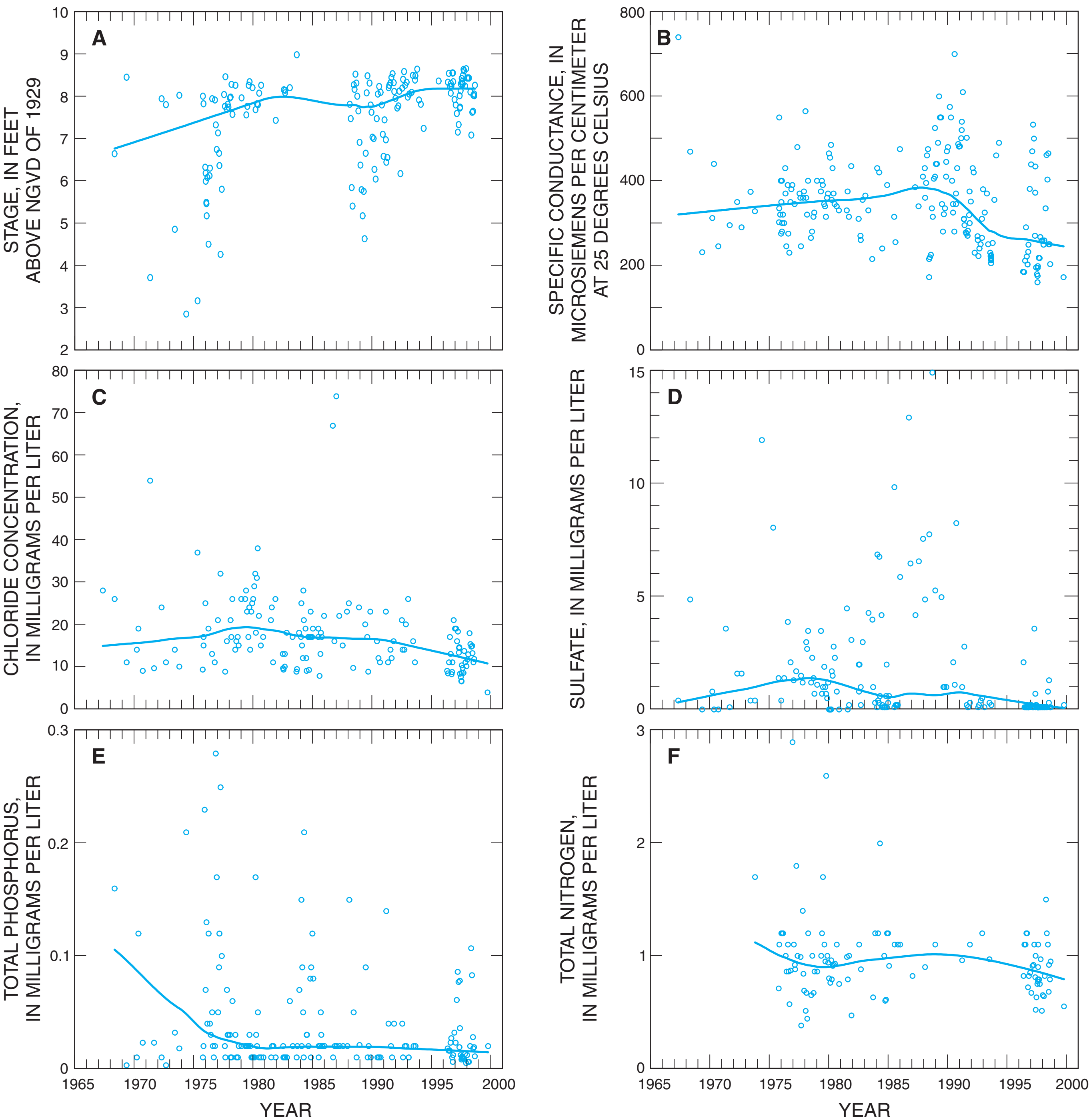


Figure 12. Stage (water level) and water-quality data with loess smooth lines for period of record at Bridge 105 and 40-Mile Bend section.

[Trends or lack of trends at the 95 percent confidence level follows. (a) Linear regression for stage gave a significant upward trend for 1967-1999. (b) Uncensored seasonal Kendall test for specific conductance with stage adjustment gave no significant trends for 1967-1999, 1967-1988, and 1989-1999. (c) Uncensored seasonal Kendall test with stage adjustment for chloride gave no significant trends for 1967-2000, 1967-1980, and 1981-2000. (d) Tobit regression for sulfate gave significant downward trends that may be influenced by changes in laboratory reporting level for 1970-1999 and 1980-1999. No significant sulfate trends were found for 1970-1980, 1970-1990, 1970-1996, 1980-1990, 1985-1999, and 1990-1999. Less-than and zero values comprised 29 percent of the sulfate data. (e) Tobit regression for total phosphorus gave a significant upward trend for 1970-1980; a significant downward trend for 1990-1999; and no significant trends for 1970-1999; 1980-1990; 1980-1999. Only 5 percent of the total phosphorus data were less-than values, so trends should not be influenced much by changes in reporting levels. (f) Uncensored seasonal Kendall test for total nitrogen with stage adjustment gave no significant trend for1975-1985 and a significant downward trend for 1975-1999.]

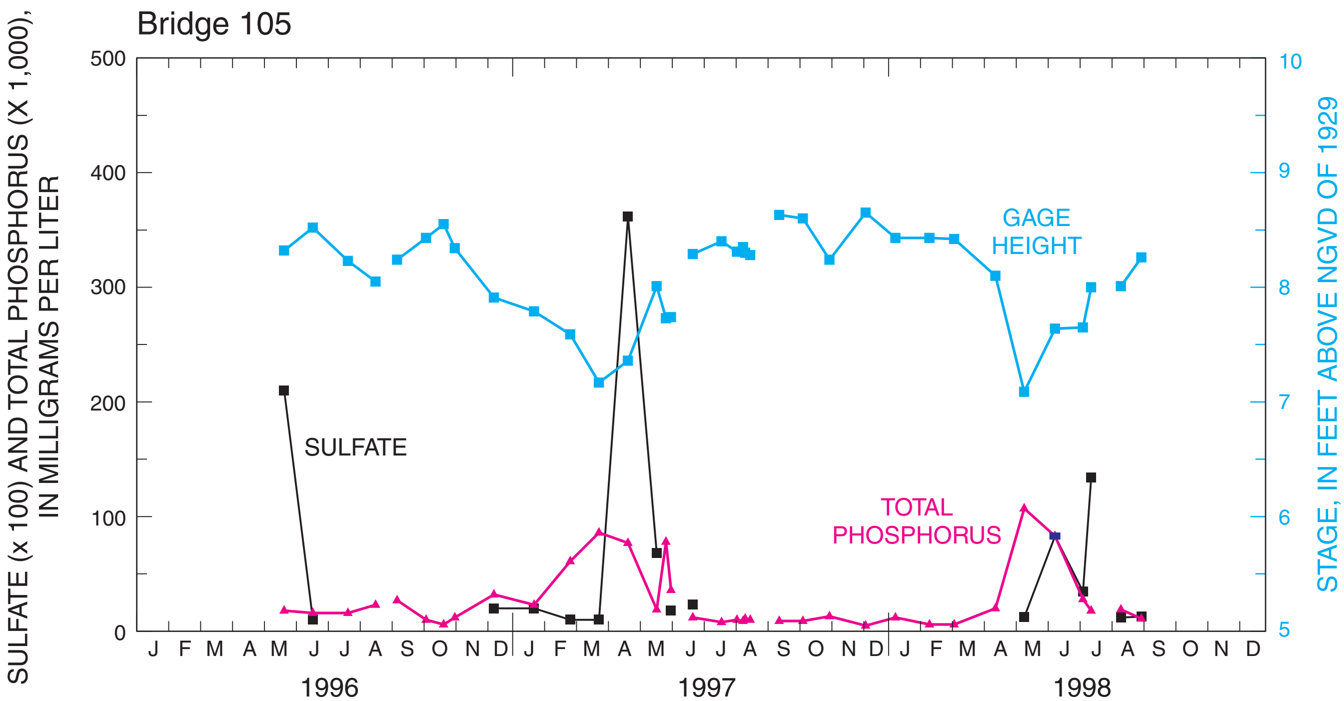


Figure 13. Stage (water level) at Bridge 105 and concentration of sulfate (times 100) and total phosphorus (times 1000) from January 1996 to January 1999.

