Tidal Flux Variation in the Lower Pearl River and Lake Pontchartrain Estuaries of Mississippi and Louisiana

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Abstract

Three tidal gages were constructed to collect hydraulic and water-quality properties that could be used to compute the tidal flux of the Pearl River and Lake Pontchartrain estuarine systems in Mississippi and Louisiana. The gages record continuous tidal stage, velocity, water temperature, specific conductance, and salinity, and transmit these data via the GOES satellite for output to a USGS real-time Internet portal. A 25-hour tidal study was completed during a maximum slack tide period in September 2001, which measured hydraulic and water-quality properties. These data were correlated with data recorded by the gages. Relations were developed for stage and area, and for an index acoustic velocity signal and average velocity. Continuous tidal inflow/outflow was computed for all three gages. Tidal effects were attenuated using a ninth-order Butterworth low-pass filter. Net inflows were recorded at two of three sites during the tidal study. The data will be used to help calibrate a regional RMA2 flow model.

Introduction

During 2000-2001, the U.S. Geological Survey (USGS), in cooperation with the Ocean Modeling and Prediction Division of the U.S. Naval Oceanographic Office (NAVOCEANO), constructed tidal gages at the East Pearl River at CSX Railroad near Claiborne, Mississippi, at the Rigolets at CSX Railroad near Rigolets, Louisiana, and at the Chef Menteur Pass at CSX Railroad at Chef Menteur, Louisiana, to collect data that could be used to compute the tidal flux of the Pearl River and Lake Pontchartrain estuarine systems in Mississippi and Louisiana. The gages record continuous tidal stage, velocity, water temperature, specific conductance, and salinity, and transmit these data via the National Oceanic and Atmospheric Administration's Geostationary Operational Environmental Satellite (GOES) for output to the USGS real-time Internet portal at:

http://water.usgs.gov/ms/nwis/rt

This effort provides tidal flow data that assist NAVOCEANO with the calibration and maintenance of a two-dimensional unsteady flow model (RMA2) for the Pearl River and Lake Pontchartrain estuaries in the northern Gulf of Mexico region.

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On September 13-14, 2001, during about a 25-hour low-flow tidal cycle, personnel of the U.S. Geological Survey measured discharge at the three gages, which represent major inlet/outlet conduits for the lower Pearl River and Lake Pontchartrain estuaries of Mississippi and Louisiana. Data were also collected to develop stage/area relations and to correlate several water-quality properties measured during the study with those being recorded at the gages. These data provide input to compute near-real time tidal discharge influencing Lake Pontchartrain and the Lower Pearl River estuaries. Due to the existence of numerous smaller outlets for flow in and out of the Pearl River and Lake Pontchartrain estuaries, the flows presented in this paper represent only the flows in and out of the three gaged bridges and are not representative of the entire tidal flux of these estuaries. Data presented in this paper are provisional and subject to change upon further review by personnel of the USGS.

Site Descriptions

The Pearl River and Lake Pontchartrain estuaries are located in southwestern Mississippi and southeastern Louisiana bordering the Gulf of Mexico (fig. 1). The estuarine systems of the lower Pearl River and Lake Pontchartrain in Mississippi and Louisiana are defined as the Pine Meadows of the East Gulf Coastal Plain regional geomorphic unit (Thornbury, 1965). The primary composition of the soils is recent alluvial deposits.

Mississippi has an average annual rainfall of about 68 inches near the Gulf of Mexico coast (Wax, 1990). Generally, about 70 percent of the annual rainfall occurs in the winter and early spring. Low streamflows generally occur in the late summer and early autumn. The area is affected by tropical depressions, storms, and hurricanes from the Gulf of Mexico, generally from about May through November. These tropical events can produce storm surges greater than 20 feet (Wilson and Hudson, 1969) and rainfall greater than 30 inches (Turnipseed and others, 1998).

The total drainage area of the Pearl River at the end of its definition is about 8,674 square miles. Channel-bed slopes in the vicinity of the East Pearl River at CSX Railroad near Claiborne, Mississippi, varies with tidal surge and is generally considered indeterminate, although surface-water slopes exist during runoff from upstream flood flow from the Pearl River drainage basin.

