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Continuous Tidal Streamflow and Gage-Height Data for Bass and Cinder Creeks on Kiawah Island, South Carolina, September 2007

Open-File Report 2009–1037

U.S. Department of the Interior
U.S. Geological Survey

Covers. ***Front:*** **Cinder Creek, Kiawah Island, South Carolina** *(photograph taken by Norm Shea, Director, Lakes Management, Kiawah Island Community Association, Inc.)***.**

Back: **Aerial photograph of Kiawah Island, South Carolina** *(courtesy of the National Oceanic and Atmospheric Administration, Center for Coastal Environmental Health and Biomolecular Research).*

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
	Area	
square foot (ft^2)	929.0	square centimeter (cm^2)
square foot (ft^2)	0.09290	square meter (m^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Acronyms and Abbreviations Used in this Report

EFDC	Environmental Fluid Dynamic Code
NOAA	National Oceanic and Atmospheric Administration
R^2	coefficient of determination
TMDL	total maximum daily load
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
3D	three dimensional

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Abstract

A three-dimensional model of Bass and Cinders Creeks on Kiawah Island, South Carolina, was developed to evaluate methodologies for determining fecal coliform total maximum daily loads for shellfish waters. To calibrate the model, two index-velocity sites on the creeks were instrumented with continuous acoustic velocity meters and water-level sensors to compute a 21-day continuous record of tidal streamflows. In addition to monitoring tidal cycles, streamflow measurements were made at the index-velocity sites, and tidal-cycle streamflow measurements were made at the mouth of Bass Creek and on the Stono River to characterize the streamflow dynamics near the ocean boundary of the three-dimensional model at the beginning, September 6, 2007, and end, September 26, 2007, of the index-velocity meter deployment. The maximum floodtide and ebbtide measured on the Stono River by the mouth of Bass Creek for the two measurements were –155,000 and 170,000 cubic feet per second (ft^3/s). At the mouth of Bass Creek, the maximum floodtide and ebbtide measurements during the 2 measurement days were +/–10,200 ft^3/s. Tidal streamflows for the 21-day deployment on Bass Creek ranged from –2,510 ft^3/s for an incoming tide to 4,360 ft^3/s for an outgoing tide. On Cinder Creek, the incoming and outgoing tide varied from –2,180 to 2,400 ft^3/s during the same period.

Introduction

The U.S. Environmental Protection Agency (USEPA) Region 4, through a contract with Tetra Tech, Inc., developed a methodology for a three-tiered approach for determining fecal coliform total maximum daily load (TMDL) for shellfish waters. The tiers ranged in complexity from a simple flow exceedance examination to a complex three-dimensional (3D) hydrodynamic and fate and transport model. The first tier is a mass balance approach based on the concentration of bacteria from source assessments and response sampling concentrations. The second tier uses a tidal prism spreadsheet model to account for the dilution and decay of bacteria. The third tier approach uses a multidimensional hydrodynamic model to simulate the water levels, stream velocities, and salinity to simulate the retention time of an estuarine system. The tiers were used to determine when fecal coliform levels became unsafe to permit shellfish harvesting and how the results from each tiered approach compared. One of three estuaries used to develop and evaluate the fecal coliform TMDL methodologies is an estuary on Kiawah Island that includes Bass and Cinder Creeks.

Data to support the development of the three-tiered approach for Bass and Cinder Creeks were provided by the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Geological Survey (USGS). Researchers at NOAA's Center for Coastal Environmental Health and Biomolecular Research have been studying the fate and transport of bacteria from tidal ponds on Kiawah Island to the receiving shellfish waters of Bass and Cinder Creeks. The Tetra Tech study used 4 years of continuous water-depth data in four ponds and one creek, precipitation data from one site, flow rates from the ponds to the creeks, and discrete sampling data for dry and wet weather conditions. In addition to the water-quality and hydrology data, NOAA had obtained detailed land-use and bathymetry data and had applied the 3D Environmental Fluid Dynamic Code (EFDC; Hamrick, 1992) model to Bass Creek, Cinder Creek, and the Stono River. To provide data to calibrate the EFDC model, the USGS computed a 21-day continuous record of tidal gage heights and streamflows for Bass and Cinder Creeks (fig. 1). In addition, tidal-cycle streamflow measurements were made at the mouth of Bass Creek and on the Stono River to characterize the streamflow dynamics near the ocean boundary of the 3D model.

Data Collection

To compute continuous tidal streamflows, hydrologists from the USGS instrumented two index-velocity sites on

