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Intertidal Marsh Suspended Sediment Transport Processes, Terrebonne Bay, Louisiana, U.S.A.

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ABSTRACT

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This study examines the transport processes of suspended sediment from a tidal creek/bayou onto its adjacent salt marsh in a shallow estuary with negligible freshwater inflow near Terrebonne Bay, Louisiana. Water depth, flow velocity, water temperature and salinity in a tidal bayou, and wind speed and direction nearby were measured. Water samples were collected from the bayou bank to the marsh interior at eight locations 8.5 meters apart over a tidal cycle during normal spring tides. Total suspended sediment and inorganic sediment concentrations were analyzed in the laboratory. Results from statistical methods showed that, under the normal tidal inundations, sediment concentrations decreased from bayou bank to marsh interior during flood tides. During ebb tides, sediment concentrations varied less significantly and only slightly with the distance from the bayou bank and were lower than those during flood tides. These results indicate that marsh surface sedimentation is still an active process in marshes of south Louisiana. During strong southerly winds, inorganic suspended sediment concentrations in the bayou were much higher than those in the marsh. During partial inundation and strong northerly winds, inorganic sediments in the marsh were higher than those in the bayou. This suggests that recently deposited sediment on the marsh may occasionally be resuspended and eroded. However, our computations of flow friction velocity and bottom shear stress showed that tidal currents alone in the marsh were insufficient to resuspend the deposited sediment.

ADDITIONAL INDEX WORDS: *Sediment transport processes, tidal marsh, statistical method, bottom shear stress, Terrebonne Bay, Louisiana.*

INTRODUCTION

In recent years, a significant effort has been made to quantify sediment transport processes in rivers, bays, and estuaries through coastal inlets (OZSOY and UNLUATA, 1982; WANG, 1984; BRUUN, 1986; ZARILLO and PARK, 1987). In the more complex marine environment, where coastal marshes are subject to regular tidal inundations and episodic flooding events, relatively fewer studies have been made (REED, 1989).

Louisiana Gulf coast is rapidly subsiding with subsequent wetland deterioration. From 1955 to 1978, the annual wetland loss was estimated at a rate of 120 km^2 along the modern Mississippi River delta on the southeast Louisiana coast (GAGLIANO *et al.*, 1981). In the past decade, wetland loss rates were slowing down (TURNER, 1990). In addition to the decreasing annual sediment yield of the Lower Mississippi River passing into the Gulf of Mexico, from 400 million metric tons prior to 1953 compared to the present load of 200 million metric tons (KEOWN *et al.*, 1986), the levees along the Mississippi River have resulted in the sediment load being deposited on the continental slope. The resultant reductions of the suspended sediment supply in Louisiana coastal bays equal less inorganic material available for wetland accumulation, which in turn contributes to the rapid rate of marsh deterioration.

Many factors influence wetland loss and marsh deterioration. Wetlands are converted into open waters by storms and hurricanes (TURNER, 1990). Coastal subsidence is caused by the compaction of recent sediments and mineral extraction (BAUMANN *et al.*, 1984), and by the rise of eustatic sea level (TURNER, 1991). Marsh deterioration is prompted by increased flooding and salinity along coastal regions (DELAUNE *et al.*, 1987). Accelerated saltwater intrusions through navigation

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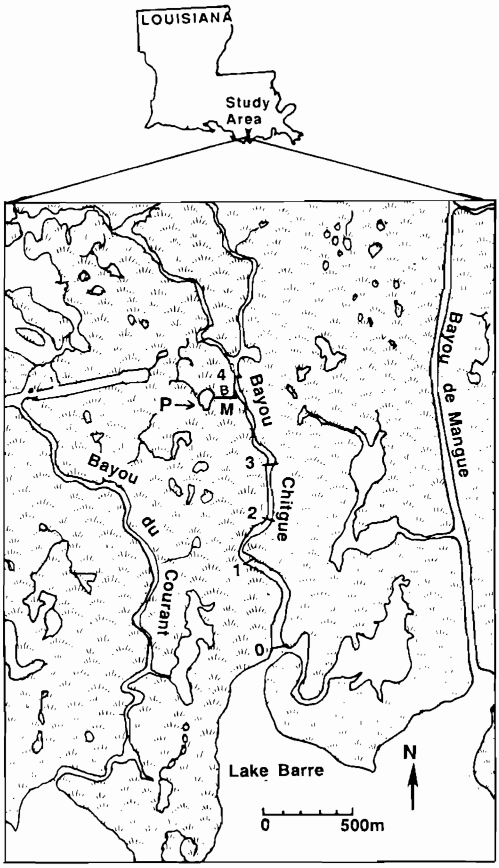

Figure 1. Map of the study area on the south coast of Louisiana showing the location of Bayou Chitique sampling stations (labelled 0, 1, 2, 3, and 4), marsh sites (labelled M), saline pond (labelled P), and boardwalk (labelled B).

channels affect the survival rate of some marshes (WANG, 1988). Marsh habitat is dependent on the ability to maintain its elevation within a specific tidal range by the sedimentation processes of vertical accretion to negate the combined effects of sea level rise (DELAUNE *et al.*, 1990).

In Louisiana's microtidal coastal basin with negligible freshwater inflow, tidal water movement and prevailing winds both play a major role in the transport of suspended sediment. Spring high tides with strong southerly and northerly winds transport suspended sediments into and occasionally out of a marsh through its adjacent tidal channel. During winter months, large amounts of sediment accumulation may occur just prior to a cold front passage when the wind is blowing from the south (REED, 1989). REJMANEK *et al.* (1988) studied the effects of wind and its orientation on the storm-induced sedimentation.

