Freshwater Flow from Estuarine Creeks into Northeastern Florida Bay

U.S. Geological Survey
Water-Resources Investigations Report 01-4164

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

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science for a changing world

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Abstract

Water-level, water-velocity, salinity, and temperature data were collected from selected estuarine creeks to compute freshwater flow into northeastern Florida Bay. Calibrated equations for determining mean velocity from acoustic velocity were obtained by developing velocity relations based on direct acoustic measurements, acoustic line velocity, and water level. Three formulas were necessary to describe flow patterns for all monitoring sites, with R^2 (coefficient of determination) values ranging from 0.957 to 0.995. Cross-sectional area calculations were limited to the main channel of the creeks and did not include potential areas of overbank flow. Techniques also were used to estimate discharge at noninstrumented sites by establishing discharge relations to nearby instrumented sites.

Results of the relation between flows at instrumented and noninstrumented sites varied with R^2 values ranging from 0.865 to 0.99. West Highway Creek was used to estimate noninstrumented sites in Long Sound, and Mud Creek was used to estimate East Creek in Little Madeira Bay. Mean monthly flows were used to describe flow patterns and to calculate net flow along the northeastern coastline. Data used in the study were collected from October 1995 through September 1999, which includes the El Niño event of 1998. During this period, about 80 percent of the freshwater flowing into the bay occurred during the wet season (May-October). The mean freshwater discharge for all five instrumented sites during the wet season from 1996 to 1999 is 106 cubic feet per second. The El Niño event caused a substantial increase (654 percent) in mean flows during the dry season (November-April) at the instrumented sites, ranging from 8.5 cubic feet per second in 1996-97 to 55.6 cubic feet per second in 1997-98.

Three main flow signatures were identified when comparing flows at all monitoring stations. The most significant was the magnitude of discharges at Trout Creek, which carries about 50 percent of the total measured freshwater entering northeastern Florida Bay. The mean monthly wet-season (May-October) flow at Trout Creek is about 340 cubic feet per second, compared to 55 cubic feet per second at West Highway Creek, 52 cubic feet per second at Taylor River, 49 cubic feet per second at Mud Creek, and 33 cubic feet per second at McCormick Creek. The other two flow signatures are the decline of freshwater discharge at McCormick Creek at the start of the El Niño event, and the absence of net-negative flows at West Highway Creek. The observed flow distribution within the study area, suggests that the overall flow direction of freshwater in the Everglades wetlands in the lower part of Taylor Slough may have a strong eastward flow component as water approaches the coastline. Data analysis also indicates that Trout Creek could potentially be used as a long-term monitoring station to estimate total freshwater flow into northeastern Florida Bay, provided that the remaining questions regarding flow patterns at McCormick Creek and the creeks in Long Sound are answered and that no major changes in flow characteristics occur in the future.

INTRODUCTION

Historical changes in water-management practices to accommodate a large and rapidly growing urban population along the Atlantic coast as well as intensive agricultural activities have resulted in a highly managed hydrologic system in southern Florida with canals, levees, and gated and pumping-control stations. These structures have altered the hydrology of the Everglades ecosystem, including Florida Bay. During the last decade, Florida Bay has experienced seagrass die-off and algal blooms. Both are possible signals of ecological deterioration that has been attributed to an increase in salinity and nutrient content of bay waters (Davis and Ogden, 1997).

With plans to restore water levels in the Everglades wetlands to more ìnaturalî conditions, changes also are expected in the amount and timing of freshwater exiting the mainland through the major creeks into northeastern Florida Bay. Flow through the estuarine creeks into northeastern Florida Bay is naturally controlled by the water-level conditions of the Everglades wetlands; regional wind patterns; and to a lesser extent, tides.

Restoration of the Florida Bay ecosystem requires an understanding of the linkage between the amount of freshwater flowing into the bay and the salinity and quality of the bay environment. Historically, there has been no accurate quantification of the amount of freshwater being discharged into Florida Bay from the mainland due to the difficulties of accurately gaging flows in shallow, bidirectional, and vertically stratified streams. In October 1995, the U.S. Geological Survey (USGS) began a study to gage several major creeks that discharge freshwater from the mainland into northeastern Florida Bay. The focus of the study was to provide flow, salinity, and water-level data for model development and calibration and also to provide data for other physical, biological and chemical studies being conducted in the area. The study was done as part of the USGS Place-Based Studies Program, which is an effort by the USGS along with various other Federal, State, and local agencies to provide earth science information needed to resolve land-use and water issues in southern Florida. Results from the study will provide scientists with essential information along the Everglades wetland/Florida Bay transition zone where data were not previously available.

Purpose and Scope

The purpose of this report is to describe the magnitude and distribution of flows at nine estuarine creeks within the mangrove zone along the northeastern coast of Florida Bay. Procedures used at five instrumented sites to calculate the cross-sectional area are presented in detail, and analyses made to establish the relations between acoustic line velocity and mean water velocity for the computation of discharge are presented. Estimation techniques also are presented for determining flows at four noninstrumented sites and for the selection of a base gage to indicate possible effects that changes in water-management practices may have on the freshwater flow into northeastern Florida Bay. General flow patterns are described by presenting seasonal variations in discharge and salinity during wet- and dry-season months and the spatial distribution of discharge from east to west along the coastline.

Description of Study Area

Florida Bay, home to several endangered species, such as the American crocodile and Florida manatee, is a valuable breeding ground for marine life and an important recreational and sport fishing area. The bay encompasses an area of about 850 mi^2 (square miles) with an average depth of less than 4 ft (feet). It is bordered by Everglades National Park to the north, the Florida Keys to the east and south, and is open to the Gulf of Mexico to the west (fig. 1).

The study area is located within the mangrove zone along the northeastern coastline of Florida Bay. This area is characterized by a natural ridge or embankment, which parallels the coastline from U.S. Highway 1 (US-1) to Flamingo (fig. 1). Relatively few creeks cut through the embankment, facilitating water exchange between Florida Bay and the Everglades wetlands. Localized rainfall, Taylor Slough, and the C-111 Canal are the main sources of freshwater into northeastern Florida Bay. Nine creeks along the southern Florida coastline were selected to study the exchange of water between the Everglades and Florida Bay. These creeks, from east to west are: East Highway Creek, West Highway Creek, Oregon Creek, Stillwater Creek, Trout Creek, Mud Creek, East Creek, Taylor River, and McCormick Creek (fig. 1 and table 1).

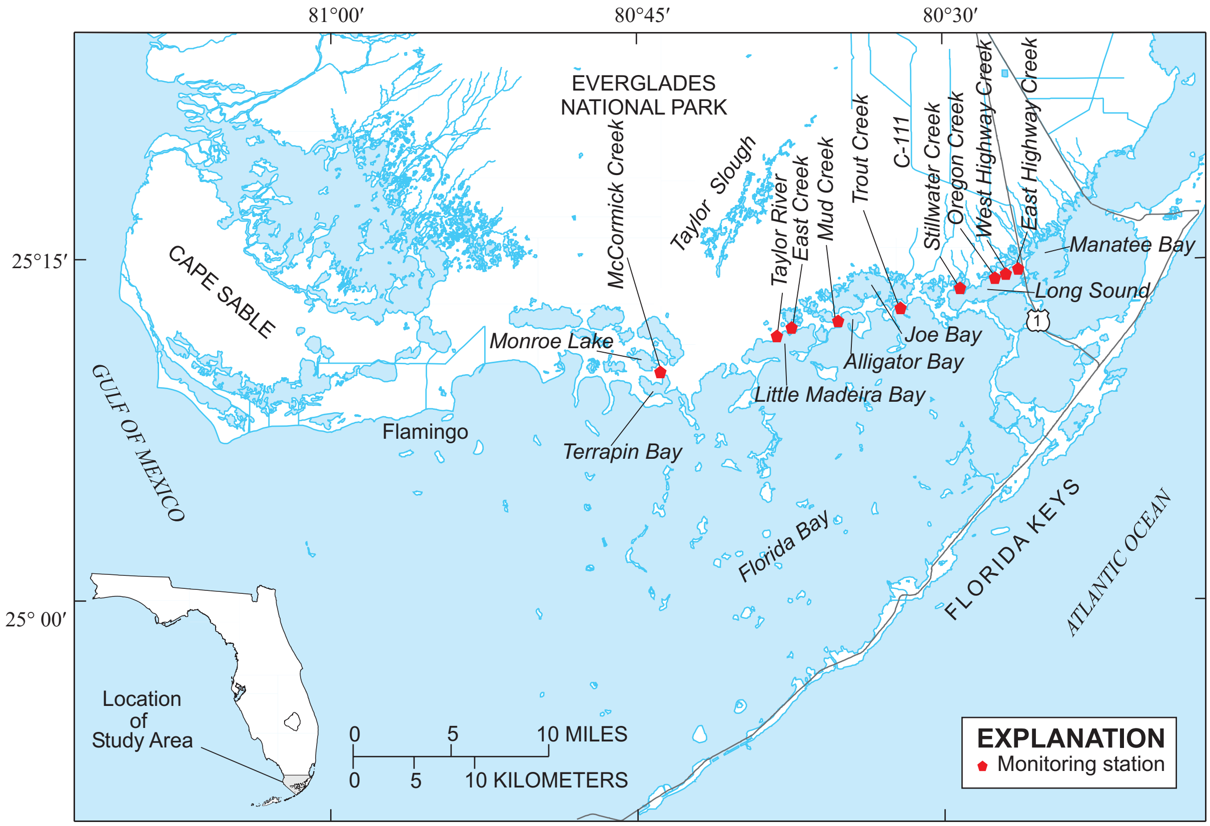

Figure 1. Location of Florida Bay monitoring stations. The instrumented and noninstrumented sites are identified in table 1.

Table 1. Description of Florida Bay monitoring stations

[Horizontal coordinate information referenced to North American Vertical Datum of 1988]

Station name	Latitude	Longitude	Type of site
East Highway Creek	251440	802628	Noninstrumented
West Highway Creek	251433	802650	Instrumented
Oregon Creek	251422	802719	Noninstrumented
Stillwater Creek	251341	802912	Noninstrumented
Trout Creek	251253	803201	Instrumented
Mud Creek	251209	803501	Instrumented
East Creek	251153	803708	Noninstrumented
Taylor River	251127	803821	Instrumented
McCormick Creek	251003	804355	Instrumented

Figure 2. West Highway Creek monitoring station in Florida Bay.

East and West Highway Creeks are located along the northeastern edge of Long Sound and are hydraulically connected to C-111 Canal and Manatee Bay. East Highway Creek is about 0.2 mi (mile) west of US-1 (fig. 1) and is about 35 ft wide and 4.5 ft deep. West Highway Creek is about 0.4 mi west of US-1 (fig. 1) and is about 65 ft wide and 5 ft deep. A photograph of the West Highway Creek monitoring station is shown in figure 2.

Oregon and Stillwater Creeks are located along the northern shore of Long Sound. Both creeks are hydraulically connected to C-111 Canal, with Stillwater Creek also connected to Joe Bay. Oregon Creek is about 0.6 mi west of US-1 (fig. 1) and is about 18 ft wide and 4 ft deep. Stillwater Creek is about 1.5 mi west of US-1 (fig. 1) and is about 30 ft wide and 4 ft deep.

Trout Creek is located at the mouth of Joe Bay and is hydraulically connected to Taylor Slough, C-111 Canal, and Long Sound. The creek is about 7 mi west of US-1 (fig. 1) and is about 500 ft long, 110 ft wide, and 5 ft deep. Photographs of the Trout Creek monitoring station are shown in figure 3.

Mud Creek is located near the mouth of Alligator Bay and is hydraulically connected to Taylor Slough and Joe Bay. The creek is about 10 mi west of US-1 (fig. 1) and is about 40 ft wide and 5 ft deep. Photographs of the Mud Creek monitoring station are shown in figure 4.

East Creek is located in Little Madeira Bay and is hydraulically connected to Taylor Slough and Mud Creek through upstream ponds. The creek is about 14 mi west of US-1 (fig. 1) and is about 25 ft wide and 4 ft deep.

Taylor River is located in Little Madeira Bay and is hydraulically connected to Taylor Slough. The creek is about 15 mi west of US-1 (fig. 1) and is about 22 ft wide and 5 ft deep near its mouth. A photograph of the Taylor River monitoring station is shown in figure 5.

