

Surface Water Discharge and Salinity Monitoring of Coastal Estuaries in Everglades National Park, USA, in Support of the Comprehensive Everglades Restoration Plan

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Abstract

Discharge and salinity were measured along the southwest and the southeast coast of Florida in Everglades National Park (ENP) within several rivers and creeks from 1996 through 2008. Data were collected using hydro-acoustic instruments and continuous water-quality monitors at fixed monitoring stations. Water flowed through ENP within two distinct drainage basins; specifically, Shark Slough and Taylor Slough. Discharge to the southwest coast through Shark Slough was substantially larger than discharge to the southeast coast through Taylor Slough. Correlation analysis between coastal flows and regulated flows at water-management structures upstream from ENP suggests rainfall has a larger impact on discharge through Shark Slough than releases from the S-12 water management structures. In contrast, flow releases from water management structures upstream from Taylor Slough appear to be more closely related to discharge along the southeast coast. Salinity varied within a wide range (0 to 50 parts per thousand) along both coastlines. Periods of hypersalinity were greater along the southeast coast due to shallow compartmentalized basins within Florida Bay, which restrict circulation.

Introduction

The Everglades in southern Florida, USA, is a diverse ecosystem substantially altered by development over the past century. The construction of a complex network of levees, canals and control structures was initiated in the late 1940s to control flooding in growing urban centers and to reclaim land for agriculture. As a consequence, nearly half of the predevelopment Everglades has been drained for these purposes (Ogden and Davis, 1994), causing a decline in wildlife abundance, especially of wading bird species. Of particular importance to ENP was the creation of barriers to flow through construction of U.S. Route 41 (Tamiami Trail) and the C-111 canal as part of the South Dade Conveyance Systems (SDCS). Reduced freshwater flows throughout the system resulted in extended dry periods in the wetlands that contribute to increased wildfires, a reduced fish habitat, and periods of extreme hypersalinity along the ENP coastline. The seagrass die-off of 1987 and periodic algal blooms in central Florida Bay are well-documented adverse effects on Florida Bay that are also believed to be caused by changes in hydrology (Ogden and Davis, 1994).

The ecology of these estuaries relies on the quantity, timing, and distribution of freshwater throughout the year to support a wide variety of commercially important fish species along with higher order predators. Coral banding research and flow modeling indicated that flows to Florida Bay have decreased since the construction of the complex network of control structures, canals, and roads south of Lake Okeechobee (Ogden and Davis, 1994). A 59-percent reduction in

freshwater flow to Shark River Slough between pre- and post-road construction (U.S. Route 41) was reported, based on coral fluorescence (Smith and others, 1989). In addition, Natural Systems Model and Adaptive Environmental Assessment Model simulations have both indicated that freshwater delivery to the coastal areas of ENP in the dry season was greater prior to the construction of water management controls (Ogden and Davis, 1994). Unfortunately, these flow models are unable to predict flows to the coast. Quantifying freshwater flow into the estuaries of Florida Bay and the southwestern coast of ENP is critical for describing changes in the Everglades system related to the Comprehensive Everglades Restoration Plan (CERP).

Historically, no accurate quantification exists of the amount of freshwater being discharged into Florida Bay and the southwestern Everglades coast from the mainland due to the difficulties of accurately gaging flows in shallow, bidirectional, and vertically stratified streams. In 1995, the U.S. Geological Survey (USGS) Greater Everglades Priority Ecosystem Science (PES) program (<http://access.usgs.gov/>) began a series of ongoing studies to monitor several major creeks and rivers that discharge freshwater into northeastern Florida Bay. The focus of these studies was to provide flow, salinity, and water level data for model development and calibration while also providing data for other physical, biological and chemical studies of the area. In 2001, the study was later expanded to include monitoring along the southwestern coast of ENP.

