AN ASSESSMENT OF COASTAL PROCESSES, DREDGED-SEDIMENT TRANSPORT, AND BIOLOGICAL EFFECTS OF DREDGING, COAST OF LOUISIANA

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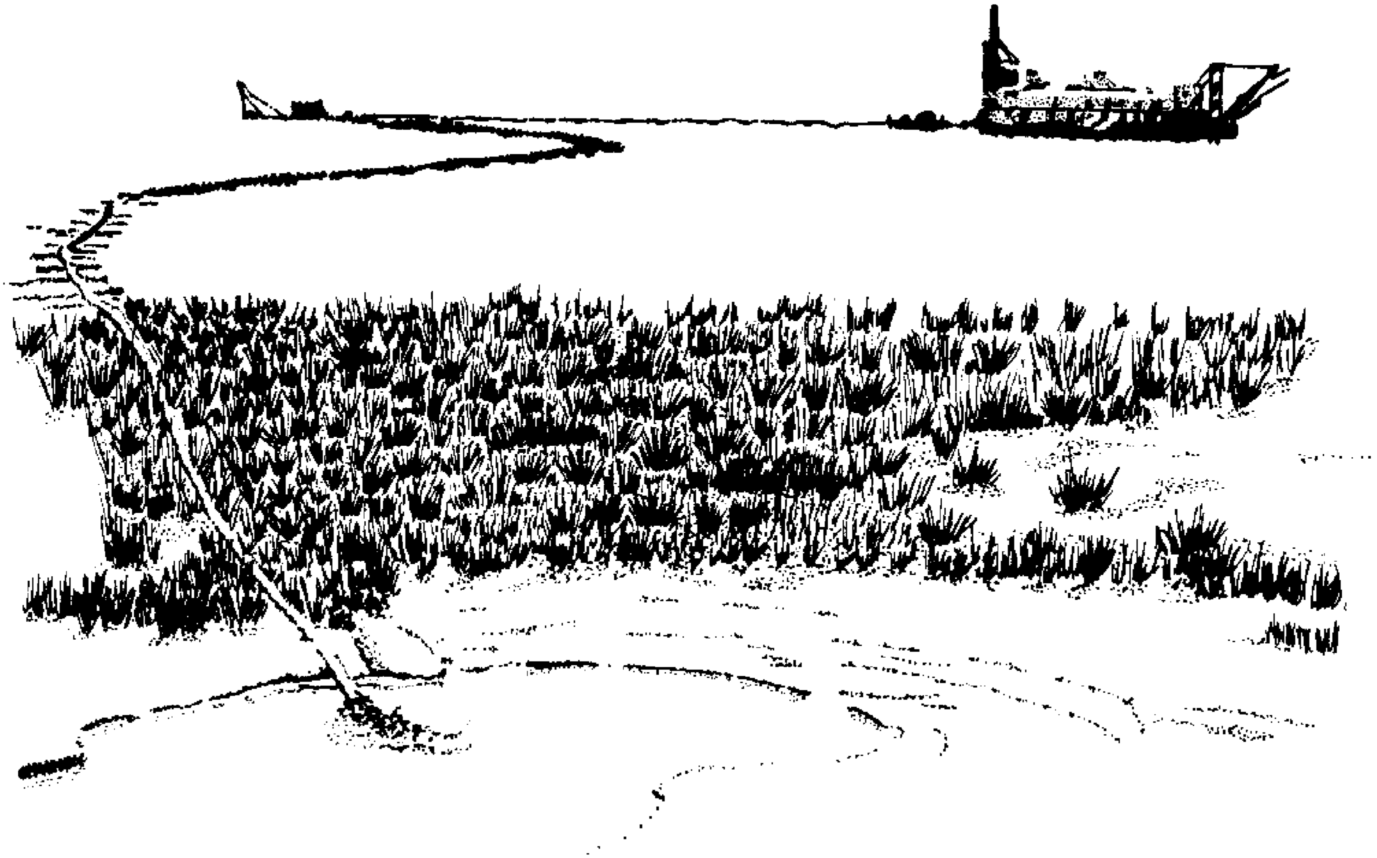

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ABSTRACT

The fate of dredged sediment in the coastal environment is controlled by regional circulation, which, in coastal Louisiana, is influenced by wind, waves, tide, freshwater input, pressure gradients, semipermanent water slopes, and large-scale Gulf circulation. A review of our knowledge of these processes, together with their effects on fine-grained dredge spoil, reveals that we lack a solid understanding of both water and sediment movement along the Louisiana shoreline. Detailed studies in specific areas provided information on localized behavior and sediment-water interactions, but the depth of understanding required for predictive capabilities does not generally exist. An assessment of biological and chemical effects of dredging range from reduction in light penetration, causing minor, short-term damage, to release of heavy metal/chlorhydrocarbons, causing severe long-term damage upon entering the food chain at sublethal levels.

General recommendations for research include conducting multidisciplinary studies covering as many components of the natural system as possible, devoting efforts to examining processes rather than to simply monitoring the environment, conducting research primarily in the field environment, and encouraging studies that consider dredged material as a potentially productive resource. Specific recommendations include further examination into cross-shelf circulation, salt balance and estuarine dynamics, wave effects on mud substrates, shear stress at the boundary and transport of dense suspensions, development of instrumentation for in situ measurements, severe storm and hurricane effects, bioisolation of toxic dredge spoil contaminants, and improvement of analytical techniques for detecting and differentiating organic compounds synthesized at the disposal site.

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INTRODUCTION

Nearly one-quarter of the dredged-material disposal sites in the United States (including Alaska and Hawaii) are located along the Gulf of Mexico coastline from Mississippi to Texas (Environmental Protection Agency, 1977). Many of the sites along the coast of Louisiana, such as those in Atchafalaya Bay, are not single disposal mounds, but rather consist of an extensive network of sediment piles 5-15 km long (Fig. 1). This fact is not surprising in light of recent estimates, which indicate that 78 percent of the terrigenous sediment in the continental United States enters the Gulf of Mexico (Curtis et al., 1973), and a substantial quantity of this sediment must be removed from harbors and channels by dredging (see appendix).

The Louisiana disposal sites are unique in that fine-grained sediments predominate, tide range is low (0.50 m), and wind effects are pronounced. The restricted depths of disposal sites and proximity to the shoreline ensure that frictional effects play a dominant role in determining the currents and hence the advection and dispersal of dredge spoil at most sites. Their location inside the brackish sediment-charged Coastal Boundary Layer (CBL) likewise indicates that the local distribution of density (salinity) exerts important controls on currents and their capacity to transport dredged sediment.

A review of literature published under the auspices of the U.S. Army Corps of Engineers Dredged Material Research Program (DMRP) indicates that a comprehensive assessment of coastal dynamics, sediment transport and dispersal, and biological and chemical effects of dredging has not been made for the Louisiana shoreline and continental shelf. Therefore, the purposes of this report are to 1) provide such an assessment of our state of knowledge concerning physical and geological processes and the chemical and biological effects of dredging and 2) suggest areas where further research is needed. This report is limited mainly to the coast of Louisiana since nationwide policies concerned with dredging are difficult to establish and apply to all regions because of differences in environmental settings, types of sediments, and dynamics of the water bodies.

The Louisiana Coast: An Overview

On the basis of origin and physiography, the Louisiana coast can be divided broadly into two segments: the chenier plain and the deltaic plain. The coastal area from the Texas border to the vicinity of Marsh Island, known as the chenier plain (Fig. 1), has a relatively smooth and regular shoreline, occasionally fronted by mudflats (Fig. 2), whereas east of Marsh Island the deltaic plain (Fig. 1) is highly irregular and is dotted with numerous bays and small lakes and few offshore barriers (Fig. 3).

Over the past several thousand years the Mississippi River has changed courses numerous times to form five major delta complexes in the eastern two-thirds of the state. Sixteen individual delta lobes have been identified from these five complexes (Frazier, 1967). Each delta remained active for 500-800 years, then

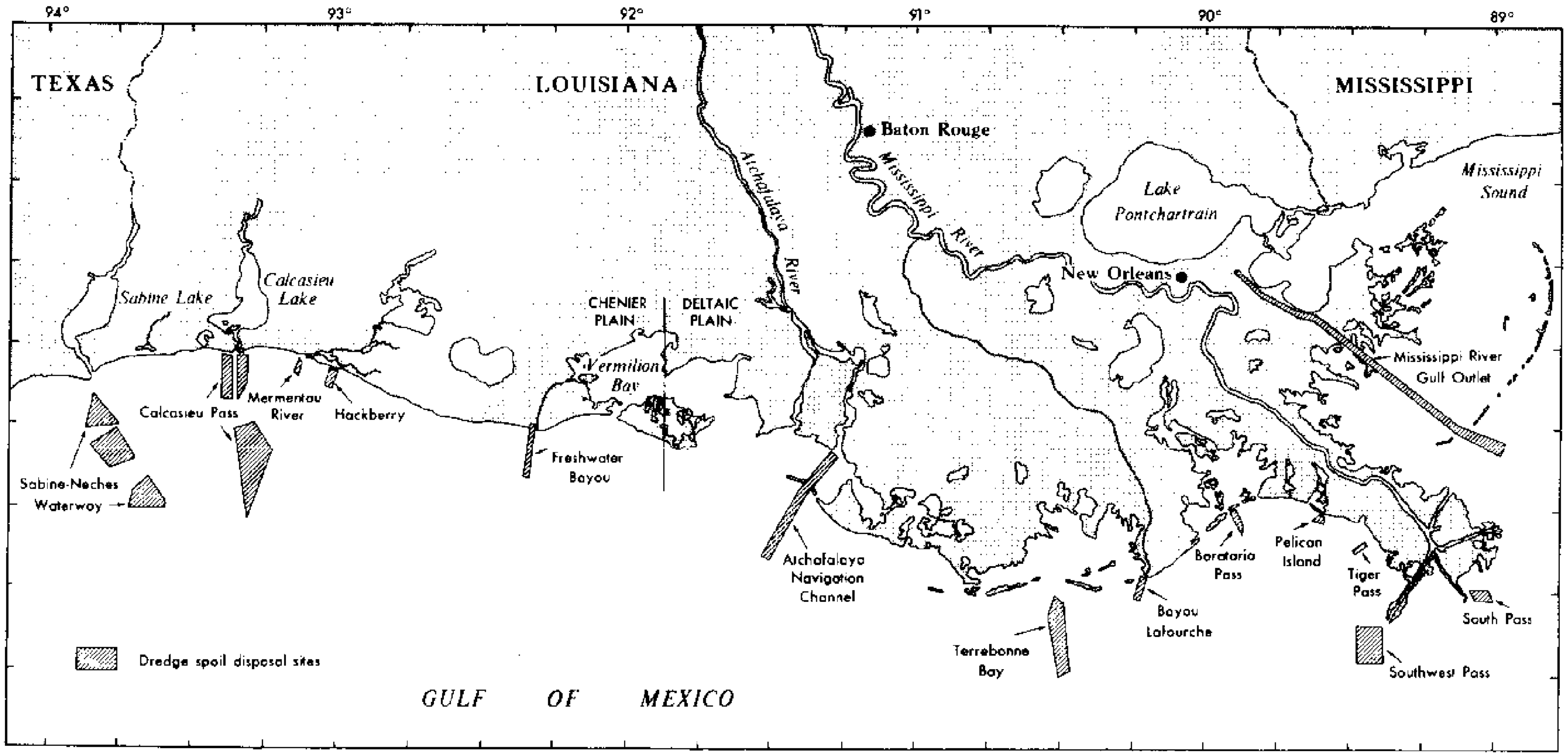

Figure 1. Dredge spoil disposal areas, coast of Louisiana. (Sources: EPA, Ocean Dumping, Final Revision of Regulations and Criteria, Frederal Register, 1977.)