Several studies, based upon comparisons of historical aerial photographs and satellite imagery, indicated an accelerating trend of wetland loss (SASSER *et al.*, 1986; HILL and TURNIPSEED, 1989). The clay marker horizon technique has been used to make estimates on the long-term average sedimentary rates of deposition in saline marshes in south Louisiana (BAUMANN *et al.*, 1984; CAHOON and TURNER, 1987). These studies have shown that the rates of sedimentation were associated with the passage of winter cold fronts. However, the relation between the rates of marsh loss and sedimentation is unclear.

The transport processes of suspended sediment from a tidal creek/bayou onto its adjacent salt marsh during short-term periods over few tidal cycles, and the processes of resuspension of cohesive sediment in coastal marshes in Louisiana are not fully understood. This study attempts: (1) to identify the processes of sediment transport onto an intertidal marsh under normal spring tides and prevailing weather conditions, and (2) to evaluate the potential of resuspension of sediments deposited on the marsh surface during a tidal cycle.

STUDY AREA

Terrebonne basin, a coastal region in south Louisiana, occupies the abandoned deltaic lobes of the Teche and Lafourche Mississippi River deltaic plain which were active 3,000 to 4,000 years ago (COLEMAN, 1981). Bayou Terrebonne, located at the eastern boundary of the basin, was one of the major distributaries of the Mississippi River during the last 1,000 years (PENLAND *et al.*, 1987). The basin is experiencing a serious wetland deterioration, and has been designated as one of the sediment-poor coastal regions by the U.S. Geological Survey and selected as one of the research study areas by WANG and SIKORA (1991) and others.

Bayou Chitique, a natural meandering channel, running north to south and opening into Terrebonne Bay via Lake Barre, was chosen as a specific study site within this coastal basin (Figure 1). The area is sourrounded by many ponds and potholes which are considered as the early stages of both natural processes and human activities by which the marsh deterioration begins and marsh is converted into open water (REED, 1989; WANG and SIKORA, 1991). There are no major fluvial channels in the area, and the flow is mainly derived from local drainage.

In this study area, marshes are subject to microtidal fluctuations and irregular floodings (CHILDERS and DAY, 1988). The diurnal tidal ranges are small, varying from 30 to 60 cm during spring tides and 10 to 20 cm during neap tides (WANG and SIKORA, 1991). The daily flooding and ebbing of diurnal tides and resulting circulation within channels are predictable under calm weather conditions (WANG, 1988). In contrast, the flow patterns in tidal marshes adjacent to bayous are less predictable. Furthermore, there is a lack of topographic features which determine whether water flowing from tidal channels to adjacent marshes during the flood tide will return via the same path during the ebb tide.

METHODS

Channel Flow Measurement

Bayou Chitique is one of numerous tidal creeks in south Louisiana. Five sampling stations along the 2.5 km lower reach of the bayou (labelled 0, 1, 2, 3, and 4 in Figure 1) were chosen for channel-flow measurements. The bayou is relatively shallow, its depth increases from 2.5 m at Station 0 to 5.5 m at Station 4. The bayou width decreases from 60 m at Station 0 to 30 m at Station 4 (WANG and SIKORA, 1991).

Prior to each field-sampling trip, hourly predicted tidal heights at Wine Island in Terrebonne Bay (NOAA, 1989) were used for planning and scheduling the field data collection and to predict when the marshes would be flooded under normal weather conditions. At Sations 1 and 4, continuous channel-flow measurements over a full tidal cycle were made during a spring tide on October 19–20, 1990 and May 16–17, 1991 to quantify changes in physical parameters during the sampling period (WANG and SIKORA, 1991). Hourly flow velocity, water temperature and salinity were taken at 1-m depth intervals.

Channel velocities were measured with a Montedoro-Whitney Current Meter, Model PVM-2A. Concurrent water temperature and salinity readings were taken at the same depth increments with a Yellow Springs Instrument SCT Meter, Model 33. Hourly water samples were collected simultaneously both at 20 cm below the water surface and 50 cm above the channel bed, using a Lamotte Water Sampler, Model JT-1. Of this sample, 250 ml was poured into a clean, pre-numbered plastic bottle and placed on ice for laboratory analysis to determine the total suspended sediment and inorganic sediment concentrations. Wind speed and direction were measured with a hand-held Wind Speed Indicator, Model 98.

Marsh Surface Flow Measurement

Two marsh plots, 2 m by 2 m, located 13.5 m and 37.5 m from the west bank of Bayou Chitique (labelled M in Figure 1), were selected for marsh surface-flow measurements (WANG and SIKORA, 1991). These marsh-plot sites appear to be more representative of overland sheet flows that take place on the marsh surface. For ease of access to marsh sites, a boardwalk, 110 m long (labelled B in Figure 1), was constructed from the west bank of Bayou Chitique to a deteriorated saline pond (labelled P in Figure 1). The vegetation in this area is dominated by *Spartina alterniflora*.

