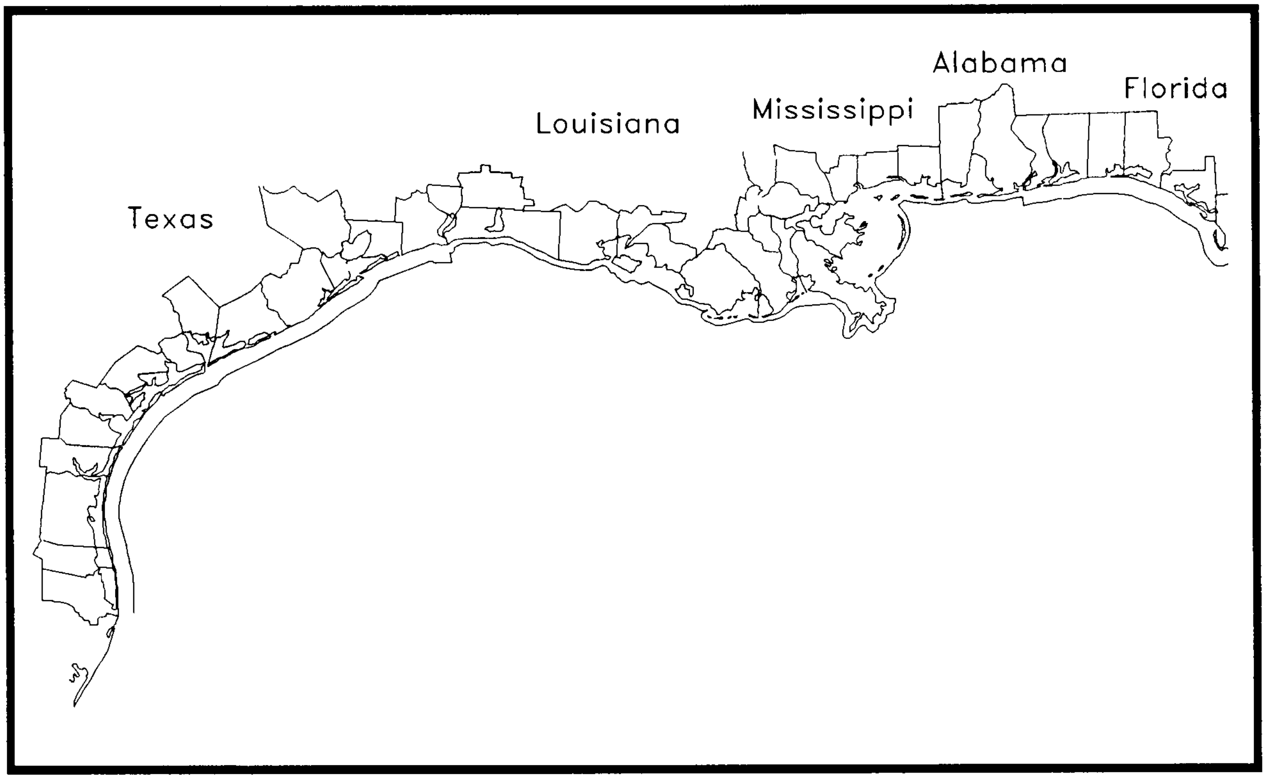
OCS Study
MMS 89-0051

An Analysis of Outer Continental Shelf Impacts

Pipelines, Navigation Channels, and Facilities in Sensitive Coastal Habitats

Coastal Gulf of Mexico

Volume I: Technical Narrative



U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region

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Volume I: Technical Narrative

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EXECUTIVE SUMMARY

Karen M. Wicker

Introduction

Since the 1950's, there has been extensive development of infrastructure, i.e., pipelines, navigation channels, and petroleum-related facilities, to support hydrocarbon production from the Gulf of Mexico's Offshore Continental Shelf (OCS) region. Outer Continental Shelf-related activities have been blamed for detrimental impacts to the barrier islands, beaches, and wetlands on the northern Gulf of Mexico coast. Prospects for new OCS activities, especially in the Eastern Gulf, required that past impacts be documented in order to gage the potential for future impacts in frontier exploration and production areas. Therefore, this study was initiated with the major objective being to document the impacts of OCS-related activities on sensitive coastal habitats in order to assess the significance and extent of past impacts and to predict future impacts. To predict future impacts, observable and quantifiable impacts of existing OCS-related facilities were correlated with construction techniques, including mitigative measures, and/or environmental conditions at the activity site, and existing Federal and State regulations governing construction in sensitive habitats.

The study area extends from Cameron County in South Texas through Bay County in the Florida Panhandle. Outer Continental Shelf-related activities include: (1) pipelines originating from Federal OCS waters, (2) navigation channels constructed and/or improved for use by OCS traffic, and (3) selected, onshore facilities. Onshore facilities had been identified by previous researchers as oil storage tanks; gas processing and treating plants; oil refineries; compressor, pumping, and metering stations; terminals; shipyards; pipe coating and/or storage yards; platform fabrication sites; service and supply bases/dock facilities; and helicopter services.

Sensitive coastal habitats are defined as barrier islands and beaches, emergent wetlands, such as fresh-to-saline marshes, and submerged aquatic grassbeds. However, emergent wetlands and aquatic grassbeds between East Bay, Texas, and the Louisiana-Mississippi border were excluded from this study, except for those wetlands associated with barrier islands. For comparative purposes, data were synthesized by coastal ecosystem: Texas Barrier Islands System, Strandplain-Chenier Plain System, Mississippi Delta System, and North Central Gulf Coast System.

A review of the literature on impacts of OCS-related activities revealed that over 25 types of direct and indirect impacts have been associated with the construction of open, non-backfilled rig cuts, pipeline canals, and channels. This gulf coast overview sought to evaluate all OCS canals and navigation channels within the selected habitats; therefore, the focus was on testing two major hypotheses using field investigative techniques and analysis of aerial photographs:

1. Emplacement of pipelines and navigation canals result in direct land loss and habitat change.
2. Emplacement of pipelines and navigation canals results in indirect land loss and habitat change.
    a. Saltwater intrusion replaces fresher hydrologic conditions with a more saline regime.

b. Erosion continues along the newly created, steep-sided, land-water interface (i.e., canal bank).

c. A weak zone is created in the beach, barrier island, and wetland substrate at the site of the canal or pipeline right-of-way (ROW) ditch which subsequently erodes as a result of natural or man-enhanced processes.

d. Natural physiographic forms and processes are altered which result in habitat change, most notably loss of vegetation.

e. Longshore transport of sediment is disrupted by entrapment of sediment into canal sinks.

Scope of Research

The research effort included four major tasks. Task 1 summarized impacts attributed to OCS-related activities and assembled relevant data on OCS pipelines, facilities, and navigation channels. Questioners went to petroleum companies to verify location, size, line content, date and construction method of pipelines initially identified from existing pipeline maps. Data were tabulated and OCS pipelines and related facilities were mapped. Pipeline construction techniques and mitigation measures were documented for individual pipelines to the extent the data permitted and were summarized for pipelines in general. Data sources included published and unpublished documents, permit applications, and personal communication with petroleum company personnel.

Navigation channels which had been dredged or improved for use by OCS-related activities were identified from government documents relating to funding of navigation projects. U.S. Army Corps of Engineers personnel, their records, and other special reports provided descriptions of the channels. Shoreline crossings of pipelines and navigation channels were delineated on 1:24,000 USGS quadrangles for analysis and on 1:250,000 maps reproduced at 1:500,000 in an Atlas designed to accompany the Technical Report.

Physical and cultural environmental parameters having a potential influence on the type and extent of OCS impacts were mapped and characterizations were written for the four coastal systems. These parameters, as grouped in the Atlas, included: (1) cultural resources, (2) vegetation, precipitation surplus, and hydrology, (3) shoreline type, depth to Pleistocene, and sediment transport direction, (4) geomorphology and shoreline change, and (5) nearshore energy levels.

State and Federal policies, guidelines, and laws presently governing emplacement of pipelines, navigation channels, and facilities in sensitive coastal habitats were documented by state. Data sources included printed documents and personal communication.

Task 2 quantified direct impacts of all OCS pipelines by : (1) measuring and comparing rate of shoreline change at shore crossings of pipeline ROW and controls for all OCS lines crossing barrier islands and beaches and (2) measuring change in canal width for OCS lines in flotation canals through barrier islands, beaches, and wetlands in the Texas Barrier Islands and North Central Gulf Coastal Systems. Analysis of modern and historic air photos provided descriptions of OCS lines, navigation channels, OCS-related facilities, and their surrounding environment. Direct impacts of three OCS navigation channels (Matagorda Ship Channel, Mermentau River Gulf of Mexico Channel, and Belle Pass), out of the 11 identified, were quantified by measuring changes in channel width and comparing differences in shoreline retreat updrift an downdrift of channel jetties.

Task 3 involved field sampling at 11 pipeline sites which were representative of various construction techniques (i.e., open flotation canal, open and backfilled push-pull ditches) employed in each coastal system. Collection and analysis of vibracores and beach profiles at ROW and control sites revealed differences in morphology and stratigraphy at the natural versus the impacted site. Bathymetric profiles and observations on water movement and salinity indicated the extent of a pipeline's impact on local circulation and drainage patterns. Percent cover estimations within 1-m^2-quadrant-sampling areas and clipping, drying, and weighing of 1/16-m^2 subsamples documented differences in plant standing crop biomass at pipeline ROW and control sites. Statistical analyses were performed with StatView computer software.

Comparison of historic and modern air photos, including interpretations along ROW and control transects, provided comparative, descriptive, and quantified data on habitat change and land loss for each pipeline site investigated in the field. Air photos were essential to locating most pipelines in the field because the ROW shore crossings are not marked.

Task 4 summarized impacts of pipelines, navigation channels, and OCS-related facilities by coastal system and related the impacts to construction techniques and system characteristics. Future impacts were discussed in terms of existing regulations, construction techniques, and system characteristics.

Conclusions Regarding Impacts

Pipelines

Of 164 Federal OCS pipelines constructed between 1950 and 1986, 70% cross barrier island complexes (including major tidal passes through island complex segments) or beaches and 30% land along marshy shorelines. The percentage of lines by coastal system are: 57% for Mississippi Delta, 34% for Strandplain-Chenier Plain, 6% for Texas Barrier Islands, and 3% for North Central Gulf Coast. Gas was carried in 65% of the lines and 77% of the lines are 20 in or less in diameter. Only one line is 42 in.

Grouping of pipelines by construction technique at the shore or island crossing is as follows: push-pull ditch (69), flotation canal (24), undetermined (15), buried in tidal pass (5), directional drilled (1). Almost all of the undetermined lines are in the Mississippi Delta System where erosion of shore or marsh interior has obscured the construction signature and collateral data on construction technique were unobtainable. The majority of push-pull ditches (43) are located in the Strandplain-Chenier Plain System. Where collateral data was unavailable, it was often difficult to discern whether the push-pull ditch had been backfilled originally or closed naturally due to siltation and revegetation.

Pipelines can be emplaced using a variety of techniques which, with incorporation of mitigation measures, can influence the extent of impact to the environment. The two major emplacement techniques used historically in wetland environments are the flotation canal and push-pull ditch. The standard flotation canal is designed to have a bottom width of 12 to 15 m and be 1.8 to 3.0 m deep. The push-pull ditch is considerably smaller, ranging in width from 2.4 to 3.0 m and having a depth of 1.2 to 2.4 m. The directional drill technique, first used on a Texas barrier island in the early 1980's, does not impact the environment along the ROW through which drilling occurs. This technique may be required more in the future for crossing short, sensitive habitats, such as barrier islands, beaches, or steep, eroding shorelines.

The extent of direct and indirect environmental impact of a flotation canal is influenced by whether the canal is left open or backfilled and/or whether it is dammed at all tidal water body crossings. The extent of impact is also influenced by environmental factors such as coastal system location, habitat type and condition (eroding, stable or prograding barrier islands and beaches; isolated, low energy, interior fresh marsh; or saline marsh on firm substrate), and sediment availability. Furthermore, spoil deposition will have variable impacts depending upon the environmental forms and processes active at the disposal site and the configuration of the deposit (i.e., continuous on one or both sides of the canal with no breaks; discontinuous on one or both sides of the canal with breaks 15 m wide every 152 m; 152-m long spoil banks alternating on both sides of the canal; or removal of spoil by dragline for backfilling or creation of new marsh habitat) with respect to hydrologic regime.

The extent of impact from the push-pull ditch technique also is influenced by whether the ditch is backfilled and/or dammed. However, the long-term success of backfilling is related to various factors such as substrate composition, marsh type and condition, and quality of the backfill operation. Spoil deposits associated with push-pull ditches are considerably smaller than those of flotation canals, but as with flotation canals, have a potential for impact related to their configuration. Smaller spoil deposits directly smother less marsh initially. However, spoil deposits can impound water when they block surface flow, thus killing brackish-to-saline marsh vegetation. For both flotation and push-pull canals, a double ditching technique can be used to ensure that the top soil is placed on top when the canal is backfilled. This is intended to expedite revegetation and lessen the potential for detrimental impacts such as land loss due to erosion along the unvegetated ROW.

Analysis of air photos and field investigations of selected OCS lines reveal that mitigative measures, when adjusted to environmental processes, can significantly lessen or eliminate long-term environmental impact in most coastal systems. Within the Texas Barrier Island System, this study found that the direct and indirect impacts of the 10 OCS pipelines were virtually nil. This is a result of several fortuitous circumstances which include: mitigative construction techniques (backfilling of ROW) across barrier islands and wetlands, environmentally sensitive ROW alignments (generally, avoidance or selection of shortest wetland crossing), a barrier island system with adequate sediment in transport, and a relatively stable and firm saline-to-brackish marsh along ROW.

Based on data from pipeline companies and interpretation of air photos, it appears that all pipelines in this area were emplaced in a push-pull ditch and/or trench across barrier islands and mainland wetlands, and that these sites were immediately backfilled to preconstruction contours; bulkheaded where necessary; and in several instances, replanted. The literature and permit data indicate that a number of these lines were intentionally routed, often at the urging of regulatory agencies, to avoid sensitive habitats and to cross as minimum an area of wetland as necessary. This is easier to do in South Texas and the North Central Gulf Coast System than in the Strandplain-Chenier Plain and Mississippi Delta Systems because these systems have uplands near the back bay and sound areas with little or no fringing wetlands.

The abundance of sand in transport along the Texas Barrier Island System quickly covered the flotation push-point canals and nearshore trenches dredged during the construction phase. This, plus the fact that the backfilled trenches across the barrier islands were comparable in sediment composition to adjacent areas, eliminated the formation of a weak zone that would be more susceptible to erosion than the adjacent beach areas. The firm, stable, coarser materials of the barrier islands and most of the wetlands crossed by these 10 lines were suitable for backfilling and recontouring. This condition avoided creation of a sunken or irregular topography along the ROW, which is more susceptible to flooding, or formation of tidal channels, both of which prevent reestablishment of emergent vegetation. The ability to backfill successfully a pipeline ROW removes the potential for: (1) saltwater intrusion via an open-water canal into interior, freshwater wetlands, (2) erosion along a ROW embryonic tidal channel, (3) alteration of natural physiographic forms and processes, (4) creation of a weak zone susceptible to future breaching, and (5) formation of a sediment sink which would remove material from the littoral system.

The rate of revegetation is commonly stated in the literature to be two years. This was the case on some lines studied, especially within more humid areas of the northernmost Texas coast. However, on dunes and barrier flats in more arid areas, revegetation success appears to require enhancement by sprigging in biodegradable mats, fertilizing, watering, and protecting the site from grazing and traffic until the vegetation is established. Field observations of one line approximately two years old revealed that evidence of revegetation was barely discernible at the ROW on the irregularly flooded marsh and barrier flats. However, this phenomenon of sparse vegetation is a common feature of the zone located between the vegetated dunes and intertidal bayside marsh. Analysis of air photos revealed no dune blowouts resulting from the placement of pipelines across barrier islands.

The reestablishment of seagrass beds was documented on the slightly elevated subaerial spoil left from the trenching of one of the field-sampled pipelines across Matagorda Bay. A review of the air photos also indicated that submerged grassbeds have spread over the backfilled trench on the backside of barrier islands for some other lines. However, more field investigations and documentation of other factors in the area which affect seagrass distribution would be needed to determine the extent of pipeline impacts on seagrass beds.

There were 55 OCS pipelines identified as crossing a barrier beach within the Strandplain of eastern Texas and the Chenier Plain of western Louisiana. Most of these lines (80%) appear to be installed using a push-pull ditch. Of the 11 lines placed in flotation canals, there were three instances of lines sharing the same canal, despite their being emplaced at various dates. These lines, each set within a ROW belonging to the same company, were all in the eastern portion of the Chenier plain where the sand-shell beach is very thin, narrow, and patchy-to-nonexistent. These flotation canals were bulkheaded inland from the shore often at chenier ridge crossings, where present.

The ROW crossings of flotation canals, and in a few instances the push-point canals for the push-pull ditches, evidenced a slightly higher rate of shore retreat than control points. The westernmost flotation canals in this system were plugged with finer-grained clay and silty clay and overtopped by a sand-shell beach comparable in width and thickness to that of the surrounding beach. The easternmost flotation canals were in an area having minimal sand or shell and therefore were not plugged by a sand-shell beach. However, analysis of air photos indicates that several of the bulkheaded canals south of Cheniere au Tigre are being filled with what appears to be fine-grained clays and organic bits (coffee grinds), probably from the Atchafalaya Delta. Because these eastern canals are not sealed with a sand beach, bulkheads have had to be rebuilt each time the shoreline retreats inland of the dam. In contrast, the sand-shell, beach-sealed canals to the west have not had their bulkheads replaced once the shoreline migrates inland of the dune. Furthermore, field studies and air photo analysis revealed that these bulkheaded flotation canals had actually filled for considerable distances inland (commonly to the inland limit of the high sea rim marsh zone) as a result of beach overwash. Several of these infilled canals contained saltmarsh vegetation for a couple of hundred meters behind the beach.

All of these flotation canals had continuous spoil banks (for those areas observed near the Gulf) and most had bulkheads at regular intervals along the canal and at water-body crossings. Field investigations revealed that one flotation canal had culverts within the spoil to facilitate drainage, but at the time of the visit, the canal had silted to the top of the culverts located nearest the beach. The continuous spoil banks with culverts may be a landowner requirement that facilitated the north-south movement of cattle across grazing wetlands while preventing impoundment of surface waters by the spoil.

The potential for direct and indirect impacts related to flotation canals crossing barrier beaches has been mitigated because the canals have remained isolated from tidal movement by maintenance of bulkheads or natural formation of beach over the cut. Therefore, widening of the canal segments located between the beach and the first bulkhead has been minimal or reversed. There is no tidal flow through the canal to cause scouring, bank erosion, or saltwater intrusion through the beach crossing. Natural nearshore processes have established the beach-berm complex in most instances so the pipeline emplacement did not permanently alter this physiographic form. However, the canal cut through the marsh substrate remains, even though presently being filled by fine-grained clay and silty clay as the shoreline retreats inland. This filled canal corridor differs from the surrounding area and has the potential for more rapid erosion should the sediment supply be reduced or removed.

These canal corridors and, to a lesser extent, the push-pull ditch corridors, across the beach are functioning as a sediment sink, but only for short segments, because all of these lines are perpendicular rather than parallel to shore. These sediment sink areas appear minimal compared to the numerous ponds and lakes that are being infilled as the shore retreats inland along the Strandplain-Chenier Plain System.

The nonbackfilled, push-pull ditches observed near the shore are experiencing the same siltation processes as the flotation canals. However, because they were originally less than 10% the size of a flotation canal, their potential for impact as a result of saltwater intrusion, erosion along the ditch interface, breaching of the shore, alteration of natural physiographic forms and processes, and function as a sediment sink is minimal.

Field and air photo observations revealed no visible impact of these push-pull ditches at the beach, except where the push-point canal is still visible. Even though pipelines are periodically exposed in the surf as the shore retreats into the zone where the line is only about 0.3 m below the marsh, this study uncovered no evidence of accelerated erosion along the pipeline corridor at the beach. Failure to sufficiently bury the pipeline originally leads to periodic habitat disturbance over the lifetime of the line because of the need to lower the line.

Within the Mississippi Delta System, impacts were researched for only those OCS lines (41 pipelines or 43% of the total number of lines) that crossed barrier islands or beaches. Surprisingly, most of these lines (30 lines) came ashore at three locations (East Timbalier Island [12 lines], Belle Pass-to-Pass Fourchon [10 lines] and Grand Isle [8 lines]). These sites contain separator facilities, terminals, and processing facilities, respectively, which serve some of these 30 lines. Five OCS lines in the western portion of this barrier island system appeared to have been installed originally in tidal passes between the islands. Nine pipelines crossed beaches on the west side of the Mississippi River Delta and also made landfall in groups: four near Pass Chaland, four west of the Empire Navigation

Channel, and one across Shell Island. East of the Mississippi River, only two OCS lines crossed the Chandeleur Island complex.

These lines were identified as OCS lines because, by the time of this study, they were connected to a platform in an OCS lease block and/or were verified as being OCS by their operator. All of these lines crossed the beach at basically a perpendicular angle. One line parallel to the beach was studied using both photographic and field methodologies in order to document impacts. When constructed this line was a non-OCS line. However, no attempt was made to evaluate the impact, either singularly or cumulatively, of several other pipelines which parallel the shore between the West Delta and East Timbalier Island. This is because, primarily, these lines appeared to have been constructed many years ago to carry petroleum products from wells located in the lower delta or state waters. More research needs to be done to document their original status (OCS or non-OCS) and significance of their impact with regard to other processes operative in the Barataria Basin and Bastian Bay area. Continued widening and deepening of tidal passes and erosion of barrier islands and marshes will expose these shore parallel lines, as well as interior marsh/bay lines, to boat traffic and fishing operations without constant vigilance to ensure that they remain buried.

It was impossible to evaluate construction techniques in relation to impacts for most of the lines in the Mississippi Delta System for several reasons: the construction data were not available from the operator or owner; the lines were old and shore processes, as well as human activities, had obscured their construction signature on the beach or across the island; the extension of the line into interior marshlands was poorly delineated on existing maps and air photos; or there had been so much erosion of interior marshes that the construction type signature was obliterated or indistinguishable.

Air photo analysis indicated that the flotation canals continued to widen in the marsh inland of the beach. However, all but one of the pipeline crossings (i.e., the Shell Island crossing) were plugged at or near the shoreline by natural beach formation processes or bulkheads. It appears that as long as there is sufficient sediment being transported alongshore, the flotation canals and push-pull ditches are filled with fine-grained clay and silty clay and overtopped by sand and shell material. Where a barrier island or beach segment is narrow and sediment supply is decreased, as was the case when the Empire jetties were constructed and extended, the beach narrows and breaches.

Further evidence of the importance of a sufficient sediment supply in offsetting the impact of dredging flotation canal across a barrier island is present in the case of two flotation canals crossing the Chandeleur Islands. Despite high erosion rates, numerous hurricane assaults, and the apparent failure to mitigate (i.e., bulkhead and backfill) these canals when originally dredged, there has been no breaching of the island or formation of a deep, tidal channel at the pipeline crossings. Littorally transported and overwash sediments have closed the canal cuts through the beach-berm complex and most of the back-bay marsh. However, one line has had to be lowered at least twice on the sound side, thereby exposing a deeper channel visible on air photos.

In general, the potential for future breaching of the shoreline in the Mississippi Delta System remains at the site of the flotation canal crossings because the width of beach infilling is small; the sediments beneath the sand-shell beach plug are unconsolidated and susceptible to erosion; and, in most cases, the width of the beach and interior marshland behind the beach is diminishing because of Gulf and bay erosion. Pipeline crossings perpendicular to the shore do not appear to have permanently altered the beach-dune complex, although this habitat is narrower at the flotation canal sites than along natural shorelines in the area. However, high spoil banks show a tendency to trap overwash sediment on the updrift side and to impound water where two spoil banks are close together and intersect minor beach ridges.

The one shore-parallel pipeline that was studied revealed that the bulkheaded canal segments had trapped overwash sediments and material eroding from the spoil banks. One segment had become elevated to the point that it was colonized by saltmarsh vegetation. The bulkheads prevented tidal scour and major erosion of the banks within the island interior. The spoil banks did not appear to have impacted wetland drainage to the extent that vegetation was destroyed by impoundment.

Only two of the eleven pipelines studied in the North Central Gulf Coast System originated in OCS waters. These two lines were installed across a stable, narrow (relative to the Louisiana delta marsh), salt marsh and backfilled. Air photo analysis and field inspection from the upland site where the lines terminated at the Chevron Refinery in Pascagoula revealed that the ROW for these lines was not visible. A non-OCS line running parallel to these lines was also camouflaged by marsh vegetation, thus indicating that these three lines were installed in such a manner as to avoid permanent impact to the wetlands. Interpretation of aerial photographs indicated that no erosion was occurring at the shoreline crossing.

Another non-OCS line in a backfilled push-pull ditch showed no indication of major erosion at the shore and water body crossing or in the interior saline to brackish wetlands. Field investigations documented that the ROW was revegetated, though lower in elevation and different in species composition than the adjacent marsh.

The five non-OCS pipelines studied in Alabama were installed using a directional drilling technique. Field inspection showed no evidence of the line at the landfall site on the shore and bluff. This was expected because the drill hole was placed inland from the shore.

The remaining two OCS lines were in flotation canals and evidenced significant impact, although not as extensive as for similar flotation canals dredged through marshes in the Mississippi Delta System. The emplacement of these two pipelines has resulted in the replacement of the shallow, sinuous, natural, east-west tidal drainage system by a straight, deeper, wider north-south flow pattern. The damming function of the bulkhead near the shore crossing is negated by erosion around its western side. Unless repaired, this break will enlarge and increase tidal flushing via the flotation canal. These two flotation canals now function as one major canal because the spoil bank between them has eroded.

Saltwater intrusion has not affected the interior marshland cut by the canal complex because the area was originally a saline-to-brackish marsh. The marsh, as a physiographic form with a roughly east-west grain (along the tidal channels of Campbell Inside Bayou and Campbell Outside Bayou and the relict beach ridges such as Campbell Island), has been altered by the dredging of the canals and deposition of spoil, and former marsh continues to be lost as the canal banks erode. However, it appears that the natural, remaining drainage network is sufficient so that spoil deposits have not impounded overland flow to the point that marsh vegetation has been destroyed by elevated water levels.

Navigation Channels

Studies of three of the 11 OCS navigation channels reveal that these channels have impacted the physiography of the nearshore environment, primarily because of the presence of jetties. These jetties trap sediment and create beach on the updrift side while accelerating erosion of the shoreline on the downdrift side.

Erosion of channel banks is substantial where the crossing consist of unconsolidated materials less suitable for supporting riprap, as is the case along the Mermentau River Navigation Channel. Bank erosion does not appear to be a problem at the Matagorda Ship Channel crossing because the channel is revetted with riprap that continues offshore in the form of jetties. This has prevented the washing out of the beach at the point where the jetties touch shore. In contrast, the sides of the Mermentau River are not stabilized and scouring has occurred at the northern end of the jetties, which requires periodic filling of the scour site and extension of the jetties inland. Erosion also occurred on the downdrift side of the Belle Pass jetty-beach contact, necessitating installation of a west-wing jetty. Deposition of maintenance material on the downdrift side of the jetties in front of the wing has created, temporarily, a beach in front of the wing jetty.

In the case of both the Matagorda Ship Channel and the Mermentau River Channel, dredging of a new ship channel and cessation of maintenance of the former channel through a natural pass or river mouth has resulted in these natural passes shoaling (at Matagorda) or completely filling with beach material (at Mermentau).

The original channel dredging (at Mermentau and Matagorda) or enlargement of the natural channel (at Belle Pass) generated an enormous amount of spoil, which was deposited in retainment areas adjacent to the channel. The material at Belle Pass is being eroded on the seaward end but remains as a high, shrub-vegetated spoil bank along the channel. The spoil material at Matagorda remains elevated, vegetated, and in the original deposit formation. The spoil at Mermentau is being eroded rapidly as the ship channel widens.

The material from maintenance dredging at the mouths of the Matagorda and Mermentau channels is deposited in deeper offshore waters and is thus being lost, in all probability, to the nearshore system. Maintenance dredging of the Mermentau channel through Lower Mud Lake results in material being deposited on the shallow lake bottom, thereby silting this water body. There appears to be no attempt yet to place this material in such a manner as to accelerate the creation of wetlands to offset the wetlands lost to original channel dredging or present channel erosion processes.

Maintenance dredging at Belle Pass has been used to create a beach on the downdrift side of the jetty and to nourish the beach updrift of the pass in front of an oil terminal. Future plans for the use of this maintenance dredged material is not known.

In general, it appears that construction and maintenance of the navigation channels studied has focused primarily on the engineering aspects of the channel. The monitoring of the ongoing effects of these channels, with the exception of nearshore profiles for the Matagorda Ship Channel, appears to be limited or nonexistent. Furthermore, the beneficial use of maintenance dredge material does not appear to be incorporated into the long-term operation of these channels.

OCS-related Facilities

An obvious direct impact of OCS facility siting in the coastal region is the filling of wetlands for site preparation and facility construction. Wetlands may be indirectly lost as a result of impoundment of surface drainage, discharge of contaminants, and expansion of development associated with OCS facilities.

Analysis of aerial photographs in reference to a listing of OCS-related facilities revealed that these facilities (i.e., oil storage; gas processing and treating plants; oil refineries; compressor, pumping, metering stations; terminals; oil and gas-related shipyards; pipe storage yards; platform fabrication sites; service base and dock facilities; and helicopter service) are not constructed on barrier beaches. Furthermore, there are few OCS-related facilities on barrier islands and these are generally constructed behind the foredunes and adjacent to major roads or other commercial-industrial developments on the bayside of the islands. Three islands in the Texas Barrier System have facilities. Galveston Island supports two oil terminals; a gas-processing plant; at least one compressor, pump, and metering station; and helicopter services on the eastern portion of the island.

Matagorda Island has several small groups of oil storage tanks, as does Mustang Island. Additionally, Mustang Island has an oil terminal. North Padre Island contains a gas processing plant, helicopter services, and a small group of oil tanks. These facilities comprise a very small percentage of the total island area.

The only barrier islands with facilities in the Mississippi Delta System are Grand Terre, Grand Isle, and East Timbalier Island. A compressor, pumping, and metering station cover 1.6 ha of former marsh on the bayside of Grand Terre. On the eastern end of Grand Isle, Exxon USA, Exxon Pipeline Company, and Conoco, Inc. cover approximately 117 ha, 9 ha, and 15 ha, respectively. These facilities provide helicopter service and boat transportation, materials handling, petroleum and natural gas processing and training for Exxon USA employees, terminal facilities for Exxon Pipeline Co., and terminal facilities and a supply-service base for Conoco, Inc.

Despite the numerous petroleum-related facilities on East Timbalier, only one complex of oil storage tanks and separator facilities was identified as being OCS-related. This complex covered less than 1 ha and included elevated walkways.

No OCS facilities were identified on barrier islands in the North Central Gulf Coast System, except for a small dock area operated by Mobile on the eastern end of Dauphin Island. The only OCS facility that appeared to impact wetlands in this system was the Chevron USA refinery at Pascagoula, Mississippi. Expansion of this site in recent years appears to have replaced about 113 ha of intertidal marsh with water storage-treatment impoundments or landfill.

A true assessment of the cumulative, direct impact of OCS facilities would require comparison of aerial photographs of each site before and after facility construction. However, in general, it appears that, except for water-dependent facilities such as supply and service bases and platform fabrication yards, which need to be at ports near the Gulf, the majority of OCS facilities are located on uplands in Texas and Mississippi and uplands and natural levees in Louisiana. Impacts of facilities on wetlands in Louisiana were not a part of this study.

The most obvious conclusion regarding the impact of OCS-related facilities is that these facilities comprise a relatively small percentage of the area of barrier islands and basically none of the area of barrier beaches. Where located on islands, facilities are generally on higher ground behind dunes and along highway systems in the vicinity of other types of development. To ascertain which came first and possibly attracted the other—the OCS facility or the other development—would require a detailed study on the land use history of each site.

Supply and service bases, in contrast, are located on the back or protected side of barrier islands along navigable waterways. Maintenance or expansion of these facilities has required dredging of channels and filling of wetlands for development. Again, a detailed land use history of these sites would be necessary to determine the extent of wetland impacts resulting solely from the construction of OCS water-dependent facilities.

In general, it appears that most OCS facilities located in the Texas Barrier Islands System and the North Central Gulf Coast System are located in interior uplands, which are closer to the Gulf in these systems and have minimal impact on wetlands.

While no studies were done on the impact of OCS-related facilities in wetlands in the area located between East Bay, Texas, and Waveland, Mississippi, a cursory review of aerial photographs reveal that numerous processing facilities; oil storage tanks; and compressor, pumping, and metering stations are located along the highways linking the chenier ridges and running along the natural levees. Because the ridges are narrow, construction of such facilities has eliminated some wetlands, but quantification of wetland loss requires detailed information on land use and comparative analyses of historic photos.

Prediction of Future Impacts

Pipelines

Decision-makers and the general public now recognize and accept the value of coastal wetlands systems. Both acknowledge the need to protect the renewable resources from wanton and unnecessary destruction whether through pipeline installation or, in fact, many other activities. Most of the regulations that are now in effect are general, that is, they protect or prohibit the use of classes of areas and make no distinction on the quality of the particular feature. For example, all states are conscious of the importance of reefs and aquatic grassbeds and describe them in such broad terms. But in dealing with the agencies, it is recognized that the regulations are becoming more specific within the guidelines established by the Federal and, more importantly, State governments.

In the future, scientists and administrators within each state will concentrate on refining the existing regulations as more and better information becomes available. Sources of this information may take the form of exchange of publications between and among states, better application of our understanding of coastal processes to the routing of pipelines, or the availability of studies that identify the most critical areas. For example, Louisiana has published only a few, general guidelines which leave much to the interpretation of the reviewer. Guideline 3.8 can be interpreted to mean that dredging across reefs is possible if the company restores the reef to its natural conditions. After considering how other Gulf coast states prohibit pipelines from crossing or adversely impacting reefs, Louisiana would be expected to modify Guideline 3.8 so pipelines will avoid crossing or adversely impacting reefs in order to preserve the many benefits they contribute to the coastal system.

With the availability of data, as a result of the added emphasis in the universities and the Federal government during the past 20 years on coastal forms and processes, scientists and engineers are now able to design and construct pipelines in a safer and more environmentally responsive manner. State programs can be expected to require that pipelines make landfall on either prograding or stable shorelines with narrow or absent fringing wetlands. These are the settings where minimal impacts can be expected. For example, pipelines could cross beaches or islands on the updrift side of jetties or groins in the active zone of sedimentation. Another possibility is to require that pipelines be buried at sufficient depth to remain below the seabed for a period of time equal to or greater than the life expectancy of the pipeline. Therefore, if the useful life of the pipeline is 40 years, the pipe must be buried to such a depth that at the end of 40 years it will not have been exposed during this period because of erosion of the shoreline.

Finally, regulations will change because new ideas on the Federal-State relationship will become accepted. The U.S. Army Corps of Engineers now processes applications for pipelines across wetlands as a Nationwide Permit, a process that may not be in the best environmental interest of the nation. In the case of Louisiana, it would seem more advisable to look at each pipeline through the review process for an individual permit. This analysis requires a more detailed investigation than what is common under the nationwide procedure and would provide for input based on the environmental and cultural conditions characterizing a particular site. A greater chance exists for state review and comment through the individual permit procedure. In the case of Texas or Mississippi, it appears that the nationwide procedure is desirable and should continue. Wetlands in these areas can be avoided; or if they are impacted, the scope of the affected areas can be quite limited in extent or quality. Therefore, the future holds a change for the application of the Nationwide Permit procedure by the Corps of Engineers in Louisiana and more stringent review of what effect pipelines really have on the coastal wetlands. Furthermore, as industry technology changes, as better installation techniques are developed, and as companies pool their assets to construct one large line to service many individually developed fields, the regulations will change to incorporate these advances.

Navigation Channels

Almost every natural major river system that discharges into the Gulf of Mexico and several large tidal passes have been modified by jetties and dredging to serve commerce. In those locations where the passes could not be economically maintained, such as the Matagorda or Mermentau systems, new channels were dug across the barriers or beaches. Finally, new channels, for example the Mississippi River Gulf Outlet Canal and the Houma Navigation Canal, were dredged where natural channel systems of the desired size did not exist.

There are few, if any, remaining channels or passes to be dredged, jettied, and enlarged for deep draft navigation needed by general commerce or the offshore oil and gas industry. In addition, maintained, shallow draft harbors (East Channel, Bayou LaBatre, Biloxi) are available to serve the demand for smaller boat access. A sufficient number of deep draft harbors are located in each of the four systems in this study area and can serve adequately the OCS industry.

In the future, environmental laws are not expected to change so drastically as to allow for excavation of any new deep draft harbor along the Gulf of Mexico. Moreover, money will also be difficult to obtain for this type of public works project and, in fact, is not always available even today for maintenance of existing channels. Present laws, regulations, and guidelines will limit new OCS support base development to lands along those channels that have the capacity to meet the needs (draft and width) of the particular industry.

OCS-related Facilities

With the exception of supply-service bases and platform fabrication sites, OCS-related facilities are not water-dependent uses. Therefore, new construction of the other OCS-related facilities is likely to be planned for upland sites in order to avoid delays in construction as a result of the need to do environmental impact statements or prepare mitigation for development in wetlands.

New construction on barrier islands can be expected to be confined to areas where other development is also present. No new construction is likely for areas designated as Coastal Barrier Resources Areas because such sites do not qualify for insurance.

Small facilities such as compressor, pumping, and metering stations may continue to be built in wetlands and barrier islands for Louisiana because of the long expanse of wetlands to be crossed before an upland site is reached. New technology, however, continues to provide for a smaller size and more efficient design, thus limiting the direct impact of their emplacement.

The primary factor operating to ensure that impacts of future OCS-related facilities will be minimized is an aware public that maintains the pressure needed to insure compliance with existing environmental regulations. From an environmental point of view, the first choice is to avoid an environmentally sensitive area. Where facilities must be built, the public and regulatory agencies must require that all environmental precautions be taken and acceptable mitigative measures be incorporated as part of the project.

CHAPTER 1: INTRODUCTION

Karen M. Wicker

Objectives

The primary objective of this study was to document the impacts of Outer Continental Shelf (OCS) related activities on sensitive coastal habitats in order to assess the significance and extent of these impacts. OCS-related activities included pipelines originating from Federal OCS waters, navigation channels constructed for use by OCS traffic, and selected onshore facilities. Onshore facilities included: oil storage tanks; gas processing and treating plants; oil refineries; compressor, pumping, and metering stations; terminals; shipyards; pipe coating and/or storage yards; platform fabrication sites; service and supply bases/dock facilities; and helicopter services.

Sensitive coastal habitats are defined as barrier islands and barrier beaches, emergent wetlands, such as fresh-to-saline marshes, and submerged aquatic grassbeds. The purpose of establishing a correlation among the OCS activities (especially type and construction techniques utilized); physical, biological, and cultural forms and processes active at the site of the activity; and the amount of observable, quantifiable impacts was to formulate predictions regarding impacts of future OCS activities along the coast of the Northern Gulf of Mexico.

As documented by a literature review, there are many divergent and often negative perceptions regarding the magnitude and extent of impact of OCS activities on sensitive habitats. By establishing correlations based on emplacement techniques and the environmental setting, it is possible to predict the impact of future OCS activities prior to construction and work within the environmental constraints to minimize or alleviate negative impacts.

Study Area

The study area encompasses selected sensitive habitats (barrier islands, barrier beaches, wetlands, aquatic grassbeds) located along the northern coast of the Gulf of Mexico from Cameron County, Texas to Bay County, Florida (Figure 1.1). For purposes of investigation, impacts with references to coastal forms and processes were collected and analyzed by coastal ecosystem modified from Terrell (1979). The Texas barrier island system, as described by Terrell (1975) stretches from the Texas-Mexico border to Galveston Bay (Rollover Pass). It is characterized by an extensive lagoon system and barrier islands and beaches composed of sand. Freshwater inflow is regular on the upper coast and coastal wetlands consist of fresh-to-saline marshes. Freshwater inflow becomes progressively diminished on the lower coast, thus resulting in formation of hypersaline conditions, massive grassbeds, and wind tidal flats with hardly any marshes.

The Standplain-Chenier Plain System lies between Eastern Galveston Bay, Texas, and Vermilion Bay, Louisiana (Terrell 1975). The area is comprised of extensive saline-to-fresh marshes and cheniers (e.g., relict beach ridges historically vegetated by live oaks). Several small river systems supply freshwater inflow.

The Mississippi Delta System, for purposes of this study, was defined as lying between Vermilion Bay and Pearl River, Louisiana. The area is characterized by broad expanses of saline-to-fresh marsh; barrier island chains east and west of the active Mississippi River

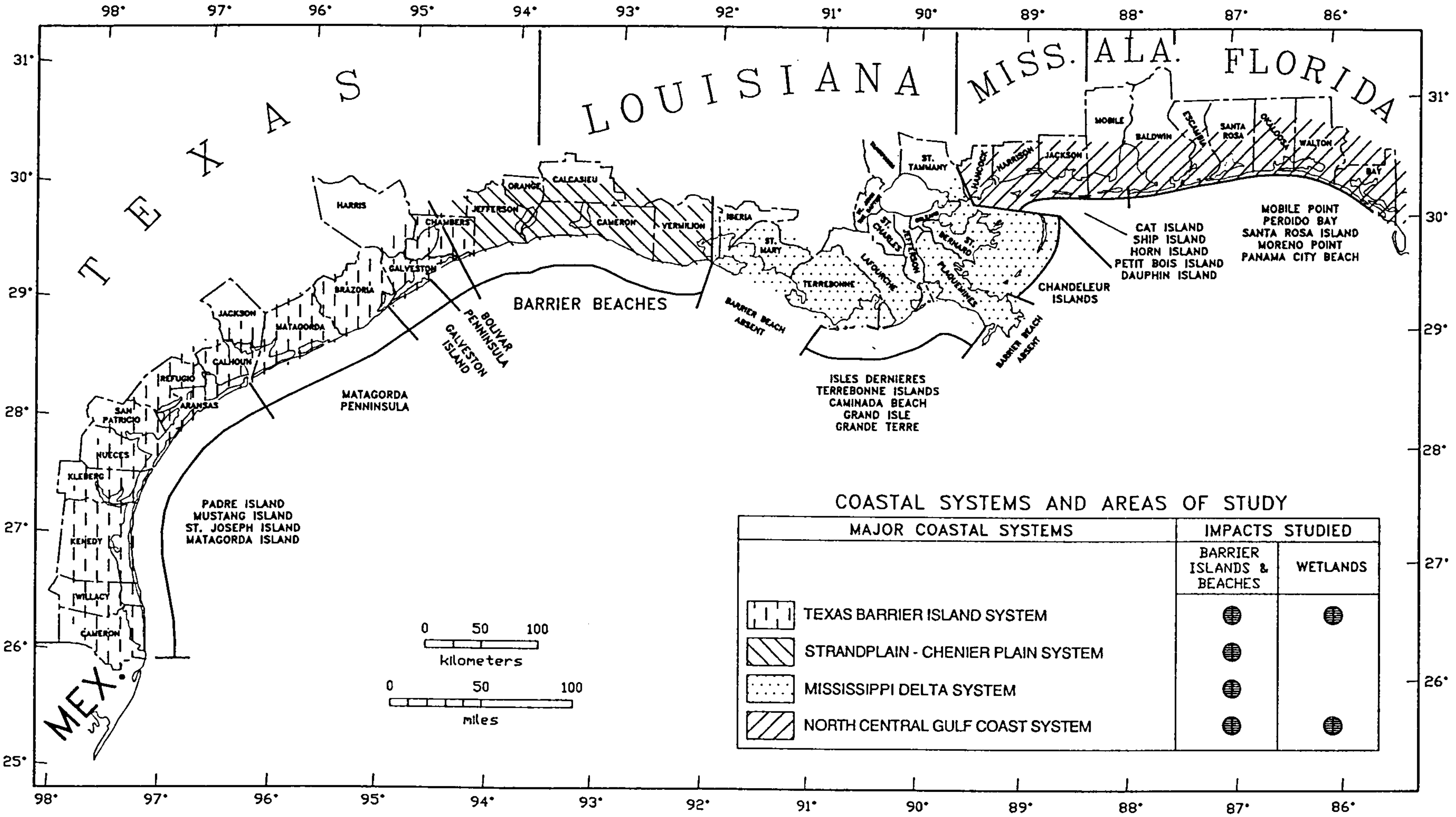

Figure 1.1. **Location of study area by coastal system and type of habitat impact studied.**

Delta; and extensive shallow, turbid, estuarine waters directly influenced by Mississippi River discharges (Terrell 1975).

The North Central Gulf Coast System has been defined as lying between the Pearl River and the eastern border of Bay County, Florida for this study, whereas, Terrell (1975) located it between Pascagoula-Horn Island and Cape San Blas. This system has white sand beaches, clear water, an extensive dune system, and a barrier island system with a relatively high-energy beach environment (Terrell 1975).

The geographical limits of sensitive habitats to be investigated varied within physiographic segments of the coastal zone because of research being conducted by others (Turner and Cahoon 1988). Specifically, the impacts of OCS activities on the marshes from East Bay, Texas to Waveland, Mississippi were studied through another Minerals Management Service (MMS) contract when this project began (Turner and Cahoon 1988). Data on impacts provided by the preceding MMS-sponsored study were incorporated into this report, for purposes of summarizing causes and extent of impacts, and predicting future impacts. For most of Texas and Mississippi and all of Alabama and panhandle Florida, the study area extended inland to include all coastal marshlands. No impacts on Louisiana marshlands were surveyed. However, this examination did observe, on a descriptive level, impacts of pipelines on wetlands in East Texas (east of East Bay). Furthermore, three pipelines west of Waveland, Mississippi were selected for field investigation because they represented the best opportunity to document the impacts of pipelines on a wetlands environment characteristic of the remainder of the North Central Gulf Coast.

All barrier islands and barrier beaches were studied to de-emphasize effects of OCS pipelines, navigation channels, and facilities (see Glossary for definition of geological terms). Pipelines making landfall along non-barrier island/beach shorelines were not included, although the owners and physical characteristics of each system were identified using available data. For example, many OCS pipelines make landfall in the vicinity of the Atchafalaya Delta and the lower Mississippi River Delta where the shoreline consists primarily of marsh-mud flats. Therefore, any OCS pipeline impacts for this area were addressed by the Turner and Cahoon (1988) study.

Scope of Study

The research effort was divided into four tasks: (1) literature research, personal consultation, and synthesis of data; (2) map and air photo analysis for gulf coast overview and site specific description and quantification of impacts; (3) field investigations and laboratory analysis; and (4) summation of relationships between activities and environment and prediction of future impacts.

In order to maximize the comprehensiveness of this study in terms of activities reviewed and environments present along the Gulf Coast, the decision was made to evaluate, at the descriptive level, all pipelines, navigation channels and selected facilities associated with OCS activities that could be located on 7.5 minute U.S. Geological Survey (USGS) topographic maps and aerial photographs. Task 1, therefore, involved the identification and verification of these activities using published and unpublished sources. Furthermore, basic information on the facilities that could have a bearing on type of impact was documented, such as type, location, size, construction date, and construction technique. Background information on environmental conditions, that is, physical, biological, and cultural parameters, of each coastal system was mapped and described with regard to how these parameters would interact with the OCS-related activities.

Task 1 also included documentation of the existing State and Federal regulations governing emplacement of OCS facilities in order to adequately discuss the type of impact to be expected from future activities. Most existing facilities were installed prior to the passage of current regulations, so any mitigation measures taken previously were usually at the request of private landowners from whom the rights-of-way were acquired or as a result of standard engineering practices for the site.

Task 2 involved the location of selected OCS-related facilities on USGS topographic maps and two or more sets of aerial photographs for the purpose of comparing and describing observable changes at the site of the facility and control sites in the vicinity. Comparative site and control data (i.e., shoreline change, habitat change, canal enlargement, etc.) were calculated for various years to further quantify impacts.

