Final Report
Analysis of Sediment Cores from the West Bay Diversion Receiving Area

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1. Introduction

A. The setting.

The Mississippi River Delta has one of the highest rate of land loss of any system on Earth. Present day rates of land loss average about 62 $km^2 yr^{-1}$, and exceeded 100 $km^2 yr^{-1}$ during the 1970s (Barras et al., 2003; Day et al., 2007). The causes of this land loss are numerous and a partial list includes high rates of subsidence, reduced sediment deposition, changes in the tidal prism of the delta's coastal bays, global sea level rise, hurricane impacts, salt water intrusion, canal construction, invasive species, and biogeochemical changes that are unfavorable for plant growth (Barras, 2006; Darby and Turner, 2008; Day et al., 2007; Fitzgerald et al., 2004; Gagliano et al., 1981; Kolker et al., 2010; Reed, 2002; Tornqvist et al., 2008). These drivers of wetland loss exist on a landscape that naturally experiences cycles of land gain and loss that result from changes in the course of the Mississippi River and occur on time scales decades to millennia (Coleman, 1988; Roberts, 1997; Tornqvist et al., 1996; Wells and Coleman, 1987).

One potentially powerful way to restore the Mississippi River Delta is to partially divert the flow of the Mississippi River, thereby allow sediments and freshwater to enter the coastal landscape in a manner that mimics natural land-building processes (Day et al., 2007; LACPRA, 2007; LADNR, 1998). Several natural and semi-natural diversions provide strong evidence of the potential for river diversions to build land. A suite of crevasses near the mouth of the Mississippi River in the 19th century initiated the subdelta cycle, leading to the creation of over 600 km^2 of land between 1840 ~ 1940 (Wells and Coleman, 1987). The Wax Lake Outlet of the Atchafalaya River (itself a distributary of the Missisippi River), has developed nearly 100 km^2 of land since its opening in 1941- with all of the subaerial land developing after the early 1970s (Kim et al., 2009; Roberts, 1997). Studies from the Davis Pond and Caernarnon and Davis Pond Freshwater Diversions indicate that these systems do deliver sediment to the coastal zone, which can lead to land creation (Day et al., 2009; Lane et al., 2007). However, in some cases the fresh marsh created does not have the same structural integrity nearby salt marshes (Day et al., 2009; Lane et al., 2007).

1.B. Recent History of West Bay.

Despite their appeal as a restoration tool, relatively little is known about diversion impacts on sediment dispersal patterns, and how diversions are affected by their underlying geology. Insights to these questions can be gained from studies in West Bay, which is the largest diversion operating that was specifically constructed for coastal restoration.

West Bay originally developed from a crevasse south of Venice, LA that opened up in 1839 (Wells and Coleman, 1987). From 1839 until the early 20th century, West Bay underwent a period of rapid land gain, developing 297 km^2 of land by 1932. After 1932, land loss exceeded land gain, and the area deteriorated under the influence of subsidence, sea level rise, storms and reduced sediment deposition (Wells and Coleman, 1987). The bay reached its present day status as mostly open water by ~ 1980 (Barras et al., 2009). Recent (post 2001) areas of land gain are largely confined to small offshoots of sub-passes off of Grand Pass along the western flank of the bay and several areas of dredge spoil along the bay's eastern edge (Barras et al., 2009).

To counteract this land loss, in 2003 a diversion was cut in the Mississippi River levee at 7.52 km above head of passes. Aside from rip-rap borders near the surface, there are no structures to regulate the flow or prevent changes in the shape of the cut. The cut was originally oriented along a SE-NW axis, at an obtuse angle relative to the direction of the river flow. The diversion was designed to carry an average of 566 m^3 sec^{-1} of fresh water with the hope of creating ~40 km^2 of fresh and intermediate marsh over a twenty year project lifespan. Construction began in September 2003 and completed in November, 2003 (http://lacoast.gov/reports/gpfs/MR-03.pdf).

1.C. Goals of this report.

This report details the sediment dynamics in the receiving basin of the West Bay Mississippi River Diversion. Two primary areas are covered 1) seasonal scale sediment dynamics as revealed by the analysis of ^{7}Be, and 2) long-term sediment dynamics as determined from x-radiography of sediment cores and the analysis of ^{210}Pb and ^{137}Cs in deeper sediment cores.