The drainage area of Lake Pontchartrain and associated estuaries at the Rigolets at the CSX Railroad near Rigolets, Louisiana, is about 5, 557 square miles. This drainage area includes the surface area of about 614 square miles from Lake Pontchartrain (Sloss, 1971). Slope in the vicinity varies with tidal surge and is generally considered indeterminate, although surface-water slopes exist during flood runoff from upstream flows. Drainage area can be considered indeterminate due to the existence of floodgates that allow for release of flood flow from the Mississippi River and other anthropogenic changes to the natural flow of the lake. The lower Pearl River and Lake Pontchartrain estuaries have their confluence with the Gulf of Mexico at Lake Bourne.

Figure 1. Location of three continuous recording stage, velocity, and water-quality parameter streamgages in the lower Pearl River and Lake Pontchartrain estuaries in Mississippi and Louisiana.

Tidal Discharge

Computing discharge in tidally affected estuaries historically has been difficult due to the unsteady flow conditions (i.e., constantly changing velocity and stage with respect to time). Measurement of discharge in these areas in recent years using ADCPs has documented, in detail, the hydraulic phenomena of tidal flow in riverine and estuarine systems, which previously could only be theorized with conventional discharge measuring techniques described by Rantz and others (1982). Turnipseed and Storm (1995) compared near simultaneous conventional and ADCP discharge measurements in tidally-affected riverine and estuarine systems near the Mississippi Gulf Coast during full downstream flows and found discharge measured by the ADCP to be within 5 percent of discharge measured by conventional methods. Simpson and Oltmann (1993) found that average cross-sectional velocities measured by the ADCP to be within 3 percent of those measured with conventional methods. Floyd (1997) described open-channel hydraulics in an estuarine environment from data gathered by ADCPs in a tidal study on the Jourdan and Pascagoula River estuaries in September 1996. Floyd detailed that when flow reversals occur from a rising tide in an estuary, the flow near the bottom of the river slows, stops, and then begins moving upstream due to the rising tide. Simultaneously, flow near the water surface slows, but continues in the downstream direction, while flow near the channel bottom is moving in the upstream direction. This phenomenon is commonly called bi-directional flow. Eventually, the rising tide completely reverses flow.

Data Collection

Water quantity is computed discretely by measuring tidal and estuarine flow through bridge openings with a 600-kHz ADCP in combination with the continuous collection of stage and velocity data at these sites. The ADCP is also used to measure and maintain accurate cross-sectional area at these sites.

The instrumentation to measure surface-water properties at the continuous data-collection stations consists of a SONTEK Argonaut-SL acoustic Doppler velocity meter (ADVM) to measure an index (point) velocity, (the use of firm, trade and (or) brand names in this report is for identification purposes only, and does not constitute endorsement by the U.S. Geological Survey) and a submersible pressure transducer, which measures the pressure of the standing water over the transducer, and converts pressure to stage. The ADVM measures velocity by transmitting a 1500-kHz frequency sound pulse into the water column about 50 feet, which is reflected off mostly sediment particles (i.e., the source of sound echoes) in the water. The submersible pressure transducer is vented to the atmosphere, therefore negating the effect of atmospheric pressure on the reading of water pressure. The tidal stage readings are automatically compensated for water temperature and density. Density in these measurements is estimated based on measured salinity. These data are continuously measured and recorded at 15-minute intervals. The configuration of instruments at the East Pearl River at the CSX Railroad near Claiborne, Mississippi, is typical of the configuration at all three gages in this area (fig. 2).

The ADCPs and ADVMs measure velocity using the Doppler shift theorem: if a source of sound is moving relative to the receiver of that sound, the frequency of the sound at the receiver changes from the original transmitted frequency. This change (known as the Doppler shift) can be accurately measured. Both instruments measure velocity by transmitting a sound pulse, which is reflected primarily off sediment particles in the water column. The ADVMs are capable of measuring inflow and outflow velocity vectors (negative and positive) of the tidal flow, as well as temperature.