Spatial Patterns in Water Quality

Water quality varies spatially across the study area because of natural variations in geology, hydrology, and vegetation, and because of differences in water management and land use. Wetlands dominate the landscape, but canals also are important hydrologic features, especially along the borders of EVER and, to a lesser extent, BICY. Water-quality conditions in the boundary canals can influence water quality in the interior of the parks, depending on the quality, amount, and timing of water released from canals into the parks. Restoration of the Everglades will involve changes in the amount, timing and location of inflows, all of which can affect water quality in the parks, and therefore, are of concern.

Park Boundary Water-Quality Conditions

Water quality along the boundaries of BICY and EVER were evaluated in the L-28I drainage system, the Barron River Canal, the S-12s control structure, and the L-31 and C-111 canals (fig. 1).

L-28 Interceptor (L-28I) Drainage System

The L-28I drainage system is in or near the northeastern part of BICY. The system was constructed in the mid-1960's to provide flood protection to the Seminole Reservation, and consists of three main canals—L-28I canal, the North Feeder canal, and the West Feeder canal. The north and west feeders convey water south and southeast through the S-190 pump station into the L-28I Canal, ultimately discharging into WCA 3A. Currently, water is confined to the canals until it discharges into WCA 3A, but restoration plans being considered include releasing some water from the West Feeder canal into the northern BICY to reestablish historic hydrologic flows to several cypress strands. Waters in the L-28I and the North Feeder canal are enriched in nutrients from agricultural lands to the north, whereas water in the West Feeder canal contains relatively low nutrient concentrations. For example, the average concentration of TP in the North Feeder canal was 0.25 mg/L during 1996-97, compared with 0.06 mg/L in the West Feeder canal (Germain, 1998). Nutrient concentrations tend to increase in the West Feeder canal during the dry season when S-190 is closed and some water from the North Feeder canal backs up into the West Feeder canal (R. Sobczak, National Park Service, written commun., 2002).

Barron River Canal

The Barron River Canal is located along the western boundary of BICY. The canal and the adjacent Highway 29 roadbed act as a major hydrologic barrier to the wetlands of the BICY. The canal drains predominately agricultural lands north of the Preserve and discharges into Chokoloskee Bay and EVER.

Water and bed sediment in the canal contain a number of pesticides and other contaminants that are a potential source of contaminants to the bay and the extreme northwestern part of EVER (Miller and McPherson, 2001: Shahane, 1994). Because the current direction of flow in the canal is south into Chokoloskee Bay or west into the Fakahatchee Strand, and because restoration plans call for even more diversion of water to the west, these areas have a greater potential of receiving contaminants from the Barron River than BICY.

S-12s Gated Structures

The S-12s are gated structures (A, B, C, D) along the Tamiami Canal between the L-67A and L-28 canals. The S-12s were constructed in the early 1960’s and release water south into the Shark River Slough in EVER. A large amount of water-quality data (particularly nutrients) has been collected over the years at these structures. Walker (1991) reported increasing trends in concentrations of TP for 1977-89 and decreasing trends for 1992-96 (Walker, 1997). As part of restoration in recent years, more water is being diverted east from the S-12s into the northeastern portion of the Shark River Slough. This trend is planned to increase, so that more of the water from the L-67 canals will flow away from the S-12s.

L-31 Canal and C-111 Canals

Construction of the L-31 canal began in 1951, and the canal was extended south of the Tamiami Trail in the late 1950’s and early 60’s. Pumping station S-332 was completed and began pumping water in 1981 into Taylor Slough in EVER. The main C-111 canal system, south of the L-31 canal system, was completed by 1982. These canal systems drain water from the Tamiami Canal and from mixed agricultural lands east of EVER. Water interchanges rapidly between surface- and ground-water sources in the porous limestone of the region. Large amounts of water-quality data have been collected in these canal systems over the years. Hydrologic restoration activities are underway and there are concerns that diversion of more water into EVER could alter water quality in the slough and in the estuarine wetlands bordering Florida Bay (Sutula and others, 2001).

Median Concentrations of Selected Constituents

Median concentrations of selected constituents were used to illustrate spatial patterns for the period 1991-2000 (figs. 14-20). The 10-year period, 1991-2000, was selected as a baseline because this length of time provides a broad range of hydrologic conditions and sufficient water-quality data at most sites, and because this time span covers a period when sampling and laboratory protocols were relatively consistent.

Median values for specific conductance generally were higher at canal and slough sites than at most other interior sites (fig. 14). At the interior sites, the highest values were at site EP, at sites in Shark River Slough of EVER, and at a canal site northeast of BICY. The high median value at site EP in EVER may result from nearby coastal influences. The high values in Shark River Slough probably are due to inflow of higher conductance waters from the L-67 canal through S-12D and S-333 into the slough. The source of the high values in the northwest BICY is possibly saltier ground water released from oil drilling operations.

Median concentrations of chloride were highest in EVER; most median concentrations were greater than 30 mg/L, and seven median concentrations were greater than 60 mg/L (fig. 15). Median concentrations at all sites in BICY were less than 30 mg/L, except at a canal site (S-190; 39 mg/L) northeast of the preserve and an interior site in the extreme northwest (A1: 53 mg/L). Site A1 is located near an oil drilling operation and the high median chloride concentration may be due to contamination from this source. The sources of most of the high chloride concentrations in EVER are canals that drain lands to the north or coastal water to the south.

Median concentrations of sulfate were highest at several Everglades canal sites, somewhat lower at the Everglades marsh sites, and lowest at the interior BICY sites (fig. 16). The source of the high concentrations of sulfate in the Everglades is primarily agricultural drainage, which has been enriched by fertilizer applications (Bates and others, 2002).

Median concentrations of TP generally were higher in BICY than in EVER and its adjacent canals (fig. 17). Several possible sources for the high concentrations in BICY include: (1) high phosphorus content in surficial (in or near the land surface) rocks, soils, or ground water; (2) a larger release or smaller uptake of phosphorus by soils and vegetation of the Big Cypress Swamp compared with the Everglades; (3) shallower water, less flow, and more ponding in Big Cypress Swamp that could favor chemical or biological processes that increase phosphorus release to the water, or simply accumulation of higher concentrations of waste from wildlife; or (4) an influence from high-phosphorus canal waters near the Preserve boundaries. For example, sites A1 and A2 have high median concentrations and are near the northwestern boundary and the Barron River Canal, and sites A5, A6, and A9 also have high median concentrations and are near the eastern boundary and the L-28 canal system. Miller and others (1999, fig. 7) found a general east-to-west increase in TP in water along the Tamiami Canal in the wet and dry seasons, and this suggests that surficial geology may be a dominant influence.

Brand (2001) reported that phosphorus concentrations are substantially higher in shallow coastal water south of Big Cypress Swamp in the 10,000 Islands area, compared with waters farther to the east in Florida Bay. He attributes the source of the higher phosphorus in the west to phosphate deposits in central Florida. The phosphorus from these deposits may be made available by erosion enhanced by phosphate mining and transport down the Peace River and along the southwest coast, and by ground water moving through the deposits and transporting phosphorus up into coastal waters (Top and others, 2001). More evidence is needed, however, to prove that shallow ground water is a source of elevated phosphorus in BICY compared with EVER.