McCormick Creek is located about 20 mi west of US-1 and is hydraulically connected to Monroe Lake and Terrapin Bay (fig. 1). The creek also has a hydraulic connection to Seven Palm and Middle Lakes (near Monroe Lake but not shown in fig. 1) and to Taylor Slough. A photograph of the McCormick Creek monitoring station is shown in figure 6.

TROUT CREEK MONITORING STATION

LOOKING SOUTH INTO FLORIDA BAY

LOOKING NORTH INTO JOE BAY

Figure 3. Trout Creek monitoring station in Florida Bay.

MUD CREEK MONITORING STATION

LOOKING INTO ALLIGATOR BAY

Figure 4. Mud Creek monitoring station in Florida Bay.

Figure 5. Taylor River monitoring station in Florida Bay.

Figure 6. McCormick Creek monitoring station in Florida Bay.

Acknowledgments

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METHODS OF INVESTIGATION

This section presents the methods that were used in the study to describe the magnitude and distribution of flow at nine estuarine creeks along the northeastern coastline of Florida Bay. The first part is a discussion of the data collected in the field at both the instrumented and noninstrumented sites (table 1). The second part describes the procedures used for the calculation of a cross-sectional area at the monitoring stations.

Field Data Collection

At all instrumented sites (West Highway Creek, Trout Creek, Mud Creek, Taylor River, and McCormick Creek), data collection included continuous 15-minute interval measurements of water level, water velocity, salinity, and temperature and periodic measurements of discharge for acoustic line velocity calibrations. All raw data at the instrumented sites were recorded by an electronic data logger and transmitted every 4 hours by way of the Geostationary Operational Environmental Satellite (GOES) into the database of the USGS Miami Subdistrict office. Data collection at the noninstrumented sites (East Highway Creek, Oregon Creek, Stillwater Creek, and East Creek) was limited to periodic discharge and salinity measurements.

Acoustic Doppler Current Profilers (ADCPís) mounted on a boat were used to measure discharge at the Florida Bay monitoring stations. The ADCP uses the Doppler shift in returned acoustic signals reflected by particles suspended in the water to determine the velocity of moving water (RD Instruments, 1989). This instrument also has the capability to measure water depth and speed and direction of the boat based on acoustic reflections from the streambed. Discharge and flow direction are both calculated from information provided by the ADCP and computer software. The mean water velocity for the stream or creek section is calculated by dividing the total discharge (measured with the ADCP) by the cross-sectional area corresponding to the water level at the time of measurement. The cross-sectional area is computed by using the site-specific stage area ratings (described later). A photograph of a boat-mounted ADCP and its operation is shown in figure 7.

Water-level data were recorded to determine water depth and to calculate the stage-dependent cross-sectional area. Water-level data were collected with an incremental shaft encoder equipped with a pulley, stainless-steel tape, weight, and float inside an 8 in. (inch) polyvinyl chloride pipe stilling well. All water-level data were originally referenced to an arbitrary elevation and then corrected to the North American Vertical Datum of 1988 after global positioning system (GPS) surveys in 1997 by the USGS.

Acoustic velocity meter (AVM) systems, which have proven to be accurate and reliable instruments capable of measuring near-zero velocities in open channels (Laenen and Curtis, 1989), were used to measure continuous water velocity. These AVM systems measure the velocity of flowing water by means of an acoustic signal (transmitted by transducers) that travels faster when carried with the flow than against it. Water velocity measured using this technique is referred to as acoustic line velocity. Traveltimes are measured from transducers located at point *a* to *b* and at point *b* to *a* as shown in figure 8. The path traveled between transducers is called the ì acoustic path.î To obtain water velocity, the difference in traveltimes between transducers is calculated in conjunction with the acoustic path length and the angle of the path length with respect to flow.

Figure 7. Boat-mounted Acoustic Doppler Current Profiler for measuring discharge at the Trout Creek monitoring station. Doppler is shown in inset.

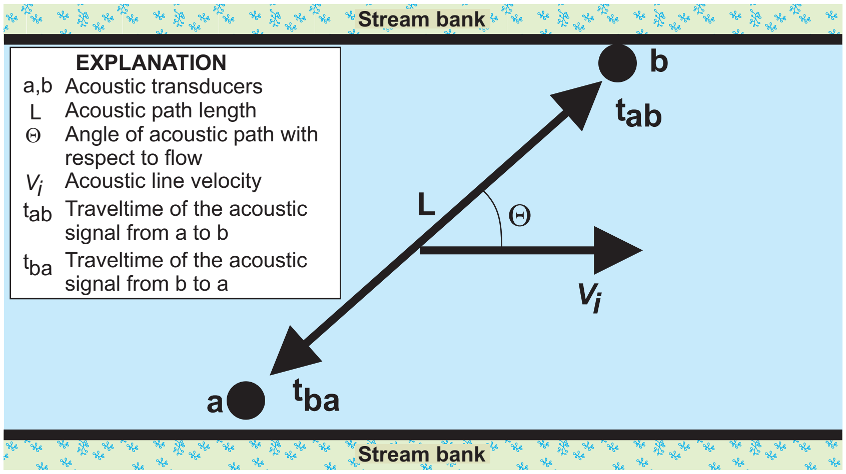

Figure 8. Velocity components used in the traveltime equation. Modified from Laenen and Curtis (1989).

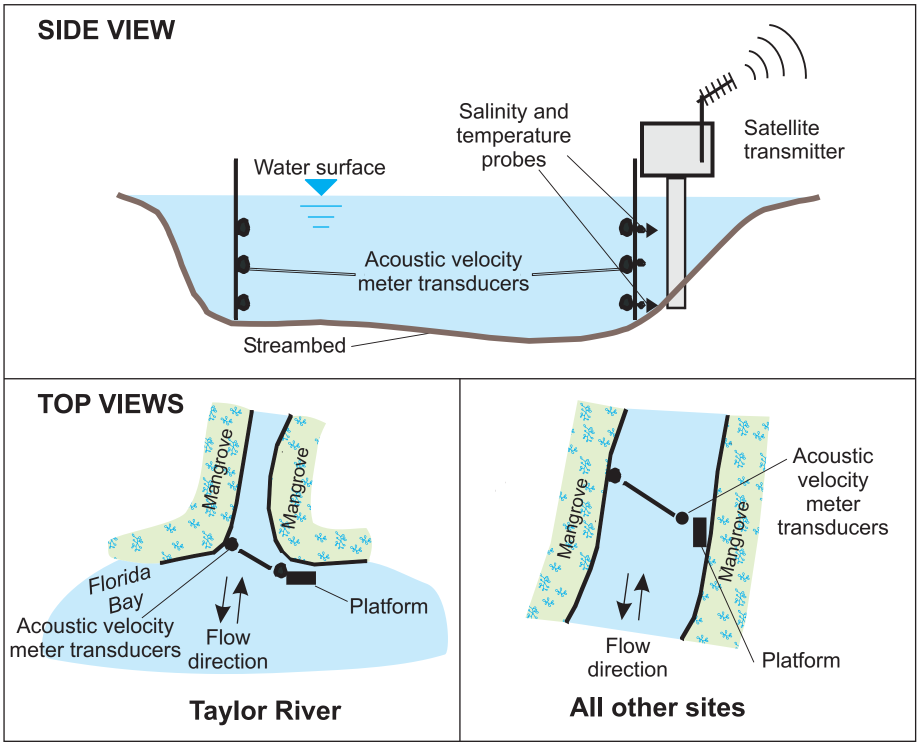

Figure 9. Acoustic instrument configurations for Florida Bay monitoring stations.

The general equation to calculate water velocity is defined by Laenen and Smith (1983) as follows:

$$V_l = \left(\frac{L}{2\cos\theta}\right)\left(\frac{1}{t_{ba}} \tilde{n} \frac{1}{t_{ab}}\right), \qquad (1)$$

where

V_l is the acoustic line velocity at the depth of the acoustic path,

L is the acoustic path length,

θ is the angle of the acoustic path with respect to the flow,

t_{ba} is the traveltime of the acoustic signal from point *b* to *a*, and

t_{ab} is the traveltime of the acoustic signal from point *a* to *b*.

The acoustic line velocity (V_l) measured by the AVM systems represents an averaged value across the stream from point *a* to *b* at a fixed depth and is considered to be an ì indexî of the mean water velocity. An index velocity is a measured velocity at the instrumented sites that can be used to compute the mean velocity. At West Highway Creek, Mud Creek, and McCormick Creek, acoustic line velocity was recorded at two depths (top and bottom); at Trout Creek and Taylor River, the acoustic line velocity was recorded at three depths (top, middle, and bottom). It was determined that all of the monitoring stations, except for Taylor River, required only one index velocity at a fixed depth to determine mean water velocity (appendix). Acoustic instrument setup configurations for the Florida Bay monitoring stations are shown in figure 9. A photograph of acoustic transducers being serviced at the West Highway Creek monitoring station is shown in figure 10.

Originally, salinity was measured at three depths (top, middle, and bottom of depth profile) for the Florida Bay monitoring stations to examine potential effects on the acoustic signals caused by salinity stratifications and to help qualify the presence of freshwater flow. The middle salinity probe was removed from McCormick Creek, Mud Creek, and West Highway Creek due to a low occurrence of salinity stratification at these sites. Temperature was measured to monitor possible vertical gradients that also could affect acoustic signals. A photograph of the salinity and temperature probes used at a Florida Bay monitoring station is shown in figure 11.

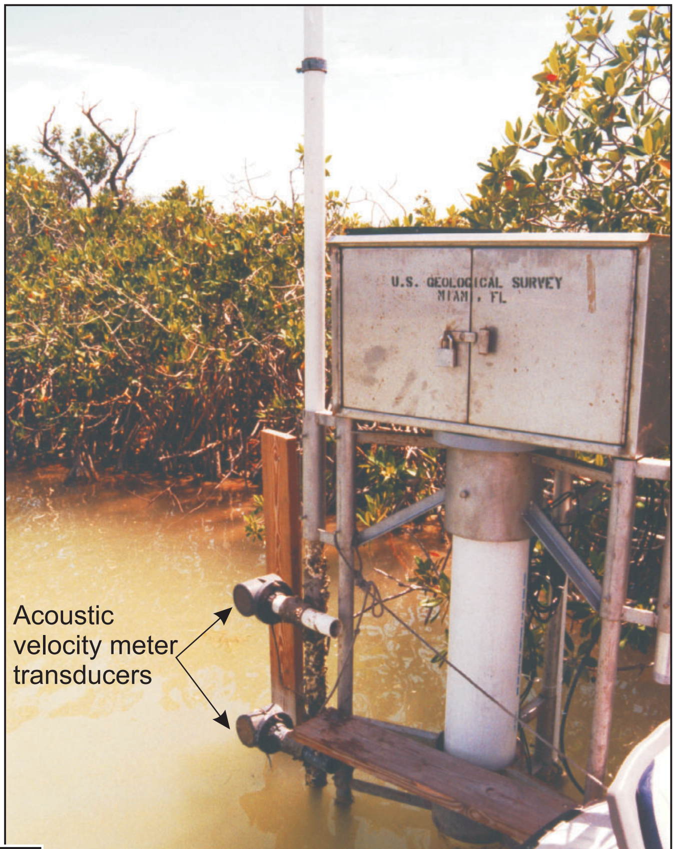

Figure 10. Acoustic transducers (above water level for servicing) at West Highway Creek monitoring station.

Figure 11. Two salinity/temperature probes used at a Florida Bay monitoring station.

Development of Cross-Sectional Area

The ADCP was used to make depth soundings at specific distances across the width of each creek along with simultaneous water-level readings at the time of measurement. The data were used to develop a relation between water level and total cross-sectional area for the individual sites. The Channel Geometry Analysis Program (CGAP) was used to compute the stage-area rating (Regan and Schaffranek, 1985).

Overbank flow may occur at extreme high-water conditions, extending the actual flow cross section a distance beyond the main channel of the stream. Based on field observations, overbank flow does not commonly occur; flow usually is confined to the creeks cutting through the embankment along the coastline of northeastern Florida Bay. In order to quantitatively assess the effect of overbank flow, accurate elevations on the embankment would be needed; however, accurate elevations currently do not exist. As a result and to maintain consistency and accuracy for calculated discharge values, a fictitious ì wallî was placed 5 ft from the bank edges as shown in figure 12. Thus, calculated discharge implies the use of areas within these ì walls,î and represents flow through the main channel. Overland sheetflow is considered a separate body of water with different velocity characteristics, and therefore, discharge estimations were not attempted for these areas. Accurate elevation data along the embankment would be needed to compare against water levels to verify that sheetflow is an insignificant contributor of freshwater to Florida Bay. Existing water levels, salinity data, and visual indicators at the Florida Bay monitoring stations indicate that the majority of freshwater flow is through the creeks and not over the embankment.