Task 3 consisted of four sets of field investigations conducted at the site of eleven OCS pipelines and two navigation channels. Vegetative, bathymetric, hydrologic, and geologic data were collected at each site. Field observations were used to corroborate site-specific air photo and map analyses. These parameters were selected because they are the major indicators of impacts which allow for correlation of quantifiable data from both ground investigations and air photo interpretation. By this technique, ground data can be extrapolated to analyses of coastwide aerial photographs.

In each of the three preceding tasks, information was generated that established the number of OCS-related activities within this study area, the variety and method of construction techniques used, the existing regulations governing present construction, the variations in environmental forms and processes within the study area, and the type of impact associated with particular construction techniques in particular environments. Data were tabulated to establish correlations among activities, environments, and impacts; summaries of information generated were prepared for each of the final three tasks. The final task consisted of analysis of the data base to allow for making statements on the actual, observable impact of OCS activities on sensitive environments of the northern Gulf of Mexico coast.

Methodology

Each of the first three major research tasks was characterized by specific methodologies, which are described in more detail in the chapters pertaining to impacts. The literature research and personal consultation focused on five primary subject areas:

1. Delineation of the study area.

2. Definition, identification and verification of OCS-related facilities.

3. Identification of previously reported impacts and causes of impacts.

4. Documentation and mapping at a scale of 1:250,000 of environmental parameters and facilities, i.e. (a) location map with OCS facilities; (b) land use and navigation channels; (c) cultural resources; (d) vegetation, precipitation surplus, and hydrology; (e) shoreline type, depth to Pleistocene, and sediment transport; (f) geomorphology and shoreline change; and g) nearshore energy levels.

5. Documentation of existing State and Federal regulations influencing facility emplacement. Reviewed data were summarized and discussed in

chapters on OCS facilities (Chapter 2), navigation channels (Chapter 3), regulations (Chapter 4), and Gulf Coast Environment (Chapter 5).

Major data sources included Gulf Coast ecological characterization studies (narratives and maps) and primary sources cited in publications generated by federally sponsored research. Literature and collateral information were also obtained from regional research facilities, universities, private companies, and State and Federal regulatory agencies.

Pipeline operators (44 companies) were contacted for verification of OCS pipelines and basic pipeline characteristics. Virtually all companies contacted responded eventually, but the thoroughness of the data provided varied considerably. A great deal of time was expended on this research phase because the acquisition of historic information on construction techniques and basic pipeline parameters was essential to execution of the research effort. Summaries of the information from these sources were presented in written and tabular form. The latter material was used to correlate significance and type of impact between pipeline characteristics and environmental characteristics.

Map and air photo analysis began with identification and acquisition of the most recent 1:24,000 and 1:250,000 USGS maps of the study area and selected aerial photographs for specific sites. Because the aerial photographs were from different years, formats ranged from black and white, quad-centered, controlled photo-mosaics, to black and white, and color infrared (CIR) prints and transparencies. Scales ranged from 1:7200 to 1:65,000. To the greatest extent possible, this study utilized aerial photographs in-house or at nearby facilities, such as Louisiana State University and the Louisiana Department of Natural Resources in Baton Rouge, and the National Cartographic Information Center, Bay St. Louis, Mississippi. Selected additional photography was purchased from the EROS Data Center, Sioux Falls, South Dakota and the Agricultural Stabilization and Conservation Service (ASCS), Salt Lake City, Utah. Collateral data, in the form of published, small-scale pipeline maps and unpublished, large-scale "as built" maps, facilitated location of pipelines on aerial photographs and large-scale USGS maps. This step (i.e., projecting data from aerial photographs of various time periods onto USGS topographical maps) was necessary in order to calculate changes along pipeline and channel rights-of-way (ROW) and controls, and to relate observable impacts to the facilities. Selected OCS facilities were also mapped for further analysis.

Map and photo data were tabulated in order to document type and amount of impact and correlate them to facility and environmental characteristics.

Once OCS pipelines were plotted on maps and aerial photographs, four sites were selected for field investigation. The field studies were intended to verify air photo data, thus allowing for extrapolation of findings to future transportation corridors, and to provide as much data as could be extracted reasonably in a one-time site visit. Sites representative of the different pipeline construction techniques were chosen for each of the four Gulf Coast systems. Two OCS navigation channels were also selected for field surveys. OCS-related facilities were observed in the field but discussion of impact was confined to air photo analysis.

The final task focused on summarizing all the data generated from the literature and personal contacts, map and photo analysis, and field investigations. Whereas Tasks 1 through 3 emphasized data collection and analysis of impacts at specific levels, Task 4 emphasized making the correlation between past activities and impacts in terms of specific Gulf Coast environments, and explicit construction techniques and future impacts with consideration of present regulations.

Organization

The data and information generated from analysis of the various types of data has been organized in a format building from the past (literature and documents, maps, and photos) to the present (field investigations and current regulations). For purposes of data presentation and discussion, OCS-related activities have been divided into pipelines, navigation channels, and facilities, and have been grouped by each of the four coastal systems. This facilitated a discussion of impacts within similar environments, as well as discussion of differences that could be expected because of environmental variation along the Gulf coast.

The large-scale maps present the physical, biological, and cultural data and appear in Volume II. The atlas aids in interpreting the causes of observable impacts and in predicting future impacts.

The objectives, scope, methodology, and report organization are presented in Chapter 1. Chapter 2 contains information on OCS pipelines and related facilities, including location, type, and construction techniques. A description of pipeline construction techniques, as well as factors influencing selection of techniques, is also discussed in Chapter 2.

Chapter 3 surveys navigation channels within the study area and presents the rationale for selecting those channels considered to be OCS-related. The environmental problems that have been attributed to OCS-related pipelines, navigation channels, and facilities are reviewed in Chapter 4. Mitigation measures that have been incorporated into construction are also summarized.

Chapter 5 contains a review of Federal, State, and local regulations governing construction of canals within the study area. The information focuses primarily on current regulations and is presented by state.

In Chapter 6, the environmental and cultural characteristics of each of the four coastal ecosystems are described. Included in the chapter are data on geology and sedimentology, climate and tropical storms, hydrology, vegetation, and land use and cultural features. Maps depicting the characteristics are printed at 1:500,000 in Volume II. The study area is covered by ten base maps and basic data has been combined into seven sets of overlays printed on each of the bases.

Chapter 7 presents the impact of OCS pipelines selected in each of the four coastal ecosystems based on analysis of field data (on geologic, hydrologic, and vegetative parameters) and discusses air photo interpretation in detail. The hypothesis and methodology used to investigate impact are described in the beginning of the chapter. This is followed by a Gulf Coast overview of impacts of OCS pipelines derived from analysis of aerial photographs.

The impact of OCS-related navigation channels and facilities is presented in Chapter 9 and is based primarily on analysis of data compiled from air photos and maps.

In Chapter 10, impacts of OCS pipelines, navigation channels, and related facilities are summarized. Based on conclusions derived from analysis of observations of past impacts, as well as present regulations governing construction of these OCS infrastructures in each of the Gulf coast states, predictions regarding future impacts are presented.

The appendices include tabulated data which were compiled, analyzed, and presented for the study.

CHAPTER 2: OCS PIPELINES AND RELATED FACILITIES: LOCATION, TYPE, AND CONSTRUCTION TECHNIQUES

Karen M. Wicker

Identification and Location

OCS Pipelines

Numerous sources were consulted to determine the location of Federal OCS pipelines. These sources included mapping projects funded by the U.S. Fish and Wildlife Service (USFWS) and Minerals Management Service (MMS) (MMS 1987; Kimber et al. 1984; Larson et al. 1980; Palik and Kunneke 1984; Smith 1984; Garofalo and Burk and Associates 1982; Wildan and Associates 1980), published industry maps (ANR Pipeline Company 1986; Chevron U.S.A. Inc. 1986; Natural Gas Pipeline Co. of America 1984a, b; United Gas Pipe Line Company 1985; Tennessee Gas Transmission Company 1982, 1986a, 1986b; Transcontinental Gas Pipe Line Corporation 1977, 1983), and State and Federal pipeline maps (Texas General Land Office 1984; Louisiana Department of Conservation 1941, 1947, 1953, 1964, 1973, 1974, 1977; Louisiana Department of Natural Resources 1986; Texas Railroad Commission 1986). Location of pipelines on USGS 1:24,000 maps was facilitated through consultation with pipeline-specific industry maps, such as small-scale regional and large-scale "as-built" maps, provided by the oil and gas industry in response to written requests for verification of data on their pipelines. (See acknowledgements for a list of companies that complied with a request for information.)

For purposes of this study, Federal OCS pipelines were defined as those lines extending gulfward of the State-Federal demarcation boundary as delineated on the most recent U.S. Geological Survey (USGS) topographic maps. A number of lines included in this study were originally constructed into state waters and only later extended to serve the Federal offshore. However, this study did not track the history of each line in order to determine its original lease block origin as a criteria for determining its OCS status.

Baseline data on individual pipelines (i.e., owner/operator, lease block origin, landfall location, size, content, construction date, and emplacement technique) has been tabulated for purposes of summarizing the information (Appendix A.1 through A.4). These data came from pipeline maps; various permit applications to the U.S. Army Corps of Engineers (USACE), Galveston and Mobile Districts; journal articles; pipeline operators; and the 1986 Operators Manual from the Minerals Management Service, Gulf of Mexico Region. The data on location, size, operator, and content has also been mapped (Maps 1A-10A, Vol. II) in order to relate pipeline data to the environmental setting and to correlate these parameters with any detectable impacts observed as a result of the air photo studies or the field investigations. While all other measurements in this report are given in metric units, pipeline diameter is left in English because of the pervasive use of this system within the industry.

One hundred sixty-four pipelines extend from the Federal offshore and make landfall in the study area. Of these, 116, or 70%, cross barrier beach or island complexes, while the remainder intersect marsh or mud-flat shorelines. The Chandeleur Pipeline 12-in and 16-in were counted twice because they cross the Chandeleur Islands in the Mississippi Delta System and make landfall in Mississippi in the North Central Gulf Coast System. Of these 164 pipelines, the majority (95 lines or 57%) enter the Mississippi Delta System, but only 46 (28%) cross a barrier island (or island complex) or beach (Figure 2.1). Of these 46 pipelines, seven (Trunkline 30 in, 30 in, Transco 26 in, Tennessee Gas 26 in, 36 in, Texas

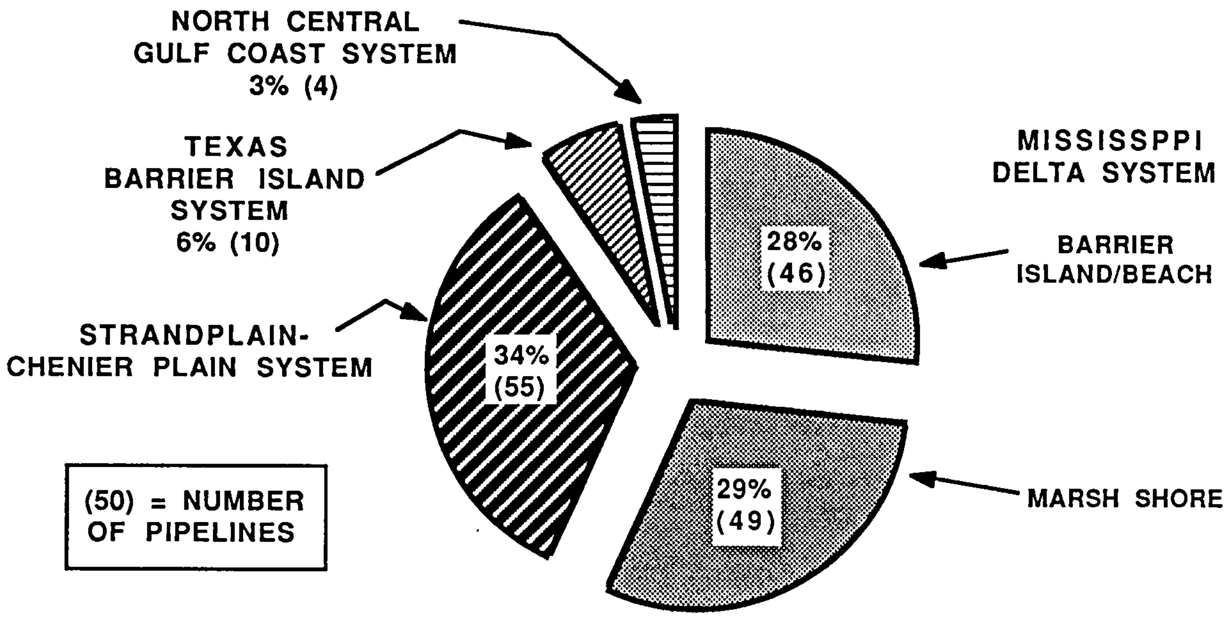

Figure 2.1. Distribution of OCS pipeline landfalls by coastal system.

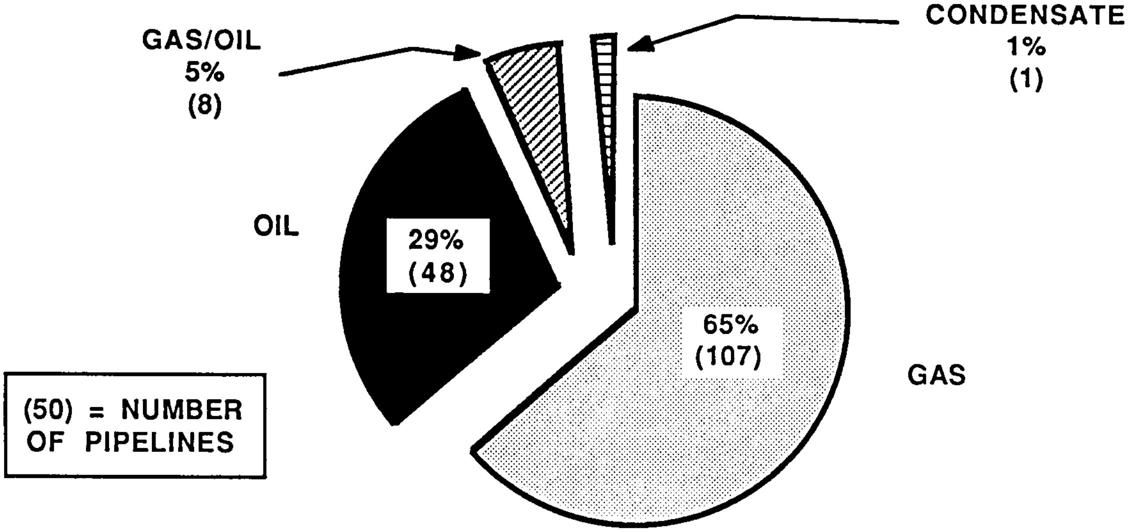

Figure 2.2. Contents of OCS pipelines making landfalls by coastal system.

Pipeline 20 in, Odeco 8 in) appear to have been laid through passes or near the tips of migrating barrier islands (e.g. Isles Dernieres) and probably did not cross the barrier island at the time of construction.

The second largest number of pipelines (55 lines or 34%) come onshore in the Strandplain-Chenier Plain System of East Texas and Western Louisiana. Only 10 OCS pipelines (6%) cross the Texas Barrier Island System. Of the six pipelines making landfall in the North Central Gulf Coast System, only two (Chandeleur Pipeline 12 in and 16 in) come directly from OCS leases. Two lines (Tennessee Gas Pipeline 30 in and 36 in) may carry some OCS products at times. Of the remaining two lines, one (Sohio 20 in) carries refined gasoline from the Alliance Refinery on the Mississippi River and the other, Chevron Pipeline 20 in, transports crude oil from a terminal near Ostrica, Louisiana. Five other pipelines (Mobile Oil Exploration and Producing SE, Inc. 16 in, 10 in, 8 in, 6 in, 6 in) landing in the North Central Gulf Coast System were also studied for purposes of determining impacts but they transport gas from or fuel to a state lease block in Mobile Bay. These latter seven lines were not included in the tabulation of data for OCS lines.

The majority of the OCS lines (107 lines or 65%) transport oil, while 29% (48 lines) transport gas (Figure 2.2). A small percentage (5% or 8 lines) transport oil and gas, and one (1%) line transports condensate.

There are approximately 41 companies operating OCS pipelines making landfall along the Gulf Coast (Table 2.1). Five companies (Chevron U.S.A., Chevron Pipeline, Gulf Oil/Gulf Refining, Tennessee Gas, and Transcontinental Gas) operate over 40% of the pipelines. Because all companies did not provide a verified list of OCS lines they currently operate, this table reflects ownership derived from recently published sources and may not reflect ownership changes caused by recent mergers. For example, Chevron recently acquired Gulf Oil pipelines and kept some but sold others, which is not reflected in Table 2.1. Furthermore, some pipeline operating companies are subsidiaries of a major company formed solely to operate one pipeline for the parent company on a consortium of OCS producers using the line.

The first OCS pipeline was an 8-in gas line installed in the Strandplain-Chenier Plain System southwest of Pecan Island, Louisiana in 1950. The offshore portions of the line are operated by Jupiter Energy Corp. and the onshore portion is maintained by Tennessee Gas Pipeline Co. (Leger 1988) (Figure 2.3). The greatest number of pipelines (10 lines) were installed in 1967. Nine pipelines were installed in 1970 and 1978. Fifty-three pipelines, or 37% of the 145 pipelines for which installation dates were identified, were installed between 1965 and 1972. Other periods of peak installation occurred between 1958 and 1961 when 17% of the lines were installed, and between 1976 and 1979 when 20% of the lines were installed. At least one line has been installed across the coast of the Northern Gulf of Mexico every year between 1954 and 1986, but the period from 1980 to 1986 has seen the fewest number of installations (11%).

An analysis of OCS pipeline sizes indicates that pipe size ranges from 4 in to 42 in with the majority (63%) of OCS lines consisting of 4-in (9%), 10-in (10%), 12-in (22%), 16-in (13%), and 20-in (9%) lines (Figure 2.4). The 12-in diameter lines represent 22% of all the lines and only one is 42 inches in diameter. Over three-fourths (127 lines or 77%) of the pipelines are 20 in or less in diameter and the majority of these (78 lines) make landfall in the Mississippi Delta System. However, only 42 of these smaller lines cross barrier island or beach systems. Of the 37 pipelines 22 in or greater in diameter, 46% make landfall in the Mississippi Delta System, 35% in the Strandplain-Chenier Plain System, and 14% in the Texas Barrier Island System. Of the 46% landing within the Mississippi Delta System, only 5 lines or 14% cross barrier beach or island systems.

Table 2.1. Distribution of OCS Pipelines By Pipeline Operator and System of Landfall.

Pipeline Operator	Texas Barrier Island	Strandplain-Chenier Plain	Mississippi Delta System BI/BB	Mississippi Delta System Marsh	North Cent. Gulf Coast	Total
American Natural Resources		3		2		5
Amoco Pipeline Co.	1					1
Amoco Production Co.		1				1
Arco Oil and Gas Pipeline Co.				2		2
Black Marlin	1					1
Blue Dolphin	1					1
Chandeleur Pipeline Co.			2		2	4
Chevron Pipeline Co.		2	1			3
Chevron U.S.A. Inc.		1	3	5		9
Columbia Gulf Transmission Co.		4				4
Conoco, Inc.		2	2	2		6
Enron Pipeline Services	2					2
Exxon Pipeline Co.			3	1		4
Exxon USA, Inc.			4			4
Gulf Oil Co.*			11	5		16
Gulf Refinery Co.*			2			2
Gulf-Tenneco		1				1
Jupiter Energy Corp. (Tennessee Gas onshore)		2				2
Kerr-McGee		1				1
Magnolia/Continental/Newport				1		1
Marathon				3		3
Mobil Oil Exploration and Producing SE, Inc.		4		1		5
Natural Gas Pipeline Co.		4				4
Odeco			1			1
Phillips Petroleum		1				1
Sea Robin Pipeline Co.		1				1
Seagull Energy Corporation	1					1
Seagull Pipeline		1				1
Seagull Shoreline Systems	1					1
Shell Offshore				3		3
Shell Pipeline			2	3		5
Southern Natural Gas			2	2		4
Tenneco Oil Co.			1			1
Tennessee Gas Pipeline Co.		8	9	4	2	23
Texas Eastern Transmission		3		2		5
Texas Gas Transmission Corp.		1		2		3
Texas Pipeline Co.			1			1
Texaco		2		2		4
Transcontinental Gas Pipe Line Co.	3	10	1	5		19
Trunkline Gas Co.		3		3		6
United Gas Pipeline Co.			1	1		2
					Total	164

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* Gulf lines acquired by Chevron USA in 1985 and are now operated by Chevron Pipeline Co. or have been sold to other companies such as Sohio Pipeline Co.

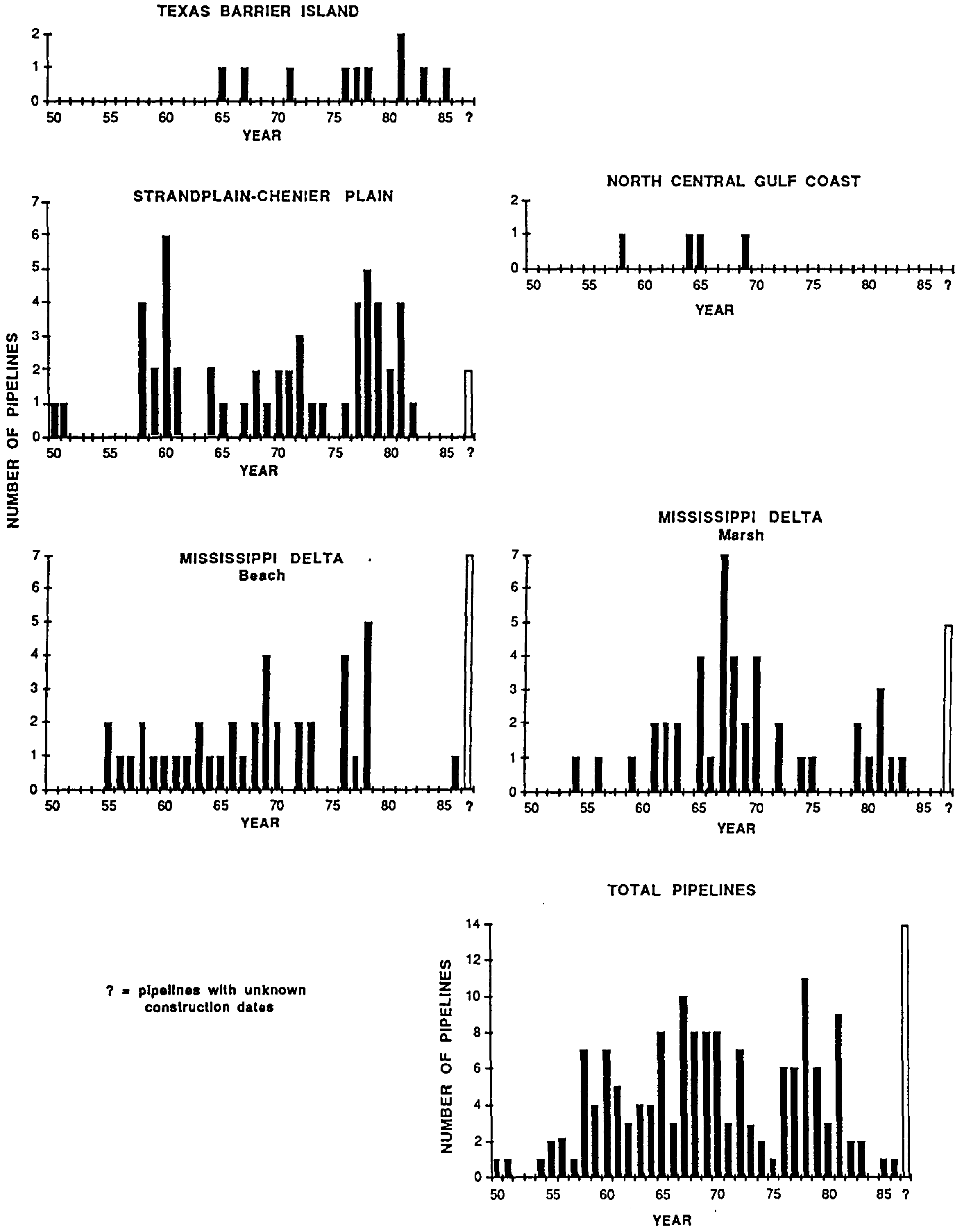

Figure 2.3. Distribution of pipelines by year of construction within the four coastal systems and by year within the entire study area.

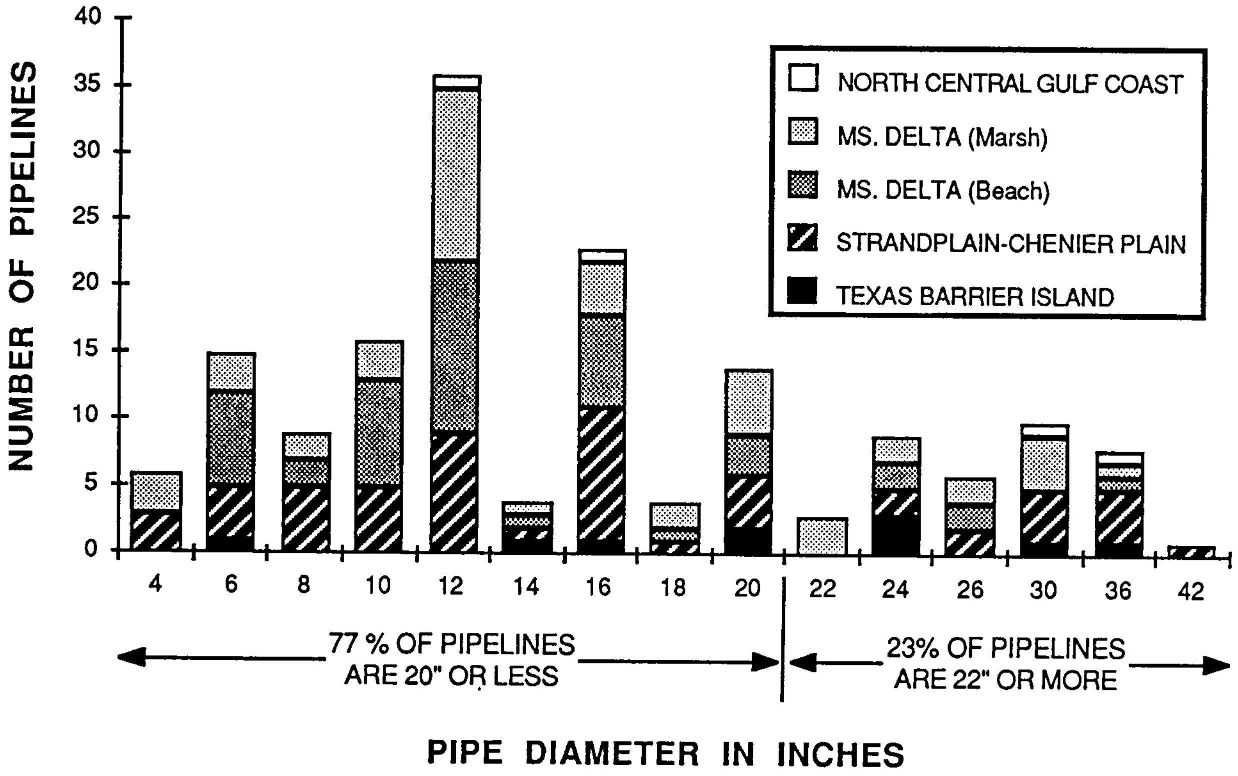

Figure 2.4. **Distribution of pipelines by pipe diameter.**

Table 2.2. OCS-related Facilities in Coastal Zone from South Texas to Northwest Florida (as mapped by recent research projects).

	Facility	Texas	Louisiana	Mississippi	Alabama	Florida
(1)	Oil Storage	present all coastal counties(c)	1(a) on barrier islands	1(a)	11(a); 15(b)	N.M.
(2)	Gas Processing and Treating Plant	74(f); 82(c)	83(f)	1(f)	2(f)	1(f)
(3)	Oil Refinery	31(f); 18 sites and 5 areas(c)	21(f)	1(f), 2(a)	3(f)	N.M.
(4)	Compressor, Pumping, Metering Stations	177(c)	2(a) on barrier islands	N.M.	N.M.	
(5)	Terminal	47(c)	N.M.	N.M.	N.M.	N.M.
(6)	Oil and Gas-Related Shipyard	5(f)	2(f); 100 in 25 coastal cities(a)	13(b)	1(f), 6(a) 11(b)	N.M.
(7)	Pipe Coating and/or Storage Yard	2(f)	9(f)	1(b)	N.M.	N.M.
(8)	Platform Fabrication Sites	2(f); 6(c)	5(f)	3(b), 1(f)	N.M.	N.M.
(9)	Service Supply Base/Dock Facilities	13(f, c)	24(f); 2(a)	4(b), 1(f)	3(f)	1(g)
(10)	Helicopter Services	80(c)	6 firms(a)	N.M.	N.M.	N.M.

N.M.: None mapped.
Source: (a) Larson et al. 1980; (b) Garofalo and Burk and Associates 1982; (c) Kimber et al. 1984; (d) Smith 1984; (e) Palik and Kunneke 1984; (f) MMS 1987; (g) Lynch and Risotto 1985.

While the pipeline landfall sites are fairly evenly distributed within each of the four coastal systems, some clustering occurs in all but the Texas Barrier Island System (Maps 1A-10A, Vol. II). Clusters consist of pipelines sharing the same canal or right-of-way or making landfall in close proximity to each other. Within the Strandplain-Chenier Plain, four landfall clusters exist and account for 66% of the pipeline landfalls in this region: (1) vicinity of Sabine River (7 lines), (2) near Johnsons Bayou (7 lines), (3) south of Grand Chenier (20 lines), and (4) west of Freshwater Bayou (9 lines). At each of these sites, various companies have constructed treatment or processing facilities along the major highways to handle the OCS products.

Of the 46 pipelines making landfall along barrier island/beach systems in the Mississippi Delta, 68% cross the beach in clusters: (1) East Timbalier Island (12 lines), (2) vicinity of Port Fourchon (9 lines), (3) eastern end of Grand Isle (7 lines), and (4) north of Bay Chaland (4 lines). At the first three sites, facilities such as tank batteries or compressor-pumping-metering stations, exist to semi-process or temporarily store OCS products.

In the North Central Gulf Coast System, half (2 lines) of the OCS "product" lines go to the Chevron Refinery at Pascagoula, while the remainder (2 lines) go through Mississippi to a refinery in Portland, Tennessee.

Several companies have two or more pipelines located in the same flotation canal. In the Strandplain-Chenier Plain, Transco and Columbia Gulf have two lines per canal (L34, L35, and L36, L37, respectively), while Trunkline has three lines (L39, L40, L41). In the Mississippi Deltaic System, Transco has four lines in one canal (L58, L59, L60, L61), while Gulf Refinery and Tennessee Gas each have the two lines per their canal (L87, L88 and L101, L102, respectively) (see Maps 1A-10A, Vol. II for location of these lines).

OCS-related Facilities

It appears that most major facilities are originally located on higher, more stable ground, such as the Pleistocene Terrace or natural levees, and near transportation corridors such as roads or navigable waterways (Maps 1B-10B, Vol. II). Expansion of some facilities may have displaced wetlands, but this has become more difficult since the early 1970's because of regulations governing dredge and fill operations in wetlands. The only way to obtain an accurate estimate of the area of wetlands displaced by OCS facilities would be to identify all such facilities and historically map their expansion into wetlands. Such data information is not available in the literature.

This study was also intended to evaluate the impact of OCS-related facilities on all barrier islands and beaches, and marshes, except those wetlands lying between East Bay, Texas, and Waveland, Mississippi. Identification of the impact of OCS-related facilities was difficult because of the lack of a comprehensive and up-to-date data base on facility type, size, location, and use by OCS-related industries. For example, the data have never been completely compiled for east Texas and the Chenier Plain region of Louisiana, though such a project is presently underway (Davis ongoing). Even companies contacted for maps showing the areal extent of major facilities were often unable to provide such maps for a variety of reasons.

However, a review of existing data (Larson et al. 1980, Garofalo and Burk and Associates 1982, Kimber et al. 1984, Smith 1984, Palik and Kunneke 1984, MMS 1987) identifies the following types of facilities located in the coastal zone of the northern Gulf of Mexico as OCS-related: (1) oil storage; (2) gas processing and treating plants; (3) oil refineries; (4) compressor, pumping, metering stations; (5) terminals; (6) oil and gas-related shipyards; (7) pipe storage yards; (8) platform fabrication sites; (9) service base and dock facilities (for oil logistical support); and (10) helicopter service. For purposes of this study, those facilities that were mapped as being within marshlands or on barrier islands and beaches have been depicted on Maps 1A-10A, Vol. II. Additional facilities identified in the course of locating pipeline landfalls were also mapped. Table 2.2 is a compilation of available data depicting the type and amount of OCS-related facilities identified by coastal system from south Texas to northwest Florida.

In general, oil storage facilities can be found throughout the region and range from single tanks to tank batteries or farms consisting of numerous tanks. The major oil storage facilities are generally associated with the oil refineries. There are 31 oil refineries in Texas, 21 in Louisiana, 1 in Mississippi, 3 in Alabama, and 0 in Florida (MMS 1987). In Texas, all the refineries are located near major cities and 71% of the refineries are in three counties: Harris, Jefferson, and Nueces. Galveston County has three refineries, Cameron and Brazoria have two refineries each, and Hardin and Chambers Counties have one each.

In Louisiana, the oil refineries are scattered throughout 11 parishes, only 8 of which are coastal (Table 2.3). The refineries are generally confined to inland areas of the coastal parishes and located primarily on elevated, better drained natural levees and Pleistocene terrace. The three refineries in Alabama are located on upland areas near Mobile. Most of the Chevron USA refinery in Pascagoula, Mississippi lies on Pleistocene terrace, but there appears to have been some plant expansion into wetland areas south of the terrace.

There are over three times as many gas processing and treating plants as there are oil refineries in this area (Table 2.4). Texas coastal parishes have at least 74 plants, while Louisiana has at least 83 (MMS 1987). In Texas, 53% of these plants are located in five coastal parishes (Chambers, Galveston, Jefferson, Nueces, San Patricio), while all the plants are located near cities or communities on upland sites. Overall, the expansion of these sites into coastal marshes has probably been minimal and could only be verified by a case study of each plant's expansion since original construction. Only three plants are located on a barrier island (e.g., Galveston).

Approximately 45% of the gas processing plants in Louisiana are located in ten coastal parishes where construction or expansion of the plant may have impacted some marshland. The extent of such impact, if any, could only be determined by case histories of each plant. However, the major portion of these plants, if not all, were constructed originally on natural levees, chenier ridges, or Pleistocene terrace.

There appear to be no marshes in the vicinity of the gas processing plants in Alabama, Florida, and Mississippi. Therefore, construction or expansion of these plants probably had no impact on marshes.

Compressor, pumping, and metering stations are quite numerous but require relatively little area, for example, less than 0.10 ha to about 1.22 ha. These stations are located at the head of a pipeline system or at the juncture of a system handling different grades of crude oil (Bell 1963). Tanks are often located at the station to receive and hold some grades while the pump transports other grades. Compressor stations are needed to force lower pressure products into higher pressure lines.

Previous studies only mapped these facilities for Texas and Louisiana (177 for all of coastal Texas and 2 for Louisiana barrier islands) (Table 2.2; Maps 1A-10A, Vol. II) Terminals were only mapped for Texas (47) (Table 2.2).

Table 2.3. Distribution of Oil Refineries in Coastal Region by Owner and State (after MMS 1987 and Lynch and Risotto 1985).

Alabama	County/Parish	City
Louisiana Land and Exploration Co.	Mobile	Saraland-Mobile
Marion Corporation	Mobile	Theodore
Mobile Bay Refining Co.	Mobile	Mobile [Chickasaw]
Louisiana		
Calcasieu Refining Co.[1]	Calcasieu	Lake Charles
Canal Refining	Acadia	Church Point
Celeron	Acadia	Mermentau
CITGO	Calcasieu	West Lake/Lake Charles
Clark Oil and Refining Co.	St. John the Baptist	Mt. Airy
Conoco, Inc.	Acadia	Egan
CPI Oil and Refining, Inc.	Calcasieu	Lake Charles
Exxon Corporation	E. Baton Rouge	Baton Rouge
Good Hope Refineries, Inc.	St. Charles	Good Hope
Gulf Oil Products Co.	Plaquemines	Belle Chasse
International Processors	St. Charles	St. Rose
Kerr-McGee	Terrebonne	Dulac
Lake Charles Refining Company	Calcasieu	Lake Charles
LaSet, Inc.	St. James	St. James
Mallard Resources	Vermilion	Gueydon
Marathon Oil Company	St. John the Baptist	Garyville
Murphy Oil Corporation	St. Bernard	Meraux
Placid Oil Company	W. Baton Rouge	Port Allen
Shell Oil Company	St. Charles	Norco
Tenneco Oil Company	St. Bernard	Chalmette
Texaco, Inc.	St. James	Convent
Mississippi		
Chevron U.S.A., Inc.	Jackson	Pascagoula
Texas		
American Petrofina Co. of Tx.	Jefferson	Port Arthur
Amoco Production Co.	Galveston	Texas City
Atlantic Richfield	Harris	Houston
Champlin Petroleum Co.	Nueces	Corpus Christi
Charter International Oil	Harris	Houston
Coastal States Petroleum Co.	Nueces	Corpus Christi
Crown Central Petroleum Corp.	Harris	Pasadena
Dow Chemical USA	Brazoria	Freeport
Eddy Refining	Harris	Houston
Exxon	Harris	Baytown
Gulf Oil Products	Jefferson	Port Arthur
Independent Refining Co.	Jefferson	Port Neches
Isthmus	Cameron	Brownsville
Koch Refining Co.	Nueces	Corpus Christi
Marathon Petroleum	Galveston	Texas City
Mid-Gulf Energy	Nueces	Ingleside
Mobil Oil Corp.	Jefferson	Beaumont
Petraco Valley Oil & Refinery Co.	Cameron	Brownsville
Phillips Petroleum Co.	Brazoria	Sweeny
Placid Oil Company	Chambers	Mt. Belview
Quintana Refinery Co.*	Nueces	Corpus Christi
Saber Refining Co.	Nueces	Corpus Christi
Shell Oil Co.	Harris	Deer Park (Houston)
South Hampton Refining Co.	Hardin	Silsbee
Southwestern Refinery	Nueces	Corpus Christi
Texaco Inc.	Jefferson	Port Arthur, Port Neches
Texas City Refining	Galveston	Texas City
Texas Independent Corp.	Nueces	Ingleside
Tipperary Refining Co.*	Nueces	Ingleside
Union Oil Co. of California	Jefferson	Nederland

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[1] data from Lynch and Risotto (1985)

* closed in 1985 (Lynch and Risotto 1985).

Table 2.4. Distribution of Gas Processing Plants in Coastal Region by Owner and State (after: MMS 1987).

Alabama	**County/Parish**	**City**
Getty Oil Co.	Mobile	Satsuma
Union Oil Co. of California	Mobile	Chunchilla
Mobile Oil Corp.	Mobile	Delchamps (Mary Ann Plant)
Florida		
Exxon	Escambia Co.	Canoe
Louisiana		
Amoco Production Co.	Calcasieu	Lake Charles
	Cameron	Grand Chenier
	E. Baton Rouge	Baker
	Lafourche	Raceland
	Livingston	Denham Springs
	Vermilion	Kaplan
Atlantic Richfield	St. Mary	Franklin
Celeron	E. Baton Rouge	Baker
	Iberville	Plaquemines
	St. Mary	Baldwin
	Terrebonne	Gibson
Chevron U.S.A., Inc.	Cameron	Johnsons Bayou
Cities Service Co.	Acadia	Crowley
	St. James	St. James
Conoco, Inc.	Acadia	Egan
	Calcasieu	Lake Charles
	Cameron	Grand Chenier
Danson Oil Co.	Cameron	Creole
Exxon Corp.	Acadia	Morse
	Jefferson	Grand Isle
	Lafourche	Thibodaux
	St. Landry	Opelousas
	St. Mary	Centerville
Getty Oil Co.	Cameron	Cameron
Gulf Energy Processing Group	St. Martin	La Rose
Kerr-McGee	St. Martin	St. Martinville
Koch Industries, Inc.	Calcasieu	Manchester
	Iberia	Bayou Postillion
Liquid Products Recovery	Assumption	Napoleonville
	Assumption	Napoleonville
Louisiana Land and Exploration Co.	Terrebonne	Houma
Marathon Oil Co.	Calcasieu	Toomey

Table 2.4 continued.

Mobil Oil Corp.	Calcasieu	Iowa
	Cameron	Cameron
	Cameron	Creole
	Lafourche	Golden Meadow
	Vermilion	Kaplan
	Vermilion	Abbeville
Mullis and Pritchard	E. Baton Rouge	Burtville
Phillips Petroleum Co.	Lafourche	Valentine
	Vermillion	Erath
Placid Oil Company	St. Mary	Patterson
	St. Mary	Patterson
	Terrebonne	Chauvin
Resources Extraction and Processing	St. Mary	Bayou Vista
Shell Oil Co.	Ascension	Geismar
	Calcasieu	Bell City
	Cameron	Johnson's Bayou
	Cameron	Hackberry
	Cameron	Johnson's Bayou
	Iberia	Weeks
	Iberville	Bayou Goula
	St. Bernard	Toca, Yscloskey
	St. Charles	Hahnville
	St. Mary	Patterson
	Terrebonne	Gibson
	Terrebonne	Chauvin
Southern Natural Gas	St. Bernard	Chalmette
Sun Exploration and Production Co.	Pointe Coupee	Lottie
Sun Gas Co.	Calcasieu	Moss Bluff
	St. Mary	Belle Isle
	Vermilion	Maurice
Superior Oil Co.	Cameron	Lowery
	Terrebonne	Dulac
	Vermilion	Kaplan
Tenneco Oil Exploration and Production	Calcasieu	Vinton
Texaco Inc.	Iberia	New Iberia
	St. Charles	Paradis
	St. Mary	Berwick
	Plaquemines	Venice
	Plaquemines	Buras
	Terrebonne	Houma
	Terrebonne	Cocodrie
	Vermilion	Erath
	Vermilion	Erath
Texaco Producing Inc.	Plaquemines	Venice
	Plaquemines	Buras
	Terrebonne	Houma
Texas Exploration Corp.	St. Landry	Eunice
Union Oil Company of California	Terrebonne	Houma
Union Texas Petroleum Corp.	St. Bernard	Toca

Table 2.4 continued.

Warren Petroleum Co.	Acadia	Mermentau
	Cameron	Johnson's Bayou
	Plaquemines	?
	St. Landry	Krotz Springs
Mississippi		
Damson Oil Corp.	Hancock	Kiln
Texas		
Alcoa	Calhoun	Port Comfort
Amoco Gas Company	Galveston	Texas City
Amoco Production Company	Brazoria	Sweeney
	Brazoria	Alvin
	Galveston	Friendswood
	Galveston	Galveston
	Nueces	Bishop
	Refugio	Refugio
	Willacy	Ramondville
Atlantic Richfield Co.	Hardin	Silsbee
	Liberty	Hull
	Refugio	Refugio
	San Patricio	Taft
Champlin Petroleum Company	Nueces	Bishop
Cities Service Company	Calhoun	Port Lavaca
	Kleberg	Riviera
	Nueces	Robstown
	San Patricio	Corpus Bay
Conoco Inc.	Jefferson	Port Arthur
Exxon Corporation	Calhoun	Port Lavaca
	Chambers	Anahuac
	Harris	Tomball
	Harris	Baytown
	Kenedy	Sarita
	Kleberg	Kingsville
	Refugio	Refugio
	Victoria	Bloomington
HNG Petrochemicals	Brazoria	Liverpool
	Nueces	Driscoll
	San Patricio	Gregory
	Victoria	Victoria
Houston Oil and Minerals Corp.	Chambers	Smith's Point
	Galveston	Texas City
	Liberty	South Liberty
Hunt Industries	Refugio	Refugio
LaVaca Gathering Company	Nueces	Corpus Christi
Liquid Energy Corp.	Aransas	Rockport
	Chambers	Winnie
	Galveston	Galveston
	Galveston	Galveston
	Jefferson	Nederland
	Jefferson	Nederland
	Nueces	Corpus Christi
	Willacy	Raymondville

Table 2.4 concluded.

Marathon Oil Company	Matagorda	Markham
	San Patricio	Sinton
Mitchell Energy & Development Corp.	Aransas	Rockport
	Chambers	Winnie
	Galveston	Galveston
	Galveston	Galveston
	Jefferson	Port Arthur
	Jefferson	Port Arthur
	Nueces	Corpus Christi
Phillips Petroleum Co.	Brazoria	Alvin
Superior Oil Co.	Jefferson	Sabine Pass
	San Patricio	Sinton
Sun Gas Company	Nueces	Petronilla
	San Patricio	Ingleside
	Victoria	Nursery
Tenneco Oil Company	Aransas	Fulton
	Matagorda	Palacios
Tenneco Oil Exploration & Production	Chambers	Smith's Point
	Galveston	Texas City
	Liberty	South Liberty
Texaco Inc.	Harris	Humble
	Matagorda	Blessing
	San Patricio	Odem
Texaco Producing, Inc.	Colorado	Eagle Lake
Texas Oil and Gas Corp.	Kleberg	Riviera
United Texas Transmission Co.	Chambers	Mont Belvieu
Valero Hydrocarbons Co.	Nueces	Corpus Christi
Warren Petroleum Co.	Jefferson	Fannett
	Orange	N. Port Neches
	San Patricio	Sinton

Shipyards

Previous researchers have used varying criteria to identify petroleum-related shipyards but the majority of yards have been identified and mapped (Table 2.5). The only shipyards mapped for Texas were major shipyards having the capacity to build ships 144 m in length or longer (MMS 1987, Kimber et al. 1984). In contrast, over 100 shipyards have been identified in 25 coastal cities in Louisiana capable of serving the petroleum industry and 62 have been mapped (Larson et al. 1980). There is one major shipyard in Pascagoula, Mississippi and 11 smaller ones, most concentrated near Biloxi and Pascagoula. Alabama has one major shipyard and five smaller yards at Mobile and 11 shipyards along Bayou La Batre. The Bayou La Batre area has been identified as "one of the more important shipyard areas in the country, and probably the largest on the entire Gulf Coast" (Smith 1984:111). This area occasionally services petroleum industry-related vessels. No oil and gas related shipyards were identified for northwest Florida (Palik and Kunneke 1985).

No study has documented the origin or expansion of these shipyards in response to increased activity in the oil and gas industry from the late 1940s to the present. Furthermore, case studies of the expansion of these facilities and mapping of associated dredge and fill activities would be needed to adequately document the impact of such facilities on marshes within the study area. However, it would appear that most of these facilities would have existed to serve other types of maritime activities (for example, fisheries, and military or recreational), although perhaps not on as large a scale of operation.

Pipe-Coating and Storage Yards

Pipe-coating and storage yards have been identified in Texas, Louisiana, and Mississippi (Table 2.6) (Maps 1A-10A, Vol. II). Such yards may cover over 40.5 ha (Davis 1984) and serve as major distribution centers for pipe-laying operations throughout the Gulf Coast region. At such facilities, steel pipe is coated to a company's specifications to protect it from corrosion when laid in the Gulf of Mexico or buried in coastal wetlands. These yards must be located on navigable waterways to facilitate transportation of pipe by barge from the yard to the site of pipe-laying operations.

Platform Fabrication Sites

The majority of platform fabrication sites occur in coastal Louisiana along waterways sufficiently deep to float the platforms to offshore locations (Table 2.7) (Maps 1A-10A, Vol. II). The fabrication sites are themselves constructed primarily on higher land along natural levees.

