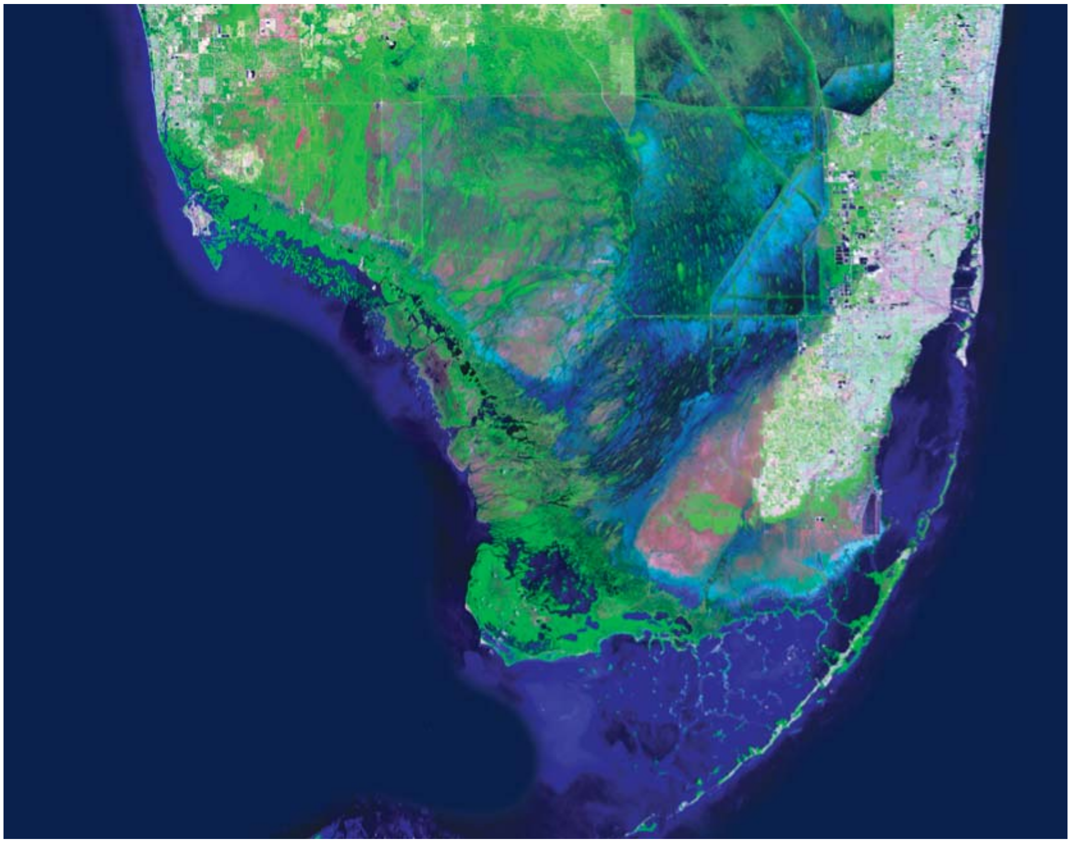
Water Flow and Nutrient Flux from Five Estuarine Rivers along the Southwest Coast of the Everglades National Park, Florida, 1997-2001

Prepared as part of the U.S. Geological Survey Place-Based Studies Initiative and the U.S. Department of the Interior Critical Ecosystem Studies Initiative of the National Park Service, Everglades National Park



Scientific Investigations Report 2004-5142

U.S. Department of the Interior
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By Victor A. Levesque

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Conversion Factors, Acronyms, Abbreviations and Datum

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square foot (ft^2)	929.0	square centimeter
square foot (ft^2)	0.09290	square meter
square mile (mi^2)	259.0	square hectare
square mile (mi^2)	2.590	square kilometer
	Volume	
cubic foot (ft^3)	28.32	cubic decimeter
cubic foot (ft^3)	0.02832	cubic meter
	Flow rate	
foot per second (ft/s)	0.3048	meter per second
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
	Mass	
ton, short (2,000 lb)	0.9072	megagram
ton per day (ton/d)	0.9072	metric ton per day
ton per day (ton/d)	0.9072	megagram per day
	Hydraulic gradient	
foot per mile (ft/mi)	0.1894	meter per kilometer

SI to Inch/Pound

Multiply	By	To obtain
	Volume	
liter (L)	33.82	ounce, fluid (fl. oz)
liter (L)	2.113	pint (pt)
liter (L)	1.057	quart (qt)
liter (L)	0.2642	gallon (gal)
liter (L)	61.02	cubic inch (in^2)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)

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

°F=(1.8×°C)+32

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

°C=(°F-32)/1.8

Specific conductance is given in microSiemens per centimeter at 25 degrees Celsius (µS/cm).
Concentrations of chemical constituents in water are given in milligrams per liter (mg/L).

Acronyms

ADAPS	Automated Data Processing System
CESI	U.S. Department of the Interior Critical Ecosystem Studies Initiative
ENP	Everglades National Park
kHz	kilohertz
MHz	megahertz
NPS	National Park Service
NWIS	National Water Information System
PBS	U.S. Geological Survey Place-Based Studies Initiative
PVC	polyvinylchloride
S-12	Water control structures
R^2	Coefficient of determination
USGS	U.S. Geological Survey
WSR	Wilcoxon signed ranks test

Datum

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83)

Water Flow and Nutrient Flux from Five Estuarine Rivers along the Southwest Coast of the Everglades National Park, Florida, 1997–2001

By Victor A. Levesque

Abstract

Discharge and nutrient fluxes for five tidally affected streams were monitored and evaluated as a part of the U.S. Geological Survey Place-Based Studies Initiative and the U.S. Department of the Interior Critical Ecosystem Studies Initiative. Locations on Lostmans Creek, and Broad, Harney, Shark, and North Rivers were selected using the criterion that a large amount of the water that flows through Shark River Slough must pass these sites. Discharge and nutrient-concentration data collection started at the Broad, Harney, and Shark River stations in January 1997 and ended in early 2001. Discharge and nutrient-concentration data collection started at the Lostmans Creek and North River stations in April 1999 and ended in early 2001. Each station was equipped with a vertically oriented acoustic-velocity sensor, water-level pressure transducer, bottom water-temperature thermistor, and specific conductance four-electrode sensor. Data collected using a vessel-mounted acoustic discharge measurement system were used to calibrate regression models of the mean river velocities and the *in-situ* index velocities. Information from these stations, in conjunction with data from other ongoing studies, will help to determine environmental effects on the southwest coast estuaries as changes in water management of the Everglades National Park continue.

Discharges from the Lostmans Creek, and Broad, Harney, Shark, and North River stations are influenced by semidiurnal tides, meteorological events, and surface- and ground-water inflow. Each of the five rivers is usually well mixed, having no greater than 500 microSiemens per centimeter at 25° Celsius difference in specific conductance from top to bottom during flood and ebb tides. Instantaneous flood discharges (water moving upstream) are typically of greater magnitude and shorter duration than instantaneous ebb discharges (water moving downstream).

Instantaneous discharge data were filtered using a low-pass filter to remove predominant tidal frequencies, and the filtered data were used to compute daily mean and monthly mean residual discharges. Lostmans Creek, and Broad, Harney and Shark Rivers each contributed from 20 to 27 percent of the total measured discharge to the Gulf of Mexico, whereas North River contributed approximately 4 percent. The main discharge region of the Shark River Slough extends from as far north as Lostmans Creek to as far south as North River. North River discharge has similar response characteristics to the other four rivers measured, but with a lesser magnitude of discharge. Comparisons of monthly mean discharges from the Tamiami Canal flow control structures S-12-A, B, C, and D located on U.S. Highway 41 (Tamiami Trail) to the five station total monthly mean discharges indicate that the discharges from the five rivers are approximately 2 to 3 times the S-12-A, B, C, D discharges, and that the measured southwest coast discharge peaks lead the S-12-A, B, C, D discharge peaks by approximately 1 month.

Residual total nitrogen and total phosphorus fluxes were estimated using linear regression models of discharge and flux. Monthly mean total nitrogen residual fluxes for the five southwest coast rivers ranged from approximately 0 to 390 short tons, whereas monthly mean total phosphorus residual fluxes ranged from approximately 0 to 6 short tons. Total nitrogen and total phosphorus residual fluxes at Lostmans Creek, and Broad, Harney, and Shark Rivers were similar in magnitude, each accounting for between 20 to 29 percent of the total measured residual flux. North River contributed between 3 to 4 percent of the total nitrogen and total phosphorus residual flux from the five rivers.

Introduction

A study of water flows and nutrient fluxes was conducted at five tidally affected rivers that receive freshwater from the Shark River Slough located in Everglades National Park, Florida (ENP) (fig. 1). The study was funded from 1996 to 2001 through the U.S. Geological Survey (USGS) Place-Based Studies Initiative (PBS), and partially funded for the final year (2001) by the U.S. Department of the Interior Critical Ecosystem Studies Initiative (CESI) in cooperation with ENP. The fundamental scientific goals of the PBS are to clarify the interactions between ecosystem stresses and responses to provide relevant, high-quality, impartial, scientific information to enable resource-management agencies that require an improved scientific information base to make informed planning decisions and to help resolve and prevent resource-management conflicts (U.S. Geological Survey, 1999). The CESI was established to provide sound scientific information for restoring ecosystems on Department of the Interior lands in South Florida, particularly in ENP. The CESI focuses on addressing urgent science information gaps and emerging research needs (U.S. Geological Survey, 2004).

Estuaries along the southwest coast of ENP receive the majority of surface water from the Shark River Slough. The slough is a broad southwest-trending arc of continuous wetland, dotted throughout with numerous tree islands (Schomer and Drew, 1982). The southwest coast of ENP is recognized as an important part of the Everglades system, and information on the timing and magnitude of discharge and nutrient flux is required to assess existing water management practices and to document changes brought about by rehabilitation efforts in the Everglades. Data described in this report are available from the USGS National Water Information System (NWIS). Additional data are available from the ENP Marsh and Marine Monitoring Network, the USGS mangrove dynamics stations, the Southeast Environmental Research Program water-quality monitoring program, and other ecological studies. Discharge data for this area of ENP were previously collected by the USGS between 1960-1967, and are available in out-of-print reports (U.S. Geological Survey, 1970, 1975).

Purpose and Scope

This report describes the timing and magnitude of water flows and nutrient fluxes for five estuarine river stations located along the southwest coast of Everglades National Park (figs. 1 and 2). The study began in late 1996 and ended in early 2001. Discharge data were collected at three stations from early 1997 through early 2001, and nutrient-concentration data were collected at these stations from February 1997 through August 2000. Discharge data were collected at two additional stations from April 1999 through May 2001, and nutrient-concentration data were collected at these additional stations from May 1999 through August 2000. Station descriptions and characteristics, equipment selected for monitoring the rivers, and procedures used for estimation of discharge and discharge errors are presented in this report. Brief descriptions of hydrodynamic characteristics at each station are presented in the Methods section of this report. Water-quality methods used to collect water samples, an overview of water-quality data collected, and procedures used for the estimation of nutrient flux also are presented in the Methods section.

Acknowledgments

Thanks are extended to DeWitt Smith, Tom Smith, numerous Dutch exchange students, Kevin Kotun, and others at the Everglades National Park Research Station who helped accomplish this study. Special thanks to Gordon Anderson of USGS, Miami for assisting with numerous field trips, arranging for exchange students to assist with field trips, and as a valuable source of information about the southwest coast study area.

Description of Study Area

The west coast of ENP is a subtropical mangrove forest and wetland area with many stream channels, lagoons, and back bays interwoven through the mangrove forests. Red mangroves dominate the land margins adjacent to the streams. Some mangroves are approximately 60 ft in height along the banks of the Shark and Harney Rivers closer to the Gulf of Mexico.

The headwaters of the five streams selected for this study are located near Lake Okeechobee and are influenced by rain events and water control structures located along the Tamiami Trail (U.S. Highway 41) (fig. 1). Drainage basin boundaries of the rivers are indeterminate due to a lack of elevation data and the flatness of the terrain. Drainage basin boundaries of these rivers within ENP have been estimated based on aerial photographs and the alignment of vegetation in satellite imagery. Within the ENP, the river basins overlap. As water in the Shark River Slough flows towards the southwest coast, distinct stream channels form and transport the water to back-country bays and the Gulf of Mexico.

The Everglades basin has a tropical savanna to subtropical climate characterized by a relatively long dry season (November to April) and a wet season (May to October) (Hela, 1952; Fernald and Patton, 1984). Annual rainfall typically ranges from 48 to 60 in., with approximately 80 percent occurring during the wet season (Schomer and Drew, 1982). Additionally, longer-term (greater than 5 years) rainfall averages exhibit a bimodal distribution pattern with a peak in May-June and a second peak in September-October (Thomas, 1974). Rainfall data collected by ENP personnel between 1996 and 2001 continue to exhibit the bimodal pattern. Average temperatures typically range from the mid-60s in the winter to low-90s (degrees Fahrenheit) in the summer (Schomer and Drew, 1982).

