COMPARISON OF SSC MEASUREMENTS WITH ACOUSTIC BACKSCATTER DATA: WEST BAY SEDIMENT DIVERSION, MISSISSIPPI RIVER.

David Perkey, Research Physical Scientist, USACE, Vicksburg, MS, David.Perkey@usace.army.mil; Thad Pratt, Research Physicist, USACE, Vicksburg, MS, Thad.C.Pratt@usace.army.mil; Naveen Ganesh, Student Intern, Mississippi State University, Starkville, MS; naveen2084@gmail.com

Abstract In recent years the use of acoustic backscatter (ABS) intensity from commercially available instruments, such as Acoustic Doppler Current Profilers (ADCP), has become a more widely used means of estimating suspended solids. To obtain accurate estimations of suspended sediment concentrations (SSC) from ABS the instrument must be calibrated to the conditions at the time of the survey. By plotting the distribution of measured SSC from water samples against the distribution of ABS intensity, a calibration equation was obtained that allowed for such a specified calibration. Calibrated SSC from ABS showed strong correlation to measured concentrations (r^2=0.97) from six separate surveys conducted at different stages of the Mississippi River's hydrograph. Because this method of calibration requires a unique equation that is tied to water samples collected in unison with the ABS data, hysteresis effects are accounted for that otherwise might be missed by performing a calibration based on conditions set in a lab or from previous surveys at similar discharge and stage levels.

INTRODUCTION

The measurement of suspended sediment concentration (SSC) is an important aspect of many stream, river, estuarine, and coastal water studies. From an environmental and ecosystem point of view, sediments can be a source of nutrients and toxins that can impact the health of organisms within the system. At high concentration, sediments in suspension can also result in the attenuation of light and limit photosynthesis. In terms of a navigation concern, the deposition of suspended sediments into shipping channels causes infill and requires occasional dredging to maintain a navigable waterway (Gartner, 2004). While measuring and recording the mass concentration of sediments in suspension is essential in many studies, a debate exists over what methods and equipment are best suited for determining the highly variable nature of suspended sediment.

Over the past few decades several studies (e.g. Chanson et al., 2007; Gartner, 2004; Land and Jones, 2001; and Thorne et al., 1990) have indicated that the use acoustic back scatter (ABS) intensity from acoustic sensors can be used to estimate SSC. These studies all point out that the use of ABS for the estimation of SSC has limitations and that factors such as variations in water density (salinity and temperature), sediment grain size and concentration, water depth (distance the signal travels from the transducers), water surface conditions, and others can result in unreliable data. Because of these sources of potential error, the acoustic sensor must be calibrated to the water conditions during deployment in order to obtain reliable SSC results. Despite these limitations and factors, acoustic sensors offer some advantages over other methods of measuring TSM, such as optical backscatter sensors (OBS) or water samples. Both OBS sensors and water samples only provide information at a specific point while ABS provides information throughout the entire water column. To collect the same amount of information, several OBS sensors or water samples would be required which can be very labor intensive. In-situ OBS sensors are also subject to biological fouling after short periods of time in productive waters. Instruments such as Acoustic Doppler Velocimeters (ADV) and Acoustic Doppler Current Profilers (ADCP) are much less susceptible to biological fouling (Gartner, 2004).

This paper will present the results and calibration method of ADCP ABS data collected for a study examining SSC and suspended sediment fluxes moving through a diversion channel on the lower Mississippi River. In an effort to restore the natural delta cycle and slow the rate of coastal marsh submergence, the State of Louisiana has constructed fresh water diversions of the Mississippi River into shallow bays and marshes to mimic historical flood events. Determining the amount of suspended sediment that is delivered to the marsh through these diversions is an important part of evaluating their effectiveness.

West Bay Diversion The Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA) West Bay Sediment Diversion Project (MR-03) is the largest constructed sediment diversion in Louisiana. The project was designed to restore and maintain approximately 9,831 acres of fresh to intermediate marsh in the West Bay area by diverting fresh water and sediment from the Mississippi River. West Bay is located on the western side of the Mississippi River Delta, south of New Orleans, near where the river discharges through four major passes into the Gulf of Mexico (Figure 1). The diversion entrance is located on the west bank of the Mississippi River 4.7 miles north of Head of Passes. It is an uncontrolled channel dredged through the bank of the Mississippi River and connects the river and West Bay. The diversion channel was initially constructed in 2003 as a 25 ft deep, 195 ft wide channel designed to deliver 20,000 cfs of Mississippi River flow into West Bay. However, after conducting a present day discharge analysis of the project conveyance channel, it was observed that the channel has approximately doubled in cross sectional area and flow capacity.