Supply-Service Bases/Dock Facilities

The logistical supply-service bases are associated with many of the dock facilities in coastal areas, with the largest number being in Louisiana (Table 2.8) (Maps 1A-10A, Vol. II). Intracoastal City, Port Fourchon, and, to some extent, Venice were developed specifically to service the offshore industry, while other ports expanded as offshore demands grew during the 1960s and 1970s. A large number of ports also exist in Texas to supply and service offshore activities, but these ports pre-dated OCS activities and served other marine interests as well as OCS activities.

Table 2.5. **Distribution of Petroleum-related Shipyards by City and State (Larson et al. 1980, Garofalo and Burk and Associates 1982, Kimber et al. 1984, Smith 1984, Palik and Kunneke 1984, MMS 1987).**

Alabama
*Mobile (6)
Bayou La Batre (11)

Florida
None in study area.

Louisiana
Bourg (2)
Caernarvon (1)
Calumet (1)
Carlyss (1)
*Chalmette (1)
Golden Meadow (1)
Harahan (2)
Harvey (3)
Houma (11)
Iberia (1)
Jennings (1)
Krotz Springs (2)
Lafayette (1)
Lafitte (1)
Larose (5)
Lockport (2)
Loreauville (1)
Madisonville (1)
Morgan City (8)
New Iberia (2)
*New Orleans (8)
Patterson (1)
Slidell (2)
St. Bernard (1)
Sulphur (1)
Venice (1)

Mississippi
Biloxi (1)
Escatawpa (1)
Greenville (1)
Greenwood Island (1)
Moss Point (3)
Ocean Springs (1)
*Pascagoula (1)
Pearlington (1)
Spanish Point (1)
Vicksburg (1)

Texas (major shipyards only)
*Beaumont
*Brownsville
*Galveston
*Orange
Port Arthur

---

* Major shipyards: building capacity 144.8 m or longer (MMS 1987).
(#) Number of shipyards at site.

Table 2.6. **Major Pipe-coating and Storage Yards by City and State (Larson et al. 1980, Garafalo and Burk and Associates 1982, Kimber et al. 1984, Smith 1984, Palik and Kunneke 1984, MMS 1987, Davis 1984).**

Alabama
None identified

Florida
None identified

Louisiana
Belle Chasse
Harvey
Houma
Intracoastal City
Lafayette
Morgan City
New Iberia
New Orleans
Venice

Mississippi
North of Industrial Seaway (along Fritz Creek)

Texas
Corpus Christi
Houston

Table 2.7. Platform Fabrication Sites (Larson et al. 1980, Garofalo and Burk and Associates 1982, Kimber et al. 1983, Smith 1984, Palik and Kunneke 1984, MMS 1987, Davis 1986, Judice 1988, Lynch and Risotto 1985).

Alabama

None identified

Florida

None identified

Louisiana

- Baldwin
    - Superior Fabricators
- Franklin
    - Twin Brothers
- Harvey
    - Avondale Shipyards, Inc.
    - J.R. McDermott, Inc.
    - Brown and Root
    - Williams-McWilliams Co., Inc.
- Houma
    - Delta Fabricators
    - Raymond Offshore Fabricators
- Lafayette
    - Teledyne Movible Offshore, Inc.
- Marerro
    - Watts Fabricators
- Morgan City
    - Apex Offshore
    - Brown and Root
    - Avondale Shipyards, Inc.
    - J.R. McDermott (Bayou Boeuf, Bayou Black)
    - Teledyne Movible Offshore
    - Service Machine Group
- New Iberia
    - Houston Systems Manufacturing
    - Universal Fabricators
- New Orleans
    - Marine Concrete Barge
    - Avondale Shipyards, Inc.
    - Williams-McWilliams Co., Inc.

Mississippi

- Gulfport
    - McDermott, Inc.
- Pascagoula
    - Ingalls Shipbuilding
    - Chicago Bridge and Iron
- Vicksburg
    - Marathon-Le Tourneau

Texas

- Beaumont
    - Bethlehem Steel
- Brownsville
    - Marathon-Le Tourneau
- Channelview
    - Vernar
- Corpus Christi
    - Brown and Root
    - Chicago Bridge and Iron
- Houston
    - Brown and Root
    - Houston Systems Manufacturing
- Ingleside
    - Brown and Root
    - Chicago Bridge and Iron
    - E.T.P.M.
    - Gulf Marine Fabricators, Inc.
    - Baker Marine
- Orange
    - American Bridge (U.S. Steel)
    - Levingston Shipbuilding
- Port Aransas
    - Brown and Root
- Port Arthur
    - Levingston Shipbuilding

Table 2.8. **Supply-Service Bases and Dock Facilities by City and State (Larson et al. 1980, Garofalo and Burk and Associates 1982, Kimber et al. 1984, Smith 1984, Palik and Kunneke 1984, MMS 1987, Lynch and Risotto 1985).**

Alabama
Bayou La Batre**
Theodore**
Mobile**

Florida
Panama City*

Louisiana
Abbeville*
Amelia**
Baton Rouge
Belle Chasse*
Berwick**
Cameron**
Cocodrie*
Creole*
Des Allemands*
Donaldsonville*
Dulac**
Fourchon**
Grand Chenier**
Grand Isle**
Golden Meadow*
Harvey*
Houma**
Intracoastal City**
Ivanhoe**
Lafayette**
Leeville**
Morgan City**
New Iberia*
New Orleans
Patterson*
Port Allen
Venice

Mississippi
Gulfport
Pascagoula**
Port Bienville

Texas
Aransas Pass**
Baytown
Beaumont
Brownsville
Corpus Christi*
Freeport**
Galveston**
Houston
Ingleside
Orange*
Pelican Island**
Port Aransas*
Port Arthur
Port Isabel*
Port Lavaca
Port Mansfield*
Port Neches
Port O'Conner**
Rockport**
Sabine Pass**
Sugarland*
Surfside
Texas City

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* Supply
** Supply and Service

Helicopter Services

No helicopter companies have been identified as presently serving the OCS petroleum industry in Mississippi, Alabama, or Florida (Table 2.2) (Maps 1A-10A, Vol. II). In recent years, Louisiana has had over 700 helicopters, representing four firms, operating out of 66 heliports and available to serve OCS area needs (Davis 1986). Within the coastal counties of Texas, there are over 80 heliports and 6 firms available to OCS activities (Davis 1984, Kimber et al. 1984).

The helicopters are used primarily to evacuate persons in emergency situations, such as accidents, injuries, or approaching hurricanes, and to ferry oil company personnel to offshore rigs when travel time must be shortened or seas are too rough for boat transport. In the late 1970's, when the offshore rig count was at its peak, there were 20,000 to 30,000 men working offshore at any one time (Davis 1984), thereby requiring a large number of helicopters to provide quick travel time. In 1981, over 90% of the 21,000 offshore wells in the Gulf of Mexico were off the Louisiana coast (Davis 1984), thus accounting for the large number of helicopters based in Louisiana. Heliports are often associated with airports, though some may operate out of company facilities covering only one or a few acres. Such locations are usually on higher, better-drained ground such as natural levees or terraces.

Pipeline Construction Techniques

The type of pipeline emplacement technique utilized and the extent to which the site is restored to preconstruction conditions can influence the ultimate impact a pipeline has on the coastal environment. It is useful to envision the pipeline and associated features as a coastal form and the emplacement technique as a coastal process. Under certain conditions, the emplacement process and resultant form can interact with existing environmental conditions and exacerbate environmental problems, such as accelerated erosion and land loss. However, environmental forces may, at some locations, overshadow the pipeline emplacement process and obscure the resultant form, regardless of the type of construction techniques used or the form left on the landscape. Knowing the correlation between the environmental setting and pipeline emplacement techniques—especially the extent to which the site can be, or the level to which it should be—restored to preconstruction conditions, provides a mechanism for mitigating both immediate, direct, and long-term, indirect impacts.

A review of pipeline construction techniques utilized on Gulf Coast beaches, barrier islands, and wetlands identifies some evolutionary changes that have minimized impacts, but reveals that there are only a few basic emplacement techniques. The four generic types of pipeline emplacement techniques are: 1) upland trenching, 2) flotation canal, 3) push-pull ditch, and 4) directional drilling. Various aspects of these construction techniques have been described in numerous reports (Longley et al. 1981, Bell 1963, Conner et al. 1976, Vincent-Genod 1984, Petroleum Extension Service and Pipe Line Contractors Assoc. 1966, and Mousselli 1986). Parameters that characterize these different techniques have been summarized in Table 2.9. Table 2.10 compares the various closure techniques associated with each of the major emplacement techniques.

Upland Trenching

The first technique, upland trenching, is the oldest because the first petroleum pipelines were laid on dry land sites. The earliest pipelines ran from producing areas to refineries and user centers and were usually placed on top of the ground except at railroad crossings (Hall 1959). In 1862, the first pipelines were laid to transport crude oil from western

Table 2.9. Physical Parameters Characterizing the Four Major Pipeline Emplacement Techniques.

	VARIATION IN EMPLACEMENT CHARACTERISTICS BY EMPLACEMENT TECHNIQUES			
EMPLACEMENT FEATURE	Upland Trenching	Flotation Canal	Push-Pull Ditch	Directional Drilling
Associated Environment	Stable, well-drained soils.	Unstable soils, shallow water bodies.	Moderately firm but wet soils.	Barrier islands and beaches; development.
Construction ROW	30.5 to 38.1 m	45.7 to 91.4 m	30.5 to 61.0 m	
Maintenance ROW	9.1 to 30.5 m	30.5 to 61.0 m	15.2 to 30.5 m	15.2 to 30.5 m
Canal Depth (base)	1.2 to 2.4 m	1.8 to 3.0 m	1.2 to 2.4 m	N.A.
Canal Width (base)**	0.9 to 2.4 m	12.8 to 15.2 m	2.4 to 3.0 m	N.A.
Lay Barge Size: (onshore to -3.7 m) 30.5 x 9.1 x 2.0 m 41.4 x 10.9 x 2.4 m 48.8 x 12.2 x 1.7 m	N.A.	lays pipe in canal	pushes pipe along canal from push-point	N.A.
Lay Barge Size: (offshore -5.5 m out): 41.4 x 12.2 x 2.6 m 76.2 x 15.2 x 3.5 m 106.6 x 18.2 x 7.0 m	N.A.	N.A.	N.A.	Connects with drill pipe feeds pipe ashore.
Pipe Barge Size: 30.5 x 9.1 x 1.8 m 41.4 x 10.9 x 2.4 m	N.A.	Brings pipe along canal to lay barge	Delivers pipe to push point	N.A.
Installation Segment Length	Indefinite	Indefinite	Approx. 24 km/ 30-in line	Approx. 914.4 m
Construction Spoil Condition	One side of trench 0.9 to 1.5 m high; 3.0 to 6.1 m base.	One or both sides of trench; continuous or broken; 0.9 to 1.5 m high; 15.2 to 25.9 m base.	One or both sides of trench; continuous or broken; 0.3 to 0.9 m high; 6.1 to 15.2 m base.	N.A.
Post Construction Condition	Backfill	Leave in place or backfill	Leave in place or backfill	N.A.
Post Construction ROW	Cleared of tall vegetation.	Deep open water; or shallow open water.	Shallow open water; or marsh vegetation.	Cleared of tall vegetation.
Equipment utilized on pipeline	Cars/trucks; backhoe or ditcher; bulldozer.	Marsh buggies, small boats; tug boats, helicopters, barge-mounted dredge; lay barges; crew/supply boats; jet barge; pipe barge.	Marsh buggies, marsh buggy or track-mounted draglines with timber mats; lay barge; small boats; crew/supply boats.	Marsh buggies; cars/trucks; bulldozer; small boats.
Mitigation	Reestablish preconstruction contours; place top soil on top; plant/seed; implement erosion control measures for topsoil.	Isolate canal hydrologically from tidal flow; backfill canal to create shallow water, and aquatic beds; deposit spoil so as not to interfere with natural drainage; incorporate canal into wetland management plan.	Double ditch spoil and place top soil on top when backfilling; replant/reseed if necessary; bulkhead filled canal at waterway intersections.	Restore drilling site to preconstruction condition; reseed/plant, implement erosion control measures for topsoil.

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* Flotation canal has pipe ditch, 0.9 to 1.5 m wide and 0.9 to 1.8 m deep in bottom to receive pipe from lay barge.

** Canal slope is dredged at 1:2 or 1:3 thereby giving a canal surface width larger than bottom width. Slumping of sides in unstable soils can further enlarge surface canal width during and post construction.

Table 2.10. Possible Project Closures Associated with the Major Pipeline Emplacement Techniques. ("x" denotes when techniques used.)

	EMPLACEMENT TECHNIQUE			
PROJECT CLOSURE TECHNIQUES	Upland Trenching	Flotation Canal	Push-Pull Ditch	Directional Drilling[1]
Leave Canal Unfilled				
1. Continuous spoil both sides canal; no breaks.		x	x	
2. Continous spoil both sides canal; 15.2 m breaks every 152.4 m.		x	x	
3. Alternating spoil deposits.		x	x	
4. Continuous spoil one side of canal; no breaks.		x	x	
5. Continous spoil one side of canal; 15.2 m breaks every 152.4 m		x	x	
Backfill Canal				
1. Single ditch spoil deposits; backfill; no remaining spoil deposits.	x	x	x	
2. Double ditch spoil deposits; backfill; no remaining spoil deposits.	x	x	x	
3. Remove spoil deposits to canal; pump in fill material.		x		
4. Leave spoil deposits adjacent to canal; pump in fill material.		x		
Right-of-Way Restoration				
1. Backfill and allow to revegetate naturally	x	x	x	x
2. Do not backfill and allow to revegetate naturally		x	x	
3. Backfill; recontour; plant; fertilize; water for set period	x		x	x
Shoreline Erosion Retardation				
1. Dams/bulkheads at or near beach crossings		x	x	
2. Dams/bulkheads at all channel crossings		x	x	
3. Dams/bulkheads at regular intervals along open canal.		x	x	
4. Plug beach crossing with sand/shell		x	x	
5. Install erosion mats at beach crossing.		x	x	

---

[1] Directional drilling involves habitat disturbance at site of drilling but does not involve trenching or canal construction.

Pennsylvania to user centers in central and eastern Pennsylvania (Hall 1959). The need to protect these lines from hazards, such as farm machinery and vandalism, and the concern for public safety resulted in lines being buried by the late 1920s (Hall 1959; Mousselli 1986). This trenching technique is still used in coastal areas having dry, firm ground such as high dune fields on barrier islands and beaches and natural levees. Generally, in coastal areas, a backhoe will dig and refill the trench which ranges from 1.2 to 2.4 m deep and 0.9 to 1.5 m wide at the bottom except through high dunes where depth and width will be higher. A bulldozer recontours the surface once the line is in place and the excavated material is backfilled. Of the four emplacement techniques, this requires the least construction right-of-way (ROW) (30.4 to 38.1 m) and maintenance ROW (15.2 to 30.4 m). The width of ROW varies with the minimum size being determined by the physical needs for construction, maintenance, and repair.

Proper site restoration measures, such as recontouring with top soil on the surface, revegetation, and installation of erosion control measures, where necessary, minimizes the extent of impact of this emplacement technique. The primary permanent impact is that the ROW is kept clear of tall vegetation such as shrubs and trees, in order to allow biweekly surveillance of the pipeline route for leaks, damage, or encroachment.

Flotation Canal

The flotation canal consists of an excavated waterway sufficiently wide and deep to accommodate, at various times and in sequence, the dredge barge, the lay barge, and the pipe supply barge. While flotation canals can be dredged in any wetland environment, they are especially common in wetland and shallow water areas where the soils are too unconsolidated and unstable to support marsh-buggy-mounted draglines. Canal depths below mean low water are determined by the draft of the inland lay barge and loaded pipe barge, which commonly draw 1.2 to 2.4 m of water.

Standard plans, as attached to permit applications or presented in the literature, cite a typical flotation canal as being 12.2 m wide and 2.4 to 3.0 m deep. This width refers to minimum bottom width as dredged by a 11.0-m-wide barge. Commonly used 12.2-m barges would dredge a bottom width of about 12.7 m. These two barge sizes appear to be the most commonly employed in wetland and shallow water environments from the 1950s to the present (Table 2.9). Barges used in offshore pipe-laying operations have always been considerably larger than the onshore variety. In the 1950s offshore barges ranged from 41.1 m x 12.2 m x 2.6 m, to 76.2 m x 15.2 m x 3.5 m. Today these barges range from 106.6 m x 18.2 m x 7.2 m, to 128 m x 39 m x 8.5 m. Semi-submersible and ship-shape lay barges are 152.4 m and 182.8 m, respectively. These larger sizes are necessary to operate in higher seas; 1.2 m for smaller barges, up to 3.4 m for the larger barges (Gard 1963).

Spoil deposition within the construction ROW was determined primarily by the property owners, ROW agreement stipulations, or, in the absence of such special conditions, the dredging company engineers. Today, State and Federal regulatory agencies attach special conditions, usually on a case-by-case basis, to pipeline permits in order to minimize the environmental impact of the process.

Historically, spoil deposits were placed in continuous lines parallel to, but slightly back from, the canal banks and mounded to the level that the spoil could be maintained before flowing outward at the base. Some landowners, even on the earliest pipeline routes demanded alternating spoil banks, leaving breaks in spoil, or even backfilling trenches in areas such as one with an abundant muskrat population and trapping leases, where the natural hydrologic regime was to be maintained. More recently these practices, such as 19.2-m breaks in spoil at least every 152.4 m, have been adapted by regulatory agencies for many of the same environmentally based reasons. However, continuous spoil banks may be required, if they are part of a permitted management program involving water level control within an impounded and managed unit.

A major difference between pipeline canals and rig or navigation canals is that once constructed, continuous water access through the canal is not required and is even discouraged by the operators in order to lessen the chance of pipeline damage. Therefore, flotation canals are almost always dammed at the point of ingress and egress (e.g., bays and gulfshore) through wetlands and at intersecting waterways, both natural and man-made. Many long pipeline canals also have weirs or bulkheads spaced at regular intervals along their course, the design and location often being determined by the property owner's contract or governmental agency conditions. The dams reduce bank erosion by minimizing boat traffic or tidal exchange. Bulkheads are also placed at the juncture of the onshore (push-pull ditch) and offshore (floatation canal push point) to lessen the possibility of erosion. These bulkheads are usually placed 61.0 m to 152.4 m inland from the shore at the time of construction.

An OCS pipeline can be emplaced using the flotation technique from shallow, nearshore areas across barrier islands or barrier beaches and wetlands until upland areas are reached. In the deeper waters, where the offshore portion of the lay operation occurs, the only dredging done involves trenching or jetting in-place pipeline, which must be covered by at least 0.9 m of material from the shore to the 61.0 m water depth (43 CFR 2883). A standard scenario for this procedure involves the dredge barge excavating a flotation channel from the nearshore area through the beach and across interior bays or wetlands to a termination point or to where upland trenching operations begin (Figure 2.5). Immediately prior to pipe-laying operations, a second dredge barge begins traversing the flotation canal and excavating a ditch in the bottom of the canal sufficiently large and deep to accommodate the pipe and provide the required amount of cover. The lay barge then proceeds along this canal, in a stop-and-go manner, welding, inspecting, and laying pipe in the ditch. The barge remains stationary while the pipe joints are welded and inspected. A tug moves the lay barge forward the length of the welded pipe section, allowing the string to slide off the stern of the barge and into the prepared trench. Pipelines transporting gas must be weighed with concrete coating or secured with iron river weights when they pass through marshes, swamps, and open water, otherwise they will float. Preliminary coating also protects the lines from corrosion (Huffman and Whipple 1965). Once in the trench, the pipe will be jetted in place to achieve the required depth of water and/or bottom material cover. As the lay barge moves along the canal, it is accompanied by regular auxiliary boat traffic consisting of crew and supply boats and pipe supply barges.

If the beach crossing is the only route for materials, and there is a lot of littoral drift along the coast, the beach opening will be maintained open during the installation procedure. Once the line is in place, this beach cut can be allowed to fill naturally with littoral drift material. Airphoto analysis, field investigations, and literature reviews indicate that most, if not all, of the flotation canals were initially dammed or bulkheaded upon completion of the line lay. Generally, these bulkheads were set back 91.4 to 121.9 m from the shoreline (Herlevic 1988). In time, and in areas of shoreline erosion, the shoreline retreats landward of the bulkhead, leaving it exposed in the nearshore and requiring the pipeline operators to construct another set back bulkhead (Figure 2.5), as insurance that the canal won't cause breaching of the existing littoral drift plug or erosion along the canal if no sand/shell plug is present.

A cross section of a typical flotation canal illustrates the initial forms resulting from dredging, for example, spoil, berm, canal, and pipe ditch (Figure 2.6). As shown in

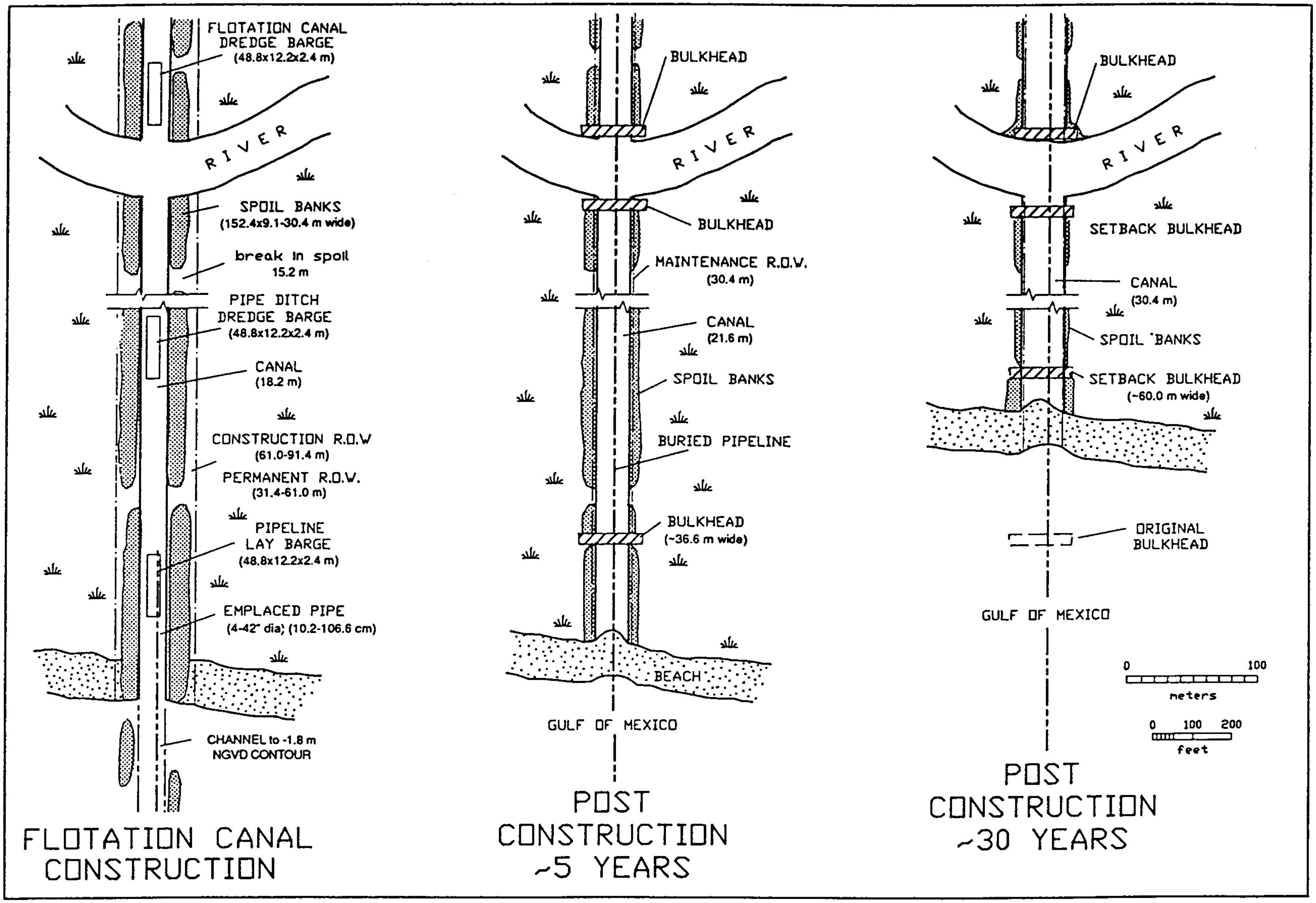
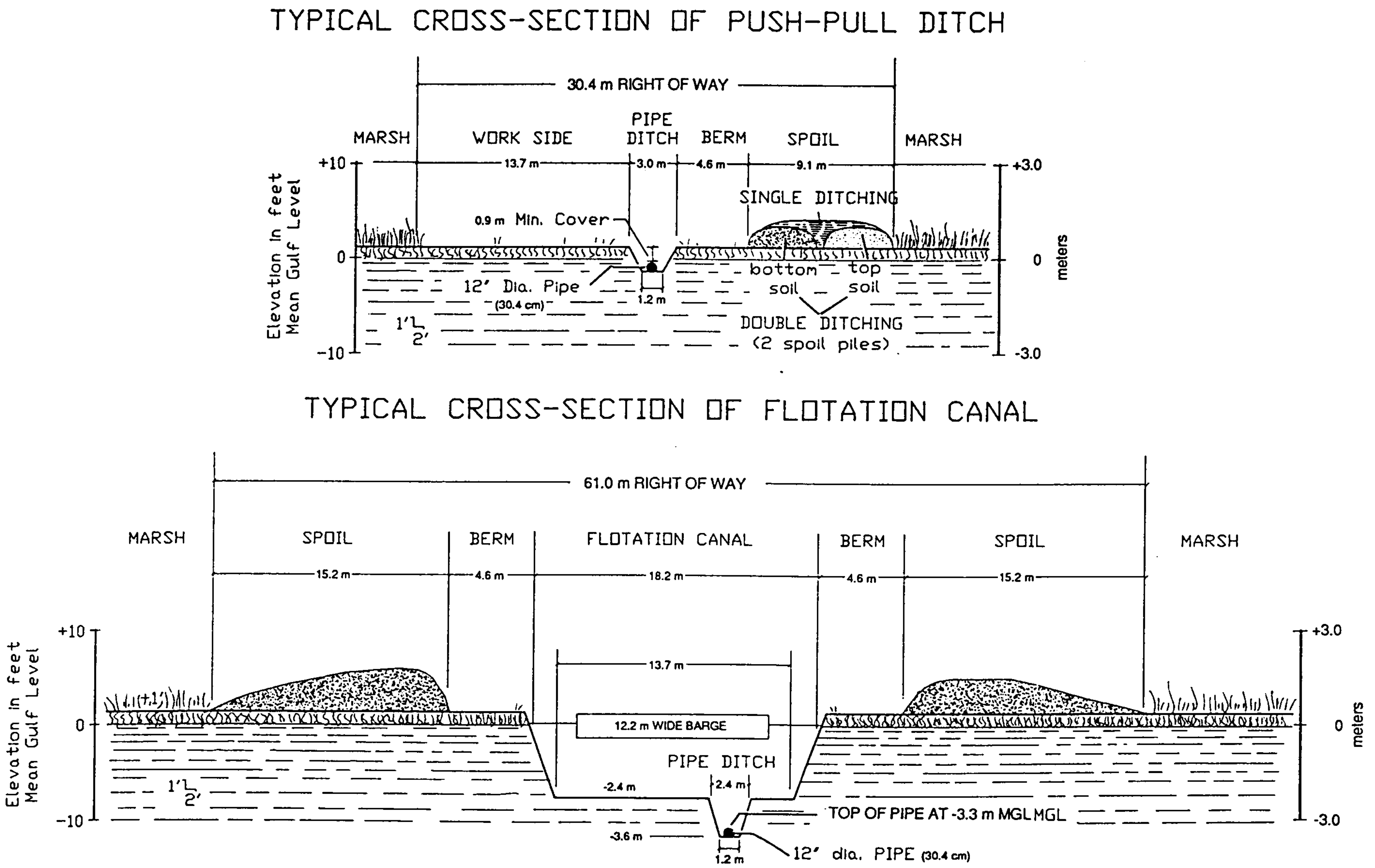


Figure 2.5. Comparison of change along a typical flotation canal over a 30-year period.


TYPICAL CROSS-SECTION OF PUSH-PULL DITCH

TYPICAL CROSS-SECTION OF FLOTATION CANAL

Figure 2.6. **Comparison of typical cross sections for a push-pull ditch and a flotation canal.**

Table 2.9, the size of each of these forms varies considerably, largely because of the variations in substrate stability and size of dredge barge. Unstable soils will flow farther, creating a lower, wider spoil area. Such soils will also slump or slough along the cut bank, causing a wider canal to be formed than depicted in design drawings. Wider, deeper draft barges will also dredge canals that are initially larger.

Push-Pull Ditch

The push-pull ditch emplacement method has the potential to result in fewer direct and indirect negative impacts on the environment than the flotation canal technique. A cross section of a typical push-pull ditch illustrates the need for a narrower construction ROW, narrower and shallower pipe ditch, and narrower spoil deposits (Figure 2.6). These ditches can be dredged in areas where soils are too wet and unstable for upland trenching techniques but sufficiently firm enough to support marsh-buggy-mounted draglines. Excavated spoil can be deposited on the side opposite the dragline work side or parallel and adjacent to both sides of the ditch if the marsh buggy is backing along the ROW. When the dragline is moving along only one side of the canal, wooden mats are sometimes placed along the ROW for the marsh buggy draglines to traverse in order to lessen impact of the marsh buggy tracts.

Historically, these ditches were probably backfilled only if landowners made this a stipulation of the ROW lease agreement. In recent years, regulatory agencies have begun to require that all ditches be backfilled and that the spoil be initially double-ditched to allow for replacement of top soil last. Double ditching is often achieved by having two ditching machines operating in tandem, with the front machine cutting and depositing the topsoil and back machine completing ditching and depositing material in separate piles (Muckley 1963). This procedure provides a seed bank that would, in theory, expedite the revegetation process along the ROW.

The accelerated rate at which pipelines can be laid using this technique, rather than the flotation method, allows for prompt backfilling of the trench and results in less soil compaction from spoil mounding, a more complete ditch filling and faster marsh recolonization of the ROW (Chabreck 1978). Two major problems associated with backfilling are: 1) grading the backfill site to a level contour to prevent ponding and 2) scraping the spoil into the ditch without gouging holes in the spoil deposit areas that then remain as shallow open water areas susceptible to erosion.

Emplacement of an OCS pipeline utilizing the push-pull method can involve establishment of a push-point at the beach with push-pull directed inland (Figure 2.7), or establishment of a push-point on an inland, navigable channel with push-pull directed gulfward across the wetland. Pipe can also be welded at the beach push-point and floated offshore with pontoons for positioning and burial between the shore and the offshore platform. In some instances, the onshore portion of the line will be laid and the ditch backfilled prior to the cutting of a push-point slip in the beach for positioning of the lay barge which will weld and deliver the pipe offshore.

The push point site resembles the typical flotation canal in both plan and cross-sectional view because it must accommodate the same type of equipment, that is, dredge barge, lay barge, and pipe supply barges. Some Gulf shore push-point sites may be double wide (24.2 to 3.4 m) to allow the pipe supply barge to navigate alongside the push barge for stockpiling of pipe onshore and/or transfer of pipe to the lay barge. The work area ROW at the shore can cover several acres of high ground and temporarily contain stockpiled pipe, supplies, and construction equipment.

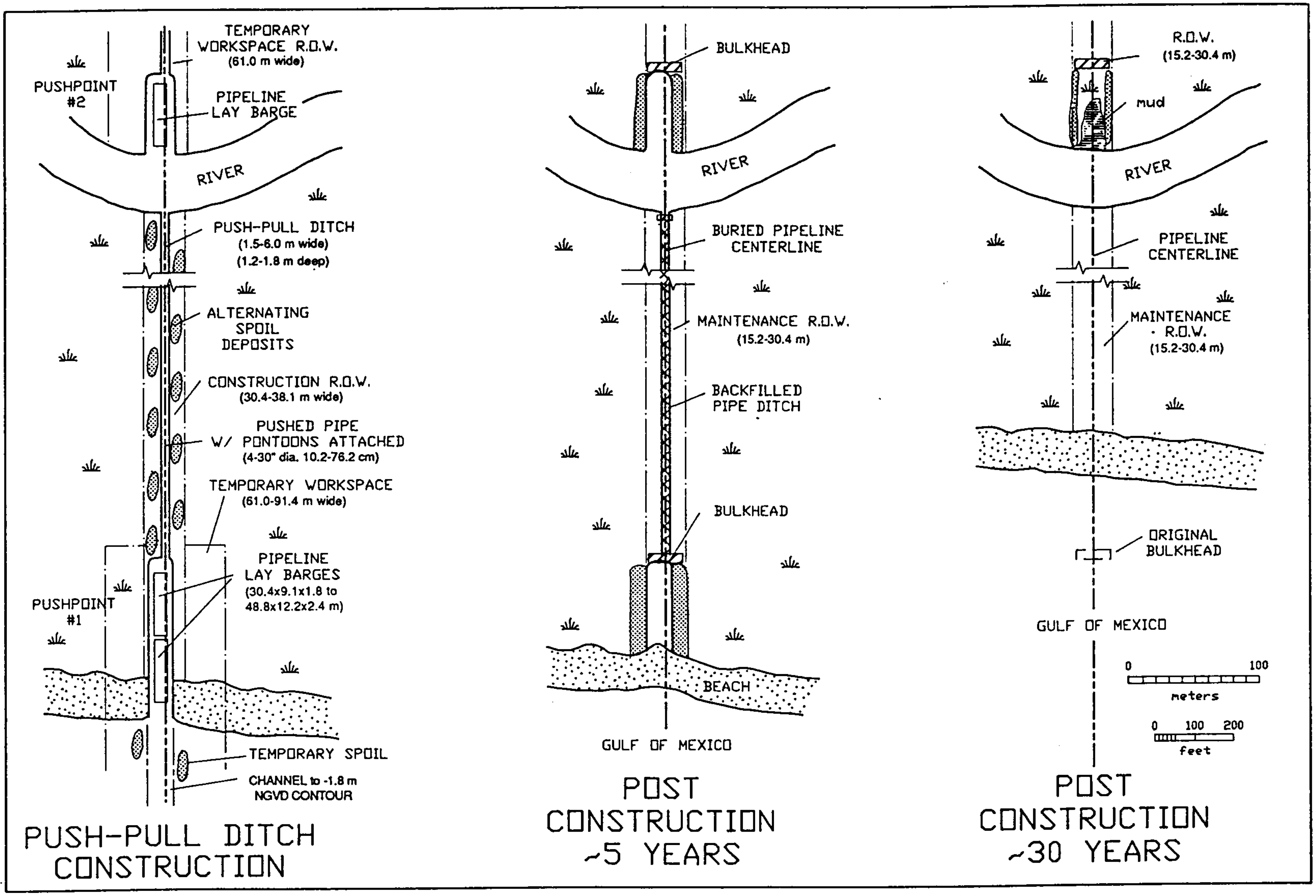


Figure 2.7. Comparison of change along a tyical push-pull ditch over a 30-year period.

Pipe up to a 30-in diameter can be pushed a maximum of 32.2 km (Smith 1981) in a straight direction. However, this technique is most commonly used for 16- to 24-in pipe up to 24.1 km long (Smith 1981). Once a segment of line is laid, the entire operation must be shifted to the next push point where a tie-in is made and construction resumes. Small boats or marsh buggies often follow the floating pipe in order to keep it moving within the channel.

Once the beach segment is in place and lay barges are removed, push-pull ditches are usually dammed at a point near the juncture of the push-point and push ditch (Figure 2.7). The ditch may or may not be backfilled. In time, and in areas of transgressive shorelines, shore processes erode the beach landward of the bulkhead, leaving it exposed in the nearshore zone. If the push ditch has been backfilled or filled naturally and revegetated, the erosion processes at the push ditch ROW will be virtually indistinguishable from those at adjacent shore sites and no erosion control measures, such as new bulkhead construction, will be needed. Where there is sufficient sand-shell supply, a sand-shell beach will veneer the pipeline ROW just as it does along adjacent areas of the beach.

Most pipelines, whether installed via the push-pull or flotation method, have about 3.0 m of cover at the beach-dune landfall site (Figure 2.8a). Where dunes are high or active, the pipe is placed below the base of the active dune. Cover back of the beach zone and in interior water bodies is at least 0.9 m and often 1.5 m. From the nearshore zone to the -61.0-m contour, the pipe must have 0.9 m of cover.

In areas of rapid shoreline retreat, pipelines can become exposed at least once during their projected life span, thereby becoming a hazard to coastal navigation, especially nearshore commercial fishing (Figures 2.8b and 2.9). Reburial of exposed lines results in additional, though usually temporary, disturbance of the wetlands and beach zone (Figure 2.8c). Commonly used methods for reburial include jet sled, side trenching, and hand jetting, or a combination of these (Herlevic 1988). Marsh-buggy-mounted draglines for side trenching usually are brought to shore by a barge moving along a route dredged by a barge-mounted dragline, a process similar to the original push-pull or flotation method of emplacement (Herlevic 1988). After the 2.4- to 3.6-m-wide trench is excavated far enough inland to ensure burial below the erosion line, the line is lowered and the trench is backfilled. If the soils are too unconsolidated to support a large enough dragline to excavate a deep trench, a flotation canal can be dredged through the marsh adjacent to the pipeline. The line is then lowered into place by hand jetting. Measurements to protect against erosion along the ROW can include bulkheading, beach fill with sand and shell, and placement of erosion-"resistant" materials at the juncture of the ROW and beach. Two recent articles detailing steps taken in lowering a line on a state refuge were provided by Herlevic (1988) (Figure 2.10).

Directional Drilling

The directional drilling technique is a relatively recent invention for pipelines that must traverse sensitive habitats such as barrier islands. It was first used on Mustang Island, Texas in 1984 for a non-OCS pipeline. Since then, at least two other pipelines have used this technique but only one (L100, Appendix A.3) was an OCS line.

This technique is confined to relatively short segments (610 to 914 m) of a pipeline and is utilized in areas where the surface features cannot be disturbed, such as major roadway, power-line, and pipeline corridors, deep navigation channels, developed areas, and sensitive habitats. In this technique, a bore hole is drilled from the landward side of and under the area which is to be avoided, and angled gulfward to emerge from the gulf bottom approximately 304 to 762 m from the shore (Figures 2.11 and 2.12). Pipe is then

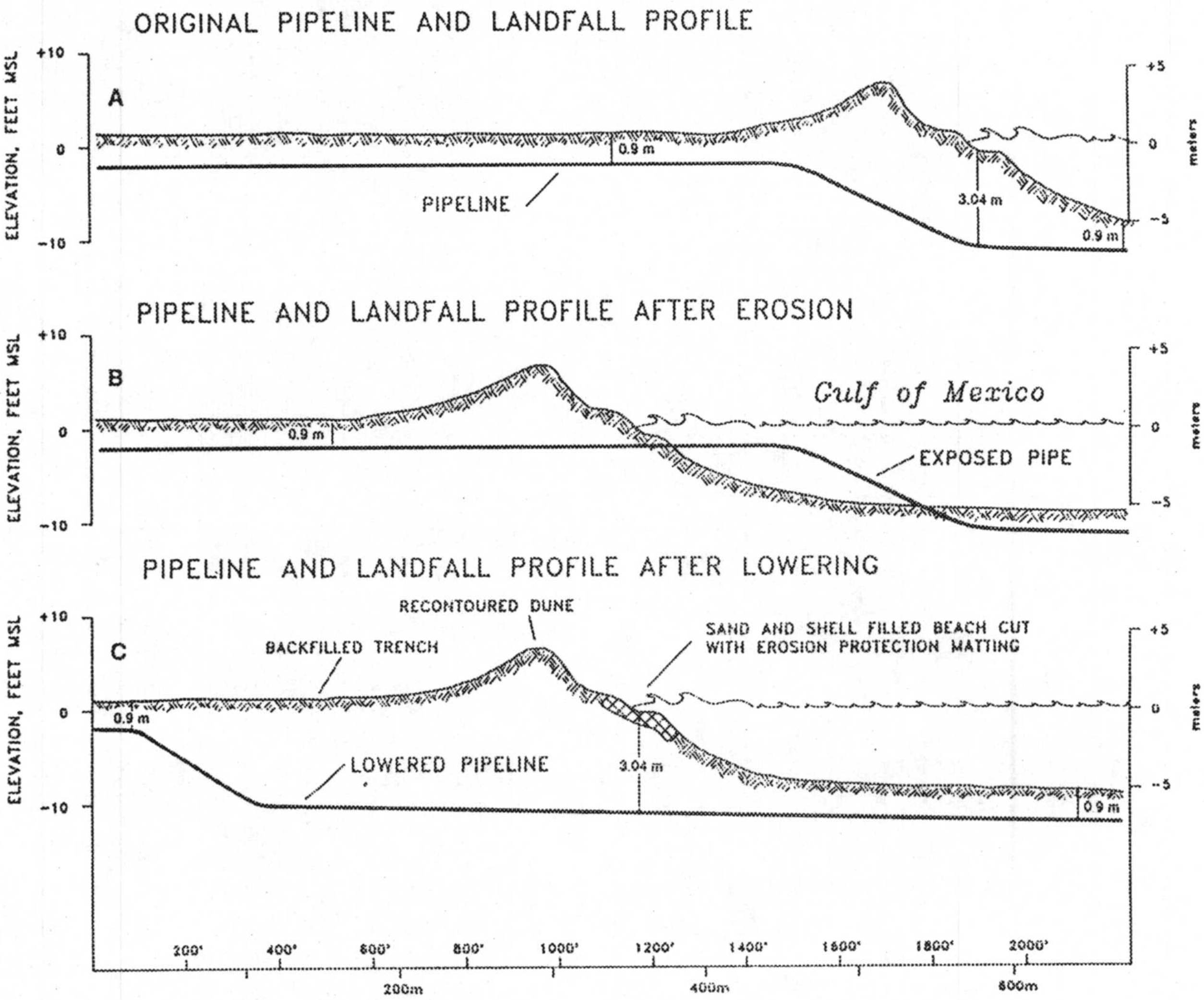


Figure 2.8. Cross section of pipeline at beach crossing at: a) time of emplacement, b) after beach retreat, and c) after lowering of pipeline.

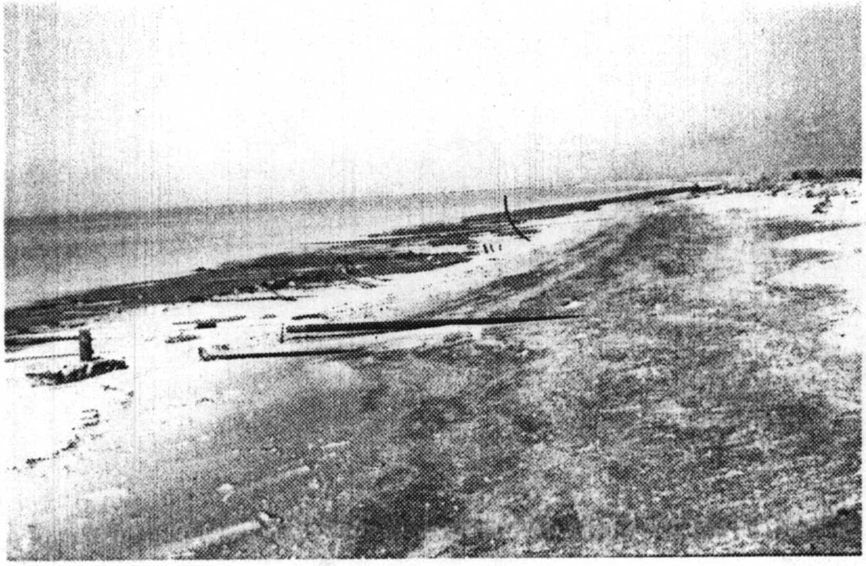


Figure 2.9. Pipelines exposed at low tide along an eroding shore in the Chenier Plain of Louisiana.

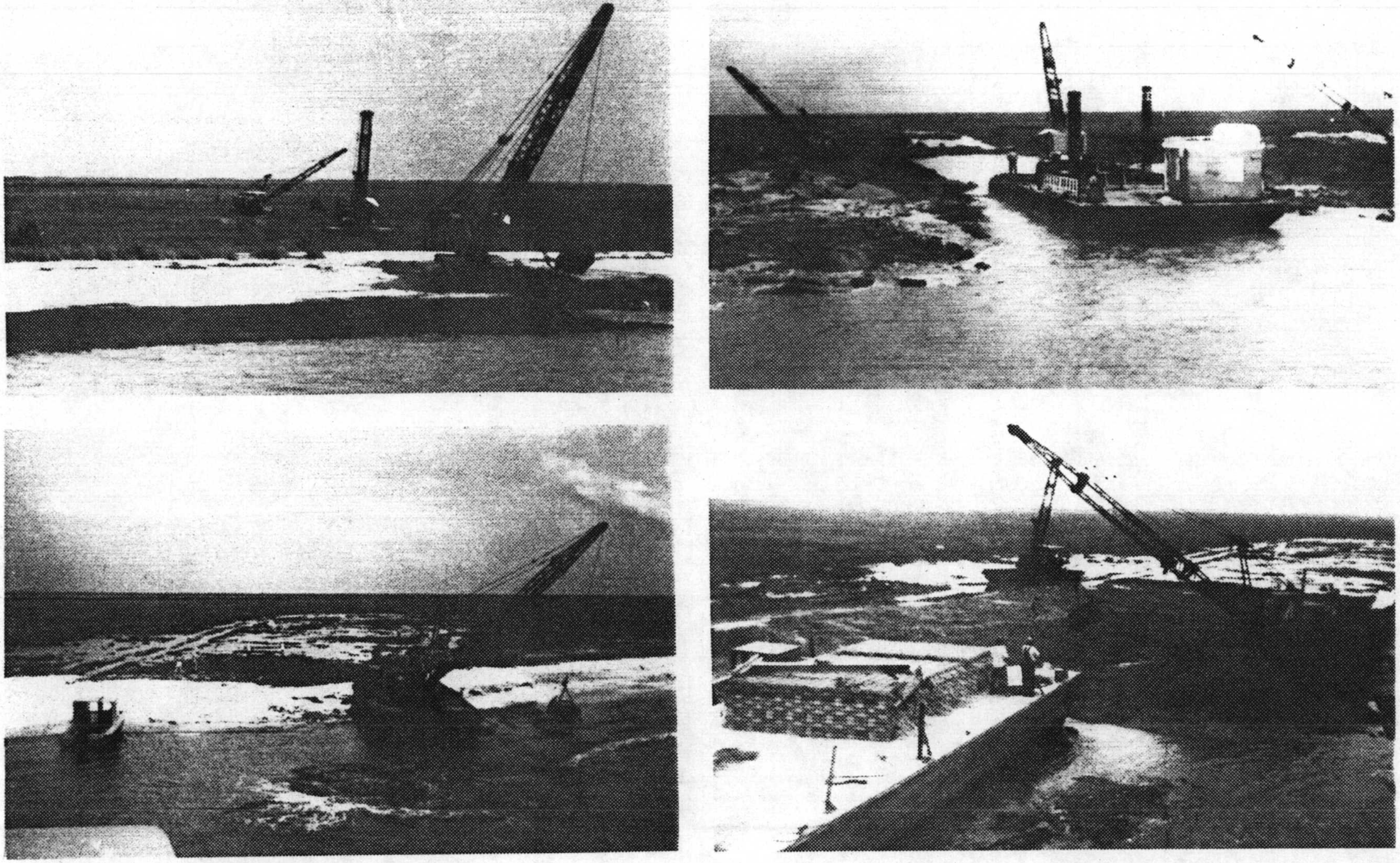


Figure 2.10. Steps taken to lower pipeline exposed as a result of 30 years of shoreline erosion: a) marsh buggy mounted draglines cutting barge slip in beach, b) barge-mounted draglines to lower pipe in nearshore zone, c) shell being spread over filled trench, d) shoreline restored to pre-construction contour and condition (Herlevic 1988).