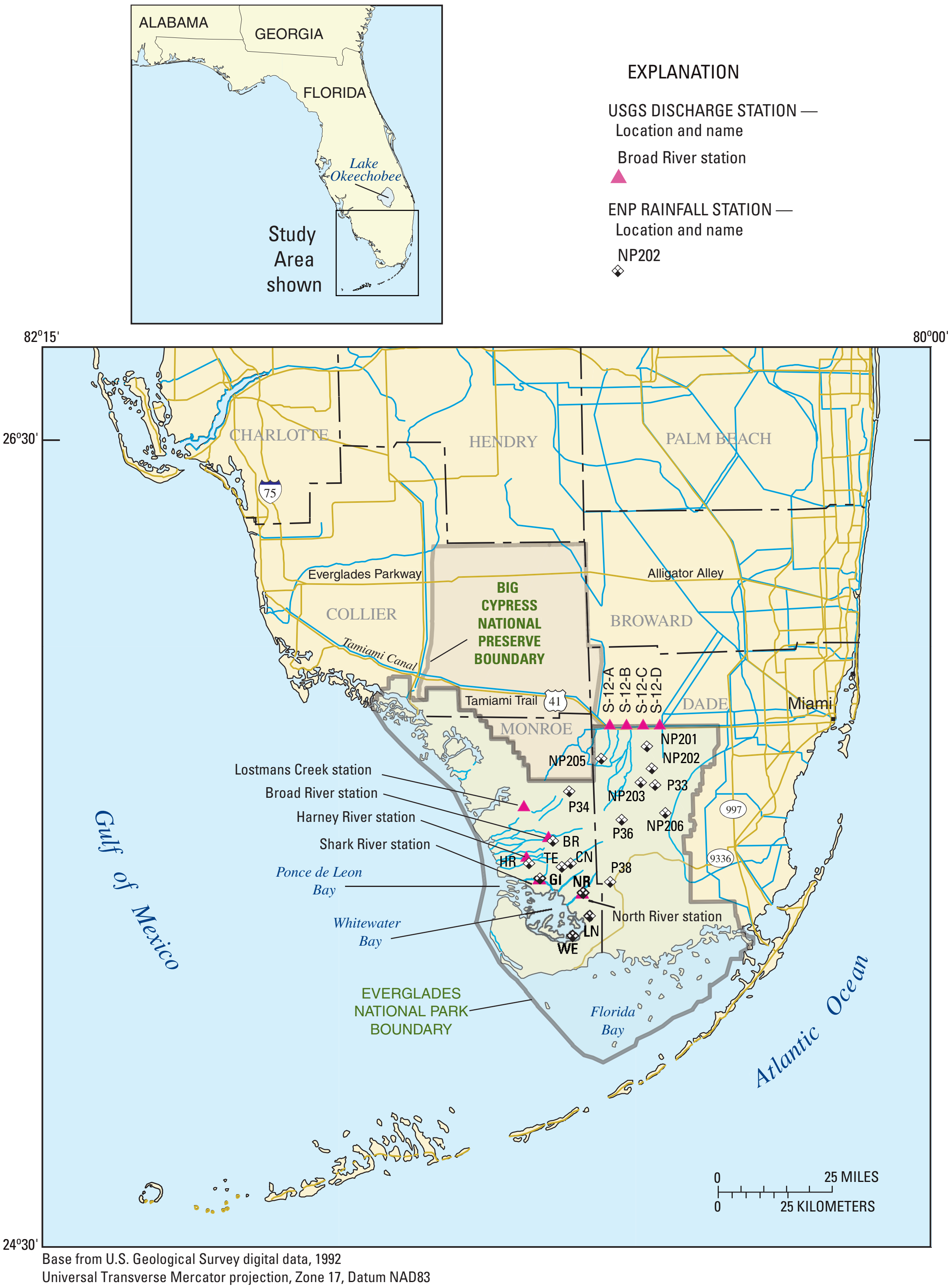

Figure 1. Location of USGS discharge stations, Everglades National Park rainfall stations, and S-12-A, B, C, and D structure locations.

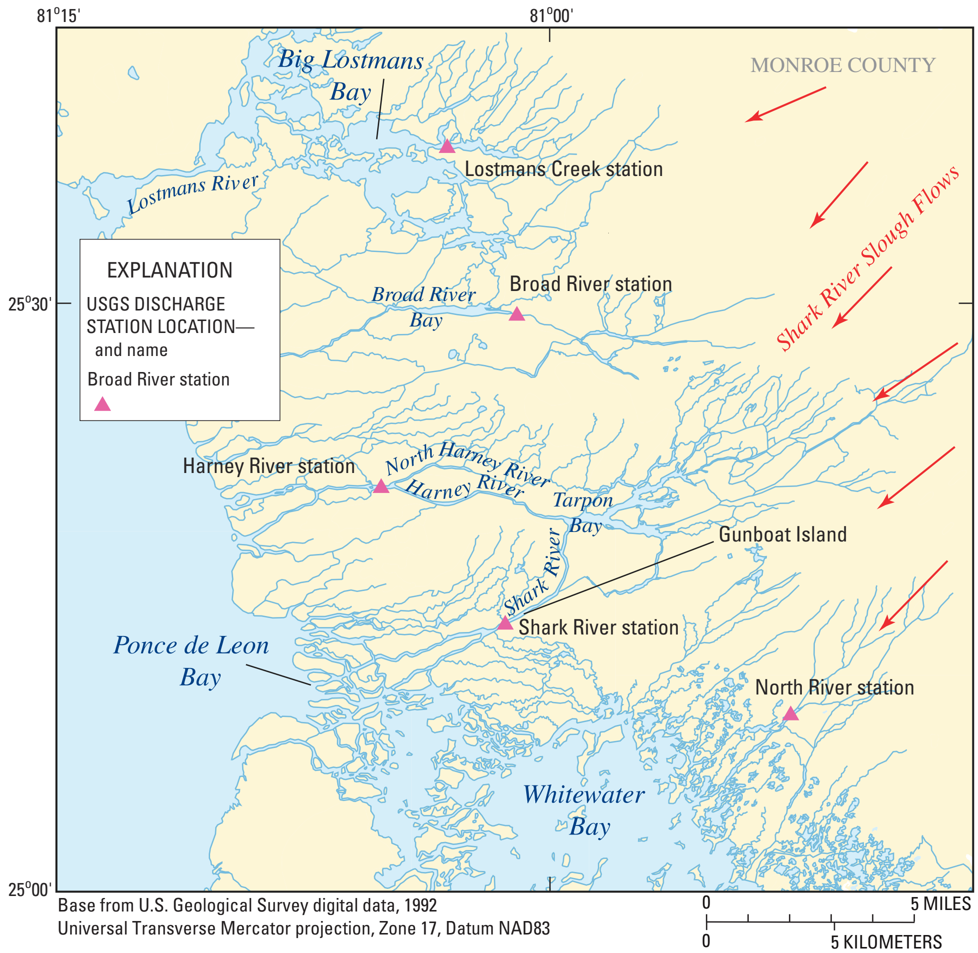

Figure 2. Location of USGS discharge stations.

Discharge and nutrient monitoring stations (fig. 2) were established in the Broad, Harney, and Shark Rivers between October 1996 and January 1997, and were discontinued in March 2001. Additional discharge and nutrient monitoring stations were established in Lostmans Creek and North River between January and April 1999 and were discontinued in March and May 2001 respectively. "Left and right bank" and "edge of water" terms used in the following station descriptions refer to their location when viewed looking downstream (direction of positive discharge or flow towards the Gulf of Mexico).

The Lostmans Creek station is the northernmost station (fig. 2, table 1). The station is approximately 13 river miles from the Gulf of Mexico and about 1 mi upstream of Big Lostmans Bay. Both riverbanks are lined with mostly red mangroves, which are 5 to 15 ft tall. The river is approximately 300 ft wide at the station, with depths ranging from

Table 1. Southwest coast discharge station identification numbers and locations.

Station name and ID	Latitude	Longitude
Lostmans Creek, 2290904	25º 33' 54" N	081º 03' 18" W
Broad River, 252953081011900	25º 29' 53" N	081º 01' 19" W
Harney River, 252551081050900	25º 25' 51" N	081º 05' 09" W
Shark River, 252230081021300	25º 22' 30" N	081º 02' 13" W
North River, 022908205	25º 20' 18" N	080º 54' 48" W

about 3 ft at the edges to about 6 ft near the center of the river at mean high tide. Normal tidal range is less than 1 ft, and velocities are less than 1 ft/s during flood or ebb tides. The left and right river edges are nearly vertical and composed of peat and fine mud. The river bottom consists of soft mud near the banks, grading to hard-packed mud littered with mollusk shells near the center of the river. Underwater visibility is usually about 4 to 6 ft.

The Broad River station is located approximately 10 river miles upstream from the Gulf of Mexico, about 1 mi upstream from Broad River Bay (fig. 2, table 1). Both riverbanks are lined mostly with red mangroves of 8 to 16 ft height. The river is approximately 200 ft wide at the station, with depths ranging from about 6 ft at the river edges to about 8 ft near the center. Riverbanks are vertical and consist of peat and fine sediments. The river bottom is covered with mud near the edges (approximately 1 to 3 ft from the edges) transitioning to exposed limestone with ridges, holes, and pinnacles less than ½ ft in elevation. Occasional small limestone spires and mollusk-encrusted limestone are distributed across the river bottom. Underwater visibility is usually 6 to 8 ft.

The Harney River station is located approximately 5 river miles from the Gulf of Mexico and about 1,800 ft downstream of the North Harney and Harney River confluence (fig. 2, table 1). Riverbanks are lined mostly with red mangroves of spectacular heights, some more than 60 ft. The river is approximately 350 ft wide with depths ranging from 0 ft at the right bank, sloping rapidly to about 13 ft near the center. The river bottom then gradually slopes up to about 9 ft at the vertical left bank. The sloped right bank is a sand beach about 10 to 20 ft wide at low tide, grading to muddy sediments as the water deepens. Within 50 ft of the right bank, these sediments transition to exposed limestone that extends across the river to within about 40 ft of the left bank. Near the left bank, the river bottom is composed of muddy sediments with a vertical peat bank. Most of the bottom at this station is exposed limestone with ridges, holes, and pinnacles less than ½ ft in elevation. Mollusks cover much of the exposed limestone bottom. Underwater visibility is usually between 2 and 4 ft.

The Shark River station is located approximately 6 river miles upstream from the Gulf of Mexico and about 1,000 ft downstream of Gunboat Island (fig. 2, table 1). The riverbanks are lined mostly with red mangroves of moderate heights (30 to 40 ft). The river is approximately 400 ft wide, with depths ranging from 7 ft at the right bank sloping to 8 or 9 ft near the center and gradually decreasing in depth back to 7 ft at the left bank. Both banks are nearly vertical and consist of peat. Some areas of mud are located along the river bottom within 1 to 3 ft from the riverbanks. The remaining cross section is exposed limestone with ridges, holes, and pinnacles approximately 1 ft in elevation. Mollusks are attached to the exposed limestone bottom. Underwater visibility is usually 6 to 8 ft.

The North River station is located approximately 4 river miles upstream from Whitewater Bay and about 16 mi from the Gulf of Mexico (fig. 2, table 1). Riverbanks are lined mostly with red mangroves of relatively short stature, with heights of only 5 to 8 ft. The river is approximately 250 ft wide with depths ranging from 4 ft at the right bank to 5 ft near the center of the river, and gradually decreasing in depth up to 3 ft at the left bank. Both riverbank edges are vertical and composed of peat and fine sediments. The bottom is composed of packed mud over harder bottom. The bottom of the river near the center is composed of fine sediments having a "pudding-like" consistency. Underwater visibility is usually between 2 and 4 ft.

Methods

The Broad, Harney, and Shark River monitoring station locations were selected based on an initial reconnaissance of the study area in June 1996 that included bathymetry, hydrodynamic characteristics, and water-quality. Aerial photography also was used to locate the monitoring stations. These three stations were established between November 1996 and January 1997. A second field reconnaissance conducted in December 1997, and a meeting with ENP personnel in October 1998, were used to locate two additional discharge and nutrient flux monitoring stations. Station installations at Lostmans Creek and North River were completed in April 1999.

Continuous monitoring of water-level, stream velocity, and specific conductance combined with periodic discharge measurements and collection of water-quality samples were required to compute the discharge and nutrient flux from the five estuarine river stations. Stream velocity (index-velocity) data were used to estimate the mean cross-section channel velocity (mean velocity) that was measured using a vessel-mounted acoustic Doppler discharge measurement system. Stream velocity data were used with the measured mean channel velocity to develop index-to-mean velocity relations. Each station was equipped with similar instrumentation. Data collected at each station were reviewed for accuracy and entered into the USGS NWIS database. Data for each station were then used to develop regression equations that were used to estimate water discharge and nutrient flux.

Water-Level and Velocity Measurements

Water level was measured at each station using Design Analysis Associates H-310 vented-submersible pressure sensors that were mounted within 2-in. inside-diameter polyvinylchloride (PVC) pipes with end caps, which functioned as stilling wells. Quarter-inch holes were drilled around the perimeter of the PVC pipe within 6 in. of the bottom. Pressure sensors were programmed to average over an 8-second period every 15 minutes. Distances to water-level surfaces were measured from fixed reference points every 4 to 6 weeks and compared to the water levels measured by the pressure transducers. Water-surface reference measurements varied less than 0.02 ft from the pressure transducer water levels during the study.