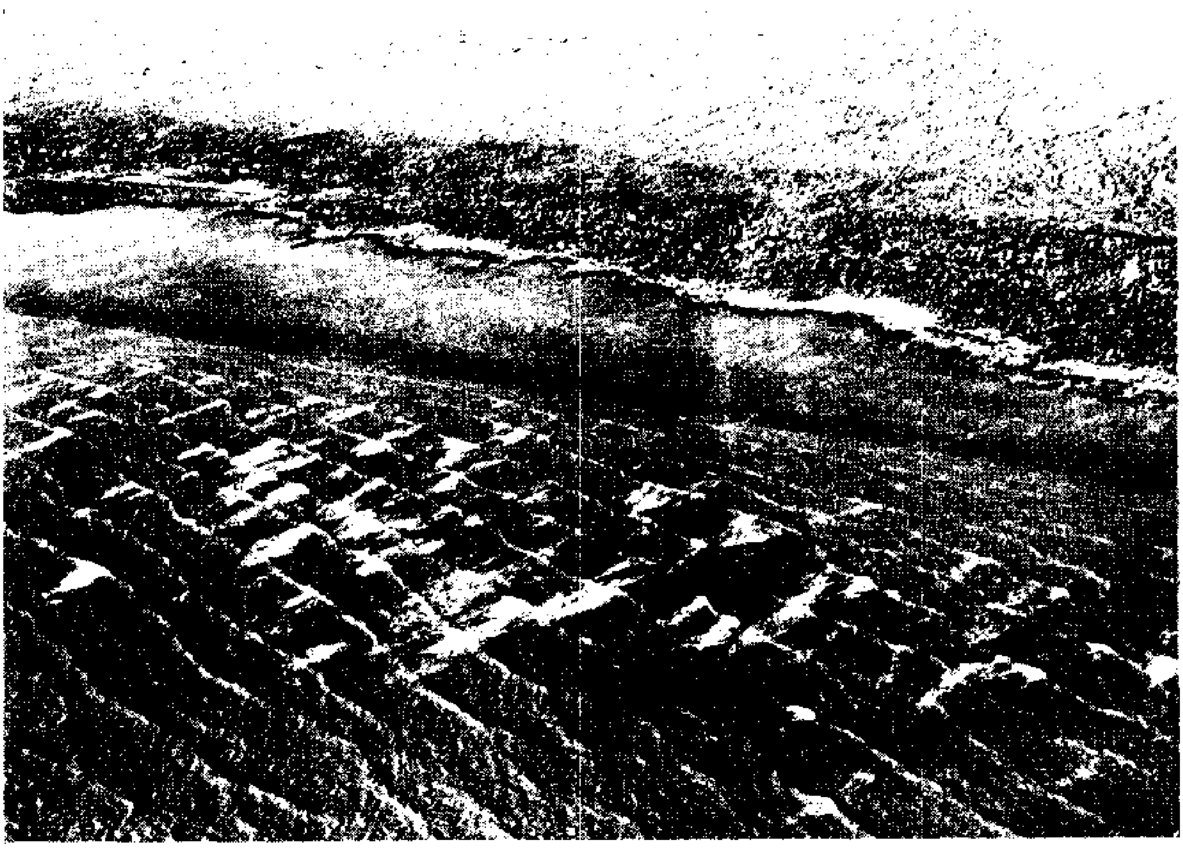

Figure 2. Louisiana chenier plain, fronted by prograding mudflat and backed by extensive salt marsh. Photo taken at low tide.

was abandoned by the river in favor of a new and shorter route to the Gulf of Mexico. The surficial sediments of the deltaic plain thus represent the deposits of older inactive, overlapping deltas.

The wedge of Recent sediments is 100-150 m thick off the modern Mississippi River delta (Fisk and McFarlan, 1955) and overlies the Pleistocene Prairie Formation. The delta deposits that now make up the coast of eastern Louisiana are in varying degrees of deterioration, with the oldest sediments generally being the most consolidated and most resistant to erosion. Barrier islands, an important coastal feature in the eastern and central deltaic area, originated as bay-mouth barriers on the flanks of abandoned natural levees and as distributary-mouth bars. Except for the cheniers of the western Louisiana coast, these barriers are the only geomorphic features that are composed of sand-sized material.

Marginal sedimentation to the west of the deltaic plain produced, during the same time period (3,000-5,000 years ago), the present-day chenier plain. Development of the chenier plain and adjacent shelf has been traced stratigraphically from cores using radiocarbon dating techniques (Gould and McFarlan, 1959). As sea level rose from -5 m to its present level, a transgressive sequence of marine sediments was deposited over the dissected Pleistocene Prairie formation, first filling estuaries, then later spreading across shallow-bay and marsh environments. During

Figure 3. Louisiana deltaic plain near Pelican Island showing shallow bays, lakes, and dredged canals. Photo taken during river flood stage.

the final stage of post-glacial rise in sea level, some 3,000 years ago, the chenier plain began to prograde rapidly, and eventually a wedge of recent sediments was deposited to a distance of 24 km offshore. Pulsations of sediment from the Mississippi River, transported by longshore currents, were responsible for the progradational stage of development. At times when the Mississippi River introduced sediment in the vicinity of the present chenier plain, the shoreline built seaward; during periods when its course took the discharge farther east, sediment influx to the chenier plain was low and wave attack was able to slow or halt the advance. Cheniers formed during these latter periods and now stand as "islands" in the marsh.

Sediment presently being transported to the chenier plain is derived from the Atchafalaya River, a distributary of the Mississippi River that today carries approximately 30% of the total water and sediment load. In the early 1950s increased sedimentation from the Atchafalaya River brought large quantities of fine-grained sediments to the eastern extreme of the chenier plain coast. Soft, fluid muds built out several hundred metres offshore as tidal flat deposits. According to Morgan et al. (1953) the eastern margin of the chenier plain near Chenier Au Tigre advanced 450 m from 1927 to 1951 as muds up to 2 m thick were deposited in the nearshore region.

Aerial overflights in November 1979 revealed that these mudflats had moved to the west and were actively prograding south of White Lake. In addition, it is reasonable to assume that new muds have accumulated subaqueously on the shelf inside the 6-m contour. Historical documentation by maps and charts (Morgan and Larimore, 1957) and by 1:20,000 color infrared aerial photography (Wells and Roberts, in press) shows that the area of mudflat accretion is enlarging and that the locus of accretion is shifting to the west. Although it is estimated that 53 x 10^6 m^3/yr of fine-grained sediment is carried from Atchafalaya Bay out onto the shelf and then west to the chenier plain (Wells and Roberts, in press), the Atchafalaya River and Bay remain major areas of deposition, and, thus of dredging and dredge spoil disposal operations in the state of Louisiana.

Estimates of fine-grained sediments entering the Gulf of Mexico from the Mississippi River range from 344 x 10^6 tons (Holeman, 1968) to 544 x 10^6 tons (Walsh, 1969) annually and, according to Kolb and Kaufman (1967), 7.5 x 10^5 tons settle every day in shallow waters surrounding the delta. Montmorillonite is the most abundant clay mineral that enters the Gulf of Mexico by river, followed by illite and kaolinite in the ratio 3:1:1. Sediments along the Louisiana shelf exhibit low shear strength and are typically underconsolidated (Fig. 4). Sedimentation rates of 300 m/1,000 years are reported for the prograding Mississippi River delta deposits while in bays and estuaries deposition occurs at rates of 2-4 m/1,000 years (Rusnak, 1967). The lowest rates of sedimentation, 1.25 m/1,000 years, are found at the edge of the Louisiana shelf.

Suspended-sediment concentrations along the Louisiana coast are variable, but many times higher than off the east or west coasts of the United States. In river plumes of the Mississippi or Atchafalaya rivers, surface waters may have concentrations of 200 to 500 mg/l in the nearshore and up to 30 mg/l offshore (Scruton and Moore, 1953). Nearshore waters along the chenier plain contain 10-100 mg/l of suspensates, depending on wave climate, bottom texture, and proximity to local rivers and bayous.

Bathymetrically, the Louisiana coast may seem monotonous to the average observer, barring, of course, the active Mississippi Delta (Fig. 1). The 20-m contour is 65-80 km offshore except at the Mississippi River delta, where sediments are introduced into the waters of the continental slope.

Coastal marshes are a product of the Mississippi River and, together with adjacent water bodies, span the entire coastline of the state. Marsh width varies from 25 to 80 km. Although coastal marshes in Louisiana are without distinct relief and are only slightly above mean Gulf level, the 1-2-m relief from associated natural levees, cheniers, beaches, and salt domes is extremely significant since areas elevated only 1 m form firm habitable land in contrast to lower marsh and swamp regions.