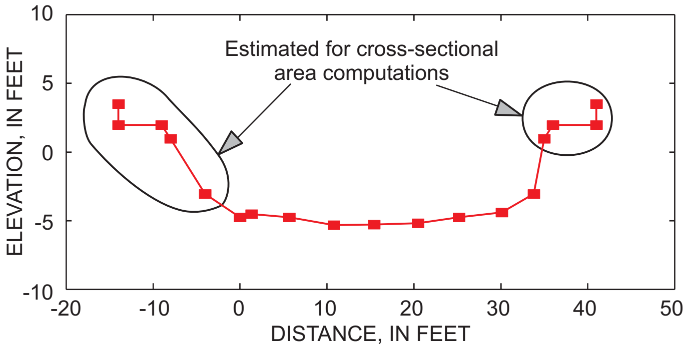

Figure 12. Cross-sectional area for the McCormick Creek monitoring station.

COMPUTING FRESHWATER FLOW FROM ESTUARINE CREEKS INTO FLORIDA BAY

As previously described, field data were collected and a stage-area rating was developed at nine monitoring stations to calculate freshwater flow from estuarine creeks into Florida Bay. Three case scenarios, based on a velocity estimation model, are presented to describe flows under varying conditions at the instrumented sites in Florida Bay (West Highway Creek, Trout Creek, Mud Creek, Taylor River, and McCormick Creek). Other methods were used to estimate flow at the noninstrumented sites in Florida Bay (East Highway Creek, Oregon Creek, Stillwater Creek, and East Creek), and the results are presented here. The subsequent sections present an analysis of seasonal flow patterns, the spatial distribution of freshwater flow and salinity distribution, discharge relations, and base-gage selection.

Velocity Estimation Model for Instrumented Sites

In order to develop a time-series record of mean water velocity for any stream using acoustic line velocity data, it is necessary to establish a relation between the recorded acoustic line velocities and directly measured mean water velocity. The relation existing between index and mean velocities can be affected by a number of physical factors that may need to be considered in the estimation model. As flow conditions change, it is impractical and usually unnecessary to account for all the physical factors affecting the velocity relation. At all monitoring stations in northeastern Florida Bay, the acoustic line velocity and water-level data were sufficient to describe the velocity relations, and no other parameters were necessary. A series of velocity measurements (back calculated from ADCP discharge measurements) made over the range of expected conditions for all significant variables was needed to define the effects of these variables on the velocity relation. The technique used to describe the velocity relation is a least squares regression model in the single or multiple variable form depending on the number of identified significant variables. The model uses the following equation form modified from Patino and Ockerman (1997):

$$V = \left[\sum_{i=1}^{n} V_i(X_i + Y_i H) \right] + C , \qquad (2)$$

where

V is the mean water velocity,

n is the total number of acoustic paths,

V_i is the acoustic line velocity; i represents the top (1), middle (2), or bottom path (3),

X_i is a regression coefficient,

Y_i is a regression coefficient associated with stage,

H is stage, and

C is the intercept or constant.

This model allows for the fact that expected changes in the mean water velocity, V, for a unit change in the acoustic line velocity, $V_{1\text{-}3}$, also can be a factor of stage. Three different cases (or forms) of this model were used to describe flow conditions at the study sites. These cases are described in detail in the subsequent sections.

Case 1

This form of the model is used to describe the simplest flow condition for which the acoustic line velocity is the only significant variable necessary to describe the mean velocity of the stream. For this case, equation 2 takes the following form:

$$V = V_i X_i + C . \qquad (3)$$

To solve equation 3, a linear regression analysis is performed using V_i (acoustic line velocity) as the independent variable, and V (mean measured velocity from ADCP discharge measurements) as the dependent variable. At the Florida Bay monitoring stations where equation 3 is used, the relation established between acoustic and mean velocities requires the use of only one of the measured acoustic line velocities; stage is not a factor; that is, the velocity profile does not change substantially with changing stage (eq. 3 has a constant slope). Equation 3 is used to describe flow conditions at McCormick Creek, Mud Creek, and Trout Creek. The data used for the analysis, rated velocity and discharge, and residual values of discharge are presented in the appendix. Residual values are the difference between measured and rated discharge.

Flow conditions at McCormick Creek are such that a relation was obtained between acoustic line and mean velocities for all measured flow conditions (fig. 13). Even though bidirectional flow can be present at this site from time to time, it does not occur frequently nor for extended periods of time. Bidirectional flow occurs mainly during times of shifting wind patterns. Computation of mean velocity and discharge was performed for the majority of record using the acoustic line velocity from the top AVM path (velocity no. 1). The equation for AVM velocity no. 1 is $V = 0.552\ V_i - 0.016$, with an R^2 (coefficient of determination) value of 0.977 and a standard error for the velocity estimate of 0.082 ft/s (foot per second).

Flow conditions at Mud Creek also resulted in a relation between acoustic line velocities and mean velocities (fig. 13). As with McCormick Creek, computation of mean velocity and discharge for Mud Creek was performed using the acoustic line velocity from the top AVM path (velocity no. 1). The equation for AVM velocity no. 1 is $V = 0.448\ V_i - 0.024$, with an R^2 value of 0.993 and a standard error for the velocity estimate of 0.031 ft/s.

Flow conditions at Trout Creek show a tight relation between acoustic line velocity and mean water velocity (fig. 13). Computation of mean velocity and discharge was performed using the acoustic line velocity from the middle AVM path (velocity no. 2). The equation for AVM velocity no. 2 is $V = 0.705\ V_2 - 0.031$, with an R^2 value of 0.995 and a standard error for the velocity estimate of 0.056 ft/s. The velocity relation for Trout Creek is shown in figure 13 (using velocity no. 2).

Case 2

Case 2 is used to describe velocities at sites that present different flow conditions for positive and negative flows. Because different spatial velocity variations were observed for positive and negative flows at West Highway Creek, it was necessary to use two different forms of the model – one for each flow direction. Positive flow is described by the same model form as case 1 (eq. 3); negative flow is described by a form of the model that allows for stage (water level) to be included as a secondary variable. For case 2, the equation takes the form:

$$V = V_i(X_i + Y_i H) + C . \qquad (4)$$

Equation 3 for positive flow is solved using the same independent and dependent variables as described in case 1. To solve equation 4, a multivariate regression analysis is performed using V_i and the product $V_i \times H$ as the independent variables, and V as the dependent variable. For this model form, the relation established between the index velocity and the mean velocity is stable, but not constant for all flow conditions because the slope of the line varies with changing water level. Case 2 represents a velocity relation for which every expected change in V for a unit change in V_i also is dependent on the stage.

Flow conditions at West Highway Creek resulted in a relation between acoustic line velocity and mean velocities, with the use of equation 3 for positive flow and equation 4 for negative flow. Computation of mean velocity and discharge was performed using only the top (velocity no. 1) acoustic velocity. The equation for velocity no. 1 in the positive direction is $V = 0.736\ V_1 - 0.013$, with an R^2 value of 0.962 and a standard error for the velocity estimate of 0.048 ft/s. For negative flow, the equation for velocity no. 1 is $V = V_1\,(-0.921 + 1.094H) - 0.041$, with an R^2 value of 0.957 and a standard error for the velocity estimate of 0.034 ft/s. A comparison of results obtained with and without the inclusion of water level as a secondary variable in the estimation model for velocities in the negative direction indicates that including the secondary variable substantially improves the R^2 value and standard error. The R^2 value increased from 0.759 to 0.957, and the standard error decreased from 0.077 to 0.034 ft/s at West Highway Creek.

The relation obtained between the mean measured velocity and estimated velocity for West Highway Creek is shown in figure 14 (using acoustic line velocity no. 1). Figure 14 is not a rating of computed velocity as a function of acoustic line velocity because the computed velocity is a function of gage height as well as acoustic line velocity. This plot shows actual measured mean velocities relative to computed

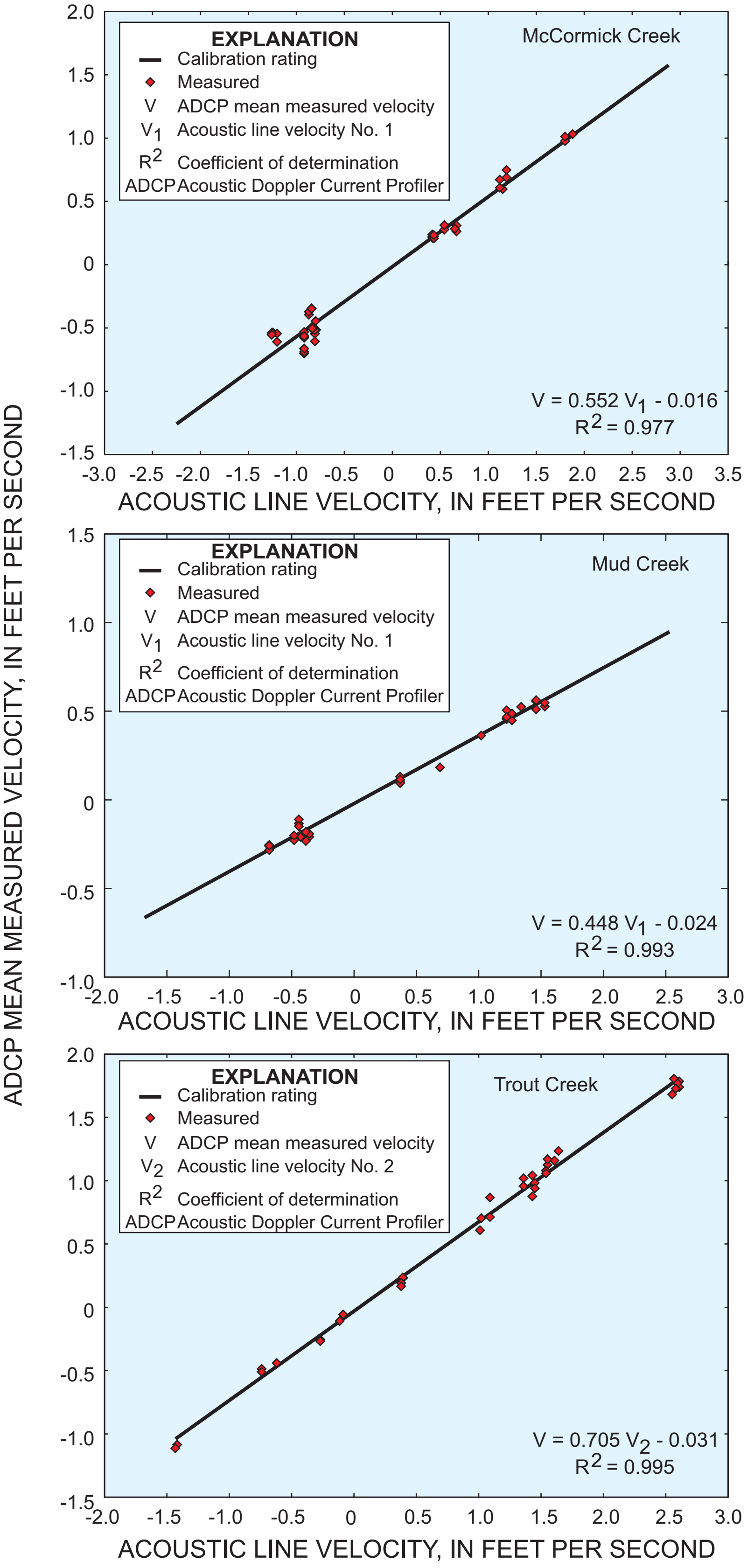

Figure 13. Velocity relation for the McCormick Creek, Mud Creek, and Trout Creek monitoring stations.