A work plan to evaluate the West Bay sediment diversion effects on the lower Mississippi River in the vicinity of the diversion and the West Bay receiving area was proposed and funded to provide data for evaluating over-all project performance in regard to the restoration and maintenance goal. Data was collected in the time period between March and September of 2009 and the SSC and suspended flux portions of the study will be discussed in this paper.

METHODS

Several issues impacted the survey strategies in this reach of the Mississippi River. The first involves the seasonal presence of a salt-water wedge, which enters the main stem at discharges below 8,500 m^3/s (Soileau et al., 1989). Recent observational studies have shown the wedge to be an effective sediment trap for fine particulates in the channel thalweg in this area of the river (Galler and Allison, 2008). The high levels of discharge that occur during the spring freshet causes a retreat of this salt wedge and can result in unusually high levels of SSC that are not seen at similar discharge levels at other times of the year. In addition to the unique levels of SSC associated with the spring freshet, hysteresis effects cause similar stages and discharges to have significantly different sediment fluxes during rising and falling limbs of the hydrograph. A second factor was the limited availability of historical and real time observational data in this reach, either measurements of sediment transport or detailed bathymetry (multi-beam/swath) necessary to plan an observational grid. This data limitation extends to the absence of nearby monitoring stations for anything but river stage.

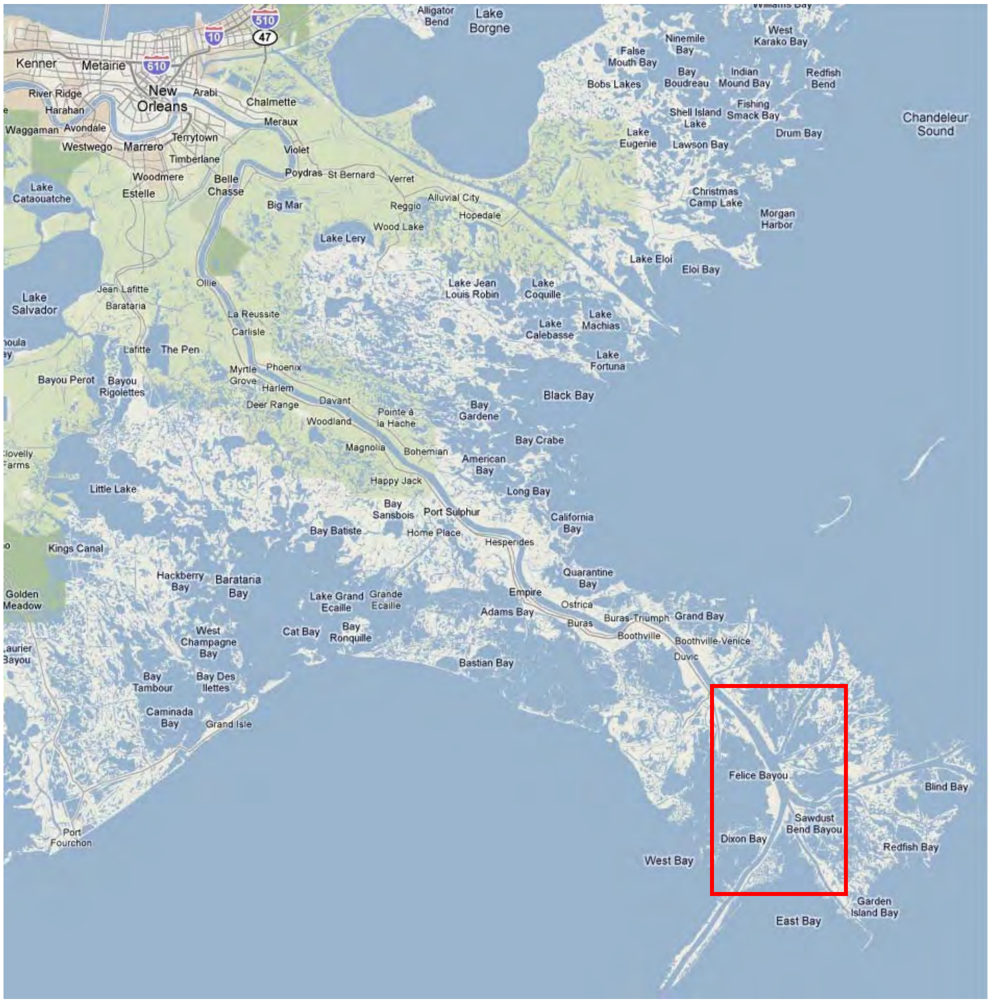

Figure 1 Map of the lower Mississippi River, south of New Orleans, LA. Study area is highlighted in red box.

The likelihood that suspended sediment concentrations differ significantly over a small spatial and temporal scale, along with the limited availability of observational data suggested that a single integrated survey combined with historical monitoring data was unlikely to answer the objectives. To address the fact that sediment fluxes do not co-vary linearly with water discharge in this region of the river, six sampling trips were conducted at different stages of the river's hydrograph from April-September, 2009.

Survey and Sampling Lines Transect lines were established to observe flow and sediment flux of the Mississippi River in the area near the West Bay diversion (Figure 2). Two lines were established across the main channel of the Mississippi River; one located upstream of West Bay diversion (river mile 5.2) and the other downstream of the diversion (river mile 4.5). Five sampling locations were equally spaced, along each of these lines for water samples to be collected. A third transect line was placed across the mouth of the West Bay diversion (WBDMR). Due to an observed eddy in the flow