During the tidal study, two boat-mounted 600-kHz ADCPs were used to measure discharge and area at the three study sites. The speed of sound in a fluid is affected by both density and temperature. Therefore, accurate definition of water temperature and salinity and their change with respect to time is needed to accurately measure velocity with an acoustic signal in a tidal estuary. Measurements of water temperature and specific conductance were made about every hour during the tidal study to verify recorded values of these parameters. According to the specifications of the SONTEK Argonaut-SL, water temperature changes of greater than 5 degrees Celsius (^{o}C) and salinity changes of greater than 12 parts per thousand (ppt) must occur before there is greater than a 1-percent change in the speed of sound. During the tidal study, the maximum range in measured water temperatures and salinity was about 3 ^{o}C and about 10 ppt, respectively. Therefore, it can be assumed that changes in water temperature and salinity had no significant effect on the speed of sound (hence velocity) measured by the ADVM during this study.

Results

Tidal Study Discharge measurements

East Pearl River at CSX Railroad near Claiborne, Mississippi. During the tidal study, 159 discharge measurements were made at this site, averaging one measurement about every 10 minutes. The maximum measured inflow and outflow discharges at this site were –36,800 cubic feet per second (ft^3/s) and 50,200 ft^3/s, respectively (fig. 3). The average measured discharge was 10,000 ft^3/s, which is attributable to rainfall runoff in the lower basin in early September. The average monthly discharge at the Pearl River at Bogalusa, Louisiana, in September 2001 was 12,200 ft^3/s. The range in computed stage was 1.28 to 3.00 ft above sea level (1.72 ft difference). The average stage was 2.18 ft above sea level.

The Rigolets at CSX Railroad near Rigolets, Louisiana. During the tidal study, 47 discharge measurements were made at this site, averaging one measurement about every 34 minutes. The maximum measured inflow and outflow discharges at this site were –235,000 ft^3/s and 201,000 ft^3/s, respectively (fig. 3). The average measured discharge was -27,900 ft^3/s. Negative average discharge at this site is attributed to the existence of numerous unmeasured outlets from the estuaries where outflow could be exiting the estuarine system rather than passing through the gaged bridge.