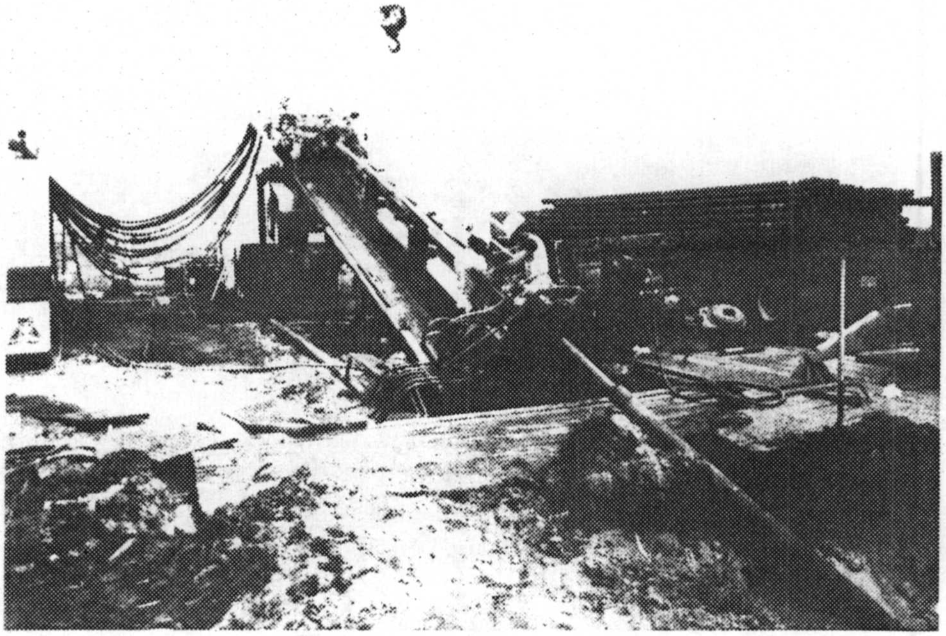


Figure 2.11. Bore hole being directionally drilled from the beach to offshore (Knight 1988).

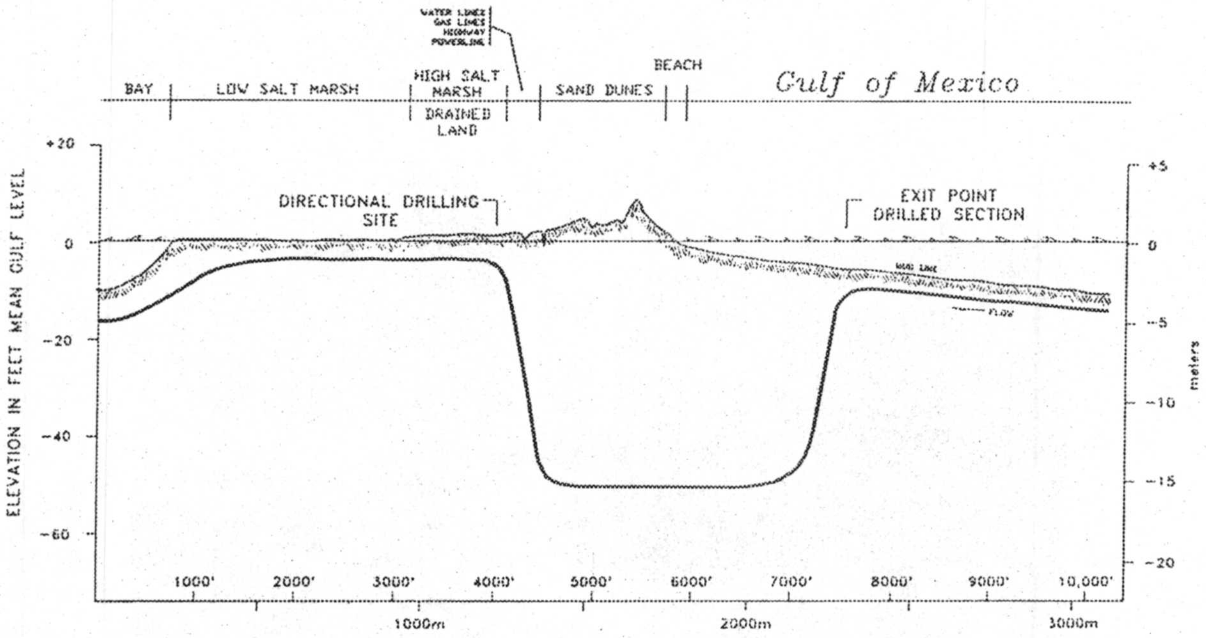


Figure 2.12. Cross section of directionally drilled pipeline across barrier island.

threaded through the bore hole to shore. Within a barrier island system, the entire line would probably be laid using upland trenching methods until the unstable back marsh and back bay areas are reached. Here conventional flotation, or more likely, push-pull methods are employed.

With the directionally drilled technique, no cuts are made in the beach. The only habitat disturbance involves site clearance and grading for drilling equipment placement and operation. Under present regulations, these sites are to be restored to grade, and revegetation may be required.

Factors Influencing Selection of Emplacement Techniques

Pipeline companies have the right to condemn property for use of pipeline ROW, so factors other than the possibility of ROW acquisition often influence ROW selection. Major factors that are often cited are as follows:

1. Distance between origin and destination (with the shortest route generally being the most desirable in terms of time and amount of pipe required) (Smith 1981).

2. Difficulty of emplacement as a result of terrain conditions (i.e., uplands; wetlands; shallow, non-navigable water bodies) (Mousselli 1986, Gard 1963).

3. Number of property owners with which to negotiate ROW lease stipulations.

4. Difficulty in negotiating with landowners or regulatory agencies ROW lease stipulations (ranging from complete site restoration to pre-construction conditions to minimal restoration or on- or off-site environmental mitigation) (Muckley 1963, Ivey 1958).

5. Presence of foreign lines, navigation channels, or other transportation corridors that must be passed under (Smith 1981).

6. Environmentally-sensitive habitats and threatened or endangered species habitat which must be avoided.

7. Number of jurisdictional bodies with which to negotiate, such as state and county/parish highway and road departments, flood and drainage boards, railroads, power companies having interfering easements, Corps of Engineers and state coastal zone agencies.

8. Type and density of development along proposed ROW.

The primary objective for pipeline operators is to select a transportation corridor that allows for prompt emplacement of a line, in terms of engineering practices and compliance with ROW stipulations from Federal and State agencies and private landowners, along the shortest distance practicable. Principal considerations governing selection of ROW and emplacement techniques are economic factors and environmental and safety concerns (Vincent-Genod 1984). The speed with which a pipeline can be put in place has long been a vital factor in the decision-making process (Love 1957). Table 2.11 contains a listing of the major advantages and disadvantages of the four major techniques that are considered when selecting a route and a technique.

Table 2.11. Comparison of Advantages and Disadvantages of Major Emplacement Techniques.

Upland Trenching

Advantages	Disadvantages
1. Requires narrower construction ROW	Cannot be used in areas with flooded or unconsolidated soils.
2. Excavated trench can be backfilled and successfully restored.	
3. Easy site access for construction and any subsequent maintenance.	

Flotation Canal

Advantages (Gard 1963)	Disadvantages
1. Easy access if have to return for repairs or lowering line for new navigation channels crossing ROW.	1. Construction directly removes marsh and shallow water habitat and replaces it with linear, deep water habitat, and wetland edge subject to continued erosion.
2. Line originally placed deep enough to allow for later pipelines to be placed over original line without having to lower it.	2. Provides a corridor for saltwater intrusion, tidal scour, and freshwater drainage which must be managed in order to lessen negative environmental impacts.
3. Construction can be quicker than push ditch under some circumstances.	3. Initially it disturbs more habitat than the other three techniques and can leave a form on the landscape that has potential for long-term alteration of pre-construction environmental forms and processes.
4. The pipe is manipulated less than in push-ditch technique.	
5. Cheaper and less hazardous tie-ins where it is necessary to set valves and pass under other lines.	

Push-Pull Ditch

Advantages	Disadvantages
1. Small ditch similar to that associated with upland trenching techniques.	1. Route has to be fairly straight because line cannot be pushed or pulled around bends.
2. Can be backfilled and recontoured to approximate preconstruction elevations and will revegetate in most instances. (The success of revegetation is somewhat influenced by other environmental conditions in area, such as subsidence, degree of adjacent marsh breakup, presence of unblocked cross-channels and water bodies, etc.)	2. Pipe must be handled more frequently, as it it continuously pushed along flooded trench prior to final burial.
3. Usually cheaper to construct becuase it requires less dredging.	3. More expense is involved in having additional crew members attach, detach, and retrieve pontoons from the floating pipe.
4. Requires less ROW clearing in swamp environments; therefore, is quicker and cheaper to trench.	4. Can be more expensive to construct if site requires numerous stop work and relocate push-point operations.
	5. More difficult to access if pipe has to be repaired or lowered because of later crossing by navigation channel or foreign line.
	6. Marsh buggy traffic along ROW during construction can lead to long-term or permanent marsh destruction.

Directional Drilling

Advantages	Disadvantages
1. Provides for avoidance of sensitive habitats, transportation corridors, and developed areas.	1. May be limited to use in areas where bore hole can be maintained during drilling and pipe threading process.
2. Less disturbance of site than in other techniques, thereby facilitating quicker site recontouring and restoration.	

CHAPTER 3: IDENTIFICATION OF OCS NAVIGATION CHANNELS

Rod E. Emmer

Ports have always been important to the economic activity of the Gulf of Mexico. The history of all of the major cities and many of the small communities of the Gulf is directly tied to waterborne commerce and the maritime industry. Ports serve as the commercial transfer point for agricultural products and mineral resources, as well as manufactured goods and petrochemical products originating in the interior of the United States. They also serve as the gateway to the United States for foreign goods, such as bananas from Central America, oil from South America, and cars and electronics from Europe and Asia. Not only do ports serve commerce but they are also centers of support and supply activities for the domestic fishing industry and for the extraction of oil and gas from the outer continental shelf.

Natural harbors are found at several locations along the Gulf of Mexico, but were only accessible through tidal passes or across river mouth bars. Navigable waterways are integral components of all harbor systems; as long as the ships did not exceed the natural channel capacity, no insurmountable problems existed. However, with the advent of larger sailing ships and, eventually, motorized vessels, improvements to these natural water courses became essential to serve the deeper draft ships. The restrictions (tidal deltas, bay and river mouth bars, and shallow nearshore bars and bottoms) had to be eliminated. Dredges excavated channels; jetties confined flows, while at the same time interrupting longshore sediment transport; and canals were dug where no natural water courses existed. Although they are, for the most part, very beneficial for the local and regional economy, many projects caused adverse primary and secondary impacts on the surrounding physical and biological environment. Primary impacts are those that "are caused by the action and occur at the same time and place" as the action. Secondary impacts are those that "are caused by the action and are later in time or farther removed in distance, but are still reasonably foreseeable" (40 CFR 1508.8). As a result of the nation's growing awareness of the values of the natural systems and our final acknowledgement that projects do cause detrimental effects, the Federal and State governments have been trying to determine which actions are responsible for degradation of the coastal areas. Activities associated with the extraction of oil and gas from the Outer Continental Shelf (OCS), of which navigation canals are one element, have been cited as major causes of deterioration of the coastal systems.

The purpose of this section, then, is to determine which navigation projects were dredged or improved for the purpose of better serving the OCS activities in the Gulf of Mexico. First, the characteristics of OCS-related vessels are presented; second, a brief summary of the history of the project is given; and finally, those navigable waterways which were initially dredged or later improved for the purpose of facilitating the OCS oil and gas industry are identified. A project is defined as OCS-related if:

1. channel improvements are cited in the published literature as supporting or intending to support OCS activities; or
2. the OCS industry is cited as benefiting from a project and the savings to the industry are made part of a Benefit/Cost Analysis.

Channel improvements (project) authorized for depths to or exceeding 9 m before 1947 (when the first Outer Continental Shelf activities started) are considered to be in response to foreign trade, not to a demand from the OCS industry. To determine which navigation systems are OCS-related, it is necessary to specify the channel requirements for OCS vessels and to identify the beneficiaries of the navigation system.

OCS Navigational Needs

During the early years of OCS oil and gas extraction in the Gulf of Mexico companies used a variety of existing watercraft modified to serve the industry. Shrimp boats were converted to carry supplies to the platforms; surplus Navy ships served as floating crew quarters. Eventually specialized boats were designed and constructed to meet the particular needs of the industry (Table 3.1). Table 3.2 shows the dimensions of the typical types of vessels that are used in the offshore industry.

In addition to these typical vessels (Table 3.1), the industry must provide for supplying fabrication yards. Fabrication yards are on navigable waterways that are usually 4.6 to 9.1 m deep with a horizontal clearance of 64.0 to 106.1 m. Pipe yards are also on channels that must be from 4.6 to 9.1 m deep (Clark et al. 1978) because some supply boats may require 9.1 m of water.

Project Beneficiaries

Many natural channels in the study area have been improved for navigation by dredging to widen or deepen a water course or the nearshore or by the construction of jetties to confine flow or affect sediment movement. Several artificial channels have been dredged to facilitate waterborne commerce. Table 3.3 summarizes important characteristics about channels in the study area which cross either wetlands, a barrier beach, or a barrier island arc. The locations of these channels are shown on Maps 1B-10B in Volume II. The channels in the table are in sequence from south Texas to Florida. In the case of Louisiana, the study area is limited to either the barrier beach or barrier island systems of the coast. Therefore, navigation channels which do not cross a barrier island or beach are not included in this report. Examples of projects which are OCS-related but are not shown because they are not in the study area are Bayous Boeuf, Black, and Chene, and the Lower Atchafalaya River near Morgan City and Grand Pass, a distributary of the Mississippi River, in Plaquemines Parish.

Navigation Channels

Texas

In extreme south Texas is the Rio Grande and Brazos Santiago, the gateways to interior Texas and northern Mexico. The Rio Grande is a shallow, meandering river with its Head of Navigation 402.2 km up the river (Alperin 1977). Shifting sandbars and poor anchorages put the Rio Grande at a decided disadvantage compared to the Brazos. Good anchorages on the Brazos close to the Gulf and the railroad eliminated use of the Rio Grande for navigation in 1870. Improvements by the Federal government to the Brazos began in 1878. In 1919 Congress authorized a 5.4-by-121.9-m channel through the pass. In 1927, a 518.2-m north jetty and a 426.7-m south jetty were erected. An improved jetty system and a 7.6-by-91.4-m channel were completed by 1935. In 1945 the Brownsville Channel entrance was set for 10.6 m and the channel was deepened to 10.0 m across the Laguna Madre. The Brownsville and Port Isabel turning basins were dredged to 9.8 m. Today the channel is 11.0 to 11.6 by 91.4 m. The inner channels and turning basins for Brownsville and Port Isabel kept pace with the depths across the bar and through the jetties (U.S. Army Corps of Engineers, New Orleans District [USACE] 1979).

Table 3.1. **Types of Vessels Used in the OCS Industry (after Clark et al. 1978).**

Type of Vessel	Description
Crew	For personnel transport; high speed boat.
Utility/supply	General maintenance and movement of light-weight equipment and cargo.
Supply	For transport of bulk cargo.
Utility	Maintenance and general work.
Tug	Light to heavy towing.
Tug-supply	Moderate towing and transport of portable equipment and cargo.
Crew/utility	Personnel transfer and general work.
Crew/supply	Transfer of personnel and equipment.

Table 3.2. **Characteristics of Typical Support Vessels Serving the OCS Industry (Clark et al. 1978).**

Type Vessel	Length	Draft	Width
65 ft Class Crewboat	65	10	17
100 ft Class Crewboat	90	7.5	21
110 ft Class Production/ Utility Vessel	110	11	25
165 ft Class Supply Vessel	166	13	38
8000 Horsepower Class Tug/Supply Vessel	210	17.5	40

Table 3.3. Characteristics of Maintained Navigation Channels through Barrier Islands and Barrier Beaches and within the Coastal Zone.

Name	County, State	Authorized to Corps of Engineers Except as Noted	Completed	Channel Depth x Width in Meters[1]	Structures in in Meters	Present Outer Bar Channel in Meters	Present Jetty Channel in Meters	Comments
Brownsville Channel (Brazos Santiago)	Cameron, Texas	1919	1960	7.6 x 91.4	North Jetty 1929.4 South Jetty 1552.0	11.6-11.0 x 91.4	11.6-11.0 x 91.4	For agricultural commerce
Port Mansfield Channel	Willacy, Texas	Local interest USACE 1959	1957 1962	4.8 x 76.2	North Jetty 701.0 South Jetty 691.8	4.8 x 76.2	4.8 x 76.2	Fishing interests
Corpus Christi Ship Channel, Aransas Pass	Nuevo, Texas	1899, 1902 1905, 1907	1906 1919	7.6 x between jetties	North Jetty 2816.6 South Jetty 2250.9	14.3 x 213.4	13.7 x 182.8-222.5	For ocean-going commerce
Matagorda Ship Channel	Matagorda, Texas	1958	1967	11.6 x 91.4	North Jetty 1798.3 South Jetty 1828.4	11.6 x 91.4	11.6 x 91.4	For Alcoa bauxite ships and OCS activities
Freeport	Brazoria, Texas	1889, private co. 1899 USACE	1908 orig. jetties complete	7.6 x between jetties	North Jetty 2346.9 South Jetty 2633.4 Relocation and rehabilitation authorized in 1970	14.3 x 121.9	13.7 x 121.9	Commerce and competition with Galveston
Bolivar Roads (including Houston ship channel and Galveston channel)	Galveston, Texas	1890	1897	7.6 x between jetties	North Jetty 7896.4 South Jetty 10851.8	12.8 x 243.8	12.2 x 243.8	Commerce
Sabine River	Jefferson, Texas	1912 —	1920 East Jetty 1929 West Jetty 1912 Channel	7.9 x between jetties	East Jetty 7702.2 West Jetty 6662.9	12.8 x 2438	12.2 x 243.8-152.4	Pine lumber replaced by chemical and petroleum industry

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[1] Original data in English units, which were converted to metric and rounded.

Table 3.3 continued.

Name	County, State	Authorized to Corps of Engineers Except as Noted	Completed	Channel Depth x Width in Meters	Structures in in Meters	Present Outer Bar Channel in Meters	Present Jetty Channel in Meters	Comments
Calcasieu River	Cameron, Louisiana	1937 1946	Jetties 1942 1949	9.8 x 121.9 11.2 x 121.9	East Jetty 2627.4 and 2078.8 from shoreline West Jetty 2453.6 and 2071.1 from shoreline	12.8 x 243.8	12.2-12.8 x 243.8	For general commerce
Mermentau River	Cameron, Louisiana	1941	1952	278.7 sq m below mean low gulf	—			For discharge of flood flows
Mermentau River, Gulf of Mexico Navigation Channel	Cameron, Louisiana	East Cameron Port, Harbor and Terminal District of Cameron Parish	1971	4.6 x 61.0	East Jetty approx. 304.8 m; West Jetty approx. 548.6 m	4.6 x 61.0	4.6 x 61.0	Navigation for industry
Freshwater Bayou	Vermilion, Louisiana	1963	1968	3.6 x 76.2	—	12 x 250	—	Serve offshore oil industry and fishing industry
Houma Navigation Canal		1955 by Terrebonne Parish 1962 USACE	1962	4.6 x 45.7	—	5.4 x 91.4	—	For offshore oil industry, USACE Maintenance in 1962
Belle Pass	Lafourche, Louisiana	1935 1960	1939 1968	1.8 x 18.2 6.0 x 91.4	Jetties completed, East Jetty approx. 731.5 m; West Jetty approx. 457.2 m	6.0 x 91.4	6.0 x 91.4	Greater Lafourche Port Commission deepens and widens in 1967-68 for OCS activities, fishing, and commerce.

Table 3.3 continued.

Name	County, State	Authorized to Corps of Engineers Except as Noted	Completed	Channel Depth x Width in Meters	Structures in in Meters	Present Outer Bar Channel in Meters	Present Jetty Channel in Meters	Comments
Grand Bayou Pass	Plaquemines, Louisiana	1938	1934	1.8 x 18.2	—	unknown	—	Fishery industry
Empire Canal	Plaquemine, Louisiana	1946	1950	2.7 x 24.3	East Jetty 554.1 West Jetty 683.6	2.7 x 24.3	2.7 x 24.3	Fishing industry and inshore oil industry
Mississippi River Gulf Outlet	St. Bernard Plaquemines, Louisiana	1956	1967	11.6 x 182.8	North dike=4828.0 South dike=13,309.0	11.0 x 152.4	11.0 x 152.4	For deep draft commerce to New Orleans
Cadet Bayou (Bayou Caddy)	Hancock, Mississippi	1969	1970	2.4 x 30.4				Small commercial industries, recreational boats
Wolf and Jordan Rivers	Hancock, Mississippi	1907	1908	2.1 x 30.4				Small craft
Gulfport Harbor including commercial small boat harbor	Harrison, Mississippi	1899		5.8 x 91.4		9.8 x 91.4	—	Channel
		1948	1950	9.1 x 67.0				Ocean-going commerce, maintenance serves some OCS activities
		1958	ongoing	2.4 x 30.4				
Biloxi Harbor	Harrison Jackson, Mississippi	1931	1980	3.0 x 45.7 West of Deer Island 3.6 x 45.7 Biloxi Bay Channel		3.6 x 45.7 3.0 x 45.7	— —	Small craft and fishing boats
Pascagoula Harbor	Jackson,	1913	1965	6.4 x 91.4 original channel	—	12.2 x 106.6	—	Ocean-going commerce; navy ship builders, 12.2 x 61.0 x 457.2 m impounding areas at western end of island

Table 3.3 concluded.

Name	County, State	Authorized to Corps of Engineers Except as Noted	Completed	Channel Depth x Width in Meters	Structures in Meters	Present Outer Bar Channel in Meters	Present Jetty Channel in Meters	Comments
Bayou La Batre	Mobile, Alabama	1925	1967	3.6 x 30.4				Began 1925, upgraded 1945, 1965 for fishing industry
Mobile Harbor including smaller supplemental projects	Mobile, Alabama	1902	1981	12.8 x 182.8		12.8 x 182.8	—	Ocean-going commerce
Perdido Pass Channel	Baldwin, Alabama	1965	1969	3.6 x 45.7	East Jetty - 487.6 West Jetty - 518.2	—	3.6 x 45.7	East Jetty has 304.8 m weir and deposition basin to permit passage of littoral drift; dredged and redeposited; marinas; small craft
Pensacola Harbor	Escambia, Florida	1939 1962	1965	9.8 x 152.4 10.6 x 152.4	—	11.2 x 243.8	11.2 x 243.8	General commerce; Navy maintains at 11.2 x 243.8 since 1958
East Pass Channel	Okaloosa, Florida	1930 1965	1931 1969	1.8 x 30.4 3.6 x 54.8	East Jetty - approx. 152.4; West Jetty - approx. 762.0	3.6 x 54.8	3.6 x 54.8	304.8 m weir in west jetty to allow for littoral passage; dredged and redeposited
Panama City Harbor	Bay, Florida	1935 1948	1934 1949	8.8 x 137.2 9.8 x 137.2	East Jetty - 632.46 West Jetty - 882.7	10.4 x 137.2	10.4 x 137.2	Originally dredged under National Industrial Recovery Act; Jetties rehabilitated between 1961-1968

The Port Mansfield channel crosses Padre Island and gives the town of Port Mansfield and its commercial and sports fishing fleets a direct outlet to the Gulf, an action accomplished by Willacy County in the mid 1950s (Alperin 1977). Jetties of tetrapods were completed in September 1957 and were destroyed by a storm in November 1957. Two years later Congress authorized the Corps to improve the channel and rebuild the jetties. Work on the 4.8-by-76.2-m channel was completed in 1962 (USACE 1979).

Corpus Christi Bay has always been a center of commercial activity on the Texas coast. Access to the bay was through Aransas Pass when private companies initiated efforts at improvement in 1852 (Alperin 1977). Between 1880 and 1885, a 1676.4-m jetty was built from Mustang Island. Other efforts were never really successful. The Federal government became involved through the Rivers and Harbors Act of 1899. By 1919 the jetties reached their present length of 2816.6 m for the north jetty and 2250.9 m for the south jetty. The overall navigation system within Corpus Christi Bay is composed of several projects including turning basins, inner basins, branch channels, a jetty channel, and the outer bar channel, collectively known as the Corpus Christi Ship Channel. Each of these individual projects was initiated at the request of the public, usually represented by special interest groups dependent on shipping for some part of their livelihood. The 1913 authorized depth of 7.62 m was deepened to 9.1 m by 1930, including the channel from Aransas Pass to the Corpus Christi channel. In 1954 a branch channel 9.8 m deep was dredged to the vicinity of the Reynolds Metals Company at LaQuinta, Texas (USACE 1979). Today, 59,000 deadweight ton ships can pass fully loaded through the 13.7-m channel.

The next channel to the north is Pass Cavallo where improvements (3.6 m across the bar) were proposed in 1879 (Alperin 1977). A single jetty was begun in 1881; however, the project was abandoned in 1888. Pass Cavallo served in its natural state for shallow draft vessels serving the offshore oil and gas industry. By 1949 the outer bar reduced traffic to boats of less than 1.8 m of draft. The Corps attempted a 5.2-by-41.1-m channel in 1949, but by 1952 the channel had shoaled to 2.4 m. In 1958 Congress authorized the first deep draft project for Matagorda Bay, a 11.6-by-91.4-m, artificially cut channel with jetties (USACE 1979). The primary impetus for the project was the desire to satisfy the needs of ALCOA to bring in South American bauxite to its Texas complex on vessels drawing 10.4 m. Prior to this, bauxite was brought in on barges from Corpus Christi Bay. Also benefiting from the channel was the fishing industry, and the oil and gas exploration and production industry which could transport materials, equipment, and supplies for offshore (U.S. House 1958). These latter two activities were minor when compared to the ALCOA benefits, but they still contributed to the need for the action. Within the bay system small projects were undertaken before 1945. One of these is the Port Lavaca Channel, which was started in 1910 and by 1958 was 3.6 by 38.1 m.

The Brazos River basin was especially important to the sugar and cotton trade in Texas as early as 1832 (Alperin 1977). Moving the agricultural products to market was a problem because of the shifting river mouth bar where depths varied from 1.2 to 3.0 m, too shallow for many of the carriers. Congress authorized improvements to the mouth of the Brazos in 1880 with the construction of two jetties. However, the work was suspended in 1886 for lack of funds. The Brazos River Channel and Dock Company received Congressional authorization to improve the mouth, which they tried to do between 1889 and 1896. The company lacked the finances to complete the jetties and as a result gave the work back to the United States in 1899. Under the federal government, jetties were completed by 1908 and even with no dredging the channel deepened to between 4.0 and 5.8 m. Because of the lack of commercial activity no dredging was undertaken until 1950 when a 11.6-m channel was authorized to serve the petrochemical industries of the area. The navigation channel is now 13.7 to 14.3 m deep across the outer bar and into the jetty channel (USACE 1979).

Size, depth, its central location, and the fact that it had the best railroad facilities on the Gulf made Galveston Bay the most important shipping center on the Texas coast (Alperin 1977). In the 1870s, jetties were constructed to improve the crossings of the mouth bars, but by 1879, no important results could be identified. Congress increased appropriations and by 1890 the south jetty extended 579.1 m from Avenue A in Galveston into the Gulf. After a USACE study showed Galveston Bay to be an important estuarine system in Texas, work on the navigation projects intensified. By May 1897 the south jetty was 10,851.8 m and the north jetty was 7,896.9 m. The channel across the outer bar was 7.8 m. In 1902, the channel was authorized to 9.1 m by 365.8 m (USACE 1979). By 1935 the Houston Ship Channel was 9.8 m deep and 121.9 m wide through Galveston Bay. "Houston Ship Channel" is a name given to a collection of navigation projects which serves the city. Individual projects included under this name are side channels, straightening of bends, turning basins, and major extensions into smaller water courses. For example, in 1913 the Texas City channel was 9.1 by 91.4 m. To the northeast the Anahuac Channel was authorized in 1905. In 1912 a 1.8-m channel to Liberty, Texas was authorized; by 1946 the Trinity River project resulted in a channel 2.7 by 61.0 m through Trinity Bay from the Houston Ship Channel. Improvements in support of commerce and trade through the ports of the bay have continued; today the jetties are well maintained and the channel is 12.8 m deep.

A part of the boundary between Louisiana and Texas is the Sabine River, a channel which serves the commerce of the region. Under natural conditions Sabine Pass was only 5 ft deep at low tide (Alperin 1977). Between 1875 and 1881 the Corps dredged a 3.6-m channel. To complement the dredging program, jetties were begun in 1883. The east jetty was completed in 1920 (7,702.2 m), while the west jetty was completed in 1929 (6,662.9 m) (USACE 1979). The impetus for this activity was initially the lumber industry and by 1901, with the discovery at Spindletop, the petroleum industry. By 1909 the need for a 9.1-m channel between the jetties was recognized, but it would require the passage of the 1922 River and Harbor Act to reach the 9.1-m depth between the Gulf and Beaumont. Similar to other navigation systems on the Gulf coast the Sabine Neches Waterway is actually a number of individual projects such as turning basins, channel alignment, deepening and widening, and placement of jetties sponsored over a period of years. In 1935 a 10.4-m channel was authorized. Trade and commerce are the primary beneficiaries of these navigation improvements.

Louisiana

East of the Sabine River is the Calcasieu River, a water course which had many impediments to its use by large ships. First, the channel had to be snagged, which the Corps began in 1872 (Alperin 1977). Second, the river flowed into Calcasieu Lake where there was a mouth bar to cross in order to get into the Gulf. Calcasieu Parish tried to avoid these problems and gain access to the Gulf by dredging a canal to the Sabine River. By 1926 Lake Charles was functioning as a deep water port through this canal. In 1937 the Corps was authorized to make the Calcasieu River useful for navigation by providing a 9.8-by-121.9-m channel with jetties (2072.6 m) (USACE 1979). In 1946 the depth was increased to 11.2 m. At present, the authorized channel is 12.8 by 243.8 m, and was completed in 1968.

East of the Calcasieu River is the Mermentau River, the only natural water course that crosses the Chenier Plain between the Calcasieu and West Cote Blanche Bay. After flowing from the Pleistocene terrace across the Chenier Plain, the Mermentau River is deflected to the west before eventually cutting through Grand Chenier and flowing to the Gulf. Corps of Engineers' action on the Mermentau was authorized by the Flood Control Act of 1941. The project was designed to improve discharge of flood waters in the lower

Mermentau by enlarging the channel to a minimum cross section of 278.7 sq m below mean gulf level (USACE 1979).

Intensive use of the lower Mermentau River to Grand Chenier was the result of actions by the East Cameron Port, Harbor, and Terminal District of Cameron Parish. The District dredged the Mermentau River, Gulf of Mexico Navigation Channel in 1971 (Cowdrey 1977). This artificial waterway is 7.4 km long with channel dimensions of 4.6 by 61.0 m. The east jetty is 304.8 m long, while the west jetty is 548.6 m. The Corps was given maintenance responsibility by the Water Resources Development Act of 1976 (PL94-587). The Navigation Channel was dredged to accommodate the petroleum and commercial fishery interests primarily based on Grand Chenier. Users of the waterway include crew boats, supply boats, utility boats, and shrimp boats (U.S. House 1976).

A second artificial water course across the Chenier Plain is the Freshwater Bayou channel which extends from the Gulf Intracoastal Waterway into the Gulf of Mexico to the 3.6-m contour. The project with a navigation channel of 3.6 by 38.1 m through the wetlands and 3.6 by 76.2 m offshore was authorized by the River and Harbor Act of 1960 (USACE 1979). Jetties are authorized when needed, but have not yet been built. The project was completed in 1968. The purpose of the Freshwater Bayou project is to serve the offshore oil industry and the fishing industry (Cowdrey 1977).

The next project of interest east of Freshwater Bayou is the dream that finally became reality, the Houma Navigation Canal. The canal was dredged directly from the Gulf to Houma, a shortcut that had been in the thoughts of the business community in Terrebonne Parish for many years because navigation to the Gulf had been along natural water courses, a trip that was very long and very slow (Anon 1962). In 1954 the Police Jury appointed the Terrebonne Parish Deep Water Channel Committee, an assemblage of prominent local citizens who wanted development in the Houma area from the rapidly growing oil industry. The Houma Navigation Canal seemed the best way to attract companies, as a canal would provide 29.0 km of attractive sites near Houma. Private money and parish bonds were used to dredge the 74.8-km canal. The project channel is 4.8 by 45.7 m within a 182.8-m right-of-way. In 1962 the River and Harbor Act provided for USACE maintenance of the canal (USACE 1979). In 1973 the Cat Island Pass channel was authorized to 5.4 by 91.4 m. The project was completed in 1974.

The next project which crosses a barrier beach or island system in Louisiana is the Belle Pass channel and jetties at the mouth of Bayou Lafourche. Bayou Lafourche, an old course of the Mississippi River, has always been a main transportation corridor for south-central Louisiana. In 1935 the River and Harbor Act authorized a 1.8-by-18.2-m channel from LaRose to the Gulf with a set of jetties at the mouth of Belle Pass (USACE 1979). The jetties were completed in 1939, and it was not until 21 years later that additional work was done on the Pass. The River and Harbor Act of 1960 provided for restoration and extension of the jetties and a 3.6-m channel. However, such a channel was not satisfactory with local interests. The Greater Lafourche Port Commission obtained a permit from the Corps to dredge a 6.0-by-91.4-m channel from inside the shoreline to the 6.0-m contour offshore (Coastal Environments, Inc. 1977). The work was completed in 1968. The purpose of the project enlargement was to provide for deeper draft ships using Port Fourchon. These ships included offshore oil-and gas-related supply, utility, and crew boats. Port Fourchon is a major support base for the offshore activities. The channel is now at a 6.0-m depth.

Two channels on the west bank of Plaquemines Parish cross barrier islands or barrier beaches—Grand Bayou Pass and the Empire Canal. Grand Bayou Pass (U.S. Senate 1938) was the principal route for shrimp and fishing boats from the Gulf of Mexico to the canneries and road at Buras, Empire, and Myrtle Grove. A distributary of the Mississippi River, the channel had a natural depth of 2.4 m that was maintained by tidal action. However, the 1915 hurricane widened the inlet and diminished the scouring action of the tidal currents; as a result, the channel depth was reduced to between 0.9 and 1.2 m. The 1938 River and Harbor Act included dredging a 1.8-by-18.2-m channel through the entrance bar, a project which was completed in 1939. Since then the entrance has deteriorated and no longer serves as a major access route to the interior. This role has been assumed by the Empire Canal which extends from the community of Empire to the Gulf. Local interests requested federal assistance for the project. The purpose of the project was to reduce damage to the fishing fleet which then had to use much shallower natural waterways to allow for basing of deeper draft trawlers for offshore shrimping and to benefit the oil industry (U.S. House 1946). The oil industry seems to be that which existed within the coastal wetlands because the canal would be used by barges carrying oil from producing fields to refineries up the Mississippi River. The companies did not want to build expensive pipelines across the marsh. Most of the benefits expected from the project would accrue to the seafood industry. The Empire Canal (River and Harbor Act of 1946) included dredging a 2.7-by-24.4-m channel and two jetties, a 554.1-m east jetty and a 683.6-m west jetty. The work was completed in 1950 (USACE 1979).

The final channel in Louisiana, the Mississippi River Gulf Outlet (MRGO), crosses the Chandeleur Islands arc. The New Orleans business community had always been fascinated with the idea of a sea level, deep draft channel to the port of New Orleans. Such a facility shortens the distance to the open Gulf, allows shipping to avoid the bar at the mouth of the Mississippi River, and eliminates problems with annual floods of the Mississippi River. Numerous studies investigated possible routes, such as through Lake Pontchartrain or the Barataria estuary. Strong political action on the part of the City resulted in the project being authorized in 1956 (Cowdrey 1977). The 11.0-by-152.4-m channel extends from Orleans Parish through St. Bernard Parish, and into Plaquemines Parish. Once through the Chandeleur Island Arc, the channel is 11.5 by 182.8 m. Initial dredging was completed in 1967. Two jetties extend across Chandeleur Sound: the north jetty is 4,828.0 m; the south jetty, 13,309.0 m (USACE 1979).

Mississippi

Mississippi has three navigation channels which cross the barrier islands arc. Gulfport is the westernmost port and has always been a center of commerce for the state. Originally, the port developed to serve a fairly large lumber-exporting business. With the depletion of the forest products, the port turned to more diverse commerce. Today it primarily handles general cargo and bananas from Central America. Work on the navigation channel across Mississippi Sound, that is, between the mainland and the barrier islands, began with the River and Harbor Act of 1899 (U.S. Senate 1957). The Act provided for a 7.9-m channel through Ship Island Pass and a 5.8-by-91.4-m channel across Mississippi Sound. This work was completed by the Gulf and Ship Island Railroad Company at a cost of $1,603,594. However, the Federal government only paid $150,000 because that was the limit established by the River and Harbor Act. The 1930 River and Harbor Act prescribed a 8.2-by-91.4-m Ship Island Bar channel, a 7.9-by-67.0-m channel across Mississippi Sound, and a 7.9-m anchorage. Completed in 1934, the Corps dredged the channel several feet below project depth to accommodate Navy vessels using the port in 1944 and 1945. The 1948 River and Harbor Act empowered the Corps to deepen the bar channel by 0.9 m, the Mississippi Sound segment by 1.2 m, and the anchorage by 1.2 m. The project was completed in 1950.

Adjacent to and west of the Gulfport anchorage is a 10.5-ha commercial, small boat harbor constructed by local interests under the sponsorship of the Gulfport Port

Commission (U.S. Senate 1957). The project was completed in 1952. By 1956 the local interests requested that the Corps accept responsibility for maintenance of the access channel into Mississippi Sound. As a result of a Corps study, a 2.4-by-30.4-m channel from the harbor to the 2.4-m contour (1310.6 m) was adopted as part of the Federal system by the River and Harbor Act of 1958. One of the beneficiaries of the project is the offshore petroleum industry. In 1956 eight vessels between 18.2 and 31.6 m in length and drawing 1.6 to 2.2 m of water operated in the harbor. These vessels were used to transport supplies and equipment to the offshore drilling areas. However, the greatest benefits were attributable to the commercial fishing industry.

East of Gulfport is the Biloxi Harbor, a multipurpose complex catering to the smaller craft—fishing boats, tugs, and barges. The project has been built in phases beginning in 1931. In 1966 a channel project 3.6 by 45.7 m connecting Mississippi Sound with Biloxi Bay and Back Bay of Biloxi and extending further to the west as the Industrial Seaway through Gulfport Lake and about 2 mi beyond was made part of the River and Harbor Act. This phase was completed in 1975. A commercial small craft harbor was authorized in 1979 and completed in 1980. Deer Island is immediately offshore from the mainland and has navigation channels on either side (USACE 1979).

East of the harbors in Mississippi is the Pascagoula system, which includes Bayou Casotte and the Pascagoula River. The town originally known as Scranton was a major port for the fishing industry, the handling of yellow pine lumber from the interior, and shipbuilding. By 1910 there was a 6.4-m dredged channel extending through Horn Island Pass (U.S. House 1912). The Corps was authorized to work in the Pascagoula area in 1913. Ingalls Corporation arrived in 1930 and became Mississippi's largest industry. By 1954 a 10.6-by-99.0-m channel was through Horn Island Pass (U.S. House 1954). The access channel across Mississippi Sound is now 11.6 by 106.6 m. At the western tip of Petit Bois is a 12.2-by-61.0-by-457.2-m impounding area; the pass channel is 12.2 by 106.6 m. The project was completed in 1965 (USACE 1979). Accommodations exist for ocean shipping, ship building and repair, barges, a commercial fishing fleet, and recreational craft.

Two small navigation projects are along the coast and make small water courses accessible from deeper waters. Cadet Bayou (Bayou Caddy) is west of Waveland, Mississippi and was authorized in 1969. The project, a 2.4-by-30.4-m channel from the Bayou into Mississippi Sound, was dredged to serve a boat yard, marinas, private wharves, and recreational boating. Dredging activities were commenced and completed in December 1970. East of here and within Bay St. Louis is the Wolf and Jordan Rivers project to serve small boats. Authorized in 1907, the 2.1-by-30.4-m channel was completed in 1908.

Alabama

Alabama has only one major port and navigation system, the Mobile Bay channel and harbor complex. Mobile was established in 1702 and has served as a focus of trade ever since. Lumber and naval stores were the two important, early export items and were later replaced by cotton from interior plantations. Agricultural products, iron and steel from Birmingham, and petroleum are major products today. The Corps of Engineers was first authorized to improve the Mobile system in 1902 to enhance its use in foreign trade. By 1940 the Mobile channel was 9.8 by 91.4 m. In 1954 the Corps began to enlarge the channel to its present depth of 12.8 by 182.8 m, a project completed in 1965 (USACE 1979).

Several other improvement projects are associated with the Mobile channel. The United States dredged the Theodore Channel (9.8 by 53.3 m) plus a turning basin and dock facilities in 1943 (U.S. House 1970). The channel served the U.S. Army Theodore Ammunition Depot. In 1965 the Mobile City Industrial Development Board and the Alabama State Docks acquired the 1826-ac depot and created the Theodore Industrial Park, the location today of several heavy industries. Bon Secour River (3.0 by 24.4 m) was dug for the seafood industry and boat repair. It was authorized in 1963 and completed in 1964. Dog and Fowl Rivers (2.4 by 45.7 m and 2.4 by 30.4 m, respectively) serve a boat-fabricating yard and marinas. They were authorized in 1969 and completed in 1973. Fly Creek (1.8 by 24.4 m) for recreational and fishing boats was authorized in 1950 and completed in 1957. Dauphin Island Bay (2.1 by 15.2 m) channel and anchorage (authorized in 1945 and 1954 and completed in 1959) serves the seafood docks, the public dock, and the recreational craft on Dauphin Island.

West of Mobile Bay is Bayou LaBatre (U.S. House 1964). The first Corps effort was part of the 1925 River and Harbor Act which authorized a 1.8-by-30.4-m channel. The work was completed in 1926. The channel was upgraded as a result of the 1945 River and Harbor Act to 2.7 by 30.4 m. The last modification to the project began with the River and Harbor Act of 1965, which specified a 3.6-by-30.4-m channel. All of the benefits for these improvements accrue to 25 large shrimp trawlers and 5 medium-class snapper boats based at Bayou LaBatre. Bayou Coden which connects with the Bayou LaBatre was dredged to 1.2 by 12.2 m to serve the fishing and oyster industry (authorized in 1945, completed in 1956). The 1969 River and Harbor Act deepened and widened the channel to 2.4 by 30.4 m and now claims benefits for access to recreational marinas. The project was completed in 1976.

Perdido Pass Channel is in Alabama very close to the Florida state line (U.S. Senate 1964). Improvements to navigation began in 1939 when, at the urging of local interests, a 1.8-to-2.1-by-4.6-m channel was dredged across the entrance bar. This apparently complemented a Federal project authorized by the River and Harbor Act of 1930 for a 2.1-by-12.2-m channel. In 1953 local interests again persuaded Alabama to enlarge the channel, this time to 3.0 to 4.8 m by 18.2 to 30.4 m. In 1965 the Corps was authorized to dredge a 3.6-by-45.7-m channel with jetties for the commercial and recreational boating interests within the bay. Dredging and construction of the jetties (east jetty = 487.6 m; west jetty = 518.2 m) were completed in 1969. Flowing into Escambia Bay are the Escambia and Conecuh Rivers. In 1958, Congress provided that a 3.0-by-30.4-m channel would be dug to provide access for barges needed by the chemical industry near the bay and for coal barges for the Gulf Power Company generator. Both improvements were completed in 1960.

Florida

Within the Florida section of the study area are three channel and harbor systems. Pensacola is on the largest natural, landlocked, deep-water harbor in the state and because of its natural attributes changed hands many times since its first settling by the Spanish in 1696. Pensacola was chartered as a city in 1822 and the U.S. Navy yard was established in 1825. The port has served many industries, including forest products, turpentine, rosin, insulating wall board, as well as furniture, agriculture, and commercial fishing. The Naval Air Station was established in 1914 to train Navy pilots for aircraft carriers. By 1939 the Federal government had completed an entrance channel of 9.8 by 152.4 m, the bay channel, and approach channels to the docks. In 1962 the Corps recommended a 10.6-by-152.4-m channel to handle larger cargo vessels (U.S. House 1962). However, the Navy desired a 11.2-by-243.8-m channel so aircraft carriers could enter and exit the bay safely. Thus, the Navy is responsible for financing the incremental part of a deeper channel. The Bayou Chico project (entrance channel, bayou channel, and turning basin) was part of the 1945 River and Harbor Act, but these enlargements have been deferred for restudy. Flowing into East Bay is the Blackwater River. Congress funded channel improvements on the system in 1905. The 2.7-by-30.4-m channel for the grain elevator and petroleum terminal at Milton was completed in 1916.

No other water courses, either natural or dredged, cross the barrier island complex until the East Pass channel from the Gulf of Mexico into Choctawhatchee Bay, Florida (U.S. House 1964). For the most part, this is an area whose economy revolves around commercial fishing and the recreation industry. The original project for East Pass was authorized by the River and Harbor Act of 1930 and provided for a 1.8-by-30.4-m channel, which was completed in 1931. By 1945 the Corps had dredged the channel to 3.6 by 54.8 m, but it was not maintained and eventually shoaled to a 6-ft depth. By 1951 the channel was again dredged to 3.6 by 54.8 m. But it was not until 1965 that the Corps was authorized to construct two jetties at the channel. Beneficiaries of the channel improvements include charter fishing boats, commercial fishing boats, private pleasure boats, and U.S. Department of Defense.

The last navigation project in the study area is the Panama City Harbor and entrance channel (U.S. House 1947). The entrance to the Panama City harbor has been under Federal improvement since 1910 when East Pass, the natural channel, was dredged to 6.7 by 61.0 m. In 1931 a very large pulp mill was built near Panama City and became one of the biggest employers in the state. As part of the Public Works Program under the National Industrial Recovery Act, an artificial channel was dredged to 8.8 by 137.2 m through the barrier beach and twin 213.4-m jetties were built into the Gulf. The project was completed in 1934. In 1948 the Corps began improvements on the navigation system by dredging the channel 3 ft deeper and extending the jetties, an effort completed in 1949 (USACE 1979). Within St. Andrews Bay are authorized anchorages, loading basins, turning basins, and connecting navigation channels. The Grand Lagoon Channel (2.4 by 30.4 or 45.7 m) was authorized in 1967 and completed in 1972. Panama City Harbor is for general ocean commerce, but is mostly used by International Paper Company and a fuel company.

Conclusions

The objective of this section is to determine which of the navigation channels within the study area, if any, were improved to benefit the OCS oil and gas industry. Two criteria were used to make this decision: first, whether a project was cited in the literature as supporting or intending to support the OCS activities; and second, whether the OCS activity is used to justify a project, such as appearing on the benefit side of a benefit/cost analysis. If either criterion is satisfied, then the project is considered to be the result of the OCS petroleum activity. However, if the channel was greater then 9.1 m in depth before 1947 or OCS activity could take place without further improvements, then the project was judged not to be the result of OCS activity, regardless of subsequent activities on the water course.

There are seven channels along the Texas coast that have been improved for navigation. Only one meets the criteria established and thus is identified as resulting from OCS activity—the Matagorda Ship channel. House Document 388 (1958) includes oil and gas companies for offshore exploration, the transportation of materials, supplies, and equipment as prospective commerce for the channel. It is stated that the oil and gas exploration and production industry for the offshore will benefit from the construction of the Matagorda Ship Channel. Other channels in Texas were either built for foreign commerce and/or in support of the local fishing industry. Except for the Port Mansfield Channel, which serves the fishing industry, all of the navigation channels are either equal to or deeper than the Matagorda Ship Channel. In the case of jetty length the same phenomena is noted. The longest jetties, on Bolivar Roads and Sabine River, are four to six times the length of the Matagorda Ship Channel jetties. Only the jetties on the Port Mansfield Channel are shorter.