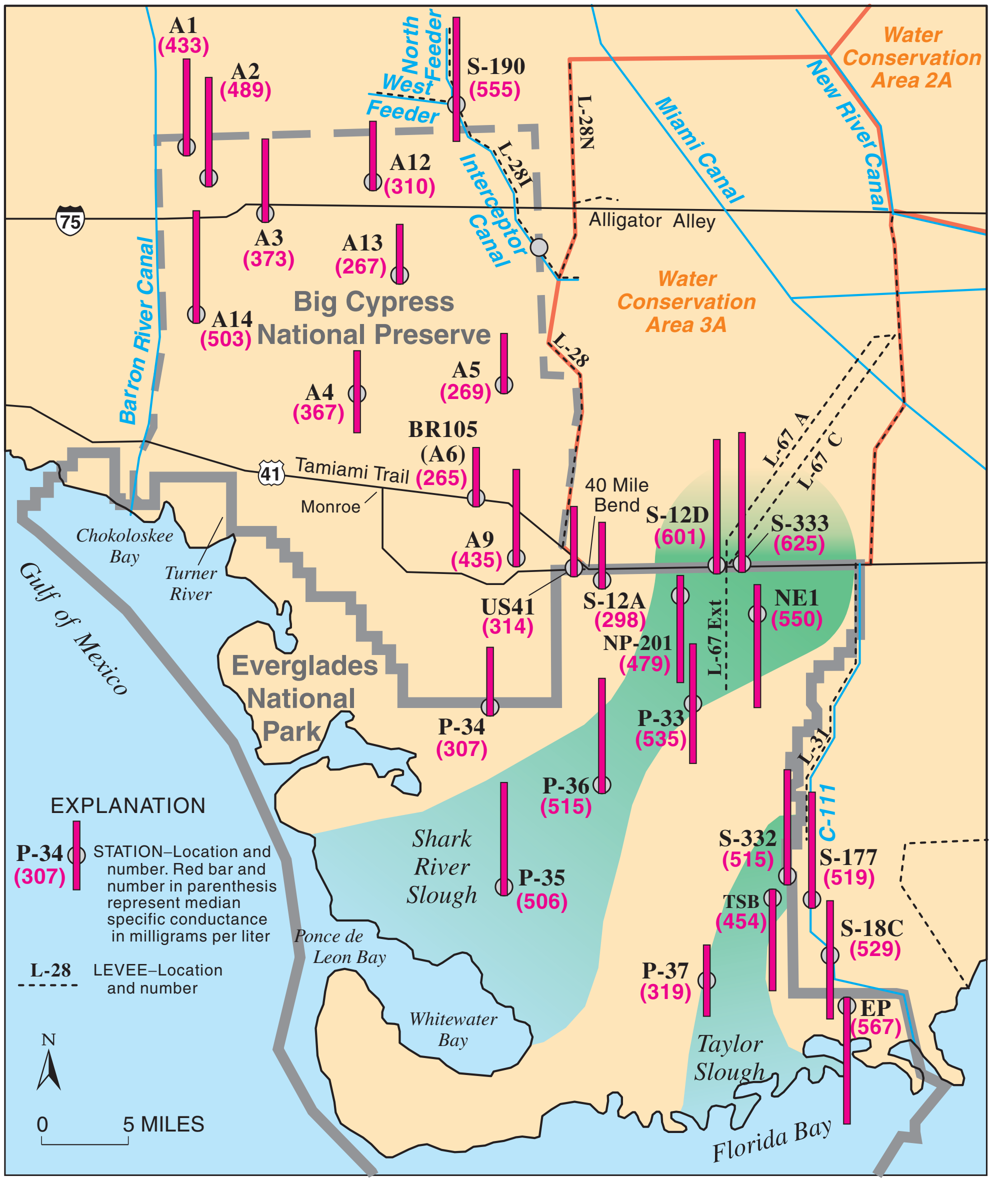


Figure 14. Median specific conductance at Big Cypress National Preserve and Everglades National Park sites and nearby canal sites, 1991-2000.

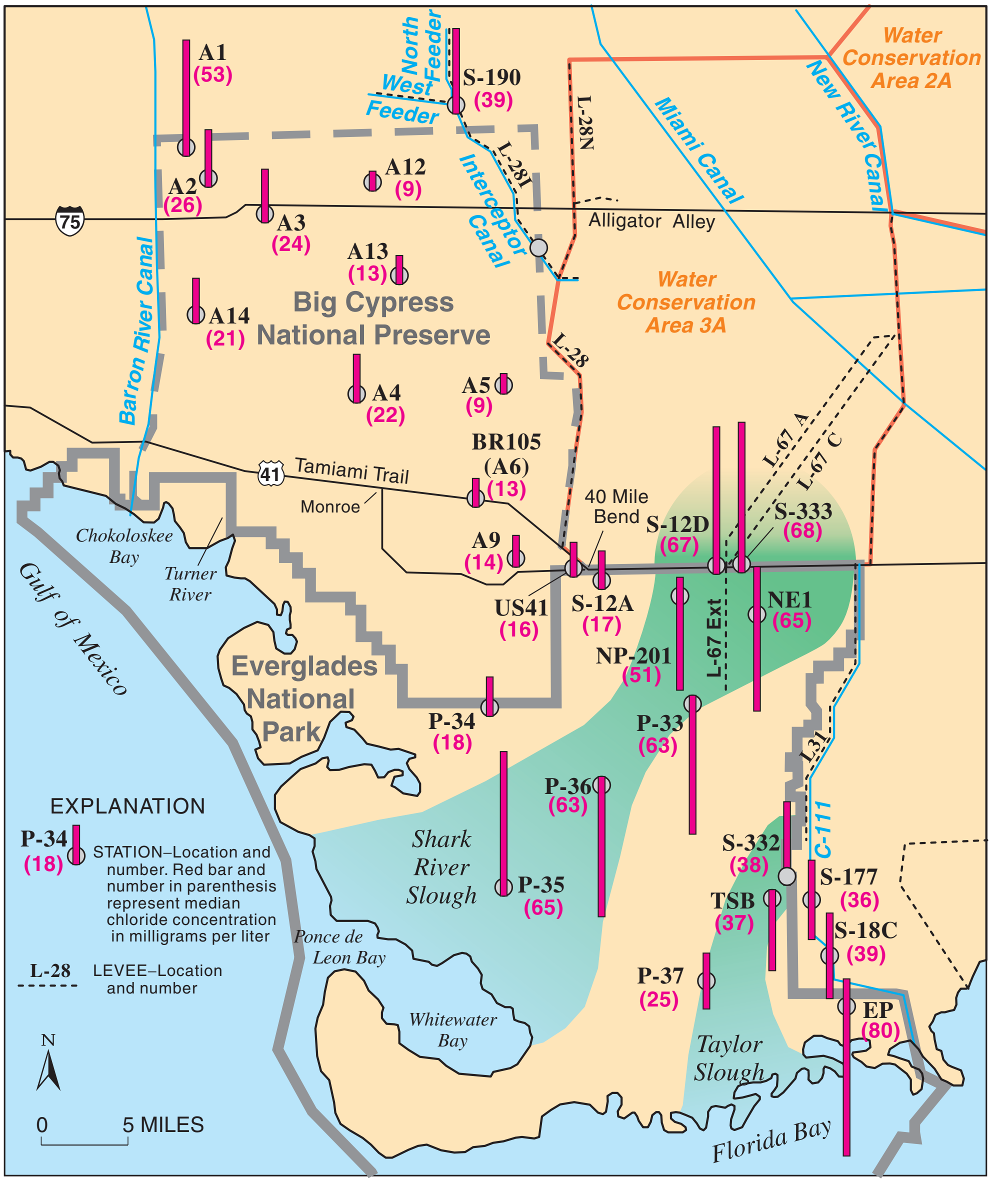


Figure 15. Median chloride concentrations at Big Cypress National Preserve and Everglades National Park sites and nearby canal sites, 1991-2000.