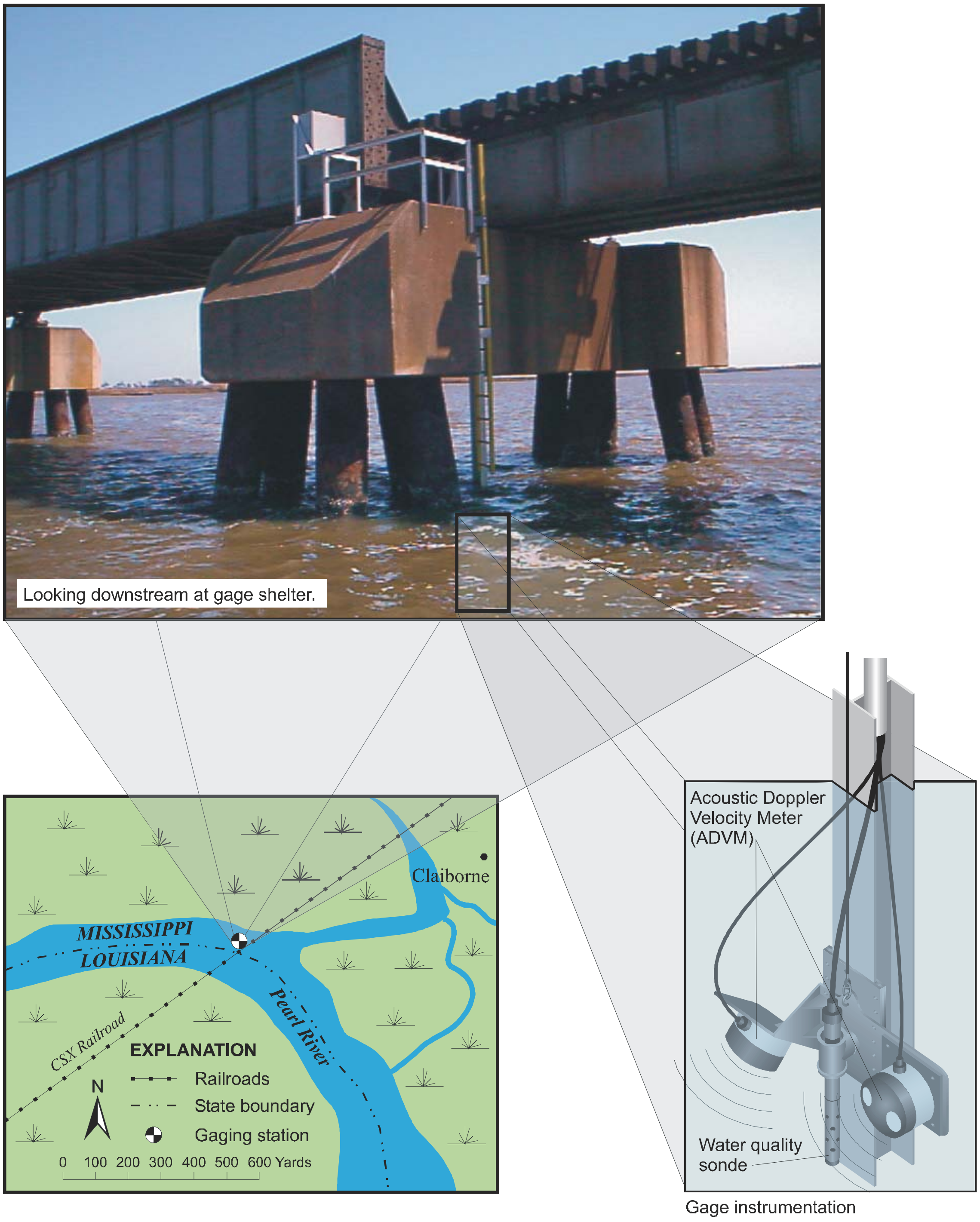

Figure 2. Plan view of the USGS continuous recording stage, velocity, and water-quality parameter streamgage at the East Pearl River at CSX Railroad near Claiborne, Mississippi, with inset of gage instrumentation.

