Flow and Salinity Characteristics of the Upper Suwannee River Estuary, Florida

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 99-4268

Prepared in cooperation with the
SUWANNEE RIVER WATER MANAGEMENT DISTRICT

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By Gina M. Tillis

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Flow and Salinity Characteristics of the Upper Suwannee River Estuary, Florida

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Abstract

Continuous stage and salinity data were recorded from August 1995 to December 1997 at four gages located in the upper Suwannee River Estuary. Continuous velocity data were recorded at two of the four gages and continuous discharge data were computed for these two gages. Additional salinity data were collected at 15 monitoring sites from November 1992 to October 1997. Wind-speed data collected at Cedar Key, Florida, during the study period were utilized in the regression analysis. Correlations were developed to describe the longitudinal extent of the saltwater/freshwater interface (defined as 0.5 parts per thousand (ppt) salinity) and salinity distribution in the upper Suwannee River Estuary. On East Pass, the median of difference between daily maximum and daily minimum stage ranged from 2.92 feet for a gage at river mile 3.8 to 3.33 feet for a gage at river mile 1.2. Velocities tended to be unidirectional with some instances of bilateral flow. Reversal in flow direction was common and coincided with rising tides. Monthly mean discharges for the Suwannee River near Wilcox, Florida, during the study period typically were lower than the average for the period of record (1931–97). Discharge near Wilcox averaged 4,000 cubic feet per second (ft^3/s) lower than the long-term average from June to September 1996. An El Niño event induced precipitation that was responsible for higher than average monthly mean discharge measured near Wilcox during November and December 1997.

The maximum observed salinity concentrations for the study period ranged from 28.20 ppt at river mile 3.8 to 31.00 ppt at river mile 1.9. Median daily fluctuations of salinity at river miles 3.8 and 1.2 were 0.12 and 11.31 ppt, respectively. The maximum daily upstream extent of the saltwater/freshwater interface was at or upstream from river mile 4.0 for about 50 percent of the study period. The interface was at or upstream from river mile 3.8 and river mile 2.8 40 and 57 percent of the time. The interface was downstream from river mile 1.2 and river mile 1.9 11 and 21 percent of the time, respectively. The median daily maximum salinity for the four gages ranged from 0.22 ppt at river mile 3.8 to 11.50 ppt at river mile 1.2.

Multiple linear-regression models were developed to determine the isohaline location for 0.5, 2, 5, 10, 15, and 20 ppt salinity, and to predict the maximum daily salinity concentrations at gages as a function of stage, river discharge, and wind. The salinity at a location was inversely proportional to the daily mean discharge at the Suwannee River near Wilcox. Under extreme low-flow conditions (3,500 ft^3/s), the regression models predicted that the interface would occur at river mile 7.2, upstream from the Gopher River confluence with the Suwannee River. Wind speed did not have a substantial influence on model predictions.

The period of record for the Suwannee River at Wilcox was applied to appropriate regression models to produce a synthetic record of historical salinity distributions. Two withdrawal scenarios, a 10-percent diversion and a 1,000 ft^3/s diversion, were evaluated relative to high-, medium-, and low-flow conditions and compared to actual salinity distributions. The 10-percent and 1,000 ft^3/s withdrawals scenarios resulted in the isohaline of 0.5 ppt migrating 0.6 and 1.58 miles upstream from the actual isohaline location for a low-flow condition of 4,500 ft^3/s, and migrating 0.14 and 0.65 miles upstream from the actual isohaline location for a high-flow conditions of 20,300 ft^3/s for Wadley Pass.

INTRODUCTION

The Suwannee River flows from its headwaters in the Okefenokee Swamp to the Gulf of Mexico (fig. 1). The river is spring fed and receives runoff from the Alapaha, Withlacoochee, and Santa Fe Rivers and other tributaries. The river is 240 miles (mi) long and has an approximate drainage area of 9,640 square miles (mi^2), including part of the watershed in the Okefenokee Swamp, which is indeterminate (Franklin and Meadows, 1996). The Suwannee River at Wilcox, Florida, is influenced by tides when discharge is less than 17,500 cubic feet per second (ft^3/s). The upper Suwannee River Estuary, as defined by Mattson and Krummrich (1995), consists of the lower 7 to 9 mi of the Suwannee River inside the mouths of East Pass and West Pass (fig. 2); the estuary is a complex ecosystem characterized by a diverse range of vegetation with various salinity tolerances. The estuary provides a valuable habitat for birds, fish, mammals, and invertebrates, serves as a nursery for juvenile fish, and contributes nutrients to nearshore areas. The hydraulic response of the estuary, however, is poorly understood; difficulty in gaging tidal flow by using traditional methods limited the ability to analyze salinity-flow relations.

Natural systems such as wetlands, flood plains, native ecological communities, and aquifer recharge areas within the Suwannee River Basin serve vital ecological functions, including water-quality treatment, water supply, flood-water conveyance and attenuation, fish and wildlife habitat, and recreational and economic values. The ecological health of these systems depends on maintaining natural variability of the hydrologic cycle as reflected by the magnitude, duration, and timing of streamflow, rising and falling water levels of lakes, rivers, and aquifers, and the interaction of surface and ground waters. Alterations to the natural hydrologic regime by human activities can adversely affect the natural systems and their functions. Reduction in streamflow from the Suwannee River can result in upstream movement of saltwater, thereby affecting the ecology of the upper estuary. Natural-system requirements must be better understood to establish minimum flow and water-level requirements that will allow adequate water for the present and future needs of the natural system and the human population.

In 1994, the U.S. Geological Survey (USGS) and the Suwannee River Water Management District (SRWMD) entered into a cooperative agreement wherein the USGS agreed to provide, over the course of a long-term program of investigation, much of the information needed for the SRWMD to establish minimum flow and water-level requirements. This report is one of the products designed to accomplish this goal.

Purpose and Scope

The purpose of this report is to describe the flow and salinity characteristics of the upper Suwannee River Estuary and describe their interrelation. Data on stage, river discharge, wind, and salinity are used to describe the hydrologic characteristics and extent of saltwater distribution in the upper estuary. The study period was from August 1995 to December 1997.

Previous Studies

Several USGS studies conducted in southwestern Florida have focused on the relation of salinity distributions in estuaries as a function of stage and discharge in an effort to predict freshwater-withdrawal effects on salinity distributions (Giovannelli, 1981; Yobbi and Knochenmus, 1988a,b; Stoker and others, 1989; Fernandez, 1990; Hammett, 1992; and Orlando and others, 1993).

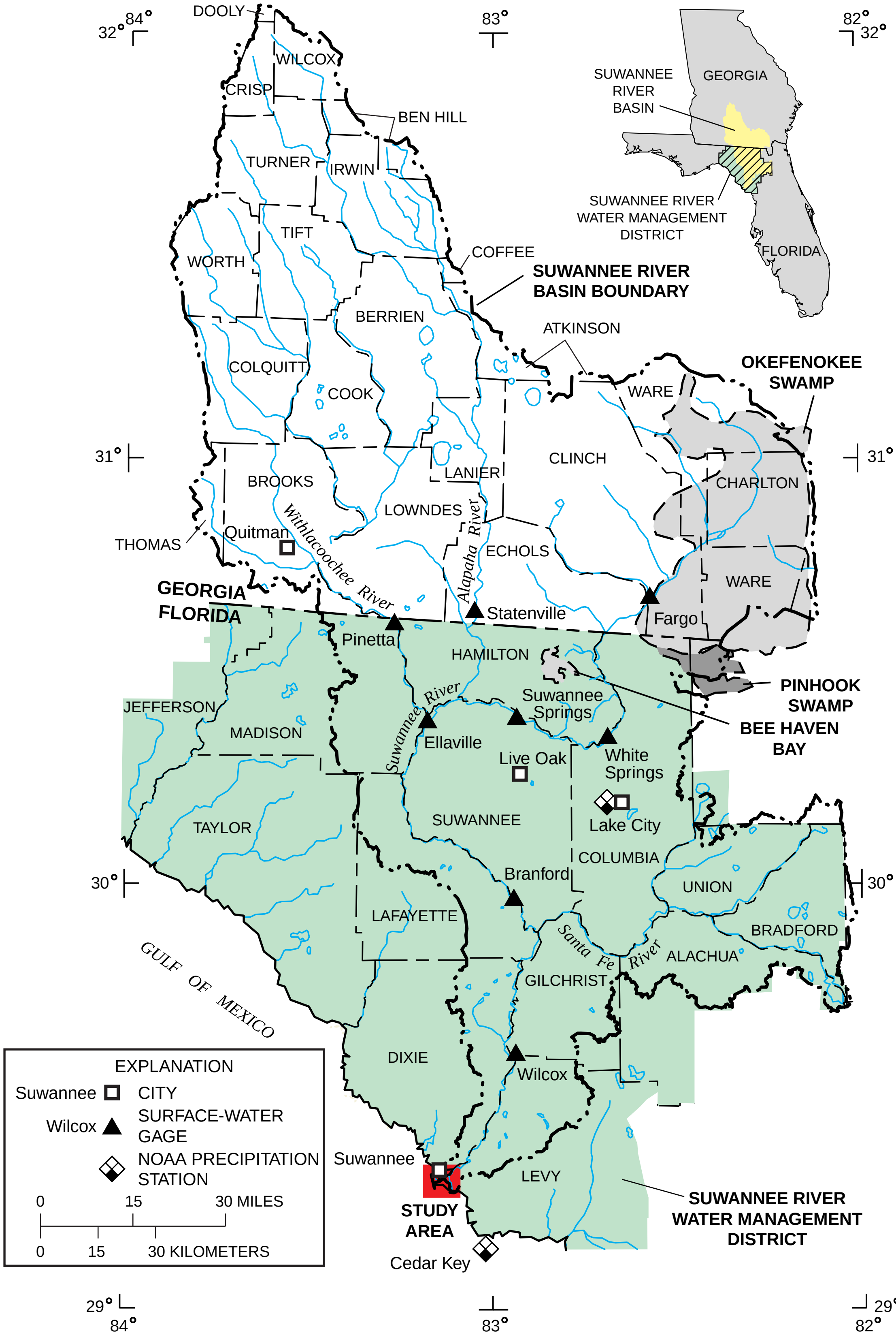


Figure 1. Location of the study area in the Suwannee River Basin, Suwannee, Florida.

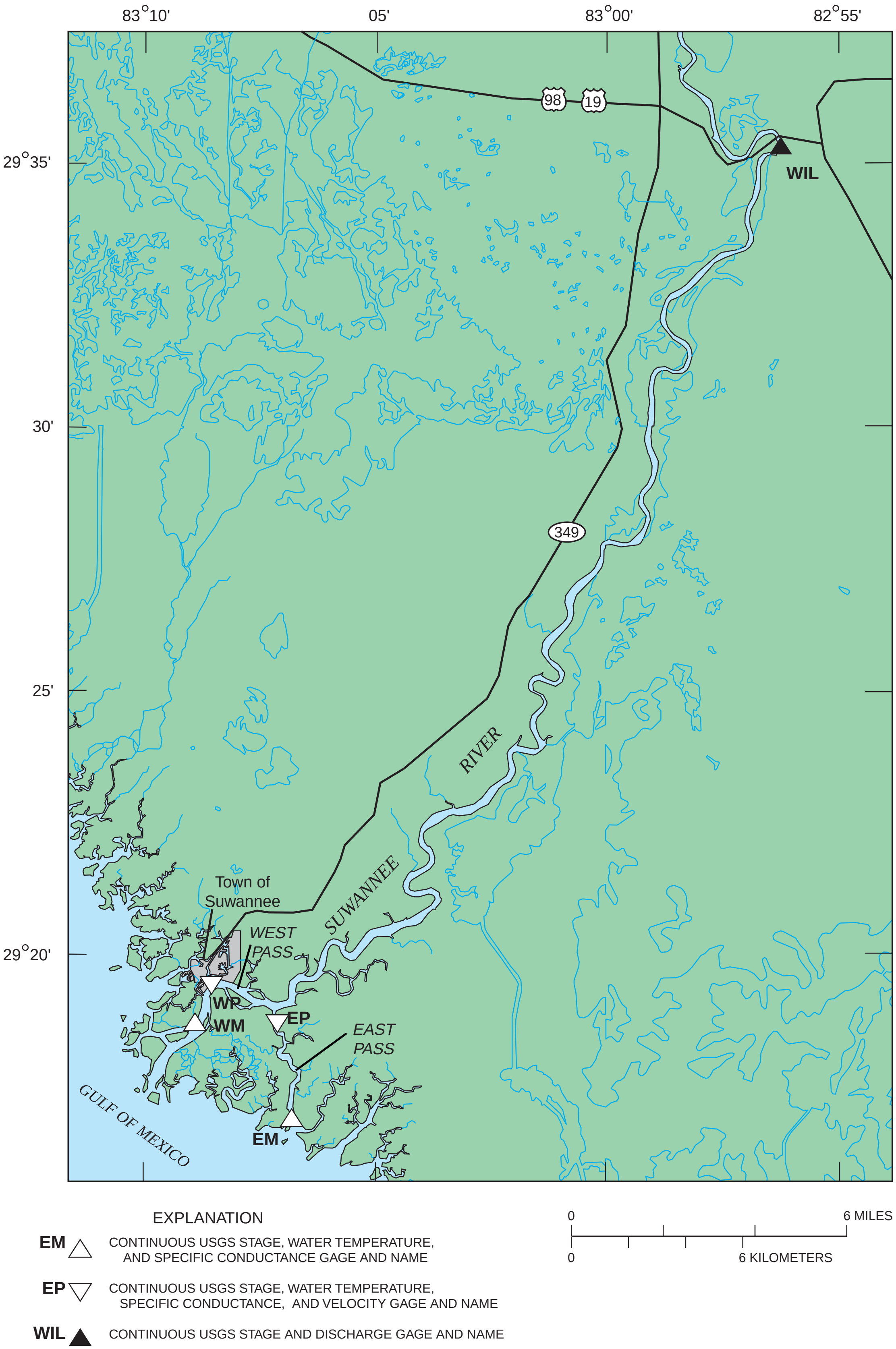


Figure 2. Location of EP (291841083070800), EM (291652083064100), WP (291930083082800), WM (291842083085100), and WIL (02323500) continuous gages, lower Suwannee River Basin, Florida.

The University of South Florida conducted an in-depth study on the physical factors (wind, sea level, river discharge, currents, salinity, and water temperature) affecting the dynamics of the Suwannee River Sound (Siegel and others, 1996). This study focused on the nearshore areas rather than salinity intrusion upstream of the Suwannee River mouth. Data were analyzed on a daily, synoptic (3 to 10 days), and a seasonal basis. About 40 percent of the salinity variation was due to tidal fluctuation, whereas 20 percent was due to nontidal sea-level fluctuation occurring during the synoptic period and resulting from the passage of frontal systems.

The SRWMD, in conjunction with the Florida Game and Fresh Water Fish Commission (GFC), established a network of monitoring sites where salinity was measured in the estuary from February 1993 to February 1995 (fig. 3). The purpose of the network was to characterize spatial and temporal distribution of salinity (Mattson and Krummrich, 1995). The study concluded that mean salinities tended to be higher in West Pass than in East Pass; mean salinities were higher in Wadley Pass than in Alligator Pass. In Wadley Pass, the dredged channel apparently allowed greater penetration of saltwater, whereas in Alligator Pass, the channel is shallow and, therefore, subject to domination by freshwater discharge from the river (Mattson and Krummrich, 1995). The highest salinities were observed during low-flow periods from August to November and in May and June. High-flow conditions, which commonly occur during February to April, corresponded with near zero salinities measured at all monitoring sites. A saltwater wedge was detected in fall (October and November) and in early spring (March and April). Data collected from the SRWMD/GFC study have been incorporated into the current study.

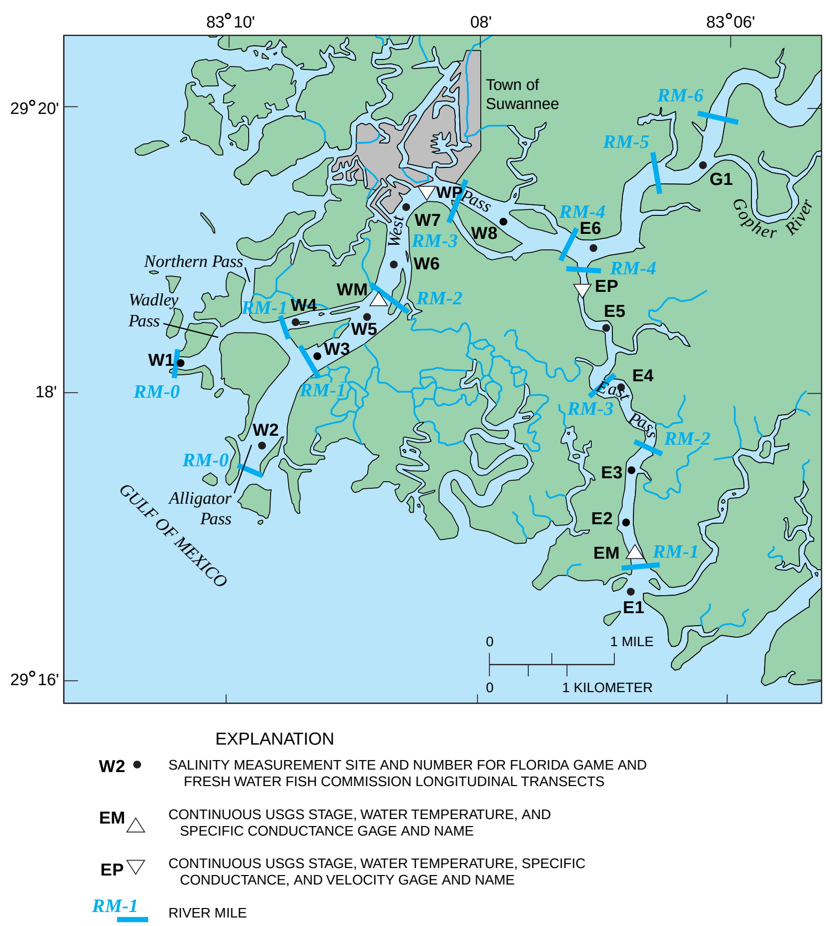


Figure 3. Location of the upper Suwannee River Estuary gages and data-collection sites, Suwannee, Florida.

Approach

An analysis was performed to relate salinity concentrations and extent of saltwater intrusion in the upper Suwannee River Estuary to river stage, freshwater inflow, tidally affected flow, and wind. The analysis was conducted by utilizing multiple linear regressions, a statistical approach that determines a best-fit equation between one dependent variable and one or more independent variables, on data collected in East and West Passes and at Wilcox. Regressions commonly are evaluated based on the value of certain statistical parameters, such as the square of the correlation coefficient (R^2) and P-values.

The correlation coefficient, R^2, is the proportion of variability in the dependent variable that is accounted for by the independent variables of the model. An adjusted R^2 value was used for evaluation in the regression analysis, as the number of independent variables regressed varied (that is, varying degrees of freedom). The adjusted R^2 penalizes regression models that contain insignificant explanatory variables. Typically, an adjusted R^2 value equal to or greater than 0.9 is considered excellent, and a value between 0.9 and 0.8 is considered good. Based on preliminary analysis, an adjusted R^2 of 0.7 was set as an acceptable regression model.

The level of significance for each independent variable in a regression model is measured by a dimensionless P-value. The smaller the P-value, the more likely the variable is significant in the regression (Helsel and Hirsch, 1995). The critical value for rejecting a model is set at 0.05 or 0.1; the critical value was 0.1 for this study. Regression models with P-values exceeding 0.1 for independent variables were considered poor and were not reported.

Several regressions were log-transformed based on residual plot results. Simply transforming calculated values from a log-regression equation back into the original units introduces a negative bias in the results that was corrected by using a “smearing” estimator (Helsel and Hirsch, 1995, p. 257).

Multiple linear-regression models were developed to characterize salinity distribution in the upper estuary and concentrations at particular data-collection sites as a function of stage and discharge. Historical salinity distributions were determined from regression models. The effect that withdrawal of freshwater would have upon salinity distributions in the upper estuary was evaluated by using 10-percent diversion and 1,000 ft^3/s diversion scenarios. Diversion scenarios were used to illustrate the effects of discharge on the maximum daily upstream extent of the saltwater/freshwater interface (0.5 parts per thousand (ppt) isohaline) in the Suwannee River and the daily maximum salinity concentration at particular data-collection sites.