The unequaled wildlife productivity of the Louisiana coastal region is certainly related to the abundance and diversity of plant growth in the marsh (Fig. 5). Chabreck (1972), on the basis of the classification by Penfound and Hathaway (1938), has divided coastal marsh vegetation into four types: fresh, intermediate, brackish, and saline. Generally, these marsh types run in east-west bands, parallel to the coast, with saline marsh nearest the shoreline and fresh marsh farthest from the coast. Characteristic swamp and marsh vegetation is given by Frazier and Osanki (1968), Gould and Morgan (1962), and Penfound and Hathaway (1938).

Figure 4. One-day-old footprints in soft muds along central Louisiana coast.

Marsh soils are classified as peats, mucks, and clays. The dominant morphological characteristics are the dark brown and black colors of the peats, mucks, and organic clays and the gray colors associated with waterlogged, reduced soil conditions (Lytle, 1968). Inorganic soil materials are silts, silty-clays, and clays of recent alluvial and marine origin. Peats are soils that contain plant parts only partially decomposed, with over 50% organic matter. Mucks contain well-decomposed plant parts and have an organic content of 15-20%.

Plant growth on marsh substrates is extremely rapid. Flora as well as fauna are in a state of constant change as they adapt or fail to adapt to natural changes within the rapidly evolving deltaic plain. Marsh vegetation such as oyster grass (*Spartina alterniflora*), maiden cane (*Panicum hemitomon*), water hyacinth (*Eichhornia crassipes*), and wiregrass (*Spartina patens*) can easily become established in one growing season. For example, within a year after gaining subaerial exposure, the new Atchafalaya Delta of south-central Louisiana had become vegetated and today (7 years later) has a luxuriant growth of both marsh plants and woody vegetation.

Despite the influx of sediment from the Mississippi River, which supplies silt and clay to the marsh system, the coast of Louisiana is eroding perhaps faster than any other coastal state in the United States (Fig. 6). Compaction of sediment during and after deposition results in water loss and therefore subsidence. To survive, the marsh surface must accrete vertically by accumulating organic and

Figure 5. Emergent vegetation on new mudflats in Atchafalaya Bay.

inorganic sediment at a rate that keeps pace with subsidence and sea level rise. Areas with vigorous stands of marsh vegetation have obviously been able to achieve this elevation. As the process of subsidence continues in other areas, inundation of interlevee basins and enlargement of lakes and bays occurs as natural levees slowly lose surface expression. Breton Sound, Chandeleur Sound, Barataria Bay, and Timbalier Bay are all areas that were formerly marsh on the outer reaches of deltas but now are subaqueous environments. Recognition of the natural cyclic behavior of the Louisiana coast, such as that cited above, is important to understanding and responding to the rapid environmental changes that can occur, even without the interference of man.

STATE OF KNOWLEDGE

Physical Processes

Circulation in the coastal waters of Louisiana is a complex combination of spatially and temporally varying forcing mechanisms and their interaction with the complicated geometry of the eastern Louisiana coast. The 1,500 km of shoreline from Pearl River to Sabine Pass offers a variety of environments which affect coastal circulation. For example, the modern delta of the Mississippi River

Figure 6. Eroding marsh, western Louisiana coast.

protrudes 80 km into the Gulf of Mexico, altering large-scale circulation patterns and modifying wave fields as well as tide. Bottom topography influences the local current field by introducing frictional boundary effects which help to steer the currents. Rapid changes in coastline configuration, such as in the vicinity of Atchafalaya Delta, impart a time dependency to coastal circulation.

The forcing mechanisms for regional circulation in Louisiana's coastal waters include wind, waves, tide, freshwater input, pressure gradients, semi-permanent water slopes, and large-scale Gulf circulation (Murray, 1976). The paucity of data and the incomplete results of many studies make it difficult to determine the effects of these parameters. Murray (1976) has, however, summarized existing studies and recommended areas of research where knowledge is lacking. Given in the following paragraphs is a summary of our state of knowledge of processes that control water movement and, by extension, sediment transport, in coastal Louisiana.

Studies that correlate wind data from various locations (Chew, 1964; Muller, 1977) indicate that winds are relatively consistent in an east-west direction. The winds are from the eastern quadrant approximately 70 percent of the year. During summer, winds are southeasterly, shifting to northeasterly in autumn. Winter winds are stronger and more variable as a result of the passage of numerous frontal systems. With the arrival of spring, winds shift back to the southeast. Westerly winds are rarely observed (Murray, 1976)at any time of the year, and, as a result, most of the wind-driven surface water movement is to the west.

On short time scales (hours) the upper layers of water respond quickly to shifts in wind direction; therefore, surface flow may be initiated in any direction during a given time period (Fig. 7). The intensity and consistency of the wind stress, as well as density layering effects, will determine whether the surface effect is felt throughout the water column. The influence of locally intense winds may be the dominant factor affecting the three-dimensional circulation in the coastal region. Murray (1972), during a field program east of the Mississippi delta, reported that winds blowing on the surface waters in a stratified water column in shallow water (15 m) will drive the surface layer in the direction of the wind, while flow in the lower layer is in the opposite direction.

Northers associated with the passage of strong cold fronts may lower sea level drastically in the nearshore region and also impart enough energy into the waters to destroy stratification and mix the water from surface to bottom. These effects are also important on short time scales (hours to days). In the shallow Atchafalaya Bay, where a new delta is developing, onshore southerly winds induce flow of shelf water into the bay and retard the discharge of river water into the Gulf such that substantial water setup occurs prior to frontal passage. With arrival of the front, winds shift to offshore, bay level drops rapidly, and current velocities increase in the distributary channels. Results of initial experiments indicate that

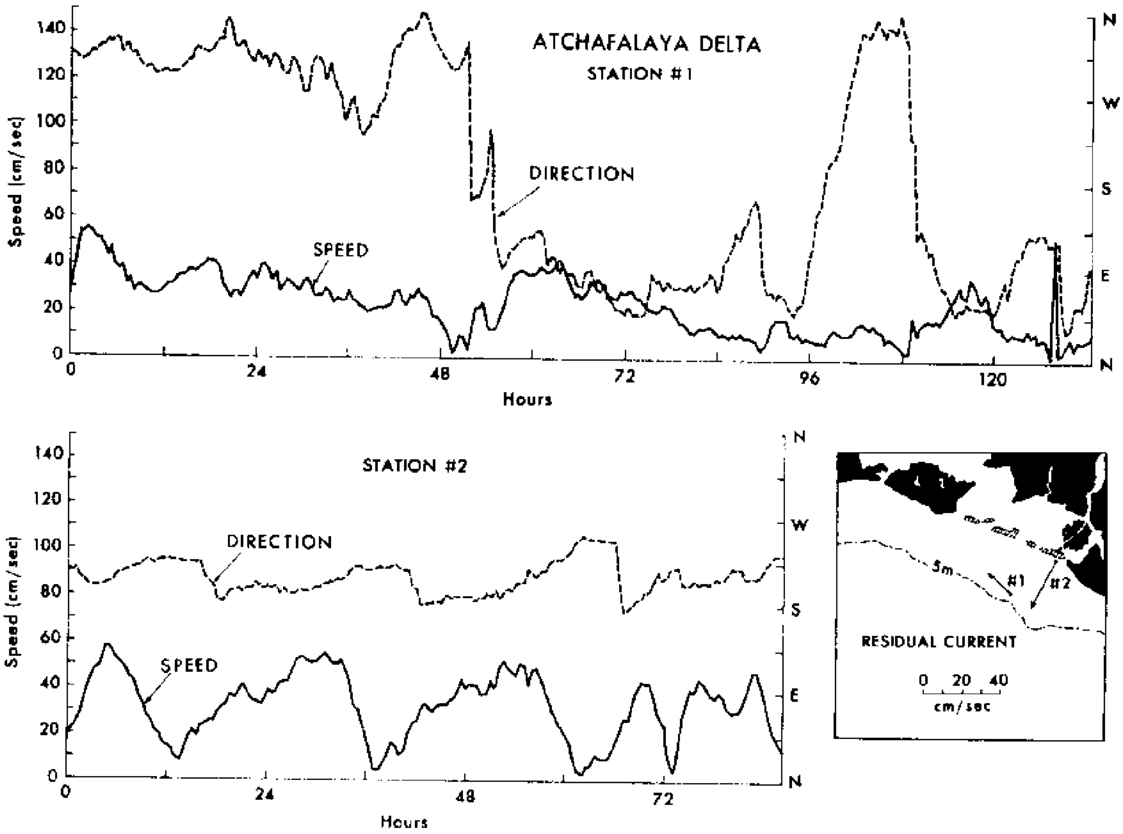

Figure 7. Examples of current speed and direction taken seaward of Atchafalaya Bay (see Fig. 1) in spring 1980. Residual currents are shown on the inset. Rapid change in current speed and direction at station #1 is the result of shift in wind caused by frontal passage.

this produces onshore-offshore flow segregation and that front-induced sediment movement is important in determining sand body geometry of delta lobes (Kemp and Wells, in press).

Current velocities along the western coast of Louisiana are reported to be directly proportional to the curl of wind stress, being at a maximum in spring and autumn and at a minimum in summer (Sturges and Blaha, 1976). This observation suggests that these coastal currents may be largely generated by the local winds (Chew, 1964).

Gulf Tropical Disturbances, which include hurricanes, occur infrequently from late spring through early fall. Winds can be extremely strong and can approach from any direction except northwest through northeast. Hurricanes usually have a net drift to the northwest and drive oceanic waters onto the shelf and into the estuaries. Data given by NOAA (1977) indicate that on the shelf of western Louisiana the average number of years between the occurrence of tropical cyclones and hurricanes is 2.3 and 4.9, respectively.

The response of continental shelf waters to the passage of such storms has been investigated on several occasions. Bottom currents near the west Florida coast during Hurricane Camille as high as 160 cm/sec were observed (Murray, 1970). Direction of the bottom currents rotated from alongshore to seaward as the storm approached. Just prior to the arrival of the storm the wave-driven longshore current extended beyond the normal breaker zone (Murray, 1970). The response of deeper waters on the central Texas coast to Hurricane Anita has also been described. Maximum velocities of 70 to 80 cm/sec (2 to 3 times normal values) were observed near the bottom at the time of maximum wind stress (Smith, 1978). Published accounts of hurricane damage on the western Louisiana coast (Morgan et al., 1958; Chamberlain, 1959) attest to the strength of these periodic events.