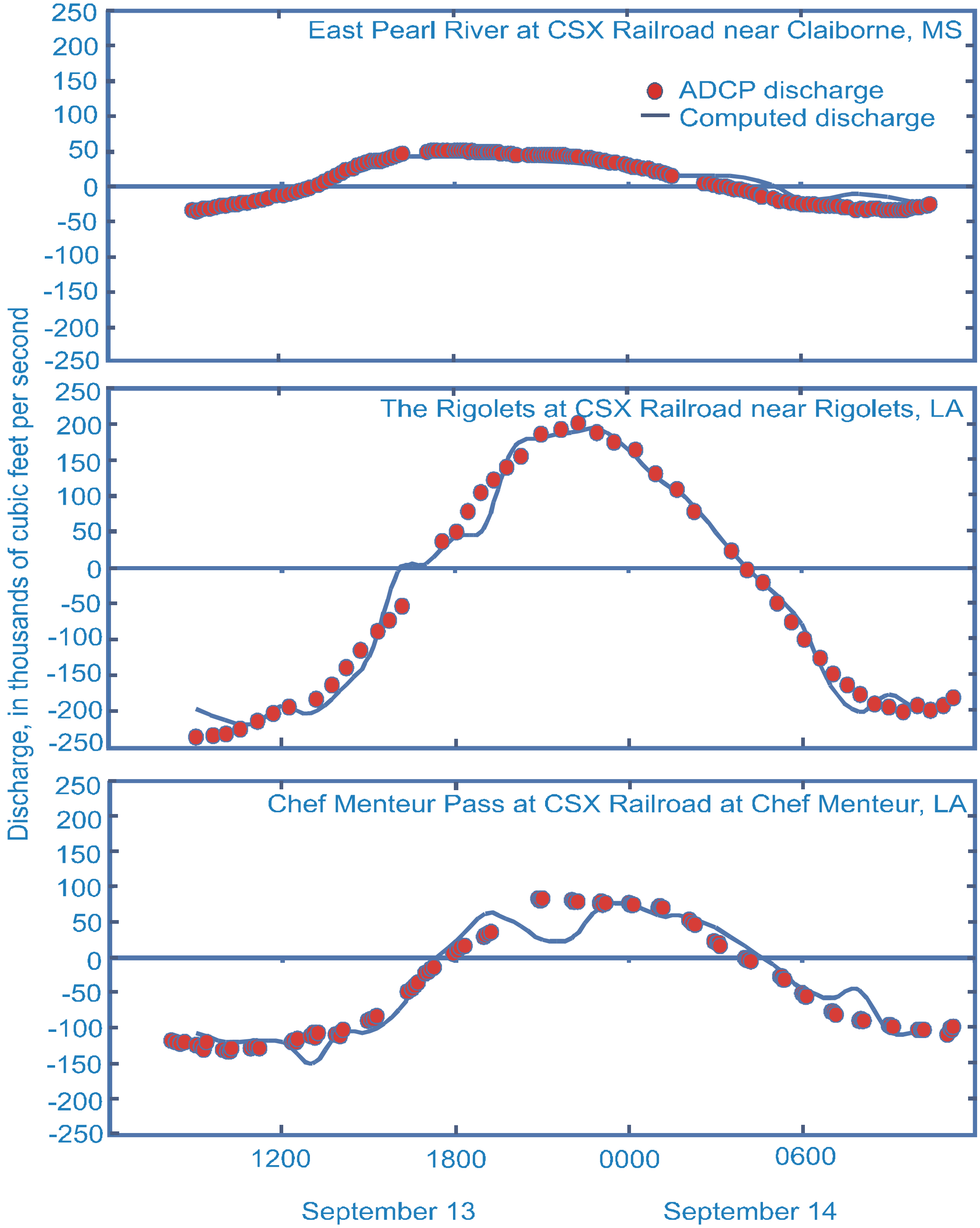

Figure 3.--ADCP measured discharge and computed discharge from index velocity ratings at three gages in the lower Pearl River and Lake Pontchartrain estuaries of Mississippi and Louisiana.

Also, changing tides can result in temporary storage of water. The range in computed stage was 1.50 to 2.80 ft above sea level (1.30 ft difference). The average measured stage was 2.10 ft above sea level.

Chef Menteur Pass at CSX Railroad at Chef Menteur, Louisiana. During the 25–hour tidal study, 111 discharge measurements were made at this site. Measurements were made just before and after each hour and then averaged. The maximum measured inflow and outflow discharges at this site were –131,000 ft^3/s and 84,400 ft^3/s, respectively (fig. 3). The average measured discharge was -25,700 ft^3/s. Negative average discharge at this site is attributed to the existence of numerous unmeasured outlets from the estuaries where outflow could be exiting the estuarine system rather than passing through the gaged bridge. Also, changing tides can result in temporary storage of water. The range in computed stage was 11.69 to 13.18 ft above an assumed datum (1.49 ft difference). The average stage was 12.33 ft above an assumed datum.

Continuous Unsteady Discharge Computation

Discharge was measured for unsteady flow conditions at the three gages by using boat-mounted ADCPs during the tidal study and during regular gage-maintenance trips. Typical cross sections for all three gages were derived from selected ADCP measured depths and distances. Stage/area ratings were developed from these cross sections (fig. 4).

