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MEASUREMENT OF TIDAL FLUX FOR THE LOWER PEARL RIVER AND LAKE PONTCHARTRAIN ESTUARIES OF MISSISSIPPI AND LOUISIANA USING ACOUSTIC DOPPLER VELOCITY TECHNOLOGY

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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 assist in computing the tidal flux of the Pearl River and Lake Pontchartrain estuarine systems in Mississippi and Louisiana. Each gage records continuous tidal stage, velocity, water temperature, specific conductance, and salinity, and transmits these data via satellite 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 the RMA2 flow model for the Pearl River and Lake Pontchartrain estuaries in the northern Gulf of Mexico region in Mississippi and Louisiana.

On September 13-14, 2001, during about a 25-hour low-flow tidal cycle personnel of the U.S. Geological Survey measured discharge at three CSX Railroad crossings. These railroad crossings represent the major inlet/outlet conduits for Lake Pontchartrain, 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 small outlets for flow in and out of the Pearl River and Lake Pontchartrain estuaries, the surface-water and water-quality data presented in this paper represent only conditions 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 revision upon further review by 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 (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 8,670 square miles. The drainage area of Lake Pontchartrain and associated estuaries at the Rigolets in Louisiana,--including the surface area of about 614 square miles from Lake Pontchartrain--is about 5,560 square miles (Sloss, 1971). Lake Pontchartrain has several outlets other than the Rigolets. Drainage area at the Rigolets 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. Surface-water slopes in the vicinity at both sites vary with tidal surge and are generally considered indeterminate, although surface-water slopes exist during flood runoff from upstream flows. The lower Pearl River and Lake Pontchartrain estuaries have their confluence with the Gulf of Mexico at Lake Bourne.

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 acoustic Doppler current profilers (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). The ADCP is an instrument that profiles a three-dimensional array of velocity and also measures position and depth, which allows for the calculation of discharge across a given channel section. The ADCP measures three-dimensional velocity using four downward-pointed transducers, set in a Janus configuration, that transmit and receive sonic pulses backscattered from sediment particles throughout the water column. It also measures position, boat speed, and depth of the water column using an internal compass and data obtained from the four-transducer assembly. The instrument is driven by a 12-volt battery and a laptop computer in the boat. A significant problem is introduced if there is channel-bed movement, which results in the ADCP appearing to move in reverse to the channel-bed movement (that is, the ADCP appears to move upstream in a river environment in which the channel bed is moving downstream). However, no channel bed movement was apparent during the tidal study at these sites.

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 due to a rising tide in an estuary, the flow near the bottom of the river slows, stops, and then begins moving upstream as the tide rises. 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.

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.

SURFACE-WATER 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 parameters 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.

WATER-QUALITY DATA COLLECTION

Data collection to characterize the quality of the water in these estuaries consists of the collection of discrete water samples to calibrate in situ water-quality monitors, which continuously record water temperature, specific conductance, and salinity. All three gages are equipped with water-quality probes, which measure water temperature and specific conductance, and compute salinity from measurements of specific conductance and water temperature at 15-minute intervals.