In Louisiana, nine channels impact barrier islands or barrier beaches and four of these channels were either dredged or modified specifically to serve the OCS industry. These four are: the Mermentau River, Gulf of Mexico Navigation Channel; Freshwater Bayou; Belle Pass; and the Houma Navigation Canal. The rationale for the Corps assuming maintenance of the Mermentau River, Gulf of Mexico Navigation Channel was to serve the users, including crew boats, supply boats, and utility boats, in addition to the fishing industry (U.S. House 1976). Cowdrey (1977), in his history of the New Orleans District, Corps of Engineers, states that Freshwater Bayou was dredged to serve as an access route for the OCS industry. The Houma Navigation Canal was a private venture which eventually was accepted by the Corps for maintenance. It was dredged specifically to provide a more direct route across Terrebonne Parish so that the OCS-related industries would locate near Houma. Finally, the story of Belle Pass is slightly different. An improved channel and jetty system existed. However, local interests obtained a permit to increase the depth of the channel and extend the jetties so that larger OCS-related vessels would use Port Fourchon. Thus, OCS incentives contributed significantly to the modification of a navigation project. The Houma Navigation Canal and Freshwater Bayou do not have jetties extending into the Gulf. The Belle Pass Jetties are an extension of older jetties, while the Mermentau Channel jetties were constructed specifically for the project. In both cases they are relatively short compared to the 13,309.0-m jetty on the Mississippi River Gulf Outlet or the 2627.4-m jetty on the Calcasieu River.

Three channels are OCS-related (Bayous Boeuf, Black, and Chene; the Lower Atchafalaya River south of Morgan City; and Grand Pass south of Venice) but do not cross either barrier islands or barrier beaches. Therefore, no detailed consideration or study was rendered on these because they are beyond the limits of the study area.

Nine navigation systems were investigated in Mississippi, Alabama, and the panhandle of Florida. Only the small commercial boat harbor in association with the Gulfport Harbor was identified as resulting from OCS activity. All other systems were dredged and improved in a desire to support and encourage commerce, the local fishing industry, recreational boating, or the military.

CHAPTER 4: ENVIRONMENTAL PROBLEMS ATTRIBUTED TO OCS-RELATED PIPELINES, NAVIGATION CHANNELS, AND FACILITIES

Karen M. Wicker

Introduction

There are approximately 1364 km of barrier island-barrier beach shoreline along the Gulf Coast from Cameron County, Texas to Bay County, Florida (Table 4.1). The Texas Barrier Island System has the longest expanse of barriers (39%), followed by the North Central Gulf Coast (26%), the Strandplain-Chenier Plain (23%), and finally, the Mississippi Delta System (12%). Of the three systems with barrier island shorelines, the Texas Barrier Island System has the longest island shore (64%), followed by North Central Gulf Coast (22%) and Mississippi Delta (14%). The Texas Barrier Island System is backed by relatively narrow lagoon and bay systems, whereas the water bodies behind the North Central Gulf Coast and Mississippi Delta islands are wider. There are five major passes, all of which have to be dredged to maintain navigable depths associated with the five islands in Texas. In the Mississippi Delta System there are six barrier island complexes cut by nine passes (e.g., Isles Dernieres, Timbalier, Grand Isle, Grand Terre, Bastian-Shell, Chandeleur, only one of which is dredged to maintain navigation (e.g., Houma Navigation Channel). Each island complex contains one or more islands that are separated by passes. The North Central Gulf Coast System has seven large islands (Cat, Ship, Horn, Petit Bois, Dauphin, Perdido Key, Santa Rosa) and two smaller islands (Shell and Crooked) with 10 passes, two of which (Horn Island Pass and Pelican Passage) are dredged for navigation.

The barrier beaches in the study area either directly front the mainland (terrace headland or Strandplain-Chenier Plain) or front peninsulas. In some instances, river channels cut through the beaches to the Gulf but there are very few large embayments immediately behind these barrier beaches.

While there has been erosion along almost all barrier islands as they migrate both landward and along the coast, the most severe erosion has been identified for barrier islands within the Mississippi Delta System. Between 1880 and 1980, Louisiana's total barrier island area decreased from 98.6 km^2 to 57.8 km^2 for a loss of 41% (Penland and Boyd 1982). Within this century, these islands have been migrating landward at an average rate of 50 m/yr and have decreased in area at a rate of 65 ha/yr (Mendelssohn et al. 1983). Several islands in Louisiana lost land area because of dredging of navigation channels, marinas, and well access and pipeline canals, and because of natural shoreline erosion. As these islands migrate inland, the marshland behind them is also retreating inland as a result of erosion.

Emergent grasslands (fresh and non-fresh marsh vegetation) cover over 1.2 million ha of the study area with the largest expanse being in the Mississippi Delta System (Table 4.2). Wetland habitats have been delineated and digitized for each of the four coastal systems (Kimber et al. 1984; Wicker et al. 1980, 1983; Wicker 1980, 1983; Rathbun et al. 1987; National Wetlands Inventory 1985), but the data has been tabulated and analyzed only for Louisiana and Mississippi with regard to habitat type and change between the mid-1950's and late-1970's. Data presented in Table 4.2 is incomplete for three states and refers to only two habitat types (fresh and non-fresh marsh). However, the data provide an indication of the distribution of marshes and some areal changes among the coastal systems by state. For example, very large losses of fresh marshes occurred in both the Chenier Plain (42%) and Delta (55%) systems of Louisiana and Mississippi (46%), while there was very little loss for Alabama (less than 19%) during this same period. Data are

Table 4.1. Length of Barrier Island and Barrier Beach Shorelines by Coastal System. (Measured from 1:250,000 USGS maps.)

COASTAL SYSTEM	Barrier Shore Length in Km		
	ISLAND	BEACH	TOTAL
TEXAS BARRIER ISLANDS			527
Texas	461	66	
STRANDPLAIN/CHENIER PLAIN			311
Texas		69	
Louisiana		242	
MISSISSIPPI DELTA			162
Louisiana	105	57	
NORTH CENTRAL GULF COAST			366
Mississippi	48	41	
Alabama	28	44	
Florida	77	128	
TOTALS	719	647	1366

Table 4.2. Comparison of Area of Fresh and Non-fresh Emergent Vegetation by Coastal System in Study Area for 1950's and 1970's.

Coastal System	Fresh Marsh (area in ha) 1950s	Fresh Marsh (area in ha) 1970s	Non-Fresh Marsh (area in ha) 1950s	Non-Fresh Marsh (area in ha) 1970s	Change Fresh Marsh	Change Non-Fresh Marsh
Texas Barrier Island[1]	23,846*	n.a.	44,453*	n.a.	n.a.	n.a.
Strandplain-Chenier Plain						
Texas (Orange & Jefferson)[1]	8,035*	n.a.	65,059*	n.a.	n.a.	n.a.
Louisiana[2]	180,693	104,340	174,367	177,244	-76,353	+2,877
Mississippi Delta[3]	361,665	163,822	552,015	627,142	-197,843	+75,127
North Central Gulf Coast						
Mississippi[3]	2,633	1,418	26,932	25.920	-1215	-1,012
Alabama[4]	3,593	3,566	16,533	14,383	-27	-2,150
Florida[1]	n.a.	350	n.a.	8,752	n.a.	n.a.

Source:
1. Alexander, C.E. et al. 1986
2. Wicker, K.M. et al. 1983
3. Wicker, K.M. 1980
4. Rathbun, C.E. et al. 1987

* These acreages are under-calculated. Longley (1981) recently determined that there were 167,069 ha of wetlands in all of coastal Texas.

not available to calculate loss for Florida and Texas for either fresh or non-fresh marshes. In contrast, non-fresh marsh increased in the Louisiana Chenier Plain region (2%) and Mississippi Delta (13%). Non-fresh marsh area declined in Mississippi (4%) and Alabama (13%). Louisiana wetland loss occurred in both fresh and non-fresh zones, but there was an overall increase in salt marsh because salt marsh plants invaded formerly fresh marsh areas, thereby changing the association of the marsh zone. Fresh marsh was lost also because of dredging, erosion, fresh marsh dieback with replacement by open water, and reclamation for industrial, commercial, and residential development. Losses in Mississippi and Alabama were primarily a result of drainage and fill operations associated with commercial, residential, and industrial development and some shoreline erosion (Wicker et al. 1980, Rathbun et al. 1987).

A comparison of spatial distribution of barrier islands, barrier beaches, and wetlands, as well as areal changes that have occurred within these habitat types during the latter half of the twentieth century, provides a focus for the correlation between impacts of pipelines, navigation channels and facilities and changes in habitat type and geomorphic forms as a result of environmental variations. The correlation between the massive amount of barrier island and wetland loss in Louisiana (41% and 16%, respectively) within the past 22 years and the large number of OCS pipelines making landfall within the Chenier Plain and Mississippi Delta Systems are further evidence as to why there has been a focus on the role of OCS-related facilities in land loss and habitat change in some areas, primarily coastal Louisiana.

The causes for land loss in Louisiana are numerous and there is much controversy concerning the order of contributing factors. Major causes itemized recently, in order of decreasing importance, by Coleman et al. (1984:1) include the following:

1. Changes in the depositional site and stage in the delta cycle.
2. Composition and localized differential subsidence.
3. Sea level changes and their short-term variations.
4. Man's modification of the river system (dams and levees) which results in decreased sediment yield and overbank flooding.
5. Dredging of canals.
6. Biological degradation.
7. Fluid extraction.
8. Short-term catastrophic events (hurricanes and wave reworking).
9. Regional geosynclinal downwarping.
10. Long-term climate changes.

Of these causes, seven (numbers 1, 2, 3, 6, 8, 9 and 10) have been operative in this area prior to the accelerated rate of land loss, which began after the mid-1950's (Figure 4.1). The three causes that have become prominent since the mid-1950's and coincide with the period of accelerated land loss are numbers 4 (modification of the river system), 5 (dredging of canals), and 7 (fluid extraction).

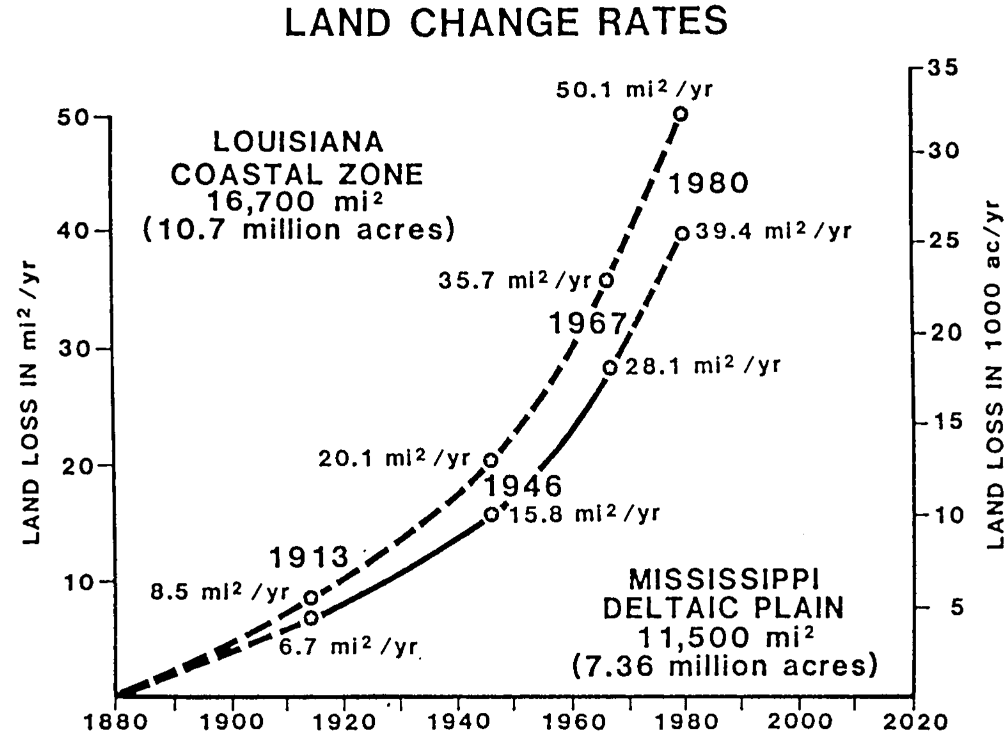

Figure 4.1. Comparison of curves showing rates of land loss for the Mississippi Deltaic Plain Region (Louisiana) and the Louisiana coastal zone region (Mississippi Delta and Chenier Plain): 1880-1980 (Gagliano 1984).

The coincidence of accelerated rates of land loss and proliferation of oil- and gas-related activities and facilities (both OCS and non-OCS) focused research on the causes of land loss and the petroleum industry, primarily rig access canals, pipeline canals, navigation channels, and infrastructures. One of the first reports concerning this causal relationship identified numerous negative impacts associated with oil and gas activities (St. Amant 1971) (Table 4.3). This article was followed by another study identifying and quantifying impacts of all types of canals, dredging activities, and land reclamation projects in coastal Louisiana (Gagliano 1973). These two initial studies enumerated most of the detrimental aspects of canals and/or navigation channels but did not include a systematic program of fieldwork to quantify cause and effect relationships between these activities; other environmentally detrimental processes; and observable, mappable impacts such as land loss.

OCS Pipelines

In the early 1970's, two major studies funded by the petroleum industry discussed the environmental problems confronting the gas pipeline industry and gathered field data to qualify and quantify selected effects of pipelines on coastal marshes within the Gulf Coast region (McGinnis et al. 1972, Willingham et al. 1975). The first study (McGinnis 1972) calculated that the average amount of habitat change directly attributed to pipeline canals varied from 0.25 ha/km for push-ditch canals to 1.5 ha/km for flotation canals, assuming the average flotation canal to be 15.2-m-wide at the water surface. Furthermore, land impacted by spoil disposal from push-ditch and flotation canals was 8.3 ha/km and 9.3 ha/km, respectively. In the second study (Willingham et al. 1975), field data collection focused on plant and animal productivity in nearshore marine, dune,

Table 4.3. Types of Impacts. Associated with Open, Non-backfilled Rig Cuts and Pipeline Canals and Navigation Channels.

Type of Impact	Impact Site	Research
Direct		
1. Removal of aquatic and wetland habitat (flora) and non-mobile fauna through dredging and spoil deposition (variable)	Wetlands	Gagliano 1973; St. Amant 1971; Gulf South Research 1980; Nichols 1959; Willingham et al. 1985; Hinchman and George 1987; McGinnis et al. 1971; Darnell 1976; Blackmon 1979; Dozier et al. 1983; Turner 1987; Craig and Day 1987
2. Impostion of uniformly deep, straight drainage channel within wetland formerly having only overland flow and/or sinuous channels decreasing in depth toward headland	Wetland	Gagliano 1973; St. Amant 1971; Gagliano and Wicker 1988; Turner et al. 1982; Craig and Day 1971
3. Loss or reduction in habitat quality and value	Wetlands Barrier dunes	Gagliano 1973; St.Amant 1971; Tabberer et al. 1985
4. Segmentation of natural physiographic units or forms	Wetlands barrier islands/ beaches	Gagliano 1973; Mossa et al. 1985; van Beek and Meyer-Arendt 1982
5. Destruction of historic and archaeological sites	Wetlands	Gagliano 1973
6. Release of large amounts of nutrients from the interstitial water of the dredged sediment (temporary)	Wetlands	Frankenberg and Westerfield 1968; Conner et al. 1976
7. Oxidation of sulfides to sulfuric acid (temporary)	Wetlands	Frankenberg and Westerfield 1968; Conner et al. 1976
8. Increase in turbidity and oxygen demand (temporary)	Wetlands	Frankenberg and Westerfield 1968; Conner et al. 1976; St. Amant 1971
9. Breaching of foredunes leaving them bare, unstable and susceptible to erosion (when backfilled but unvegetated)	Barrier islands/ beaches	Hinchman and George 1967 Mendelssohn et al. 1983.
10. Creation of sediment sinks for washovers	Barrier islands/ beaches	Penland et al. 1987; Mossa et al. 1985; van Beek and Meyer-Arendt 1982
11. Create weak spot in island	Barrier islands/	Penland et al. 1987; Mossa et al. 1982; van-Beek and Meyer-Arendt 1982
Indirect Impacts		
1. Floral and faunal changes due to saltwater intrusion (such as destruction of freshwater marshes, productive oyster grounds and muskrat areas and waterfowl feeding and wintering areas)	Wetlands	Craig and Day 1977; Darnell 1976; Gagliano 1973; St. Amant 1971; Tabberer et al. 1985; McIntire and Morgan 1980; Dozier et al. 1983; Turner 1987; Turner, Costanza & Scaife 1982
2. Land loss	Wetlands, barrier islands/ beaches	Gagliano 1973; St. Amant 1971; Willingham et al. 1975; Wicker et al. 1980, 1983; McGinnis et al. 1972; Turner 1987; Gagliano and Wicker 1988; Turner and Cahoon 1987; Howard et al. 1984

Table 4.3 concluded.

4. Accelerated erosion due to increased length of land-water interface exposed to waves from wind and boat-generated waves	Wetlands, barrier islands/ beaches	Gagliano 1973; St. Amant 1971; Johnson and Gosselink 1982; Craig and Day 1977; Turner 1987; Darnell 1977; Wicker et al. 1982; Howard et al. 1984
5. Increased freshwater runoff and loss of freshwater storage in some areas	Wetlands	Gagliano 1973; Craig and Day 1977;
6. Increased saltwater flooding of former freshwater areas	Wetlands	Gagliano 1973; St. Amant 1971; Craig and Day 1977; Darnell 1977; Wicker et al. 1982
7. Impoundment and flooding in some areas	Wetlands	Gagliano 1973; Darnell 1971; Turner 1987; Turner and Cahoon 1988; Mendelssohn et al. 1987; Mendelssohn and McKee 1987
8. Accelerated erosion due to increase in tidal prism volume	Wetlands, barrier islands/ beaches	Gagliano 1973
9. Alteration in circulation patterns in bays and sounds	Wetlands	Gagliano 1973; St. Amant 1971
10. Alteration and/or disruption of longshore drift of sand	Barrier islands/ beaches	Gagliano 1973; Penland and Boyd 1982; Mossa et al. 1985
11. Introduction of agricultural, urban, and industrial pollutants	Wetlands	Gagliano 1973; Craig and Day 1977
12. Changes in water cycling rates and volumes	Wetlands	St. Amant 1971
13. Silting considerable distances from site of activity resulting from change in direction and velocity of currents	Wetlands (interior water bodies)	St. Amant 1971
14. Increase the likelihood of island/beach breaching	Barrier islands/ beaches	Penland et al. 1987; Mossa et al. 1985; McIntire and Morgan 1980; van Beck and Meyer-Arendt 1982; Mendelssohn et al. 1987

marsh, and canal habitats containing pipelines. The research team found that "...the impact on the environment exists according to the degree of disturbance" (Willingham et al. 1975:4.1.8) which was in turn determined by the type of construction (flotation or push ditch) and type of mitigation, such as backfill, recontour, revegetate, and canal closure.

Field investigations of the backfilled portions of an OCS gas pipeline crossing Matagorda Peninsula, Bay, and mainland, Texas, revealed that:

Soil, plant, and animal systems from small profile dunes (1-6 feet) have tremendous resiliency compared to marshes. Small dunes appear to recover within a few years after installation of pipelines. Large primary dunes will surely require more time. These processes of dune reconstruction can be accelerated by plantings of dune vegetation, such that dune communities can be expected to recover within a few years, to soil, plant, and animal conditions similar to an undisturbed small dune (Willingham et al.:1975 3.1.9)

The impact of other OCS pipelines on marshland, as derived from field studies and overflight and air photo observations, was summarized as follows:

1. Discontinuous levees of low profile would seem to disrupt the marshland the least from a long-term (years and decades) aspect while material placed in high profile, continuous corridors would be the most detrimental.
2. Backfilling of canals approximately 5 to 10 ft wide and 3 to 4 ft deep when first constructed permitted plants and animals to completely reinvade the pipeline transect.
3. When backfilling had not occurred, production of marsh grasses and foliage-inhabiting animals were at lower levels (number of individuals, biomass, etc.) in the pipeline transect than in the control.
4. Root-matting by the marsh grasses and the build-up of sod-plant slabs were observed in the push-type canals...
5. ...in many canals that are 35 to 60-feet wide, particularly where boat traffic exists, erosion of the banks may be great.
6. ...when marshland is converted to canals, there seems to be a loss in overall primary or plant productivity, regardless of a partial compensation by aquatic plant productivity.
7. ...pipelining does not totally remove any of the important components of the ecosystem, although these components are usually affected more in pipelined areas than in control or referenced areas (Willingham et al. 1975:4.1.2 to 4.1.8).

Since this study, there have been at least four reports documenting the vegetation recovery rate along backfilled pipeline ROW in wetlands and on barrier islands: Chabreck (1979), Odegard et al. (1982), Tabberer et al. (1985), and Hinchman and George (1987).

In the late 1970's, Chabreck (1979) established a wetland revegetation and monitoring program (for high and low brackish and high and low salt marsh) for a 24-in OCS gas pipeline emplaced between east Texas and west Louisiana using a push ditch (2.4 m wide x 1.5 m deep) and backfill technique. There were three primary objectives to this study:

1. Restore vegetation within the disturbed portions of the construction zone at densities equivalent to those on adjacent undisturbed areas.
2. Compare natural revegetation rates in single-ditched and double-ditched areas.
3. Develop alternative revegetation methods to augment natural revegetation if necessary (Chabreck 1979:1).

Delay in completion of the pipeline which delayed replanting for the season, drought, and cattle grazing along a portion of the ROW influenced the revegetation program in certain instances, but these were not factored into the conclusions. Chabreck's (1979) study revealed that after two years, natural vegetation recovery was virtually complete on the low salt marsh ROW but less than 50% completed on the high salt marsh ROW area in Texas. In Louisiana, the ROW area had recovered satisfactorily but "plant density and cover were slightly less than for that of control plots" (Chabreck 1979:10). His comparison of natural recovery rates with planted recovery rates indicated that "...planting had no significant effect on the recovery rate of vegetation in the areas planted" (Chabreck 1979:11). A comparison of double-ditch versus single-ditch construction indicated that "...the double-ditch method produced slightly greater revegetation rates" (Chabreck 1979:11).

Odegard et al. (1984) studied the recovery rate of vegetation on Padre Island two years after it was disturbed by emplacement of a pipeline in 1979. They concluded that "data derived from this study indicate that vegetative cover, species composition, and diversity of the ROW disturbed during pipeline construction are trending toward equilibrium with the associated undisturbed control area adjacent to the ROW" (Odegard et al. 1982:247). Furthermore, "visual evaluation confirmed that the impacts of Hurricane Allen on the vegetation and topography of the study area were equally borne by the ROW and adjacent undisturbed areas" (Odegard et al. 1982:247). Hinchman and George (1987) continued the observation on the same Padre Island pipeline ROW studied by Odegard et al. (1984) and confirmed that by 1984 "the entire ROW was visually indistinguishable from the adjacent undisturbed area."

A study by Tabberer et al. (1985) also assessed the impact of five push-ditch-emplaced pipelines on Louisiana wetlands by focusing on two objectives: 1) determine and quantify the effects of pipeline installation on fish and wildlife habitat in the brackish and saline marsh zones of coastal Louisiana, and 2) determine whether the habitat is recovering after construction. Their conclusion based on field observations, analysis of vegetation canopy cover, and determination of Habitat Suitability Indices (HSI) for selected fauna was that pipeline construction results in "marsh loss and the reduction in habitat value for fish and wildlife" (Tabberer et al. 1985:35). In general, they found that canopy cover in the pipeline corridor was less than 70% of that recorded in the control corridor and could be as high as a 90% reduction over the pipeline. However, 5 m from the pipeline, canopy cover reduction was about 50%. The degree of impact, however, varied by geographic region and was greatest in the Mississippi River Deltaic Plain Region, an area of highly organic soils. Reduction in HSI values was primarily related to removal of emergent vegetation which provides food and cover.

The interpretation, mapping, and digitizing of 1956 and 1978 habitats in coastal Louisiana (Wicker 1980, 1983; Wicker et al. 1980, 1983) provided a detailed, coastwide base which could be analyzed for establishing causal relationships between the construction of rig access, pipeline canals, and navigation channels and land loss and/or habitat change. Using habitat map data that showed canals represented about 2.4% of Louisiana's coastal area in 1978 and about 10% of the direct land loss between 1956 and 1978, Turner et al. (1982) looked for a pattern of land loss that could be correlated to canal density. Their study concluded that "land loss rates across the coastal zone since the 1890's, among hydrologic units, and within areas of similar substrates and equal distances from the coast, are all positively related to estimates of canal density" (Turner et al. 1982:73). Furthermore, they determined that "coastal erosion rates in Louisiana are largely an indirect result of canal dredging activities or use" and that "...canals are causal agents for at least a majority (perhaps as much as 90%) of the present land loss..." (Turner et al. 1982:73, 82).

With regard to the cause of barrier island erosion, the Turner et al. (1982) study took issue with previously derived observations such as those proposed by McIntire and Morgan (1980). The Turner et al. (1982) study proposed that "...increases in barrier island erosion rates may be more symptomatic of the problem" of marsh loss rather than the cause. They postulated that as marshland behind the islands eroded, a larger tidal prism with greater water volume and velocity would develop and negatively impact water and sediment balances for the soil- and dune-binding plants, thus increasing the rate of barrier island loss.

The earlier study by McIntire and Morgan (1980) was undertaken at the request of the Louisiana Department of Justice to determine what, if any, impact OCS gas pipelines had on wetland and barrier island erosion. Viewing a series of aerial photographs of the Grand Terre barrier island complex, taken pre- and post-pipeline canal construction, they determined that one OCS gas pipeline canal...accelerated the rates of coastal retreat. More significantly, presence of the canal aided in the break-up of the deltaic barriers, especially the eastern Grand Terre Islands. This in turn allowed increased tidal salt water exchange with the bay whose increased salinity resulted in the vegetational and ecological changes documented elsewhere (McIntire and Morgan 1980:3).

No other factors, such as hurricanes, subsidence, tidal prism enlargement, natural rate of shoreline retreat or barrier island breakup, were factored into this analysis of the role one pipeline canal had in the destruction of the Grand Terre Barrier Island complex or the interior marsh loss.

The Morgan and McIntire (1980) study was one part of a larger research effort (Gulf South Research Institute [GSRI] 1980) to document the impact of OCS gas pipelines in the entire coastal zone of Louisiana. Using the area of impact calculated by McGinnis et al. (1972), they determined that the 2,378 km of OCS gas pipelines had impacted 23,345 ha by converting 3,592 ha to canal and 19,754 ha to spoil. Furthermore, it was determined that between 1932 and 1978 over 5,670 ha of shoreline eroded with the land loss rate increasing progressively:

1932-1954	299 ac/yr (121 ha/yr)
1954-1969	308 ac/yr (124 ha/yr)
1969-1978	352 ac/yr (142 ha/yr) (GSRI 1980:27)

An inference was made that the rate of shoreline erosion was related to OCS activities because "the increase in rates of land loss parallels the increase in offshore oil exploration" (GSRI 1980:27).

Later studies have also made the correlation between oil and gas activities and accelerated barrier island erosion (Penland et al. 1987, Mossa et al. 1985, van Beek and Meyer-Arendt 1982). Canals, rig cuts, and navigation channels have been blamed for: direct land loss due to dredging and indirect loss due to disruption of sediment transport; removal of sediment from the system through deposition into canal sinks; and breaching of barrier islands, as a result of channels left open and subject to scouring, and erosion of backfilled weak areas vulnerable to overwash and erosion.

Studies by Mossa et al. (1985) and Penland et al. (1987) described two patterns of barrier island canals, shore-normal and shore-parallel. Both types are considered to serve as sediment sinks for washovers, thereby removing sediment from the system, and to leave weak areas which may result in breaching. The shore-parallel canal was considered to be the one more capable of impact because its location lengthwise of an island removes more land both directly upon dredging and indirectly through subsequent erosion.

In view of the controversy over causes of land loss and habitat changes in Gulf Coast environments, a comprehensive study was undertaken recently to "...isolate and quantify the impacts of OCS-related activities upon habitat changes..." in coastal marshes from eastern Texas to western Mississippi (Turner and Cahoon 1987:5). The direct and indirect impacts of OCS-related activities, e.g., pipeline canals, facilities and navigation channels, with regard to habitat change and land loss were investigated in relation to other causes for land loss and habitat change such as salinity increases, subsidence, and alteration in sediment input from the Mississippi River.

Analysis of previously interpreted habitat changes between 1955/56 and 1978 for Louisiana and western Mississippi (Wicker 1980, 1981; and Wicker et al. 1980, 1981) revealed that 288,686 ha of coastal land was converted to open water (Turner and Cahoon 1987). For the Louisiana portion of the study area, wetland loss was 288,424 ha, of which 25.6% or 73,905 ha were lost as a result of the direct impact of activities which created spoil, canals, and urban and agricultural development. Quantification of direct impacts attributed to OCS activities are presented in Table 4.4.

OCS pipelines directly impacted 12,012 ha for an average impact rate of 2.49 ha/km (Baumann et al. 1987:57). Impact includes habitat change as a result of canal dredging and spoil deposition. Using a graph for comparison of canal width and impact in acres per mile (McGinnis et al. 1972) results in an area of impact that is approximately 82 ft or 25 m wide. The direct impacts, however, were found to be variable and dependent upon construction techniques, geologic region (deltaic versus chenier plain), habitat type, age and diameter of pipeline, and other factors that were not examined (Baumann et al. 1987:66). Impacts were higher in the wetland habitats in the deltaic plain where the pipelines were randomly distributed and not backfilled. Impacts were lower in the chenier plain, on beach habitats, and when the pipelines were in a corridor and backfilled (Turner and Cahoon 1987:11). Furthermore, older, larger diameter pipelines were said to have had higher impacts than younger, smaller-diameter pipelines (Turner and Cahoon 1987:11).

OCS Navigation Channels

There have been few studies focusing specifically on impacts of OCS navigation channels. Of the six channels CEI identifies as being constructed, at least partially for OCS

Table 4.4. **Direct Impacts to Wetlands Attributable to OCS Activities in the East Central Coastal Area of the Gulf of Mexico (Baumann et al. 1987:60, Exec. Summary, Main Vol.).**

		Pipelines	Navigation Channels	Totals
Canal:	Length (km)	4,440	331	4,771
	Area (ha)	8,507	34-2,005	8,541-10,512
Spoil:	Length (km)	849	242	1,091
	Area (ha)	3,466	23-880	3,489-4,346
Facilities:	Length (km)	11.3	—	11.3
	Area (ha)	38.5	—	38.5
Totals[a]:	Length (km)	4,827	331	5,158[a]
	Area (ha)	12,012	58-2,885	12,070-14,897

[a] Totals are not cumulative, e.g., pipeline can have both spoil length and canal length along the same section of line. Facility area can occupy spoil area.

activities (see Chapter 3), all were completed prior to the requirements for a detailed environmental impact statement. Furthermore, except for the Matagorda Ship Channel (USACE, GAL. 1980), regular surveys are not undertaken to ascertain the impact of these channels on adjacent coastal areas and processes, and few impact statements have been prepared for maintenance dredging (USACE, GAL. 1974) or modification (CEI 1977).

Studies of other navigation channels have indicated that there are a number of impacts common to man-made channels, including man-made navigation improvements to existing channels, such as the following:

1. Land loss due to initial dredging (Gagliano 1973, Baumann et al. 1987).

2. Habitat loss due to initial dredging, spoil deposition, and jetty construction (Gagliano 1973, Baumann et al. 1987).

3. Subsequent erosion along unconsolidated, unprotected canal banks due to wind and boat/ship-generated waves (Howard et al. 1984, Johnson and Gosselink 1982).

4. Disruption of littoral drift resulting in accretion on the updrift side of jetties and erosion on the downdrift side (Coastal Environments, Inc. 1977; Everts 1980; Dantin et al. 1984, 1978; Peyronnin 1962; USACE, GAL. 1980).

5. Saltwater intrusion along a deep canal dredged from a saline environment into a freshwater environment (Wang 1987, Wicker et al. 1982, Gosselink et al. 1979).

6. Destruction of freshwater environments as a result of saltwater intrusion (Gosselink et al. 1979, Baumann et al. 1987, Wicker et al. 1982).

The only study previously directed at ascertaining the impact of OCS navigation channels was focused on Louisiana. It determined that these channels directly impacted, at a maximum, 2,885 ha of coastal area, resulting in a loss of 2,293 ha of wetland and beach habitat (Baumann et al. 1987:67). OCS navigation channels were defined by OCS use and it was observed that "OCS traffic appears to comprise a relatively small percentage of the total commercial traffic using navigation channels..." (Baumann et al. 1987:67).

OCS-related Facilities

There have been few studies to quantify the impact of OCS-related facilities on coastal environments. Two of the earliest reports identified the types of facilities associated with OCS exploration and production activities and provided data on area of land and water depth required by such facilities, in general, as well as the type of impact on air and water quality and solid waste generated (New England River Basins Commissions 1976; Clark et al. 1978) (Table 4.5).

A study on the oil and gas industry's impacts on coastal Louisiana focused on land use and socioeconomic patterns (Davis and Place 1983). One major finding is that "the limited land on the natural levees was being transformed into commercial, industrial, and transportation corridors" to serve hydrocarbon-related industries (Davis and Place 1983:49). The development of these corridors was accompanied by an expansion into adjacent wetlands using land reclamation projects to create dry, habitable ground (Davis and Place 1983). Furthermore, a comparison of urban and built-up land use by settlement strips in coastal Louisiana in 1972 revealed that there was "a very large area devoted to extractive use compared to other urban or built-up uses" (Davis and Place 1983:56). However, these data do not reflect how much of the extractive development replaced former wetlands or water bodies.

The only study attempting to quantify the impact of OCS facilities on coastal wetlands was undertaken by Baumann and others (1987) and utilized habitat data from 1978 air photo interpretations (Wicker et al. 1980, 1983). These data, however, appear to only pertain to coastal Louisiana.

OCS-related facilities were responsible for between 11,589 and 13,631 ha of the direct impacts or 4.0 to 4.7% of all wetland loss between 1955/56 and 1978. OCS facilities had an indirect impact, accounting for 10,000 to 36,000 ha or 4 to 13% of all wetland loss in the study area. Combined, OCS facilities directly and indirectly caused 8 to 17% of all the land loss or 22,000 to 50,000 ha (Turner and Cahoon 1987:22).

Mitigation Measures Commonly Used

Mitigation is an action that eliminates or reduces an adverse impact to an acceptable level. Mitigation can be concurrent with the unavoidable action and involve construction techniques which will diminish the impacts. Mitigation can also occur after construction and involve actions to restore the site to as near pre-construction conditions as possible. If environmental impacts occur despite the mitigation actions taken during or after construction, the damage can be lessened through compensation by creating, restoring, or enhancing an environment similar to that unavoidably impacted by the action.

Table 4.5. Onshore Impacts Related to Selected OCS Activities (After New England River Basins Commission 1976).

	REQUIREMENTS AND IMPACTS				
ONSHORE FACILITY	LAND	WATER FRONT DEPTH	AIR EMISSIONS	WASTEWATER CONTAMINANTS	SOLID WASTES
TEMPORARY SERVICE BASES	4 - 6 ha ALL WEATHER HARBOR	4 - 6 m AT PIER	HYDROCARBONS FROM FUEL STORAGE TANKS AND VEHICLE OPERATION	HYDROCARBONS, HEAVY METALS FROM BILGE AND BALLAST WATER	OIL CONTAMINATED DRILL CUTTINGS
PERMANENT SERVICE BASES	10 - 20 ha ALL WEATHER HARBOR	4 - 6 m AT PIER	HYDROCARBONS FROM FUEL STORAGE TANKS AND VEHICLE OPERATION	HYDROCARBONS, HEAVY METALS FROM BILGE AND BALLAST WATER	OIL CONTAMINATED DRILL CUTTINGS
REPAIR AND MAINTENANCE YARDS	VARIABLE	VARIABLE	VARIABLE	VARIABLE	VARIABLE
STEEL PLATFORM FABRICATION YARDS	81 - 405 ha ON NAVIGABLE WATERWAYS	4 - 9 m AT PIER	SAND AND METAL DUST, HYDROCARBONS, ORGANIC COMPOUNDS, CARBON MONOXIDE, SULFUR OXIDES, NITROGEN OXIDES	HEAVY METAL, PARTICULATES	PACKAGING MATERIALS, METAL SCRAPS, DEBRIS
STEEL PLATFORM INSTALLATION SERVICE BASES	2 ha ON WATERFRONT	4 - 6 m AT PIER	VARIABLE	VARIABLE	VARIABLE
GENERAL SHORE SUPPORT	VARIABLE	VARIABLE	VARIABLE	VARIABLE	VARIABLE
PIPELINES AND LANDFALLS	24 ha IF TERMINAL REQUIRED	NA	MINIMAL, CHIEFLY HYDROCARBONS NITROGEN OXIDES, AND SULFUR OXIDES FROM COMPRESSORS	NA	NA
PIPELINE INSTALLATION SERVICE BASES	2 ha	4 - 6 m	NA	NA	NA
PIPE COATING YARDS	40 - 60 ha ON WATERFRONT	6 - 9 m	CARBON MONOXIDE, SULFUR OXIDES, NITROGEN OXIDES, HYDROCARBONS, PARTICULATES, PROCESS MACHINERY, LEAKS FROM VALVES, SEALS, STORAGE TANKS, AND VEHICLE EMISSIONS	THERMAL EFFLUENT, ANTI-FOULING CHEMICALS, CONTAMINATED PROCESS WATERS, BOD, COD, ETC.	CONTAMINATED PROCESS SOILDS AND EFFLUENT SOLIDS REQUIRING SPECIAL HANDLING, VARIOUS PACKAGING AND DOMESTIC WASTES
PARTIAL PROCESSING PLANTS	6 ha / 100,000 BARRELS PROCESSED	NA	HYDROCARBONS, HYDROGEN SULFIDE, SULFUR OXIDES, AND NITROGEN OXIDES	SUSPENDED SOLIDS, OIL AND GREASE HEAVY METALS, PHENOLS, HALOGENS AND CHROMIUM	
GAS PROCESSING AND TREATMENT PLANTS	20 - 30 ha	NA	HYDROGEN SULFIDE, SULFUR OXIDES, HYDROCARBONS, PARTICULATES, CARBON MONOXIDE, AND NITROGEN OXIDES	DISSOLVED HYDROCARBONS, SULFURIC ACID, CHROMIUM, ZINC, PHOSPHATES BASES, AND SULFITE	SLUDGES, SCALE, SPENT DESSICANTS FILTRATION MEDIA, OIL ABSORBANTS
MARINE TERMINALS (1)	12 ha WATERFRONT	15 - 18 m SHELTERED WATER AT MID-DEPTH PIER OR MOORING BUOY	HYDROCARBONS FROM TANKS AND TRANSFERS, EXHAUST EMISSIONS FROM VESSELS AND COMPRESSORS	BOD, COD, SUSPENDED SOLIDS, OIL AND GREASE FROM BILGE, BALLAST STORM WATER, CHRONIC SMALL SPILLS, POSSIBLE LARGE SPILLS	CONTAMINATED SLUDGE AND SEDIMENTS
REFINERIES	405 - 608 ha	10 - 15 m	PARTICULATE MATTER, SULFUR OXIDES, CARBON MONOXIDES, HYDROCARBONS	HYDROCARBONS, ALKALINE SUBSTANCES, PARTICULATES, METAL FRAGMENTS	CONCRETE, METAL SCRAPS, CONTAMINATED AND UNCONTAMINATED DEBRIS
PETROCHEMICAL COMPLEXES	VARIABLE	VARIABLE	VARIABLE	VARIABLE	VARIABLE
CONCRETE PLATFORM FABRICATION YARDS (2)	MINIMUM 20 ha	10 - 15 m AT PIER 46 - 91 m ADJACENT	SAND, CEMENT, AND METAL DUST, HYDROCARBONS AND ORGANIC COMPOUNDS CARBON MONOXIDE, SULFUR OXIDE, NITROGEN OXIDES FROM VEHICLES	PARTICULATES, HEAVY METALS, CHEMICALS	PACKAGING MATERIALS, METAL SCRAPS, CONTAMINATED AND UNCONTAMINATED DEBRIS

(1) There are terminals on the Gulf Coast Waterways, such as on the Mississippi River, but the maintained drafts are from 7.6 to 12.8 m.

(2) Most platforms on the Gulf Coast are welded metal and are floated out of Navigation Channels maintained at depths of 4.5 to 6.0 m.

Almost concurrent with the laying of the first OCS pipeline, it was recognized, especially by some wetland owners, that pipeline canals could have negative impacts on coastal environments (Resen 1956, Ivey 1958, Myers 1962). Open, undammed pipeline canals were seen as conduits for fresh or saline waters which could alter pre-canal water salinities and impact production of fisheries, oysters, and muskrats (Ivey 1958). Some of the earliest canals were, therefore, blocked by dams at each water body intersection in order to (1) prevent changing the channel flow, (2) guard against erosion, and (3) prevent saltwater intrusion into marshes (Resen 1956:90).

Some landowners also required that canals, both flotation and push-pull, be backfilled, at least in areas having valuable renewable resources, such as muskrat-inhabited marshes leased for trapping or portions of wildlife refuges. Leaving breaks in the spoil or alternating spoil deposits was another method used as early as the mid-1950's to lessen environmental impact by preventing alteration of the hydrologic regime and impoundment of flood and surface water runoff.

By the early 1980's, each of the Gulf coastal states had developed separate guidelines for canal dredging and spoil deposition or incorporated such guidelines into their coastal zone programs (Table 4.6). From Table 4.6, it appears that Texas has the fewest guidelines to lessen environmental impact. However, Texas has been developing a comprehensive mitigation program to lessen impacts on state-owned submerged lands. While Texas does not have a Federally-approved coastal zone program, the Texas General Land Office (GLO) does manage 1.42 million ha of submerged, State-owned land and issues leases and easements for a variety of projects, including pipelines, on these lands. Where environmental damage associated with a GLO lease or easement is unavoidable, the State requires mitigation, such as revegetation of disturbed area, recontouring of land, and replacement of oyster reefs (Davenport and Irby 1987). In particular, mitigation projects are to:

1. be located at or near the site of the damage,
2. provide in-kind replacement of habitat lost,
3. replace habitat or compensate for damage at a ratio of 3 to 1 (Davenport and Irby 1987:2550).

Table 4.7 contains a list of mitigation practices associated with the three main types of pipeline emplacement techniques. These actions are becoming more commonly used as a result of special conditions being attached to the permit or at the insistence of the landowners granting ROW.

Table 4.6. **Guidelines for Construction of Pipelines in Gulf Coast States.**

	GUIDELINES	TEXAS	LOUISIANA	MISSISSIPPI	ALABAMA	FLORIDA
1	Bury Pipeline Below Gulf Inlet, River or Stream Crossing at Least to Federal Standards (-48" in soil and -24" in consolidated rock under rivers, streams, and harbors; -36" in soil and -18" in consolidated rock in offshore locations less than 12 feet deep)	* (-24")	* (-48") (-36")	*	* (-24")	*
2	Evenly Backfill Trenches to Reasonably Conform to Surrounding Area's Bottom Profile	*	*	*	*	-
3	Take Erosion Prevention Measures at Shoreline	*	+	+	*	*
4	Double Ditching Will be Encouraged	-	-	*	-	-
5	Use "Push Ditch" Method and Backfill or Method that does not Degrade Wetlands	-	*	*	*	*
6	Revegetate Disturbed Wetlands	-	+	*	*	*
7	Plug and Maintain Plug at all Waterway Crossings Where Non-Navigation Canals, Channels, Ditches Connect More Saline Areas with Fresher Areas	-	*	+	-	-
8	Select ROW to Avoid Shell Reefs, Submerged Grassbeds, and Marshes	+	+	+	+	+
9	Avoid or Minimize Damages to Important Spawning Nesting, Nursery or Rearing Areas	-	*	*	*	-
10	Avoid Adverse Impacts on Areas of High Biological Productivity or Irreplaceable Resource Areas	-	*	-	*	*
11	Utilize Proceedures to Protect Sea Turtles and Their Nests Between May 1 and Oct. 30	-	-	-	-	*
12	Use Existing Corridors, ROWs, Canals and Streams	-	+	+	-	-
13	Permanent Blockage of Surface Drainage is Prohibited	-	-	*	-	-
14	Avoid or Minimize Clearing of Natural Vegetation from River or Stream Banks, so that a Screen of Natural Vegetation is Left in the ROW	*	-	-	*	-
15	Dredging Shall Not Traverse Barrier Islsands (Nor Adversely affect Barrier Islands)	-	*	*	*	-
16	If Beach, Tidal Pass, Reef or other Natural Gulf Shoreline Must be Travesed, it Must be Restored Immediately Upon Completion of Construction	-	*	-	*	*

*	Always Required
+	Required to Maximum extent Feasible/Practicable
-	Not Specifically Noted
1	Texas General Land Office 1975
2	Louisiana Department of Natural Resources and U.S. Department of Commerce 1980, Troy 1983
3	Mississippi Department of Wildlife Conservation and U.S. Department of Commerce 1983, Ladner et al. 1984
4	Alabama Department of Conservation & Natural Resources 1982, Alabama Department of Environmental Management 1985
5	Florida Department of Natural Resouces, Division of Beaches and Shores, n.d.

Table 4.7. **Examples of Mitigation Actions that can be Implemented to Lessen Long-term Impacts of Pipelines (after Longley et al. 1978).**

Mitigation	Upland	Flotation	Push-Pull
Plan route to impact minimum amount of wetlands and shallow water bodies	x	x	x
Recontour site surface (uplands)	x		
Recontour site subsurface (water bottoms)		x	
Replace top soil on top (double ditch)	x	x	x
Revegetate site	x		x
Dam canal at all intersecting water bodies	na	x	x
Backfill canal as soon as possible	na	x	x
If backfill not possible, place spoil so as not to interfere with natural wetland hydrology	na	x	x
Incorporate canal and spoil into wetland management plan for site or region	na	x	x
During construction, have buggy-mounted dragline traverse center of area to be dug to lessen area of spoil and vegetation being impacted	na	na	x
Minimize trips to and from site in marsh buggy during survey and dredging process to lessen area impacted by tracks	na	x	x
Where necessary, install water control structures to facilitate management of altered wetland site	na	x	x
Directionally drill under environments to be avoided, such as barrier beaches	x	x	x

CHAPTER 5: FEDERAL AND STATE ENVIRONMENTAL LAWS AFFECTING THE LOCATION OF OCS PIPELINE CORRIDORS ACROSS BARRIER ISLANDS, BEACHES, AND COASTAL WETLANDS

Rod E. Emmer

Introduction

Today, Federal and State environmental laws, regulations, and guidelines influence the location of transportation corridors for pipelines and the installation techniques employed during construction. But such control of hydrocarbon pipeline routes within the states bordering the Gulf of Mexico was certainly not always the case. Earliest pipelines crossed sparsely settled areas where ownership was in large tracts. Lines were laid from the beginning point to the terminus in as straight a route as possible and as quickly as possible (Hall 1959). In most instances, as problems were encountered they were simply avoided by offsetting the pipeline. Even into the 1960's the critical two elements in pipeline design were construction techniques and safety of the facility (Bell 1963); the environment was only considered in its realm as a hazard. For example, Hangs and Lewis (1963) cite the crossing of major rivers as expensive and often difficult. In order to successfully overcome the obstacle, a company had to consider the technical, economic, and political factors before proceeding with its project. Cursory mention is made of environmental regulations or concerns, in this case only a passing reference to the presence of marine organisms and the fact that the U.S. Fish and Wildlife Service had an interest in preserving oyster beds and marine life in bays. Gard (1963) treats marshes, swamps, bays, and lakes as impediments which could be conquered by engineering practices. Horne (1960) refers to swamps and streams as pitfalls in pipeline construction that should be avoided.