General Hydrology of the Study Area

The upper Suwannee River Estuary is in the Gulf Coast area of the Suwannee River Water Management District (fig. 1). The study area includes the reach of the river from the mouth of each pass upstream to the confluence of Gopher River with the Suwannee River, about 5.6 mi upstream of the river mouth (fig. 3). River miles along the Suwannee River were based on an origin (river mile) that was determined from digital, 1:24,000 scale USGS topographic maps. The origin was designated in Alligator Pass where the centerline of the river intersects with the western boundaries of Dixie and Levy Counties. River miles for East Pass were determined by starting at river mile 4.2 (RM–4.2), which was just upstream of where the river forks into East and West Passes, and then “numbering” the river miles along East Pass toward the mouth.

The Suwannee River is the second largest discharging river in Florida and the major freshwater source to the upper estuary. The discharge pattern of the river is more closely correlated with climatological conditions in this region than any of the other coastal rivers in Florida (Orlando and others, 1993). The climate of the study area is typified by warm, humid summers and mild winters. Average air temperatures range from the mid-50’s in winter to the low-80’s during summer. Relative humidity is high, ranging from 70 to 83 percent. In north Florida, the wet season occurs during winter (January–March). Rainfall during the study period was 4 inches lower than normal based on rainfall data from the National Oceanic and Atmospheric Administration (NOAA) station at Lake City (fig. 1). Average annual rainfall for Lake City, which is considered representative for the Suwannee River Basin, is 55.49 inches per year (National Oceanic and Atmospheric Administration, 1995, 1996, 1997). Cumulative rainfall and departure from the 30-year (1961–90) normal for water years 1995–97 are shown in figure 4.

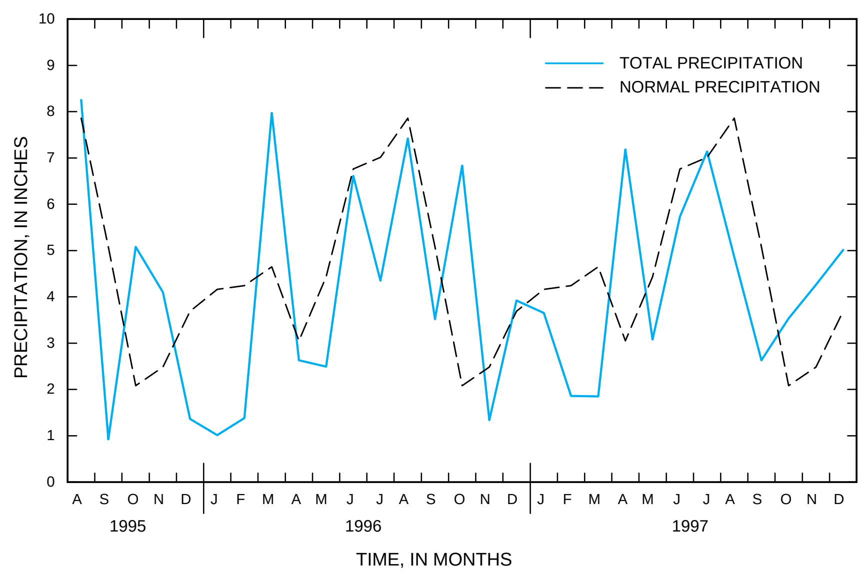


Figure 4. Cumulative rainfall and departure from the 30-year normal (1961–90) for the National Oceanic and Atmospheric Administration station at Lake City, Florida.

Base flow for the Suwannee River upstream from White Springs originates as drainage from the Okefenokee Swamp in southern Georgia and Bee Haven Bay (Hamilton County) and Pinhook Swamp (Columbia County) in northern Florida (fig. 1). This base flow is augmented downstream by inputs from springs and spring-fed tributaries discharged from the Floridan aquifer system along the Suwannee River. Discharges from known springs between Wilcox and Gopher River are less than 2 percent of the discharge at Wilcox. Runoff from tributaries comes from the Alapaha, Withlacoochee, and Santa Fe Rivers. A substantial amount of ground water from the Floridan aquifer system is contributed to the river downstream from White Springs as diffuse leakage. Although numerous springs have been identified along the Suwannee River, none have been documented along the river in the Suwannee Estuary.

Monthly mean discharge data collected from August 1995 to December 1997 at Wilcox were compared to the maximum, minimum, and mean monthly discharge data for water years 1931–97 (fig. 5). Monthly mean discharge at Wilcox during most of the study was lower than average. Discharge averaged 4,000 ft^3/s lower than the long-term average from June to September 1996. El Niño is attributed as the source for higher than average monthly mean discharge during November and December 1997. The El Niño warm phase disrupted the habitual flow patterns and velocities of the jetstreams in the Northern Hemisphere, thus resulting in an unusually warm fall with increasingly heavy tropical rainfall through December 1997 (National Oceanic and Atmospheric Administration, 1995, 1996, 1997).

Mean monthly discharge at Wilcox for the period of record (October 1930 to September 1931; October 1941 to December 1997) varied from 7,630 ft^3/s in the dry season (November) to 15,830 ft^3/s in the wet season (April). The maximum monthly mean discharge was 57,260 ft^3/s in April 1948, and the lowest monthly mean discharge was 3,580 ft^3/s in December 1956. The mean annual discharge for the period of record was 10,430 ft^3/s. The highest annual mean discharge was 24,560 ft^3/s in 1948, and the lowest annual mean discharge was 4,290 ft^3/s in 1955. The lowest recorded daily mean discharge was 2,960 ft^3/s that occurred on October 25, 1981. The average annual runoff (in inches) for the period of record was 14.70 (Franklin and Meadows, 1998). For comparison, the average annual runoff (in inches) for the period of study was 15.34, 8.43, and 12.32 for water years 1995, 1996, and 1997, respectively (Franklin and Meadows, 1998).

A “bird’s-foot” river delta has formed at the mouth of the Suwannee River (fig. 3) as a result of a low-slope coastal shelf and freshwater discharge from the river as opposed to an arcuate delta and barrier islands (Siegel and others, 1996). East Pass, which meanders in a southerly direction toward the Gulf of Mexico, is about 300 feet (ft) wide and typically 20 ft deep. West Pass is about 900 ft wide and typically 10 ft deep. Less than a mile downstream from the town of Suwannee, West Pass subdivides into Northern Pass, Alligator Pass, and Wadley Pass (fig. 3). Alligator Pass is about 600 ft wide and is typically 3 to 6 ft deep at high tide. Wadley Pass is about 300 ft wide, and is typically 7 to 10 ft deep at high tide. In general, salinity concentrations were higher in Wadley Pass than in East or Alligator Passes, most likely owing to the presence of the dredged channel (Mattson and Krummrich, 1995).

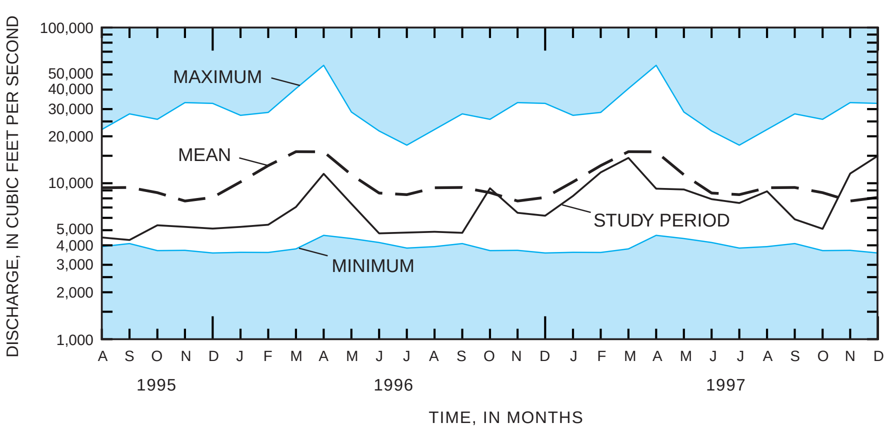


Figure 5. Monthly mean discharge for the study period, and maximum, mean, and minimum monthly mean discharge for the for the period of record for the Suwannee River near Wilcox, Florida.

The upper estuary is subject to mixed semidiurnal tides, commonly experiencing two unequal high and two unequal low tides each day that occur every 6.2 hours (Siegel and others, 1996). During the study period, the median range of daily stage was typically 3 ft. Maximum of differences between daily maximum and daily minimum stage occurred on October 8, 1996, corresponding with the passage of Hurricane Josephine in the Gulf of Mexico (fig. 6). This event was more than double the range in stage that normally occurs.

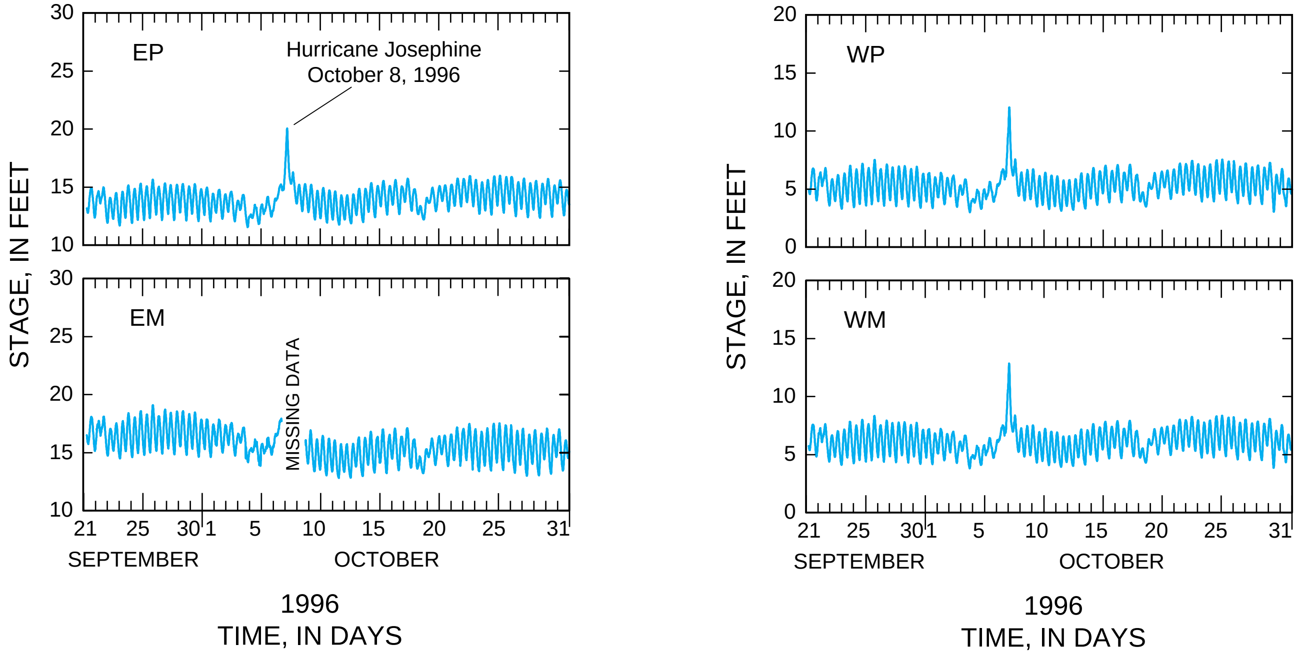


Figure 6. Suwannee River stage data at EP (291841083070800), EM (291652083064100), WP (291930083082800), and WM (291842083085100) gages, September 21 to October 31, 1996, Suwannee, Florida.

Orlando and others (1993) classified the Suwannee Estuary as having intermediate salinity levels that varied moderately, reflecting neither saltwater nor freshwater dominance. Freshwater inflow was identified as a dominant factor influencing salinity variability in the estuary on a monthly to seasonal scale. Meteorological events are important influences in episodic salinity events in the upper estuary; Mattson and Krummrich (1995) reported that salinity at the most upstream site seemed to be principally affected by hurricanes and storms, as well as extreme low flows during droughts.

Acknowledgments

The author would like to thank John Good, Tom Mirti, and Rob Mattson of the Suwannee River Water Management District who contributed invaluable data and ideas during the course of this study, as well as the Florida Game and Fresh Water Fish Commission for the use of their data from the salinity monitoring network. The author also would like to thank Marvin A. Franklin, Paul E. Meadows, John R. Pittman, A. Ernie Alvarez-Nazario, Donald M. Stephens, Gregory B. Donley, and Kenny A. Kalan of the U.S. Geological Survey who contributed countless hours collecting and processing data.

DATA COLLECTION

Direct measurements of stage, velocity, and salinity made from August 1995 to December 1997 were used in this analysis. Stage and salinity were recorded at four gages as shown in figure 2. Gages are located at river miles 1.9 (WM–291842083085100) and 2.8 (WP–291930083082800) on the West Pass and at river miles 1.2 (EM–291652083064100) and 3.8 (EP–291841083070800) on the East Pass (table 1; fig. 3). Continuous velocity data were recorded at the WP and EP gages. Stage and velocity data collected from the WP and EP gages were used to develop ratings to calculate discharge. Salinity data recorded at the four gages were supplemented with synoptic field measurements (fig. 3) to define vertical and longitudinal salinity distributions in the upper Suwannee River Estuary. These synoptic data were collected by the USGS, SRWMD, and GFC. Salinity was calculated from the measured temperature and conductivity of the water. Recorded discharge and stage-level data from as early as 1930 and continuously since 1941 were available for a long-term gage, referred to as WIL (02323500), 33 mi upstream from the river mouth (Franklin and Meadows, 1996). The location of data-collection gages and sites as well as the type and frequency of the data collected are presented in table 1.

Table 1. Location of data-collection gages and sites, distance in river miles, characteristics measured, and sampling frequency, lower Suwannee River Basin, Florida

[Distance is upstream from river mouth; mi, miles; min., minutes]

Data-collection gages and sites	Latitude	Longitude	Distance (mi)	Characteristics	Sampling frequency
EP (291841083070800)[a]	29.307	83.118	3.79	discharge, salinity, stage	15 min.
EM (291652083064100)[a]	29.275	83.107	1.15	salinity, stage	15 min.
WP (291930083082800)[a]	29.322	83.138	2.78	discharge, salinity, stage	15 min.
WM (291842083085100)[a]	29.307	83.142	1.89	salinity, stage	15 min.
WIL (02323500)[a]	29.589	82.937	33.46	discharge, stage	15 min.
G-1[a,b]	29.327	83.104	5.63	salinity	monthly
E-6[a,b]	29.317	83.118	4.19	salinity	monthly
E-5[a,b]	29.308	83.116	3.42	salinity	monthly
E-4[a,b]	29.301	83.114	2.73	salinity	monthly
E-3[a,b]	29.291	83.113	1.79	salinity	monthly
E-2[a,b]	29.285	83.114	1.45	salinity	monthly
E-1[a,b]	29.277	83.113	.84	salinity	monthly
W-8[a,b]	29.320	83.130	3.39	salinity	monthly
W-7[a,b]	29.322	83.143	2.62	salinity	monthly
W-6[a,b]	29.315	83.145	2.17	salinity	monthly
W-5[a,b]	29.309	83.148	1.74	salinity	monthly
W-4[a,b]	29.308	83.157	1.18	salinity	monthly
W-3[a,b]	29.304	83.155	1.18	salinity	monthly
W-2[a,b]	29.294	83.162	.29	salinity	monthly
W-1[a,b]	29.303	83.173	.02	salinity	monthly

[a]U.S. Geological Survey.
[b]Florida Game and Fresh Water Fish Commission.

Data were analyzed for daily ranges in stage, discharge, and salinity, as well as impacts from Hurricanes Opal (1995) and Josephine (1996). Duration curves were developed from collected stage, discharge, and salinity data at selected gages.

Continuous Data

Stage data were recorded continuously at the long-term WIL gage. Discharge was calculated from a slope-stage discharge relation (Rantz, 1982a,b). An auxiliary stage recorder was 9 mi downstream from the base gage.

Water temperature and conductance were recorded continuously by using water-quality monitoring probes. The probes automatically computed salinity in parts per thousand based on water temperature and conductance (YSI Instruction Manual). Salinity measurements were recorded continuously at the EP, EM, WP, and WM gages.

Gages were equipped with instruments that measured and recorded data at 15-minute intervals. Stage measurements were recorded continuously at the EP, EM, WP, and WM gages (table 2). Stage-area ratings were developed at the EP and WP gages. These ratings were used to compute the cross-sectional area of the river at the gages from the stage measurements.

Velocity measurements were recorded continuously at the EP and WP gages by using an acoustic velocity meter (AVM) which was used to record average index velocity on a 15-minute interval. The horizontal AVM paths were about 60 ft and 50 ft for the EP and WP gages, respectively. Mean velocities were determined by measuring the channel cross section with an Acoustic Doppler Current Profiler (Gordon, 1996). A rating was developed relating the index velocity, recorded by the AVM, to the mean velocity in the cross section. An example of an Acoustic Doppler Current Profiler measurements for the EP and WP gage cross sections are shown in figure 7. The discharges at the EP and WP gages were computed on a 15-minute interval using the product of the mean velocity, computed from the index velocity rating, and the cross-sectional area of the river, computed from the stage-area rating. The rating is considered fair because of the difficulty in rating a tidally influenced river. The scatter of individual measurements around the average rating was ±15 percent.

Table 2. Stage data comparing median daily range of stage, maximum daily range of stage as a result of tropical storm influence, and daily maximum stage statistics, Suwannee, Florida

[ft, feet; pct., percentile]

Long-term gage	Median daily stage range[a] (ft)	Maximum daily stage range[b] (ft)	Date recorded	Daily maximum stage statistics							
				Mean	Standard deviation	Coeffiplcient of variation	10th pct.	25th pct.	50th pct.	75th pct.	90th pct.
EP (291841083070800)	2.92	6.48	10/8/1996[d]	14.98	.73	.05	15.83	15.38	14.98	14.56	14.16
EM (291652083064100)	3.33	5.73	10/5/1995[c]	16.65	0.84	0.05	17.52	17.05	16.65	16.20	15.71
WP (291930083082800)	3.00	7.59	10/8/1996[d]	6.43	.71	.11	7.14	6.84	6.47	6.07	5.61
WM (291842083085100)	3.08	7.59	10/8/1996[d]	7.21	.74	.10	7.96	7.61	7.25	6.84	6.32

[a]Median of differences between daily maximum and daily minimum stage.
[b]Maximum of differences between daily maximum and daily minimum stage.
[c]Hurricane Opal (gage unoperational during Hurricane Josephine).
[d]Hurricane Josephine.

EP (291841083070800) GAGE, SUWANNEE, FLORIDA

WP (291930083082800) GAGE, SUWANNEE, FLORIDA

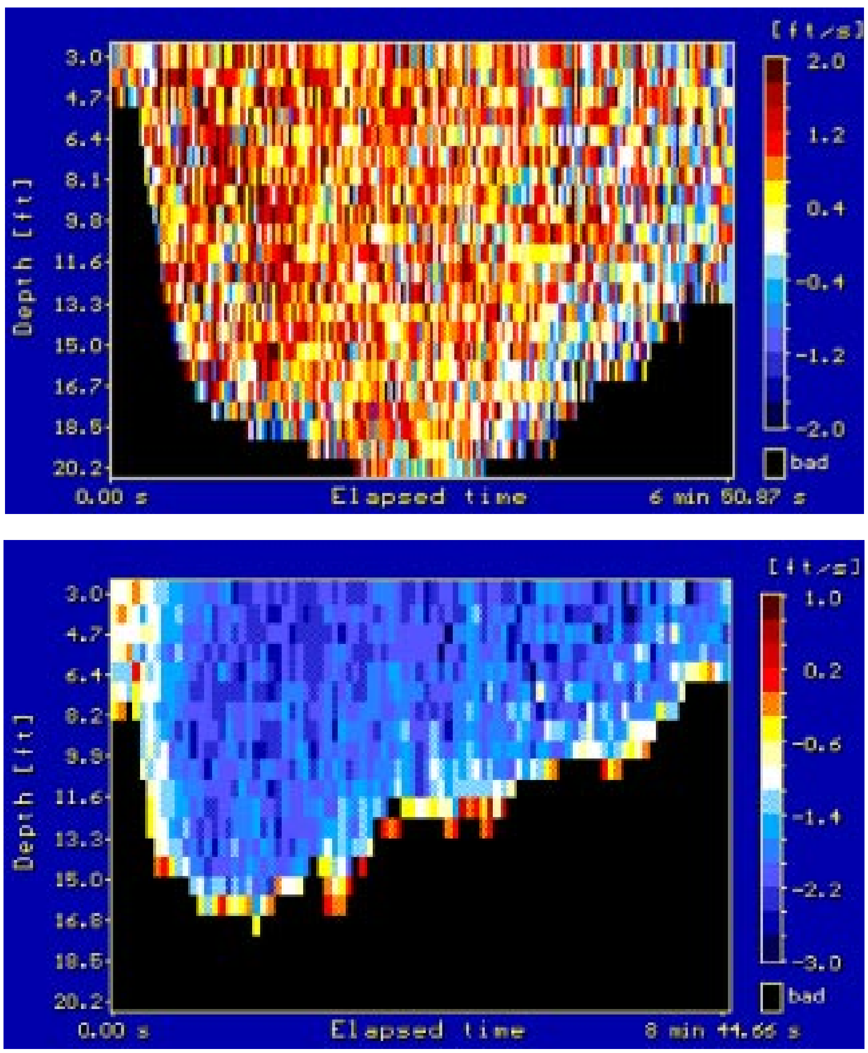


Figure 7. Acoustic Doppler Current Profiler measurements for cross sections of the Suwannee River at the EP (291841083070800) and WP (291930083082800)) gages, May 20, 1997, Suwannee, Florida.