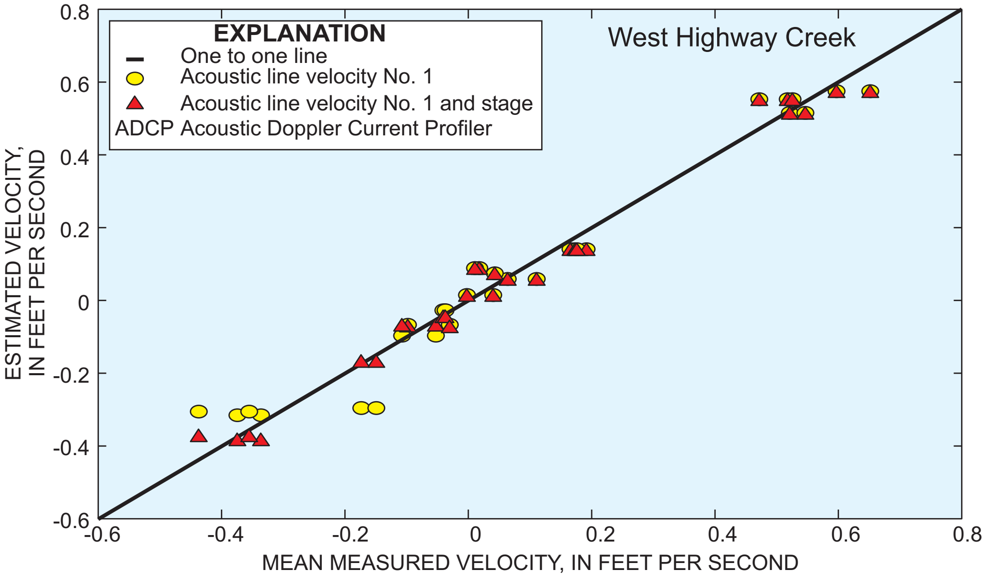

Figure 14. Mean measured to estimated velocity relation for the West Highway Creek monitoring station.

velocities in order to depict how the equation fits the field measurements. The data used for the rating analysis, rated velocity and discharge, and residual values of discharge are presented in the appendix.

Case 3

Case 3, used for Taylor River, describes the most complex form of the velocity estimation model as applied in the study. Due to the gage location at the mouth of Taylor River, changes in width and depth of flow, in combination with conditions caused by freshwater flowing out into more saline, denser water, can create very distinct vertical and/or horizontal circulation patterns. Circulation patterns were found by observing the velocity and salinity profile at Taylor River. A generalized sketch of a vertical circulation pattern in relation to depths of recorded velocities is shown in figure 15. The form of the model used assumes inclusion of multiple acoustic line velocities and the relation of each to stage, as necessary, to describe the mean velocity of the stream due to the complex flow patterns at the site. For this case, equation 2 takes the following form:

$$V = V_1(X_1 + Y_1H) + V_2(X_2 + Y_2H) + V_3(X_3 + Y_3H) + C, \quad (5)$$

where V_1 is the acoustic line velocity from the top path nearest to the water surface, V_2 is the acoustic line velocity from the middle path, V_3 is the acoustic line velocity from the bottom path nearest to the streambed, H is the stage, and $X_{i\text{-}3}$ and $Y_{i\text{-}3}$ are regression coefficients related to the acoustic path.

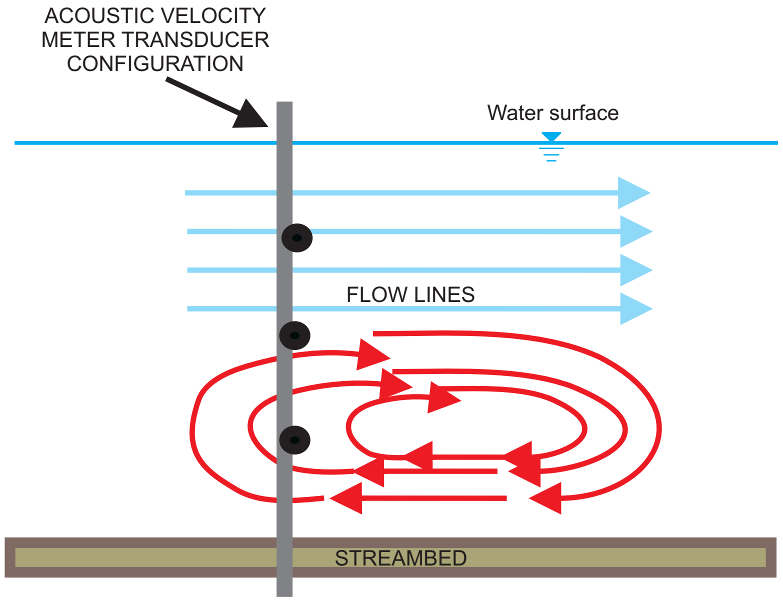

Figure 15. Complex flow characteristics with vertical circulation patterns at the Taylor River monitoring station.

To solve equation 5, it is necessary to perform a multivariate regression analysis using acoustic velocities V_1, V_2, and V_3 and the product of each velocity and stage V_1H, V_2H, and V_3H as the independent variables with the mean measured velocity, V, as the dependent variable. The relation established between the acoustic line velocities and the mean velocity is less stable for case 3 than for cases 1 and 2. Case 3 is used to describe a relation between V and V_i ($i = 1,2,3$), with similarities to the relation described for the negative portion of case 2. Furthermore, every expected change in V for a unit change in V_i for case 3 also depends on the stage, where the main difference is that all three acoustic line velocities are necessary to describe the system to the best accuracy.

Velocity patterns at the mouth of Taylor River present a circulation in the vertical plane; therefore, the estimation model needs to include all three acoustic line velocities as previously described. The vertical velocity profile at this site is constantly changing depending on the magnitude and direction of the flow, the salinity of bay waters, and the stage at Taylor River. These conditions at the mouth of Taylor River are characterized by localized bidirectional flow that exists for extended periods caused by friction created in the water column when outflowing freshwater rises above denser, saltier, more saline bay water. Velocity conditions, as shown in figure 15, describe those found at the mouth of the creek where the instruments were located. ADCP measurements used to calculate mean measured velocities were made about 40 to 50 ft upstream of the mouth where flow was uniform and unidirectional from top to bottom. A good relation was observed between the direction of V_1 (top velocity) and the direction of the net flow. Unlike the top velocity, V_2 and V_3 alternated between positive and negative values depending on the direction and magnitude of the flow and the water level in the bay. The velocity relation for the Taylor River monitoring station is described by $V = V_1\,(0.231 + 0.665H) + V_2\,(0.375 - 0.202H) + V_3\,(0.377 - 0.407H) + 0.161$, with an R^2 value of 0.964 and a standard error of 0.085 ft/s. The relation of estimated velocity to mean measured velocity (using velocity nos. 1, 2, and 3) is shown in figure 16. The graph in figure 16 is not a rating of computed velocity relative to acoustic line velocity because the computed velocity is a function of gage height and acoustic line velocity. This plot shows actual measured mean velocities relative to computed velocities and depicts how the equation fits the field measurements. Data used for the rating analysis, rated velocity and discharge, and residual values of discharge are presented in the appendix.

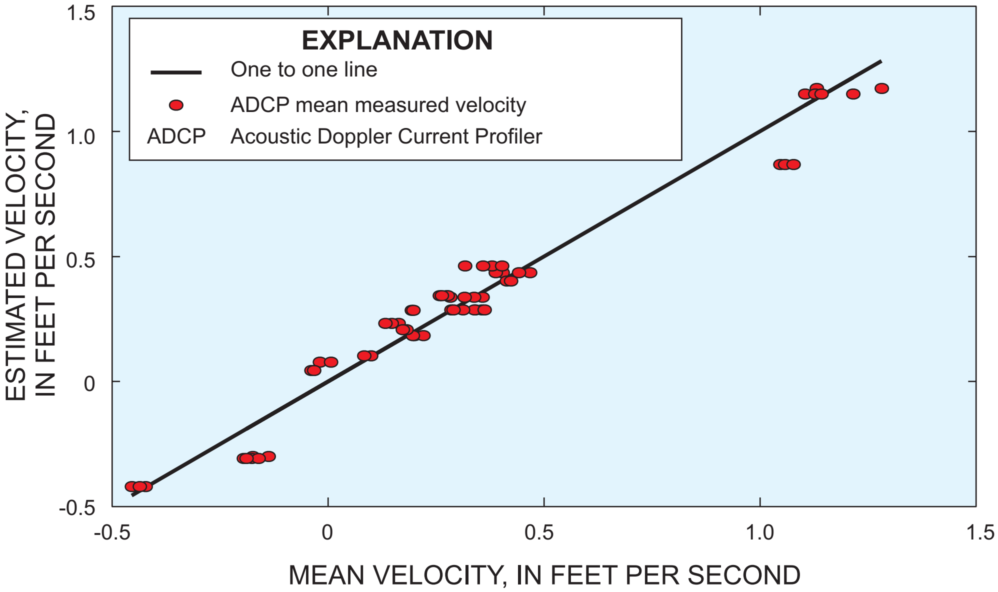

Figure 16. Mean measured to estimated velocity relation for the Taylor River monitoring station.

Table 2. Different forms of the velocity estimation model tested for the Taylor River monitoring station

Model form	Independent variable	Equation	Coefficient of determination (R^2)	Standard error (feet per second)
a	V_1	$V = 0.653\ V_1 + 0.087$	0.615	0.271
b	V_2	$V = 0.830\ V_2 - 0.024$	.817	.186
c	V_3	$V = 0.611\ V_3 + 0.569$	.204	.389
d	$V_{average}$	$V = 1.190\ V_{avg} + 0.206$	.896	.140
e	V_1, V_2, H	$V = V_1\ (0.146 + 0.538H) + V_2\ (0.515 - 0.081H) + 0.018$	.933	.112
f	V_1, V_2, V_3, H	$V = V_1\ (0.231 + 0.665H) + V_2\ (0.375 - 0.202H) + V_3\ (0.377 - 0.407H) + 0.161$	.964	.085

The velocity relation improves significantly as variables are added to the estimation model (table 2). The velocity relation, which includes V_1, V_2, and H (model form ì eî in table 2) was used for those periods when bottom velocity was missing due to AVM malfunctioning. Removing the bottom acoustic line velocity variable resulted in an R^2 value of 0.933 and a standard error of 0.112 ft/s.

Estimated Flow at Noninstrumented Sites

It was not economically feasible to instrument all streams or creeks discharging into northeastern Florida Bay; therefore, alternatives were required to estimate flow through the four noninstrumented sites (table 1). The analysis performed in Long Sound at East Highway Creek, Oregon Creek, and Stillwater Creek used 15-minute discharge data from West Highway Creek as the independent variable and instantaneous ADCP discharge measurements at the noninstrumented site as the dependent variable. Results of the analyses for determining discharge at these sites are presented in table 3. The relation of flows between instrumented and noninstrumented sites varied with R^2 values ranging from 0.865 to 0.99. The relation of discharge between West Highway Creek and three of the noninstrumented sites (Stillwater Creek, Oregon Creek, and East Highway Creek) is shown in figure 17. Further investigation and more data are needed to improve accuracy of records, assess current flow conditions, and describe the distribution of freshwater flow in the Long Sound area.

Analyses were performed between measured discharge at East Creek and computed discharge at Taylor River and Mud Creek. Data from Mud Creek showed the strongest relation to discharge measured at East Creek and were used in the relation given in table 3 to calculate monthly discharges for East Creek. The relation between measured discharge at East Creek and computed simultaneous discharge at Taylor River (an R^2 value of 0.87) and Mud Creek (an R^2 value of 0.98) is shown in figure 18.