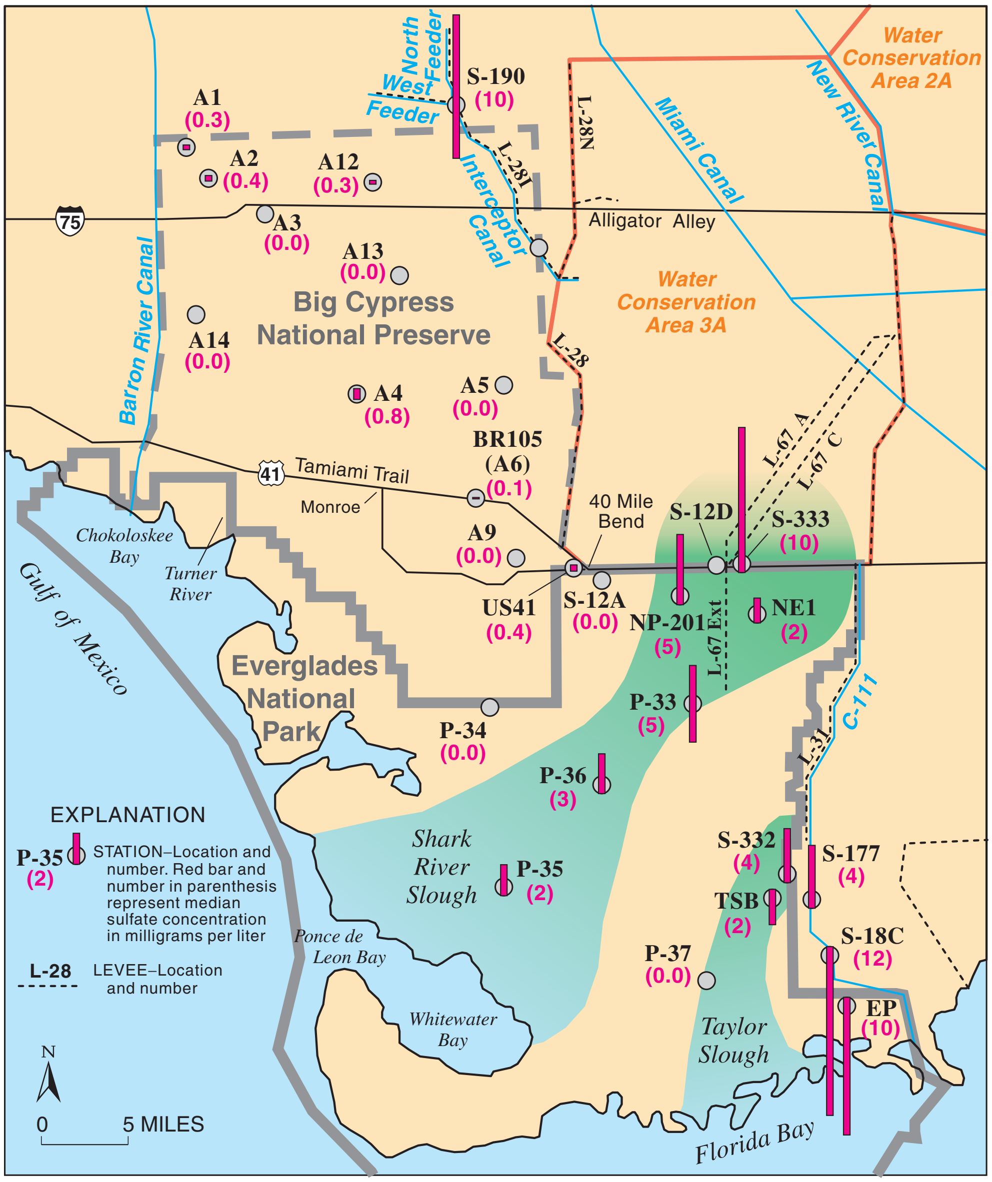


Figure 16. Median sulfate concentrations at Big Cypress National Preserve and Everglades National Park sites and nearby canal sites, 1991-2000.

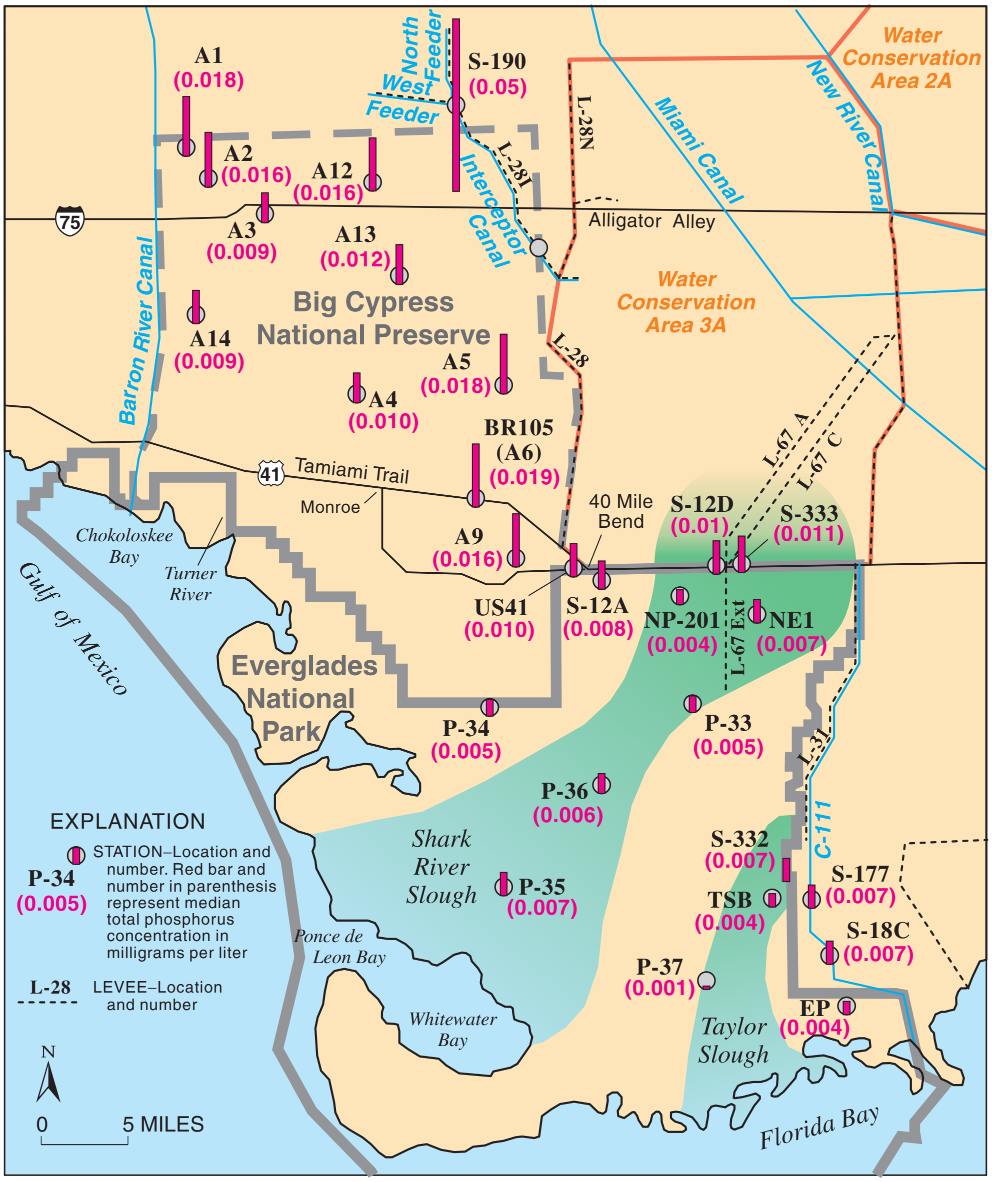


Figure 17. Median total phosphorus concentrations at Big Cypress National Preserve and Everglades National Park sites and nearby canal sites, 1991-2000.

Median concentrations of TN ranged from 0.64 to 1.8 mg/L; there were no obvious patterns between canals and interior sites or across the landscape (fig. 18). The inorganic forms of nitrogen (nitrite plus nitrate), however, tended to be higher in canals near the Everglades than in the interior marshes of either BICY or EVER (fig. 19). Median concentrations of nitrite plus nitrate ($N0_2$+$N0_3$) were greater than 0.03 mg/L in C-111 basin canals, whereas median concentrations at most sites in the interior were less than 0.01 mg/L. Median concentrations of ammonia plus ammonium ion ($NH_3 + NH_4^{+1}$) were 0.04 mg/L or less, except at several C-111 basin canals (fig. 20). Possible reasons for the higher inorganic nitrogen in the canals include: (1) less biological uptake in the canals due to less contact with vegetation and bottom sediments and their associated micro-organisms, (2) greater inputs of ground water enriched in inorganic nitrogen into canals than into marshes, or (3) greater inputs of fertilizers to canals because of proximity to agriculture.

Most concentrations of unionized ammonia (NH_3, the most toxic form of ammonia) were below Class III criteria (0.02 mg/L) indicative of adverse effects on aquatic life; median values in BICY, EVER, and nearby canals were less than 0.001 mg/L. The SFWMD (2000) reported that NH_3 periodically exceeded Class III criteria in EVER; most years there were few or no exceedances and the maximum number of exceedances (13.6 percent) occurred in 1992.