Two types of vertically oriented acoustic Doppler velocity systems were used to measure 2-min averages of velocity through the water column every 15 minutes:

(1) SonTek ADP 1.5 and 3 MHz velocity profilers, and

(2) SonTek Argonaut-XR 3 MHz depth-averaging velocity sensors.

Vertically oriented velocity profilers were used because vertical stratification of flow was possible, and because these sensors allow variations in the velocity profiles in the water column to be measured during all conditions. It has been suggested (Chiu and Said, 1995) that if the maximum velocities in an open channel can be measured, then all other velocities in a cross section can be theoretically estimated using channel geometry. Therefore, the use of vertically oriented velocity systems should allow the systems to be placed in regions of maximum velocities, where the maximum amount of information about open-channel flow is contained (Chiu and Said, 1995). Theoretically, the most reliable relations between index velocity and measured-mean velocity could be acquired using this method. Unfortunately, maximum flood and maximum ebb velocities often do not occur in the same region of the river cross section. However, repeatable relations between index and mean velocities can be calculated despite this characteristic.

One drawback to using a vertically oriented index-velocity system is the limited amount of across-channel volume that is measured. In rivers and streams with variable cross-channel flow distribution, this could prove to be a problem. If water flow is relatively uniform and flow patterns are always the same across the channel, vertically oriented sensors can provide an alternative to horizontally oriented index-velocity systems.

Discharge Measurements

River discharge was measured directly using a vessel-mounted acoustic discharge system (Simpson and Oltmann, 1992). An RD Instruments 1.2 MHz acoustic Doppler discharge measurement system was used to measure discharge for calibration and validation of the index-to-mean velocity relation at all stations every 4 to 6 weeks. The discharge section edges were marked with buoys and unmeasured edge section distances were measured using optical and laser range finders. Discharge values were calculated using manufacturer's software. Individual discharge measurements took between 4 to 10 minutes to complete.

Discharge measurements were collected over varying ranges of tidal level and tidal phase for about one year to develop an index-to-mean velocity relation for each station. Multiple measurements were made during 3- to 6-hour periods to better characterize variations in flow caused by variations in tide, inflow, and wind effects, and to reduce serial correlations between measurement sets. Discharge data collected after the calibration period were used to check the accuracy of the water-level/velocity/discharge relations for the duration of the study and to apply corrections or shifts to the index-to-mean velocity relations if required. Corrections to the velocity regressions were not required at four of the five stations during the study. The Harney River station index-velocity data were corrected for June 1998 because of an electronics problem that caused the index-velocity data to be biased low.

Water-Quality Sampling

Water-quality samples also were collected every 4 to 6 weeks during trips for discharge measurement and equipment maintenance. Daily fluctuation in water quality was assumed to be represented by samples collected near flood maximum and ebb maximum based on previous studies in west-central Florida (Stoker and others, 1995, 1996). Water-quality samples were collected for the determination of total nitrogen and total phosphorus concentrations and to estimate total nitrogen and total measured phosphorus flux at the southwest coast stations. Samples were collected at each station at least once daily, and typically were collected during flood, ebb, and slack tides.

Depth-integrated samples were collected at three cross-stream locations using a stainless-steel-weighted Teflon™ bottle. A modified downrigger was used to regulate descent and ascent speed of the weighted Teflon™ bottle. Depth-integrated water samples from the three cross-stream locations were combined and mixed in a polyethylene churn and then distributed to individual sample bottles. Water sample bottles were then bagged in plastic and placed in a cooler with ice. All water-quality samples were analyzed at the USGS laboratory in Ocala, Fla. Water samples were analyzed for total and dissolved ammonia, ammonia-plus-organic nitrogen, nitrate-plus-nitrite, nitrite, phosphorus, and orthophosphate. Analytical methods used in this study are documented in Fishman and Freidman (1989). Field measurements of water temperature, specific conductance, dissolved oxygen, and pH were collected concurrently during water-quality sample collection at each location to identify cross-stream and vertical variability.

Approximately 20 percent of the water samples collected were field quality-assurance samples. Two types of quality-assurance samples were collected: (1) duplicate samples and (2) equipment blanks. Field quality-assurance samples were sent to the laboratory with routine samples. Field measurement sensors were calibrated at the beginning of each day for each parameter.

In-situ temperature and specific conductance sensors were used to collect 15-minute-interval data near the water surface and at the bottom of the water column at each station. Near surface temperature and conductance sensors were removed after 3 years at the Broad, Harney, and Shark River stations because data indicated the rivers to be well-mixed from the top to the bottom of the water column. *In-situ* temperature and specific conductance sensors were checked for accuracy every 4 to 6 weeks both before and after cleaning using three conductance standards. Any adjustments to data from the sensors based on field calibrations were made using variable shifts in the USGS Automated Data and Processing System (ADAPS).

Computation of Discharge

Discharge was computed using both a water depth to cross-sectional area relation and an index-to-mean velocity relation. Water depth to cross-sectional area relations were developed using 2nd-order polynomial equations. Velocity relations were developed using linear regression analysis of measured data. Random and systematic instantaneous discharge errors were evaluated.

Cross-Sectional Area Relation

River station cross-section bathymetry was measured using a 200 kHz recording fathometer. Cross-section elevation data not measured directly with the fathometer were measured using stadia rod and laser distance measurements. Water-level data were used with cross-section bathymetry data to determine cross-sectional area for any given water level. The water-level to cross-sectional area relation equations are shown in table 2.

Table 2. Southwest coast station cross-sectional area regression equations.

[Area in square feet; depth, water level in feet]

Station name	Water-depth-to-cross-sectional area equation
Lostmans Creek	Area = 0.19 * depth^2 + 277.2 * depth +10.2
Broad River	Area = 0.28 * depth^2 + 185.9 * depth + 256.1
Harney River	Area = 2.20 * depth^2 + 365.0 * depth + 1527.8
Shark River	Area = 0.35 * depth^2 + 423.9 * depth + 901.6
North River	Area = 0.37 * depth2 + 246.6 * depth + 5.9

Index-Velocity Relation

Linear index-to-mean velocity regression models (index-velocity relations) were developed for each station relating index velocity to mean velocity computed from measured discharge. Mean velocity was computed by dividing the measured discharges by the cross-sectional area (determined from the cross-sectional area equations) of the channel for the mid-time of the discharge measurement. Index velocities were then plotted against the mean channel velocities and analyzed using multiple-linear regression techniques. The independent variables used in the multiple-linear regression analysis were index velocity, index-velocity squared, and water level; whereas the dependent variable was mean-channel velocity (mean velocity). Index velocity was the only significant linear predictor of mean velocity for each station. However, the index-velocity relations had significant changes in slope for positive (downstream) and negative (upstream) velocities at the Broad, Harney, and Shark River stations. Index-to-mean velocity relation plots for the five stations are shown in figures 3A-E. The index-to-mean velocity equations and basic statistics are shown in table 3. Instantaneous discharge for each river station was computed by multiplying estimated mean velocity (using the index-to-mean velocity relation equations) by area (using the water level to cross-sectional river area relation equations).

Estimation of Discharge Error

Uncertainty in estimating instantaneous discharge is produced by random and systematic errors. Random discharge errors can be removed by data averaging, whereas systematic discharge errors cannot be removed by averaging. Two principal sources of error in the estimate of instantaneous discharge are instrument errors associated with measurement of water depth and index velocity, and errors associated with the cross-sectional area and mean-velocity equations (Sloat and Gain, 1995). Two methods of estimating discharge error are discussed in this report. The first method uses the standard error of the estimate of the regression equations for estimating mean velocity in the river; the second method compares the difference of computed discharge (estimated using regression equations) to measured discharge and then uses the Wilcoxon Signed-Ranks test to determine if the median difference between the values is different from zero. A difference from zero indicates a bias in the computed discharge.

The first method estimates instantaneous discharge error by multiplying the standard error estimate for each index-to-mean velocity regression equation by the corresponding median cross-sectional area. The instantaneous discharge errors using the standard error and median cross-sectional areas are listed in table 3 along with basic regression statistics for the velocity regression equations. Residual plots of the index-to-mean velocity regression equations were analyzed and appear to be random, indicating that biases are unlikely. Maximum instantaneous discharge errors were approximately 213, 65, 326, 453, and 193 ft^3/s for Lostmans Creek, Broad River, Harney River, Shark River, and North River, respectively (table 3). The maximum discharge errors as a percentage of maximum instantaneous discharge are 9, 2, 2, 4, and 18 percent for Lostmans Creek, Broad River, Harney River, Shark River, and North River, respectively. Random errors associated with individual acoustic discharge measurements were estimated to be less than 3 percent of the true discharge based on a simple random error model for acoustic discharge measure-

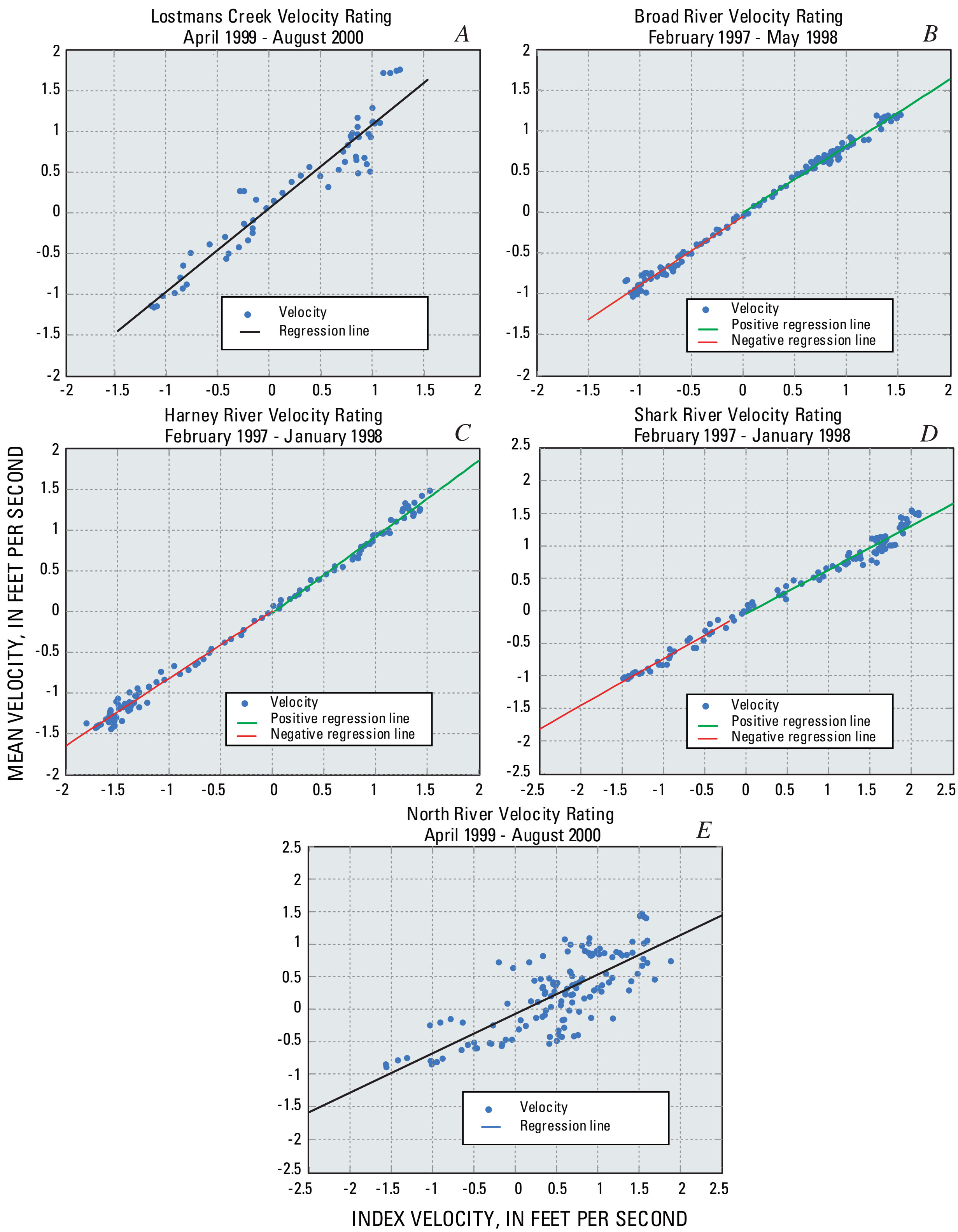

Figure 3. Index velocity to mean velocity regression relations for Lostmans Creek, Broad River, Harney River, Shark River, and North River stations.

Table 3. Index velocity regression equations and discharge error estimates using standard error estimate method.

