# SEDIMENTATION AND HISTORICAL CHANGES IN FLUVIAL-DELTAIC WETLANDS ALONG THE TEXAS GULF COAST WITH EMPHASIS ON THE COLORADO AND TRINITY RIVER DELTAS

by

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## INTRODUCTION

The most extensive losses in coastal wetlands in the United States over the last two decades have occurred along the Gulf Coast. Wetlands are disappearing at an alarming rate on the Mississippi River Deltaic Plain, indicating a reversal in the trend of net progradation of the delta that characterized much of the past 5,000 years (Gagliano and others, 1981). The land-loss rates have accelerated geometrically during the 20th century, apparently as a result of natural and artificial processes, the latter including artificial levees and control structures that have harnessed the Mississippi River and virtually eliminated the deltaic sedimentation processes of overbank flooding, crevassing, and upstream diversion; extensive canalization and accelerated subsidence related to mineral extraction compound the problem (Gagliano and others, 1981). Investigations of marsh losses in Louisiana indicate that marsh aggradation (vertical accretion) rates are not keeping pace with relative (apparent) sea-level rise (DeLaune and others, 1983; Hatton and others, 1983; Baumann and others, 1984; Boesch and others, 1984).

Although less extensive than in Louisiana, losses in wetlands along the Texas coast have also been documented (McGowen and Brewton, 1975; Gosselink and others, 1979; Johnston and Ader, 1983; White and others, 1984; 1985; 1987). Some of the most dramatic changes have occurred in fluvial-deltaic areas such as near the mouths of the San Jacinto and Neches Rivers where wetland losses totaled more than 4,000 hectares (10,000 acres) between the mid 1950's and the late 1970's (White and others, 1985; 1987). The losses are characterized by submergence and displacement of marshes, swamps, and fluvial woodlands by shallow subaqueous flats and open water, indicating, as in Louisiana, that marsh aggradation rates are not keeping pace with relative sea-level rise.

This report is part of a study funded by the Texas Parks and Wildlife Department and Texas Water Development Board with funds allocated by the Texas Legislature for comprehensive studies of the effects of freshwater inflows on the bays and estuaries of Texas.[1]

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[1] In response to House Bill 2 (1985) and Senate Bill 683 (1987), as enacted by the Texas Legislature, the Texas Parks and Wildlife Department and the Texas Water Development Board must maintain a continuous data collection and analytical study program on the effects of and needs for freshwater inflow to the State's bays and estuaries. As part of the mandated study program, this research project was funded through the Board's Water Research and Planning Fund, Authorized under Texas Water Code Sections 15.402 and 16.058 (e), and administered by the Department under interagency cooperative contracts No. IAC (86-87)1590, IAC(88-89)0821 and IAC(88-89)1457.

## Wetland Sedimentation

The high rates of wetland loss in Louisiana have made it the center of wetlands research including studies in marsh sedimentation. There have been few studies of sedimentation in Texas marshes. Investigations have principally focused on shoreline changes in an effort to document erosion and accretion (advancement of the shoreline) (McGowen and Brewton, 1975; Morton, 1977; Morton and Paine, 1984; Paine and Morton, 1986; White and Morton, 1987). This field investigation, which has as a primary objective of documenting local marsh aggradation (vertical accretion) rates, is apparently the first of its type in Texas coastal marshes.

Rivers discharging into the bays and estuaries along the Texas coast have constructed deltas that are the sites of extensive marshlands and forested wetlands. Fluvial sediments delivered by the rivers help maintain these valuable natural resources. Marshes are dependent upon sediment deposition not only for nutrient supply, or fertilization, but also in order to maintain their intertidal position. Accordingly, comparisons of marsh aggradation rates with rates of relative sea-level rise provide critical information for predicting marsh vegetation survival. If sediment deposition is such that marsh aggradation rates can keep pace with rates of relative sea-level rise, the marsh can survive and even flourish, but if aggradation rates fall behind, the marsh will drown and be replaced by open water. Relative sea-level rise as used here, refers to a rise in sea level with respect to the surface of the land; the components of this relative change are a combination of actual sea-level rise and land-surface subsidence.

A major objective of the field investigation on sedimentation was to document marsh aggradation rates using artificial-marker horizons similar to those used in Louisiana (DeLaune and others, 1983; Baumann and others, 1984). In addition, sediments from a few cores were radiochemically dated using $^{210}$Pb to determine long-term (approximately 100 years) aggradation rates. Two deltaic areas were selected for the field study: the Colorado River delta and the Trinity River delta. Both areas have significantly extended their deltas within historic times, and both are fed by rivers whose sediment loads have, more recently, been significantly reduced (Figs. 1 and 2).

## Historical Changes in Fluvial-Deltaic Wetlands

Extensive conversions of marshes to open water in the Neches River delta and alluvial valley (White and others, 1987) highlight the need to examine the extent of similar historical changes in wetlands in each of the major river systems discharging into estuarine areas along the Texas coast.

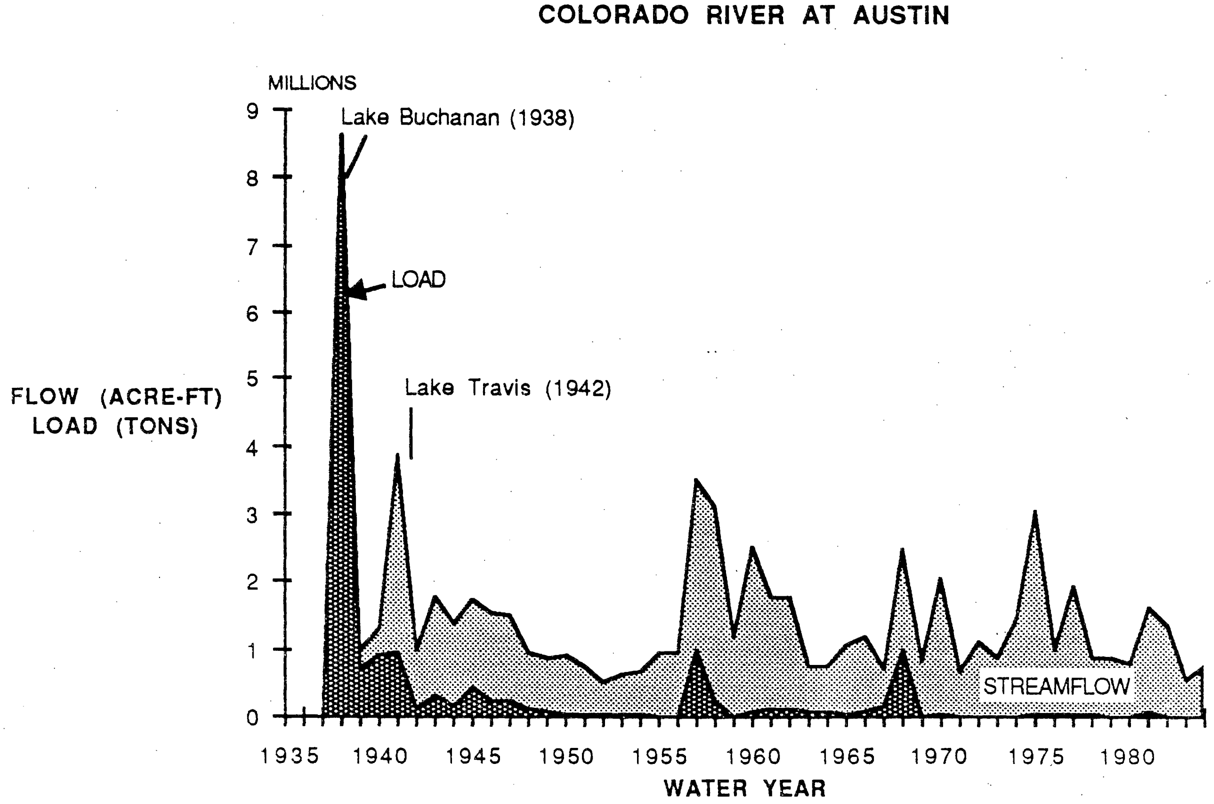


Figure 1. Annual streamflow and suspended sediment load of the Colorado River. (Data from Stout and others, 1961; Adey and Cook, 1964; Cook, 1967; Cook, 1970; Mirabal, 1974; Dougherty, 1979; and unpublished records from Texas Water Development Board, available through TNRIS.)

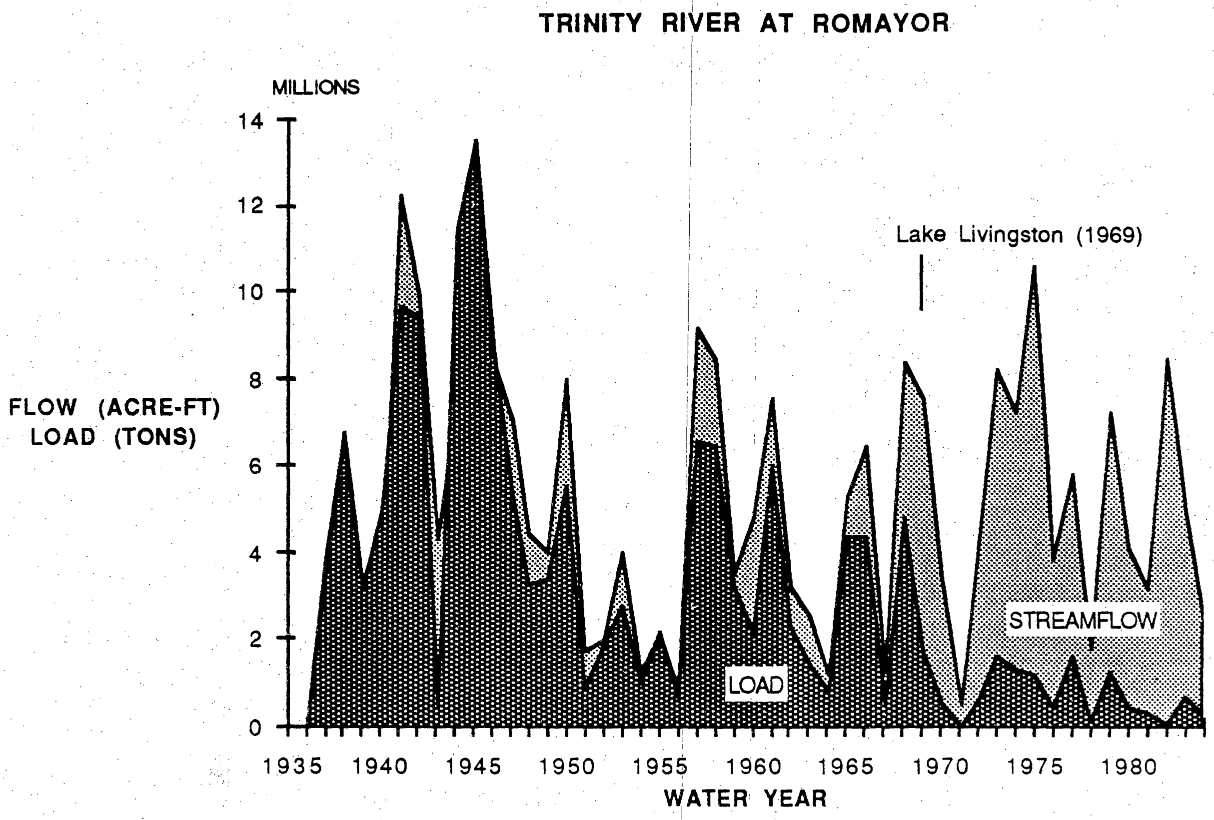


Figure 2. Annual stream flow and suspended load of the Trinity River. (Source of data same as for Fig. 1.)

Seven rivers were selected for investigation: Colorado, Guadalupe, Lavaca, Neches, Nueces, San Jacinto, and Trinity (Fig. 3).

The principal focus of the historical investigation was to document changes in emergent vegetation in fluvial-deltaic wetlands to determine the extent to which the vegetated areas are being replaced by open water or barren flats. The distribution of (1) vegetated wetlands (which includes marshes, swamps, and fluvial woodlands) and (2) water/barren flats were mapped on sequential aerial photographs dating from the 1930's to the late 1970's or 1980's. Units delineated on aerial photographs were digitized, plotted on maps, and the areal distribution of wetland vegetation and water/barren flats computed and graphed to determine trends and magnitudes of historical changes.

## WETLAND SEDIMENTATION: COLORADO AND TRINITY RIVER DELTAS

### General Settings

#### Colorado River Delta

The Colorado River delta (Fig. 4) has had a relatively unique history of development. Its progradation across the eastern arm of Matagorda Bay (a distance of about 6 km) occurred over approximately six years after removal of a log raft along the channel in 1929 (Wadsworth, 1966). Selection of the Colorado River delta for field studies is an outgrowth of a proposal to investigate the effects of the Colorado River diversion project. Efforts are currently underway to divert the Colorado River into Matagorda Bay (USACE, 1981). The increase in sediment load delivered to the bay is expected to promote delta progradation at the mouth of the diversion channel. It is anticipated that the prograding delta will be the site of marsh development as smooth cordgrass (*Spartina alterniflora*) and other salt-water and brackish-water marsh plants colonize the new land, which is expected to amount to approximately 810 ha (2,000 acres) in 50 years (USACE, 1981; van Beek and others, 1980). Tiger Island Cut, an artificial distributary channel that supplies sediment to the only currently active delta lobe, will be closed as part of the design recommendations. Thus, the locus of sediment deposition on the Colorado River delta will shift as a result of the diversion project.

These planned modifications at the mouth of the Colorado River provide a unique opportunity to investigate changes in fluvial sedimentation, and to document marsh aggradation rates in a river system whose sediment regime is principally suspended load composed of silt and clay. Most bedload (sand) transported by the river (along its lower drainage basin) is trapped upstream from the delta in a shallow draft navigation channel and silting basin that is periodically dredged (USACE,

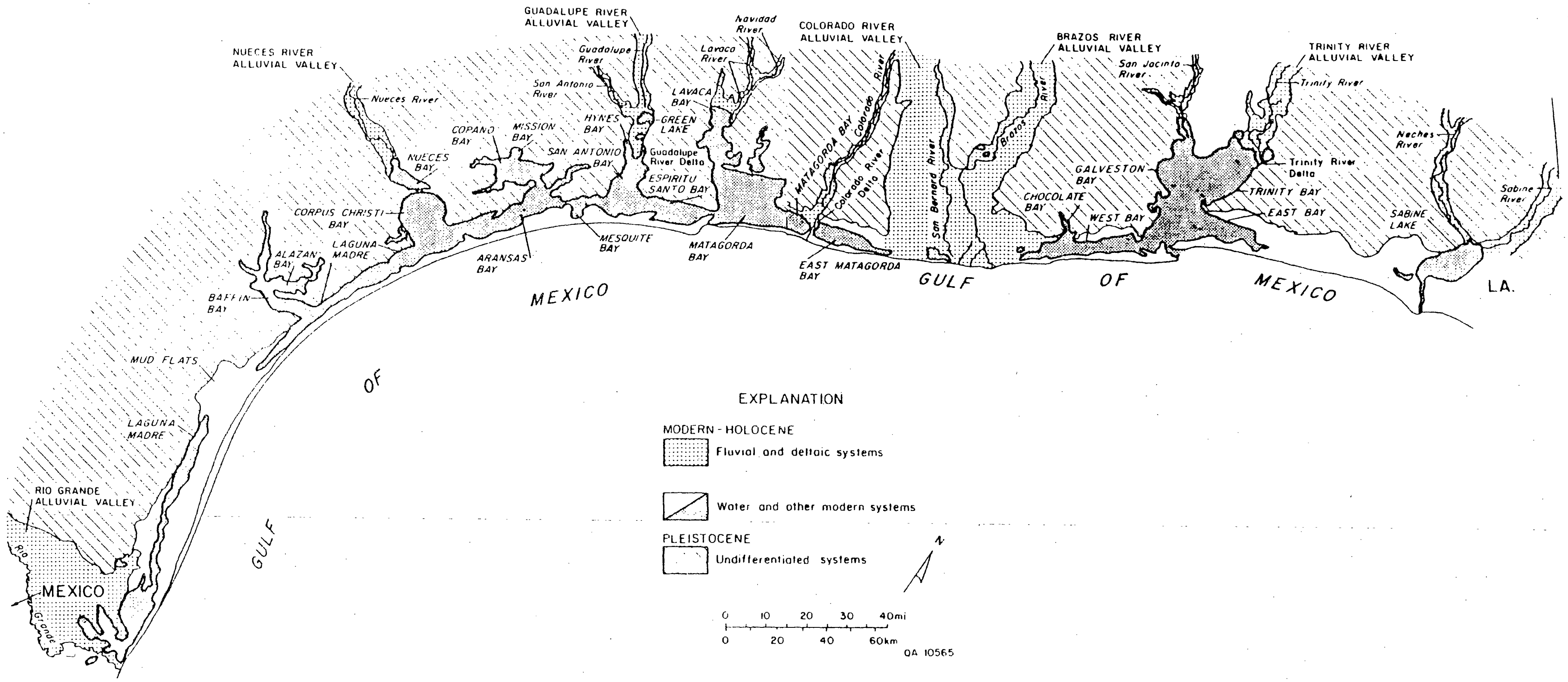


Figure 3. Bay-estuary-lagoon and major fluvial-deltaic systems along the Texas Gulf Coast. (Modified from LeBlanc and Hodgson, 1959.)

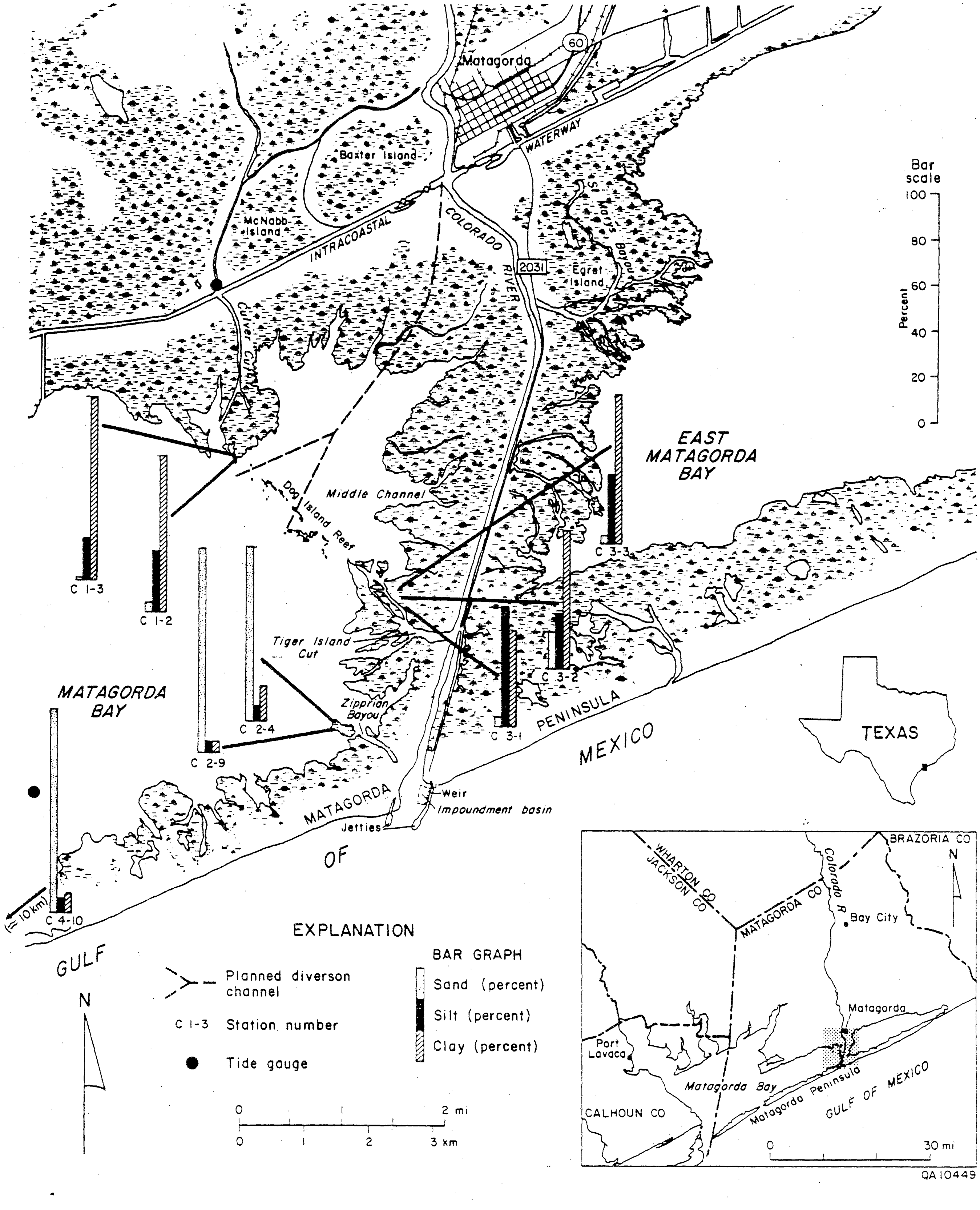


Figure 4. Index map of the Colorado River delta showing locations of profiling and vegetation transects, sediment textural composition, and tide gauge locations. The first number in the station identification code identifies the marsh transect, and the second number the artificial-marker horizon along the transect. Textural data are based on analyses of samples collected in March 1988.

1977). Sediment supplied to the deltaic area is derived from less than 10 percent of the river drainage basin, the remainder of the drainage basin lies above the Highland Lakes chain, which effectively traps sediment delivered to it (Ward and others, 1980).

The Colorado River delta marsh is primarily a proximal salt-water marsh community (a community in relatively close proximity to the estuarine system and thus more frequently flooded than higher salt marshes such as along natural levees, White and others, 1983; 1985). This proximal marsh is composed principally of *Spartina alterniflora,* mixed locally with *Scirpus maritimus,* grading at slightly higher elevations into species such as *Distichlis spicata, Batis maritima, Salicornia* spp., and *Lycium carolinianum* as well as patches of *Borrichia frutescens* and *Monanthochloe littoralis.* More common at higher elevations, such as on berms and levees, are *Spartina patens, Spartina spartinae, Iva frutescens,* and *Borrichia frutescens.* Specific vegetation assemblages for the different marsh transects are presented in later sections, as is sediment distribution.

Hydrological studies of the delta indicate complex interactions among several channels (Colorado River channel, Intracoastal Waterway, Culver Cut, and Tiger Island Cut; Fig. 4) that cross the delta plain (TDWR, 1978). Computer model computations indicate that only rarely (because of high artificial levees) is any part of the Colorado River delta west of the river inundated by freshwater overbanking during floods (TDWR, 1978). Computations indicate that about 80 percent of river flow along the Colorado River channel above Tiger Island Cut is diverted through the cut at flows of 2,000 cubic feet per second ($ft^3$/sec), but the percent of diversion through the cut diminishes as river flow increases to 8,000 $ft^3$/sec, above which diversion through Tiger Island Cut levels off and remains at a constant 62 percent (TDWR, 1978; 1980). As pointed out by Ward and others (1980), however, these results, which indicate decreasing flow through Tiger Island Cut with increasing river flow, do not agree with results of an earlier computer model (the conflict apparently has not yet been resolved). "Thus, the Colorado Delta exhibits a unique and complicated hydrodynamic regime influenced by tidal fluctuations, the degree of river mouth shoaling, and the magnitude of freshwater inflows in the Colorado. Field studies have yet to adequately define the flow regime, and the mathematical model representations of the system give conflicting results" (Ward and others, 1980, p. 49).

The astronomical tidal range in Matagorda Bay averages 0.2 m (0.7 ft) (Diener, 1975). The tidal period varies from diurnal to semi-diurnal generally twice during each 30 day period (Holliday, 1973). The diurnal tide has one high and one low tide about 12 hours apart over a 24 hour period. A diurnal tide continues for eight days followed by up to six days of semi-diurnal tides having two highs and two lows in 24 hours (Holliday, 1973). Holliday (1973) reports that as the tide approaches a semi-diurnal period a slack tide can persist for up to nine hours. The slack tide decreases the fluctuation from ebb to flood to 0.06 to 0.15 m (0.2 to 0.5 ft). Satellite photographs taken during this period show confused bay turbidity patterns, suggesting a reduction in current velocities and duration (Holliday, 1973).

Wind tides in Matagorda Bay greatly affect the extent of marsh inundation in the delta. The Texas Department of Water Resources (TDWR, 1980) reports that flooding of marshes within the delta is "largely the result of tidal activity, or a combination of high bay and Gulf tides and southerly winds." Most of the marshes on the delta north of Tiger Island Cut and east of Culver Cut may be inundated as a result of the interaction of high lunar tides and wind tides (TDWR, 1980).

## Trinity River Delta

The Trinity River delta (Fig. 5) has had a history of less rapid progradation compared to the Colorado River delta, however, it has the distinction of being the only other estuarine delta along the Texas coast to have significantly grown, or prograded into its estuary (Trinity Bay) since the mid-1800's (Shepard, 1953). Among many human modifications that affect the hydrodynamics of the delta and its environments are dredging of the Trinity River channel and extension of the channel (Anahuac Channel) into Trinity Bay beyond the delta, and partial construction of Wallisville Lake dam (shown in Fig. 5 as a levee) along the southern margin of Old River Lake and Old River. (The quantity of sediment periodically dredged from Anahuac Channel is presented in White and Calnan, 1989).

The Trinity River delta is characterized by considerably lower salinities than the Colorado River delta, and marshes are more reflective of brackish water conditions. Vegetation includes *Alternanthera philoxeroides, Phragmites australis, Bacopa monnieri, Scirpus olneyi, Scirpus maritimus, Echinochloa* spp. *Typha* spp., *Eleocharis parvula, Paspalum lividum, Paspalum vaginatum, Cyperus* spp., *Aster* spp., *Spartina patens, Spartina spartinae, Panicum dichotomiflorum, Sphenoclea zeylanica,* and *Pluchea* sp.

The astronomical tidal range in Trinity Bay averages 0.3 m (1 ft) (Diener, 1975). Marmer (1954) classified the tide at Round Point, Trinity Bay as daily or diurnal in which one high and one low occur in a 24 hour period.

The Texas Department of Water Resources used the verified inundation model for this system to study the extent of marsh inundation due to tidal and river floods in the delta (TDWR, 1981). Flooded surface area was determined under both high and low tidal amplitudes for six flood peaks on the Trinity River (Fig. 6). Each of the flood cases was simulated with both a high and low driving tide "to differentiate those areas which would be inundated as a result of high flows, and

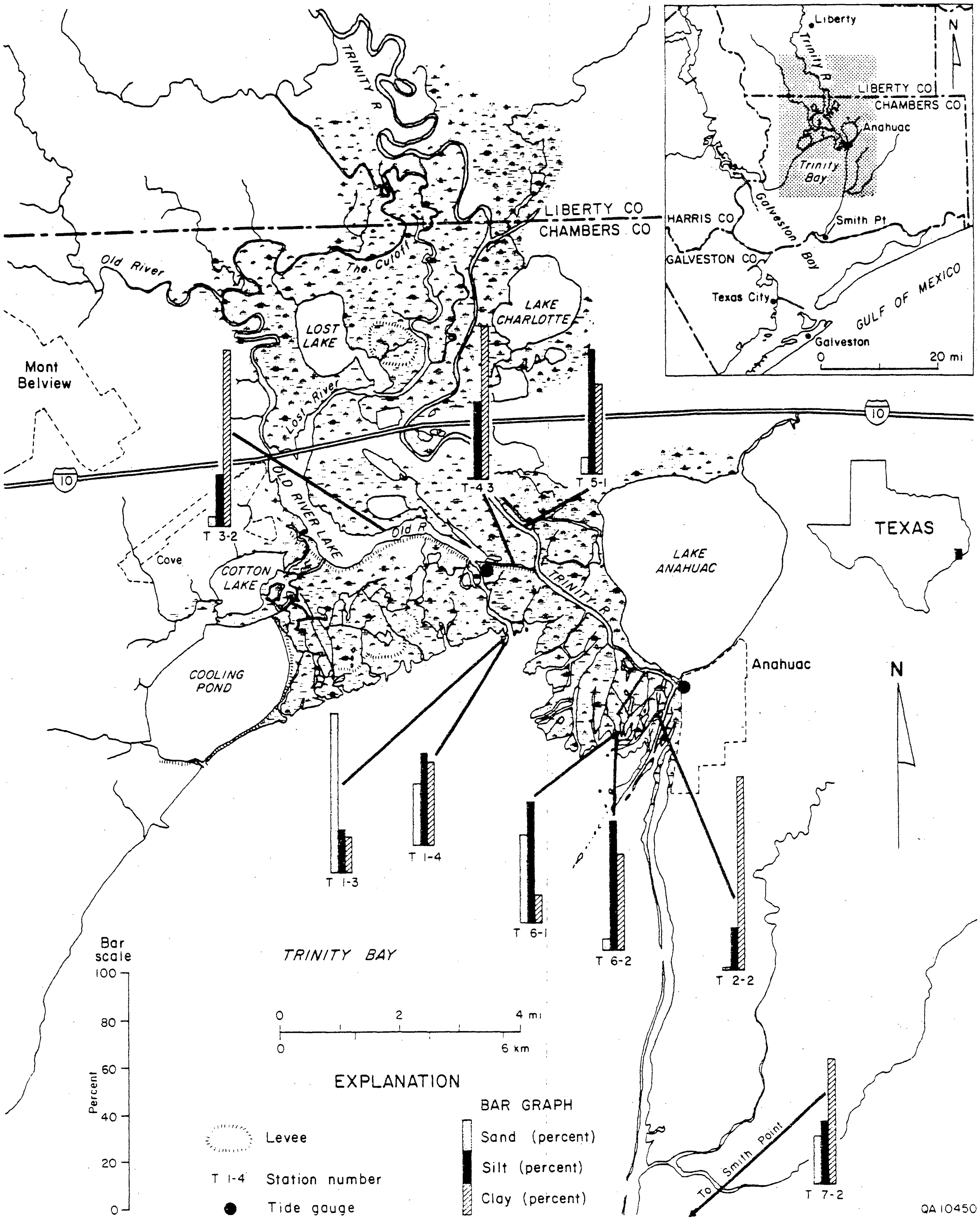


Figure 5. Index map of the Trinity River delta showing locations of profiling and vegetation transects, sediment textural composition, and tide gauge locations. See figure 4 for explanation on station number identification codes. Textural data are based on analyses of samples collected in March 1988.

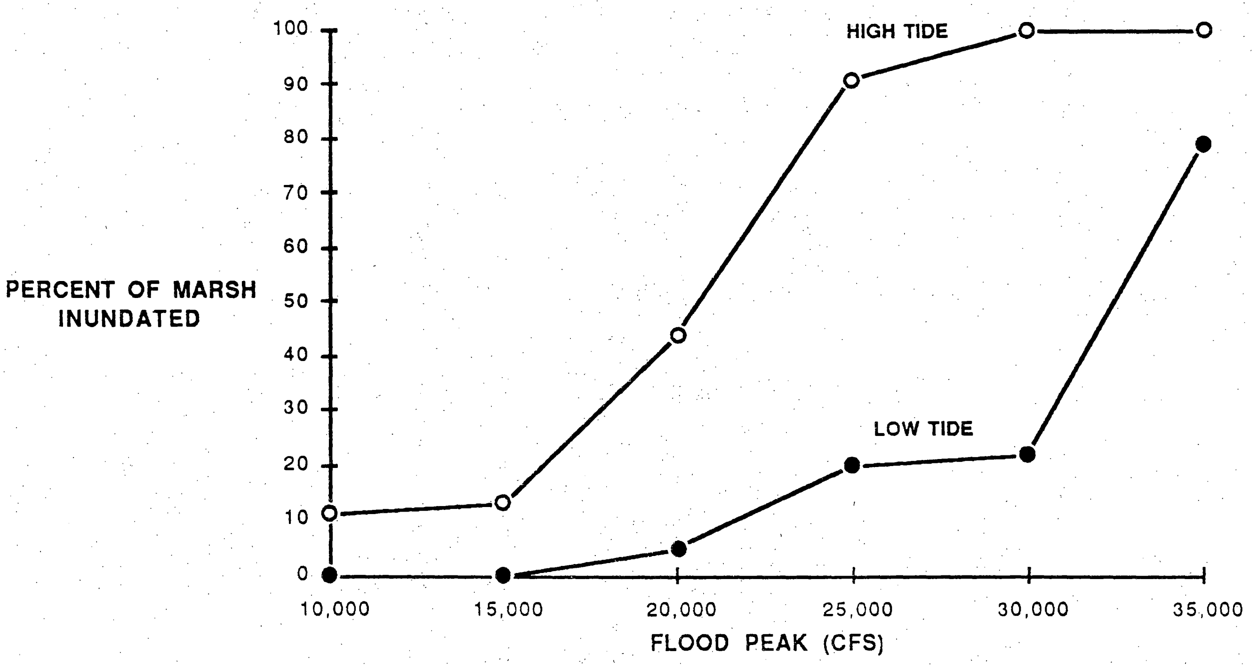


Figure 6. Simulated inundation of the Trinity River delta marsh versus peak discharge of the Trinity River under high and low tidal conditions. (From Texas Department of Water Resources, 1981).

those areas which would be inundated as result of interaction of high freshwater inflow and high tidal amplitude" (TDWR, 1981). With low tidal conditions, the model indicates that no inundation will occur within the delta during floods of less than 15,000 $ft^3$/sec. Floods with discharge in excess of 30,000 $ft^3$/sec will sharply increase the percentage of area inundated. With low tides, a 35,000 $ft^3$/sec flood will inundate 79 percent of the marsh (TDWR, 1981). High tides will cause some inundation within the area for all six of the simulated peaks. High tides and floods above 30,000 $ft^3$/sec will completely inundate the area (TDWR, 1981). With average diurnal tides and a peak discharge of 25,000 $ft^3$/sec nearly 85 percent of the marsh is flooded; total inundation, with average diurnal tides, occurs at a peak discharge of 35,000 $ft^3$/sec.

## Methods

Four profiling and vegetation transect sites were established in the area of the Colorado River delta and seven in the Trinity River delta (Figs. 4 and 5 show locations of sites in delta areas). Elevations, bearings, vegetation characteristics (vegetation types, densities, and heights), and salinities (where possible) were measured and recorded along the transects. Elevations were surveyed primarily with a planetable and telescopic alidade (Fig. 7); at one site (transect 3) in the Colorado River delta a short segment was also surveyed using profiling rods (a method described by Emery, 1961). Distances along transects were measured with a 30 m (100 ft) fiber-glass measuring tape.

### Marsh Transects and Artificial-Marker Horizons

Artificial-marker horizons (1 $m^2$ in size) composed of white Na-Feldspar clay (Fig. 8) were placed along each marsh transect for the purpose of measuring marsh aggradation rates (DeLaune and others, 1983; Baumann and others, 1984). A total of 9 marker horizons in the Colorado River delta study area, and 11 in the Trinity River delta were initially established. Additional markers were established during later periods either to replace eroded markers or to allow for additional measurements of sediment deposition during spring floods should they occur during 1989. Thus, a total of 10 markers were established in the Colorado delta and 16 in the Trinity delta during the study (tables 1 and 2).

Siting of the transects and markers were determined primarily with regard to (1) spatial relationships among the marsh, river, channel, and bay environments, (2) representation of various marsh types including relative elevations, (3) relationship with respect to existing and planned artificial modifications of the fluvial-deltaic system, (4) accessibility of the site, and (5)

Figure 7. Plane table, telescopic alidade, and profiling rod used in taking elevations along transects.

Figure 8. Artificial-marker horizon at station T 4-3.

Table 1. Dates marker beds established and trenched in the Colorado River delta.

| Transect-Marker Bed | Date Marker Beds Established | Dates Marker Beds Trenched | | | | |
|---|---|---|---|---|---|---|
| 1-2 | 6/25/87 | 3/28/88 | 7/20/88 | | 3/14/89 | 6/20/89 |
| 1-3 | 6/25/87 | 3/28/88 | 7/20/88 | 11/9/88 | 3/14/89 | 6/20/89 |
| 1-13 | 2/9/88,3/14/89 | | 7/20/88 | | | 6/20/89 |
| 1-14 | 7/20/88 | | | 11/9/88 | 3/14/89 | 6/20/89 |
| 2-4 | 6/26/87 | 3/28/88 | 7/19/88 | 11/9/88 | 3/14/89 | 6/19/89 |
| 2-9 | 6/27/87 | 3/28/88 | 7/19/88 | 11/9/88 | 3/14/89 | 6/19/89 |
| 3-1 | 12/17/87 | | 7/18/88 | 11/8/88 | 3/15/89 | 6/19/89 |
| 3-2 | 12/17/87 | | 7/18/88 | 11/8/88 | 3/15/89 | 6/19/89 |
| 3-3 | 12/17/87 | | 7/18/88 | 11/8/88 | 3/15/89 | 6/19/89 |
| 4-10 | 12/16/87 | | 7/19/88 | 11/8/88 | 3/14/89 | 6/19/89 |

Table 2. Dates marker beds established and trenched in the Trinity River delta.

| Transect-Marker Bed | Date Marker Beds Established | Dates Marker Beds Trenched | | | | | |
|---|---|---|---|---|---|---|---|
| 1-3 | 12/8/87,3/7/89 | 3/22/88 | 7/26/88 | 11/16/88 | 3/7/89 | | |
| 1-4 | 12/8/87 | 3/22/88 | 7/26/88 | | 3/7/89 | | |
| 2-2 | 12/8/87 | 3/22/88 | 7/26/88 | | 3/8/89 | 6/21/89 | 8/15/89 |
| 2A | 3/8/89 | | | | | 6/21/89 | 8/14/89 |
| 3-2 | 12/9/87 | | 7/26/88 | | 3/7/89 | 6/21/89 | 8/15/89 |
| 3-4 | 12/9/87 | | 7/26/88 | | 3/7/89 | | 8/15/89 |
| 4-3 | 12/9/87 | 3/22/88 | 7/26/88 | | | | |
| 4-3A | 7/26/88 | | | | 3/7/89 | | |
| 4-extension | 7/26/88 | | | | | 6/22/89 | 8/14/89 |
| 5-1 | 12/9/87 | | | 11/15/88 | 3/8/89 | 6/21/89 | 8/14/89 |
| 5-2 | 7/26/88 | | | | | 6/21/89 | 8/14/89 |
| 6-1 | 12/10/87 | 3/23/88 | 7/27/88 | | | | |
| 6-2 | 12/10/87 | | | | | | |
| 6-2A | 3/23/88 | | 7/27/88 | | 3/8/89 | 6/22/89 | 8/15/89 |
| 7 | 12/10/87 | 3/23/88 | 7/25/88 | | 3/8/89 | | |
| 7A | 3/8/89 | | | | | 6/21/89 | |

susceptibility to disturbance by human or animal activity. Artificial-marker horizons were placed in levee or streamside, bay margin, and backmarsh areas (tables 3 and 4).

The Trinity River delta setting is the more complex of the two deltas. It has numerous distributary channels, some active but many inactive. Inland parts of the delta are dominated by fluvial processes in contrast to delta-front areas where estuarine processes are more influential. Markers were placed in each area as well as in areas affected by both fluvial and estuarine processes. Areas grazed by cattle, which include most of the private land in the Trinity delta, were avoided. Marsh systems bayward of the Wallisville dam network (shown as a levee in Fig. 5) were also avoided except in one delta-front area near the mouth of the distributary that flows to the bay from Old River (Fig. 5). In selecting the specific location for a marker horizon along a marsh transect, care was taken to avoid animal paths (nutria are extremely abundant in the Trinity delta and trails are numerous). Wetland environments in which markers were placed are presented in table 4.

In contrast to the Trinity delta, the Colorado River delta appears to be dominated by estuarine processes. Near distributary channels at Tiger Island Cut and Culver Cut, however, fluvial processes also have a role in sedimentation. Markers were placed along distributary-channel levees, bay margins, and in backmarsh areas including one barrier flat environment (table 3).

Relative elevations of the marker horizons were determined by comparing surveys of water levels at the various sites with tide-gauge readings (Fig. 9) for specified times (Fig. 10). Water level elevations were surveyed each time a marsh site was visited, and average relative elevations for the different artificial markers were determined. Elevations calculated for markers located nearest to the available tide-gauge sites (Figs. 4 and 5) are more reliable than more distant sites.

In the Colorado River delta area, three marsh-transect sites were established in June of 1987 (White and Calnan, 1987) (Fig. 3; transect sites are identified by the first number in the station number code) and a fourth site was established in December 1987 (the first month of the contract period for 1987-88). Artificial-marker horizons were established primarily in June and December 1987 (table 1). The six marsh-transect sites in the Trinity River delta were established in December 1987, the date of most marker horizons (table 2). A marsh site was selected away from each delta for "control" purposes. In the Trinity Bay area, this marsh site was located at Smith Point (T 7), approximately 22 km away from the delta (Fig. 5). In the Colorado River-Matagorda Bay area, a marsh on Matagorda Peninsula (C 4) approximately 15 km southwest of the delta, was selected. In addition, a marine grass bed was examined along the Matagorda Peninsula approximately 21 km southwest of the mouth of the Colorado River in July 1988. Working with Warren Pulich (Texas

Table 3. Salt-marsh environments where artificial-marker horizons were established in the Colorado River delta.

| **MARSH ENVIRONMENT** | **ARTIFICIAL MARKER STATION NUMBER** |
|---|---|
| LEVEE | |
| *Borrichia, Batis, Distichlis* | C 3-1 |
| *Borrichia, S. patens, Batis* | C 1-14 |
| BARRIER FLAT | |
| *Monanthochloe* | C 2-9 |
| BAY MARGIN-DISTRIBUTARY INFLUENCED | |
| *Spartina alterniflora* | C 2-4 |
| BACKMARSH-DISTRIBUTARY INFLUENCED | |
| *Distichlis, Scirpus maritimus* | C 1-2 |
| *Spartina alterniflora, Scirpus maritimus* | C 1-3 |
| *Spartina alterniflora, Distichlis* | C 3-2 |
| *Spartina alterniflora* | C 3-3 |
| BACKMARSH/BAY-MARGIN INFLUENCED | |
| *Spartina alterniflora* | C 4-10 |

Table 4. Brackish wetland environments where artificial-marker horizons were stablished in the Trinity River delta.

| WETLAND ENVIRONMENT | VEGETATION | STATION NO. |
|---|---|---|
| BAY/CHANNEL MARGIN | ANNUAL | T 1-4 |
| BAY/CHANNEL MARGIN | ANNUAL | T 1-3 |
| BAY/CHANNEL MARGIN | ANNUAL | T 6-1 |
| FLUVIAL CHANNEL LEVEE | WOODLAND | T 5-1 |
| DISTRIBUTARY CHANNEL LEVEE | WOODLAND/PERENNIAL | T 3-2 |
| BAY/CHANNEL MARGIN | PERENNIAL | T 6-2A |
| BACKMARSH/TIDAL CHANNEL | PERENNIAL | T 2-2 |
| BACKMARSH | PERENNIAL/ANNUAL | T 3-4 |
| LEVEE FLANK/POND MARGIN | PERENNIAL/ANNUAL | T 4-3 |
| BAY MARGIN (SALT MARSH) | PERENNIAL | T 7 |

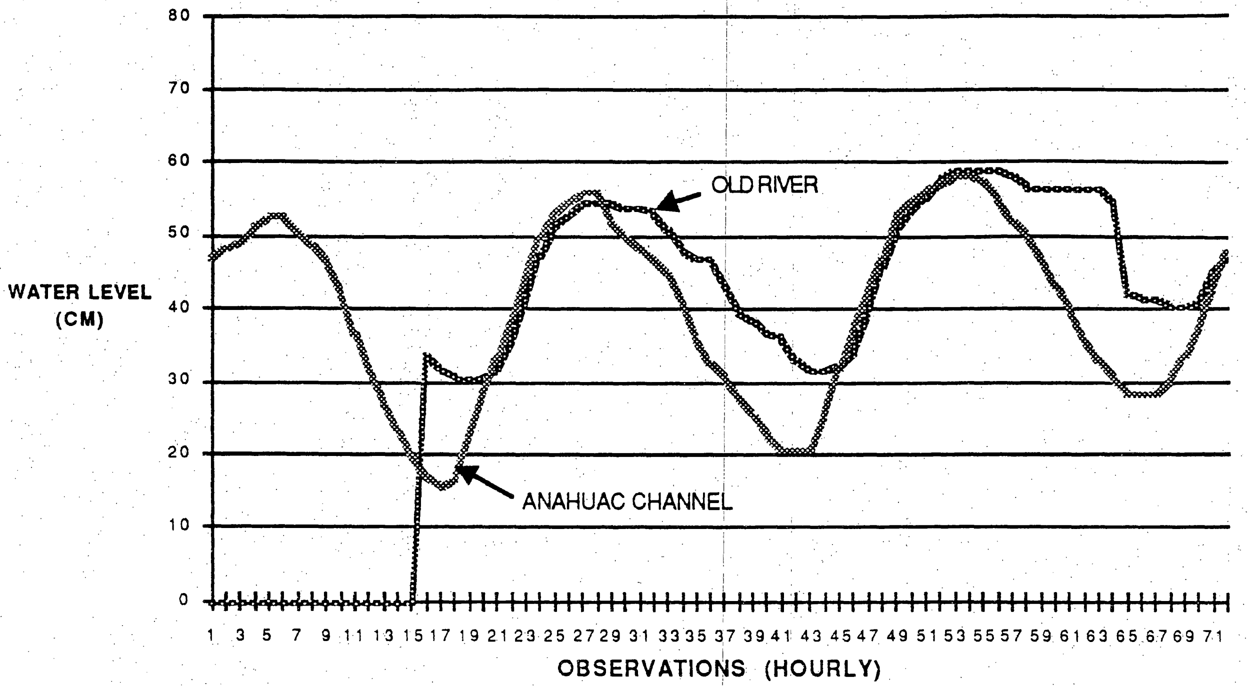


Figure 9. Tide level at Old River and Anahuac Channel gauges on December 8-10, 1987, Trinity River delta. Data provided by the Texas Water Development Board and Texas Parks and Wildlife Department.

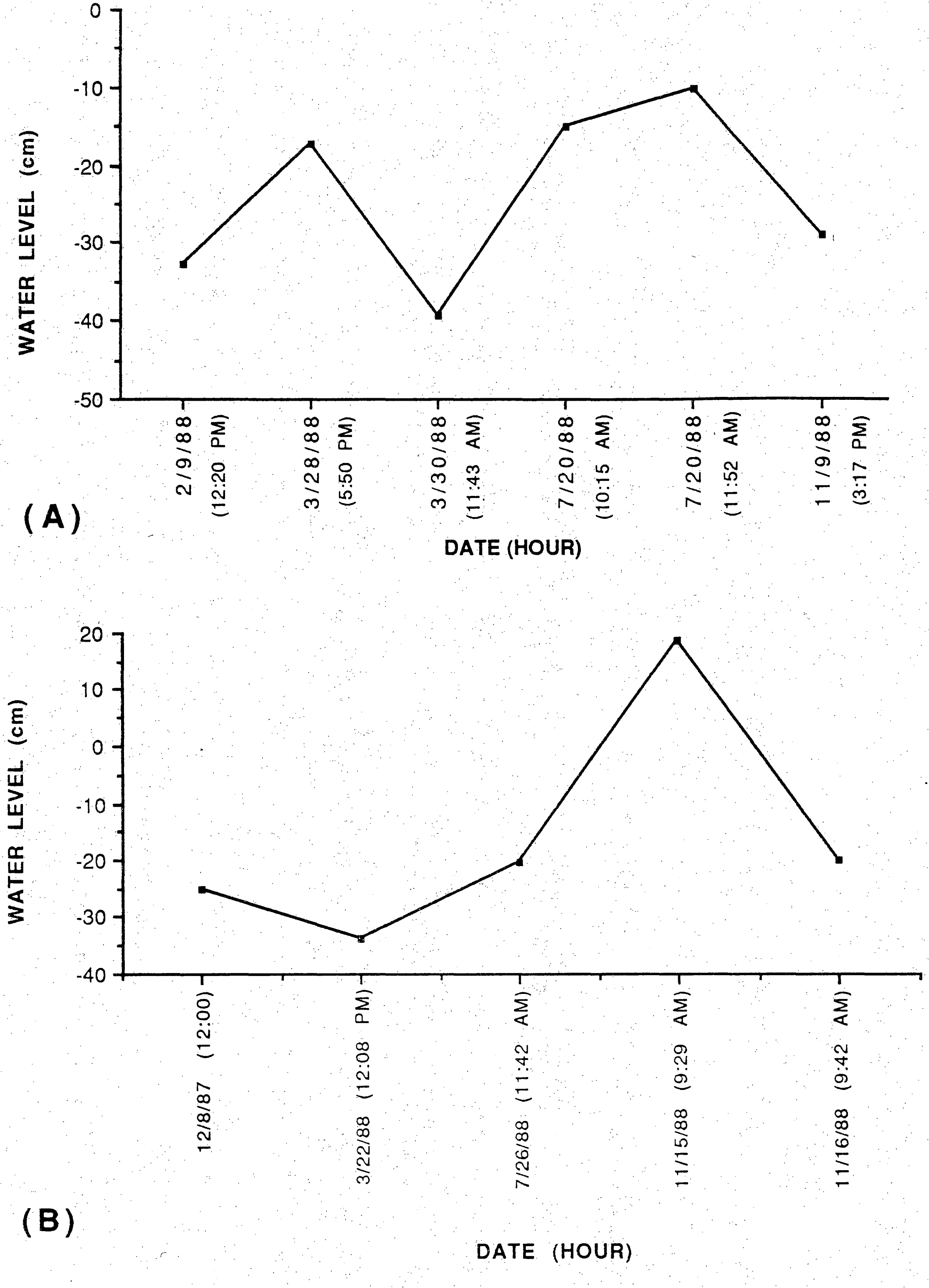


Figure 10. Water levels surveyed on different dates and times at (A) marsh transect 1, Colorado River delta, and (B) marsh transect 1, Trinity River delta. These data were used in conjunction with tide-gauge records to determine relative elevations of marker horizons. The substantial drops in water levels between 3/28/88 and 3/30/88 in the Colorado delta and between 11/15/88 and 11/16/88 in the Trinity delta were due to frontal passage (northers).

Parks and Wildlife Department), water depths and species composition (Fig. 11) were recorded at stakes placed along a line from the seagrass bed to shore.

At a few selected sites where artificial-marker horizons were established, 1-m long brass rods (3 mm in diameter) were driven into the ground near the marker beds, and the heights of the rods above the marsh surface were carefully measured; these sedimentation/erosion pins serve as partial backups to the marker horizons for estimating sedimentation or erosion. The rods were established at stations C 2-9, C 3-3, T 1-4, and T 7. In addition, aluminum pans, 17.5 × 17.5 cm and 5.5 cm deep (Fig. 12), were placed at selected marsh sites in both deltaic areas in March 1988; seven pans were established in the Colorado River delta area, and six in the Trinity River delta. The pans were set out primarily for observational purposes, that is, to note gross differences in organic and inorganic accumulation with respect to relative elevations and marsh type.