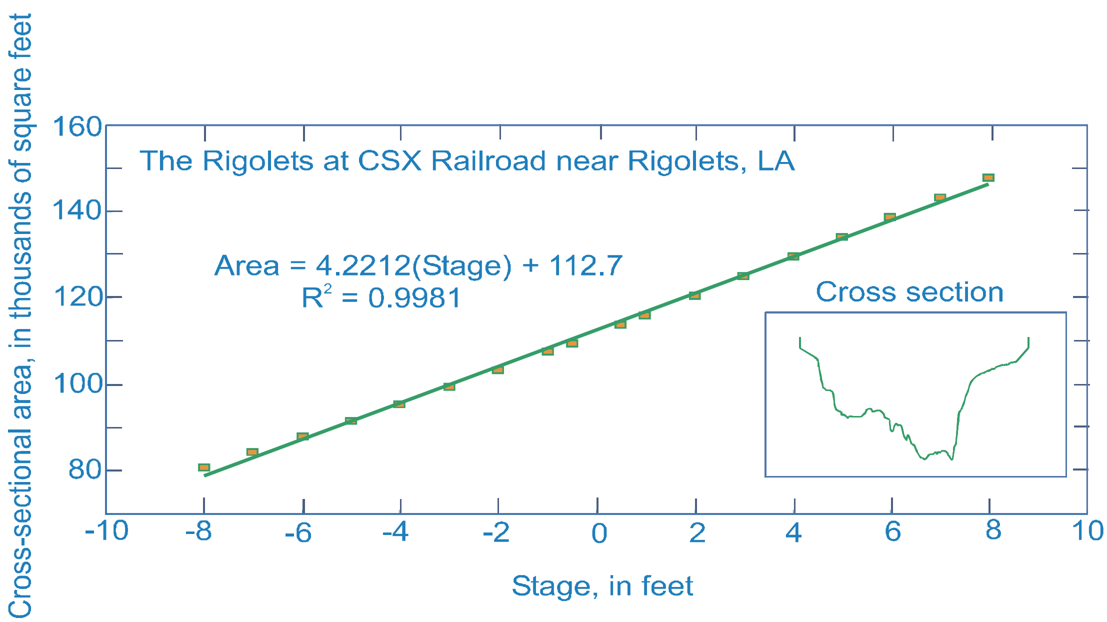

Figure 4.-- Stage / area velocity relations developed from ADCP sounded cross sections surveyed September 13-14, 2001, at the Rigolets at CSX Railroad near Rigolets, Louisiana.

Relations were also developed between the average velocity and the instantaneous velocity computed from the ADVM. Average velocity for the cross section was computed from measured total discharge divided by total area. The product of an average velocity for the entire channel cross section (derived from a linear regression of average velocity and instantaneous velocity) and an area for a given range in gage height from -2.0 to 8.0 ft above sea level was used to compute discharge during low-flow periods that were affected by tidal fluctuation. Results (i.e., y-offsets (in feet above sea level), slopes, and coefficients of determination (R^2 – a dimensionless coefficient that represents the proportion of variability of the instantaneous velocity that is accounted for the by the average velocity)) of a linear regression computed for average velocity / ADVM velocity relations for the three gages follow:

Site name	y-offset (feet)	Slope	R^2
East Pearl River at CSX Railroad near Claiborne, MS	0.118	0.8633	0.9456
The Rigolets at CSX Railroad near Rigolets, LA	0.0437	0.6147	0.9794
Chef Menteur Pass at CSX Railroad at Chef Menteur, LA	0.9076	0.4954	0.9099

Average velocity/instantaneous velocity relations were relatively good for the three sites as shown in the average velocity/instantaneous velocity relation developed for the gage at the Rigolets at CSX Railroad near Rigolets, Louisiana (fig. 5).