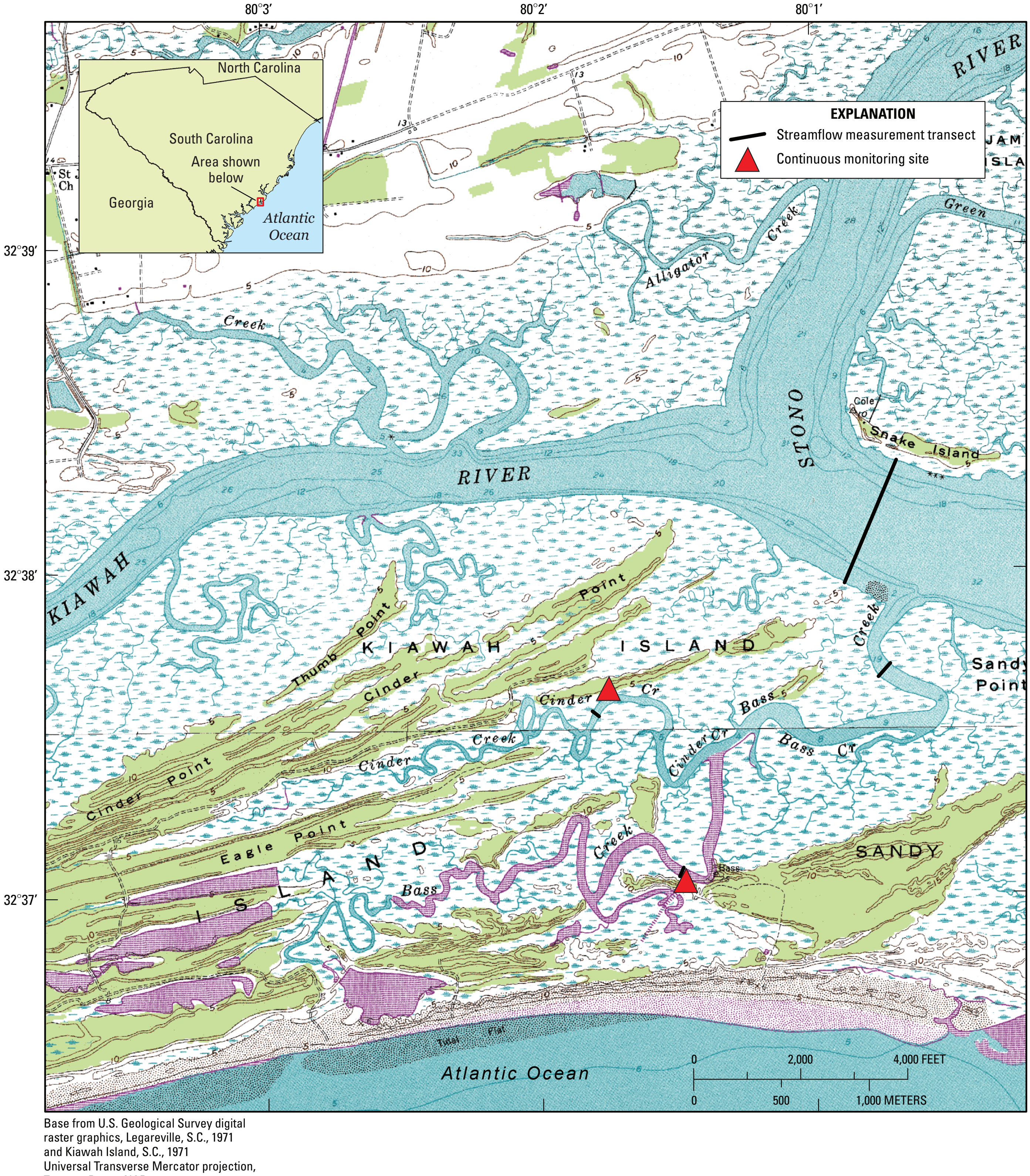

Figure 1. Location of continuous monitoring sites and streamflow measurement transects on Bass and Cinder Creeks and the Stono River.

Bass and Cinder Creeks with continuous acoustic velocity meters and water-level sensors (fig. 1). On Bass Creek, an instrumentation mount for the acoustic velocity meter was attached to the concrete revetment during low tide (fig. 2). On Cinder Creek, the instrumentation was attached to the public dock (fig. 3).

In addition to monitoring tidal velocities and gage heights, physical measurements of streamflow were made over two tidal cycles at the index-velocity sites. These measurements were used to develop stage-area curves for the index-velocity sites and for relating the index velocity to the mean velocity of the cross section. Tidal-cycle streamflow measurements also were made at the mouth of Bass Creek and on the Stono River to characterize the streamflow dynamics near the ocean boundary of the 3D model (fig. 1).

Figure 2. Views upstream and downstream on Bass Creek and of the instrumentation mount at the location of the continuous index-velocity site.

Figure 3. View downstream and of the public dock where the index-velocity instrumentation was attached on Cinder Creek.

Continuous Velocity and Gage-Height Data

The index-velocity sites were maintained from September 6, 2007, to September 27, 2007. The two sites were instrumented with Sontek Argonaut-SL (side-looker) acoustic Doppler velocity meters equipped with a vertical acoustic beam for measuring gage height (Sontek, 2008). The instruments were mounted approximately 3 feet (ft) above the bottom of the creeks. At Bass Creek, the velocity meter collected data in dynamic bin intervals from 22.97 to 65.62 ft (7 to 20 meters) from the instrument. At Cinder Creek, the dynamic bin intervals were from 3.28 to 32.81 ft (1 to 10 meters) from the instrument. Both sites used a 120-second averaging interval prior to the 15-minute data-collection interval. Figure 4 shows the 15-minute time series of gage height and velocity for Bass and Cinder Creeks, respectively. The data indicate a typical semi-diurnal tidal cycle of two low and high tides per day. Due to power supply problems, data are missing for Bass Creek from September 15–18, 2007, and for Cinder Creek from September 14–15, 2007. On Bass Creek, the offset, which is the difference between tape-down point elevation and the water-surface elevation when the acoustic velocity meter is set up, was lost in the data logger. The relative range of the gage-height values between September 18 and September 25 are correct but offset from the gage-height data of September 6–14, 2007. The two index-velocity sites were serviced on September 25, 2007, and a measured offset was entered into the Bass Creek data logger. During the data-collection period, the tidal range (elevation difference between one high and low tide) at Bass and Cinder Creeks ranged from 2 to 8 ft. The velocity time series data for the two sites are very similar. Maximum floodtide velocity (negative flows into the creek) was about 2 feet per second (ft/s) for the two creeks, and maximum ebbtide velocities (positive flows out of the creek) were 3.0 ft/s for Bass Creek and 2.5 ft/s for Cinder Creek.