Table 3. Results of correlation analyses for determining discharge at the East Highway Creek, Oregon Creek, Stillwater Creek, and East Creek monitoring stations

[Q_{WHWY} is discharge value at West Highway Creek, and Q_{MUD} is discharge at Mud Creek]

Site name	Acoustic Doppler Current Profiler measurements		Relation	Coeffcient of determination (R^2)	Standard error (feet per second)
	Distance from mouth (feet)	Number of measurements			
East Highway Creek	150	17	$Q = 0.521\ Q_{WHWY} - 6.7$	0.935	13.50
Oregon Creek	150	15	$Q = 0.353\ Q_{WHWY} + 0.57$	.914	11.6
Stillwater Creek	50	15	$Q = 0.347\ Q_{WHWY} + 2.87$	.865	15.89
East Creek	30	21	$Q = 0.827\ Q_{MUD} + 10.7$	.99	9.68

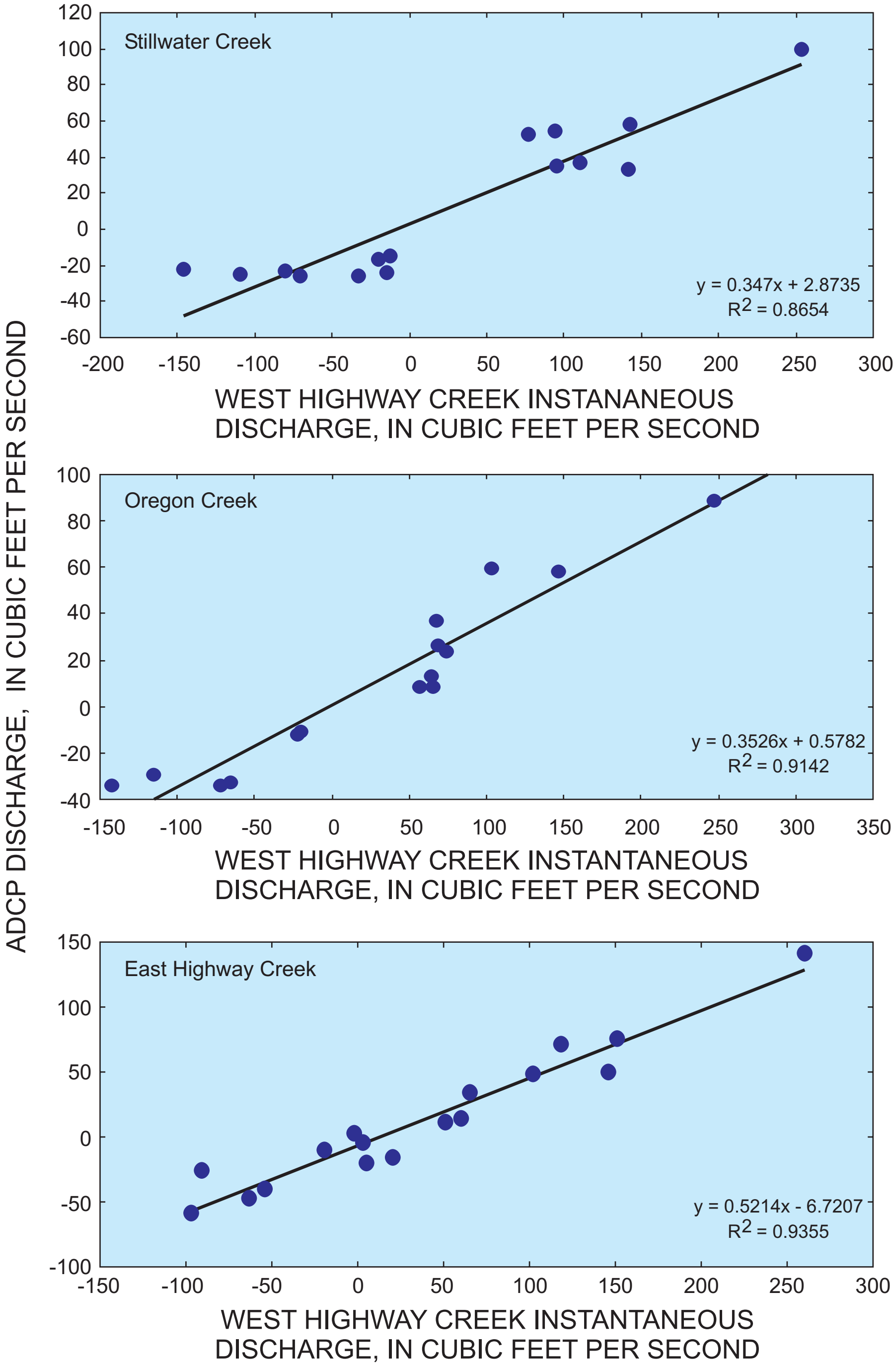

Figure 17. Relation of discharge between the West Highway Creek monitoring station (instrumented site) and the Stillwater Creek, Oregon Creek, and East Highway Creek monitoring stations (noninstrumented sites). R^2 is coefficient of determination, and ADCP is Acoustic Doppler Current Profiler.

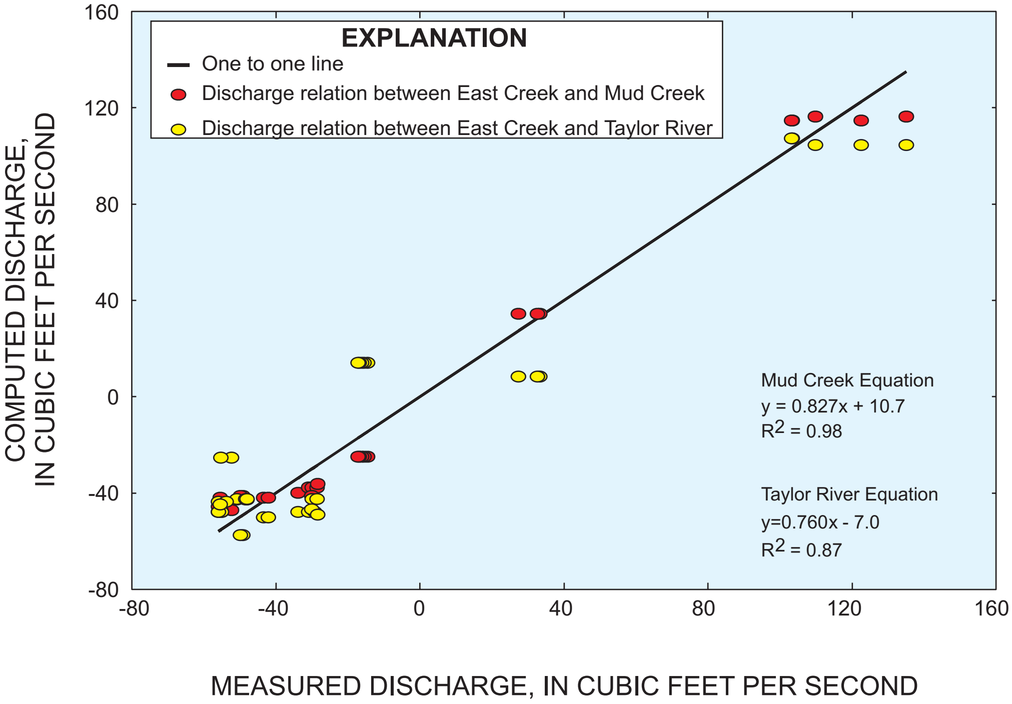

Figure 18. Relation of discharge between the East Creek monitoring station (noninstrumented site) and the Taylor River and Mud Creek monitoring stations (instrumented sites). R^2 is coefficient of determination.

Discharge Analysis and General Streamflow Characteristics

As previously described, velocity and area relations developed for each site were used to calculate discharge time-series data for all monitoring stations along the northeastern coastline of Florida Bay. Signatures of ebb and flood tides at these sites are either nonexistent or substantially dampened by: (1) a large number of carbonate mud banks that divide Florida Bay into a series of basins, (2) US-1 along the Florida Keys, and (3) regional wind forces (Davis and Ogden, 1997). In the study area, the flow direction is mainly dictated by the wet or dry conditions of the Everglades wetlands and regional wind speed and direction. As a result, commonly used data filters were not used to extract tidal influence for net-flow calculations, but rather, mean monthly discharge values were used instead to account for storage and to represent net flows for all sites.

Seasonal Flow Patterns

Discharge data were collected to analyze seasonal flow patterns at the creeks in northeastern Florida Bay. The period of record was from October 1995 through September 1999 and included extreme weather events, such as the effects of El NiÒo of 1998. For comparison purposes, data were interpreted under wet-season (May to October) and dry-season (November to April) conditions.

Total seasonal discharge records indicate that about 80 percent of the total freshwater entering northeastern Florida Bay occurs during the wet season. The mean freshwater discharge for all five instrumented sites during the wet season from 1996 to 1999 is 106 ft^3/s (cubic feet per second) . The wet season usually begins with an abrupt decrease in salinity along the mangrove zone. This dry-to-wet season transition is present at all sites and is shown for Taylor River in figure 19. Discharges for all five instrumented sites (West Highway Creek, Trout Creek, Mud Creek, Taylor River, and McCormick Creek) over various wet- and dry-season periods from 1996 to 1999 are shown in figure 20. Results indicate that the El NiÒo event had a substantial effect on the magnitude of dry-season freshwater discharges, while having a negligible effect on wet-season flows. The mean freshwater discharge of 55.6 ft^3/s for all five instrumented sites during the 1997-98 dry season (fig. 20B) represents a 654 percent increase compared to mean dry-season flows of 8.5 ft^3/s during the previous year (fig. 20A). Throughout the monitoring period (1996-99), the mean monthly wet season (May-October) flow at Trout Creek is about 340 ft^3/s, compared to 55 ft^3/s at West Highway Creek, 52 ft^3/s at Taylor River, 49 ft^3/s at Mud Creek, and 33 ft^3/s at McCormick Creek.

Spatial Distribution of Freshwater Flow and Salinity

Calculated and estimated discharge data for the monitoring stations in the study area were used to describe the spatial distribution of flow into northeastern Florida Bay. Discharge into northeastern Florida Bay is greatest in Trout Creek, with about 50 percent of the total calculated freshwater flow. Thus, Trout Creek is the main artery connecting this area of the bay to Taylor Slough and the C-111 Canal. The percentage distribution of total freshwater flow for the monitoring stations in northeastern Florida Bay from March 1996 through September 1999 is shown in figure 21. Overbank flow is excluded because of a lack of available data; however, overbank flow is negligible or nonexistent most of the time. Mean monthly flows and salinity values were also compared to describe similarities (or lack thereof) between the instrumented sites as shown in figure 22.

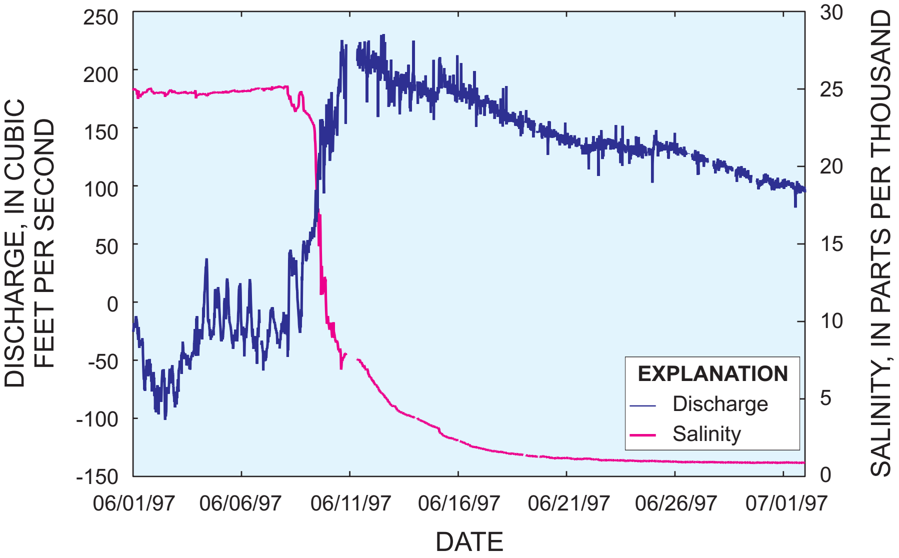

Figure 19. Brackish water (dry season) to freshwater (wet season) transition at the Taylor River monitoring station.