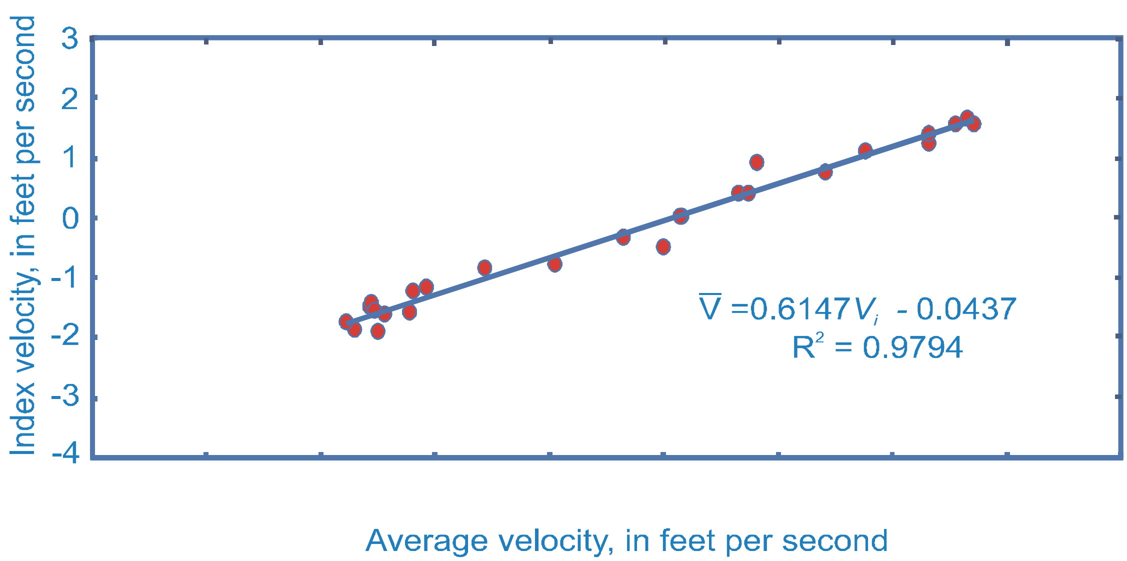

Figure 5.--Average velocity ($\overline{V}$) / index velocity (V_i) relations developed from ADCP discharge measurements, cross-sectional surveys and ADVM velocities collected during September 13-14, 2001, at the Rigolets at CSX Railroad near Rigolets, Louisiana.

Discharges computed from the stage/area and index velocity ratings at these gages correlated fairly well with discharges measured during the tidal study (fig. 3).

Numerous outlets exist for the lower Pearl River and Lake Pontchartrain estuaries that were not measured. This, in combination with continually changing tides, extreme spring tide and base-flow conditions in the basin, helps to explain why the average measured discharge at the Rigolets at CSX Railroad near Rigolets, Louisiana, and Chef Menteur Pass at CSX Railroad at Chef Menteur, Louisiana, were inflow (negative) discharges.

To better characterize outflow from the estuaries, 15-minute continuous stage and discharge data were filtered using a 9th-order Butterworth low-pass filter, which flattens tidal waves to provide a synthetic data set with no apparent tidal effect (fig. 6). After removing the tidal effect in the months of September and October 2001, the Butterworth low-pass filtered data indicate that in base flow conditions, temporary estuarine storage of water occurs in sequential spring tide cycles in September and October at these sites. Due to the existence of unmeasured outlets in these estuaries the data are not conclusive.