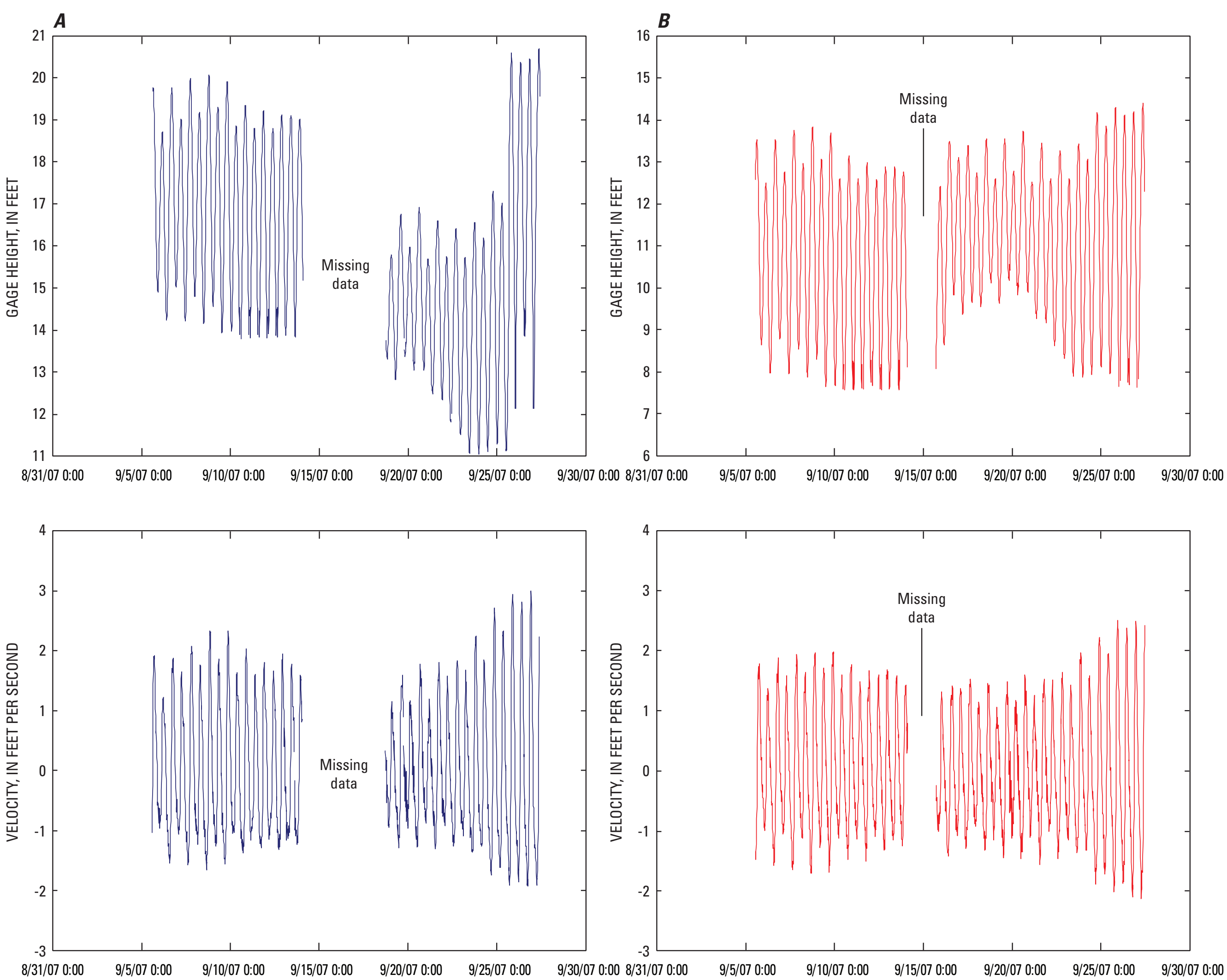

Figure 4. Gage heights and velocity for Bass Creek and Cinder Creek.

Discrete Streamflow Measurements

Twice during the 21-day deployment of the index-velocity gages, tidal-cycle streamflow measurements were made over a 10–13 hour period at four sites: the Stono River west of the mouth of Bass Creek, the mouth of Bass Creek, and the two index-velocity sites. Measurements were made with RD Instruments Rio Grande acoustic Doppler current profilers (1,200 kilohertz; RD Instruments, 2008) on September 6 and 26, 2007. Quality-assurance procedures described by Oberg and others (2005) were followed for the streamflow measurements. The measured streamflows for the four sites are shown in figures 5–8. Gage heights also are presented to show where in the tidal cycle the streamflow measurements were made. For the Stono River and mouth of Bass Creek streamflow measurements (figs. 5 and 6), gage heights from the NOAA, National Ocean Service, U.S. Customs House gage in Charleston Harbor with a 6-minute delay are shown. For measured streamflow at the two index-velocity sites (figs. 7 and 8), the gage heights are from the continuous monitor at each site.

The maximum floodtide and ebbtide measured during the 2 measurement days occurred on September 26, 2007, for all four sites (table 1). The maximum floodtide and ebbtide measured on the Stono River by the mouth of Bass Creek for the two measurement periods was –155,000 and 170,000 cubic feet per second (ft^3/s), respectively (table 1). At the mouth of Bass Creek, the maximum floodtide and ebbtide measurements during the 2 days was +/–10,200 ft^3/s. At the

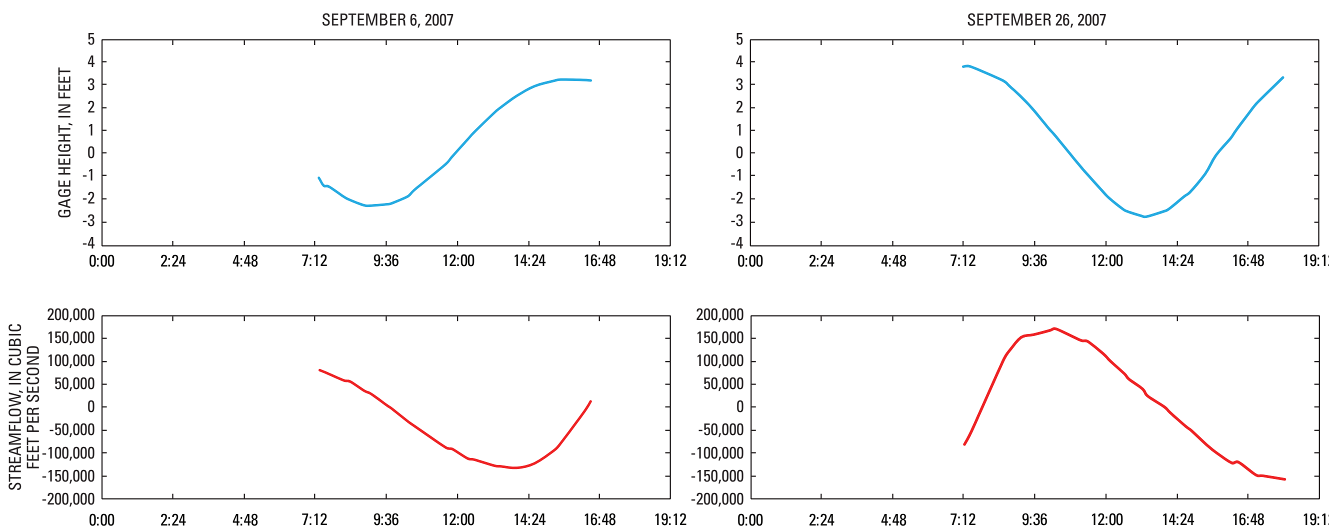

Figure 5. Measured streamflow on the Stono River and gage heights from the National Oceanic and Atmospheric Administration, National Ocean Service, U.S. Customs House gage for September 6 and 26, 2007.

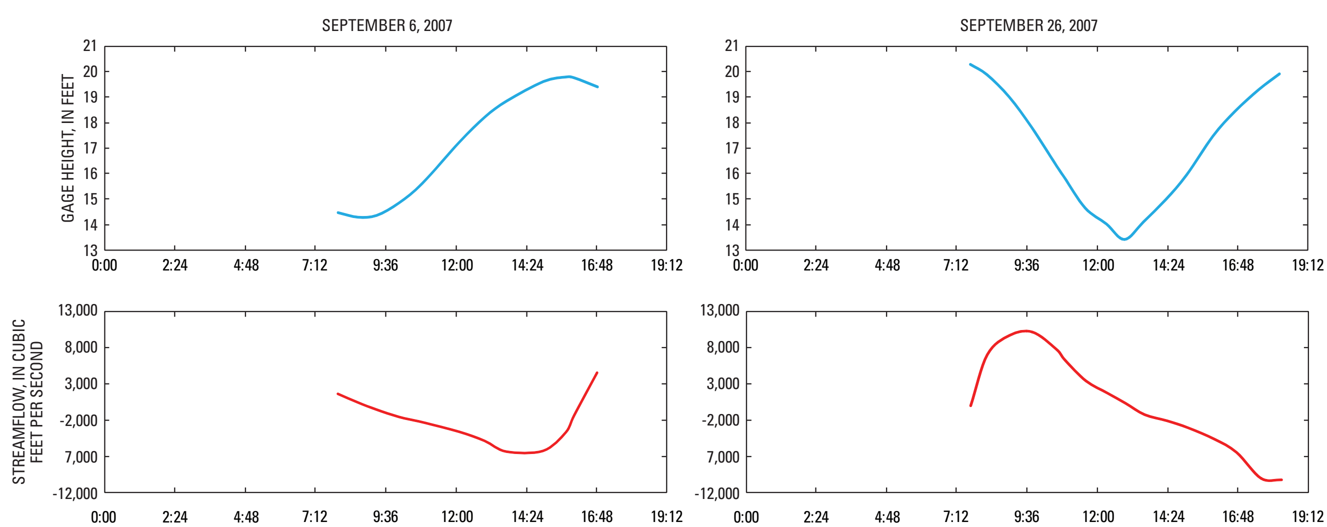

Figure 6. Measured streamflow at the mouth of Bass Creek and gage heights from the National Oceanic and Atmospheric Administration, National Ocean Service, U.S. Customs House gage for September 6 and 26, 2007.