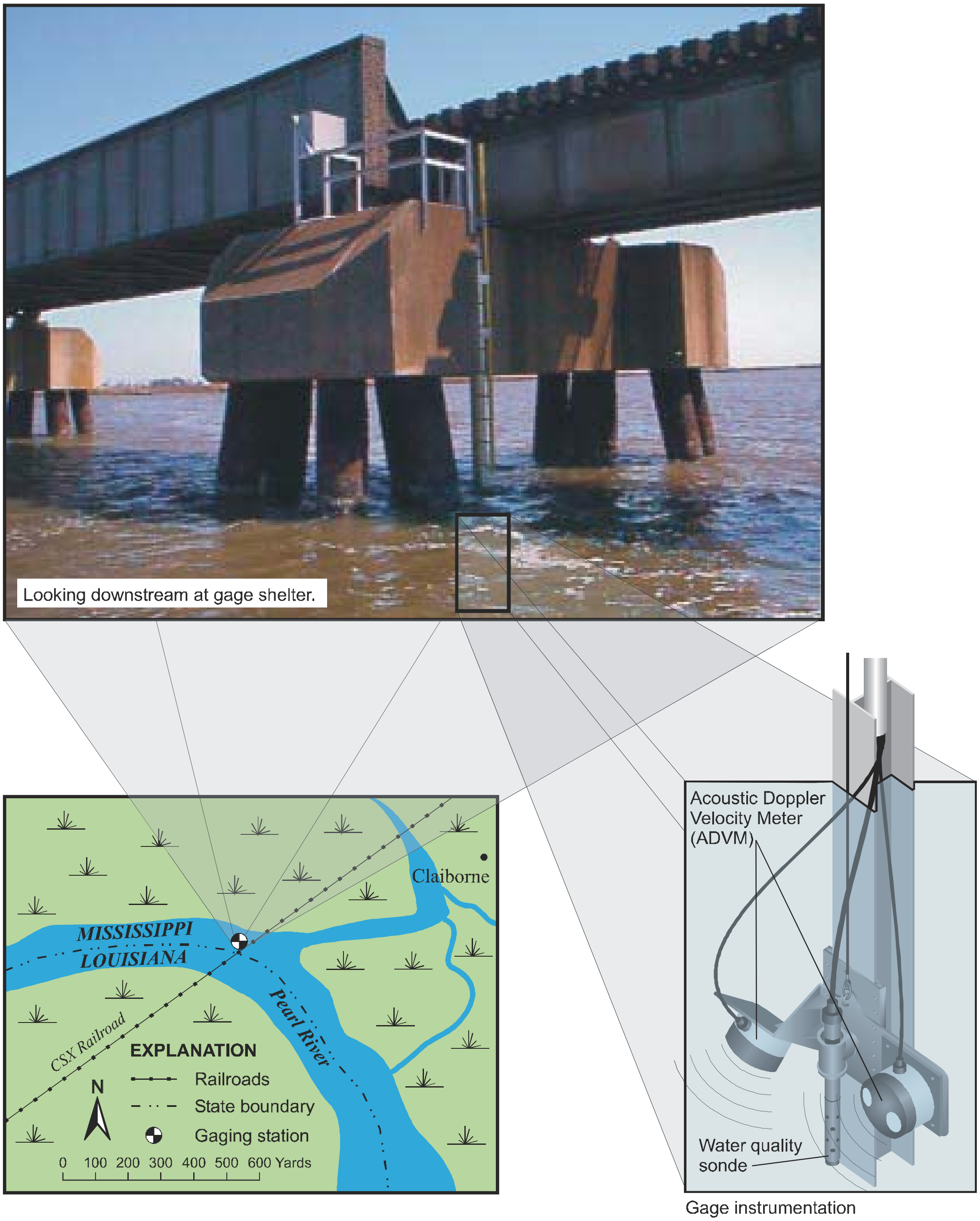

Figure 2. Plan view of the USGS continuous recording stage, velocity, and water quality parameter streamgage at the East Pearl River at CSX Railroad near Claiborne, Mississippi, with inset of gage instrumentation.

During the tidal study of September 13-14, 2001, at the Rigolets and East Pearl gages, independent measurements of temperature and specific conductance were made at about 25, 50, and 75 percent of the cross-sectional width at a depth of approximately 1 foot to note changes in these parameters during the study and to correlate with in situ measurements at the gages. Water temperature and specific conductance data measured during the study were later used to adjust speed of sound in the computation of discharge from the ADCP transects.