Wave energy along the northern Gulf of Mexico is low as a result of limited fetch, but it is nevertheless responsible for some of the longshore circulation in the nearshore zone. The incident angle of the wave field determines these circulation patterns. Waves from the southeast driven by southeast winds induce a longshore transport to the west. However, littoral currents may respond more directly to winds and tides than to waves, and much of the coastal water and sediment movement is driven by tidal exchange through estuary passes.

Table 1 gives a summary of wave climate for the Louisiana coast. The most frequent wave is a 1-m, 4.5-sec wave from the southeast with an occurrence of 21%. Because wave power (energy) is a function of wave height squared, the importance of high waves is greater than is apparent from their occurrence frequency. Whereas the 1-m, 4.5-sec wave has an occurrence frequency of 21%, it accounts for only 7% of the power generated offshore; the southeast 1.5-m, 6-sec wave (Fig. 8), with an occurrence frequency of 20%, contributes 25%. As Table I shows, approximately 93% of waves along coastal Louisiana are 1-2 m high and have a period of 4.5-6 sec when wind speeds are greater than 10 km/hr (Stone, 1972).

Becker (1972) found that energy available for mechanical modification of the land-water interface was greatest where deep water occurs close to the strand line and where the foreshore bottom slope is steep. Highest power levels thus occur along the Mississippi River delta, and lowest levels along Marsh Island and Atchafalaya Bay. Studies off the Mississippi River delta by Tubman and Suhayda

Table 1
Annual Wave Climate Summary

Wave		Direction				
H (m)	T (sec)	E (%)	SE (%)	S (%)	SW (%)	Total (%)
1.0	4.5	13	21	8	5	47
1.5	6.0	9	20	9	8	46
2.0	7.0	1	1	1	0	3
2.5	8.0	1	0	2	1	4
		24	42	20	14	100

Modified from Becker, 1972

(1976) show that, despite the higher energy levels, rate of wave energy loss is an order of magnitude greater than over sandy bottoms of similar slope. The basic mechanism for wave energy loss is the elastic response by delta muds to wave pressure forces, which results in oscillations of a bottom mudwave 1-2 cm high.

Larger waves generated by frontal passages, tropical storms, and hurricanes have shaped the coastline of western Louisiana, redistributed the abandoned deltaic material of the central and eastern coast, and remain an important force in moving sediments over the entire continental shelf and in the coastal waters. The wave field of a single hurricane can contain more energy than is expended normally in a full year. During Hurricane Camille in 1969, a 100-year hurricane having winds over 90 m/sec, the maximum observed wave heights were 23 m; wave heights greater than 6 m would be expected all across Louisiana under such wind conditions. General estimates as to future extremes in wave action indicate that in 30 m of water a maximum wave height of 10.5 m can be expected every 2 years (Suhayda, 1976).

Data from south of Timbalier Pass reveal that wind and wave directions are generally coherent (Wiseman et al., 1975b), with directions being the same 80% of the year. This indicates that waves generated by local winds have more influence than swell in driving the circulation. Glenn (1972) and Brower et al. (1972) reported similar data with respect to significant wave height, but problems with the data set are large enough to question those conclusions (Wiseman et al., 1972b).

Tides along the Louisiana coast are complicated but reasonably well understood. An excellent introduction to tidal characteristics in the Gulf of Mexico was written by Marmer (1954), who provided information on the relative importance of semidiurnal (twice-a-day) and diurnal (daily) tidal components. Immediately west of the Mississippi River delta the dominant tidal components are diurnal (K_1 and O_1), and Louisiana tides display a tropic-equatorial cycle of low range. When the diurnal components interfere constructively, tropic tides result; when they interfere destructively, equatorial tides result.

Long-term variations in water level (months to years) recorded on tide gages appear to be coherent around the Gulf. Among the processes that can cause such sea level changes are atmospheric pressure (Groen and Groves, 1963), offshore currents (Montgomery, 1938), solar heating (Pattullo et al., 1955), wind stress

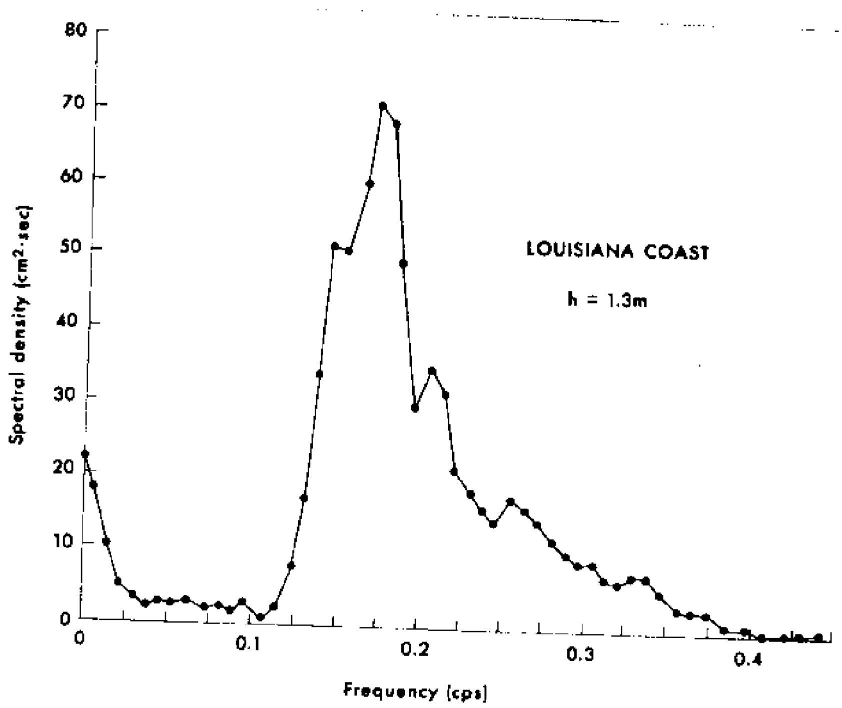

Figure 8. Spectrum of 6-sec waves from the southeast in November, central Louisiana coast.

(Miller, 1957), and river runoff (Roden, 1960). As discussed previously, subsidence explains much of the apparent sea level rise.

According to tide tables of the National Ocean Survey (NOS, 1980), maximum tide range is from 0.30 to 0.75 m. Corange lines (lines of equal range) show areas of amplified tide on the western Louisiana shelf, particularly in the vicinity of Calcasieu Lake-Sabine Lake. Significantly higher tidal currents would be expected in these regions. Cotide lines (lines of equal phase) show the tide wave generally progresses across the Louisiana coast from west to east, with high tide arriving some 7 hours earlier at Calcasieu Lake than at Barataria Bay.

A bimonthly cycle of declination of the moon causes the strongest currents at highest tides (tropic tides) and weakest currents at lowest tides (equatorial tides). During equatorial tides evidence of semidiurnal tidal components (M_2 and S_2) becomes more pronounced.

Tidal currents in the Mississippi River bight are typically 10-15 cm/sec, rotating clockwise over a tidal cycle (Murray, 1976). Strongest currents occur near Southwest Pass of the Mississippi River, where severe bottom curvature has produced a complex pattern of cotide lines. Tidal current measurements in the vicinity of Terrebonne Bay also show clockwise rotation with an 8 cm/sec amplitude (Oetking et al., 1974). The bottom current is better developed here due to increased distance from the Mississippi River and smoother vertical density gradients (Murray, 1976). Measurements made at two tidal stations off Grand Isle showed weak, well-behaved tidal currents with a residual current directed westerly in response to local winds (Harper, 1974). Results of detailed data collection west of Terrebonne Bay have not been published although several data reports are available through NOS. These data, most collected for the Department of Energy's Strategic Petroleum Reserve Project, have been collected seaward of Atchafalaya Bay, Calcasieu Lake, and Sabine Lake.

One of the outstanding features of Louisiana waters is the tremendous amount of freshwater discharge from the Mississippi and Atchafalaya rivers. Together with the large volumes of fresh water, sediment enters the coastal environment via these dynamic rivers. Whereas the waters of the Mississippi River are discharged as a concentrated, jetlike feature (Wright and Coleman, 1974), Atchafalaya River waters are dispersed through the shell islands of Atchafalaya Bay (Thomson, 1955; Roberts et al., 1980). Lesser amounts of fresh water enter the coastal region through smaller rivers and bayous, brackish bays, and estuaries. The abundant rainfall in south Louisiana (>1.5 m/yr) is transported through these numerous outlets into the Gulf. Low salinities may therefore be maintained at the surface, resulting in a stratified water column, as observed by Gagliano et al. (1969). Two-layered flow is possible in such a stratified water column. Geostrophic considerations of the freshwater outflow result in flow of these coastal waters to the west (Wiseman et al., 1975a). The introduction of the fresh water also establishes density gradients, which initiate current movement. Although the resulting gravitational circulation in river mouths and tidal passes in Louisiana has not been investigated, buoyancy effects are known to occur at the mouth of rivers in conjunction with plume spreading (Wright and Coleman, 1974).

The above summary of coastal processes and the general movement of Louisiana's coastal waters may be supplemented by only a limited number of specific recent investigations. Examination of Mississippi River delta processes, a numerical study of Chandeleur-Breton Sound, and an intense study of the Mississippi Bight area in conjunction with the Louisiana Offshore Oil Port (LOOP) project are three examples. Those studies of the delta that are not geological in nature have dealt with spreading of the freshwater plume to the distributary-mouth bar (Wright and Coleman, 1974) or the movement of drogues at various levels around the passes (USACOE, 1959). Results of the latter study show a confused pattern of water movements in the vicinity of South and Southwest passes, and the data set is not long enough to permit any concrete conclusions about the processes of the delta area.

The numerical model of Chandeleur-Breton South by Hart (1978), which included energy considerations, reinforced earlier conclusions regarding the importance of wind and tides in a shallow-water system. The Chandeleur-Breton Sound encompasses a large portion of eastern Louisiana coastal waters.

The Mississippi Bight of Louisiana is one area of the coastal waters that has been studied with considerable competence. Much of the research was completed in conjunction with the Louisiana Offshore Oil Port project. Results of this project (Wiseman et al., 1975b) offer some insight into several areas where dredge spoil is deposited (Southwest Pass, Tiger Pass, Pelican Island, Barataria Pass). Results show that, although a large tongue of low-salinity water from the Mississippi River stretches south along the Texas coast to the Mexican border, it is confined to the shelf. This is an indication of the long-term westerly drift along the Louisiana coast. Variations in hydrography may be attributed to local wind conditions, seasonal changes in surface heat flux, runoff from the Mississippi River and coastal bays, and intrusions from the deep Gulf of Mexico (Wiseman et al., 1975b).