Vertical and Longitudinal Profiling Data

Supplemental salinity data were recorded by using portable water-quality monitoring instrumentation in 31 supplemental surveys conducted at 15 sites that extend from the mouth of the major passes (in the Gulf of Mexico) to the confluence of Gopher River and the Suwannee River at river mile 5.6 (site G1; fig. 3). The equipment was calibrated prior to the start of each field trip. Salinity data were collected vertically through the water column for near-water surface (0.5 ft under the water surface), midcolumn (3-ft increments), and near-bottom depths (1.5 ft above the bottom). Samples were taken in the deepest part of the channel.

The SRWMD and GFC collected salinity-distribution data at the 15 supplemental sites during November 1992 and on a monthly basis from February 1993 to February 1995. Samples were collected at high tide during the full moon, which presumably corresponded to the maximum longitudinal penetration of saltwater in the upper estuary. Sampling was timed to bracket the high tides so that measurements were made no more than 1.5 hours before or after the scheduled high tide.

The USGS collected additional salinity surveys from May to October 1997, encompassing the range of tidal cycles. The May 1997 measurements were collected over a 3-day period. The maximum salinity measured at each site per day was used in the regression analysis of the daily maximum extent of isohaline location.

FLOW AND SALINITY CHARACTERISTICS

The salinity characteristics of the upper estuary are influenced greatly by discharge characteristics. Figures 8 and 9 illustrate the relation between salinity, stage, velocity, and discharge as a function of time. The maximum salinity occurred after the peak stage at the gages and within an hour of the minimum discharge. The phase-lags for tidal highs and lows for all the gages with respect to the EM gage are listed in table 3. Figure 10 is a plot of the instantaneous stage data for the WM gage from September 7 to October 16, 1996, and shows the effect of neap tide and Hurricane Josephine on the stage. Neap tides are a decreased range of tides that occur during the first and third quarters of the moon (National Oceanic and Atmospheric Administration, 1990). Three neap tides occurred during this period (fig. 10).

Flow Characteristics

Flow and velocity in the upper Suwannee River Estuary are affected by tidal effects and meteorological events. Gages in the upper estuary are influenced by tide and may experience flow reversal (negative flows) with each tidal cycle. Tidally affected flow in an estuary is superposition of tidal flow on freshwater discharge. The extent of flow reversal depends on tides, wind, and freshwater discharge from the river. At the EP gage, negative flow (flow in the upstream direction) had the greatest magnitude about 30 minutes prior to high tide. At high tide, the magnitude of negative flow changed, becoming more positive. Within about 30 minutes after high tide, the EP gage recorded net positive flow (fig. 9).

Figure 11 illustrates a time series of instantaneous stage and instantaneous discharge at the EP and WP gages and the sum of gage discharges for January 30–31, 1997. Daily mean discharges for the period of study at the WIL, EP, and WP gages are shown in figure 12. The effect of Hurricane Josephine on October 8, 1996, resulted in the maximum and minimum observed instantaneous discharges at the EP and WP gages (table 4).

Velocities typically ranged from -1.4 to 2.5 feet per second (ft/s) on West Pass at the WP gage and -2.2 to 2.7 ft/s on East Pass at the EP gage (negative values denote flow in the upstream direction). When Hurricane Josephine struck Florida, the range of velocities (-3.3 to 3.0 ft/s) on East Pass increased, whereas an increased range of velocities on the West Pass was not as noticeable. Daily freshwater flows at the WIL gage during the study period averaged about 7,410 ft^3/s and ranged from a low of 2,310 ft^3/s to a high of 18,200 ft^3/s during a severe storm (table 4). The minimum and maximum instantaneous flows measured at the EP gage were -19,300 and 16,700 ft^3/s, respectively, corresponding to the approach and arrival of Hurricane Josephine. For the same time period, the minimum and maximum instantaneous flows measured at the WP gage were -25,000 and 29,700 ft^3/s, respectively. The maximum daily mean discharge was 9,110 and 16,800 ft^3/s at the EP and WP gages, respectively. West Pass and East Pass discharged about 64 and 36 percent of the total flow, respectively.

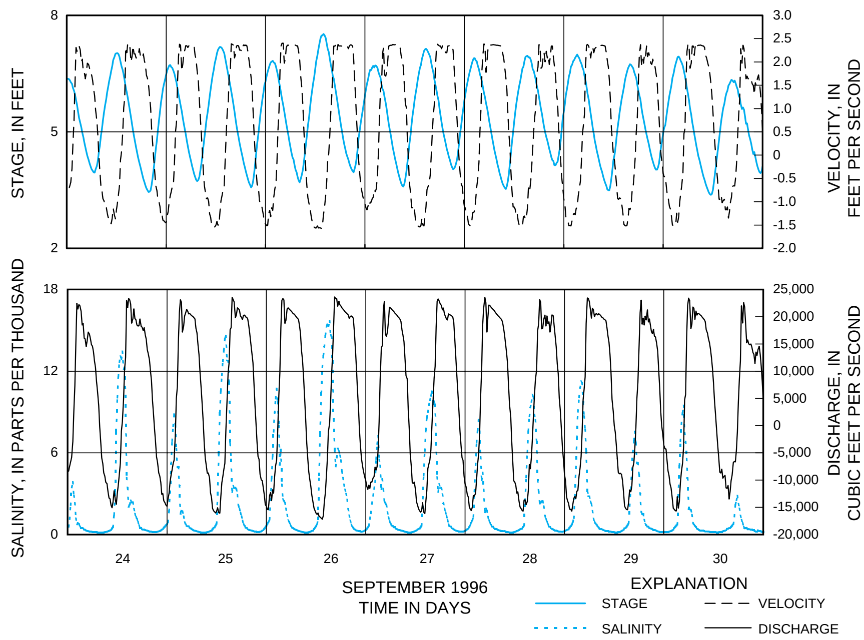


Figure 8. Stage, velocity, salinity, and discharge data at the WP (291930083082800) gage, September 24–30, 1996, Suwannee, Florida.

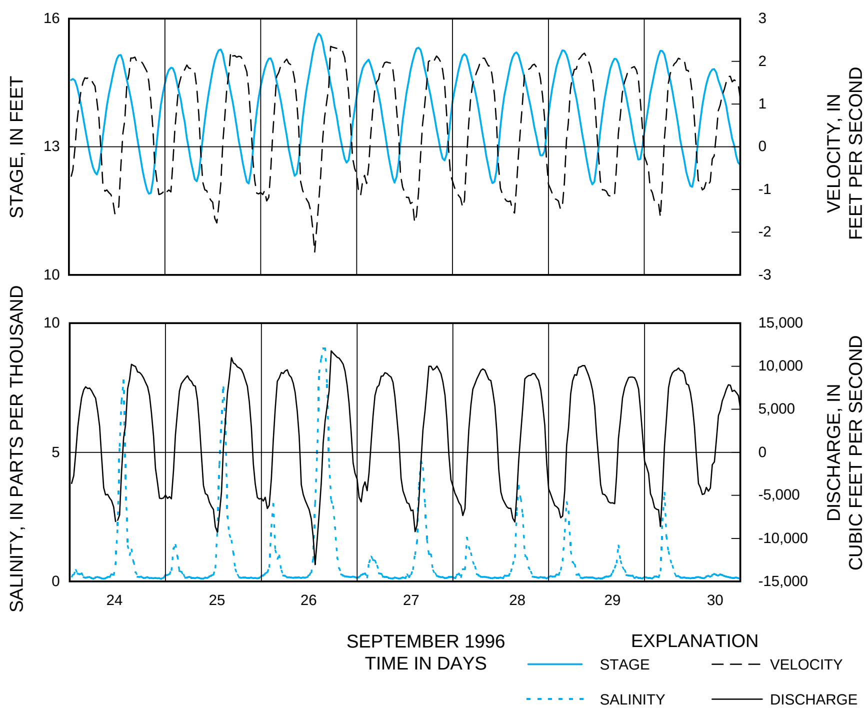


Figure 9. Stage, velocity, salinity, and discharge data at the EP (291841083070800) gage, September 24–30, 1996, Suwannee, Florida.

Acoustic Doppler Current Profiler measurements contain detailed information about vertical and horizontal velocity distributions. Measurements made in the estuary provided additional information on the flow dynamics under varying discharge conditions, including instances of bidirectional flow. In figure 7, the EP gage measurement was conducted at high tide when discharge was -3,900 ft^3/s. The West Pass measurement was conducted at low tide when discharge was 18,200 ft^3/s.

Discharge duration curves were developed for the EP, WP, and WIL gages by using the daily mean discharge (fig. 13). At lower flows, discharge at the WIL gage was greater than the sum of discharges at the EP and WP gages. The difference likely is due to rating errors.

Table 3. The phase-lag for tidal highs and lows for all gages with respect to the EM (291652083064100) gage, lower Suwannee River Basin, Florida

Long-term gage	Peak lag time (minutes)	Trough lag time (minutes)
EP (291841083070800)	+45	+30
WP (291930083082800)	+30	+30
WM (291842083085100)	+15	+15
WIL (02323500)	+240	+270 to 300

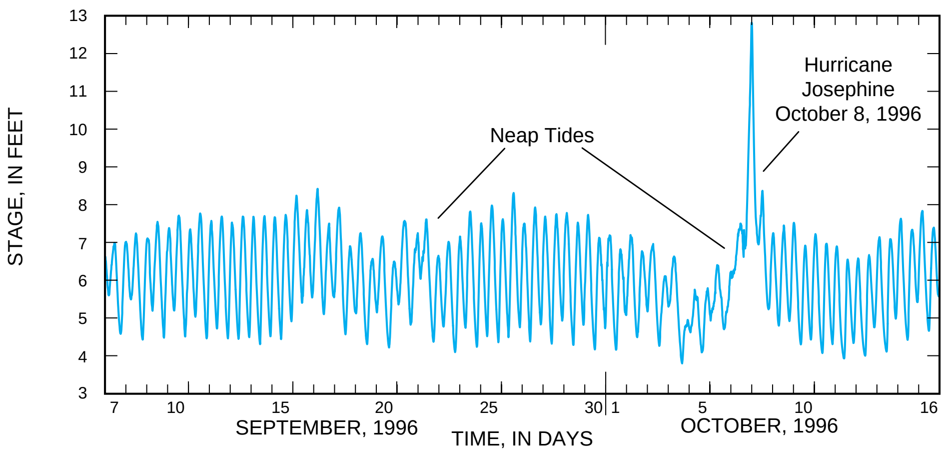


Figure 10. Stage data for the WM (291842083085100) gage, September 7 to October 16, 1996, Suwannee, Florida.

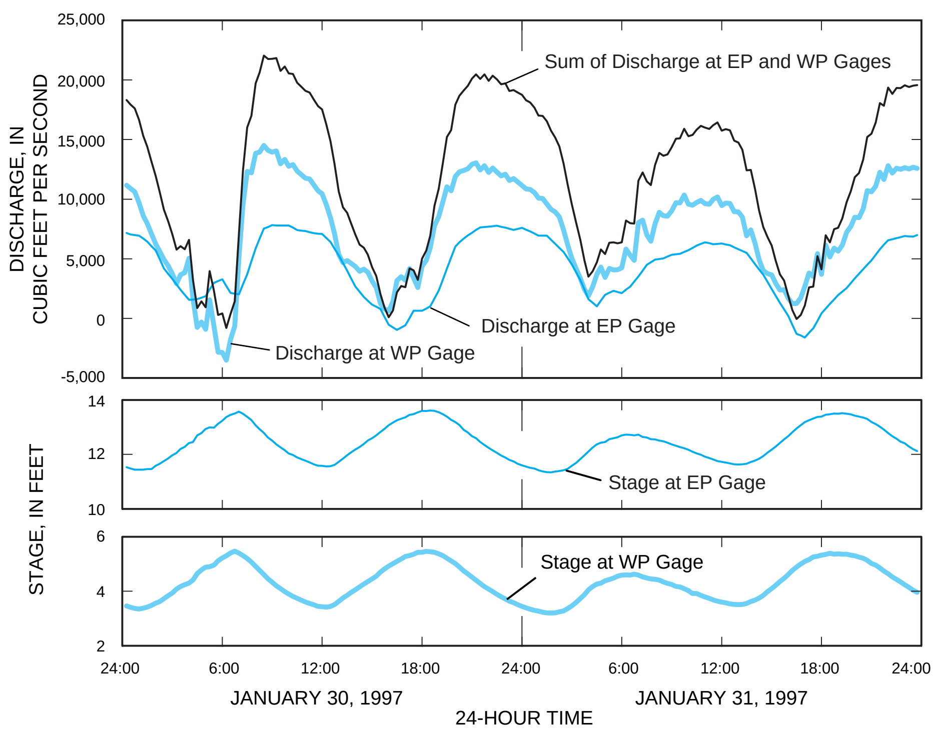


Figure 11. Stage and discharge data at the EP (291841083070800) and WP (291930083082800) gages, and the sum of discharges at the EP and WP gages from January 30–31, 1997, Suwannee, Florida.

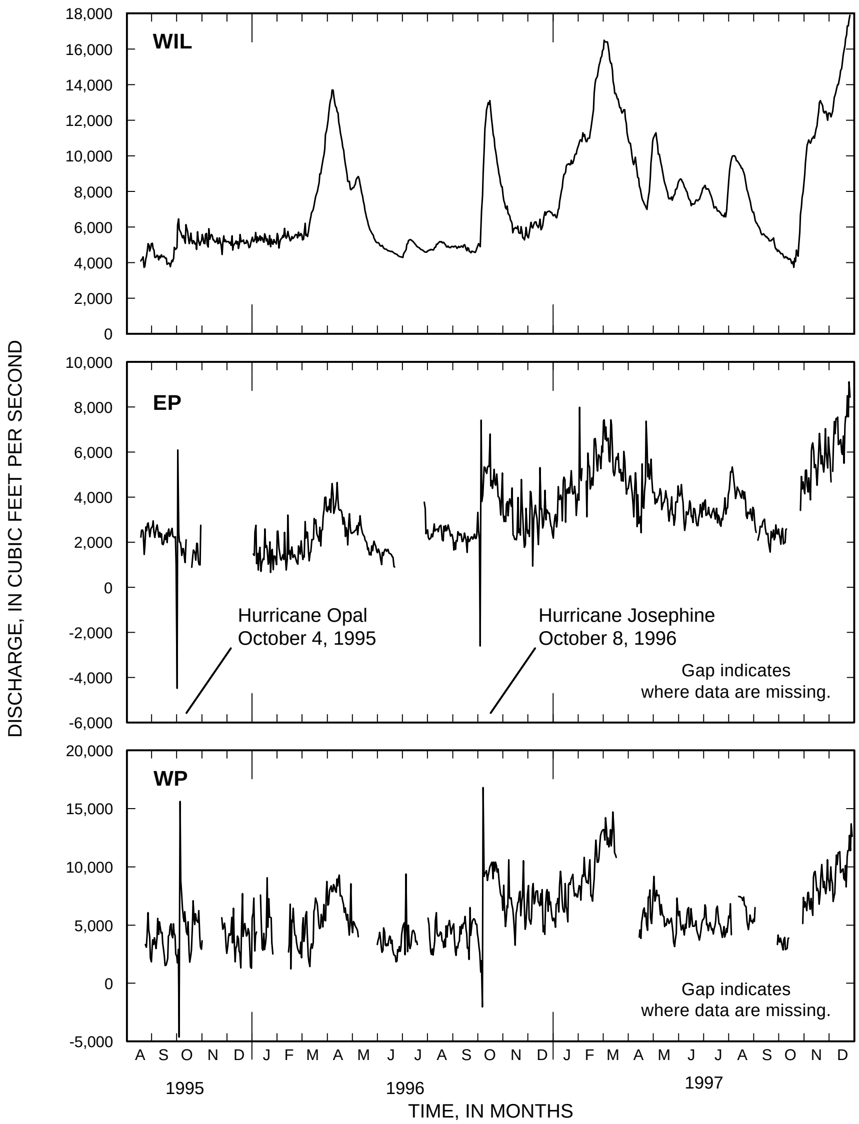
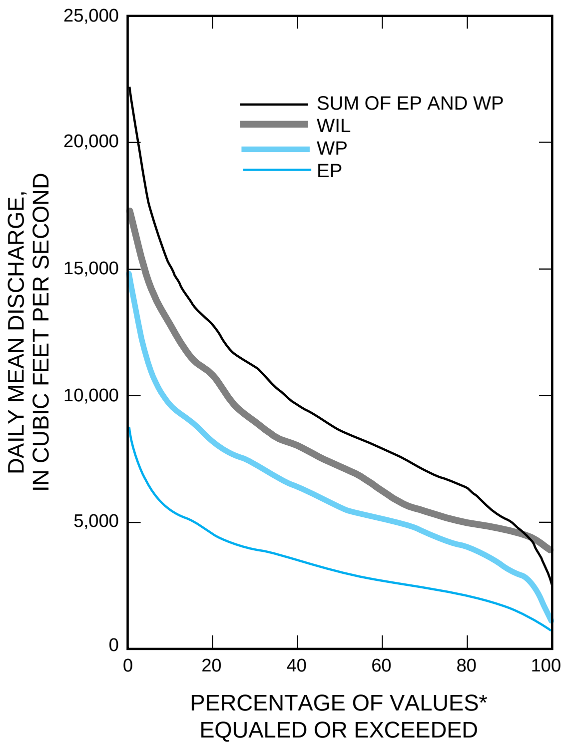


Figure 12. Daily mean discharge for the WIL (02323500), EP (291841083070800), and WP (291930083082800) gages, August 1995 to December 1997, lower Suwannee River Basin, Florida.

Table 4. Discharge data comparing maximum daily mean discharge, minimum observed instantaneous discharge, maximum observed instantaneous discharge, and daily mean discharge statistics during the study period, lower Suwannee River Basin, Florida

[ft^3/s, cubic feet per second; pct., percentile; --, no data]

Long-term gage	Maximum daily mean dishcarge (ft^3/s)	Minimum observed instantaneous discharge (ft^3/s)	Maximum observed instantaneous discharge (ft^3/s)	Daily mean discharge (ft^3/s)							
				Mean	Standard devia-tion	Coeffi-cient of variation	10th pct.	25th pct.	50th pct.	75th pct.	90th pct.
EP (291841083070800)	9,110	-19,300	16,700	3,285	1,563	0.48	5,419	4,190	2,950	2,220	1,557
Date recorded	12/30/97	10/7/96	10/8/96								
WP (291930083082800)	16,800	-25,000	29,700	5,931	2,631	.44	9,410	7,490	5,360	4,100	2,980
Date recorded	10/8/96	10/7/96	10/8/96								
WIL (02323500)	17,900	2,310	18,200	7,410	3,081	.42	12,400	9,160	6,130	5,060	4,600
Date recorded	12/31/97	10/16/97	12/31/97								
Sum of EP and WP	24,210	--	--	9,490	4,061	.43	15,156	11,673	8,625	6,698	5,041
	10/8/96										



*Duration of days when data available at all three sites.