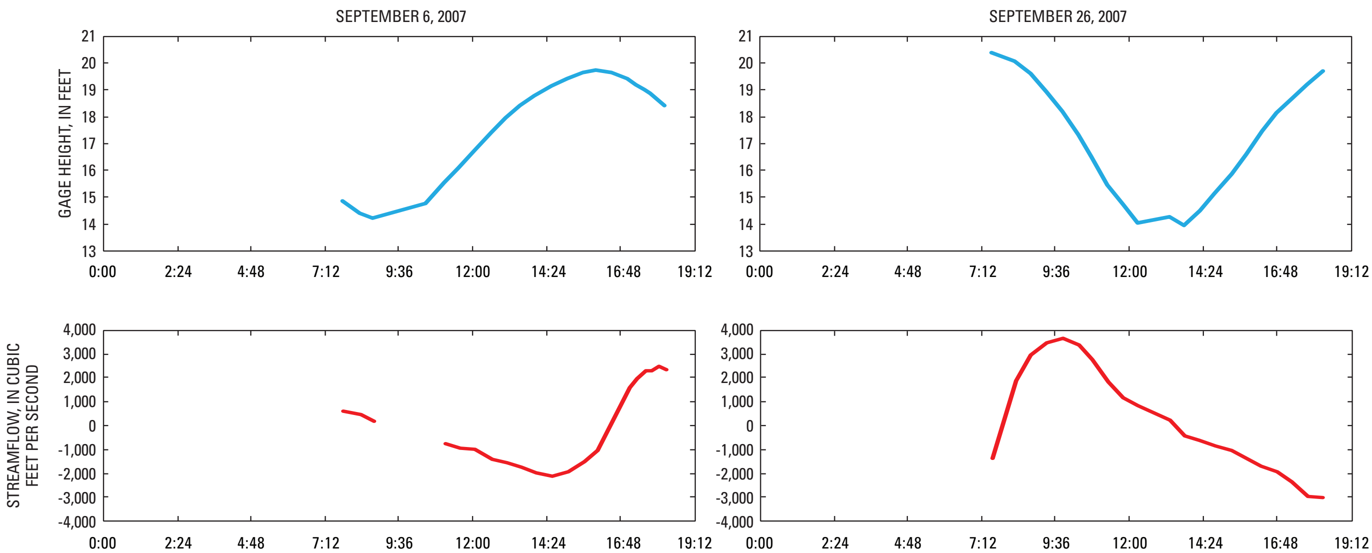

Figure 7. Measured streamflow and gage heights at Bass Creek for September 6 and 26, 2007.

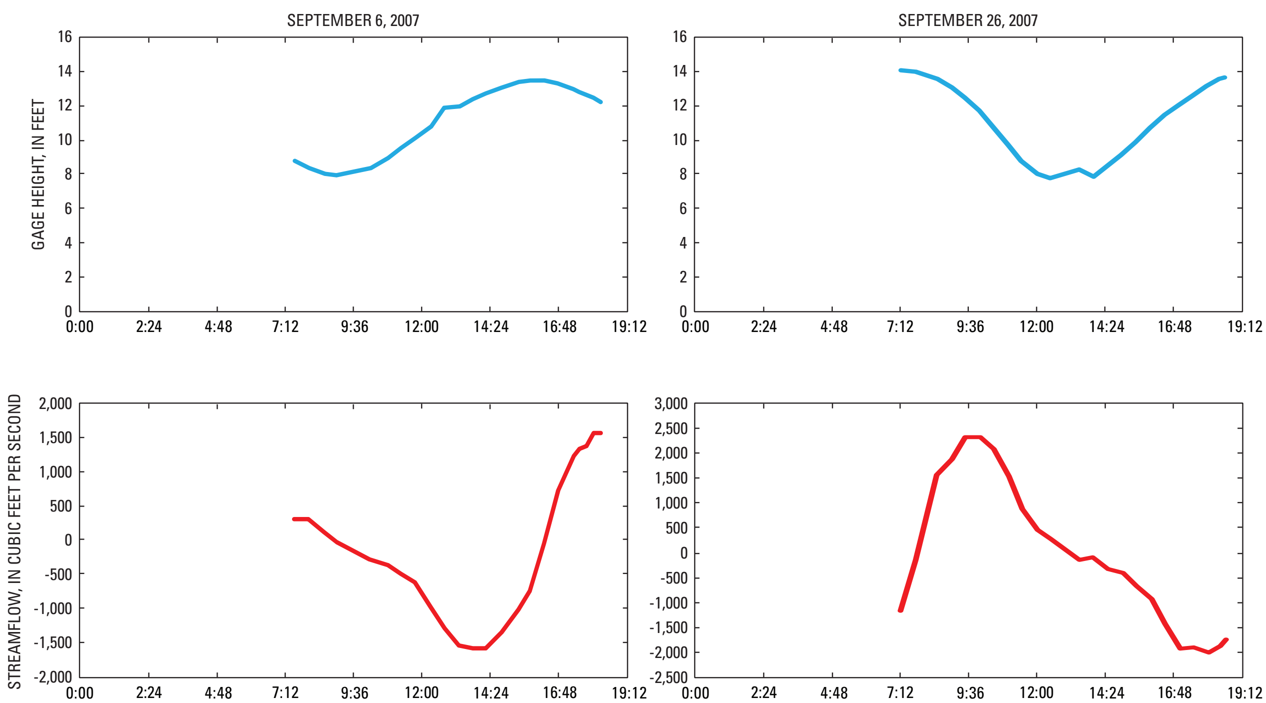

Figure 8. Measured streamflow and gage heights at Cinder Creek for September 6 and 26, 2007.

Table 1. Maximum streamflow measured during floodtide and ebbtide at four locations on Kiawah Island, South Carolina, on September 6 and 26, 2007.