On most occasions, water flow across intertidal salt marshes is not measurable by electromagnetic flow meters used to measure channel flow velocities, because the flow depth on the marsh surface is relatively shallow and over-marsh surface flow velocity is relatively slow. These problems are approached indirectly by tracking a visible substance applied to the water surface (WANG and SIKORA, 1991). A special marsh-flow instrument system has been designed (SIKORA and WANG, 1991). The concept of this measuring device is similar to that of BURKE and STOLZENBACH (1983). The device utilizes a camera and timer to photographically track the sequential movement of dye plumes diluted with ambient water and released onto the marsh-water surface. The over-marsh surface velocity can then be estimated from the travel distance of the dye at a predetermined time interval. This apparatus has been tested in the field during several sampling trips and modified subsequently. From these field tests, the most appropriate sampling periods for conducting dye experiments were 4 to 6 hours before and after the daily tidal peak. A series of dye-plume experiments were then carried out at two marsh plots during a spring tide on May 16–17, 1991 to quantify the dynamics of marsh surface flow (WANG and SIKORA, 1991).

During the May 16–17, 1991 sampling trip, the predicted high tides at Wine Island were 50 to 55 cm above mean sea level. It had been raining for several days before the trip. Superimposed upon the rain, a steady southerly wind of 3.5 to 5.5 m/sec caused 30 to 50 cm of water flooding on the

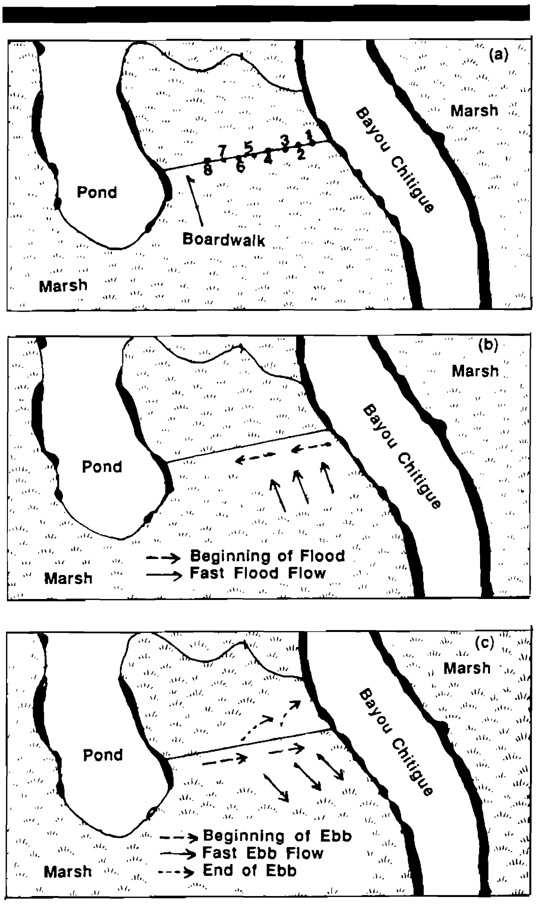

Figure 2. (a) Location of sediment sampling sites (labelled 1, 2, 3, 4, 5, 6, 7, and 8) along the boardwalk (not to scale); (b) Observed flow patterns on the marsh during the flood tide on May 16–17, 1991; (c) Observed flow patterns on the marsh during the ebb tide on May 16–17, 1991.

marsh. During the fast rising and falling water levels, the exceptional high-water depths at the marsh sites were sufficient to measure the velocity profiles within the marsh directly by current meter at 2 to 5-cm depth intervals. These velocity profiles were used to evaluate the frictional velocity and the boundary shear stress. Replicate water samples in the salt marsh were collected along the boardwalk, from the west bank of the bayou toward the saline pond, at eight sites, located 8.5 meters apart (labelled 1, 2, 3, 4, 5, 6, 7, and 8 in Figure 2a).

Laboratory Analysis

Inorganic sediment constitutes a large fraction of marsh soil solids in salt marshes and contributes to stable marsh accretion and wetland accumulation (DELUANE *et al.*, 1990). Water samples were analyzed for total suspended sediment, organic and inorganic sediment concentrations by a modification of EPA Method 160 (USEPA, 1979). Whatman glass microfiber filters (GF/C, pore size = 1.2 μm, diameter = 4.7 cm) were used to filter the water samples. Filters were weighed immediately before use. A 200 ml well-mixed water sample was filtered through the glass fiber filter, and the residue retained on the filter was dried for 24 hours at 60 °C and reweighed. The dry filters were then ignited at 500 °C to burn off the organic matter. The burned filters were reweighed. The total suspended, organic, and inorganic sediment concentrations were determined (LU, 1991).

Statistical Methods

The randomized block design (SAMUELS, 1989) was used in this study. In this method, the experimental units are grouped into blocks. The objective of grouping is to have the units in a block as uniform as possible so that observed differences are largely due to treatments and experimental errors are minimized (STEEL and TORRIE, 1980). Each block contains an equal number of treatments. Blocks and treatments are orthogonal to one another. It is this property that leads to the simple arithmetic involved in the analysis of variance of the data sets.

In this study, sampling times or water depths on marsh surface (designated as blocks), and distances from bayou bank to the marsh interior (designated as treatments) are two important factors controlling suspended sediment transport from a tidal bayou onto its adjacent marshes. In this analysis, the randomized block design (RBD) consisted of 4 blocks and 8 treatments for both flood half-tide and ebb half-tide during May 16–17, 1991 sampling period. The RBD model is written as:

$$Y_{ij} = \mu + \alpha_i + \beta_j + \epsilon_{ij} \qquad (1)$$

where i is the treatment index, j is the block index, Y_{ij} is the inorganic sediment concentration for ith treatment and jth block, μ is the overall mean, α_i and β_j are the effect of ith treatment and jth block on sediment concentrations, respectively, and ϵ_{ij} represents experimental error.