Subsequent concerns over the ability to detect and evaluate change in water quality along the mangrove transition zone of ENP resulted in the identification of several critical gaps in the multi-agency data collection network near Florida Bay and the southwestern coast of Florida. To address these concerns, the USGS in cooperation with the U.S. Army Corps of Engineers as part of the CERP Monitoring and Assessment Plan (MAP), expanded the study in 2003 to include 10 additional monitoring stations along the mangrove transition zone for a total of 35 monitoring stations along the entire coastline of ENP. The expanded effort provided a more comprehensive understanding of potential changes to the system that may occur as a result of planned restoration efforts particularly in the mesohaline zone of ENP. The mesohaline area of ENP serves as a nursery for many oceangoing fish and is an important feeding ground to both native and migratory birds (Davis and Ogden, 1997). The study serves as a system-wide assessment tool providing critical hydrologic information near the coast to support ecological and water-quality assessments conducted by the USGS and other State, Federal and private agencies.

Data Collection Methods

Field-measured Water Level

Surface-water levels were recorded every 15 minutes using shaft encoders, pressure sensors, or acoustic beams. During routine field visits, down-to-water measurements were conducted to verify the accuracy of water level readings from measurement points of known elevation. The field sensor was adjusted or recalibrated for discrepancies greater than 0.02 foot (ft). Corrections to the water level data were performed in the USGS automated data processing system (ADAPS) database following guidelines presented in Sauer (2002) and the USGS Fort Lauderdale Quality Assurance Plan (Lietz, 2003). Site elevations were determined by the USGS National Mapping Discipline using static survey techniques and Airborne Height Finder (AHF) survey (U.S. Geological Survey, 2003). All water level information was referenced to the North American

Vertical Datum of 1988 (NAVD 88). Levels were checked at each site every 3 years by performing optical leveling surveys following methods discussed by Kennedy (1990).

Discharge Computation

Velocity data were collected every 15 minutes using acoustic Doppler velocity meters and were calibrated using an acoustic Doppler current profiler (ADCP) for the computation of continuous discharge. Discharge data were computed using continuous water level and water velocity data along with associated channel area and measured index velocity ratings. Area ratings were developed using depth soundings from available ADCP measurements or manual cross-section measurements at each site. Index velocity ratings were developed using regression analyses to determine relations between instrument velocity (index velocity) and mean cross-sectional velocity from ADCP measurements. Index velocity ratings were necessary for computing discharge at these sites because there is no simple relation between stage and discharge for tidal streams (Rantz, 1982).

Field-measured Salinity and Water Temperature

Salinity and water temperature data were collected with continuous monitors at one or two depths in the water column, dependent on the water depth at the site. Salinity was measured in the water column to help determine the presence of freshwater flow, bi-directional flow, and to examine the potential effects of salinity and salinity stratification on acoustic signal propagation. A single continuous water-quality monitor was present at sites where salinity conditions throughout the water column were highly correlated or where stratified conditions were not observed. Temperature was measured to acquire physical information on creek characteristics, and to monitor possible vertical temperature gradients that also could affect acoustic signals. Ambient salinity conditions were measured during field visits with a quality-assured reference probe that was calibrated and/or verified against a range of laboratory specific conductance standards as a check against the deployed field probes. Salinity and temperature probes were cleaned, calibrated, and checked against laboratory standards every 4 to 6 weeks.

Discharge Data Filtering

Terrestrial discharge (the focus of this study) approximates freshwater flow from ENP to the coast due to rainfall and water management activities. Tidal discharge is positive (ebb tide) and negative (flood tide) and does not sum to zero over a day because tidal cycles are slightly greater than 24-hours in duration, which can introduce bias into a calculation of daily tidal data. The Godin mathematical filter was used to obtain the terrestrial component of net daily discharge (Godin, 1982) at all monitoring stations affected by tides.

Discharge and Salinity at Shark Slough and Taylor Slough

Discharge to the coast of ENP is routed through two major sloughs named Shark Slough and Taylor Slough. These sloughs are isolated from each other with Shark Slough draining to the southwest coast of ENP (Gulf of Mexico) and Taylor Slough draining to the southeast (Florida Bay). Major estuaries, sloughs, and control structures are depicted in Figure 1.