[USGS, U.S. Geological Survey; ft³/s, cubic feet per second]

Location	USGS station number	September 6, 2007		September 26, 2007	
		Floodtide, ft³/s	Ebbtide, ft³/s	Floodtide, ft³/s	Ebbtide, ft³/s
Stono River	323821080004700	–133,000	80,800	–155,000	170,000
Mouth of Bass Creek	323702080012700	–6,320	4,600	–10,200	10,200
Bass Creek	323738080003900	–2,220	2,520	–3,010	3,640
Cinder Creek	323739080014400	–1,580	1,570	–2,010	2,320

two index-velocity sites, the maximum measured floodtide was –3,010 and –2,010 ft³/s at Bass and Cinder Creeks, respectively, and the maximum measured ebbtide was 3,640 and 2,320 ft³/s, respectively.

Computation of Continuous Streamflow Data

The computation of continuous streamflow record at the index-velocity sites was accomplished in three steps (Ruhl and Simpson, 2005). The first step was to develop stage-area curves to establish the relation between the tidal stage at the site and the cross-sectional area. The second step was to develop velocity ratings to convert the index velocity to a mean velocity for the cross section. The first two steps are accomplished using the data from the tidal-cycle streamflow measurements. The final step is computing the streamflow by multiplying the cross-sectional area (determined by the stage-area curve) by the mean velocity (computed by the velocity rating).

Estimation of Gage-Height Record for Bass Creek

Before computing the continuous streamflow for Bass and Cinder Creeks, the Bass Creek gage-height record for September 18–25, 2007, required correction. The concurrent gage-height records from September 6 to September 14 for the two index-velocity sites were used to estimate the gage-height record for Bass Creek for the period September 18–25. The gage-height data at the index-velocity sites are referenced to an abitrary datum and not tied to a vertical datum, such as the North American Vertical Datum of 1988. The difference in the mean gage heights for the concurrent period was computed (6.23 ft) and used to adjust the Cinder Creek gage heights to the values of the Bass Creek gage heights (fig. 9). The estimated values for Bass Creek for the concurrent period are accurate, and the coefficient of determination (R^2) between the measured and estimated gage heights is 0.9994.

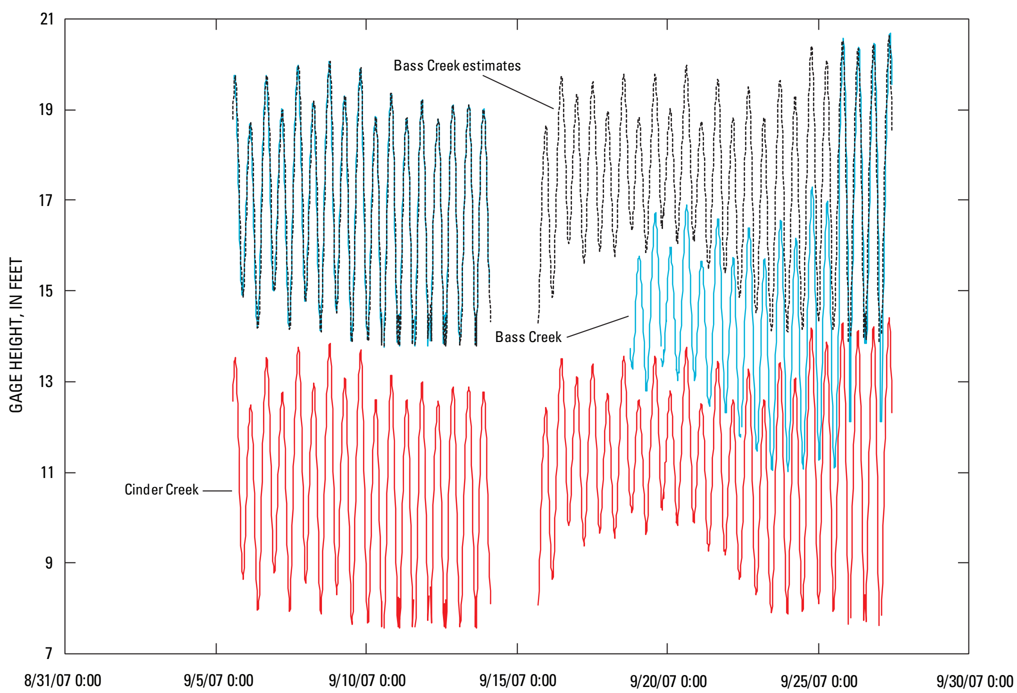

Figure 9. Gage-height hydrographs for Bass and Cinder Creeks and estimated gage heights for Bass Creek. Difference in mean gage heights for concurrent period of good data (September 6 to 14, 2007) is 6.23 feet, and the R^2 for Bass Creek estimates is 0.9994.

Development of Stage-Area Curves

The cross-sectional areas computed during the two tidal-cycle measurements were related to the measured gage heights at the time of the measurements for each index-velocity site. Stage-area curves that correlate the gage height to cross-sectional area were developed using linear regression (fig. 10). The coefficient of determination (R^2) for each site is high (>0.98), indicating that gage height represents the majority of the variability in cross-sectional area through the tidal cycle. The scatter of the measured area around the linear fit of data may be due to the streamflow measurements being made at slightly different locations.