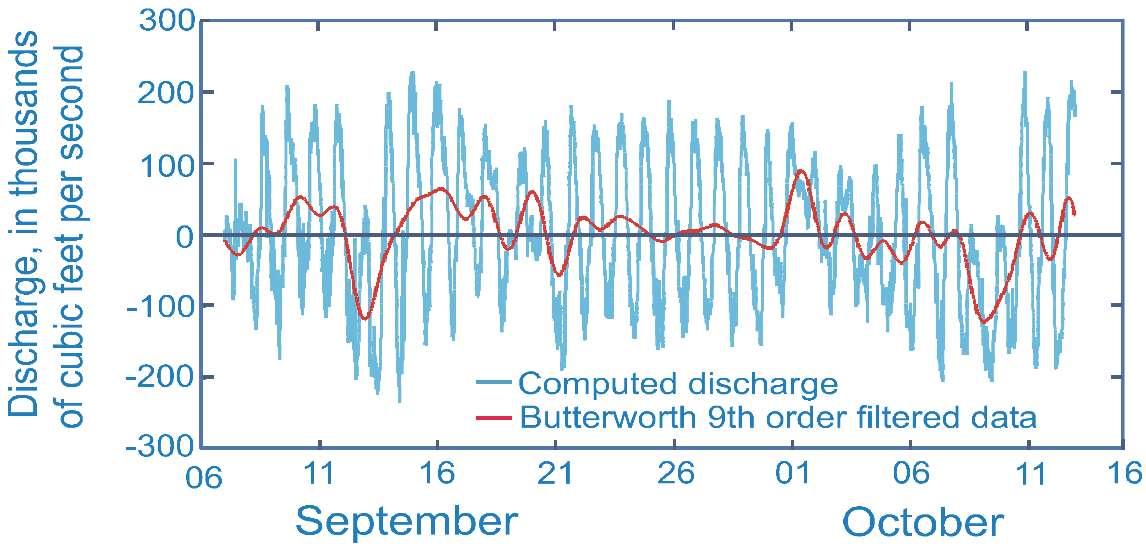

Figure 6.--Computed discharge and filtered discharge using a Butterworth 9th order filter showing periods of temporary storage of tidal flow from September 7-October 12, 2001 at the Rigolets at CSX Railroad near Rigolets, Louisiana.

Summary

The U.S. Geological Survey, in cooperation with NAVOCEANO, is collecting data on the quantity and quality of water in the lower Pearl River and Lake Pontchartrain estuaries of Mississippi and Louisiana. Continuous stage, velocity, water temperature, specific conductance and salinity data, as well as other channel characteristics have been collected, processed, and computed since October 2001 at three USGS continuous recording streamgages in the lower Pearl River and Lake Pontchartrain estuaries in Mississippi and Louisiana. A tidal study to measure hydraulic and hydrologic parameters was completed on September 13-14, 2001. The tidal study provided data to correlate continuously recorded surface-water data at the three gages and to construct a means of computing continuous discharge at these sites. Analysis of the discharge data indicated that temporary storage of tidal data could occur in these estuaries during low riverine outflows and maximum spring tide conditions. This research provides stage/discharge information through time at these three gages, as well as a variety of other characteristics of the lower river reaches of the Pearl River and Lake Pontchartrain Basins.

References

Floyd, P. C., (1997). "Measurements of tidal effects on stage and discharge on the Jourdan and Pascagoula Rivers near the Mississippi Gulf Coast." *Proceedings of the 27th Mississippi Water Resources Conference (March 25-26, 1997)*, Jackson, MS, 35-41.

Rantz S.E., and others, (1982). "Measurement and computation of streamflow—Volume 1: Measurement of stage and discharge." *U.S. Geological Survey Water-Supply Paper 2175.*

Simpson M.R., and Oltmann, R.N.., (1993). "Discharge measurement system using an acoustic Doppler current profiler with applications to large rivers and estuaries." *U.S. Geological Survey Water Supply Paper 2395.*

Sloss, R., (1971) *Drainage area of Louisiana streams,* State of Louisiana Department of Transportation and Development Basic Records Report No. 6 (Reprinted 1991).

Thornbury, W. D., (1965) *Regional geomorphology of the United States,* John Wiley & Sons, Inc.

Turnipseed, D.P., Giese, G.L., Pearman, J.L., Farris, G.S., Krohn, M.D., and Sallenger, A. H., Jr., (1998). "Hurricane Georges: Headwater flooding, storm surge, beach erosion and habitat destruction on the Central Gulf Coast." *U.S. Geological Survey Water-Resources Investigations Report 98-4231*.

Turnipseed, D.P., and Storm, J.B., (1995). "Streamflow characteristics of the lower Pascagoula River, Mississippi." *Proceedings of the 25th Mississippi Water Resources Conference (April 11-12, 1995),* Jackson, MS, 258-268.

Wax, C.L., (1990). "General Climatology of Mississippi--Floods and Droughts." *National Water Summary 1988--Hydrologic Events and Floods and Droughts, USGS Water Supply Paper 2375,* Reston, VA.

Wilson, K.V., Sr., and Hudson, J.W., (1969). "Hurricane Camille tidal flooding of August 1969 along the Gulf Coast, Pass Christian quadrangle, Mississippi" *U.S. Geological Survey Hydrologic Investigations Atlas HA-402*.