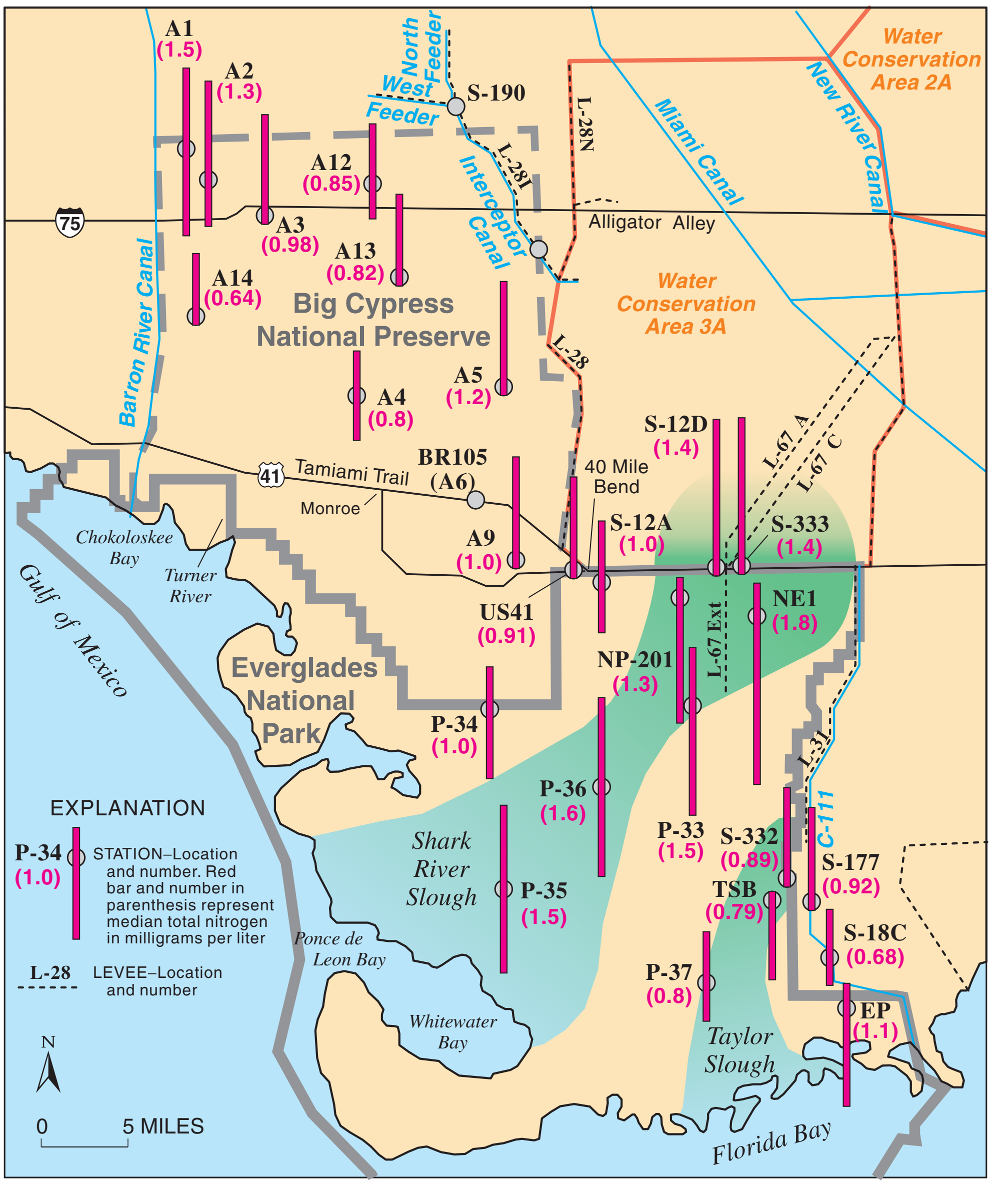


Figure 18. Median total nitrogen concentrations at Big Cypress National Preserve and Everglades National Park sites and nearby canal sites, 1991-2000.

Trace Elements in Water

Waller (1982) summarized trace element concentrations in water from 20 stations in and near EVER during 1959-1977. Average concentrations generally were lower in canals than in marshes, which he speculated was due to the more stable chemical and biological processes in the canals. Most average trace element concentrations were below the U.S. Environmental Protection Agency's aquatic life criteria of 1977.

The SFWMD (2000) summarized spatial and temporal trends of total (unfiltered and digested) trace elements in EVER for the 19-year period of record (water years 1981-1999). Only cadmium, copper, lead, and zinc exceeded the Class III criteria (table 4-12). The interior marsh sites had the highest number of exceedances for total iron (> 1 mg/L) compared with other locations in the Everglades. Total iron was correlated ($r^2 = 0.61$) with turbidity and this suggested a possible source of the iron was from sediment re-suspension.

We summarized trace element data for total arsenic, cadmium, copper, lead, iron, and zinc in water samples collected in BICY, EVER, and nearby canals over the baseline period 1991-2000 in figure 21. Few trace elements exceeded the Class III criteria for aquatic life. The greatest percentage of exceedances was for total iron from marsh sites in EVER where 8 percent of the samples exceeded the criterion of 1.0 mg/L.

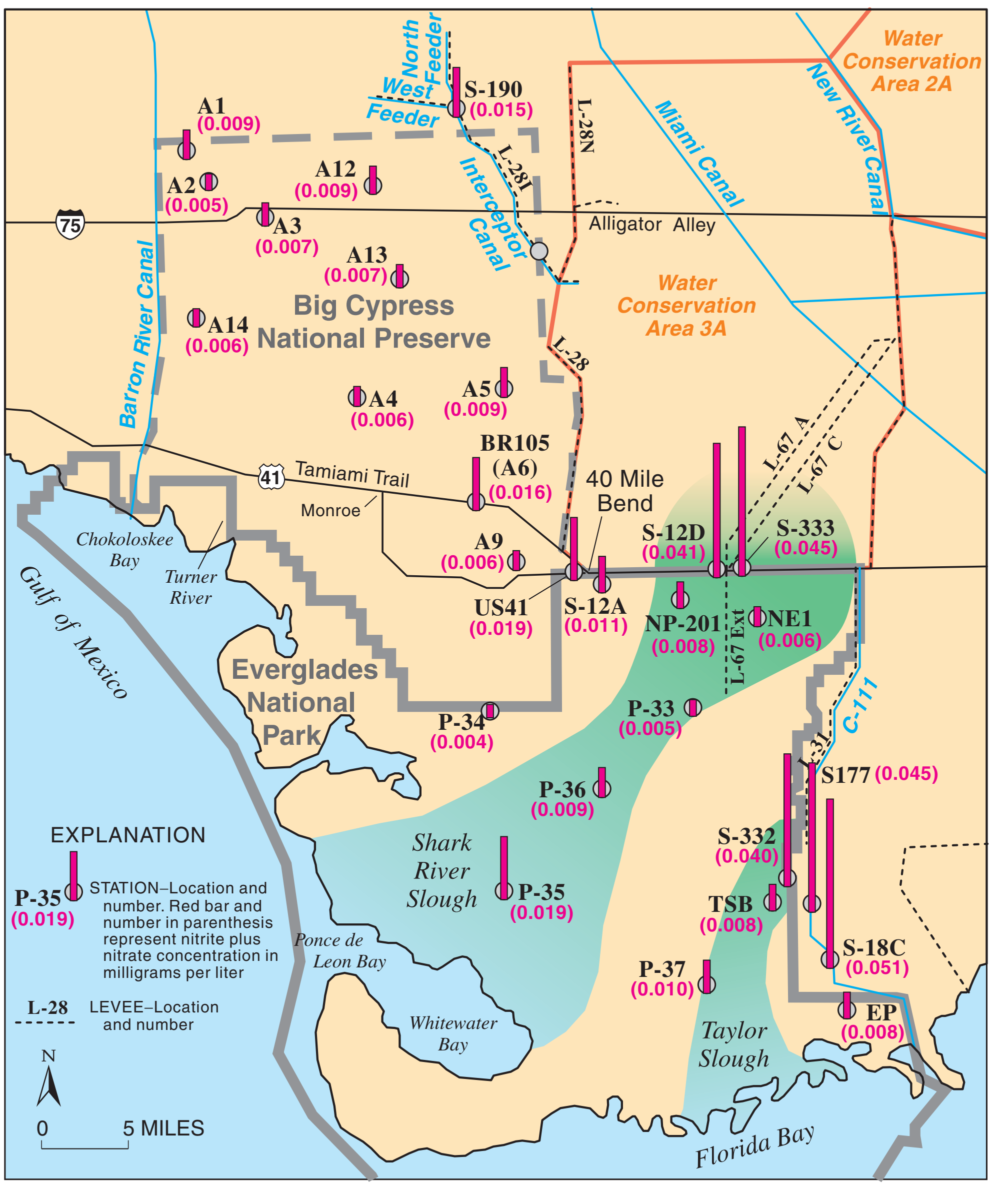


Figure 19. Median concentrations of nitrite plus nitrate at Big Cypress National Preserve and Everglades National Park sites and nearby canal sites, 1991-2000.