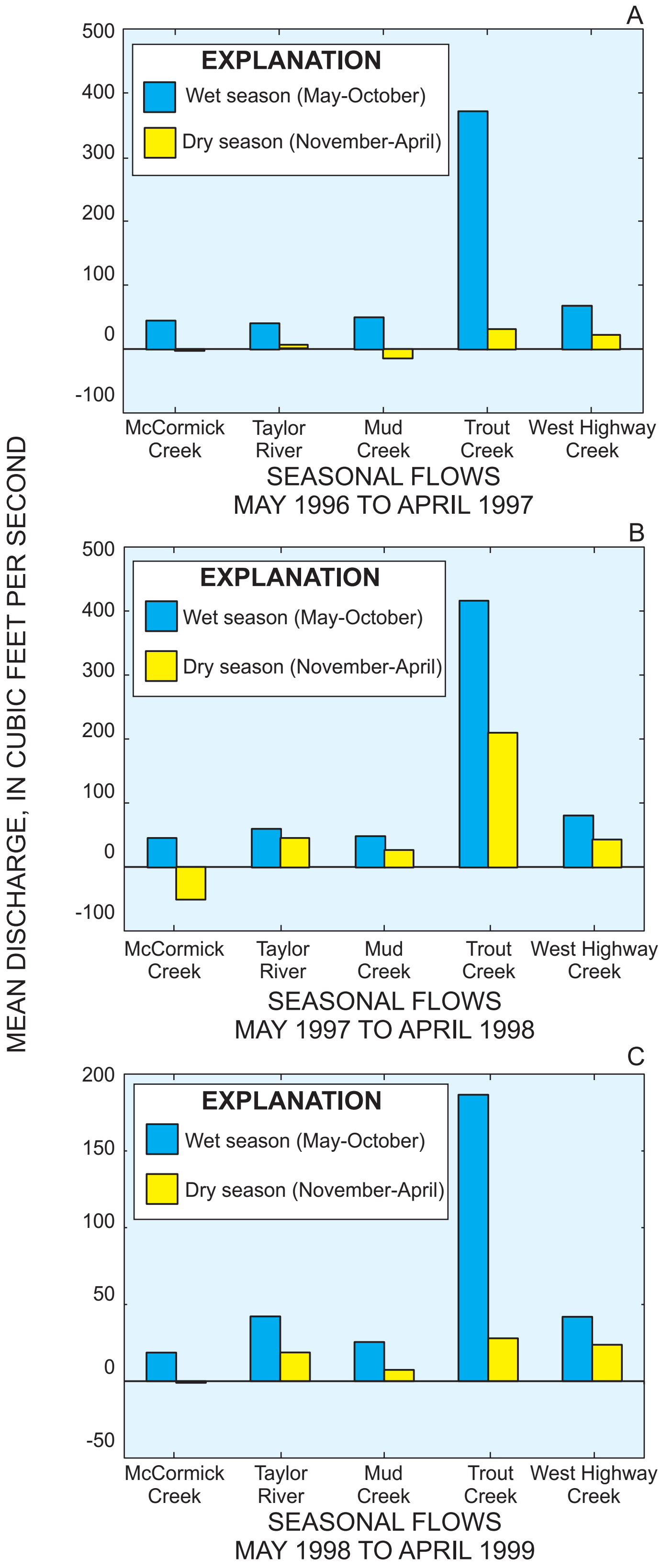

Figure 20. Wet- and dry-season freshwater discharges for the McCormick Creek, Taylor River, Mud Creek, Trout Creek, and West Highway Creek monitoring stations, May 1996 to April 1999.

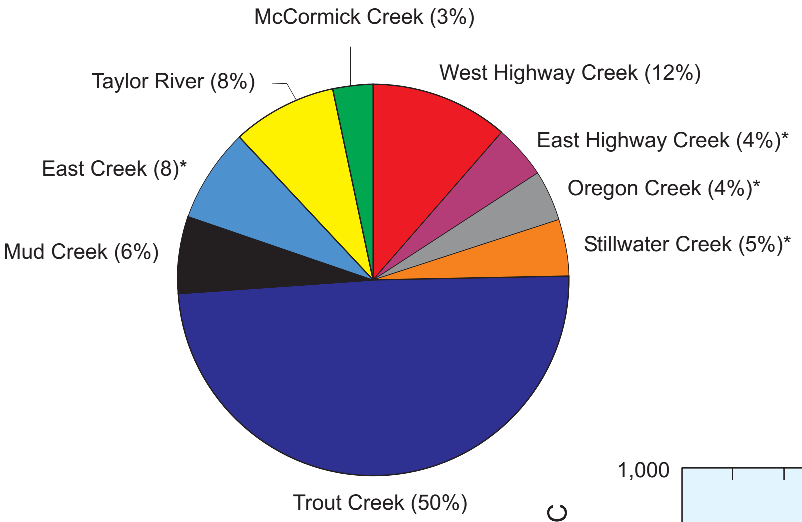

Figure 21. Percentage distribution of total freshwater discharge for the Florida Bay monitoring stations, May 1996 to September 1999. Asterisk indicates estimated value.

Results indicate three major flow signatures at monitoring stations from east to west. They include the pattern exhibited by West Highway Creek, which rarely shows monthly net-negative flow; Trout Creek, which shows the largest magnitudes of flow; and McCormick Creek, which drifted from the rest of the stations, showing net-negative flows (decline of freshwater flows) toward the Monroe Lake area at the start of the El NiÒo event in June 1997 (fig. 22A). Discharge at McCormick Creek deviates from all other sites, resulting in an increase of negative (inland) flow at this site during a period of net positive freshwater outflow at all other stations beginning in November 1997. Analysis of regional wind patterns and water levels in the Everglades wetlands along Taylor Slough during the El NiÒo dry season may help explain flow patterns in McCormick Creek during the period. Mean monthly salinity values also indicate major flow signatures as shown in figure 22B. McCormick Creek maintains the highest salinity of the instrumented sites, supporting the concept that flow in the creek is sometimes separated or disconnected from Taylor Slough flows. In contrast, Taylor River usually maintains the lowest salinity. The rest of the instrumented sites share a similar salinity pattern over time (fig. 22B).

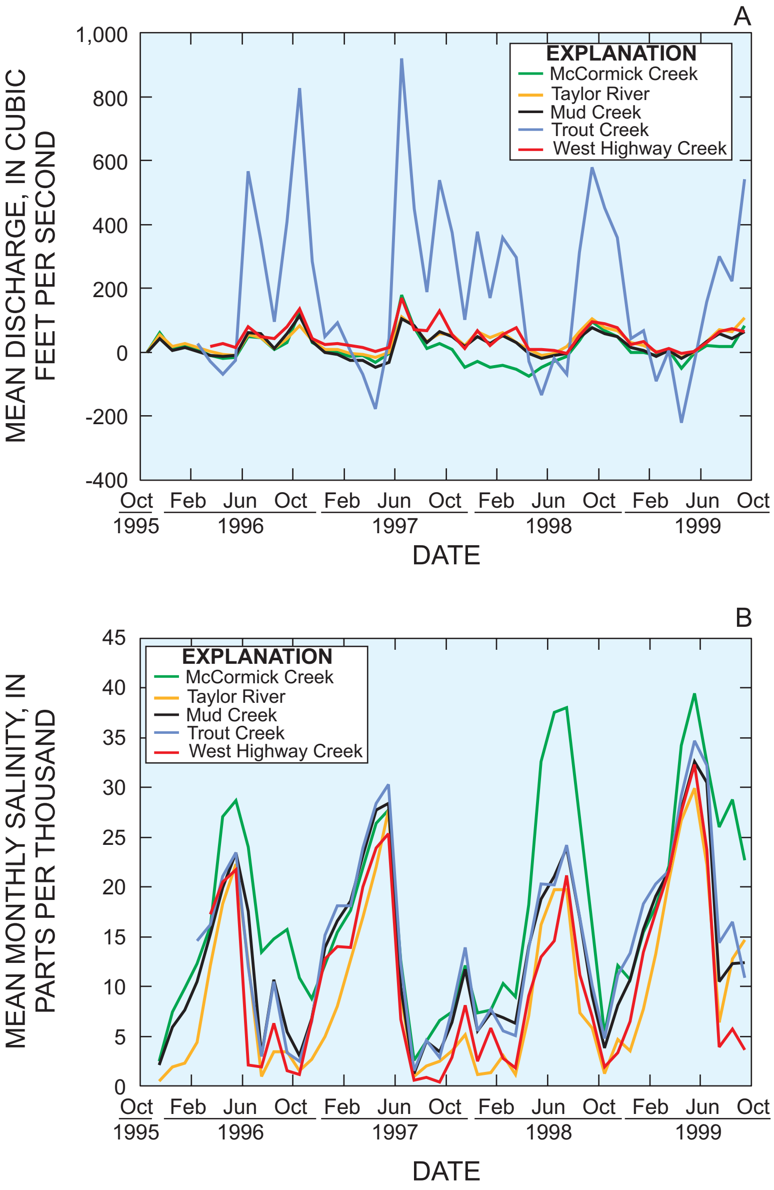

Figure 22. Mean monthly flows and salinity values for the McCormick Creek, Taylor River, Mud Creek, Trout Creek, and West Highway Creek monitoring stations, October 1995 through September 1999.

The continued study of discharge and salinity in the study area would be necessary to extend the analysis period beyond the influence of extreme hydrologic events, such as El NiÒo, which occurred during the study period. Further investigation would also provide short-term (monthly and seasonal) and long-term flow trends along the northeastern coastline of Florida Bay during ongoing Everglades restoration changes.

Base-Gage Selection and Discharge Relation

An analysis of mean monthly discharge was used as a base-gage selection process. Using only one monitoring station or ì base gage,î further analysis can be made to determine whether changes in water-management practices affect freshwater flow into northeastern Florida Bay. Trout Creek, having the largest magnitude of flow, was selected as the test base gage for the study. The analysis was performed using mean monthly discharge values because these values account for any upland flows (negative discharge) into storage and are assumed to represent net flows. The relation of discharge between Trout Creek and four monitoring stations (McCormick Creek, Mud Creek, Taylor River, and West Highway Creek) is shown in figure 23.

The separation of McCormick Creek discharges from the rest of the monitoring stations is evident in the R^2 value of 0.629 obtained for the discharge relation to Trout Creek. A longer study period would be needed to determine if this separation is only a short-term drift caused by El NiÒo. When ignoring discharge data during the El NiÒo event, an R^2 value of 0.807 is obtained.

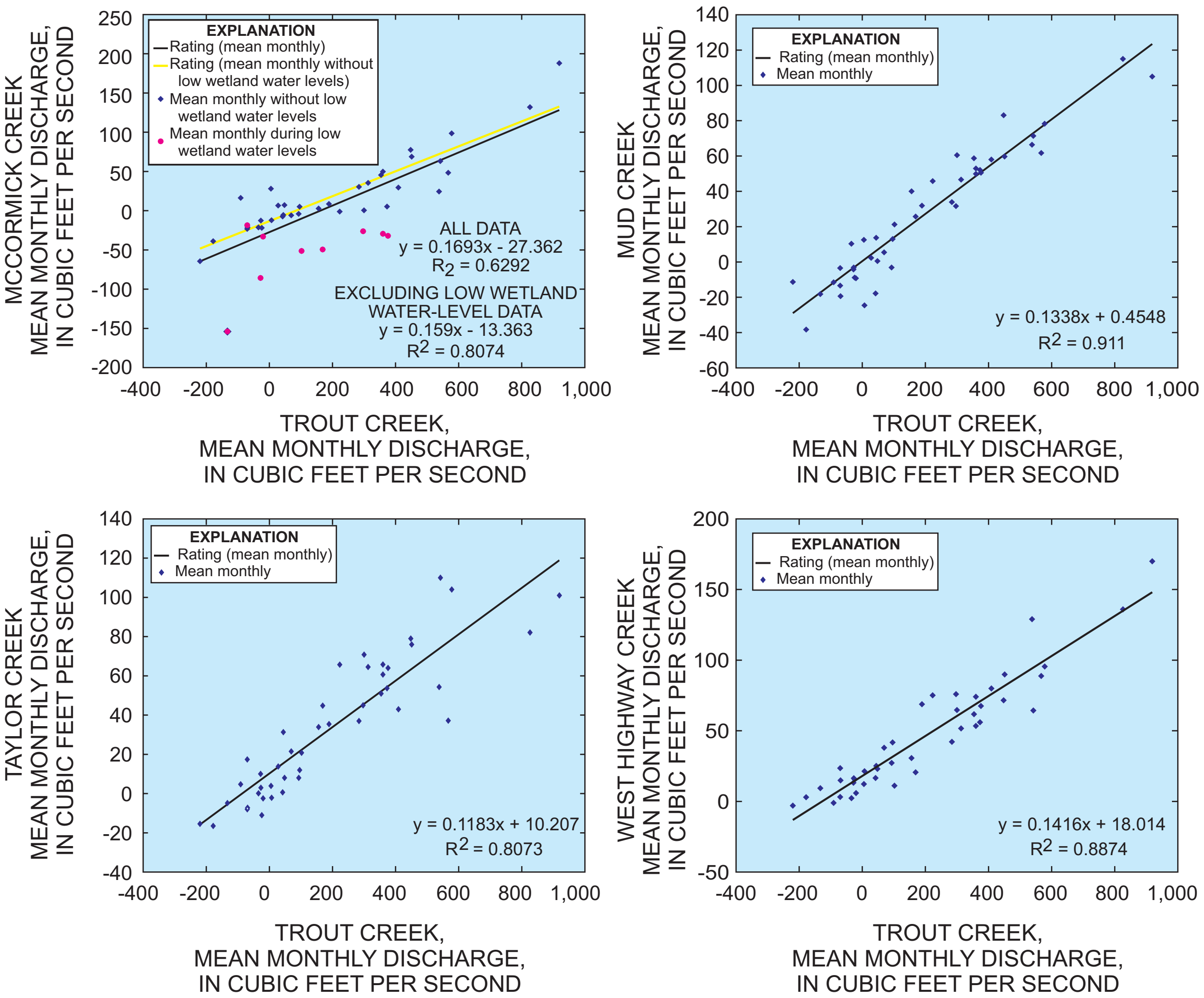

Figure 23. Relation of discharge between Trout Creek and other selected monitoring stations in northeastern Florida Bay. R^2 is coefficient of determination.

