BARATARIA/PLAQUEMINES BARRIER SHORELINE RESTORATION PROJECT GEOTECHNICAL INVESTIGATION AND ANALYSIS

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I. INTRODUCTION

This study was conducted for the National Oceanic and Atmospheric Administration (NOAA), National Marine Fisheries Service. The purpose of the study was to investigate potential sediment sources for the development of two barrier island restoration projects within the Barataria/Plaquemines barrier shoreline. The results of geotechnical investigations are included, and will be used in the design phase to delineate borrow areas for the Barataria barrier shoreline restoration projects at Pelican Island and Chaland Headland. The geotechnical study was conducted by Coastal Planning & Engineering, Inc. (CPE), as subcontractor to Tetra Tech EM Inc., with support from the University of New Orleans (UNO) Coastal Research Laboratory.

II. PROJECT BACKGROUND

Located on the western flank of the Mississippi River deltaic region, the Barataria barrier shoreline study area is about 30 miles long, ranging from the Grand Terre Islands to Sandy Point (Figure 1). The barrier shoreline provides unique habitat for coastal fisheries and provides a barrier which protects inshore wetlands and coastal communities from tidal inundation, storm surge, and wave action. The Barataria shoreline, and associated wetlands, represent the most rapidly eroding wetlands in the U.S. More than 100,000 acres of marsh have disappeared from the study area since 1932. Shoreline retreat along the Barataria shoreline ranges from 2 to 100 feet per year (ft/yr), averaging about 18 ft/yr over the last 100 years. Wetland loss rates in this area are the highest in Louisiana. If major barrier island restoration efforts are not undertaken (Stone and McBride, 1998), most wetlands remaining behind the barrier shoreline may be lost within the next 20 years.

Significant progress towards the restoration and maintenance of the Louisiana barrier island systems was made possible with the passage of a federal law entitled "Coastal Wetlands Planning, Protection and Restoration Act" in 1990. As a result, in Louisiana, several barrier island restoration projects are in progress within the scope of the program including the restoration of the Barataria/Plaquemines barrier shoreline.

The Barataria shoreline was divided into seven sub-reaches for consideration as restoration projects. In order to organize and evaluate the complex data sets needed to support the site selection process, a decision matrix was developed. Eleven separate criteria were evaluated for the seven sub-reaches which provided the framework for the selection of two sites of the seven potential sub-reaches. Pelican Island and Chaland Headland sub-reaches were identified as the best candidates for the restoration projects.

The restoration of the barrier islands includes consideration of an increase in beach/dune cross-section, and improvement of the bayside marsh platform. The enhancement of the beach and dune will provide increased protection from storm-related surge and wave attack, through the prevention of island breaching or loss of major portions of the islands. Restoration of the marsh platform behind the barrier islands will reinforce the long-term stability of the island system against major storm events. Prevention of island breaching (inlet cutting) and limitations on overtopping (washover) during storms are the primary mechanisms by which the project will provide storm protection.

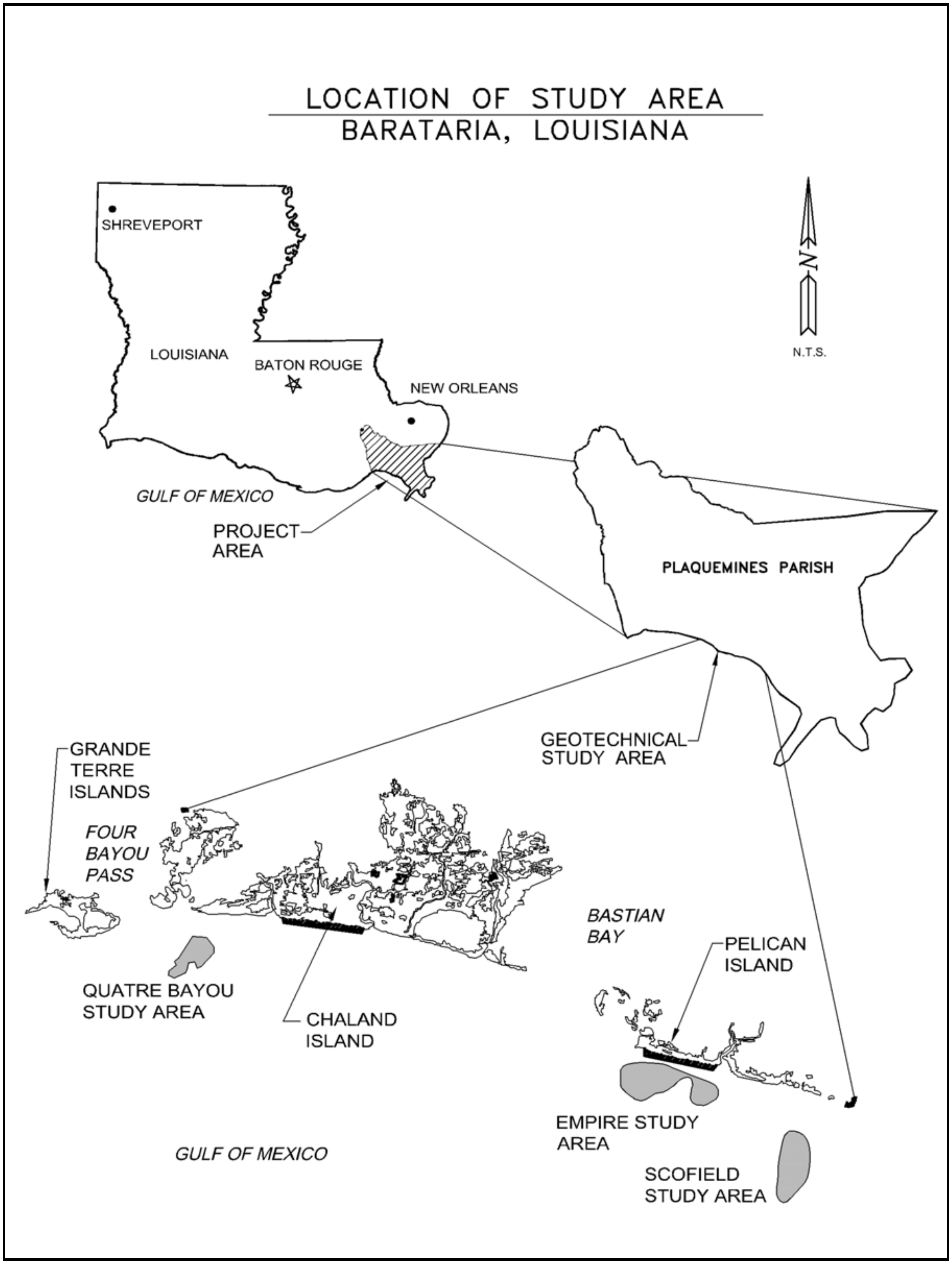


Figure 1: Inner shelf areas investigated.

An important aspect for the success of large scale restoration of barrier shorelines is to locate sand deposits for use in the restoration effort, and to develop cost-effective strategies to deliver the sands to deteriorating barrier islands. The main objective of this investigation was to conduct geotechnical investigations in order to determine if sand resources existed in areas adjacent to the Barataria/Plaquemines barrier shoreline, which were suitable for the restoration effort.

III. STUDY AREA AND PROJECT LOCATION

A. Study Area

The study area includes the Barataria barrier island complex, which is 30 miles in length and located 48 miles south-southeast of New Orleans, on the western flank of the Mississippi River delta plain. The area of primary concern is also referred to as the Plaquemines Shoreline.

B. Project Areas

The two project areas are located on two separate barrier islands in the Barataria barrier island complex (Figure 1), as follows:

1. Pelican Island: Pelican Island is approximately 2.6 miles long, and extends from Fontanelle Pass to Scofield Pass in the Barataria Basin. It is located approximately eight miles south of Sunrise, Louisiana (Figure 1).

2. Chaland Headland: The barrier island extends from Pass La Mer east to Chaland Pass, and is 2.8 miles in length. It is situated approximately 15 miles south of Diamond, Louisiana (Figure 1).

C. Deposit Sites

After initial review of the Phase I reconnaissance study (conducted by USGS and reported by Kindinger et al., 2001) four areas for additional studies (Quatre Bayou, Empire, Scofield and Sandy Point) were recommended. In consultation with the client, the three areas closest to the project sites were selected to conduct detailed geotechnical studies, and included Quatre Bayou, Scofield and Empire. The areas are briefly described below.

The three areas selected for additional geotechnical investigations (Quatre Bayou, Empire and Scofield) contain deposits directly related with the abandonment of deltaic complexes during the Holocene sedimentary history of the deltaic plain and/or modern ebb-tidal shoal development. The Quatre Bayou is a relatively large study area located offshore Quatre Bayou Pass and Pass Ronquille, west of Chaland Island (Figure 1). Deposits in this region are related to modern ebb-tidal shoal development (nearshore region) and ancient distributary channels and distributary mouth bars (overburden deposits located further offshore) (Kindinger et al, 2001; Suter et al., 1991). The Empire study area is located offshore the Empire Jetties and Pelican Island (Figure 1). The area was described by previous authors (Kindinger et al, 2001, Suter et al., 1991) as containing potential deposits of fluvial origin (channel fill deposits) overlain by modern marine muds. The Scofield study area is located offshore Scofield Bay, southeast of Pelican Island (Figure 1). This is the smallest area of investigation. Deposits in this area present sedimentary characteristics similar to the Empire area (Kindinger et al., 2001) and consist of channel fill material with highly variable composition (Kindinger et al., 2001; Suter et al., 1991).

The Sandy Point site, not selected for additional investigation, is located offshore of the Scofield study area. This area was not included in the investigation because areas of potential sand sources (Scofield and Empire) were located closer to the project area. Sandy Point was recommended as a backup area for detailed geotechnical investigation if the Scofield and Empire sites did not contain sufficient sand resources for restoration of Pelican Island.

IV. GEOLOGY AND GEOMORPHOLOGY

A. General Background Information

In order to better appreciate the sedimentary geology and geomorphology of the Mississippi River deltaic plain, the essential phenomena of river diversions (avulsion) and delta switching are summarized in terms of major deltaic depositional events throughout the geologic history. These processes will be addressed in the following sections by emphasizing the formation of transgressive sand bodies and evolution of modern barrier islands.

Throughout the deltaic plain, late Pleistocenic mud-rich and stiff clay deposits underlie the modern quaternary depositional deltaic sequence. Typically this Pleistocene facies is denser than overlying Quaternary sediments. On the top of the Pleistocene deposits is the late Wisconsin erosional exposure surface. This unconformity ranges in elevation from about -60 feet beneath New Orleans to as much as -460 feet at the shelf edge southeast of the Balize subdelta (Stanley et al., 1996). These late Pleistocene sediments have been attributed to the Prairie formation (Campbell, 1972), and more recently, to the Prairie Complex (Saucier and Snead, 1989). The late Wisconsin surface is an unconformity that is characterized by stream rejuvenation and fluvial incision, sedimentary bypassing of the shelf, and abrupt basinward shift of facies and subsequent coastal onlap.

Subaerial exposure of the continental shelf during the late Pleistocene lowstand facilitated deep fluvial entrenchment (*viz*., formation of incised river valleys). Valley landscape across the present day shelf was then common. Valleys at that time cut into the shelf sediments as

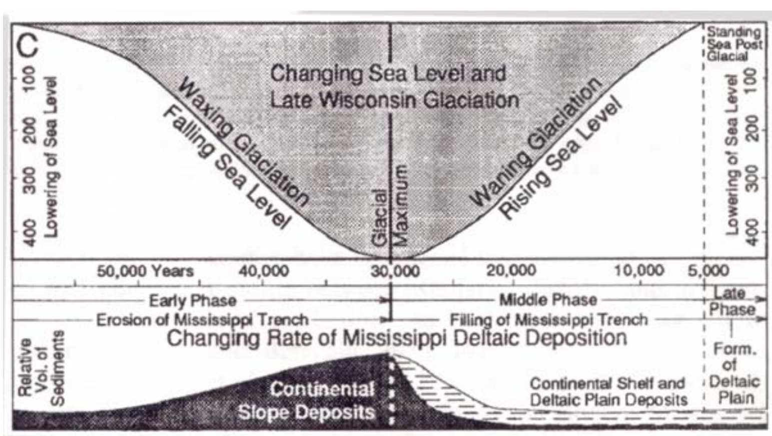


Figure 2: Diagram illustrating the effect of late Pleistocene and Holocene sea level oscillations on the Mississippi deltaic deposition (after Fish and McFarlan, 1955).

deeply as 390 feet (Fisk, 1944). The shoreline during the lowermost sea-level stand in the study area, dated by Fisk (1944) and Fisk and McFarlan (1955) as 30,000 YBP, was positioned near the present day shelf edge (Figure 2). Thick shelf edge deltas developed during this period, and seaward migration of deltaic deposition toward the shelf edge was common (Fisk, 1955; Suter and Berryhill, 1985).

Coleman and Roberts (1988) recognized seven isotopic stages during the late Quaternary, and attributed these to seven sea-level cycles. Interpreting borehole and seismic data, they correlated the cycles with seven distinct stratigraphic units, in which five are pertinent to the study area. According to Coleman and Roberts, Stage 1 (0-12,500 YBP) appears to be correlated with the Holocene deltaic facies, Stage 2 (12,500-24,000 YBP) with the Preoria Loess, Stage 3 (24,000-59,000 YBP), Stage 4 (59,000-71,000 YBP) with the Prairie Complex, and Stage 5 (71,000-128,000 YBP) with the Sangamon Prairie complex.

Following the lowstand of the last glacial maximum (at about 18,000 BP), a transgressive phase took place where sea level rose rapidly until the early Holocene (7000 to 8000 YBP), at which time the rate of rise decreased dramatically (Coleman et al., 1998). As sea level rose, fine-grained terrigenous sediment accumulated as a function of changed hydrodynamic conditions. Fisk (1944) reported that initial filling of valleys, resulting from glacial outwash, consisted of graveliferous and coarse sand facies. Once a major part of the fill was completed and the fluvial channel completely flooded by the marine transgression, a highly organic clay rich facies dominated the final fill sequences in a typical fining upward stratigraphic sequence. Holocene deposits overlying the Pleistocene surface form major sequence boundaries in sedimentary packages. This includes the development of a widespread, shelly, silt and sand transgressive strandplain facies that formed in response to rapid sea level rise. At this time, progradational deltaic facies accumulated as sea-level rise decelerated. Also, cyclic depositional events reflected the abandonment of the sediment source from one part of the delta plain to another (Fisk, 1955). The depositional sequences of the delta plain thus contain depositional cycles of various dimensions which reflect rapid pulses of deltaic deposition operating on different spatial and time scales (Roberts et al., 1994).

Older lobes of the Mississippi delta began to accumulate sediment about 7,000 YBP, where the rate of sea level rise slowed down and sea level had nearly reached its present level (Roberts, 1997; Fisk et al., 1954). During this period, south Louisiana was characterized by frequent shifting of the locus of deposition, rapid subsidence, local regressions and transgressions as a function of balance between relative sea level rise and sediment supply. Resulting from this process was the buildup of a cyclic sediment column and wide-spread transport and rework of fine grained sediments adjacent to the active deltas (Coleman et al., 1998).

At the present time, a coalescence of eighteen delta lobes within six major delta complexes (Figure 3) make up the Holocene deltaic plain (Coleman et al., 1998). The entire deltaic plain is transgressive, with the exception of the Birdfoot (Balize complex) and the Atchafalaya River delta complex. The most recent abandoned lobes are the Late Laforche and Plaquemines of which both exhibit erosional headlands with flanking spits and barrier islands.

The modern Mississippi River drainage basin encompasses 1,291,342 square miles. The basin is an order of magnitude greater in area than the Rio Grande drainage basin and two orders greater than the Brazos drainage basin (Coleman, 1982). Average maximum and minimum water discharge of the Mississippi River are 75,730 cy/s and 3,701 cy/s respectively. The annual sediment discharge of the Mississippi River is of an order of magnitude greater than all of other gulf coast rivers combined (Winker, 1991). The annual sediment yield to the Gulf of Mexico is 1.63 x 10^{12} lb (Coleman, 1988), 65% of which is clay and about 35% silt and fine sand (Coleman, 1982). The Mississippi drainage basin crosses several climatic zones and includes areas that were glaciated during the last several glacial cycles. The modern Balize Delta contains 11,030 square miles, with 9,227 square miles that are subaerialy exposed (i.e. not submerged). Deltaic sand bodies, such as distributary mouth bars, channel sands, and bay-fills are all relatively fine grained (fine sand and coarse silt).