Marsh transect profiles and marker beds were located by compass bearings and distances with respect to cedar posts (1.8 m long) driven into the marsh substrate. Compass bearings were also taken on visible structures (channel markers, water towers, tide gauges, etc.) for backup purposes. One site (transect 1 on the Colorado River delta) was tied to a bench mark (Appendix A).

Sites in both field areas were revisited at about 3 to 4 month intervals (tables 1 and 2). Artificial marker beds were inspected or trenched to document the rate of sedimentation that had occurred between periods. To measure sediment deposited above the marker horizons, sediment was cut away along a shallow, narrow, vertical trench that intersected the marker bed (Fig. 13). The length of the trench was generally from 0.3 to 0.5 m, along which at least 10 measurements were made and averaged to determine the depth of sediment deposited above the horizon. The excavated trench was carefully filled with similar marsh sediment in an effort to lessen disturbance of the remaining marker horizon for future measurements.

## Cores for Radiochemical Dating

A total of five cores ranging from approximately 0.6 to 1 m (2 to 3.3 ft) in length were collected from the deltas to determine long-term rates of sedimentation; 3 cores were taken in the Trinity delta (near sites T 2-2, 3-2, and 3-4) and 2 in the Colorado delta (near C 1-3 and 3-2). The cores were taken by twisting thin-wall aluminum and plastic pipes, with diameters of approximately 7.5 cm (4 in), into the marsh substrate. To assist in the coring process the cutting end of the coring tube was sharpened; holes were drilled at the other end for insertion of a metal rod, which served as a handle for twisting and extracting the core. If compaction in the core was more than 5 percent,

Figure 11. Marine grasses *Halodule wrightii* and *Halophila engelmannii* from a grass bed on the bay margin of Matagorda Peninsula.

Figure 12. Aluminum sediment pan at station C 3-1 as it appeared in July 1988.

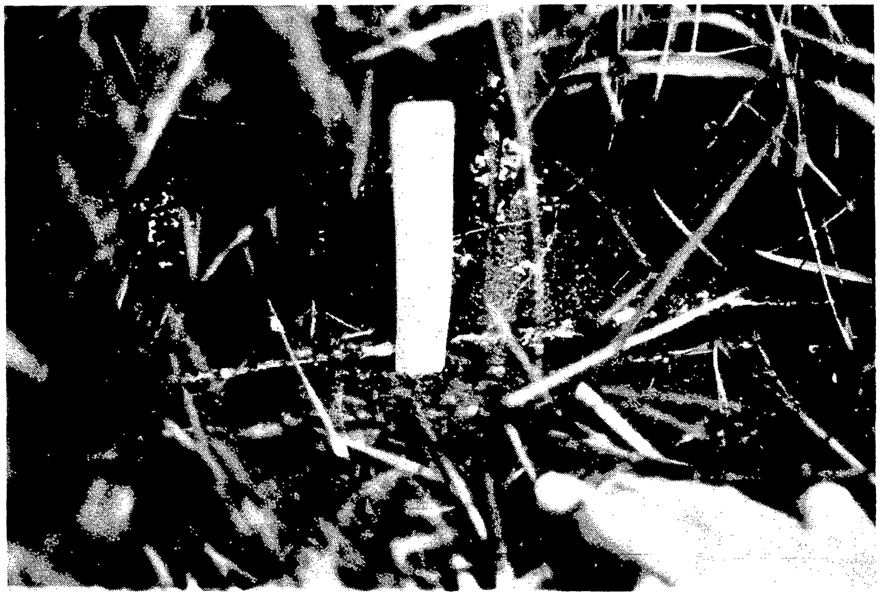


Figure 13. Vertical trench cut in March 1988 intersecting the artificial-marker horizon at station C 2-4 in the Colorado River delta. Ruler is 15 cm (6 in) in length.

the core was discarded. Care was taken to assure that the entire core was retrieved when extracting the core barrel from the marsh soil.

Cores were taken to the Bureau of Economic Geology's Core Research Laboratory where they were cut in half (longitudinally). One half was inspected and described and the other half was shipped to Teledyne Isotopes for analysis of $^{210}Pb$ from which sedimentation rates can be inferred (Koide and others, 1973; Smith and Walton, 1980). The radiochemical procedure is presented in Appendix B.

## Textural and Organic Analyses

Another part of the field investigation included collecting surficial marsh samples near the artificial marker beds for laboratory analyses of organic/inorganic and sand, silt, and clay percentages (methods are presented in Appendix C). Grain size scales used for sediments were based on the Wentworth size class (Wentworth, 1922), in which sand particle size ranges from 2 mm down to 62.5 microns, silt from 62.5 to 3.9 microns, and clay extends below 3.9 microns. Moisture content of the sediments was also analyzed. Samples were collected from the top 2 to 4 cm of the marsh surface. Sand, silt, and clay percentages determined from collections made in March and July 1988 are presented in figures 14 and 15.

## Documentation of Flood Events

Major flood events that occurred during the monitoring period included Hurricane Gilbert in September of 1988, and Trinity River flooding in the spring and early summer of 1989 (flooding in June of this year was associated with Tropical Storm Allison). Although Hurricane Gilbert made landfall in Mexico, tides were 0.9 to 1.2 m (3 to 4 ft) above normal for several days in the Matagorda and Trinity Bay areas. All artificial-marker horizons were flooded during this period (Figs. 16 and 17). Also, Hurricane Chantal made landfall near Trinity Bay on August 1, 1989. This was a minimal storm and effects on delta marshes appeared to be minor.

Flooding of the Trinity River delta apparently occurred on several occassions in the spring and summer 1989, as documented by release rates from Lake Livingston (Fig. 18), stream-gauge heights measured at Romayor, and field observations. River flow and gauge heights along the Trinity River at Romayor were provided by the U. S. Geological Society. Release rates from Lake Livingston were provided by the Trinity River Authority.

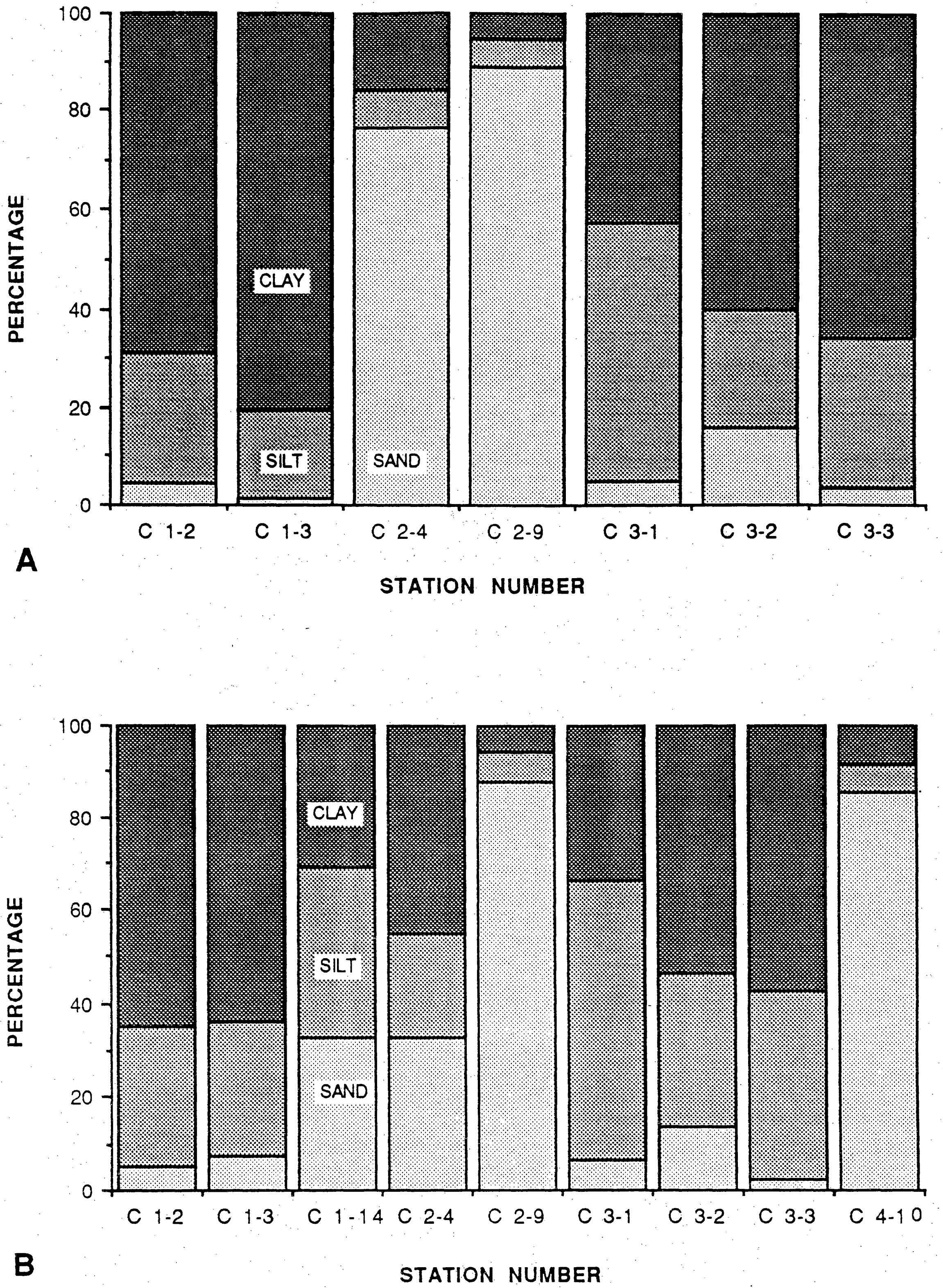
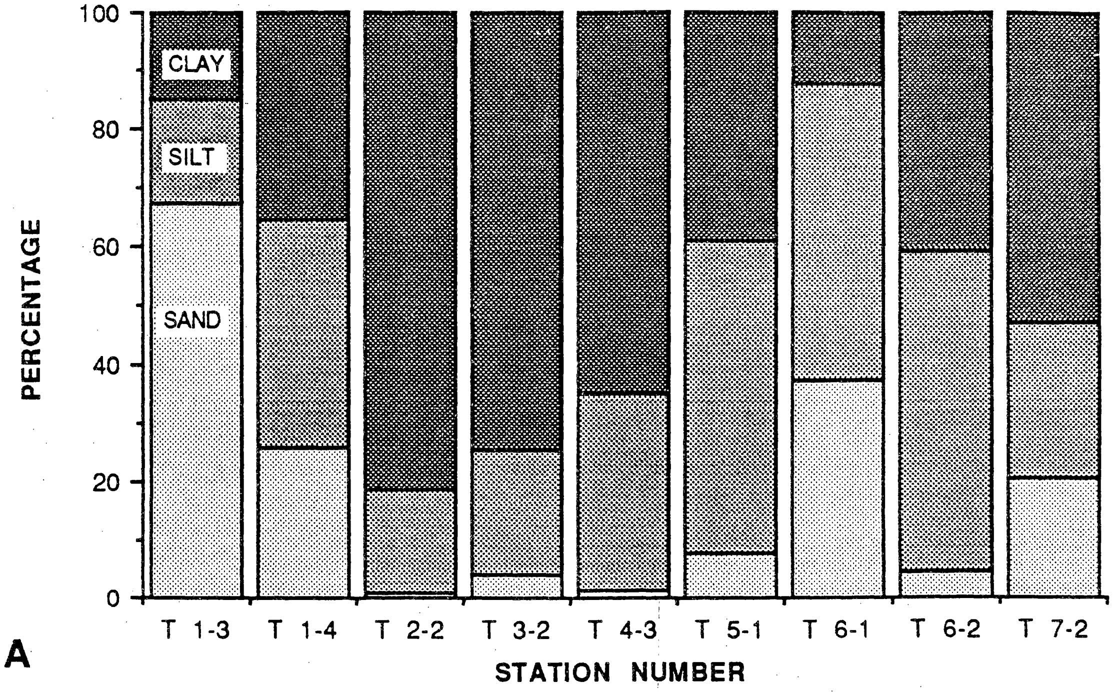


Figure 14. Percentages of sand, silt, and clay in sediments collected near selected stations in the Colorado River delta. Sediments were collected in March 1988 (A), and July 1988 (B).



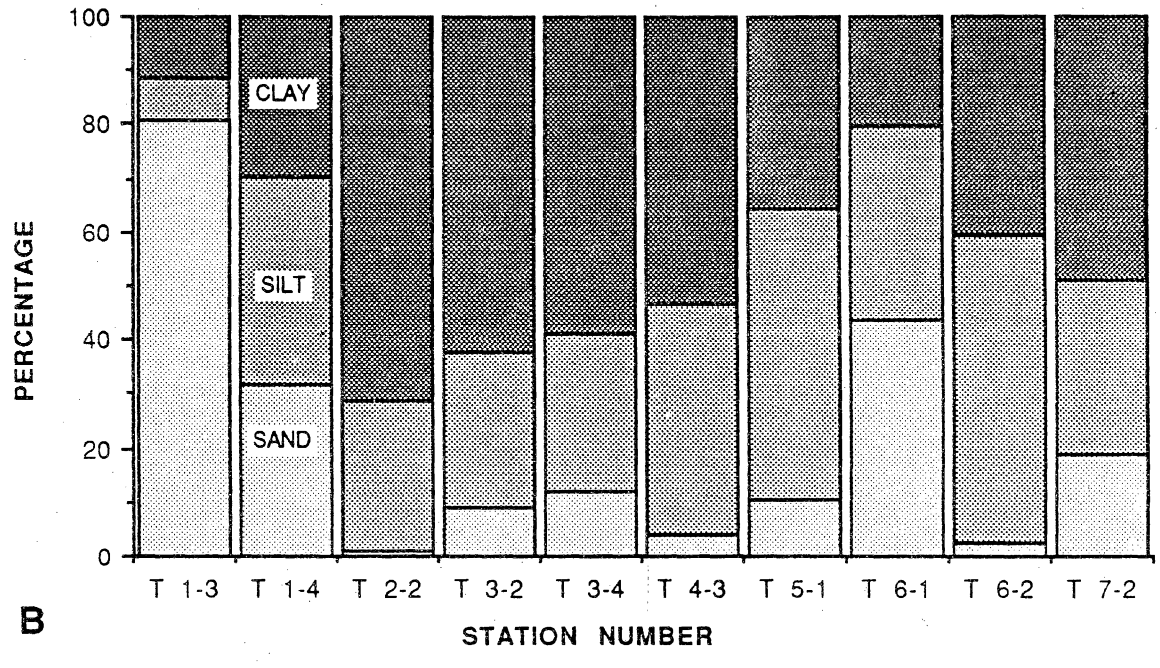


Figure 15. Percentages of sand, silt, and clay in sediments collected near selected stations in the Trinity River delta. Sediments were collected in March 1988 (A), and July 1988 (B).

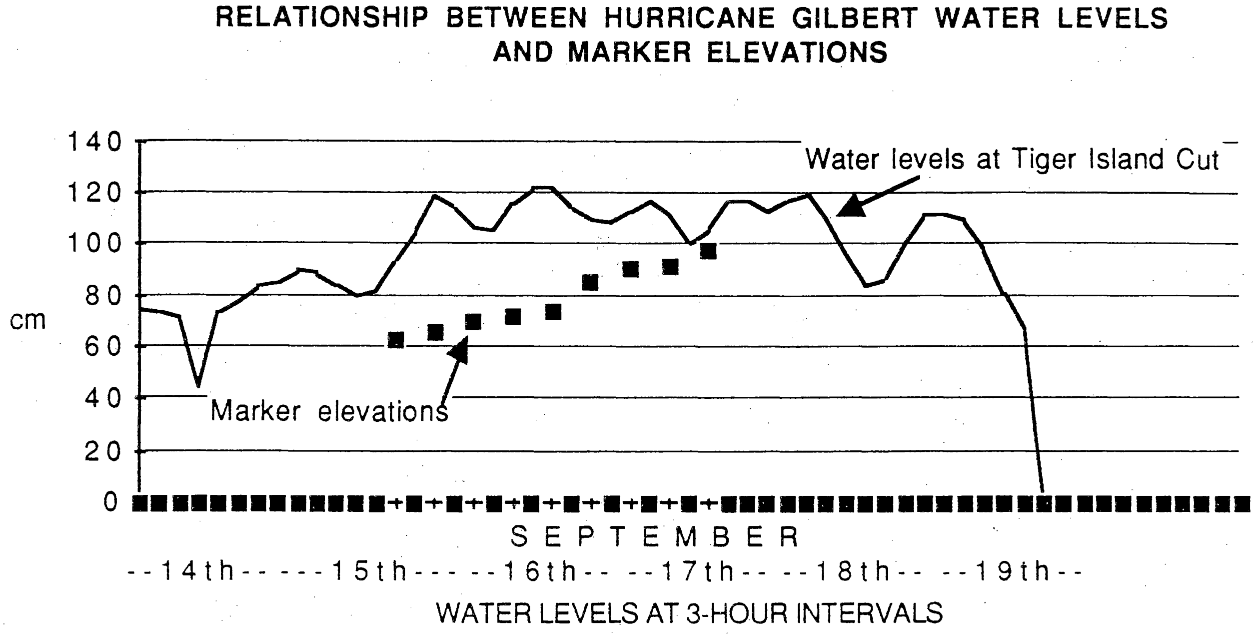


Figure 16. Relationship between water levels recorded at the Tiger Island tide gauge during Hurricane Gilbert and relative elevations of artificial-marker horizons in the Colorado River delta.

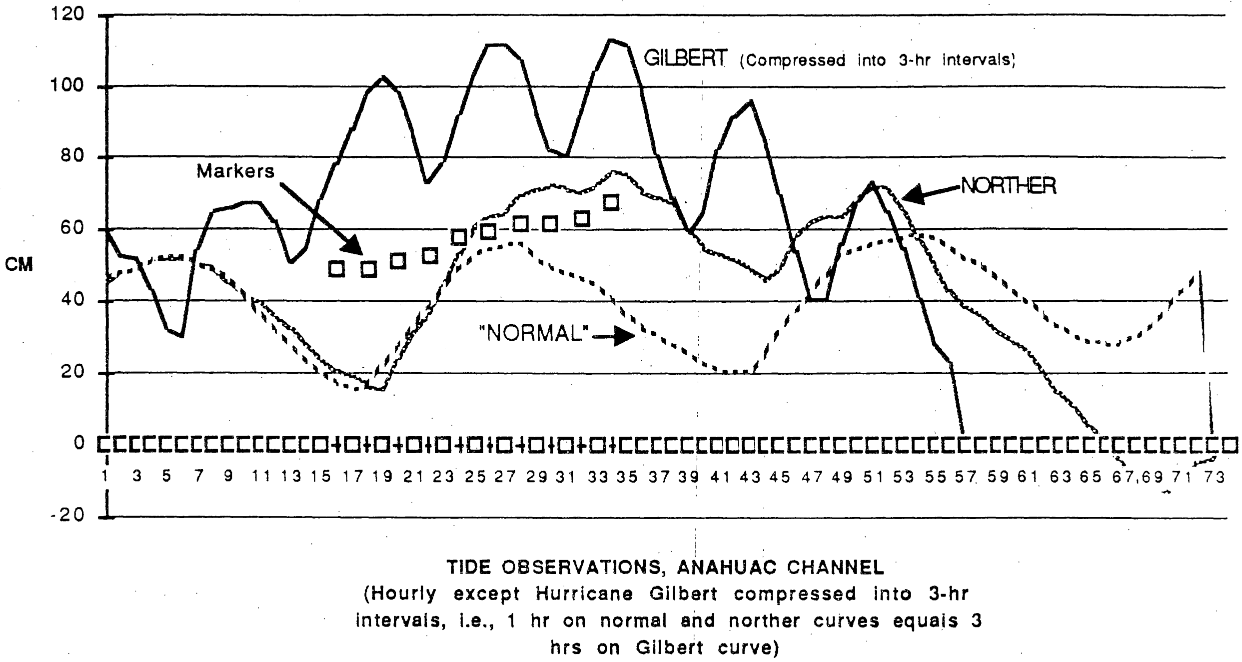


Figure 17. Relative elevations of artificial-marker horizons in the Trinity delta in relation to water levels recorded at the Anahuac Channel tide gauge during Hurricane Gilbert, frontal passage (norther), and "normal" conditions. Note the rise in water level along the norther curve after hourly tide observation 19; the rise in tide reflects the effects of strong south to southeast winds blowing Gulf water into the bays prior to the shift in wind direction to the north as the front arrives. The subsequent drop in bay water levels as north winds blow water out of the bay occurs after hourly observation 52. Although the rise in water levels preceding frontal passage are high enough to flood all marker horizons for about 7 hours, the duration of flooding is not nearly as long as that associated with Hurricane Gilbert (observations compressed in the above figure), which flooded markers for approximately 90 hours.

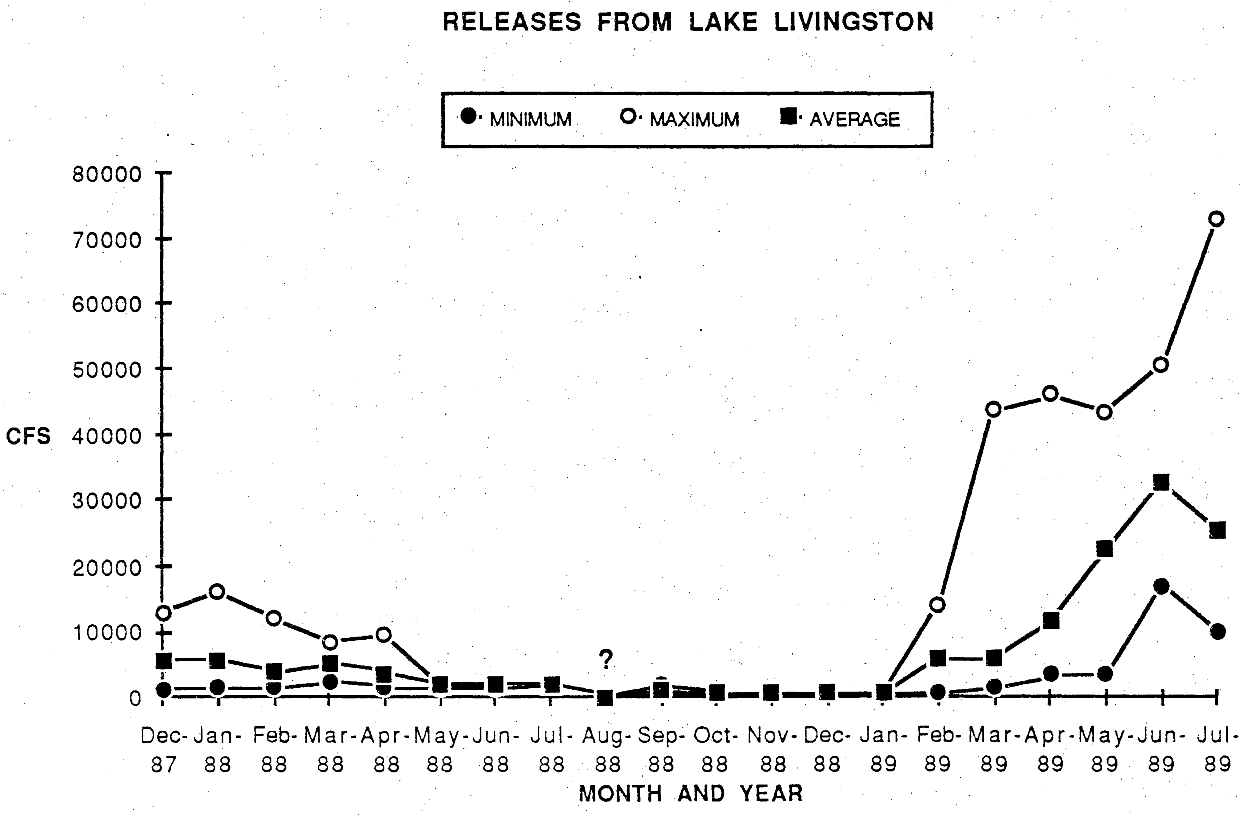


Figure 18. Water releases from Lake Livingston in ft$^3$/sec from December 1987 through July 1989. (Data from Trinity River Authority.)

To document flood levels, and in some cases flood duration in the marshes, tide records for selected periods were obtained from the Texas Parks and Wildlife Department and Texas Water Development Board. Digital data for some tide gauges in the Trinity delta available through Texas Parks and Wildlife Department allowed a more complete depiction of tidal levels for that area (Fig. 9).

### Vegetation Surveys

Vegetation cover and relative species abundance were taken at most stations during the first sampling period, usually June or December 1987 in the Colorado River delta and December 1987 in the Trinity River delta. Vegetation cover and relative species abundance in the Colorado River delta are shown in percent in Appendix A. General comments on species composition and abundance at stations in the Trinity River delta are also included in the Appendix A. Representative vegetation heights for each species were measured at each station during the first sampling period in the Colorado River delta. In addition, heights of most species present at each marker bed station in both deltas were recorded during each sampling period or in the winter (December 1987; February 1988), early spring (March 1988) summer (June 1987; July 1988; June 1989) and late fall or early winter (November 1988) in the Colorado River delta (table 5), and in winter (December 1987), early spring (March 1988), summer (July 1988; June 1989; August 1989) and late fall or early winter (November 1988) in the Trinity River delta (table 6).

### Salinities

Salinities were taken with an S-C-T meter (Salinity-Conductivity-Temperature meter) at most transects in the Colorado and Trinity River deltas during the sampling trips in December 1987, February 1988 (Colorado River delta only), March 1988, July 1988, November 1988, and March, 1989 (tables 7 and 8). Salinity data may only be an estimate as the S-C-T meter may not have been functioning properly during some of the sampling trips. In addition to measured salinities, data from Pullen and Trent (1969) on salinities in the Trinity River delta and from Martinez (1974, 1975) on salinities in Matagorda Bay near the Colorado River delta are used to supplement the measured data. Salinity data for other bay-estuary-lagoon systems can be found in the draft literature synthesis of White and Calnan (1989).

Table 5. Seasonal vegetation heights at marker beds in the Colorado River delta.

| Transect-station and date | Vegetation heights (range in cm)<br>Spartina alterniflora | Borrichia frutescens | Batis maritima | Distichlis spicata | Monanthochloe littoralis | Scirpus maritimus | Spartina patens |
|---|---|---|---|---|---|---|---|
| 1-2 June 1987 | | 49-58 | | 64-107 | | 94-109 | |
| 1-2 March 1988 | | 57 | | 39-44 | | 60-64 | |
| 1-2 July 1988 | | 67 | | 49 | | | |
| 1-2 Nov 1988 | 49 | | | 30-49 | | | |
| 1-2 Mar 1989 | | | | 21-27 | | 34-46 | |
| 1-2 June 1989 | 53-66 | 32-35 | | 33-39 | | | |
| 1-3 June 1987 | 70-91 | | | | | | |
| 1-3 March 1988 | 50-76 | | | | | | |
| 1-3 July 1988 | 66-74 | | | | | | |
| 1-3 Nov 1988 | 49-70 | | | | | | |
| 1-3 Mar 1989 | 34-52 | | | | | | |
| 1-3 June 1989 | 49-72 | | | | | | |
| 1-13 Feb 1988 | | | 55 | 61 | | | |
| 1-14 July 1988 | | 61-79 | 51-53 | | | | 66-84 |
| 1-14 Nov 1988 | | 58-70 | 49-58 | | | | |
| 1-14 Mar 1989 | | 61-76 | 37-40 | | | | |
| 1-14 June 1989 | | 65-69 | 36-52 | | | | |
| 2-4 June 1987 | 73 | | | | | | |
| 2-4 Mar 1988 | 48-59 | | | | | | |
| 2-4 July 1988 | 57-74 | | | | | | |
| 2-4 Nov 1988 | 52-67 | | | | | | |
| 2-4 Mar 1989 | 40-52 | | | | | | |
| 2-4 June 1989 | 53-59 | | | | | | |
| 2-9 June 1987 | | | 15 | | 8 | | |
| 2-9 Mar 1988 | | | 20-36 | | 9-17 | | |
| 2-9 July 1988 | | | | | 15-17 | | |
| 2-9 Nov 1988 | | | 13-20 | | 13-15 | | |
| 2-9 Mar 1989 | | | | | 9-15 | | |
| 2-9 June 1989 | | | | | 12-16 | | |
| 3-1 Dec 1987 | | 69-71 | 74 | 61 | | | |
| 3-1 July 1988 | | 66-72 | 60-64 | Dead | | | |
| 3-1 Nov 1988 | | 64-65 | 58-64 | | | | |
| 3-1 Mar 1989 | | 49-76 | 34-46 | | | | |
| 3-1 June 1989 | | 60-70 | 32-66 | | | | |
| 3-2 Dec 1987 | 61-69 | | | 41-48 | | | |
| 3-2 Mar 1988 | 25-56 | | | 33-53 | | | |
| 3-2 July 1988 | 45-67 | | | 40-45 | | | |
| 3-2 Nov 1988 | 43-70 | | | 30-46 | | | |
| 3-2 Mar 1989 | 27-40 | | | 21-31 | | | |
| 3-2 June 1989 | 37-51 | | | 27-36 | | | |
| 3-3 Dec 1987 | 76 | | | | | | |
| 3-3 Mar 1988 | 50-56 | | | | | | |
| 3-3 July 1988 | 58-63 | | | | | | |
| 3-3 Nov 1988 | 58-70 | | | | | | |
| 3-3 Mar 1989 | 40-52 | | | | | | |
| 3-3 June 1989 | 59-66 | | | | | | |
| 4-10 Dec 1987 | 58 | | | | | | |
| 4-10 July 1988 | 37-40 | | | | | | |
| 4-10 Nov 1988 | 36-45 | | | | | | |
| 4-10 Mar 1989 | 21-24 | | | | | | |
| 4-10 June 1989 | 31-40 | | | | | | |

Table 6. Seasonal vegetation heights at marker beds in the Trinity River delta.

| Transect-station and date | Vegetation heights (range in cm) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Spartina alterniflora | Alternanthera philoxeroides | Echinochloa crusgalli | Bacopa monnieri | Scirpus olneyi | Juncus roemerianus | Panicum dichotomiflorum | Sphenoclea zeylanica | Pluchea sp. | Crinum americanum | Paspalum lividum | Aster sp. | Paspalum vaginatum |
| 1-3 Dec. 1987 | | | | | | | 67-140 | | 110 | | | | |
| 1-3 Mar. 1988 | | | | | | | 30-75 | | | | | | |
| 1-3 July 1988 | | | | 15 | 72-152 | | | | | | | | |
| 1-3 Nov. 1988 | | | | 100% cover (not measured) | | | | | | | | | |
| 1-3 Mar. 1989 | | No vegetation | | | | | | | | | | | |
| 1-3 June 1989 | | No vegetation | | | | | | | | | | | |
| 1-3 Aug. 1989 | | No vegetation | | | | | | | | | | | |
| 1-4 Dec. 1987 | | | | | | | | 112 | | | | | |
| 1-4 Mar. 1988 | | | | | | | | 51-109 | | | | | |
| 1-4 July 1988 | | | | | 114 | | | | | | | | |
| 1-4 Nov. 1988 | | | | | | | | | | | | | |
| 1-4 Mar. 1989 | | No vegetation | | | | | | | | | | | |
| 1-4 June 1989 | | No vegetation | | | | | | | | | | | |
| 1-4 Aug. 1989 | | | | | sparse | | | | | | | | |
| 2-2 July 1988 | | 91-104 | | | | | | | 122 | 46-61 | | | |
| 2-2 Nov. 1988 | | 43-67 | | | | | | | 122 | <30 | | | |
| 2-2 Mar. 1989 | | Vegetation dead | | | | | | | | | | | |
| 2-2 June 1989 | | 52-61 | | | | | | | | 61-76 | | | |
| 2-2 Aug. 1989 | | 37-48 | | | | | | | | 55-68 | | | |
| 3-2 Dec. 1987 | | | | | | | | | | <30 | | | |
| 3-2 Mar. 1988 | | | | | | | | | | 17-25 | | | |
| 3-2 July 1988 | | | | | | | | | | short, near surface | | | |
| 3-2 Nov. 1988 | | 30-37 | | | | | | | | 24 | | | |
| 3-2 Mar. 1989 | | Vegetation dead | | | | | | | | | | | |
| 3-2 June 1989 | | 72-76 | | | | | | | | 80 | | | |
| 3-2 Aug. 1989 | | short, near surface | | | | | | | | short, near surface | | | |
| 3-4 Dec. 1987 | | <10 | | | | | 25-70 | | | | | | |
| 3-4 July 1988 | | 61 | 117 | | | | | | 100 | | | | |
| 3-4 Nov. 1988 | | | | | | | 140 | | | | | | |
| 3-4 Mar. 1989 | | Vegetation dead | | | | | | | | | | | |
| 3-4 June 1989 | | 60-65 | | | | | | | | | | | |
| 3-4 Aug. 1989 | | <5 | | | | | | | | | | | |
| 4-3 Dec. 1987 | | Mostly bare; vegetation dead | | | | | | | | | | | |
| 4-3 Mar. 1988 | | <6 | | | | | | | | | | | |
| 4-3 July 1988 | | 61-91 | 152 | | 104-140 | | | | | | | | |
| 4-3 Nov. 1988 | | | | | | | | | | | | | |
| 4-3 Mar. 1989 | | Vegetation dead | | | | | | | | | | | |
| 4-3 June 1989 | | | | | | | | | | | | | |

Table 6 (cont.)

| Transect-station and date | Spartina alterniflora | Alternanthera philoxeroides | Echinochloa crusgalli | Bacopa monnieri | Scirpus olneyi | Juncus roemerianus | Panicum dichotomiflorum | Sphenoclea zeylanica | Pluchea sp. | Crinum americanum | Paspalum lividum | Aster sp. | Paspalum vaginatum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Vegetation heights (range in cm) | | | | | | | | |
| 4-4 July 1988 | | 61-91 | 152 | | 96-129 | | | | | | | | |
| 4-4 Nov. 1988 | | <43 | | | | | | | | | | | |
| 4-4 Mar. 1989 | | Vegetation dead | | | | | | | | | | | |
| 4-4 June 1989 | | | | | | | | | | | | | |
| 4 ext. Nov. 1988 | | | | | | | | | | | 46-76 | 64 | 61 |
| 4 ext. Mar. 1989 | | Vegetation dead | | | | | | | | | | | |
| 4 ext. June 1989 | | | | | | | | | | | | | 34-50 |
| 4 ext. Aug. 1989 | | 2-4 | | | | | | | | | | | 2-4 |
| 6-1 Mar. 1988 | | | | | 5-12 | | | | | | | | |
| 6-1 July 1988 | | | | | 122-135 | | | | | | | | |
| 6-1 Nov. 1988 | | | | | | | | | | | | | |
| 6-1 Mar. 1989 | | No vegetation | | | | | | | | | | | |
| 6-1 June 1989 | | | | | 91-93 | | | | | | | | |
| 6-1 Aug. 1989 | | | | | 110-137 | | | | | | | | |
| 6-2 July 1988 | | 55-67 | | | | | | | | | | | |
| 6-2 Nov. 1988 | | 18-21 | | | | | | | | | | | |
| 6-2 Mar. 1989 | | No vegetation | | | | | | | | | | | |
| 6-2 June 1989 | | 60-65 | | | | | | | | | | | |
| 6-2 Aug. 1989 | | 30-50 | | | | | | | | | | | |
| 7 Dec. 1987 | 61 | | | | | 142 (away from marker) | | | | | | | |
| 7 Mar. 1988 | 43-46 | | | | | | | | | | | | |
| 7 July 1988 | 79-89 | | | | | | | | | | | | |
| 7 Nov. 1988 | 40-45 | | | | | | | | | | | | |
| 7 Mar. 1989 | 38-41 | | | | | | | | | | | | |
| 7 June 1989 | 72-79 | | | | | | | | | | | | |
| 7 Aug. 1989 | 79-109 | | | | | 116-131 (away from marker) | | | | | | | |

Table 7. Temperatures and salinities at transects in the Colorado River delta.

| Transect | Date* | Salinity (ppt) | Temperature (°C) |
|---|---|---|---|
| 3 | 12/17/87 | 22.0 | 14.0 |
| 4 | 12/16/87 | 24.5 | 10.5 |
| 1 | 2/9/88 | 17.5 | -- |
| 1 | 3/28/88 | 18.0 | 24.0 |
| 2 | 3/29/88 | 23.0 | 25.0 |
| 3 | 3/30/88 | 19.0 | 17.5 |
| 1 | 7/18/88 | -- | -- |
| 2 | 7/19/88 | 34.0 | -- |
| 3 | 7/18/88 | 32.0 | 34.0 |
| 4 | 7/19/88 | 34.0 | -- |
| 1 | 11/9/88 | -- | -- |
| 3 | 11/9/88 | 29.5 | 23.0 |
| 4 | 11/8/88 | 31.0 | 25.0 |
| 1 | 3/14/89 | -- | -- |
| 2 | 3/14/89 | -- | -- |
| 4 | 3/14/89 | 24.0 | 20.0 |

* SCT meter was not functioning in June 1989.
-- Measurements were not taken.

Table 8. Temperatures and salinities at transects in the Trinity River delta.

| Transect | Date* | Salinity (ppt) | Temperature (°C) | Transect | Date | Salinity (ppt) | Temperature (°C) |
|---|---|---|---|---|---|---|---|
| 1 | 12/8/87 | 3.0 | -- | 1 | 3/22/88 | 0 | 20.0 |
| 2 | 12/8/87 | 0 | 17.0 | 2 | 3/22/88 | -- | -- |
| 3 | 12/9/87 | 0.5 | 17.0 | 3 | 3/22/88 | 0 | 25.0 |
| 4 | 12/9/87 | 0 | 17.5 | 4 | 3/22/88 | 0 | 16.0 |
| 5 | 12/9/87 | 0 | 17.0 | 5 | 3/22/88 | 0 | 16.0 |
| 6 | 12/10/87 | 0 | 16.5 | 6 | 3/23/88 | 0 | 18.0 |
| 7 | 12/10/87 | 15.5 | 20.5 | 7 | 3/23/88 | 12.0 | 23.5 |
| 1 | 7/26/88 | 2.0 | 34.0 | 1 | 11/15/88 | 13.0 | 23.0 |
| 2 | 7/26/88 | -- | -- | 2 | 11/15/88 | 6.0 | 22.0 |
| 3 | 7/26/88 | 0.5 | 34.0 | 3 | 11/15/88 | 11.0 | 24.0 |
| 4 | 7/26/88 | 0 | 32.0 | 4 | 11/15/88 | 4.0 | 22.0 |
| 5 | 7/26/88 | 0 | 32.0 | 5 | 11/15/88 | -- | -- |
| 6 | 7/27/88 | 2.5 | 32.0 | 6 | 11/15/88 | 12.0 | 23.5 |
| 7 | 7/25/88 | 19.0 | 34.0 | 7 | 11/14/88 | -- | -- |
| 1 | 3/7/89 | 0 | 11.0 | | | | |
| 2 | 3/8/89 | 0 | 8.0 | | | | |
| 3 | 3/7/89 | 0 | 15.5 | | | | |
| 4 | 3/7/89 | 0 | 10.0 | | | | |
| 5 | 3/8/89 | 0 | 11.5 | | | | |
| 6 | 3/8/89 | -- | -- | | | | |
| 7 | 3/8/89 | -- | -- | | | | |

* SCT meter was not functioning in June 1989.
-- Measurements were not taken.

## Results

### Colorado River Delta

Artificial-marker horizons were monitored over different time periods depending on the date in which they were established (table 1). About half were monitored for 24 months and the other half 15 to 18 months. The longer periods of time are desirable to include infrequent meteorological events that have an important role in sediment deposition. In addition, because there is a seasonal variation in aggradation (less deposition occurring during winter), a 24-month period that includes all seasons twice, provides the best results. Furthermore, longer periods of time help to "equilibrate" the aggradation rate with respect to burrowing organisms (primarily fiddler crabs on the Colorado River delta) that redistribute sediment on the marker horizons.

#### Marsh Aggradation Rates

Rates of sediment deposition (aggradation), as determined from the artificial-marker horizons in the Colorado River delta area, range from approximately 2 mm/yr to about 12 mm/yr (table 9). The highest rates of marsh aggradation, 11.7 and 11.9 mm/yr, occurred at stations C 2-4 and 3-1. The lowest rate, < 2 mm/yr, was documented at station C 2-9.

Rather consistent trends in aggradation are apparent for some depositional environments (table 9). Backmarsh-distributary influenced sites (C 1-2, 1-3, 3-2, and 3-3) vary less than 1 mm; aggradation rates range from 8.5 to 9.3 mm/yr and average 9.0 mm/yr. These four sites are intertidal *Spartina alterniflora* marshes (Figs. 19 and 20); sediment deposition at these sites prior to September of 1988 when Hurricane Gilbert made landfall, was apparently related to normal estuarine intertidal processes. The location of these marshes in the intertidal zone contributed to the higher aggradation rate by increasing the frequency of inundations and the period of time during which deposition occurred.

Aggradation by period at the different marker horizons (stations) is depicted in figure 21. The low amount of deposition of less than 1 mm/yr at stations C 1-14 and C 3-1 through July 1988 was expected because these sites are on topographically high levees (Figs. 22, 23, 24, and 25) that apparently were not inundated during this period. Differences in inundation and sediment accumulation between the intertidal sites and levee sites were shown by water and materials trapped in sediment pans in July 1988. The sediment pan at C 3-1 (levee site) contained no observable water or inorganic sediments but only a small amount of organic debris from surrounding plants

Table 9. Salt marsh environments and aggradation rates in the Colorado River delta. (Numbers in parenthesis are station numbers.)

| MARSH ENVIRONMENT | MARSH ACCRETION RATE (mm/yr) |
|---|---|
| LEVEE | |
| *Borrichia, Batis, Distichlis* (3-1) | 11.9 |
| *Borrichia, S. patens, Batis* (1-14) | 5.4 |
| BARRIER FLAT | |
| *Monanthochloe* (2-9) | 1.9 |
| BAY MARGIN-DISTRIBUTARY INFLUENCED | |
| *Spartina alterniflora* (2-4) | 11.7 |
| BACKMARSH-DISTRIBUTARY INFLUENCED | |
| *Spartina alterniflora* (3-3) | 9.3 |
| *Spartina alterniflora, Scirpus maritimus* (1-3) | 9.2 |
| *Distichlis, Scirpus maritimus* (1-2) | 8.9 |
| *Spartina alterniflora, Distichlis* (3-2) | 8.5 |
| BACKMARSH/BAY MARGIN | |
| *Spartina alterniflora* (4-10) | 5.7 |

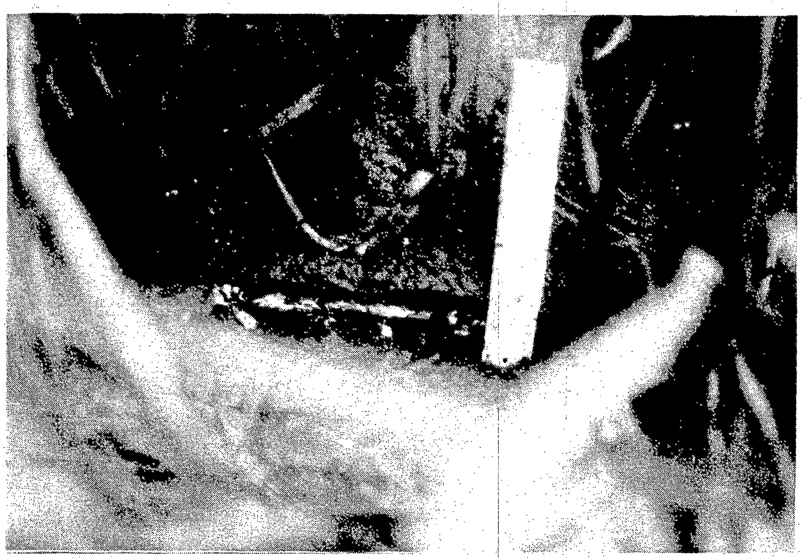


Figure 19. Vertical trench intersecting the artificial-marker horizon C 1-3 in the Colorado River delta. Ruler is 15 cm (6 in) in length. Vegetation is *Spartina alterniflora*.

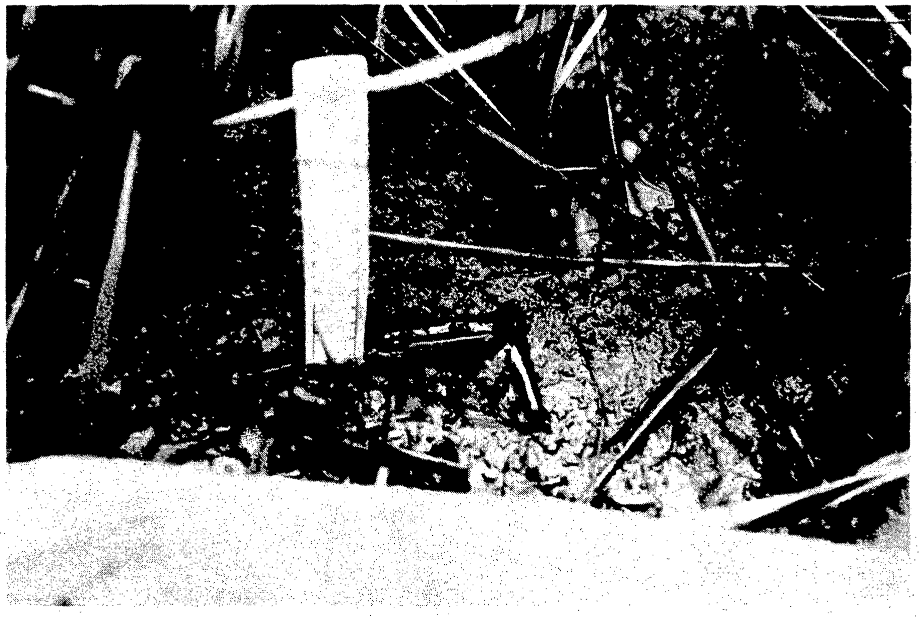


Figure 20. Vertical trenches at right angles intersecting artificial-marker horizon C 3-3 in the Colorado River delta. Ruler is 15 cm (6 in) in length. Vegetation is *Spartina alterniflora*.

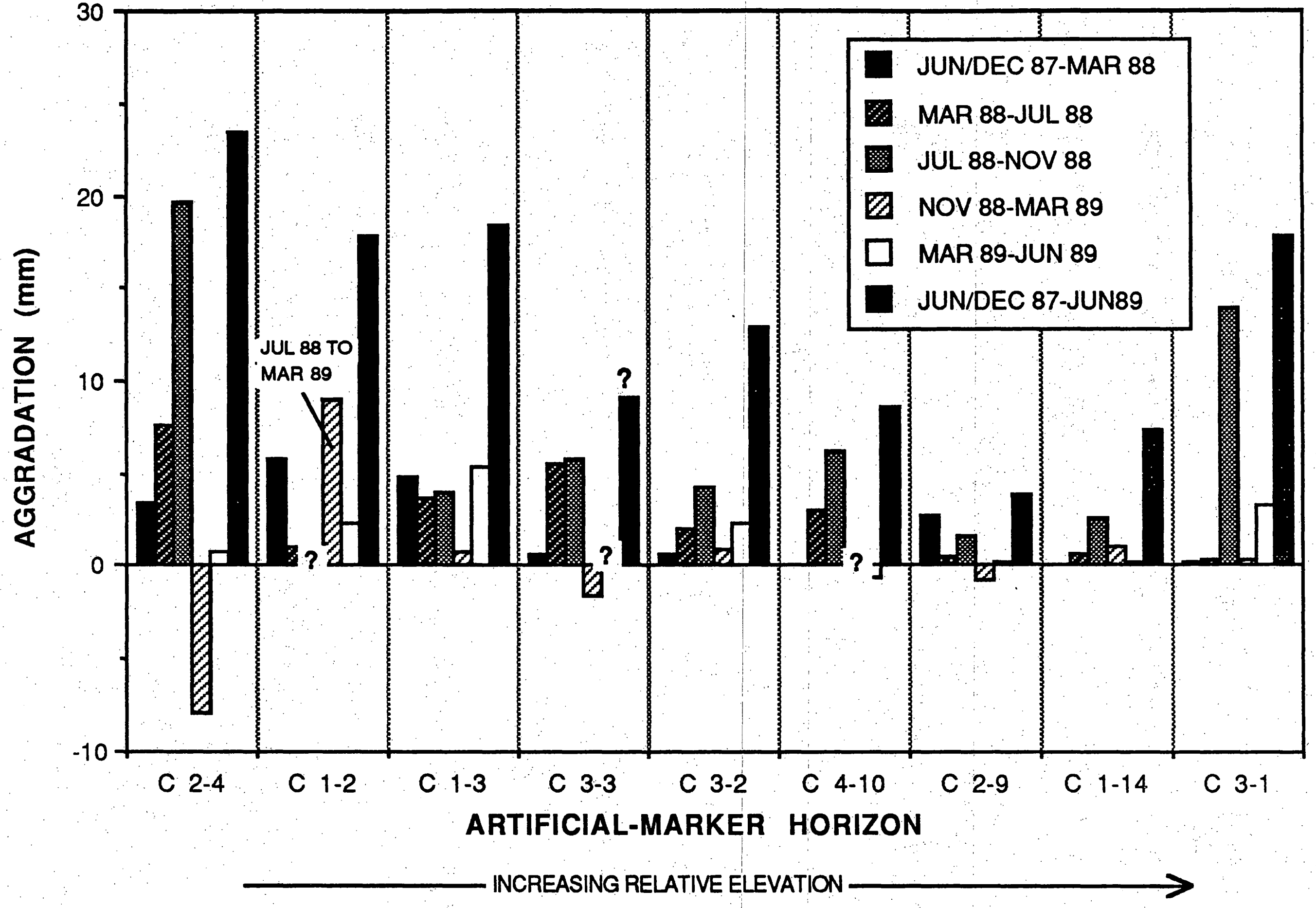


Figure 21. Sediment accumulation (aggradation) above artificial-marker horizons during specified periods, Colorado River delta study area. Marker horizons are arranged according to relative elevations.