[All equations are for mean velocity in the stream, in feet per second. R^2, correlation coefficient; ft/s, feet per second; ; ft^2, square feet; ; ft^3/s, cubic feet per second; V_m, mean velocity in feet per second; V_i, measured index velocity in feet per second; S.E.E, standard error of the estimate]

Station	Number of discharge measurements	Equation	R^2	Standard error of the estimate (ft/s)	Median cross-sectional area (ft^2)	Instantaneous discharge error for median cross-sectional area (ft^3/s) (S.E.E. * median area)
Lostmans Creek	58	$V_m = 1.031\ V_i + 0.092$	0.92	0.23	927	213
Broad River						
Positive velocity	86	$V_m = 0.8182\ V_i + 0.012$	0.98	0.05	1,379	65
Negative velocity	47	$V_m = 0.919\ V_i - 0.001$	0.98	0.04	1,379	54
Harney River						
Positive velocity	53	$V_m = 0.9388\ V_i - 0.02$	0.98	0.06	4,521	254
Negative velocity	71	$V_m = 0.827\ V_i + 0.005$	0.96	0.07	4,521	326
Shark River						
Positive velocity	89	$V_m = 0.6926\ V_i - 0.054$	0.94	0.10	4,362	453
Negative velocity	47	$V_m = 0.7564\ V_i + 0.0007$	0.94	0.08	4,362	331
North River	131	$V_m = 0.7017\ V_i - 0.04181$	0.60	0.17	1,143	193

ment systems (Simpson and Bland, 2000). Simpson and Bland (2000) also noted that the measurement of less than the entire river cross section for an index velocity may result in sampling bias (systematic error). The index-velocity methods used in this study sampled a relatively small horizontal cross section of the rivers and could be biased. Other methods of index-velocity measurement such as horizontal-averaging velocity systems can also be biased, so care must be used when determining any index-to-mean velocity relation.

The second method for estimating instantaneous discharge error provides information about discharge random error and bias. Discharge errors were calculated by subtracting the computed discharge from the measured discharge, and then basic statistics (minimum, maximum, mean, and standard deviation) were calculated for the discharge errors. The standard deviations of the discharge error are similar to the errors computed using the first method (table 3). Additional discharge measurements that were not used to develop the index-velocity relations were used in this method for three of the five stations (Broad, Harney, and Shark Rivers which had data-collection periods that were 2 years longer).

The Wilcoxon-Signed-Ranks test (WSR) was used to compare the difference between the medians of computed discharges and measured discharges. The WSR test can provide information relating to biases between the computed and measured discharges. The median values for discharge error are not significantly different from zero for four of the five stations based on the WSR probabilities (table 4).

Table 4. Computed discharge error estimation based on measured discharge and Wilcoxon Signed Ranks probability for determining median error is different from zero.

[Error = computed discharge minus measured discharge; ft^3/s, cubic feet per second; WSR, Wilcoxon Signed Ranks test]

Station name	Number of discharge measurements	Minimum error (ft^3/s)	Maximum error (ft^3/s)	Mean (ft^3/s)	Median (ft^3/s)	WSR probability that median difference is zero	Standard deviation (ft^3/s)
Lostmans Creek	69	-334	490	16	6	0.85	209
Broad River	227	-350	335	-9	-5	0.29	98
Harney River	196	-1,268	900	-10	-31	0.67	337
Shark River	205	-1,208	1,055	74	125	0.002	398
North River	131	-378	510	12	3	0.62	192

The median values not significantly different from zero (probabilities 0.29 to 0.85) indicate that bias in the discharge is unlikely. However, the Shark River WSR probability less than 0.002 indicates that the median error for discharges is significantly different from zero, which could indicate a positive bias for computed discharge.

The Shark River instantaneous discharge bias based on the WSR is between 74 and 125 ft^3/s (table 4), indicating that the true discharges for the Shark River may be slightly lower than the values in this report. This bias may be attributed in part to the confluence of a small creek that enters the Shark River upstream of the discharge measurement section that was not well represented using the index-velocity system.

The North River station had the greatest percentage error in instantaneous discharge, as expected based on the velocity regression model ($R^2 = 0.60$ compared to 0.92 to 0.98 for the other stations). However, the long-term North River mean discharge should be close to the actual discharge because residual plots (figs. 4A-E) of the index-to-mean velocity regression data and Wilcoxon-Signed-Ranks test (table 4) indicate the uncertainty is random and the mean and median WSR errors are not significantly different from zero. The poor index-to-mean velocity regression model for the North River indicates the velocity sensor was located in a section of the river that did not represent the mean channel velocity all of the time. In addition, a relatively low tidal range (typically less than ½ ft) measured at this station could allow the flow distribution across the channel to be easily changed by wind forcing. Additionally, the channel geometry (wide and relatively shallow with no distinct center channel and confluence of two river sections upstream of the station) also could have contributed to a poor index-to-mean velocity relation.

Discharge Characteristics

Discharges from the Lostmans Creek, Broad, Harney, Shark, and North Rivers are predominantly influenced by semidiurnal astronomical tides, longer period astronomical tides, wind events, and water inflow (rain, surface water, and ground water). Discharge flow direction at these stations was one dimensional except for brief periods (less than 20 minutes) during slack water between flood and ebb tide. During these periods, flow was vertically and horizontally bidirectional (moving upstream and downstream). For a typical tidal cycle, the flood discharges (water moving upstream, denoted as negative values) were usually of greater magnitude and shorter duration (4 to 5 hours) than the ebb discharges. Ebb discharges (water moving downstream, denoted as positive values) were slightly less magnitude than the flood discharges but longer duration (5 to 7 hours) (fig. 5).

Residual discharge in this report refers to the discharge data after filtering the instantaneous discharge with a digital filter. Filtering allows the computation of daily mean and monthly mean discharge values without aliasing the data. Aliasing of data causes the introduction of a false signal that is not contained in the original data. Aliasing occurs when the sampling frequency is less than twice the highest frequency contained in the measured data (Orfanidis, 1996). A 9th order Butterworth low-pass filter was used to attenuate semidiurnal tidal fluctuations of less than about 40 hours in the instantaneous discharge data (Roberts and Roberts, 1978). The order of the Butterworth filter comes from the selection of the corner frequencies (normalized passband frequency (1/80), and normalized stopband frequency (1/60)), the passband ripple (1 decibel), and the stopband attenuation (15 decibel). The corner frequencies are normalized to the Nyquist frequency (Nyquist, 1928). These parameters are used to determine the minimum order of the Butterworth low-pass filter (9th order) in the Matlab Signal Processing Toolbox (The MathWorks, Inc., 1998). After the minimum order of the filter is determined, the Matlab Signal Processing Toolbox is used to design a Butterworth filter based on the order of the filter and the cutoff frequency. The cutoff frequency is a number between 0 and 1 where 1 corresponds to one-half the sampling frequency (The MathWorks, Inc., 1998). After all these values are determined, the input data are processed through a forward and reverse digital filter that preserves the original phase of the input data. Data resulting from this process are called residual data.

Values of residual discharge include freshwater inflow, ground-water inflow, and storage due to prevailing winds or long-term (greater than 40 hours) astronomical tides. Storm events with strong associated winds are noticeable in the residual discharge data. Daily mean and monthly mean data were determined using the residual discharge data.

The five station's total monthly mean discharges were compared to ENP monthly rain totals and USGS discharges from the S-12 A, B, C, and D (S-12) structures along the Tamiami Trail (U.S. Highway 41) (fig. 1, figs. 6A-E). Residual discharge responses to rainfall for the Lostmans Creek, Broad, Harney, and Shark River stations show similar patterns and magnitudes, whereas the North River station residual discharge response was similar to the other four stations but with a lesser magnitude (figs. 6A-E). Negative mean residual discharges are typical in the southwest coast estuaries from March to May, as the mean water level in the Gulf of Mexico begins to increase after reaching a low in late winter and surface runoff is reduced because of lower rainfall during the winter. Residual discharge peaks at the coast stations typically lead the discharge peaks at the S-12 structures by about 1 month. The relatively flat terrain and the rapid response of the measured coast discharges to rainfall in the Shark River Slough may explain the measured coast discharge peak leading the S-12 discharge peak. It also is possible that the flow releases through the S-12 structures do not begin until water levels on the upgradient side of the structures begin to rise. Linear regression analysis of S-12 total discharge to the five station total discharge (lagged by 1 month) indicate that the total monthly mean discharge for the five rivers is approximately two to three times greater than the total discharge at structures S-12 (fig. 7).

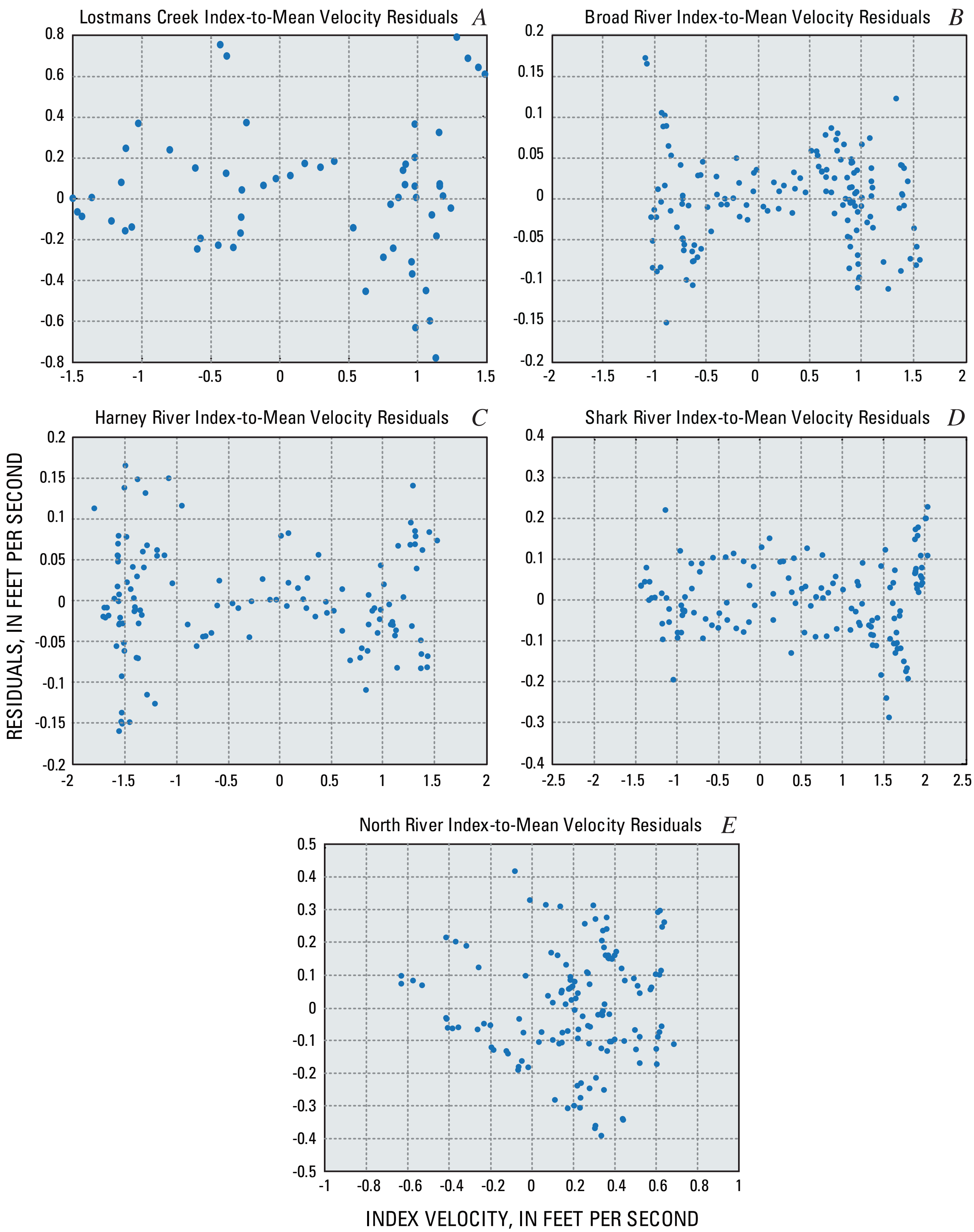

Figure 4. Residual plots of index-to-mean velocity regression relations for Lostmans Creek, Broad River, Harney River, Shark River, and North River stations.

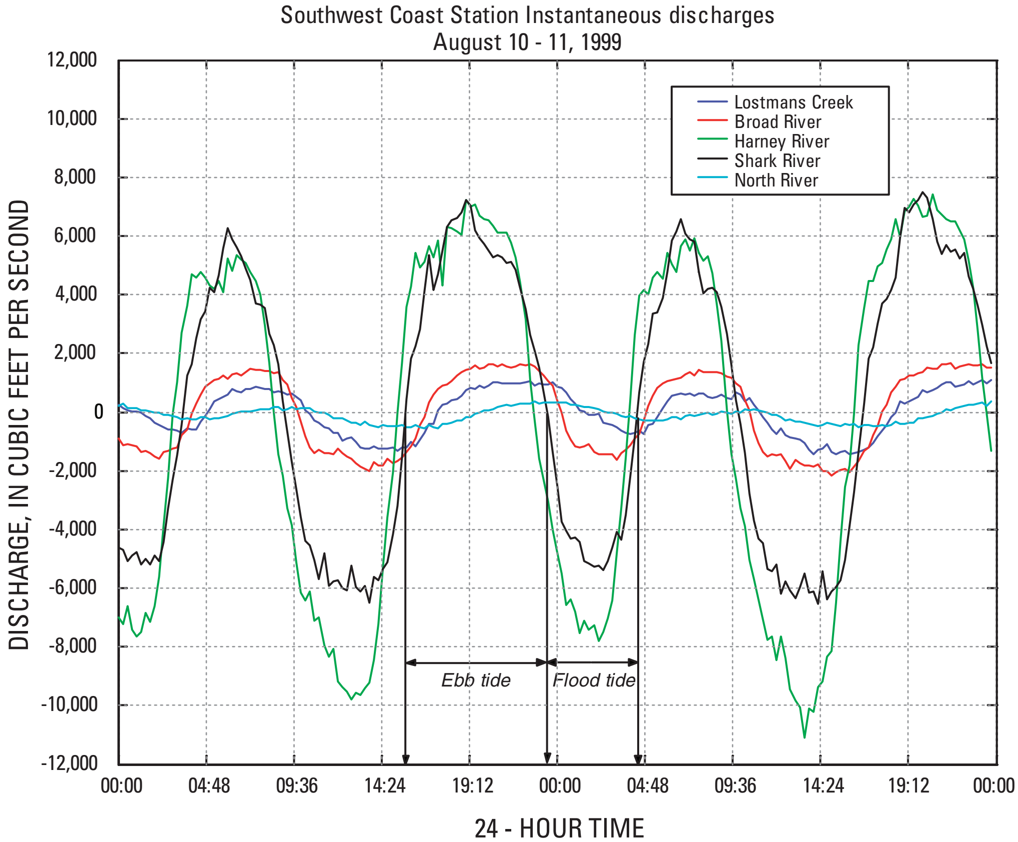

Figure 5. Typical instantaneous discharge cycle for five stations along the southwest coast of the Everglades National Park.