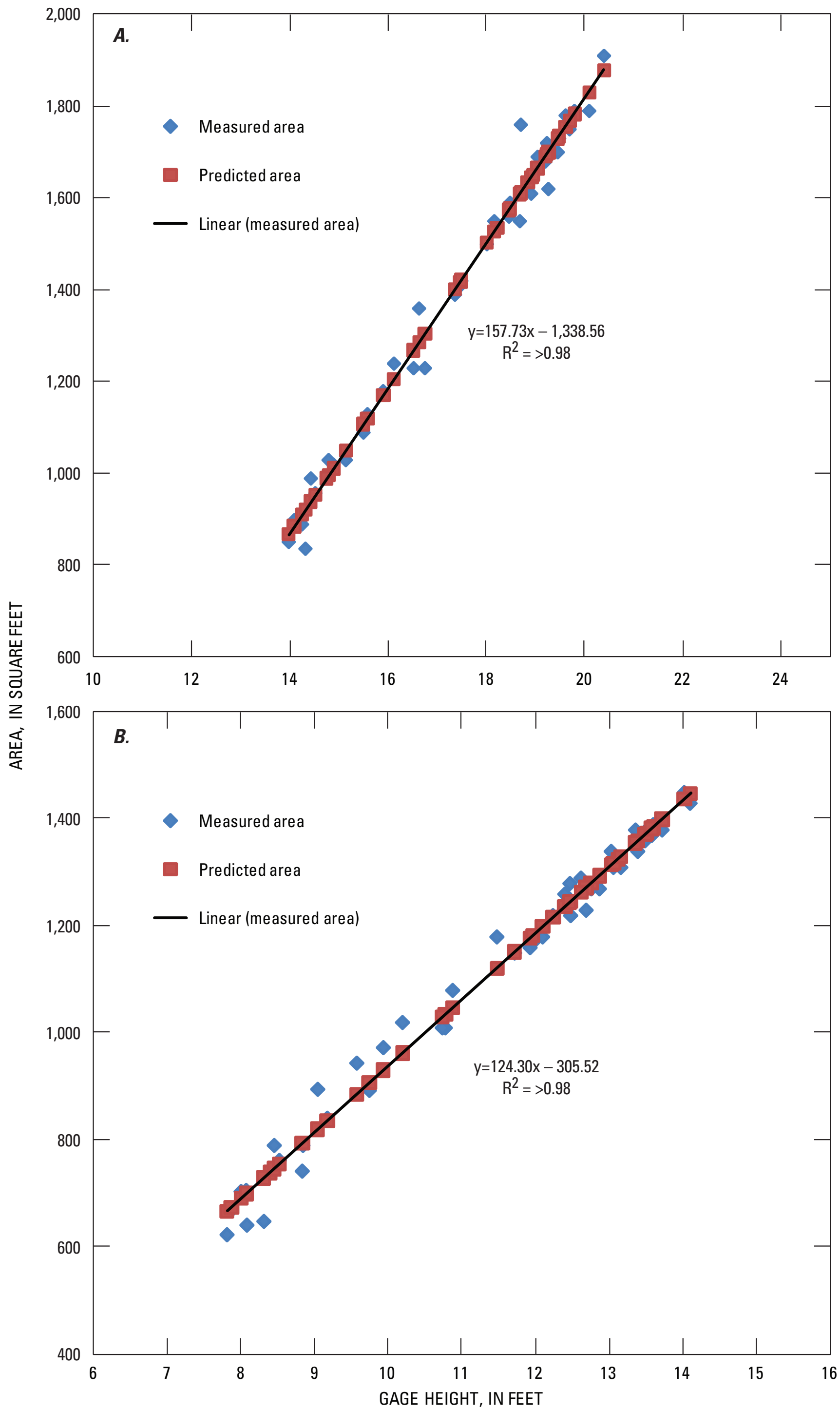

Figure 10. Stage-area curves for Bass and Cinder Creeks.

Development of Index-Velocity Ratings

Index-velocity meters measure an integrated line velocity in a particular part of the water column and is not a mean velocity for the cross section. In order to compute continuous streamflow at the index-velocity sites, the index velocities need to be adjusted to the mean velocity of the cross section. Mean measured velocities were computed from the tidal-cycle measurements made on September 6 and 26, 2007 (figs. 7 and 8), by dividing the measured streamflow by the area determined from the stage-area curve. Linear regression was used to correlate the index velocity to the mean measured velocity for the cross section for the two sites (fig. 11). The velocity rating covers a range of index velocities from –1.5 to 2.4 ft/s for Bass Creek and –1.5 to 2.0 ft/s for Cinder Creek. The R^2 for velocity ratings are greater than 0.99, indicating that the

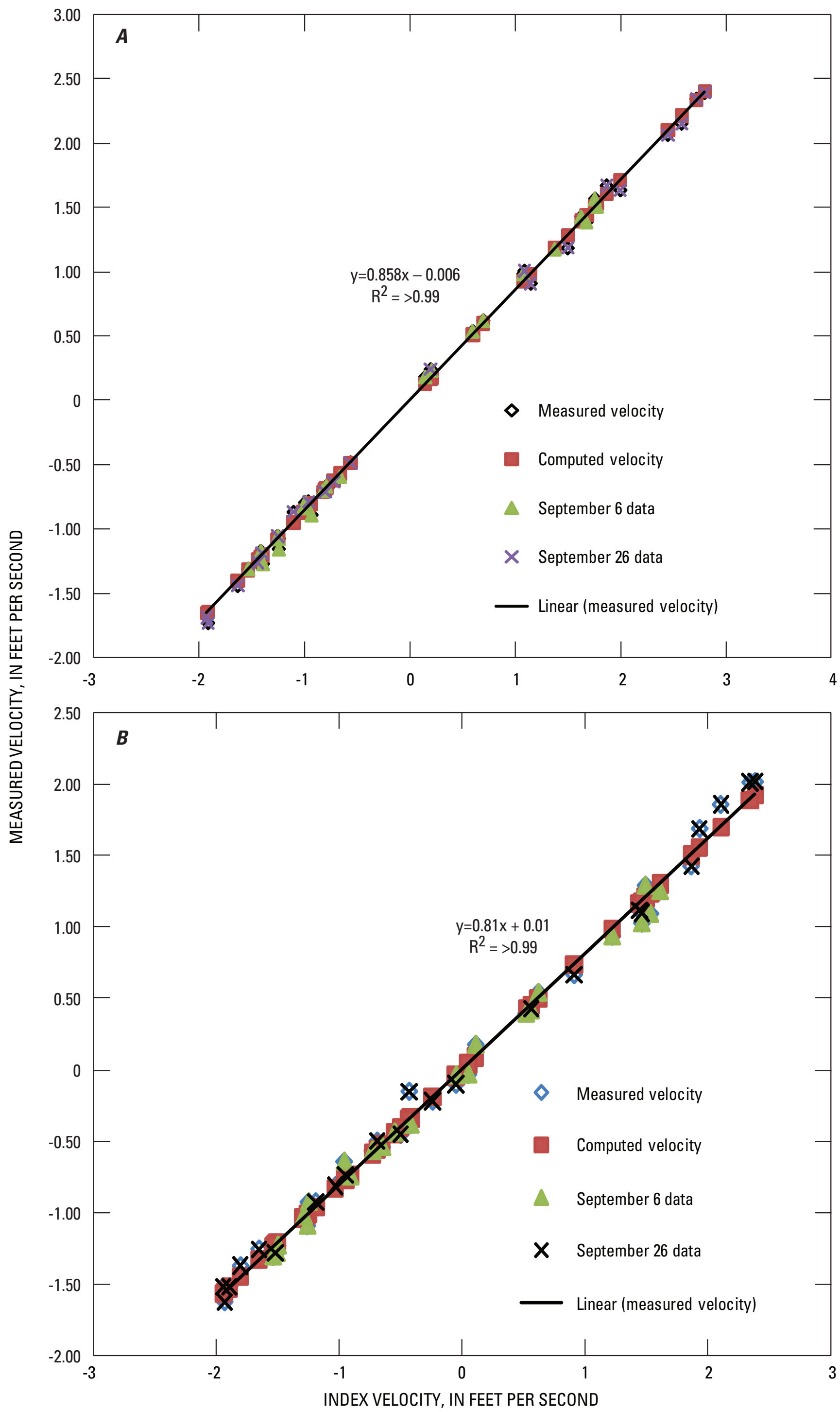

Figure 11. Velocity rating curves for Bass and Cinder Creeks.

regression explains about 99 percent of the variability between the index and mean cross-sectional velocity at the two sites.