Additionally, even though the relation between Trout Creek and West Highway Creek is high with an R^2 value of 0.887, continued monitoring of flows into Long Sound would be needed to determine the effects of planned restoration changes in the C-111 Canal. Trout Creek and Mud Creek show the highest relation with an R^2 value of 0.911, whereas Trout Creek and Taylor River have an R^2 value of 0.807. These analyses indicate that Trout Creek could potentially be used as a long-term monitoring station, provided that the aforementioned questions regarding flow patterns at McCormick Creek and those into Long Sound can be resolved. Regardless of flow patterns, however, changes in water-delivery management practices over the course of the Everglades restoration process could substantially alter flow characteristics of the creeks from present-day conditions.

SUMMARY AND CONCLUSIONS

Restoration of the Florida Bay ecosystem requires an understanding of the linkage between the amount of freshwater flowing into the bay and the salinity of the bay environment. A study was conducted at nine monitoring stations to estimate freshwater flows from the mainland into Florida Bay. Data collected from the monitoring stations in estuarine creeks included water level, acoustic line velocity, salinity, and temperature. Velocity ratings along with cross-sectional areas were developed to calculate discharge. The discharge data were used to analyze seasonal flow patterns and to describe the spatial distribution of freshwater flow and salinity. Additionally, an analysis of discharge was used as a base-gage selection process to determine whether one monitoring station could indicate how changes in water-management practices can affect freshwater flow into northeastern Florida Bay.

The technique used to describe the relation of acoustic line velocity to mean velocity is a least squares regression model in the single or multiple variable form. Three forms of an equation were required to describe flow patterns at five instrumented sites (West Highway Creek, Trout Creek, Mud Creek, Taylor River, and McCormick Creek). For the acoustic-to-measured velocity relation, R^2 values ranged from 0.977 to 0.995 at three of the sites (Trout Creek, Mud Creek, and McCormick Creek). In calculating discharge for positive and negative flow, the R^2 values were 0.962 and 0.957, respectively, at West Highway Creek. When using the most complex form of the model to calculate discharge, the R^2 value was 0.964 with a standard error of 0.085 ft/s at Taylor River. Removing an acoustic velocity variable from the equation resulted in an R^2 value of 0.933 and a standard error of 0.112 ft/s at the same site.

To gain a better understanding of freshwater flows into Florida Bay, discharge at noninstrumented sites were considered. These noninstrumented sites include East Highway Creek, Oregon Creek, Stillwater Creek, and East Creek. Techniques were used to establish relations between discharge at each of these sites and discharge at a nearby instrumented site. For the sites in Long Sound (East Highway Creek, Oregon, and Stillwater Creeks), an analysis was performed using 15-minute discharge from nearby West Highway Creek. For East Creek in Little Madiera Bay, an analysis was performed using 15-minute discharge data from nearby Mud Creek and Taylor River. The strongest relation was between East Creek and Mud Creek. More data collected at new and existing monitoring stations could improve the accuracy of the records and provide a better description of the distribution of freshwater flow in Long Sound.

Flows in the streams along the northeastern coastline of Florida Bay do not present the typical ebb and flood tidal signatures of most estuarine streams. These tidal signatures are either nonexistent or substantially dampened by the large number of mud banks that divide Florida Bay into a large number of sub-basins by U.S. Highway 1 along the Florida Keys, and by regional wind forces. Analysis of seasonal flows indicate that about 80 percent of the annual freshwater entry to northeastern Florida Bay occurs during the wet season (May-October), with a sharp and distinct transition from brackish to freshwater at the start of the wet season. The effect of El Niño on dry-season flows are evidenced by a substantial increase in mean dry-season discharge at the monitoring stations from 8.5 ft^3/s in the 1996-97 season to 55.6 ft^3/s. Regional wind patterns and shallow depth in the Everglades wetlands following El Niño also are the probable cause for a divergence in flow pattern between McCormick Creek and the rest of the monitoring stations in the area during this period.

Three main flow signatures were identified when comparing flows at all monitoring stations, with the most significant one being the magnitude of discharges at Trout Creek, which carries about 50 percent of the total measured freshwater entering northeastern

Florida Bay. The other two main signatures are the drifting of flows in McCormick Creek to the north following the El Niño event and the absence of net negative flows at West Highway Creek. The observed east-to-west flow distribution, and especially the magnitude of flows through Trout Creek in comparison with the other creeks, suggests that overall flow of freshwater in the Everglades wetlands along Taylor Slough may be directed farther eastward than previously thought.

Trout Creek was the base gage selected for analysis and used to determine if one station could indicate how changes in water-management practices on the mainland may affect freshwater flows into northeastern Florida Bay. Analyses indicate that Trout Creek could potentially be used as the long-term monitoring station, provided that questions regarding the flow patterns at McCormick Creek and Long Sound streams are answered and that flow characteristics do not change substantially.

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APPENDIX

Data Set Used to Develop Velocity Relations for the Monitoring Stations

[Velocity no. 1 is the acoustic line velocity from the top AVM path nearest to the water surface; velocity no. 2 is the acoustic line velocity from the middle AVM path; and velocity no. 3 is the acoustic line velocity from the bottom AVM path nearest to the streambed. Abbreviations: AVM, acoustic velocity meter; ft, feet; ft/s, feet per second; ft^2, square feet; ft^3/s, cubic feet per second; -- not used or not applicable]

McCormick Creek

Measurement No.	Date	Measured discharge (ft^3/s)	Velocity no. 1 (ft/s)	Stage (ft)	Rated area (ft^2)	Measured velocity (ft/s)	Rated velocity (ft/s)	Rated discharge (ft^3/s)	Residuals (ft^3/s)
1	01-15-96	48.2	0.42	-0.88	223.8	0.22	0.22	48.4	0.2
2		49.7	.42	-.88	223.8	.22	.22	48.4	-1.3
3		52.3	.42	-.88	223.8	.23	.22	48.4	-3.9
4		49.5	.43	-.88	223.8	.22	.22	49.5	.1
5		47.6	.43	-.88	223.8	.21	.22	49.5	2.0
6		51.5	.43	-.88	223.8	.23	.22	49.6	-1.9
8	02-02-96	-172.2	-.92	-.42	254.1	-.68	-.52	-133.2	39.0
9		-169.9	-.92	-.42	254.1	-.67	-.52	-133.2	36.7
10		-141.3	-.92	-.42	254.1	-.56	-.52	-133.2	8.1
11		-165.0	-.92	-.42	254.1	-.65	-.52	-133.2	31.8
12		-147.2	-.92	-.41	254.8	-.58	-.52	-133.5	13.7
13		-149.9	-.92	-.41	254.8	-.59	-.52	-133.5	16.4
14		-165.5	-.92	-.41	254.8	-.65	-.52	-133.5	32.0
15		-147.7	-.92	-.41	254.8	-.58	-.52	-133.5	14.2
16	03-18-96	-145.5	-1.24	-.24	266.0	-.55	-.70	-186.4	-40.9
18		-159.7	-1.21	-.23	266.7	-.60	-.68	-182.5	-22.8
20		-147.4	-1.21	-.23	266.7	-.55	-.68	-182.5	-35.1
21		-146.4	-1.25	-.22	267.3	-.55	-.71	-188.8	-42.4
22		-149.3	-1.25	-.22	267.3	-.56	-.71	-188.8	-39.5
23	06-11-96	74.3	.56	-.50	248.9	.30	.29	73.1	-1.2
24		76.2	.56	-.50	248.9	.31	.29	73.1	-3.1
25		69.9	.56	-.50	248.9	.28	.29	73.1	3.2
26		76.1	.56	-.50	248.9	.31	.29	73.1	-3.0
27		75.4	.65	-.50	248.9	.30	.34	85.4	10.0
28		67.2	.65	-.50	248.9	.27	.34	85.4	18.2
29		70.6	.65	-.50	248.9	.28	.34	85.4	14.8
30		69.8	.65	-.50	248.9	.28	.34	85.4	15.6
31	10-20-96	214.3	1.19	.07	286.5	.75	.64	183.8	-30.5
32		197.2	1.19	.07	286.5	.69	.64	183.8	-13.4
33		171.5	1.15	.08	287.1	.60	.62	177.8	6.3
34		193.1	1.12	.08	287.1	.67	.60	173.1	-20.0
35		174.7	1.12	.08	287.1	.61	.60	173.1	-1.6
37	11-20-96	-138.9	-.80	-.25	265.4	-.52	-.46	-121.5	17.4
38		-145.0	-.81	-.25	265.4	-.55	-.46	-123.0	22.0
39		-114.2	-.81	-.25	265.4	-.43	-.46	-123.0	-8.8
40	11-20-96	-156.2	-.81	-.25	265.4	-.59	-.46	-123.0	33.2
41		-139.2	-.81	-.25	265.4	-.52	-.46	-123.0	16.2
42		-134.5	-.83	-.25	265.4	-.51	-.47	-125.9	8.6
43		-137.7	-.83	-.25	265.4	-.52	-.47	-125.9	11.8
44		-136.9	-.83	-.25	265.4	-.52	-.47	-125.9	11.0
46	12-17-96	-96.7	-.86	-.56	244.9	-.39	-.49	-120.2	-23.5
47		-92.7	-.86	-.56	244.9	-.38	-.49	-120.2	-27.5
48		-87.9	-.84	-.55	244.9	-.36	-.48	-117.5	-29.6
49		-88.5	-.84	-.55	244.9	-.36	-.48	-117.5	-29.0
50	06-12-97	308.3	1.80	.50	315.7	.98	.98	308.9	.6
51		319.7	1.80	.50	315.7	1.01	.98	308.9	-10.8
53		325.6	1.88	.50	315.7	1.03	1.02	322.9	-2.7

Mud Creek

Measurement No.	Date	Measured discharge (ft^3/s)	Velocity no. 1 (ft/s)	Stage (ft)	Rated area (ft^2)	Measured velocity (ft/s)	Rated velocity (ft/s)	Rated discharge (ft^3/s)	Residuals (ft^3/s)
1	12-08-95	-32.1	-0.42	-0.72	145.3	-0.22	-0.21	-31	-1
2		-33.6	-.42	-.72	145.3	-.23	-.21	-31	-3
3		-36.6	-.48	-.72	145.3	-.25	-.24	-35	-2
4		-37.9	-.48	-.72	145.3	-.26	-.24	-35	-3
5		-34.7	-.48	-.72	145.3	-.24	-.24	-35	0
6		-33.5	-.37	-.71	145.6	-.23	-.19	-27	-6
7		-31.5	-.37	-.71	145.6	-.22	-.19	-27	-4
8		-36.3	-.39	-.72	145.3	-.25	-.20	-29	-8
9		-30.2	-.39	-.72	145.3	-.21	-.20	-29	-2
10	01-13-96	76.2	1.23	-1.12	130.9	.58	.53	69	7
11		71.0	1.23	-1.12	130.9	.54	.53	69	2
12		70.7	1.23	-1.12	130.9	.54	.53	69	2
13		71.9	1.23	-1.12	130.9	.55	.53	69	3
14		82.7	1.46	-1.19	128.4	.64	.63	81	2
15		83.4	1.46	-1.19	128.4	.65	.63	81	3
16		77.9	1.46	-1.19	128.4	.61	.63	81	-3
17		79.9	1.53	-1.18	128.7	.62	.66	85	-5
18		82.1	1.53	-1.18	128.7	.64	.66	85	-3
19		69.2	1.26	-1.16	129.4	.53	.54	70	-1
20		73.4	1.26	-1.16	129.4	.57	.54	70	4
21		80.2	1.34	-1.13	130.5	.61	.58	75	5
22	01-14-96	-23.3	-.43	-.91	138.4	-.17	-.22	-30	6
23		-20.7	-.43	-.91	138.4	-.15	-.22	-30	9
24		-25.1	-.43	-.91	138.4	-.18	-.22	-30	5
25	02-01-96	-44.8	-.68	-.70	146.0	-.31	-.33	-48	3
26		-47.5	-.68	-.70	146.0	-.33	-.33	-48	0
27		-44.0	-.68	-.70	146.0	-.30	-.33	-48	4
28		-44.4	-.68	-.70	146.0	-.30	-.33	-48	3
29	03-20-96	64.0	1.02	-.55	151.4	.42	.43	66	-2
30		32.7	.69	-.50	153.2	.21	.29	44	-11
31	04-11-96	17.7	.37	-.84	141.0	.13	.14	20	-2
32		16.4	.37	-.84	141.0	.12	.14	20	-4
33		20.6	.37	-.84	141.0	.15	.14	20	1
34		16.5	.37	-.84	141.0	.12	.14	20	-4
35		18.8	.37	-.84	141.0	.13	.14	20	-1