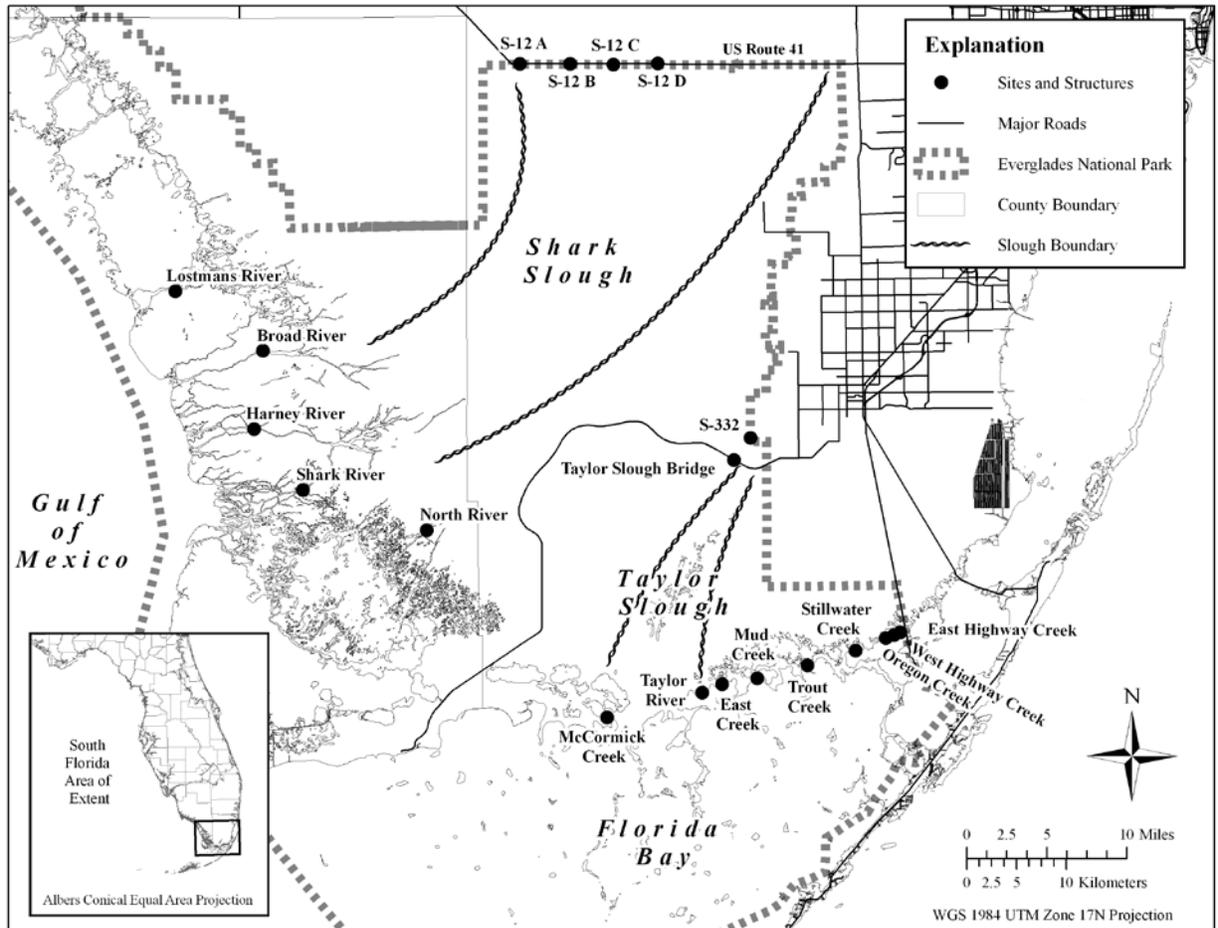


Figure 1. Locations of coastal monitoring stations, water management structures, and slough boundaries.

Southwest Coast of ENP

Five major rivers along the southwest coast of ENP were measured to compute a total volume of discharge to the Gulf of Mexico. Annual discharge volumes were 1,480,200 acre-ft (2004), 1,924,560 acre-ft (2005), 1,226,110 acre-ft (2006), 726,340 acre-ft (2007) and 1,707,420 acre-ft (2008) (Fig. 2). The mean annual discharge contribution for each river was 33 percent from Lostmans River, 17 percent from Broad River, 32 percent from Harney River, 14 percent from Shark River, and 3 percent from North River.