PRELIMINARY RESULTS

Preliminary results of tidal study discharge measurements, continuous unsteady discharge computations, and tidal study water-quality measurements are described in the following section. Continuous discharge measurements were made at all three gages during the September 13-14, 2001 tidal study, but the timing between measurements was irregular; therefore, an average discharge at 1-hour intervals was computed by interpolating between discharge measurements and then averaging the 1-hour discharges for the tidal cycle (25 hours). This same method was used to compute tidal stage, water temperature, specific conductance, and salinity data.

Tidal Study Discharge Measurements

<u>East Pearl River at CSX Railroad near Claiborne, Mississippi</u>. During the tidal study, 159 discharge measurements were made at the 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.

<u>The Rigolets at CSX Railroad near Rigolets, Louisiana</u>. During the tidal study, 47 discharge measurements were made at the 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. 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.

<u>Chef Menteur Pass at CSX Railroad at Chef Menteur, Louisiana</u>. During the 25–hour tidal study, 111 discharge measurements were made at the 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.

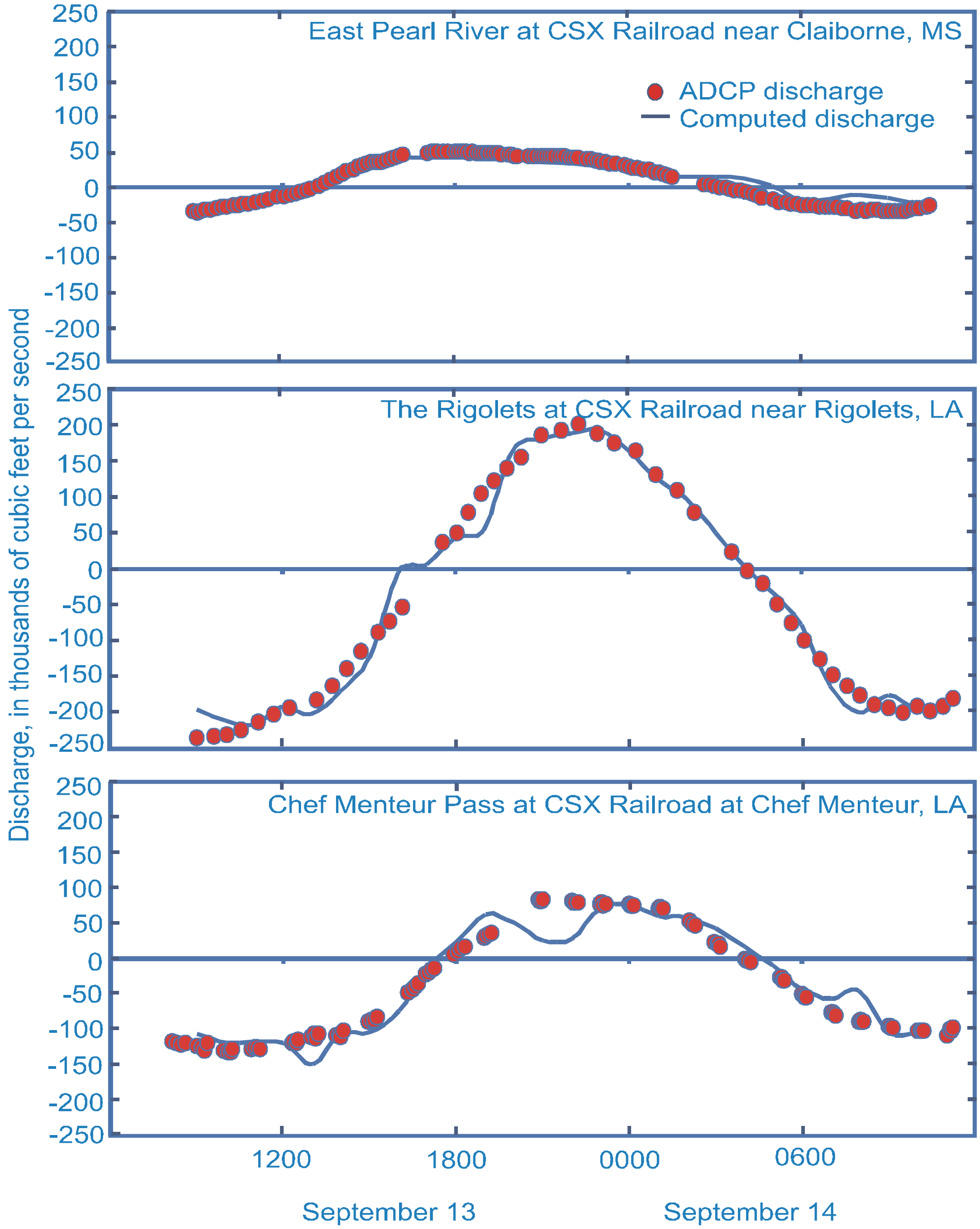

Figure 3.--ADCP measured discharge and computed discharge from index velocity ratings at three gages in the lower Pearl River and Lake Pontchartrain estuaries of Mississippi and Louisiana.

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 ADCP measured depths and distances. Stage/area ratings were developed from these cross sections (fig. 4). Relations were also developed between the average velocity and the instantaneous velocity computed from the ADVM (fig. 5).