2. Methodology

To more fully understand the quality of sediment deposited, and the rates of sediment deposition in the West Bay, we collected a series of sediment cores across the bay (Fig. 1). We collected both short (~ 15 cm) cores and long (70~100 cm) cores. These cores were collected with a hand-held piston corer and 6.6 cm inner diameter clear acrylic core tubes. Cores were sealed in the field and then returned to the laboratory and kept cold for further analysis. Cores were collected on September 20 and September 22, 2009. This was before dredging operations began to place sediments in the middle of West Bay with the hope of enhancing land building. Thus our study provides key information into how one unmodified receiving basin functions, but given recent modifications, may not be fully applicable to all locations in West Bay today.

In the laboratory, cores were first x-radiographed using a Logos Imaging Digital Imaging System at 300 dots per inch (dpi) resolution. Subsequently, cores were cut in half longitudinally. Sample material was dried at 60^{o}C, and water content was determined based on the loss of water after 24 hr. To more fully understand the rates of deposition in West Bay, sediment core were analyzed for the particle reactive, naturally occurring radioisotopes ^{7}Be, and ^{137}Cs. ^{7}Be is produced in Earth's upper atmosphere when solar rays interact with and split atoms of O and N, in a process known as spallation. Atoms of ^{7}Be are then delivered to Earth's surface via rain and dry deposition. Given Be's affinity for particle surfaces and the short half life (53 days) of this nuclide, ^{7}Be makes an excellent tracer of seasonal-scale sediment dynamics.

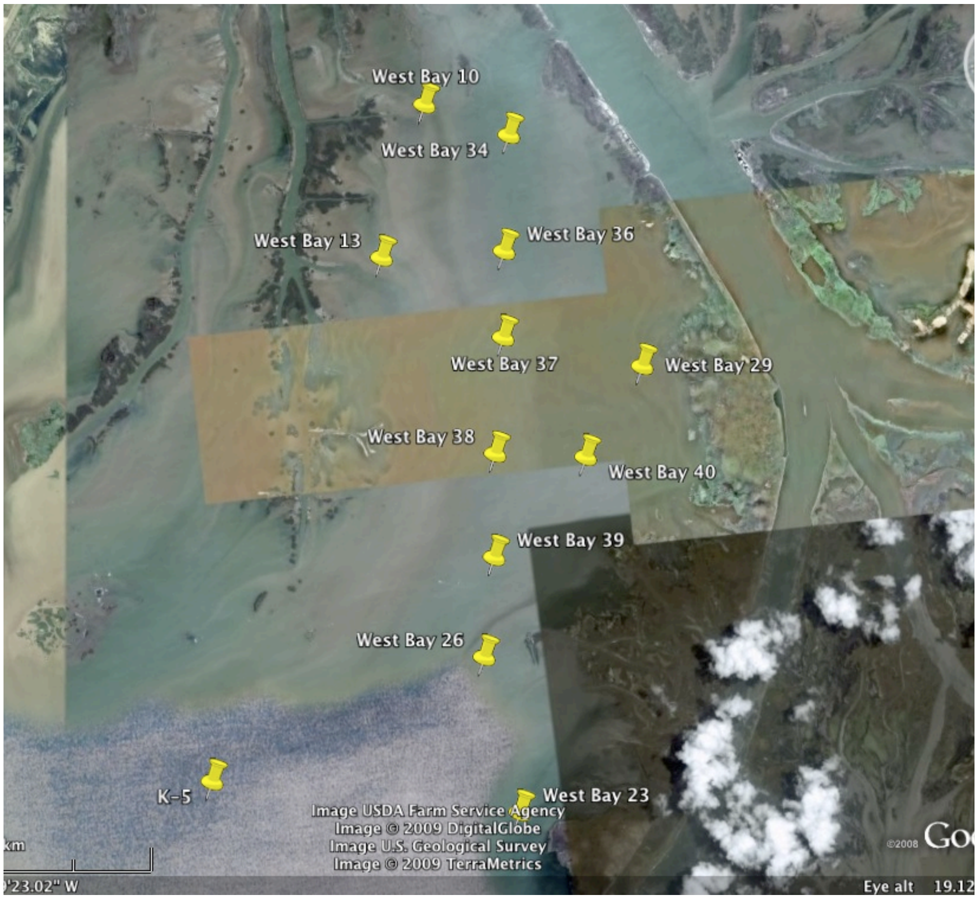

Fig. 1 Sampling locations in West Bay. These points include cores that were originally contracted by the LA S&T program as well as additional samples that were collected contemporaneously.