The results of the development of the velocity rating also can be seen in the graph of the measured, indexed, and computed velocities for Cinder Creek for September 26, 2007 (fig. 12). The index-velocity meter measured higher ebb (positive) velocities and lower flood velocities (negative) than the measured mean velocities. To adjust the index velocity to the mean cross-sectional velocity, the velocity rating (linear regression) was computed for Cinder Creek (fig. 11B) to determine the mean cross-sectional velocity for the site.

Continuous Streamflow Record

The continuous (15-minute interval) streamflow data at the index-velocity sites are a product of the mean velocity and the cross-sectional area. The mean velocity is calculated from the 15-minute index-velocity data, and the cross-sectional area is computed from the 15-minute gage-height time series. For the period September 18–26, 2007, the estimated Bass Creek gage heights were used to determine the cross-sectional areas. Streamflow hydrographs for Bass and Cinder Creeks are shown in figure 13. The floodtide streamflows are similar on Bass Creek and Cinder Creek, with the streamflows slightly larger on Bass Creek. The maximum floodtide streamflow for Bass and Cinder Creeks was –2,510 and –2,180 ft^3/s, respectively, and occurred on September 26, 2007, at both sites. The maximum ebbtide streamflow for Bass and Cinder Creeks was 4,360 and 2,400 ft^3/s, respectively, and occurred on September 25, 2007, on Bass Creek and September 27, 2007, on Cinder Creek.

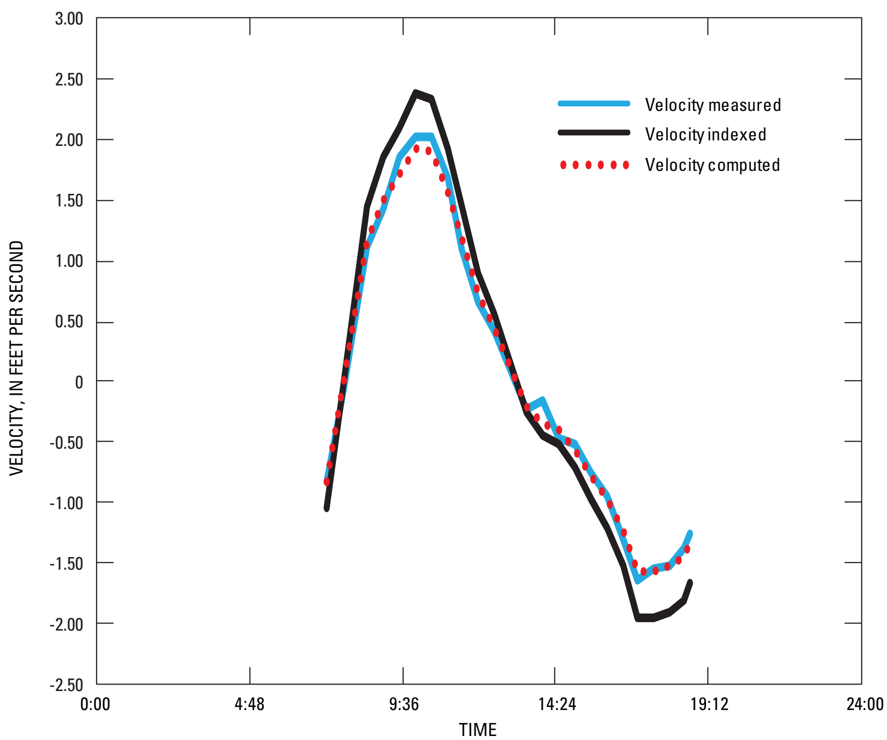

Figure 12. Measured, indexed, and computed velocities for Cinder Creek for September 26, 2007.

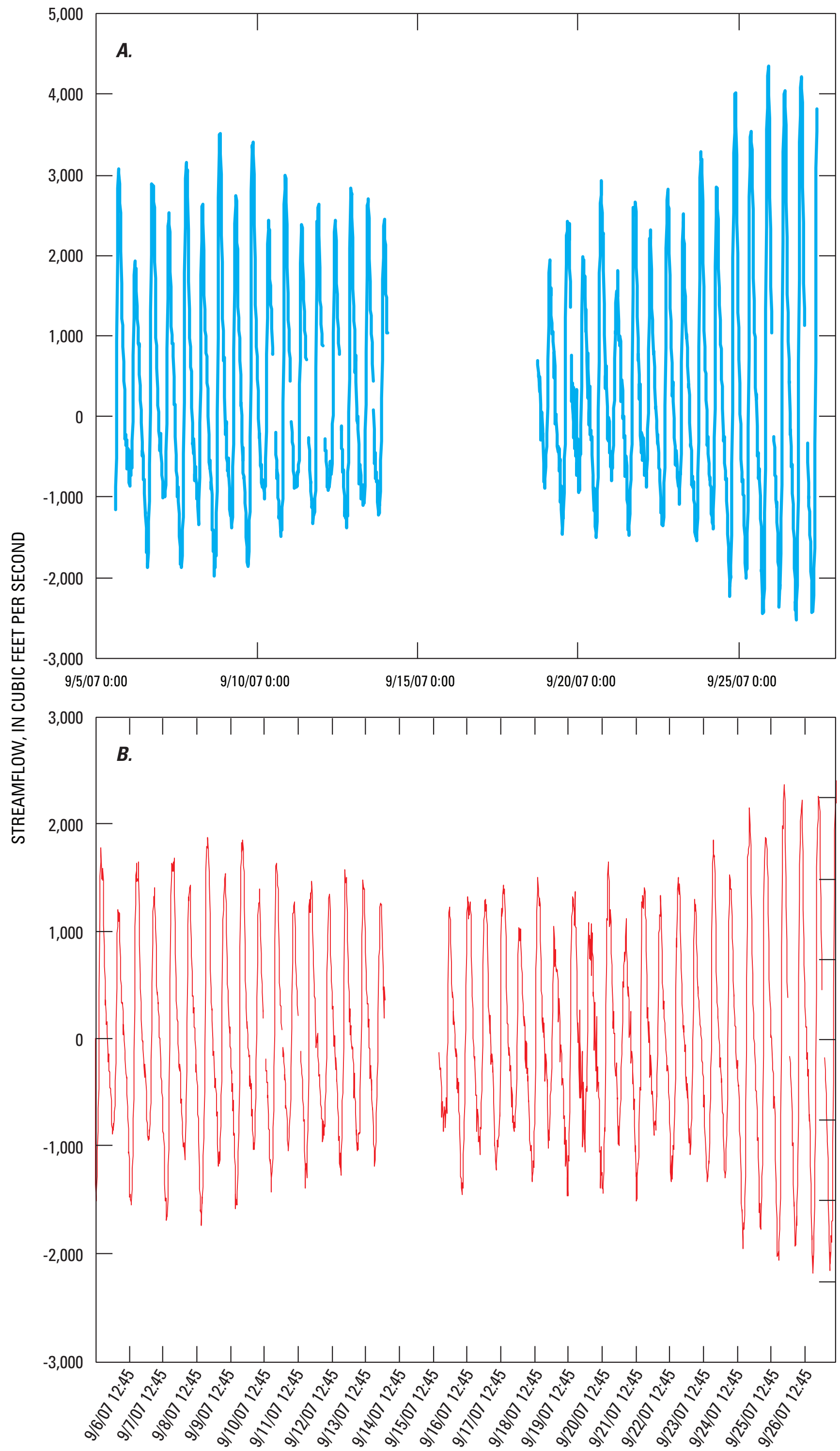

Figure 13. Streamflow hydrographs for Bass and Cinder Creeks.