B. Evolution of the Mississippi Deltaic Plain – The Delta Cycle

Deltas are dynamic depositional systems that can exhibit a wide range of sedimentary features. Deltaic sediments often undergo rapid and abrupt changes and have high lateral and vertical variability in sedimentary properties over short distances (Roberts, 1997). Scruton (1960) employed the term delta cycle in reference to alternating phases in deltaic sedimentation. Each delta cycle begins with (1) sedimentation and rapid growth (constructional/progradational phase), followed by (2) systematic loss of flow efficiency, (3) sediment dispersal and abandonment of the delta by the sediment delivery system (delta switching), and last (4) delta deterioration (destructional phase). The coastal plain of Louisiana exhibits all stages of the delta cycle, from the newly constructed Atchafalaya-Wax Lake bayhead deltas, to the abandoned destructive deltas (e.g. Lafourche) (Roberts, 1997). The Mississippi deltaic plain is characterized by major river diversions which promote large-scale delta lobes. These delta complexes occur on the millenia scale. Bay fills are built and abandoned on a centennial scale, whereas the smallest sub-deltas exist for two centuries, on average (Coleman and Gagliano, 1964).

River avulsion (rapid channel switching) and diversion, which often result in delta switching, are responsible for the present complex and diverse geomorphology and stratigraphy of the Mississippi deltaic plain. Study of the sedimentary record suggests that delta building occurred at different locations about every 1000 to 2000 years (Roberts, 1997; Coleman et al., 1998) (Figure 3). The Mississippi River has thus built a broad and complex coastal plain through these fundamental processes.

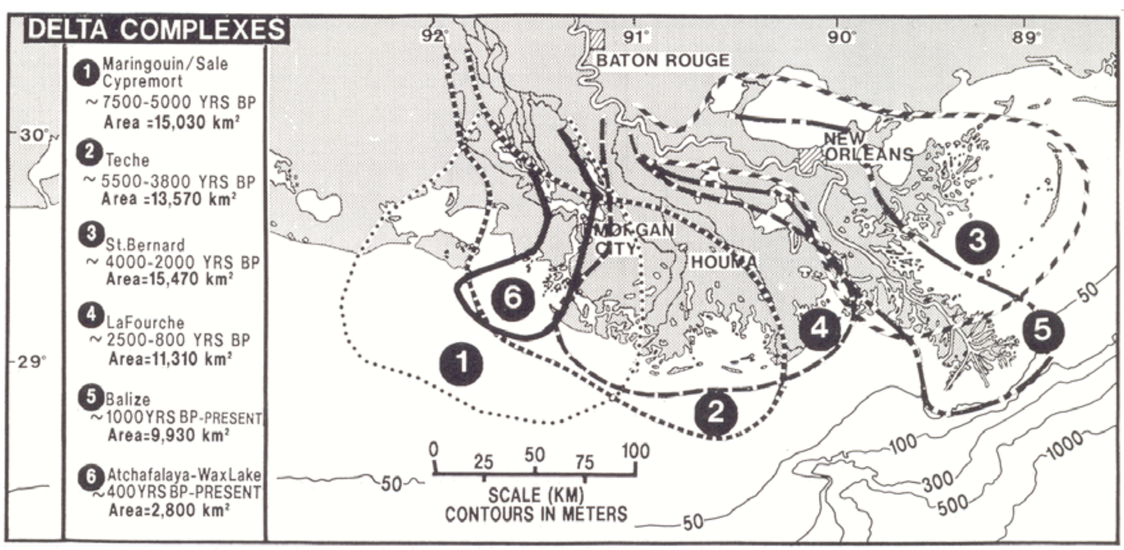


Figure 3: Holocene deltaic complexes of the Mississippi River.

Trowbridge (1930) and Russell (1936, 1940) were among the first researchers to recognize abandoned courses of the Mississippi River and resultant abandoned delta lobes. Later Fisk and co-researchers (*viz.* Fisk, 1944, 1947, 1952, 1955, 1961; Fisk and McFarlan, 1955), using detailing mapping techniques and several core borings, further identified the processes of delta switching and deltaic plain construction.

During delta switching events, diversion of water and fluvial sediment initiates processes and depositional events that culminate in the construction of major delta complexes. By way of modern example, the recent Atchafalaya River diversion is forcing delta-building in Atchafalaya Bay and starting a phase of progradation of that section on central Louisiana (Roberts, 1997).

In exploring the geometries of sediment bodies and facies architecture of deltas in the Louisiana Coastal Plain, Fisk et al., 1954 and Fisk, 1955, two main types of deltaic systems were identified, those developed in the inner shelf in shallow water (inner shelf and bayhead deltas) and those developed in deeper water of the middle to outer shelf. Inner shelf deltas (e.g. St. Bernard and Lafourche; Figure 3) occur in the limited area of the inner continental shelf and are relatively thin (90 feet thick). Inner shelf deltaic systems tend to have many distributaries that cause sediment facies to display large lateral variations (Coleman, et al., 1998). Sands deposited at the mouths of the distributaries on inner shelf deltas often merge to form a semi-continuous sand sheet, referred as delta front sheet sands by Fisk (1955). These sands vary in thickness from 18 to 60 feet and account for volumetrically significant sand deposits in these deltas (other significant sand deposits in these systems include distributary mouth bars). Generally, the continuity of these sands is broken by distributary channels that erode far below the deposited deltaic sediments. Consequently, sands deposited in distributary-fills are commonly found to be stratigraphically below their distributary mouth bar counterparts, and are usually overlain by fine-grained sediments (silts and clays with organic matter). Deep water deltas are usually thicker and occur in areas with greater accommodation space. A good example is the modern Balize Delta Complex (often referred as the "Birdfoot"). It is only the Holocene delta that prograded into middle/outer continental shelf waters. Large accommodation space contributes to the delta thickness. The Balize Delta Complex is about 620 feet thick. Clay rich prodelta deposits over lie a base that ranges between 150 to 300 feet in thickness. Distributary mouth bar deposits in the Balize Delta occur as thick linear trends, described by Fisk (1961) as bar-fingered sands.

During late (destructive) stages of a delta cycle, the abandoned delta complex subsides, that is, sinks due to compaction. As coastal processes rework the seaward margin, the delta lobe enters a transgressive-destructive phase where erosional headlands, flanking barriers, barrier island arcs and erosional headlands develop (Figure 4) (Penland et al., 1988). The genesis and evolution of transgressive depositional systems in the Louisiana deltaic plain are detailed by Penland et al. (1988) in a three-stage geomorphic model (see Figure 4). This evolution begins when marine processes transform the abandoned delta complex into a Stage 1 erosional headland with flanking barriers. In this stage, sediment is supplied to flanking barrier development by shoreface erosion. Relative sea-level rise, land loss, and shoreface erosion leads to submergence of back barrier lands and the separation of the Stage 1 barrier from the mainland shoreline, forming the Stage 2 barrier island arc. When relative sea-level rise and overwash processes overcome the ability of the barrier island arc to maintain its subaerial integrity, submergence initiates the formation of inner shelf shoals (Stage 3). Following submergence, the drowned barrier islands (now the inner shelf shoal) continue to be re-worked by marine/coastal processes to form a marine sand body in the inner shelf. This is the last stage in the evolution of transgressive depositional systems. These evolutionary processes were termed by Penland et al. (1988) as "transgressive submergence."

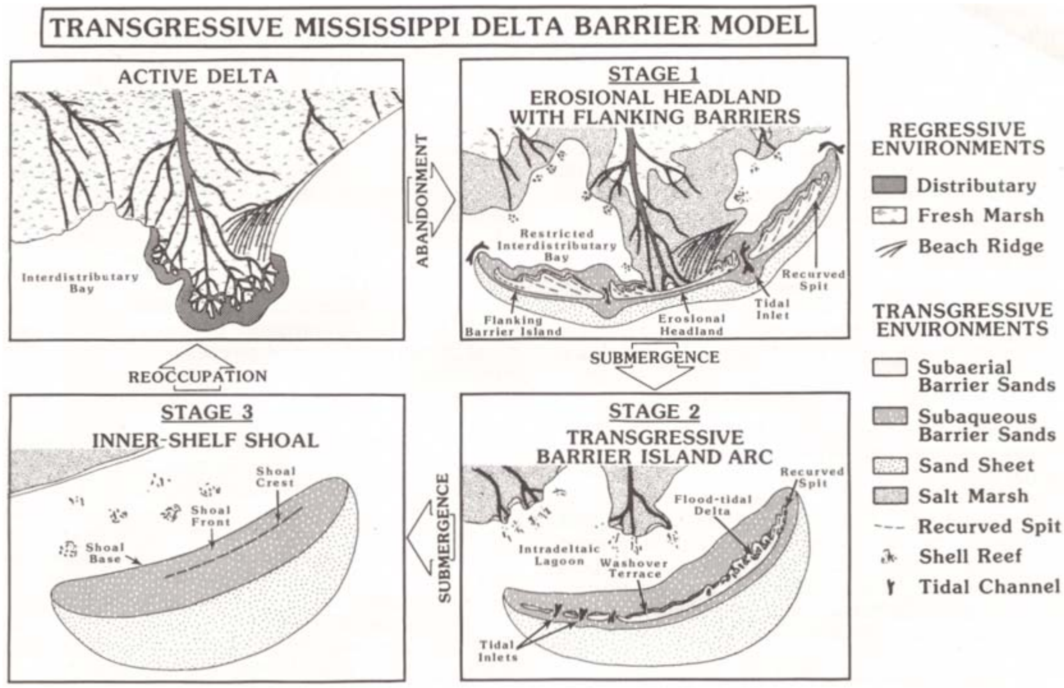


Figure 4: Three stage evolutionary model of transgressive depositional systems in the Mississippi River delta plain as suggested by Penland et al. (1988).

The controlling variables that differentiate transgressive submergence of Penland et al. (1988) from other models of shoreline sand formation (e.g. shoreface retreat of Fisher, 1961 and Swift, 1975; and in-place drowning of Sanders and Kumar, 1975) are (1) high rates of relative sea-level rise, (2) the low gradient continental shelves with limited local sand sources, and (3) a storm-dominated process environment.

Formation of barrier island arcs by mainland detachment processes (Stage 2) produces a characteristic coarsening upwards of the stratigraphic signature that is commonly found in barrier islands arc sequences. Lagoonal muds grade upwards into interbedded lagoonal muds and flood-tidal delta sands to washover sands capped by beach, washover and dune sediments (Penland et al., 1988). Reworked inner shelf shoals exhibit a stratigraphic sequence that grades rapidly from silt and sand in the base, to shoal front sand capped by shoal crest sand and shell on the surface (Penland *et al*., 1988).

Examples of the Stage 1, Flanking barriers, include the Bayou Lafourche Barrier System which is derived from the abandoned Lafourche delta complex, and the Plaquemines Barrier System that is derived from the recently abandoned lobe of the modern Balize Delta Complex. Examples of the Stage 2, barrier island arcs include the Isles Denieres which is derived from the Lafourche Delta Complex, and the Chandeleur Islands that are derived from the St. Bernard Delta Complex. Examples of the Stage 3 inner shelf shoals are the Trinity Shoal which is associated with the Teche Delta Complex and the Ship Shoal that is associated with the Marigouin Delta Complex.

The primary source of sediment for barrier island development during transgression comes from erosion of deltaic headlands and subsequent longshore transport of sand into flanking barrier spits. Spits are breached by storm overwash, while submergence ensures increasing back barrier tidal prisms necessary for tidal inlet opening and maintenance leading to the development of flanking barrier islands.

At about 7,000 YBP, delta building began in the area of Isles Denieres (Marigouin) and sequentially switched to the west near Marsh Island (Teche), then east near New Orleans (St. Bernard), west again (south of Donaldsonville) (Lafourche), then southeast of Belle Chase (modern) (Coleman et al., 1998). Today the delta plain is divided into active and abandoned deltas. Delta building is restricted to the modern Birdfoot delta and to the Atchafalaya Delta Complex. The four remaining complexes (Marogouin, Teche, St. Bernard and Lafourche) are abandoned. The Plaquemines delta of the modern Balize Complex is also abandoned (Coleman et al., 1988). The most recent phase of the Atchafalaya diversion started in the 1940s and 1950s and represents a "new chapter" of the Louisiana coastline development (Roberts and Coleman, 1996).

The subdeltas of the modern Balize deltaic system have progressed through the exponential growth phase of their delta cycles and are now slowly deteriorating with high rates of land loss being observed. The Barataria/Plaquemines barrier shoreline is located in the boundary area of the abandoned Plaquemines delta (of the modern Balize Complex) and the abandoned Lafourche delta. Both areas are in the transgressive deteriorating phases with accelerated rates of land loss.

C. The Barataria/Plaquemines Barrier Islands and Inlets Geomorphology

The Louisiana barrier island coast, which includes the Barataria barrier islands, consists of a series of erosional headlands and flanking barrier islands that are formed by the re-working of abandoned Mississippi delta complexes (Penland *et al.*, 1988). Barataria/Plaquemines barrier islands are backed by the Barataria Basin, an interdistributary wetland system located between the abandoned Lafourche and Plaquemines Delta Complexes (Penland and Ramsey, 1991). The basin consists of Lac Des Allemands, Lake Salvador, Little Lake, Caminada Bay and Barataria Bay. The seaward margin of this deltaic estuary is delimited by the Caminada-Moreau coast, Grand Isle, Grand Terre Islands, and Cheniere Ronquille. Caminada Bay and Barataria Bay are connected to the Gulf of Mexico by Barataria Pass, Caminada Pass, Pass Abel, Quatre Bayou Pass, and Pass Ronquille (Penland and Ramsey, 1991).

The thickness of the Holocene sedimentary section in the Barataria Basin increases from 30-47 feet in the upper basin to over 310 feet at Grand Isle (Kolb and van Lopik, 1958). The basin contains approximately 152,120 acres of swamp, 173,320 acres of fresh marsh, 59,490 acres of intermediate marsh, 102,720 acres of brackish marsh, and 133,600 acres of saline marsh (UNO, 2002). Lindstedt (1982) reported that Barataria Bay (Figure 1) increased its open saline and brackish water environments by over 50% between 1978 and 1982. Although the entire tidal prism in Barataria Bay is not available to tidal inlets, the expanding bay area results in increases in the tidal prism and tidal current velocities with an improvement of sediment transport effectiveness through the inlets. The inlets thus gradually experience a transitional phase from a wave-dominated to a tide-dominated phase.

Levin (1993) identified five inlet morpho-types occurring along the shoreline of the Mississippi River Delta Plain (Figure 5). The morpho-types include (1) new wave dominated inlets with intertidal flood deltas, (2) new transitional inlets with small, restricted throats, (3) tide-dominated inlets with deep channels and large ebb-tidal deltas, (4) older transitional inlets with flattened ebb tidal deltas, infilling tidal channels and spits detached from the adjacent barriers, and (5) older wave-dominated inlets with subtidal flood tidal deltas. When a deltaic lobe is abandoned, the inlets evolve from wave to tide-dominated as bay area and tidal prism increase. Along the eastern Barataria shoreline, Barataria Pass has been tide dominated since the late 1880s, Pass Abel was ephemeral and wave-dominated before becoming permanently established in 1930, Quatre Bayou Pass has evolved from a new transitional inlet type to a tide-dominated inlet between the 1880s and 1950s, while Pass Ronquille did not breach until 1934.

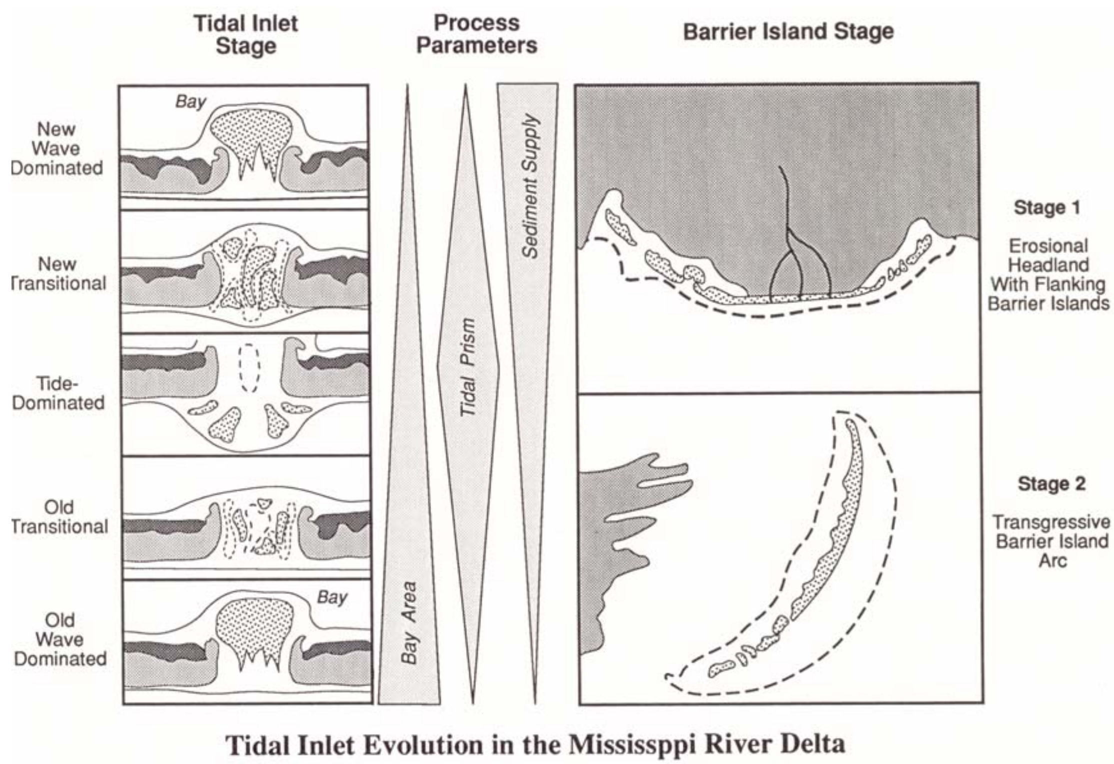


Figure 5: Summary diagram of tidal inlet evolution in abandoned delta lobes (after Levin, 1993).