To more fully understand the long-term history of sediment accumulation, cores were analyzed for ^{137}Cs, a product of ^{235}U fission. Large quantities of ^{137}Cs were released into Earth's atmosphere through nuclear weapons testing, which peaked in 1963 and was subsequently eliminated by the US and the Soviet Union. This history allows one to use a peak in ^{137}Cs activities in a sediment core as an indicator of the year 1963 (DeLaune et al., 1978; Milan et al., 1995). To detect these isotopes ~ 15 g of ground, dried sample was placed into a petri dish and run on a low energy germanium detector. ^{7}Be, and ^{137}Cs were determined from the 477 and 661.6 KeV photokeaks, respectively (Analysis for ^{137}Cs also yields data on ^{210}Pb, which proved to be a less than ideal chronometer, given the non-steady state nature of deposition on West Bay. ^{210}Pb activities for these cores are available in the supplemental data).

3. Results and Discussion

This paper summarized and interprets results from this research. The full datasets are available in the appendices.

3.A. Sediment dynamics during summer/fall of 2009 as revealed by ^{7}Be.

Beryllium-7 is a short-lived, naturally-occurring, particle-reactive radionuclide. It is produced in Earth's upper atmosphere when cosmic rays from the sun interact with atoms of nitrogen and carbon, splitting the atoms in two. Beryllium-7 is the delivered to Earth's surface through rain and dry deposition. Chemically, this element is particle reactive, it rapidly attaches to sediment (esp. silt and clay) surfaces. Physically, the isotope ^{7}Be has a half-life of 53 days. These chemical and physical properties make the radionuclide an excellent tracer of seasonal sediment dynamics (Sommerfield et al., 2000; Sommerfield et al., 1999).

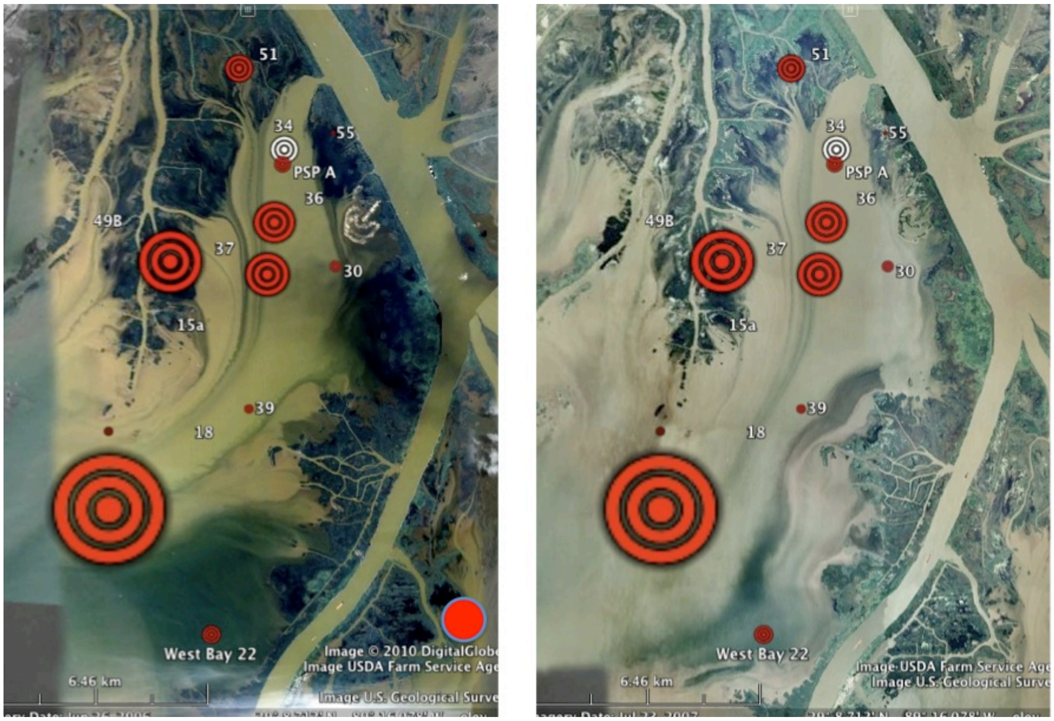

Figure 2 ^{7}Be inventories in West Bay sediments relative, where the dots are proportional to the size of the inventory. The left image is from June, 2006 and the right image is from September, 2007. The red dot in the lower right hand corner of the first image is for scale, it indicated 25 dpm/cm^{2}.