Figure 13. Daily mean discharge duration curves for the WIL (02323500), WP (291930083082800), and EP (291841083070800) gages, and the sum of discharges at the WP and EP gages for the study period, lower Suwannee River Basin, Florida.

Salinity Characteristics

Salinity variability in the estuary is affected by wind, meteorological events, river discharge, mixing and diffusion, and tide. Orlando and others (1993) found that, on a weekly and seasonal basis, wind was a minor secondary influence on salinity variability in Suwannee Sound. Episodic meteorological events, such as hurricanes and storms, have a substantial effect on salinity at the upstream gages.

Salinity distribution data were collected at 15 sites that extend from the mouth of major passes to the confluence of Gopher River with the Suwannee River. Top and bottom salinity data from each survey are shown in figure 14 for West Pass and in figure 15 for East Pass. Plots are arranged in order of increasing daily mean discharge at the WIL gage.

The highest recorded surface salinities ranged from 26.9 ppt at the mouth of Wadley Pass (W1; fig. 3) to 1.2 ppt at the confluence with Gopher River (G1; fig. 3). The highest recorded bottom salinities ranged from 29.8 ppt at the mouth of Wadley Pass to 1.2 ppt at the confluence with Gopher River. The highest salinities generally were observed at all sites during low flow. During high flow, saltwater was flushed out of the system and salinity was zero at all sites. Similar to data collected in other studies, salinity generally was highest in Wadley Pass, probably due to the dredged channel in the pass. Slightly lower salinity was measured in Alligator Pass, probably due to the shallow channel depth and freshwater contributions from the river. The greatest stratification between surface and bottom salinities generally seemed to occur in fall and early spring.

During the study, maximum salinity concentrations ranged from 28.20 ppt at the EP gage to 31.00 ppt at the WM gage (tables 5 and 6); the salinity of ocean water typically ranges from 33 to 35 ppt. Median daily salinity ranges at the WM and EM gages were 8.37 and 11.31 ppt, respectively; the upstream WP and EP gages had median daily salinity concentrations of 0.73 and 0.12 ppt, respectively. The saltwater/freshwater interface was at or upstream from the EP and WP gages 40 and 57 percent of the time, respectively. The interface was downstream from the EM and WM gages 11 and 21 percent of the time, respectively. Median daily maximum salinity concentrations at the four gages ranged from 11.50 ppt at the EM gage to 0.22 ppt at the EP gage (table 5). Monthly maximum salinity concentrations were highest in September (table 6). Daily mean salinity concentrations for the period of study at the EP, EM, WP, and WM gages are shown in figure 16.

Salinity duration curves were developed for the four gages based on daily maximum salinity concentrations observed during the study period (fig. 17). Salinity concentrations were highest at the EM gage and lowest at the EP gage owing to tidal influence. Salinity concentrations were nearly zero (less than or equal to 0.5 ppt) a the EP and WP gages for 60 and 43 percent of the study period, respectively. The 5.0 ppt salinity concentration represents the break between oligohaline (0.5 to 5.0 ppt salinity) and mesohaline (5.0 to 18.0 ppt salinity) conditions. Oligohaline areas are ecologically important as the initial recruitment and nursery areas for many estuarine species (Mattson and Krummrich, 1995). The 5.0 ppt salinity level occurred at or upstream from the EP and WP gages 15 and 32 percent of the time, respectively. Salinity concentrations of 5.0 ppt occurred downstream from the EM and WM gages 26 and 38 percent of the time, respectively.

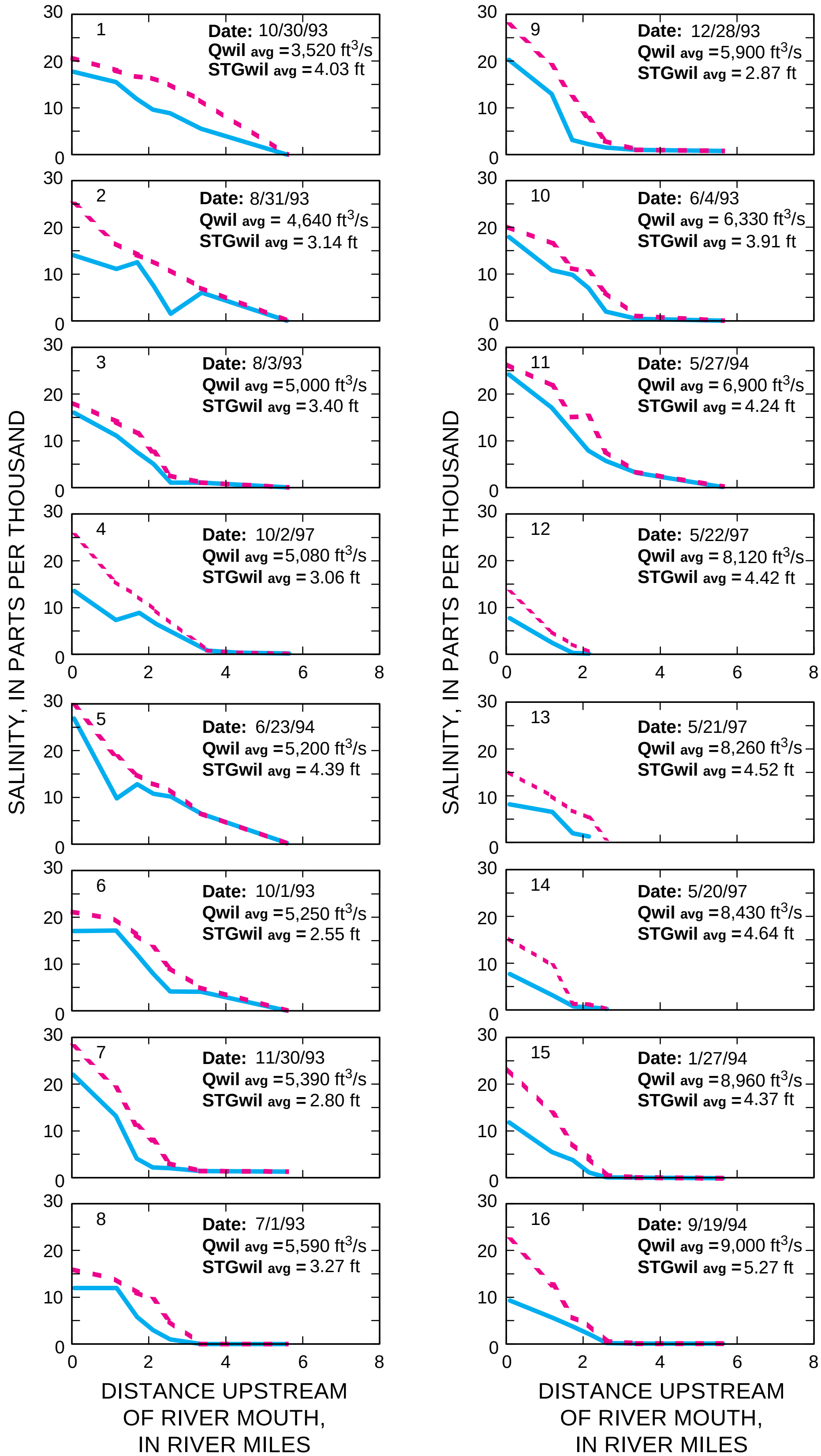


Figure 14. Field measurements of near-surface and near-bottom salinity as a function of river mile for West (Wadley) Pass of Suwannee River, Suwannee, Florida. Plots are arranged in order of increasing daily mean discharge for the Suwannee River near Wilcox (WIL-02323500).

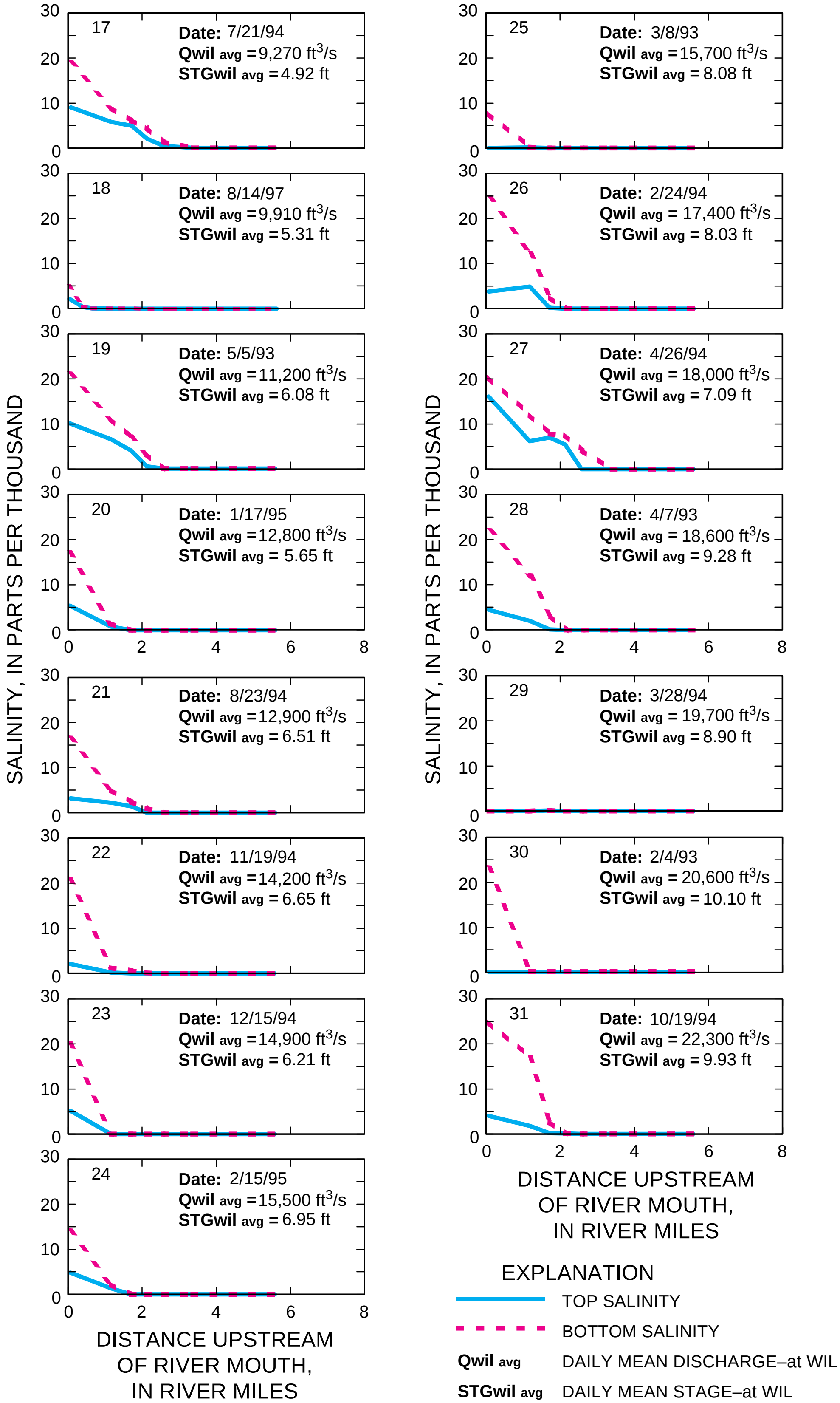


Figure 14. Field measurements of near-surface and near-bottom salinity as a function of river mile for West (Wadley) Pass of Suwannee River, Suwannee, Florida. Plots are arranged in order of increasing daily mean discharge for the Suwannee River near Wilcox (WIL-02323500). (Continued)

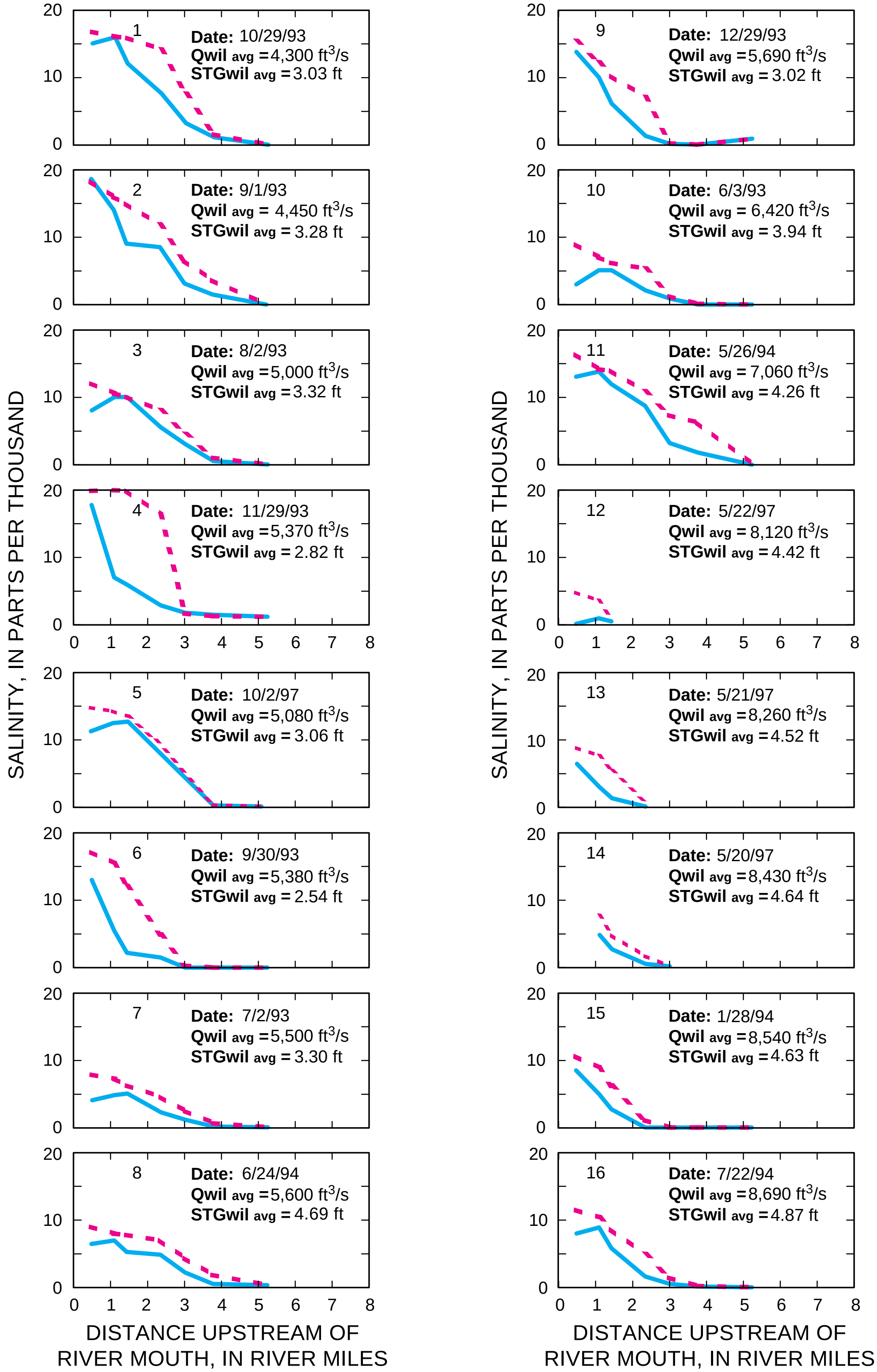


Figure 15. Field measurements of near-surface and near-bottom salinity as a function of river mile for East Pass of Suwannee River, Suwannee, Florida. Plots are arranged in order of increasing daily mean discharge for the Suwannee River near Wilcox (WIL-02323500).

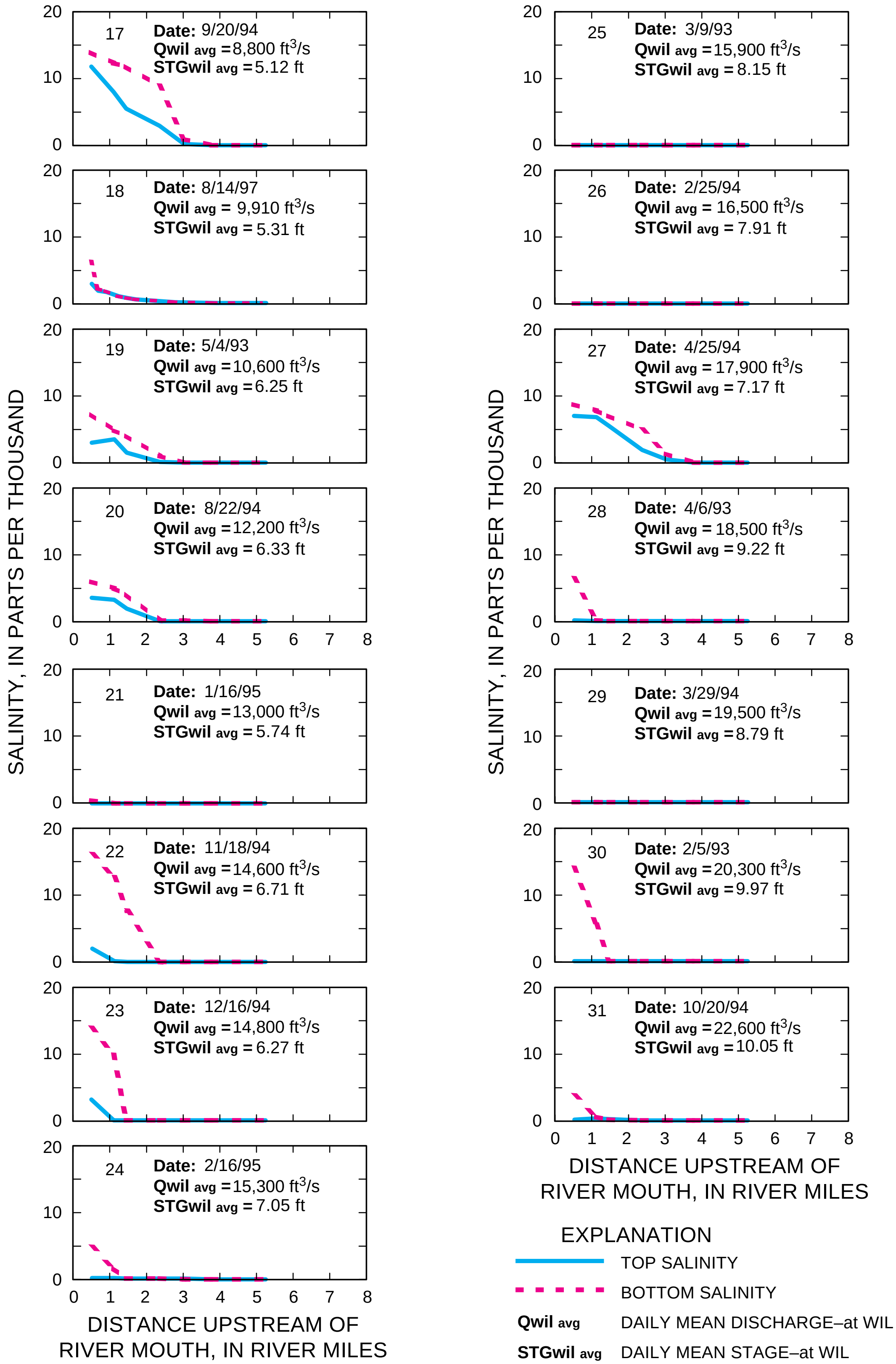


Figure 15. Field measurements of near-surface and near-bottom salinity as a function of river mile for East Pass of Suwannee River, Suwannee, Florida. Plots are arranged in order of increasing daily mean discharge for the Suwannee River near Wilcox (WIL-02323500). (Continued)

Table 5. Salinity data comparing median and maximum daily salinity range and statistics on daily maximum salinity, Suwannee, Florida

[ppt, parts per thousand; ft^3/s, cubic feet per second; pct., percentile]

Long-term gage	Median daily salinity[a] (ppt)	Maximum daily salinity[b] (ppt)	Saltwater/ freshwater interface[c] (percent)	Maximum observed salinity (ppt)	Date recorded	Daily mean salinity (ppt)							
						Mean	Standard deviation	Coefficient of variation	10th pct.	25th pct.	50th pct.	75th pct.	90th pct.
EP (291841083070800)	0.12	27.18	40	28.20[d]	10/5/95	2.14	3.95	1.85	7.29	2.35	0.22	0.12	0.08
EM (291652083064100)	11.31	26.23	89	30.90[d]	10/4/95	10.88	7.01	.64	19.63	16.70	11.50	4.72	.36
WP (291930083082800)	.73	26.55	57	29.70[d]	10/4/95	4.09	5.40	1.32	12.67	6.87	.87	.17	.10
WM (291842083085100)	8.37	27.70	79	31.00[d]	10/4/95	8.85	7.08	.80	18.20	14.73	8.53	1.27	.11

[a]Median of differences between daily maximum and daily minimum salinity.
[b]Maximum of differences between daily maximum and daily minimum salinity.
[c]Percentage of time 0.5 ppt salinity was equaled or exceeded.
[d]Hurricane Opal.