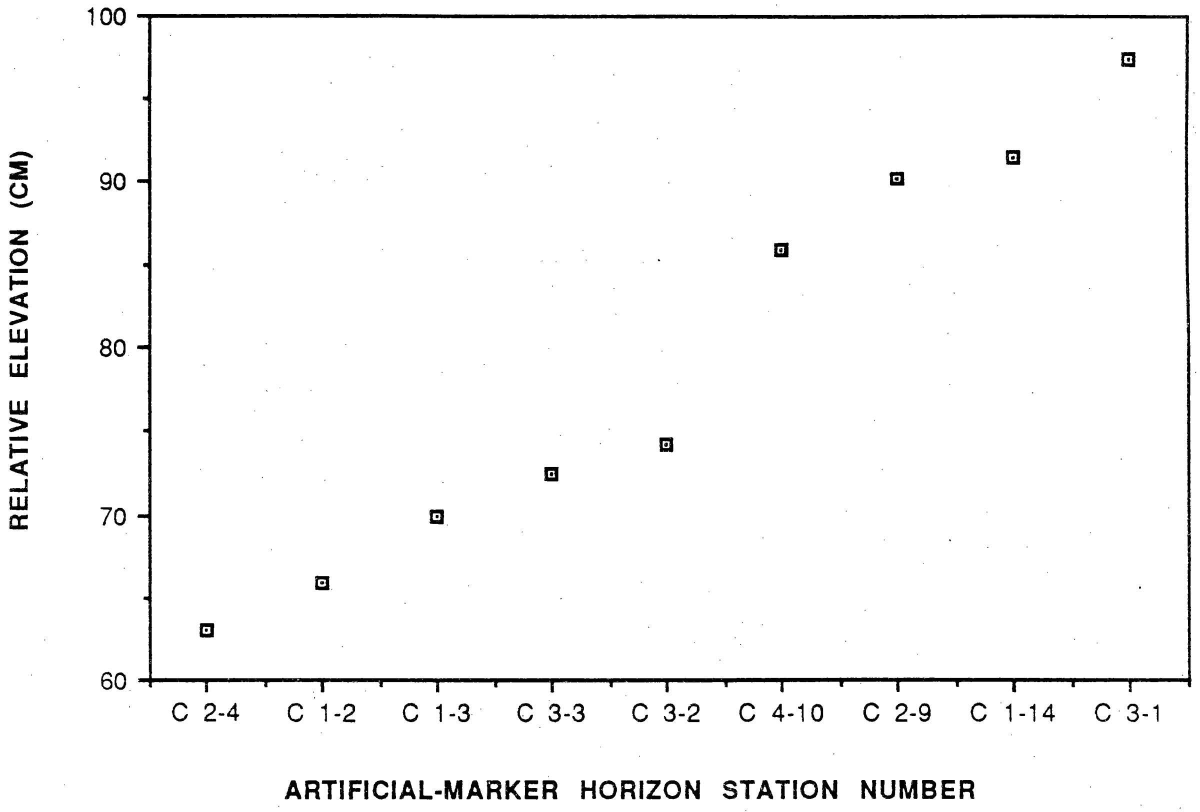


Figure 22. Relative elevations of artificial-marker horizons, Colorado River delta. Relative elevations are approximations determined with respect to water levels measured at tide gauges (Fig. 3).

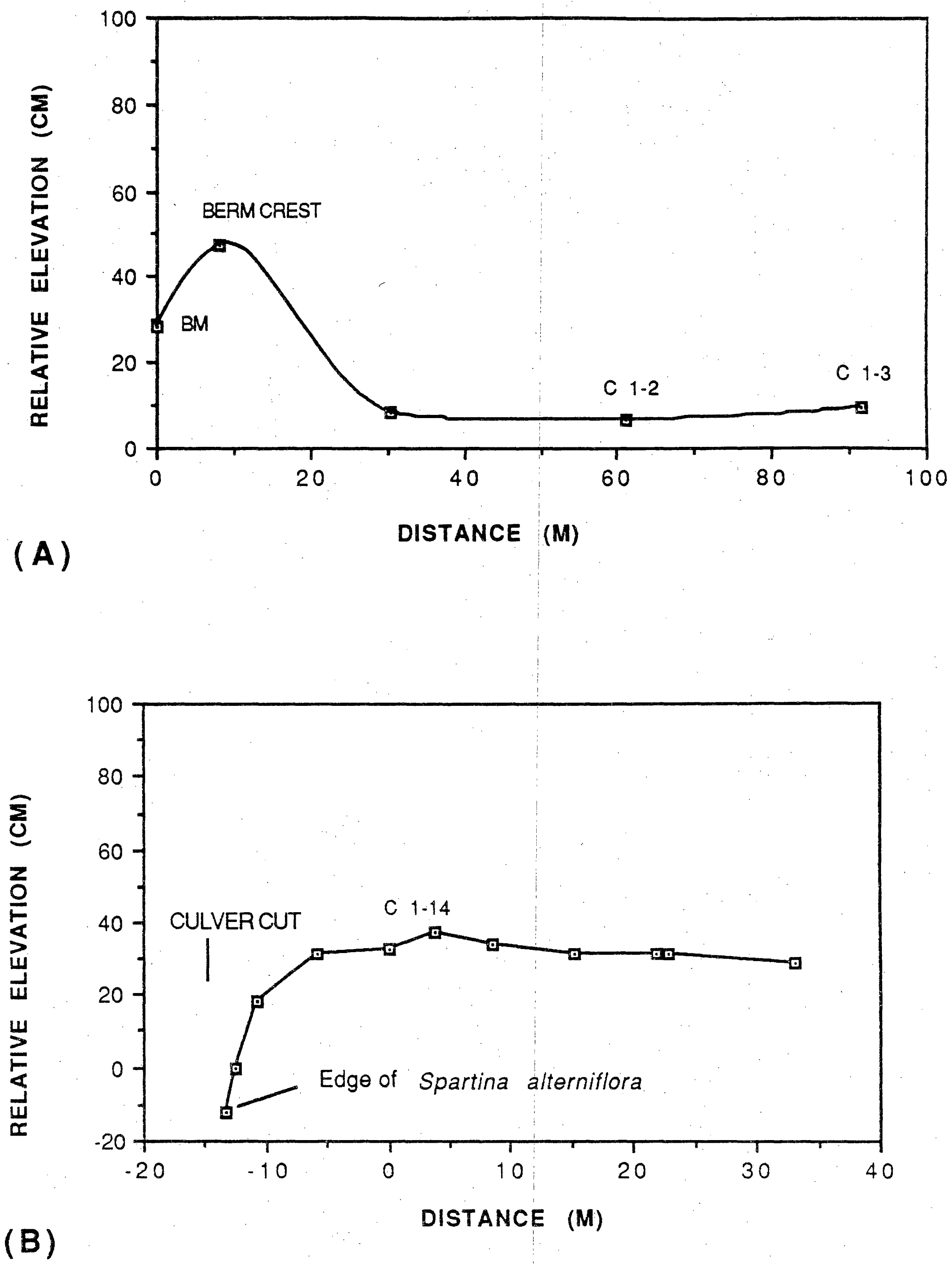
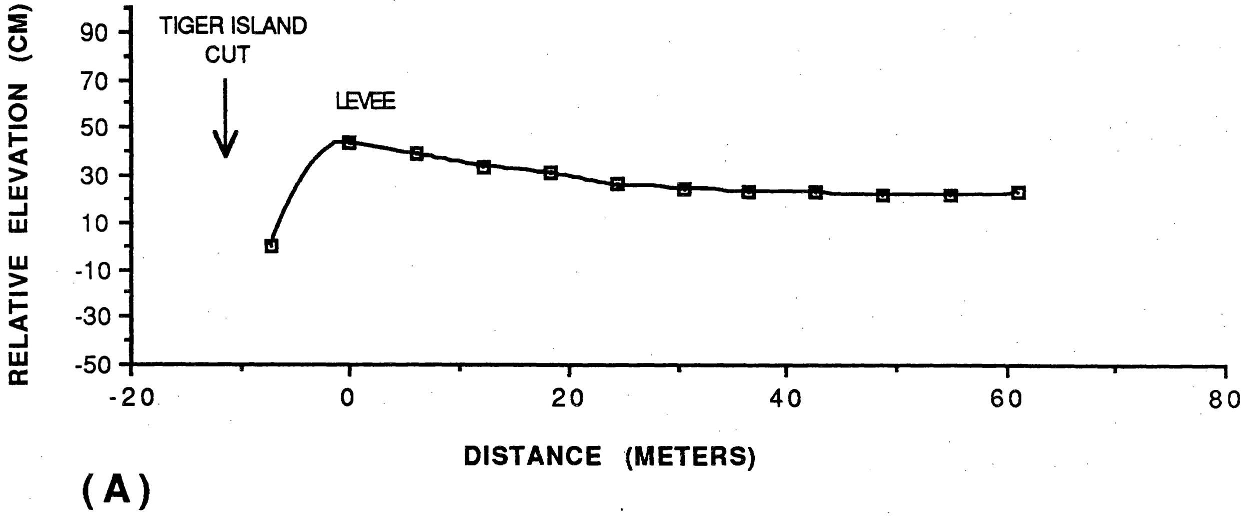


Figure 23. Profiles along marsh transect C 1 near Culver Cut, Colorado River delta. Profile (A) extends from south to north with the south end intercepting a storm berm that borders the marsh boundary along Matagorda Bay; artificial-marker horizons C 1-2 and C 1-3 are located along this profile. Profile (B) extends from the margin of Culver Cut eastward toward the north end of profile A. Marker horizon 1-14 is located on profile B.



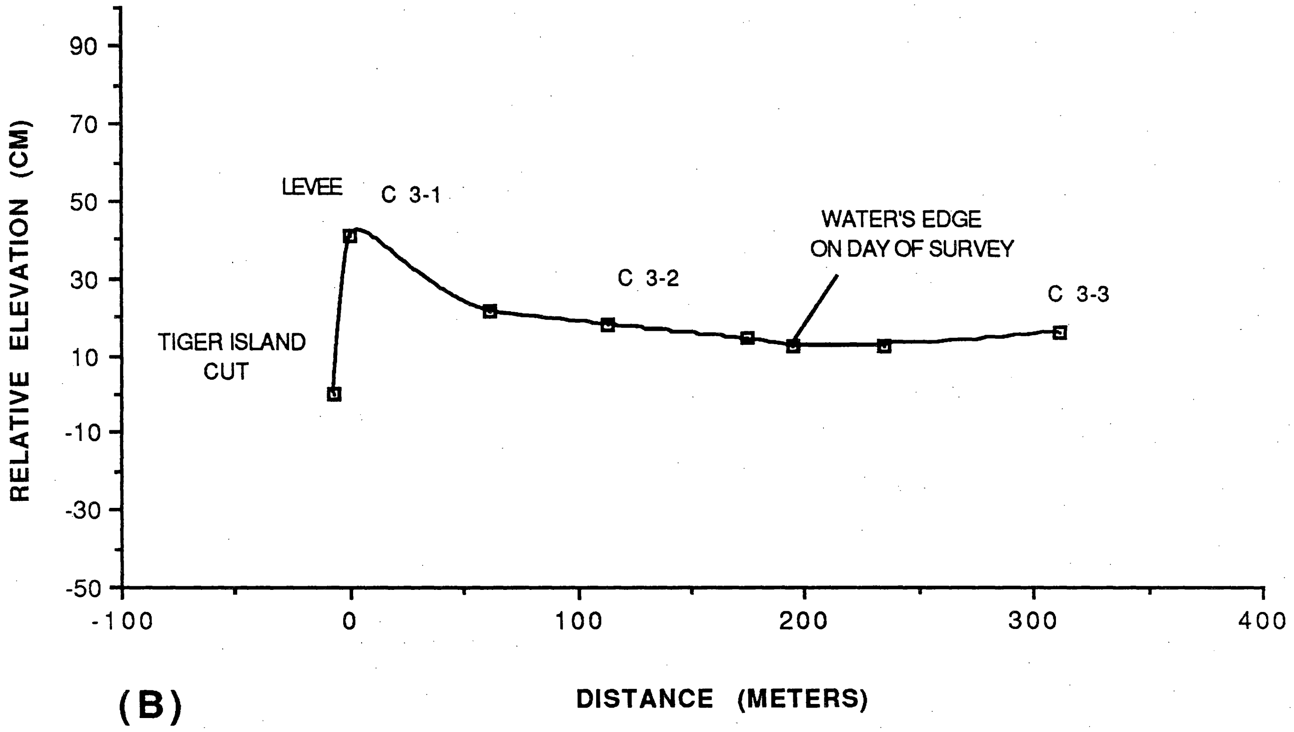


Figure 24. Profiles along marsh transect C 3 near Tiger Island Cut, Colorado River delta. Relative elevations (not adjusted to sea-level datum) determined with profiling rods along the initial 60 m (200 ft) of the transect are shown in (A); elevations based on plane table survey of about 300 m (1000 ft) of the marsh transect are shown in (B).

Figure 25. Plane table and telescopic alidade set up on levee along Tiger Island Cut near station C 3-1, Colorado River delta. View is toward backmarsh stations C 3-2 and 3-3.

(Fig. 12). In contrast, the pan at C 3-3 was filled with water and contained about 4 mm of sediment.

"Storm tides" associated with Hurricane Gilbert's landfall in September 1988, appear to have flooded all marker horizons for a period of about 3 to 4 days (Fig. 16). Examination of the markers in November 1988 indicated significant deposition had occurred, particularly at levee site C 3-1 and bay-margin site 2-4 (Fig. 26). Both of these sites are near Tiger Island Cut. Sediment accumulation on the marker and in the aluminum pan at C 3-1 in November was about 1.5 to 2 cm thick (Fig. 27). No measurable deposition had occurred at this site prior to this period. This is in contrast to intertidal station 3-3 (Fig. 20) where deposition generally occurred throughout the monitoring period.

The levee site (C 3-1) and bay margin or distributary influenced site (C 2-4) have very similar rates of about 12 mm/yr. Both of these sites are located less than 10 meters from the margin of a distributary channel (C 3-1) and bay shoreline (C 2-4) (Fig. 4). However, station C 2-4 is in a topographically low *Spartina alterniflora* marsh, where aggradation, although punctuated by deposition during Hurricane Gilbert, was still significant from June 1987 to July 1988 before the hurricane. Negligible deposition occurred at the levee site (C 3-1) along Tiger Island Cut before Hurricane Gilbert. The Culver Cut levee site (C 1-14) across the bay from Tiger Island Cut received considerably less sediment than C 3-1 during the period that included the hurricane (Jul 88 - Nov 88, Fig. 21).

The lowest amount of deposition in a *Spartina alterniflora* marsh occurred at station C 4-10, which is located on Matagorda Peninsula about 15 km southwest of the Colorado River delta. This site is characterized as backmarsh with bay-margin influence; it is located near the landward margin of a *Spartina alterniflora* marsh about 25 m from a protected southern shoreline and about 75 m from a more active northward facing shoreline bordered by a storm berm. The average rate of deposition at this site is 5.7 mm/yr (table 9). The lower rate at this site compared to the other *Spartina alterniflora* marshes is apparently due in part to its distance from the delta where associated distributary and tidal channels supply sediments to the deltaic sites. In addition, station C 4-10 is characterized by a much sandier substrate (87 percent sand) than the other *Spartina alterniflora* sites, indicating it is removed from any abundant source of mud.

The lowest rate of sediment accumulation was in a sparsely vegetated marsh of predominantly *Monanthochloe littoralis* on Matagorda Peninsula (station C 2-9). The low rate of accumulation is attributed more to the apparent infrequent inundation of this site than to the sparseness of vegetative cover (Fig. 28). The substrate at this site is composed of almost 90 percent sand (Fig. 4) derived principally from gulfward environments. Transport of the sand apparently occurs through

Figure 26. Sediment deposition at marker C 2-4 primarily from Hurricane Gilbert. Photograph was taken in March 1989 after winter storms had apparently removed some of the sediment that had accumulated above the marker horizon from July to November 1988, a period that included the hurricane (see aggradation for Jul-Nov 88 in Fig. 21). Compare sediment thickness in the above photograph with figure 13, which shows this marker as it looked in March 1988.

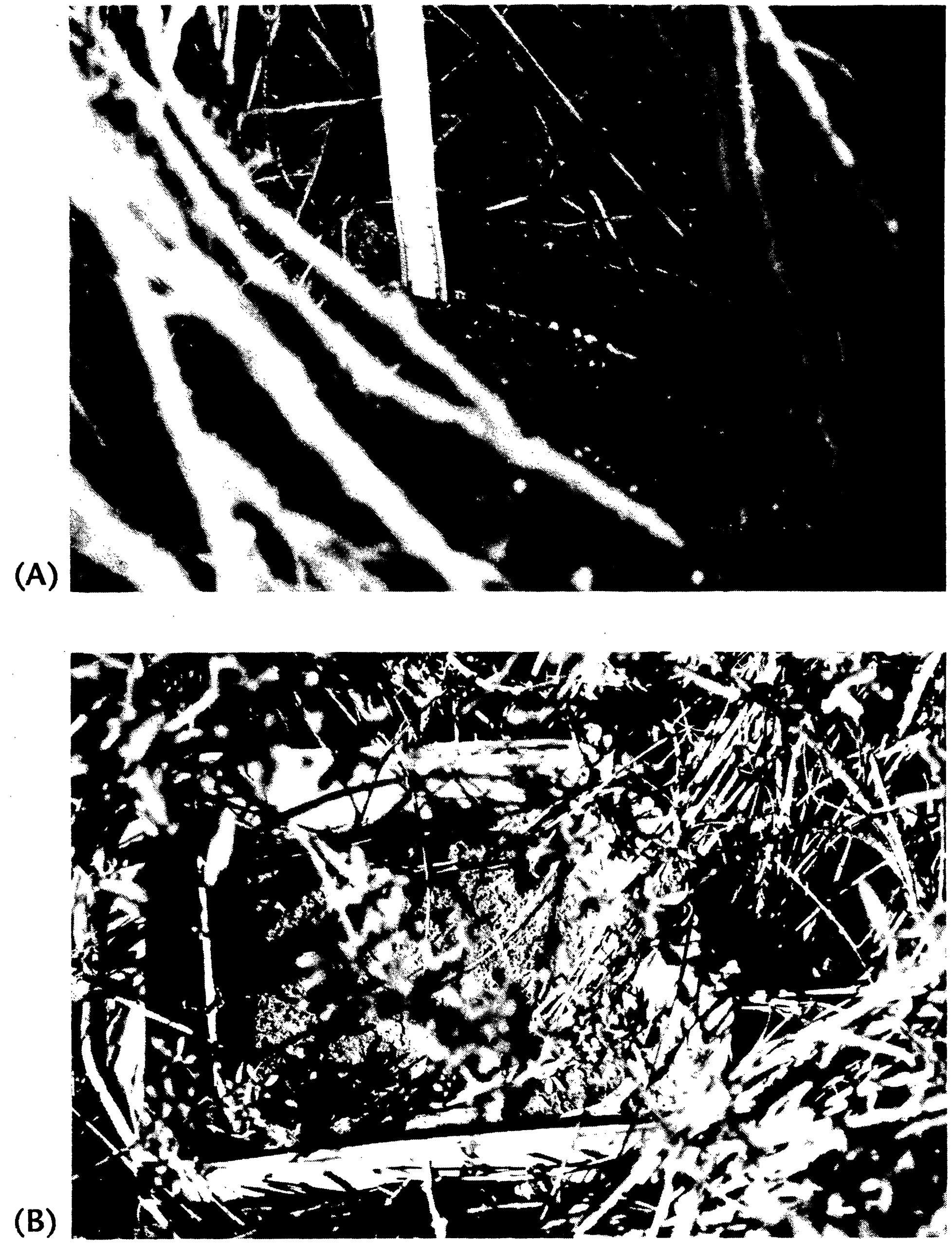


Figure 27. Sediment accumulations above marker C 3-1 (A) and in a nearby aluminum pan (B) as of November 1988. This deposition is attributed to Hurricane Gilbert, which made landfall in September 1988.

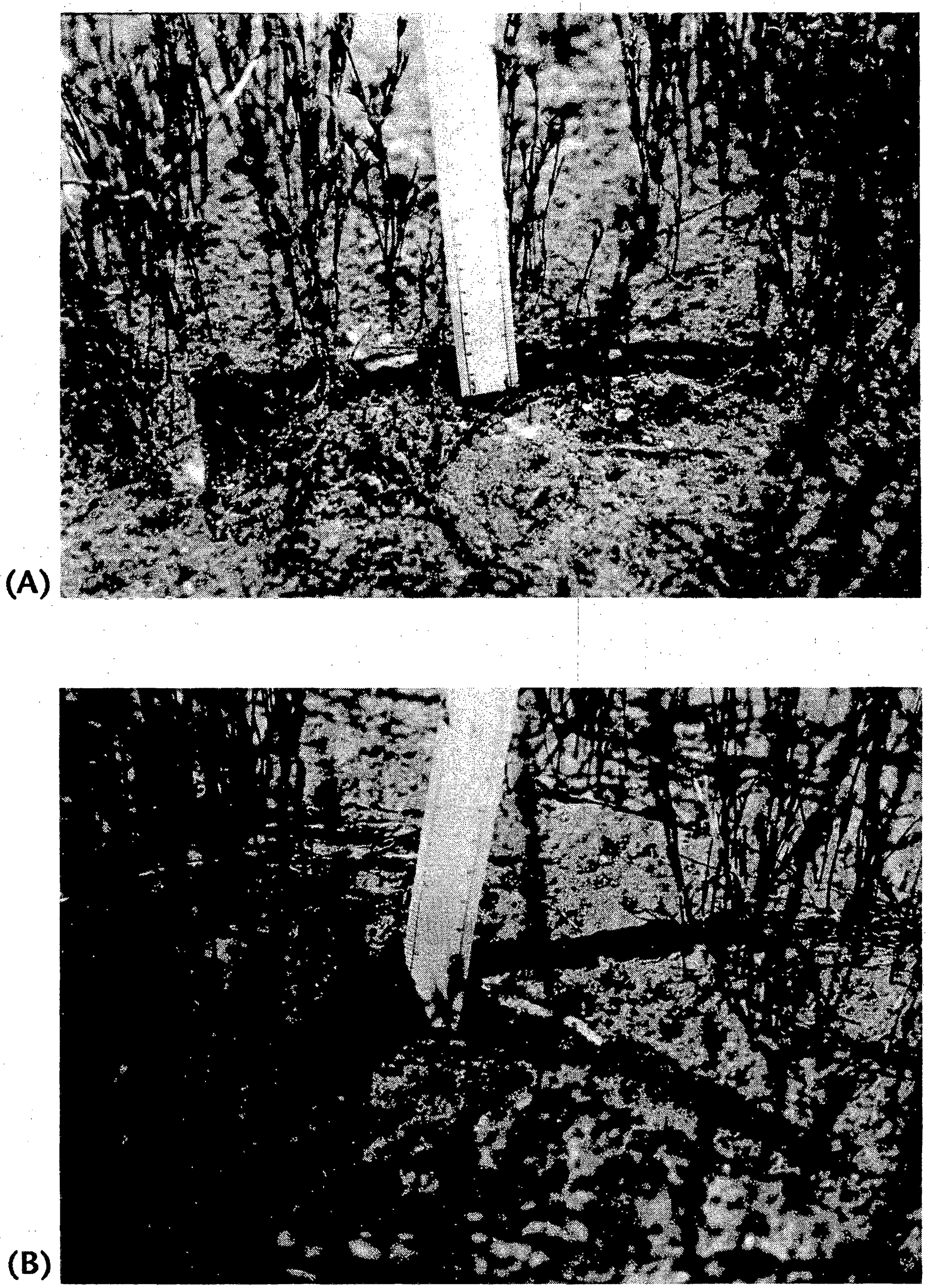


Figure 28. *Monanthochloe littoralis* marsh at station C 2-9. Photograph at (A) shows the marker horizon in July after a vertical trench was cut exposing the marker in cross section. The photograph at (B) shows the marker and overlying sediment as it appeared in a trench in March 1989. Sediment deposition at this site was the lowest of all sites located in the Colorado River delta study area (Fig. 21).

hurricane washover and eolian processes (McGowen and Brewton, 1975; White and others, 1985). Hurricane Gilbert, however, did not appreciably affect this site; the percent of sediment accumulation during the period (July to November 1988) in which the hurricane made landfall amounted to just over 30 percent of the two year total (table 10).

A core taken of sediments from Matagorda Bay northwest of stations C 2-4 and 2-9 as part of the reconnaissance work preceding this study (White and Calnan, 1987), penetrated a sand horizon that probably was deposited by Hurricane Carla in 1961. Approximately 30 cm of mud had accumulated above this sand horizon, indicating a rate of deposition of about 12 mm/yr (averaged over 26-year period) at this shallow bay-bottom site. The rate is almost identical to estimates of relative sea-level rise based on Swanson and Thurlow's (1973) subsidence rates for Freeport (about 70 km to the northeast) and Port Aransas (about 135 km to the southwest). If subsidence in the Colorado River delta is similar to these areas, it supports Rusnak's (1967) hypothesis that sediment accumulation in estuaries is equal to sea-level rise. It should be noted, however, that long-term sedimentation rates in the Colorado River delta are lower than 12 mm/yr (see following section on aggradation based on $^{210}$Pb analyses).

**Seasonal/Hurricane Aggradation.** Seasonal variations in sediment aggradation were recorded by most marker horizons (Figs. 29 and 30, and table 10). The least amount of deposition occurred during winter months. For example, deposition during the winter of 1988-89 represented an average of only 3 percent of the total occurring at the various sites during the monitoring periods (table 10). Deposition during the preceding winter at four markers, which define this winter period (markers C 3-1, 3-2, 3-3, and 4-10), averaged a similarly low amount of about 2.5 percent.

The months registering the highest amount of deposition were July to November, 1988, a period that includes Hurricane Gilbert. An average of about 60 percent of the total sediment that had accumulated on the marker horizons to March 1989 was deposited during this period (table 10). A high of almost 95 percent was deposited at levee site C 3-1 along the margin of Tiger Island Cut. This deposition can be attributed to Hurricane Gilbert, and indicates that over a 15-month period this levee site received most of its sediment during a single depositional event. Over the 18-month period of observation of this levee site, deposition attributable to the hurricane amounts to about 80 percent of the total (Fig. 30).

**Aggradation and Relative Elevation.** There is a relatively strong inverse relationship between the relative elevation of marker horizons and aggradation rates, if levee site C 3-1 is excluded from linear regression analysis (Fig. 31). The correlation coefficient (r) between relative elevation and aggradation is -0.857. The topographically higher marker horizons received less sediment than lower horizons. This relationship supports Pethick's (1981) conclusion of a statistical relationship

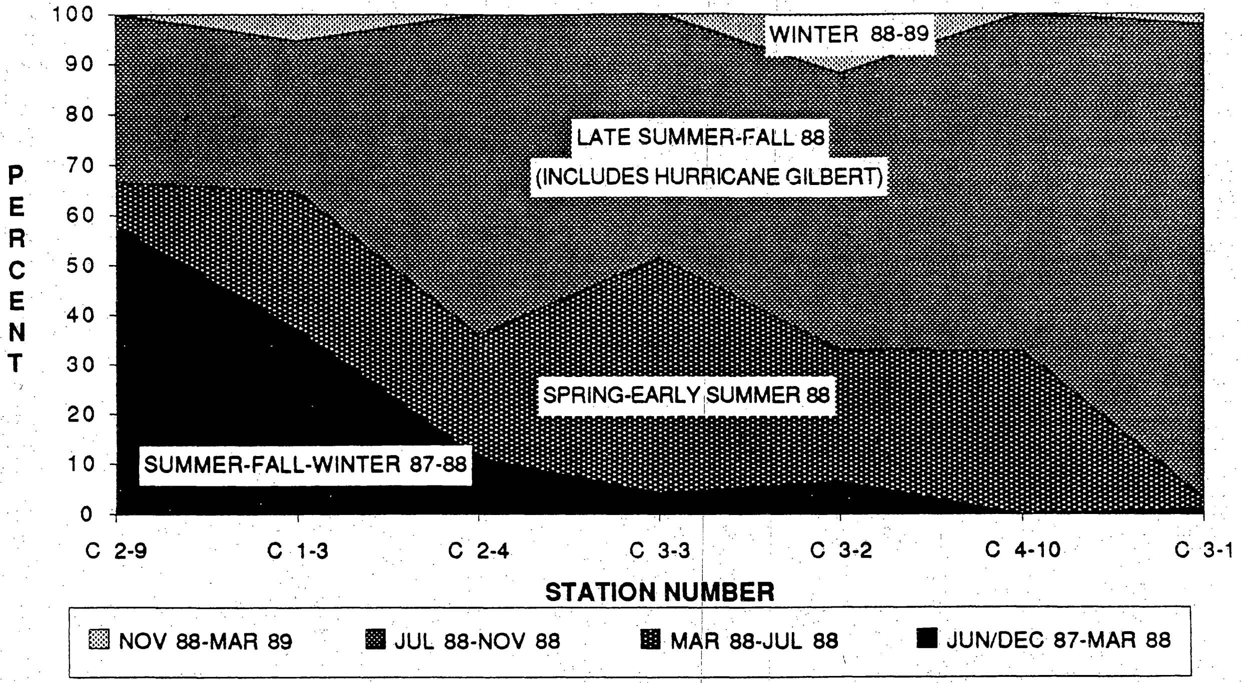


Figure 29. Seasonal aggradation in percent at eight marker horizons from June/December 1987 to March 1989, Colorado River delta.

Table 10. Percentage of the total aggradation above artificial-marker horizons that occurred during specified periods, Colorado River delta.

| MARKER HORIZON | SUMMER, FALL, AND/OR WINTER (Percent) | SPRING AND SUMMER (Percent) | LATE SUMMER AND FALL (Percent) | WINTER (Percent) |
|---|---|---|---|---|
| | | | | |
| C 2-9 | 58 | 9 | 33 | 0 |
| C 1-3 | 37 | 28 | 30 | 5 |
| C 2-4 | 11 | 25 | 64 | 0 |
| C 3-3 | 4 | 47 | 49 | 0 |
| C 3-2 | 7 | 26 | 55 | 12 |
| C 4-10 | 0 | 33 | 67 | 0 |
| C 1-14 | 0 | 16 | 81 | 3 |
| C 3-1 | 2 | 2 | 95 | 2 |
| | | | | |
| AVERAGE | 15 | 23 | 59 | 3 |

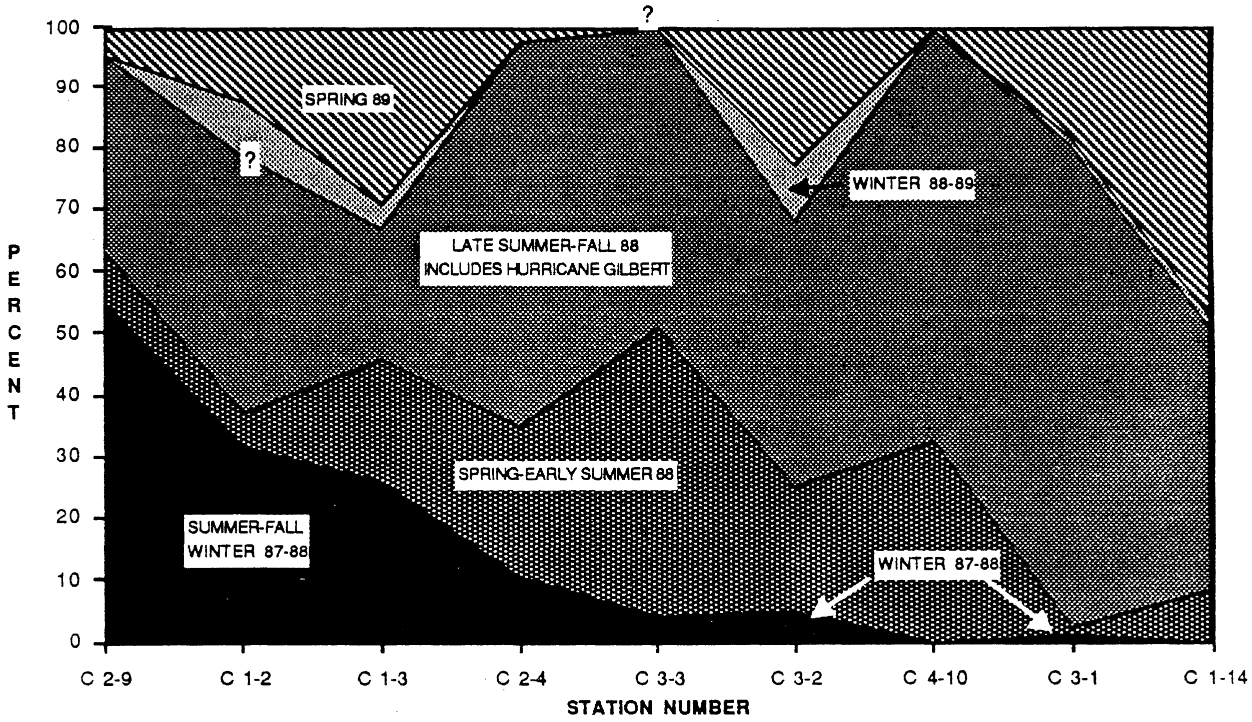


Figure 30. Seasonal aggradation in percent at all marker horizons from June/December 1987 to June 1989, Colorado River delta.

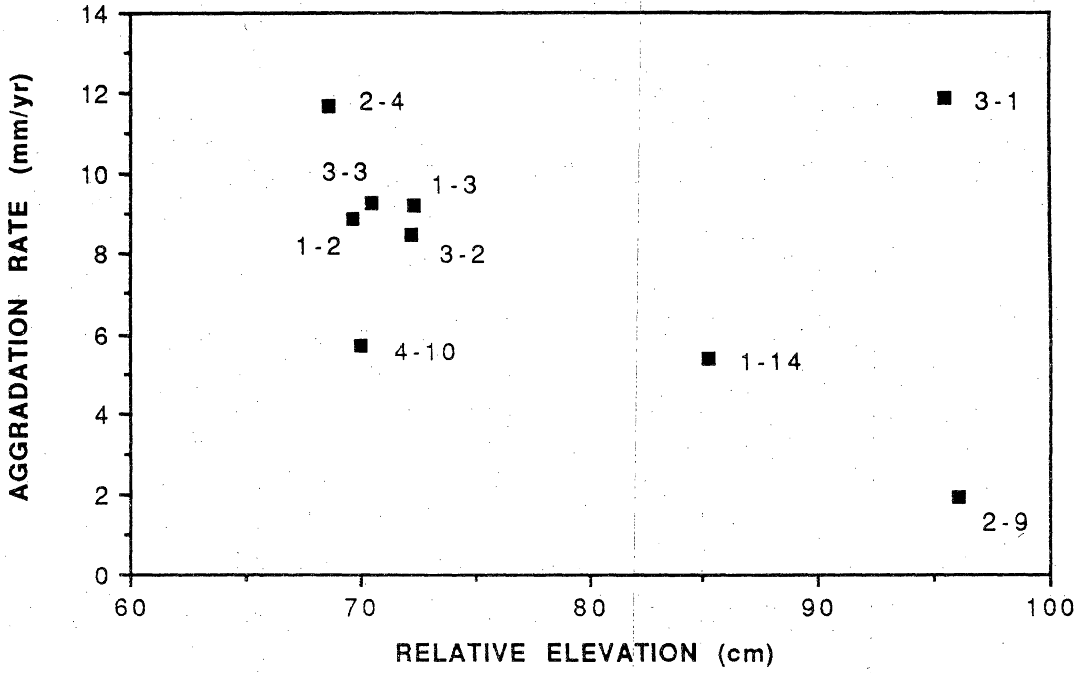


Figure 31. Aggradation versus relative elevation at artificial-marker horizons, Colorado River delta.

between marsh elevation/age and vertical accretion rates in which topographically lower, young marshes have higher rates of accretion than topographically higher, older marshes. The concept is that younger marshes are lower in elevation, which amplifies the depth and frequency of inundations compared to older marshes. The statistical relationship may be reduced by major storms or floods, however, when sediment is deposited at higher elevations such as on natural levees.

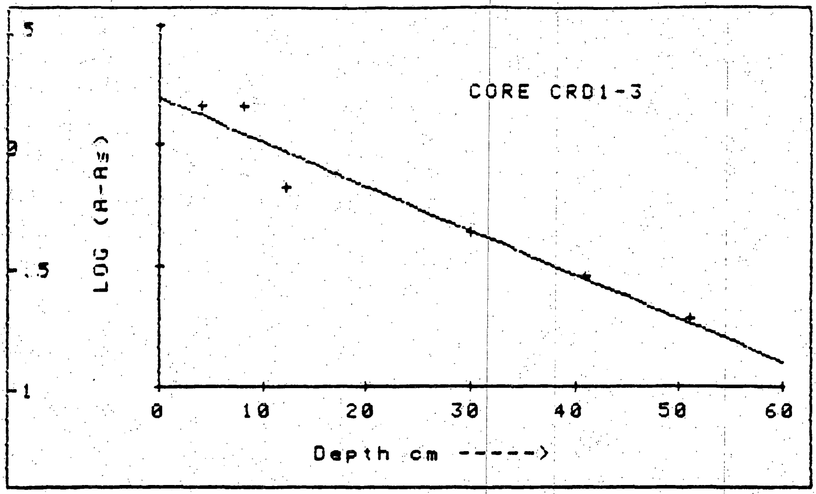
**Aggradation Based on $^{210}$Pb.** Longer term aggradation rates using $^{210}$Pb analyses in cores were determined at two sites, one near station C 1-3 and the other near C 3-2 (Fig. 4). Sedimentation rates inferred from the core analyses are 7.4 mm/yr at station C 1-3, and 7.6 mm/yr at C 3-2 (Fig. 32). These rates are 1.8 to 0.9 mm/yr lower than the rates determined from artificial-marker horizons at these sites (table 9). The slightly higher, short-term rates determined from the marker horizons are possibly due to lower amounts of compaction and organic decomposition in the surface sediments compared to deeper sediments in the core.

### Sediment Composition

**Textures.** Results of textural analysis at the different marsh transects on the Colorado River delta are illustrated in figures 4 and 14 (based on data from Appendix C). Sediments collected near the marker beds at the three transects show clay to be significantly more abundant (ranging up to 80 percent) than silt (maximum of about 30 percent) in the low marshes, while in the levee marsh, station C 3-1, silt was slightly more abundant (about 50 percent) than clay (about 40 percent). Sand was not a significant component of the marshes sampled except on nearby Matagorda Peninsula where it was predominant (ranging up to almost 90 percent).

Comparisons of the sediment textural distribution along transect C 3 indicate that variations in sediment composition are related, in part, to distances from the Tiger Island Cut distributary channel and to elevations of the sampling sites. Accordingly, sediments from station C 3-1, the levee site close to the distributary channel (Fig. 4), has a higher silt content than sediments from stations C 3-2 and 3-3, which are further from the distributary channel and at lower elevations (Fig. 22). The change in texture is indicative of the process of sediment deposition during overbank flooding, in which coarser material is deposited near the channel (levee) where flood waters rapidly lose velocity and sediment-carrying capacity. In a study of a delta lobe on the eastern half of the Colorado River delta, Kanes (1970) reported that the low-marsh sediments were characteristically finer grained than the higher marsh. He suggested that the sediments on the higher marsh were derived from the river during floods, while the low-marsh sediments were derived from turbid bay waters.

(A)



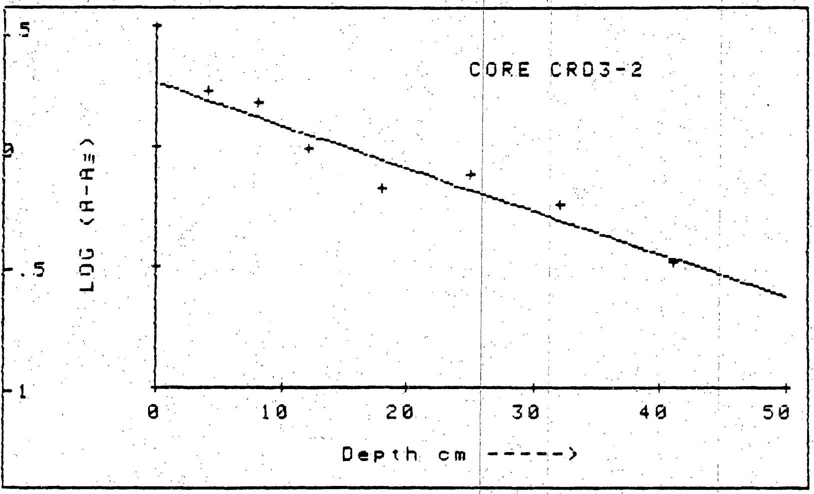
Supported Pb-210 (As) measured at 0.44 pCi/gm at 60-62 cm

Regression: Y = -0.0182X + 0.191

Correlation R square: 0.945

Inferred sedimentation rate: 0.74 cm/yr

(B)



Supported Pb-210 (As) measured at 0.44 pCi/gm at 49-51 cm

Regression: Y = -0.0178X + 0.264

Correlation R square: 0.914

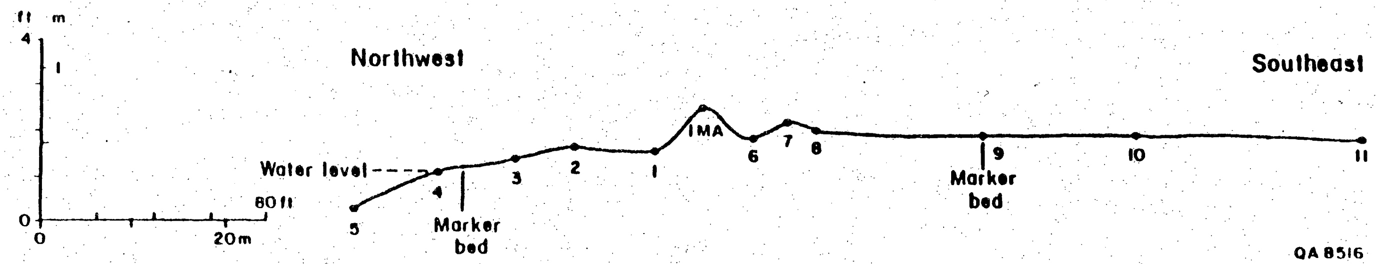
Inferred sedimentation rate: 0.76 cm/yr

Figure 32. Inferred sedimentation rates from the distribution of $^{210}$Pb activity versus depth in cores collected at Colorado River delta stations C 1-3 (A) and C 3-2 (B). The respective sedimentation rates are 0.74 cm/yr and 0.76 cm/yr. Additional data on $^{210}$Pb analyses are presented in Appendix .

The sand-rich marsh substrates at station C 2-9 near Zipprian Bayou on the edge of Matagorda Peninsula, and station C 4-10 located in a *Spartina alterniflora* marsh on the Peninsula approximately 15 km to the southwest of the delta, reflect the predominantly sandy composition of this coastal barrier (Fig. 4). The higher concentrations of silt and clay at station C 2-4, which is located on the margin of the peninsula, indicates a bayward source of mud that is deposited in this intertidal *Spartina alterniflora* marsh zone (Fig. 33). Sediments collected from stations C 1-2 and C 1-3 near Culver Cut have clay concentrations ranging from 70 to 80 percent, which are the highest of any sediment samples collected from the Colorado River delta (Fig. 14). The high clay content is related to the location of these sites in topographically low marshes (away from distributary channels) where fine inorganic sediments are deposited in low-energy environments (Fig. 23). Sediment at levee site C 1-14 contained approximately equal proportions of sand, silt, and clay (Fig. 14B), however, the predominant constituent (53 percent) is shell material (gravel-size), which is not shown in figure 14. The concentration of shells and shell hash is indicative of the relatively high wave and current energy at this channel-margin, levee environment.

Differences in textures of sediments collected in March 1988 and July 1988 (Fig. 14) may represent spatial as well as seasonal differences. As noted in the methods sections, sediments were collected near the marker horizons but not right above them, and accordingly, there may have been textural differences at collection sites for a given station. The largest variation in texture composition occurred at station C 2-4, which had sand-silt-clay percentages of 77-7-16 in March and 33-22-45 in July. Post Hurricane Gilbert analyses in November provided results of 33-1-66. The higher percentage of sand (77 percent) in March compared to July and November (33 percent) suggests that winter months are periods of more intense reworking of sediments due to winter storms. Finer material—silt and clay—would be winnowed out during these periods and the sand concentrated. During the spring, summer, and early fall, aggradation rates were higher (as shown by marker horizons) and finer material (silt and clay) deposited. This is a possible explanation for textural composition at C 2-4, which is near the water's edge on the bayward side of Matagorda Peninsula, but other sites in the delta did not show a similar degree of coarsening during winter months (Fig. 14).

Textural analysis of sediment collected at stations in November 1988 after Hurricane Gilbert, indicated a significant increase in clay at all sites sampled (C 1-3, 1-14, 2-4, 2-9, 3-1, and 3-3). Clay increased an average of 30 percent. The levee site along Tiger Island Cut (C 3-1) showed a significant increase in sand, ranging from an average of about 5 percent in March and July to 22 percent in November. This increase in sand on the levee is probably the result of strong currents associated with the hurricane surge. The increased clay content at all sites may be reflective of the



| Station # | Vegetation types |
|---|---|
| 1MA | *Borrichia frutescens* and *Spartina patens* codominant |
| 1 | Edge of *Borrichia frutescens* and *Spartina patens*, beginning of *Batis maritima* (composes 90% of community between 1 and 2) |
| 2 | *Distichlis spicata* dominant; scattered *Borrichia frutescens* and *Spartina alterniflora* |
| 3 | Edge of *Spartina alterniflora* dominance; scattered *Distichlis spicata*, *Salicornia virginica* and *Batis maritima* |
| 4 | *Spartina alterniflora*, about 60% cover |
| 5 | Edge of marsh; *Spartina alterniflora*, about 20% cover |
| 6 | *Batis maritima* dominant; scattered *Spartina patens*, *Salicornia virginica*, and *Borrichia frutescens* |
| 7 | *Spartina patens* dominant (75%), *Borrichia frutescens* subdominant (25%) |
| 8 | Edge of *Spartina patens*, beginning of *Batis maritima* dominance; scattered *Borrichia frutescens* and *Avicennia germinans* |
| 9 | *Monanthochloe littoralis* dominant (80%), *Batis maritima* subdominant (20%); scattered *Salicornia virginica* |
| 10 | *Batis maritima* dominant (80%); scattered *Salicornia virginica*, *Distichlis spicata*, and *Spartina alterniflora* |
| 11 | *Distichlis spicata* and *Batis maritima* codominant; edge of patch of *Scirpus maritimus* |

Figure 33. Profile and vegetation types along one leg (approximately 110 m or 360 ft) of marsh transect C 2 on Matagorda Peninsula, Colorado River delta study area.

duration and depth of flooding during the hurricane, which possibly contributed to the settling of fine, clay particles as hurricane flood waters receded.

**Organics.** Total organic carbon (TOC) concentrations in marsh sediments of the Colorado River delta range from highs of 4 to 5 percent at stations along transect C 1 near Culver Cut, to lows of less than 1 percent at stations C 2-4 and 2-9 on Matagorda Peninsula (Fig. 34). There is a high positive correlation between percentages of clay and TOC (correlation coefficient, r, = 0.94 to 0.96) (Fig. 35). Gross organics (roots, leafs, stems, etc.) were physically removed from the samples before analysis of TOC; percentages are presented in figure 36. In Colorado River delta sediments, the highest amount of TOC and gross organics, combined, is approximately 13 percent at station C 1-3. Because the collection of gross organics in a sample did not follow standardized procedures, however, these measurements must be considered more qualitative than quantitative when making comparisons between samples.

**Moisture Content.** Moisture or water content of the sediments correlates positively with sediment textures. Sediments with high concentrations of mud (silt and clay) have higher amounts of water than sediments with high concentrations of sand. The percent water in the sandy sediments collected at station C 2-9 is the lowest (< 20 %) of all sediments sampled (Fig. 37). There is a high positive correlation between sediment textures and moisture content as reported in other studies (Fig. 38).

### Salinity

Measured salinities ranged from 17.5 ppt at transect C 1 in February 1988 to 34 ppt at transect C 2 and transect C 4 in July 1988 (table 7). Salinities at transects C 2 and C 4 were generally the highest and transect C 1 the lowest. Martinez (1974, 1975) took surface salinities at a station near Dog Island Reef (an oyster reef near the delta). Salinities averaged 17.3 ppt in 1974 and 16.0 ppt in 1975. High salinities were recorded in July (24.0 ppt) and October (22.0 ppt), and lows were recorded in May (11.0 ppt) and June (0 ppt).

### Seasonal Changes in Vegetation

As previously mentioned, changes in species cover, species composition, and vegetation height were not as striking in the Colorado River delta as in some areas of the Trinity River delta. Species that were first noted at a station, usually in June or December 1987, were also present in the same relative abundance in June 1989. Vegetation at marker bed stations on transect C 1 was generally tallest in June and shortest in March (table 5). *Spartina alterniflora* at marker bed stations

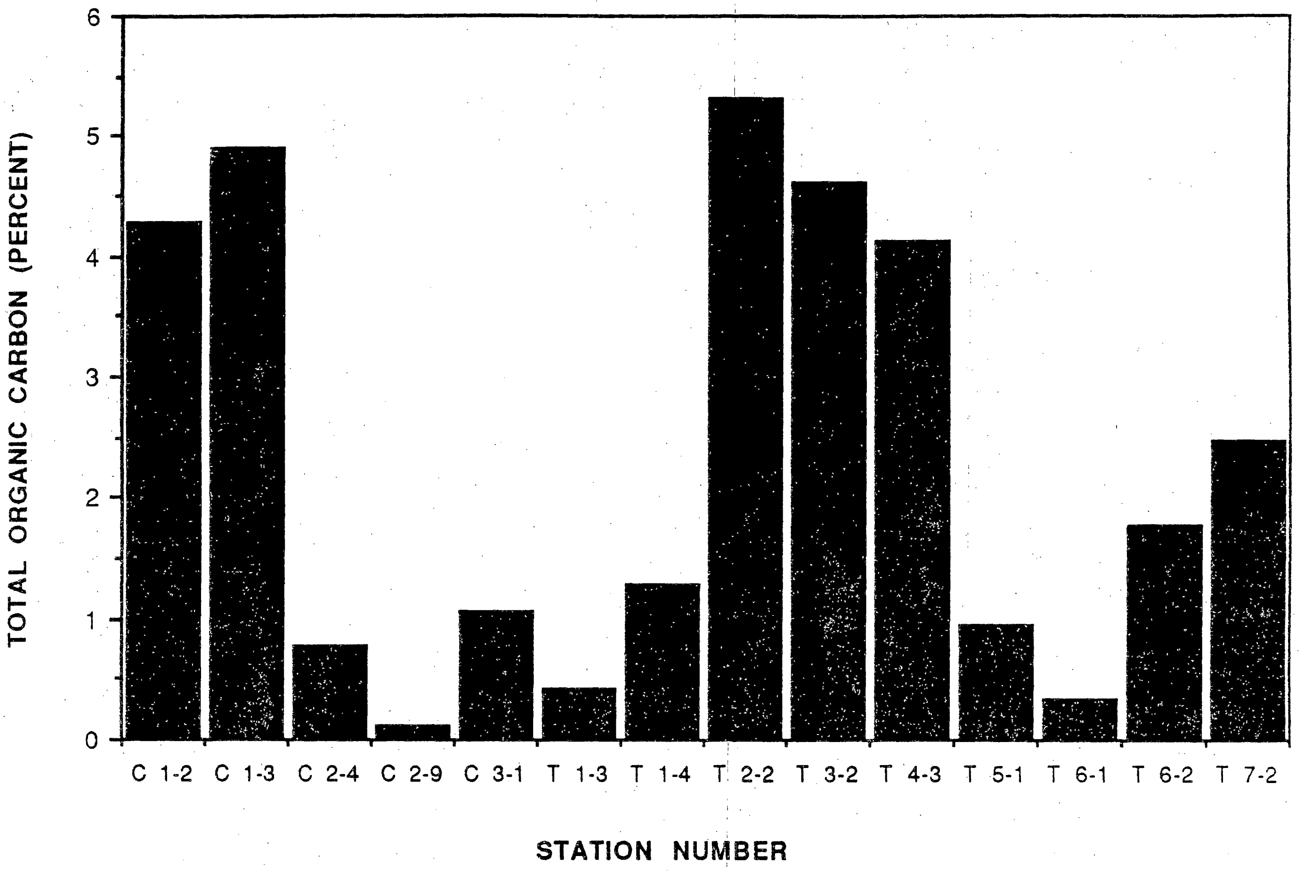


Figure 34. Percentage of total organic carbon (TOC) in sediment at stations in the Colorado and Trinity River deltas.