The cores in this project were collected in late September, 2009, and thus reveal patterns of sediment distribution over the past ~150 days, with over half the signal resulting from sediment dynamics over the past ~50 days.

Activities of ^{7}Be in these West Bay cores ranged from non-detectable in core 34, and at depth in cores 30,PSP-A, 17, 22 and 49B, to a maximum of 54.21 ± 5.37 in core 18, interval 0- 1 cm (See Appendix 1). Typically, activities were the greatest at the surface and decreased with depth, consistent with general theory (Sommerfield et al., 2000; Sommerfield et al., 1999).

The presence of ^{7}Be in a core can be used as an indicator of sediment deposition rates. ^{7}Be was measured at a depth of at least 4.2 cm in core 18, indicating sedimentation rates of > 1cm/month at this site. Slightly slower deposition rates occurred at cores 36, 37, 39, 15a, and 55. Cores with 1-2 cm of deposition include 30, PSP-A, 22, 17, and 49B. Core 34 apparently had no sediment deposition. In general, these sediment deposition rates would be considered extremely high – rates in the Mississippi River delta typically range from 0.5 – 1.5 cm/yr. However, it is not clear from these short-term rates alone compare to the long-term trends.

A complementary method of determining regional patterns of sediment deposition is to examine the inventories of ^{7}Be in the sediments. Inventories can be determined from the 7Be activities and the bulk density of the sediments as follows:

$$J = \sum_{b}^{t} A * \rho_d$$

where J is the inventory b and t are the bottom and top of the core and A is the activity of each interval (dpm/g) of sediment and ρ_d is the dry bulk density of each interval (g/cm^{3}) (Berner, 1980).

An image of the ^{7}Be inventories in the sediment cores can be seen in Figure 2, overlain on top of Google Earth Imagery that shows patterns of sediment distribution in the water column. While these images are not from 2009, the fact that they appear twice suggests that they are reoccurring patterns. The interpretation of these data is that ^{7}Be inventories match patterns of sediment flow, and these patterns of sediment flow are dominated by the West Bay diversion and flow off of Main Pass. Figure 3 shows ^{7}Be inventories as they are compared with areas of bathymetric change in the bay (Barras et al., 2009). Here there is a qualitative relationship between the two, with areas of land gain that are aligned to areas of sediment deposition. The relationships between ^{7}Be inventories and land gain are the focus of ongoing work.