Trout Creek

Measure-ment No.	Date	Measured discharge (ft^3/s)	Velocity no. 1 (ft/s)	Stage (ft)	Rated area (ft^2)	Measured velocity (ft/s)	Rated velocity (ft/s)	Rated discharge (ft^3/s)	Residuals (ft^3/s)
29	05-16-96	111.3	--	-1.04	493	0.225	0.254	125	14.19
31		109.5	--	-1.04	493	.222	.254	125	19.55
32		111.6	--	-1.04	493	.226	.254	125	13.89
43	06-12-96	547.1	--	-.68	538	1.047	.992	519	-28.37
44		483.6	--	-.68	538	.925	.992	519	35.13
47		662.4	--	-.69	536	1.270	1.141	595	-67.15
48		621.5	--	-.68	538	1.189	1.113	582	-39.67
49		608.2	--	-.68	538	1.163	1.085	567	-41.21
50		625.3	--	-.68	538	1.196	1.085	567	-58.31
51		523.9	--	-.69	536	1.005	1.007	525	1.00
52		507.4	--	-.69	536	.973	1.007	525	17.50
53		544.6	--	-.67	539	1.039	.943	494	-50.68
54		520.2	--	-.67	539	.993	.943	494	-26.28
55	07-18-96	539.3	--	-.98	500	1.110	1.070	520	-19.43
56		530.8	--	-.98	500	1.093	1.070	520	-10.93
57		307.9	--	-.94	505	.628	.694	340	32.60
58		356.0	--	-.94	505	.726	.701	344	-12.02
59		437.5	--	-.95	504	.894	.751	367	-70.05
60		359.6	--	-.95	504	.735	.751	367	7.85
61	08-14-96	101.2	--	-.82	520	.195	.247	128	27.21
62		91.3	--	-.82	520	.175	.247	128	37.11
64		-33.6	--	-.82	520	-.065	-.087	-45	-11.61
67		-52.0	--	-.82	520	-.100	-.101	-53	-.60
68		-133.3	--	-.82	520	-.256	-.215	-112	21.60
69		-137.9	--	-.82	520	-.265	-.215	-112	26.20
70	08-14-96	-226.6	--	-.82	520	-.436	-.463	-241	-14.39
71		-229.1	--	-.82	520	-.440	-.463	-241	-11.89
72		-254.7	--	-.82	520	-.490	-.548	-285	-30.62
73		-263.7	--	-.82	520	-.507	-.548	-285	-21.62
74	10-20-96	1,091.0	--	-.07	615	1.774	1.823	1,121	30.44
75		1,070.7	--	-.07	615	1.741	1.823	1,121	50.74
76		1,087.3	--	-.06	616	1.764	1.816	1,119	32.09
77		1,068.3	--	-.06	616	1.733	1.809	1,115	46.72
78		1,102.1	--	-.06	616	1.788	1.802	1,111	8.54
79		1,047.8	--	-.06	616	1.700	1.795	1,106	58.46
80	11-19-96	-625.3	--	-.39	574	-1.089	-1.031	-592	33.18
81		-637.0	--	-.39	574	-1.109	-1.038	-596	40.81

West Highway Creek

Measurement No.	Date	Measured discharge (ft^3/s)	Velocity no. 1 (ft/s)	Stage (ft)	Rated area (ft^2)	Measured velocity (ft/s)	Rated velocity (ft/s)	Rated discharge (ft^3/s)	Residuals (ft^3/s)
7	03-20-96	-49	-0.29	-0.72	283	-0.173	-0.165	-47	2
8		-42	-.29	-.72	283	-.149	-.165	-47	-5
10		-28	-.06	-.70	284	-.098	-.068	-19	9
1g	04-12-96	-29	-.09	-.86	274	-.107	-.066	-18	11
2g		-14	-.09	-.86	274	-.052	-.066	-18	-4
3g		5	.14	-.86	274	.018	.090	25	20
4g		3	.14	-.86	274	.011	.090	25	22
5g		-1	.04	-.85	274	-.003	.017	5	5
6g		11	.04	-.85	274	.040	.017	5	-7
11	05-17-96	43	.21	-1.04	261	.165	.142	37	-6
12		50	.21	-1.04	261	.192	.142	37	13
13		45	.21	-1.04	261	.173	.142	37	-8
13		46	.21	-1.04	261	.176	.142	37	-9
15		29	.10	-1.04	261	.111	.061	16	-13
16		17	.10	-1.04	261	.064	.061	16	-1
17		-10	-.02	-1.03	262	-.038	-.043	-11	-1
18		-11	-.02	-1.03	262	-.040	-.043	-11	-1
19		-10	-.02	-1.03	262	-.037	-.043	-11	-2
34	10-21-96	181	.72	.21	348	.521	.517	180	-1
35		190	.72	.21	348	.546	.517	180	-10
36		227	.80	.21	348	.652	.576	200	-26
37		208	.80	.21	348	.597	.576	200	-8
38	11-18-96	176	.77	.10	340	.518	.554	188	12
39		179	.77	.10	340	.525	.554	188	10
40	11-21-96	161	.77	.10	340	.472	.554	188	28
41		-122	.31	-.11	325	-.375	-.380	-124	-2
42		-109	-.31	-.11	325	-.336	-.380	-124	-14
43		-142	-.30	-.11	325	-.437	-.369	-120	22
44		-116	.30	-.11	325	-.355	-.369	-120	-5
45	12-16-96	12	.12	-.67	286	.043	.075	22	9
46		-9	-.06	-.67	286	-.030	-.070	-20	-11

Taylor River

Measure-ment No.	Date	Measured discharge (ft^3/s)	Velocity no. 1 (ft/s)	Velocity no. 2 (ft/s)	Velocity no. 3 (ft/s)	Stage (ft)	Rated area (ft^2)	Measured velocity (ft/s)	Rated velocity (ft/s)	Rated discharge (ft^3/s)	Residuals (ft^3/s)
4	12-08-95	32.6	0.50	0.76	-0.72	-0.70	80.58	0.405	0.436	35	-3
5		37.7	.50	.76	-.72	-.70	80.58	.468	.436	35	3
6		35.6	.50	.76	-.72	-.70	80.58	.442	.436	35	0
7		31.3	.50	.76	-.72	-.70	80.58	.388	.436	35	-4
8		33.4	.46	.69	-.71	-.69	80.76	.414	.404	33	1
9		34.2	.46	.69	-.71	-.69	80.76	.423	.404	33	2
10	01-14-96	22.2	.89	.13	-.70	-.85	77.88	.285	.287	22	-0
11		26.5	.89	.13	-.70	-.85	77.88	.340	.287	22	4
12		27.8	.89	.13	-.70	-.85	77.88	.357	.287	22	5
13		26.4	.89	.13	-.70	-.85	77.88	.339	.287	22	4
14		24.3	.89	.13	-.70	-.85	77.88	.312	.287	22	2
15		28.2	.89	.13	-.70	-.85	77.88	.362	.287	22	6
16		22.6	.89	.13	-.70	-.85	77.88	.290	.287	22	0
17	01-15-96	27.6	.74	.58	-.78	-.89	77.16	.358	.338	26	2
18		21.8	.74	.58	-.78	-.89	77.16	.283	.338	26	-4
19		26.1	.74	.58	-.78	-.89	77.16	.338	.338	26	0
20		24.4	.74	.58	-.78	-.89	77.16	.316	.338	26	-2
21	02-02-96	-38.8	-.80	-.02	-.59	-.44	85.40	-.454	-.419	-36	-3
22		-36.1	-.80	-.02	-.59	-.44	85.40	-.423	-.419	-36	-0
23		-37.2	-.80	-.02	-.59	-.44	85.40	-.436	-.419	-36	-1
24	02-08-96	15.0	.42	.20	-.38	-1.02	74.80	.200	.185	14	1
25		16.5	.42	.20	-.38	-1.02	74.80	.221	.185	14	3
26		14.7	.42	.20	-.38	-1.02	74.80	.196	.185	14	1
30	04-11-96	21.7	.11	.51	-.09	-.79	78.96	.275	.345	27	-6
31		20.4	.11	.51	-.09	-.79	78.96	.258	.345	27	-7
32		21.9	.11	.51	-.09	-.79	78.96	.277	.345	27	-5
33		20.8	.11	.51	-.09	-.79	78.96	.263	.345	27	-6
39	05-16-96	14.9	.17	.40	-.20	-.91	76.80	.194	.286	22	-7
40		15.2	.17	.40	-.20	-.91	76.80	.198	.286	22	-7
42	05-16-96	12.6	.14	.38	-.32	-.88	77.34	.163	.234	18	-5
43		11.4	.14	.38	-.32	-.88	77.34	.147	.234	18	-7
44		10.3	.14	.38	-.32	-.88	77.34	.133	.234	18	-8
49	06-11-96	26.0	.21	.66	.02	-.62	82.02	.317	.463	38	-12
50		31.1	.21	.66	.02	-.62	82.02	.379	.463	38	-7
51		33.0	.21	.66	.02	-.62	82.02	.402	.463	38	-5
52		29.4	.21	.66	.02	-.62	82.02	.358	.463	38	-9
61	07-18-96	82.1	.63	1.07	.41	-.82	78.42	1.047	.869	68	14
62		83.0	.63	1.07	.41	-.82	78.42	1.058	.869	68	15
63		84.5	.63	1.07	.41	-.82	78.42	1.078	.869	68	16
70		14.4	.61	-.04	-.61	-.78	79.14	.182	.209	17	-2
71		13.7	.61	-.04	-.61	-.78	79.14	.173	.209	17	-3
82		7.9	.42	-.17	-.63	-.75	79.68	.099	.105	8	-0
73		6.7	.42	-.17	-.63	-.75	79.68	.084	.105	8	-2
74		-1.5	.26	-.12	-.58	-.73	80.04	-.019	.078	6	-8
75		.5	.26	-.12	-.58	-.73	80.04	.006	.078	6	-6
76		-3.1	.12	-.15	-.46	-.72	80.22	-.039	.045	4	-7
77		-2.6	.12	-.15	-.46	-.72	80.22	-.032	.045	4	-6
78		-14.0	-.57	-.15	-.65	-.70	80.58	-.174	-.299	-24	10
79		-11.1	-.57	-.15	-.65	-.70	80.58	-.138	-.299	-24	13
80		-14.3	-.51	-.25	-.66	-.69	80.76	-.177	-.307	-25	10
81		-13.0	-.51	-.25	-.66	-.69	80.76	-.161	-.307	-25	12
82		-15.7	-.51	-.25	-.66	-.69	80.76	-.194	-.307	-25	9
83		-15.3	-.51	-.25	-.66	-.69	80.76	-.189	-.307	-25	9
84	10-20-96	105.2	.90	1.27	-.4	-.06	93.00	1.131	1.174	109	-4
85		119.2	.90	1.27	-.4	-.06	93.00	1.282	1.174	109	10
86		102.7	.88	1.24	-.44	-.06	93.00	1.104	1.151	107	-4
87		113.1	.88	1.24	-.44	-.06	93.00	1.216	1.151	107	6
88		104.9	.88	1.24	-.44	-.06	93.00	1.128	1.151	107	-2
89		106.3	.88	1.24	-.44	-.06	93.00	1.143	1.151	107	-1
90		-34.0	-.57	-.23	-.93	-.09	92.40	-.368	-.366	-34	-0
91		-35.2	-.57	-.23	-.93	-.09	92.40	-.381	-.366	-34	-1
92		-38.5	-.57	-.23	-.93	-.09	92.40	-.417	-.366	-34	-5