Table 6. Duration analyses of daily maximum salinity at the EM, EP, WP, and WM gages during the study period, Suwannee, Florida

Month	Daily maximum salinity, in parts per thousand										
	Mean	High	Low	Percentage of time salinity was equal to or greater than							
				5	10	15	25	50	75	90	95
EP (291841083070800)											
January	2.87	18.90	0.06	11.50	10.06	7.00	3.78	0.25	0.11	0.08	0.08
February	.88	14.80	.05	4.74	2.06	1.15	.64	.17	.08	.06	.05
March	.43	4.61	.04	3.19	.83	.54	.17	.10	.07	.05	.04
April	.18	1.78	.05	.53	.36	.16	.14	.11	.09	.06	.06
May	.26	2.62	.07	.70	.51	.39	.22	.16	.13	.10	.08
June	1.55	11.80	.11	8.32	3.81	2.78	1.37	.23	.15	.12	.12
July	1.20	8.67	.15	5.82	3.82	2.56	1.01	.22	.18	.16	.16
August	2.51	16.00	.10	9.12	6.76	5.69	3.86	.79	.19	.14	.10
September	4.92	15.40	.18	13.28	11.32	9.62	7.88	3.85	1.17	.34	.25
October	4.47	28.20	.05	18.56	14.86	12.12	6.67	.61	.19	.09	.08
November	1.49	11.40	.06	9.30	4.60	3.05	1.08	.15	.09	.07	.07
December	2.56	21.20	.05	13.04	7.89	5.98	3.09	.18	.09	.06	.06
All days	2.14	28.20	.04	11.30	7.29	5.06	2.35	.22	.12	.08	.06
EM (291652083064100)											
January	12.45	25.80	0.10	23.59	20.49	18.87	16.95	12.85	8.83	1.79	0.90
February	8.73	26.50	.10	18.70	17.06	16.20	13.70	7.91	2.89	.26	.16
March	5.42	21.10	.00	17.26	13.80	11.40	9.76	2.66	.40	.10	.09
April	4.41	20.00	.00	12.23	11.16	9.77	7.65	2.39	.11	.08	.00
May	4.78	10.80	.18	9.10	8.59	7.92	6.99	5.56	1.68	.36	.32
June	7.85	16.40	3.04	15.05	12.50	10.34	9.13	7.79	5.14	4.65	4.26
July	8.26	15.60	.80	13.76	13.30	12.09	10.80	9.56	4.96	3.02	1.52
August	12.79	22.70	3.41	19.68	19.10	18.23	16.00	12.70	10.06	6.09	4.30
September	16.72	25.30	9.42	20.67	19.90	19.80	18.75	16.70	14.85	13.06	12.12
October	16.70	30.90	.60	23.43	22.15	21.35	19.70	17.70	14.00	11.05	6.83
November	11.69	23.20	.11	21.47	19.94	19.05	17.70	12.60	5.63	.87	.19
December	11.25	25.60	.05	22.02	20.40	19.54	18.20	12.90	2.08	.09	.08
All days	10.88041	30.9	.00	20.82	19.63	18.5	16.7	11.5	4.72	.36	.11

Table 6. Duration analyses of daily maximum salinity at the EM, EP, WP, and WM gages during the study period, Suwannee, Florida (Continued)

Month	Daily maximum salinity, in parts per thousand										
	Mean	High	Low	Percentage of time salinity was equal to or greater than							
				5	10	15	25	50	75	90	95
WP (291930083082800)											
January	3.81	18.30	0.10	17.73	13.50	11.00	6.56	0.19	0.13	0.10	0.10
February	2.35	19.20	.05	13.73	9.20	6.22	.98	.13	.09	.06	.05
March	1.82	12.40	.05	9.86	6.41	5.23	.96	.12	.08	.05	.05
April	.49	3.98	.06	2.57	1.41	.67	.26	.12	.08	.06	.06
May	1.06	7.00	.08	4.47	3.38	2.70	1.34	.22	.13	.10	.09
June	3.44	17.00	.12	12.85	10.80	8.89	5.75	1.12	.30	.17	.14
July	3.21	21.80	.10	18.08	8.10	5.04	4.12	.47	.15	.11	.10
August	4.54	20.50	.07	13.52	11.66	9.76	7.43	2.50	.35	.09	.07
September	8.18	18.40	.31	16.85	15.40	14.25	12.53	8.33	3.02	.87	.53
October	4.30	29.70	.08	17.86	13.18	10.29	4.98	.83	.29	.18	.14
November	4.48	17.00	.13	14.70	11.96	9.56	7.79	.48	.22	.14	.13
December	6.55	19.70	.15	17.46	15.00	11.97	9.23	6.27	.71	.22	.19
All days	4.09	29.70	.05	15.67	12.67	10.20	6.87	.87	.17	.10	.07
WM (291842083085100)											
January	10.14	21.70	0.10	20.59	17.98	17.14	15.70	9.89	4.96	0.23	0.16
February	7.34	24.60	.05	17.64	15.74	15.40	13.40	4.72	.53	.09	.08
March	4.44	15.80	.05	13.99	13.28	12.47	7.98	1.40	.12	.08	.05
April	3.52	15.90	.06	11.59	9.12	8.64	5.86	1.16	.13	.08	.06
May	4.05	11.00	.10	9.51	8.74	8.28	7.03	3.89	.33	.14	.12
June	6.54	19.40	.15	13.42	10.68	10.28	8.81	6.10	3.47	.98	.51
July	8.83	23.90	.25	22.62	20.74	20.28	16.20	7.06	2.38	.77	.47
August	10.26	23.20	.19	22.50	19.15	17.83	16.85	11.03	1.21	.35	.26
September	14.42	22.10	5.70	19.80	19.00	17.90	17.20	14.80	11.80	9.88	8.65
October	13.48	31.00	.08	24.44	20.98	19.30	17.70	13.90	9.17	4.71	.80
November	9.41	23.80	.05	21.90	19.10	18.14	15.20	8.53	.89	.08	.07
December	8.96	21.30	.04	20.46	18.32	17.22	15.30	9.96	.08	.06	.05
All days	8.85	31.00	.04	20.60	18.20	16.94	14.73	8.53	1.27	.11	.07

Longitudinal salinity surveys showed that the water column in the estuary generally was well mixed at and upstream from the EM and WM gages (figs. 14 and 15). However, downstream from the gages, vertical salinity stratifications, as indicated by differences between near-surface and near-bottom salinity concentrations, were noticeable at low freshwater inflow and became more pronounced as inflow increased. The longitudinal extent of the saltwater wedge also depended on the quantity of freshwater inflow. The greater the inflow, the further downstream the wedge would occur. Near-bottom salinity concentrations were affected by freshwater inflow as evidenced by the oligohaline and freshwater salinity (<5.0 ppt) measurements for near-bottom readings made during high-flow conditions.

Salinity patterns are related to short-term discharge at Wilcox as well as to seasonal and long-term (months) freshwater runoff and salinity in the estuary and in the Gulf of Mexico. During a period of unusually low freshwater inflow (<10,000 ft^3/s) from June to December 1993, a saltwater wedge was present upstream from the EP and WP gages (Mattson and Krummrick, 1995). Data indicate that discharges exceeding 13,000 ft^3/s typically occur from February to March and tend to push the saltwater/freshwater interface into the Gulf of Mexico. Although the April 26, 1994, survey (graph 27 in fig. 14) was conducted under high-flow conditions (18,000 ft^3/s), the saltwater wedge was upstream from the WP gage. A duration analysis indicates that the maximum daily upstream extent of the saltwater/freshwater interface was at or slightly upstream from river mile 4.0 on West Pass for about 50 percent of the study period.

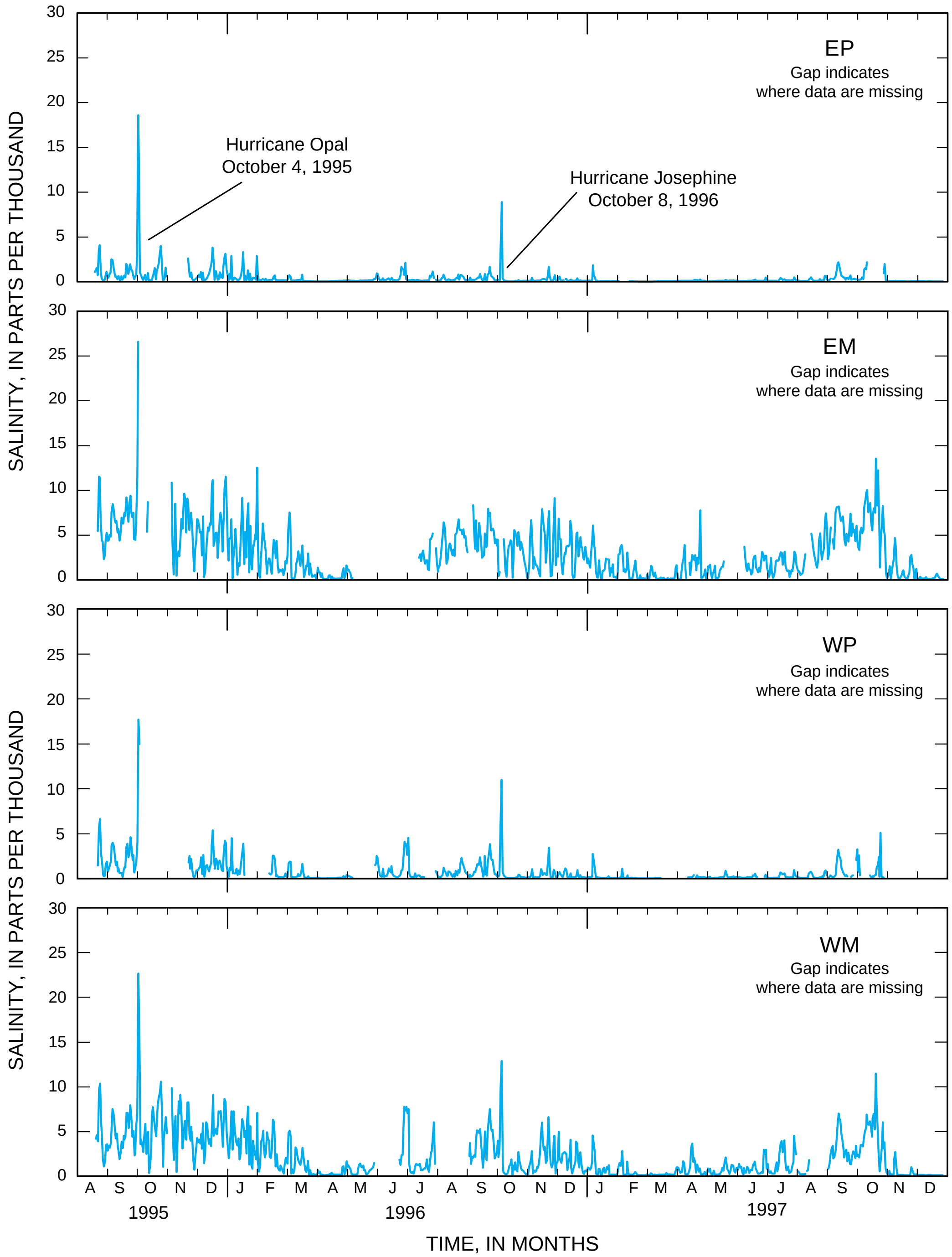


Figure 16. Daily mean salinity for the EP (291841083070800), EM (291652083064100), WP (291930083082800), and WM (291842083085100) gages, August 1995 to December 1997, Suwannee, Florida.

Data indicate that salinity levels continue to increase for some time after high tide. Figure 18 compares salinity levels at East Pass gages under high- and low-flow conditions. At the EP gage, salinity concentrations remained below 0.10 ppt during high-flow conditions, whereas concentrations were two orders of magnitude greater under low-flow conditions. Instantaneous salinity data were plotted for the WP and WM gages (fig. 19). As shown in figure 19, there is no distinct contrast between salinity concentrations at the two gages inasmuch as they are only about 1 mile apart.

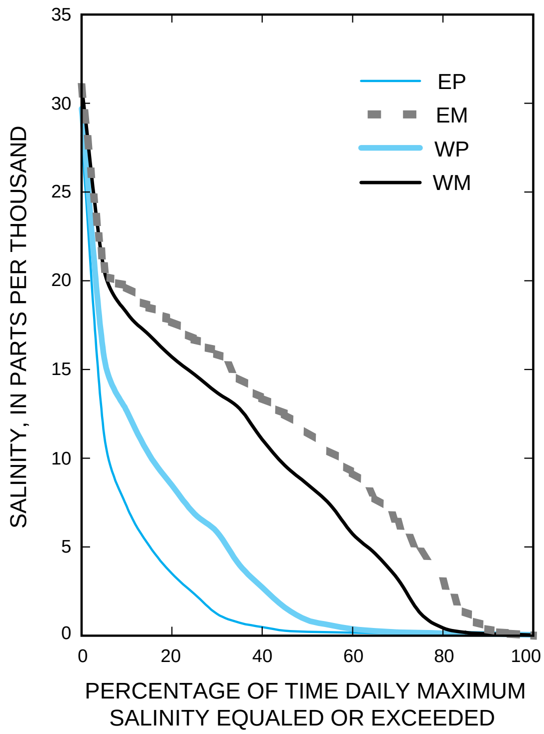


Figure 17. Duration of daily maximum river salinity at the EP (291841083070800), EM (291652083064100), WP (291930083082800), and WM (291842083085100) gages from August 1995 to December 1977, Suwannee, Florida.

The effect that high-, medium-, and low-flow conditions have on the vertically averaged salinity distribution is illustrated in figure 20 (East Pass) and figure 21 (West Pass). In general, salinity concentrations tended to be higher in West Pass. During extended periods of high flow, salinities tended to be zero, even at some distance into the gulf. During low flows, salinity concentrations at the most upstream site (G1) remained near zero, except during eposodic events.

Regression Analysis

The regression analysis of relating salinity in the estuary to discharge at the WIL gage was conducted in three parts. The first part of the analysis consisted of developing regressions to predict the location of the 0.5, 2, 5, 10, 15, and 20 ppt isohalines. The second part consisted of regressions to predict daily maximum salinity at the four gages. The third part of the analysis consisted of testing various withdrawal scenarios.

The first part of the analysis developed a correlation relating the maximum upstream extent of the 0.5, 2, 5, 10, 15, and 20 ppt isohalines to the daily mean discharge and daily mean stage of the WIL gage.

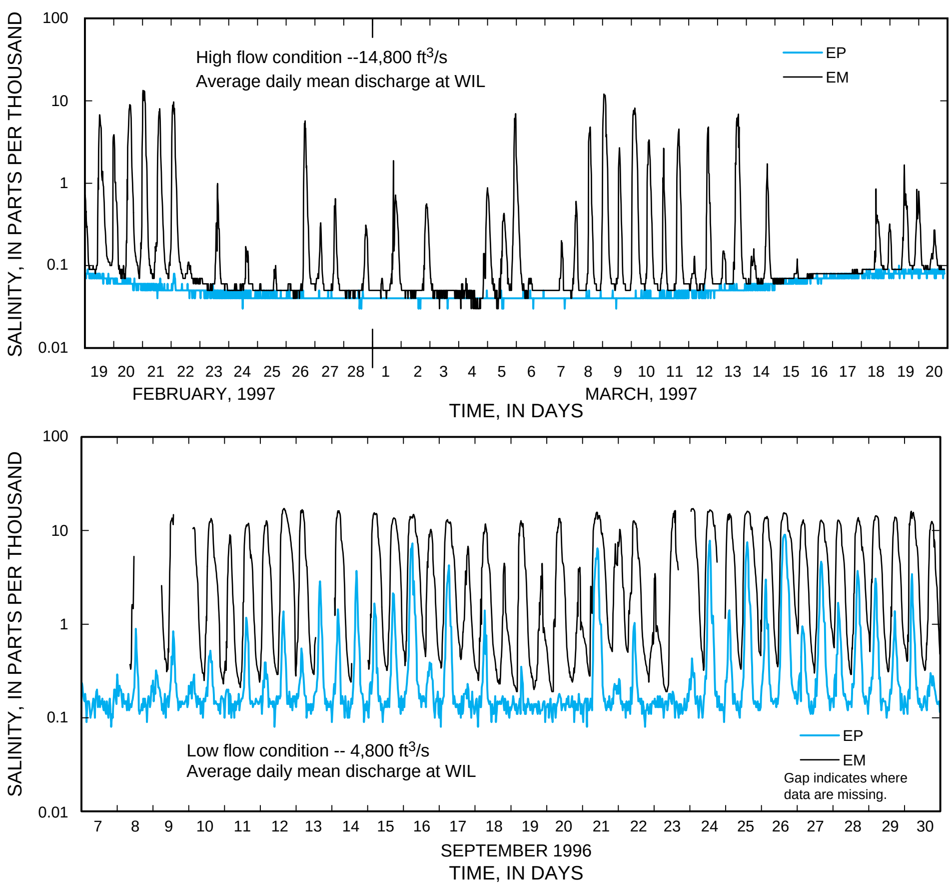


Figure 18. Typical salinity patterns associated with high- and low-flow conditions at the EP (291841083070800) and EM (291652083064100) gages, Suwannee, Florida.

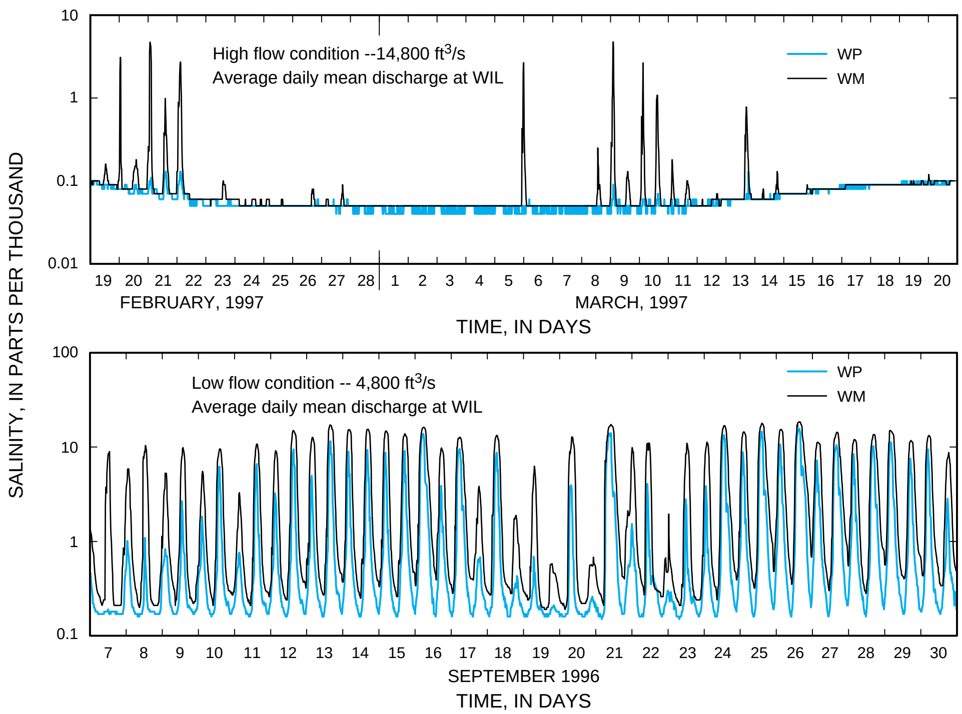


Figure 19. Typical salinity patterns associated with high- and low-flow conditions at the WP (291930083082800) and WM (291842083085100) gages, Suwannee, Florida.