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 was used to compute discharge. Results (i.e., y-offsets (in feet above sea level), slopes (in feet per foot), and coefficients of determination (R^2 – a dimensionless coefficient that represents the proportion of variability of the instantaneous velocity that is accounted for 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 (feet/foot)	R^2
East Pearl River at CSX Railroad near Claiborne, MS	-0.1085	1.0953	0.9456
The Rigolets at CSX Railroad near Rigolets, LA	-0.0437	0.6147	0.9794
Chef Menteur Pass near Chef Menteur, LA	0.9076	0.4954	0.9099

Average velocity/instantaneous velocity relations were relatively good (R^2 values ranging from 0.9099 to 0.9794) for the three sites (fig. 5).

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, and base-flow conditions in the basin, helps to explain why the average measured discharges at the Rigolets at CSX Railroad near Rigolets, Louisiana, and Chef Menteur Pass at Chef Menteur, Louisiana, were inflow (negative) discharges.

Tidal Study Water-Quality Measurements

<u>East Pearl River at CSX Railroad near Claiborne, Mississippi.</u> Water temperature, specific conductance, and salinity were recorded from a boat at a depth of about 1 foot during the 25-hour tidal study. During normal tidal flow, these parameters are also continuously measured at a depth of about 2 to 4 ft at the gage. The maximum and minimum water temperatures measured discretely from a boat at this site during the tidal study were 29.0 and 26.4 ^{o}C, respectively. The average measured water temperature was 27.3 ^{o}C. The maximum and minimum specific conductance values measured from the boat during the tidal study at this site were 16,000 and 800 microsiemens per centimeter at 25 ^{o}C (µS/cm), respectively. The maximum and minimum specific conductance values measured and recorded by the continuous gage during the tidal