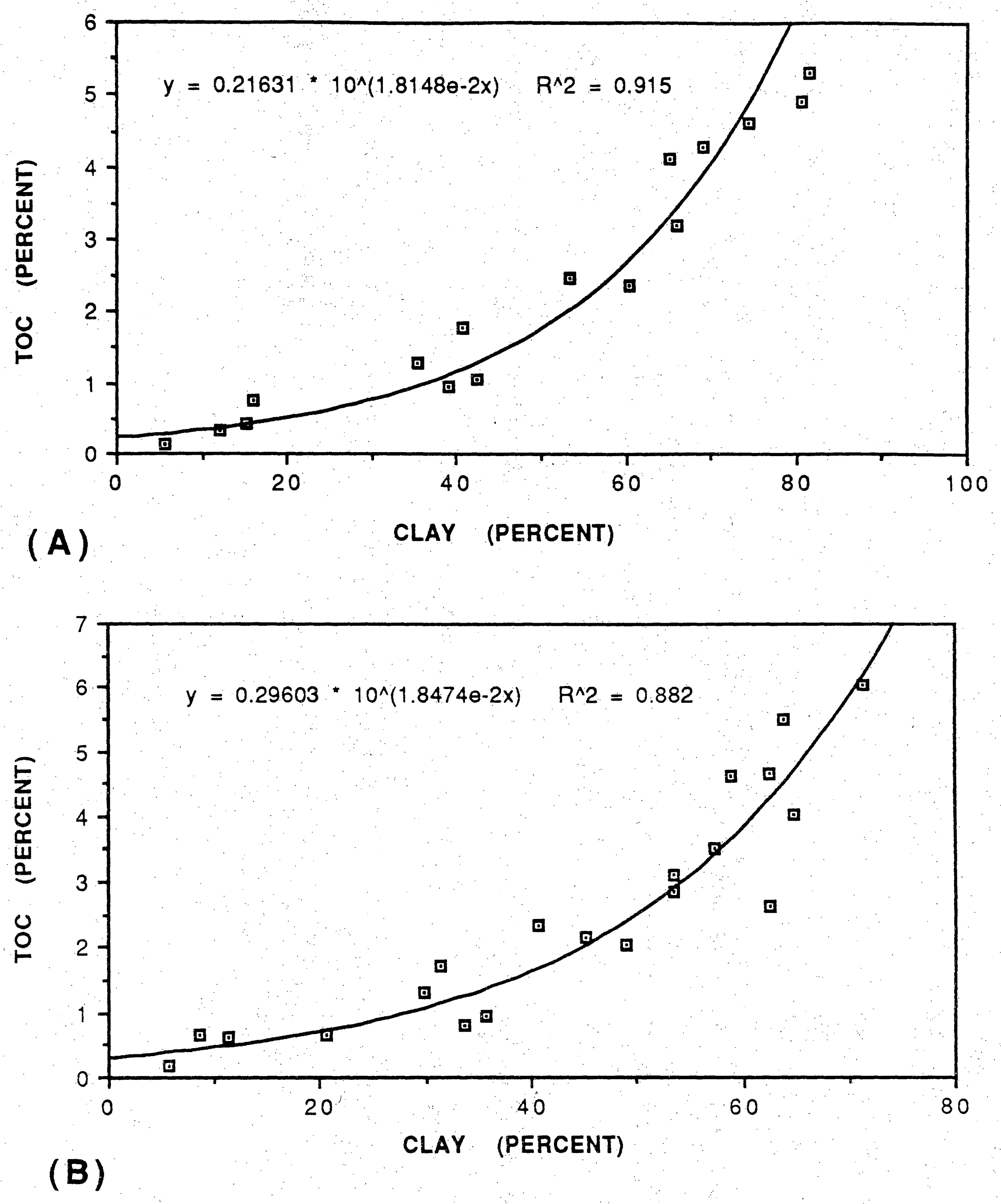


Figure 35. Scattergram and exponential relationship between total organic carbon (TOC) and clay in sediment at stations in the Colorado and Trinity River deltas. Sediments collected in March 1988 are shown in (A), and in July 1988 at (B).

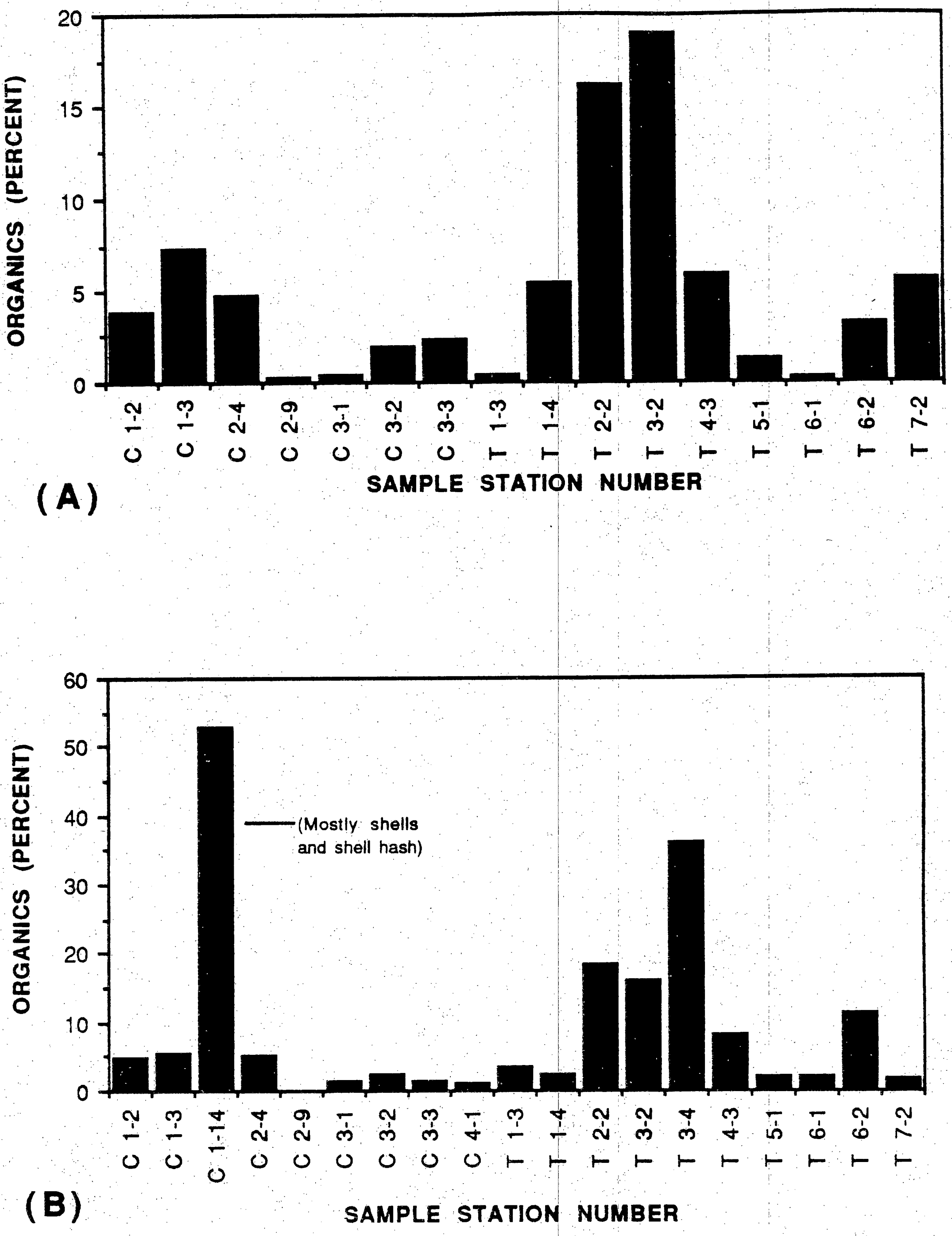


Figure 36. Percentage of gross organics in sediments collected in March 1988 (A) and July 1988 (B) at stations in the Colorado and Trinity River deltas.

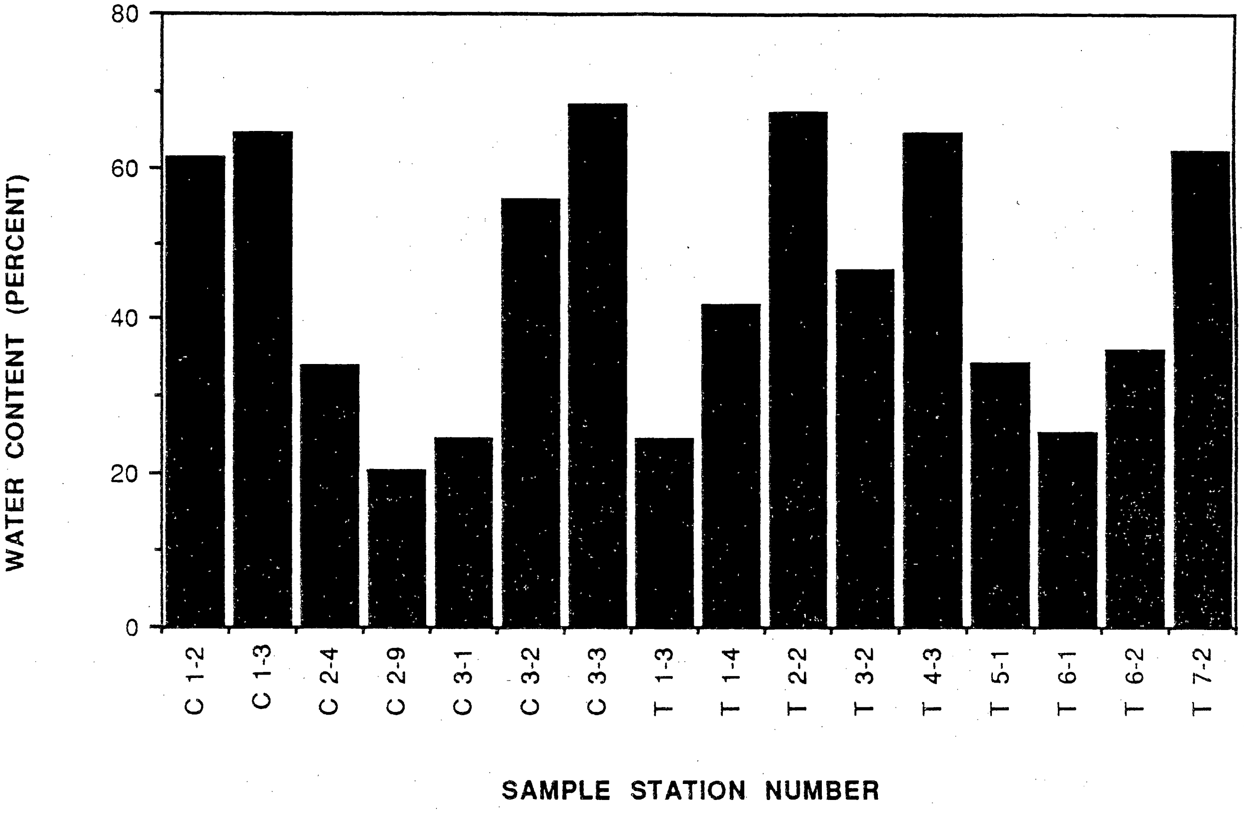


Figure 37. Percent water content in sediments collected in March 1988 at stations in the Colorado and Trinity River deltas.

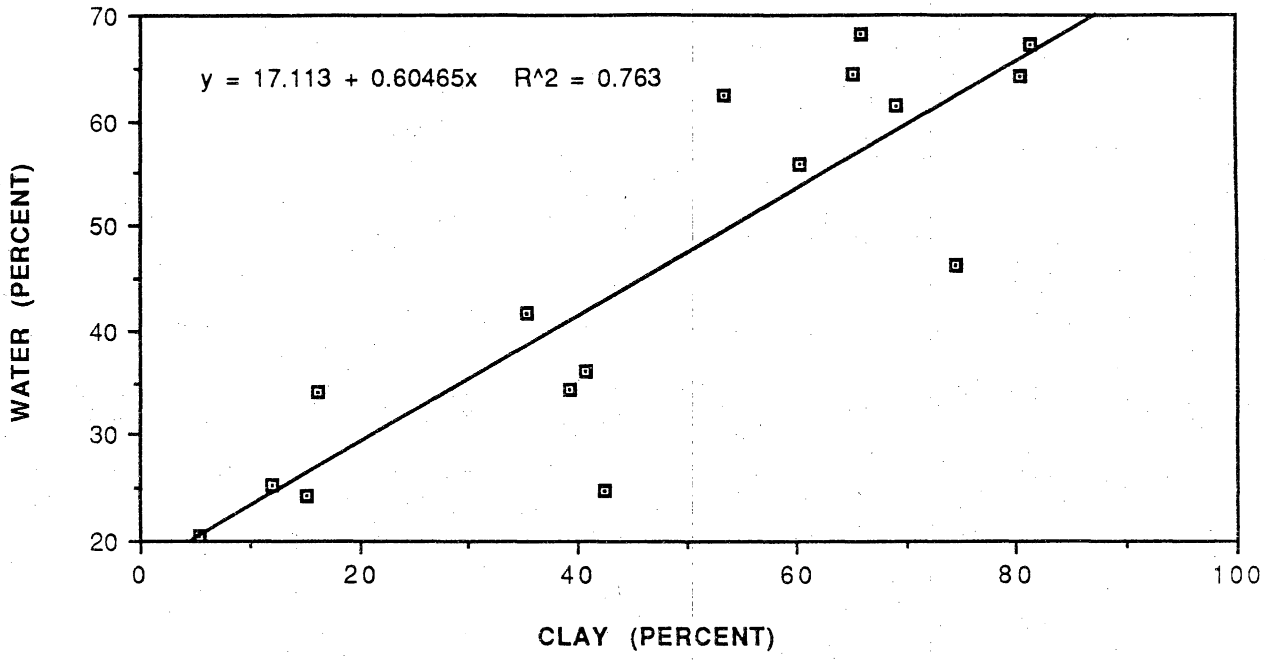


Figure 38. Scattergram and linear regression line for water content and clay in sediment at stations in the Colorado and Trinity River deltas. This high positive correlation is in agreement with numerous previous studies of water-soil relationships.

on transects C 2, C 3, and C 4 was tallest in June, July, and December and generally shortest in March. Heights of the other species on transects C 2, C 3, and C 4 were either about the same during the study period or not enough measurements were taken to determine differences (table 5).

### Trinity River Delta

The field investigation of the Trinity River delta was begun in December 1987; thus, two years of data on aggradation rates were not collected as in some areas in the Colorado River delta. The longest period in which marker horizons were observed was approximately 20 months (December 1987 to August 1989; table 2). Some markers were established for shorter periods in order to (1) replace markers that had eroded (T 6-2), (2) provide backup for markers that were becoming difficult to see in trenches (T 4-3, backed up by 4-3A, and 7, backed up by 7A), and (3) provide additional coverage to document deposition during possible flood events in the spring of 1989 (T 2A, placed on levee on transect 2; 4-extension, placed on levee across Old River Cutoff from transect 4; and 5-2, placed higher on levee approximately 6.5 m, or 21 ft, from T 5-1).

During the first year of the study (December 1987 to December 1988), streamflow records from the Romayor gauging station upstream from the delta indicated that only during one week in January 1988 were flows sufficient to flood part of the deltaic marshes. Discharge exceeded 15,000 $ft^3$/sec during a 5-day period in early January 1988 (USGS discharge data sheets, unpublished). It is estimated that about 10 percent of the delta is flooded at these flow rates combined with high tide (TDWR, 1981; Fig. 6). However, from March 1989 through mid-July 1989, rainfall in the Trinity River basin was excessive and discharges from Lake Livingston exceeded 30,000 $ft^3$/sec on 45 days, including 24 continuous days in May and June 1989. Releases reached a high of more than 50,000 $ft^3$/sec in June and 70,000 $ft^3$ in early July 1989 (Fig. 18). On July 3, 1989, according to The Houston Post (July 4, 1989), citing Tom Fountain (a meteorologist with the National Weather Service), the Trinity River crested in Liberty, Texas, at 8.8 m (29 ft), which is near the record of 9.0 m (29.4 ft) set in 1942.

Flood conditions in the delta during some periodic surveys (November 1988 and June 1989) restricted the collection of data at some sites. Certain marker horizons were not trenched when flooded in order to avoid disturbing the site and affecting future measurements. Only marker horizon T 5-1 was trenched in November 1988, and marker horizons T 2-2, 2 A, 3-2, 4-extension, 5-1, 5-2, 6-4, and 7 in June 1989 (table 2). Brass rods at T 1-4 and 7 were useful for backup measurements when the marshes were flooded. However, record floods in July 1989, combined with Hurricane Chantal in early August, reworked the surface at T 1-4 so extensively that neither the brass rod nor a cedar post (Fig. 39) used for control could be found in mid-August 1989. Two other cedar posts

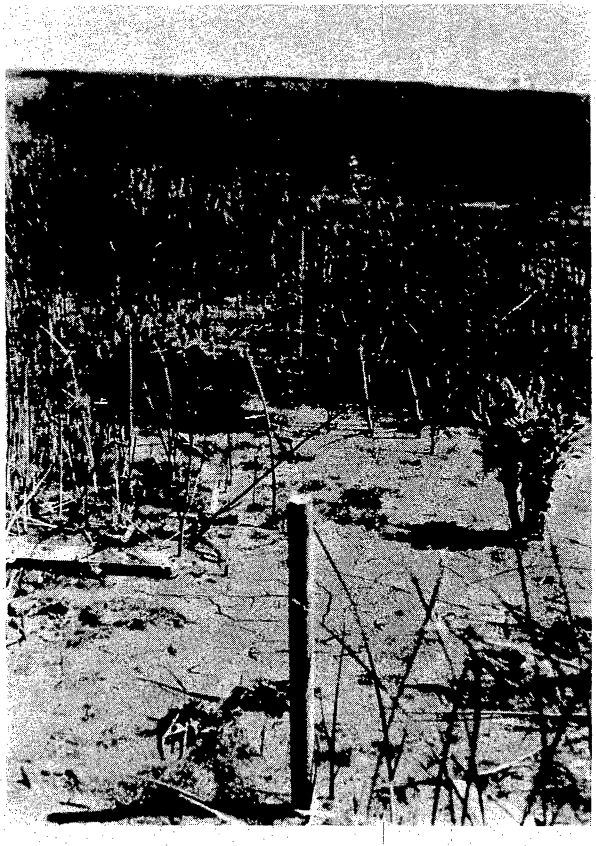


Figure 39. Post established for control purposes near station T 1-4, Trinity River delta. The artificial-marker horizon, which is a few meters beyond the post is not visible because of burial by sediments. Vegetation is dominated by annual species, primarily *Scirpus*.

located in slightly more protected areas along the marsh transect were not removed by the storms, although a significant amount of sediment was reworked around the base of the posts.

### Marsh Aggradation Rates

During the first 15 months of the study, sediment accumulation rates in the Trinity delta were variable, ranging from some sites that eroded (T 6-2, 1-3, and 1-4) to one where more than 28 mm of sediment accumulated in less than 8 months (T 4-3). Near record floods during the spring and summer of the second year produced abnormally high accumulation rates locally, including one Trinity River levee site (T 5-1) where more than 50 mm of sediment was deposited between June and August 1989. Organic sediments had a larger role in the aggradation process in this brackish-water marsh system of the Trinity delta than was observed in the salt-water marshes in the Colorado River delta.

The complexity of the Trinity River delta, and the more widely varying aggradation rates compared to the Colorado River delta, required a more detailed examination of aggradation above the artificial-marker horizons to understand the processes affecting sedimentation. This detailed account, which supports much of the following discussion is presented in Appendix D.

The thickness of sediment that accumulated above each marker horizon for the different time periods is presented in figure 40. The markers in the figure are arranged in approximate order of increasing relative elevation. Relative elevations of markers are approximations based on the height of markers relative to local water levels, which were tied to water levels at tide gauges at a specific time; tide gauges used were at Anahuac Channel near the town of Anahuac, and at Old River between marsh transects T 3-2 and T 4-3 (Fig. 5).

Some consistent relationships are apparent when aggradation rates are evaluated in terms of wetland environments (table 11). The three marker horizons with no net aggradation (T 1-4, 1-3, and 6-1) were all located in delta-front environments (bay/channel margin). Although some sediment accumulated above these markers from December 1987 to July 1988 (Fig. 41), the markers were eroded by March 1989, indicating net erosion of the marsh surface and zero aggradation. These relatively high-energy environments are characterized by sandy substrates and annual vegetation (Fig. 39). In addition, sediments are extensively bioturbated by nutria. The dieback of vegetation coupled with bioturbation intensify the impact of winter storms and produce a dynamic environment in which sediment is vigorously reworked by waves and currents. The finer material, silt and clay, is winnowed out and transported into lower energy (more protected) environments where it settles or is trapped; sands are concentrated in the higher-energy zones.

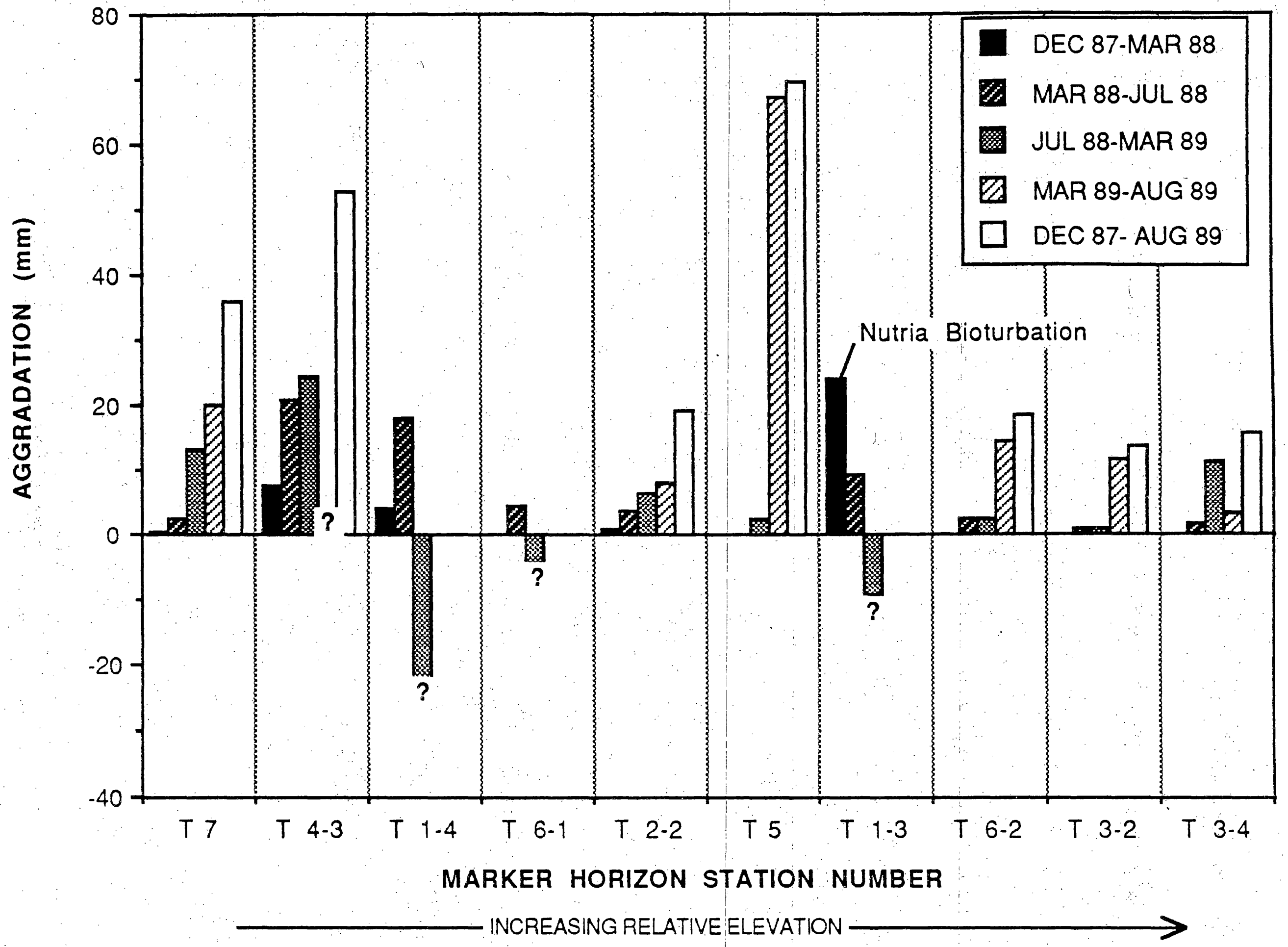


Figure 40. Sediment accumulation (aggradation) above artificial-marker horizons during specified periods, Trinity River delta study area. Marker horizons are arranged according to relative elevations.

Table 11. Brackish wetland environments and aggradation rates in the Trinity River delta.

| **WETLAND ENVIRONMENT** | **VEGETATION** | **STATION NO.** | **AGGRADATION RATE (mm/yr)** | | |
|---|---|---|---|---|---|
| | | | To Mar 1989 | To June 89 | To Aug 89 |
| BAY/CHANNEL MARGIN | ANNUAL | T 1-4 | 0 | No Measure | NM |
| BAY/CHANNEL MARGIN | ANNUAL | T 1-3 | 0 | NM | NM |
| BAY/CHANNEL MARGIN | ANNUAL | T 6-1 | 0 | NM | NM |
| FLUVIAL CHANNEL LEVEE | WOODLAND | T 5-1 | 1.8 | 11.5 | 42.3 |
| DISTRIBUTARY CHANNEL LEVEE | WOODLAND/PERENNIAL | T 3-2 | 1.9 | 5.7 | 8.3 |
| BAY/CHANNEL MARGIN | PERENNIAL | T 6-2A | 4.8 | 6.5 | 13 |
| BACKMARSH/TIDAL CHANNEL | PERENNIAL | T 2-2 | 8.8 | 11.9 | 11.6 |
| BACKMARSH | PERENNIAL/ANNUAL | T 3-4 | 12.5 | NM | 9.5 |
| BAY MARGIN (SALT MARSH) | PERENNIAL | T 7 | 12.6 | 17.2 ? | 16.8* |
| LEVEE FLANK/POND MARGIN | PERENNIAL/ANNUAL | T 4-3 | 39 | NM | NM |

* Measured from brass rod

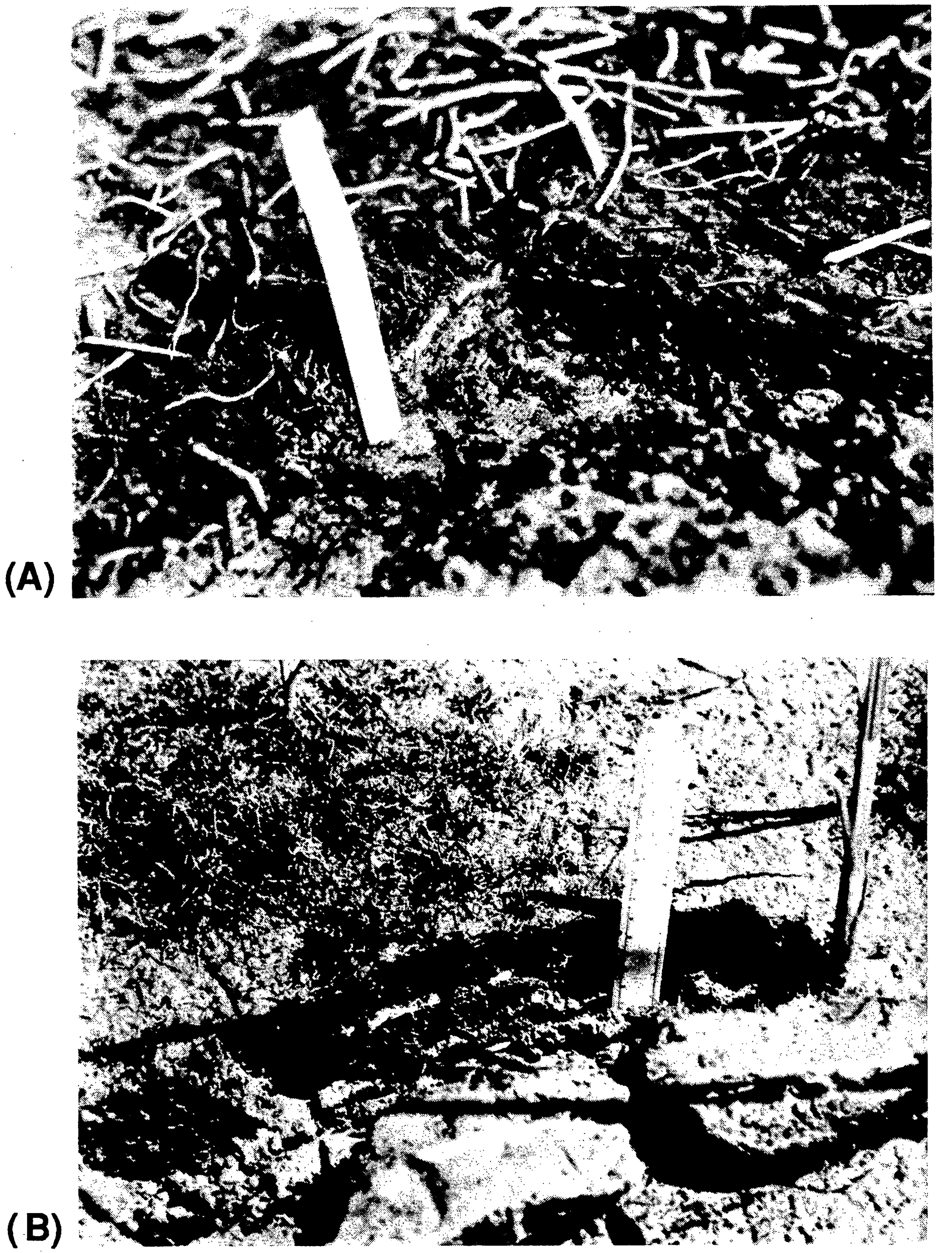


Figure 41. Trenches exposing the artificial-marker horizon at Trinity River delta station T 1-4 in (A) March 1988, and (B) July 1988. Ruler is 15 cm (6 in) in length.

The only delta/bay margin environment that registered aggradation over the period of study was at station T 6-2A. This site is slightly higher in elevation than nearby eroded marker T 6-1, and is characterized by alligatorweed, which persists through the winter months and helps stabilize the surface. The lower physical energy of this environment compared to T 6-1 can be inferred not only by the perennial vegetation, but also by the lower percentage of sand in the marsh soil (compare stations T 6-1 and 6-2 in Fig. 15). The previous marker in this area (T 6-2, Fig. 5) was located at the margin of the perennial vegetation near an erosional scarp, and it was eroded during the winter of 1987-1988. Marker T 6-2A was a replacement for this eroded marker and was placed further away from the eroding shoreline.

Fluvial-channel levee sites characterized by forested wetlands (woodlands) (T 5-1), and scattered woodlands and marsh vegetation (T 3-2) had low rates of aggradation (< 2 mm/yr) to March 1989 (Figs. 42 and 43) (table 11). Spring/summer floods in 1989 (Fig. 18) dramatically increased the rate of deposition as reflected in August measurements of sediment thickness (Fig. 38) and rates of aggradation (table 11). The much higher rate of aggradation at station 5-1 reflects its location near the Trinity River where flooding was at a maximum.

Observations along the Trinity River downstream from Old River Cutoff in August 1989, after the major flood event (Fig. 18), showed a substantial amount of clean, fine-grained sand deposited on natural levees (deposition probably occurred upstream as well, but upstream sites were not examined). One survey along the western side of the river approximately 1.1 km (0.7 mi) downstream from Old River Cutoff showed sand deposits as thick as 25 cm at a distance of about 5.2 m (17 ft) from the channel cut bank, but sediment thickness decreased away from the levee toward the backmarsh, and at about 27 m (90 ft) from the channel less than 0.5 cm of sandy mud had been deposited (other measurements are presented in Appendix D). It appears that the fine sand was carried in suspension and deposited as current velocity diminished across the levee. This cursory, post-flood survey indicated that the sand deposits (as well as mud deposits) thinned rapidly away from the river toward backmarsh environments and downstream.

Aggradation rates in backmarsh environments (T 2-2, and 3-4) ranged from about 9 to 13 mm/yr for the period from December 1987 to March 1989 (table 11). The higher rate at T 3-4 was apparently due to organics from a debris line (composed primarily of alligatorweed stems) that settled on the marker in the winter of 1987-88. Based on measurements made in June 1989, the aggradation rate at T 2-2 increased from about 9 mm/yr to approximately 12 mm/yr; the rate remains about the same when based on measurements made in August 1989 (table 11). Marker horizon T 3-4 was not trenched in June 1989 because of flood conditions, but measurements in August 1989 indicated that the organic material previously deposited had continued to decompose and compact,

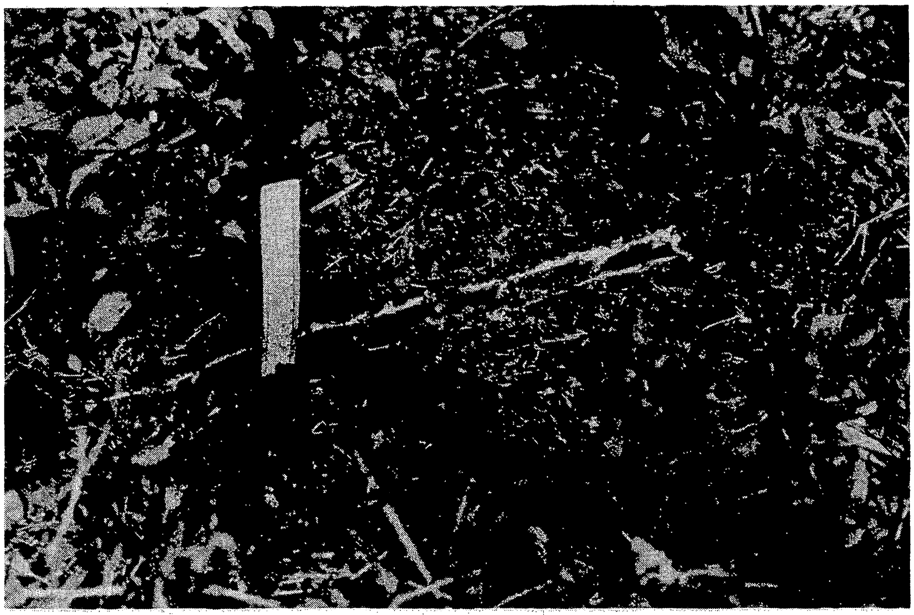


Figure 42. Artificial-marker horizon at station T 5-1 located on a natural levee along the Trinity River. Vertical trench shows marker and overlying sediment as it appeared in March 1989.

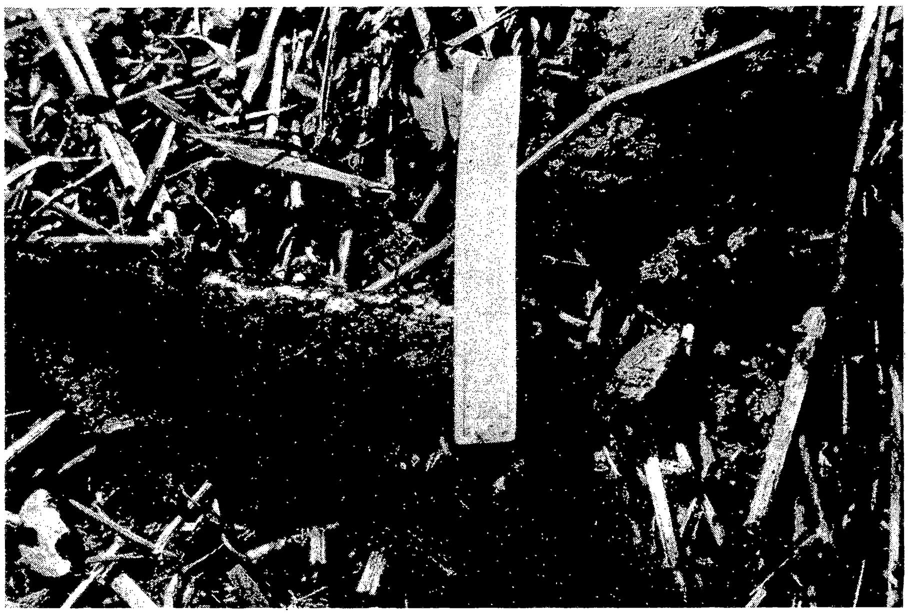


Figure 43. Sediment plug and marker extracted from trench at station T 3-2 in March 1989.

and a small amount of mud (silt and clay) had been deposited. The measurements indicated substantially less deposition at this site during the spring and summer floods of 1989, compared to marker horizon T 3-2, which is located much closer to the margin of Old River (Fig. 5); T 3-2 is about 20 m (65 ft) from the water's edge, and T 3-4 is about 61 m (200 ft). Rates of aggradation increased through time for T 3-2 and decreased for T 3-4 (table 11), as a result of differences in sediment supplied to these sites during spring and summer floods.

The highest rate of aggradation from December 1987 to March 1989 (table 11) occurred at marker T 4-3 located at the base of a distributary levee and on the margin of a tidally influenced pond. The marker horizon could not be examined after March 1989 (Fig. 40) because of flooded conditions during subsequent trips. However, the location and setting of this site (discussed in Appendix D) suggests that a relatively high rate of deposition continued through August 1989.

The bay margin salt-marsh at Smith Point had a rate of aggradation of about 13 mm/yr until March 1989. Measurements in June 1989 show a higher rate of deposition (table 11), but the rate is questionable because (1) it is based, partly, on an alternate marker horizon (7A) established in March 1989, and (2) hummocky conditions in June 1989 indicated that some of the marker horizon had probably been eroded (the marker could not be located in depressions). The rate of aggradation presented in the column "to Aug 89" in table 11, is based primarily on measurements of the brass rod. (Marker horizon measurements were used for the period December 1987 to March 1988, and the brass rod for the remaining period—March 1988 to August 1989.) Measurements of the brass rod indicated an increase in sediment thickness of about 2 cm between June and August 1989. This sediment may have been the result of Hurricane Chantal, which made landfall during this period.

**Seasonal Aggradation.** As in the Colorado River delta, seasonal variations in sediment aggradation were recorded by most marker horizons (Figs. 44 and 45). The lowest percentage of deposition occurred during winter months as reflected in measurements of sediment accumulation from December 1987 to March 1988 (Figs. 40 and 45). Only one marker horizon showed substantial deposition (T 1-3), but it was anomalous and caused by nutria bioturbation (Fig. 45). (This nutria deposit is not included in figure 44). Because of flooding during site visits in November 1988, only one marker horizon could be examined (T 5-1). Accordingly, it was the only measurement that allowed the differentiation of sediments deposited in the winter of 1988-89 from sediments deposited in late summer and fall of 1988 (Fig. 46). A negligible percentage of the total deposition occurred during successive winters at this site.

Winter months also were periods of erosion in bay margin areas. Distance measurements from a control point to two erosional scarps along the bay margin at marsh transect T 6, showed the scarps retreated approximately 1 m (3.3 ft) during each winter of observation (December 1987 to March

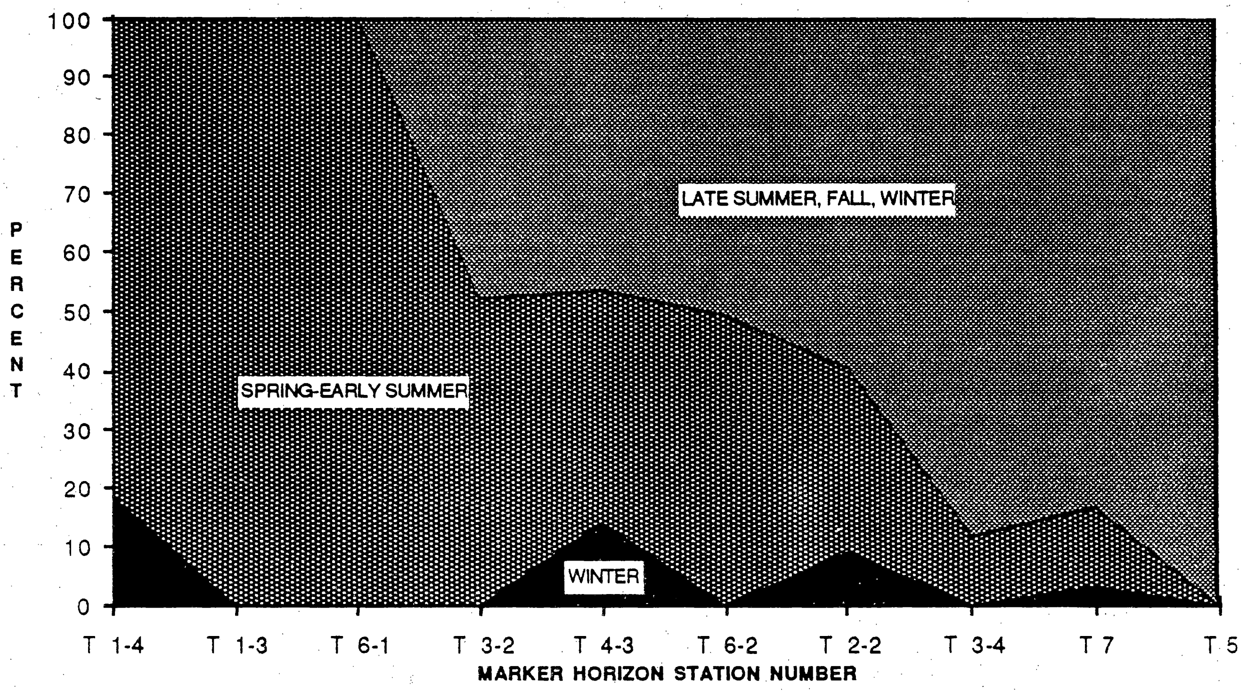


Figure 44. Seasonal aggradation in percent from December 1987 to March 1989 at marker horizons in the Trinity River delta. Deposition from nutria bioturbation at Station T 1-3 between December 1987 and March 1988 is not shown.

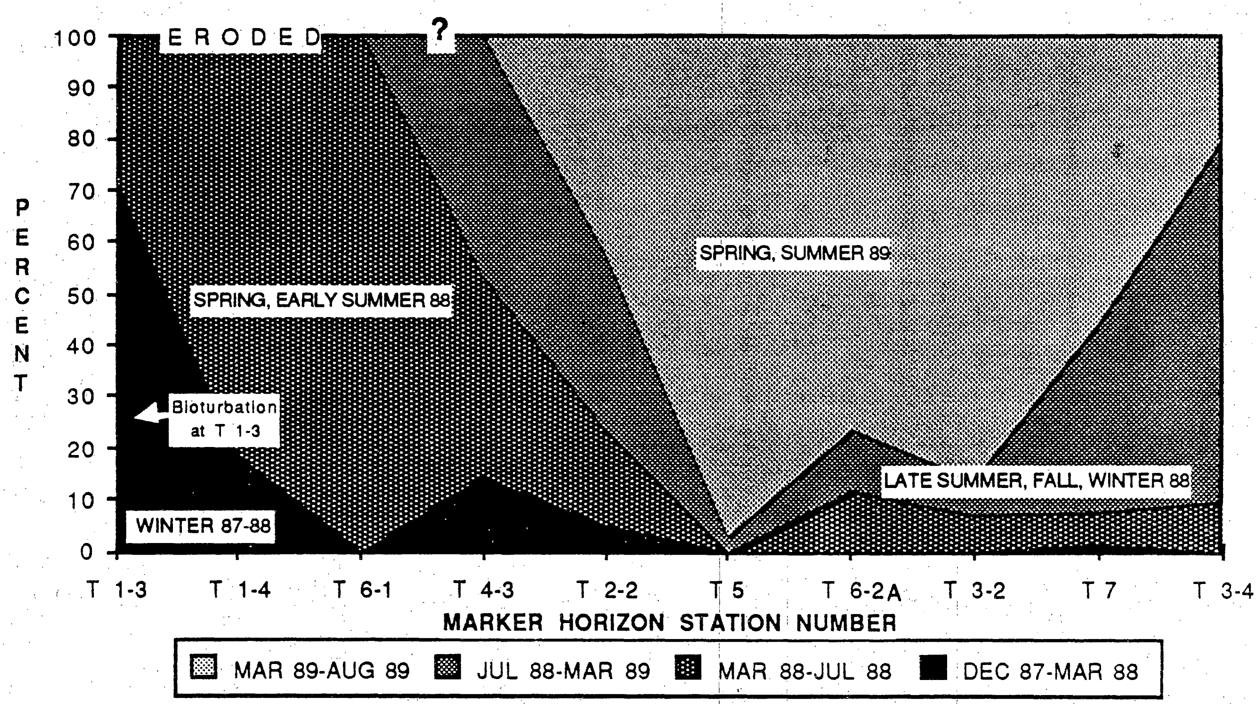


Figure 45. Seasonal aggradation in percent from December 1987 to August 1989 at marker horizons in the Trinity River delta.

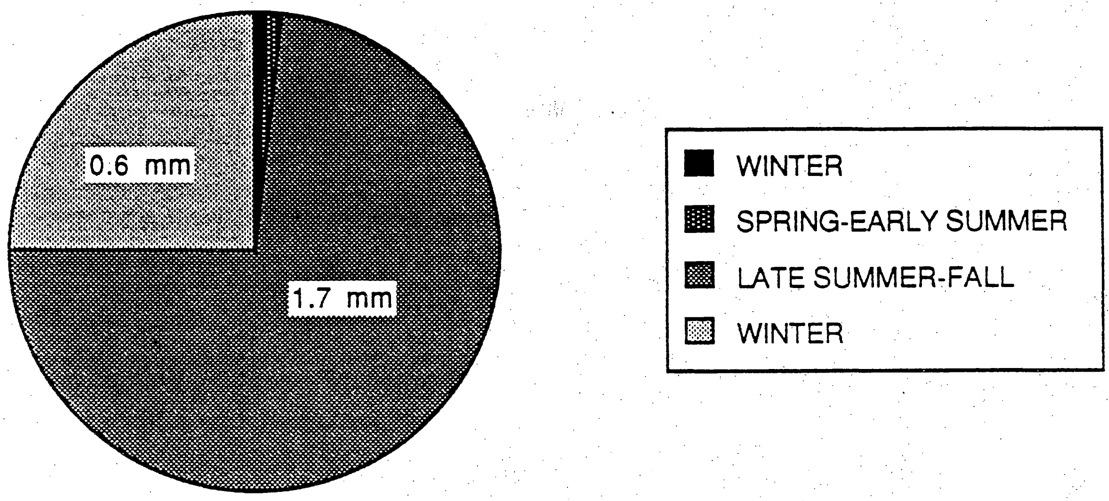


Figure 46. Seasonal aggradation from December 1987 to March 1989 at station T 5-1 located along the Trinity River.

1988 and November 1988 to March 1989). The erosional scarps did not retreat measureably during other periods. In addition, four marker horizons that were eroded (T 1-3, 1-4, 6-1, and 6-2) were apparently eroded during winter months. Marker T 6-2, which was eroded during the first winter, was replaced by marker horizon T 6-2A. The other three markers, although surviving the first winter (1987-88), were eroded during the second (winter of 1988-89), which was the most severe of the two based on field surveys of vegetation cover (compare Figs. 47B and E) and current ripples preserved in the sandy substrates of these delta-front environments. Erosion was probably the result of winter storms.

The conclusion that marker horizons were eroded during winter months instead of during Hurricane Gilbert is based on observations in November 1988 after the hurricane. Vegetation at these sites was still relatively abundant in November (for example, reference the photograph of the area near station 1-3 taken in November 1988; Fig. 47D). In March 1989, however, barren sandy surfaces (Fig. 47E) marked by current ripples indicated that these bay margin, delta-front environments had been subjected to higher energy conditions during winter months than during the hurricane. These observations were backed by measurements of the brass rod at station T 1-4, and of control posts between stations T 1-4 and 1-3. These measurements (discussed in Appendix D) indicated that the sandy surface had been eroded downward approximately 40 mm between November 1988 and March 1989, which was more than enough to remove the sediments that had accumulated above the marker horizons as well as the horizons themselves. Numerous wave and current modified depressions at these stations (T 1-3 and 1-4) and at station T 6-1 indicated extensive nutria bioturbation during winter months, which undoubtedly contributed to the erosion of the loosely compacted, bioturbated surface sediments.

During the initial 15 months, the highest percentage of deposition occurred in spring and early summer 1988, and in late summer to winter of the same year (Fig. 44). Only levee site T 5-1 was examined in November 1988, which provided a measure of deposition during the late summer and fall 1988—a period that included Hurricane Gilbert. About 75 percent of the deposition at T 5-1 (to March 1989) occurred during this period (Fig. 46). Since other marker horizons were not examined before March 1989 (due to flooding), it was not possible to document deposition occurring during late summer and fall; it is probable that measureable deposition occurred at bay/channel margin stations (T 1-3, 1-4, and 6-1). Sediments that may have accumulated during this period, however, were eroded along with the marker horizons by March. Markers that were still in tact and were trenched in March 1989 revealed that about 50 percent (T 3-2, 3-4, 6-2) to almost 100 percent (T 5-1) of the deposition during the first 15 months occurred from late summer through winter—a period that included Hurricane Gilbert (Fig. 44). The affect of the hurricane on deposition appears to have been most pronounced at stations T 5-1, 3-4, 7, and perhaps 2-2.