A north-south section through the Bight area reveals that these waters vary throughout the year. A July section shows a strong halocline and a strong thermocline at 5-10 m with a secondary halocline in the north resulting from runoff in the upper 2-3 m. The October section shows less stratification than during July, with surface cooling occurring, as shown by a weak temperature stratification. In

January the temperature section has little structure and stable stratification is maintained. Nearly isothermal temperatures are observed in April, but the salinity is strongly stratified due to runoff (Wiseman et al., 1975a).

Surface circulation in the Bight is in the form of a clockwise gyre, which is easily seen in satellite photographs (Rouse and Coleman, 1976). This circulation, which appears in 70% of the data, is mixed vertically with ambient coastal water (Wiseman et al., 1975b). Shear in the velocity data indicates the presence of density stratification. In the lower layer heavy Gulf water persistently intrudes at depth to the central core of the Mississippi Bight (Murray and Wiseman, 1976) and reveals the possibility of upwelling on the Louisiana shelf.

Recently, the decision to use Louisiana's coastal waters for brine disposal in conjunction with the Strategic Petroleum Reserve Program has led to the collection of extensive background data by government agencies and private consulting firms. When these data are released, much can be learned about circulation in the coastal waters.

Sediment Dynamics

Very little research on the transport and dispersal of fine-grained sediments has been conducted in coastal Louisiana, and virtually none of the research efforts was undertaken specifically to determine the fate of dredged sediment. However, we now know from studies in other regions that muds behave in a fundamentally different fashion from the way sand behaves, primarily as a result of the cohesive forces present on the surfaces of clay particles. In cohesive beds the net attractive interparticle surface forces, electrochemical forces, control the resistance to erosion. They are not constant forces, but are a function of fluid characteristics and have time-dependent strength properties (Partheniades, 1971). The same forces are responsible for the behavior of fine sediment suspensions. Because fine cohesive sediments behave in a more complicated way than coarse sediments, a rigorous approach to their behavior in a flow field is extremely difficult.

Much of the sediment dredged from rivers and bayous along the Louisiana coast consists of precisely this material--cohesive, gel-like silts and clays that are referred to variously as fluid mud, soft silt, fluff, and "la creme de vase." These fine-grained sediments, deposited during the last several hundred years, are common in channels of the Mississippi River delta and associated embayments to the west. Median diameters of individual particles are only a few microns, and fine sediments are transported in suspension, even when flocculated into agglomerates many times larger.

The primary reason that dredged cohesive sediments are so important is that they may be nuclei for adsorption of many pollutants, such as radioisotopes, petroleum products, halogenated hydrocarbons, pesticides, metals, and oils and greases. Their transportation and subsequent deposition are thus controlled by the fine-grained sediment dispersal systems. Knowledge of long-term stability of dredged muds is essential, as is the retention of fine sediment in the estuarine circulation system.

Unfortunately, the behavior of fine-grained sediment in general, and fluid mud in particular, is often contradictory to our intuitive expectations (Wells, 1977). Furthermore, it appears to be highly site specific. For example, even when abundant measurements of flow characteristics exist, an understanding of velocity thresholds required to erode the sediments is lacking. Laboratory and field studies (Parthenaides, 1971) show that silts and clays can often withstand current velocities that are capable of transporting sand-sized particles and, in a single series of experiments, velocities necessary to initiate suspension span nearly an order of magnitude (Allersma et al., 1967; Delft Hydraulics Laboratory, 1962).

Although erosion velocities required to suspend fine-grained sediments are controversial, studies such as those carried out in situ (Young and Southard, 1978) offer the best hope for providing answers. In the study by Young and Southard in which a SEAFLUME was utilized in Buzzard's Bay, Massachusetts, the critical erosion velocity for bioturbated muds was found to be lower than for noncohesive sands and the erosion velocities only metres apart were noted to vary by a factor of two. Additional complications arise because the overall behavior of cohesive sediments cannot be attributed to one or even several bulk sediment properties, e.g., density and water content, but must include other important parameters such as viscosity, shear strength, and flocculation state. To transfer a sample of cohesive sediment from field to laboratory without disturbing these latter properties is virtually impossible.

Despite this discouraging introduction to sediment dynamics, new and useful information has become available on dredged sediment behavior since 1970 (Basco et al., 1974; Holliday, 1978). Cronin et al. (1970), in a study of dredged material in upper Chesapeake Bay, found that discharge increased turbidity levels over an area of 3.9 to 4.9 square kilometres (1.5 to 1.9 sq mi) around the discharge site. Suspended sediments in upper layers of water were carried in a tidal plume for 5 km, but essentially disappeared within 2 hours after pumping ceased. It was estimated that 12% of the deposited sediment disappeared from the pile within 150 days.

Saila et al. (1972), using precision depth soundings, determined the disposition of dredged material near Newport, Rhode Island. From isopach maps constructed to determine the volume of sediment in place after more than 1 year, they found 5.46×10^6 yd^3 of the original 5.5×10^6 yd^3 still remained. More recent surveys and observations revealed that the disposal mound underwent a definite change in configuration.

Gordon (1974) monitored by transmissometer the descent and initial spreading of dredged material in Long Island Sound. Even in the presence of a tidal stream sediments (silts) were found to travel to the bottom as a high-speed, turbulent jet. Upon impact a density current spread laterally, but sediment was not carried outside a circle of 120 m radius. Approximately 1% of the material discharged remained in the water column to settle at the fall velocity of individual particles.

Nittrouer and Sternberg (1975) investigated the fate of dredged sediment that was deposited in a tidal channel of Puget Sound. The stability of silt and clay-sized sediment was found to be controlled by dilution resulting from the dredging process during the disposal operation, depth of water at the disposal site, and intensity of near-bottom processes (waves and currents). In order to maximize the stability of a dredged sediment deposit, they concluded that disposal should minimize in-place disturbance of sediment and that shallow, low-energy environments are best.

Bokuniewicz et al. (1976), also working in Long Island Sound, focused attention on various processes that were capable of suspending and transporting dredged sediment. Repeated bathymetric surveys over a disposal mound revealed that after initial self consolidation no significant changes in configuration could be detected. Whereas wind-driven flow in water depths greater than 18 m (60 ft) was determined to be too weak for resuspension, winter storms and a hurricane were found to be significant.

Parker and Kirby (1977) and Kirby et al. (1979) have studied for a number of years the movement of fluid mud into shipping channels and its detection by echo sounding techniques in Great Britain and the Netherlands. Mobile suspensions of mud have been identified as those that develop naturally in high-turbidity estuaries and move in response to tidal circulation. On spring and intermediate tides, mobile suspension with sediment concentrations of 150,000 mg/l (≈ppm) were observed moving at speeds of 20-40 cm/sec. During times when tides are weak (neap tide cycle), near-bottom layers may become static and can be detected on echo sounders as "false bottom" returns. A problem of definition arises from static suspensions in that a decision must be made as to whether the first echo, "false echo," or second echo marks the bottom. Dredging when the top reflector indicates minimum navigation depth may in fact simply hinder natural consolidation of a material soft enough to permit passage of a vessel. It was found that waiting to dredge until the second echo reached minimum navigation depth could also be unsatisfactory because it reveals a greater navigational depth than actually exists. A good understanding of sediment dynamics, together with time series measurements of sediment density to determine the "real" bottom, were recommended.

Bohlen et al. (1979) found that resuspension by dredging represented a small perturbation in estuarine suspended sediment in the Lower Thames River, Connecticut. At most, the mass of suspended sediments was increased by 25%, but this increase was localized in an area that was less than 2.5% of total estuarine area. Sediment concentrations adjacent to the dredge were 200-400 mg/l, and the plume decreased rapidly (within 700 m) to background levels. Storm events, however, were noted to increase suspended sediment values by a factor of two throughout the estuary;these events occur 1-3 times a year, whereas dredging occurs once in 10 years.

Bokuniewicz and Gordon (1980), in a review of dredge spoil operations, found that in silt-clay spoil only a few percent were lost into the water column, and most was deposited on the bottom within a few hundred metres of impact point. The principal factor controlling degree of dispersion upon impact was said to be cohesion of spoil. Impact energy of clod-like spoil would be dissipated by plastic deformation if less than 0.8 m in diameter, and larger clods would break apart upon impact. Compact spoil deposits were observed to be most likely to result when sediment is dredged with a clam shell and released in small quantities at low speed over a soft bottom. Finally, lateral spreading as a turbidity current was noted to produce thin deposits; overlap from successive deposits would not produce a thick deposit because, as slope of deposit increases from deposition, gravity causes the turbidity current to run farther from the point of deposition. At disposal sites in Lake Erie, Danek et al. (1977) found maximum thickness of only 0.5 m after disposal by hopper dredge, thus resulting in a very large surface area for interaction with overlying water.

Because the processes that affect movement of dredged material are identical with those that influence natural sediments of the same size and physical character, results of basic research can broaden the data base and provide further insight into artificially emplaced sediments. For example, results of studies (Morgan et al., 1953; Wells and Roberts, in press) which show that turbid sediments from Atchafalaya Bay are entrained into a westerly drift system and thus carried to the eastern margin of the chenier plain (Fig. 9) can also explain the fate of dredge spoil that has been resuspended. Figure 10 shows the volume of sediment that might be transported under normal conditions from Atchafalaya Bay and then deposited offshore versus that which is carried farther west. The implication is that dredged sediment (see Fig. 1), should it be entrained into the water column from the bay or from offshore, would likely move west, toward the chenier plain, confined in a narrow band referred to as a mud stream, and would be transported in water moving with a net speed of perhaps 10 cm/sec. Its final resting place could be the mudflats of the eastern chenier plain.