at the entrance into the diversion this transect line was moved further into the cut after the May 29-30 survey (WBD). Three water sample locations were placed along the original transect across the mouth of the diversion, while only two sample locations were placed on the shorter transect line within the cut due to a broad, shallow shelf that limited boat maneuverability. Seven additional distributaries, located near the West Bay diversion, were also monitored with a single transect line and sample location being placed across their entrance from the river.

Acoustic Doppler Current Profiler (ADCP) Data All velocity, discharge, and acoustic backscatter data was collected with a RD Instruments, Inc. (RDI) 600 kHz ADCP. The ADCP was mounted to the vessel and lowered so that the transducers were 1-2 ft below the water surface. Vessel heading, velocity and location were recorded with a Hemisphere vector GPS system. Prior to collecting water samples two ADCP survey lines were run along the sample transect line (one in each direction) to collect discharge, average velocity, and acoustic backscatter. The vessel then moved to each water sampling location along the transect line and recorded ADCP data simultaneously while water samples were collected.

Water Samples All water samples were collected in clean 1L HDPE plastic bottles. At each collection point a depth profile of 3-5 samples was collected in duplicate. When average flow velocities were above 2.0 ft/s a P-6 isokinetic sampler was used to collect water samples. The sampler was lowered to each target depth and bottles were filled to 50-75% capacity to ensure that over filling and flushing of sediment did not occur. Water flows below 2.0 ft/s were insufficient to purge the air from within the P-6 sampler and fill the bottle. Therefore, a Shurflow water pump (max flow rate 1.8 gpm) was used to collect water samples when average flows were below 2.0 ft/s. In these instances a water hose was attached to a 100 lb weight and lowered to each target depth. Sufficient time was allowed to flush the water line before filling a bottle from a specified depth. After collection, samples were stored upright in a cooler and transported back to the lab for analysis.

Suspended Sediment Concentrations (SSC) Each sample for SSC was shaken to re-suspend particles and then poured into a 1L graduated cylinder to record the volume. The samples were then transferred into a ground glass vacuum filtration system (8-lb vacuum maximum) and drawn through a pre-weighed, 90 cm diameter, glass fiber filter with 0.7μm particle retention. The sample bottles, graduated cylinders, and filter towers were rinsed several times with distilled water to make sure that all particles were introduced to the filter. The filters were then dried in a low temperature oven overnight at approximately 50 ˚C. The filters were then re-weighed and SSC was calculated for each sample.