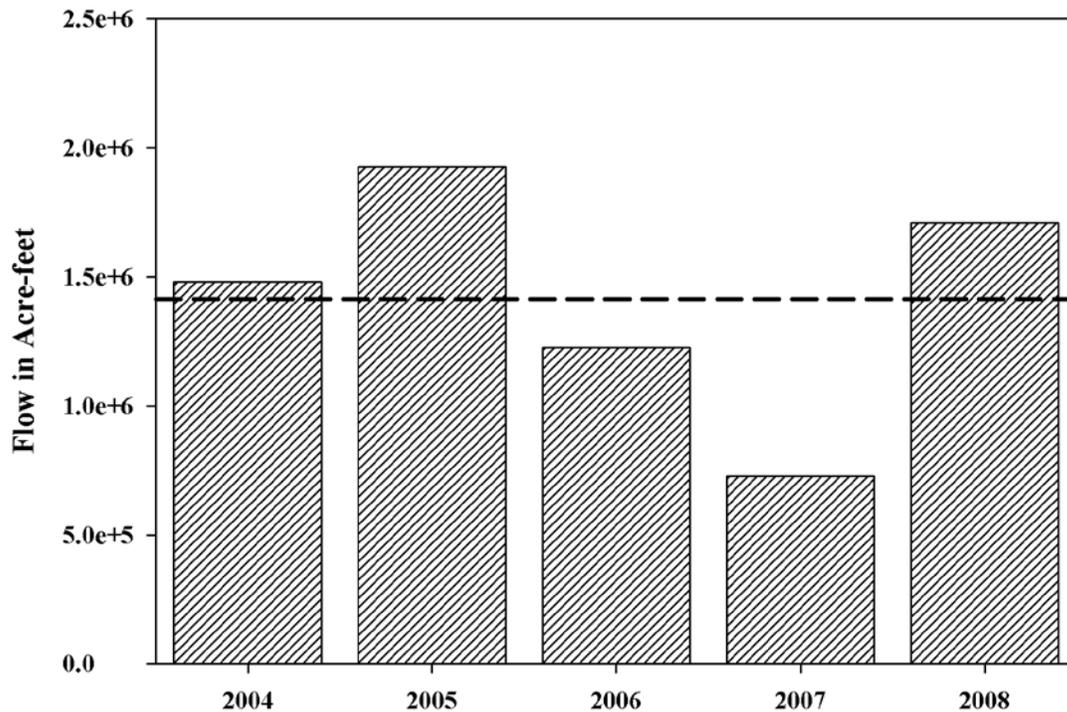


Figure 2. Combined annual discharge at 5 major rivers along the southwest coast of ENP plotted with the 5-year mean (dotted line).

Mean monthly salinity fluctuates seasonally at the five rivers along the southwest coast by as much as 35 ppt throughout the year (Fig. 3). The range of salinity from 2004-2008 was 0.3 to 38.7 ppt at Lostmans River, 0.2 to 37.0 ppt at Broad River, 0.5 to 36.6 ppt at Harney River, 0.3 to 35.8 ppt at Shark River, and 0.2 to 34.1 ppt at North River. There is an observed salinity gradient from the north (Lostmans River), which is saline, to the south (North River), which is brackish. The exception to this gradient is at Broad River where salinity data were similar with those at North River.