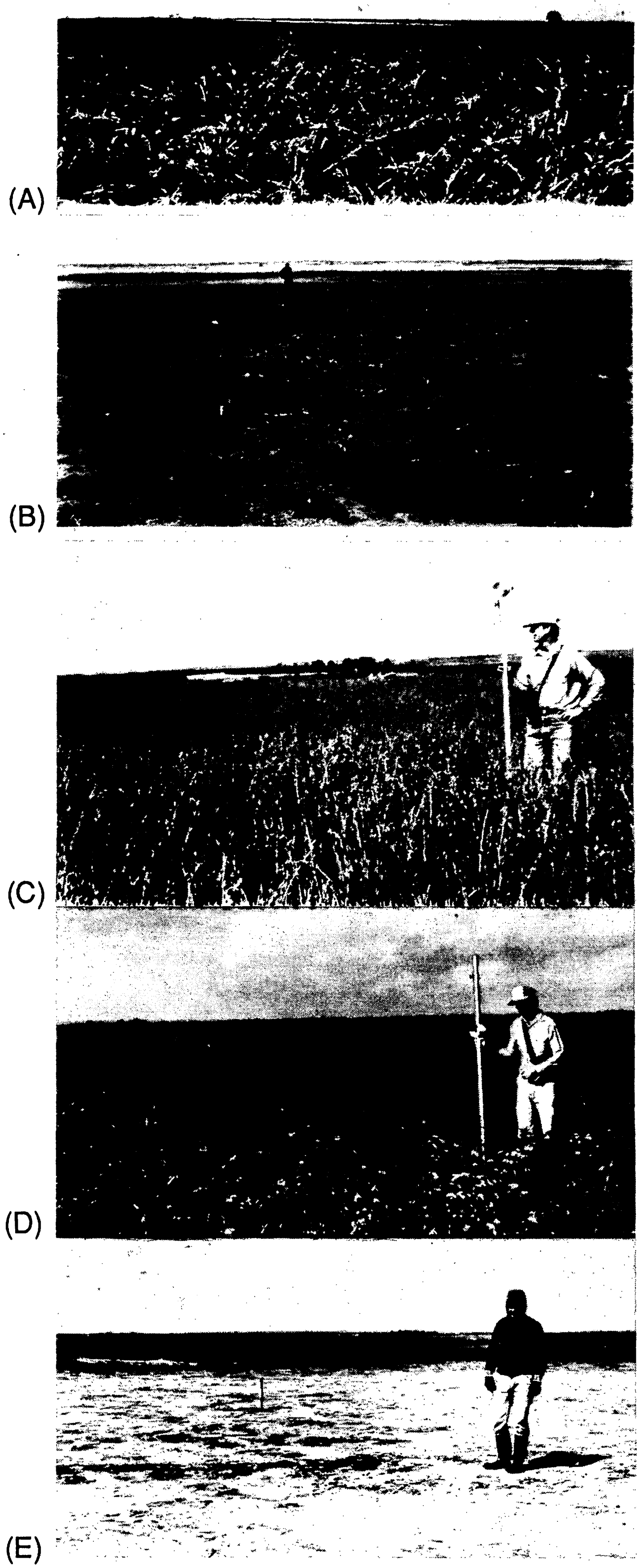


Figure 47. Photographs showing seasonal changes in vegetation at Trinity delta transect 1 during (A) December 1987, (B) March 1988, (C) July 1988, (D) November 1988, and (E) March 1989.

Seasonal deposition percentages changed rather dramatically for several marker horizons during the spring and early summer of 1989 (Fig. 45). This period encompasses near record flooding along the Trinity River that occurred in July 1989 (Fig. 18). Marker horizons T 5-1, T 3-2, and T 6-2A, appear to have been affected most by the flooding, because more than 80 percent of the total deposition at these sites occurred during this period (Fig. 45). About 60 percent of the deposition at T 7 (salt marsh) occurred during this period, but it likely was influenced more by Hurricane Chantal than flooding along the Trinity River. Least affected by the flooding were marker-horizons T 3-4 and T 2-2 (both backmarsh environments) where only 20 to 40 percent of the total deposition occurred during the spring and early summer of 1989 (Fig. 45). Marker horizon T 4-3 was not trenched after March 1989, so the amount of deposition at this site was not recorded. Bay margin, delta-front environments where markers T 1-2 and 1-4 had been established, were extensively reworked by flood waters. Measurements of control posts indicated both deposition and erosion occurred as sand waves migrated across the surface; these changes are discussed in detail in Appendix D.

**Aggradation and Relative Elevation.** The strong inverse relationship between relative elevations of marker horizons and aggradation rates noted for the Colorado River delta (Fig. 31), applies only to selected periods in the Trinity River delta. The correlation coefficent (r) is approximately -0.80 for the period of December 1987 to July 1988—a period marked by no hurricanes or major flood events. However, erosion of sediments from topographically low, bay-margin sites and deposition on topographically higher levee sites during following months, a period that included Hurricanes Gilbert and Chantal and near record floods along the Trinity River (in part associated with Tropical Storm Allison), essentially nullified the correlation between relative elevation and aggradation rate.

**Aggradation Based on $^{210}$Pb.** Analyses of $^{210}$Pb in cores taken near stations T 2-2, 3-2, and 3-4 were conducted to determine longer-term rates of sedimentation (Appendix B). Sedimentation rates inferred from core analyses are 6.8 mm/yr at T 3-2, 5.2 mm/yr at 3-4, and 4.2 mm/yr at T 2-2. These rates are lower than in the Colorado River delta, which averaged 7.5 mm/yr.

In the Trinity River delta, short-term rates based on artificial marker horizons (table 11) are significantly higher than long-term rates based on $^{210}$Pb. Higher rates are probably due in large part to lower amounts of compaction and organic decomposition in the surface sediments compared to deeper sediments in the core. Organic material is more abundant in the brackish-water marshes of the Trinity delta than in salt-water marshes of the Colorado delta, and it was particularly abundant in backmarsh areas in which these cores were taken. Higher short-term rates at several sites, of course, were related to storm events that occurred during the spring and summer 1989.

## Sediment Composition

**Textures.** Sediment samples collected from the brackish-water marsh system on the Trinity River delta (Figs. 5 and 15) have a somewhat more variable textural composition than those from the Colorado delta. Maximum concentrations of clay and silt are about 80 percent and 30 percent in low (back) marshes; higher wetlands along levees had higher silt content ranging to a maximum of near 55 percent, while maximum content for clay was near 40 percent. Marshes with sandier substrates were located on progradationally active delta lobes (based on aerial photographic analysis) near the bay margin. Near the distributary channel connecting Old River to Trinity Bay (Fig. 5), the concentrations of sand, silt, and clay (based on March 1988 sample collections) were 67, 18, and 15 percent, respectively (station T 1-3). The marsh at this latter site was only partly vegetated; sediment samples contained less than 0.5 percent organic carbon. The station with the highest clay content is located west of Anahuac Channel (west of Anahuac, station T 2-2, Fig. 5 and 15). The sediments in this marsh, where vegetation is predominantly *Alternanthera philoxeroides* (alligatorweed) and *Crinum americanum* (swamp lilly), is composed of about 80 percent clay and less than 2 percent sand (Fig. 15). This marsh area is probably supplied by both overbank flooding from the Trinity River along the Anahuac Channel, and tidal flooding from a nearby tidal channel. Its distance from the river channel (> 70 m or 230 ft) helps explain the low silt and sand content of the sediments.

High silt and sand content at stations T 1-3, 1-4, 5-1, 6-1 and 6-2 indicates their locations in relatively high-energy environments near active channels and bay-margin sites. Sediment collected at station 1-3 had the highest amount of sand, ranging from 70 percent in March 1988 to more than 80 percent in July 1988 and March 1989. The marsh substrate at Smith Point (T 7-2), away from the delta, is composed of approximately 50 percent clay, with the remaining percentages composed of about 30 silt and 20 percent sand (Figs. 5 and 15).

**Organics.** Highest percentages of TOC occur in sediments with high clay percentages (T 2-2, 3-2, and 4-3; Fig. 34). As noted in the Colorado River delta, there is a high positive correlation between percent clay and TOC (Fig. 35). The lowest concentrations of TOC (< 0.5 percent) are in sediments with the highest percentages of sand (stations T 1-3 and 6-1). Gross organics (discussed in the preceding section of the Colorado delta) are very high in two sediment samples collected from the Trinity River delta. Sediments from stations T 2-2 and 3-2 contain from 15 to 20 percent gross organics, which are the highest concentrations excluding T 3-4 (Fig. 36). Separation of organics in sediments collected in the summer (July) from site T 3-4 showed that concentrations exceeded 35 percent (Fig. 36B). This high value is attributed to organic debris that settled across the marker horizon at T 3-4 in the winter of 1987-1988 (this was mentioned previously under the section "Marsh Aggradation Rates," and is discussed in more detail in Appendix D). Percentages of gross organics were lowest in sandier sediments (T 1-3 and 6-1) where they composed less than 1 percent. Sediments with the highest amounts of gross organics generally contain the highest TOC concentrations.

**Moisture Content.** The water or moisture content of sediments from the Trinity delta marsh, follow trends similar to those in the Colorado delta. There is a strong positive correlation with percent clay in the sample. Thus, the highest water content was in sediments collected at stations T 2-2 and 4-3, and the lowest water content was in sediments from stations 1-3 and 6-1, which have the highest sand concentrations (Fig. 37).

### Salinity

Measured salinities at all transects, except transect 7, during the five sampling trips were near 0 parts per thousand (ppt) (table 8). Salinities at transect 7 (Smith Point transect) ranged from 12 to 19 ppt and averaged 15.5 ppt. Pullen and Trent (1969) took salinities during 1965 in Anahuac Channel of the Trinity River near the USGS tide guage at Anahuac. The 29 salinity measurements averaged 6.2 ppt and ranged from less than 1 to 17.7 ppt. Salinities were also taken at a station in Lost River near Wallisville during 1965 (Pullen and Trent, 1969). The 88 measurements averaged 3.6 ppt and ranged from near 0 to 18.8 ppt.

### Seasonal Changes in Vegetation

Changes in vegetation cover and species composition were much more dramatic in the Trinity River delta (Fig. 48) than in the Colorado River delta. For example, *Alternanthera philoxeroides* was present at several transects during all sampling periods, December 1987, March 1988, July 1988, November 1988, March 1989, June 1989, and August 1989, but it was generally sparse and not very tall until the summer sampling trips of July 1988 and June 1989 when it became very dense and over 91 cm (3 ft) tall in some areas (table 6). Also, *Scirpus olneyi* was either not noted or was very sparse during December, March, and November at transects T 1 and T 6; in July 1988, it was one of the tallest and most abundant species. However, in June 1989, it had virtually disappeared from transect 1 and was not as dense at transect T 6 as it was in July 1988. *Scirpus olneyi* was still very sparse at transect T 1 in August 1989, but it was dense at transect T 6. In contrast, several species that were most abundant in the winter (December), died back and were not present in the summer

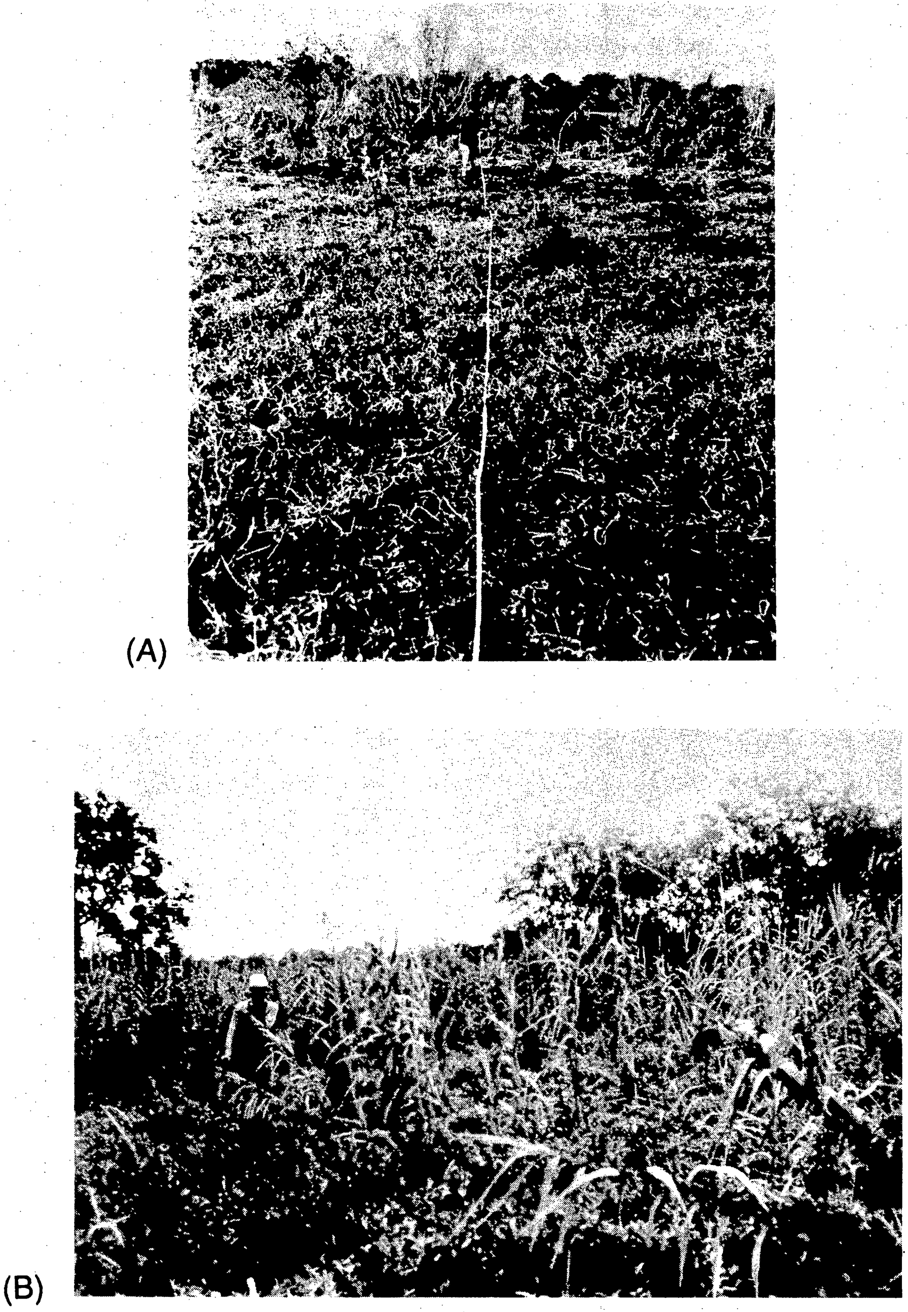


Figure 48. Seasonal changes in vegetation at transect 2 showing increase in plant density from December 1987 (A) to July 1988 (B). View toward Trinity River.

(July). Vegetation changes were especially evident at transects T 1 and T 6, and these changes will be discussed in detail.

Transect 1 - Vegetation in December 1987 was dominated by *Panicum dichotomiflorum, Pluchea* sp., and *Sphenoclea zeylanica.* All three species were tall, ranging from over 67 to 140 cm (2 to 4.5 ft) in height (table 6 and Fig. 47A). Some *Bacopa monnieri* was noted at marker bed station T 1-3. Vegetation in March 1988 was sparse and characterized by a die-back of *Panicum dichotomiflorum, Pluchea* sp., and *Sphenoclea zeylanica* (Fig. 47B). Both *P. dichotomiflorum* and *S. zeylanica* were much shorter and less dense than in December. Vegetation changes in July 1988 were especially striking, as there was no evidence of *Panicum* or *Sphenoclea,* and *Scirpus olneyi* was the dominant species. Dense stands of *Scirpus,* ranging from 72 to 152 cm (3 to 5 ft) in height, were present over much of the area (table 6 and Fig. 47C). *Scirpus olneyi* was not noted in November 1988 or March 1989. In July, *Bacopa monnieri* grew in dense, mounded, circular areas near marker bed station T 1-4 and was in flower. *Eleocharis parvula* accompanied the *Bacopa* at marker bed station T 1-4 and was also present at marker bed station T 1-3 (Fig. 41). In March 1989, virtually all vegetation had disappeared, and, except for some sparse growth of *S. olneyi* at marker bed station T 1-4, vegetation had not reappeared in June or August 1989.

Transect 6 - Vegetation was very sparse in December 1987. Marker bed station T 6-1 was located in a wet, barren area with no vegetation. Some very sparse, short *Alternanthera philoxeroides* was located near marker bed station T 6-2. In March 1988, *A. philoxeroides* was still low and fairly sparse, and shoots of *Scirpus olneyi* (heights of less than 12 cm [0.4 ft]) were noted at marker bed station T 6-1. Vegetation changes in July were dramatic. Tall, dense stands of *S. olneyi* were present at marker bed station T 6-1, and dense stands of *A. philoxeroides* were dominant at marker bed station T 6-2. *Scirpus olneyi* ranged from 122 to 135 cm (4 to 4.5 ft) in height (table 6). *Alternanthera philoxeroides* was very short at station T 6-2 in November, 1988, and no vegetation was present at either marker bed station in March 1989. In June and August 1989, dense stands of *S. olneyi* and *A. philoxeroides* were again present at markers T 6-1 and T 6-2, respectively.

## HISTORICAL CHANGES IN FLUVIAL-DELTAIC WETLANDS

Extensive displacement of marshes by open water in the Neches River delta and alluvial valley (White and others, 1987) highlighted the need to examine the extent of similar changes in each of the major river systems discharging into estuarine areas along the Texas coast. Seven rivers were selected for investigation: Colorado, Guadalupe, Lavaca, Neches, Nueces, San Jacinto, and Trinity (Fig. 3).

The distribution of wetlands (marshes, swamps, and fluvial woodlands, for example) were mapped on sequential aerial photographs from the 1930's to the late 1970's or 1980's. Each map area is characterized by either three or four time periods—1930's, 1950's, 1970's, or 1980's. Sources, dates and scale of photographs used in each area are shown in Appendix E.

The principal focus of the historical investigation was to document changes in emergent vegetation to determine the extent to which vegetated areas are being replaced by open water or barren flats. Basically, two map units were delineated on photographs: (1) vegetated areas, primarily wetlands but locally including uplands, dredged spoil, and transitional areas, and (2) areas without vegetation consisting of water and barren flats. By combining water and barren flats, the problem of variations in tidal levels that affect the size of water bodies is largely eliminated.

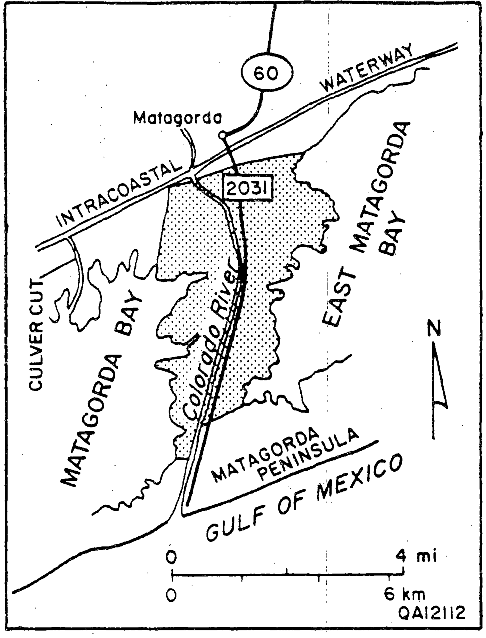
Map areas in each delta and valley are generally restricted to regions in the lower alluvial valley, and do not encompass the entire wetland system. In the Neches River valley, major losses of wetlands have previously been reported in the lower valley by White and others (1987), so the map area for this investigation was restricted to a stretch upstream from the previously mapped zone.

In each of the map areas except along the San Jacinto and Neches Rivers, vegetation and water/barren flats were mapped and digitized. In the San Jacinto River valley, an area marked by severe subsidence, water was mapped as a single unit and the remainder of the map area was combined within the vegetation category; thus, the vegetation unit, although primarily composed of wetlands, also includes some developed areas and barren-spoil deposits. In the Neches River valley, because of the extensive disposal of dredged spoil along the river, spoil areas were mapped as a separate unit.

Digitization of all map areas was at an approximate scale of 1:24,000. In areas where aerial photographs were at a smaller scale (1979 photographs; Appendix E), delineations were enlarged to 1:24,000 for digitization. Comparison of digitized images indicated less than 1 percent error was produced by this process. Maps of the digitized areas were plotted at 1:24,000. Smaller plots depicting the wetland chronology are shown for each area in Appendix F. The areal extent of each map unit was computed and graphed to analyze trends.

## Colorado River Delta

The Colorado River delta has had a unique history of rapid progradation across the eastern arm of Matagorda Bay (Wadsworth, 1941; Kanes, 1965, 1970; and Manka and Steinmetz, 1971). Sequential aerial photographs show that a small delta in 1930 (less than 325 ha [800 acres]) had grown to more than 2,070 ha (5,111 acres) in 1956 (Fig. 49). (The map area does not include the



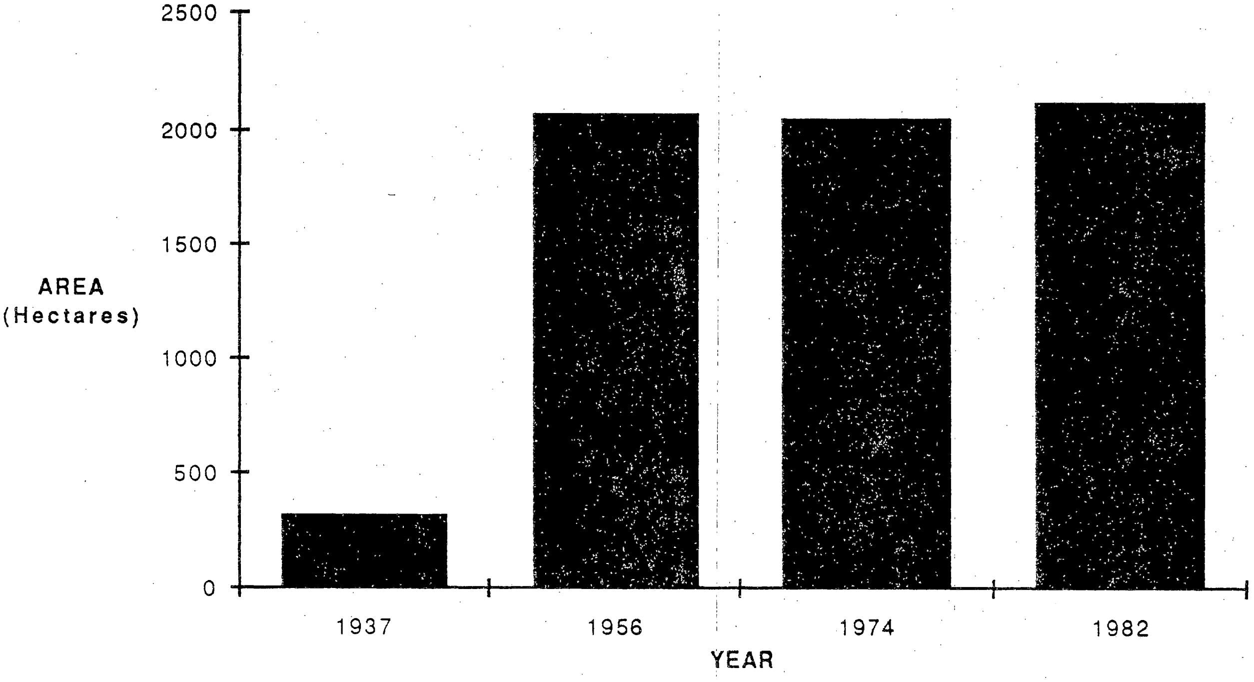


Figure 49. Index map and historical changes in vegetated wetlands, Colorado River delta.

entire delta; see Fig. 50). The history of delta growth and development is summarized in a previous section, and is treated more thoroughly in the literature synthesis (White and Calnan, 1989).

Analysis of marsh-water relationships in the delta after 1956 indicates that marshes on the northeastern half of the delta (that portion east of the Colorado River and bordering East Bay, Fig. 50) decreased in area by approximately 53 ha (130 acres) between 1956 and 1974 (Fig. 50). However, over the 8-year period between 1974 and 1982, this side of the delta remained relatively stable, with about a 22-ha (55-acre) increase in vegetated area. This small areal increase may be due more to slight mis-matches in scale from the 1974 and 1982 photographs than to an actual expansion in marsh area. Other evidence indicates that this side of the delta is deteriorating and supports Manka and Steinmetz's (1971) conclusion of delta degradation.

The southwestern half of the delta contrasts with the deteriorating northeastern half. Emergent marsh vegetation in the southwestern half increased by about 31 ha (76 acres) between 1956 and 1974, and by about 77 ha (190 acres) between 1956 and 1982 (Fig. 50). Increases on the southwestern half of the delta appear to be associated primarily with progradation of the delta at Tiger Island Cut. Between 1979 and 1987 (based on aerial photographs taken during these years) the Tiger Island Cut subdelta continued to prograde into Matagorda Bay, adding approximately 55 ha (135 acres) for an average rate of about 7 ha/yr (17 acres/yr).

A look at the delta as a whole indicates that although there was a slight decrease in the areal extent of emergent vegetation between 1956 and 1974, there was an increase of about 2 percent between 1956 and 1982 (Fig. 51). This increase can be attributed to expansion of marshes on the southwestern half of the delta, primarily at the Tiger Island Cut subdelta. Sediment delivered to this subdelta is apparently fluvial, estuarine, and marine in origin (see previous discussion on sedimentation, Colorado River delta). The Colorado River delta is the only delta in which the total area of vegetated wetlands increased after the 1950's (see conclusions).

### Guadalupe River Delta

Geological development of the Guadalupe River delta at the head of San Antonio Bay was described by Donaldson and others (1970). Over the past 2,000 yrs, the Guadalupe delta has had a history of delta-lobe growth, abandonment, and deterioration. A major modification to the delta occurred in 1935 when Traylor Cut was dredged, diverting approximately two-thirds of the discharge from the Guadalupe River into shallow Mission Lake (Morton and Donaldson, 1978). This diversion resulted in the progradation of a small subdelta into the southwest corner of the lake (Donaldson,

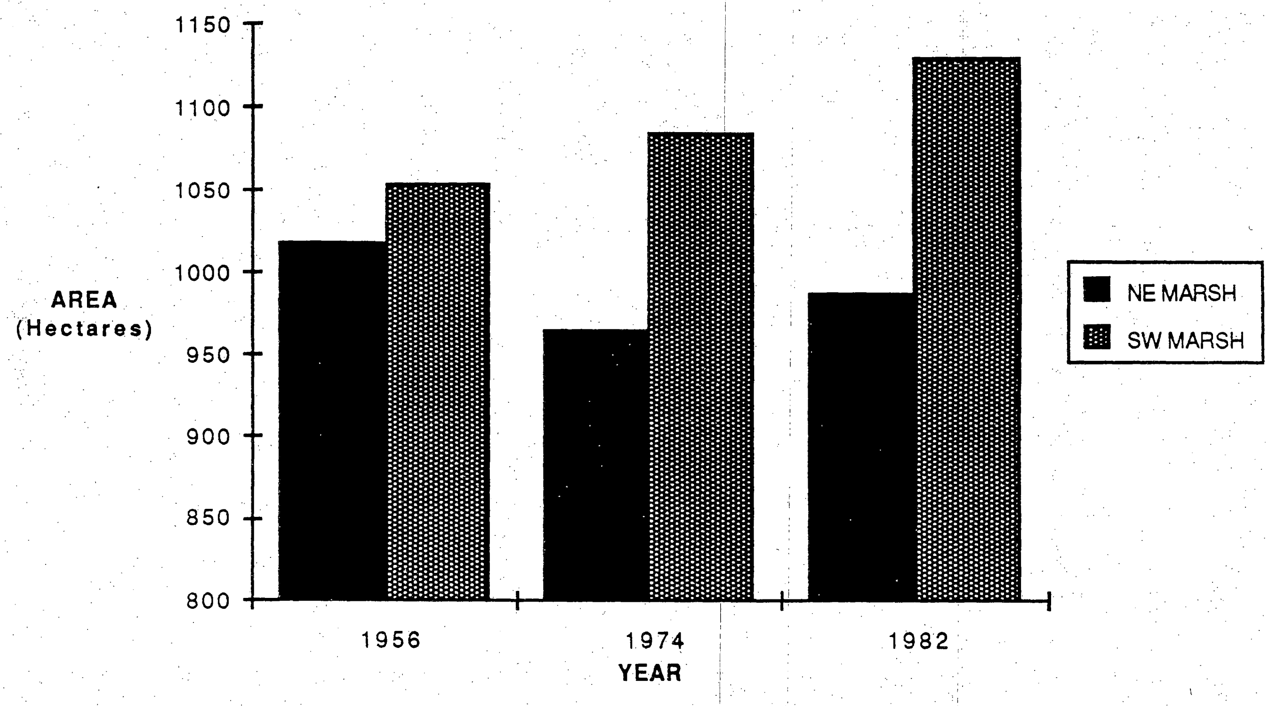


Figure 50. Comparison of historical changes in deltaic marsh areas northeast and southwest of the Colorado River. See index map in figure 49 for marsh areas.

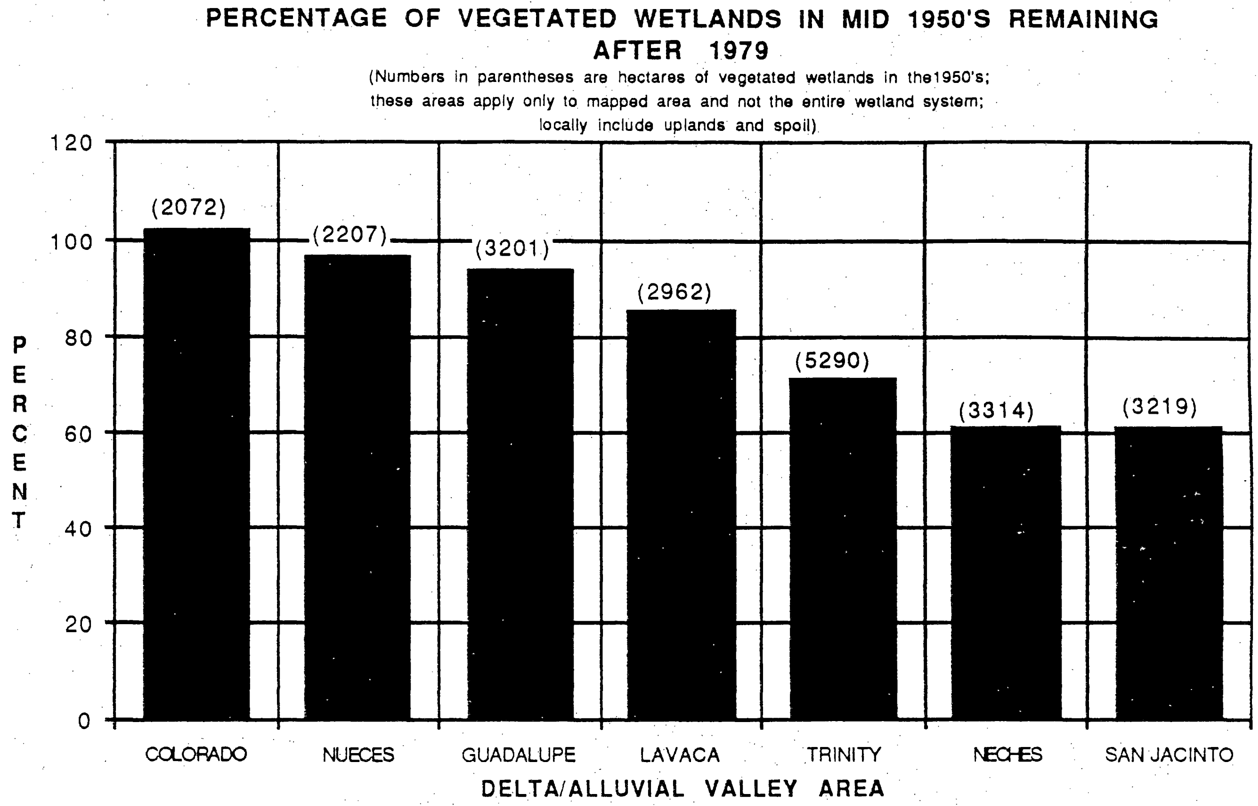


Figure 51. Comparison of mid-1950's vegetated wetlands with post-1979 wetlands in the seven fluvial-deltaic areas investigated.

and others, 1970; White and Morton, 1987). Older delta lobes, which front San Antonio Bay, are undergoing deterioration through erosion and submergence.

Sequential aerial photographs of the delta taken in 1930, 1957, 1974, and 1979 indicate that the total area of vegetated wetlands declined by about 305 ha (750 acres) between 1930 and 1957, and by about 265 ha (655 acres) between 1957 and 1974 (Fig. 52). From 1974 to 1979, a small increase in vegetated wetlands of about 65 ha (160 acres) is indicated (this apparent increase may be partly due to differences in map boundaries delineated on the 1974 and 1979 photographs). The decrease in vegetated wetlands from 1930 to the 1970's is approximately matched by an increase in water and barren flats.

Subdivision of the delta into three areas (Fig. 53) allows a more detailed examination of changes that have occurred. Since 1930, the transformation of vegetated wetlands to open water and barren flats has been more extensive in the older parts of the delta (areas 1 and 3; Fig. 53). In area 1, emergent vegetation decreased by more than 105 ha (259 acres) between 1930 and 1957, and by 170 ha (420 acres) between 1957 and 1974. Area 3 had its largest decline in vegetation (approximately 200 ha, or about 500 acres) between 1930 and 1957. Between 1957 and 1974, there was a small decrease in area-3 vegetation (less than 10 ha [25 acres]), which was followed by an apparent increase of about 20 ha (50 acres) between 1974 and 1979. Changes in area 2 were less extensive than in areas 1 and 3, from 1930 to 1979 (Fig. 53). Area 2 has been modified by human activities including (1) dikes and levees that pond water, and (2) Traylor Cut, which has promoted development of wetlands on the subdelta formed at its mouth. Vegetated areas decreased by about 87 ha (215 acres) between 1957 and 1974, but this loss was largely offset by an increase in vegetation between 1974 and 1979 (Fig. 53). Accordingly, from 1930 to 1979, vegetation in area 2 decreased by less than 10 ha (25 acres).

In general, emergent vegetation on the Guadalupe River delta became less extensive as areas of open water and barren flats expanded. Between 1930 and 1979, there was a loss of more than 500 ha (about 1,235 acres) of vegetation, and an approximately equal gain (510 ha, or about 1,260 acres) in water/barren flats. These changes indicate that marsh aggradation rates have not kept pace with rates of relative sea-level rise in some areas. Donaldson and others (1970) estimated that about 30 cm (1 ft) of subsidence has occurred in older parts of the delta (area 1, Fig. 53). Progradation of the Traylor Cut subdelta and the establishment of new wetlands has not been enough to compensate for losses of vegetation. A comparison of the total area of vegetation existing in 1979 with the total in 1930 shows a reduction of about 15 percent during this 49-yr period.

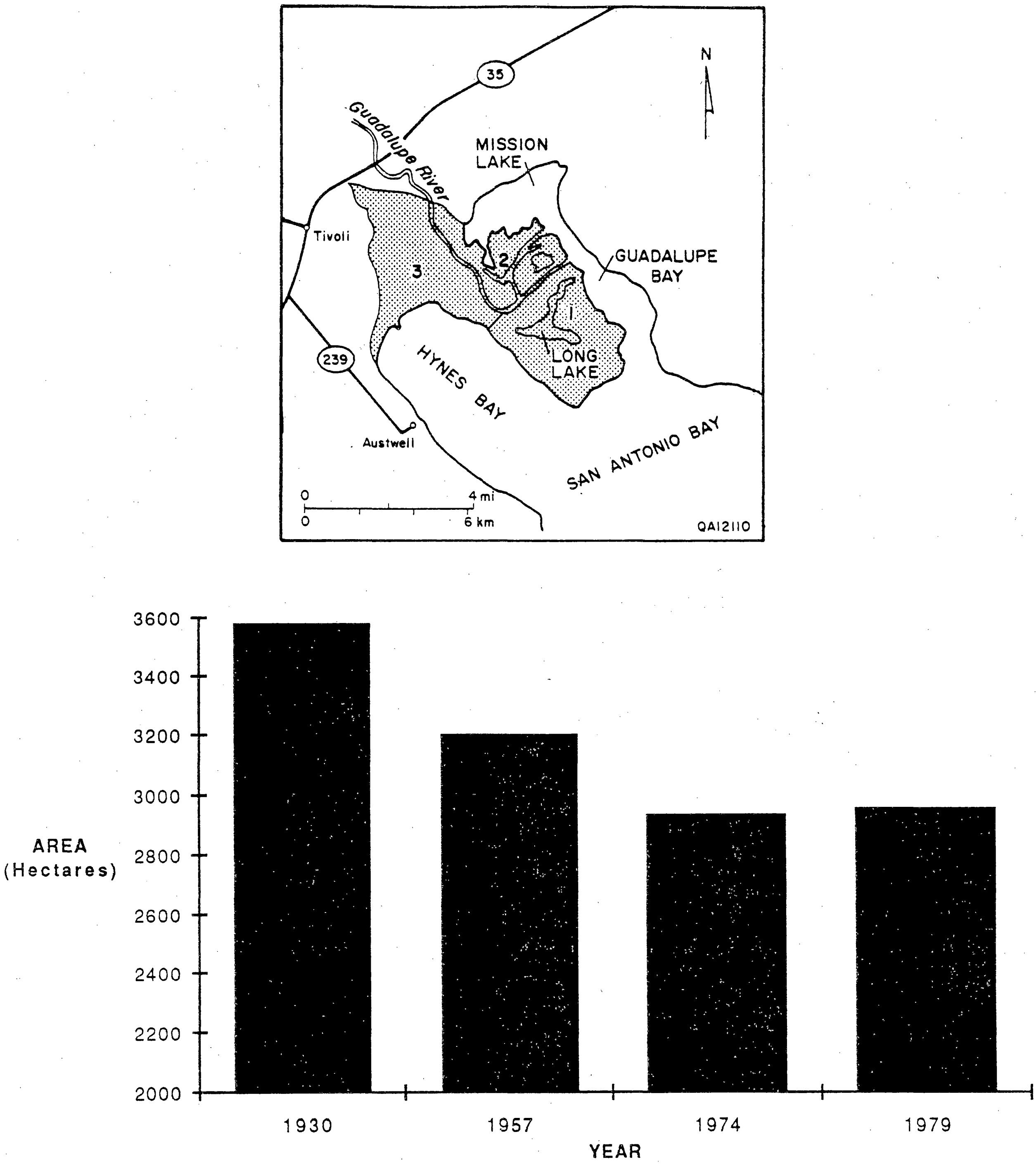


Figure 52. Index map and historical changes in vegetated wetlands, Guadalupe River delta.

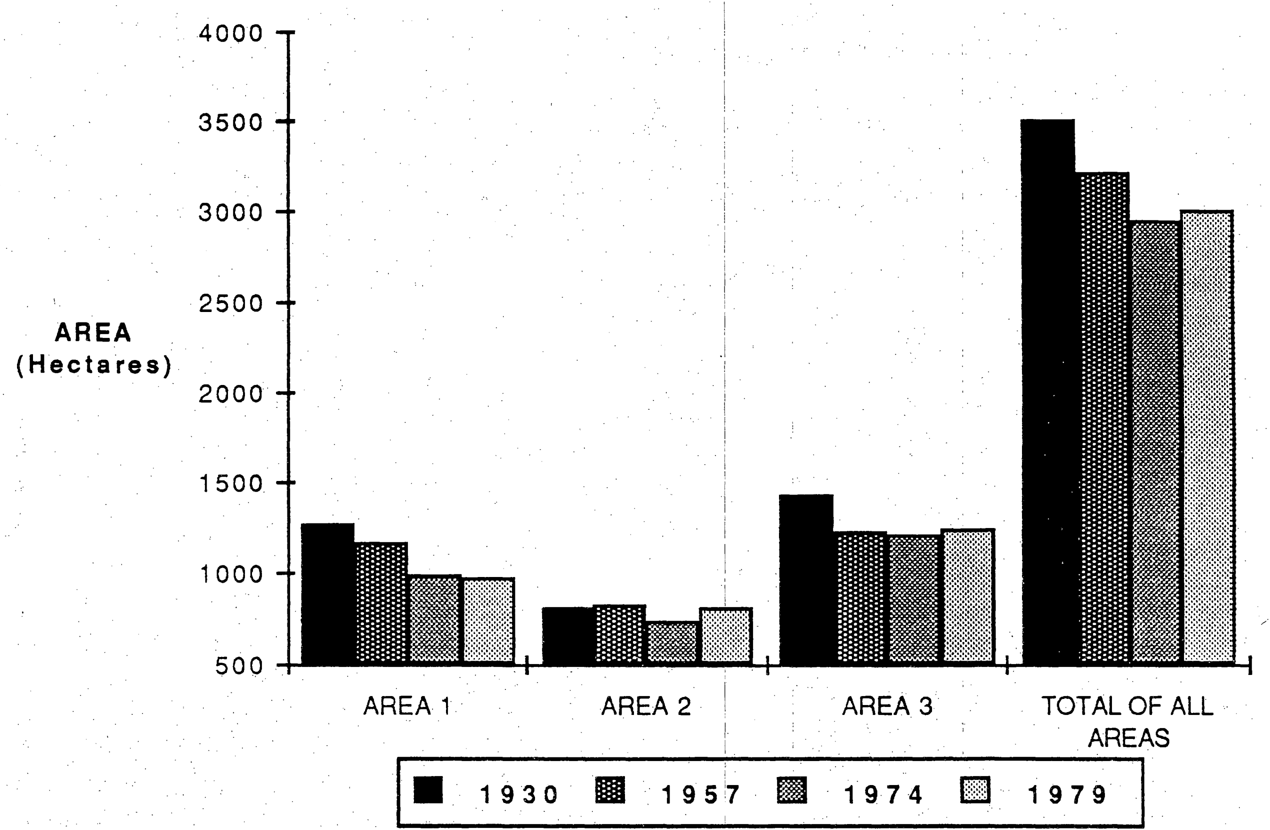


Figure 53. Historical changes in vegetated wetlands in three areas of the Guadalupe River delta.

## Lavaca River Delta

Analysis of historical changes from 1930 to 1979 in the Lavaca River delta indicates vegetation in this area is also being replaced by water/barren flats. A comparison of photographs taken in 1930 with those taken in 1958 shows a decrease of 153 ha (378 acres) of vegetated wetlands between 1930 and 1958 (Fig. 54). During that same time period of 28 years, water/barren flat areas increased by 113 ha (278 acres). The largest decrease in vegetation and increase in water/barren flats occurred between 1958 and 1979, when vegetated areas decreased by 430 ha (1,061 acres) and water/barren flat areas increased by 309 ha (764 acres) (Fig. 54). Approximately 85 percent of the vegetated area present in the late 1950's was present in the late 1970's (Fig. 51). Some declines in wetlands between 1930 and 1958 and between 1958 and 1979 may not only be due to increases in water/barren flat areas, but also to the slumping of the western margin of the Lavaca River valley wall. Differences in scale between the 1930, 1958, and 1979 photographs also may account for some slight decreases in marsh area.

Most of the historical changes in the delta are occurring in Menefee Flats (Fig. 54) and in the lower delta, west of the Lavaca River. In these two areas, water/barren flat areas have increased significantly, especially between 1958 and 1979. Water/barren flats increased by 95 ha (234 acres) (57 percent) in Menefee Flats between 1958 and 1979 and by 131 ha (323 acres) (54 percent) in the lower delta, west of the Lavaca River. During the 49-yr period between 1930 and 1979, water/barren flat areas increased by 104 ha (256 acres) (65 percent) in Menefee Flats and by 204 ha (504 acres) (122 percent) in the lower delta, west of the Lavaca River.

Factors contributing to the increase in water/barren flat areas in the Menefee Flats and adjacent areas include land-surface subsidence and the discharge of oil-field brines (White and others, 1989). Subsidence in the Menefee Flats area locally exceeded 30 cm (1 ft) from 1918 to 1973 (Ratzlaff, 1980). If subsidence is not offset by land-surface aggradation, then wetlands can extend into more inland and prairie grassland upland areas (White and others, 1989). Another factor contributing to the loss of vegetation may be the discharge of highly saline oil-field brines from drilling activities in the Menefee Flats area. Mackin (1971) reports that brine was discharged at a rate of 14,000 barrels per day in the Menefee Flats area.

## Neches River Delta

The most extensive loss of wetlands in a modern estuarine fluvial-deltaic system along the Texas coast has occurred along the Neches River (White and others, 1987). Between the mid-1950's and 1978, about 3,800 ha (9,410 acres) of marshes were displaced primarily by open water along an

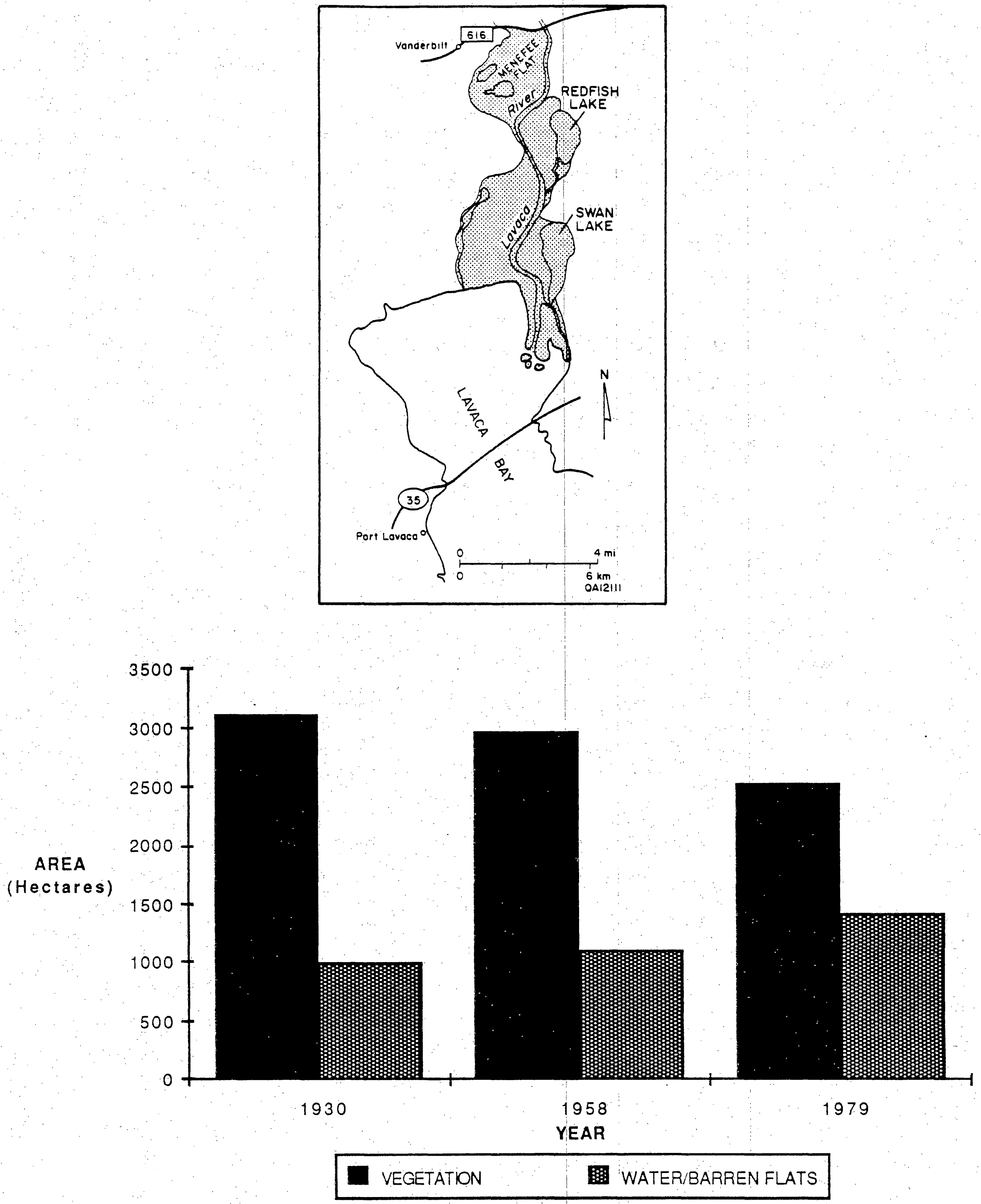


Figure 54. Index map and historical changes in vegetation and water/barren flats, Lavaca River delta and alluvial valley.

approximately 16-km (10-mi) stretch of the lower Neches River valley (Fig. 55). For historical analysis in this study, a stretch of the alluvial valley upstream from this site was selected (Fig. 56).

Analysis of the areal extent of vegetated lands, water/barren flats, and dredged spoil on aerial photographs taken in 1938, 1956, and 1987, reveals that there has been a substantial decline in vegetated areas (fresh-water marshes, woodlands, and swamps) since 1938 (Fig. 56). Areas of emergent vegetation decreased by about 342 ha (845 acres) between 1938 and 1956,[2] and by approximately 1,305 ha (3,222) acres between 1956 and 1987. The rate of loss of vegetated wetlands was 19 ha/yr (47 acres/yr) for the earlier period and 42 ha/yr (104 acre/yr) for the latter period. The major loss in vegetated wetlands between 1938 and 1956 was a result of a large navigation basin dredged in a marsh area adjacent to the Neches River (Fig. 56). In fact, this artificial change accounts for practically all of the loss in vegetation from 1938 to 1956.

The substantial increase in rate of loss from 1956 to 1987 can be attributed to several factors including subsidence and associated relative sea-level rise, spoil disposal, construction of canals and levees, and reduction in fluvial sediments delivered to the marshes. Extensive displacement of marsh vegetation by shallow subaqueous flats and open water occurred in the northern part of the map area indicating that aggradation rates did not keep pace with relative sea-level rise. In the map area as a whole, vegetated wetlands decreased in area by approximately 45 percent from 1938 to 1987.

## Nueces River Delta

Net progradation occurred along the northern shoreline of Nueces Bay between 1867 and 1982 (Morton and Paine, 1984). However, subsidence and the loss of fluvial sediments along the Nueces River may be contributing to an increase in water and barren areas and a loss in vegetation in the interior marshes.