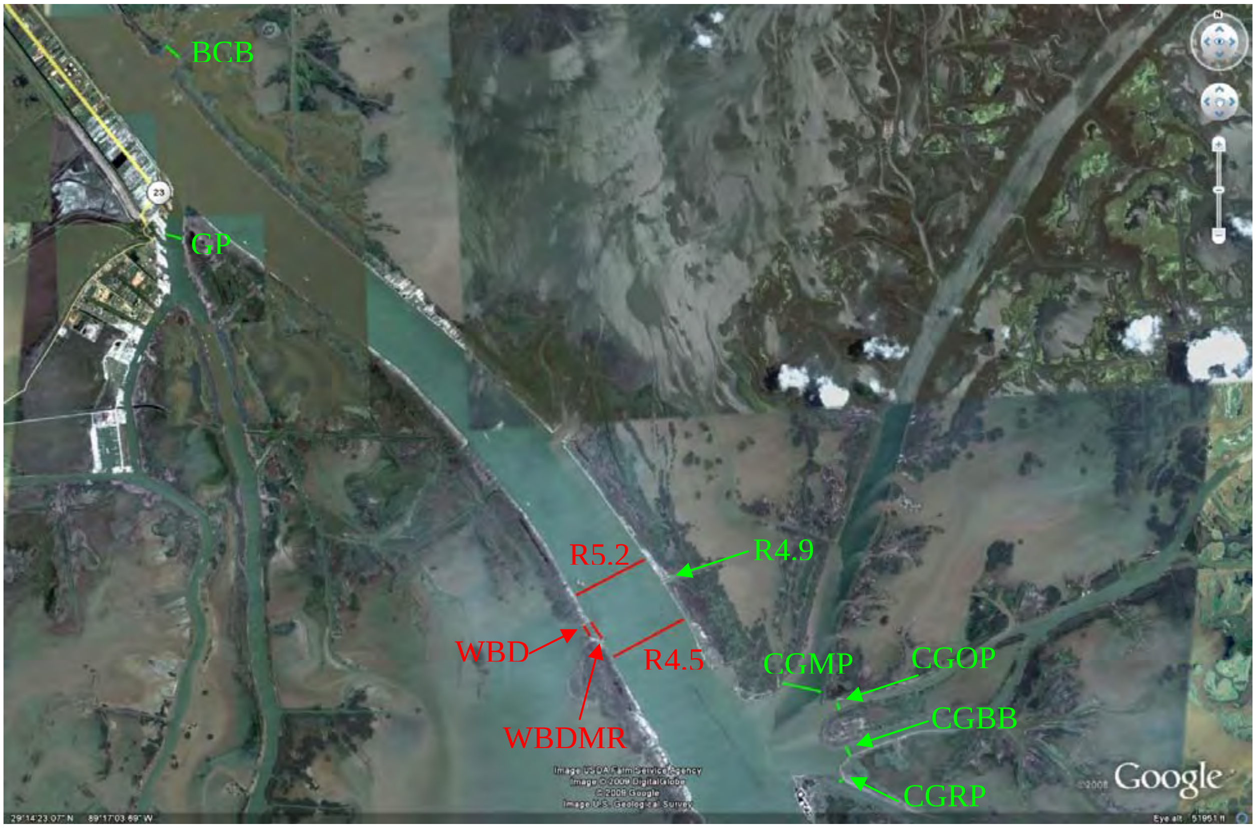

Figure 2 Survey lines in study area. Red lines indicate transects with multiple water sample locations, green lines indicate transects across the additional diversions added to the study in May.

Conductivity, Temperature, and Depth (CTD) Temperature and salinity profiles were collected simultaneously with water samples during the May 29-30 and September 23-24, 2009 sampling trips using CTD sensors. In May a D&A Instruments OBS-3A was secured to the cable approximately 0.5-1 ft above the P-6 sampler. In September a YSI 600XLM V2 was similarly attached to the cable at the same location as the intake of the water hose.