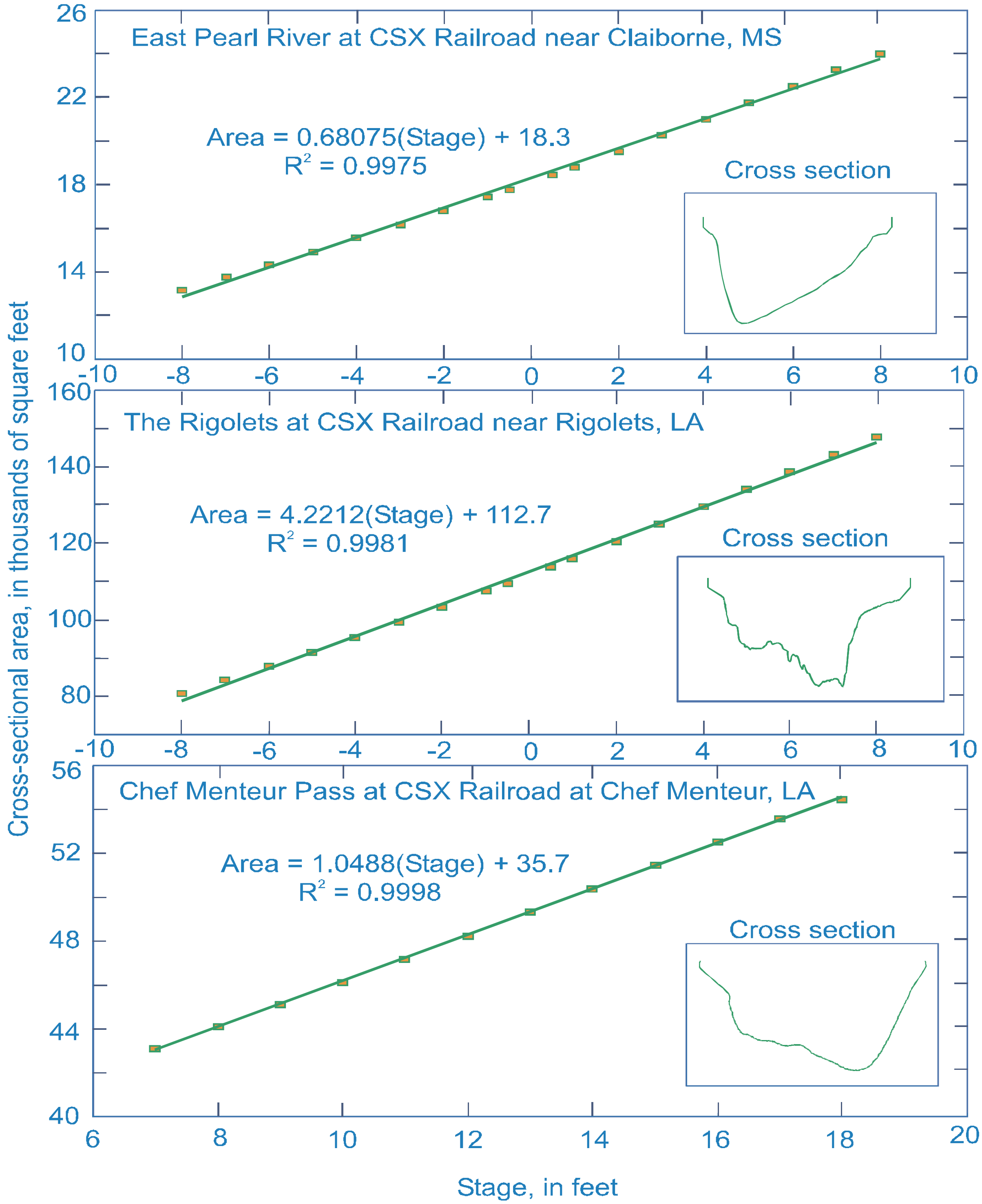

Figure 4.-- Stage / area velocity relations developed from ADCP sounded cross sections surveyed September 13-14, 2001, at 3 gages in the lower Pearl River and Lake Pontchartrain estuaries of Mississippi and Louisiana.