General public awareness of and concern for the environment began in the mid-1960s when more popular books documenting the deteriorating air and water systems were published and, of greater significance, read by the general public. In addition, television graphically brought the catastrophic scale of pollution into the living rooms of every American. Grounding of the Torry Canyon off the south coast of England and the Santa Barbara drilling accident showed tar on the beaches, waterfowl covered with oil, and a devastated local economy. In response to the changing public attitude about the environment, Congress passed the National Environmental Policy Act (NEPA) of 1969 (42 U.S.C. 4321 - 4347). The NEPA forced consideration of unquantifiable environmental amenities and values in the decision-making process. No longer would projects be evaluated only on economic and technical considerations. Other legislation either followed from Congress or were reinterpreted by the agencies to provide greater protection for the environmental resources of the nation.

Safety is an an important concern during the construction and operation of pipelines because leaks, spills, and explosions jeopardize the public safety and the natural environmental values and integrity of the surrounding areas. The Materials Transportation Bureau and the Office of Operations and Enforcement, U.S. Department of Transportation, are responsible for safety (Code of Federal Regulations, Title 49, Chapter I, Parts 191-193 and 195). From the environmental perspective, these regulations appear to have minimal effect on locating pipeline corridors. When natural hazards, such as washouts, floods, unstable soils, landslides, or other problems are encountered, transmission lines are designed and built to protect the facilities. In the open water these hazards include shifting bottom sediments, currents, and hurricanes, as well as ship anchors and fishing operations. While engineering practices can mitigate these potential problems, the larger pipelines would tend to avoid the more densely populated stretches of coast. In general, the industry relies on technology to overcome most of the physical and cultural obstacles to locating and building a pipeline (Vincent-Genod 1984). But technology by itself is only a part of the methodology when locating pipeline corridors. Regulations to protect the quality of the environment can now significantly influence pipeline placement.

The purpose of this section is to identify the Federal and State agencies who could have a significant role in the location of pipeline corridors across barrier islands and beaches and coastal wetlands.

Federal Role

By 1982 thirty-eight Federal programs in six departments and four agencies affected activities in wetlands of the United States (Zinn and Copeland 1982). This has increased since then with the enactment of the Barrier Island Resources Program. The more significant pieces of Federal legislation are outlined in Table 5.1. Minerals Management Service does not exercise jurisdiction over the location and installation of OCS pipelines once they reach state waters (MMS 1983). Most of the responsibility for the selection of pipeline corridors and the construction of the facility, excluding the safety aspects, belongs to the U.S. Army Corps of Engineers through its Section 404 permit process (Clean Water Act, as amended; 33 U.S.C. 1251 et seq.) and the Section 10 permit process (Rivers and Harbors Act of 1899; 33 U.S.C. 401 et seq.). Section 10 applies when a pipeline crosses navigable waters. Pipeline applications for a Corps of Engineers Section 404 permit, discharge of dredged or fill material into wetlands, are under the provisions of 33 CFR 330.5 (a) (12), which declares these activities to be covered by a nationwide permit. A nationwide permit (33 CFR 325.5) is a type of general permit issued by the Corps for selected activities throughout the United States. When the project meets specified conditions (Table 5.2), the project may proceed without the need for an individual or regional permit.

The Corps of Engineers has issued Regional Permits for minor structures and activities within Alabama and Mississippi (Regional Permit Nos. ALG 16 and MSG16, respectively). Submerged pipelines may be loosely laid or buried and the trench shall be backfilled. The bottom shall be restored to preconstruction status and excess material shall be placed on confined, upland sites. In addition to that which is required by both states, Alabama requires revegetation of wetlands with native species if the area has not revegetated naturally within one year of completion of the project. General and special conditions apply to all activities authorized by the permits.

Within the Galveston District, USACE, pipeline construction, specifically the placement pipelines by directional drilling in all navigable waters within the District, is processed under the provisions of a general permit. Standard General Conditions apply (ENG FORM 1721, Sep 82). In addition, 13 Special Conditions relating specifically to the authorized work are identified and include such actions as avoiding wetlands, submerged vegetation, and reefs; restoring impacted areas to preproject conditions; not conducting any work near Whooping Cranes or Eastern Brown Pelicans during critical periods; and not affecting National Register properties.

Galveston has also issued a General Permit for construction of subaqueous pipeline crossings which do not exceed 152 m in length. Twenty-six Special Conditions apply to a project, including protection of wetlands, cultural resources, and threatened or endangered species, and coordination with Texas and Louisiana agencies.

Table 5.1. The More Significant Pieces of Federal Legislation that May Affect the Siting of Transportation Corridors through the Coastal Wetlands.

Section 401 of the Clean Water Act, as amended, 33 U.S.C. 1341 - the discharge of pollutants into waters of the United States and compliance with applicable effluent limitations and water quality standards;

Section 404 of the Clean Water Act, as amended, 33 USC 1251 et seq. - establishes a permit procedure for activities requiring discharge of dredged or fill material into waters of the United States or wetlands.

Section 10 of the Rivers and Harbors Act of 1899 33 USC 401 et seq. - prohibits obstructing or filling of navigable waterways.

Section 307(c) of the Coastal Zone Management Act of 1972, as amended 16 U.S.C. 1456(c) - the activity must be consistent with the state's federally approved coastal zone management program;

Section 302 of the Marine Protection, Research and Sanctuaries Act of 1972, as amended 16 U.S.C. 1432 - the designation of marine sanctuaries in ocean and coastal waters necessary for the purpose of preserving or restoring such areas for their conservation, recreation, or aesthetic values;

Fish and Wildlife Act of 1956 16 U.S.C. 742a, et seq.

Migratory Marine Game-Fish Act 16 U.S.C. 760c - 760g

Fish and Wildlife Coordination Act 16 U.S.C. 661 - 666c - the protection of the quality of the aquatic environment as it affects the conservation, improvement, and enjoyment of fish and wildlife resources. Consultation with the U.S. Fish and Wildlife Service, the National Marine Fisheries Service, and the state wildlife agency is mandatory;

The National Historic Preservation Act of 1966 16 U.S.C. 470 - the protection of properties listed in the National Register of Historic Places or which are eligible for such listing;

Preservation of Historical and Archaeological Data Act of 1974 16 U.S.C. 469 et seq. - recovery and preservation of data from significant historical and archaeological sites; and

The Endangered Species Act 16 U.S.C. 1531 et seq. - to conserve threatened and endangered species and the ecosystems on which these species depend.

Table 5.2. **Conditions that Determine Whether a Project May Receive a Nationwide permit from the Corps of Engineers.**

1. That any discharge of dredged or fill material will not occur in the proximity of a public water supply intake;

2. That any discharge of dredged or fill material will not occur in areas of concentrated shellfish production unless the discharge is directly related to a shellfish harvesting activity authorized by paragraph (a)(4) of this section.

3. That the activity will not jeopardize a threatened or endangered species as indicated under the Endangered Species Act, or destroy or adversely modify the critical habitat of such species. In the case of Federal agencies, it is the agencies' responsibility to review its activities to determine if the action "may affect" any list species or critical habitat. If so, the Federal agency must consult with the Fish and Wildlife Service and/or National Marine Fisheries Service;

4. That the activity will not significantly disrupt the movement of those species of aquatic life indigenous to the waterbody (unless the primary purpose of the fill is to impound water);

5. That any discharge of dredged or fill material will consist of suitable material free from toxic pollutants (see Section 307 of Clean Water Act) in toxic amounts;

6. That any structure or fill authorized will be properly maintained;

7. That the activity will not occur in a component of the National Wild and Scenic River System;

8. That the activity will not cause an unacceptable interference with navigation; and

9. That the best management practices listed in 33 CFR 330.6 should be followed to the maximum extent practicable.

Data Sheet from New Orleans District, USACE, Surveillance Enforcement Section. Undated.

Regardless of whether the project meets the above conditions, a pipeline does require a Section 10 permit if it crosses navigable waters. The need for these permits automatically initiates coordination with several Federal agencies, such as, the U.S. Fish and Wildlife Service, the National Marine Fisheries Service, and the Environmental Protection Agency.

The review process forces consideration of threatened and endangered species, cultural resources, the integrity of the renewable resource base of the coastal zone, consistency with the state's approved coastal zone management program, and the impacts of the project on water quality of the project area. Therefore, in order to eliminate delays in project implementation it is easiest, although probably not least expensive, to avoid selected areas. Maps 1C-10C and 1D-10D, Vol. II show sensitive areas that should be avoided when planning a transportation corridor. In addition, it would be wise not to discharge into breeding areas for migratory waterfowl or in spawning areas during spawning seasons, impede the movement of aquatic species, impound water or restrict flows, or fill wetlands (33 CFR 330.6).

State Role

States also control the location of transportation corridors and the construction of pipelines in coastal wetlands and across barrier islands and beaches. Chapter 4 discusses guidelines for the installation of pipelines which the Gulf Coast states have developed under various programs.

Texas

Texas' rejection of the Coastal Zone Management Act of 1972 reinforces the perception of Texans as "an independent breed" (Graber 1981). However, Texas has enacted several pieces of legislation addressing coastal management issues including the Coastal Public Lands Management Act (1973) and the Dune Protection Act (1973). Today, permitting for pipelines is handled through two agencies: the Railroad Commission of Texas and the General Land Office. The Railroad Commission of Texas (RCT) is granted regulatory authority over the oil and gas industry by Texas Administrative Code Section 70 and Paragraph 91.101 of the Texas Natural Resources Code. Environmental concerns of the Commission focus on potential liquid hydrocarbon leaks on aquifers and at the crossings of rivers and major streams. The Commission also regulates the safety of gas and liquid pipelines.

The GLO along with the School Land Board manages the 12.3 million ac of state-owned lands. Authority for the GLO to grant right-of-way easements is in the Texas Natural Resources Code (TNRC), Chapters 51.291 and .292. Rules for resource protection and conservation of the state's public lands and waters are in the Texas Administrative Code, Chapter 31, Section 13.11 through 13.14. It appears that the GLO is the key agency for coordination when pipelines cross "unsold public school land, the portion of the Gulf of Mexico within the jurisdiction of the state, and all islands, saltwater lakes, bays, inlets, marshes, and reefs owned by the state within tidewater limits" (TNRC 51.291). This includes some 1.4 million ha of submerged state-owned lands (Davenport and Irby 1987).

To assist in locating and determining the impacts of proposed rights-of-way, the GLO has prepared a set of maps at a scale of 1:24,000 (the USGS 7.5 minute topographic maps) showing the location of submerged state tracts (Figure 5.1). Sensitive areas within these state tracts were identified by U.S. Fish and Wildlife Service, National Marine Fisheries Service, U.S. Army Corps of Engineers, Texas Parks and Wildlife Department, Texas Antiquities Committee, and the GLO. Sensitive areas or elements of concern are:

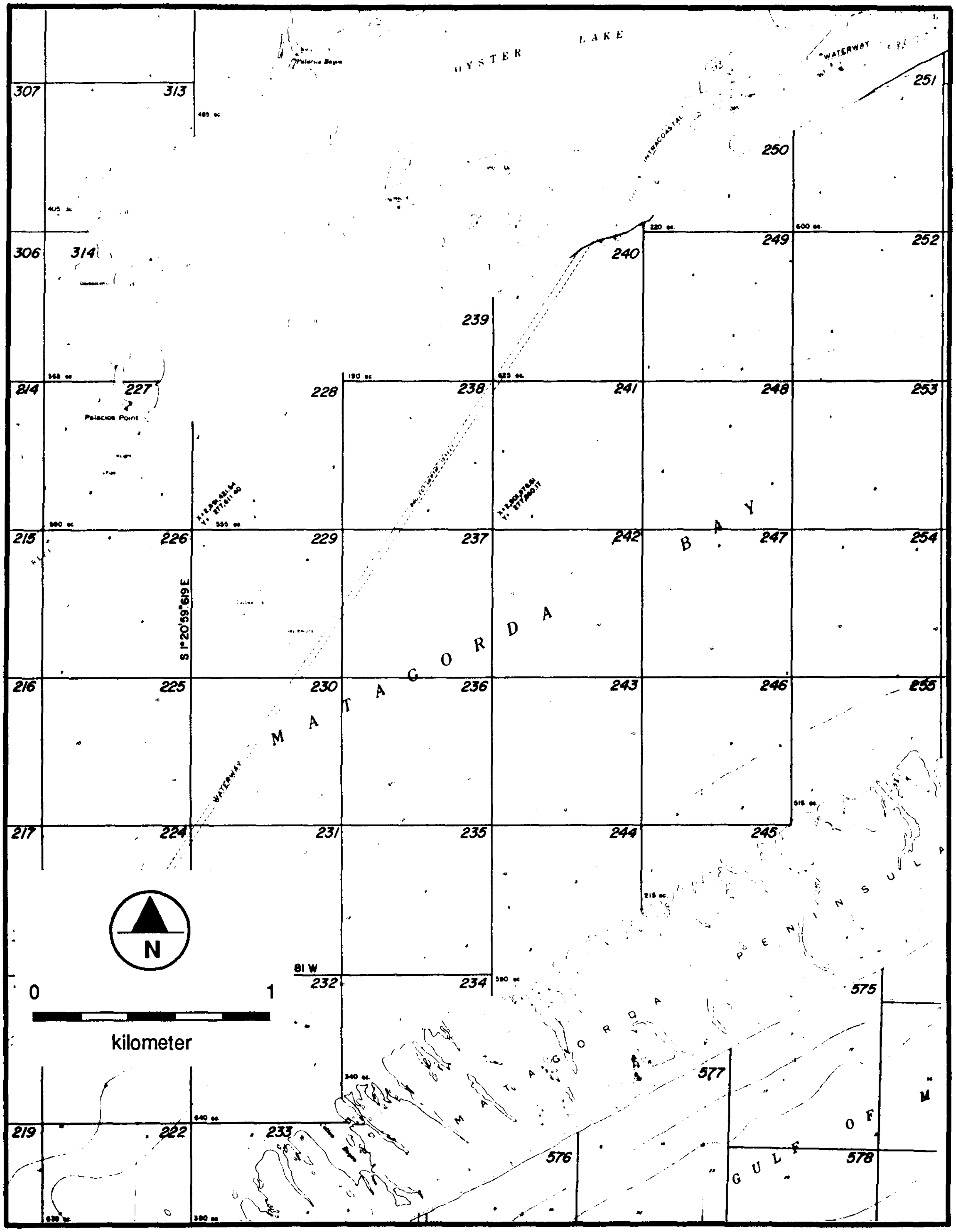

Figure 5.1. Reduced version of 7.5 min topographic map that shows state tracts. Use map No. 289 6-412 (Texas General Land Office 1988).

algal flats
archaeological sites
bay bottoms (of high biological productivity)
clam beds (*Rangia*)
hydrology
mangroves
marshes
navigational safety
nursery habitat
oyster reefs
recreational values
rookeries
submerged grassbeds

Each element is assigned a Resource Management Code (RMC) (Tables 5.3 and 5.4). Each code represents a development guideline submitted to the GLO by one of the participating state or federal regulatory agencies, with the intent of explaining how development of a tract can be accomplished without causing damage to the natural biologic resources present in the area.

In the example presented in Figure 5.1 and in Table 5.3, an applicant for a pipeline which would cross State Tract No. 227 would be advised that:

1. No dredging or propwashing is allowed because of sensitive estuarine habitats.

2. No dredging or propwashing is allowed in shallow waters of 4 ft or less which contain sensitive habitats.

3. Reefs are to be avoided.

4. No dredging or spoiling is allowed within 500 ft of any shell reef.

5. All hydrocarbon storage facilities must be enclosed with containment levees on land above mean high water and above contiguous marshes.

6. Spoil must be placed and contained on lands above mean high water and above contiguous marshes.

For State Tract No. 575S in the Gulf of Mexico, no specific concerns have been identified by the Federal or state agencies. However, the applicant must contact the Antiquities Committee and the State Historic Preservation Office in order to protect cultural resources which may occur in the tract.

The intention of the RMC System is not to restrict development on submerged lands, but rather to alert prospective operators to the need for precautionary construction techniques and/or avoidance of areas where sensitive resources are located. If the permit applicant can demonstrate to the satisfaction of the regulatory agencies that sensitive resources on a tract will not be damaged by the proposed work, work within the tract can proceed unhindered in most cases. If adverse impacts to natural resources are unavoidable, the proposed project may still be possible if an acceptable mitigation plan is approved by the regulatory agencies.

A permit applicant coordinates with representatives of the GLO to obtain more detailed information on the resources of the tracts. A number of publications provide general information about the Texas estuaries (as well as the entire Gulf coast) and can be used for immediate reference. Figure 5.2 shows the distribution of flora and fauna in Matagorda Bay. State Tracts No. 227 and 575S are superimposed for reference purposes. Tract No. 227 serves as a wintering area for adult waterfowl. The nearshore functions as

Table 5.3. Resource Management Recommendation Codes (RMRC) Assigned to State Tracts 227 and 575S, Matagorda Bay, Texas (Texas General Land Office 1988).

State Tract No. 227 is 590 acres in Matagorda Bay southwest of Palacios Point. (Submerged Area Map No. 2896-412.)

AGENCY	Resource Code (Table 5.4)
TPWD*	DA, MF, OV, SA
TAC	MA
USFWS	DB, MB, MF, OO, OV, SD
NMFS	DB, MB, OO, OV, SD
COE	MA

State Tract No. 575S is 600 acres in the Gulf of Mexico on the Matagorda Peninsula shoreline. (Submerged Area Map No. 2896-412.)

AGENCY	Resource Code (Table 5.4)
TPWD*	MA
TAC	MK
USFWS	MA
NMFS	MA
COE	MA

TPWD*	Texas Parks and Wildlife Department
TAC	Texas Antiquities Committee
USFWS	U.S. Fish and Wildlife Service
NMFS	National Marine Fisheries Service
COE	Corps of Engineers, U.S. Army

Table 5.4. Selected Definitions and Explanations of Texas GLO Resource Management Codes (Texas General Land Office 1988).

Channels

CA Use existing channels only. Maintenance dredging of existing channels may be allowed.

No new dredging will be authorized on this tract; however, pre-existing channels may be maintenance dredged if sensitive habitats are not impacted and all proposed on-tract work is coordinated with the commenting agency.

CC Use one channel for production of tract. If no channel is present on the tract, the commenting agencies may authorize dredging of a single channel to provide access for development.

Valuable habitats exist on this tract. To minimize destruction of these resources, access should be limited to a single channel that leads to a central drilling location and avoids submerged grasses and other sensitive habitats. The location of the channel and method of construction must be coordinated with the commenting agency.

CE Backfill access channel if well is non-producing or when abandoned.

An access channel may be dredged, but the area must be restored to its original contour to allow re-establishment of its previous productivity.

Dredging

DA No dredging or propwashing on this tract.

Water depths on this tract may be sufficient for access without dredging or propwashing. This code is assigned to protect sensitive estuarine habitats. Dredging or propwashing would destroy or degrade these habitats and reduce the productivity of the bay system.

DM No dredging or propwashing within 1500 feet of shoreline at mean low water.

The rationale for codes DL and DM is as follows:

Prohibits dredging activities in sensitive estuarine habitats which occur uniformly within one of the above-stated distances from the shoreline. Development of the tract may be accomplished by directional drilling from portions of the tract outside these restricted zones.

Table 5.4 continued.

Miscellaneous

MA	No special recommendations. The agency submitting this code has no specific concerns for the tract at this time.
MB	Avoid reefs during pipeline construction and geophysical surveying. Routing of pipelines should avoid reefs to protect them from sedimentation and/or destruction during laying of the pipelines. Geophysical surveying activities are prohibited on the reefs.
ME	Avoid submerged grassbeds, marshes, and other sensitive resource areas. Coordinate drilling location(s), production activities, access routes, and rights-of-way with the commenting agency. Sensitive marine habitats exist within the subject tract, but oil and gas exploration and other activities may be permissible if sensitive areas are left undisturbed. Contact the commenting agency for assistance and information.
MF	Show routes and method(s) of pipeline installation on Corps of Engineers and General Land Office application plat maps. Providing this information on application plat maps allows the regulatory agencies to review pipeline routes and installation methods. The agencies can then notify the developer if modification of the plans is needed to protect sensitive areas.
MH	No wheeled or tracked vehicles on marshes or submerged grassbeds. Prohibition protects submerged grassbeds that are easily damaged by such vehicles.
MJ	No landfill roadways placed below mean high water or in wetlands. Placement of landfill roadways in shallow water areas and periodically inundated wetlands on this tract is prohibited to avoid covering of valuable habitats and alteration of tidal currents.
MK	State archaeological landmarks and other cultural resources protected by state law are located on this tract and should not be disturbed. State Underwater Archaeologists at the Texas Antiquities Committee offices in Austin, Texas, must be contacted prior to development activities. Prospective developers must obtain information about archaeological survey requirements and avoidance of valuable historical artifacts on this tract from the Texas Antiquities Committee.

Table 5.4 continued.

ML This tract contains private oyster leases. Work affecting these leases should be coordinated with the private lease holder.

This code is designed to provide notice that private oyster leases are present on the state tract. Names and addresses of individuals holding private oyster leases are available from the Texas Parks and Wildlife Department.

MM Navigational concerns such as safety fairways and anchorage areas exist within this tract. Laying of pipelines on the tract is subject to special routing and burial requirements.

All work on this tract should be coordinated with the Corps of Engineers to insure compliance with Federal regulations regarding navigation channels, anchorage areas, safety fairways, and other navigational concerns.

MN Use low-profile structures for all permanent production facilities to minimize visual impact.

Requires that all structures on the tract be low-profile to minimize their visual impact.

MO Work in tract is subject to Endangered Species Act review.

Consult with the commenting agency for information.

MP Work in this tract is subject to special recommendations or restrictions by federal, state, or local governments. Contact the commenting agency for information.

A city or other governmental body with jurisdiction over this tract should be consulted. Contact the commenting agency for information.

Oil and Gas Development

OA No surface drilling locations on this tract. Directional drilling from adjacent areas should be considered.

Extremely productive marine habitat exists over so much of the tract that drilling activity and dredging of access channels would significantly damage the marine ecosystem. Spillage of petroleum is considered too high a risk, and dredging would cause unacceptable loss of habitat. Directional drilling from off-tract locations should be considered for mineral development of this state tract.

OB No drilling in water less than 4 feet as measured from mean low water.

Tract has areas both shallower and deeper than 4 feet; the shallow areas contain sensitive habitats which need protection.

Table 5.4 continued.

OE	Limited number of surface locations on this tract. Consult with the commenting agency for details. Number and spacing of drilling surface locations on this tract may be limited to minimize hazards to recreational boating. Consult with the commenting agency for specific information.
OH	Drill only from water deeper than 6 feet as measured from mean low water, or from land above mean high water. Tract has both deep (greater than 6 feet) and shallow water areas and/or adjacent uplands. To protect sensitive habitats in the shallow water, drilling is to be confined to the deep-water areas or adjacent uplands.
OI	Confine drilling to NE quarter of tract.
OJ	Confine drilling to NW quarter of tract.
OK	Confine drilling to SE quarter of tract.
OL	Confine drilling to SW quarter of tract.

The rationale for codes OI, OJ, OK, and OL is as follows:

Sensitive aquatic habitats occur within a portion of this tract. The use of "quarter-subdivisions" is an effort to be more specific about the area of concern.

OM	Avoid drilling and construction of platforms on the top or slopes of reefs, banks, hard bottoms, or artificial reefs on this tract. Prohibits drilling activity on these underwater features to protect the fish and other valuable marine organisms attracted to the area.
ON	Contain all liquid and solid drilling by-products and dispose of on upland sites. The discharge of drilling waste materials (e.g., bit cuttings, drilling muds, hydrocarbon-based cleaning fluids, etc.) on this tract is prohibited. Sensitive habitats and marine organisms may be damaged or destroyed by the toxic or physical effects of such materials. No oil sheen should occur as a result of drilling activity.
OO	No drilling, dredging, or spoiling within 500 feet of any shell reef. These activities are prohibited within 500 feet of reefs to avoid damage by toxic wastes or petroleum, by sedimentation, or by physical removal of reef material.
OQ	No drilling within 500 feet of shoreline at mean low water.
OR	No drilling wihtin 1000 feet of shoreline at mean low water.
OS	No drilling within 1500 feet of shoreline at mean low water.

Table 5.4 continued.

The rationale for codes OQ, OR, and OS is as follows:

Prohibits drilling activities in sensitive habitats which occur uniformly within one of the above-stated distances from the shoreline. Access to minerals within this restricted zone may be possible by directional drilling from other portions of the tract.

OV All hydrocarbon storage facilities must be contained in leveed sites on land which is above mean high water and landward of all contiguous marshes. Surge tanks are to be designed for demonstrated minimum capacity.

Accidental spillage of petroleum-related products poses a threat to the overall quality of Texas bay and estuarine systems. Pipelines should be used to transport all well products to upland sites where levees can be used for containment of accidental spills.

OW No surface drilling locations within one mile of shoreline at mean low water.

Prohibits location of surface drilling activity within one mile of public beaches to minimize impact on recreational activities.

Rights-of-Way

RW All or part of this tract falls within the right-of-way of a Federally maintained navigation channel and/or disposal area.

The Corps of Engineers does not permit permanent structures within the right-of-way of a federal navigation channel or spoil disposal site. Development may be accomplished by directional drilling from portions of the tract which are outside the Federal right-of-way. Contact the district offices of the U.S. Army Corps of Engineers in Galveston, Texas, for details and assistance.

Spoiling

SA No spoiling.

Sensitive aquatic habitats exist on all or part of this tract. Spoiling in these sensitive areas would degrade or destroy the overall productivity of the tract and the bay system in general.

SD Place and contain spoil on land within levees above mean high water and landward of contiguous marshes.

Sensitive habitats on this tract can be protected by placing spoil on islands, existing spoil areas, or nearby mainland sites where levees can be used to contain material.

SE Use existing spoil banks for spoil disposal.

Sensitive areas of this tract can be protected if spoil disposal is limited to those sites which have been previously altered by the placement of spoil material.

Table 5.4 continued.

SF No spoiling in NE quarter of tract.

SG No spoiling in NW quarter of tract.

SH No spoiling in SE quarter of tract.

SI No spoiling in SW quarter of tract.

The rationale for codes SF, SG, SH, and SI is as follows:

> Quarter-tract subdivisions are used to be more specific about the area of concern. Consult with the commenting agency for details.

SN Orient spoil banks in a direction which will not create detached tidal pools; avoid continuous spoil banks.

> Placement of dredged material in a manner that would isolate smaller bay areas from the larger aquatic system, and thereby reduce productivity of the smaller area and the whole system, is prohibited. Spoiling should be done in a discontinuous bank and alternating from one side of the channel to the other. Spoiling in a continuous bank may significantly alter bay system current patterns, and is prohibited.

Time Limitations

TA No drilling within two miles of the Gulf shoreline in the area of Padre Island National Seashore. Drilling activity between two miles and three miles of this shoreline is also prohibited between March 15 and September 15.

> Drilling activity within two miles of the Gulf shoreline in the area of Padre Island National Seashore is restricted to protect both the aesthetic and recreational values of the public beaches. Drilling is allowed within the area from two miles to three miles from shore during the tourist off-season (September 15 to March 14) but drilling activity in this strip must commence before January 16 to insure adequate completion time before the March 14 deadline. Access to minerals in the two-mile zone along the Gulf beach may be achieved by directional drilling from upland sites on Padre Island if authorized by the National Seashore, or from state tracts beyond the two-mile limit. Contact the commenting agency for information.

TB Whooping crane critical habitat. No construction, dredging, or drilling between October 15th and April 15th. No permanent structure higher then 15 ft above mean low water.

> All oil and gas exploration activity on this tract is restricted during the period from October 15th to April 15th to protect whooping cranes which winter in the Aransas National Wildlife Refuge area. All permanent structures on this tract must be 15 ft or less in height.

Table 5.4 concluded.

TC	No disturbance of a rookery at any time. No drilling, dredging, seismic exploration, or other construction within 1000 ft of a rookery between February 15 and September 1. Bird nesting islands must be left undisturbed. Oil and gas, and seismic, and other development operations are prohibited within 1000 ft of the rookery areas during the peak nesting season from February 15 to September 1.

Table 5.5. **State Guidelines which Influence Locations of Transportation Corridors through Louisiana Barrier Islands and Beaches and Wetlands (La. Dept. of Natural Resources and U.S. Dept. of Commerce 1980).**

Guideline 3.5	Existing corridors, rights-of-way, canals, and streams shall be utilized to the maximum extent practicable for linear facilities.
Guideline 3.7	Linear facilities involving dredging shall not traverse or adversely affect any barrier island.
Guideline 3.8	Linear facilities involving dredging shall not traverse beaches, tidal passes, protective reefs, or other natural gulf shoreline unless no other alternative exists. If a beach, tidal pass, reef, or other natural gulf shoreline must be traversed for a non-navigation canal, they shall be restored at least to their natural condition immediately upon completion of construction. Tidal passes shall not be permanently widened or deepened except when necessary to conduct the use. The best available restoration techniques which improve the traversed area's ability to serve as a shoreline shall be used.
Guideline 6.8	Surface alterations shall, to the maximum extent practicable, be located away from critical wildlife areas and vegetation areas. Alterations in wildlife preserves and management areas shall be conducted in strict accord with the requirements of the wildlife management body.
Guideline 6.9	Surface alterations which have high adverse impacts on natural functions shall not occur, to the maximum extent practicable, on barrier islands and beaches, isolated cheniers, isolated natural ridges or levees, or in wildlife and aquatic species breeding or spawning areas, or in important migratory routes.

(Source: La. Dept. of Natural Resources and USDC, NOAA 1980)

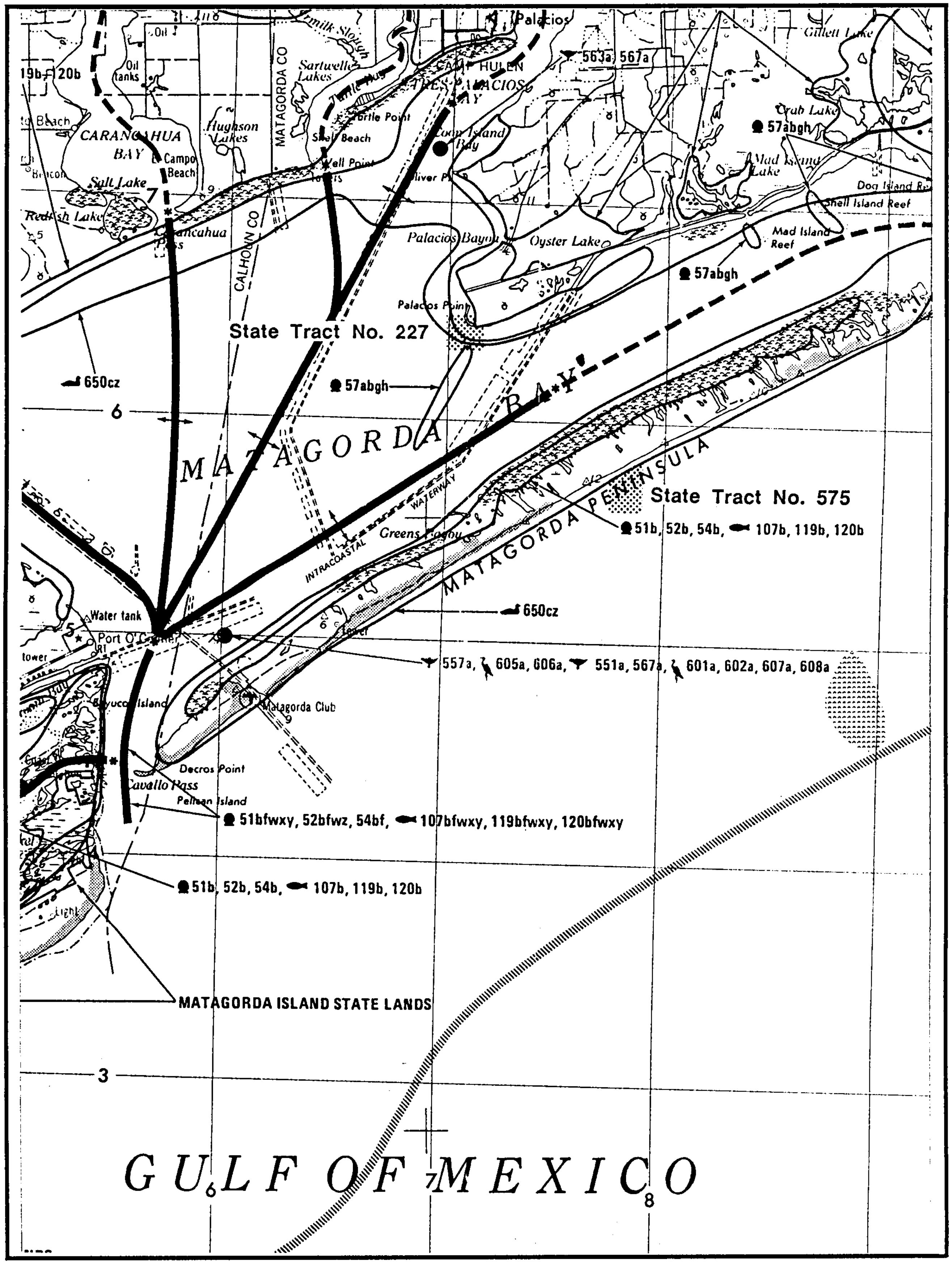

Figure 5.2. Distribution of flora and fauna in the portion of the Matagorda Bay containing State Tract No. 227 (USFWS 1982).

a nursery area for white and brown shrimp, blue crabs, drum, sheepshead, and southern flounder.

The School Land Board, of which the Commissioner of the GLO is chairman, has authority over coastal public lands and the issuance of coastal easements. Coastal public lands means "all or any portion of the State-owned submerged lands, the waters overlying those lands, and all State-owned islands in the coastal area" (Rules 135.18.01.001). Decisions for issuance of a permit are based on set criteria (Rule 135.18.01.003). Structures and activities, which include dredging, channels, roads, piers, and docks, must also avoid oyster reefs, highly productive wetland areas, and submerged grass bed areas.

Texas laws and guidelines do not prohibit pipelines from crossing anywhere along the coast. In 1981 a pipeline crossed Padre Island National Seashore. However, restrictions that appear in federal laws and conditions that may be applied by state agencies could effectively prohibit construction in selected areas. For example, it is highly unlikely that a pipeline would cross critical habitat (feeding, breeding, or nesting areas) for threatened and endangered species during the time the areas are in use. Mitigation is a key to construction and it is a reflection of the agencies level of enforcement. For example, the GLO requires that mitigation "be located at or near the site of the damage, provide in-kind replacement of habitat loss, and replace habitat or compensate for damage at a ratio of 3 to 1" (Davenport and Irby 1987).

Louisiana

The 1978 Louisiana Legislature declared that it is the public policy to protect, develop, and, where feasible, restore or enhance the resources of the state's coastal zone (Act 361, the State and Local Resources Management Act of 1978, as amended; L.R.S. 5.49:213.1-.23). Before this Act, the state had, for the most part, ignored the renewable resource values of the barrier islands and beaches. State policies on land, water, and biological resources in the coastal zone were not well defined (Louisiana Department of Natural Resources and U.S. Department of Commerce [USDC], National Oceanic and Atmospheric Administration [NOAA] 1980). For all practical purposes, only the Louisiana Department of Wildlife and Fisheries had taken an active role in protecting parts of the coastal zone, and their efforts were directed toward the wetlands and not the barrier islands and beaches. But the 1978 legislature changed that by affirming the importance of the coastal zone and creating the Coastal Management Section (CMS) to administer the program. Louisiana's program was approved by the Federal government in September 1980. CMS was transferred from the Governor's Office through two state-level Departments and now resides within the Department of Natural Resources as the Coastal Management Division (CMD). Recent statewide elections and restructuring of agencies will probably result in the Coastal Management Division being moved from the Department of Natural Resources.

The CMD relies on guidelines within the state program when reviewing permit applications for pipelines crossing submerged lands, barrier islands and beaches, and wetlands (Maps 1A-10A, Vol. II). Guideline 3, Linear Facilities, and Guideline 6, Surface Alterations (Table 5.5), are most appropriate for pipelines crossing the study area. Areas of high biological productivity, irreplaceable resources, critical wildlife and vegetation areas, wetlands, reefs, beaches, tidal passes, natural gulf shorelines, and barrier islands shall either not be traversed or if traversed, not be adversely affected, and shall be restored to their natural condition through the best available techniques. However, in several instances, the phrase "to the maximum extent practicable" appears as a modifier and allows for a varied interpretation during implementation (Houck 1983).

Existing guidelines appear to conflict with each other when the issue is crossing barrier islands. Guideline 3.7 prohibits the crossing of barrier islands if it requires dredging or an adverse impact. Guideline 3.5 allows for the use of existing rights-of-way and does not exclude barrier islands. Therefore, it seems that pipelines may cross barrier islands as long as they remain within existing rights-of-way and reduce adverse impacts to the maximum extent practicable.

The State Historic Preservation Office reviews permits and is responsible for protecting sites either eligible for or on the National Register of Historic Places. When a site is located, a determination is made as to the eligibility of the site for the Register and mitigation is performed when necessary. Mitigation normally takes the form of data recovery rather than relocation of a transportation corridor.

Mississippi

Mississippi has demonstrated a concern for its coastal systems since 1973 when the legislature enacted the Coastal Wetlands Protection Law. The purposes of the law were to preserve the coastal wetlands and ecosystems in a natural state and to prevent their destruction. Rules, regulations, guidelines, and procedures for achieving these purposes were adopted by the Mississippi Marine Resources Council (now defunct) in July 1973 and amended in April 1975. The Mississippi Coastal Zone Management Program which applies to Hancock, Harrison, and Jackson Counties (Mississippi Bureau of Marine Resources and USDC, NOAA 1980), was basically set by the legislature in early 1979. The Office of Coastal Zone Management (USDC, NOAA) approved the state program in September 1980.

The Mississippi Coastal Program is administered by the Mississippi Commission on Wildlife Conservation. Daily operations, including permitting of regulated activities, are through the Bureau of Marine Resources, Department of Wildlife Conservation. For example, the Bureau of Marine Resources has primary regulatory control over waterfront industrial sites below the ordinary high tide line. Above the ordinary high tide line environmental jurisdiction on issues related to air and water pollution resides with the Bureau of Pollution Control; for activities affecting surface and ground waters, the Bureau of Land and Water Resources; and for activities that may affect archaeological and historical resources, the Department of Archives and History. The latter three agencies are also active in the coastal zone through their review responsibility and comments on coastal permit applications.

Mississippi regulations provide guidance to state agencies in managing coastal resources in order to achieve the goals of the state's program. Reasonable industrial expansion is important, but not at the overall expense and degradation of the coastal wetlands, water quality, wildlife, fish, and aquatic life. The state tries to balance activities in the coastal zone by encouraging development in areas where they will not conflict with the fragile coastal resources. A coastal wetlands use plan has been developed and is the basis for permitting by the State for those wetlands below ordinary high tide. Districts (Industrial Development, Commercial Fishing and Recreational Marinas, General Use, Preservation, Special Management Areas) have been mapped, and allowable uses are described (Mississippi Bureau of Marine Resources and USDC, NOAA 1983). Thus, for the transportation of oil and gas from the Outer Continental Shelf (OCS) through the Mississippi coastal zone, the state regulates activities through its Federally approved coastal zone program (Tables 5.6 and 5.7).

Transportation of OCS oil and gas is a complex issue which requires coordination between the Federal and State governments. In response to the need for a planning tool, the Bureau of Marine Resources has prepared a technical report for routing OCS pipelines

Table 5.6. Mississippi Pipeline Regulations.

1. Permanent open water canals in marshlands for installation shall not be used.
2. Where dredging is required in marshland, all excavation shall be backfilled with the excavated material after installation of the appropriate structure, with care taken to maintain the original marsh floor elevation in both the excavated area and spoil area. Spoil shall be temporarily stockpiled in discontinuous banks so that sheet flow is not interfered with.
3. After dredging and backfilling is complete, all altered marshland shall be sprigged with characteristic marsh vegetation.
4. In open water areas, spoil shall be deposited in discontinuous piles on opposite sides of the excavation, which shall be backfilled after project completion.
5. Alignments of new projects shall be designed to use existing rights-of-way.
6. Projects shall be aligned along the least environmentally damaging route (e.g. avoid submerged grass, shellfish beds, artificial reefs, hard banks, etc.).
7. Projects shall be aligned to avoid shipwrecks and areas of unique historical and cultural interest.

(Source: Mississippi Bureau of Marine Resources, USDC, NOAA 1983)

Table 5.7. Activities Associated with Pipelines and Support Facilities that are Regulated in Mississippi.

Applicable Subpart	Activity
Part III	
A	Docks and Piers
B	Boat Ramps
D	Bulkheads and Seawalls
G	Channels and Access Canals
H	Dredged Material Disposal
I	Impoundments and Other Water Level Controls
N	Activities Affecting Coastal Wetlands
O	Filling Other than Dredged Material Disposal

(Source: Mississippi Bureau of Marine Resources, USDC, NOAA 1983) within the Mississippi coastal zone. Figure 5.3 shows the coastal areas where pipeline use is classified as Unsuitable or Suitable with Stipulations. An unsuitable designation means the area is "considered undesirable for transportation activities or may interfere with such activities" (Ladner and Franks 1986). Pipelines are not absolutely prohibited, but avoidance of these areas will reduce the potential for encountering environmental and sociocultural problems. A best route will be determined by "a balance between environmental protection and economic development." Features classified as unsuitable include: barrier islands, endangered species habitat, special benthic features (oyster beds and leases, seagrass beds), historic and archaeological sites, marinas, ports, and harbors.

Areas classified as Suitable with Stipulations (acceptable with conditions) include the remainder of the coastal zone below ordinary high tide line or below the point of riverine tidal influence. Stipulations will be developed when specific transportation corridors are proposed. Decisions on pipeline corridors above the ordinary high tide level not described as Unsuitable will be made on a case-by-case basis until maps and narratives are prepared. The State's coastal program guidelines encourages the use of existing rights-of-way to reduce or avoid the alteration of undisturbed or sensitive areas.

Mississippi has made the decisions necessary for companies to prepare long-term strategies and plans for routing OCS pipelines through the state waters, barrier islands, and wetlands. The state clearly presents its program while allowing flexibility in final decision-making. It must be recognized that the Mississippi coastal zone has certain physical and biological characteristics that afford the state the luxury of avoiding problem areas while allowing for the construction of pipelines. Wide tidal passes exist between the offshore barrier islands. Mississippi Sound has scattered and discontinuous reefs and sensitive areas. The Pleistocene uplands are the shoreline of the sound in some areas or have only very narrow fringing wetlands. The BMR wisely incorporated the environmental opportunities that existed into its plan and thus should be able to avoid conflicts with future transportation corridors.

Alabama

The Alabama coastal zone extends inland to the (3.048 m) contour. The Alabama Coastal Area Board (CAB) was created by the Alabama Coastal Area Act of 1976 and is the principal agency with authority in the coastal zone. The act sets state policy for preserving, protecting, restoring, or enhancing the resources of the coastal zone while allowing for development. Increasing and competing demands by a growing population made safeguarding the ecologically fragile, but valuable resources, imperative. In 1979, operational rules and regulations were developed as part of the state's coastal zone management program to minimize detrimental effects of projects on wildlife, wildlife habitat, fisheries, and cultural resources. Regulations were developed for energy facilities, dredging and fill, shoreline erosion, wetlands, submersed grassbeds, oyster reefs, beaches, dunes, cultural resources, fisheries, and wildlife. Interestingly, no specific regulations apply to pipeline placement in or through the coastal zone (Table 5.8). The Alabama program was approved by the Federal Government in September 1979.

Construction activities within the coastal zone require coordination with specific departments of state government. If the action affects beaches and/or dunes in Mobile County, the Alabama Department of Environmental Management must be contacted. The department also administers permit requirements and determines consistency of the project with the state's coastal management program. For projects involving construction in or on wetlands, water bottoms, navigable waters, marshes, swamps, bogs, etc., the permitting responsibility is with the Department of Conservation and Natural Resources. Finally, the Alabama State Docks Department (ASDD) licenses dredging and filling or any

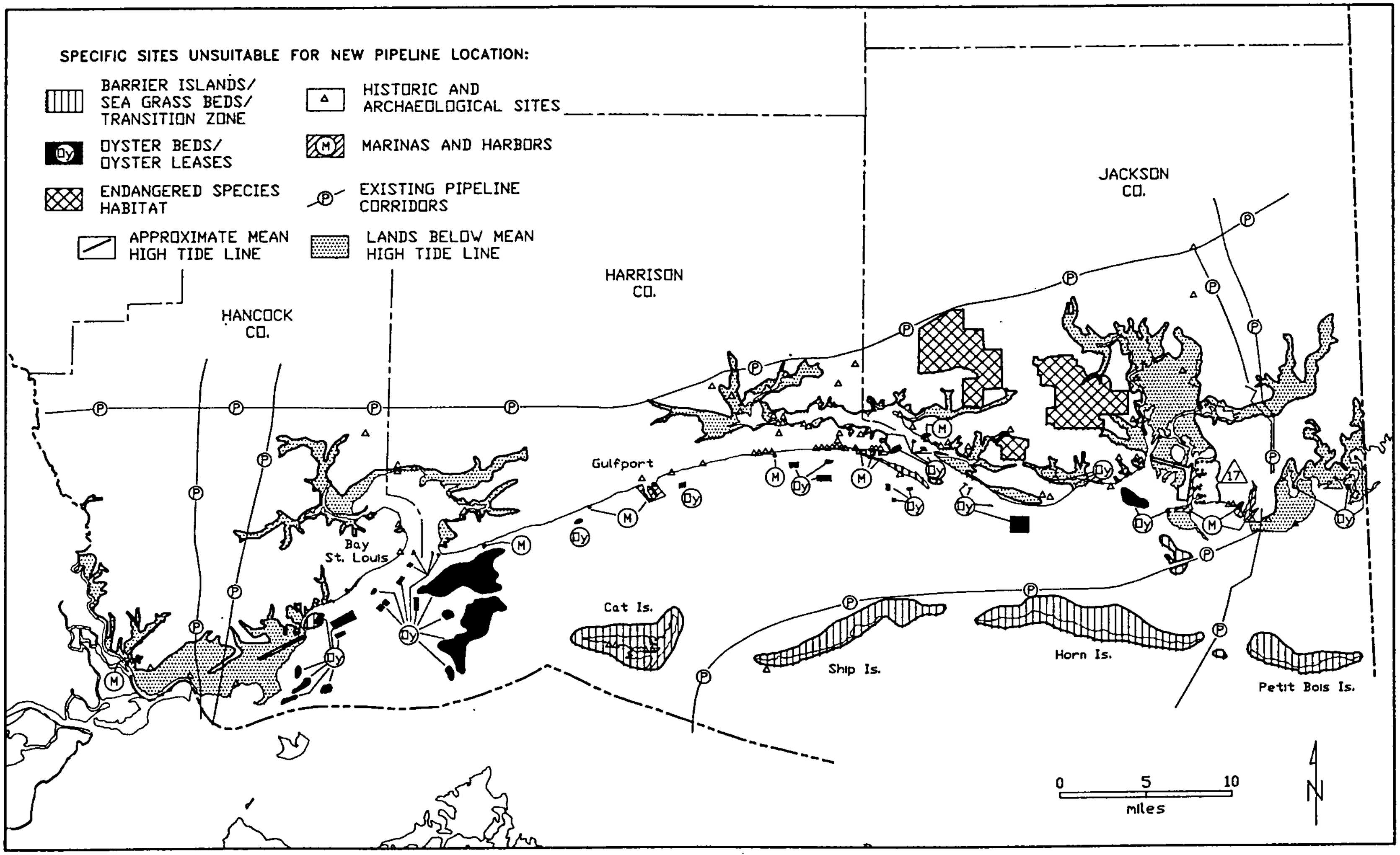

Figure 5.3. Areas within the Mississippi coastal zone that are unsuitable for transportation corridors or suitable only with stipulations (Ladner and Franks 1986).

Table 5.8. Selected Regulations that Apply to the Siting of Energy Related Facilities in the Alabama Coastal Zone. (Source: Alabama Department of Environmental Management, Division 8, Coastal Program. Adopted October 9, 1985.)