ADCP Back Scatter Calibration with SSC This method of calibrating ADCP back scatter to SSC values has been developed over several years of application. It involves the relationship between the distribution function of the ABS energy values and the Total Suspended Sediment Concentration (TSSC) distribution function. First, a representative ADCP transect file for each sampling trip was read and the energy values were counted to create the distribution function for the acoustic backscatter. Because sound adsorption in water is impacted by salinity (Francois and Garrison, 1982; Ainslie and McColm, 1998), the sound adsorption data was corrected for salinity changes in the water column by using the data from the CTD profiles prior to creating the distribution function. The correction of the back scatter energy for changes in salinity was performed within the WinRiver ™ software that was used to collect the ADCP data. Next, a distribution for all of the corresponding SSC samples was created. Each time a concentration value occurred then a count value was added to a distribution function. The premise for the calibration method is that the two distribution functions are related for that particular stage and time. After the two distribution functions were populated, then the value for each function in one percent increments were paired (Figure 3). These paired values were regressed against each other with a second order polynomial to define a calibration curve between the two data sets. The calibration equation was then applied to the ADCP ABS data to convert backscatter to SSC values.

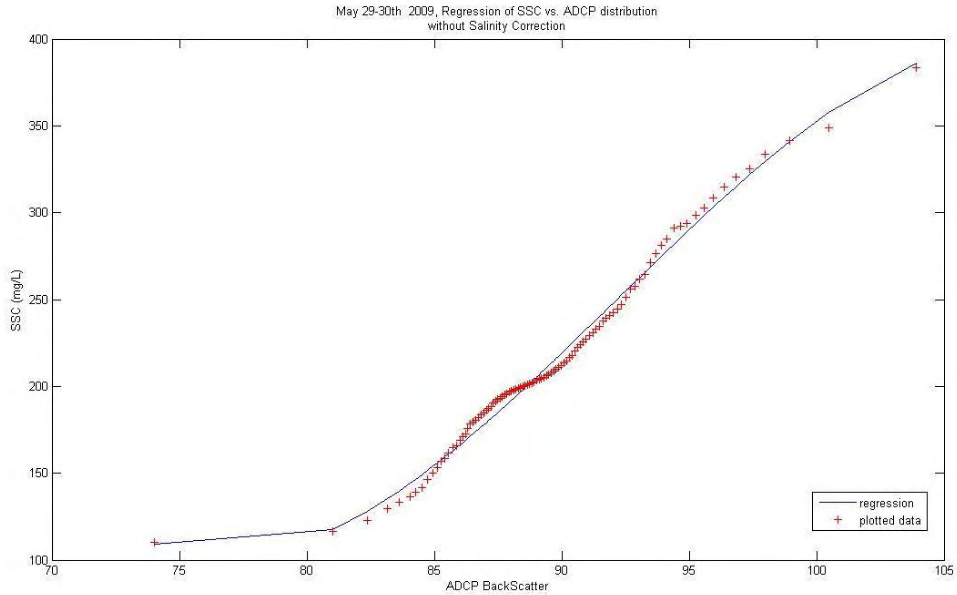

Figure 3 Example of the regression obtained from plotting the SSC distribution against the ADCP back scatter distribution for the May 29-30, 2009 survey.

Due to side lobe errors, which are a result of echoing near the river bottom, the conversion of backscatter data is unreliable for near-bed concentrations (Land and Jones, 2001). To address this problem a Rouse profile was applied to the converted ADCP ABS data as they approached the bed. A maximum concentration value has to be supplied by the user to tell the method where to start applying the Rouse profile algorithm to the concentration profile. This value was derived from the actual SSC obtained from the water samples that were collected. The choice of this value was an iterative process to try to achieve the closest fit to the actual field samples. In addition to the SSC from the water samples, ADCP backscatter data was collected during the entire sampling operation. These backscatter data were converted to SSC values for the entire sampling period. The converted SSC values at the specific depth elevation were extracted to compare to the actual physical samples. This comparison showed how well the calibration process worked. If the converted data near the bed was too high as compared to the water sample data then we would increase the value of the pick point in applying the Rouse profile in the conversion process. The process might be repeated several times until the best fit was achieved.

Suspended Sediment Flux Calculations Two methods were used to calculate suspended sediment fluxes. The first method utilizes the water velocity and the SSC that was collected by the ADCP during the transect surveys. The velocity data for each cell or bin from an ensemble was multiplied by SSC values for each corresponding cell that was obtained through the calibration process. The product of the water flux with the concentration at each cell yields the sediment flux through that cell. This process is done throughout the entire profile at which time the values for each ensemble are summed for the entire cross section. The resultant value is in mg/sec which is then converted to tons/day for the cross section.