Transgressive depositional systems of the Barataria barrier shoreline consists of a central erosional headland in Bayou Lafourche, fronted by the Caminada-Moreau coast with a pair of recurved spits and flanking barrier islands on either side (Caminada Pass spit and Grand Isle to the east and the Timbalier Islands to the west) (Coleman et al., 1998, Kindinger et al., 2001). Since delta abandonment, sand eroded from the shoreface is the sediment source for the development of these flanking barriers. The primary modern sediment sources are the Bayou Lafourche distributaries and the Cheniere-Caminada beach-ridge plain.

The Caminada Moreau coast is a thin, discontinuous mainland beach with marsh outcropping on the beach face and in the surf zone at certain locations. The presence of these features indicates a negative sediment budget and rapid shoreline retreat. Deltaic stratigraphic sequences consist of clays to fine sands representing prodelta, delta front, beach ridge and distributary deposits (Penland *et al.*, 1988).

Flanking barriers that occur downdrift from erosional headlands migrate laterally. That is, the flanking barriers move in the direction of predominant longshore transport by erosion of the updrift ends with accretion downdrift (List et al., 1997). The Caminada Pass spit was formed by downdrift spit accretion through the process of lateral migration from the Bayou Lafourche erosional headland. The Timbalier Islands and Grand Isle formed through similar processes (Roberts, 1997). These are predominantly low-relief barriers. Approximately 52% of the late Lafourche Delta shoreline is composed of a low barrier beach in the form of a thin continuous washover sheet that is approximately 3 feet above the sea level. As a result, this shoreline is subject to constant washover processes during hurricanes and storms (Boyd and Penland, 1981).

Episodic breaching of the barrier during overwash events often results in the formation of tidal passes which initiate the cycle of inlet evolution described by Levin (1993) (Figure 5). Flanking barrier growth and breaching resulted in the development of large tidal inlets at Caminada Pass and Barataria Pass (Stone and McBride, 1998, Levin, 1993). Due to subsidence and land loss, Barataria Bay has continued to increase in size and depth, resulting in an increased volume of water stored in this system and increased tidal prisms. These combined factors have subsequently lead to an increase in inlet cross-sectional area, tidal current velocity, and sediment storage capacity, leading to further changes in the morphological characteristic of the tidal inlets. These changes range from wave-dominated inlets with flood tidal deltas to tide-dominated inlets with large ebb-tidal delta (Levin, 1993).

Situated east of the Lafourche Delta Complex, the Plaquemines Delta was actively receiving sediments from the Mississippi River distributaries between approximately 905 and 305 YBP. During this time, the deltas prograded southwesterly, resulting in a delta between Barataria Bay and Sandy Point. Following abandonment, the distributary mouth bars and beach ridges of the Plaquemines Delta were transformed into numerous small erosional headland sand sources.

The Barataria/Plaquemines barrier shoreline has undergone significant movement and reduction in size during the past 100 years. Presently, many of the barrier islands of this shoreline reach have been reduced to low relief fragmented mounds of sand that are easily overwashed by storm events.

V. SEA LEVEL RISE, SHORELINE CHANGES, AND LAND LOSS IN THE STUDY AREA

At about 15,000 YBP, the sea level in the Gulf of Mexico was located at about -420 feet lower than its present level. By about 8,000 YBP, it rose exponentially to about -30 feet below its present level (Curray, 1960). After 3,600 YBP, it rose more gradually to its present position (Coleman and Smith, 1964). Due to high rates of relative subsidence and a diminishing sediment supply, combined with repeated storm impacts, Louisiana's barrier shorelines are the fastest eroding shorelines in the nation. In some locations, erosion of the Louisiana barrier islands exceeds 65 ft/yr (Penland and Boyd, 1981).

Recent relative sea level rise (on a 100-year scale) is commonly estimated using tidal records. For a tidal record to be sufficient for this purpose, the record must be at least 37 years long, or twice the length of the 18.6 year lunar nodal cycle. Tidal measurements have been gathered at Grand Isle since the 1940's, permitting estimates of relative sea level rise such as the ones presented by Penland and Ramsey (1991) and by the National Research Council (1987).

Penland and Ramsey (1991) estimated an averaged 0.43 inch per year (1.11 cm/yr) relative sea level rise for the Barataria barrier shoreline, which is five to ten times the global eustatic rate of sea level rise (Douglas, 1991). These researchers found an inverse relationship between thickness of holocene sediments and rates of relative sea level rise for the deltaic plain. Relative sea level rise in the Mississippi deltaic plain is driven mainly in response to compactional subsidence, which varies as a function of sediment thickness, composition and age (Morgan and Larimore, 1957). At the Chenier plain, where the Holocene sediment thickness is less than 30 feet, lowest sea-level rates were measured. Conversely, for the delta plain, where the thickness of Holocene sediments is greater than 150 feet, the highest relative sea-level rise rates were observed. Thus, high rates in the Louisiana deltaic plain may be attributed to the natural compaction of the recently deposited sediments.

Relative sea level rise along the Louisiana coast reduces land area through two means; (1) transgressive submergence or "drowning" and deterioration of barrier island systems (Figure 4) and other models of barrier submergence (Swift, 1975; Sanders and Kumar, 1975; Penland et al., 1988); and (2) adjustment of the beach profile that accompanies increases in mean water level (The "Bruun rule" Bruun, 1962).

Using the U.S. Army Corps of Engineers rate of 0.036 feet/year per year prior to 1986 and the National Research Council (1987) method after 1986, CPE (2002) estimated shoreline recession for Pelican Island and Pass de La Mer. The results indicate a shoreline recession, from 2002 and 2022, due to sea level rise, on the order of 120 feet for Pelican Island and 124 feet for Chaland Headland. Detailed analysis of shoreline changes in the project areas and the contribution of relative shoreline loss to these changes is based on recent (Williams, et al., 1992), digitized topographic maps and the 2000 beach surveys. Examination of long-term bathymetric changes by List *et al.* (1997) found well-defined patterns of sediment distribution in the longshore direction. This research indicated that the longshore components play an important role in sediment removal in the area, as reported by CPE (2002). Additional comprehensive studies of historical shoreline change for the deltaic plain have been conducted along Louisiana's outer shore by Morgan (1955), Morgan and Larimore (1957), and McBride and Byrnes (1995).

Due to the high rates of subsidence (and consequent relative sea level rise) and the sediment starved nature of abandoned deltaic systems, Louisiana currently leads the nation in area lost to coastal erosion and wetland deterioration. Louisiana's barrier islands have decreased in area by more than 40% on average, and account for 80% of the total national wetland loss (Stone and McBride, 1998). Predictions based on past erosion rates (eg. Stone and McBride, 1998, CPE, 2002) suggest that many barrier islands are likely to completely erode away and be transformed into submarine sand bodies within the next several decades. Significant wave heights in the bay area could dramatically increase without intervention through barrier island restoration.

VI. PREVIOUS WORK RELATED TO SAND RESOURCES ON THE LOUISIANA INNER SHELF

A. Sand Sources and Local Geology

Kindinger et al. (2001) and Suter et al. (1991) conducted two comprehensive sand resource assessments in the study area. The sand targets identified by these authors are closely associated with depositional systems such as spit platforms, delta sheet sands, ebb-tidal deltas, distributary mouth bars, and distributary-channel fills. Other large depositional areas containing beach quality sands in the adjacent regions are related to inner shelf shoals (Stage 3 of Penland et al., 1988).

Ebb tidal delta deposits on micro-tidal storm dominated coasts (the study area) typically have channel-margin linear bars, swash bars, lateral flood channels, a main ebb channel and terminal lobe (Boothroyd, 1985). Sediments are typically poorly sorted fine sand with varying but small amounts of shell. Distributary mouth bar deposits form as shoals which are associated with the seaward extent of a river distributaries (Kindinger et al., 2001). Morphologically, the river mouth contains a channel, natural levee, distributary mouth bar, delta front, and prodelta (Coleman, 1982). Sediments here are commonly well-sorted sands with varying amounts of clay and silt (Coleman, 1982). Channel fill deposits have been identified as cut-and-fill, cross-bedded sand and silt beds related to lower stands of sea level, or paleo-distributary channel locations during active delta phases. Channel abandonment and flooding by subsequent marine transgression usually create depositional systems which are varied in terms of sedimentary bodies and stratigraphy. Over time, the channel can be filled with fine-grained poorly sorted sediments (Coleman, 1982). Stratigraphically, channel fill deposits usually exhibit fining upward sequences. Although channels can be recognized from seismic records, a distinction between muddy and sandy facies that fill these channels is difficult to distinguish in the record (Kindinger et al., 2001). Field verification to investigate the textures of channel fill deposits is therefore necessary. Often, deeply incised channels resulting from prior river diversions are covered by thick mud overburden and are difficult to extract for beach fill purposes (CPE, 2000, CPE, 2002a). Smaller distributary channels of abandoned deltaic systems often have sand deposits covered by less than 20 feet of mud, such as the deposits identified by Kindinger *et al.* (2001) and CPE (2002b – Holly Beach).

B. Previous Studies

The following studies are briefly summarized.

1. Suter et. al (1991). Nearshore Sand Resources of the Mississippi Delta Plain: Marsh Island to Sandy Point

This study was conducted by the Louisiana Geological Survey personnel (Suter, J.R., Penland, S. and Ramsey, E.R.) to compile pre-existing information and collect additional field data from Marsh Island to Sandy Point in order to identify areas of potential inner shelf sand deposits.

The study included investigation of 4,785 line miles of seismic data which was gathered using a uniboom seismic profiler and 162 vibracores over a long stretch of coastline. Fifty-five potential sand deposit sites were identified. According to Suter et al. (1991), the potential sand sites represented depositional environments such as recurved spit and spit platform deposits, tidal channel fills, distributary channel fills shoreface deposits, ebb and flood tidal deltas, and inner shelf shoals. Between Belle Pass and Sandy Point (adjacent to the Barataria Basin) about eighty percent of the total sand volume identified was present in the form of channel fill deposits (tidal channel fills and distributary channel fills).

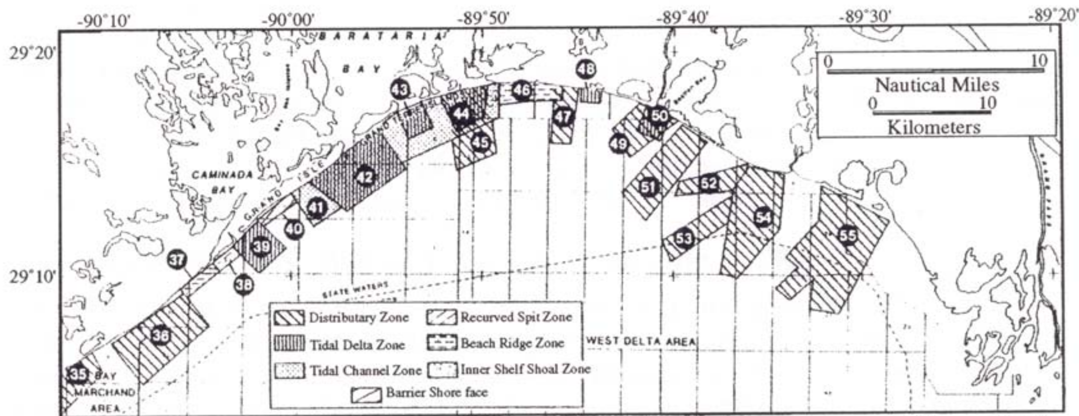
Of the fifty-five potential sand deposits identified by Suter et al. (1991), twenty-one are located in the areas adjacent to the Barataria/Plaquemines Barrier Shoreline (between Belle Pass and Sandy Point, areas 34 to 55; Figure 6). These areas were of interest in the present investigation and contain approximately 1.15 billion cy of “sand” (Suter et al., 1991).

As previously stated, 80% of these are composed of channel fill deposits. The method applied by Suter et al. (1991) to calculate sand volumes in channels is subject to significant errors because of the nature of the assumptions used to develop the volume. Procedures to calculate sand volume in valley fill deposits used by the authors were based on the following equation:

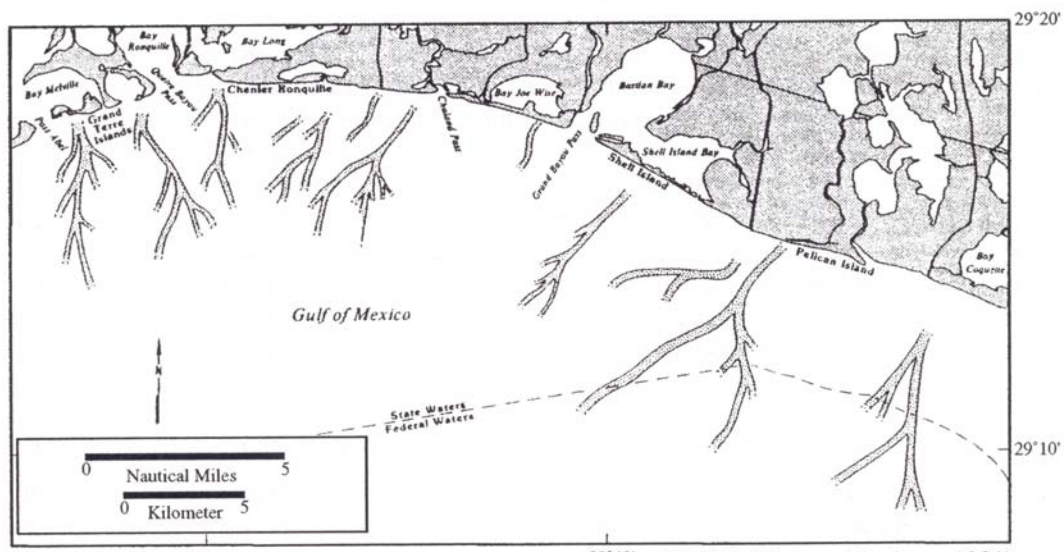
$$(Thickness - 6.6) * 0.75 * Area)/2 \qquad \text{(Eq. 1)}$$

Equation 1 describes that the volume of sand contained in the valley fill deposits is equal to the exposed area of the deposits, multiplied by its thickness and corrected by the values of three geological assumptions. The assumptions used by Suter include: (1) 6.6 feet of overburden for all deposits; (2) an average value of 75% sand composing the channel fill deposits and (3) channels represent 50% of the whole extent of the area delimited (see areas in Figure 6).

Our analysis of the data presented by Suter *et al.* (1991) indicates that from the 1.15 billion cy of sand identified (between Belle Pass and Sandy Point) about 145 million cy were identified based on the interpretation of seismic records and application of equation (1). Another 436 million cy were identified from seven areas using a very limited number of cores (maximum of 1 vibracore per borrow area) and extrapolated by seismic interpretations and the assumptions of equation (1). Nevertheless, in spite of the drawbacks associated with the sand volume estimates (Suter et al., 1991), this information provides a general overview of the depositional systems in the area and can be used to identify areas for future investigation.



(Modified from Suter and others, 1991)



(Modified Suter and others, 1991)

Figure 6: Sand deposits identified by Suter et al. (1991) in the study area and the location of the major infilled channels.

2. Kindinger et al., 2001. Sand Resources, Regional Geology and Coastal Processes for the Restoration of the Barataria Barrier Shoreline

A cooperative effort was developed between the U.S. Geological Survey, University of New Orleans (UNO – Coastal Institute), and U.S. Army Corps of Engineers to conduct the investigation. The investigation included 652.5 line miles of high resolution, single-channel seismic profiles using "Boomer" and "Chirp" sources, as well as more than 250 sediment vibracores and borings. Kindinger et al. (2001) identified between 396 to 596 million cy of sand, defined as sediment with grain sizes ranging from 0.02 mm to 0.78 mm. This comprehensive investigation, together with the understanding of local geological/geomorphological background, was the basis for the geotechnical investigation reported herein.

Nine sand targets were identified within the Barataria study area, including six in the central section and in three in the eastern section (Figure 7). Minimum criteria used to define and identify the sand sources were: (1) more than 60% sand; (2) minimal sand thickness of 3 feet for surficial deposits, or greater than 5 feet for sand deposits covered by mud overburden; and (3) maximum depth of deposits below mean sea level not to exceed 60 feet (i.e. below practical dredging depth). The target deposits identified by Kindinger et al. (2001) are presented in Figure 7, summarized in Table 1, and briefly described below.