The Lostmans Creek, Broad River, Harney River, and Shark River stations had approximately equal residual flow between 20 to 27 percent of the total measured coast discharge when total measured residual discharge was between about 1,250 to 3,000 ft^3/s (figs. 8A-E). Residual flow distribution estimates for the five rivers were made based on 6 months of residual monthly mean discharges when all stations had complete months of residual discharge data. Over a longer 11-month period with concurrent data during 1998, the Broad, Harney, and Shark Rivers residual flows were evenly divided, with each river accounting for 30 to 35 percent of the three-station total residual discharge. The similarity in residual discharge between Lostmans Creek, Broad, Harney, and Shark Rivers indicates that the Shark River Slough outflow region extends at least as far north as Lostmans Creek, and possibly as far south as North River. However, residual flow magnitudes decrease significantly at North River. North River typically accounted for only about 4 percent of the total residual flow for all stations during periods with concurrent data.

Discharge and Water-Level Synopsis

The following sections include brief discussions of discharge characteristics of individual stations comparing the tidal ranges and response of each station to significant hydrologic events. To allow easy comparison of tidal ranges, water levels were converted to mean-normalized water levels (normalized water level). The mean water level during the 1999-2001 period was subtracted from the water level to compute a normalized water level. Because of their remoteness, the stations were not surveyed to a vertical datum. The mean water level of the rivers is typically lower during the winter and early spring along the southwest coast of Florida, and it is not unusual for strong southeast winds to precede a cold front and force water out of the estuaries. Then, strong northwest winds (20 to 25 miles per hour) occur after the front that forces water back into the estuaries.

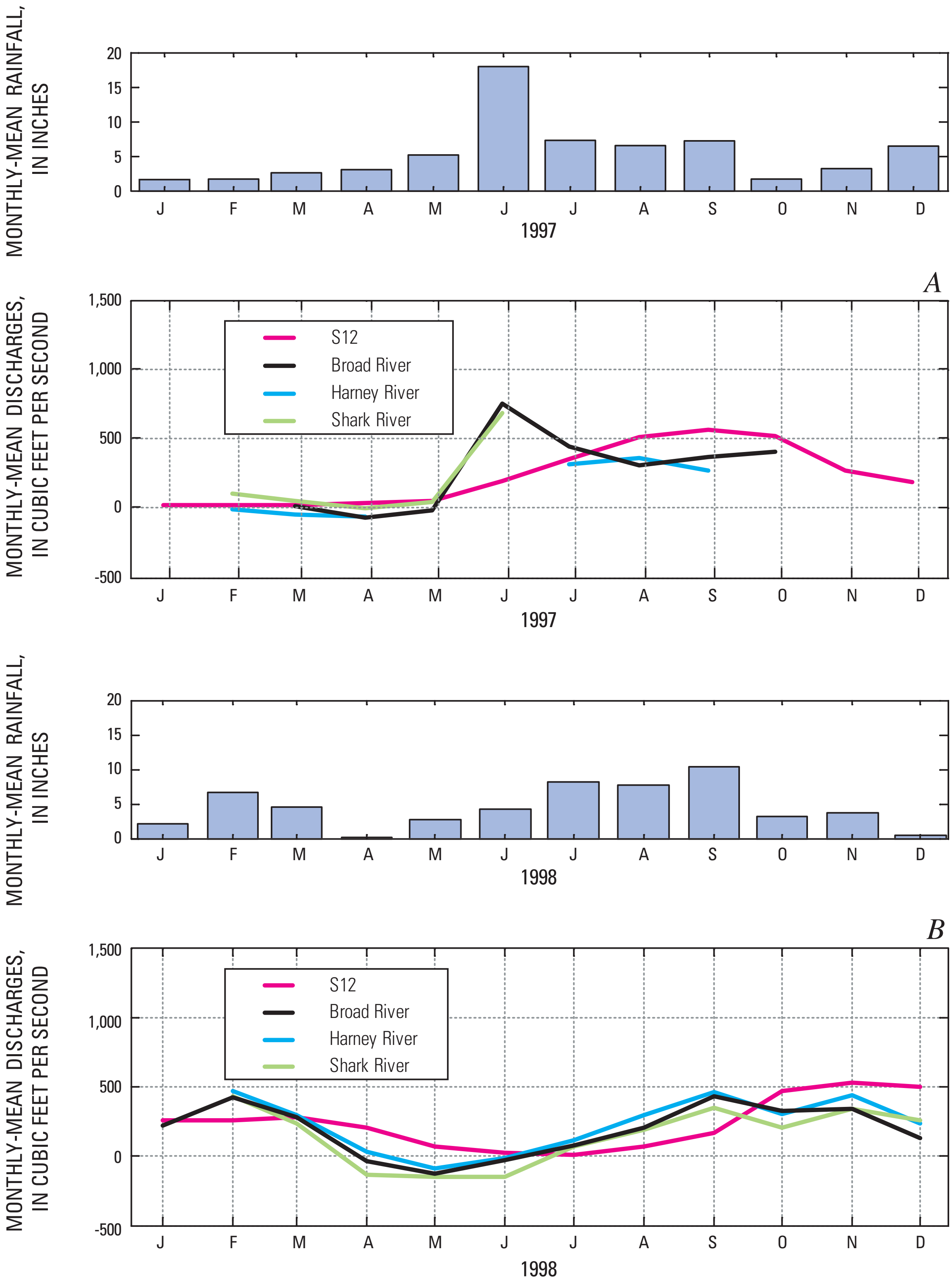

Figure 6. Monthly mean residual discharge for the five southwest coast stations, S-12-A, B, C,and D monthly mean discharge, and ENP average monthly total rainfall for 1997-2001.

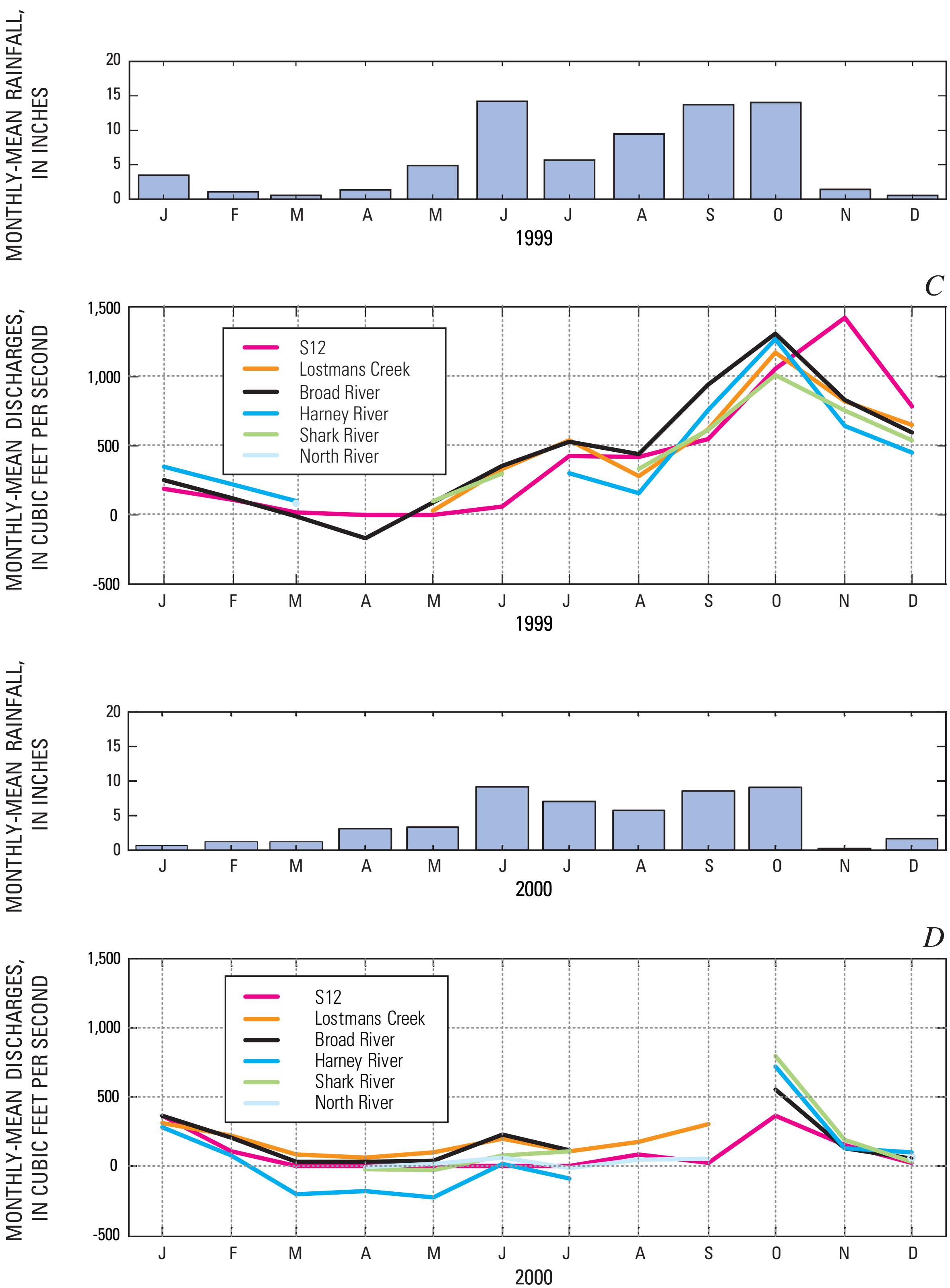

Figure 6. Monthly mean residual discharge for the five southwest coast stations, S-12-A, B, C,and D monthly mean discharge, and ENP average monthly total rainfall for 1997-2001. (Continued)

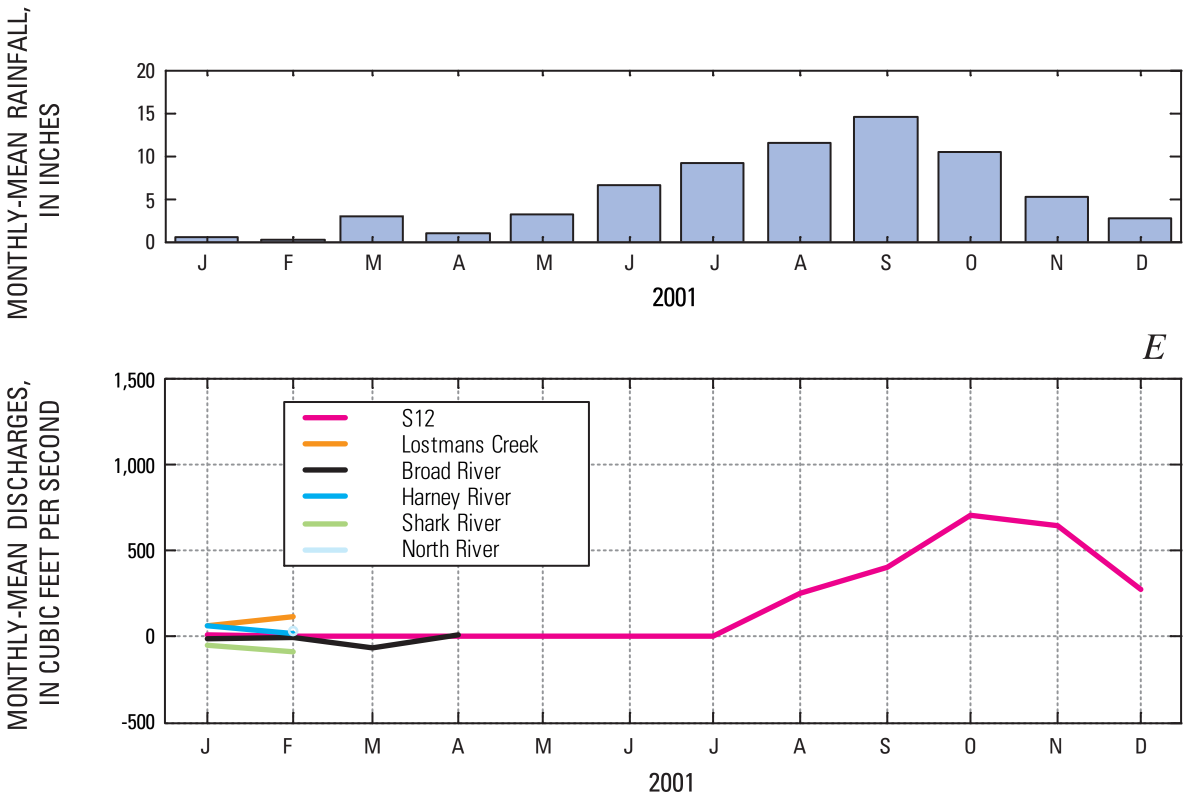

Figure 6. Monthly mean residual discharge for the five southwest coast stations, S-12-A, B, C,and D monthly mean discharge, and ENP average monthly total rainfall for 1997-2001. (Continued)