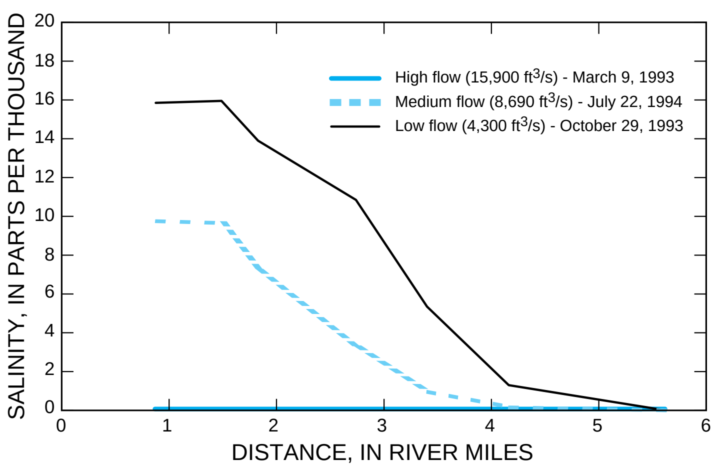


Figure 20. Vertically averaged salinity distribution in East Pass near Suwannee, Florida, under high-, medium-, and low-flow conditions at the WIL (02323500) gage.

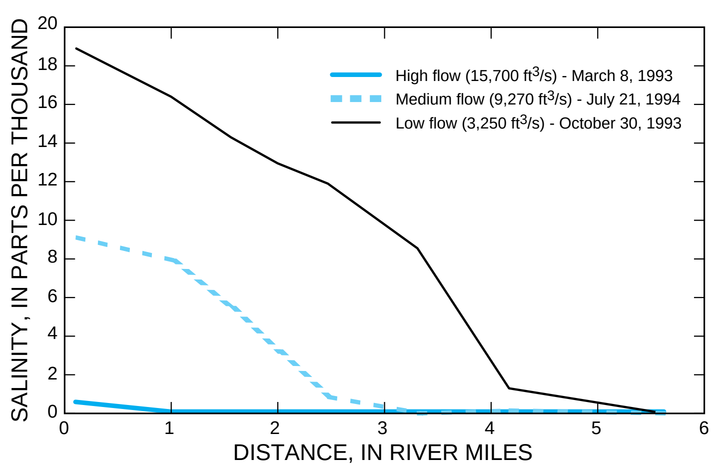


Figure 21. Vertically averaged salinity distribution in West Pass near Suwannee, Florida, under high-, medium-, and low-flow conditions at the WIL (02323500) gage.

This analysis was conducted for surface, bottom, and vertically averaged salinity. Vertically averaged salinity is the average of the surface, midcolumn, and bottom salinity data collected at a site. Salinity concentrations that were within less than a 1.0 ppt range of the target salinity were used in each of the isohaline computations (that is, measurements greater than 9.0 and less than 11.0 ppt were included in the analysis for the 10.0 ppt isohaline).

Regressions were conducted against several variables, including daily mean discharge, daily mean stage, and the 5-day moving average of the daily mean discharge at the WIL gage. In addition, regressions were performed by using the natural log, inverse, square, and square root of these variables. The correlations were ranked according to the adjusted R^2 value and P-value. The best correlations for each salinity level are presented in tables 7, 8, and 9 for vertically averaged, surface, and bottom salinities, respectively.

The regression analyses showed that salinity concentrations tended to be inversely proportional to the daily mean discharge at the WIL gage. These regressions were used to predict the maximum longitudinal extent of isohalines for the vertically average salinity under high- (20,300 ft^3/s), medium- (8,120 ft^3/s) and low- (4,500 ft^3/s) flow conditions (figures 22–24). Isohaline locations shown in red were calculated from the regressions, whereas locations shown in yellow were estimated (figures 22–24). The estimated isohaline locations are based on regressions that were considered unsatisfactory (based on adjusted R^2 values or P-value criteria) or outside the valid range of flows. The 0.5 ppt isohaline occurred at river miles 1.30, 3.13, and 5.60 on West (Wadley) Pass for the high-, medium-, and low-flow conditions. The computed location of the 0.5 and 5.0 ppt isohalines, as a function of daily mean discharge observed at the WIL gage during the study period, are shown in figure 25. Most of the adjusted R^2 values were below satisfactory criteria. The river-mile location of the saltwater/freshwater interface was inversely proportional to the daily mean discharge at the WIL gage.

The second part of the analysis developed predictive equations for the daily maximum salinity that occurred at fixed gages as a function of several variables, including the following: daily maximum, mean, and minimum discharge and stage at the WP and EP gages; daily maximum, mean, and minimum stage at the WM and EM gages; the daily mean discharge and stage, and the 5-day moving average of the daily mean discharge at the WIL gage; and wind data.

Table 7. Relation of daily maximum extent of vertically averaged isohaline location to daily mean discharge at the long-term WIL (02323500) gage, referenced in river miles for longitudinal profiling data, lower Suwannee River Basin, Florida

[ppt, parts per thousand; adjusted R^2, square of the correlation coefficient; inv, inverse of; Qwil, daily average discharge at the WIL gage, in cubic feet per second (ft^3/s); L = distance upstream of mouth, in river miles; Q, discharge; <, less than; -- no data]

Salinity (ppt)	Pass	Predictive equations	Adjusted R^2	Standard error (miles)	P-values		Observations	Range of valid flows (ft^3/s)
					Intercept	invQwil		
0.5	Wadley	L = 0.0716 + 24, 866.442 inv(Qwil)	0.621	0.871	0.895	<0.001	24	5,000 < Q < 22,300
	Alligator	L = -0.483 + 27,563.246 inv(Qwil)	.706	.879	.305	< .001	30	5,000 < Q < 19,700
	East	L = 1.034 + 19,140.513 inv(Qwil)	.524	.927	.024	< .001	29	5,000 < Q < 22,600
2	Wadley	L = 0.697 + 14,756.883 inv(Qwil)	.572	.757	.090	< .001	23	4,300 < Q < 16,100
	Alligator	L = 0.690 + 14,538.903 inv(Qwil)	.518	.803	.127	< .001	23	4,300 < Q < 11,500
	East	L = -0.636 + 23,466.756 inv(Qwil)	.714	.863	.237	< .001	18	4,300 < Q < 14,200
5	Wadley	L = 0.491 + 11,510.539 inv(Qwil)	.568	.377	.371	.019	8	5,250 < Q < 11,200
	Alligator	L = -0.222 + 15,330.883 inv(Qwil)	.631	.502	.550	< .001	15	5,250 < Q < 18,600
	East	L = 0.140 + 12,244.100 inv(Qwil)	.323	.830	.817	.008	18	4,300 < Q < 14,800
10	Wadley	L = -0.211 + 10,903.292 inv(Qwil)	.684	.462	.607	.004	9	4,640 < Q < 18,000
	Alligator	L = -0.0796 + 8,298.490 invQwil)	.417	.540	.830	.004	16	4,640 < Q < 18,600
	East	L = 0.218 + 9,379.995 inv(Qwil)	.293	.679	.737	.027	14	4,300 < Q < 14,600
15	Wadley	L = -0.564 + 8,930.498 inv(Qwil)	.811	.365	.097	.004	7	3,520 < Q < 22,300
	Alligator	Poor regressions	--	--	--	--	--	--
	East	L = -0.00152 + 5,254.469 inv(Qwil)	.231	.276	.998	.189	6	4,300 < Q < 7,060

Table 8. Relation of daily maximum extent of surface isohaline location to daily mean discharge at the long-term WIL (02323500) gage, referenced in river miles for longitudinal profiling data, lower Suwannee River Basin, Florida

[ppt, parts per thousand; adjusted R^2, square of the correlation coefficient; inv, inverse of; Qwil, daily average discharge at the WIL gage, in cubic feet per second (ft^3/s); L = distance upstream of mouth, in river miles; Q, discharge; <, less than; -- no data]

Salinity (ppt)	Pass	Predictive equations	Adjusted R^2	Standard error (miles)	P-values			Observa-tions	Range of valid flows (ft^3/s)
					Intercept	invQwil	Qwil		
0.5	Wadley	L = -0.0932 + 23,263.150 inv(Qwil)	0.501	1.064	0.851	<0.001	--	35	5,000 < Q < 22,300
	Alligator	L = -0.166 + 23,091.685 inv(Qwil)	.514	1.108	.718	< .001	--	37	5,000 < Q < 22,300
	East	L = 0.477 + 21,648.379 inv(Qwil)	.536	.966	.257	< .001	--	35	5,000 < Q < 22,600
2	Wadley	L = -0.0946 + 18,194.593 inv(Qwil)	.573	.847	.839	< .001	--	26	4,300 < Q < 22,300
	Alligator	L = -0.241 + 18,902.498 inv(Qwil)	.597	.829	.591	< .001	--	27	4,300 < Q < 22,300
	East	L = -0.976 + 23,269.530 inv(Qwil)	.561	.908	.112	< .001	--	28	4,300 < Q < 14,600
5	Wadley	L = -0.112 + 12,620.466 inv(Qwil)	.585	.692	.772	< .001	--	15	3,520 < Q < 18,600
	Alligator	L = -0.0191 + 11,611.399 inv(Qwil)	.606	.571	.971	.005	--	10	3,520 < Q < 15,300
	East	Poor regressions	--	--	--	--	--	--	--
10	Wadley	L = 3.620 - 0.000344 (Qwil)	.705	.531	< .001	--	0.006	8	3,520 < Q < 11,200
	Alligator	L = 4.365 - 0.000470 (Qwil)	.415	.644	.027	--	.1	6	4,640 < Q < 18,000
	East	Poor regressions	--	--	--	--	--	--	--

Table 9. Relation of daily maximum extent of bottom isohaline location to daily mean discharge at the long-term WIL (02323500) gage, referenced in river miles for longitudinal profiling data, lower Suwannee River Basin, Florida

[ppt, parts per thousand; adjusted R^2, square of the correlation coefficient; inv, inverse of; Qwil, daily average discharge at the WIL gage, in cubic feet per second (ft^3/s); L = distance upstream of mouth, in river miles; Q, discharge; <, less than; -- no data]

Salinity (ppt)	Pass	Predictive equations	Adjusted R^2	Standard error (miles)	P-values		Observa-tions	Range of valid flows (ft^3/s)
					Intercept	invQwil		
0.5	Wadley	L = -0.283 + 26,321.712 inv(Qwil)	0.455	1.219	0.685	<0.001	28	5,080 < Q < 22,300
	Alligator	L = -0.183 + 26,944.905 inv(Qwil)	.649	.937	.689	< .001	29	5,080 < Q < 22,300
	East	L = 0.523 + 22,482.189 inv(Qwil)	.502	1.034	.337	< .001	28	5,080 < Q < 22,600
2	Wadley	L = 0.0544 + 19,017.355 inv(Qwil)	.638	.783	.918	< .001	17	4,300 < Q < 16,500
	Alligator	L = 0.352 + 17,385.884 inv(Qwil)	.492	.860	.649	.003	14	4,300 < Q < 16,500
	East	L = -0.0752 + 20,834.282 inv(Qwil)	.403	1.213	.935	.005	16	4,300 < Q < 17,900
5	Wadley	L = -0.255 + 17,647.149 inv(Qwil)	.620	.488	.689	.007	9	5,250 < Q < 12,900
	Alligator	L = 0.520 + 13,570.930 inv(Qwil)	.750	.285	.339	.016	6	5,250 < Q < 9,270
	East	L = 0.536 + 12,667.758 inv(Qwil)	.442	.682	.278	.004	15	5,000 < Q < 20,300
10	Wadley	L = -0.523 + 15,066.774 inv(Qwil)	.847	.236	.290	.002	7	4,640 < Q < 8,430
	Alligator	L = -0.166 + 11,282.642 inv(Qwil)	.480	.653	.733	.005	13	4,640 < Q < 18,000
	East	Poor regression	--	--	--	--	--	--
15	Wadley	L = -0.869 + 11,938.871 inv(Qwil)	.309	.830	.426	.070	9	3,520 < Q < 8,430
	Alligator	L = 0.0814 + 8,207.097 inv(Qwil)	.319	.583	.917	.084	8	3,520 < Q < 9,270
	East	Poor regressions	--	--	--	--	--	--

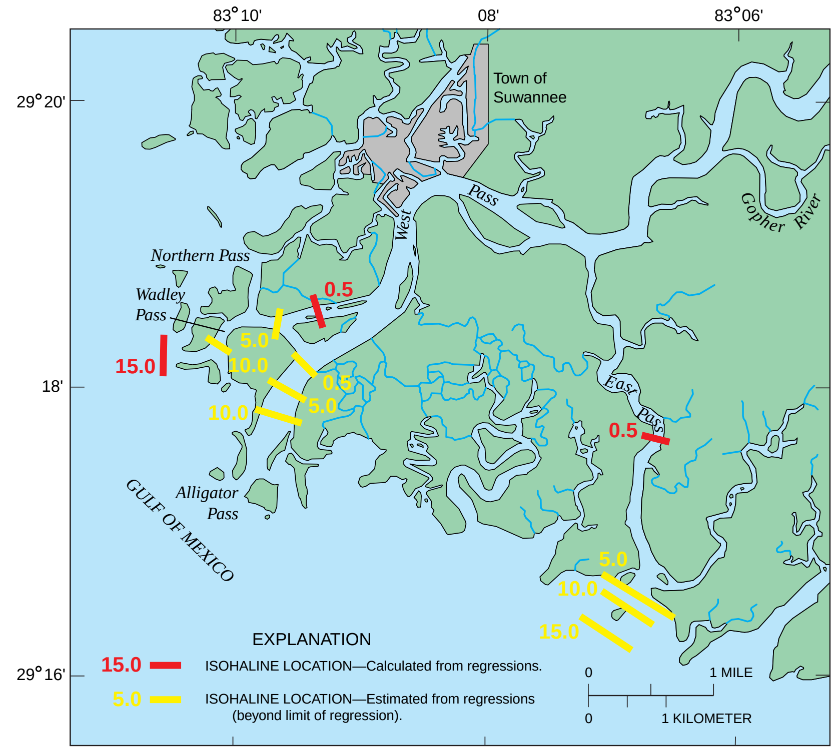


Figure 22. Vertically averaged salinity distribution in the upper Suwannee River Estuary near Suwannee, Florida, under high-flow conditions at the WIL (02323500) gage.

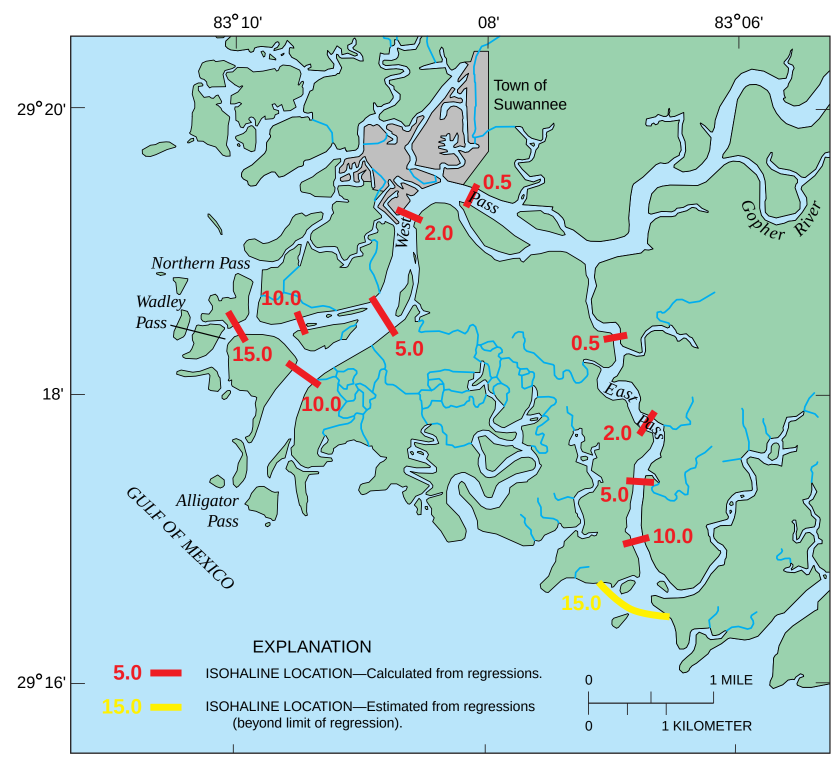


Figure 23. Vertically averaged salinity distribution in the upper Suwannee River Estuary near Suwannee, Florida, under medium-flow conditions at the WIL (02323500) gage.

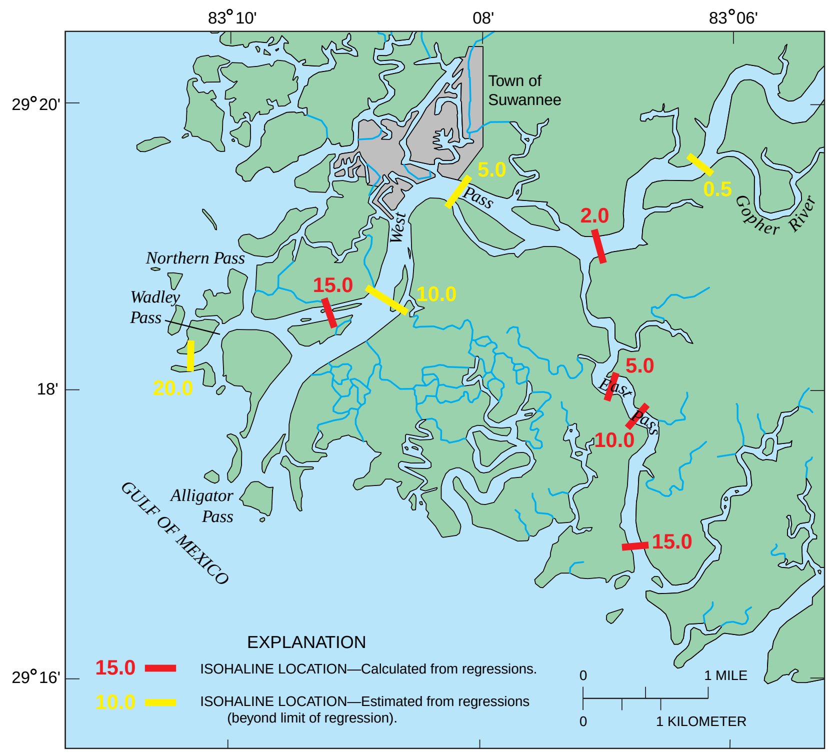


Figure 24. Vertically averaged salinity distribution in the upper Suwannee River Estuary near Suwannee, Florida, under low-flow conditions at the WIL (02323500) gage.

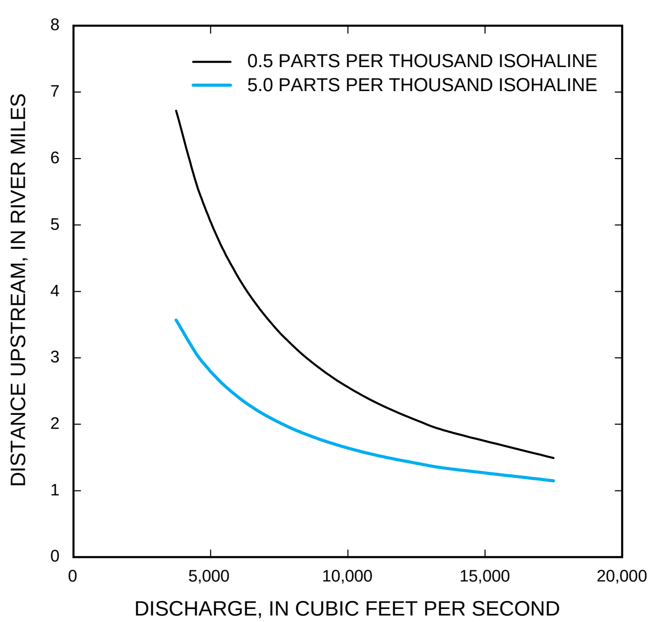


Figure 25. Estimated location of 0.5 and 5.0 ppt isohalines on the West Pass near Suwannee, Florida, as a function of daily mean discharge at the WIL (02323500) gage.

In addition, regressions were performed by using the natural log, inverse, square, and square root of these variables. Data on wind speed and direction were collected by NOAA at Cedar Key. The best correlations are presented in table 10.

Generally, the best correlation for upper estuary gages was a natural log relation of salinity as a function of stage, discharge, and wind, although all adjusted R^2 values were below the 0.7-test criterion. The best correlation for daily maximum salinity at the EM gage was a linear relation with daily mean discharge and daily mean stage at the WIL gage. There was a slight improvement in adjusted R^2 values by adding wind data to the regression models. The north component of the wind data had the greatest influence on salinity at the EM gage, whereas the east component affected salinities at the WM and EP gages, although wind components had a slight improvement on adjusted R^2 values.