Between Belle Pass to Caminada Inlet (western section), no significant sand resources were found beyond the shoreface which met minimal criteria. From Caminada Inlet to Grand Bayou Pass (central section), deposits associated with ebb-tidal deltas and shoreface/barrier environments were identified (Caminada Inshore, Barataria Inshore and Quatre Bayou Shallow deposits – Figure 7). Quatre Bayou and Barataria ebb-tidal deltas are considered to be the most significant deposits because they contain fine-grained sand to silty sand with abundant shell material which were an average of 6.6 feet thick. In the deeper offshore areas, deposits associated with buried distributary mouth bar or channel fill deposits are delimited as Barataria Offshore, Quatre Bayou Deep and Quatre Bayou D2 (Figure 7). These sedimentary deposits contain massive to laminated sands with no shell content and are about 14 ft thick.

In this central section, shallow water deposits (*viz*. Caminada, Barataria and Quatre Bayou) are exposed on the surface (no mud overburden) and are estimated to contain between 28 and 39 million cy of material which meet minimum criteria. The deep water deposits (*viz.* Barataria offshore, Quatre Bayou deep and Quatre Bayou D2) are overburden, infilled distributary channels and distributary mouth bar sediments. These deposits present higher sediment variability and are estimated to contain between 135 to 244 million cy of material that meet the minimum criteria adopted by Kindinger et al. (2001). The two largest deposits, Barataria Offshore and Quatre Bayou deep, are overburden by 5 to 15 feet of mud. Quatre Bayou D2 is the smallest deposit (7 to 10 million cy) and is overburden by about 30 to 40 feet of mud.

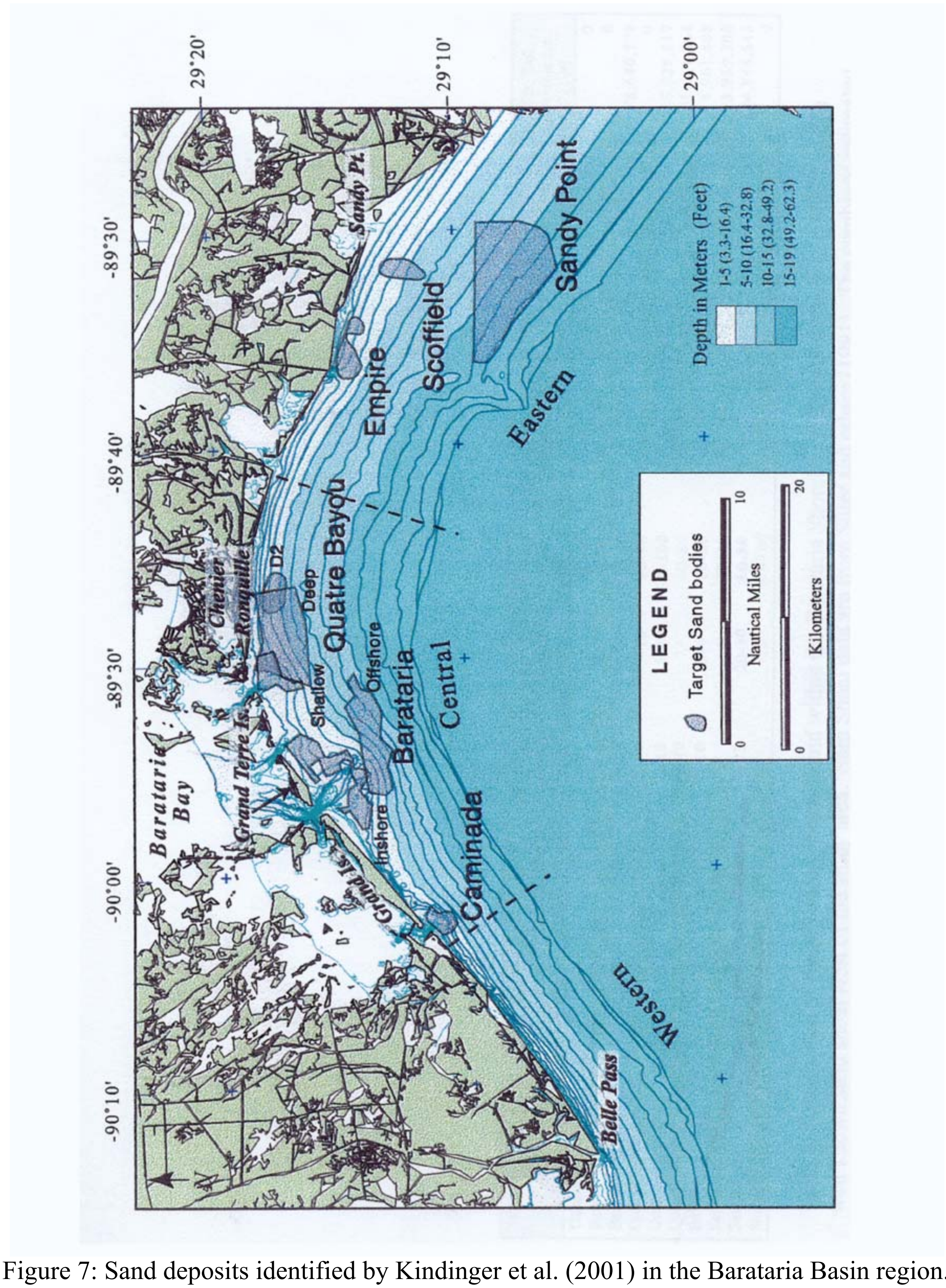


Figure 7: Sand deposits identified by Kindinger et al. (2001) in the Barataria Basin region.

Between Pass Abel to Sandy Point (eastern Section) three deposits were identified, including the Empire, Scofield and Sandy Point deposits (Figure 7). These deposits together account for about 233 to 310 million cy of massive to laminated sands and muddy sands.

Sandy Point was the largest deposit identified by Kindinger et al. (2001). Using 16 vibracores and seismic lines, it was estimated that the Sandy Point deposit contains a "sand" volume between 220 to 294 million cy with about 245 million cy of mud overburden. It was estimated that between 80% to 90% of the sediments had a mean grain size between 0.02 mm to 0.18 mm. Using a more conservative approach, and by analyzing the Kindinger et al. (2001) data in a GIS database, it was determined during this study that the Sandy Point sand body is not a continuous and non-interrupted deposit, as previously described by Kindinger et al. (2001) (Figure 7). The Sandy Point deposit contains highly variable sedimentary facies. Sand depocenters (areas with greater sand thicknesses) within the Sandy Point "sand" body are concentrated on the south to central sections (further offshore), while the north portion (closer to the shore) is mud-dominated. Even though the deposit does not cover an area as large as originally described by Kindinger et al. (2001) the data available suggests that the depositional area is relatively large (when compared to all the other potential deposits identified by Kindinger et al. (2001) and potentially contains sufficient sand volume to meet present and future requirements for the project area beach nourishment projects.

The deposits identified by Kindinger et al. (2001) in the Barataria Basin show varying amounts of mud overburden (ranging from zero to forty feet) and impact the cost effectiveness associated for use in barrier island restoration. With this consideration in mind, values presented by these authors were analyzed to verify the ratios of mud/sand for each deposit. The results are presented in Table 1.

Table 1: Mud/sand ratios for deposits identified by Kindinger et al. (2001).Volumes are provided in million cubic yards.

Target Area	**% min**	**% max**	**% avg**	**Vsand min**	**Vsand max**	**VolOvb**	**mud/sand avg.**	**mud/ sand worst case**
Caminada	60	80	70	3.7	5	0	0.00	0.00
Barataria Inshore	60	85	72.5	18.4	26	0	0.00	0.00
Barataria Offshore	60	80	70	34.7	46	78.6	2.78	3.78
Quatre Bayou	60	80	70	6.1	8.1	1	0.20	0.27
Quatre Bayou Deep	70	100	85	92.8	132.6	156	1.63	2.40
Quatre Bayou D2	50	80	65	7.3	9.8	61	10.98	16.71
Empire	60	80	70	5.8	7.8	15	3.15	4.31
Scofield	80	90	85	7.4	8.3	14	2.10	2.36
Sandy Point	60	80	70	220.1	294	244	1.36	1.85
Ship Shoal	80	100	90	1276.7	1592.8	1595.8	1.24	1.56

Notation:

%min = minimum percent sand estimated

%max = maximum percent sand estimated

%avg = Averaged percent sand

Vsandmin = Minimum sand volume estimated

Vsandmax= Maximum sand volume estimated

VolOverb= Volume of mud overburden

Mud sand avg = ratio of parts of mud per parts of sand, using averaged values for sand volume and corrected for averaged sand percentages

Mud/sand worst case = ratio of parts of mud per parts of sand, using minimum values for sand volume and corrected for minimum percent sand.

Values in Table 1 indicate that inshore sand deposits and ebb-shoal deposits may be economically feasible sand sources for barrier island restoration. Offshore sources may be more expensive to use. For example, the Quatre Bayou D2 borrow area (Figure 7) contains an average ratio of mud/sand of 11, indicating that for every cubic yard of sand, eleven cubic yards of mud must be removed. Although large volumes of sand exist in offshore Louisiana, the mud overburden overlying these deposits should be considered to determine if it is feasible to mine the sand deposits.

Ship Shoal, west of the study area, was also mentioned as a possible sand resource by Kindinger et al. (2001) because this drowned barrier island contains twice the volume as the combined volume of the 9 sites identified in their study. Ship Shoal is estimated to contain an excess of 1.3 to 1.6 billion cy of good quality sands (80% to 100% sand, 0.25 to 0.02 mm).

Kindinger et al. (2002) sand volume estimates also include silt sized sediments (i.e., 0.02 mm, 5.5 phi; Wentworth, 1922; ASTM, 1987) in the sand volumetric estimations, resulting in a greater sand volume than may be feasible for engineering purposes. Nevertheless, a considerable volume of quality sand is available in Ship Shoal. Ship Shoal is not an unrestricted sediment deposit for use in barrier island restoration, but has limitations. For example, oil infrastructure (e.g., oil rigs and pipelines) represent potential hazards to dredging activities and can reduce dredgeable sand volumes. Oil rigs and pipelines occurring within the limits of the potential sand deposits were not considered in the regional sand resources assessment of Kindinger et al. (2001), and will impact the volume of sand available for excavation.

3. Holly Beach Breakwater Enhancement and Sand Management Plan: Evaluation of Offshore Sand Sources Near Holly Beach, Louisiana, 2000 (Coastal Planning & Engineering, Inc., 2000)

Sediment deposits in western Louisiana were investigated by CPE (2000) in order to define potential sediment resources and borrow areas for restoring the beach at Holly Beach, Louisiana. Several large beach compatible sand deposits were identified by CPE off Peveto Beach and in the offshore banks.

A total of eighteen (18) standard penetration cores and nineteen (19) vibracores were collected in the offshore paleo-channel, including thirteen (13) vibracores in the Sabine Bank. The cores identified a large sand deposit buried beneath soft Holocene muds and stiff Pleistocene clay (Prairie Formation).

Deposits buried underneath the Prairie formation in the Peveto Channel were divided into five dredging areas that account for about 4,200,000 cy of material, including 3,500,000 cy of sand. The borrow areas were located 4.0 to 7.7 miles from shore. The sediment had an average grain size of 0.15 mm and about 15% silt content with a mud and clay overburden averaging about 4 feet thick.

In addition to the borrow areas, two deposits were identified on the Sabine Banks that accounted for as much as 22,000,000 cy of beach quality sand. The Sabine Bank deposits were located 6.5 to 22.0 miles from shore and were composed of olive gray sand with varying amounts of shell hash. Average grain size was 0.24 mm and the silt content did not exceed 5%. Both deposits were identified as acceptable in permits from State and Federal agencies, including the Minerals Management Service (MMS). The Holly Beach project was advertised for bid with both sand deposits available, and with a bid requested for use of either deposit. Based on the bids, the cost to construct the project was nearly double using the offshore deposits; thus, the Peveto Beach deposit was used to construct the project. Project construction was underway at the time of the preparation of this report, with high quality sand being placed on the beach at Holly Beach. The experience at

Holly Beach has demonstrated that beach compatible sands from channel fills with mud/clay overburdens can be feasible sources of beach nourishment sand.

4. Other Studies of Potential Sediment Sources

Stanley et al. (1996) mapped the extent of a transgressive strandplain facies widely distributed as a continuous shelly silt and sand sheet immediately above the Wiscosinan Unconformity. These sand deposits are attributed to the landward migration of the shoreline during the latest rapid sea level rise. These facies were traced from beneath the modern Birdfoot delta to New Orleans and dated 30,000 to 5,000 YBP by radiocarbon methods. Unfortunately this predominantly sand facies lie deep beneath Holocene muddy deltaic sequences (about 360 to 500 feet), making them unsuitable for barrier island restoration.

Penland et al. (1988) described isolated and filled tidal-channels scars found offshore from the Timbalier Islands, marking the retreat path of the Bayou Lafourche Barrier System. He also emphasized that large tidal sand bodies (sand-dominated ebb tidal deltas) also occur east of the Bayou Lafourche headland at the ebb-tidal deltas of Caminada Pass and Barataria Pass. Caminada Pass extends 1.2 miles offshore and is 1.8 miles wide. Barataria Pass, which extends 3.7 miles offshore, is about 5.0 miles wide and represents prospective sand sources in the area.

Morpho-stratigraphic characteristics of the Ship Shoal system were detailed by Penland et al. (1988) and Suter et al. (1991). The shoal is a sandy submerged barrier island (Stage 3 of Figure 4) and is about 31 miles long with widths ranging from 3.0 to 4.3 miles in the central area to between 5.0 and 7.4 miles in the eastern area. Relief varies from 16 to 22 feet and water depths over the shoal range from 9 feet in the west to 25 feet in the east. The entire transgressive shoal sequence averages 16 to 19 feet thick throughout its extent. Landward oriented asymmetry of the shoal indicates that it is migrating landward. Comparison of historic bathymetric profiles (between 1887 to 1983), performed by Penland et al. (1988) suggest that the shoal has migrated landward more than 0.6 miles in about a century. The stratigraphic position of the Ship Shoal indicated that it is a transgressive sand body that has migrated to its present position under conditions of sea-level rise, shoreface erosion, and submergence. Sand volumes estimated for the shoal exceed 2 billion cy of beach compatible sands according to Suter et al., 1991.

VII. BARATARIA BARRIER ISLAND SHORELINE PROJECT DEVELOPMENT - SAND SOURCE ENGINEERING CONSIDERATIONS

A. Local Sediment Sources: Independent of water depth considerations, use of sediment sources under 10 miles distance from a project area allows for hydraulic cutterhead dredges to transport the material. In addition, limitations due to the shallow depths adjacent to the project area are minimized as cutterhead dredges require considerably less water depth to operate. In recognition of the economic and logistical constraints, a regional sand search for the project area was conducted and completed which allows for use of cutterhead dredges to construct the barrier island restoration projects. Geotechnical information provided in the Offshore Sand Resources Report (Kindinger et al., 2001) was used to select areas for further study. However, more comprehensive data was required to identify sand sources, ensure the quality and quantity of the borrow material, as well as identify potential debris or obstructions within the area. This additional data was collected by CPE (2001) and is reported herein.

B. Ship Shoal: Conceptual projects and project costs, assuming the use of local sand sources, were developed by CPE, 2001. After evaluating the potential use of sand from the Ship Shoal as the borrow material for the projects, CPE engineers concluded that this source is not feasible at this time for the Barataria Restoration project, based primarily on economics. As a general rule, hydraulic cutterhead dredging is less expensive to accomplish (per unit cost) than hopper dredging. The use of Ship Shoal sand would require the transportation of the material a distance of 40 to 50 miles to the Barataria Island project areas which is a hopper dredging distance. The cost to use Ship Shoal sand is estimated to be approximately two and a half to three times the cost incurred using local (close proximity) sources, even considering the additional fill requirements based on use of the fraction of finer material in the local sediment sources. It is anticipated that Ship Shoal will eventually be used to restore or maintain the barrier islands of Louisiana, as it contains a substantial volume of beach compatible material. Development of an effective delivery method to utilize the sand may reduce the cost to use Ship Shoal sand.

VIII. EQUIPMENT AND PROCEDURES

Hydrographic and geotechnical survey equipment utilizing the present technology, and advanced survey procedures were used to conduct the geotechnical investigation. The equipment utilized for the study are presented in Table 2.