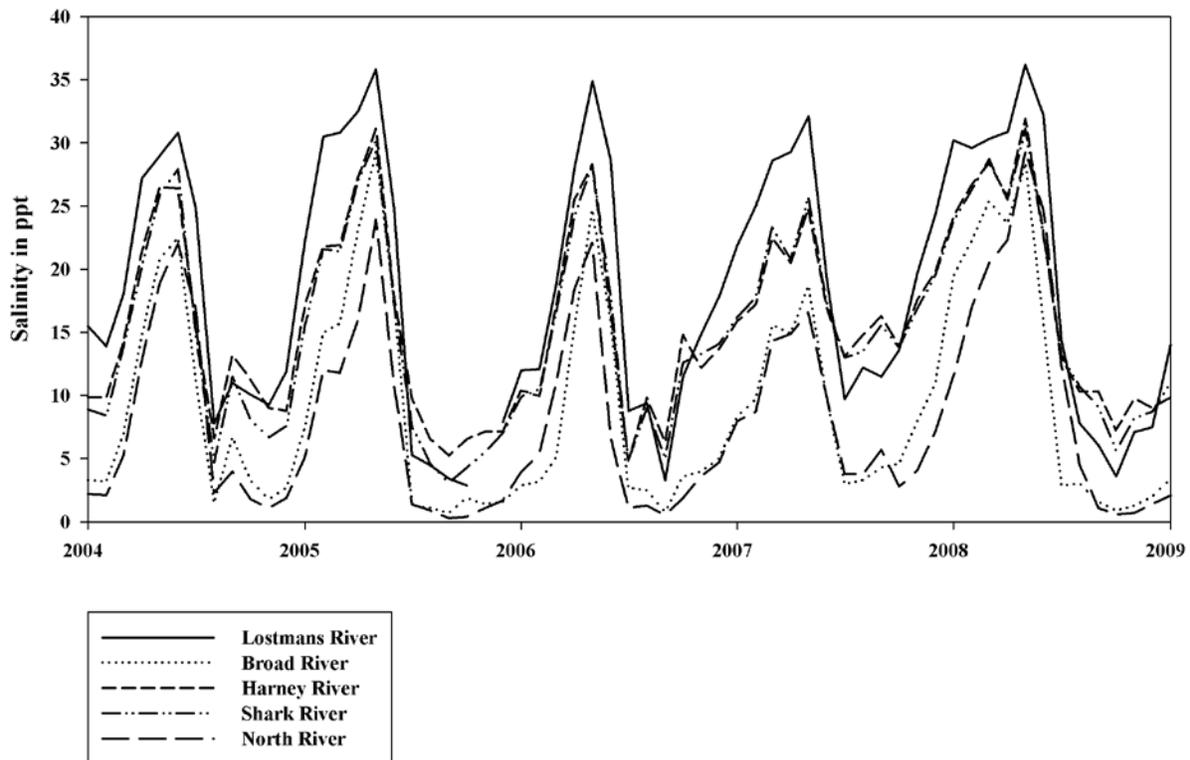


Figure 3. Comparison of mean monthly salinity at 5 major rivers along the southwest coast of ENP.

Southeast Coast of ENP

Nine creeks and rivers along the southeast coastline of ENP were measured to compute a total volume of discharge to Florida Bay. Discharge volumes annually were 301,340 acre-ft (1996), 332,900 acre-ft (1997), 275,680 acre-ft (1998), 376,370 acre-ft (1999), 230,340 acre-ft (2000), 362,820 acre-ft (2001), 380,080 acre-ft (2002), 338,650 acre-ft (2003), 154,130 acre-ft (2004), 506,170 acre-ft (2005), 221,560 acre-ft (2006), 267,880 acre-ft (2007), and 197,597 acre-ft (2008) (Fig. 4). The mean annual discharge contribution for each estuary was 5% from East Highway Creek, 11% from West Highway Creek, 3% from Oregon Creek, 3% from Stillwater Creek, 46% from Trout Creek, 8% from Mud Creek, 8% from East Creek, 10% from Taylor River, and 6% from McCormick Creek.

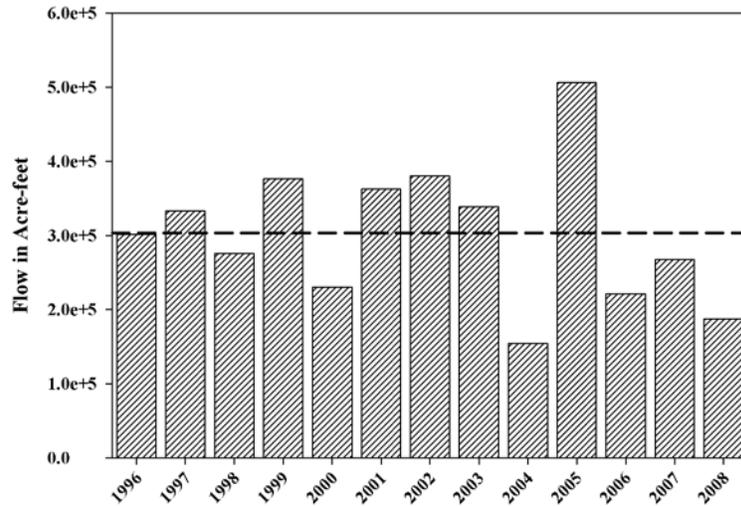


Figure 4. Combined annual discharge at 9 major creeks and rivers along the southeast coast of ENP plotted with the 13-year mean (dotted line).