The second method of calculation for suspended flux utilized a technique developed by the United States Geological Survey (USGS) called the “moving boat method” (Smoot and Novak, 1969). This method does not use the converted acoustic backscatter to make the flux calculation but instead a mean concentration from the suspended sediment samples taken at each cross section. This concentration is then multiplied by the sum of all the water discharge values calculated for each bin in the transect and yields a total flux for the cross section.

RESULTS

During the April survey water samples were successfully collected along the WBDMR transect and across 60% of the R5.2 transect. However, equipment failure prevented the collection of the remaining samples. A full series of samples and ADCP surveys were collected from those transects around West Bay for the remaining trips. Collection of water samples and ADCP surveys from the seven additional distributaries in the West Bay region started during the May 29^{th} trip and continued through September, 2009.

SSC Concentration values of discrete water samples ranged from 12-769 mg/L across all transects, depths, and sampling trips. However, on average SSCs were highest in late May and lowest in July and September. Table 1 shows the averaged SSC values from the water samples obtained for each transect and sampling trip. The second order polynomial regression curves used to calibrate the ABS gave r squared values ranging from 0.87 to 0.99 for all trips, and a comparison of the resulting calibrated ABS concentrations to concentrations measured from the water samples shows similar results between the two methods. This is seen best when each method’s average SSC from each survey trip are plotted against each other (Figure 4). The resulting graph shows a linear correlation between the two methods with an r^2 =0.97.

In most instances the percent difference in average concentration for individual transect lines was 20% or less. The concentrations along the individual transects from the June and July surveys show the largest variability between the two methods, with an average difference of 30% between transects. In June, most of this difference can be attributed to the Baptiste Collette Bayou (BCB) transect, which displayed nearly a 100% difference between the two methods (tables 1 and 2). No clear or definite explanation can be made for why this occurred at this one particular location. The variability seen in the concentrations of transect lines in July may be due in part to the salinity correction applied to the data. Measured discharges in July and September were below the threshold at which a salt water wedge has been observed to enter the river (Soileau et al., 1989), and therefore the salinity sound adsorption correction was applied to the ADCP data from these trips. Because salinity data from CTD casts were only available from the September survey, the ADCP data from July was corrected with salinity information obtained in September. While both July and September surveys occurred during low discharges, the salinity conditions in the river may not have been spatially uniform. Therefore, the salinity correction applied in July may have skewed the ABS SSC results and accounted for some of the increased percent difference that is seen for that sampling trip.

These low concentration values in July and September correspond to the lowest measured discharges and low river stage, while the higher SSC in late May corresponds to highest stage and discharge over the course of the study (Table 3). While the highest and lowest observed concentrations both correlated with highest and lowest discharge, it is important to point out that discharge and stage can not always be linked directly to SSC. For example, the recorded river stage was 3.4 ft at the time of both the April and July surveys, however, the measured discharge in April was approximately twice of what was measured in July. In both the water samples and the acoustic backscatter, the resulting mean sediment concentration of the transects surveyed in April was approximately six times greater than the mean concentration observed in July (Tables 1 and 2). This demonstrates the significant hysteresis effects that can exist within a system and the potential problems associated with assuming similar physical conditions of a river at different points in time based solely on similar stage or discharge levels. To further illustrate this point the June and July acoustic backscatter data was calibrated to suspended concentration using the equation obtained with the April regression (Table 4). These results show that while the surveys were conducted with similar discharge levels (April and June) and with identical river stages (April and July) the regression equation obtained to calibrate ABS to SSC is specific to the unique conditions of the river at the time of the survey and how critical it is to pair ABS data to measured concentrations from the same time and stage when performing the calibration described above. That calibration curve is only good for the stage in which it was collected because the relationship of the acoustic backscatter energy to SSC is a function of the material characteristics in suspension. As the source, size distribution and concentration change with the hydrograph then the backscatter distribution function will change and take a slightly different shape.