In the post analysis of variance technique (ANOVA), the contrast and least square difference (LSD) methods were used (SAS INSTITUTE, 1985), when the results of RBD statistics showed that the treatments were significantly different. The purpose of this analysis is to determine whether suspended sediments do deposit on the marsh when marshes are inundated. Inorganic sediment can only be deposited when the marsh is inundated, but not all inundations will contribute to the same amount of sediments.

Finally, the unpaired t-test technique (SAMUELS, 1989) was used in this study to identify whether sediment concentrations were significantly different between the bayou and the adjacent marshes under prevailing weather conditions. Three data sets, collected on January 25–26, March 8, and March 21–22, 1991 (WANG and SIKORA, 1991) were chosen for comparisons.

Turbulent Shear Stress

The purpose of this analysis is to evaluate the resuspension potential of sediment deposited on the marsh surface. The bed and the fluid motion above the bed interact by means of friction forces which operate within the boundary layer to exchange momentum between the moving fluid and the bed. The friction force per unit area of the plane within the fluid near the bed can be expressed by the turbulent shear stress. It is the bottom shear stress which is the most important physical parameter for sediment resuspension. In our marsh sites, the vegetation density, in terms of vegetated area within 1 m^2, varied from 40% to 60%. For more dense vegetation, sediment trapping by grasses could account for some amount of suspended sediments (STUMPF, 1983).

In a turbulent boundary layer, flow velocity is reduced near the bed because of the bed friction. The reduction is greatest near the bottom and decreases upward. The turbulent shear stress is governed by the velocity gradient in the near-bed zone and the distance from the boundary (DYER, 1986). A logarithmic velocity profile is formed, such that

$$u/u_* = (1/\kappa)\ln(z/z_0) \qquad (2)$$

where u is the horizontal flow velocity within the lower part of boundary layer, u_* is the friction velocity, κ is von Karman's constant, z is the vertical distance from the bed, and z_0 is known as the roughness length to be found at the interception of the velocity profile.

A quadratic formula is then used to compute the bottom shear stress (DYER, 1986):

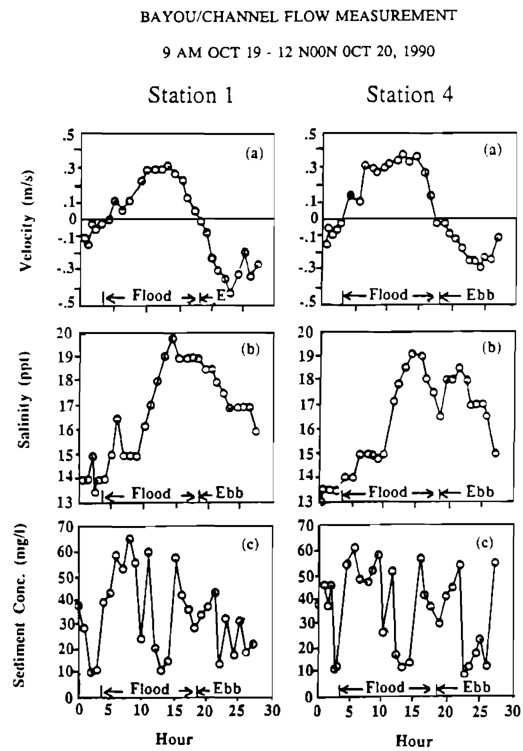

Figure 3. Depth-averaged (a) flow velocity; (b) water salinity, and (c) sediment concentration in Bayou Chitique at Stations 1 and 4, depth = 3.0 and 5.5 m, on October 19–20, 1990 (WANG and SIKORA, 1991).

$$\tau_0 = \rho u_*^2 \qquad (3)$$

where τ_0 is the bottom shear stress, and ρ is the fluid (water) density.

RESULTS

Results of Channel Flow Measurement

Channel flow measurements conducted on October 19–20, 1990 represent a typical change in physical parameters over a full tidal cycle during a spring tide. Vertical profiles of velocity showed well-behaved laminar flow in the channel (WANG and SIKORA, 1991). Temperature and salinity showed little variation with depth, indicating a well-mixed tidal channel. Sediment concentrations showed large fluctuations between sampling periods during maximum flood and ebb tides.

Figure 3a, b, and c show the depth-averaged results of flow velocity, water salinity, and sediment concentration at Station 1 (near bay station, channel depth 3.5 m) and Station 4 (farthest in-