A comparison of historical photographs taken in 1930 of the Nueces River delta with those taken in 1959 and 1979 shows a slight decrease of 54 ha (133 acres) in vegetated wetlands between 1930 and 1959 and a decrease of 75 ha (185 acres) between 1959 and 1979 (Fig. 57). The decrease

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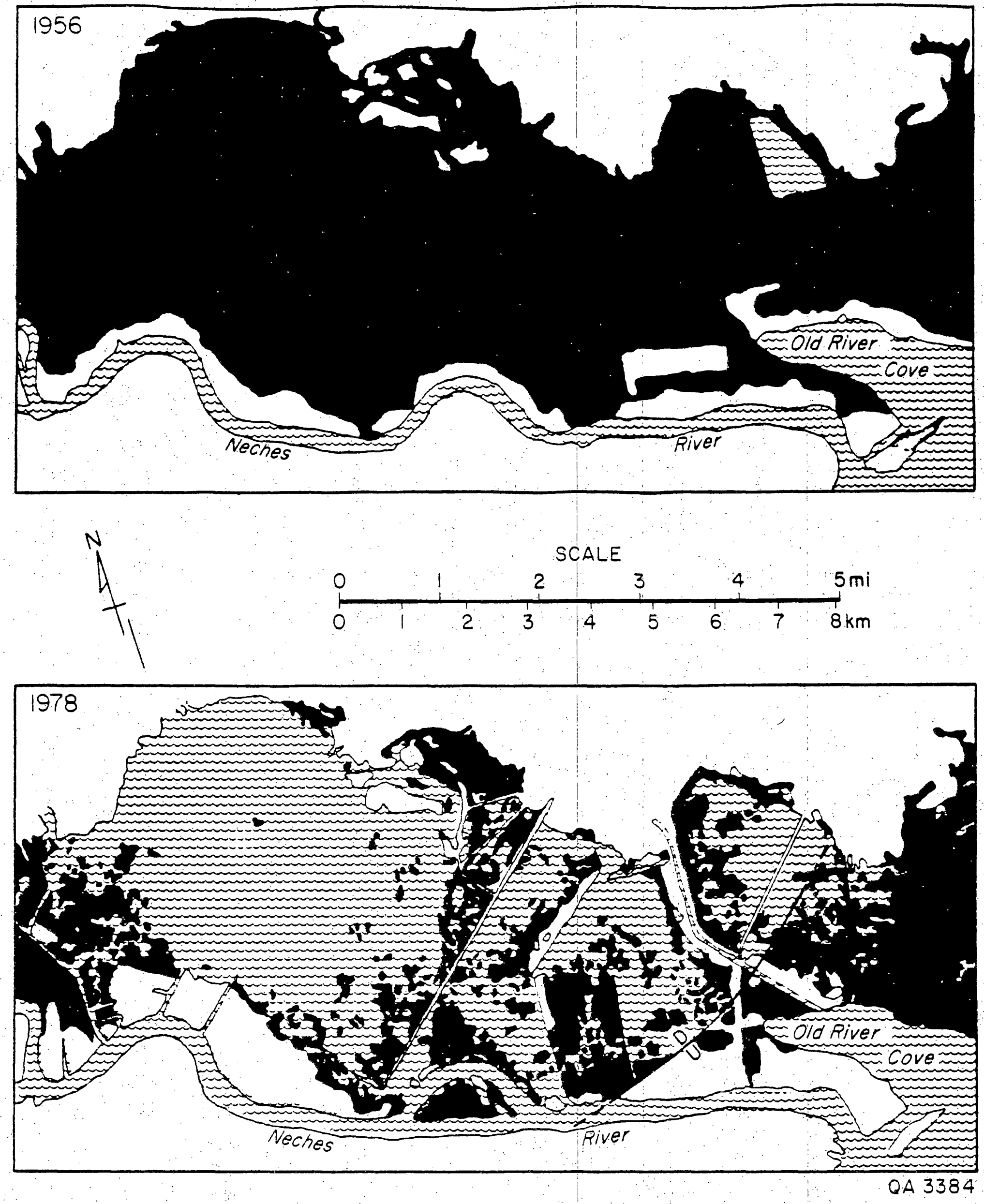
[2] It should be noted that for mapping purposes (because of differences in photographic scales) the area of spoil along the Neches River in 1938 was assumed to be equal to that existing in 1956 (i.e., spoil areas mapped on 1956 photographs were also used for 1938). However, the area of spoil was actually a little less extensive in 1938 compared to 1956. Thus, the amount of vegetated land in 1938 was larger than measured, which means that the loss between 1938 and 1956 is a little larger than the reported 342 ha (845 acres).



| Map Unit | 1956 | | 1978 | | Net Change* | |
|---|---|---|---|---|---|---|
| | Acres | Hectares | Acres | Hectares | Acres | Hectares |
| Water | 2,560 | 1,037 | 11,070 | 4,483 | +8,510 | +3,446 |
| Marsh | 15,740 | 6,375 | 6,330 | 2,564 | −9,410 | −3,811 |

* Loss of additional 900 acres (365 hectares) of marsh primarily due to spoil disposal.

Figure 55. Changes in the distribution of wetlands between 1956 and 1978 in the lower Neches River valley near the head of Sabine Lake. The fault crossing this area (downthrown side labeled D, upthrown side labeled U) apparently contributed to the changes. (From White and others, 1987.)

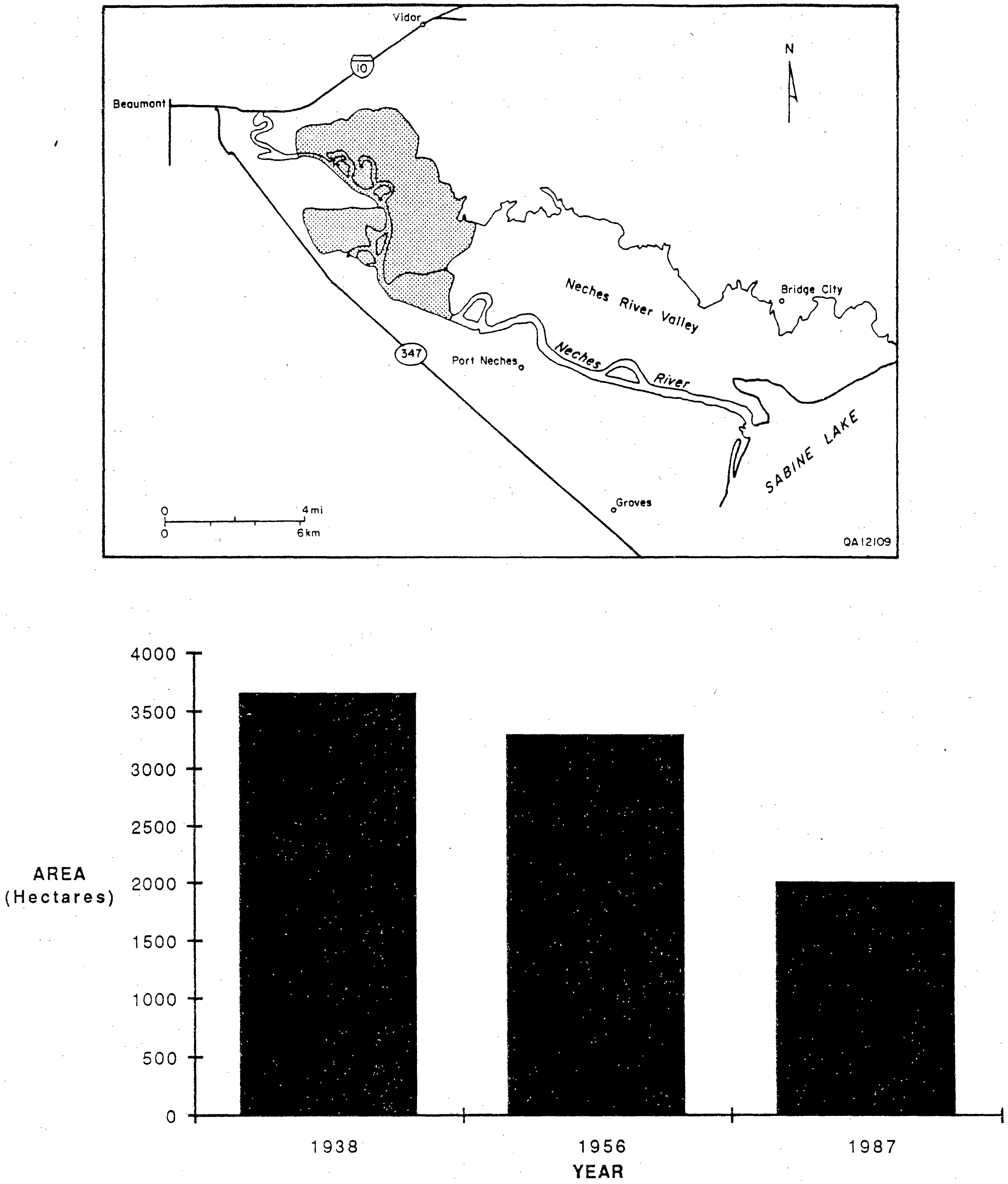


Figure 56. Index map and historical changes in vegetated wetlands, Neches River alluvial valley.

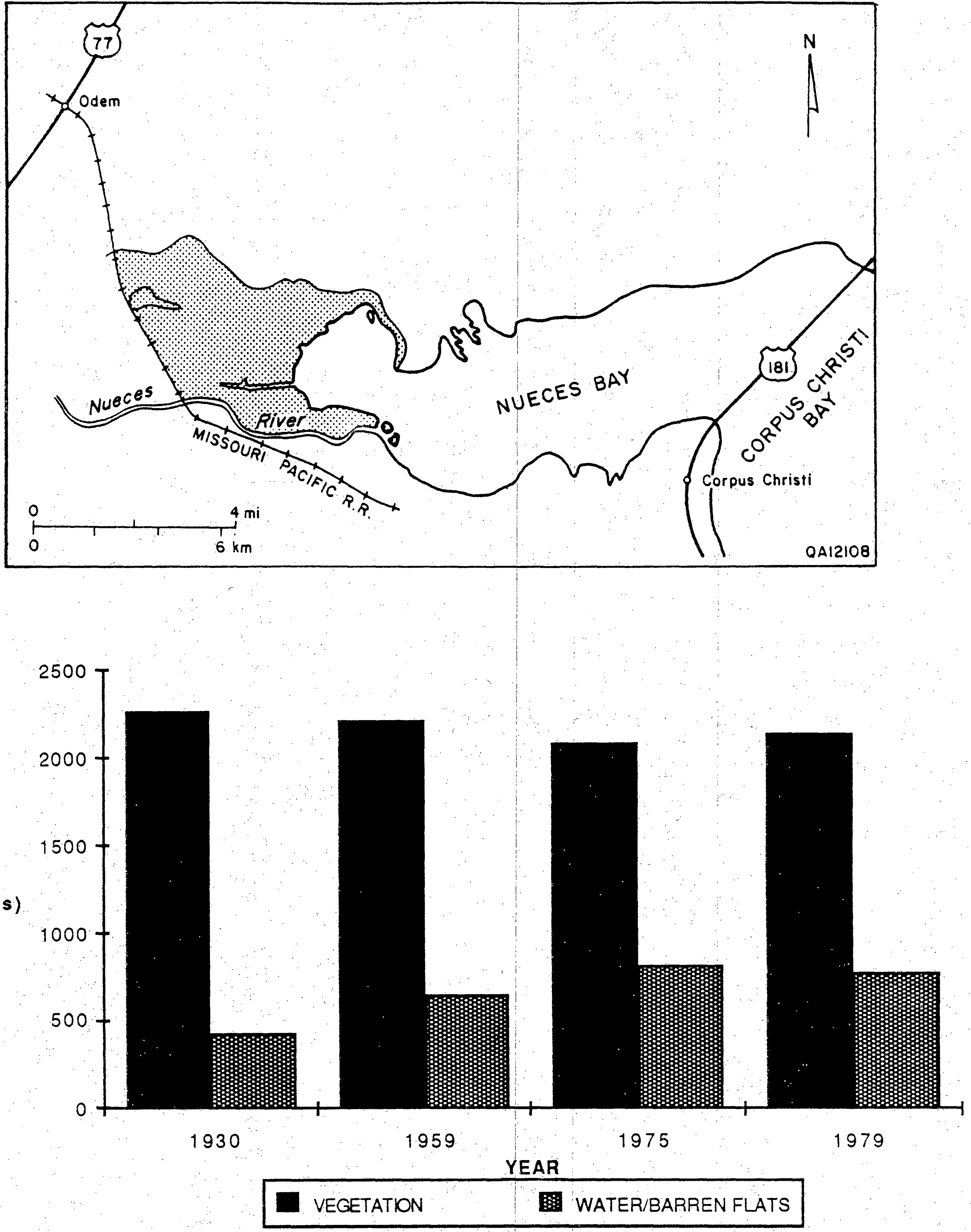


Figure 57. Index map and historical changes in vegetation and water/barren flats, Nueces River delta and alluvial valley.

in vegetated area over the 49-yr period between 1930 and 1979 was 129 ha (318 acres). Approximately 97 percent of the vegetated area present in the late 1950's was present in the late 1970's (Fig. 51).

Historically, the shoreline of Nueces Bay has been accreting or advancing into the bay (Morton and Paine, 1984). Although accretion has produced a larger total area (an area that includes both vegetation and water/barren flats), there has been a decline in interior vegetated marshes as they are replaced by water or barren flats. For example, between 1930 and 1959, the total area increased by 164 ha (405 acres), but the water/barren flat areas increased by 218 ha (538 acres) for a net loss of 54 ha (133 acres) in vegetated area (Fig. 57). Between 1959 and 1979, the total area increased by 52 ha (129 acres), but the water/barren areas increased by 127 ha (314 acres) for a net loss of 75 ha (185 acres) of vegetation. During the 49-year period between 1930 and 1979, the total area increased by 216 ha (534 acres), but the water/barren flat areas increased by 345 ha (852 acres) for a net loss of 129 ha (318 acres) of vegetation.

Morton and Paine (1984) monitored historical shoreline changes between 1882 and 1982 along the northern shoreline of Nueces Bay and found high net rates of accretion (advancement of the bay shoreline) between 1882 and 1930. Aerial photographs taken in 1959 indicate progradation ended sometime between 1930 and 1959. Although Morton and Paine (1984) recorded net progradation between the late 1800's and 1982, a comparison of interior marshes on photographs taken in the mid 1950's and late 1970's shows an increase in shallow subaqueous flats and a decrease in marsh area (White and others, 1983). Subsidence (Brown and others, 1976) and the loss of fluvial sediments from the Nueces River may account for the increase in water and barren flats and the loss of marsh vegetation.

### San Jacinto River Delta

A comparison of aerial photographs taken in 1930 with those taken in 1956 and 1986 indicates a replacement of extensive areas of wetlands/uplands by open water in the San Jacinto River valley. During the 26-year period between 1930 and 1956, vegetated areas (primarily wetlands) decreased by 590 ha (1,456 acres) (Fig. 58) or 51 percent. However, a larger change occurred more recently between 1956 and 1986, when vegetated lands decreased by 1,259 ha (3,109 acres) (70 percent). The decrease over the entire 56-year period between 1930 and 1986 was 1,849 ha (4,565 acres). Only about 51 percent of the wetland/upland areas that were present in 1930 were still present in 1986. Approximately 60 percent of the wetland/upland areas present in 1956 were still present in 1986 (Figs. 51 and 58).

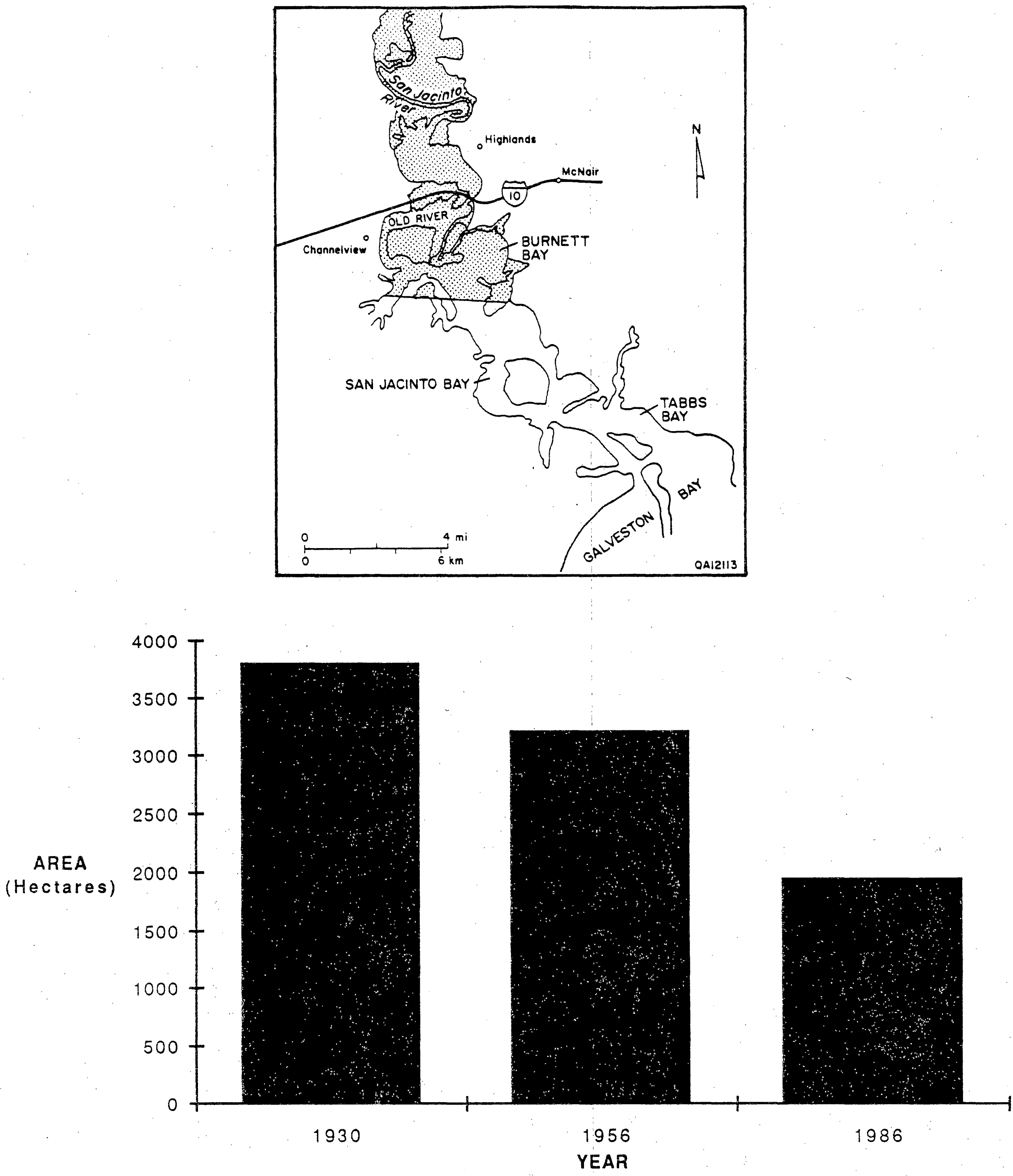


Figure 58. Index map and historical changes in vegetated wetlands, San Jacinto River delta and alluvial valley.

Fluvial woodlands, swamps, and fresh to brackish marshes are primarily being replaced by open water (White and others, 1985); however, vegetated areas are also being replaced by spoil and development within the lower river valley. All spoil and developed areas were included in the wetland/upland category for areal calculations. Water-filled depressions resulting from sand and gravel extraction were included in the open-water map unit.

The primary reason for extensive losses of wetlands along the San Jacinto River valley is subsidence caused by ground-water withdrawal (White and others, 1985; White and Calnan, 1989). Subsidence rates of as high as 60 mm/yr (2.3 in/yr) (Gabrysch, 1984) are apparently greatly exceeding the rates of aggradation in the area. Also, the reduced volume of sediment reaching the mouth of the river as a result of reservoir development in the river basin is not contributing much to aggradation rates in the wetlands (White and Calnan, 1989).

## Trinity River Delta

The Trinity River is the only river besides the Colorado that has significantly extended its delta since the mid 1800's (Shepard, 1953). Historical analysis of the delta using aerial photographs taken in 1930, 1956, 1974, and 1988 shows that progradation of the delta continued from 1930 to 1956 when approximately 600 ha (1481 acres) of vegetated wetlands were added to the delta (Fig. 59). New additions to the delta from 1956 to 1974 were relatively small, and vegetated areas overall underwent a large reduction of about 1,445 ha (3,568 acres). The majority of this loss (more than 1,030 ha [2,543 acres]) was due to a power-plant cooling reservoir that was constructed in the southwest corner of the delta. Although the area of vegetated wetlands continued to shrink by about 90 ha (222 acres) between 1974 and 1988, the rate of loss for this period was much lower than the preceding period, 1956 to 1974 (Fig. 59).

Subdivision of the delta into 5 areas (Fig. 60) for detailed examination of historical changes shows that the most extensive decrease in vegetated lands occurred in area 5 where the cooling reservoir is located (Fig. 59). Area 1, which is the active lobe of the delta, had the largest increase in vegetated wetlands with the addition of about 356 ha (880 acres) between 1930 and 1956 (Fig. 60). Since 1956, however, area-1 vegetated wetlands have decreased in size as water and barren flats have expanded. The decrease in vegetation from 1956 to 1988 was about 267 ha (660 acres), with about 80 percent of the loss occurring between 1956 and 1974. Area 2, the smallest area delineated, remained relatively stable throughout the monitoring period (Figs. 59 and 60). Area 3 has been modified with numerous dikes and levees; many water features appear to be artificially controlled. Following the replacement of about 193 ha (477 acres) of vegetated lands by water and

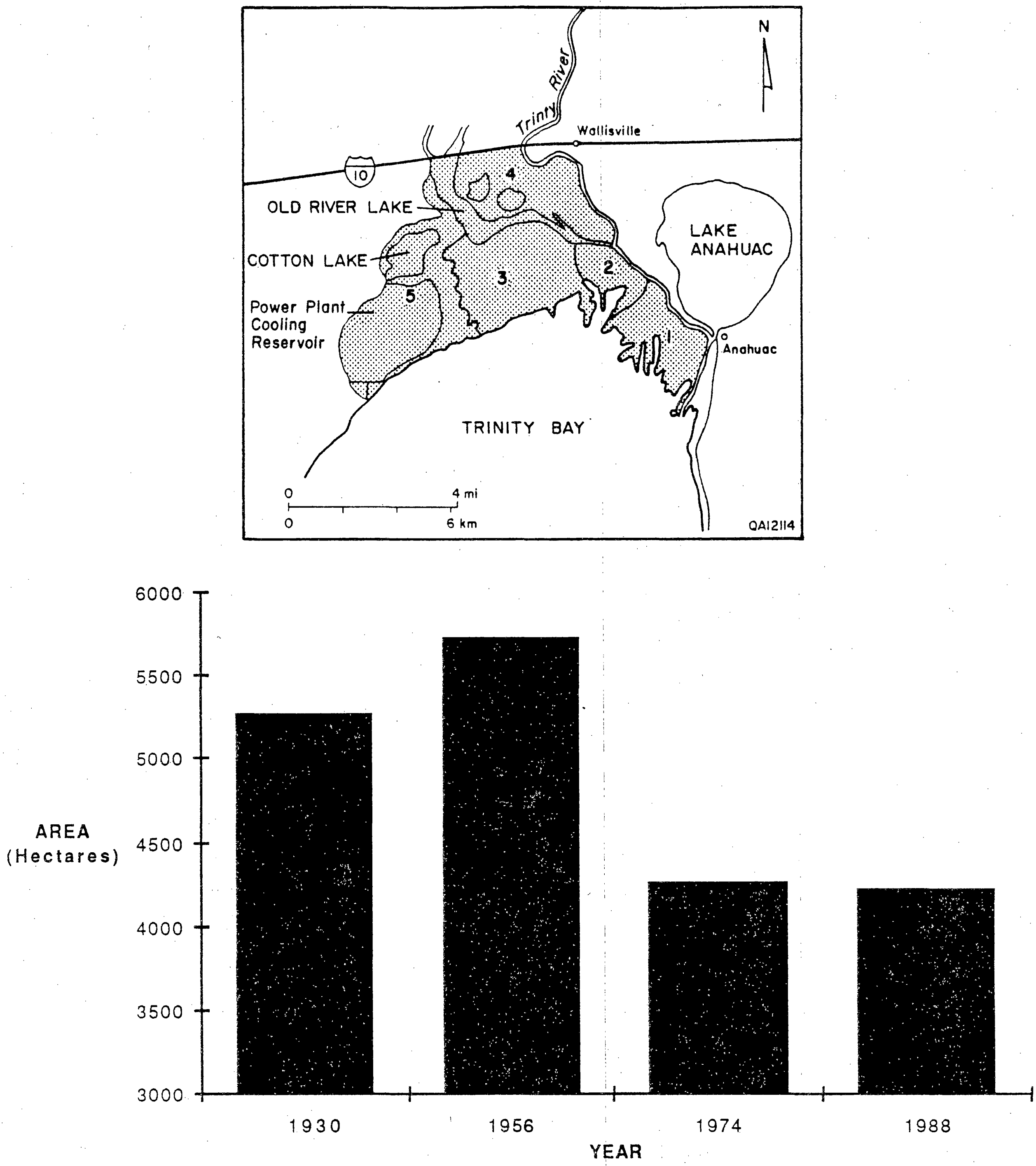


Figure 59. Index map and historical changes in vegetated wetlands, Trinity River delta.

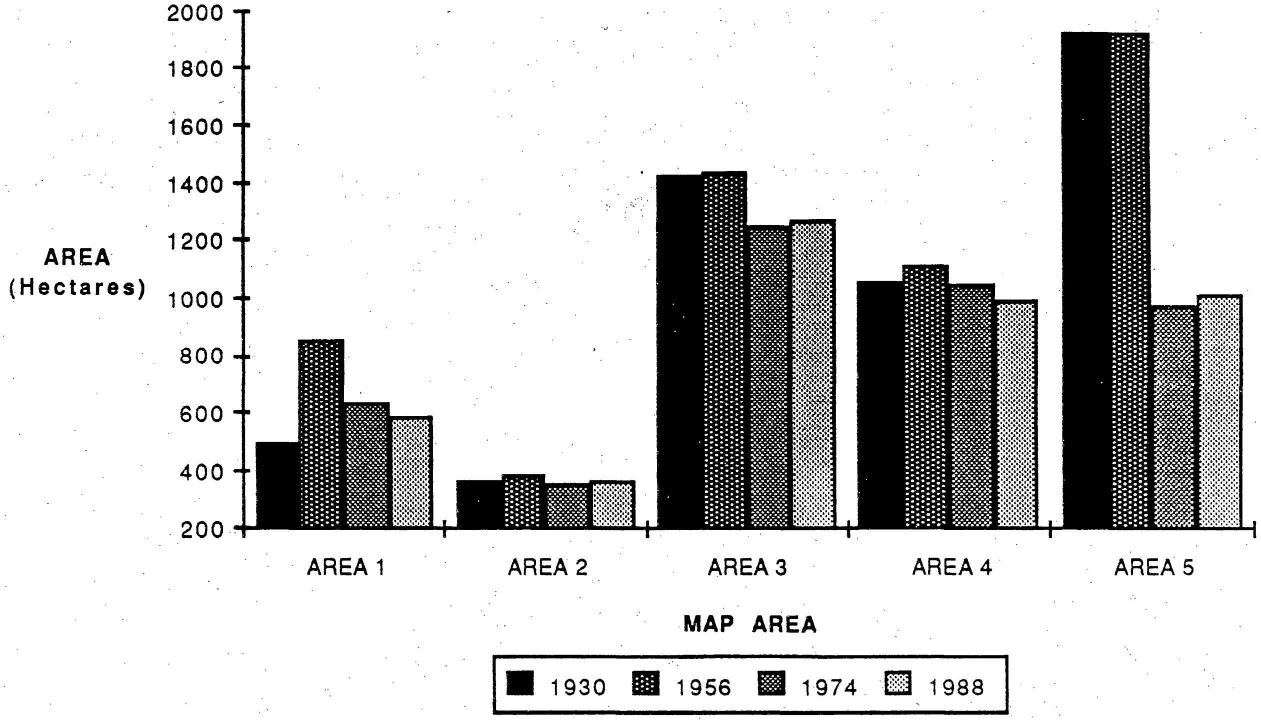


Figure 60. Historical changes in vegetated wetlands in five areas of the Trinity River delta. Refer to the index map in figure 59 for location of map areas.

barren flats between 1956 and 1974, there was little change (an increase of about 26 ha [65 acres] of vegetated lands) between 1974 and 1988 (Fig. 60). Area 4 shows a trend similar to area 1. An increase in vegetated lands (52 ha [128 acres]) between 1930 and 1956 was followed by a relatively steady decrease in vegetation from 1956 to 1988. Certain water features in area 4 show a systematic expansion through time. Changes in the various areas are rather dramatically illustrated in the sequence of figures for the Trinity delta shown in Appendix F.

Examination of the delta as a whole indicates that expansion of vegetated wetlands between 1930 and 1956 was followed by a relatively sharp reduction between 1956 and 1974. Less dramatic changes occurred between 1974 and 1988. A comparison of the areal extent of vegetated wetlands present in the delta in 1956 with their extent in 1988, shows a reduction of about 30 percent (Fig. 51). Approximately 90 percent of this change can be attributed to the cooling reservoir. Systematic encroachment of water into areas 1 and 4 of the delta (Fig. 60), however, suggests that aggradation rates of vegetated wetlands in these areas are not keeping up with rates of relative sea-level rise. Marked reductions in suspended sediments transported by the Trinity River (Fig. 2) and subsidence (Gabrysch, 1984) are among the factors that appear to have contributed to the decline of vegetated wetlands.

## SUMMARY AND DISCUSSION

Salt-water marshes in the Colorado River delta and brackish-water marshes in the Trinity River delta were monitored over a period of 18 to 24 months to document sediment accumulation rates. Vegetation types, vegetation heights, elevations, and sediment composition were among the other types of information collected during periodic surveys. Short-term marsh aggradation rates were determined primarily by using artificial-marker horizons established at selected sites along marsh transects. Eleven artificial-marker horizons were initially placed in wetlands in the Trinity River delta study area, and nine in the Colorado River delta study area. Long-term aggradation rates were determined by radiochemical dating (using $^{210}$Pb) of cores from the marshes. A total of five sediment cores ranging in length from 0.6 to 1 m (2 to 3.3 ft) were collected along selected marsh transects; 3 cores were from the Trinity River delta and 2 from the Colorado River delta. In addition, historical changes in vegetation and water/barren flats were analyzed in deltaic and alluvial-valley wetlands near the mouths of seven rivers (Colorado, Guadalupe, Lavaca, Neches, Nueces, San Jacinto, and Trinity). Historical analyses are based on aerial photographs taken in the 1930's to the 1980's.

Numerous factors affect salt-marsh sedimentation as listed in table 12. These factors also apply to the brackish-water marshes in estuarine areas. Salt-marsh aggradation rates on the Colorado

Table 12. Processes and conditions influencing salt marsh aggradation rates. (Compiled by Oenema and DeLaune, 1988.)

**FREQUENCY AND DURATION OF FLOODING**

**SUSPENSION CONCENTRATION**

**TIDE RANGE**

**STORM FREQUENCY**

**EXPOSURE TO WAVE ATTACK**

**VEGETATION CHARACTERISTICS**

**BIODEGRADATION**

**COMPACTION OF SURFACE SEDIMENTS**

**SUBSIDENCE**

River delta are not substantially different from those in salt marshes reported for other areas of the Gulf Coast (table 13). These rates, which are commonly higher than those recorded along the Atlantic Coast, are apparently related to higher rates of relative sea-level rise that characterize the Gulf Coast in Louisiana and Texas (table 13). (Higher rates of relative sea-level rise would tend to raise aggradation rates due to more frequent inundation of the marshes; these relationships are discussed in the literature synthesis report, White and Calnan, 1989). The highest short-term rates (based on sediment accumulations above artificial-marker horizons) in the Colorado River delta were about 12 mm/yr and occurred in (1) a bay margin-distributary influenced environment vegetated by *Spartina alterniflora,* and (2) a levee along an active distributary channel where *Borrichia, Batis,* and *Distichlis* were the predominant vegetation. These sites are comparable to the streamside saline marshes of the Louisiana Deltaic Plain where the reported rate is 13.5 mm/yr (table 13). Short-term aggradation rates (based on marker horizons) in backmarsh-distributary influenced environments in the Colorado River delta were rather consistent, with four sites varying less than 1 mm/yr; aggradation rates range from 8.5 to 9.3 mm/yr and average 9.0 mm/yr. These sites are intertidal *Spartina alterniflora* or *Scirpus maritimus* marshes. Sediment deposition at these sites prior to September 1988, when Hurricane Gilbert made landfall, was apparently related to normal estuarine intertidal processes. The location of these marshes in the intertidal zone contributed to the higher aggradation rate by increasing the frequency of inundations and the period of time during which deposition occurred. The short-term backmarsh rates are higher than those reported in Louisiana, which are 7.5 mm/yr in saline backmarshes (table 13); however longer-term rates based on $^{210}$Pb dating are similar, at 7.6 mm/yr and 7.4 mm/yr for two backmarsh sites in the Colorado delta. Higher rates detected by the artificial-marker horizons compared to the core analyses are probably due in large part to lower amounts of compaction and organic decomposition in the surface sediments above the marker horizons compared to deeper sediments in the cores.

Seasonal variations in sediment aggradation were recorded by most marker horizons in the Colorado River delta. The least amount of deposition occurred during winter months. Sediment accumulation during each of two winter periods (December 1987–March 1988 and November 1988–March 1989) represented an average of only 2.5 to 3 percent of the total deposition at the various sites. The months registering the highest amount of deposition were July to November 1988, a period that includes Hurricane Gilbert. About 50 percent of the total sediment that accumulated on marker horizons was deposited during this period. A high of almost 80 percent was deposited at a levee site along the margin of Tiger Island Cut. This deposition can be attributed to Hurricane Gilbert, and indicates that over an 18-month period this levee site received most of its sediment during a single depositional event. Before Hurricane Gilbert made landfall in September 1988,

Table 13. Marsh aggradation (vertical accretion) rates measured in coastal Louisiana and along the U. S. Atlantic coast (from Boesch and others, 1983).

| Location | Marsh type | Marsh accretion rate (mm/yr) | Mean sea-level rise (mm/yr) | Source |
|---|---|---|---|---|
| Louisiana Deltaic Plain | Freshwater | | 11.0 | Hatton and others (1983) |
| | streamside | 10.6 | | |
| | backmarsh | 6.5 | | |
| | Intermediate (Spartina patens) | | | " " |
| | streamside | 13.5 | | |
| | backmarsh | 6.4 | | |
| | Brackish (S. patens | | | " " |
| | streamside | 14.0 | | |
| | backmarsh | 5.9 | | |
| | Saline (S. alterniflora) | | 13.0 | DeLaune and others (1978); Baumann (1980) |
| | streamside | 13.5 | | |
| | backmarsh | 7.5 | | |
| Chenier Plain | Salt-brackish (S. patens) | 7.0 | 12.0 | Baumann and and DeLaune (1982) |
| Georgia | S. alterniflora | 3-5 | | Summarized by Hatton and others (1983) |
| Delaware | S. alterniflora | 5.0-6.3 | 3.8 | " " |
| New York | S. alterniflora | 2.5-6.3 | 2.9 | " " |
| Conn. | S. alterniflora | 8-10 | 2.5 | " " |
| | S. patens | 2-5 | | |
| Mass. | S. alterniflora | 2-18 | 3.4 | Redfield (1972) |

sediment deposition on levee marshes was insignificant (< 1 mm) because no flood event sufficient to inundate these marshes had occurred.

Letzsch and Frey (1980) found a seasonal variation in deposition on Georgia marshes; minimum deposition occurred in autumn, through winter and spring, and maximum deposition occurred in summer. The differences apparently correlate, to some degree, with the seasonality of storm-wind incidence. Baumann and others (1984) in a study of marsh sedimentation in the Mississippi Deltaic Plain also concluded that there is a seasonal component to sediment deposition but it varied depending on sediment sources. In marshes receiving fluvial sediment, spring river flooding contributed from 91 to 69 percent of sediments in streamside and inland marshes, respectively. Marshes away from a fluvial input received the largest percentage of sediments (36 to 40 percent) from hurricanes and tropical storms. During periods without hurricanes, rates of aggradation were highest during winter, when winter storms were the primary depositional event. Stevenson and others (1986) postulated that hurricanes and storms may play a critical role in sediment budgets in areas where tides are weak and irregular and sediment inputs are low or reduced relative to past levels. This is in agreement with Stumpf's (1983) conclusion that storms control marsh sediment supply in microtidal areas, and that sedimentation depends directly on storm frequency and sediment availability. Rejmanek and others (1988), in a study of the Mississippi River deltaic plain, concluded that while normal riverine flooding resulted in minimal marsh aggradation, hurricanes had an important impact on sedimentation; for example, hurricanes deposited more than 2.2 cm of sediments in marshes adjacent to bayous as far as 7 km inland from the bay shore.

Analysis of sediment accumulation with respect to relative elevation in the Colorado River delta indicates an inverse relationship (r = -0.857) between elevations of most marker horizons and aggradation rates. The topographically higher marker horizons received less sediment than lower horizons, supporting Pethick's (1981) conclusion of a statistical relationship between marsh elevation/age and vertical accretion rates. The concept is that younger marshes are lower in elevation, which amplifies the depth and frequency of inundations and sediment accumulation compared to older, topographically higher marshes. The statistical relationship may be reduced by major storms or floods, however, when sediment is deposited at higher elevations, such as on natural levees.

Rates of marsh aggradation in the Trinity River delta were more variable and less predictable than in the Colorado River delta, in part reflecting the more complex setting of the Trinity delta brackish-water marsh system. In addition, the field investigation in the Trinity delta was begun later in the year (December 1987), which provided a monitoring period of about 20 months compared to two years at some sites in the Colorado delta. During the first 15 months of study in the Trinity delta, variations in sediment accumulation ranged from erosion at bay-margin sites to deposition of more than 28 mm in less than 8 months at a site farther inland. The estuarine shoreline near one of the eroded marker horizons, retreated (moved landward) approximately 1 m during a 3.5-month winter period (December 1987 to March 1988) indicating both vertical and lateral erosion of this area. Erosion did not occur during the succeeding two periods (March to July and July to November), but retreated another meter during the following winter (November 1988 to March 1989), indicating, as in the Colorado River delta, that there is a seasonal factor in the deposition and erosion of marsh sediments. Minimum deposition occurs in winter, and maximum occurs in late spring to early fall when major flood events (hurricanes, tropical storms, and river flooding) are more likely to occur.

Near record flooding along the Trinity River during the spring and early summer of 1989 had a major effect on sediment deposition at levee and bay/channel margin sites. Maximum flooding at Liberty, which coincided with release rates from Lake Livingston exceeding 70,000 $ft^3$/sec, almost equaled the record set in 1942. In addition to this peak flood event, the frequency and duration of flooding was excessive from May through mid-July of 1989, during which daily release rates from Lake Livingston exceeded 30,000 $ft^3$/sec on 45 occasions. The major flood event produced abnormally high amounts of sediment accumulation on levees along the Trinity River. One levee marker located less than 5 m from the channel cut bank recorded the most deposition. Between March and August 1989, approximately 6.7 cm of sediment accumulated, which is more than 95 percent of the total deposition at this site over a 20-month period. In fact, between June and August 1989, more than 5 cm of sediment was deposited at this site, which probably can be attributed to the near record flood in early July. On another levee several miles downstream along Anahuac channel, aggradation during this same two-month period (June–August 1989) was less than 2 cm. However, this represented about 95 percent of the sediment that had accumulated at this location since March 1989.

Surveys along the Trinity River in August 1989 after the major flood event disclosed relatively thick deposits of clean, very fine-grained sand deposited on levees downstream from Old River Cutoff. A few measurements revealed that the recently deposited sand was as thick as 25 cm locally near the channel, but thinned rapidly away from the river toward backmarsh environments and downstream. The fine sand was apparently carried in suspension and deposited as flood-water velocities diminished across the levee. Deposition of silt and clay in backmarsh areas did not appear to be nearly as significant as sand deposition on the levees. This supports streamflow records that show a large reduction in suspended load (primarily silt and clay) since Lake Livingston was constructed in 1969. The deposited sand was apparently derived from scouring of the channel floor and erosion of point-bar sands downstream from the reservoir.

Delivery of large amounts of suspended sediments during flood events is supported by studies of Trinity River's suspended load. Rice (1967) determined that approximately 80 percent of the sediment discharged by the Trinity River in 1965 occurred during two major floods. The larger flood accounted for 59 percent of the year's total load. Significant deposition can take place on levees during flood events if river flood waters are carrying large sediment supplies. Sedimentation rates of levee environments along the Atchafalaya delta were correlated with annual flood events by van Heerden and others (1981), whose designations indicated that high rates of sedimentation exceeded 0.3 m (1 ft), medium rates ranged from 0.15 to 0.30 m (0.5 to 1 ft) and low rates were less than 0.15 m (0.5 ft) per annual flood.

Bay/channel margin markers in delta-front environments were subjected to large amounts of physical energy during storms and flood events. Although sediment accumulated above markers in this environment during the first spring, the markers were eroded during the second winter, indicating net erosion of the marsh surface and zero aggradation. These relatively high-energy environments are characterized by sandy substrates and annual vegetation. The dieback of vegetation in winter, coupled with extensive nutria bioturbation, intensify the impact of winter storms and produce a dynamic environment in which sediment is vigorously reworked by waves and currents. The delta front environments are near distributary channels and are modified by a combination of fluvial and estuarine processes, which can result in erosion or deposition as existing deltaic sediment is reworked during flood events.

Organics were a more significant component of the marsh sediments in the brackish-water marshes of the Trinity River delta than the salt-water marshes of the Colorado River delta. (This subject, organic and inorganic deposition, is treated more thoroughly in the literature synthesis [White and Calnan, 1989]). However, thick peat deposits that characterize marshes in the Mississippi River delta are apparently not a part of the Trinity River delta, probably for several reasons. Frey and Basan (1985) noted that very few marshes along the Gulf Coast have been studied in detail geologically, and suggest that the marsh sediments (except for the Mississippi delta complex) seem to be similar to those of the southeastern Atlantic coast, which were described as dominantly inorganic with insignificant amounts of peat. Suggested reasons for the absence of thick peat deposits are (1) tidal flushing, (2) rapid degradation of plant material by intense biologic activity, and (3) extremely slow rates of coastal warping or submergence. Comparison of total organics in sediments in Texas brackish marshes and salt marshes indicates lower concentrations than reported by Frey and Basan (1985) for Georgia salt marshes. In addition, textural composition of inorganic sediments in these Texas deltaic marshes differ somewhat from the Georgia marshes. Inorganic sediments of a representative southern Coastal Plain salt marsh (near Sapelo Island) contained approximately constant proportions of silt and clay, where maximum amounts, respectively, were 60 percent and 55 percent; sand is uniformly low in the low marsh with sand and muddy sand predominant in the high marsh (Frey and Basan, 1985). In the Colorado River delta study area, both intertidal and higher marshes located near sand-rich Matagorda Peninsula were expectably high in sand with concentrations near 80 percent. A levee marsh away from the peninsula along an active distributary channel (Tiger Island Cut), however, while siltier than lower marshes in the area, had a low sand content (< 5 percent). Sand content in sediment at this levee site increased to 22 percent, however, after Hurricane Gilbert; the increase indicates higher energy conditions at this site during the hurricane. In the Trinity delta study area, marsh sediments near the bay margins and levees were rich in sand and/or silt. Clay, which is most abundant in low-energy backmarsh environments, had a concentration at one site that is nearly 5 times higher than the combined sand and silt content at the site.

A seasonal change in vegetation type and cover is a significant process in some brackish marsh areas in the Trinity River delta. Relatively barren intertidal flats at one site, had become thickly vegetated with a seasonal bullrush *Scirpus olneyi* by July. At another site, a seasonal plant that is dominant during the fall, *Panicum dichotomiflorum* (fall panic), had declined and almost disappeared by March and was totally replaced by *S. olneyi, Bacopa* sp. and other species by mid summer. This seasonal variation can affect both organic and inorganic erosion, transport, and deposition. For example, the dieback of vegetation in winter increases the chances of erosion in delta-front environments during winter storms. Organic matter from the dead annual vegetation may be exported into the bay or it may be transported into more inland parts of the delta where it is trapped by perennial vegetation. During the spring and summer, thick stands of annual bullrush or other annual species help trap sediment and increase sedimentation.

According to subsidence rates reported by Swanson and Thurlow (1973) and Gabrysch (1984), marsh aggradation rates in these deltaic areas may have to average more than 10 to 11 mm per year to remain emergent. Predicted increases in global sea-level rise (Barth and Titus, 1984) may increase these minimal rates for marsh survival in the more distant future. Although short-term rates generally exceed rates of 11 mm/yr in levee and streamside marshes, long-term rates range from a low of 4.2 mm/yr in the Trinity delta to 7.6 mm/yr in the Colorado River delta.

Historical analysis of fluvial-deltaic and alluvial valley wetlands along the Texas coast indicates that vegetated wetlands are being replaced by water and barren flats in all of the deltas. The rate of replacement varies from less than 5 percent to about 50 percent for the period of analysis (generally from the mid 1930's to 1979 or later). Both the Colorado and Trinity deltas increased in size between the mid 1930's and mid 1950's, but the Colorado River delta is the only one of the seven analyzed that increased in total vegetated area after the mid 1950's (vegetation increased by about 2 percent between 1956 and 1982) (Fig. 61 and table 14). Although the eastern half of the Colorado delta is undergoing slow deterioration in which vegetated wetlands are being replaced by water and barren flats, the western half has increased in size due primarily to delta growth apparently as a result of marine, estuarine, and to a lesser extent, riverine processes. Other deltas had a reduction in total vegetated wetland area after the 1950's with the greatest losses occurring along the San Jacinto (40 percent reduction) and Neches (40 percent) rivers, and smaller losses occurring along the Trinity (30 percent), Lavaca (15 percent), Guadalupe (6 percent), and Nueces (3 percent) Rivers.

The total area of vegetated wetland loss in all areas studied amounts to about 8,100 hectares (20,000 acres),[3] with more than half occurring in the Neches River valley. Among the factors contributing to the losses are subsidence and associated relative sea-level rise, and reductions in sediments supplied to the wetlands not only as a result of reservoir development in river drainage basins, but also as a result of channelization and spoil disposal, which can prevent overbank flooding. Man-induced subsidence plays a major role along the San Jacinto River and possibly along the Neches River. Another factor that probably contributed to differences in areas of vegetated wetlands in the 1950's compared to the 1970's and 1980's is the drought that characterized the mid 1950's. Ponds, tidal flats, and other topographic lows may have supported emergent vegetation during the drought when water levels were lower, especially in brackish-water areas. After the drought, these areas would become constantly inundated and could revert to open-water bodies or barren flats. On the other hand, it is possible that lower water levels and reductions in fresh-water inflows during the drought increased salinities in tidal flats, particularly in salt-water marshes, leading to expansion of barren areas. Water and barren flats are more extensive on 1950's photographs than on the mid-1930's. Nevertheless, the degree to which the drought affected changes in vegetated wetlands remains speculative.

Reductions in sediment supplied to deltaic areas as a result of dams and water diversion upstream contributes to wetland losses, but there does not appear to be a one-to-one correlation between decreasing suspended sediment load along rivers and decreasing wetlands. Rivers with the largest reduction in suspended load are the Nueces, Colorado, Trinity, and probably San Jacinto and Neches. Although the Nueces River delta ceased its progradation into Nueces Bay sometime before

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[3] This total area includes losses along the Neches River reported by White and others (1987).

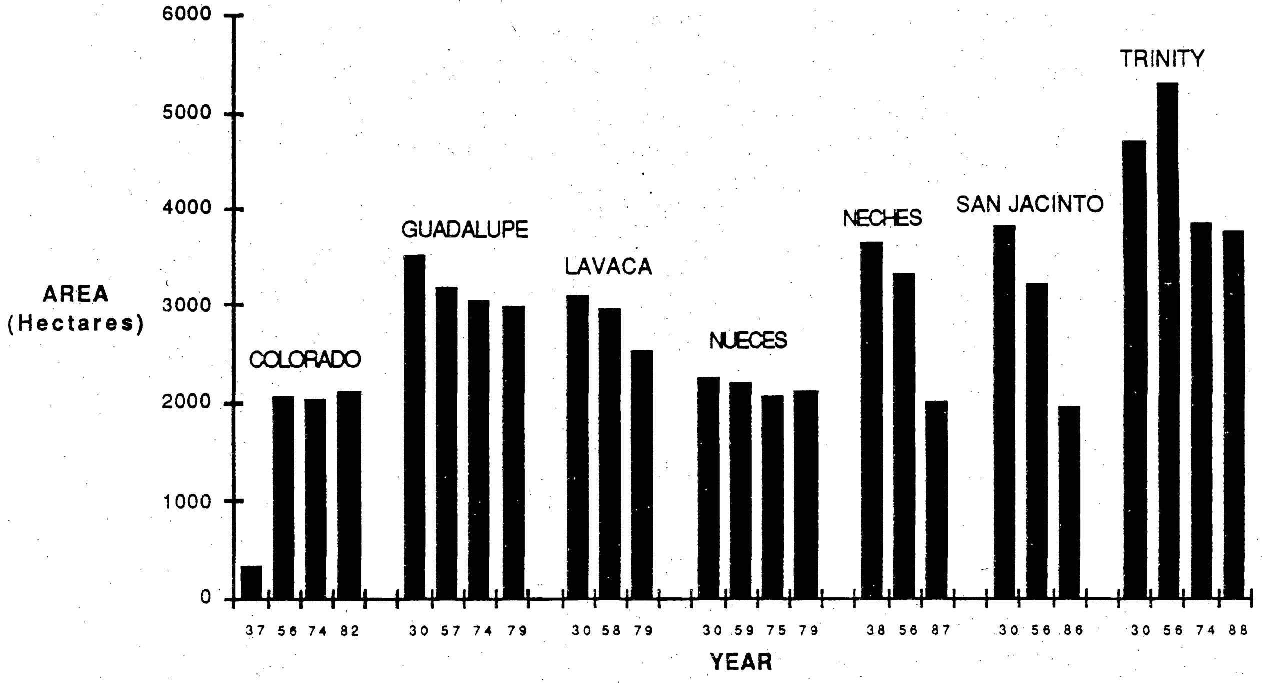

Figure 61. Summary of historical changes in vegetated wetlands in the seven fluvial-deltaic areas investigated.

Table 14. Areal extent of vegetated wetlands by river system and year.

| Fluvial-Deltaic Area and Year | Vegetated Area (Hectares) | Vegetated Area (Acres) |
|---|---|---|
| **Colorado River** | | |
| 1937 | 324 | 799 |
| 1956 | 2072 | 5117 |
| 1974 | 2050 | 5061 |
| 1982 | 2115 | 5222 |
| **Guadalupe River** | | |
| 1930 | 3510 | 8667 |
| 1957 | 3201 | 7903 |
| 1974 | 3048 | 7526 |
| 1979 | 3008 | 7428 |
| **Lavaca River** | | |
| 1930 | 3115 | 7690 |
| 1958 | 2962 | 7313 |
| 1979 | 2532 | 6252 |
| **Nueces River** | | |
| 1930 | 2261 | 5582 |
| 1959 | 2207 | 5449 |
| 1975 | 2076 | 5126 |
| 1979 | 2131 | 5262 |
| **Neches River** | | |
| 1938 | 3656 | 9027 |
| 1956 | 3314 | 8182 |
| 1987 | 2008 | 4958 |
| **San Jacinto River** | | |
| 1930 | 3809 | 9404 |
| 1956 | 3219 | 7948 |
| 1986 | 1960 | 4839 |
| **Trinity River** | | |
| 1930 | 4694 | 11589 |
| 1956 | 5290 | 13061 |
| 1974 | 3846 | 9495 |
| 1988 | 3757 | 9276 |

1959 (Morton and Paine, 1984), transformation of vegetated wetlands to nonvegetated wetlands is taking place very slowly (about 0.1 percent a year). The Colorado River delta has shown an overall gain in vegetated wetlands since the mid 1950's. Diversion of the Colorado River into Matagorda Bay, a project presently underway, should increase the rate of marsh expansion. About 65 percent of the loss in the Trinity River delta marshes is due to a power plant cooling pond constructed after 1956. Still, vegetated areas in the Trinity delta are undergoing a gradual transformation to open water and barren flats. This trend is supported by analyses that show long-term marsh sedimentation rates (average of 5.4 mm/yr) are lower than estimated subsidence rates (average 6.5 mm/yr for the years 1943 to 1978, Gabrysch, 1984). San Jacinto and Neches River alluvial valleys are undergoing the most rapid changes. Subsidence is the overriding factor in the San Jacinto area, which is near the center of maximum subsidence due to groundwater withdrawal in the Houston area (Gabrysch, 1984). In the Neches River valley, a combination of factors including subsidence, dredged channels, spoil disposal on levees, and reduction in sediments transported by the Neches River, are apparently contributing to wetland losses.