Research into wave effects on mud substrates has shown that fluid muds are suspended at wave frequency and perhaps transported by wave-induced currents in shallow water (Wells, 1977; Wells et al., 1979). By monitoring variations in sediment density on or very near the bottom simultaneously with surface wave activity, a sequence of time series records such as the two shown in Figure 11 can be obtained. The wave by wave density fluctuations are the result of clouds of sediment lifted from the bottom as each wave passes a given point. Some of the

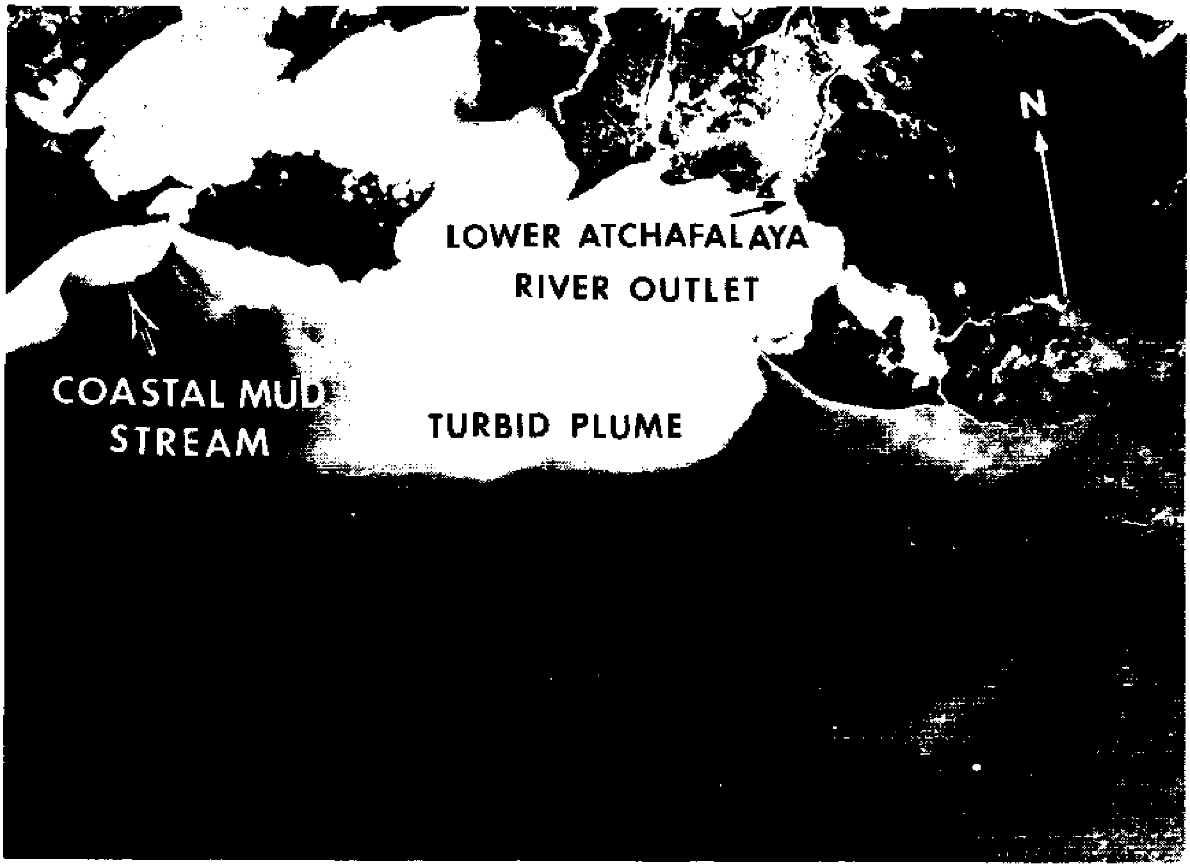

Figure 9. ERTS image (band 5) of Atchafalaya Bay and central Louisiana coast taken in 1973.

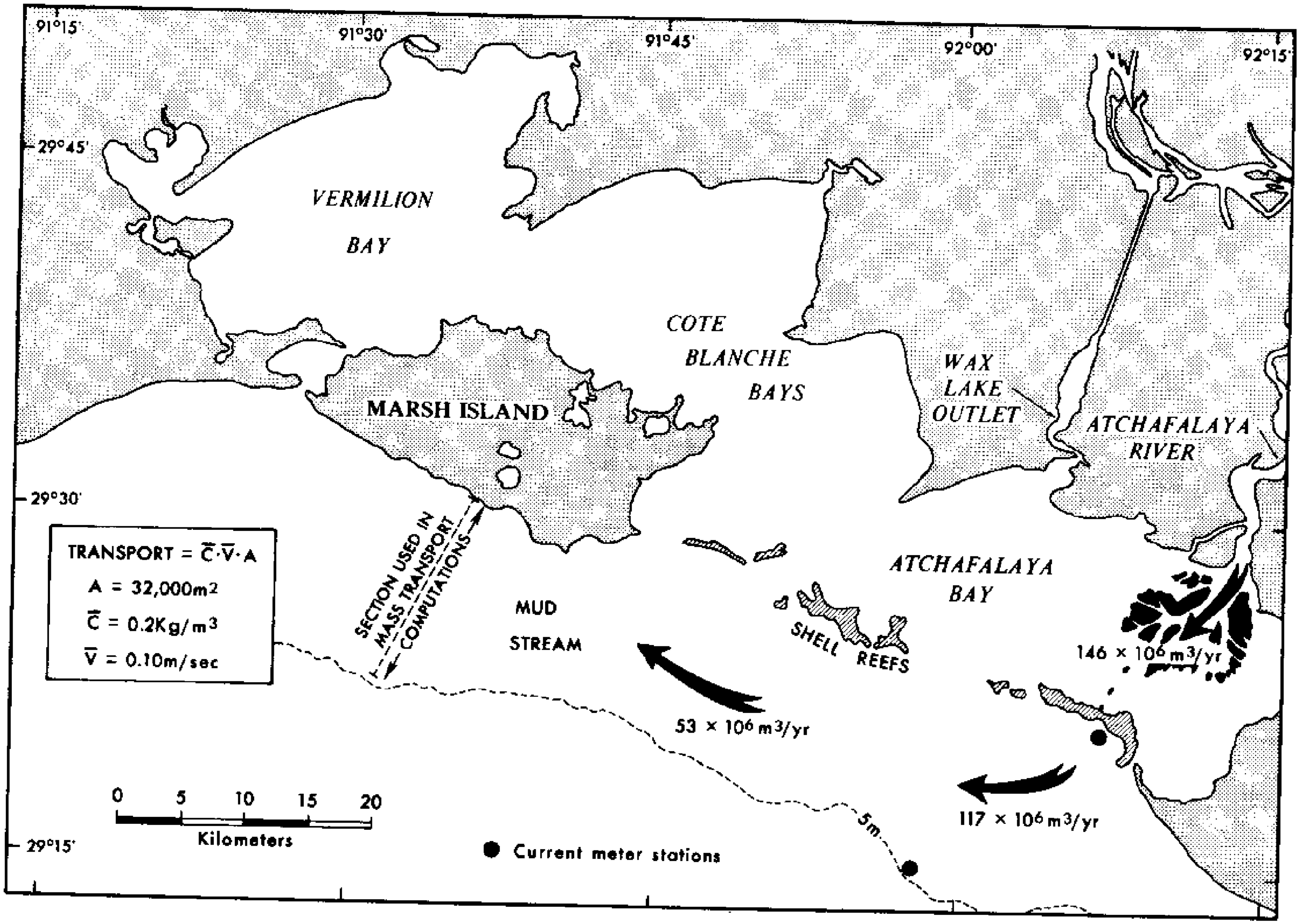

Figure 10. Central Louisiana coast showing computed values of volume flux of sediment into and through the Atchafalaya system. The coastal mud stream carries approximately 50 x 10^6 m^3/yr of silt and clay to the chenier plain.

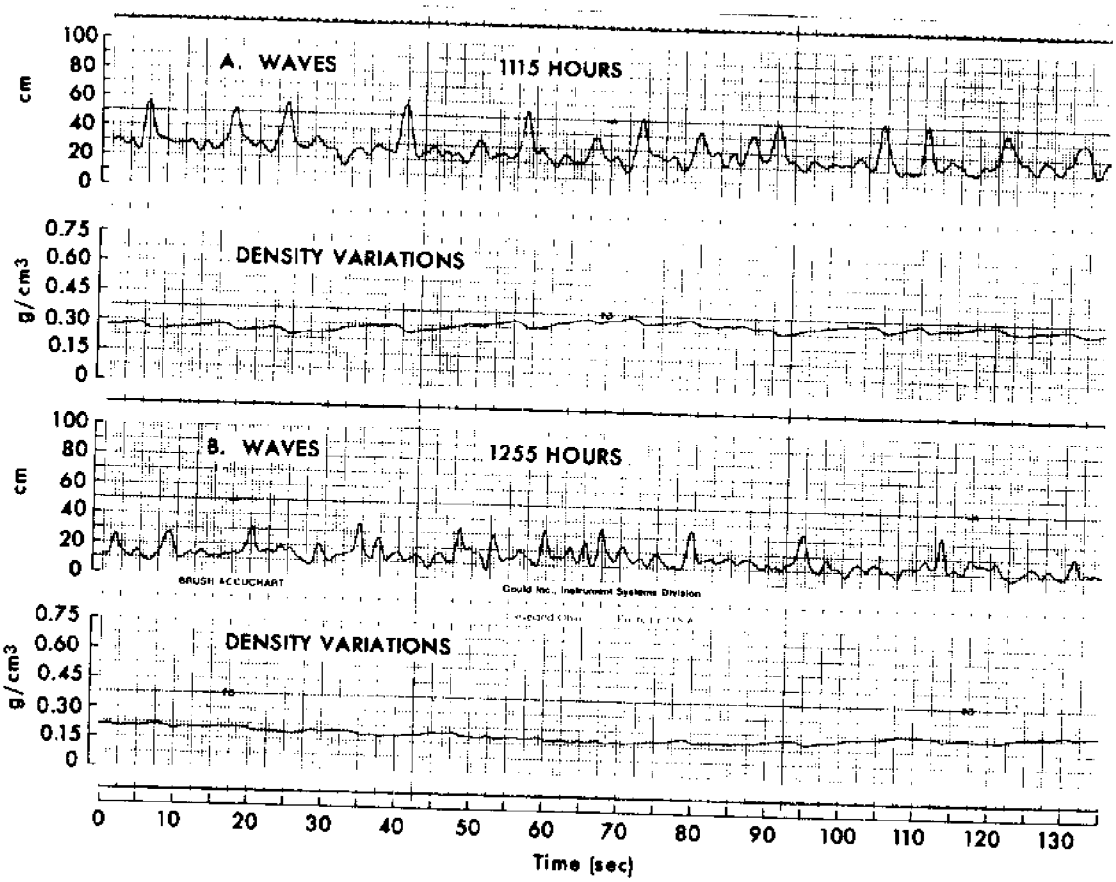

Figure 11. Wave-by-wave variations in near-bottom mud density recorded during the passage of waves at 1.5 hr below low tide (A) and at low tide (B). Slight decrease in magnitude of density variations in (B) is a result of removal of 10 cm of mud between instrument sensors (from Wells, 1980).

suspended sediment settles back to the bottom, and the rest is advected by net currents. If this process continues for very long, substantial quantities of mud can be removed from the bottom. From 1115 hours to 1255 hours waves suspended approximately 10 cm of extremely soft bottom sediment (Wells, 1980).