Table 2

Equipment

Navigation	Fathometer (Bathymetry)	Sub-bottom Profiler (Seismic)	Side Scan Sonar	Vibracores
Trimble 4000 SE Land Surveyor II Global Positioning System (GPS) interfaced with Coastal Oceanographic “HYPACK” Navigation Processing System	**Innerspace 448 Digital Survey Fathometer**	**X-STAR Full Spectrum Digital Sub-bottom Profiler (EG&G) SB-512**	**Klein 590 Dual Frequency Side Scan Sonar**	**Rossfelder P-3 electric vibracoring system, 3-phase, 230 volt, 50-60 hertz power source**

A. Navigation System

The navigation and positioning system used during the survey was a Trimble AgGPS Global Positioning System (GPS) interfaced to the Coastal Oceanographic Hydrographics System (HYPACK). A Pro Beacon receiver provided differential GPS from the U. S. Coast Guard Navigational Beacon located at English Turn, Louisiana. The Trimble Navigation Model AG132 is designed for moderate precision static and dynamic processing applications. The AgGPS initially receives the civilian signal from the global positioning system (GPS) NAVSTAR satellites. The locator automatically acquires and simultaneously tracks GPS satellites and precisely measures code phase and Doppler phase shifts, and then computes position and velocity. The AgGPS also automatically determines time, latitude, longitude, height, and velocity at a rate of once per second. The Trimble AgGPS accuracy, with differential correction used in this study, provides for a position accuracy of one to three meters, which is more than adequate for geotechnical investigations for sediment sources.

The U.S. Army Corps of Engineers (USACE) has conducted tests of the U.S. Coast Guard beacons and found an accuracy of at least 1.5 meters approximately 94% of the time.

B. Single Beam Survey Grade Fathometer

The Innerspace 448 fathometer was used to obtain water depth readings. It operates at a frequency of 208 kilohertz and is a digital survey-grade sounder capable of operating in a range of depths of 1.5 to 500 feet. Prior to use, the fathometer was calibrated and further checked periodically throughout the survey. Calibration of the fathometer was achieved by use of an Odom Digital Pro speed of sound velocity meter. Speed of sound through water, and other selected parameters, are adjusted to accurately reflect the water conditions within the survey area. In addition, tide elevations were collected at fifteen minute intervals during all bathymetric survey operations using an electronic tide gauge adjacent to the project site. Using the tidal gauge information, depths recorded by the fathometer were then corrected for tidal fluctuations allowing conversions of all elevations to NAVD 88.

C. Portable Lunchbox Computer

The portable "lunchbox" computer, manufactured by Broadax System, Inc. (BSI), is a multi-platform workstation in a compact and rugged aluminum alloy enclosure. It can be easily customized for mobile computing applications where there is a requirement for massive data storage capacity. It has the ability to survive harsh field conditions, a requirement for this study. The BSI portable lunchbox computer has six expansion slots and two drive bays, a 3.5-inch floppy drive and a CD R/W drive. The expansion slots provide six serial ports which were used to interface with the Side Scan Sonar system, Seismic Sub-bottom Profiler, Single Beam Sounder, Magnetometer and Differential Global Positioning system during the surveys. These six serial ports transmit and receive data at a rate of up to 922,000 baud and contain a 64-byte hardware buffer. The serial ports are individually addressed and can be addressed within the range of 0000 hex to FFF8 hex at 0008 hex intervals.

D. Coastal Oceanographic Hydrographic Data Collection and Processing (HYPACK) Program

The navigational and fathometer systems were interfaced with the onboard computer, and the data integrated in real time using the Coastal Oceanographic survey program. The Coastal Oceanographic Hydrographic Data Collection and Processing (HYPACK) program is a state-of-the-art navigation and hydrographic surveying system. On-line screen graphic displays include the pre-plotted survey lines, the updated boat track across the survey area, adjustable left/right indicator, as well as other positioning information such as boat speed, quality of fix and line bearing. All data obtained is recorded on the computer's hard disk and transferred to a CD each day during the survey to provide a back-up of the raw survey data.

E. Side-Scan Sonar

A Klein Dual frequency side-scan sonar system was used to verify the unconsolidated sediment surface, and to map ocean bottom features such as exposed pipelines, underwater wrecks, submerged oil and gas wells and other features, which affect borrow area delineation and may even introduce hazards to dredging activities. The side-scan was towed at an optimum position and depth to ensure isolation from the other sources of interference, and for optimum record quality. The digital side-scan data was merged with positioning data

(DGPS via HYPACK), video displayed, logged to hard copy on a graphic recorder and logged to disk for post processing and/or replay. The position of the sensor relative to the DGPS antenna was documented to ensure proper positioning of the data. Range scales selected provided over 100% coverage of the survey area. Dual frequency provided a differential aid to interpretation.

The sonar imagery produced from the system utilizes the latest advances in sonar technology to produce images that are corrected for slant range, ship speed, and signal amplitude. The side scan sonar image of reflected acoustic energy is much like an image produced through radar. Darker returns represent areas where more acoustic energy is returned (reflected back) to the sonar, such as pipes, dense debris targets, rock ledges, or sand ridges. Light returns are representatives of low reflectivity zones, or materials which are unconsolidated or otherwise of lower density.

High-power, short-duration acoustic pulses are transmitted from two transducers mounted in the towfish. The pulses are emitted in a thin, fan-shaped pattern that spreads downward to either side of the fish in a plane perpendicular to its path. As the fish follows the tow vessel's track, this beam scans a bottom segment ranging from the point directly beneath the fish outward on each side. Acoustic energy reflected from the seafloor is received by the same set of transducers, and amplified and transmitted as electrical energy to the towing vessel. The electrical signals are processed, amplified, and converted to hard copy by the side scan recorder.

A sonar mosaic of the potential sediment sources was produced using the side-scan sonar data and Triton Elics Delphmap software (Figure 8 a, b, c).

F. Seismic Survey (Sub-Bottom Profiler)

Seismic investigation of sediments was accomplished by the use of a chirp subbottom profiler. The subbottom profiler sends an acoustic signal or pulse through the ocean bottom, in turn, which is reflected back by surface and subsurface geological features. The reflected acoustical signals are received at the survey vessel and appear in the form of a recording chart signature. Each distinct layer in the sediment is indicated as a surficial trace, which is recorded on the strip chart as well as in an electronic format onboard the survey vessel. The chart shows the presence of the sediment surface and other distinct layers or features within the sediment, including both consolidated and unconsolidated materials. Integrated with available information from previously conducted vibracore surveys, the seismic data was

used to develop a preliminary isopach of sediment types prior to conducting the detailed vibracoring surveys.

An EdgeTech Chirp – X-STAR seismic profiler was used in this investigation. The profiler was towed by the vessel at an optimum position and depth for collection of the seismic profiles. The effects of vessel heave were mitigated with averaging software. The digital seismic data was merged with positioning data (DGPS via HYPACK), video displayed, logged to hard copy on a graphic recorder and logged to disk for post processing and/or replay. The position of the sensor relative to the DGPS antenna was documented to ensure proper positioning of the data. During this procedure, the display was continuously monitored to ensure data integrity and quality. Significant features and anomalies were noted and logged as the survey progressed.

The EdgeTech Chirp Full Spectrum Digital SubBottom Profiler X-STAR is a wideband FM (Frequency Modulated) high-resolution subbottom profiler. It generates cross-sectional images of the seabed and collects digital normal incidence reflection data over many frequency ranges. X-Star transmits an FM pulse that is linearly swept over a full spectrum frequency range (also called a “chirp pulse”) – for example 5-12 kHz over 20 milliseconds. The acoustic return received at the hydrophone is matched filtered with the outgoing FM pulse generating a high-resolution image of the subbottom stratigraphy.

Because the FM pulse is generated by a digital to analog converter with a wide dynamic range and a transmitter with linear components, the energy, amplitude, and phase characteristics of the acoustic pulse can be precisely controlled. This precision produces high repeatability and signal definition required for sediment characterization

Seismic chart interpretations were conducted based on the profiled sediment horizons detected by the sub-bottom profilers using Triton Elics SGIS (Seismic Georeferenced Interpretation System) software. The final data was converted to “xyz” files of the sediment layers, and used to develop sediment volumes and sediment location, in coordination with vibracore information.

G. Vibracores

A total of eighty-one (81) vibracores were obtained within three potential borrow areas of Quatre Bayou, Scofield, and Empire, as previously delineated in the regional sand search conducted in 2000 (Kindinger et al., 2001). Vibracores were obtained in areas that, based on previous geotechnical investigations, could potentially contain sand deposits which were determined to have sufficient sediment thickness for practical and efficient dredging. The location of, and spacing between, vibracores were selected to investigate areas which were promising based on previous studies conducted by Kindinger and others. As the investigation progressed, and vibracores were examined, additional vibracore placement was modified in order to optimize data collection for the purpose of locating borrow material.

Vibracores were collected onboard the R/V *G.K. Gilbert.* The *Gilbert* is a 50-ft aluminum semi-V-hulled Munson Hammerhead vessel built in Edmonds, WA. It is powered by three

6V92 turbo-diesels coupled to Hamilton Jets, which can make 34 knots. The shallow draft of 2.5 ft, and jet propulsion system, permits geotechnical investigations and vibracoring surveys to be performed in shallow water. The *Gilbert* is equipped with 2 generators that provide 25 kilowatts of 220 volt, 3-phase power to operate equipment, instruments, and computers. The vessel is also equipped with a 6-ton Hiab Sea-Crane.

The vibracore rig consists of a Rossfelder P-3 electric vibracoring system. This system requires a 3-phase, 230 volt, 50-60 hertz current and in practice can be deployed to depths of 100 meters without special adaptations. It is equipped with a penetrometer designed by the USGS which records voltage changes during penetration, which are then calibrated to core penetration depth.

Cores were collected in 3-inch diameter by 20-foot long aluminum tubes. Whenever refusal occurred (core penetration ceased) with an initial penetration of less than 15 feet, the sampled portion was removed from the pipe, a new liner inserted, and a jet pump hose was attached just below the vibracore head. The rig was again lowered to the bottom and jetted to the sediment just above refusal depth. The jet was then turned off and the vibrator resumed taking the lower part of the core. Immediately upon removal of the plastic liner from the core pipe, the sediment filled liners were measured, marked, cut into 5-foot sections, and sealed.

The cores were delivered to Grand Isle on a daily basis, and transported to the University of New Orleans Geotechnical Laboratory. In the laboratory, the cores were then split in half lengthwise, visually evaluated and logged by a CPE geologist. The results of the daily core evaluation were used to refine the location of the subsequent cores. Opening and analyzing cores within a day allowed for continued refinement of the coring pattern and focused the investigation on the most promising sediment resources.

IX. SEDIMENT SIZE ANALYSIS METHODOLOGY

Sieve analyses was conducted for vibracore sand samples in accordance with the American Society for Testing and Materials Standard Materials Designation D422-63 for particle size analysis of soils (ASTM, 1987). This method covers the quantitative determination of the distribution of sand size particles. The following procedure was followed:

- A sample weighing approximately 100 grams was placed in a clean and pre-weighed porcelain bowl and dried in a 230° F oven.
- The dried sample was weighed using an electronic balance accurate to 0.01 g.
- The sample was then soaked in a solution of sodium hexa meta phosphate ($NaHPO_4$) for at least 4 hours. This solution is a deflocculant, which aids in dispersal of fines.
- This mixture was stirred vigorously and then poured into a No. 230 sieve.
- The sample was washed until the fine fractions were completely removed and the wash water was clear.
- The remaining sample was returned to the porcelain bowl using extreme care to avoid any loss. The sample was then dried in a 230°F oven.

- The sample was then passed through a series of sieves separated at 0.5N intervals (-4.0N to 4.0N).
- The upper 6 sieves (for –4.0N to –5.0N) were hand-shaken vigorously for approximately 1 minute.
- The rest of the sieves were placed in a mechanical sieve shaker for thirty minutes.
- The sample remaining on each sieve was weighed.
- The results were entered into a gradation analysis program developed by Coastal Planning and Engineering which computes mean, median, sorting, and silt/clay percentages for each core sample, and plots grain size distribution curves using both Graphic and Moment methods.

Grain-size analysis of vibracore mud and clay samples was conducted by the University of New Orleans. Mechanical sieving technique is inappropriate for determining the textural statistics of very fine sediment fractions (silt into clay range). For this project, the University of New Orleans was contracted to analyze the mud and clay samples using a Coulter LS200 particle-size analyzer. The Coulter LS200 particle-size analyzer employs laser diffraction to measure the size distribution of sedimentary particles. The LS200 utilizes size-dependent optical characteristics of particles to determine the population of particle sizes within a sediment sample.

The LS200 instrument package primarily consists of a water circulation system, a laser-light source, detectors, and a desktop computer. Prior to analysis, an aliquot of sediment is placed on a petri dish and mixed into slurry in order to break apart cohesive clay clasts as well as separate major shell fragments from the siliciclastic sample portion. Approximately 5 to 10 grams of each slurried sediment sample is then added to the instruments water-filled containment vessel where the sediment particles become entrained within the circulating fluid. Following the addition of the sediment, the sediment-water mixture is sonicated for 8 seconds to further disseminate any remaining cohesive clay particles. The sediment and water is then circulated through a laser-light beam. The scattering of the laser light as it passes through the sediment water mixture is recorded in detectors mounted opposite the laser source. Recorded diffraction patterns identify the size distribution of the sediment because of an inverse relationship that exists between particle size and laser-light scattering.

Definition of Borrow Area and Calculation of Borrow Area Composites:

Vibracore logs and textural properties of the samples were used for the identification of sand deposits within the investigated areas. Final mapping and characterization of sand deposits were done by adopting the following procedures:

(1) Vibracores were analyzed for the identification and delineation of sedimentary beds that meet the minimum criteria specified for the project.

(2) The boundaries of the quality sand beds in the vibracores were correlated with seismic reflectors in order to map deposit continuity between vibracores and lateral extent of the sand deposits. Based on vibracore and seismic information, a potential borrow area was identified in each study area. Material within the potential borrow areas meet the specified requirements for beach quality sand.

(3) All vibracore layers that would potentially meet the 60% sand requirement for beach placement were mechanically sieved by CPE. Sieve data for vibracores within the potential borrow areas were used to create vibracore and area composites (Appendix A-1). Only layers containing sands that meet specified criteria were used in composite calculations. Composites are used to determine the final textural properties of each potential borrow area.

The Cumulative Percents and Composite Distribution tables found in Appendix A-1 were used to compute the composites of vibracores within the potential borrow area boundaries. Sieve data for all vibracores within a borrow area were entered into the spreadsheet. The length represented by each sample was entered into the effective length column. Vibracore composites were calculated by averaging the cumulative percent retained on each sieve, weighted by the effective length (Equation 2). Statistical parameters for the vibracore composite were then calculated and presented on gradation analysis reports and grain size distribution curves (Appendix A-3 and A-4).

Equation 2

$$\ddot{O}\ Composite = (\%_{cumulative} * L_{effective}) / L_{total}$$

Where:

Ö Composite= Composite of the cumulative percent retained on each sieve.

$\%_{\text{cumulative}}$ = Cumulative percent data retained on each sieve.

$L_{\text{effective}}$ = Effective length which is the length represented by the sample.

L_{total} = Sum of all the effective lengths in the core.

Potential borrow area composites were calculated from the vibracore composites using Equation 2. When calculating area composites, the effective length is the total length of the sand in each vibracore located in the borrow area, and the total length is the sum of the effective lengths of all the vibracores located in the borrow area.

X. STUDY RESULTS

The geological/geotechnical investigation was conducted in three distinct phases: (1) literature review, (2) hydrographic and geophysical investigations (bathymetry, side scan, seismic and magnetometer) and (3) vibracores acquisition and analysis.

Geophysical and geotechnical investigations were conducted by CPE in three distinct areas (see Figure 1). According to Phase I regional sand investigation, conducted by the USGS and USACE, potential beach compatible deposits are present and feasible for exploration (Kindinger et al., 2001; Suter et al., 1991). The Phase II investigation was conducted between 08/04/02 and 08/15/02. Approximately 155 miles within the three areas (Figure 1) were surveyed in detailed (bathymetry, seismic, side scan and magnetometer). Bathymetry and side scan sonar investigations were conducted to verify surface topographical-geomorphological relationships that can indicate locations of suitable deposits and to determine optimal vibracore locations. Side scan sonar surveys were also used to identify locations of potential obstacles to dredging activities such as pipelines. Geotechnical survey tracklines are presented in Figure 8 (a, b ,c). A seismic survey was conducted to augment geotechnical investigations and to assist in the analysis of subsurface structure and stratigraphy of investigated areas. Seismic records are contained in Appendix A-11. An example of correlation of seismic interpretations with vibracore data is presented in Figure 10 (a, b, c).

A total of 81 vibracores were retrieved from the three study areas (40 from Quatre Bayou, 31 from Empire and 10 from Scofield). The cores were described, logged and the sand samples were analyzed by CPE . Silt and mud samples were analyzed by UNO using a laser sediment analyzer. The 241 sand samples extracted from these cores were analyzed (sieved) by CPE and 218 mud samples were analyzed by UNO. The final granulometric characteristics of the samples were added to vibracore core log descriptions (See Appendices A-2 through A-7 for sieve analysis data, cumulative frequency curves and vibracore logs). Locations of sand deposits within the three study areas are shown in Figure 10 (a, b,c).