Summary

The U.S. Environmental Protection Agency Region 4, through a contract with Tetra Tech, Inc., developed a methodology for a three-tiered approach for determining fecal coliform total maximum daily load for shellfish waters. An estuary that includes Bass and Cinder Creeks on Kiawah Island was one of three estuaries used to develop and evaluate the fecal coliform TMDL methodologies.

Data to support the development of the three-tiered approach for Bass and Cinder Creeks were provided by the National Oceanic and Atmospheric Administration and the U.S. Geological Survey. To provide data to calibrate the Environmental Fluid Dynamic Code model, hydrologists from the U.S. Geological Survey instrumented two index-velocity sites on Bass and Cinder Creeks with continuous acoustic velocity meters and water-level sensors to compute a 21-day continuous record of tidal streamflows. In addition to monitoring tidal cycles, streamflow measurements were made at the index-velocity sites, and tidal-cycle streamflow measurements were made at the mouth of Bass Creek and on the Stono River to characterize the streamflow dynamics near the ocean boundary of the three-dimensional model.

Tidal-cycle streamflow measurements were made over a 10–13 hour period at four sites during the 21-day deployment of the index-velocity sites. The maximum floodtide and ebbtide measured on the Stono River by the mouth of Bass Creek for the two measurement days were –155,000 and 170,000 ft^3/s, respectively. At the mouth of Bass Creek, the maximum floodtide and ebbtide measurements during the 2 days were +/–10,200 ft^3/s. Tidal streamflows for the 21-day deployment on Bass Creek ranged from –2,510 ft^3/s for an incoming tide to 4,360 ft^3/s for an outgoing tide. On Cinder Creek, the incoming and outgoing tide varied from –2,180 ft^3/s to 2,400 ft^3/s during the same period.

Acknowledgments

The authors thank the staff from the other agencies who participated in the Bass Creek study: Craig Hesterlee and Tim Wool of the U.S. Environmental Protection Agency Region 4; Thomas Siewicki and Scott Cross of the National Oceanic Atmospheric Administration; and Steven Davie and Edward Moye of Tetra Tech, Inc. The authors also thank Norm Shea, Director of Lake Management, Kiawah Island Community Association, for providing access to the gaging sites.

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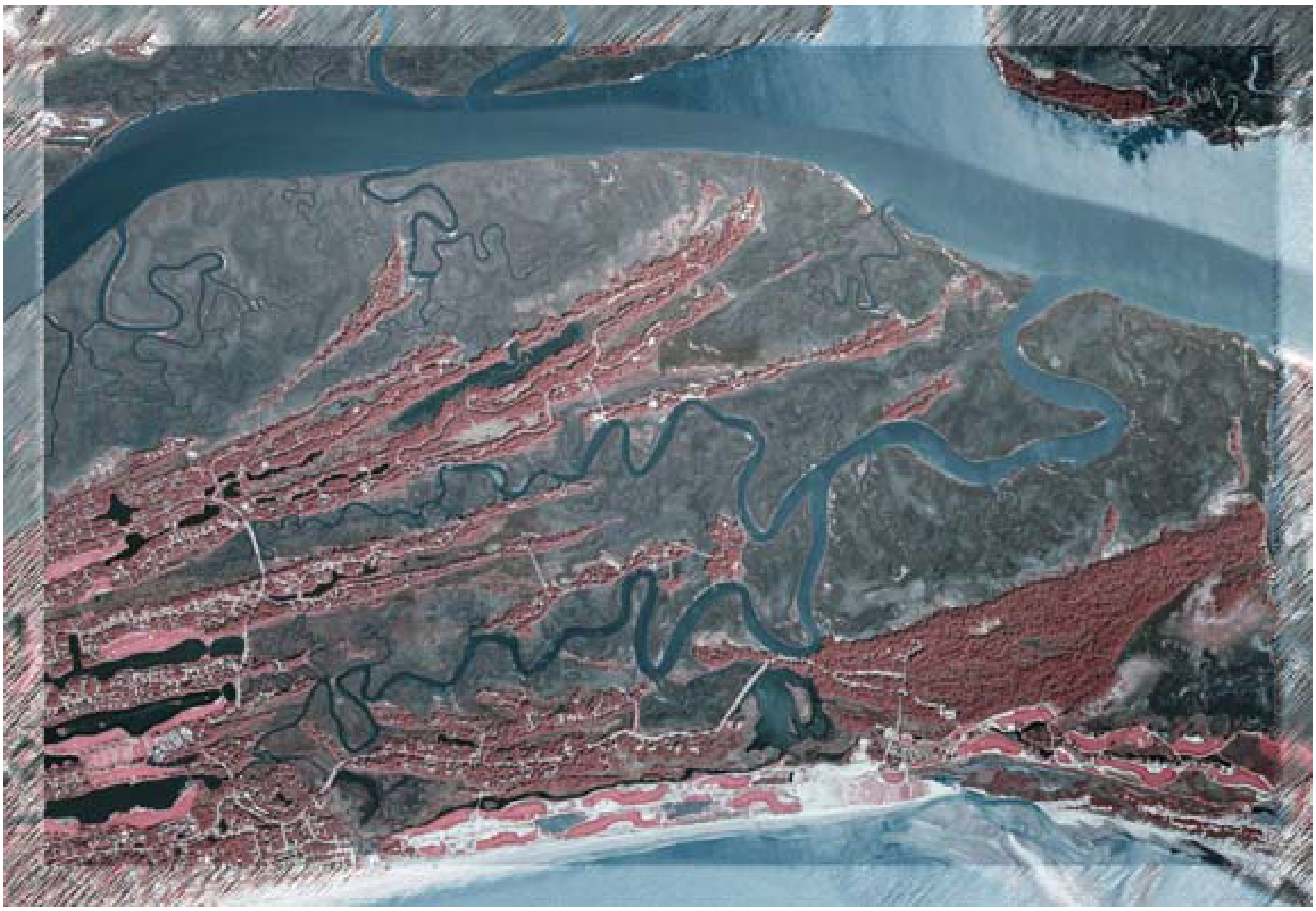

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