Monthly salinity values were measured at five of the nine creeks and rivers along the southeast coast of ENP. Salinity fluctuated seasonally by as much as 40 ppt throughout the year (Fig. 5). The range in salinity from 1996-2008 was 1.0 to 54.5 ppt at McCormick Creek, 0.2 to 50.5 ppt at Taylor River, 0.2 to 49.0 ppt at Mud Creek, 0.3 to 47.8 ppt at Trout Creek, and 0.2 to 42.7 ppt at West Highway Creek. Salinity data show a gradient from the west to the east with higher salinity to the west at McCormick Creek and brackish to fresh in the east at West Highway Creek. Taylor River was the exception to this observation with salinity values typically lower than those further to the east.

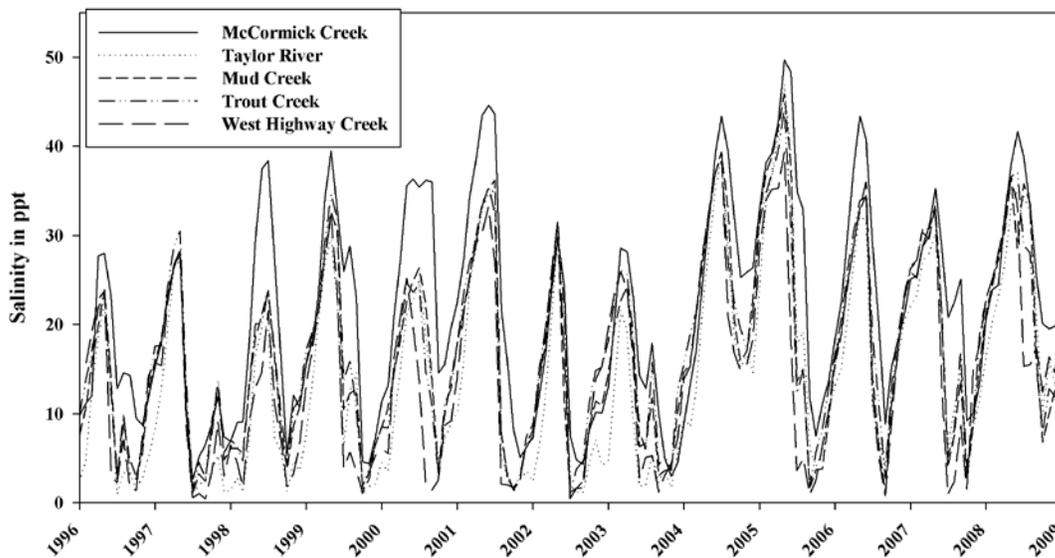


Figure 5. Comparison of mean monthly salinity at 5 major rivers and creeks along the southeast coast of ENP.

Comparison of Discharge at Coastal Monitoring Stations with Regulated Discharge at Control Structures

Correlation analysis was performed on discharge between the four S-12 structures and the terrestrial component of residual net discharge at the five major rivers along the southwest coast of ENP using 3 years of data collected from 2004-2007. Discharge from the S-12 structures, vertical lift gates which are used to control water flow into ENP under U.S. Route 41, moves through Shark Slough, a shallow, wide drainage basin, to the five rivers that flow to the coast. The analysis showed that the coastal discharge peak preceded the S-12 discharge peak by one month with a correlation value of 0.77 (Fig. 6). 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 preceding the S-12 structure discharge peak. After implementation of CERP, the impact on coastal discharge from the water management system upstream can be further evaluated.