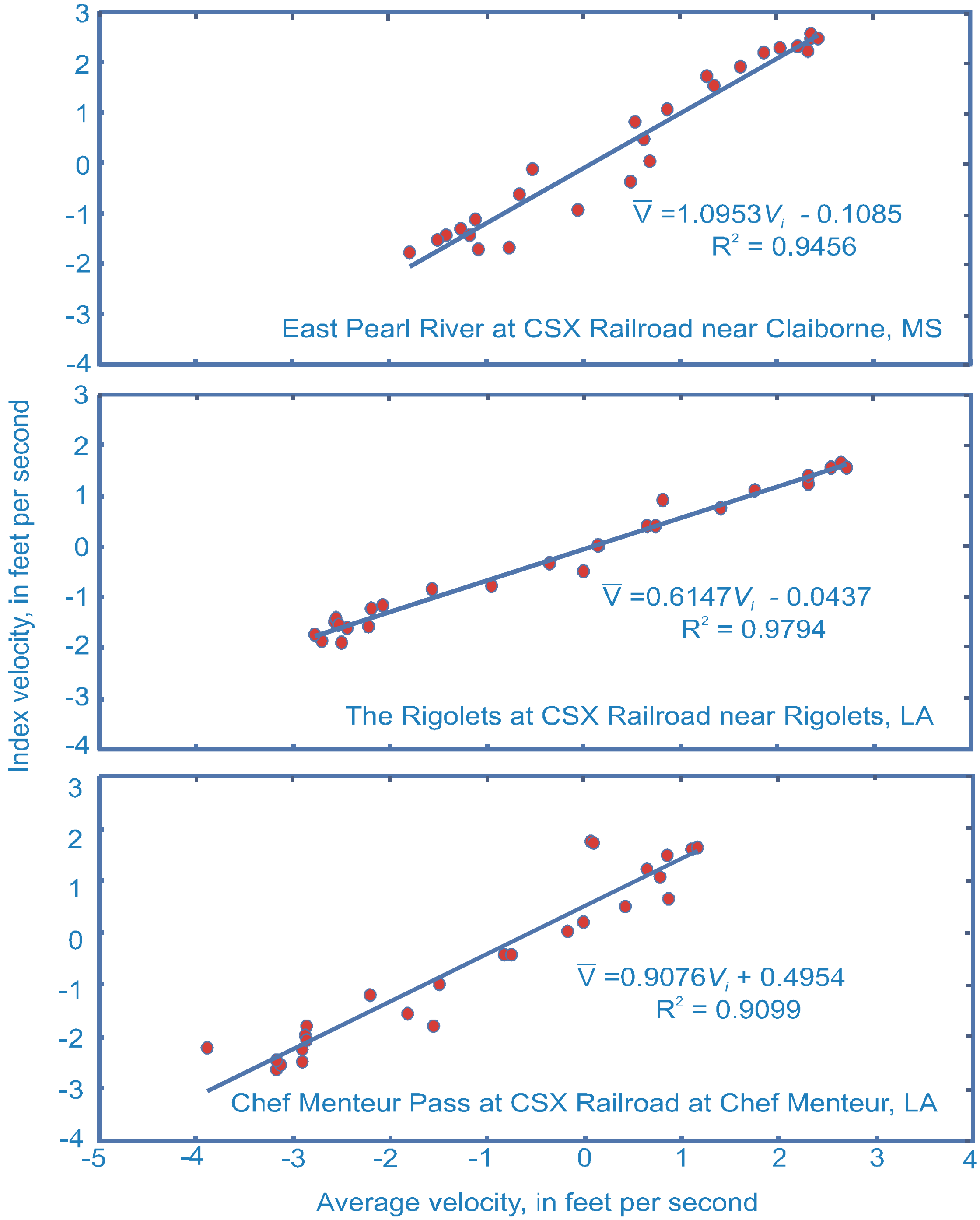

Figure 5.--Average velocity ($\overline{V}$) / index velocity (V_i) relations developed from ADCP discharge measurements, cross-sectional surveys and ADVM velocities collected during September 13-14, 2001, at three gages in the lower Pearl River and Lake Pontchartrain estuaries of Mississippi and Louisiana.

study were 18,700 and 900 µS/cm, respectively. The average boat-measured and recorded specific conductance values were 7,100 and 8,000 µS/cm, respectively. The maximum and minimum salinity values computed from boat measurements during the tidal study at this site were 9.2 and 0.4 ppt, respectively (fig. 6). The maximum and minimum salinity values recorded by the continuous gage during the tidal study were 11.0 and 0.4 ppt, respectively (fig. 6). The average measured and recorded salinity values were 4.0 and 4.6 ppt, respectively. Specific conductance and salinity values measured from the boat were consistently less than those values recorded by the gage because the gage measurement point was several feet deeper in the water column. This site was significantly influenced by freshwater flow from upstream runoff in the Pearl River Basin during the ebb tide cycle.