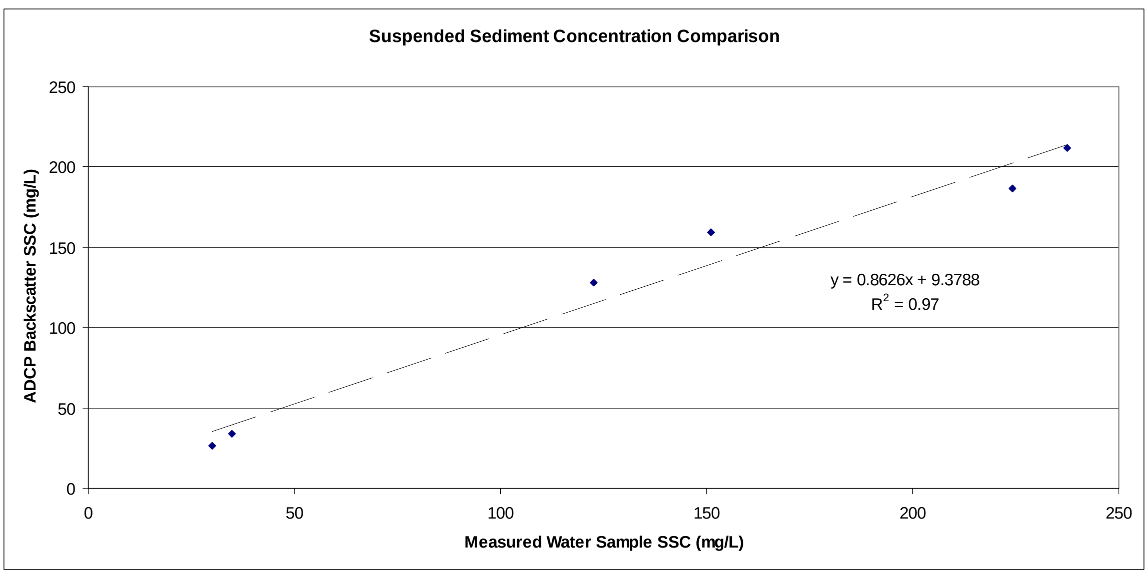

Figure 4 Plot comparing the two methods used to obtain SSC. Average concentrations btained from ADCP back scatter is plotted on the y-axis, while average results from water samples are plotted on the x-axis. Linear regression shows r^2=0.97.

Table 1 Averaged SSC values of water samples for each transect and survey trip.

Averaged SSC (mg/L) Water Samples						
	April 22-23, 2009	May 5-6, 2009	May 29-30, 2009	June 16-17, 2009	July 20-23, 2009	Sept 22-24, 2009
R5.2	229.64	152.92	218.30	139.10	32.46	33.00
R4.5		150.00	232.51	144.11	35.78	29.54
GP			224.23	102.94	29.42	31.08
BCB			404.13	115.19	83.93	29.44
WBD/WBDMR	218.53	149.78	244.60	111.49	22.84	31.67
R4.9			180.85	99.39	61.35	30.03
CGRP			239.23	96.92	25.56	26.44
CGBB			260.97	91.83	25.45	24.28
CGOP			202.87	82.89	24.61	25.80
CGMP			248.19	99.89	27.25	26.89
Average	**224.08**	**150.90**	**245.59**	**108.37**	**36.86**	**28.82**

Table 2 Averaged SSC values calculated from calibrated ABS for each transect and survey trip.

Averaged SSC (mg/L) ADCP Back Scatter						
	April 22-23, 2009	May 5-6, 2009	May 29-30, 2009	June 16-17, 2009	July 20-23, 2009	Sept 22-24, 2009
R5.2	197.82	148.77	212.74	164.99	43.15	29.97
R4.5		165.56	229.06	214.68	38.54	27.70
GP			208.55	227.02	21.42	28.39
BCB			293.17	97.71	24.46	29.64
WBD/WBDMR	179.41	161.08	216.79	103.22	35.65	32.69
R4.9			141.67	155.94	41.54	27.71
CGRP			181.77	72.99	26.07	23.31
CGBB			210.11	72.27	23.92	23.33
CGOP			201.21	73.18	28.64	23.08
CGMP			205.94	79.80	40.45	24.13
Average	**188.62**	**158.47**	**210.10**	**126.18**	**32.39**	**26.99**

Table 3 Stage (ft) from Venice, LA and measured discharge (ft^3/s) from transect at River mile 5.2.