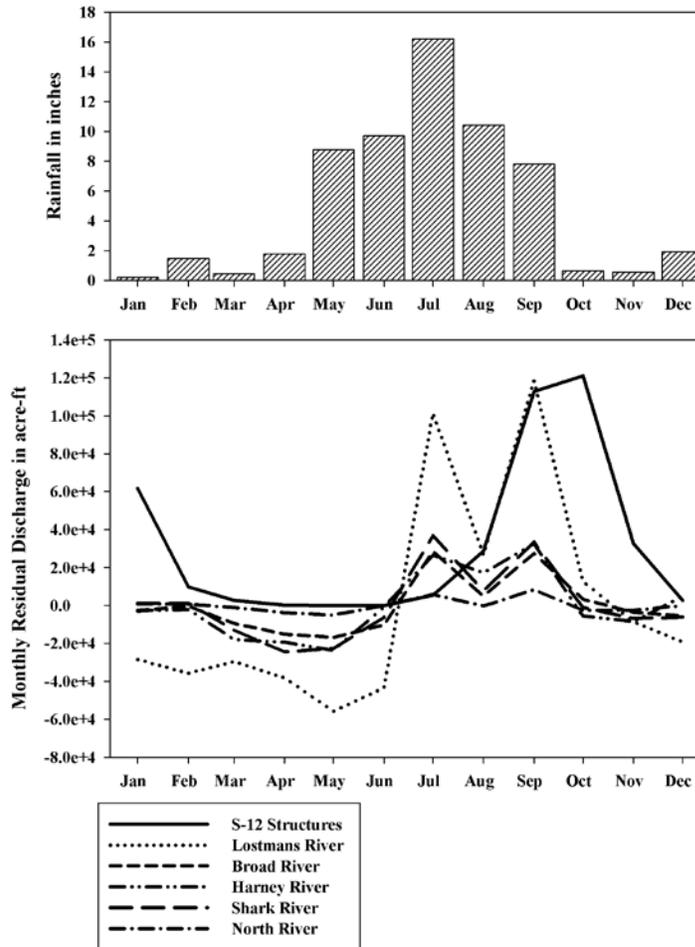


Figure 6. Monthly mean residual discharge for the five southwest coast stations, S-12 A, B, C, and D monthly mean discharge, and monthly total rainfall at North River for 2006.

Correlation analysis also was performed on terrestrial discharge between Taylor Slough Bridge and three representative coastal stations along the southeast coast of ENP. Flow from Taylor Slough Bridge moves through Taylor Slough, a shallow, wide drainage basin to the southeast coastline of ENP. McCormick Creek represents the western most drainage area for Taylor Slough, Taylor River the center, and Trout Creek represents the most easterly. The highest correlations between discharge peaks at the bridge and discharge peaks at the three coastal sites occurred after one day. This finding means when flow increased at Taylor Slough Bridge due to an event such as heavy rainfall, the flow downstream at the coast would peak one day later. Specifically, daily-lagged correlation coefficients between Taylor Slough Bridge and the three coastal sites, McCormick Creek, Taylor River, and Trout Creek were 0.68, 0.69, and 0.59, respectively.

Seasonal Effects on Discharge and Salinity

Tropical weather activity and wet-season duration have a profound affect on salinity and flow conditions within these estuaries. A short wet season in 2004 caused dry season salinities along the southeast coast of ENP to be greater than the 13-year mean conditions by almost 7 ppt. While annual discharge to the coast during 2004 was the lowest recorded; discharge during the following year (2005) was the highest recorded due to Hurricanes Katrina and Wilma. During Hurricane Katrina, 7 inches of rain fell on ENP, which substantially reduced the high salinities observed during the dry season of 2005 (Woods and Zucker, 2007). A short wet season in 2006 began a 2-year period of elevated salinity over both the dry and wet seasons along the southwest coast. Annual discharge to the coast from 2006 through 2007 was below the mean for the 5 years of data collection.

Summary and Conclusions

Freshwater discharge and salinity data have been collected for 13 years along the southeast coast of ENP and for 5 years along the southwest coast of ENP. Annual discharge to the southeast coast of ENP ranged from 154,130 acre-ft to 506,170 acre-ft from 1996 through 2008. Annual discharge to the southwest coast of ENP ranged from 726,340 acre-ft to 1,924,560 acre-ft from 2004 through 2008. Coastal flow response to discharge peaks in the Taylor Slough drainage basin occur much faster than in Shark Slough basin, likely due to the smaller geographic area of Taylor Slough. While Taylor Slough Bridge is not a control structure, it is a good proxy for determining the volume of water being added into Taylor slough from the S-332 pumping structure as part of the SDCS. Information on the effects of hurricanes and droughts has been valuable for determining the natural system variability. These data will be useful for detecting future effects from restoration and could play a role in developing adaptive management strategies.

Acknowledgements

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