Quatre Bayou Study Area

The Quatre Bayou study area is located offshore Quatre Bayou Pass and Pass Ronquille, west of Chaland Island (Figure 1). Previous studies (*viz*. Kindinger et al, 2001; Suter et al., 1991) attributed the deposits in this region to sedimentary environments such as modern ebb-tidal shoals (nearshore region) and ancient distributary channels and distributary mouth bars (overburden deposits). Modern ebb-tidal shoal deposits are exposed on the surface and were reported to be relatively uniform sedimentary facies (Kindinger et al., 2001; Levin, 1993). Conversely, ancient distributary channel fill and channel mouth bar deposits show greater lateral and vertical variability and are, in the study area, overlain by an admixture of silts, clays, and organic materials that are her grouped into the inclusive category of “mud.” The Quatre Bayou study area contains sedimentary characteristics of both depositional environments (modern shoals and distributary channels). Water depths in the study area range from 11 to 20 feet (NGVD-88) (Figure 9a). Shallower water depths occur at the north and eastern ends of the study area, while greater water depths occur in the south-southwestern ends (Figure 9a).

Forty vibracores were acquired from the Quatre Bayou study area. Most cores that were obtained from water depths shallower than 14 ft contained a bed of surficial sands that fluctuated from 1 to 4 feet thick. This particular deposit provides a relatively narrow sand layer which cannot be efficiently extracted by dredge. Additionally, sand volumes were not sufficient for efficient dredge extraction.

Nevertheless, areas of the Quatre Bayou deposit contain sufficient volumes, and layers, for barrier island restoration. The most promising deposit in the Quatre Bayou study area is a subsurface layer that is covered by an average of about 7.0 feet (ranges from 4.0 to 9.6 feet) of mud. Thickness of the beach-compatible deposits ranges from 3.7 to 15.5 feet; with an average thickness of approximately 10.4 feet. Percent silt ranges from 5% to 39%, averaging 22%. The mean grain size ranged from 0.08 mm (3.56N) to 0.18 mm (2.84N) and averages 0.09 mm (3.42N). Correlation of seismic data and vibracore data (Figure 10a), was used to identify and map this subsurface sand deposit (Figure 11a). The resultant map shows that the depocenters (areas of greater sand thickness) are locally isolated in the study area and do not form a continuous sand body as previously described by Kindinger et al. (2001). The total calculated volume for this sand deposit is about 3,669,800 cy of clean sand (4,775,900 cy sand and silt), with approximately 4,279,000 cy of mud overburden (Table 5).

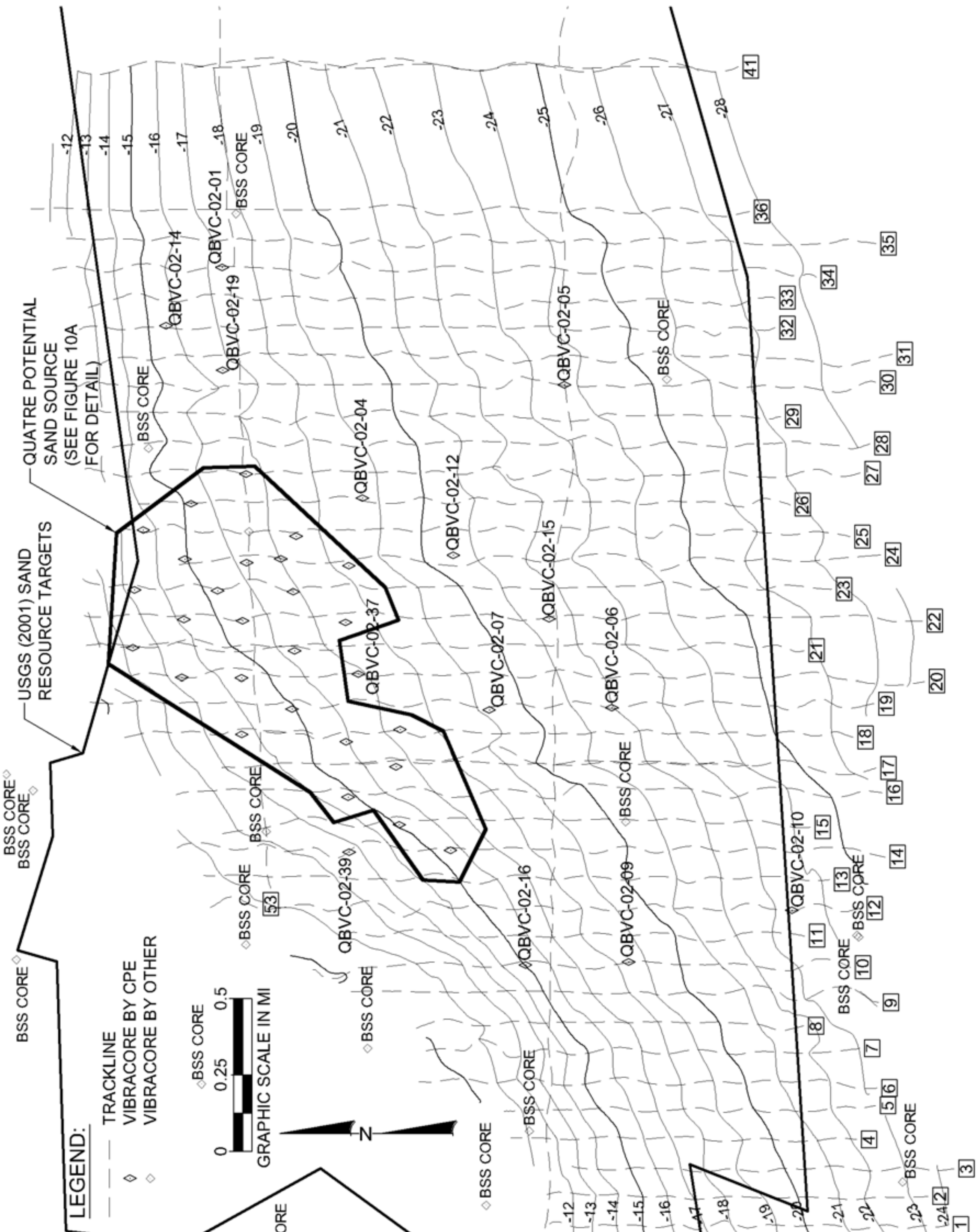


Figure 9a: Bathymetric contours (solid lines), seismic tracklines (dashed lines) and vibracore locations for the Quatre Bayou study area.

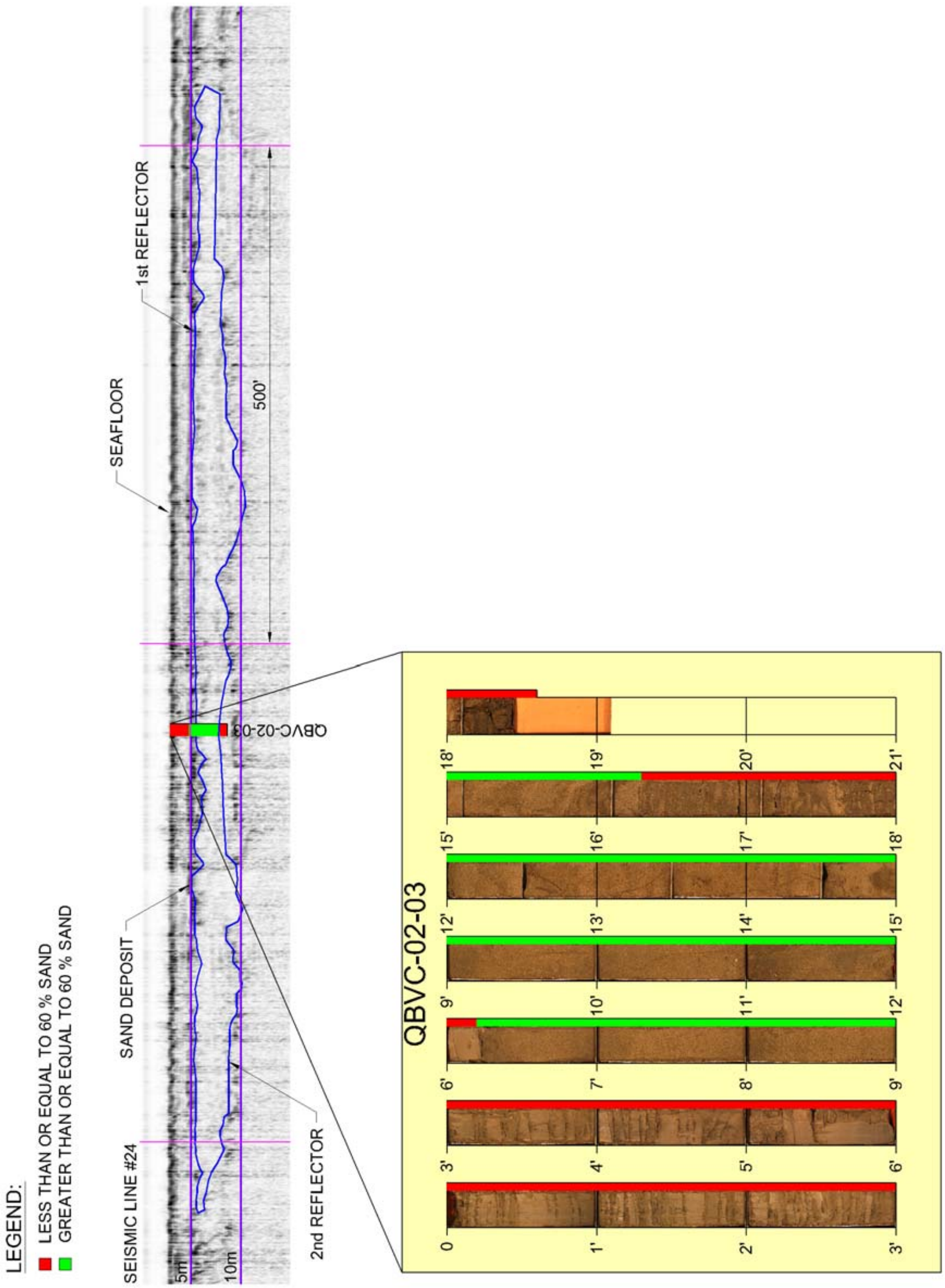


Figure 10a: Seismic reflectors correlated with vibracore data (showing mud and sand beds) for the Quatre Bayou study area.

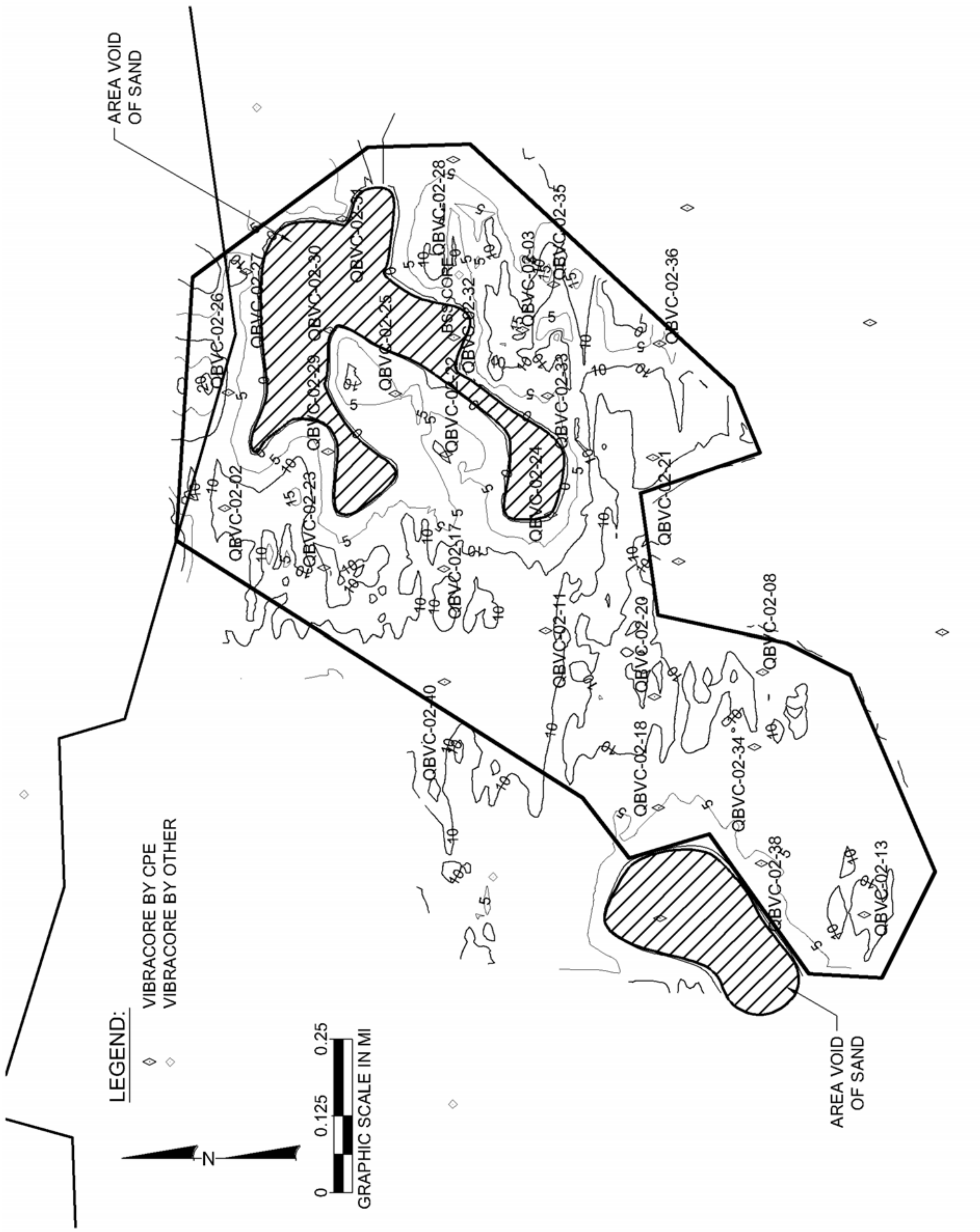


Figure 11a: Isopach indicating the spatial distribution and lateral extent of suitable sand deposits within the Quatre Bayou study area.

Empire Study Area

The Empire study area is located offshore the Empire Jetties and Pelican Island (see Figure 1). Previous studies (e.g. Kindinger et al., 2001; Suter et al., 1991) attributed the deposits in this area to fluvial sedimentary environments (channel fill deposits) overburden by modern muds.

The area contains highly variable sedimentary and stratigraphic structures, is oriented in a shore parallel direction. Three pipelines intersect the deposit (Figure 9b). Water depths in the study range from 12 feet on the landward boundary, to 20 feet (NGVD-88) on the seaward boundary (Figure 9b). Parallel bathymetric contours indicate a flat surface geomorphology that is mainly featureless (Figure 9a).

Of the thirty-one vibracores acquired from the Empire study area, eleven contained sedimentary beds with more than 60% fine sands and thicknesses greater than 3.0 feet. These sand beds were irregularly distributed throughout the study area, varied in thickness from 3.1 to 7.5 feet (but averaged about 4.0 feet in thickness) and contained laminated silts and clays. A capping layer of mud overlaid the sand beds and ranged in thickness from 0.0 to 5.6 feet (but averaged about 3.5 feet in thickness). Percent silt in the sand facies ranged from 3.7 to 24.8%, with an average of 15.5%; mean grain size ranged between 0.09 to 0.15 mm.

The sandy beds located in this study area were identified from vibracore data and correlated with seismic reflectors (Figure 10b). Detailed analysis of seismic profiles between the vibracores containing clean sand revealed variable vertical and lateral structures, not continuous sand layers. Dark mud (clay-silts) reflectors, which were mapped in the seismic records (Figures, 10b, c), dominated areas immediately adjacent to the seismic reflectors that correlated with the sandy beds. A detailed map of the spatial distribution of these sandy beds was based on the interpretation of seismic and vibracore data (Figure 11b). The map demonstrates that the sand pockets occupy relatively small areas, surrounded by more extensive mud and clay dominated areas. The nature of the small sand pockets and the seabed infrastructure (i.e. presence of oil and gas pipelines), preclude the design of dredgeable borrow areas that would provide sufficient volumes of sandy sediments (>60% sand) for project construction.

The total volume of clean sand contained in the pockets in the Empire Study Area is about 255,800 cy, with approximately 272,400 cy of mud (silt and clay) overburden (Table 5). The Empire Study Area was described by Kindinger et al. (2001) as containing between 5.8 to 7.8 million cy of fluvial sands. Detailed analysis conducted as part of this study and based on a total of thirty-one vibracores and detailed seismic records show that the deposits described by Kindinger et al. (2001) are actually discontinuous. The Empire deposit does not contain a continuous sand body, but rather composed of highly variable sand/mud/clay beds and laminates. Due to this highly variable vertical and lateral structure, large volumes of clean sand-dominated sediments do not exist. Therefore, use of limited sand deposits located within the Empire Study Area for barrier island projects is insufficient for project construction, unless dune and beach restoration is greatly reduced.