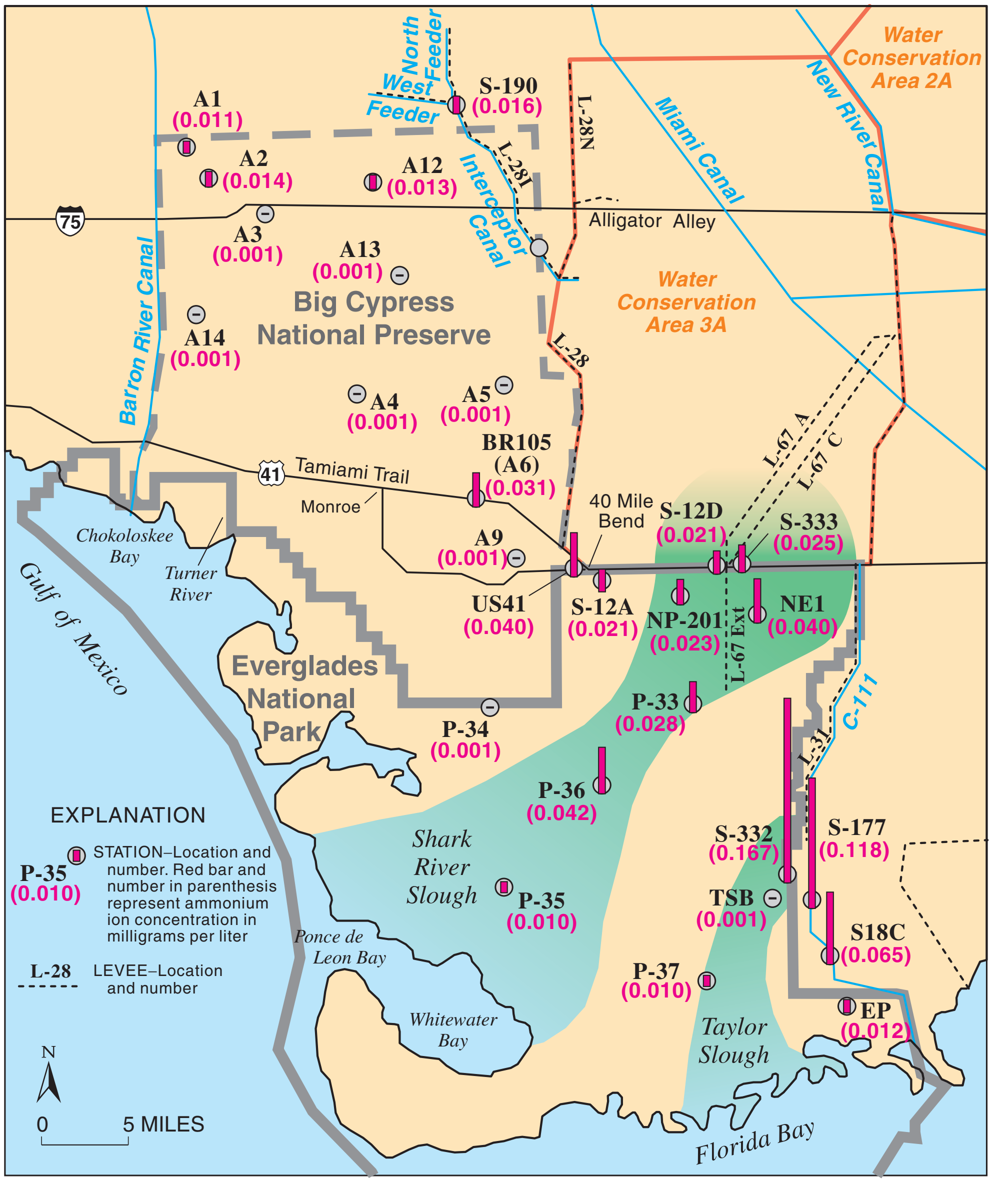
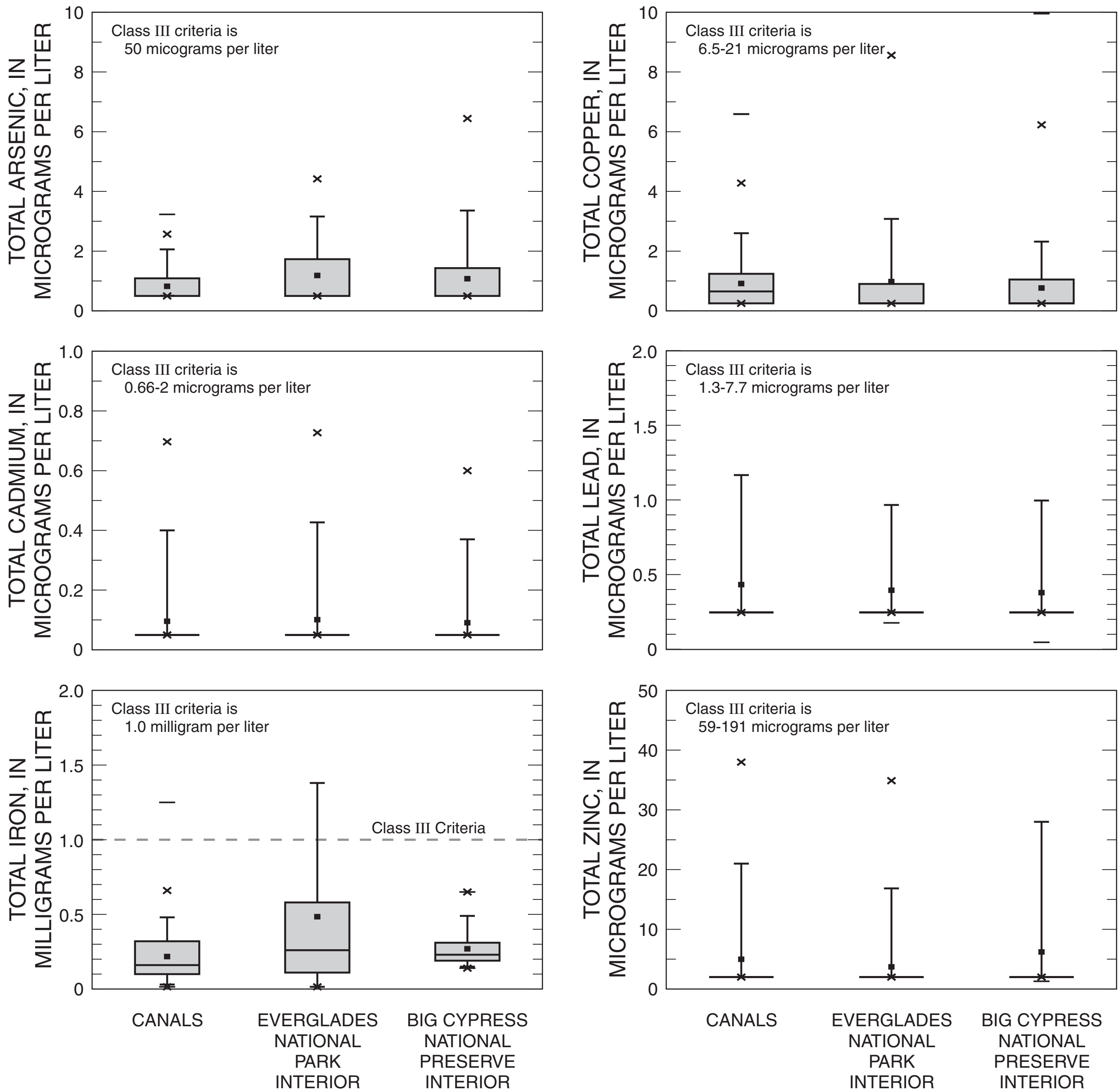


Figure 20. Median concentrations of ammonia plus ammonium ion at Big Cypress National Preserve and Everglades National Park sites and nearby canal sites, 1991-2000.