8-1-.06 (4)	All energy facility siting, construction, and operation must meet the requirements established elsewhere in this Chapter.
8-1-.07 (1)	Dredging and filling operations shall not be permissible if such activity is determined by the Department to degrade the coastal area.
8-1-.08 (1)	Any use intended to mitigate a shoreline erosion problem in the coastal area shall use non-structural erosion control methods to the maximum extent practicable, including but not limited to preservation and restoration of dunes, beaches, wetlands and submersed grassbeds, and shoreline restoration and nourishment.
8-1-.13 (1)	Before undertaking any project in wetlands or submersed grassbed areas, the applicant must demonstrate to the satisfaction of the Department that the proposed activity will not degrade the natural function of the wetlands or submersed grassbeds to support present levels of plants and animals, act as a buffer against storm surges, or any other natural functions.
8-1-.15	Protection of Oyster Reefs. Uses within the coastal area that degrade oyster reefs shall not be permissible.
8-1-.18 (1)	All development in the coastal area shall to the maximum extent practicable avoid adversely affecting historic, cultural, or archaeological resources of the coastal area.
8-1-19	Protection of Fishery Habitats. To the maximum extent practicable, all uses within the coastal area shall be undertaken in such a way as to not degrade fishery habitats.
8-1-20	Protection of Wildlife and Wildlife Habitats. To the maximum extent practicable, all uses within the coastal area shall be undertaken in such a way as to preserve and protect existing wildlife and wildlife habitats. In particular, endangered species and their habitat, as designated by appropriate federal and state agencies, shall be protected to the maximum extent practicable.

construction that affects navigable water of the state. The ASDD is primarily concerned with conflicts between the proposed project and the public's right of navigation.

The Alabama coastal program is designed to protect and enhance the renewable resource base of the state by maintaining the plants and animals in the coastal zone. This is achieved through protection of wetlands and grassbeds and the natural integrity of the beach and dune systems. As a result, wildlife and fisheries habitat, oyster beds, and critical areas for threatened and endangered species are protected. In addition, cultural resources are preserved and protected.

The Alabama Coastal Program provides for two types of special management areas: Geographic Areas of Particular Concern (GAPC) and Areas for Preservation and Restoration. The GAPC are defined as areas that "have been determined to be of particular concern because of their coastal-related values or characteristics or because they may face special pressures" (Alabama Coastal Area Board and USDC, NOAA 1979). Any activities within these unique and important zones require more than normal analysis and evaluation during the permit application review process. Alabama has classified the Port of Mobile and the Mobile-Tensas River Delta as GAPC (Figure 5.4). The Port was selected because of its significant importance to the economic base of the state. It is an area where development must take place but in harmony with the coastal resources. To guide activities, a prioritized list (from highest to lowest) has been developed:

1. Uses that are water-dependent and improve or promote port operations and development.

2. Uses that are water-related and improve or promote port activities.

3. Uses that are not water-dependent nor water-related but improve and promote port activities.

The coastal program discourages those uses that significantly degrade or interfere with port operations. However, other activities are not necessarily excluded from the port but have a lower priority.

The second GAPC is the Mobile-Tensas River Delta (Figure 5.4), a low, mostly wetland zone of 289 sq mi between the confluence of the Tombigbee and Alabama Rivers and Mobile Bay. The delta is on the National Register of Natural Landmarks because of its very productive natural areas and diverse habitats. From the highest to lowest, the priorities of use for the delta are (Alabama Coastal Area Board and USDC, NOAA 1979):

1. Uses that preserve, enhance, or protect the natural function of tidal and freshwater wetlands located in the delta.

2. Uses that are water-dependent and maintain the wetlands in the delta at a level necessary to provide present natural functions.

3. Uses of public or private need that maintain the deltaic wetlands at a level necessary to provide natural functions.

Although the GAPC designation does not specifically exclude activities, the state discourages those uses that "degrade the integrity and natural functions of the wetlands in the delta beyond present levels" (Alabama Coastal Area Board and USDC, NOAA 1979).

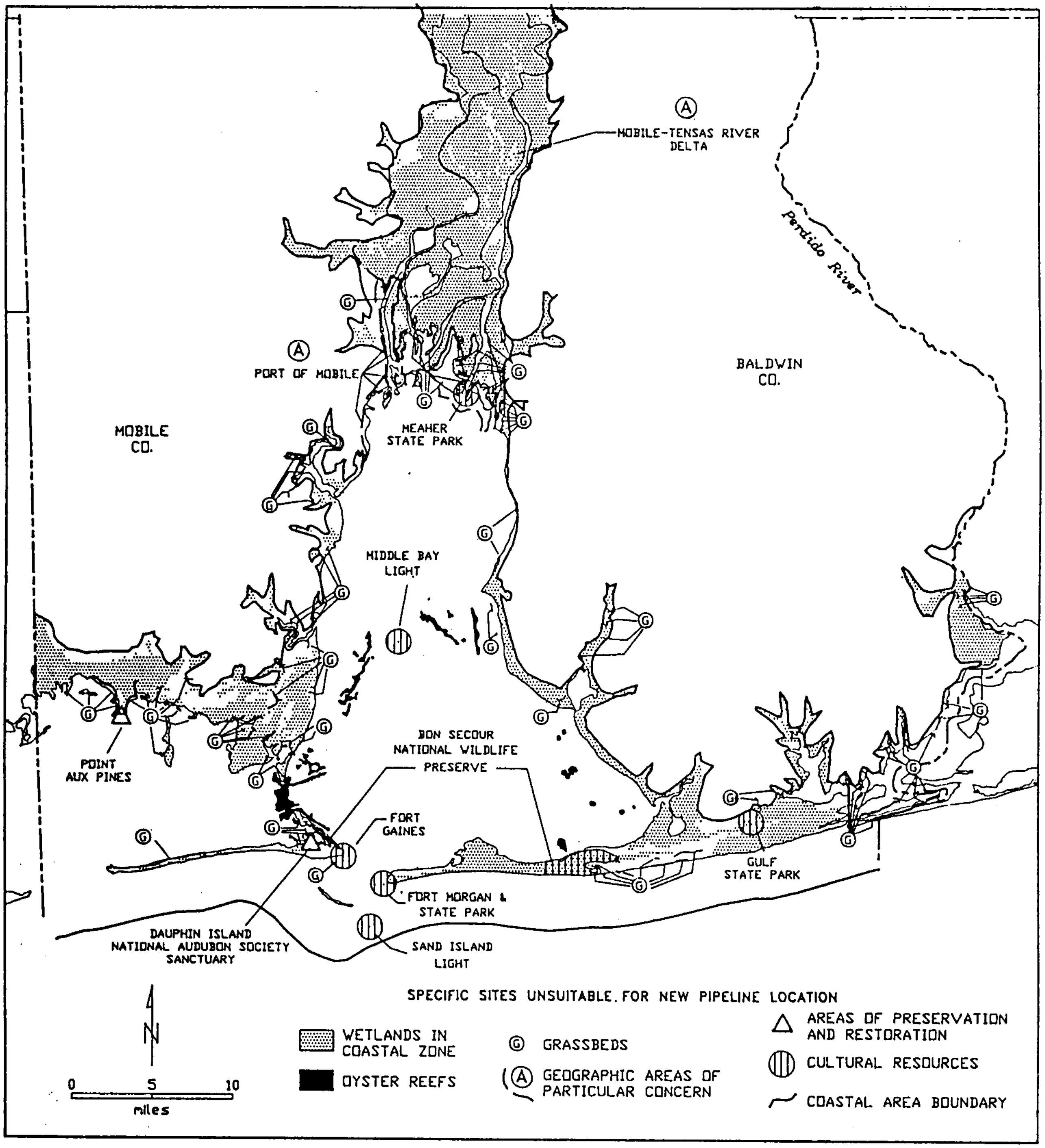

Figure 5.4. **Elements within the Alabama coastal zone that should be protected and maintained (Alabama Coastal Area Board and USDC, NOAA 1979).**

A second category of special management areas are Areas for Preservation and Restoration (APR). The APR have very special value for conservation, recreation, or ecology and therefore will receive special regulatory consideration to preserve the area in its natural condition. Uses that degrade these areas will be discouraged. The Point aux Pins wetlands southwest of Bayou La Batre and the National Audubon Society Wildlife Sanctuary on Dauphin Island are the two APR (Figure 5.4). Point aux Pins has been described as the most pristine coastal wetland system in Alabama. It is owned by the Board of Trustees, University of Alabama, and is used for education and research, and as a wildlife refuge. In order to preserve the estuary, the state prohibits activities that would degrade the natural state. On the eastern end of Dauphin Island is the National Audubon Society Wildlife Sanctuary. The 64.4-ha sanctuary provides habitat for migratory birds, terrestrial and semi-aquatic species. Activities which alter the natural state shall be prohibited.

Those elements within the coastal area which should be maintained and protected are (Figure 5.4): wetlands, submersed grassbeds, oyster reefs, and cultural resources. The state also wishes to avoid degrading fishery habitat, wildlife habitat, and dunes and dune vegetation. Finally, the state provides that:

1. No person shall construct any new structure, or make any substantial improvement to any existing structure, on, beneath, or above the surface of any land located between mean high tide and the construction control line.

2. No person shall construct any new structure on, beneath, or above the surface of any state-owned lands located in the following areas:

   a. between mean high tide and a line originating at plane coordinate (x = 339,562.58 feet; y = 83,758.99 feet) and extending South 77° 59' 16" West in Baldwin County;

   b. between mean high tide and Alabama Highway 180 between plane abscissas (x = 339,562.58 feet and x = 343,833.77 feet); or

   c. in Sections 2 and 3 of Township 4 South, Range 33 West in Baldwin County.

Alabama has indirectly established a procedure for routing pipelines through its coastal zone. The process is not as formalized or structured as the one in Mississippi, but it is definitive. Certain areas should be avoided when pipeline corridors are defined.

Florida

The Florida legislature declared the highest and best uses of the coast to be as a source for public and private recreation. Protection of the coast for recreation requires that the natural conditions be preserved as much as feasible. The 1968 Florida Constitution declared the beaches below the mean high waterline to be in the public trust. As a result of the Florida Coastal Management Act of 1978, the state proposed a Coastal Management Program which was approved by the Federal Government in September 1982. A unique feature which makes the program completely different from all others is that the entire State and territorial waters are considered part of the coastal zone. The Department of Environmental Regulation, the lead agency for coastal-related issues, coordinates activities with the Department of Natural Resources, the Department of Veteran and Community Affairs, and the Interagency Management Committee.

The Florida program emphasizes the protection of beaches, dunes, and wetlands from destruction by development. Regulation of dredge and fill activities is designed to improve or maintain water quality and to protect and preserve wetlands in the state. The Department of Environmental Regulation (DER) has permitting authority for pipelines because installation usually requires dredge and fill in State-owned submerged lands and wetlands. The DER has jurisdiction over potential water pollution sources if the activity degrades water quality below the specified standards for that class of water body. The DER provides highest protection to waters within:

National Parks
Wildlife Refuges
State Parks or Recreation Areas
National Seashores
State Aquatic Preserves
National Monuments
National Marine Sanctuaries
National Estuarine Sanctuaries
Other Special Waters

Table 5.9 lists outstanding Florida waters in the study area.

Table 5.9. Outstanding Waters in Florida (Fernald 1981).

County	Area
Escambia	Big Lagoon State Recreation Area
Santa Rosa	Blackwater River State Park
Okaloosa	Fred Gannon Rocky Bayou State Recreation Area
Walton	Grayton Beach State Recreation Area
Okaloosa	Henderson Beach State Recreation Area
Bay	St. Andrews State Recreation Area
Walton	Eden State Gardens
Escambia	Perdido Key State Preserve
Escambia	Escambia Bay Bluffs
Walton	Grayton Dunes
Escambia/Santa Rosa	Gulf Islands
Escambia/Santa Rosa	Fort Pickens State Park and State Aquatic Preserve
Bay	St. Andrews State Park
Santa Rosa	Yellow River Marsh and State Aquatic Preserve

Outstanding Florida waters are those that are demonstrated to be of exceptional recreational or ecological significance (Figure 5.5). In addition to those listed above, there is Basin Bayou State Recreation Area in Walton County and Audubon Island State Wilderness Area in Bay County. State wilderness areas are permanent preserves and are forever off-limits to incompatible human activities. These areas are dedicated in perpetuity to be managed for the protection and enhancement of its natural qualities for public enjoyment and use. The state aquatic preserves such as Fort Pickens (Santa Rosa County) and Yellow River Marsh (Santa Rosa County) are examples of state owned submerged lands with exceptional biological, aesthetic, and scientific value.

The DER gives special consideration to Class II waters "as existing or potential sites of commercial and recreational shellfish harvesting as a nursery area for fish and shellfish" [Chapter 17-4.28(8) (a)]. Figure 5.6 shows the Class II waters and the shellfish harvest areas throughout the Florida Panhandle. Although the Department can issue permits or certificates for dredging and filling in these zones, the applicant must satisfy the department that adequate plans and procedures have been made to protect the area from significant damage. Work in any other class of water cannot affect Class II waters. The Department "shall not issue a permit for dredging or filling directly in areas approved for shellfish harvesting by the Department of Natural Resources [Chapter 17-4.28 (8) (a)].

The Florida Department of Natural Resources (DNR) manages many of the state's natural resources that may be affected by OCS pipelines. DNR administers submerged lands, conservation areas, aquatic preserves, state parks, wilderness areas, and endangered lands. They are also responsible for shoreline use and protection as well as for the management and conservation of the marine fishery resources. The Department of Veteran and Community Affairs coordinates activities among other agencies when the issue involves the Areas of Critical State Concern.

Beaches and dunes receive the highest protection through the Florida coastal program. Wetlands, shellfish areas, and other aquatic systems are also important and must be considered in locating transportation corridors. However, it appears that pipelines may cross the coastal zone at any location if the applicant can satisfy Florida authorities that the project will not significantly degrade the water quality of the project area, and that the applicant will protect existing and potential sites of commercial and recreational shellfish harvesting and nursery areas for fish and shellfish.

Similar to all the other states the project must comply with Federal regulations for protecting the environment.

Conclusions

Physical, biological, and cultural elements now influence the location and selection of pipeline corridors across barrier islands and beaches and through wetlands. Consideration of these environmental concerns was brought about by the enactment of Federal legislation which in turn encouraged states and local governments to become more responsive to issues beyond company budgets and construction techniques. Even though Texas chose not to participate in the Federal coastal zone program, the state instituted its own controls on the routing of pipelines. Although no outright restrictions exist on where a pipeline can be located, many specific conditions can be attached to a permit to control when and how the pipeline is installed. Interpretation of these guidelines depends, at least in part, on the many studies of the value of the Texas coastal zone prepared before the state rejected further Federal money. In contrast to Texas, Louisiana relied on and still heavily depends on Federal money for its coastal program. The Coastal Management Division is responsible for guiding pipelines through or around the barrier beach and barrier island complexes that fringe most of the coastal zone.

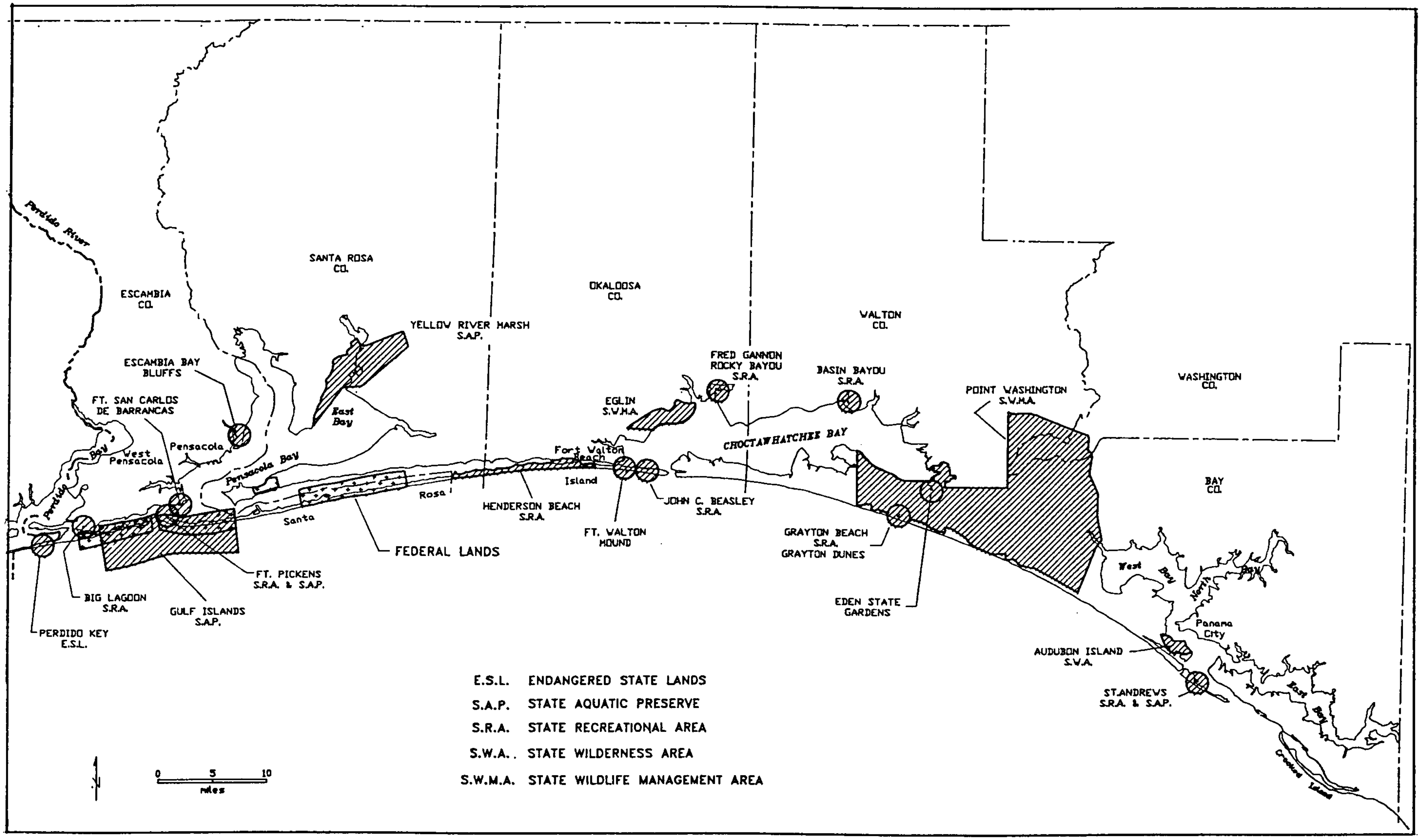

Figure 5.5. Designated conservation areas in the coastal Florida Panhandle (USFWS and MMS 1984).

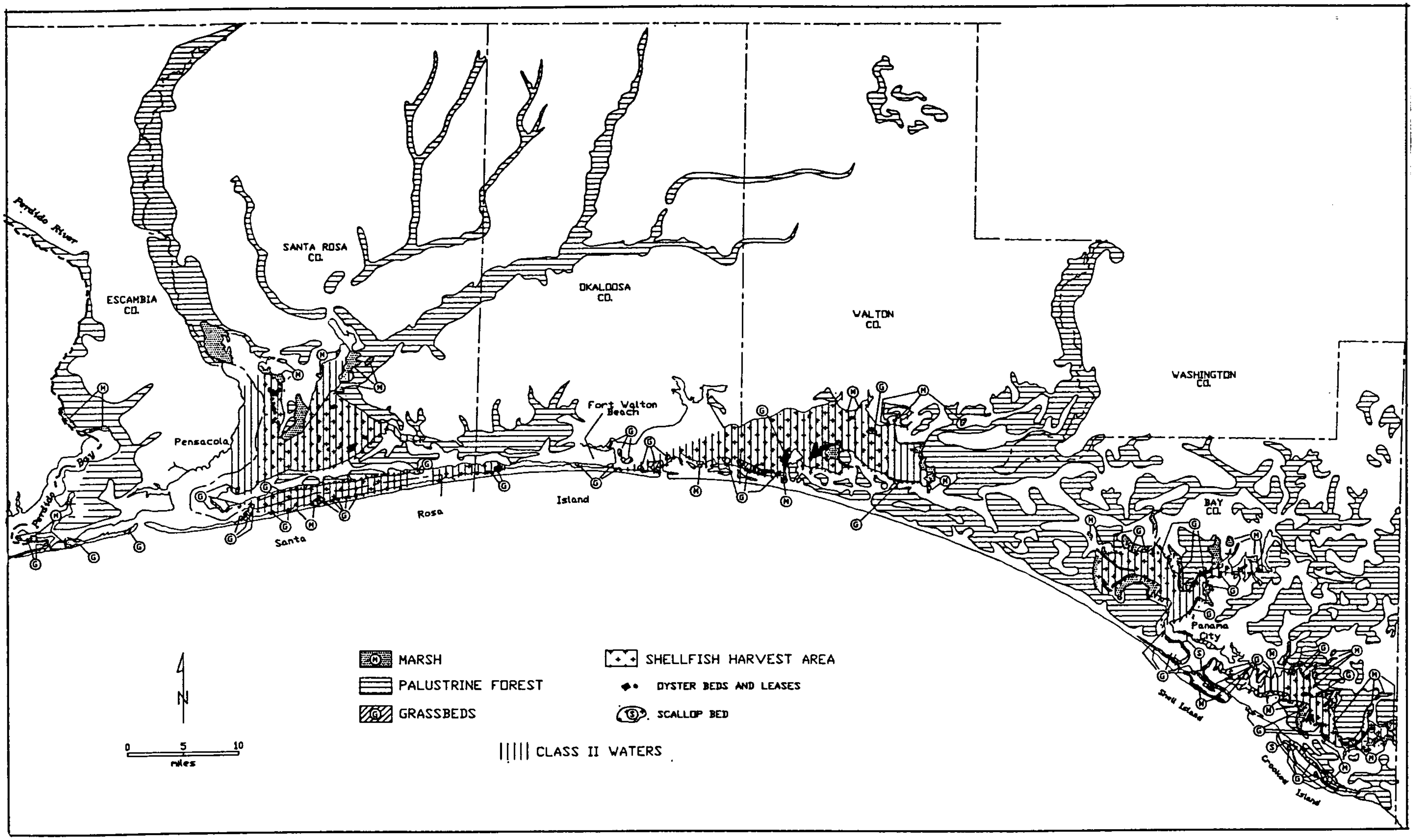

Figure 5.6. Class II waters and shellfish harvesting areas in the coastal Florida Panhandle (Florida Department of Environmental Regulation 1987; USFWS and MMS 1984).

While its neighbors to the west waited a period of a year after the Coastal Zone Management Act of 1972 to initiate coastal programs, Mississippi enacted a coastal wetlands protection law in 1973 and has been in the process of modifying and refining its rules, regulations, and procedures to the present. In fact Mississippi has the most definitive and clearly presented statement of its ideas of where pipelines should be located. However, the procedure allows flexibility for site and project-specific decisions when guiding pipelines through the complex coastal systems of barrier islands, reefs, sensitive areas, fringing wetlands, and developments. Companies can now plan long-term strategies for locating pipelines and feel fairly comfortable in the outcome of the process. Alabama was also one of the later entrants into actively protecting its coastal zone. Although Alabama has no specific regulations for locating pipelines its operational rules are designed to protect the renewable resources of its estuaries, bays, and barrier islands. The easternmost and final state within the study area is also the last to have its coastal zone plan approved by the Federal Government. Like Texas, Florida pipelines can apparently cross anywhere in the coastal zone, as long as the permit applicant demonstrates to state officials that the project will not adversely impact selected systems, such as wetlands, shellfish areas, beaches, dunes, or the water quality. From review of the State and Federal guidelines it becomes apparent that no longer are wetlands and bays treated as impediments that must be conquered by the engineer. Today, environmental systems are almost universally recognized and accepted as vital and important components of the coastal setting that deserve and will receive special consideration when projects are planned and built.

Analysis of the Federal and State regulations and guidelines dealing with pipelines in the coastal zone leads to several basic principles for future construction. It is assumed, of course, that the applicant for a pipeline project is seeking the most expeditious processing of its project possible. First, oyster beds, shell reefs, submerged grassbeds, and wetlands should be avoided. Use of these areas may not be outrightly prohibited, but the planning for each project and the mitigation required will make the project time-consuming and possibly more costly than if an alternate route were selected. Second, barrier islands should be crossed only when no other corridor is practical. Like the above, habitats crossing barrier islands requires extensive planning and significant mitigation to reduce or avoid adverse impacts. Third, unique features, such as areas of critical biological or cultural concern, high biological productivity, or irreplaceable resources, may be insurmountable obstacles to the location of pipeline corridors. Some areas may never be crossed, for example, the Point aux Pines wetlands in Alabama or a national register site, such as Fort Morgan. Fourth, construction within beach/dune complexes requires extensive mitigation for the protection or reconstruction of the systems. Rights-of-way may be restricted; vegetation must be replanted; or the topography of the site must be duplicated. Finally, from the environmental planning perspective, the Mississippi approach to clearly defining pipeline corridors while leaving some flexibility in final decisions should be duplicated by other states.

CHAPTER 6: GULF COAST ENVIRONMENT

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D. Roberts, S. Pierce, and R. Emmer

Introduction

The study area stretches along the Gulf Coast from Cameron County, Texas to Bay County, Florida. For this report, the geographic classification of the Gulf Coast developed by Terrell (1979) has been used as a framework for the presentation of a detailed discussion of the environmental parameters that could influence the type and magnitude of pipeline and navigation channel impacts.

The Texas Barrier Islands System is characterized by an extensive lagoon system fronted by barrier islands and backed by drowned river mouths. The freshwater inflow varies from regular along the upper coast to limited along the lower coast. For this reason, coastal wetlands are confined to the upper coast and submerged grassbeds in hypersaline lagoons characterize the lower coast (i.e., Corpus Christi Bay southward). The description of this region is by island/beach and bay systems: (1) Padre Island (Laguna Madre), (2) Mustang Island-Matagorda Island (Corpus Christi, Aransas, Espiritu Santo Bays), (3) Matagorda Peninsula (Matagorda and East Matagorda Bays), (4) Brazos Delta Headland, and (5) Galveston Island-Bolivar Peninsula (West, Galveston and East Bays).

The Strandplain-Chenier Plain System reaches from eastern Chambers County, Texas through Vermilion Parish, Louisiana. This coastal region contains extensive wetlands fronted by barrier beaches or mud flats. The most extensive wetlands in the Texas coastal plain are in this system. Freshwater enters the region from several small watersheds. There are no extensive embayments along this portion of the Gulf Coast. Cheniers, that is, long, linear oak-covered and abandoned beach ridges, are a unique geomorphic feature of this otherwise low-lying, low-relief coastal wetland.

The Mississippi Delta System, as defined in this study, extends along the coast from West Cote Blanche Bay-South West Pass eastward to the Louisiana-Mississippi border as delineated by the Pearl River. This system is distinguished from other coastal regions because of its very extensive fresh-to-saline marshes, numerous shallow water embayments and sounds, high subsidence rate, and high volume of Mississippi River water and sediment discharge. Active and abandoned delta lobes in this system are composed of silty sediments (of terrigenous origin) and organic muck (i.e., peat). The waters are very turbid within the bays and behind the extensive barrier island arcs lying east and west of the active Mississippi River delta.

The major barrier island-barrier beach units and associated water bodies within this region are Isles Dernieres (Caillou Bay and Pelto Lake), Timbalier Islands (Terrebonne and Timbalier Bays), Caminada-Moreau Headland, Grand Isle (Caminada Bay), Grand Terre to Sandy Point (Barataria, Ronquille, Long, Joe Wise, Bastian, and Coquette Bays), and Breton-Chandeleur Islands (Breton and Chandeleur Sounds). The active Mississippi and Atchafalaya Deltas are characterized by marsh-mud-flat shores rather than sand/shell barrier beaches. Because this study focused on the impact of OCS activities on barrier islands and beaches in Louisiana, these geographic subunits were not described.

The North Central Gulf Coast system is characterized by white sand beaches, clear water, and extensive dunes. The eastern portion has an almost continuous stretch of barrier islands and beaches closely parallel to or connected to the mainland. Wetlands hug the

Pleistocene uplands along the coastline and within several large estuaries. The western portion is distinguished by five major barrier islands lying 4.8 to 19.3 km offshore of the mainland. The coastal zone is very narrow in this area with marshlands of limited extent confined mostly to tidal channels and the lee side of barrier islands. The major geographic subdivisions for this system are: (1) Mississippi Sound containing Cat Island, Ship Island, Horn Island, Petit Bois Island, Dauphin Island; and (2) Mobile Bay-to-Florida Panhandle complex of Gulf Shores-Mobile Point (Mobile and Bon Secour Bays), Perdido Key (Perdido Bay), Santa Rosa Island (Pensacola Bay and Santa Rosa Sound), Destin-St. Andrews (Choctawhatchee and St. Andrew Bays), and Crooked Island (East Bay and St. Andrew Sound). Major water bodies having marshlands on the landward side of Mississippi Sound are the Pearl River, Back Bay of Biloxi, Pascagoula Bay, and Point aux Chene to Heron Bays.

The remainder of this chapter describes the four coastal systems in terms of (1) geology and sedimentology, (2) climate and tropical storms, (3) hydrology, (4) vegetation, and (5) land use. Where possible these descriptions are by subsystem as identified previously.

Geology and Sedimentology

Shoreline evolution in the Gulf of Mexico is related primarily to the redistribution of fluvial/deltaic sand bodies that have been reworked by marine currents and waves. Barrier islands and barrier beaches are the principal depositional systems associated within this evolutionary sequence. Theories of barrier island formation include spit segmentation (Gilbert 1885), shoal aggradation (De Beaumont 1845), beach ridge detachment (Hoyt 1967), and composite development (nucleation on pre-Holocene higher grounds) (Otvos 1985). A combination of the above processes occurs during different stages of the barrier island evolution throughout the Gulf Coast. Stages of Holocene shoreline evolution have been well documented for Texas (Morton and McGowen 1980), Louisiana (Gould and McFarlan 1959, Penland and Boyd 1981), and Mississippi-Florida (Otvos 1985), and will be discussed in the following sections.

Sedimentary deposits have been described in terms of both transgressive and regressive events and sequences. Transgressions and regressions are related to local relative sea-level changes and the rate of sedimentation or erosion (Figure 6.1) (Curray 1965). The distinction between transgressive and regressive stratigraphic sequences is fundamental to the understanding of barrier island and barrier beach shoreline evolution (Figure 6.2). A transgressive sequence is one in which marine deposits overlie sediments from more landward environments as the shoreline moves inland. In contrast, a regressive sequence is one in which landward sediments are found on top of marine deposits as the shoreline moves seaward.

Transgressive landforms exhibit a predominantly low-profile morphology. Low-profile barriers are characterized by: (1) narrow widths, (2) low, sparsely vegetated, discontinuous dunes, (3) numerous, closely-spaced, active washover channels, and (4) thin sand cores overlying stiff deltaic muds. Regressive barriers comparatively exhibit high-profile morphologies. These are characterized by: (1) broad widths; (2) high, continuous, well-vegetated, fore-island dunes; (3) few, if any, active washover channels; (4) parallel accretion ridges; and (5) relatively thick sand cores (Morton and McGowen 1980). A generalized diagram of high- and low-profile barrier island environments is shown in Figure 6.3 (White et al. 1978).

Relative sea-level rise is the primary control on the location, stratigraphy, and topographic profile of the Gulf of Mexico shorelines. The morphologic evolution of barriers and beaches is also a consequence of both tidal range and mean annual nearshore

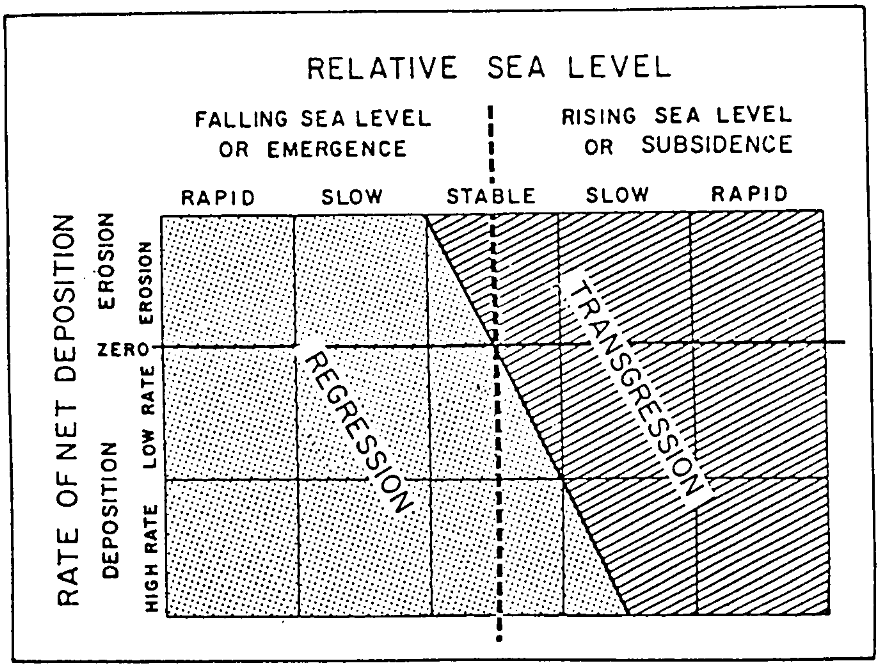


Figure 6.1. Relationship of transgressions and regressions to local relative sea-level changes and the rate of sedimentation or erosion (Curray 1964).

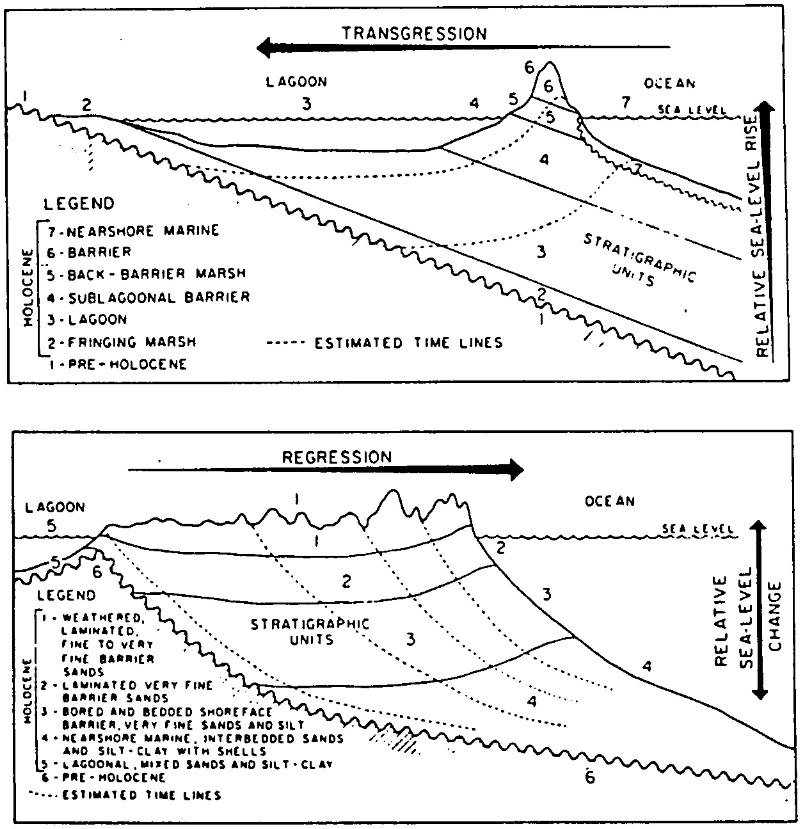
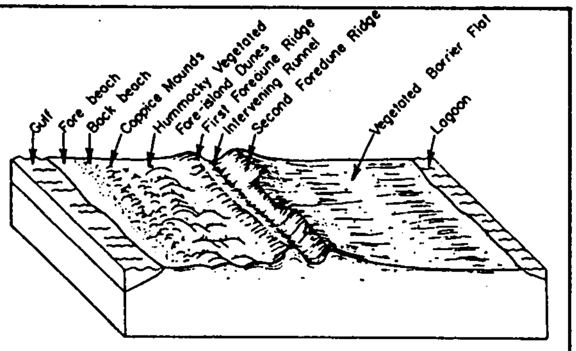
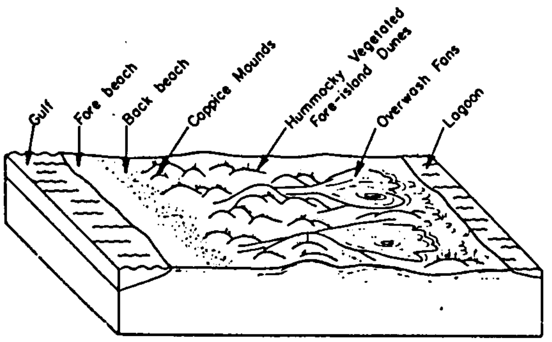


Figure 6.2. Comparison of transgressive and regressive depositional sequences (Kraft 1979).



High-Profile Barrier Island



Low-Profile Barrier Island

Figure 6.3. **Comparative morphologic illustrations of high-and low-profile barrier island environments (White et al. 1978).**

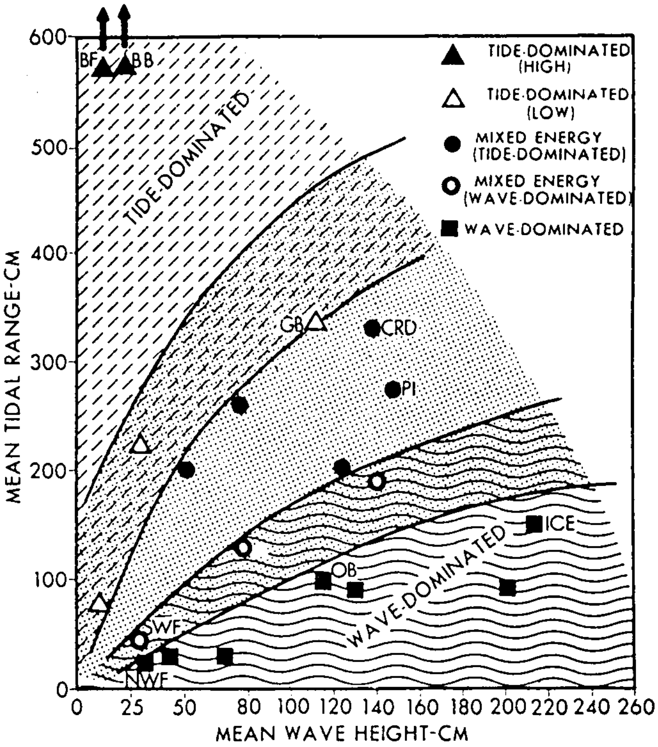


Figure 6.4. **Barrier island morphology as a function of tide range and mean wave height (Hayes 1979).**

wave energy (Nummedal and Fisher 1978; Hayes 1979; Nummedal and Penland 1981). Coastlines along the Gulf of Mexico are morphologically classified as wave dominated or tide dominated (Figure 6.4). Wave-dominated coastlines predominate in the study area with the exceptions of Galveston Island and Grand Isle, which are tide-dominated (Nummedal 1983). Wave dominated coasts are characteristically long, generally narrow, and cut by widely separated tidal inlets with large sand accumulations in the back-barrier bays (flood-tidal deltas) and small or nonexistent ebb-tidal deltas (seaward shoals).

Tide-dominated barrier islands are characteristically drumstick shaped. They are separated by stable tidal inlets with an average spacing of 15 km and associated large ebb-tidal deltas. Galveston Island and Grand Isle are tide-dominated, in spite of a tidal range of less than 50 cm, because of the large, tidal prisms produced by their respective bays (Galveston and Barataria).

Texas Barrier Island System

The Texas coast exhibits four distinct types of shorelines: erosional deltaic headlands, peninsulas, barrier islands, and a Holocene progradational delta (i.e., Brazos) (Figures 6.5 and 6.6). Major features and characteristics of the Texas barrier island coastal region, such as shoreline type, littoral transport, sediment type and source, tidal inlets, tidal deltas, shoals, dune topography, depth to Pleistocene, shoreline change, washovers, and associated bay/lagoons are summarized in Table 6.1 by beach segment and illustrated on Maps 1-E through 4-E (shoreline type, depth to Pleistocene, and sediment transport); and 1-F through 4-F (geomorphology and shoreline change), Vol. II.

The Texas coast exhibits both transgressive and regressive landforms which are nearly equally represented (Morton 1979) (Figure 6.7) and clearly illustrate the principles described by Curray (1965). Transgressive sequences have developed along the deltaic headlands (South Padre Island, Rio Grande Delta; Freeport, Brazos-Colorado Delta; between Galveston Bay and the Sabine River, Trinity Delta) because of marine processes removing sediment. Regressive barriers (North Padre, Mustang, San Jose, Matagorda, East Galveston Islands) evolved in the adjacent embayments which have acted as sediment sinks. Interdeltaic embayments have been the primary location for the development of broad regressive barrier strandplains throughout the evolution of the Texas coastal plain (Galloway et al. 1982, Winker 1979).

Padre Island

South Padre Island originated when lobes of the Rio Grande delta began to subside between 3,400 and 1,900 yrs before present (B. P.) (Lohse 1962). Dominant marine processes reworked the shoreline sands into transgressing offshore shoals, which eventually coalesced to form south Padre Island. In the northern and central regions, island formation occurred approximately 4,500 years B. P. when sands were eroded from submerged Pleistocene sediments on the adjacent shelf. The sands were concentrated into offshore shoals by waves breaking on the gently sloping inner shelf (Fisk 1959, Brown et al. 1977). The shoals became a series of emergent, low, discontinuous sandy islands aligned parallel to their mainland shoreline. Spit accretion in conjunction with longshore drift allowed the islands within the discontinuous chain to coalesce. The southern sandy transgressive peninsula was eventually connected to the northern islands, resulting in the formation of modern Padre Island.

Padre Island demonstrates both regressive (high-profile) and transgressive (low-profile) characteristics in its northern and southern regions, respectively. The northern and central segments exhibit a broad, well developed beach face composed of sand and shells.

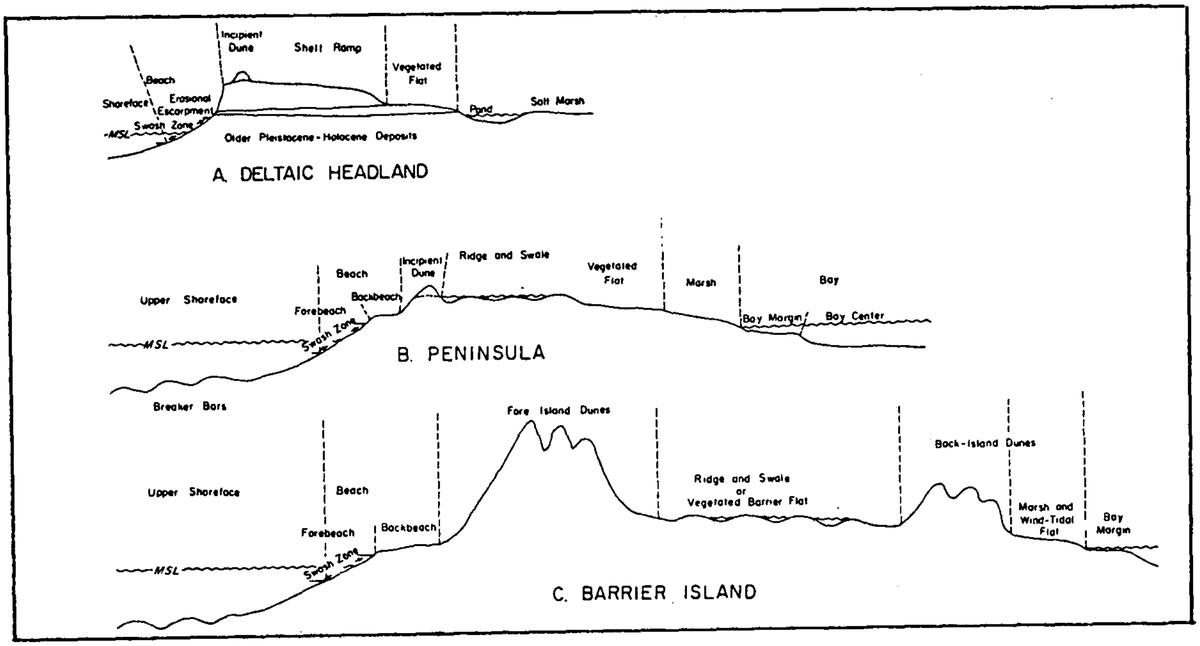


Figure 6.5. Generalized profiles across shoreline features associated with: (a) erosional deltaic headlands, (b) peninsulas, and (c) barrier islands (McGowen et al. 1977).

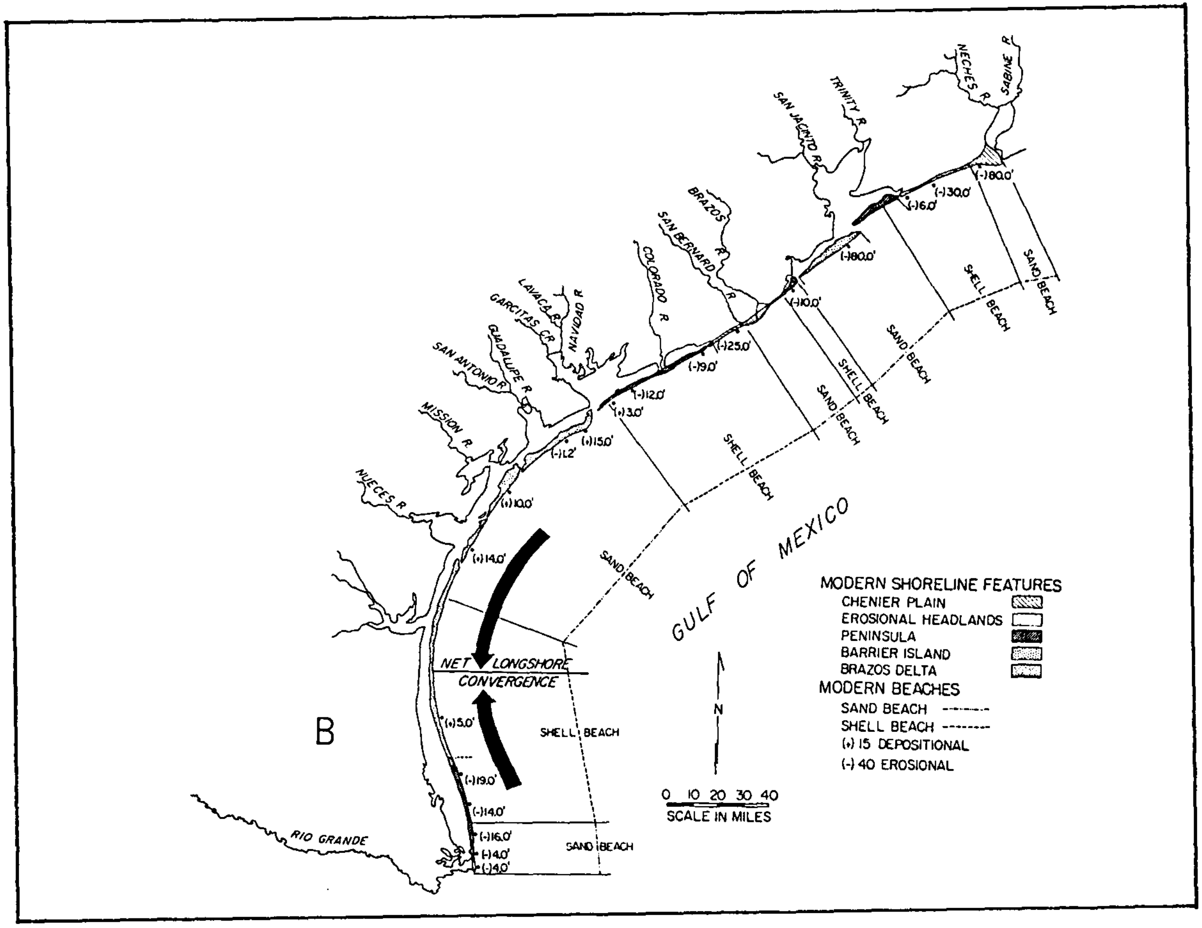


Figure 6.6. Location of principal Gulf shoreline types (chenier plain, erosional deltaic headland, peninsula, barrier island, and Brazos delta) and distribution of sand and shell beaches (McGowen et al. 1977).