<u>The Rigolets at CSX Railroad near Rigolets, Louisiana</u>. Water temperature, specific conductance, and salinity values were recorded from a boat at a depth of about 1 foot during the 25-hour tidal study. During normal tidal flow, these parameters are also continuously measured at a depth of about 2 to 4 ft at the gage. The maximum and minimum water temperatures measured discretely from a boat at this site during the tidal study were 28.7 and 27.1 ^{o}C, respectively. The average measured water temperature was 27.9 ^{o}C. The maximum and minimum specific conductance values measured from the boat during the tidal study at this site were 11,500 and 3,600 µS/cm, respectively. The maximum and minimum specific conductance values measured by the continuous gage during the tidal study were 15,500 and 2,900 µS/cm, respectively. The average measured and recorded specific conductance values were 8,000 and 9,900 µS/cm, respectively. The maximum and minimum salinity values computed from boat measurements during the tidal study at this site were 7.5 and 1.5 ppt, respectively (fig. 6). The maximum and minimum salinity values recorded by the continuous gage during the tidal study were 9.0 and 1.5 ppt, respectively (fig. 6). The average measured and recorded salinity values were 4.4 and 5.6 ppt, respectively. Specific conductance and salinity measured from the boat were consistently less than those parameters recorded by the gage because the gage measurement point was several feet deeper in the water column.

<u>Chef Menteur Pass at CSX Railroad at Chef Menteur, Louisiana</u>. Water temperature, specific conductance, and salinity were continuously recorded at the gage. The maximum and minimum water temperatures recorded by the gage at this site during the tidal study were 29.3 and 27.4 ^{o}C, respectively. The average measured water temperature was 28.4 ^{o}C. The maximum and minimum specific conductance values measured by the continuous gage during the tidal study were 12,700 and 9,600 µS/cm, respectively. The average recorded specific conductance was 10,900 µS/cm. The maximum and minimum salinity values recorded by the continuous gage during the tidal study were 7.2 and 5.3 ppt, respectively. The average recorded salinity value was 6.2 ppt.

Measurements made during the September 13-14, 2001, tidal study correlated well with continuous measurements at the gages at the East Pearl River and Rigolets; however, an insufficient amount of data exists at this time to develop correlations between flows of the Pearl River and other tributaries and spatial variations in the water quality across the Mississippi Sound. Preliminary analysis indicates that salinity data obtained from the USGS monitoring and sampling program on the Mississippi Gulf Coast correlate well with the data obtained from the laboratory analysis for the normal ranges of salinity (Runner and Floyd, 2000).