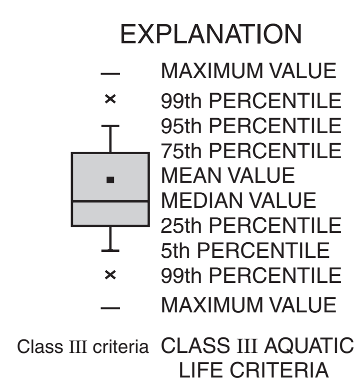


Figure 21. Trace element concentrations in water at Big Cypress National Preserve and Everglades National Park sites and nearby canals, 1991-2000. (Class III aquatic life criteria are indicated for each element. Criteria that are dependent on hardness were calculated using average hardness values. Less-than values were set to ½ of the lowest reported less-than value.)

Pesticides and Other Organic Compounds in Water

The most frequently detected pesticides and other organic compounds in water at EVER, BICY, and nearby canal sites are listed in tables 1 and 2. Out of 556 samples, each sample, on average, had one pesticide detection. The only pesticide concentrations that exceeded aquatic life criteria were two detections of the herbicide atrazine.

In an earlier study, Waller (1982) summarized data on pesticide analyses from water samples collected at 20 stations in EVER and surrounding areas during 1965-1977. Two percent of the over 1,700 samples analyzed had detectable pesticides (very low concentrations reported as “trace” to 0.017 µg/L), with the most frequently detected being dieldrin, diazinon, DDT, DDE, DDD, 2,4-D, and silvex.

In more recent studies (Miller and McPherson, 2001; Miller and others, 1999; McPherson and others, 2000), several pesticides were detected in water from the Barron River Canal, the Tamiami Canal, and the C-111 canal at S-177. In the Barron River Canal, nine pesticides (18 detections including estimated values) were detected in water samples collected in October 1998. The most commonly detected pesticides included atrazine, deethylatrazine, and tebuthiuron; however, no concentrations exceeded Canadian aquatic-life criteria (Canadian Council of Ministers of the Environment, 2001). At the C-111 Canal at S-177, the most commonly detected pesticides in a 3-year intensive sampling period, 1996-98, were atrazine, metolachlor, tebuthiuron, and endosulfan. Detections and concentrations were seasonal, and generally peaked in winter and spring. During the 3-year sampling period, detections of the insecticide, endosulfan, were frequent in 1996, but became less frequent in the following 2 years (McPherson and others, 2000).

Pesticides and Other Organic Compounds in Bed Sediment

The most frequently detected pesticides or other organic compounds in bed sediment from seven canal sites near EVER or BICY are given in table 3. Canadian aquatic life criteria (Environment Canada, 1999) were exceeded for p,p´-DDE (16 percent of the samples), lindane (3 percent), and heptachlor expoxide (1 percent).

Waller (1982) reported that one or more chlorinated hydrocarbon insecticide residues (DDT, DDE, DDD, chlordane, dieldrin) were detected in bottom sediment from nearly all 20 stations sampled in and around EVER and at every station in the Park. Average concentrations in EVER for dieldrin, chlordane, DDD, DDE, and DDT were 0.2, 1.8, 3.5, 4.2, and 0.9 µg/kg, respectively.

Table 1. Summary of most frequently detected pesticides and other organic compounds in water for the period of record at selected sites in and near Big Cypress National Preserve and Everglades National Park

[µg/L, micrograms per liter]

Compound	Number of detections by compounds	Number of determinations by compounds	Detections per determination	Highest measured concentration	Lowest measured concentration[1]	Aquatic life criteria	Number of exceedances	Class III criteria, fresh waters[4]
Atrazine, unfiltered, µg/L	116	304	0.382	13.2	0.01	[2]1.8	2	
Atrazine, filtered, µg/L	90	99	0.909	0.87	0.00347	[2]1.8	0	
Metolachlor, filtered, µg/L	83	99	0.838	0.0635	0.0036	[2]7.8		
Deethylatrazine, filtered, µg/L	73	99	0.737	0.0225	0.00107			
Tebuthiuron, filtered, µg/L	61	99	0.616	0.0494	0.0027	[2]1.6	0	
Endosulfansulfate, unfiltered, µg/L	43	374	0.115	0.45	0.0033			
EPTC, filtered, µg/L	29	99	0.293	0.0148	0.00081			
2,6-Diethylaniline, filtered, µg/L	23	99	0.232	0.0054	0.00098			
Simazine, filtered, µg/L	20	99	0.202	0.0979	0.00361	[2]10	0	
Chlorpyrifos, filtered, µg/L	19	99	0.192	0.0234	0.00249			
Endosulfan I, unfiltered, µg/L	17	55	0.309	0.05	0.001		0	0.056
Malathion, filtered, µg/L	16	99	0.162	0.0837	0.00324	[3]0.1	0	0.1
Hexazinone, unfiltered, µg/L	15	153	0.098	0.031	0.019			

[1]There are less-than values in the data set that might represent concentrations lower than the reported “lowest measured concentrations.”
[2]Environment Canada, 1999, Canadian Interim Criteria.
[3]U.S. Environmental Protection Agency, 1999.
[4]Florida Department of Environmental Protection, 1996.

Table 2. Most frequently detected pesticides and other organic compounds in water for period of record at selected sites in and near Big Cypress National Preserve and Everglades National Park

[Other compounds were detected such as chlorinated pesticides, but at lower frequencies]

Site	Atrazine, unfiltered	Atrazine, filtered	Metolachlor, filtered	Deethylatrazine, filtered	Tebuthiuron, filtered	Endosulfan sulfate, unfiltered	EPTC, filtered	2,6-Diethylaniline, filtered	Simazine, filtered	Chlorpyrifos, filtered	Endosulfan I, unfiltered	Malathion, filtered	Hexazinone, unfiltered	Number of sample collected (not all samples were were analyzed for the compound of interest)	Average detections per sample (some values are approximate)
Bridge 105	0	2	0	1	0	0	0	0	0	0	0	0	0	7	0.43
S-333	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0.00
S-18C	17	0	0	0	0	2	0	0	0	0	0	0	0	72	0.26
TSB	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0.00
P-33	0	2	0	2	3	0	0	0	0	0	0	1	0	18	0.44
P-36	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0.00
P-35	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0.00
S-177	0	84	80	68	58	0	28	23	19	19	16	16	0	85	4.84
S-177SFWMD	15	0	0	0	0	5	0	0	0	0	0	0	2	65	0.34
S-178SFWMD	13	1	1	1	0	36	1	0	0	0	1	0	0	67	0.81
S-175SFWMD	24	0	0	0	0	0	0	0	0	0	0	0	4	26	1.08
S-332SFWMD	39	0	0	0	0	0	0	0	0	0	0	0	9	100	0.48
S-12D	0	3	2	3	3	0	0	0	1	0	0	0	0	3	4.00
US41-25	8	0	0	0	0	0	0	0	0	0	0	0	0	64	0.13
Total for all sites	116	90	83	73	61	43	29	23	20	19	17	16	15	556	1.09

Table 3. Most frequently detected pesticides and other organic compounds in bed sediment at seven canal sites near Big Cypress National Preserve and Everglades National Park (S-333, S-18C, S-177, S-178, S-175, S-332, US41-25)

[µg/kg, micrograms per kilogram]