Scofield Study Area

The Scofield Study Area is located offshore Scofield Bay, southeast of Pelican Island (Figure 1). Compared to the Empire and Quatre Bayou study areas, the Scofield study area is considerably smaller, and is located adjacent to significant oil

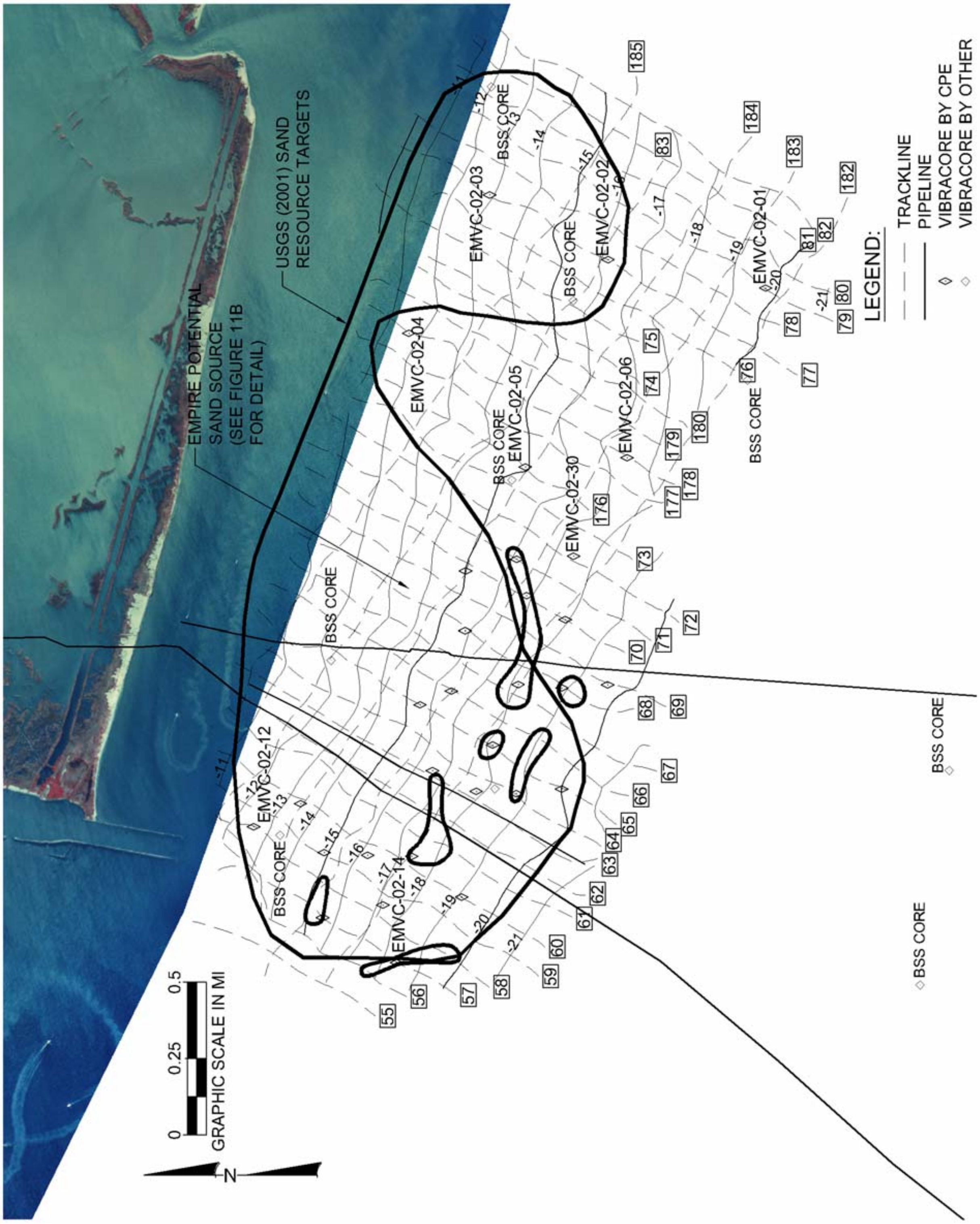


Figure 9b: Bathymetric contours (solid lines), seismic tracklines (dashed lines), and vibracore locations for the Empire study area.

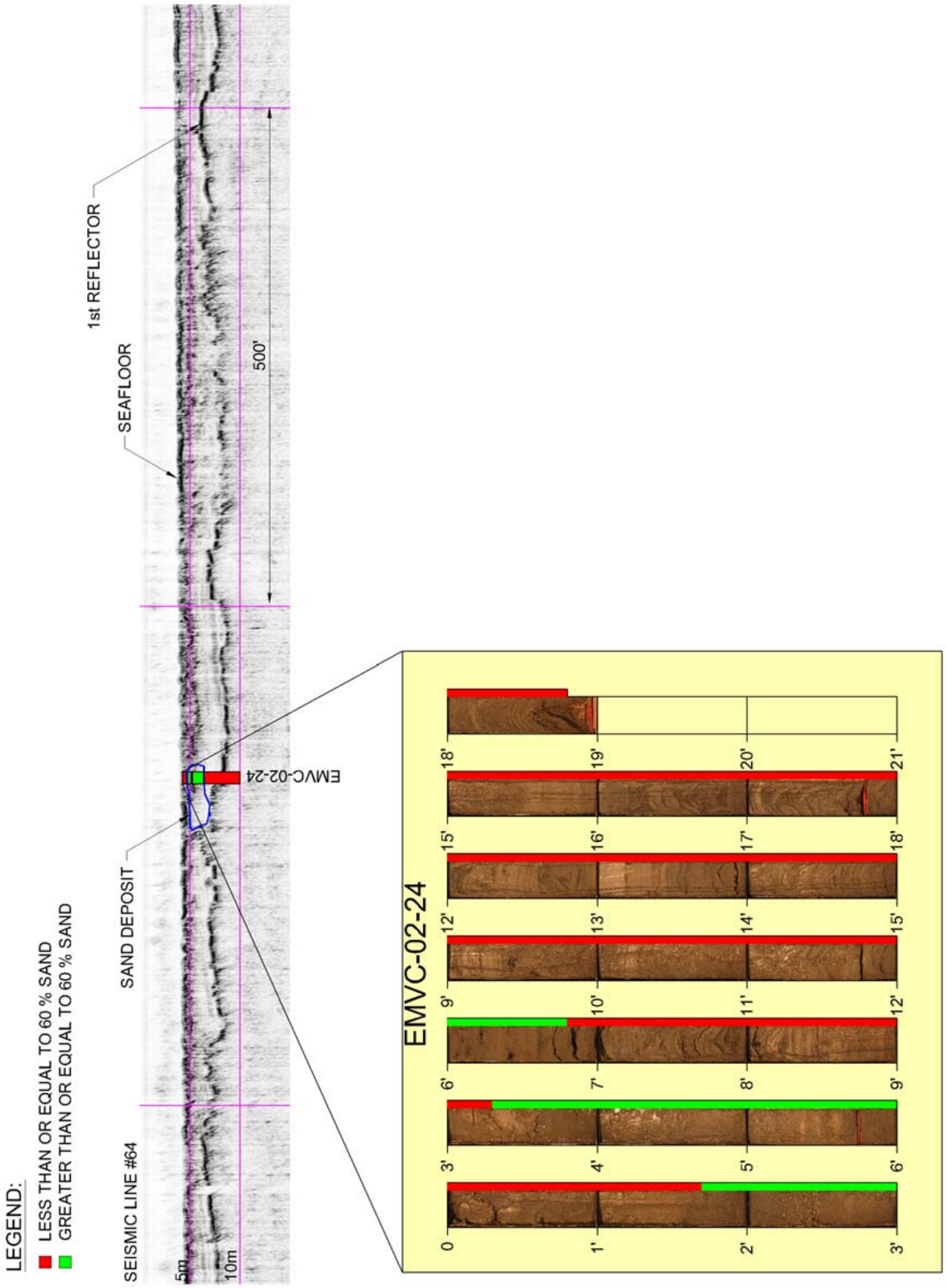


Figure 10b: Seismic reflectors correlated with vibracore data (showing mud and sand beds) for the Empire study area.

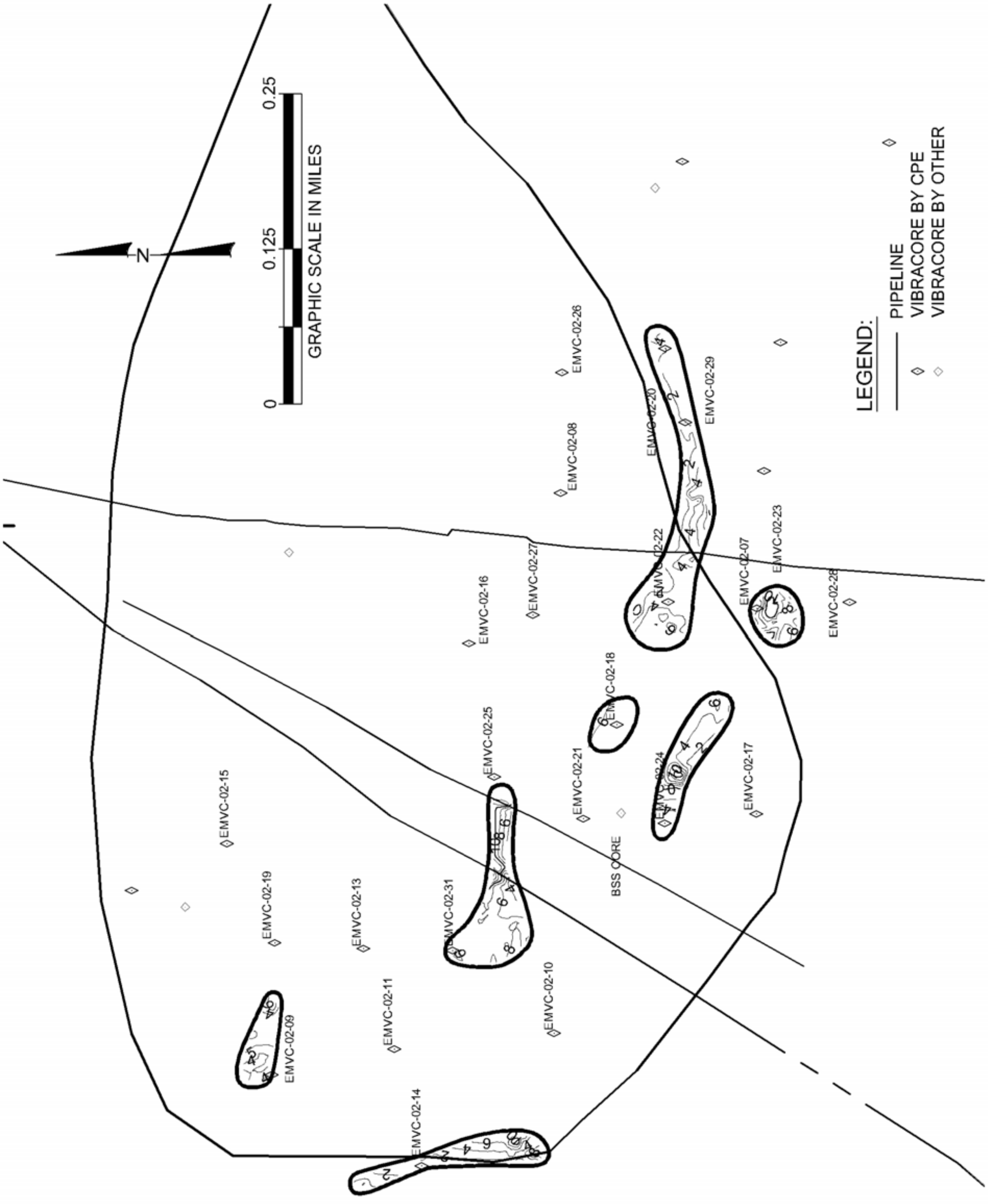


Figure 11b: Isopach indicating the spatial distribution and lateral extent of suitable sand deposits within the Empire study area.

exploration infrastructure. Previous investigators reported that channel fill deposits characterize the Scofield area (e.g. Kindinger et al., 2001; Suter et al., 1991). Water depths range between 18 and 20 feet (NGVD-88) and bathymetric contours exhibit a shore oriented "V" configuration typical of fluvial channels (Figure 9c).

A total of 10 vibracores were acquired from the Scofield study area. Six vibracores contained beach compatible material (> 60% sand) in sand beds containing silt/clay laminaes. Thickness of the sand beds varied from 7.3 to 10.7 feet, but averaged about 9.0 feet. The thickest sand layers were contained in vibracores numbered 02 and 09, in the western section of the study area adjacent to two oil and gas facilities (Figure 9c). The lateral extent of the sand beds (pockets) were highly limited, as demonstrated by vibracore numbers 01 and 04 (dominated by silt and clay beds) located adjacent to cores that contained thick sand beds (see Appendix 2). The sand was generally covered by about 6.5 to 10.1 feet of mud (7.5 feet average). Percent silt in the sand facies varied from 18.3% to 43.4% (27.7% average) and mean grain size ranged from 0.08 mm (3.57N) to 0.11 mm (3.15N) with an average of 0.10 mm (3.38N). The Scofield deposit, when compared to Empire, occupies a smaller area, but contains thicker sand pockets.

The sandy beds located in this study area were identified from vibracore analysis and correlated with seismic data (Figure 10c). Detailed analysis of seismic profiles between the vibracores that contained beach compatible material revealed an extremely variable vertical and lateral structure. The spatial distribution of buried sands was identified and mapped (Figure 11c). Figure 11c shows the sand distribution concentrated in one distinct area with limited lateral extent and interrupted by areas dominated by muddy beds (silts and clays) and/or oil infrastructure such as rigs and pipelines. Large volumes of clean, sand-dominated deposits within the study area were not present. The total calculated volume for the clean sand deposit is about 271,800 cy,with approximately 659,500 cy of mud overburden (Table 5).

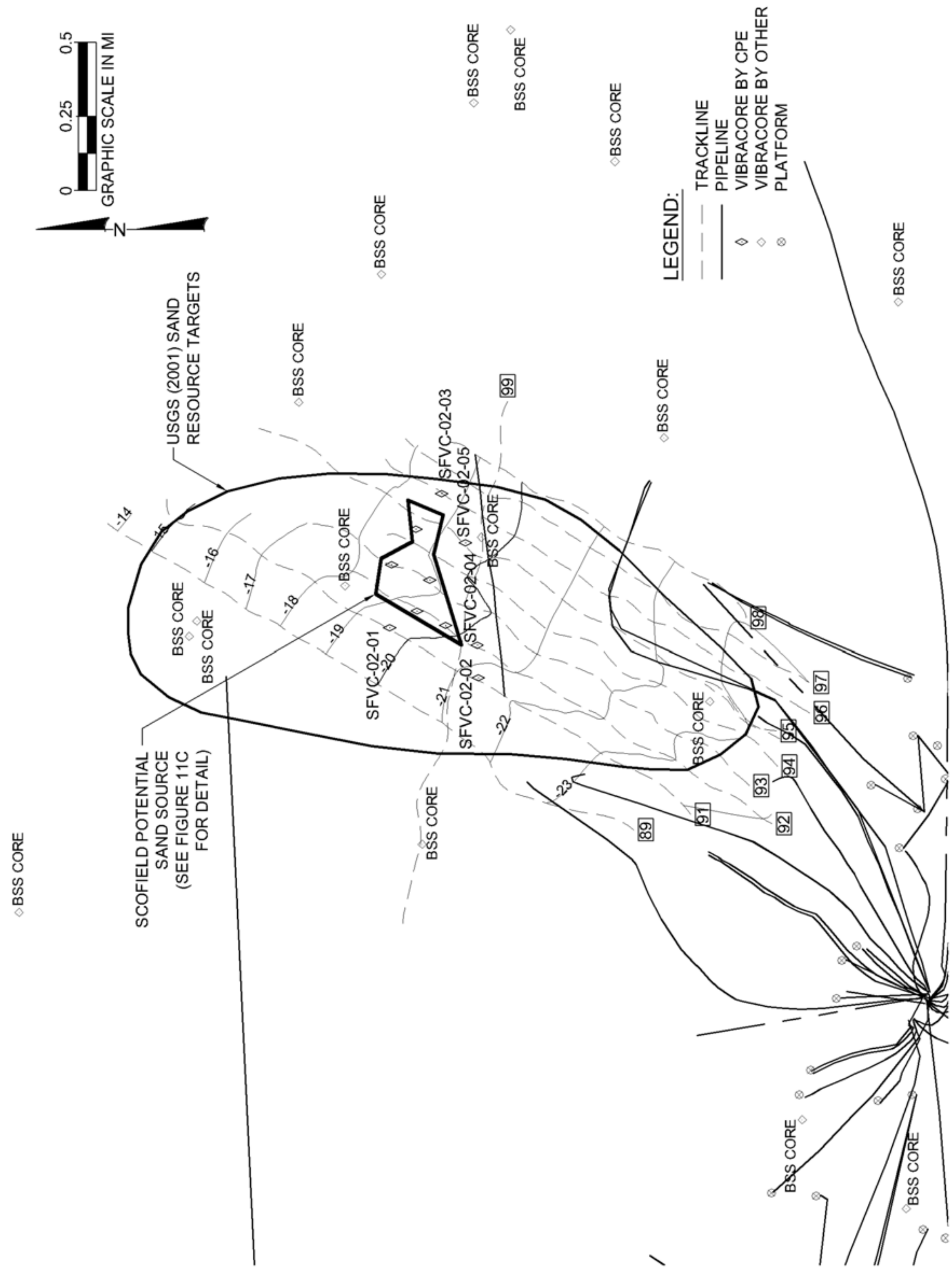


Figure 9c: Bathymetric contours (solid lines), seismic tracklines (dashed lines), and vibracore locations for the Scofield study area.