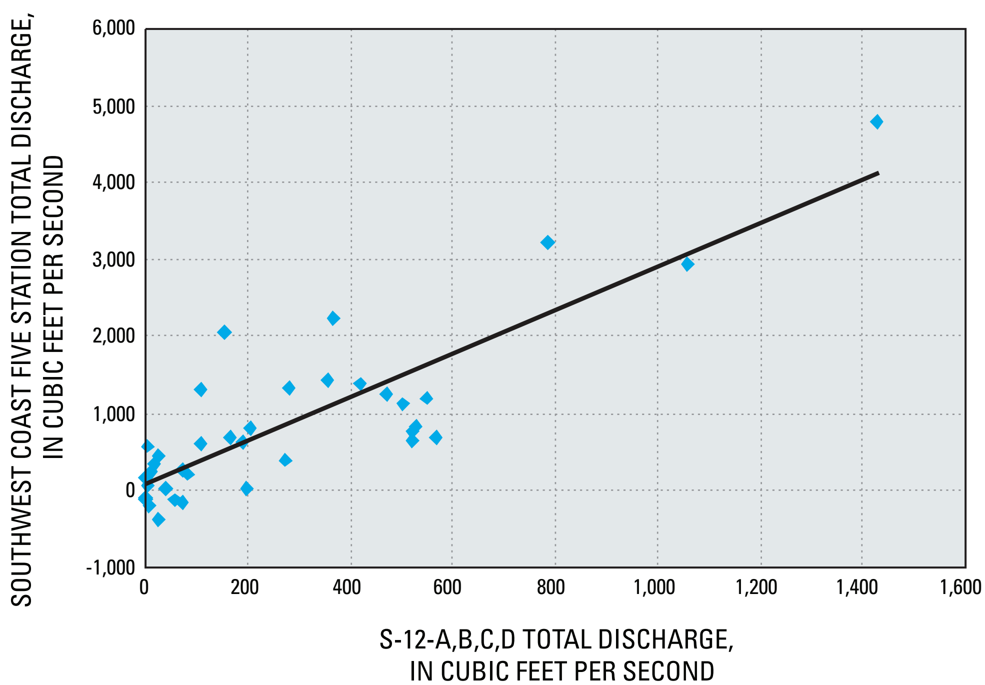

Figure 7. Southwest coast stations monthly mean residual discharge (coast station discharges lagged by 1 month) to S-12-A, B, C, and D monthly mean discharge regression relation.

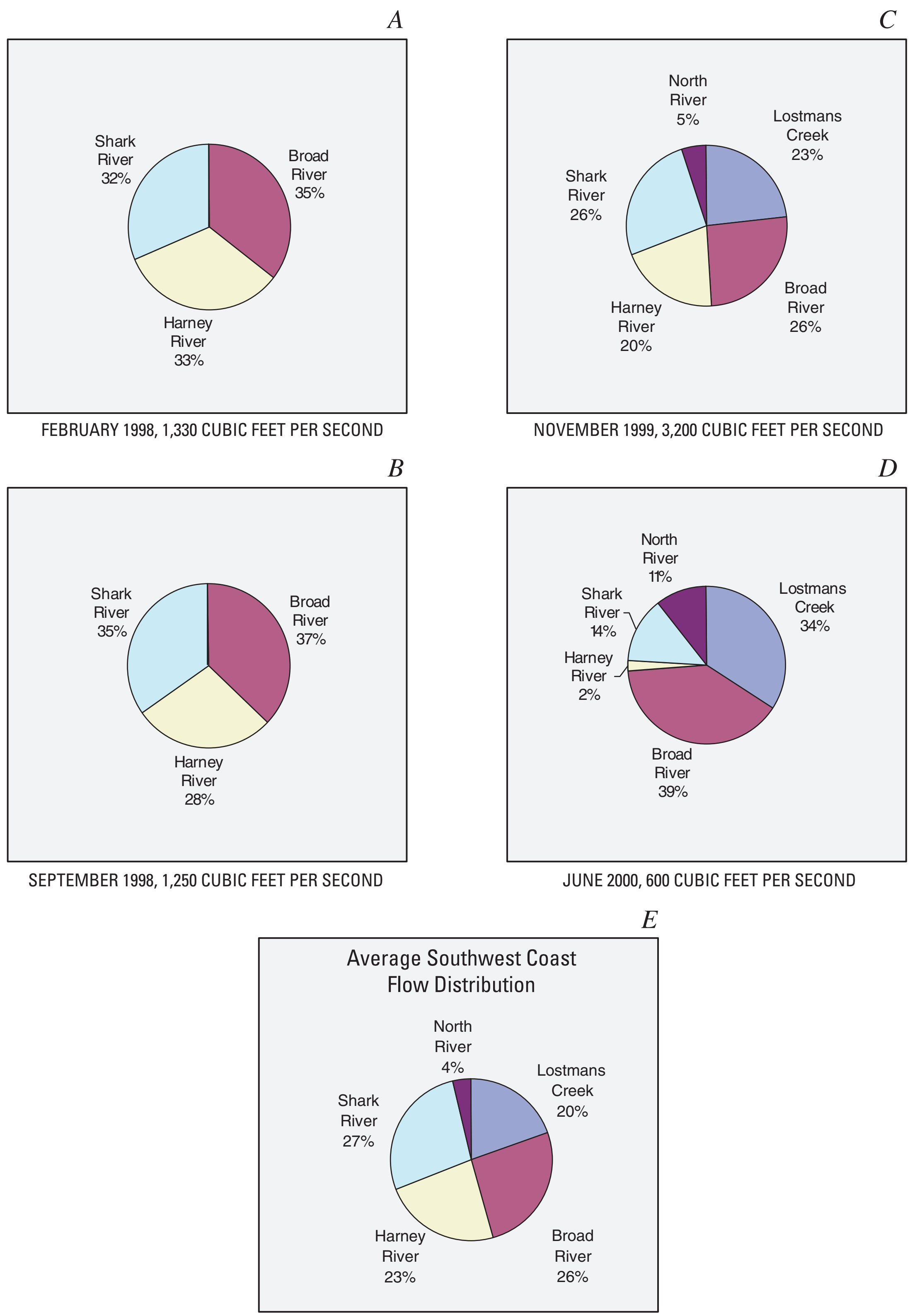

Figure 8. Monthly mean and 2-year average residual discharge distributions for selected periods of concurrent data between 1998-2000.

Lostmans Creek Station

The Lostmans Creek normalized water level ranged from -1.64 to 2.13 ft during the study. Index velocities greater than 1 ft/s occurred during less than 10 percent of the study period. Computed instantaneous discharges at the Lostmans Creek station ranged from -2,600 ft^3/s during the passage of Tropical Storm Harvey on September 21, 1999, to +2,400 ft^3/s during the passage of Hurricane Irene on October 15, 1999. The maximum residual discharge of +1,560 ft^3/s also occurred during the passage of Hurricane Irene, and the minimum residual discharge of -835 ft^3/s occurred on March 27, 2000, during the passage of a strong cold front during a period of lower mean water level at the station.

Residual discharge for January through December 2000 was less than during 1999 because of less rainfall. Approximately 70 in. of rainfall fell on ENP in 1999 (average of 16 stations shown in fig. 1), whereas only 51 in. fell in 2000 (Everglades National Park, 1996-2001). The daily mean residual discharge during the study period ranged from -610 to +1,470 ft^3/s. A strong cold front in March 2000 caused water to pile up in the mangrove forests and resulted in the largest negative daily mean residual discharge for the study period of -610 ft^3/s. The rest of the year was relatively uneventful, with a maximum daily mean residual discharge of approximately 800 ft^3/s, which was about half the maximum for 1999. Lostmans Creek absolute residual discharge (absolute value of residual discharge) was greater than 500 ft^3/s for 20 percent of the study period, and absolute instantaneous discharge (absolute value of instantaneous discharge) was greater than 500 ft^3/s approximately 50 percent of the study period.

Broad River Station

The Broad River station normalized water levels ranged from -2.03 to +2.05 ft during the study, with a typical spring-tide water-level range of approximately 2 ft. The maximum index velocity recorded was +2.99 ft/s during the passage of Hurricane Irene in October 1999, and the minimum index velocity, -1.78 ft/s, occurred during the passage of a strong cold front in January 2001. Computed instantaneous discharges at the Broad River station ranged from -2,400 ft^3/s during the passage of a frontal storm system on April 30, 1999, to +3,500 ft^3/s during the passage of Hurricane Irene on October 15, 1999. There were some periods when the instantaneous discharge did not reverse (move upstream) for as long as a month. The maximum residual discharge was +2,500 ft^3/s during the passage of Hurricane Irene, whereas the minimum residual discharge was -1,700 ft^3/s during the passage of a cold front on February 4, 1998. The Broad River station daily mean residual discharge ranged from -1,320 to +2,040 ft^3/s.

Harney River Station

The Harney River station normalized water levels ranged from -2.95 to +3.42 ft, with a typical spring-tide water-level range of approximately 4 ft. Maximum velocities for flood tide occurred right of river center (looking downstream), and maximum ebb flows occurred left of river center based on acoustic discharge measurements. The maximum index velocity recorded was 2.7 ft/s during the passage of Tropical Storm Harvey on September 21, 1999, and the minimum index water velocity recorded was -3.2 ft/s earlier on the same day as winds blew onshore. Computed instantaneous discharges at the Harney River station ranged from -12,000 to +10,000 ft^3/s during the study. The daily mean residual discharge during the study period ranged from -2,290 to +4,860 ft^3/s.

Harney and Shark Rivers are both connected to Tarpon Bay. Acoustic discharge measurements on the Harney River approximately 300 ft downstream of Tarpon Bay from the June 1996 reconnaissance identified a short period of time when the Harney River flow was flooding (moving upstream), while the Shark River flow slightly downstream of Tarpon Bay had been ebbing a short time before. These measurements suggest that during specific periods, water can move upstream into Tarpon Bay from the Harney River while Tarpon Bay water is flowing downstream into the Shark River. The contrary flood and ebb flows are believed to be a rapid occurrence (duration less than 15 minutes), because flow in the Shark River was upstream (flooding) when it was measured about 10 minutes later. These contrary flows would tend to reduce the daily mean residual discharge values for the Harney River station while artificially increasing those at the Shark River station. However, the short duration of the flows and the uncertainty of how often the contrary flows occur suggest they will probably not significantly affect long-term mean residual discharges for either station.

Shark River Station

The Shark River station normalized water levels ranged from -2.63 to +3.08 ft. The maximum water level occurred during the passage of Tropical Storm Harvey on September 21, 1999, and the minimum water level occurred as Hurricane Georges passed offshore in the Gulf of Mexico on September 25, 1998. Similar to the Harney River station, maximum velocities for flood flows occurred right of the river center and maximum velocities for ebb flow occurred left of river center based on acoustic discharge measurements. Index velocities ranged from -2.5 to +3.0 ft/s, and a typical tidal cycle range was usually ±2 ft/s. The maximum water velocity occurred during the passage of Tropical Storm Harvey on September 21, 1999, and the minimum occurred during the passage of Tropical Storm Mitch on November 5, 1998. The passage of Tropical Storm Mitch on November 5, 1998. The Shark River station instantaneous discharges were slightly less than the Harney River station and ranged from -10,000 to +8,000 ft^3/s. The daily mean residual discharge during the study period ranged from -1,970 to +3,790 ft^3/s.

North River Station

The North River station normalized water levels ranged from -1.67 to +2.06 ft. The maximum water level occurred during the passage of Tropical Storm Harvey on September 21, 1999, whereas the minimum water level occurred during the passage of a cold front on January 15, 2000. Index velocities ranged from -1.1 to +1.8 ft/s and a typical tidal cycle range was -0.2 to +0.4 ft/s. The maximum water velocity occurred during the passage of Hurricane Irene on October 15, 1999, and the minimum velocity occurred during the passage of Tropical Storm Harvey on September 21, 1999. The North River station instantaneous discharges were the lowest of the five stations and ranged from -1,100 to +1,100 ft^3/s. The daily mean residual discharge during the study period ranged from -360 to +530 ft^3/s.

Water Quality and Nutrient Flux

Water-quality data consisted of nutrient-concentrations from water samples collected during the study and *in-situ* water-quality measurements. Concentrations of constituents in duplicate samples were within 5 percent of original sample concentrations, and equipment blank sample concentrations indicated there was no significant contamination from the sampling procedure. Nutrient-concentrations and the *in-situ* water-quality parameters generally exhibited seasonal variations, although short-term variation of concentrations and water-quality measurements also occurred.