Even lacking wave or current activity, Wells et al. (1980) found that soft, gel-like muds can flow on very low slopes (0.03-0.08 degree) simply as a result of gravity. Underconsolidated dredged muds have been documented to flow easily during disposal and, in fact, have been termed mudflows and density flows (turbidity currents) by O'Neal and Sceva (1971) and May (1973). It appears that results of studies dealing with sediment instabilities on low slopes may be beneficial to understanding behavior of fresh, unconsolidated spoil and that field data on resuspension by waves and currents are essential for older spoil deposits.

Chemical and Biological Effects

Agencies responsible for harbor and waterway maintenance in coastal Louisiana are required to seek methods and locations for dredged materials disposal that minimize risks to estuarine productivity and public health. A spoil discharge into coastal waters constitutes an environmental perturbation with a radius of impact broadly determined by three factors. These are (a) the nature of the material discharged, (b) the dynamics of the receiving environment, and (c) the recovery potential of affected biota. Decision makers weighing alternatives need to understand the degree to which stresses caused by subaqueous dumping are confined in space and time. Acute site-restricted impacts from which recovery is rapid are obviously of less concern than those that persist for years or cannot be contained. In this section a review of the range of potential hazards is given, with a focus on those most problematical in the Louisiana setting.

Assessing the effects of dredged material disposal off U.S. coasts, Pequegnat et al. (1978) divided potential biological impacts into those caused primarily by physical-mechanical habitat alteration and those caused by chemical releases from introduced sediments (Table 2). Alterations of the first type are limited (a) to the short-term turbidity increase and rapid sedimentation directly associated with disposal operations and (b) to subsequent current modification by spoil mound geometry. Transitory changes in water chemistry may be observed as a result of initial equilibration of dredged sediments with redox, pH, and salinity conditions at the disposal site. Most material dredged during waterway and harbor maintenance has a high clay and organic matter content such that it is usually devoid of oxygen and often contains high interstitial concentrations of ammonium nitrogen (Gambrell et al., 1978). Discharge into coastal waters thus commonly results in temporary dissolved oxygen depletion accompanied by dissolved ammonium concentration increases, occasionally to near toxic levels (Windom, 1973; Lee et al., 1975). Elutriate test results and field monitoring have generally shown, however, that heavy metals and chlorinated hydrocarbons, which are the toxins of primary concern in dredged sediments, are not released or are released only in negligible amounts during water column passage (Lee et al., 1975, 1977; Brannon et al., 1976, 1978; Burke and Engler, 1978). Long-term containment of these toxins after settlement of the sediment plume is potentially a far more serious problem. Contaminated sediments have been implicated as a chronic source for the heavy metal and chlorinated hydrocarbon accumulations observed in aquatic and benthic organisms (Young and Jon, 1976; Belaire and Alexander, 1976; Giam et al., 1978). Movement of soluble Mn, Fe, Cu, Ni, Co, Zn, and Hg from metal-rich sediments into overlying water has been reported (Trefry, 1977; Bothner et al., 1980) and phytoplankton can scavenge these and other metals from the water column (Sims, 1975; Horowitz and Presley, 1977; Presley and Boothe, 1977). Additional evidence suggests that deposit and filter feeders are able to accumulate chlorinated hydrocarbons from sediment particles (Rosales et al., 1979; Pequegnat et al., 1978). Presumably as a consequent of food chain magnification, toxins of both classes have been found in fin and shell fish tissue at levels which threaten human health (Irukayoma, 1967; Young and Jon, 1976).

The scale on which massive riverine inputs of water and materials influence Louisiana coastal waters is reflected in annual requirements for maintenance dredging unsurpassed in the United States (Boyd et al., 1972). Given the unique dynamics of the deltaic environment, much of the literature generated elsewhere regarding the potential biological impacts of short-term fluctuations in turbidity, nutrients, or dissolved oxygen associated with dredged material disposal cannot be readily applied. Wind/wave mixing within the coastal boundary layer effectively distributes oxygen and suspended sediments to depths of 30 m. As a result, the euphotic zone is naturally restricted by turbidity to the upper 1-3 m (Sklar, 1976). Despite this apparent limiting influence, primary production rates in the Mississippi Bight are among the highest reported for U.S. estuaries (Thomas and Simmons, 1960; Fucik, 1974; Sklar, 1976) and present a marked contrast to oligotrophic

Table

Assessment of Potential Environmental Impacts Related to Subaqueous Dredged Materials Disposal

Effect	Short-Term Impact		Long-Term Impact	
	Input Mode	Rel. Damage Potential	Input Mode	Rel. Damage Potential
Turbidity Increase				
1) Light penetration reduced		Minor - Effect highly localized		Important if grassbeds or corals present LOCAL
2) Dilutes food particles with useless material	Cloud of suspended fine-grained material created during disposal operations	Minor - Effect highly localized	Chronic resuspension by wind/wave action and current scour	Important if large sessile population of filter feeders present (oysters) - LOCAL
3) Particulate toxins available to biota		? - Depends on concentration and type toxins in sediment and and density of filter feeding organisms at dump site		Severe - potential for bioaccumulation or magnification in food web - WIDESPREAD
Bottom Sediment Buildup				
1) Sessile organisms smothered	Settlement of dredged materials on bottom	Important if benthic biomass high LOCAL	Bedload sediment transport by currents	Important if movement affects adjacent areas of high benthic biomass
2) Bottom topography altered		None		? - Local hydrodynamics changes may be beneficial or detrimental - affect distribution of larvae
Dissolved O_2 Depletion				
1) Sessile organisms suffocated	Water column exposure of high BOD, COD materials during disposal operations	Minor - effect highly localized	High O_2 demand by reduced sediments at bottom	Important if O_2 regeneration rate low - diversity of benthic community reduced - LOCAL
Nitrogen Released				
1) Algal growth stimulated	Ammonia release from reduced sediments of high organic content during water column exposure	? - Increased productivity may be considered positive or negative MINOR - LOCAL	Benthic regeneration across sediment/water interface	Important if O_2 regeneration low and eutrophy results in anoxia in bottom waters
2) Acute toxicity		? Undocumented in field MINOR - LOCAL		? Unlikely LOCAL
Heavy Metal/Chlorhydrocarbon Release				
1) Dissolved species concentrations increased in water column	Desorption from clays, oxidation of insoluble precipitates during water column exposure of reduced sediments	Important if significant uptake by phytoplankton occurs - possible bioaccumulation	Chronic resuspension and flux across sediment/water interface	? Severe - potential for bioaccumulation or magnification. Toxins enter food chain at sublethal levels
2) Deposit feeders contaminated		? Minor - Local	Reworking of contaminated sediments by burrowing organisms	? Severe - organisms exposed to high toxin concentrations in interstitial waters. Digestion processes may introduce otherwise unavailable toxins into food web. Toxins enter food chain at sublethal levels
3) Acute Toxicity		?		

*Adapted from Pequegnat (1978).

conditions east of the river (Bittaker, 1975) and in the offshore Gulf (El-Sayed, 1972). Fishery yields are correspondingly high, and the catch from Louisiana coastal waters represents approximately 30% by dollar value of total U.S. commercial fisheries (Lindall et al., 1972; Turner et al., 1975). Much of the fertility of this zone is attributed to nutrients outwelling from the Mississippi-Atchafalaya system (Ho and Barrett, 1977; Sklar, 1976) and to the flux of organic matter from extensive marshes (Walford, 1968; Happ et al., 1977).

Smothering of small and nonmotile benthic fauna at dump sites is potentially as serious a problem in Louisiana as elsewhere. Qualitative information on infaunal macrobenthic assemblages is available (Behre, 1950; Dawson, 1966; Barrett et al., 1978), but quantitative work of the type necessary to assess ecosystem level damage and recovery potential remains for the future. This effect of dredged spoil disposal as well as any that might result from alteration of existing current regimes by spoil mound geometry will presumably have to be evaluated on a site by site basis after adequate safeguards for the prevention of toxin release have been established.

Avoiding contamination of biota with toxic metals and chlorinated hydrocarbons must assume the highest priority in selecting dump sites in Louisiana coastal waters.

Heavy metals enter the Gulf through the Mississippi-Atchafalaya system primarily associated with clays and as oxide coatings on particles (Andren and Harris, 1975; Trefry and Presley, 1976b). Although the total input of heavy metal pollutants, including the most dangerous toxins (As, Cd, Hg, and Pb) to Louisiana coastal sediments, is extremely high (Trefry and Shokes, 1979), the massive volume of suspended sediment also introduced dilutes concentrations in deposited material to levels little above background values (Trefry and Presley, 1976b; Holmes, 1976). Highly contaminated sediments such as those in the Houston Ship Channel (Trefry and Presley, 1976a) will be confined in Louisiana to areas immediately adjacent to polluting industries.

The most widespread and persistent toxic chlorinated hydrocarbons in the Louisiana coastal marine environment are the polychlorinated biphenyls (PCBs) and the pesticide DDT and its metabolites. One of the best documented effects of chlorinated hydrocarbons is that relating DDT to eggshell thinning and reproductive failures in Louisiana Brown Pelican populations (Blus et al., 1979a, b). Although far less is known about transport modes for chlorinated hydrocarbons than for trace metals, laboratory studies suggest movement in the particulate load (Burks and Engler, 1978). Giam et al. (1978) have collected data from throughout the Mississippi Delta area and find particularly high contamination associated with zones of intense industrial and agricultural activity.