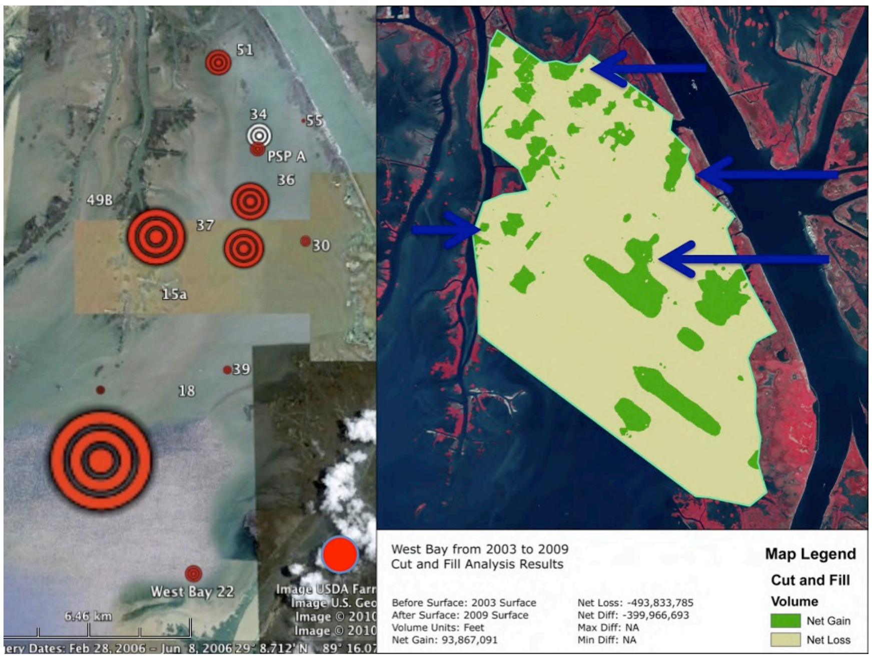

Fig. 3 ^{7}Be inventories relative to cut and fill analysis (Barras, 2009). The red dot in the lower right hand corner of the first image is a scale bar indicating 25 dpm cm^{-2}. The blue arrows indicate areas where sedimentation appears to be leading to shoaling.

3.B Understanding Decadal-Scale Patterns in Sediment Deposition in West Bay

3.B.1 Patterns in X-radiography

The x-radiographs of sediment cores from West Bay generally show strong and distinct laminations (Fig. 4; Appendix 2). This suggests that sediment deposition is driven by pulsed events from the river. Textural analysis indicates that this data is largely silty, with small amounts of sand, particularly at the bottom of core 36 (Kolker et al., In Prep). The fact that these laminations have been preserved suggests that sediments are not regularly resuspended and then redeposited. This is an interesting finding, because West Bay is a large, open and shallow system, and one might expect such a system to have relatively high rate of sediment resuspension, and poor preservation of such material. Two possible mechanisms can be invoked to explain this pattern; either resuspension is truly low, and burial rates are fast, or sediments are resuspended and quickly removed from the system. This possibility can be further explored through measurements of sediment accumulation.

3.B.2 Understanding Rates Using ^{210}Pb and ^{137}Cs

Longer-term patterns of sediment deposition can be revealed by the distribution of ^{137}Cs and ^{210}Pb in sediment cores from this bay (Appleby and Oldfield, 1992; Cochran et al., 2006; Milan et al., 1995). Cores were selected for detailed analysis based on x-radiography, and the need for spatial resolution. Cores were sections into ~ 2 cm intervals and examined to a range of depths. This strategy allowed us to examine some cores in detail while also allowing us to understand sediment dynamics at a number of locations.

The geology and chemistry of ^{210}Pb and ^{137}Cs allow them to be used as in-situ chronometers. ^{210}Pb is produced from the decay of ^{226}Ra, which is present in both crustal rock and seawater. ^{226}Ra decays into the gas ^{222}Rn, which outgases into the atmosphere and then decays through a series of short-lived intermediates into ^{210}Pb. ^{210}Pb rapidly falls out from the atmosphere and is deposited onto Earth's surface. Like ^{7}Be, it is particle reactive. However, it has a much longer half-life, 22.3 years. In conditions where the initial activity of ^{210}Pb is constant, profiles of unsupported ^{210}Pb ($^{210}Pb_{XS}$) can be used to calculate sediment accumulation rates. Profiles of $^{210}Pb_{XS}$ are presented in Figure 5 and the full ^{210}Pb data is available in the Appendix 3. These plots seem to vary widely, suggesting the importance of episodic sediment events and a non-steady state intrusion of ^{210}Pb (See Appendix 3). Therefore, this nuclide is not the ideal geochronometer for this situation. On the other hand, ^{137}Cs appears to be a superior chronometer in this setting (Milan et al., 1995). This isotope is produced from ^{235}U fission. Large quantities of ^{137}Cs were released into the atmosphere during atmosphere weapons testing, which peaked and then effectively ended in 1963. At such, a peak in the concentration of ^{137}Cs makes an excellent indicator of the year 1963. Profiles of ^{137}Cs are presented in Figure 6 and rates of sediment accumulation can be determined from the amount of sediment overlying the 1963 peak. Cores 15a, 30, 34 and 36 have particularly distinct peaks, leading to sediment accumulation rates that range from 0.7 to 1.5 cm yr^{-1}.