River Stage and Discharge (Venice, LA)						
	April 22-23, 2009	May 5-6, 2009	May 29-30, 2009	June 16-17, 2009	July 20-23, 2009	Sept 22-24, 2009
Stage (ft)	3.40	3.60	4.35	3.85	3.40	3.1
Discharge (ft^3/s)	522275	439471	731665	584234	241445	331724

Table 4 Averaged SSC values calculated for the June and July survey trips utilizing the calibration equation obtained during the April survey. The % difference in suspended concentration obtained by using the April equation is also reported.

SSC (mg/L) ADCP Backscatter				
	June w/ April Correction	% Difference	July w/ April Correction	% Difference
R5.2	140.07	17.80	146.20	238.83
R4.5	138.99	54.46	138.86	260.30
GP	104.26	6.28	190.28	788.27
BCB	158.71	43.04	154.73	532.51
WBD	104.01	0.75	147.38	313.38
R4.9	181.91	14.28	134.70	224.26
CGRP	114.63	36.33	182.62	600.39
CGBB	112.09	35.52	170.05	610.92
CGOP	120.39	39.21	143.70	401.70
CGMP	107.63	25.86	137.49	239.87
Average	**128.27**	**27.35**	**154.60**	**421.04**

Suspended Sediment Flux As expected, suspended flux values followed the same trends as the SSC data. Fluxes were highest in late May and lowest in July and September. Likewise, a strong linear correlation was also observed between the two methods used to calculate suspended sediment fluxes (Figure 4). In most cases the moving boat method gave larger flux values. This is likely due to the fact that the whole cross section is treated with one mean concentration value in this method. Therefore any cross sectional variability, which was observed during the surveys, is not accounted for with the moving boat method.

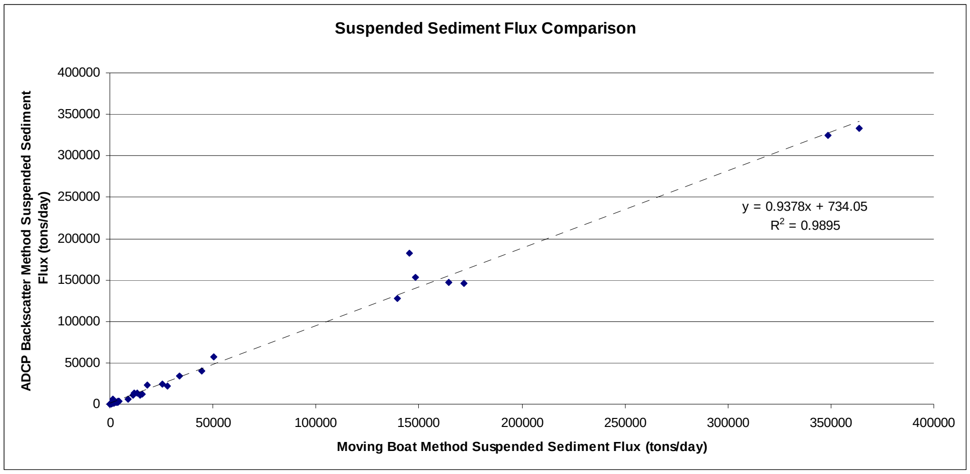

Figure 5 Plot comparing the two methods used to calculate suspended sediment Flux. Fluxes utilizing concentration from ADCP back scatter is plotted on the y-axis, while fluxes from the moving boat method are plotted on the x-axis. Linear regression shows r^2=0.99.

CONCLUSIONS

1) SSC values are highly variable and hysteresis effects result in periods of similar river stage and discharge having dissimilar suspended concentrations. Therefore, if ABS is to be used to determine SSC it is important that the data be calibrated to the conditions at the time of the survey.
2) By fitting a regression curve to a plot of the distribution of measured SSC samples against ABS energy a calibration equation can be generated that allows for the calculation of SSC values from ABS that is specific for the river conditions at the time of collection. Results of this applied calibration shows strong correlation between measured SSC values and those obtained from ABS.
3) Our data indicates that this calibrated ABS can be used to calculate suspended sediment fluxes that are comparable to standard USGS methods. This new method, however, is sensitive to cross channel variability and may provide a more accurate flux measurement.

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