Once a sediment has been identified as contaminated with toxic metals or hydrocarbons, disposal efforts must be targeted toward minimizing the biological availability of these substances. Considerable laboratory and field work has been summarized in manual form by Gambrell et al. (1978). Although exceptions are noted, the recommended approach for both metals and organochlorines is to dispose of contaminated dredged material in a quiescent environment away from economically and ecologically important biological populations. The immobilization of most metals is best accomplished under reducing conditions where insoluble sulfides can act as an effective trap. Efforts should be made to ensure minimal resuspension of stable mounds and, in cases of highly contaminated material, a covering with clean or less contaminated material is suggested.

RECOMMENDATIONS FOR RESEARCH

Based on our present level of understanding of coastal processes, sediment dynamics, and the chemical and biological effects of dredge spoil dispersal, the following general recommendations for research are given:

1) Conduct *multidisciplinary* studies. Biological effects of dredging and dredge spoil disposal cannot be understood without knowledge of water characteristics and natural circulation, nor can chemical effects be assessed without knowledge of transport of the sediments that may be contaminated. Major research efforts, therefore, must include as many components of the natural system as possible, and funding should be directed toward coherent projects that fit into the larger framework of a *research program.* The most common missing ingredient in biological and ecological studies is the role played by physical oceanographic processes, whereas the most common missing ingredient in studies of sediment dynamics is the effect of biological processes on sediment stability and morphology.

2) Examine *processes* in the natural system. At present our ability to model natural systems or to simply collect background data far exceeds our understanding of the processes that interact to govern the system. The recommendation is, therefore, to place emphasis on such questions as *why* sediments move, *what* controls the rate of adsorption of pollutants to clay particles, or *how* silt tolerances of the organisms we are attempting to protect relate to arbitrary units of turbidity that are allowed legally. Decisions that are based on answers to the above questions are more meaningful than those based on mathematical or laboratory simulations or on examination of vast amounts of data collected only for the purpose of monitoring the environment. We can no longer afford to simply measure things; rather, we must recognize and seek an understanding of important processes.

3) Conduct research in the *natural* environment. Natural systems are exceedingly complex, and much research has understandably been directed toward studies that reduce the number of variables by using a laboratory setting. However, certain aspects of dredge disposal research cannot be studied adequately except in the field. Mechanics of fine-grained sediment entrainment and the determination of circulation in coastal waters are two examples; research efforts in these and other areas should be limited to field projects.

4) Encourage research that considers dredged material as a *potentially productive resource.* The U.S. Army Corps of Engineers now views dredged material as a potentially useful resource rather than a waste product and the DMRP has examined new and innovative ways to use this material. Although highly polluted sediment may never be considered a beneficial resource, certainly much of the sediment is valuable for land improvement and the creation of new marsh. Spoil mounds in Atchafalaya Bay have been used for exactly these purposes and may serve as a haven for wildlife as well as recreational land for controlled hunting and camping.

Based on identification of weak areas, specific recommendations call for research directed toward:

1) Study of cross-shelf variation in coastal currents within the low-salinity, high-turbidity coastal boundary layer (CBL). The gradient in velocities

within the CBL and its migration in time and space is essential information in order to understand potential transport of spoil material. It is important to note that as recently as 1976 a review of our state of knowledge (Murray, 1976) indicated that we lacked even a rudimentary understanding of the mechanics of water motion along most of the coast.

2) Detailed study of salt balance in a major estuary in which dredging and/or disposal operations are taking place. Dynamics of turbulent mixing and diffusion of salt are essential in processes of flocculation, water density variations, buoyant river plume expansion, and ion exchange in particulate matter.

3) Investigation of estuarine dynamics in major Louisiana estuaries where siltation occurs. Scope of research should be sufficient to include water levels, balances of heat, momentum, and salt, and nature of tidal currents.

4) Study of wave effects on mud substrates and the ability of fine-grained sediments to withstand wave scour. Although muddier waters seem to coincide with higher waves, the relationships are known only qualitatively and need to be further defined. In shallow water when wave orbits do not close, the potential exists for transporting as well as suspending fine-grained sediments.

5) Study of transport of dense suspensions. Dense suspensions of sediment near bottom are associated with dredged muds during and shortly after disposal. Because of the high sediment concentrations, even slow or creeping motion of such materials can transport large volumes of sediment. Previous studies have shown that this material moves both by the force of gravity and by current flow in a layer near the bottom.

6) Determination of shear stress required for sediment erosion. Earlier discussion in this report indicates this is a difficult task; at the same time, it is one of the most important, since the stability and final configuration of spoil mounds depends on their ability to withstand wave and current stresses.

7) Development of instrumentation that is capable of monitoring in situ suspended sediment concentration, current speed and direction, and sediment properties, such as density and strength. Simultaneous time series data are needed for extended periods of time (weeks to months). Studies have already been made in prototype instrument development which should provide a base for further work: sediment density measurements using a nuclear densimeter (Parker et al., 1975); sediment flux measurements using a concentration-velocity (CV) probe (NOAA, 1978); and simultaneous sediment density/wave height measurements using pressure transducers (Wells, 1977; Fredericks and Wells, 1980).

8) Assessing the effects of severe storms and hurricanes on spoil deposits. For obvious reasons, nearly all water column measurements have been made under fair-weather conditions and continuous time series data taken during severe storms or hurricanes are scarce. Because more energy may be expended in a single storm than during the rest of the year, the benefits of obtaining any data are great. A particularly worthwhile study in coastal Louisiana would be the careful documentation of seasonal effects as a result of storms associated with strong cold fronts from mid-November through mid-March.

9) Research directed toward ensuring bioisolation of toxic dredge spoil contaminants. An assumption of most of the geochemical work cited in this report is that toxin bioavailability is regulated by inorganic precipitation/dissolution kinetics. Research summarized by Woods (1974) indicates that this may not be entirely true. Observed bacterial synthesis of toxic and bioavailable decomposition products such as methyl-mercury in contaminated sediments is not readily predicted by thermodynamic models but may be the primary mechanism introducing some toxins into the aquatic food web. The suggestion here is that productive future efforts will be those that study toxin synthesis and accumulation at the microbial and meiobenthic trophic levels.

10) Improvement and standardization of analytical techniques for detecting and differentiating organic compounds synthesized at the disposal site. Diffusion/dispersion models for predicting mobility of these substances in the disposal site environment require development and testing against field data. These physical-chemical data ideally should be in the form of in situ synoptic time series which may be used to identify processes controlling advection, diffusion, and dispersion of toxic substances under nonequilibrium conditions. The development of instrumentation able to provide this sort of information should also be considered a primary research goal.

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APPENDIX

Methods of Dredging and Types of Disposal

The methods by which sediments are dredged and the manner of their subsequent disposal may affect the ultimate fate of dredged material in Louisiana coastal waters. The following paragraphs provide a brief summary of dredging and disposal techniques with emphasis on those most widely utilized in Louisiana.

Dredges used to create or maintain waterways can be divided into two basic types: hydraulic and mechanical. The most common hydraulic dredges are hopper and pipeline; the most common mechanical dredges are clam shell and dragline buckets. Hydraulic dredges lift bottom sediment by means of pumps, then transfer this dredged material into hopper bins for transport to place of disposal (hopper dredge) or into a pipeline system for discharge at a remote disposal site, perhaps 10 to 15 km away (pipeline dredge). Whereas pipeline dredges are restricted to relatively protected waters (bays, lakes, rivers) because of potential pipeline uncoupling, hopper dredges are self propelled, highly mobile, and are ideal in rough water or in situations that prohibit pipeline pumping for long distances.

The bucket dredge in its simplest design contains a drop bucket attached to a system for lifting dredged material to the surface. The dredged materials are usually placed in barges for transport to a disposal site. According to Boyd et al., (1972), they are well-suited for working in small or confined areas.

Nationwide as of 1973, hydraulic dredges accounted for 99% of the total volume of material dredged with 57% of the total work being performed by hopper dredges and 42% by pipeline dredges (Pequegnat et al., 1978). Bucket and other types accounted for only 1% (Pequagnat et al., 1978). In coastal Louisiana (See Fig. 1), 33% of dredging is by hopper dredge and 67% by pipeline dredge (Boyd et al., 1972). Cost is approximately one dollar per cu yd (as of 1978) which translates to over $200 million annually.

Disposal operations are performed on land and in open water. Prior to the recognition of environmental concerns, cost traditionally dictated the location of disposal sites, and thus open-water disposal was more common (Pequegnat et al., 1978). The technique for hopper dredges in open water is to circle a disposal area while opening bottom doors to release dredged material in a short period of time; discharge can range from 500-8000 cu yd (385-6160 cu m) (Boyd et al., 1972). Pipeline disposal, the method most common in Louisiana, can be carried out either in open water or on land. Distances to disposal sites can be increased with the aid of booster pumps along the pipeline route. In contrast, mechanically dredged materials are loaded into barges and towed to open water disposal sites. A fundamental difference in spoil disposal from hydraulic versus mechanical dredges is the amount of water, hence bulk density, of the material. As mechanical dredges pick up sand sized sediment, water drains off and density of sediment remains nearly that of the in situ sediment (Mohr, 1976). In contrast, hydraulic dredges add water in order to dilute sediment to a slurry and thus increase the volume of dredged material which needs to be handled (Pequegnat et al., 1978). Slurries transported through pipeline to open water can be discharged directly onto the water surface, deflected into a spray, or injected under the water's surface (Boyd et al., 1972).

During the years 1974-1976 approximately 450 million cu yd (~350 million cu m) per year of dredged material were discharged as a result of dredging by the Corps of Engineers (Pequegnat et al., 1978). Of this total only 20-22% was discharged or dumped into the ocean. Data given by Pequegnat et al., (1978) show that the largest volume of dredged material is generated along the Gulf coast and of all the coastal Corps of Engineers Districts, Galveston, New Orleans, and Mobile account for two-thirds of total maintenance dredging. In coastal Louisiana (New Orleans District) open water disposal, which includes bays, estuaries, and river mouths, accounted for 67% of the some 145.6 million cu yd (112 million cu m) of material dredged annually during the 1974-1976 time period (Boyd et al., 1972). Further details of disposal operations and behavior of sediment during and immediately after disposal are given by Pequegnat et al., (1978).