Compound	Number of detections by compound	Number of determinations by compound	Detections per determination	Highest measured concentration	Lowest measured concentration	Aquatic life criteria	Number of exceedances
p,p´-DDE, bottom material, µg/kg	50	170	0.294	89	1.4	[1]15	27
Endosulfan sulfate, bottom material, µg/kg	17	168	0.101	120	1.6		
Endosulfan beta, bottom material, µg/kg	15	168	0.089	24	0.67		
p,p´-DDD, bottom material, µg/kg	13	171	0.076	15	1.7		
Chlordane technical, bottom material, µg/kg	12	185	0.065	155	0.2		
p, p´-DDT, bottom material, µg/kg	10	182	0.055	11.6	0.28		
Heptachlor, bottom material, µg/kg	10	185	0.054	12.9	0.25		
Endosulfan alpha, bottom material, µg/kg	9	168	0.054	16	1.1		
Lindane, bottom material, µg/kg	8	185	0.043	34.2	0.19	[1]1.38	5
Aldrin, bottom material, µg/kg	8	185	0.043	600	0.2		
α-BHC, bottom material, µg/kg	6	182	0.033	6.62	1.1		
β-Benzene hexachloride, bottom material, µg/kg	5	181	0.028	40.6	1.4		
δ-Benzene hexachloride, bottom material, µg/kg	5	174	0.029	35.2	6.17		
2,4-D, bottom material, µg/kg	4	177	0.023	1090	12.8		
Endrin, bottom material, µg/kg	3	185	0.016	2.12	0.22	[1]42	0
Heptachlor epoxide, bottom material, µg/kg	3	185	0.016	35	1.53	2.74[2]	2
2,4,5-T, bottom material, µg/kg	3	175	0.017	1130	1.4		
o,p’-DDT, bottom material, µg/kg	2	25	0.080	1.85	1.02		
Arochlor 1254 (PCB), bottom material, µg/kg	2	113	0.018	2.3	1.3		
Arochlor 1016 (PCB), bottom material, µg/kg	1	102	0.010	235.4	235.4		
Malthion, bottom material, µg/kg	1	185	0.005	4200	4200		
Atrazine, bottom material, µg/kg	1	171	0.006	9.14	9.14		
Mirex, bottom material, µg/kg	1	66	0.015	15.7	15.7		
Dieldrin, bottom material, µg/kg	0	185	0	0	0	[1] 110	0

[1]Gilliom and others, 1998
[2]Canadian Council of Ministers of the Environment, 2001

Miller and McPherson (2001) sampled bed sediment at nine sites on the Barron River and one site on the Turner River in October 1998. No pesticides were detected in bed sediment, except for two measurable concentrations of p,p´-DDE and one of p,p´-DDD, neither of which exceeded aquatic-life criteria.

Earlier studies have reported pesticides and other organic compounds in the Barron River Canal. Law Engineering and Environmental Services (1993) found high concentrations of semivolatile organic compounds in bed sediments near a creosote wood treatment facility near Jerome, Florida. Grabe (1996) found 99 parts per billion (µg/kg) of α-BHC (a degradation product of lindane) in bed sediments of the canal. A number of pesticides have been reported in surface water and bed sediment in Collier County, Florida, during 1989-92, including aldrin, α-BHC, chlordane, dieldrin, endosulfan sulfate, endosulfan I, endrin, and heptachlor (Shahane, 1994).

Water-Quality Monitoring Network Design for Future Studies

At least three objectives for water-quality monitoring in BICY and EVER can be identified: (1) continued documentation of baseline water-quality conditions, (2) early detection of any changes that may occur as a result of water-management alterations, and (3) documentation of possible effects of restoration activities on water quality. To adequately document baseline water-quality conditions, at least some of the current long-term, remote sites need to be maintained and sampled. Continued sampling at these sites provides a way to gage changes in water-quality conditions resulting from natural events or human activities over many years. These sites are located where hydrologic data, such as water levels and discharge, are available. Maintaining sampling parameters, protocols, and frequencies similar to those that have been carried out for previous years will help ensure effective statistical evaluations. Monthly sampling has been identified as an appropriate frequency for some types of monitoring (Robertson and Roerish, 1999; Stansfield, 2001), but budget considerations may require some modifications. The second objective of providing early detections of changes in water quality may require establishing of new sites and different sampling frequencies or parameters from those used for the baseline sites. Changes in agricultural and domestic chemicals used to control weeds and pests may dictate the need to analyze new compounds. To detect the effects of upstream water modifications, it may be desirable to sample near the park boundary, to sample during runoff-events, and to sample a small selected number of constituents more frequently than monthly. Automatic sampling or continuous monitors may be appropriate, and sampling along transects may help identify sources of constituents. Both baseline water-quality monitoring and question-driven monitoring will help document potential effects of restoration on water quality.

Summary

Major physical alteration of the south Florida landscape and associated water management practices, including canal and levee construction, agriculture and residential development, and operation of pumps and flood gates in the 1900’s, have greatly altered both the volume, timing, distribution, and quality of surface water in this system. Everglades National Park (EVER, established 1947) and Big Cypress National Preserve (BICY, established 1974) were both established by Congress to preserve and protect large areas of the south Florida ecosystem that had remained relatively intact and free of agricultural and urban development. Because they are located at the downgradient end of the altered system, they are subject to effects of upstream water management practices.

The National Park Service (NPS) maintains hydrologic monitoring sites for measuring water level (stage) and water quality in EVER and BICY. Water-quality data collection and analyses have been carried out in EVER for over four decades, and in BICY since at least the early 1970’s when the proposed Big Cypress “Jetport” triggered a flurry of environmental investigations. These long-term data sets provide a historical baseline (beginning as early as 1959) for assessing hydrologic conditions and making a wide range of management decisions. We assessed selected water-quality data collected in the Park and Preserve and in nearby canals between 1959 and 2000. The data used were primarily from the South Florida Water Management District (SFWMD), but also includes data from the U.S. Geological Survey (USGS), and the NPS.

Seasonal changes in water levels and flows in BICY and EVER affect water quality. As water levels and flows decline during the dry season, physical, geochemical, and biological processes increase the breakdown of organic materials and the build-up of organic waste, nutrients, and other constituents in the remaining surface water. For example, during much of the year, concentrations of total phosphorus in the marshes of BICY and EVER usually are less than 0.01 milligram per liter (mg/L), but during the dry season, concentrations can rise briefly above this value, and occasionally, usually under drought conditions, exceed 0.1 mg/L.

Long-term changes in water levels, flows, water management, and upstream land use also affect water quality in BICY and EVER, based on analysis of available data (1959-2000). Specific conductance and concentrations of chloride increased in Taylor Slough and Shark River Slough in the mid-1980’s and early 1990’s. For example, chloride concentrations more than doubled from 1960 to the 1990’s, primarily due to canal transport of high dissolved-solids water into the sloughs. Trends in concentrations of sulfate and total phosphorus during the period are likely attributable, at least in part, to high percentages of less-than and zero values combined with changes in reporting levels over the period of record. High values in nutrient concentrations in marshes of BICY and EVER were evident during dry periods, and attributable to increased nutrient releases from breakdown of organic bottom sediment, or to increased build-up of nutrient waste from concentrations of aquatic biota and wildlife in remaining ponds, or in the EVER, to an increased ratio of nutrient-rich canal water to marsh water. Long-term changes in water quality are less pronounced in western EVER and BICY, however, seasonal and drought-related changes are evident.

Water quality varies spatially across the region because of natural variations in geology, hydrology, and vegetation and because of differences in water management and land use. Nutrient concentrations are relatively low in BICY and EVER compared to concentrations in parts of the northern Everglades, near agricultural and urban lands. Concentrations of total phosphorus generally are higher in BICY (median values, 1991-2000, were mostly greater than 0.015 mg/L) than in EVER (median values, 1991-2000, less than 0.01 mg/L), probably because of higher phosphorus in natural sources such as

shallow soils, rocks, and ground water in the Big Cypress region than in the Everglades region. Concentrations of chloride and sulfate are higher in EVER (median values in Shark River Slough, 1991-2000, mostly greater than 2 mg/L of sulfate and 50 mg/L of chloride), than in BICY (median values, 1991-2000, less than 1 mg/L of sulfate and at most sites less than 20 mg/L of chloride), probably because of the canal transport system, which conveys more water from an agricultural source into EVER than into BICY.

Trace elements and contaminants such as pesticides and other toxic organic compounds are in relatively low concentrations in BICY and EVER compared to concentrations found in parts of the northern Everglades near agricultural and urban sources. Atrazine was the most frequently detected pesticide in water; atrazine exceeded the aquatic-life criteria in less than 1 percent of the samples, or in 2 out of 304 samples. The pesticides heptachlor expoxide, lindane, and p,p'-DDE exceeded aquatic-life criteria in canal bed sediments in 1, 3, and 16 percent of the samples, respectively.

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