Water-Quality Characteristics

Broad, Harney, and Shark Rivers were well mixed, with a difference in specific conductance from top to bottom usually no greater than 500 µS/cm during flood and ebb tides. Lostmans Creek and North River were usually well mixed, but there were occurrences of slightly stratified flows (top-to-bottom difference 2,000 µS/cm) near the beginning of the wet season, or after significant rainfall events. Specific conductance at the Lostmans Creek and Broad River stations remained at 250 to 800 µS/cm from August through December 1999 because of rainfall from the summer season and two late-season tropical systems (39 in. of rainfall). Specific conductance at the Lostmans Creek and Broad River stations was less than 1,000 µS/cm for 30 percent of the study period.

All stations had relatively high total nitrogen concentrations of about 1 to 2 mg/L and very low total phosphorus concentrations, typically less than 0.04 mg/L (tables 5 and 6). Concentrations for total nitrogen and total phosphorus were very similar in magnitude and range at all five stations. Infrequently, a duplicate sample's phosphorus concentration was 10 to 20 percent different than the original sample concentration. Discussions with the USGS laboratory personnel identified possible interference with the low-level phosphorus analysis method, when used on saline water, that could result in erroneous phosphorus concentrations. Nitrite and nitrate concentrations were detected at very low levels and ranged from below the detection limit of 0.002 to 0.070 mg/L.

Total nitrogen concentrations were approximately 75 to 85 percent dissolved nitrogen, and total phosphorus concentrations were approximately 35 to 50 percent dissolved phosphorus. Dissolved nutrients are readily available to plants, and analyses indicated that approximately three-quarters of the total nitrogen and half of the total phosphorus are available in the dissolved form.

Total nitrogen concentrations for the five stations generally were inversely related to specific conductance (saltier water had lower nitrogen concentrations), but the relations were not statistically significant. However, at four of the five stations (all but the Shark River station), total phosphorus concentrations were directly related to specific conductance and the relations were statistically significant ($p = 0.0$ to 0.11), which means that as the water became saltier (increased specific conductance water from the Gulf of Mexico), the total phosphorus concentrations increased. Two models were tested for estimating total measured phosphorus flux. One model used specific conductance as the independent variable to estimate phosphorus concentration for any given specific conductance. The second model is a more direct method that used discharge as the independent variable to estimate total phosphorus flux for any given discharge. In the second method, nutrient-concentration is multiplied by instantaneous discharge at the time of sample collection and a conversion factor to yield flux in short tons (2,000 pounds) per day. The flux values are then used as the dependent variable and discharge is the independent variable, and a linear regression equation is used to describe the relation (Helsel and Hirsch, 1992). The two models gave similar results for monthly mean phosphorus flux. The second more direct method of estimating total nitrogen and total phosphorus flux was selected to estimate total station fluxes.

Nutrient Flux

Nutrient fluxes were estimated for the five stations to provide information about loading to the estuarine system and the Gulf of Mexico from the upgradient regions of Everglades National Park. Instantaneous nitrogen and phosphorus fluxes were estimated using regression methods based on total

Table 5. Southwest coast station nitrogen concentration basic statistics.

[mg/L, milligrams per liter]

Station name	Number of samples	Total nitrogen (mg/L)			Dissolved nitrogen (mg/L)		
		Maximum	Minimum	Mean	Maximum	Minimum	Mean
Lostmans Creek	22	1.30	0.54	0.88	1.10	0.38	0.72
Broad River	60	1.60	0.48	0.94	1.32	0.45	0.80
Harney River	71	1.62	0.55	0.87	1.22	0.46	0.73
Shark River	65	1.13	0.54	0.83	1.12	0.42	0.70
North River	23	1.70	0.56	1.10	1.31	0.20	0.80

Table 6. Southwest coast station phosphorus concentration basic statistics.

[mg/L, milligrams per liter; <, less than]

Station name	Number of samples	Total phosphorus (mg/L)			Dissolved phosphorus (mg/L)		
		Maximum	Minimum	Mean	Maximum	Minimum	Mean
Lostmans Creek	22	0.032	0.005	0.014	0.016	< 0.002	0.005
Broad River	60	0.024	0.003	0.012	0.012	< 0.002	0.004
Harney River	71	0.042	0.010	0.021	0.024	0.003	0.009
Shark River	65	0.034	0.007	0.015	0.105	< 0.002	0.008
North River	23	0.028	0.005	0.015	0.013	< 0.002	0.006

measured nitrogen flux and total measured phosphorus flux (dependent variables) and 15-minute instantaneous discharge (independent variable) (figs. 9A-J; tables 7 and 8).

Residual nutrient fluxes were calculated by processing the instantaneous nutrient flux data with the same 9th order Butterworth low-pass filter that was used to calculate residual discharge. Nutrient fluxes are a function of discharge; therefore, the nutrient fluxes for the five stations are proportional to discharge. Residual nutrient flux distributions for the five stations with concurrent data are shown in figures 10A-D. Total residual nitrogen fluxes and total residual phosphorus fluxes at the Lostmans Creek, Broad, Harney, and Shark River stations were evenly distributed, with each station accounting for between 23 to 27 percent of the five station total fluxes during low and high flow conditions. The North River station total residual nitrogen and total residual phosphorus fluxes accounted for 4 percent of the five station total fluxes, a value similar to the residual discharges for that station.

Total residual nitrogen flux from the five river stations was about 1,280 short tons for August 1999 through January 2000, the highest flow period during the study. Total residual phosphorus flux from the five river stations was about 17 short tons for the same period, reflecting the low total phosphorus concentrations measured in the five rivers.

Summary

A study of discharge and nutrient fluxes was conducted at five tidally affected rivers that receive freshwater from the Shark River Slough of Everglades National Park, Florida. The study was funded through the U.S. Geological Survey Placed Based Studies Initiative, and partially funded for the final year by the U.S. Department of the Interior Critical Ecosystem Studies Initiative in cooperation with Everglades National Park (ENP). Data collection began at three stations between November 1996 and January 1997, and two additional stations were added in April 1999.

This study quantified residual discharge and residual nutrient flux from five estuarine rivers along the southwest coast of ENP. This is the first phase of a long-term effort to monitor estuarine river discharge to the southwest coast of Florida and evaluate estuarine discharge from ENP and Big Cypress National Preserve as rehabilitation of the Everglades System progresses.

River discharges were estimated using acoustic velocity systems and linear regression models. Instantaneous discharges for each station varied between -2,600 to +2,400 ft^3/s for the Lostmans Creek station; -2,400 to +3,500 ft^3/s for the Broad River station; -12,0000 to +10,000 ft^3/s for the Harney

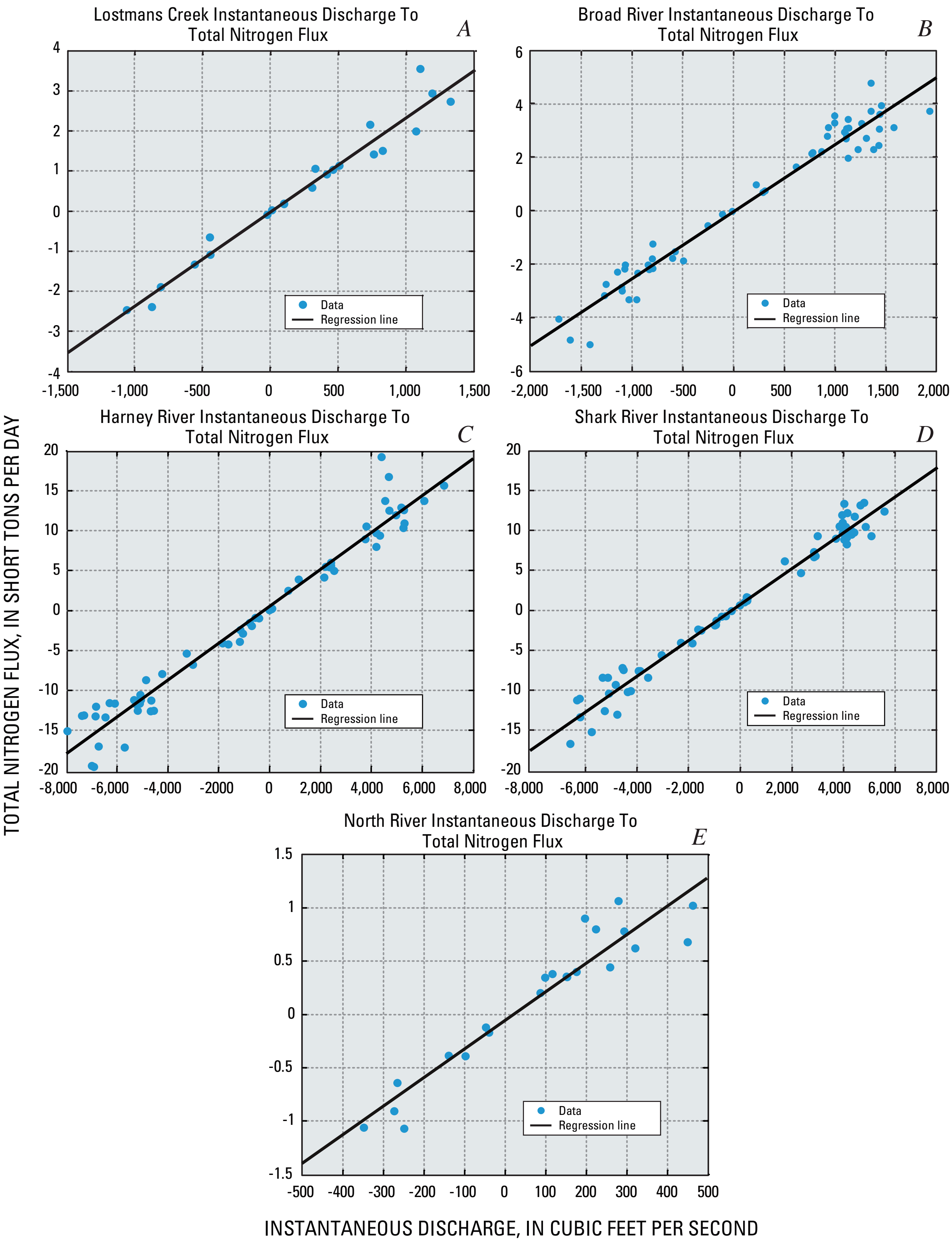

Figure 9. Southwest coast stations discharge to nutrient flux regression relations.

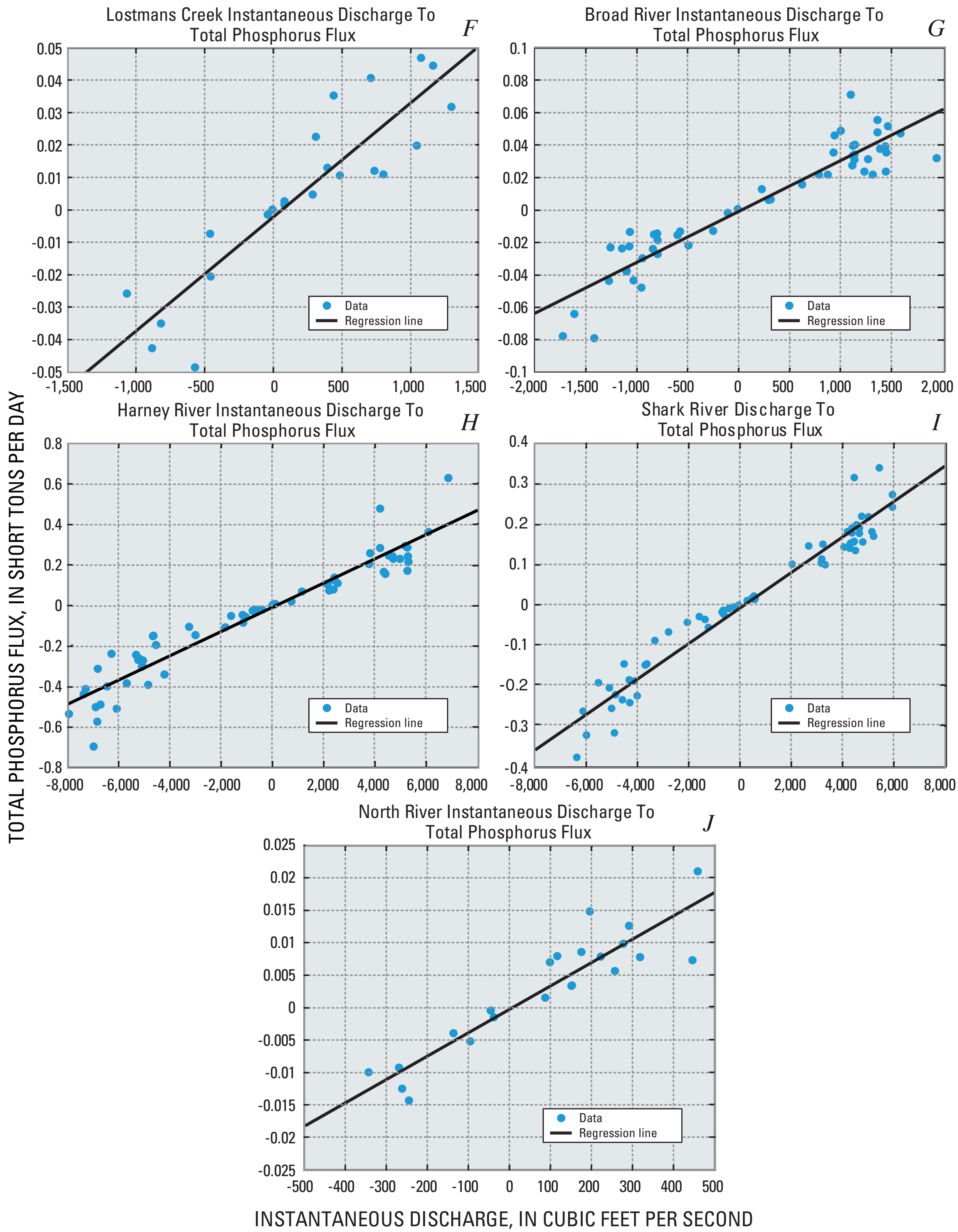

Figure 9. Southwest coast stations discharge to nutrient flux regression relations. (Continued)

Table 7. Regression equations used to estimate total nitrogen flux.