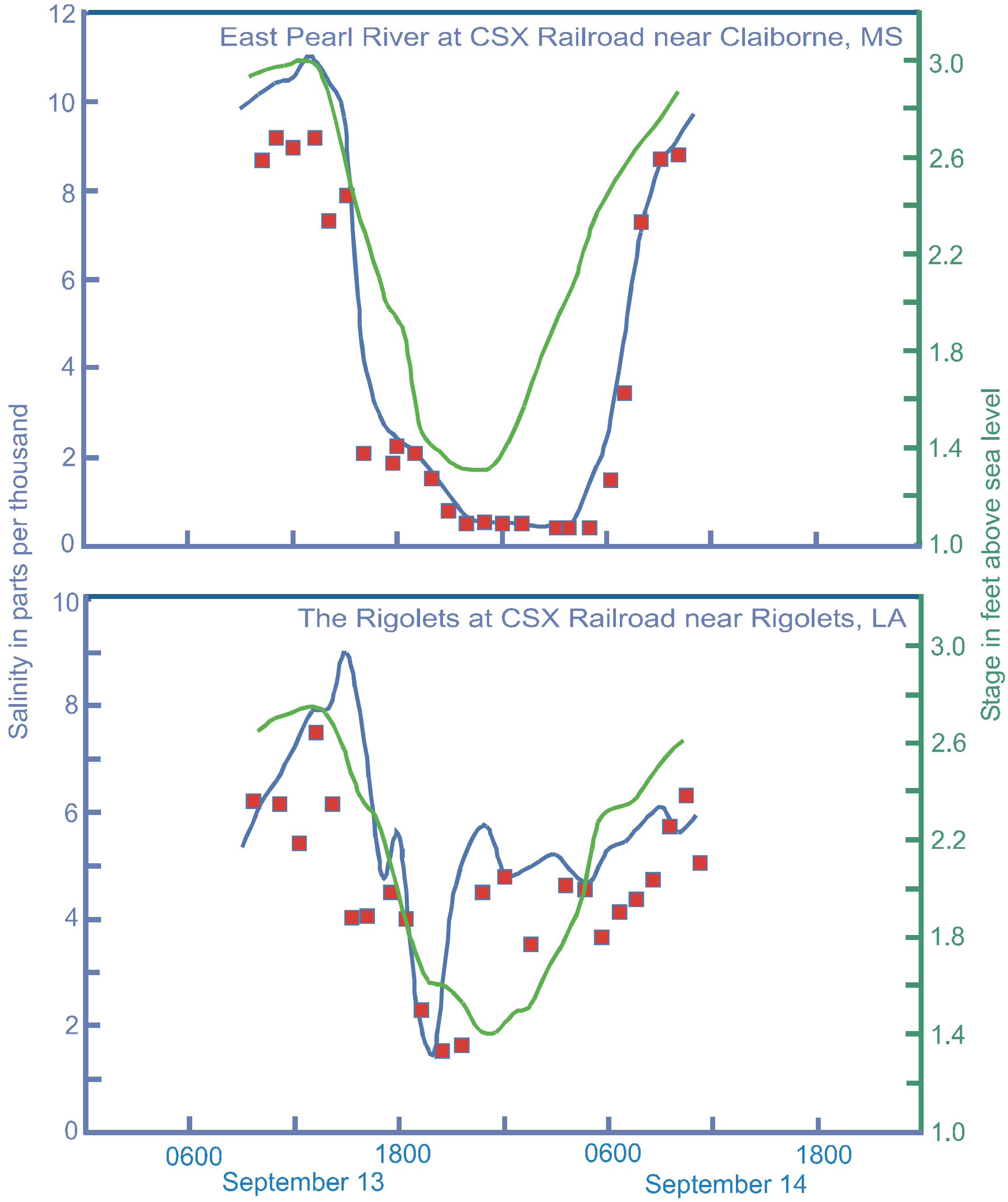

Figure 6.--Measured salinity at depths of about 1 foot, recorded salinity at gage at depths of about 2 to 4 feet and tidal stage at the East Pearl River at CSX Railroad near Claiborne, Mississippi and the Rigolets at CSX Railroad near Rigolets, Louisiana, from September 13 to 14, 2001.

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 and water-quality data at the three gages and to construct a means of computing continuous discharge at these sites. Analysis of the data 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.

Salinity computed by using data collected by the water-quality monitors installed at the gages was generally higher than salinity measured discretely from boats during the tidal study. Preliminary analysis indicates that salinity data obtained from the USGS monitoring and sampling program on the Mississippi Gulf Coast correlate well with the data obtained from the laboratory analysis for the normal ranges of salinity. However, limited data for periods of low salinity and point sampling of salinity do not accurately define salinity decreases due to freshwater influence or adequately provide a method to measure average salinity for the entire depth of the water column.

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