MARSH SURFACE FLOW MEASUREMENT

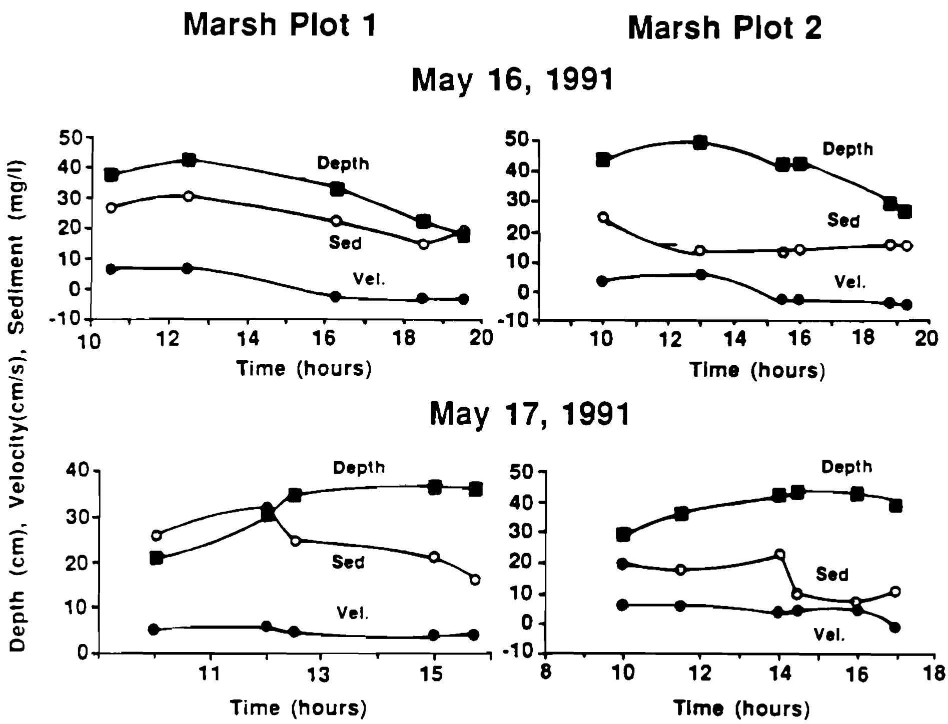

Figure 4. Over-marsh water depth, flow velocity, and inorganic suspended sediment concentration at marsh site, Plots 1 and 2, adjacent to Bayou Chitique on May 16–17, 1991 (WANG and SIKORA, 1991).

land station, channel depth 5.5 m), respectively. Channel flow velocity at Station 4 which peaked at 40 cm/sec, was higher than Station 1, during the flood tide but slower on the ebb tide (Figure 3a). Station 1 showed an ebb-dominated channel flow which also peaked at 40 cm/sec. Temperature throughout the sampling period ranged from 16 to 21 °C, exhibiting a distinct warming trend during the day. During the sampling period, salinity at Station 1 varied from 14 to 20 ppt, at Station 4 it ranged from 13 to 19 ppt (Figure 3b), resulting in a negligible horizontal gradient along the 2 km reach of Bayou Chitique. Sediment concentrations showed similar patterns at both stations, in the range of 10 to 65 mg/l as expected in this sediment-poor coastal region (Figure 3c).

Results of Marsh Surface Flow Measurement

Before May 16–17, 1991 sampling trip, it had been raining for several days. During the sampling period, steady southerly winds (3.5–5.5 m/sec) combined with a relatively high spring tide in the range of 50–55 cm, resulted in the highest water depth, 30 to 50 cm, on the marsh surface of all sampling trips conducted in our 2-year field study (WANG and SIKORA, 1991). The flow depth on marsh surface responded quickly to the tidal cycle as the predicted tidal height at Wine Island reached 20 to 25 cm. Flow directions on the marsh were observed to change with the tidal phases as depicted in Figure 2b and c. At the beginning of both flood and ebb tides, flow directions were parallel to the boardwalk, at nearly a right angle with the bayou bank. During fast flows of both flood and ebb tides, flow directions were oblique to the boardwalk (LU, 1991).

During the 10 hours of daylight (0900–2000 hr), a series of dye-plume experiments were carried out at two marsh plots, Plot 1 and Plot 2, located 13.5 m and 37.5 m from the west bank of

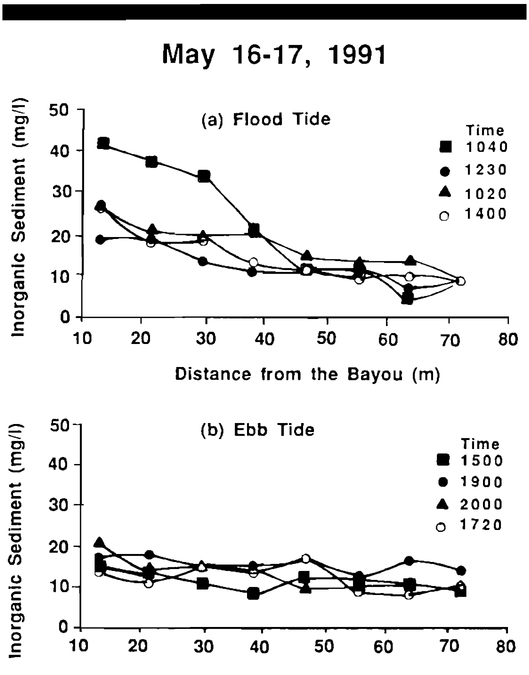

Figure 5. Inorganic suspended sediment concentration versus distance from the bayou bank collected on May 16–17, 1991 during (a) flood tide and (b) ebb tide (Lu, 1991).

Bayou Chitique, respectively (labelled M in Figure 1). At Plot 1, the vegetation, *Spartina alterniflora* with clumps of *Juncus roemerianus*, was more dense than Plot 2. The marsh surface elevation at Plot 1 was about 2 cm higher than Plot 2. The resulting flow depths at Plot 2 was about 6–8 cm higher than that at Plot 1 throughout the 10-hour sampling period (Figure 4). Over-marsh surface flow velocities were estimated from movement of dye-plumes over time (Figure 4). The results showed that over-marsh surface flow velocities were relatively slow, ranging from 4 to 8 cm/sec, about 10 to 20% of channel flow during the same sampling time period. Inorganic suspended sediment concentration varied from 10 to 30 mg/l. At Plot 1, the sediment concentration was about 5 mg/l higher than at Plot 2 (Figure 4).