[All equations are for total nitrogen flux in short tons per day. Q, discharge in cubic feet per second; R^2, correlation coefficient]

Station	Number of water quality samples	Total nitrogen flux equation (short tons per day)	R^2	Standard error of the estimate (short tons per day)
Lostmans Creek	22	Flux = 0.00235 Q - 0.00385	0.96	0.34
Broad River	60	Flux = 0.00252 Q - 0.04141	0.95	0.60
Harney River	71	Flux = 0.00231 Q + 0.53058	0.96	2.14
Shark River	65	Flux = 0.00221 Q + 0.21612	0.97	1.46
North River	23	Flux = 0.00269 Q - 0.05611	0.90	0.21

Table 8. Regression equations used to estimate total phosphorus flux.

[All equations are for total phosphorus flux in short tons per day. Q, discharge in cubic feet per second; R^2, correlation coefficient]

Station	Number of water quality samples	Total phosphorus flux equation (short tons per day)	R^2	Standard error of the estimate (short tons per day)
Lostmans Creek	22	Flux = 0.00003501 Q - 0.002378	0.80	0.012
Broad River	60	Flux = 0.00003170 Q - 0.001453	0.88	0.013
Harney River	71	Flux = 0.00005428 Q - 0.012177	0.95	0.064
Shark River	65	Flux = 0.00004390 Q - 0.008485	0.96	0.037
North River	23	Flux = 0.00003626 Q - 0.000306	0.84	0.004

River station; -10,000 to +8,000 ft^3/s for the Shark River station; and -1,100 to +1,100 ft^3/s for the North River station. Maximum instantaneous discharge errors were approximately 213, 65, 326, 453, and 193 ft^3/s for Lostmans Creek, Broad River, Harney River, Shark River, and North River, respectively. The maximum discharge errors as a percentage of maximum instantaneous discharge are 9, 2, 2, 4, and 18 percent for Lostmans Creek, Broad River, Harney River, Shark River, and North River, respectively. Instantaneous discharge data were filtered using a 9th order Butterworth low-pass filter to remove predominant tidal frequencies, and the filtered data were used to compute daily mean and monthly mean residual discharges. The similarity in residual discharge between Lostmans Creek, Broad, Harney, and Shark Rivers indicates that the Shark River Slough outflow region extends at least as far north as Lostmans Creek, and possibly as far south as the North River. Regression analysis of monthly mean residual discharges indicate that the Lostmans Creek, Broad River, Harney River, Shark River, and North River systems discharge approximately two to three times the amount of water flowing through the Tamiami canal S-12 structures along U.S. Highway 41. Monthly mean residual discharges at the five stations along the southwest coast are at a maximum approximately 1 month before the S-12 structures reach their maximum discharges. Most of the total daily mean residual discharge from the five rivers is evenly distributed between Lostmans Creek, Broad, Harney, and Shark Rivers with each river contributing between 20 to 27 percent of the residual discharge. In contrast, the North River typically discharged only 4 percent of the total residual discharge during the same period.

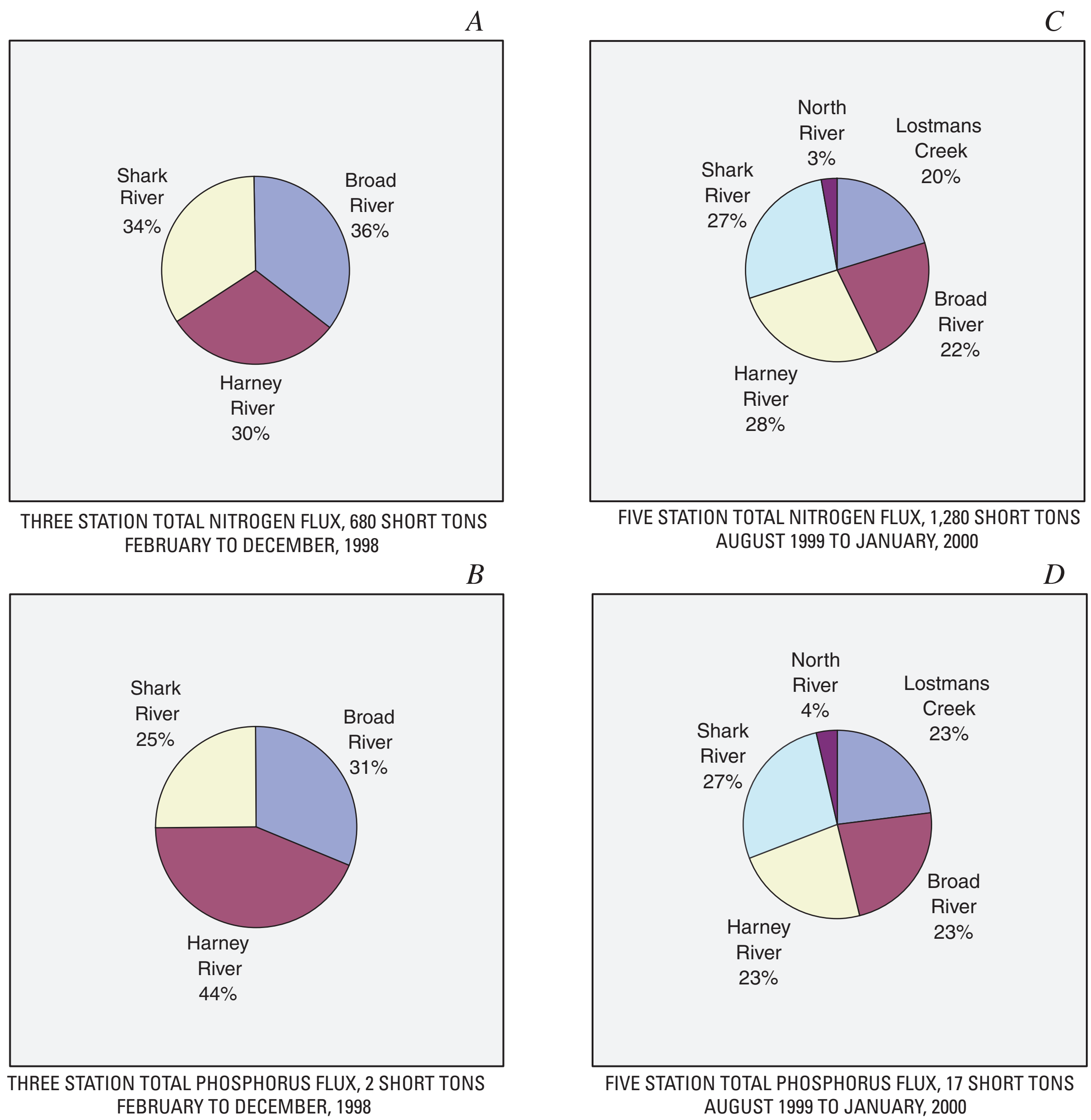

Figure 10. Southwest coast three and five station total nitrogen and total phosphorus flux distributions for selected periods of concurrent data.

The concentrations of total nitrogen and total phosphorus were similar in magnitude and range at all five stations; therefore, nitrogen and phosphorus flux distributions resemble the residual discharge distributions. Total nitrogen and total phosphorus residual fluxes from the five rivers were estimated using linear regression models of total nitrogen and total phosphorus flux to instantaneous discharge. Instantaneous nutrient flux data also were filtered using a 9th order Butterworth low-pass filter to remove predominant tidal frequencies, and the filtered data were used to compute residual nutrient fluxes. Total nitrogen residual flux was 1,280 short tons, and the total phosphorus residual flux was 17 short tons for a high flow period between August 1999 and January 2000. The distribution of residual fluxes was similar to the distribution of residual discharges. Lostmans Creek, and Broad, Harney, and Shark Rivers contributed approximately equal amounts of total nitrogen (20 to 27 percent of the total), whereas the North River contributed 4 percent of the total nitrogen. Lostmans Creek, and Broad, Harney, and Shark River stations discharged between 23 to 27 percent of the five station total phosphorus residual flux, whereas the North River discharged 3 percent of the five station total phosphorus residual flux.

References Cited

Chiu, C-L, and Abidin Said, C.A., 1995, Maximum and mean velocities and entropy in open-channel flow: Journal of Hydraulic Engineering, v. 121, no. 1, p. 26-35.

Everglades National Park, [1996-2001], Marsh and marine monitoring network data summary, 1996–2001, Physical Science Inventory and Monitoring Program: South Florida Natural Resource Center.

Fernald, E.A., and Patton, D.J., 1984, Water resources atlas of Florida: Tallahassee, Florida State University, Institute of Science and Public Affairs, 291 p.

Fishman, M.J., and Friedman, L.C., 1989, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1, 545 p.

Helsel, D.R., and Hirsch, R.M., 1992, Statistical methods in water resources: Amsterdam, Elsevier, 522 p.

Hela, I., 1952, Remarks on the climate of southern Florida, Bulletin of Marine Science Gulf Caribbean 2, p. 438-447.

Nyquist, Harry, 1928, Certain topics in telegraph transmission theory: Transactions of the American Institute of Electrical Engineers, v. 47, p. 617-644.

Orfanidis, S.J., 1996, Introduction to signal processing: Upper Saddle River, N.J., Prentice-Hall, 798 p.

Roberts, Jo, and Roberts, T.D., 1978, Use of the Butterworth low-pass filter for oceanographic data: Journal of Geophysical Research, v. 83, no. C11, p. 5510-5514.

Schomer, N.S., and Drew, R.D., 1982, An ecological characterization of the lower Everglades, Florida Bay, and the Florida Keys: U.S. Fish and Wildlife Service, Office of Biological Services, FWS/OBS-82/58.1, 246 p.

Simpson, M.R., and Bland, Roger, 2000, Methods for accurate estimation of net discharge in a tidal channel: Institute of Electrical and Electronics Engineers Journal of Oceanic Engineering, v. 25, no. 4, p. 437–445.

Simpson, M.R., and Oltmann, R.N., 1992, Discharge-measurement system using an acoustic Doppler current profiler with applications to large rivers and estuaries: U.S. Geological Survey Open-File Report 91-487, 49 p.

Sloat, J.V., and Gain, Scott, 1995, Applications of acoustic velocity meters for gaging discharge of three low-velocity tidal streams in the St. Johns River basin, northeast Florida: U.S. Geological Survey Water-Resources Investigations Report 95-4230, 26 p.

Stoker, Y.E., Levesque, V.A., and Fritz, E.M., 1996, Discharge, water-quality characteristics, and nutrient loads from McKay Bay, Tampa, Florida, 1991-1993: U.S. Geological Survey Water-Resources Investigations Report 95-4167, 47 p.

Stoker, Y.E., Levesque, V.A., and Woodham, W.M., 1995, The effect of discharge and water quality of the Alafia River, Hillsborough River, and the Tampa Bypass Canal on nutrient loading to Hillsborough Bay, Florida: U.S. Geological Survey Water-Resources Investigations Report 95-4107, 69 p.

The Mathworks, Inc., 1998, Matlab Signal Processing Toolbox User's Guide: Chapter 6, p. 29, 34, 134.

Thomas, T.M., 1974, A detailed analysis of climatological and hydrological records of south Florida, with reference to man's influence upon ecosystem evolution, in Gleason, P.J., ed., Environments of south Florida: Present and past: Miami Geological Society, Memoir 2, p. 82-122.

U.S. Geological Survey, 1970, Surface water supply of the United States 1961-65—Part 2: South Atlantic Slope and eastern Gulf of Mexico Basins—Volume 2: Basins from Ogeechee River to Carrabelle River: U.S. Geological Survey Water-Supply Paper 1905, 772 p.

U.S. Geological Survey, 1975, Surface water supply of the United States 1966-70—Part 2: South Atlantic Slope and eastern Gulf of Mexico Basins—Volume 2: Basins from Ogeechee River to Carrabelle River: U.S. Geological Survey Water-Supply Paper 2105, 797 p.

U.S. Geological Survey, 1999, USGS Placed-Based Studies Initiative, Program Priorities: Accessed November 30, 1999, at URL *http://sofia.usgs.gov/pbs/prog_priorities.html*.

U.S. Geological Survey, 2004, About CESI: Accessed March 2004, at URL *http://fl.water.usgs.gov/cesi/aboutcesi.htm*.