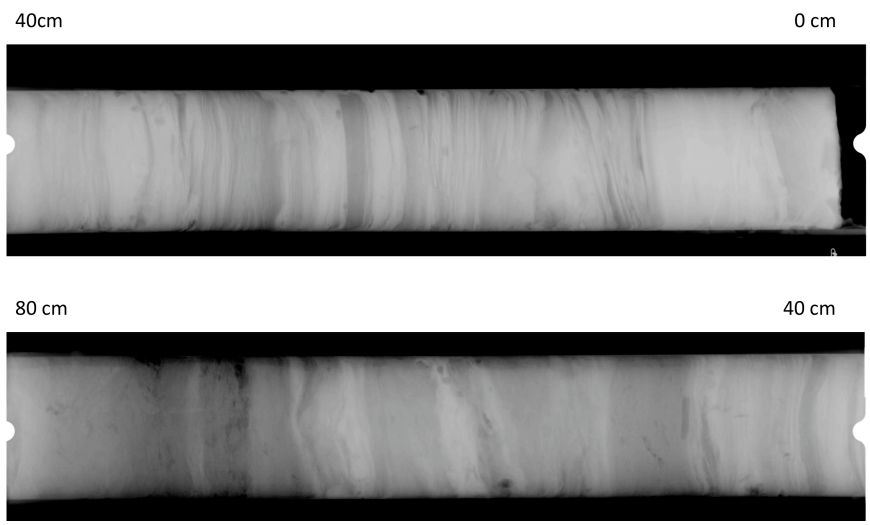

Fig. 4. X-radiograph of core WB S09 - 36, showing strong and distinct sediment laminations.

There are several interesting patterns in these cores that appear. One such pattern is the contrasting rates found in cores 15a and 30, which lie on the western and eastern sides of the bay, at roughly the same latitude the same and distance from the diversion. Core 15a, which is located near Grand Pass, has an accumulation rate that is roughly 30% greater than the rate at core 30, suggesting that Grand Pass has remained a locally important sediment source in the bay. This perspective is consistent with an aerial imagery of West Bay, showing small progradational features on the western side of the bay. Core 34 and 36 show sediment accumulation rates of 0.8 to 1.5 cm yr^{-1}, respectively (Table 1). The higher rates observed in core 36 may reflect its position subsiding regions in West Bay.

^{137}Cs may also serve useful as an indicator of the impact of the West Bay diversion on sediment accumulation in West Bay. Cores 15a, 34, 36, and to a lesser extent cores 30 and 18, show a similar pattern: a peak at depth, a mid core minimum, and with a smaller increase in concentrations towards the top of the core. One explanation is that this increase represents the mobilization of older material following the opening of the West Bay diversion in 2003. This may reflect a "recent" and, “diversion derived,” sedimentary package, whose limits are bounded by the core top and the ^{137}Cs minimum. (Strictly speaking the lower limit is bounded by the ^{137}Cs minimum and the next core interval with a ^{137}Cs increase). Assuming this peak is diversion derived, the amount of new deposition is 8.9 – 27 cm thick, corresponding to a new sedimentation rate of 1.5 - 4.5 cm yr^{-1} for the period 2003-2009 (Table 1).

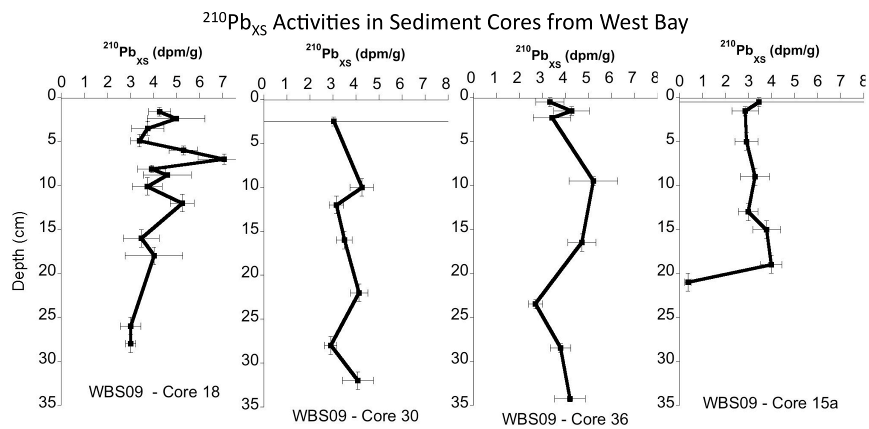

Fig. 5. Examples of ^{210}Pb profiles from sediment cores from West Bay.