Results of Statistical Models

Tables 1a and b list the inorganic sediment concentrations collected on May 16–17, 1991 during the flood and ebb tides, respectively. Figure 5 plots the spatial distribution of suspended inorganic

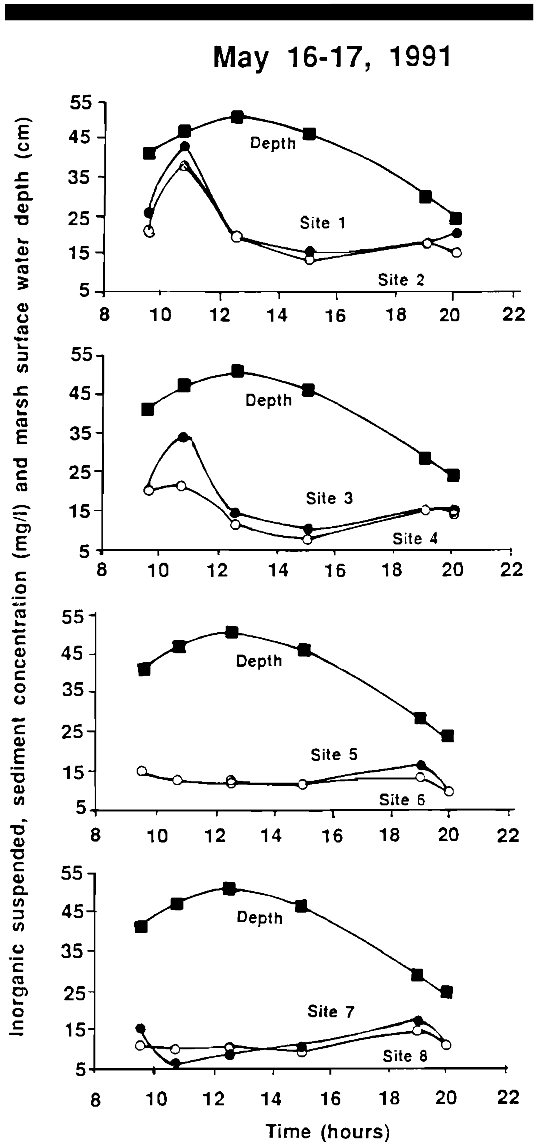

Figure 6. Time series of inorganic suspended sediment concentration and water depth at sediment sampling sites collected on May 16–17, 1991 (Lu, 1991).

sediment concentrations from the bayou bank to marsh interior. The SAS computer outputs, constructed as source tables for data sets in Table 1, are displayed in Table 2. In Table 2, the Pr values (probability of exceeding the F value) were less than 0.05 for both the treatment and the block. During the flood tide, the results indicated that the sediment concentrations were significantly different among the treatments, that is, sediment

Table 1. *Inorganic sediment concentrations in mg/l collected in the marsh on May 16–17, 1991 (see Figure 2a for treatment or sample site location).*

Block	Treatment 1	2	3	4	5	6	7	8
				(a) During flood tide				
1	42.4	38.0	34.4	21.6	12.8	12.4	5.6	10.0
2	19.2	19.6	14.4	11.6	11.6	12.4	8.4	10.4
3	26.0	21.2	20.0	20.4	15.2	14.4	14.8	10.4
4	27.6	18.4	19.2	14.4	12.4	10.4	11.2	10.0
				(b) During ebb tide				
1	15.5	14.0	11.2	8.4	12.4	12.0	10.8	9.6
2	17.2	18.0	15.6	15.6	16.8	13.2	16.8	14.4
3	20.8	14.8	15.6	14.4	10.0	10.0	10.4	10.8
4	13.6	11.2	15.2	14.0	17.2	9.2	8.4	10.8

concentrations in the marsh were different at different distances from the bayou (Table 2a). During the ebb tide, the variations of sediment concentration were less significant (Table 2b). The results of contrast and least square difference methods revealed that both treatments 1 and 2 were different from treatments 7 and 8. The time series plots (Figure 6) showed that sediment concentrations near the bayou were higher than those far from the bayou during flood tide. During ebb tide, sediment concentrations varied only slightly with the distance. Table 3 summarizes the statistical results of least square difference. It can be seen from Table 3a that during flood tide, sediments were gradually deposited on the marsh. During ebb tide, however, sediment concentrations were not significantly different among treatments if treatment 1 was omitted (Table 3b).

Unpaired t-tests were then used to test whether inorganic suspended sediment concentrations were significantly different between the bayou and its adjacent marsh under prevailing weather conditions due mainly to the different wind speed and wind direction. The results of unpaired t-tests summarized in Table 4 show the effects of wind on bayou and marsh sediments. Under calm weather with easterly wind (January 25–26, 1991), sediment concentrations were not significantly different between the bayou and the marsh and both concentrations were relatively low. When northerly winds were strong (March 8, 1991), sediment concentrations on the marsh were significantly different, with sediment concentrations in the marsh much higher than those in the bayou. When southerly wind prevailed (March 21–22, 1991), the opposite was true with sediment concentrations in the bayou much higher than those in the marsh. Figure 7 plots the inorganic suspended sediment concentrations in Bayou Chitique and its adjacent marsh under various weather conditions.