## CONCLUSIONS

Aggradation rates in the Colorado River delta salt-water marshes are similar to other Gulf coast salt marshes, where the highest rates occur in streamside areas (levee and bay margin) and lowest rates occur in backmarsh environments.

Aggradation rates in the Trinity River delta, while also displaying the general trend of higher rates on levees (streamside environments) than in backmarsh areas, are more variable than in the Colorado River delta. In addition, delta front/bay-margin areas, are dynamic environments characterized by seasonal changes in vegetation, intense bioturbation, and episodes of extensive, and apparently rapid, deposition and erosion as storm waters rework surface sediments.

There is a seasonal variation in marsh sedimentation with highest rates occurring in spring, summer, and fall, and lowest in winter when erosion may be associated with winter storms (frontal passage) and loss of vegetation.

Hurricanes can be major depositional events as demonstrated by Hurricane Gilbert, which during one year of the study accounted for more than 95 percent of the annual sediment deposition at a levee site, and an average of about 60 percent at other sites in the Colorado River delta.

Hurricane Gilbert was also an important depositional event in the Trinity delta, but it was overshadowed by near-record flooding along the Trinity River during the spring and summer of 1989. The river floods shifted the depositional pattern by accounting for more than 95 percent of the total sediment that accumulated on river levee sites, and a significant although lesser percentage (about 20 to 40 percent) in backmarsh environments.

Sedimentation rates in both the Colorado and Trinity deltas were inversely related to marsh elevations during storm-free periods. Topographically low, backmarsh environments had higher aggradation rates than levee environments because the lower elevations increased the frequency and duration of flooding. However, deposition on topographically higher levees during major flood events (hurricanes and river floods) essentially nullified the correlation between marsh elevation and sedimentation.

Long-term sedimentation rates in the Colorado River delta are higher than in the Trinity River delta. In the Colorado delta, these rates are apparently equal to or higher than rates of relative sea-level rise, but in the Trinity River delta relative sea-level rise (the major component of which is subsidence) appears to be surpassing sedimentation. These conclusions are consistent with historical analyses of trends in the deltaic wetlands, which indicate an overall increase in marsh area in the Colorado River delta, and an overall decrease in the Trinity River delta.

The general trend in fluvial-deltaic wetlands along the Texas coast is one in which vegetated wetlands are being replaced by water and barren flats. The most extensive losses of vegetated wetlands have occurred along the San Jacinto and Neches Rivers, which, together, account for more than 70 percent of the total losses documented. Losses of vegetated wetlands are significantly less along other rivers including the Nueces, Guadalupe, and Lavaca. Factors contributing to losses include (1) those processes that result in a rise in water level relative to the land's surface including man-induced subsidence, natural regional compactional subsidence, and global sea-level rise, and (2) those processes that tend to reduce sediment input into marshes including (a) reservoir development in river drainage basins, which reduces river sediment loads, and (b) channelization and disposal of spoil on natural levees, which can alter water circulation patterns and prevent overbank flooding.

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# APPENDIX A

Texas Parks and Wildlife Department Project
Marsh Transects

MARSH TRANSECTS -- COLORADO RIVER DELTA AREA

MARSH TRANSECT 1 (Near mouth of Culver Cut)
(Lat: 28 00' 30"; Long: 96 00' 32") 6/25/87, 4:00 - 6:00 pm

| Sta.# | Description | Distance from BM (feet) | Rod level/ H. Inst. (feet) | Rel. Elev. comp to BM (feet) | Rel. Elev. comp. to water (feet) | Compass Bearing | Comments | Tem/Sal/Con C/ppt/Mmhos | Vegetation/ other comments |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 32/1/25 | Temp, sal, cond, taken in open bay about 0.5 mi from transect |
| BM | COE bench mark | 0 | 4.12 | 0 | .94 | | BM .94'abve grn | | |
| 4 | berm | 27 | 3.5 | .62 | 1.56 | S83W | | | S. patens dominant, others Salicornia, Borrichia, Iva frutescens |
| 1 | | 100 | 4.78 | -.66 | .28 | N23W | | | Scirpus maritimus, 100% |
| 2 | marker bed | 200 | 4.84 | -.72 | .22 | | | | Distichlis spicata (85%), Scirpus maritimus (10%), Borrichia frutescens |
| 3 | marker bed | 300 | 4.75 | -.63 | .31 | | | | Spartina alterniflora (95%), Scirpus maritimus |
| | water (apprx) | | 5.06 | | 0 | | | | |

MARSH TRANSECT 1 WEST EXTENSION (toward Culver Cut from sta 3 above) (2/9/88, 10:00am-12:30pm)
(Lat.-Long. approx. same as above; tides were lower than during 6/25/87)

Larger circular Distichlis patch, height of Dist. 1.8-2'; scattered stunted S. a

| Sta.# | Description | Distance from 1B (feet) | Rod level/ H. Inst. (feet) | Rel. Elev. comp to 1B (feet) | Rel. Elev. comp. to water (feet) | Compass Bearing | Comments | Tem/Sal/Con C/ppt/Mmhos | Vegetation/ other comments |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 10.5/18.5/220x100 taken in Culver Cut | |
| 1B | post/alidade | 0 | 4.2 | 0 | 1.07 | N60E to sta. 3 | post Hght=3.0' | | This site approx. on levee, indistinct here, not much elevation change |
| 5 | | 28 | 4.16 | .04 | 1.11 | | | | From 1B to sta 5 - mixed Distichlis, Borrichia, Batis, sta 5 begins Distichlis dominance |
| 6 | | 50 | 4.25 | -.05 | 1.02 | | | | Circular patch of Distichlis (1.8-2'tall); scattered stunted S. alterniflora |
| 7 | | 72 | 4.25 | -.05 | 1.02 | | | | Distichlis (1.8-2' tall), edge of S. alter. appearance |
| 8 | | 75 | 4.25 | -.05 | 1.02 | | | | Edge of S. alter. (dead 3.2' tall, live 2') dominance to sta 3 |
| 3 | Same as 3 above | 108.6 | 4.33 | -.13 | .94 | | .25 square meter marker of red glitter added to northwest corner of marker bed site set on 6/25/87 (above) | | |
| 9 | | 19 | 4.25 | -.05 | 1.02 | S50W from 1B | toward Culver C | | Contact between S. alter. (1'tall); Scirpus maritimus (3-3.5') |
| 10 | | 35 | 4.67 | -.47 | .6 | | | | Pure S. alterniflora (dead 4' tall, live 2') |
| 11 | water level | 40.8 | 5.27 | -1.07 | 0 | | 12:20 pm, 2-9-88 | | edge of water in S. alter. (approx same height, a few stems up to 5.5') |
| 12 | edge S. alterniflora | 43.6 | 5.67 | -1.47 | -.4 | | | | edge of S. alter. along Culver Cut (dead 2.5', live 1.5') |
| 13 | marker bed | 12.3 | 4.05 | .15 | 1.22 | N6E from 1B | .25 sq. m of red glitter | | Batis (appr. 1.8' tall)-Aster subulatus? (2') codominant, D. spicata and S. patens on edge |
| 14 | marker bed | 23 | 4.49 | -.29 | | | | | |

MARSH TRANSECT 2 (Matagorda Peninsula near Zipprian Bayou)
(Lat: 28 36' 18"; Long: 95 59' 33") 6/26/87, 10:30 am - 2:30 pm
1st leg of transect

Iva, Phragmites, S. patens on higher levee along Culver Cut toward Intracoastal Waterway

| Sta.# | Description | Distance from 1MA (feet) | Rod level/ H. Inst. (feet) | Rel. Elev. comp to 1MA (feet) | Rel. Elev. comp. to water (feet) | Compass Bearing from 1MA | Comments | Tem/Sal/Con C/ppt/Mmhos | Vegetation/ other comments |
|---|---|---|---|---|---|---|---|---|---|
| 1MA | post/alidade | 0 | 4.2 | 0 | 1.42 | | | | Borrichia frutescens and Spartina patens, codominant |
| 1 | | 15.52 | 5.2 | -1 | .42 | N220W | | | Edge of Borrichia frutescens and Spartina patens, beginn. of Batis maritima |
| 2 | | 47.456 | 5.14 | -.94 | .48 | | | | Distichlis spicata dom., scat. B. frutescens and S. alterniflora |
| 3 | | 64.544 | 5.28 | -1.08 | .34 | | | | Edge of S. alternilfora dom.; scat. D. spicata, Salicornia, and Batis |
| 4 | marker bed | 91.648 | 5.62 | -1.42 | 0 | | | | S. alterniflora, approx. 60% |
| 5 | edge of marsh | 119.584 | 6.42 | -2.22 | -.8 | | | | Edge of marsh; S. alterniflora, about 20% cover (water 0.80ft deep) |
| 6 | | 16.512 | 4.9 | -.7 | .72 | S27E | | | Batis maritima dominant; scat. S. patens, Salicornia, & B. frutescens |
| 7 | | 29.824 | 4.54 | -.34 | 1.08 | | | | S. patens dominant (75%), B. frutescens (25%) |
| 8 | | 40.416 | 4.65 | -.45 | .97 | | | | Edge of S. patens, begin. of Batis dom.; scat. B. frutescens & Avicennia germinans |
| 9 | marker bed | 96.96 | 4.72 | -.52 | .9 | | | | Monanthochloe dominant (80%), Batis (20%), scat. Salicornia |
| 10 | | 150.56 | 4.64 | -.44 | .98 | | | | B. maritima (80%), scat. Salicornia, Distichlis, and S. alterniflora |
| 11 | | 227.872 | 4.72 | -.52 | .9 | | | | D. spicata and Batis codominant; edge of patch of Scirpus maritimus |
| | water level | | 5.62 | | 0 | | | | |

2nd Leg of Transect

| Sta.# | Description | Distance from 2MA (feet) | Rod level/ H. Inst. (feet) | Rel. Elev. comp to 2MA (feet) | Rel. Elev. comp. to water (feet) | Compass Bearing from 2MA | Comments | Tem/Sal/Con C/ppt/Mmhos | Vegetation/ other comments |
|---|---|---|---|---|---|---|---|---|---|
| 12 | | 205.728 | 5.54 | -1.28 | -.34 | S55W | N55E frm sta 11 | | Distichlis dominant, Batis abundant, Salicornia scattered; 90% cover |
| 13 | | 146.208 | 5.57 | -1.31 | -.37 | | | | Batis dom.; some Salicornia and S. alterniflora; 80 % cover |
| 14 | | 94.208 | 5.57 | -1.31 | -.37 | | | | Edge of S. alterniflora, Batis codominant |
| 15 | | 52.16 | 5.55 | -1.29 | -.35 | | | | S. alterniflora (100%); 80 % cover, wet substrate, mud veneer ovr sand |
| 16 | | 11.52 | 5.34 | -1.08 | -.14 | | | | Batis begins; Distichlis mixed with S. alterniflora twrd sta. 15 |
| 2MA | post/alidade | 0 | 4.26 | 0 | .94 | | | | Berm near shore; S. patens dominant; scat. Borrichia, clump of Iva frutescens |
| 17 | | 16.992 | 5.22 | -.96 | -.02 | N63E | | | S. alterniflora (100%); 90 % cover |
| 18 | | 44.96 | 6.4 | -2.14 | -1.2 | | water 1.2' deep | | Edge of S. alterniflora in water |
| | water level | | 5.2 | | 0 | | | | |

MARSH TRANSECT 3 (Col. Riv. Delta at Parker's Cut)
(Lat: 28 37' 15";Long: 95 58' 54") 6/26/87, approx. 4:30 pm

| Sta.# | Description | Distance from 3A (feet) | Rod level/ H. Inst. (feet) | Rel. Elev. comp to 3A (inches) | Rel. Elev. comp. to water (feet) | Compass Bearing from 3A | Comments | Tem/Sal/Con C/ppt/Mmhos | Vegetation/ other comments |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | profiling rods used to measure elevations | | |
| 3A | post (.9m high) | 0 | 0 | 0 | 1.44 | | dist. to bank | | |
| | water level | 23.68 | -1.44 | -17.28 | 0 | elev. correct? | frm top of bnk | | |
| 1 | | 20 | -.17 | -2 | 1.27 | N65W | | | Distichlis, Batis codominant; Borrichia and Lycium scat., height appx. 1.25' |
| 2 | | 40 | -.33 | -4 | 1.11 | | | | Batis and Borrichia codominant; height appx. 1' 2" |
| 3 | | 60 | -.42 | -5 | 1.02 | | | | Batis (1'2"), Lycium (1'8"), Borrichia (1'10") |
| 4 | | 80 | -.58 | -7 | .86 | | | | Batis (1'9") dominant, scat. Borrichia (1'10"), Lycium (2'to2'5"), Distichlis (2'), S. alt. (1'8") |
| 5 | | 100 | -.63 | -7.5 | .81 | | | | Batis (1'7"), Distichlis (2'4"), scat. S. alt. (1'7"), Borrichia (1'5"), (100% cvr) |
| 6 | | 120 | -.67 | -8 | .77 | N70W | | | Batis (1'6"), Distichlis (2'2") codominant; increase in S. alt. (2'4"), sparse Salicornia (1'7") |
| 7 | | 140 | -.69 | -8.25 | .75 | | | | Batis (1'8"), Distichlis (1'8") codominant, S. alt. (2'3"), 100% cvr |
| 8 | | 160 | -.71 | -8.5 | .73 | | | | Batis (1'8"), Distichlis (1'9"), codomin., scat. Salicornia (2'1"), S. alt. (2' 5") |
| 9 | | 180 | -.73 | -8.75 | .71 | | | | Batis (1'7") dominant, Distichlis (1'8"), S. alt. (2'6") |
| 10 | | 200 | -.69 | -8.25 | .75 | | | | Batis (2') dominant, Distichlis (2'), S. alt. (2'2") |
| 11 | | 220 | | | | | btwn 10 and 13 | | Distichlis dominant with scat. S. alt. and patches of Scirpus maritimus and Borrichia |
| 13 | | 400 | | | | | | | S. alterniflora (1'9") dominant from this point to edge of marsh |

Establishment of marker beds (white feldspar clay) on Transect 3, 12/17/87, 9:00 am, extremely low tides from "norther"
Temp. = 14 C, Sal. = 22 ppt., Cond. = 280 uMhos

| | | | | |
|---|---|---|---|---|
| 1st | post (3' high) | sta. 3A ( see above) | | |
| 1st | marker bed | 11'to post | N14E frm post 1 mb 28.5 to bnk | Distichlis dominant (48%), Batis (35%), Borrichia (20%), vegetation height > 2' up to 2'3" |
| 2nd | post(3'5.5 in) | 372' from 1st post | | |
| 2nd | marker bed | 13'10" from 2nd post | N63E pst to mb | S. alterniflora (2' to 2'3") 55%, Distichlis (1'4" to 1'7") 45% |
| 3rd | post | 650' from 2nd post | | |
| 3rd | marker bed | 17' from 3rd post | S32W pst to mb | 100% S. alterniflora (leaf tip up to 2'5"; stem and spikelet 3') |
| 4th | post (3'5in) | 712'from 3rd post | | Edge of S. alterniflora, beginning of mud flats/bay |

Establishment of elevations along transect 3 using planetable; 7/20/88, 1;23 pm, high tides

| Sta # | Description | Distance frm 3A (ft) | Rod level/ H. Inst. (ft) | Rel. Elev. comp to 3A (ft) | Rel. Elev. comp to wtr (ft) |
|---|---|---|---|---|---|
| water | Parkers Cut; 1:23 pm | -21.25 | 6.24 | -1.35 | 0 |
| 3A | 1st post and Marker | 0 | 4.89 | 0 | 1.35 |
| 1 | red flag | 200 | 5.53 | -.64 | .71 |
| 2 ' | 2nd post and Marker | 372 | 5.65 | -.76 | .59 |
| 2.2 | red flag | 572 | | -.88 | .47 |
| 2.3 | water level; 2:30 pm | 637 | | -.93 | .42 |
| 2.4 | red flag | 772 | | -.93 | .42 |
| 3 | 3rd post and marker | 1022 | | -.82 | .53 |

MARSH TRANSECT 4 (Matagorda Peninsula about 1.25 mi east of Phillips Bayou)
(Lat: 28 32' 10"; Long. 96 07' 20") 12/16/87, 11:45 am

| Sta.# | Description | Distance from 4A (feet) | Rod level/ H. Inst. (feet) | Rel. Elev. comp to 4A (feet) | Rel. Elev. comp to water (feet) | Compass Bearing from 4A | Comments | Tem/Sal/Con C/ppt/Mmhos | Vegetation/ other comments |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 10.5/24.5/260x100 | |
| 4A | post/alidade | 0 | 4.7 | 0 | 2.82 | N35E | post 2.29' | | |
| 1 | edge of water | 72.75 | 7.52 | -2.82 | 0 | | | | |
| 2 | top of sand berm | 56 | 7.1 | -2.4 | .42 | | behind oysters | | |
| 3 | seawrd edge of S. al | 44 | 7.3 | -2.6 | .22 | | | | S. alterniflora up to 4' high |
| 4 | lndwrd edge of S. al | 29 | 6.51 | -1.81 | 1.01 | | | | S. alterniflora up to 2' high |
| 5 | edge of S. patens | 23.5 | 5.87 | -1.17 | 1.65 | | | | S. patens (1.4-2.3' high, incrs. toward berm), mixed with scat. Fimbristylis |
| 6 | edge of patens | 47.5 | 5.55 | -.85 | 1.97 | S35W | | | S. patens mixed with Batis, Distichlis, Borrichia toward flats |
| 7 | edge of Monan. | 47.25 | 5.81 | -1.11 | 1.71 | | | | Monanthochloe bome prodominant |
| 8 | New bearing | 116.92 | 5.85 | -1.15 | 1.67 | S56W from 4A | | | Edge of Monanthochloe (short 6-7") and sand flat |
| 9 | edge of S. alt. | 150.25 | 5.98 | -1.28 | 1.54 | | | | patches of annual Salicornia in area, scat. Batis |
| 10 | Marker bed | 207.25 | 6.24 | -1.54 | 1.28 | | | | marker bed in dense S. alterniflora (1.7-1.9'), |
| 11 | edge of S. alt | 293.58 | 6.52 | -1.82 | 1 | | | | |

## MARSH TRANSECTS - TRINITY RIVER DELTA AREA

### MARSH TRANSECT 1 (mouth of Long Island Bayou)
(Lat: 29 46 54; Long: 94 44 10) 12-8-87, 1:54 pm (when water level measu

| Sta # | Description | Distance from 1A (feet) | Rod level H. Inst. (feet) | Rel. Elev. comp. to 1A (feet) | Rel. Elev. comp. to water (feet) | Compass Bearing | Comments | Tem/Sal/Con C/ppt/Mmhos | Vegetation/ other comments |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Panicum dichotomiflorum (fall panic) , Bacopa, scattered cyperus, Aster, Pluchea? |
| 1A | post(62cm)/alidade | 0 | 4.34 | 0 | .82 | (Alidade sta) | Height Instr. | | bare muddy sand |
| 1 | post (79cm high) | 175 | 4.61 | -.27 | .55 | S31W from 1A | | | |
| 2 | edge of water | 58.17 | 5.16 | -.82 | 0 | S85E from 1A | | | |
| 3 | marker bed, ctr. | 40.71 | 4.22 | .12 | .94 | S50W from 1A | | | fall panic appx. 4.2' hi |
| 1B | post/alidade | 175 | 4.3 | -.27 | .86 | S31W from 1A | Loc.=sta. 1 | | |
| 4 | marker bed, ctr. | 282.5 | 4.57 | -.23 | .59 | S32W from 1B | 107.5' from 1B | | Brass rod, 15.45cm high in NW corner of marker bed |
| 5 | sed. pan | 39.17 | 4.61 | -.27 | .55 | S51E from 1A | 34' from water | | |
| | | | | | | | 10' to edge veg | | |

### MARSH TRANSECT 2 (southeast of channel marker 16 on Trinity R.)
(Lat: 29 45' 54"; Long: 94 41' 33") 12-8-87, 4:05 pm

| Sta # | Description | Distance from 2A (feet) | Rod level H. Inst. (feet) | Rel. Elev. comp to 2A (feet) | Rel. Elev. comp. to water (feet) | Compass Bearing | Comments | Tem/Sal/Con C/ppt/Mmhos | Vegetation |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | thick mats of alligator weed between levee and marker,<br>scattered Phragmites on levee, some trees (willows), |
| 2A | post/alidade | 0 | 4.43 | 0 | 1.72 | N50E-Ch Mkr 16 | post 90cm high | | dead vines over Phragmites, some Bacopa near marker, |
| | waters edge | 43 | 6.15 | -1.72 | 0 | | | | other green leafy plant, probably swamp lilly (no flowers) |
| | cut bank | 21 | 4.8 | -.37 | 1.35 | | | | |
| 1 | top of levee | 19.33 | 3.9 | .53 | 2.25 | | sal. near (1.5m | | |
| 2 | marker bed | 200 | 4.74 | -.31 | 1.41 | N81W from 2A | from) marker = | 19/5/72x100 | sparse at mkr |
| | post(80.2cm high) | | | | | N79W post-marke | 13.25' to mkr c | | alligator weed |

### MARSH TRANSECT 3 (Northern shore of Old River near Round Lake)
(Lat: 29 48' 41"; Long: 94 46' 07") 12-9-87, 10:34 am

| Sta.# | Description | Distance from 3A (feet) | Rod level/ H. Inst. (feet) | Rel. Elev. comp to 3A (feet) | Rel. Elev. comp. to water (feet) | Compass Bearing | Comments | Tem/Sal/Con C/ppt/Mmhos | Vegetation/ other comments |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Old River TSC= | 17/0.5/10x100 | on levees--fluvial woodlands of chinese tallow, Phragmites, |
| | | | | | | | nearby pond = | 15/3/40x100 | scattered swamp lilly near pond |
| 3A | post/alidade | 0 | 4.58 | 0 | .52 | | post 75cm high | | |
| 1 | post(75cm also) | 53.8 | 4.23 | .35 | .87 | S13E from 3A | S6W to pile across channel | | post 9.92' from water's edge |
| 1a | waters edge | 63.75 | 5.1 | -.52 | 0 | | | | |
| 2 | marker bed | 19.25 | 4.6 | -.02 | .5 | S66W from 3A | under chinese tallow | | in cluster of chinese tallow; understory--swamp lilly, 32 plants in sq. m lilly < 30 cm h |
| 3 | post(103 cm high) | 156 | 4.43 | .15 | .67 | N14W from 3A | | | |
| 4 | marker bed | 136.75 | 4.45 | .13 | .65 | S2W from st 3 ( | 19.25' from 3) | | alligator weed low < 10 cm; corner of marker Echinochloa crusgalli? up to 70 cm, lowest 25 cm |

### MARSH TRANSECT 4 (northern shore of channel that connects Lost River with Trinity River)
(Lat: 29 48' 12"; Long: 93 43' 55") 12-9-87, 2:29 pm

| Sta.# | Description | Distance from 4A (feet) | Rod level/ H. Inst. (feet) | Rel. Elev. comp to 4A (feet) | Rel. Elev. comp. to water (feet) | Compass Bearing | Comments | Tem/Sal/Con C/ppt/Mmhos | Vegetation/ other comments |
|---|---|---|---|---|---|---|---|---|---|
| 4A | post/allidade | 0 | 4.86 | 0 | 1.22 | | | 17.5/0.0/25x10 | Area of alligator weed possibly in transition to open water; |
| 1 | top of berm/levee | 15 | 4.3 | .56 | 1.78 | | | | Thick growths of Phragmites on levee, also spiney aster, Paspalum; Sesbania across channel; |
| 2 | waters edge | 17.92 | 6.08 | -1.22 | 0 | | | | Location of post due W of USACOE Wallisville structure near locks, 50' toward Tri. R. from old |
| 3 | marker bed | 52.5 | 5.75 | -.89 | .33 | N15E from 4A | | | metal post on bnk marker site mostly barren mud flat; 1-2" water on east half of m.b.; |
| | | | | | | | | | subaerial on west half |

### MARSH TRANSECT 5 (East bank of Trinity River approx. 7 km upstream from confuence of Old River and Trinity R.)
(Lat: 29 48' 44"; Long: 94 43' 45") 12-9-87; about 3:30pm

| Sta.# | Description | Distance from 5A (feet) | Rod level/ H. Inst. (feet) | Rel. Elev. comp to 5A (feet) | Rel. Elev. comp. to water (feet) | Compass Bearing | Comments | Tem/Sal/Con C/ppt/Mmhos | Vegetation/ other comments |
|---|---|---|---|---|---|---|---|---|---|
| 5A | post/alidade | 0 | 4.62 | 0 | 1.46 | | nat. levee | | fluvial woodlands, willows, bald cypress, oaks, tallow, near cypress swamp; |
| | waters edge | 32.42 | 6.08 | -1.46 | 0 | | post 98cm high | 17/0.0/20x10 | Currents strong; local fisherman said river on rise; |
| | marker bed (ctr) | 21 | 5.22 | -.6 | .86 | S10W from 5A | | | recent deposit of mud at marker site (mud cracks)--few leaves |

### MARSH TRANSECT 6 (near mouth of east distributary of Old River Pass--edge of delta)
(Lat: 29 46' 54"; Long: 94 42' 18") 12-10-87, 10:30 am

| Sta.# | Description | Distance from 6A (feet) | Rod level/ H. Inst. (feet) | Rel. Elev. comp to 6A (feet) | Rel. Elev. comp. to water (feet) | Compass Bearing | Comments | Tem/Sal/Con C/ppt/Mmhos | Vegetation/ other comments |
|---|---|---|---|---|---|---|---|---|---|
| 6A | post/alidade | 0 | 4.54 | 0 | .76 | | post 66cm high | | |
| 1 | marker bed | | 4.92 | -.38 | .38 | S37W | | | sparse, stubby, dead, Scirpus olneyi |
| 2 | marker bed | 25.67 | 4.61 | -.07 | .69 | S72W from 6A | :N32E from 6B | | predominately alligator weed in this area |
| 3 | erosional scarp | 31.17 | 5.6 | -1.06 | -.3 | | 3.83' to mkr 2( | | water .3' deep |
| 6B | post | | | | | | 15' to mkr 1(ed | | |
| | water level | | 5.3 | -.76 | 0 | | | | |

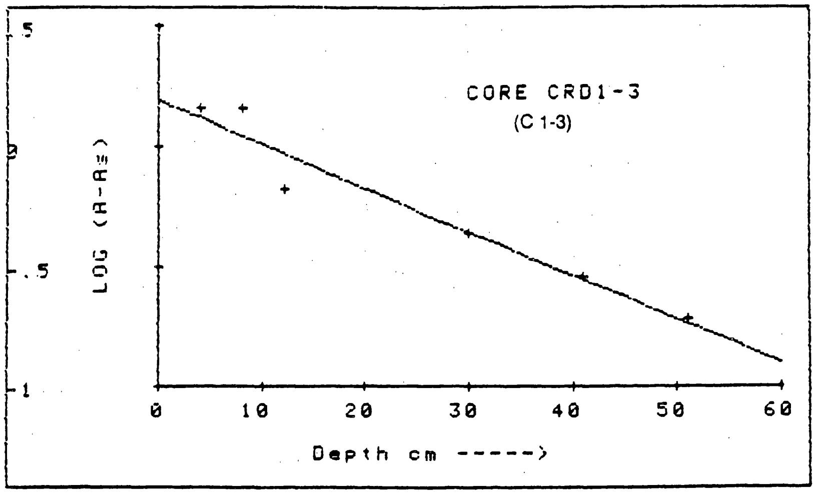
### MARSH TRANSECT 7 (near Smith Point)
(Lat: 29 32' 08"; Long: 94 46' 25") 12-10-87, 3:40 pm

| Sta.# | Description | Distance from 7A (feet) | Rod level/ H. Inst. (feet) | Rel. Elev. comp to 7A (feet) | Rel. Elev. comp. to water (feet) | Compass Bearing | Comments | Tem/Sal/Con C/ppt/Mmhos | Vegetation/ other comments |
|---|---|---|---|---|---|---|---|---|---|
| 7A | stake/alidade | 0 | 4.93 | 0 | 1.22 | | | | Spartina patens, scattered Iva frutescens on shell berm |
| 1 | post | ? | 5.58 | -.65 | .57 | S35W from sta 7 | | | base of berm and beginning of Juncus roemerianus |
| | edge of water | | 6.15 | -1.22 | 0 | S35W to post (1 | 25' frm st 1 | 20.5/15.5/230x1 | |
| | hi edge of S.altern. | | 5.65 | -.72 | .5 | | 15' from st 1 | | |
| | edge S.al trwd markb | 8.83 | 5.26 | -.33 | .89 | | | | contact S. patens and S. alterniflora, S. alt. continues to marker |
| | marker bed (ctr) | 37.33 | 5.89 | -.96 | .26 | S12E from 7A | 33.67 frm st 1 | | S. alterniflora |
| | edge water frm mb | 43.5 | | | | S22W wtr to mar | | | S. alterniflora |
| | edge water from mb | 34.25 | | | | N66W wtr to mar | | | S. alterniflora |

# APPENDIX B

## ABSTRACT OF RADIOCHEMICAL PROCEDURE FOR LEAD-210 ANALYSIS

The Pb-210 activity is determined radiochemically by assaying the beta activity of its daughter product Bi-210. Stable lead and bismuth carriers are added to the sample and it is leached with 6N hydrochloric acid. The sample is then filtered and the filtrate is evaporated, oxidized with nitric acid, and finally dissolved in 1.8N hydrochloric acid. The solution is passed through an anion exchange column. Lead is eluted first with 0.05N hydrochloric acid and with 9N hydrochloric acid, then bismuth is eluted with 2N sulphuric acid. The bismuth is precipitated as the oxychloride and is collected by vacuum filtration on a 1-inch glass fiber disc. The bismuth yield is determined gravimetrically. The filter disc is mounted on a nylon planchet and is covered with a Mylar film for beta assay in a low-level, gas flow geiger counter. The sample is recounted approximately 5 days later to check the sample for Bi-210 (5-day half-life) radioactive decay.



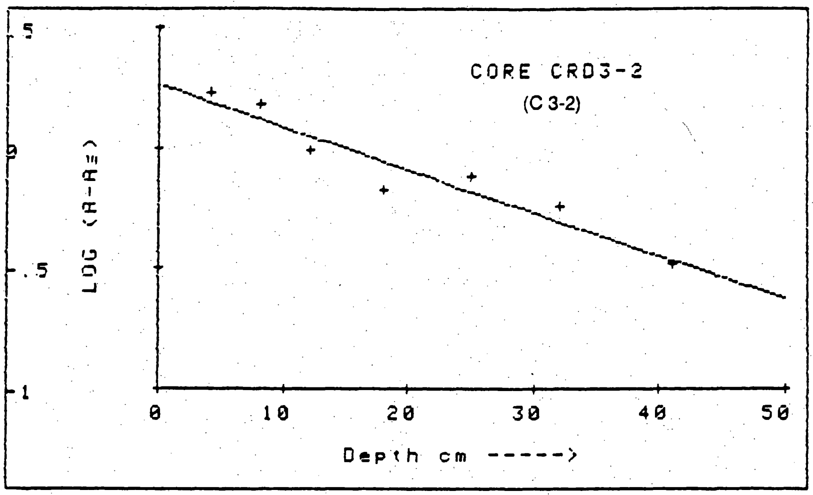
Supported Pb-210 (As) measured at 0.44 pCi/gm at 60-62 cm

Regression: Y = -0.0182X + 0.191

Correlation R square: 0.945

Inferred sedimentation rate: 0.74 cm/yr

| Depth cm | Pb-210 pCi/gm dry |
|---|---|
| 3- 5 | 1.8 +- 0.2 |
| 7- 9 | 1.8 +- 0.1 |
| 11-13 | 1.1 +- 0.1 |
| 17-19 | 0.46+- 0.10 |
| 29-31 | 0.88+- 0.14 |
| 40-42 | 0.72+- 0.16 |
| 50-52 | 0.63+- 0.18 |
| 60-62 | 0.44+- 0.07 |
| 74-76 | 0.83+- 0.14 |
| 88-90 | 0.84+- 0.13 |



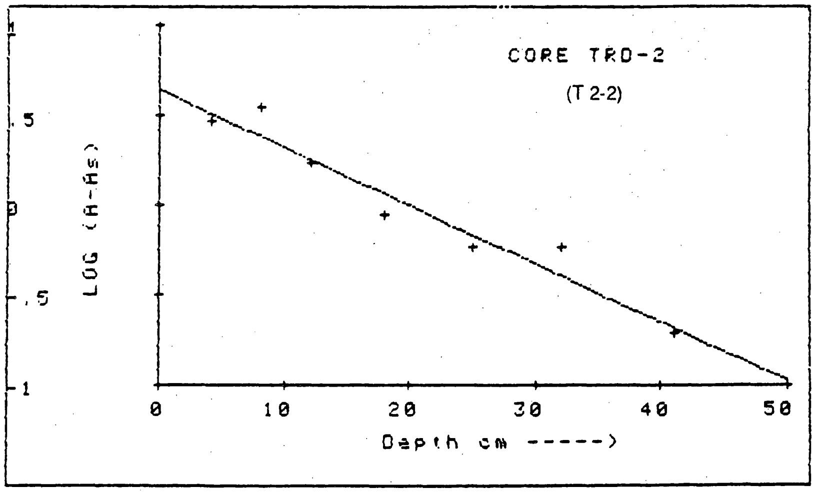
Supported Pb-210 (As) measured at 0.44 pCi/gm at 49-51 cm

Regression: Y = -0.0178X + 0.264

Correlation R square: 0.914

Inferred sedimentation rate: 0.76 cm/yr

| Depth cm | Pb-210 pCi/gm dry |
|---|---|
| 3- 5 | 2.1 +- 0.1 |
| 7- 9 | 1.9 +- 0.2 |
| 11-13 | 1.4 +- 0.1 |
| 17-19 | 1.1 +- 0.2 |
| 24-26 | 1.2 +- 0.1 |
| 31-33 | 1.0 +- 0.1 |
| 40-42 | 0.76+- 0.07 |
| 49-51 | 0.44+- 0.06 |



Supported Pb-210 (As) measured at 0.53 pCi/gm at 120 cm in core TRD3A

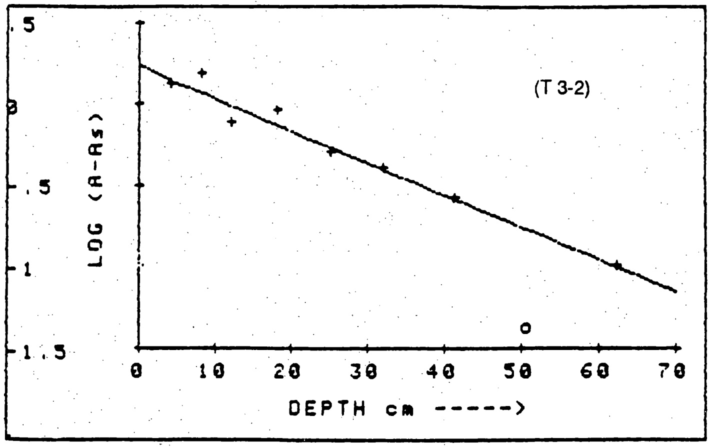
Regression: Y = -0.0322X + 0.641

Correlation R square: 0.939

Inferred sedimentation rate: 0.42 cm/yr

| Depth cm | Pb-210 pCi/gm dry |
|---|---|
| 3- 5 | 3.4 +- 0.1 |
| 7- 9 | 4.0 +- 0.2 |
| 11-13 | 2.2 +- 0.1 |
| 17-19 | 1.4 +- 0.1 |
| 24-26 | 1.1 +- 0.1 |
| 31-33 | 1.1 +- 0.1 |
| 40-42 | 0.72+- 0.06 |
| 50-52 | 0.23+- 0.05 |

TELEDYNE
ISOTOPES



Supported Pb-210 (As) measured at 0.6 pCi/gm in deepest sample.

Regression: Y = -0.0199X + 0.233

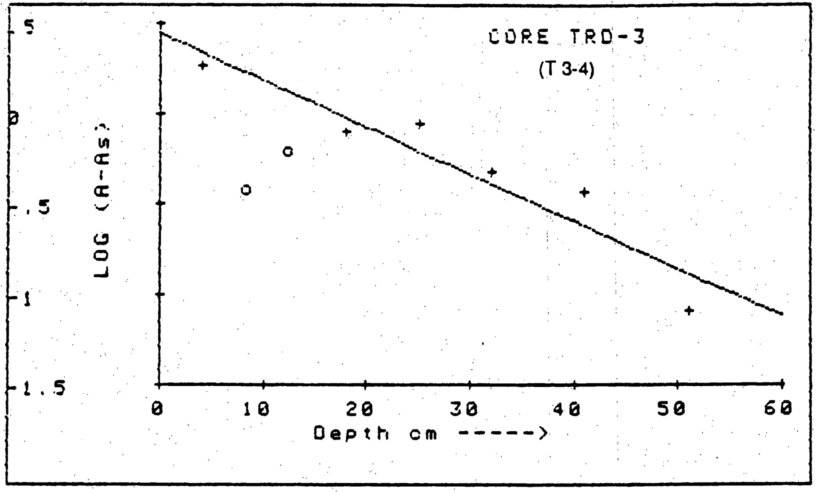
Data point at 50-52 cm ( labelled "o" ) was omitted from regression.

Correlation R square: 0.970

Inferred sedimentation rate: 0.68 cm/yr

| Depth cm | Pb-210 pCi/gm dry |
|---|---|
| 3- 5 | 1.9 +- 0.1 |
| 7- 9 | 2.1 +- 0.2 |
| 11-13 | 1.3 +- 0.1 |
| 17-19 | 1.5 +- 0.2 |
| 24-26 | 1.1 +- 0.1 |
| 31-33 | 1.0 +- 0.1 |
| 40-42 | 0.86+- 0.07 |
| 50-52 | 0.64+- 0.08 |
| 61-63 | 0.70+- 0.07 |
| 73-75 | 0.60+- 0.10 |

Bill White
TPWD
05/89



Supported Pb-210 (As) measured at 0.53 pCi/gm at 120 cm in core TRD3A

Anomalous points marked "o" were omitted from regression

Regression: Y = -0.0261X + 0.446

Correlation R square: 0.888

Inferred sedimentation rate: 0.52 cm/yr

| Depth cm | Pb-210 pCi/gm dry |
|---|---|
| 3- 5 | 2.3 +- 0.1 |
| 7- 9 | 0.88+- 0.07 |
| 11-13 | 1.1 +- 0.1 |
| 17-19 | 1.3 +- 0.1 |
| 24-26 | 1.4 +- 0.1 |
| 31-33 | 1.0 +- 0.1 |
| 40-42 | 0.89+- 0.09 |
| 50-52 | 0.61+- 0.10 |

# ANALYSIS REPORT

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(512) 471-7721 (ext. 426)

MINERAL STUDIES LABORATORY
BUREAU OF ECONOMIC GEOLOGY
THE UNIVERSITY OF TEXAS AT AUSTIN

DWK
DAVID W. KOPPENAAL, Ph.D
CHIEF CHEMIST

| INVESTIGATOR: | PROJECT/ACCOUNT: | DATE: | REPORT #: |
|---|---|---|---|
| Bill White | Texas Parks-Wildlife | May 11, 1988 | R-036-88 |

## SAMPLE PREPARATION / TREATMENT

The samples were air dried initially. Upon inspection of the dry samples the decision was made to wet sieve the samples to remove the large amounts of gross organic matter associated with the solid fraction of the sample. The remaining solid fraction was dried again, ground to a course product, and split using a sample splitter to yield a homogeneous starting material. One split ( approx. 20 g) was dried at 105 C for 24 hours to determine the moisture content of the dried solids. A second subsample (approx. 70 g) was treated with hydrogen peroxide for several days until no further reaction could be observed. The remaining solids were then wet sieved to separate the sand fraction from the silt/clay fraction. The silt/clay fraction was then centrifuged to remove the majority of the water, transfered to a volumetric cylinder, and the analysis for particle size determination by hydraulic separation (pipet method) was performed. The organic/inorganic carbon determinations were done on the initial split which was used to determine the moisture content

## SAMPLE ANALYSIS METHODS

| Constituents | Technique | MSL Procedure # |
|---|---|---|
| Texture | Hydraulic Separation | --------- |
| Organic Cabon | Coulometric Titration | SWI 1.7 |

## RESULTS

Table 1 contains the requested data for the samples.
Table 2 contains the gross sample data by weight.
Table 3 contains the replicate and reference data collected for the sample set.

< less than indicated value
* reported value near detection limit
nd - not determined
ins - insufficient sample

**COMMENTS**

The textural data is related only to the solid fraction of the sample. This fraction does not include the gross organic material or the water associated with the samples as recieved.

**SAMPLE DISPOSITION:**

The samples are to be archived.

**ANALYSTS:**

T. Pinkston TP
S. Tweedy SWT

## Table 1

### White/Calnan Textural Data (percentage)

| MSL ID#/ SPL ID # | SAND | SILT | CLAY | ORG. CARBON | INORG. CARBON |
|---|---|---|---|---|---|
| 88-480 / TRD 1-3 | 67.3 | 17.6 | 15.1 | 0.43 | 0.02 |
| 88-481 / TRD 1-4 | 25.7 | 39.0 | 35.3 | 1.28 | 0.00 |
| 88-482 / TRD 2-2 | 0.9 | 17.7 | 81.4 | 5.31 | 0.00 |
| 88-483 / TRD 3-2 | 4.3 | 21.3 | 74.4 | 4.60 | 0.02 |
| 88-484 / TRD 4-3 | 1.2 | 33.6 | 65.2 | 4.13 | 0.00 |
| 88-485 / TRD 5-1 | 7.8 | 53.1 | 39.1 | 0.95 | 0.01 |
| 88-486 / TRD 6-1 | 37.2 | 50.7 | 12.1 | 0.34 | 0.00 |
| 88-487 / TRD 6-2 | 4.6 | 54.7 | 40.7 | 1.77 | 0.00 |
| 88-488 / TRD 7-2 | 20.3 | 26.3 | 53.4 | 2.48 | 0.00 |
| 88-489 / CRD 1-2 | 4.6 | 26.3 | 69.1 | 4.28 | 0.17 |
| 88-490 / CRD 1-3 | 1.4 | 18.1 | 80.5 | 4.90 | 0.00 |
| 88-491 / CRD 2-4 | 76.5 | 7.4 | 16.1 | 0.77 | 0.00 |
| 88-492 / CRD 2-9 | 88.9 | 5.6 | 5.5 | 0.12 | 0.36 |
| 88-493 / CRD 3-1 | 4.8 | 52.7 | 42.5 | 1.06 | 1.50 |
| 88-494 / CRD 3-2 | 16.0 | 23.7 | 60.3 | 2.39 | 0.73 |
| 88-495 / CRD 3-3 | 3.6 | 30.5 | 65.9 | 3.20 | 0.47 |

Note: The sand/silt/clay percentages are relative only to solid fraction of the sample and not the entire sample.

## Table 2

White/Calnan Gross Sample Data
(grams)

| MSL ID#/ SPL ID# | GROSS ORG. | GROSS WATER | GROSS SOLIDS | GROSS SAND | GROSS SILT | GROSS CLAY |
|---|---|---|---|---|---|---|
| 88-480 / TRD 1-3 | 3.1 | 296.4 | 914.4 | 615.4 | 160.9 | 138.1 |
| 88-481 / TRD 1-4 | 31.0 | 413.8 | 545.5 | 139.9 | 212.7 | 192.9 |
| 88-482 / TRD 2-2 | 29.5 | 374.0 | 152.6 | 1.4 | 27.0 | 124.2 |
| 88-483 / TRD 3-2 | 49.1 | 222.0 | 208.9 | 9.0 | 44.5 | 155.4 |
| 88-484 / TRD 4-3 | 18.4 | 566.3 | 293.5 | 3.7 | 98.6 | 191.2 |
| 88-485 / TRD 5-1 | 7.9 | 327.7 | 620.5 | 48.4 | 329.5 | 242.6 |
| 88-486 / TRD 6-1 | 2.0 | 280.8 | 825.2 | 306.8 | 418.6 | 99.8 |
| 88-487 / TRD 6-2 | 17.2 | 304.1 | 520.0 | 23.7 | 284.6 | 211.7 |
| 88-488 / TRD 7-2 | 17.5 | 518.5 | 296.1 | 60.2 | 77.8 | 158.1 |
| 88-489 / CRD 1-2 | 11.0 | 450.1 | 273.2 | 12.6 | 71.8 | 188.8 |
| 88-890 / CRD 1-3 | 19.4 | 476.9 | 245.5 | 3.5 | 44.4 | 197.6 |
| 88-491 / CRD 2-4 | 36.4 | 399.1 | 737.6 | 564.0 | 54.7 | 118.9 |
| 88-492 / CRD 2-9 | 2.0 | 260.6 | 1004.4 | 892.9 | 55.8 | 55.7 |
| 88-493 / CRD 3-1 | 2.3 | 183.3 | 556.3 | 26.8 | 293.2 | 236.3 |
| 88-494 / CRD 3-2 | 6.3 | 408.2 | 316.0 | 50.6 | 74.8 | 190.6 |
| 88-495 / CRD 3-3 | 6.3 | 584.0 | 265.3 | 9.5 | 81.0 | 174.8 |

Note: Gross Sand + Silt + Clay = Gross Solids.
Note: Gross Organics are reported on a air-dried basis. This part of the sample consisted of plant matter except for sample 88-492/CRD 2-9 which consisted of marine shells primarily.

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DAVID W. KOPPENAAL, Ph.D
CHIEF CHEMIST

## Table 3

## Replicate and Reference Material Data (percentage)

| MSL ID# / SPL ID# | CLAY | ORG. CARBON | INORG. CARBON |
|---|---|---|---|
| 88-485-1/ TRD 5-1 | 39.4 | 0.95 | 0.01 |
| 88-485-2 | 38.7 | 0.96 | 0.01 |
| Average Value | 39.1 | 0.96 | 0.01 |
| Std. Dev. | 0.5 | 0.007 | 0.0 |
| % RSD | 1.3 | 0.7 | 0.0 |
| 88-489-1/ CRD 1-2 | 69.1 | 4.24 | 0.17 |
| 88-489-2 | 69.1 | 4.29 | 0.17 |
| 88-489-3 | | 4.32 | 0.17 |
| Average Value | 69.1 | 4.28 | 0.17 |
| Std. Dev. | 0.0 | 0.04 | 0.0 |
| % RSD | 0.0 | 0.9 | 0.0 |
| MRG-1 / Gabbro | | 0.01 | 0.27 |
| | | 0.02 | 0.27 |
| | | 0.03 | 0.27 |
| Average Value | | 0.02 | 0.27 |
| Accepted Value | | (see note below) | 0.27 |
| Bias | | | 0.00 |
| % Bias | | | 0.00 |

Note: There is no accepted value for organic carbon in this reference material, data is provided only to illustrate the precision of the data.

< less than indicated value
* reported value near detection limit

nd - not determined
ins - insufficient sample

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DWK
DAVID W. KOPPENAAL, Ph.D
CHIEF CHEMIST

| INVESTIGATOR: | PROJECT/ACCOUNT: | DATE: | REPORT #: |
|---|---|---|---|
| William A. White | Texas Parks & Wildlife | October 17, 1988 | R-053-88 |

## SAMPLE PREPARATION / TREATMENT

The samples were wet sieved to remove the large amounts of gross organic matter associated with the solid fraction of the sample. The remaining solid fraction was dried, ground to a course product, and split using a sample splitter to yield a homogeneous starting material. One split ( approx. 20 g) was dried at 105 C for 24 hours to determine the moisture content of the dried solids. A second subsample (approx. 70 g) was treated with hydrogen peroxide for several days until no further reaction could be observed. The remaining solids were then wet sieved to separate the sand fraction from the silt/clay fraction. The silt/clay fraction was then centrifuged to remove the majority of the water, transfered to a volumetric cylinder, and the analysis for particle size determination by hydraulic separation (pipet method) was performed. The organic/inorganic carbon determinations were done on the initial split which was used to determine the moisture content

## SAMPLE ANALYSIS METHODS

| Constituents | Technique | MSL Procedure # |
|---|---|---|
| Texture | Hydraulic Separation | --------- |
| Organic Cabon | Coulometric Titration | SWI 1.7 |

## RESULTS

Table 1 contains the requested data for the samples.
Table 2 contains the gross sample data by weight.
Table 3 contains the replicate and reference data.

## COMMENTS

The textural data is related only to the solid fraction of the sample. This fraction does not include the gross organic material or the water associated with the samples as recieved.

< less than indicated value
nd - not determined
* reported value near detection limit
ins - insufficient sample

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THE UNIVERSITY OF TEXAS AT AUSTIN

DAVID W. KOPPENAAL, Ph.D
CHIEF CHEMIST

**SAMPLE DISPOSITION:**

The samples are to be archived.