Core	Peak Depth	^{137}Cs - 1963 Accumulation Rate (cm/yr)	Thickness of "Recent ^{137}Cs"	"Recent Accumulation Rate"
15a	44-46	1.0	20	3.3
18	8.5-9.1	0.2	8.9	1.5
30	31-33	0.7	23-27	3.8-4.5
34	34-36	0.8	14-18	2.3-3.0
36	66-68	1.5	17.5-23	2.9-3.8

Table 1. ^{137}Cs- derived sediment accumulation rates. The “Recent ^{137}Cs “covers the ^{137}Cs that is near the core top (see text).

3.C. Assessment of Sediment Accumulation Rates

This study has presented effectively three distinct sedimentation rates calculated for three separate time periods. There are ^{7}Be rates for the period June – September, 2009, ^{137}Cs rates for the period 2003-2009 and ^{137}Cs rates for the period 2003-2009. To a first approximation, the ^{7}Be and the short-time scale ^{137}Cs rates are of the same order of magnitude. While some differences exist, for example, core 18 has high ^{7}Be sediment accumulation rates and a slow short-term ^{137}Cs accumulation rate.

However, these differences are probably a result of changes in river flow over time, and changes in winds and storm impacts that drive variability. Indeed, other studies from West Bay have shown considerable season-to-season variability in sediment accumulation in West Bay (Andrus, 2007). It is reasonable to look for correlations between the long-term and short-term sediment accumulation rates presented in this document. There is a suggestion that the long-term and short-term ^{137}Cs accumulation rates positively associated with the short-term ^{137}Cs rates and the ^{7}Be inventories are negatively associated, though in both cases the relationships are not significant at the $p<0.05$ level. The reason for this lack of correlation may simply be a function of the small sample size, or it may reflect fluctuations in seasonal and historic sediment transport pathways that are beyond the scope of this study.

The more complex problem is: why are the short-term rates are substantially greater than the long-term rates? There are several possible, non-mutually exclusive reasons for this. One possibility is that the long-term rates in West Bay are unusually low, however, this is not the case. Long-term (^{137}Cs and ^{210}Pb determined) accumulation rates in the nearby Delta Wildlife Refuge ranging from 1.3 to >1.59 cm/yr, while rates in Barataria Bay and Breton Sound 0.67 ± 0.49 and 0.80 ± 0.17 cm/yr (Wilson and Allison, 2008). This