Table 2. *Analysis of variance for sediment data sets collected in the marsh on May 16–17, 1991.*

Source of Variance	DF	SS	MS	F	Pr > F
		(a) During flood tide			
Treatment	7	1395.97	199.42	7.51	0.0001
Block	3	336.08	112.03	4.22	0.0175
Error	21	557.32	26.54		
Total	31	2289.38			
		(b) During ebb tide			
Treatment	7	107.50	15.36	2.83	0.0303
Block	3	81.02	27.01	4.98	0.0091
Error	21	113.86	5.42		
Total	31	302.38			

Marsh Bottom Shear Stress

Bottom shear stress was estimated from field measurements of marsh vertical velocity profiles. On May 16–17, 1991, the marsh sites in our study area were inundated about 8 to 10 hours daily. The water depth on the marsh surface reached 30 to 50 cm. The vegetation was mostly submerged when marsh flow depth approached 10 to 15 cm. A series of velocity profiles were measured on the marsh from 3 cm above the bed, at 2 to 5-cm depth intervals to a total flow depth of 25 to 30 cm (LU, 1991). An average roughness length of $z_0 = 1.6$ cm, the value of the intercept of the logarithmic velocity profiles, was found. Mean velocity, $u = 4.3$ cm/sec, at flow depth, $z = 13$ cm, above the marsh bed was obtained. This flow depth was considered

Table 3. *Results of least square difference analysis for May 16–17, 1991 sediment data sets.*

	Treatment							
Sediment	1	2	3	4	5	6	8	7
Mean (mg/l)	28.8	24.3	22.0	17.0	13.0	12.4	10.2	10.0
Grouping	A	A	A					
		B	B	B				
				C	C	C	C	C
(b) During ebb tide								
Mean (mg/l)	16.8	14.5	14.4	14.1	13.1	11.6	11.4	11.1
Grouping	A	A	A	A				
		B	B	B	B	B	B	B

near the top of the logarithmic layer. Substituting these values into equations 2 and 3, the friction velocity, $u_* = 0.82$ cm/sec, and bottom shear stress, $\tau_0 = 0.67$ dyne/cm^2, were obtained.

DISCUSSION

Processes of Suspended Sediment Transport

The data for channel flow measurements, conducted on October 19–20, 1990 at two channel stations, indicated the variability of physical parameters in a tidal bayou over a full tidal cycle (Figure 3). At Station 1, a more ebb-dominated tidal flow was observed, while at Station 4, a more flood-dominated tidal flow was seen (Figure 3a). The difference in velocity patterns at the two stations could be explained, in part, as resulting from the passage of a cold front immediately before our sampling period which dewatered the marsh surrounding Station 4 (WANG and SIKORA, 1991). This dewatering enabled marsh substrate to absorb more water during the flood tide at Station 4. The suspended sediment concentrations at both stations tended to increase with increasing flow velocity but reached the lowest level of concentrations at peak flood and ebb currents (Figure 3c). This indicates that suspended sediments in coastal bays are being transported both in and out of the bayou by tidal currents.

The data for marsh surface-flow measurements, obtained from dye-plume field experiments conducted at two marsh plots on May 16–17, 1991, showed that over-marsh surface flow velocity increased with water depth on the marsh and reached 8 cm/sec near the mid-water level (Figure 4). As the water depth decreased, velocity slowed down. Suspended sediment concentrations displayed similar patterns. Concentrations were high near the mid-water level and were low at high-water level. This result indicates that some of the suspended sediments were deposited in the marsh during slack water.

The data for suspended sediment collected on the transect from the bayou bank to the marsh interior at eight sampling sites over a tidal cycle on May 16–17, 1991, indicated that suspended sediment concentrations varied with time at each sampling site (Figure 5). During flood tide, sediment concentrations differed markedly from Site 1 to Site 4. In contrast, concentrations varied only slightly from Site 5 to Site 8 throughout the tidal cycle. These data indicate that a dynamic equilibrium of suspended sediments in over-marsh surface flows has been reached. That is, at our study site, a nearly constant sediment concentration occurred to a distance of about 50 m from the bayou bank toward marsh interior. Additionally as shown in Figure 6, suspended sediment concentrations near the bayou were higher than those far from the bayou. Sediment concentra-

Table 4. *Results of unpaired t-test for bayou and marsh sediments measured under various weather conditions in 1991.*

Sampling Date in 1991	Wind		Mean Inorganic Sediment		t-test Results at 5% Level
	Speed (m/sec)	Direction	Bayou (mg/l)	Marsh (mg/l)	
January 25–26	2.5–3.0	east	9.63	8.82	not significant
March 8	5.0–7.5	north	13.97	23.75	significant
March 21–22	5.0–7.5	south	33.10	16.85	significant