Table 10. Relation of daily maximum salinity at the upper Suwannee River Estuary gage locations to daily mean discharge and daily mean stage at the long-term WIL (02323500) gage and to wind speed for estimating study period salinity distribution, lower Suwannee River Basin, Florida

[Wind-speed data is from National Oceanic and Atmospheric Administration gage at Cedar Key, Florida;
SALMAXEM = Daily maximum salinity at the EM (291652083064100) gage, in parts per thousand (ppt);
SALMAXEP = Daily maximum salinity at the EP (291841083070800) gage, in ppt;
SALMAXWP = Daily maximum salinity at the WP (291930083082800) gage, in ppt;
SALMAXWM = Daily maximum salinity at the WM (291842083085100) gage, in ppt;
QWIL = Daily average discharge at the WIL gage, in cubic feet per second (ft^3/s);
STGWIL = Daily average stage at the WIL gage, in feet (ft);
WSEMED = East component of daily median wind speed at Cedar Key, in knots;
WSNMED = North component of daily median wind speed at Cedar Key, in knots;
< = Less than;
-- = No data;
Adjusted R^2 = Square of the correlation coefficient;
ln = natural log]

Gage	Relation	Adjusted R^2	Standard error	P-value for independent variables		Bias correction factor	Obser-vations
EP[b]	ln(SALMAXEP) = 51.498 - 6.475 ln(QWIL) + 3.724 ln(STGWIL) - 0.0324 WSEMED	.632	1.072	< .001 < .001 < .001 .010	(intercept) (QWIL) (STGWIL) (WSEMED)	1.95	738
EM[a]	SALMAXEM = 17.490 - 0.00377 QWIL + 5.244 STGWIL + 0.0839 WSNMED	0.501	5.057 (1.621)	<0.001 < .001 < .001 .017	(intercept) (QWIL) (STGWIL) (WSNMED)	--	681
WP[c]	ln(SALMAXWP) = 50.954 - 6.249 ln(QWIL) + 3.106 ln(STGWIL)	.569	1.275	< .001 < .001 < .001	(intercept) (QWIL) (STGWIL)	2.24	556
WM[d]	ln(SALMAXWM) = 35.836 - 3.890 ln(QWIL) - 0.0603 WSEMED	.579	1.257	< .001 < .001 < .001	(intercept) (QWIL) (WSEMED)	2.26	723

[a]Valid for QWIL 3,740 to 17,900 ft^3/s, STGWIL 1.73 to 9.04 ft, WSNMED -9.78 to 7.99 knots.
[b]Valid for QWIL 3,740 to 17,900 ft^3/s, STGWIL 1.73 to 9.04 ft, WSEMED -9.78 to 29.47 knots.
[c]Valid for QWIL 3,740 to 16,500 ft^3/s, STGWIL 1.76 to 8.30 ft.
[d]Valid for QWIL 3,740 to 17,900 ft^3/s, WSEMED -9.78 to 29.47 knots.

A correlation matrix was calculated for variables used in the regression analysis. Because discharge was computed from stage, a high correlation between these values was expected. As expected, stage and discharge at WIL are correlated (appendix), with correlation coefficients of about 0.95. However, the addition of stage to the salinity prediction equations does improve the predictive power of the equations as compared to the prediction of salinity from discharge alone. Moreover, discharge is seen to be statistically significant in the prediction of salinity, as shown by P-values (table 10) and correlation values (appendix).

In the third part of the analysis, salinity data were computed from the regression models reported in table 10 and plotted with field-measured data (fig. 26). Computation of salinity from the regression models was fair. The criteria for rating regression models was based on adjusted R^2 and P-values. Over the range of flows, computed salinity concentrations were higher during low flows and lower during high flows. Salinity models computed for the EP, WP, and WM gages showed a natural log relation with the daily mean discharge at the WIL gage. Model-computed salinity values for the EM gage deviated the most from measured values. The model indicated a linear relation between salinity at the EM gage and the daily mean discharge at the WIL gage with an adjusted R^2 value of 0.50.

Only regressions with independent variable P-values of less than 0.1 were reported. Regressions with an adjusted R^2 value of 0.70 or greater were rarely obtained. It is probable that regressions were not as good as those found in similar studies because the Suwannee is a more complex system with channel bifurcation, storage in wetlands, less tidal penetration, and salinity source affected by river momentum.

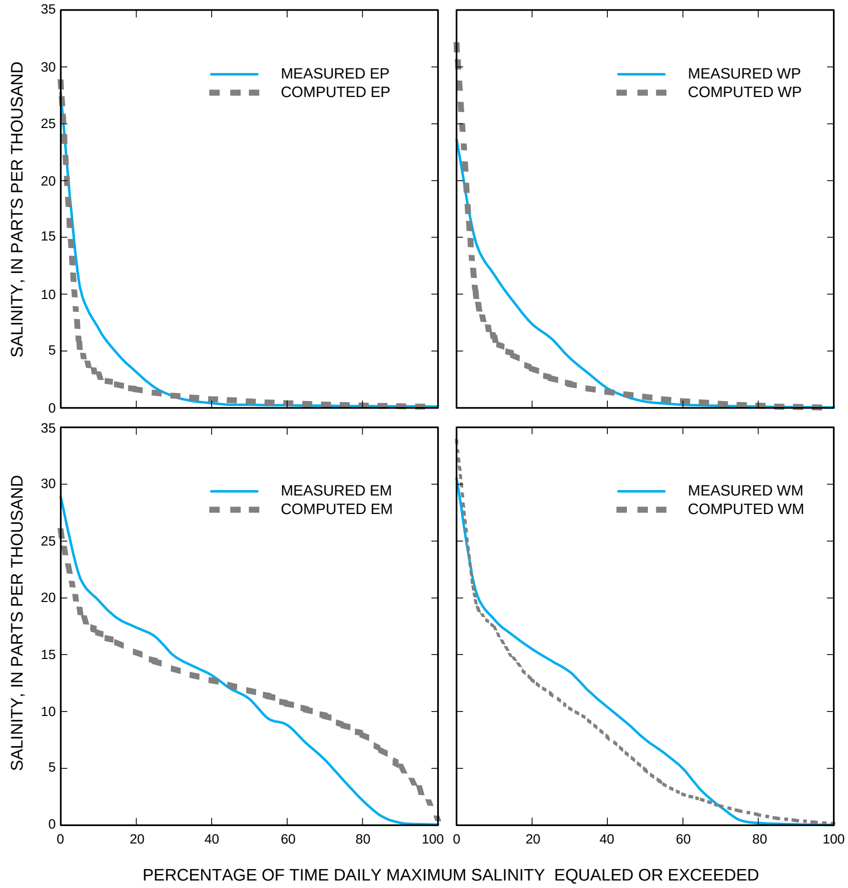


Figure 26. Comparison of measured and computed duration of daily maximum river salinity at the EP (291841083070800), EM (291652083064100), WP (291930083082800), and WM (291842083085100) gages from August 1995 to December 1997, Suwannee, Florida.

Other influencing factors include less consistent wind influences, more variability in Suwannee River salinities, dominance of tides as a driving force, and differences in flow distributions.

Historical Scenarios

The historical record from the WIL gage was used to develop a “synthetic” record of salinity in the upper estuary since 1930. Because wind data for this period of record were unavailable, wind was dropped from the relation, and regressions relating only to daily maximum salinity at each gage with daily mean discharge and daily mean stage at the WIL gage (table 11) were used to compute the synthetic record and to develop long-term salinity duration curves (fig. 27). At low salinities, synthetic salinity durations were similar at the EP and WP gages whereas salinity durations differed substantially at the EM and WM gages. Conversely, at high salinities, differences between synthetic durations were relatively small at the EM and WM gages compared to differences at the EP and WP gages.

A duration analysis for the 0.5 and 5.0 ppt isohaline locations on both East Pass and West Pass was conducted by using vertically averaged salinity regressions (table 7). Based on figure 28, the 50-percent duration of the 0.5 ppt isohaline was located at river mile 4.0 that was about 1.7 mi upstream from the 5.0 ppt isohaline.

Withdrawal Scenarios

Two withdrawal scenarios were computed by utilizing the regression models that estimated isohaline locations (table 7) and daily maximum salinity at each gage with a daily mean discharge at the WIL gage (table 12). The first scenario was a 1,000 ft^3/s withdrawal near the WIL gage. With a 1,000 ft^3/s decrease in daily discharge, the 50-percent duration of the saltwater/freshwater interface advanced upstream 0.77 mi on West Pass and 0.73 mi on East Pass.

Table 11. Relation of daily maximum salinity at the upper Suwannee River Estuary gage locations to daily mean discharge and daily mean stage at the long-term WIL (02323500) gage for estimating historical salinity distribution, lower Suwannee River Basin, Florida

[SALMAXEM = Daily maximum salinity at the EM (291652083064100) gage, in parts per thousand (ppt);
SALMAXEP = Daily maximum salinity at the EP (291841083070800) gage, in ppt;
SALMAXWP = Daily maximum salinity at the WP (291930083082800) gage, in ppt;
SALMAXWM = Daily maximum salinity at the WM (291842083085100) gage, in ppt;
QWIL = Daily average discharge at the WIL gage, in cubic feet per second (ft^3/s);
STGWIL = Daily average stage at the WIL gage, in feet (ft);
< = Less than;
-- = No data;
Adjusted R^2 = Square of the correlation coefficient;
ln = natural log]

Gage	Relation	Adjusted R^2	Standard error	P-value for independent variables		Bias correction factor	Obser-vations
EP[b]	ln(SALMAXEP) = 52.494 - 6.619 ln(QWIL) + 3.924 ln(STGWIL)	.630	1.076	< .001 < .001 < .001	(intercept) (QWIL) (STGWIL)	1.95	738
EM[a]	SALMAXEM = 17.581 - .00377 QWIL + 5.236 STGWIL	0.497	5.075 (1.624)	<0.001 < .001 < .001	(intercept) (QWIL) (STGWIL)	--	681
WP[c]	ln(SALMAXWP) = 50.954 - 6.249 ln(QWIL) + 3.106 ln(STGWIL)	.569	1.275	< .001 < .001 < .001	(intercept) (QWIL) (STGWIL)	2.24	556
WM[d]	ln(SALMAXWM) = 39.021 - 4.348 ln(QWIL) + 0.620 ln(STGWIL)	.570	1.270	< .001 < .001 .072	(intercept) (QWIL) (STGWIL)	2.25	723

[a]Valid for QWIL 3,740 to 17,900 ft^3/s, STGWIL 1.73 to 9.04 ft.
[b]Valid for QWIL 3,740 to 17,900 ft^3/s, STGWIL 1.73 to 9.04 ft.
[c]Valid for QWIL 3,740 to 16,500 ft^3/s, STGWIL 1.76 to 8.30 ft.
[d]Valid for QWIL 3,740 to 17,900 ft^3/s, STGWIL 1.73 to 9.04 ft.

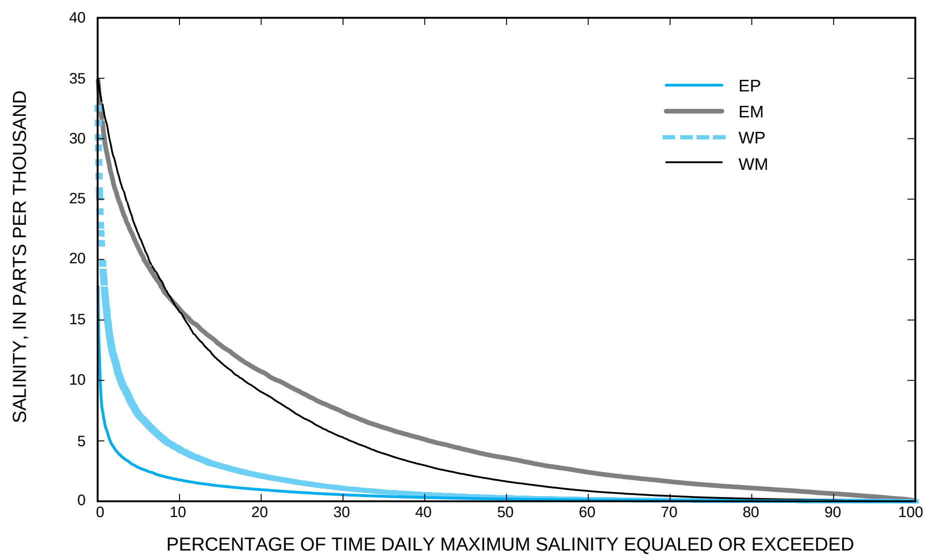


Figure 27. Predicted daily maximum salinity duration at the EP (291841083070800), EM (291652083064100), WP (291930083082800), and WM (291842083085100) gages near Suwannee, Florida, for the period of record at the WIL (02323500) gage.

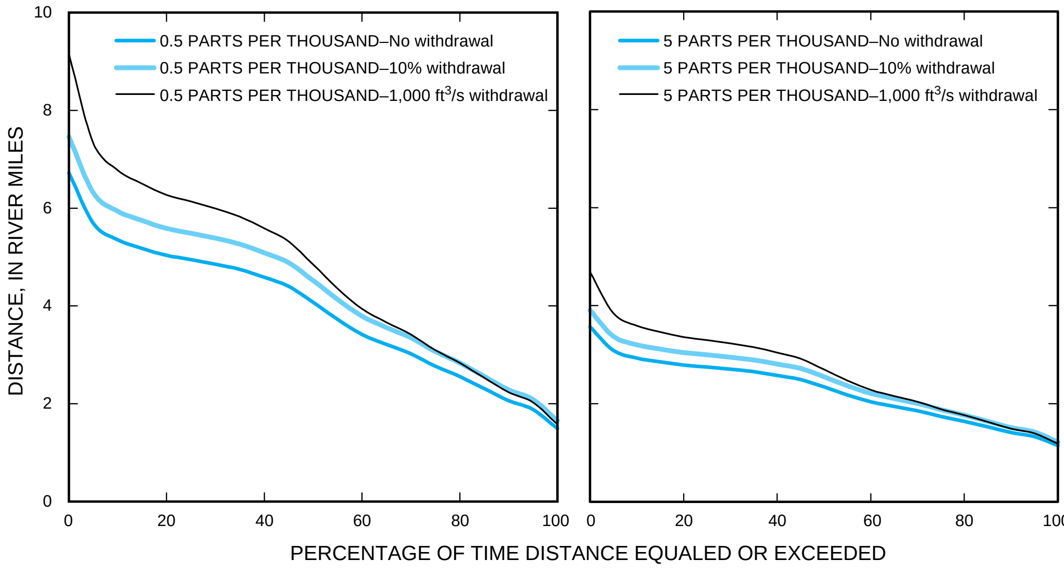


Figure 28. Results of various withdrawal scenarios on the computed duration of 0.5 and 5.0 ppt isohaline location at or upstream from particular river miles, on West Pass near Suwannee, Florida, for the study period.

Table 12. Relation of daily maximum salinity at the upper Suwannee River Estuary gage locations to daily mean discharge at the long-term WIL (02323500) gage for estimating the effect of withdrawal scenarios on salinity distributions, lower Suwannee River Basin, Florida

[SALMAXEM = Daily maximum salinity at the EM (291652083064100) gage, in parts per thousand (ppt);
SALMAXEP = Daily maximum salinity at the EP (291841083070800) gage, in ppt;
SALMAXWP = Daily maximum salinity at the WP (291930083082800) gage, in ppt;
SALMAXWM = Daily maximum salinity at the WM (291842083085100) gage, in ppt;
QWIL = Daily average discharge at the WIL gage, in cubic feet per second (ft^3/s);
< = Less than;
-- = No data;
Adjusted R^2 = Square of the correlation coefficient;
ln = natural log]

Gage	Relation	Adjusted R^2	Standard error	P-value for independent variables		Bias correction factor	Obser-vations
EP[b]	ln(SALMAXEP) = 30.269 - 3.491 ln(QWIL)	.545	1.194	< .001 < .001	(intercept) (QWIL)	2.05	738
EM[a]	SALMAXEM = 21.819 - 0.00138 QWIL	0.395	5.569 (1.717)	<0.001 < .001	(intercept) (QWIL)	--	681
WP[c]	ln(SALMAXWP) = 35.296 - 3.988 ln(QWIL)	.528	1.333	< .001 < .001	(intercept) (QWIL)	2.22	556
WM[d]	ln(SALMAXWM) = 35.496 - 3.852 ln(QWIL)	.570	1.272	< .001 < .001	(intercept) (QWIL)	2.19	723

[a]Valid for QWIL 3,740 to 17,900 ft^3/s.
[b]Valid for QWIL 3,740 to 17,900 ft^3/s.
[c]Valid for QWIL 3,740 to 16,500 ft^3/s.
[d]Valid for QWIL 3,740 to 17,900 ft^3/s

The decrease in daily discharge increased the frequency of daily maximum salinity intrusion at the WP and EP gages from 69 to 76 percent and from 58 to 63 percent, respectively. The 0.5 ppt isohaline occurred at river miles 1.36, 3.56, and 7.18 on West (Wadley) Pass during high-, medium-, and low-flow conditions. Salinity distributions under various flow conditions are presented in figures 29–31. The 0.5 ppt isohaline advanced 0.06 mi upstream during high-flow conditions for the 1,000 ft^3/s withdrawal scenario. The withdrawal results are most evident at low-flow conditions (fig. 31), advancing the interface 1.58 mi upstream during typical low-flow conditions (fig. 24).

The second withdrawal scenario was a 10-percent decrease in daily discharge near the WIL gage. The 50-percent duration of the saltwater/freshwater interface advanced 0.44 mi and 0.47 mi upstream on West Pass and East Pass, respectively. This withdrawal scenario increased the frequency of the daily maximum salinity intrusion at the WP and EP gages from 69 to 75 percent and from 58 to 63 percent, respectively. The 0.5 ppt isohaline occurred at river miles 1.43, 3.47, and 6.21 on the West (Wadley) Pass during high-, medium-, and low-flow conditions. Salinity distribution under various conditions are presented in figures 32–34. This withdrawal scenario did not affect the saltwater penetration under low-flow conditions as substantially as the 1,000 ft^3/s diversion shown in figure 31. For this withdrawal scenario, the 0.5 ppt isohaline advanced 0.61 and 0.14 mi upstream during typical low- and high-flow conditions, respectively. Under extreme low-flow conditions (3,500 ft^3/s), the regression models predicted that the interface would occur at river mile 7.2, upstream from the Gopher River confluence with the Suwannee River. Wind did not substantially influence model predictions.

The 10-percent and 1,000 ft^3/s withdrawal scenarios resulted in the 5.0 ppt isohaline migrating 0.28 and 0.73 miles upstream from the actual isohaline location for low-flow conditions of 4,500 ft^3/s, and 0.06 and 0.03 miles upstream from the actual isohaline location for high-flow conditions of 20,300 ft^3/s for West (Wadley) Pass.

The daily maximum salinity duration at the EP, EM, WP, and WM gages for the study period under 0, 10-percent, and 1,000 ft^3/s withdrawal conditions is presented in figure 35. The 1,000 ft^3/s diversion scenario had the most substantial effect at lower flows because a larger percentage of the flow was diverted.