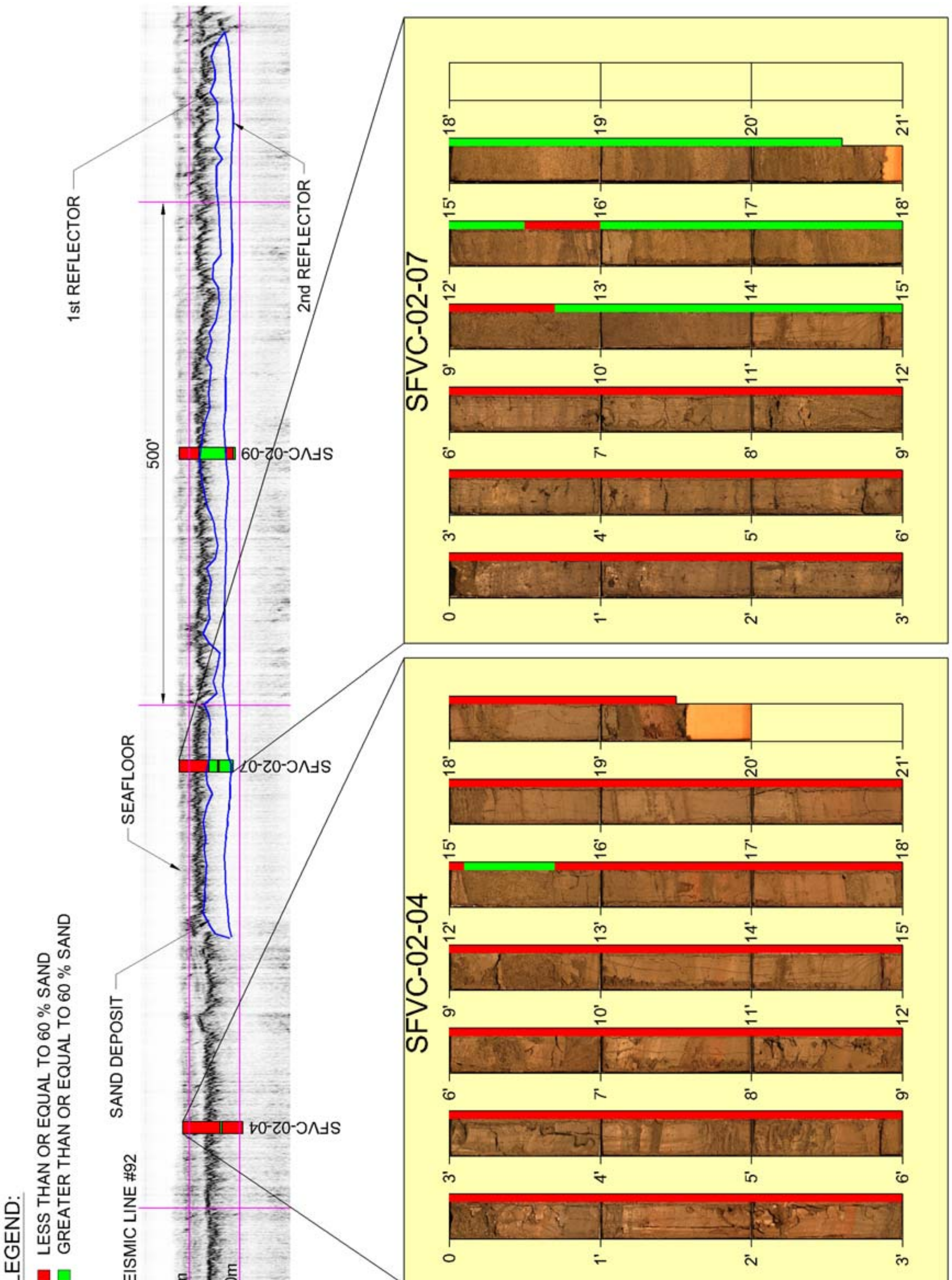


Figure 10c: Seismic reflectors correlated with vibracore data (showing mud and sand beds) for the Scofield study area.

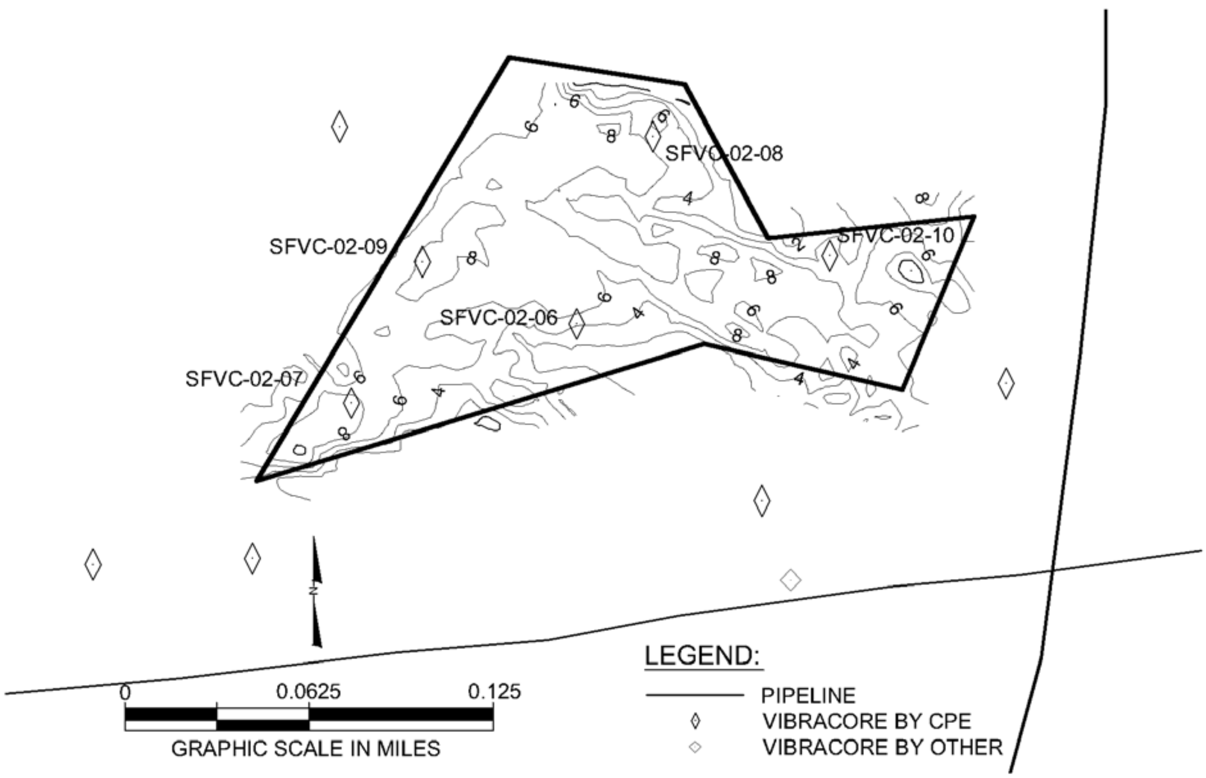


Figure 11c: Isopach indicating the spatial distribution and lateral extent of suitable sand deposits within the Scofield study area.

XI. REMOVAL OF BORROW AREA MUD OVERBURDEN

There is approximately 4.3 million cubic yards of overburden covering sand deposits within the Quatre Bayou study area. In order to access the sand deposits, the selected dredge contractor will be required to remove the overburden. The overburden will either be utilized for marsh creation, or will be excavated and transported to an underwater location which will not interfere with utilization of the designated borrow area at Quatre Bayou. Although the Scofield and Empire sediment deposits did not yield sufficient sand resources for efficient extraction, elimination of overburden is likely required for other sand resources which maybe discovered through geotechnical investigations. Mud which is extracted through dredging will be mixed with water resulting in a slurry. The materials not used in marsh creation, will be sidecast through pipelines, and deposited underwater which will result in even greater ratio of water to sediment. The project construction specifications will likely require the contractor to suspend the disposal pipeline under the surface of the water but well above bottom, depending on water depth of disposal. This will provide for additional mixing and spreading of the material and will avoid the creation of shallow areas through mud deposition away from the borrow area. The specifications will require the contractor to periodically survey the disposal site to avoid creating areas which are shallow and hazardous to navigation. The contractor will be required to relocate the discharge pipe whenever a critical water depth is met. Through this process, it will be possible to spread the overburden well away from the borrow area without creating hazard to navigation. Additionally, disposal will occur away from any oil infrastructure which may be adversely affected by placement of the sediment. An alternative to disposal on the undredged gulf bottom will be to dispose of the material in areas which have been utilized as borrow areas. However, due to the nature of the material as it is dredged and further affected by water mixing, it is unknown how much of the material will actually remain in the borrow pit. Additionally, if there are sand resources in the area, we would recommend that the overburden be transported a sufficient distance from any sand resources to avoid creating additional overburden over those resources yet to be excavated. The unit cost for removal of overburden will depend on the distance of transport of the overburden. It is estimated that overburden removal will cost between $2 and $3 a cubic yard.

XII. STUDY AREA SEDIMENT SUITABILITY ANALYSIS

The compatibility of the sand source for the three study areas was evaluated to determine their suitability with the native beach sand found at the fill sites. The overfill ratio, Ra and the renourishment factors, Rj were calculated according to shore protection manual methodology (USACE, 1986). Dean's overfill ratio method was also used (Houston, 1996). The overfill ratio, “Ra,” and Dean's method, predicts the amount of fill material required to produce, after natural beach processes, a unit volume of stable beach material. This does not include losses due to dredging processes. The overfill ratio technique is based on the assumption that sorting processes will selectively remove material from the various size classes of the borrow fill until a stable grain size distribution results. Background erosion and end losses are not considered by the overfill ratio. Rather, the renourishment factor, Rj is a measure of the stability of the placed borrow material relative to the native sand. The renourishment factor is based on the assumption that no borrow sand is completely stable and that a portion of borrow material will be eroded on an annual basis depending on the characteristics of its grain size distribution.

Overfill ratios and renourishment factors were calculated for Chaland Headland using the Quatre Bayou borrow area; and for Pelican Island using Empire and Scofield borrow areas. Native beach data are presented in Table 3. Results of the suitability analysis are given in Table 4.

Native beach composites did not include the mean high water samples. For both beaches the mean high water samples were collected and contained surficial shell deposits. These samples are not representative of the beach, and would greatly skew the composite results if incorporated into the average. The borrow area composites used in the suitability calculations represent non-shell, sandy deposits that would potentially be placed on the beach.

The sand sources considered in this investigation have overfill ratios (Ra) ranging from 1.05 to 1.56 (Table 4). The overfill quantity reflects the losses expected due to sorting of the placed material from the original textural character to a textural character more like that of the existing beach. Although Dean's method is shown, for design purposes, the most conservative overfill ratio should be used. The renourishment factors range from 1.05 to 1.38. Grain size frequency distribution curve comparisons for the native beach and the borrow areas are shown in Appendices A-12a and A-12b (pages 1619 and 1681).

Table 3

Native Beach Grain Size Data

Native Beach	Mean Grain Size (mm)	Mean Grain Size (Phi)	Sorting
Chaland Headland	0.11	3.17	0.58
Pelican Island	0.11	3.16	0.78

Table 4

Suitability Analysis of Borrow Areas

Borrow Area	Mean Grain Size (mm)	Mean Grain Size (Phi)	Sorting	Ra	Rj	Dean's Overfill Method
Quatre Bayou	0.09	3.42	0.64	1.56	1.38	1.34
Empire	0.11	3.19	0.77	1.05	1.05	1.08
Scofield	0.10	3.38	0.75	1.46	1.38	1.19

XIII. CONCLUSIONS AND RECOMMENDATIONS

In this investigation, three potential deposits (Quatre Bayou, Empire and Scofield) located adjacent to the two project sites (Chaland Headland and Pelican Island) were extensively investigated using hydrographic, geophysical, and geotechnical tools and techniques. A fourth potential sediment source, located at greater distance from the Pelican Island project site (e.g. Sandy Point) was preliminarily researched by review of historical data, and is considered another potential sand source if sufficient sand was not available in the three investigated sites. Additional geotechnical investigations of the Sandy Point sand resources will have to be conducted to determine if the material available is of sufficient quality and quantity to be further considered for use in the Pelican Island Restoration Project.

The following study results are based on detailed investigations conducted in the Quatre Bayou, Empire, and Scofield areas during this phase of the project:

A. Quatre Bayou: In the Quatre Bayou Study area, 3,669,800 cy of sand (4,775,900 of sand and silt), with 4,279,000 cy mud overburden, were identified and mapped (Table 5). Mean grain size of the sand resource is 0.09 mm and contains about 78% sand, on average. The buried sand deposits located within the Quatre Bayou study area contain both clean sand beds (<10% silt) and highly variable beds with silt-clay laminaes (10-40% silt). Results obtained for the Quatre Bayou study area indicate that it contains sufficient sand volumes to meet the volumetric requirements of the Chaland Headland barrier shoreline restoration project. The Quatre Bayou deposit is situated at about 4.5 miles from the Chaland Headland project site. Borrow areas within the Quatre Bayou study area will be refined in the design phase of the project.

B. Empire: The Empire study area contains a highly variable sedimentary and stratigraphic structure, and is divided by three oil and gas pipelines. Undesirable textural properties (i.e. high silt content in the sandy layers and predominance of silt and clay beds), limited spatial distribution of the sand deposits (i.e. sand distributed in small, isolated pockets or buried mounds), and seabed infrastructure (i.e. presence of oil and gas pipelines) strongly limit the areas that contain workable volumes of clean sandy sediments. Seven small sand deposits were identified and mapped in the Empire study area. These areas contain a total of 255,800 cy of clean sand (304,600 cy of sand and silt), with 272,400 cy mud overburden (Table 5). The largest deposit contains approximately 92,500 cy of sandy sediment and the smallest 20,150 cubic yards. The average mean grain size of the sand deposits is 0.11 mm and average percent silt of 16%. Therefore, we do not recommend the use of the sand deposits located within the Empire study area for the barrier island restoration project. The highly variable (admixtures of sand, silts and clays) deposits located within the Empire study area may be used for back barrier and marsh restoration, however sandy sediments must be obtained elsewhere to meet the volumetric requirements of the Pelican Island Restoration Project.

TABLE 5
COMPUTED COMPOSITE DISTRIBUTION FOR BARATARIA/PLAQUEMINES BARRIER SHORELINE RESTORATION PROJECT

Borrow Area	Mean Grain (Phi)	Mean Grain (mm)	Sorting (Phi)	Sand Percent	Volume of Overburden (cy)	Volume of Sand with Silt % (cy)	Volume of Sand without Silt % (cy)
Quatre Bayou	3.42	0.09	0.64	78	4,279,000	4,775,900	3,669,800
Scofield	3.38	0.10	0.75	72	659,500	375,900	271,800
Empire	3.19	0.11	0.77	84	272,400	304,600	255,800

C. Scofield: The Scofield study area is smaller than the Empire and Quatre Bayou sediment deposits and is surrounded by oil and gas infrastructure. About 271,800 cy of buried clean sand (375,900 sand and silt) with 659,500 cy of mud overburden were identified and mapped (Table 5). Sand deposits had a 0.10 mm mean grain size and contain about 72% sand, on average. Small sand volumes identified in this area are attributed to the highly variable textural properties of the sediments and the highly variable local stratigraphy. The 271,800 cy of clean sand mapped in this area are suitable for barrier island restoration, however this volume may not meet total project requirements. The overburden may be used for back barrier and marsh restoration.

D. Sandy Point: The Sandy Point site, which was not selected for investigation during this phase of the project, is located between 8 to 10 miles offshore of the Pelican Island project area. This area may be the largest potential sand deposit located near Pelican Island (Kindinger et al., 2001). Although the site is located 8 to 10 miles from Pelican Island, with the use of booster pumps, it can be excavated by cutterhead dredges. Because sufficient volumes of clean sand deposits do not exist in the Scofield and Empire study areas, a detailed geophysical and geotechnical investigation of the Sandy Point sand body may be warranted for the Pelican Island project area.

XIV. REFERENCES

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