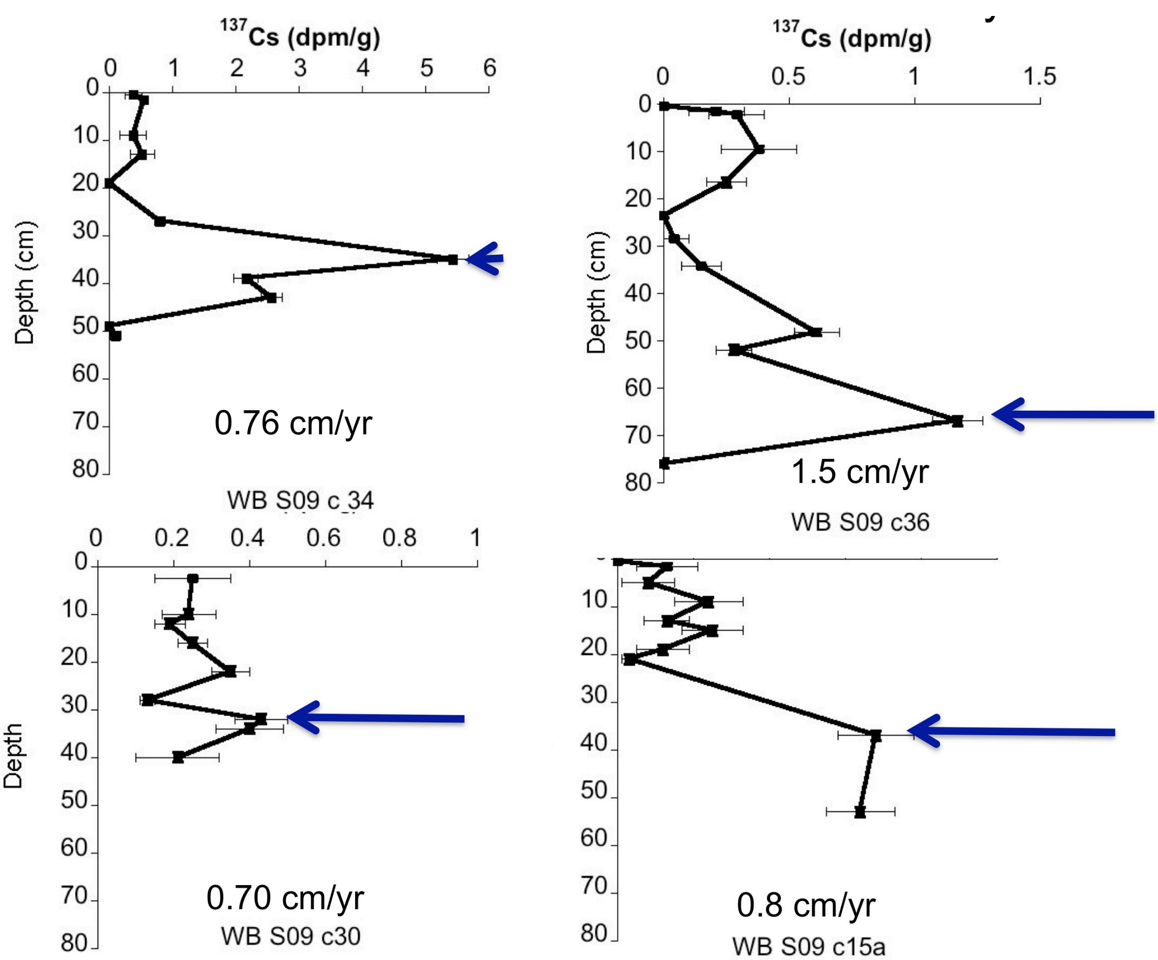

Fig. 6 Examples of ^{137}Cs activity profiles in cores from West Bay. The arrow points to the ^{137}Cs peak, interpreted as the year 1963. It is noteworthy that the activities vary from core to core. The relative concentrations between cores is not as important as the relative concentrations within each core. As such, the horizontal scales vary from core to core.

indicates that long-term rates in West Bay were not unusually low, for this region of the Mississippi River Delta. Another possibility is that higher recent rates are a result of the diversion. This explanation is satisfactory for cores 34 and 36, which lie in the diversions flow-path, but less satisfactory for core 15a, which appears heavily influenced Grand Pass. Another explanation is that the floods in 2008 and 2009, added considerable sediment to the bay, or perhaps that all recent sediments have yet to compact. This is certainly possible, and some of the x-rays do appear to show less consolidated sediments at the top of the core, while bulk density profiles in some (but not all) cores show downcore increases. Finally, it is also possible that these coring locations experienced periods of both deposition and erosion, and that the 0.7-1.5 cm/yr rates amount to a rate of net deposition. This is certainly possible, but well preserved and tightly packed stratigraphy in cores 34 and 36 would suggest require a particular sequence of sediment resuspension and export that tends to discount this possibility. Finally, many have noted that measured deposition rates are inversely proportional the measurement time period. This, "Sadler Effect" (Sadler, 1981), often invokes the compaction and erosion vs. net deposition mentioned arguments mentioned above and as discussed, cannot be entirely discounted

4. Final Implications

The ultimate implications of this study are that sediment is entering the West Bay Diversion receiving basin. These rates can be compared to rates of relative sea level rise in the region. The Grand Isle Tide Gauge shows a rate RSLR of 9.24 mm yr^{-1} for the period 1947-2006 (tidesandcurrents.noaa.gov). The gauge along Mississippi River at Venice shows a rate of RSLR of 21.8 mm yr^{-1} for the period 1953-2005, while the gauges at Port Eads and Southwest Pass show rates of RSLR of 25.5 and 25.7 mm yr^{-1} for data collected from 1953 to 2004 (USACE, In Prep). Over short-time scales, sediment deposition rates in West Bay may be equal to or greater than these local rates. However, given the depth of the bay (2-4 m), it is unlikely that this will lead to the formation of large areas of new land within the next few decades. This finding is consistent with previous studies from the lower Mississippi River (Andrus, 2007; Wells and Coleman, 1987). As a final note, an island was constructed in West Bay after this sampling in 2009, with the hope of increasing sediment retention in West Bay. The present study cannot address the impacts of this island on sediment retention in the bay, though it may lay out a path for future studies.

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