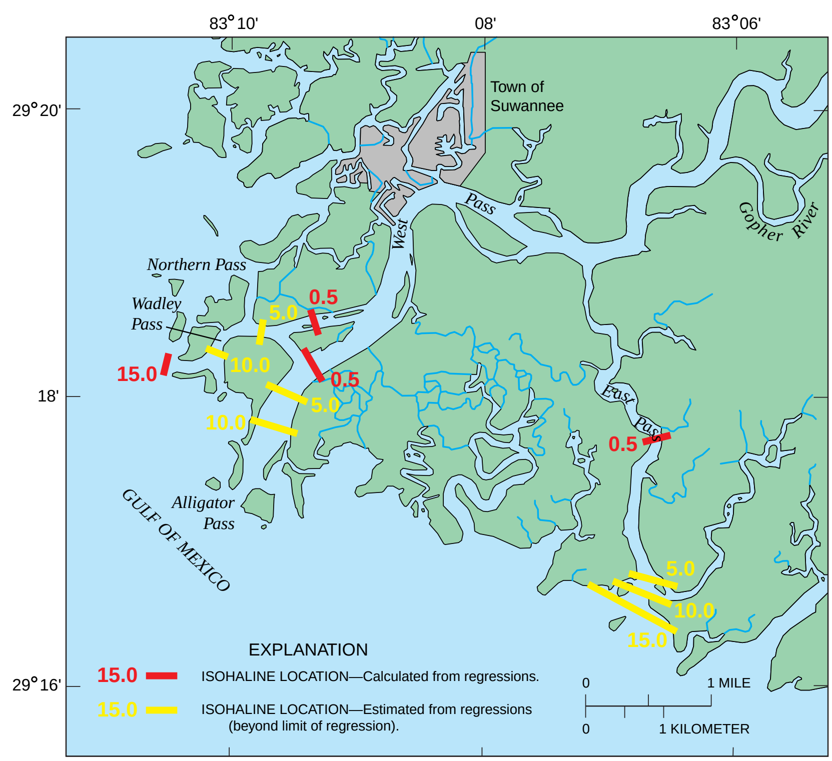


Figure 29. Vertically averaged salinity distributions in the upper Suwannee River Estuary near Suwannee, Florida, for a 1,000 cubic feet per second withdrawal scenario under high-flow conditions at the WIL (02323500) gage.

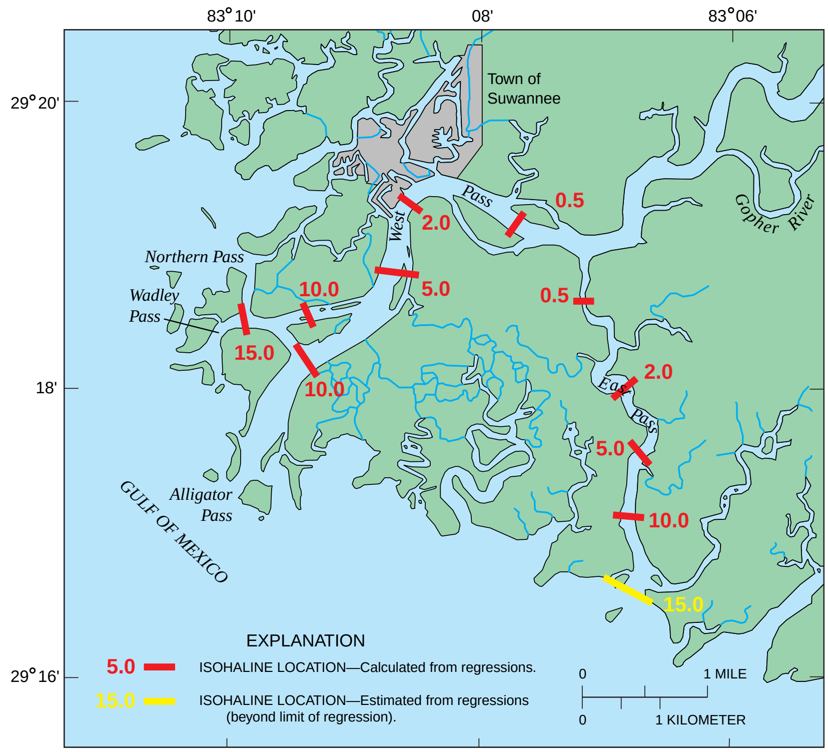


Figure 30. Vertically averaged salinity distributions in the upper Suwannee River Estuary near Suwannee, Florida, for a 1,000 cubic feet per second withdrawal scenario under medium-flow conditions at the WIL (02323500) gage.

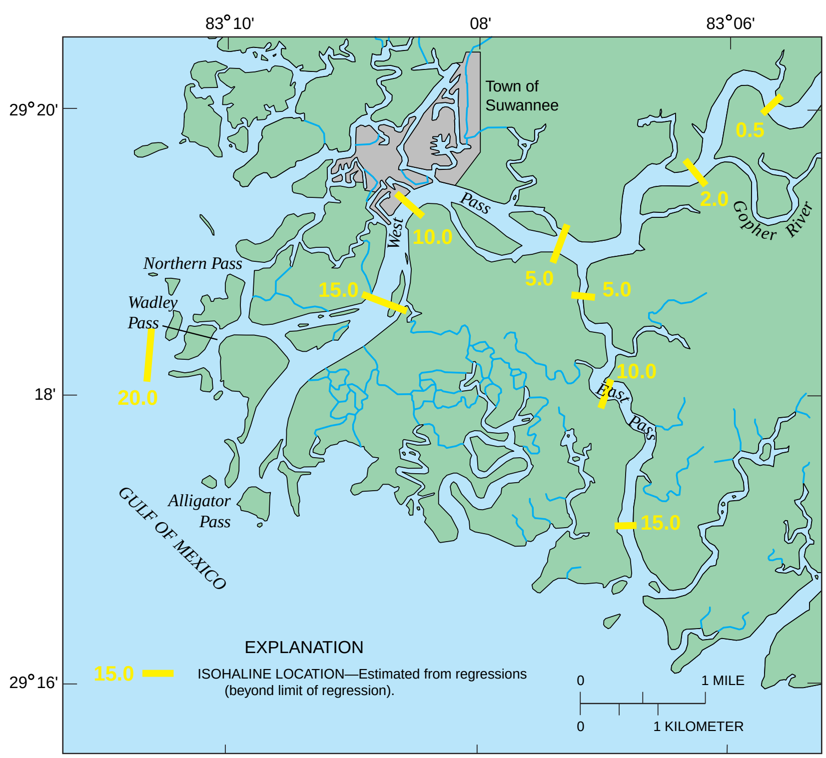


Figure 31. Vertically averaged salinity distributions in the upper Suwannee River Estuary near Suwannee, Florida, for a 1,000 cubic feet per second withdrawal scenario under low-flow conditions at the WIL (02323500) gage.

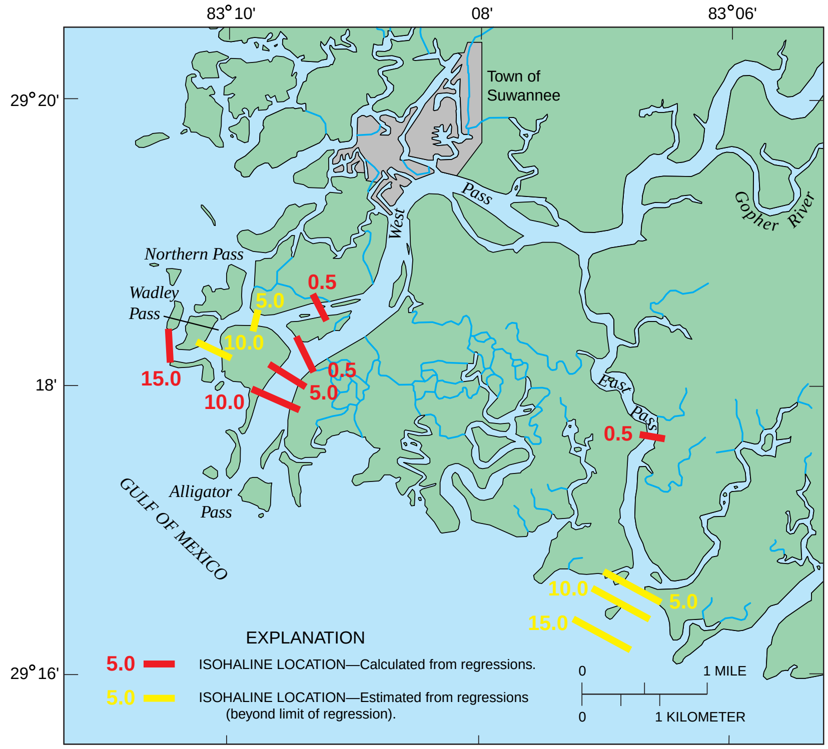


Figure 32. Vertically averaged salinity distributions in the upper Suwannee River Estuary near Suwannee, Florida, for a 10-percent withdrawal scenario under high-flow conditions at the WIL (02323500) gage.

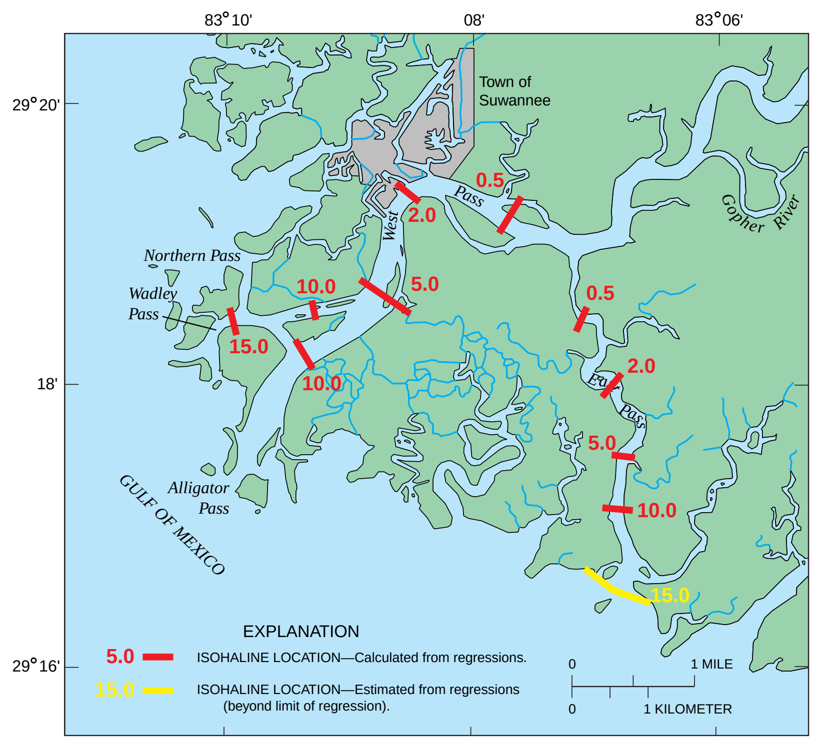


Figure 33. Vertically averaged salinity distributions in the upper Suwannee River Estuary near Suwannee, Florida, for a 10-percent withdrawal scenario under medium-flow conditions at the WIL (02323500) gage.

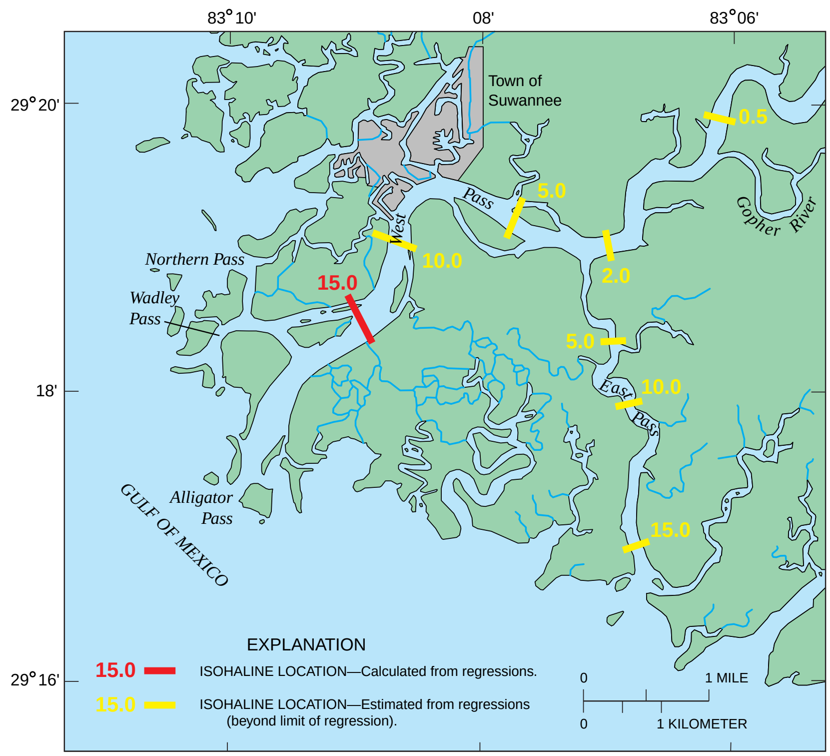


Figure 34. Vertically averaged salinity distributions in the upper Suwannee River Estuary near Suwannee, Florida, for a 10-percent withdrawal scenario under low-flow conditions at the WIL (02323500) gage.

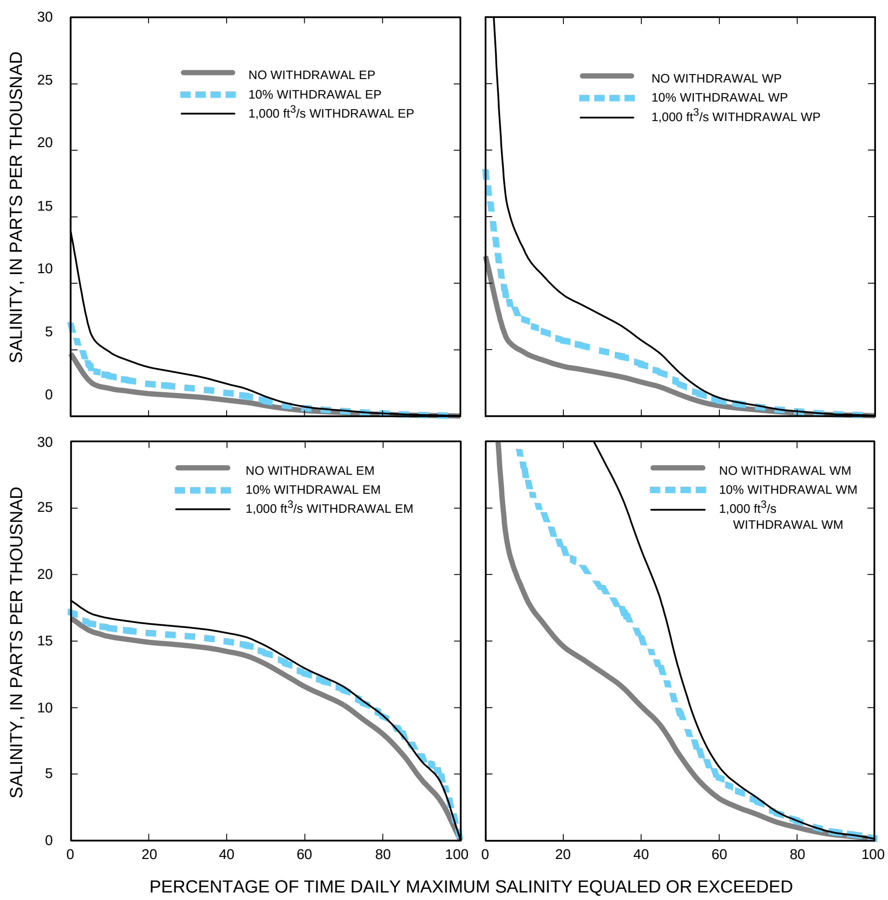


Figure 35. Comparison of the result of various withdrawal scenarios on the duration of daily maximum river salinity at the EP (291841083070800), EM (291652083064100), WP (291930083082800), and WM (291842083085100) gages near Suwannee, Florida, for the study period.

SUMMARY AND DISCUSSION

Continuous stage and salinity data were recorded at four gages in the upper Suwannee River Estuary from August 1995 to December 1997. Continuous velocity data also were recorded at two of these sites and discharge was then computed. Longitudinal salinity surveys and wind data were incorporated into this study to statistically describe the longitudinal extent of the saltwater/freshwater interface and the distribution of salinity.

Monthly mean discharge at the WIL gage for the study period was compared to the maximum, minimum, and average monthly mean discharges at the WIL gage for water years 1931–97. Flows during most of the study period were lower than normal. Discharge at the WIL gage averaged 4,000 ft^3/s lower than the long-term mean from June through September 1996. Higher than average monthly mean discharge, which was measured at the WIL gage during November and December 1997, was attributed to El Niño.

A duration analysis indicated that the maximum daily upstream extent of the saltwater/freshwater interface (equivalent to 0.5 parts per thousand (ppt) isohaline) was at or slightly upstream from river mile 4.0 on West Pass for 50 percent of the study period. The interface was at or upstream from all continuous salinity gages at least 40 percent of the time and downstream from all continuous salinity gages 11 percent of the time. The maximum salinity concentrations observed at the EP and WM gages were 28.20 and 31.00 ppt, respectively. The 50-percent duration for the four gages ranged from 0.22 (EP) to 11.50 (EM) ppt. Median daily fluctuations ranged from 11.31 ppt (EM) near the river mouth to 0.12 ppt (EP) for the most upstream gage.

Multiple linear-regression analysis was utilized to determine the location of the isohaline of 0.5, 2, 5, 10, 15, and 20 ppt as a result of various river flows and stage recorded at the WIL gage. Regression results were evaluated, based on adjusted R^2 and P-values. A value greater than 0.70 for adjusted R^2 and P-values less than 0.1 were considered satisfactory. Most of the adjusted R^2 values were below satisfactory limits. The river-mile location of the saltwater/freshwater interface was inversely proportional to the daily mean discharge at the WIL gage.

The best correlations of maximum daily salinity concentrations at the continuous recording gages in the upper estuary were in relation to daily mean discharge and daily mean stage at the WIL gage. The overall relation was a natural log-log relation of salinity with the daily mean discharge and daily mean stage at the WIL gage.

A synthetic record of salinity distribution was developed from these regression models and compared to field-measured salinity distribution. Two withdrawal scenarios, a 10-percent diversion and a 1,000 ft^3/s diversion were evaluated under high-, medium-, and low-flow conditions. A 1,000 ft^3/s daily withdrawal scenario for the study period showed the computed 50-percent duration of the saltwater/freshwater interface advanced upstream 0.77 mi on West Pass and increased the frequency of daily salinity intrusion from 69 to 76 percent at the WP gage. The location of the salinity front was more sensitive to flow diversions at lower discharges. Under extreme low-flow conditions (3,500 ft^3/s), the regression models predicted that the interface would occur at river mile 7.2, upstream from the Gopher River confluence with the Suwannee River. Wind did not have a substantial influence on model predictions.

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Appendix

Appendix. Correlation matrix of variables used in the regression analysis of daily maximum salinity at upper Suwannee River Estuary gage locations

[Wind speed data is from National Oceanic and Atmospheric Administration gage at Cedar Key, Florida;
SALMAXEM = Daily maximum salinity at the EM gage, in parts per thousand (ppt);
SALMAXEP = Daily maximum salinity at the EP gage, in ppt;
SALMAXWP = Daily maximum salinity at the WP gage, in ppt;
SALMAXWM = Daily maximum salinity at the WM gage, in ppt;
QWIL = Daily average discharge at the WIL gage, in cubic feet per second (ft^3/s);
STGWIL = Daily average stage at the WIL gage, in feet (ft);
WSEMED = East component of daily median wind speed at Cedar Key, in knots;
WSNMED = North component of daily median wind speed at Cedar Key, in knots]

	SALMAXEM	STGWIL[a]	QWIL[a]	WSEMED[a]	WSNMED[a]
SALMAXEM	1				
STGWIL	-0.511903224	1			
QWIL	-0.628806219	0.958967733	1		
WSEMED	-0.054569701	-0.123772783	-0.050028412	1	
WSNMED	0.092993052	-0.048414948	-0.048285332	-0.171460778	1
	SALMAXWM	**STGWIL[a]**	**QWIL[a]**	**WSEMED[a]**	**WSNMED[a]**
SALMAXWM	1				
STGWIL	-0.596069268	1			
QWIL	-0.694479383	0.956568647	1		
WSEMED	-0.020139959	-0.14221242	-0.065424901	1	
WSNMED	0.060414205	-0.05096906	-0.046669728	-0.145028696	1
	SALMAXEP	**STGWIL[a]**	**QWIL[a]**	**WSEMED[a]**	**WSNMED[a]**
SALMAXEP	1				
STGWIL	-0.289410919	1			
QWIL	-0.426562108	0.958143453	1		
WSEMED	-0.082071497	-0.123443447	-0.05034329	1	
WSNMED	0.047458031	-0.052720478	-0.045137697	-0.125226612	1
	SALMAXWP	**STGWIL[a]**	**QWIL[a]**	**WSEMED[a]**	**WSNMED[a]**
SALMAXWP	1				
STGWIL	-0.388257199	1			
QWIL	-0.531495224	0.948382337	1		
WSEMED	-0.092559698	-0.132282226	-0.053279444	1	
WSNMED	0.090165701	-0.02615223	-0.021540429	-0.179139707	1

[a]Variation in correlation coefficients is due to differences in number of observations.

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