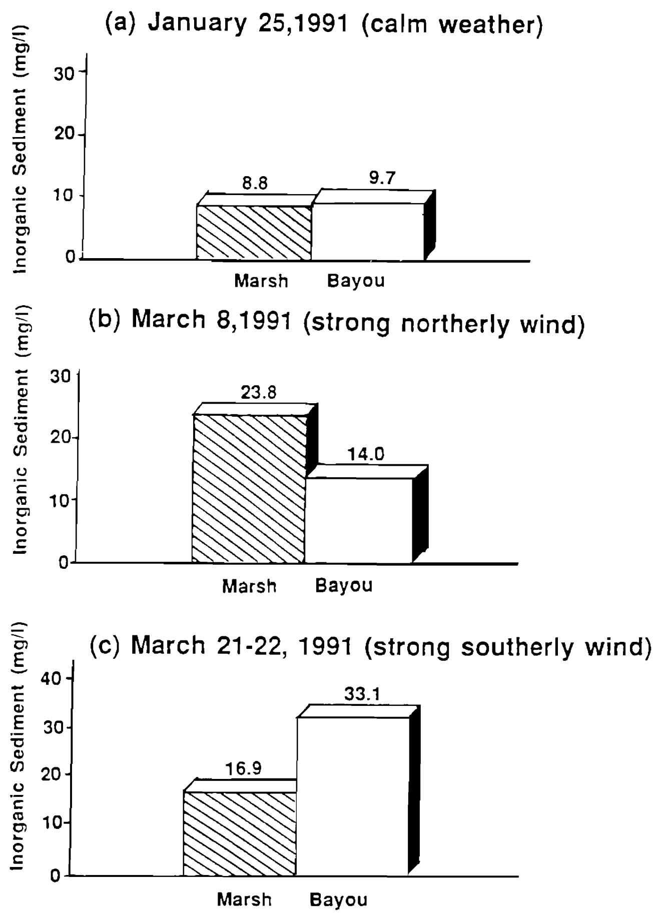

Figure 7. Depth-averaged inorganic suspended sediment concentrations in Bayou Chitique and adjacent marsh site under various weather conditions: (a) January 25–26, 1991 (calm weather); (b) March 8, 1991 (strong northerly wind); and (c) March 21–22, 1991 (strong southerly wind).

tions increased as the water level rose and then decreased before the highest water level and remained low thereafter. This implies that sediments are gradually deposited in marshes as the water floods over the marsh and that sedimentation is still occurring in south Louisiana, which supports the findings by others (Baumann, 1984; Reed, 1989).

Three additional data sets of total suspended sediments in the bayou and marsh showed the effects of wind on sediment concentrations (Figure 7). The weather was relatively calm on January 25–26, 1991. Strong winds from constrasting directions occurred on March 8, 1991 with northerly wind of 5.0–7.5 m/sec, while strong winds blew from the south (5.0–7.5 m/sec) on March 21–22, 1991. Under calm weather (Figure 7a), it appears that sediment transport by flood and ebb currents are nearly equal. During the strong northerly winds (Figure 7b), it is likely that some previously deposited sediments on the marsh surface can be resuspended and transported to the bay by ebb-tide currents. Conversely, strong southerly winds (Figure 7c) can moblize sediments in Terrebonne Bay, then flood-tide currents transport sediments from the bay through Bayou Chitique onto its adjacent marsh.

Possibility of Sediment Resuspension

The bottom shear stress was computed from field measurements of vertical profiles of marsh horizontal velocity on May 16–17, 1991 (Lu, 1991).

The bottom shear stress at our marsh sites was estimated to be τ_0 = 0.67 dyne/cm^2, which was considerably lower than the known values of critical shear stress for sediment erosion. MEHTA and PARTHENIADES (1982) found that the critical value for cohesive sediment erosion is about equal to τ_c = 1 dyne/cm^2. They further found that the critical shear stress increases both with sediment depth below the bed surface and sediment consolidation time. In our study area, marshes are flooded periodically, thus deposited sediments are often exposed to the air for lenghty time periods during low water levels. This periodic exposure to air accelerates the processes of sediment consolidation and increases the critical shear stress threshold for erosion. An estimated value of critical shear stress for silt erosion was about τ_c = 1.29 dyne/cm^2 (LU, 1991).

Our results of bottom shear stress, τ_0 = 0.67 dyne/cm^2, is much less than the value of critical shear stress, τ_c = 1 dyne/cm^2. It thus appears that sediments deposited on the marsh surface in our study area are unlikely to be resuspended by tidal currents alone. Favorable weather conditions for sediment resuspension can be met in our study area if northerly winds are strong and marsh is covered by 2 to 5 cm of water. In shallow coastal environments, wind-generated waves are important to the bottom boundary layer by not only exerting direct frictional effects on the bed, but also by increasing the shear stresses exerted by the flows (WRIGHT, 1989). Both wave-induced and current-induced shear stress are enhanced by the interaction.

CONCLUSIONS

The following conclusions are drawn based on analysis of observed data sets collected during our 2-year (1990–1991) field study:

(1) Bayou Chitique, a tidal creek with negligible river inflow in Terrebonne Bay, south Louisiana, responds quickly with the incoming tides from the open bay. Tidal currents in the bayou are slightly higher at ebb tides than those at flood tides. Suspended sediments are being transported in and out of the bayou by tidal currents.

(2) Marshes adjacent to the bayou are subject to more frequent tidal inundations and storm floodings than interior marshes. Over-marsh surface flow velocity increases with water depth and reaches maximum at mid-depth and decreases as water level falls.

(3) During flood tides, suspended sediment concentrations decrease with increasing distance from the bayou bank. During ebb tides, sediment concentrations do not vary with the distance and are lower than those during flood tides. These results support the findings by others that marsh surface sedimentation is still an active process in this sediment-poor coastal region, at least along the bayou margin.

(4) Winds have large effects on marsh sediments. Strong southerly winds mobilize sediments in the open bay, which are transported through coastal channels and dispersed onto adjacent marshes. When the marsh is inundated by only a few centimeters of water, the opposite can be true, when strong northerly winds prevail.

(5) Tidal currents in marshes are about 10 to 20% of current in the adjacent bayou. The resulting bottom shear stress in marshes is much less than the critical shear stress for sediment erosion. It appears that in our study area, tidal currents alone are insufficient to resuspend the sediments deposited on the marsh.

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