**ANALYSTS:**

S. Tweedy
L. Hay
T. McCoy

< less than indicated value
* reported value near detection limit
nd - not determined
ins - insufficient sample

## Table 1

### Sample Data
### (weight percent)

| MSL ID#/ SPL ID# | Organic | Inorganic | Sand | Silt | Clay | Total |
|---|---|---|---|---|---|---|
| | Carbon | | | | | |
| 88-715/ TRD1-3;7/88 | 0.62 | 0.00 | 80.6 | 6.5 | 9.1 | 96.8 |
| 88-716/ TRD1-4;7/88 | 1.33 | 0.00 | 31.7 | 32.5 | 25.2 | 90.8 |
| 88-717/ TRD2-2;7/88 | 6.05 | 0.00 | 0.9 | 21.6 | 56.0 | 84.6 |
| 88-718/ TRD3-2;7/88 | 4.64 | 0.00 | 8.7 | 24.8 | 54.2 | 92.4 |
| 88-719/ TRD3-4;7/88 | 4.60 | 0.00 | 11.8 | 24.2 | 48.7 | 89.2 |
| 88-720/ TRD4-3;7/88 | 3.10 | 0.00 | 4.0 | 36.9 | 46.6 | 90.6 |
| 88-721/ TRD5-1;7/88 | 0.94 | 0.02 | 10.3 | 50.5 | 33.4 | 95.2 |
| 88-722/ TRD6-1;7/88 | 0.66 | 0.01 | 43.8 | 25.5 | 14.6 | 84.6 |
| 88-723/ TRD6-2 | 2.34 | 0.00 | 2.7 | 51.8 | 37.1 | 93.9 |
| 88-724/ TRD7-2;7/88 | 2.06 | 0.00 | 18.7 | 28.6 | 43.4 | 92.8 |
| 88-725/ TRD7 Sed Pan | 2.64 | 0.00 | 5.4 | 27.2 | 53.0 | 88.3 |
| 88-726/ CRD1-2;7/88 | 4.03 | 0.31 | 5.1 | 25.7 | 55.8 | 91.0 |
| 88-727/ CRD1-3;7/88 | 5.50 | 0.04 | 7.3 | 23.1 | 51.5 | 87.4 |
| 88-728/ CRD1-4;7/88 | 1.72 | 2.55 | 32.9 | 33.0 | 28.8 | 99.0 |
| 88-729/ CRD2-4;7/88 | 2.16 | 0.16 | 32.7 | 19.0 | 38.5 | 92.5 |
| 88-730/ CRD2-9;7/88 | 0.18 | 0.33 | 87.6 | 5.2 | 4.4 | 97.7 |
| 88-731/ CRD3-1;7/88 | 0.80 | 1.52 | 6.4 | 58.3 | 32.8 | 99.8 |
| 88-732/ CRD3-2;7/88 | 2.86 | 0.88 | 13.6 | 27.5 | 44.8 | 89.7 |
| 88-733/ CRD3-3;7/88 | 3.50 | 0.00 | 2.4 | 33.1 | 47.3 | 86.4 |
| 88-734/ CRD4-1;7/88 | 0.67 | 0.03 | 85.5 | 5.1 | 7.1 | 98.3 |

## Table 2

### Gross Sample Data
(grams)

| MSL ID#/ SPL ID# | SPL WT. (rec'd) | SOLIDS (60 C.) | GROSS ORG. | GROSS WATER |
|---|---|---|---|---|
| 88-715/ TRD1-3;7/88 | 988.4 | 672.6 | 23.4 | 292 |
| 88-716/ TRD1-4;7/88 | 877.8 | 504.2 | 11.6 | 362 |
| 88-717/ TRD2-2;7/88 | 719.5 | 180.1 | 40.3 | 499 |
| 88-718/ TRD3-2;7/88 | 545.4 | 269.7 | 51.2 | 224 |
| 88-719/ TRD3-4;7/88 | 557.8 | 216.4 | 122.1 | 219 |
| 88-720/ TRD4-3;7/88 | 820.2 | 308.4 | 27.4 | 484 |
| 88-721/ TRD5-1;7/88 | 687.9 | 525.2 | 10.5 | 152 |
| 88-722/ TRD6-1;7/88 | 991.0 | 594.3 | 12.7 | 384 |
| 88-723/ TRD6-2 | 550.3 | 275.7 | 35.2 | 239 |
| 88-724/ TRD7-2;7/88 | 961.9 | 418.3 | 7.4 | 536 |
| 88-725/ TRD7 Sed Pan | 799.1 | 186.3 | 0.7 | 612 |
| 88-726/ CRD1-2;7/88 | 737.7 | 285.2 | 14.2 | 438 |
| 88-727/ CRD1-3;7/88 | 681.5 | 227.2 | 12.7 | 442 |
| 88-728/ CRD1-4;7/88 | 867.5 | 299.5 | 337.9 | 230 |
| 88-729/ CRD2-4;7/88 | 606.5 | 269.3 | 14.6 | 323 |
| 88-730/ CRD2-9;7/88 | 306.2 | 246.0 | 0.4 | 60 |
| 88-731/ CRD3-1;7/88 | 675.4 | 552.7 | 6.8 | 116 |
| 88-732/ CRD3-2;7/88 | 648.1 | 311.4 | 7.4 | 329 |
| 88-733/ CRD3-3;7/88 | 856.0 | 365.7 | 5.2 | 485 |
| 88-734/ CRD4-1;7/88 | 599.0 | 427.6 | 5.1 | 166 |

Note: Gross Organics are reported on a air-dried basis. This part of the sample consisted of plant matter except for samples CRD1-4 and CRD2-9 which consisted of marine shells primarily.

## Table 3

### Reference/Replicate Sample Data
### (weight percent)

| MSL ID# | MINERAL CARBON | TOTAL CARBON |
|---|---|---|
| 88-726-1 | 0.30 | 4.42 |
| 88-726-2 | 0.31 | 4.34 |
| 88-726-3 | 0.32 | |
| MEAN | 0.31 | 4.38 |
| STDEV | 0.01 | 0.06 |
| RELSTDEV | 3.23 | 1.29 |
| 88-728-1 | 2.63 | 4.18 |
| 88-728-2 | 2.45 | 4.27 |
| 88-728-3 | 2.60 | 4.30 |
| MEAN | 2.56 | 4.25 |
| STDEV | 0.10 | 0.06 |
| RELSTDEV | 3.77 | 1.47 |

| MSL ID# | MINERAL CARBON | TOTAL CARBON |
|---|---|---|
| MRG-1 | 0.27 | 0.30 |
| | 0.27 | 0.30 |
| | 0.28 | 0.29 |
| MEAN | 0.27 | 0.30 |
| ACCEPTED: | 0.27 | |
| BIAS | 0.00 | |
| %BIAS | 0.00 | |

Note: There is no accepted value for the total carbon content of reference material MRG-1. The data is presented here to illustrate the precision of the analysis.

# APPENDIX D

## Detailed Examination of Aggradation above Artificial-Marker Horizons,

## Trinity River Delta

During the first year of observation, organic debris accounted for most of the aggradation at stations T 3-2, 3-4, and 5-1. In fact, examination of the marker horizon at station 3-4 in March of 1988 (3.5 months after it was established), revealed that a drift line of organics, approximately 13 cm thick (primarily composed of plant stems), covered much of the marker horizon. (The driftline may have marked the boundary of high water associated with river discharges in January). The marker bed was still visable in patches indicating little or no inorganic sediment deposition. A second marker horizon along this marsh transect (station 3-2) was still exposed at the surface. The artificial marker at station T 5-1, located in a fluvial woodland assemblage on a natural levee of the Trinity River, was also still exposed, although partly covered with organic material, primarily twigs and leaves. In July 1988, accumulation of material at these three sites (T 3-2, 3-4, and 5-1) was still limited mostly to organics. The approximately 13 cm of relatively "fresh", loosely assembled organic debris deposited on marker 3-4 (observed in March) had decomposed and compacted to a layer approximately 1 to 2 cm thick by July 1988.

The largest amount of inorganic sediment deposition, during the first year, was measured at stations T 1-3 and 1-4. As previously described, transect 1 underwent extensive changes in seasonal vegetation. The marker bed at station 1-3 was affected by nutria-burrowing activity between December 1987 and March 1988 and although the marsh surface had been smoothed by natural processes by July 1988 (when the marker was trenched) the accuracy of the accumulation rate, although reasonable for this area, is uncertain. The high rate of aggradation of 22 mm in 7.5 months at nearby station T 1-4 is apparently related to estuarine sedimentary processes and perhaps the redistribution of sediments eroded from adjacent areas. Sediment deposited is primarily sand that was stabilized, and probably partially trapped, by Eleocharis parvula (dwarf spikerush). This site is near a distributary channel that connects to Old River. However, the source of the sand appears to be from existing adjacent deltaic deposits rather than from bed-load transport along the distributary. Erosion of the channel shoreline near this site is indicated from distance measurements made in March and July of 1988. The shoreline and adjacent vegetation line moved landward indicating erosion. Sampling of bottom sediments upstream along the distributary showed a fining of sediment grain size (sand to sandy mud to mud) toward Old River suggesting that the source of the sand, while undoubtedly fluvial originally, was probably not from upstream segments of this distributary channel. It is possible that previously deposited fluvial sand is being reworked into the mouth of the distributary by estuarine processes (tides, waves, and associated currents) and perhaps redistributed over the marsh surface through a combination of fluvial and estuarine processes. Extremely stong currents have been observed moving up Old River Cutoff from the Trinity River. In fact attempts to sample bottom sediments with a Ponar grab sampler along this channel were unsuccessful, apparently because of armoring of the bottom with shell material as a result of the strong currents. Clean sands were sampled along the bottom of Old River channel near Old River Lake suggesting that part of the Trinity bed load is deposited in this channel and perhaps in the lower reaches of Old River Lake. Bottom sediments in this area have not been systematically sampled, however.

By March 1989, marker horizons T 1-4, 1-3, and 6-1 had been removed by erosion. Measurements of the height of the brass rod at marker T 1-4 indicated that the marsh surface in this area had dropped (eroded down) about 4 cm between November 1988 and March 1989 for a net loss of almost 2 cm of sediment since December of 1987 (this net loss takes into account the 2.2 cm that accumulated above the marker from December 1987 to July 1988.). It should be noted that measurements using the brass rod may underestimate deposition and overestimate erosion because the rod can interfere with waves and currents, commonly resulting in a slight scouring of sediments near its base. For the period of December 1987 to July 1988 measurements of the rod height indicated only about 9 mm of deposition occurred, which is about half the average sediment thickness measured above the marker horizon for that period. Supporting evidence for the 4 cm of surface erosion between November 1988 and March 1989, however, was obtained from measurements of cedar posts placed along the marsh transect for elevation and location purposes. Measurements of the heights of three posts indicated the marsh surface had dropped from 2.7 to 4.8 cm, or an average of 4.1 cm. Measurements of the brass rod height in November 1988 (a month when the marker horizon was not trenched because of flooded conditions) indicated about 1.5 cm of erosion had occurred from July to November 1988, a period that includes Hurricane Gilbert. However, the additional 4.0 cm of sediment eroded between November 1988 and March 1989, indicates that considerably more erosion occurred during winter months than during Hurricane Gilbert.

A survey of transect 1 in June of 1989 after spring flooding, indicated surface sediments had been extensively reworked by wave and current activity. Vegetation was very sparse compared to July of the previous year. Measurements of the height of the brass rod indicated about 12 cm of sediment (predominantly sand) had been deposited. Large current ripples covered the surface where the marker horizon had been located. Heights of three cedar posts along the transect also indicated deposition of sand at thicknesses of 18, 9 and 3 cm. Deposition at one of the posts was the result of a sand wave that migrated toward the northwest across the surface burying the base of the post in about 18 cm of sediment. The down-current margin of this apron of sand was in the form of a series of scallop-shaped coalescing fans that marked the forward edge of movement. A survey of the larger parabolic lobe on which this particular marsh transect was established indicated a series of en echelon subaerial bars and troughs, that were roughly oriented northeast-southwest. This site is on the western margin of Long Island Bayou, a distributary/tidal inlet that connects to Old River Cut Off, which is an active distributary of the Trinity River. When the area is flooded by high river flow and wind tides, southeast winds blowing across bay waters apparently produce wave trains that break over the surface of this delta-front sand lobe, building it up and transporting sediment toward a shallow embayment or tidal flat located on the northwest side. A sediment pan located on the tidal flat was completely buried in sandy mud in June 1989.

Extensive changes in surface conditions and vegetation were observed at transect 1 (stations T 1-3 and T 1-4) in mid August of 1989, after extreme flooding had occurred along the Trinity River, and after Hurricane Chantal crossed the coastline in the vicinity of Trinity Bay. Sediment at both stations T 1-3 and T 1-4 was predominantly sand (estimated as greater than 80 percent) indicating high-energy conditions. The sandy surface was almost barren with only scattered patches of vegetation (Scirpus sp.), which was in marked contrast to the past summer when vegetation was abundant. The brass rod used to measure aggradation at station T 1-4, as well as a nearby cedar post used for site location and elevation measurements had been removed apparently by strong waves and currents. Two other cedar posts along the marsh transect in slightly more protected areas were still in tact, but significant reworking of sediment had occurred at their bases. Measurements at the posts in June and August 1989, indicated that 26 cm of deposition had occurred at one post, and 10 cm of erosion at the other, during this approximately 2-month period. The posts are located about 53 m (175 ft) apart. Similar to the surface features that were observed in June, sand had been transported across this delta front lobe toward the northwest and into the shallow embayment that had been previously floored by sandy mud. The migration of sand waves across the marsh surface influenced the amount of erosion or deposition that was measured at the posts. One post, whose base had been engulfed by a migrating sand wave, registered deposition, whereas the second post located in an interlying trough indicated erosion. A post that had registered deposition of 18 cm in June, registered 10 cm of erosion in August; accordingly, the net change was sediment deposition of 8 cm. Again, this delta front environment characterized by annual vegetation, is in a dynamic area. Changes appear to be most extensive during river/distributary flooding and winter storms, when sediment is vigoriously reworked by both distributary channel and estuarine processes.

Another site along the margin of the delta is marsh transect 6, which is near the mouth of a modified (dredged along its upper reaches) and probably inactive distributary channel. Two marker horizons were established at this site (Fig. 5) in December 1987. Inspections of the site in March 1988 indicated that the topographically higher marker horizon (T 6-2) had been eroded. Other evidence at the site, specifically organic debris snagged on Sesbania, indicated bayward moving currents had probably eroded the bed. Measurements of an erosional scarp bayward of the marker showed about 1 m of lateral erosion (retreat of the shoreline) had occurred during this 3.5 month period. The marker at station 6-1 was still visible at the surface indicating neither erosion or significant deposition. Parts of the marker had been disturbed by nutria burrows, but most of it was still usable as a horizon to measure aggradation. Trenching of the horizon in July 1988 indicated 4.3 mm of sediment had been deposited. This site had undergone extensive seasonal changes in vegetation. A temporary marker of red aluminum glitter, which had been established in March 1988 near the marker that had been eroded (T 6-2), indicated about 1 mm of deposition by July 1988. This site, dominated by alligatorweed, is slightly higher than station T 6-1. (A marker of white feldspar clay [T 6-2A] was re-established in this area in July 1988.) Measurements of the erosional scarp that had retreated (eroded) near this site between December and March showed no change in position between March and July, indicating a seasonal component to the erosion. Erosion during winter months was confirmed by later measurements that showed that the scarp retreated an additional meter between November 1988 and March 1989. Because the position of the scarp did not change between July 1988 and November 1988, a period that included Hurricane Gilbert, it appears that winter storms are responsible for the erosion. The amount of sediment (inorganic and organic) that accumulated at marker T 6-2A from March 1988 to July 1988, was equal to the amount that accumulated from July 1988 to March 1989. However, the amount changed significantly during the spring and early summer of 1989 (March to August), when approximately 6 times as much material accumulated above the marker horizon. This significant change can be attributed to river flooding and Hurricane Chantal.

The marker horizon documenting the highest rate of sediment accumulation during the first year of observation in the Trinity River delta is at station T 4-3 north of Old River Cutoff. Approximately 2.8 cm of sediment was deposited at this site over the 7.5 month period of observation. This site is on the margin of a pond near a levee along the Old River Cutoff channel. The reason for the high rate of deposition is probably related to the location of this site near these features. The flank of the levee is highly burrowed by nutria, and although heavily vegetated with Phragmites and other plants, this topographic high is probably a local source of the sediments that are deposited near the base of the levee on the margin of the pond. This site is also subject to inundation and sediment deposition, as water in the pond rises and falls. The high clay content of the soil at this site indicates the deposition of fine particulate matter during the waning stages of each inundation. Still the higher silt content of the sediments compared to stations T 3-2 and 2-2 perhaps reflects the proximity of this site to the levee. This area is hydrologically connected to Old River, however, and does not require overbanking of the levee to be flooded. In July, another marker horizon (4-extension) was established on the levee across the channel from this site to assist in recording deposition associated with any flood events that occurred in the spring of 1989. This levee marker apparently was not flooded until late spring and early summer. By March 1989, no significant deposition had occurred on the marker, which was still visible in patches at the surface. By late June 1989, however, about 2 cm of sediment (organic and inorganic material) had accumulated above the marker, and was apparently related to spring flood events. In August 1989, the marker horizon was trenched again but the thickness of the sediment was still about 2 cm, indicating no additional deposition at this site during the period that included additional flooding along the Trinity River and Hurricane Chantal.

Station T 2-2 is located approximately 61 m (200 ft) away from the crest of the natural levee along the Trinity River. Approximately 19 mm of sediment accumulated at this location from December 1987 to August 1989, a period of almost 20 months. The amount of sediment that accumulated was lowest during winter months of December 1987 to March 1988, and highest during the spring and summer of 1989 (March to August). Visual inspection of the accumulating sediment at this site indicated high amounts of organics. Laboratory analysis of the marsh sediments collected in March 1988 near the marker horizon showed it to contain the highest percentage of organics (> 5 percent) of any sediment sample analyzed. The plant biomass (as visually estimated from plant density) increases toward the levee from the marker bed. Thick mats of living and dead plant material, composed predominantly of alligatorweed, characterize the vegetative zone between the artificial marker and the river channel.

At the Smith Point salt-water marsh, located about 35 km south of the Trinity River delta, approximately 3 mm of sediment accumulated above the artificial-marker horizon during the initial 7.5-month period (December 1987 to July 1988). However, the rate of accumulation increased in late summer and fall, exceeding 12 mm/yr for the period of December 1987 to March 1989. This rate is similar to rates of some Spartina alterniflora marshes monitored on the Colorado River delta. A new marker horizon was placed at this site in March 1989 because the old marker was becoming more and more difficult to identify, probably due to bioturbation. The marker was trenched in June 1989, but results are suspect because the site was flooded and measurements were only partially successful. Using data on sediment accumulation for both the old and new markers, however, a rate of slightly more than 17 mm/yr was obtained for the period of record (December 1987 to June 1989). Using the brass rod at this site during a succeeding trip in August 1989, yielded a rate of 16.8 mm/yr for the period of December 1987 to August 1989. This rate is substantially higher than the rate for Spartina alterniflora marshes in the Colorado River Delta, and may indicate deposition during Hurricane Chantal, and during higher bay water levels caused by river discharge in the spring and early summer of 1989.

Marker horizons were flooded in November 1988 due to high tides, and only one marker, T 5-1, was trenched to measure sediment deposition. Approximately 1.7 mm of predominantly inorganic sediment had accumulated above the horizon since July 1988, but it represented about 75 percent of the total deposition since December 1987, and is attributed to Hurricane Gilbert, which apparently flooded all beds for a period of about 3 days in September 1988. Organic debris of loose, dry leaf litter and twigs also covered the marker, but because it was not physically combined with the underlying sediment, this material was not measured. Marker horizon T 5-1 was trenched again in June 1989 and an average of about 15 mm of sediment, largerly organic debris mixed with an apparent lesser amount of inorganic sediment, had been deposited above the marker horizon. Inorganic and organic sediment were mixed together in a well-defined layer above the marker. This relative thick deposit, which represented more than 85 percent of the total deposition since December 1987 can be attributed to flooding along the Trinity from March to June 1989. In August 1989, sediment that had accumulated above T 5-1 was measured again. The average sediment thickness above the artificial marker was 6.9 cm, indicating that 5.4 cm of sediment had been deposited since the June measurement two months earlier. This relatively thick deposit, which represents about 95 percent of the total deposition since December 1987, can be attributed to flooding along the Trinity during the latter part of June and early July. Releases from Lake Livingston on the Trinity River exceeded 70,000 cfs in July 1989; most of the sediment may have been deposited during this near record flood. Measurements at marker horizon T 5-2 located about 6.5 m (21 ft) landward of T 5-1, however, indicated no additional deposition after June of 1989, when a sediment thickness of about 1 cm had been recorded. This suggests that deposition along the river during the July flood event occurred primarily near the channel in this area, and the sediment may have been locally derived from bank and channel erosion. At another natural levee site downstream along Anahuac Channel (transect 2) deposition was much less than at T 5-1. This marker horizon (2A) was established in March 1989, and was located about 4.3 m (14 ft) from the channel cutbank. By late June only about 1 mm of sediment had accumulated on the marker, but by mid August an average thickness of about 16 mm of sediment was measured, indicating about 15 mm of deposition between June and August 1989. The sediment was clean, very-fine grained sand and was apparently deposited by the near record flooding in July. During this same period (June to August) the thickness of material accumulating above marker horizon T 2-2, located in the backmarsh about 61 m (200 ft) from marker 2A, averaged less than 1.5 mm. The sediment was composed predominantly of mud and organic material. The thinness of the deposit indicated that only a small amount of sediment reached this area during the extreme flood event that occurred in July 1989, and during Hurricane Chantal. Nevertheless, sediment accumulation during the period that encompassed these events (March to August 1989) exceeded the amount deposited during preceding periods.

Observations along the Trinity River downstream from Old River Cutoff in August 1989 showed a substantial amount of clean, fine sand deposited on natural levees (deposition probably occurred upstream as well, but upstream sites were not examined). One survey along the western side of the river approximately 1.1 km (0.7 mi) downstream from Old River Cutoff showed sand deposits as thick as 25 cm about 5.2 m (17 ft) from the channel cut bank; sediment thickness decreased away from the levee toward the backmarsh. At 22 m (72 ft), a thin deposit of muddy sand about 2 cm thick was measured, and at about 27 m (90 ft), less than 0.5 cm of sandy mud had been deposited. Measurements of the sand thickness on the west side of the channel approximately 2 mi downstream from Old River Cutoff showed the deposit to be considerably thinner near the channel than noted above. At a distance of about 14 m (45 ft) from the channel margin, the thickness of the fine sand was about 3 cm; at 27 m (90 ft) from the channel the deposit was about 1.5 cm thick and composed of a mixture of sand and mud. It appears that the fine sand was carried in suspension, and as flood waters crossed the levee velocities decreased rapidly depositing the sand. This cursory survey indicated that the sand deposits thin rapidly away from the river toward backmarsh environments and downstream. It also appears that silt and clay deposition in backmarsh areas (based on measurements at marker horizon T 2-2) was not nearly as significant as sand deposition on the levees. This supports streamflow records that show a large reduction in suspended load (primarily silt and clay) since Lake Livingston was constructed in 1969. Sand deposited on the levees was apparently derived from scouring of the channel floor and erosion of point-bar sands downstream from the reservoir.

## APPENDIX E

## Materials and Sources

### Aerial photographs used to digitize vegetation and water/barren flat areas.

| Date | Name | Source |
|---|---|---|
| *Nov. 1929 | Black-and-white mosaics, 1:24,000 | Tobin Research, Inc. |
| 1930-1931 | Black-and-white mosaics, 1:24,000 | Tobin Research, Inc. |
| 1938 | Black-and-white mosaics, 1:24,000 | U.S. Dept. of Agriculture, |
| 1956-1959 | Black-and-white mosaics, 1:24,000 | Tobin Research, Inc. |
| 1974 | Black-and-white stereo pair, 1:24,000 | General Land Office of Texas |
| 1975 | Black-and-white stereo pair, approx. 1:25,000 | U.S. Dept. of Agriculture |
| 1979 | Color-infrared stereo pair, 1:66,000 | Environmental Protection Agency |
| 1982 | Color-infrared 1:24,000 | General Land Office of Texas |
| 1986 | Color-infrared slightly < 1:24,000 | Texas Highway Department |
| 1987-1988 | Color-infrared, 1:24,000 | Texas Highway Department |

*Cited as 1930

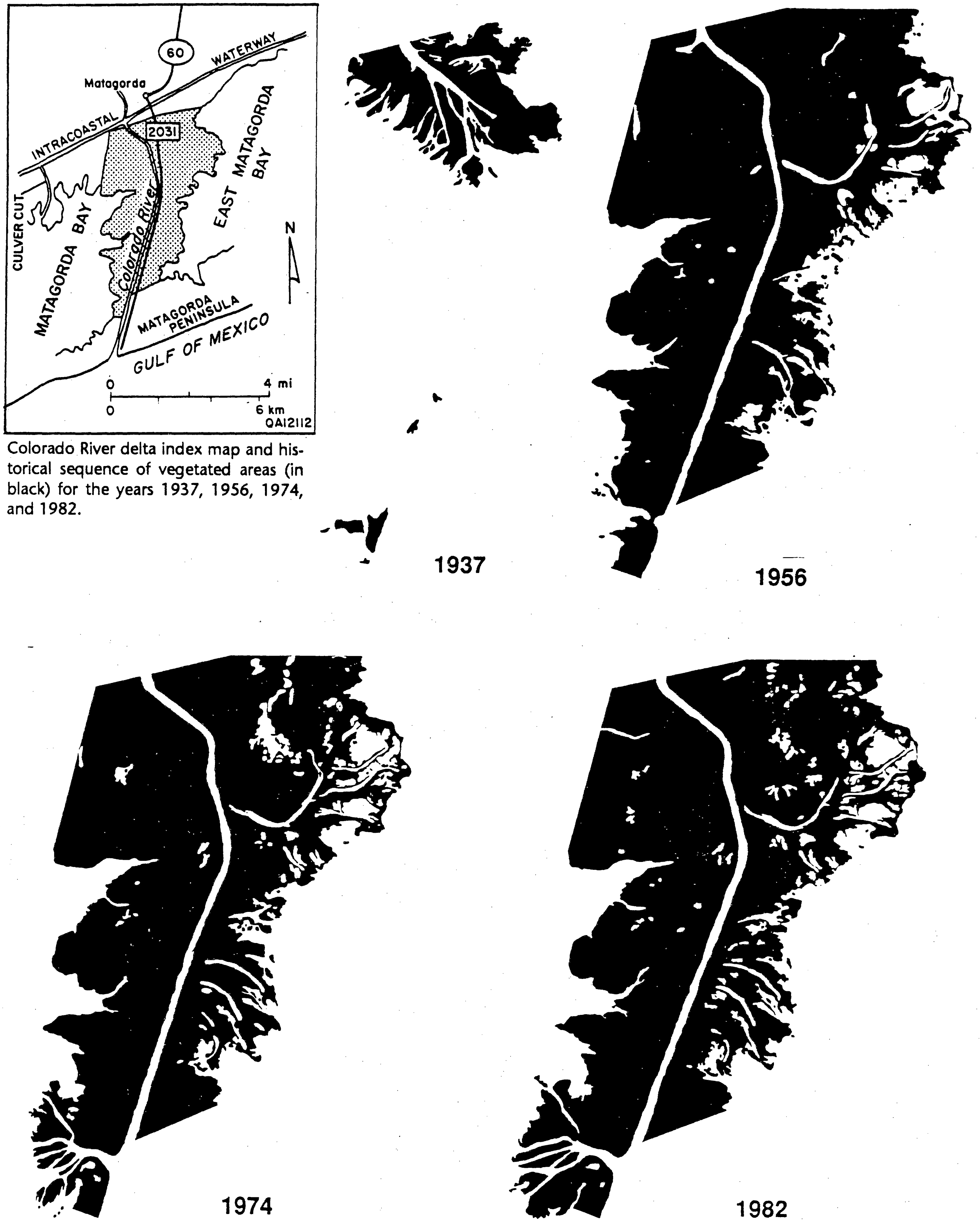
### Aerial photographs used for each river delta.

| Dates | Delta |
|---|---|
| 1929-1931 | Nueces, Guadalupe, Lavaca, Colorado, San Jacinto, Trinity |
| 1938 | Neches |
| 1956-1959 | Nueces, Guadalupe, Lavaca, Colorado, San Jacinto, Trinity, Neches |
| 1974 | Guadalupe, Trinity |
| 1975 | Nueces |
| 1979 | Nueces, Guadalupe, Lavaca, Colorado |
| 1982 | Colorado |
| 1986 | San Jacinto |
| 1987 | Neches |
| 1988 | Trinity |

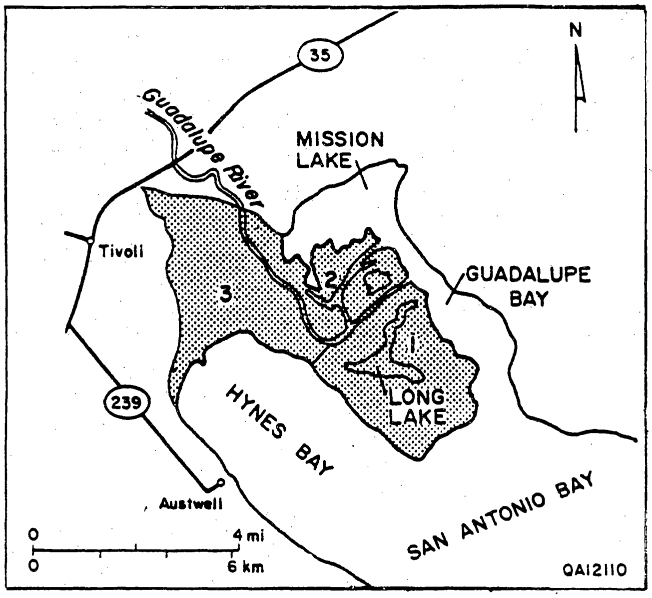
### U.S. Geological Survey 7.5-minute quadrangle maps used to construct base maps.

Anahuac (Trinity delta)
Annaville (Nueces delta)
Austwell (Guadalupe delta)
Beaumont East (Neches delta)
Corpus Christi (Nueces delta)
Cove (Trinity delta)
Highlands (San Jacinto delta)
LaPorte (San Jacinto delta)
Lolita (Lavaca delta)
Matagorda (Colorado delta)
Matagorda SW (Colorado delta)
Odem (Nueces delta)
Orangefield (Neches delta)
Point Comfort (Lavaca delta)
Taft (Nueces delta)
Terry (Neches delta)

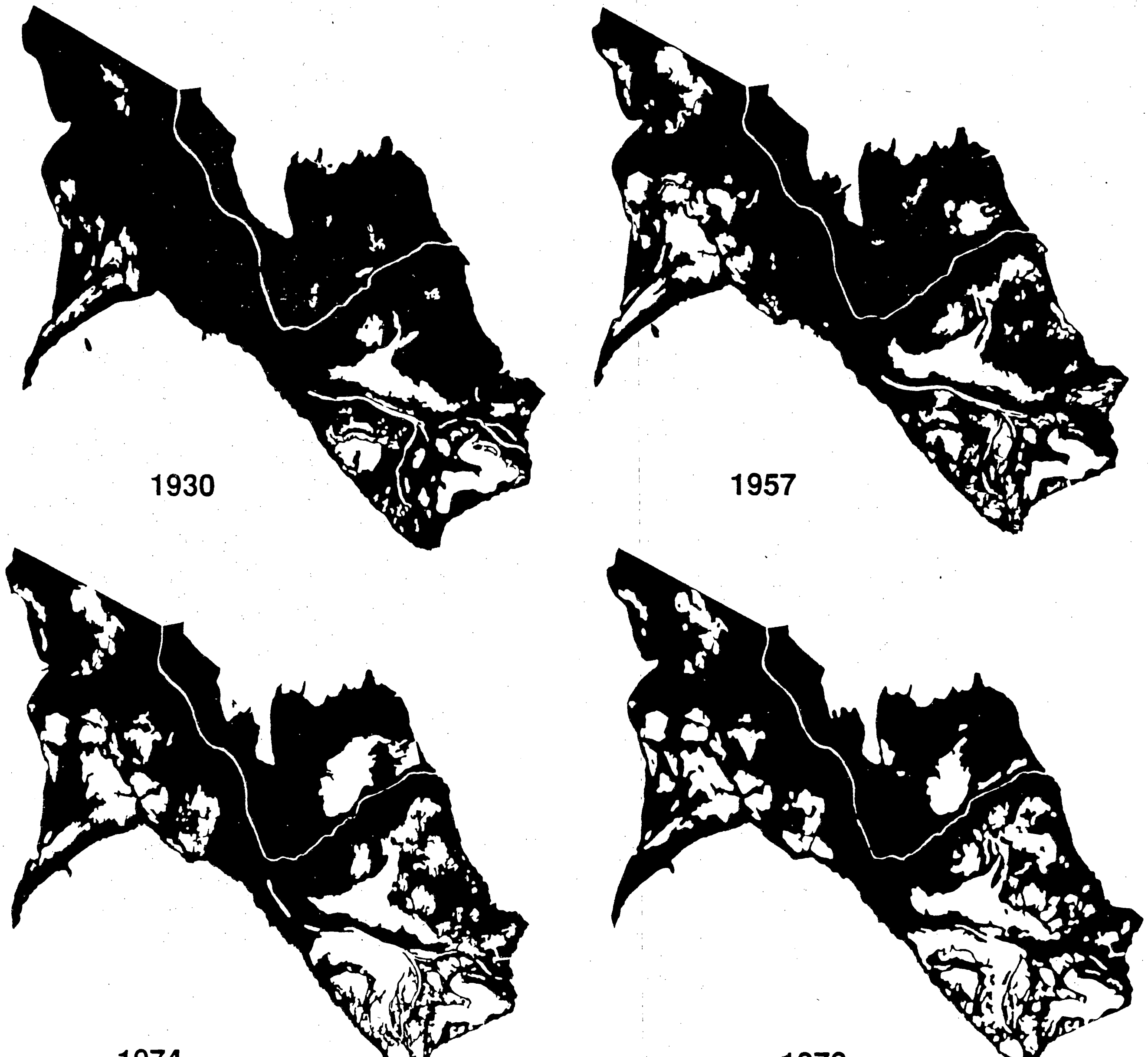
# APPENDIX F

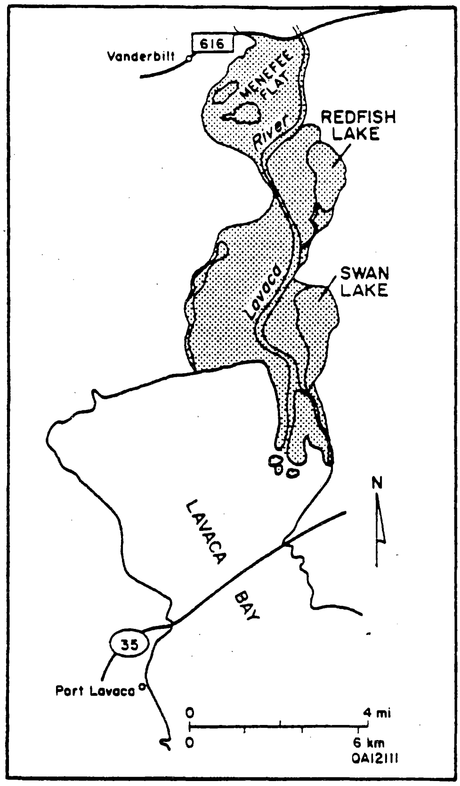


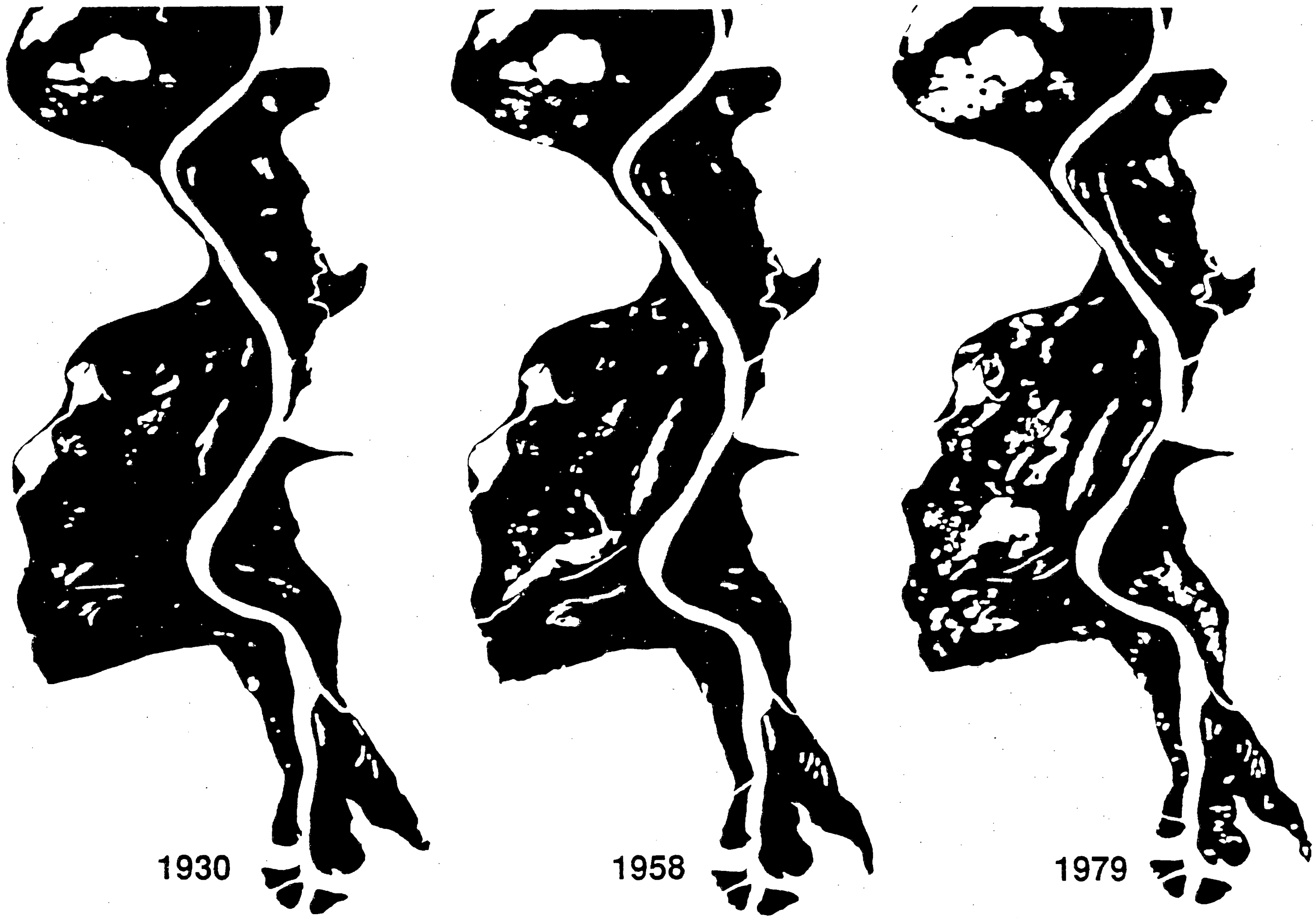
Colorado River delta index map and historical sequence of vegetated areas (in black) for the years 1937, 1956, 1974, and 1982.



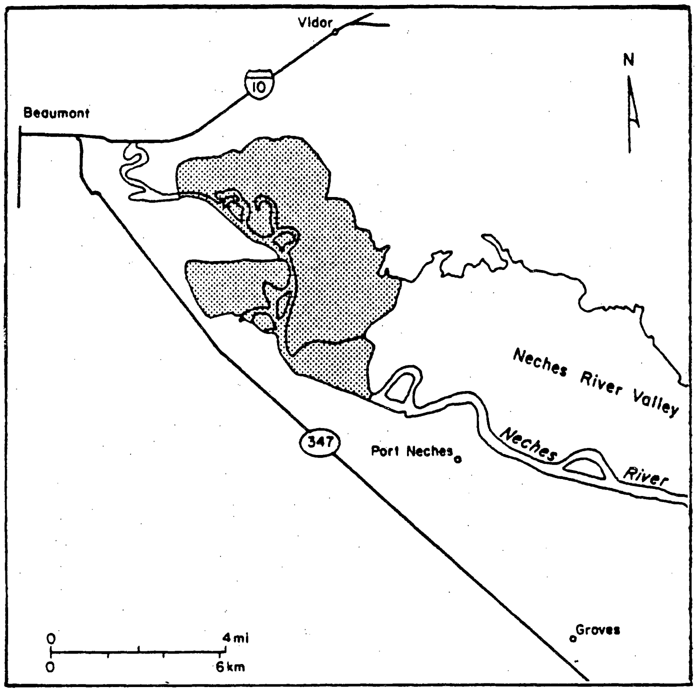
Guadalupe River delta index map and historical sequence of vegetated areas (in black) for the years 1930, 1957, 1974, and 1979.



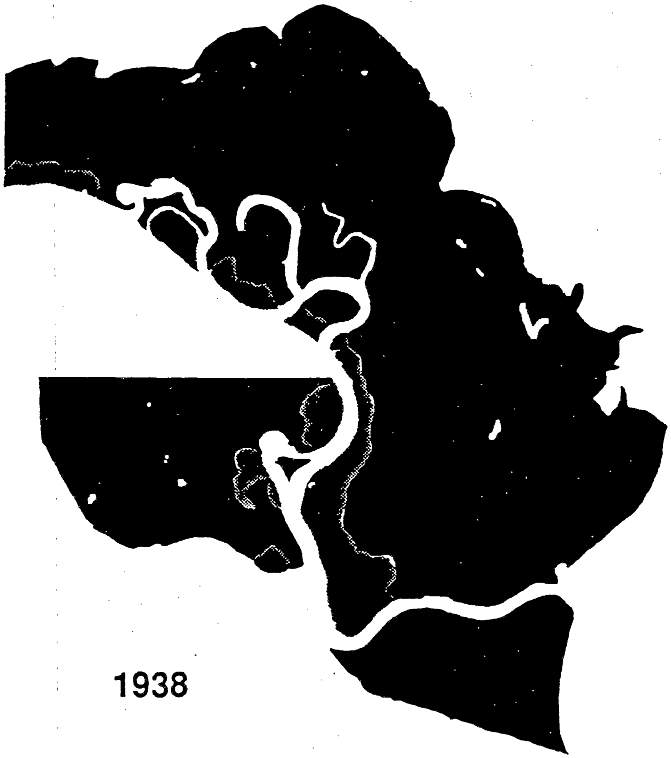




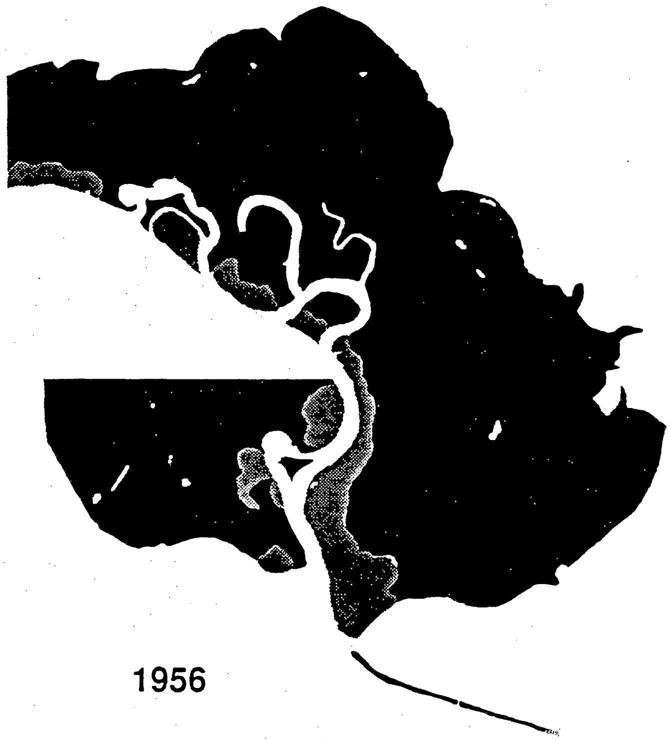
Lavaca River delta index map and historical sequence of vegetated areas (in black) for the years 1930, 1958, and 1979.



Neches River delta index map and historical sequence of vegetated areas (in black) for the years 1938, 1956, and 1987.

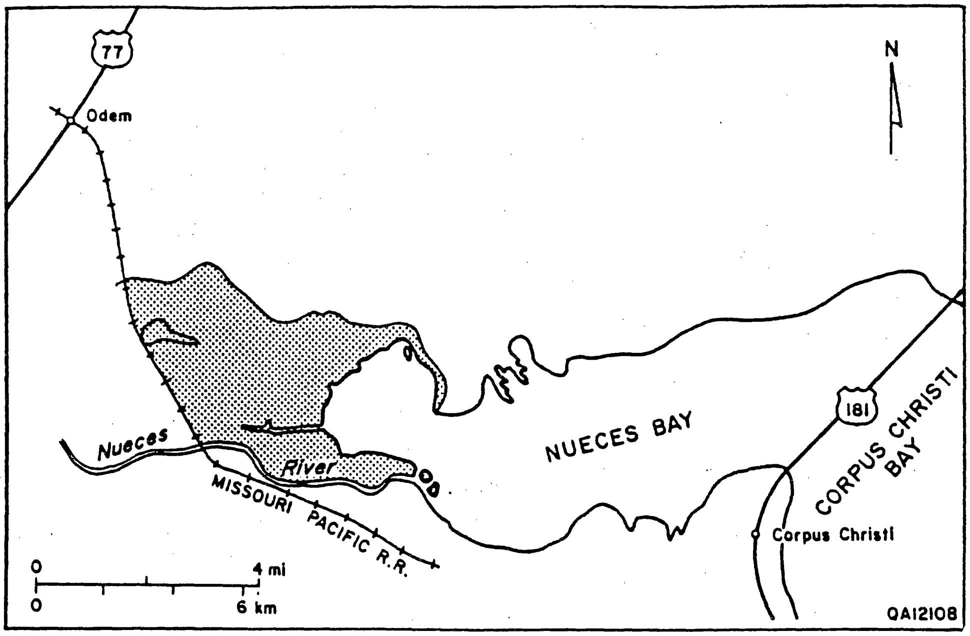


1938

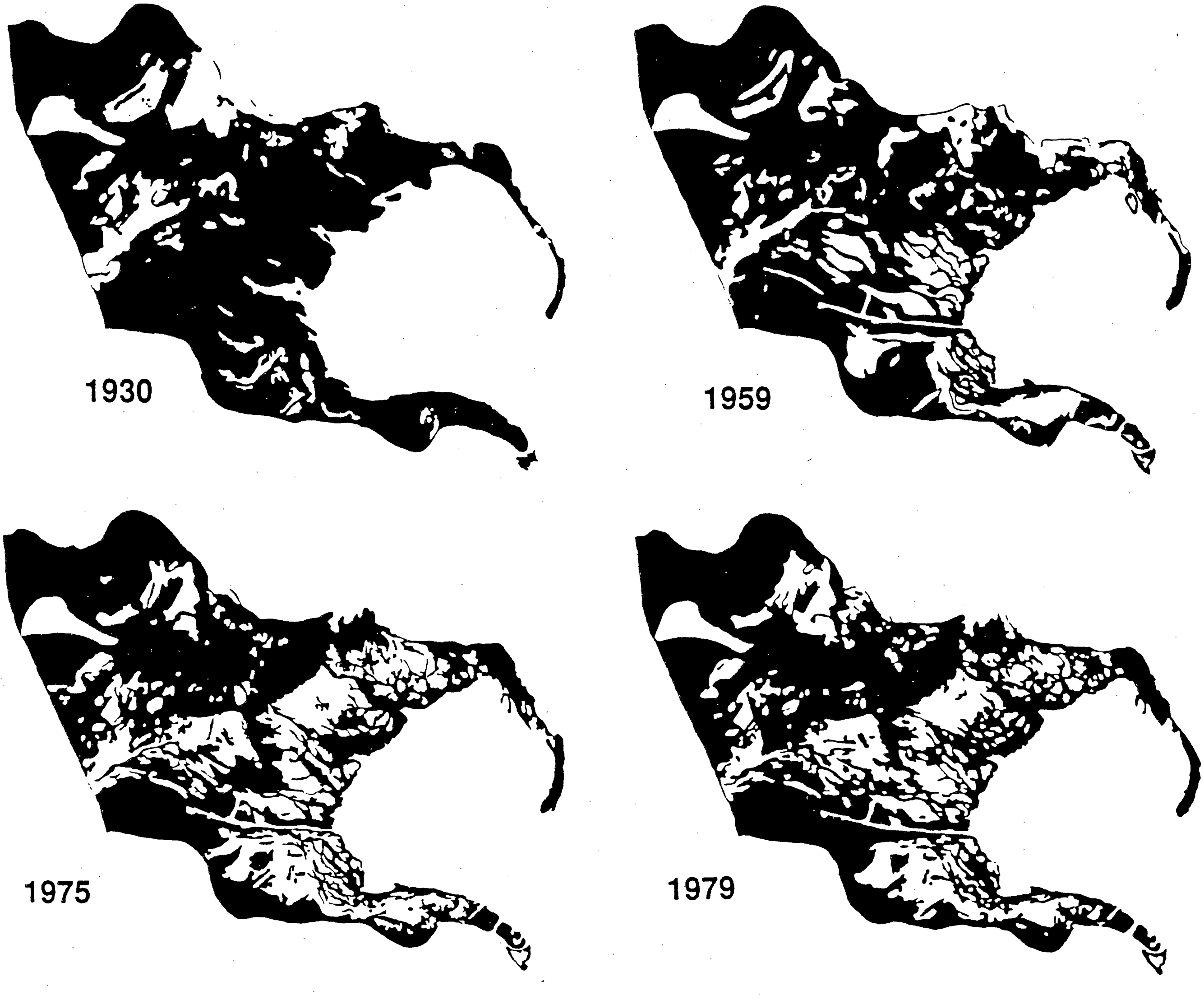


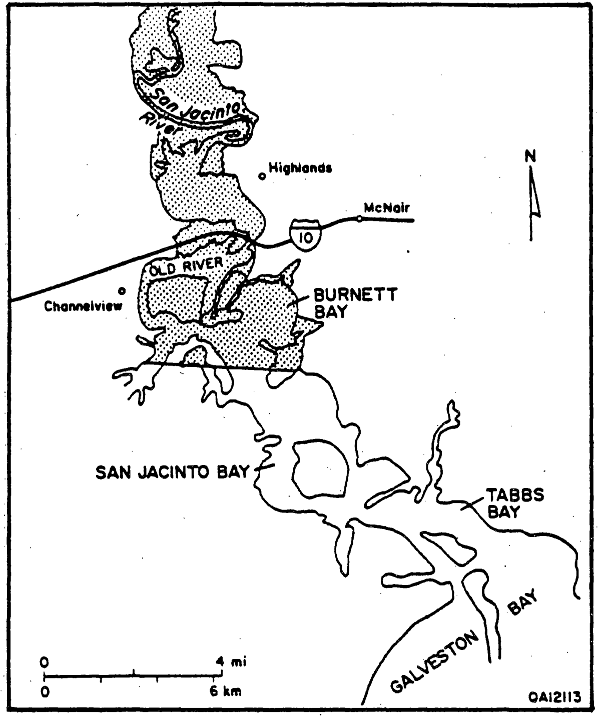
1956

1987

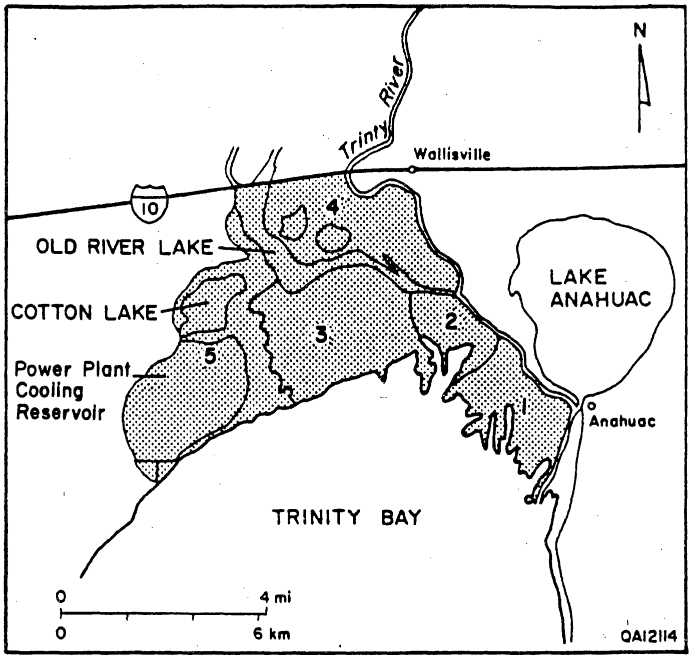


Nueces River delta index map and historical sequence of vegetated areas (in black) for the years 1930, 1959, 1975, and 1979.





San Jacinto River delta index map and historical sequence of vegetated areas (in black) for the years 1930, 1956, and 1986.



Trinity River delta index map and historical sequence of vegetated areas (in black) for the years 1930, 1956, 1974, and 1988.