Table 6.1. Characteristics of Barrier Islands, Beaches, and Associated Water Bodies within the Texas Barrier Island System.

AREA

CHARACTERISTICS	Brazos Island	South Padre Island	Central and North Padre Island	Mustang Island	St. Joseph Island
Beach Type	Transgressive Barrier Island	Transgressive Barrier Island	Regressive Barrier Island	Regressive Barrier Island	Regressive Barrier Island
Dimensions	12 km X 1.7 km	68 km X 2 km	98 km X 2 km	27 km X 1.8 km	29 km X 2 km
Shore/Island Profile	Low-Profile	Low-Profile	High-Profile	High-Profile	High-Profile
Dune Topography	Low discontinuous	Low discontinuous	Continuous with local blowouts	Continuous with local blowouts	Continuous with local blowouts
Dimensions	3.0 - 4.5 m height	3.0 - 4.5 m height	4.5 - 15.0 m height	5.0 - 6.0 m height	5.0 - 6.0 m height
Island Migration	Westward/ Shoreward	Westward/ Shoreward	Southeast/ Seaward	Southeast/ Seaward	Southeast/ Seaward
Littoral Transport	N/NE	N/NE	NNE/SSW	SW	SW
Shoreline Change	Erosion 1.2 m/yr	Erosion 4.5 m/yr	Accretion 2.7 m/yr	Accretion 4.2 m/yr	Accretion 3.0 m/yr
Tidal Inlets	Few. Occur locally adjacent to barriers.	Few. Occur locally adjacent to barriers.	Few. Occur locally adjacent to barriers.	Few. Occur locally adjacent to barriers.	Few. Occur locally adjacent to barriers.
Type	Wave-dominated	Wave-dominated	Wave-dominated	Wave-dominated	Wave-dominated
Dimensions	9.0-10.0 m depth	9.0-10.0 m depth	9.0-10.0 m depth	9.0-10.0 m depth	9.0-10.0 m depth
Frequency	Widely-separated	Widely-separated	Widely-separated	Widely-separated	Widely-separated
Washovers	Abundant fans and channels	Abundant fans and channels	Abundant fans and channels	Local fans and channels	Local fans and channels
Tidal Deltas	Occur locally	Occur locally	Occur locally	Occur locally	Occur locally
Flood	Large well-developed	Large well-developed	Large well-developed	Large well-developed	Large well-developed
Ebb	Small	Small	Small	Small	Small
Shoals	Lagoonal and adjacent to barriers	Lagoonal and adjacent to barriers	Lagoonal and adjacent to barriers	Lagoonal and adjacent to barriers	Lagoonal and adjacent to barriers
Associated Bay/ Lagoons	Laguna Madre	Laguna Madre	Laguna Madre	Corpus Christi Bay	Copano Bay
Depth	3.0 - 4.0 m	3.0 - 4.0 m	3.0 - 4.0 m	3.0 - 4.0 m	3.0 - 4.0 m
Sediment Source	Pleistocene shoals/ deltaic headlands	Pleistocene shoals/ deltaic headlands	Pleistocene shoals/ deltaic headlands	Pleistocene shoals/ deltaic headlands	Pleistocene shoals/ deltaic headlands
Nearshore	Silt, sand, shells	Silt, sand, shells	Silt, sand, shells	Sand, shells	Sand, shells
Beach	Sand, shells	Silt, sand, shells, rock fragments	Silt, sand, shells, rock fragments	Sand, shells, rock fragments	Sand, shells, rock fragments
Back Barrier	Sand, mud, shells	Sand, mud, shells	Sand, mud, shells	Sand, mud, shells	Sand, mud, shells
Bay	Sand, mud, shells	Sand, mud, shells	Sand, mud, shells	Sand, mud, shells	Sand, mud, shells

CHARACTERISTICS	Matagorda Island	Matagorda Pennisula	Brazos Headland	Galveston Island	Bolivar Pennisula
Beach Type	Regressive Barrier Island	Transgressive Barrier Island	Transgressive Barrier Island	Regressive Barrier Island	Regressive Barrier Island
Dimensions	58 km X 4 km	72 km X 2 km	52 km long	45 km X 4 km	31 km X 4 km
Shore/Island Profile	High-Profile	Low-Profile	Low-Profile	High-Profile	High-Profile
Dune Topography	Continuous with local blowouts	Low discontinuous	Low discontinuous	Continuous with local blowouts	Continuous
Dimensions	5.0 - 6.0 m height	Isolated up to 7.0 m	1.0 - 3.0 m	0.5 - 3.0 m height	0.5 - 3.0 m height
Island Migration	Southeast/ Seaward	Northwest/ Shoreward	Northwest/ Shoreward	Southeast/ Seaward	Southeast/ Seaward
Littoral Transport	SW	SW	SW	SW	SW
Shoreline Change	Accretion 0.75 - 4.5 m/yr	Erosion 3.6 m/yr	Erosion 5.3 - 7.6 m/yr	Erosion 6.0 - 24.2 m/yr	Erosion 1.8 m/yr
Tidal Inlets	Few. Occur locally adjacent to barriers.	Few Occur locally	Few Occur locally	Few. Occur locally adjacent to barriers.	Few. Occur locally adjacent to barriers.
Type	Wave-dominated	Wave-dominated	Wave-dominated	Tide-dominated	Wave-dominated
Dimensions	9.0-10.0 m depth	9.0-10.0 m depth	9.0-10.0 m depth	10.0 - 12.0 m depth	9.0-10.0 m depth
Frequency	Widely-separated	Widely-separated	Widely-separated	Widely-separated	Widely-separated
Washovers	Local fans and channels	Abundant fans and channels	Abundant fans and channels	Local fans and channels	Local fans and channels
Tidal Deltas	Occur locally	Occur locally	Occur locally	Occur locally	Occur locally
Flood	Large well-developed	Large well-developed	Large well-developed	Large well-developed	Large well-developed
Ebb	Small	Small	Small	Small	Small
Shoals	Lagoonal and adjacent to barriers	Lagoonal and adjacent to barriers	Adjacent to accretionary spits	Lagoonal and adjacent to barriers	Lagoonal and adjacent to barriers
Associated Bay/ Lagoons	Matagorda Bay	Matagorda Bay	Local bays	West Bay Galveston Bay	East Bay Galveston Bay
Depth	3.0 - 4.0 m	3.0 - 4.0 m	1.0 - 3.0 m	3.0 - 4.0 m	3.0 - 4.0 m
Sediment Source	Pleistocene shoals/ deltaic headlands	Pleistocene shoals/ deltaic headlands	Distributary mouth bar sounds	Pleistocene shoals/ deltaic headlands	Pleistocene shoals/ deltaic headlands
Nearshore	Sand, shells	Sand, shells, rock sediment	Sand, shells, mud	Silt, sand, shells	Silt, sand, shells
Beach	Sand, shells, rock fragments	Sand, shells, rock fragments	Sand, shells, mud	Sand, shells	Sand, shells
Back Barrier	Sand, mud, shells	Silt, sand, shells rock fragments	Sand, mud, shells	Silt, sand, shells	Silt, sand, shells
Bay	Sand, mud, shells	Silt, sand, mud	Sand, silt, mud	Sand, silt, mud, shells	Sand, silt, mud, shells

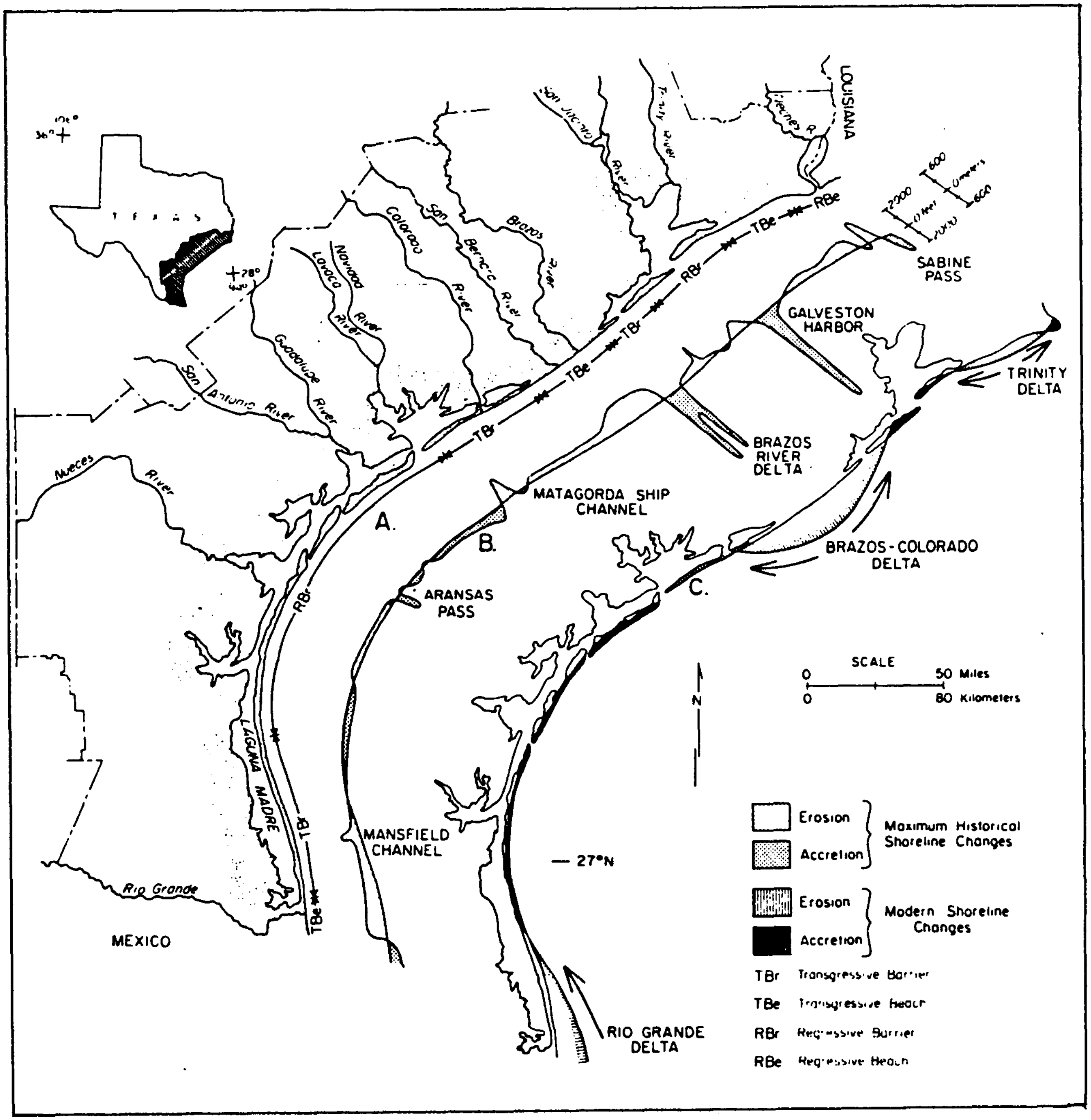


Figure 6.7. Map of Texas coast showing: (a) distribution of transgressive and regressive shorelines, (b) maximum shoreline changes between the years 1850 to 1883 and 1973 to 1975, and (c) the hypothesized late Holocene shoreline with three deltaic headlands and littoral drift cells (Morton 1979).

Continuous fore-island dunes lie immediately shoreward of the beach and range in height from 4.5 to 15 m. Continuity of the dunes is commonly disrupted by blowouts resulting from localized wind erosion. Back-island dunes, with heights up to 10 m, are active and often migrate into Laguna Madre (Hunter et al. 1972). Between the fore-island and back-island dunes there is a vegetated barrier flat, a depositional erosional surface generally less than 1.5 m above mean sea level. Figure 6.8 illustrates a stratigraphic dip section from Central Padre Island.

The southern region, including Brazos Island, exhibits a relatively thin, narrow, sandy beach. Dunes are low and discontinuous with elevations ranging from 3.0 to 4.5 m above mean sea level. Washover fans and channels are abundant (Brown et al. 1974; Morton and Pieper 1975) and are gradational with wind-tidal flat deposits toward Laguna Madre. Depth to Pleistocene ranges from 20 to 24 m (Figure 6.9). Padre Island has only one natural tidal inlet (Brazos Santiago Pass) although two man-made passes have been cut.

Laguna Madre represents an estuarine system occupying a broad entrenched stream valley behind Padre Island. The system has a very limited water exchange with the Gulf of Mexico and is extremely shallow. Sediments are composed essentially of sand, mud, and shells. Sand within the lagoon is derived from Padre Island and from the Pleistocene Ingleside barrier-strand plain system (Brown et al. 1980). Padre Island is shifting westward filling Laguna Madre with storm-washover sediments and eolian deposits. Laguna Madre is contemporaneously shifting westward to a lesser degree over the subsiding Pleistocene and Holocene coastal plain. Waves and currents rework much of the sand into a lagoon margin sand shoal. Mud is concentrated in the deeper, central part of the lagoon.

Mustang Island-Matagorda Island

The coastline extending from Corpus Christi Bay to Espiritu Santo Bay consists generally of wide, high-profile, regressive barrier islands which occupy the interdeltaic embayment between the Rio Grande and Brazos-Colorado deltas. Formation of these islands began approximately 2,500 yrs B. P. (Wilkinson 1973). Sands eroded from Pleistocene headlands and from submerged Pleistocene deposits on the inner shelf were transported by longshore currents and by onshore-directed storm waves to produce shoals and bars just offshore of the headlands. The shoals became emergent and a chain of islands was established primarily upon Pleistocene deposits along drainage divides (Shepard 1956, LeBlanc and Hodgson 1959).

The available sediment permitted gulfward accretion of beach ridges and shoreface deposits. Beach ridges are well exposed on northern St. Joseph Island, but blowouts have obscured the accretionary ridges on southern St. Joseph and Mustang Islands. The islands were separated by tidal channels which closed as a result of spit accretion across channel mouths. Tidal channels were situated in the vicinity of relief river valleys and were active for a relatively long period of time, allowing for the development of large flood tidal deltas.

Mustang, St. Joseph, and Matagorda Islands exhibit similar morphologic features, such as broad sandy beaches, high fore-island dunes, hummocky vegetated barrier flats, and active back-island and fore-island dunes that have prominent ridge and swale topography. Dune heights range up to 15 m but most fore-island dunes are only 5 to 6 m high (Wilkinson 1975). Washover fans and channels are locally abundant and vary considerably in size. Washovers may traverse the entire barrier width, but generally these features are gradational with beach and wind flat deposits (Andrews 1970). Figure 6.10 illustrates a stratigraphic dip section from the northern part of Matagorda Island.

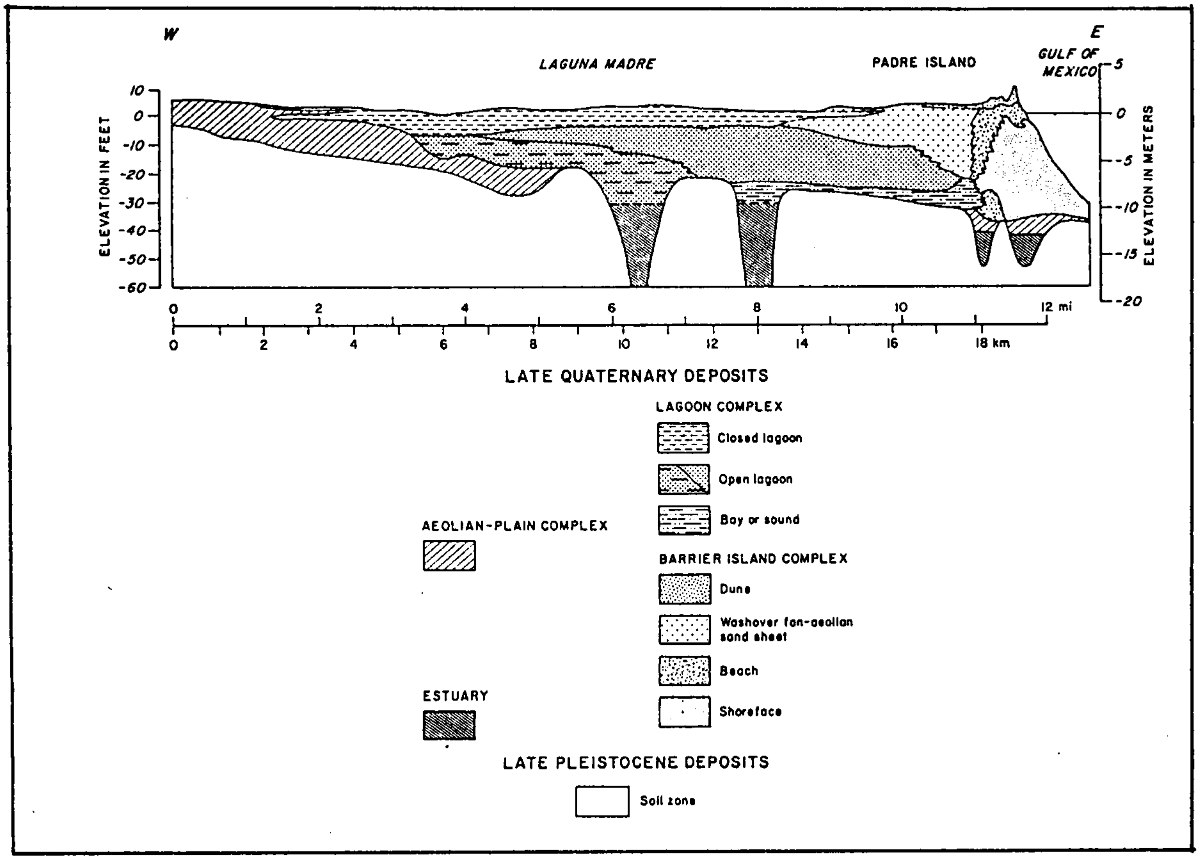


Figure 6.8. Stratigraphic dip cross section of Central Padre Island near land-cut area (Fisk 1959).

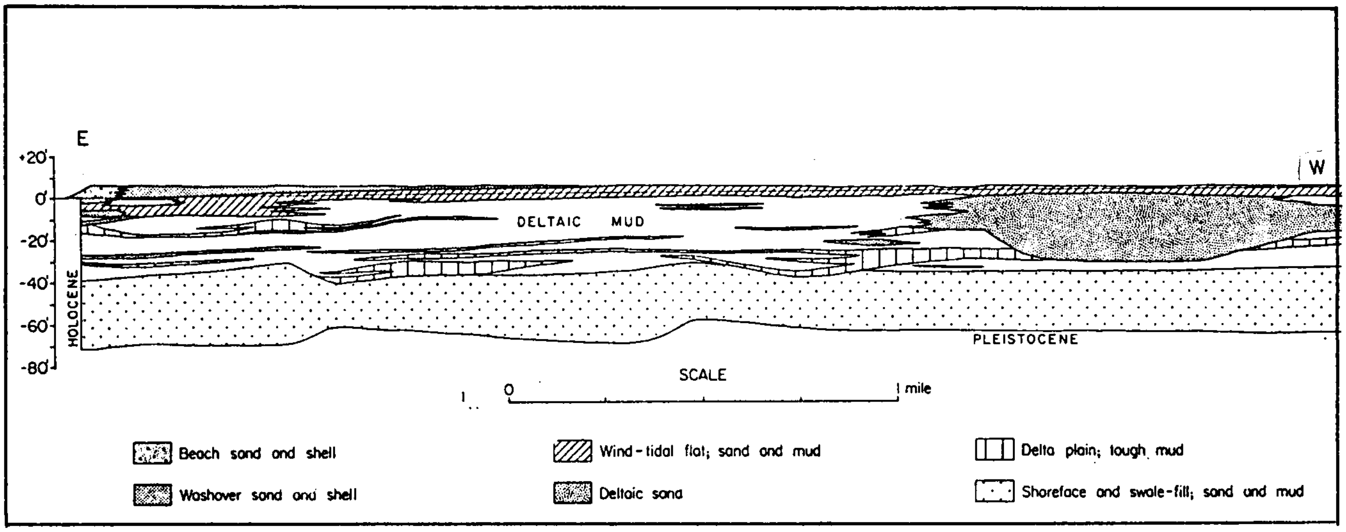


Figure 6.9. Stratigraphic dip cross section of South Padre Island, Texas (Brown et al. 1980).

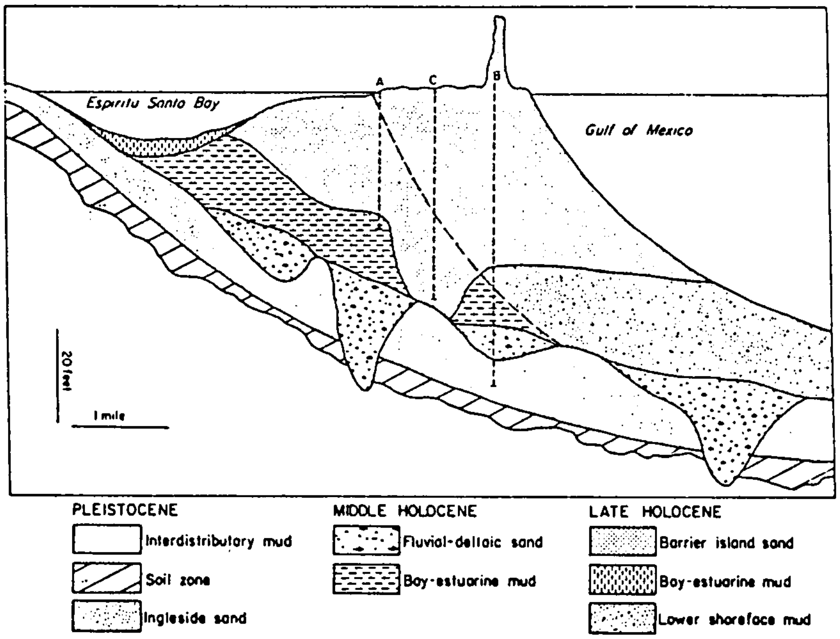


Figure 6.10. Stratigraphic dip cross section of Matagorda Island, Texas (Wilkinson 1973).

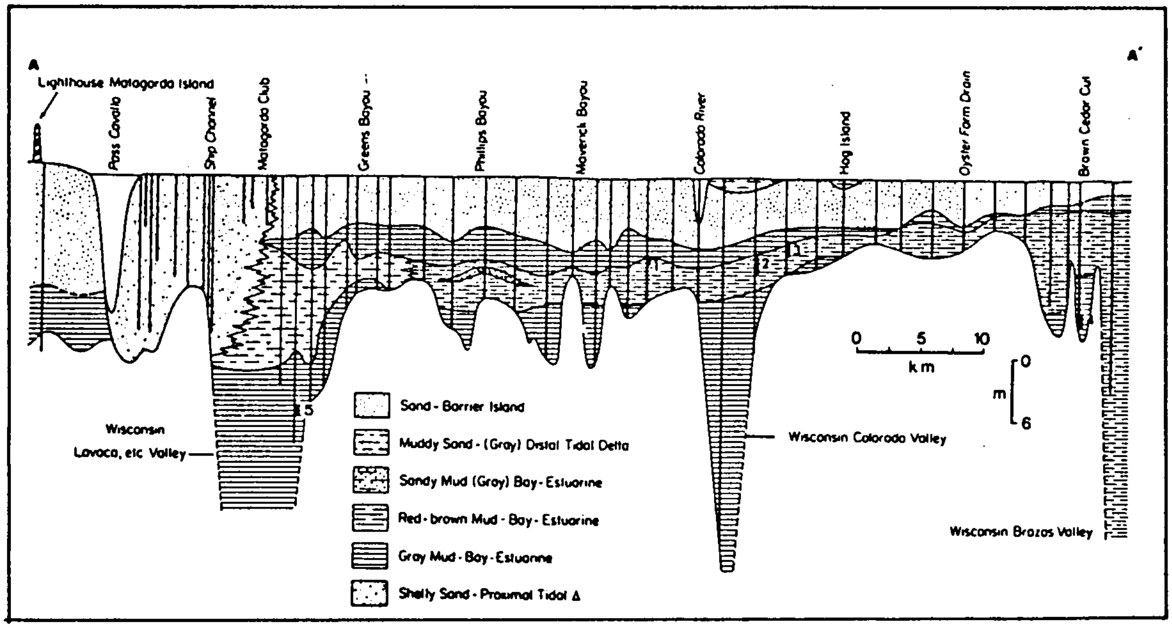


Figure 6.11. Stratigraphic strike cross section of Matagorda Peninsula, Texas (Wilkinson and Basse 1978).

The bays (Corpus Christi, Aransas, Copano, San Antonio, and Espiritu Santo) behind the islands demonstrate a diverse depositional system. Corpus Christi, Copano, and San Antonio are perpendicular to the coast and occupy drowned river valleys. San Antonio and Espiritu Santo lagoon are aligned parallel to shore and are positioned over divides between Pleistocene river valleys. The lagoons are generally shallow and consist of Holocene sand and mud with depths to the Pleistocene ranging from several meters to 35 m. Oyster reefs, interreef areas, marginal sand shoals, and grass flats are all characteristic of the environment.

Matagorda Peninsula

Matagorda Peninsula, lying southwest of the Brazos headland, is a transgressive barrier island. Formation of the island began approximately 4,000 yrs B. P. when submerged Pleistocene sediments were eroded and transported on the inner shelf to form shoals on Pleistocene topographic highs. The shoals subsequently developed into a chain of small, discontinuous barrier islands. Spit accretion extending from the Brazos-Colorado deltaic headland, approximately 1,800 yrs B. P., ultimately coalesced with the discontinuous islands to form the modern Matagorda Peninsula (Wilkinson and Basse, 1978). Sediment in the system is composed primarily of sand, shells, and a high percentage of rock fragments (sandstone, limestone, and beach rock). Morphologic features of the island are controlled primarily by storm washover and shoreline erosion (McGowen and Brewton 1975, Morton et al. 1976) which precludes development of extensive fore-island eolian dunes.

The peninsula is experiencing a predominantly landward migration, with shoreline erosion averaging 60 to 90 cm/yr. Tidal passes are situated over or near partially buried Pleistocene valleys. Flood-tidal deltas are large and consist of sand and shell. Ebb-tidal deltas are not as large nor as well defined. Figure 6.11 illustrates a depositional strike section of Holocene and late Pleistocene sediments beneath the Matagorda Peninsula.

Brazos Delta Headland

Approximately 4,500 yrs B.P., the Brazos and Colorado Rivers discharged into a common estuary that occupied late Pleistocene, drowned river valleys. After the estuary was filled, approximately 1,800 yrs B. P., the Brazos and Colorado Rivers discharged directly into the Gulf of Mexico. The Brazos River has built at least four deltas into the Gulf of Mexico during the past 1,800 years (Bernard et al. 1970, McGowen et al. 1976). The Brazos River was diverted to its present position by the U.S. Army Corps of Engineers in 1929.

The modern Brazos Delta is a wave-dominated oceanic delta (Scott and Fisher 1969). It has no distributaries, and its plain is characterized by levees, salt marshes, beach ridges, interridge areas and shallow bays and ponds (Figure 6.12). The Brazos delta has the highest rate of shoreline advance on the Texas coast (Seelig and Sorenson 1973). Locally, the delta experiences erosion and the subaerial portion of the system exhibits a cuspate form resulting from almost immediate reworking of sediments by waves and currents.

The Brazos headland and flanking transgressive barrier beaches (Surfside and Follets Islands) exhibit a dominant low-profile morphology. Beaches are thin and narrow and composed of coarse-grained sand, shells, and rock fragments. Back-barrier bays are shallow and contain sediments composed of sand and mud. Foredunes are low and discontinuous with abundant washovers resulting from sheet flooding. Littoral drift is generally westward while the shoreline migrates landward with erosion rates averaging 0.5 to 3 m/yr (Morton and Nummedal 1982). Behind the beach is an extensive salt marsh with

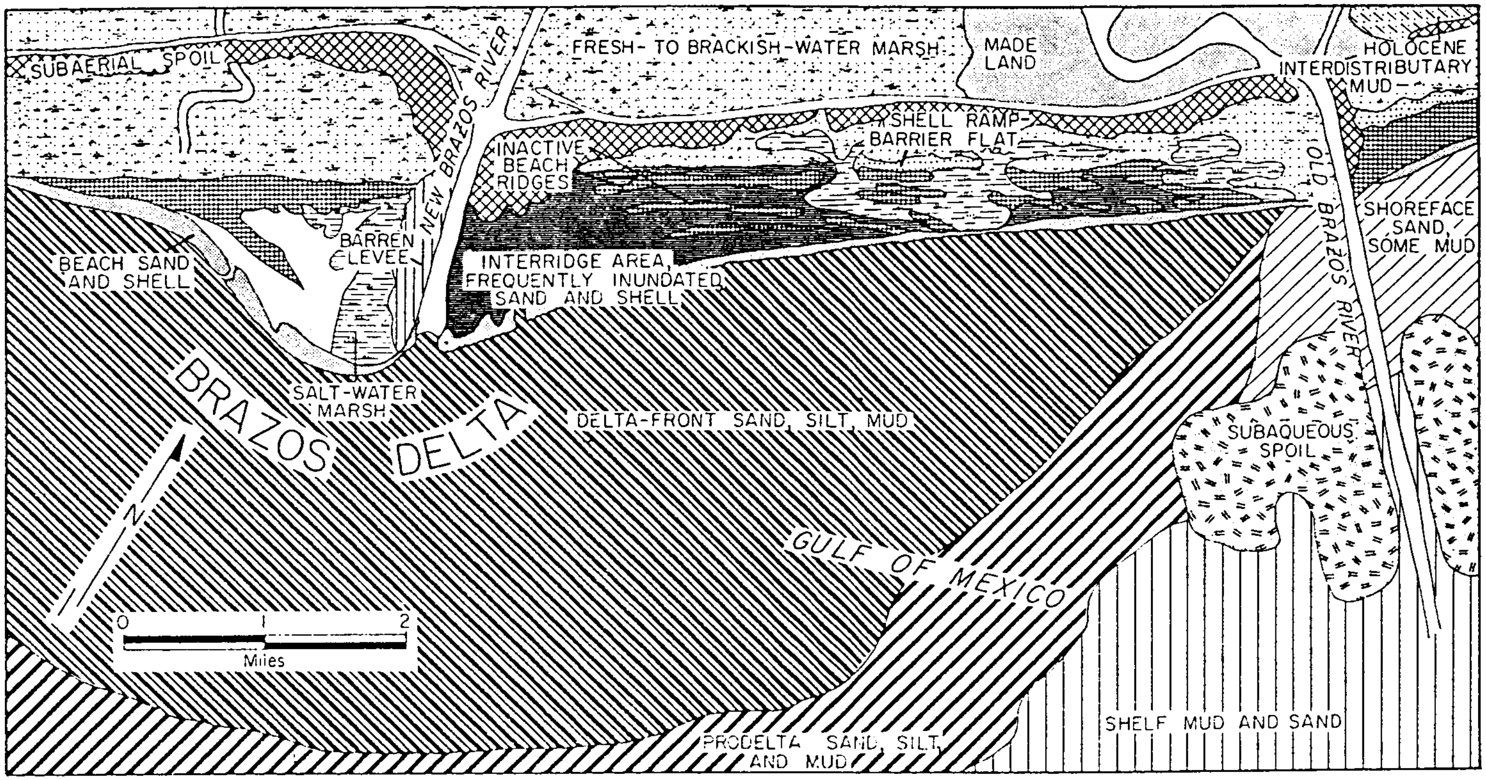


Figure 6.12. **Subaerial and subaqueous environments associated with the New Brazos River delta. The delta is a high-destructive, wave-dominated delta with a characteristic cuspate form (McGowen et al. 1976).**

numerous tidal creeks. Total thickness of the Holocene sediments near the Brazos delta is approximately 10 m.

Galveston Island to Bolivar Peninsula

Galveston Island and Bolivar Peninsula are regressive barrier islands situated along the northeast Texas coast. Morphologically, the islands are wide and are characterized as high-profile barriers. Both islands possess an extensive system of well-developed progradational sand beach ridges and sand dunes which run parallel to the shoreline. Interridge swales are composed of clayey, silty sand. Sand dunes range from 0.5 to 3.0 m in height (Bernard et al. 1962) and are generally composed of fine-grained, well sorted sand.

The islands reveal a general coarsening-upward sequence with the following facies present: shelf, transition zone, shoreface, foreshore, and eolian dune. Progradation of Galveston Island has deposited a lenticular sand body 5 to 15 m thick aligned parallel to the shoreline (Figure 6.13). Washover fans are abundant, carrying sediment to marshes established behind the islands.

The barriers are separated from the mainland by West Bay, Galveston Bay, and East Bay. These bays originate from the flooding of former entrenched valleys. Bay fill is characterized by a sedimentary sequence which can be subdivided, from oldest to youngest, into three units: (1) regressive alluvial sands, (2) transgressive fluvial sands overlain by deltaic muds, and (3) bay-estuarine muds (Morton and Nummedal 1982). Sediment sources, such as nearby distributary mouth bar sands within the bay-estuarine system, provide the modern regressive sands and muds of fluvial deltaic origin which overlie the bay-estuarine muds. Washover sediments consisting of sand and shells, additionally, overlie lagoonal deposits.

Galveston Island is separated from Bolivar Peninsula by a well defined tidal inlet. The tidal deltas are composed of silty to clayey sand with shells, and are developed toward both the open sea and the bay. The ebb-tidal delta consists of shelly sand bars over a broad, thick (12 to 20 m) shoal (Williams et al. 1979). Accretion on the updrift and downdrift ends of the islands remains continuous as a result of the hydraulic interaction between estuarine tidal flow and longshore currents (Todd 1968). Sand eroded and transported from the ebb-tidal delta is a sediment source for shoreline advancement. Subsidence in this region is affected by both sediment compaction and localized fault movement. Estimated subsidence rates vary from 0.25 cm/yr (Morton 1979) to 0.49-1.28 cm/yr (Swanson and Thurlow 1973).

Strandplain-Chenier Plain System

The broad coastal plain of East Texas is called a strandplain, whereas, a comparison area in western Louisiana is called the chenier plain. Both areas are characterized by broad, flat, low-lying, wetland-covered plains traversed by slightly elevated, better drained ridges, aligned roughly parallel to the coast. These ridges, historically, were densely vegetated by live oak, termed "Chene" in French, which lead to the region being called the chenier plain (Gould and Morgan 1962).

The major subdivisions of this coastal system are: (1) Rollover Pass to Sabine Pass, Louisiana, and (2) Sabine Pass to Southwest Pass, Louisiana. The geological characteristics of this system are delineated on Maps 4-E through 5-E and 4F through 5F, Vol. II.

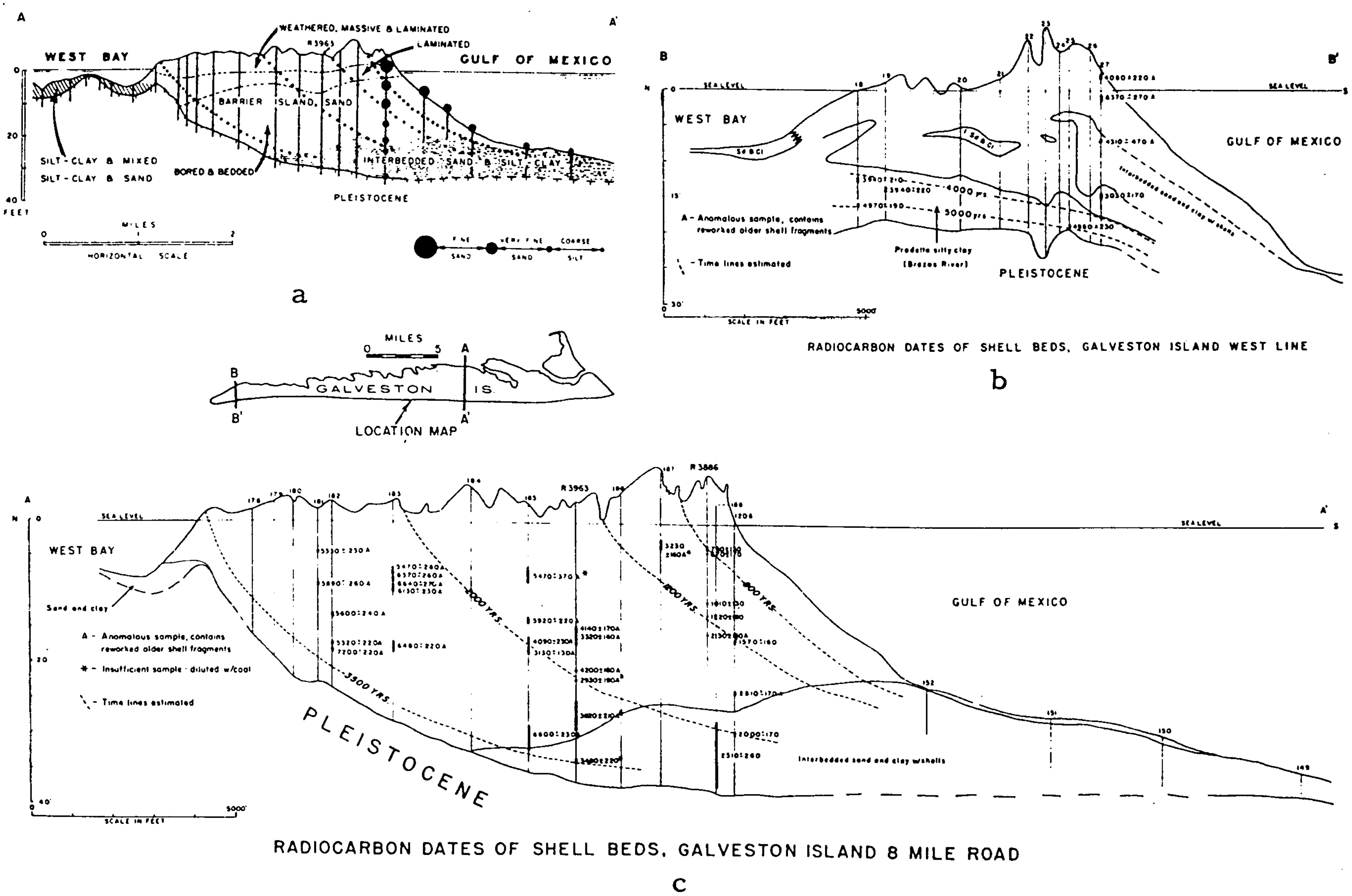


Figure 6.13. Dip cross section of Galveston Island, Texas (Bernard et al. 1970).

Rollover Pass to Sabine Pass

The Rollover Pass coastal system of east Texas demonstrates a low, broad depositional surface currently undergoing severe erosion and is, consequently, characterized as a transgressive barrier beach. Pleistocene fluvial-deltaic sediments, which were originally deposited as coalescing, low-gradient deltas into a relatively shallow water area, serve as the major sediment source (Winker 1979). Sediments are composed predominantly of muds, which were deposited in interdistributary bay and deltaic plain environments, and sands, which were deposited in distributary mouth bars and meandering fluvial channels. Erosion of the Pleistocene Trinity deltaic headland led to the formation of this transgressive barrier beach system (Barton 1930).

Near the shoreline, Holocene sedimentary deposits, approximately 1 m in thickness, overlie Pleistocene fluvial deltaic sediments. The beach along the coast is steep and narrow and is composed of a thin veneer of sand, shells, and local caliche nodules—i.e., sand grains-shell fragments cemented by calcium carbonate. Gravel lag deposits derived from Pleistocene muds are a source of coarse material. The landward migrating shoreline is characterized essentially as an overwash terrace with local poorly-developed sand dunes. High rates of erosion, ranging from 1.5 to 7.5 m/yr, occur along the transgressive beaches near the headland apex where wave energy is concentrated and sand is deficient because this is a mud-dominated delta (McGowen et al. 1977). Erosion rates show a general decrease westward from the headland apex. Pleistocene and Holocene sand percentages are low, ranging from 15 to 25% (Schumm 1963, Fisher et al. 1973). Tidal inlets are absent in this system. The physical characteristics of this area are detailed in Table 6.2.

Sabine Pass to Southwest Pass

The Sabine-Southwest Pass barrier beach system, commonly called the Chenier Plain, extends from the eastern flank of the Pleistocene Trinity delta in Texas to the western side of Vermilion Bay, Louisiana (Figure 6.14). Initial formation of this coastal area began approximately 3,000 yrs B.P. after sea level reached its present position.

The Chenier Plain consists primarily of sediments contributed by the Mississippi River subdeltas located east of the plain. Sedimentation fluctuates between periods of mud-flat/marsh progradation and shoreline erosion which produces isolated sand and shell lenses (cheniers) atop fine-grained marsh and mud-flat deposits (Gould and McFarlan 1959). Coastal outbuilding and local shoreline stability reflect a pulse of sediment from the Mississippi River whenever there is a lateral westward shift of the Mississippi River's mouth. Otvos (1969) has indicated, however, that these pulsations do not reflect large-scale shifts in delta positions. Minor changes in localized hydrological and sedimentation patterns are also responsible for alternate chenier ridge and interchenier mud-flat formation according to Otvos and Pierce (1979).

This regressive barrier beach system, although locally experiencing shoreline erosion rates ranging from 3 to 10 m/yr (Adams et al. 1978), demonstrates a general seaward thickening Holocene wedge of muddy sediments with essentially shore-parallel transgressive ridges composed of shell hash and sand (Russell and Howe 1935, Fisk 1955, Byrne et al. 1959, Gould and McFarlan 1959). This wedge, roughly 7 to 8 m thick at the present shoreline, exhibits brackish-to-marine deposits at its base which transgressively overlie Pleistocene sediments.

Morphologically, the Chenier Plain of western Louisiana is similar to the strandplain of east Texas and consists of beach ridges with interspersed mud flats; water bodies,

Table 6.2. **Characteristics of Barrier Islands, Beaches, and Associated Water Bodies within the Strandplain-Chenier Plain System.**

	AREA	
CHARACTERISTICS	**Rollover Pass to Sabine Pass**	**Sabine Pass to Southwest Pass**
Beach Type	Transgressive Barrier Beach	Regressive Barrier Beach
Dimensions	50 km long	170 km long
Shore/Island Profile	Low-Profile	High-Profile
Dune Topography	Low discontinuous	
Dimensions	0.5 - 10 m height	
Island Migration	Northwest/ Landward	South/ Seaward
Littoral Transport	SW	W
Shoreline Change	Erosion 9.1 m/yr	Erosion/Accretion -5.6 m/yr - +4.0 m/yr
Tidal Inlets	Generally absent	Locally abundant
Type		Wave-dominated
Dimensions		1.0-4.0 m depth
Frequency		Closely-separated
Washovers	Abundant fans and channels	Local fans and channels
Tidal Deltas	Occur locally	Occur locally
Flood	Small	Small
Ebb	Small	Small
Shoals	Generally absent	Occur locally
Associated Bay/ Lagoons	Local Bays	Local Bays
Depth	0 - 1.0 m	0 - 3.0 m
Sediment Source	Pleistocene Deltaic headlands	Holocene Deltaic headlands
Nearshore	Mud, sand, shells	Sand, mud, shells
Beach	Mud, sand, shells, caliche nodules	Sand, mud, shells,
Back Barrier	Mud, sand	Sand, mud, shells
Bay	Mud	Sand, mud, shells

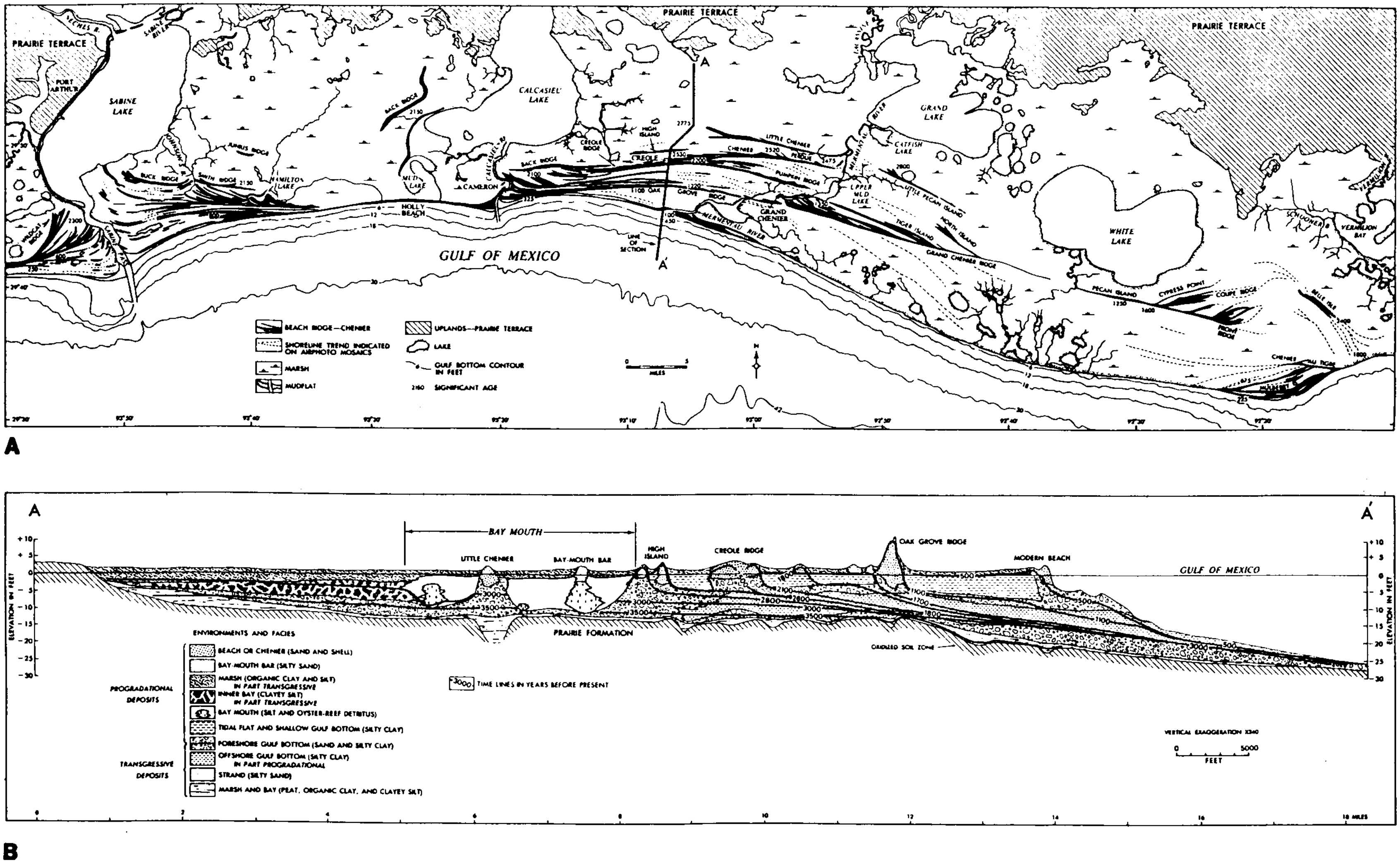


Figure 6.14. A. Geologic map of the Louisiana Chenier Plain (after Gould and Morgan 1962). B. Stratigraphic dip section of the Chenier Plain showing depositional environments and chronologic development (after Byrne et al. 1959, Gould and McFarlan 1959, Gould and Morgan 1962) (in Morton and Nummedal 1982).

including lakes, streams, and tidal inlets; and vegetated marsh. The stratigraphy demonstrates sequences of alternating or coalescing chenier ridge and inter-mud flat and marsh deposits. The cheniers are long (48 to 112 km), continuous, low ridges which are exposed subaerially above the marsh. They range from 30 to 450 m in width and are from 0.6 to 4.5 m thick. Elevation ranges from a few centimeters to 3 m. The average chenier is approximately 2.5 m thick and 200 m wide (Byrne et al. 1959). Locally, ridges converge to form composite cheniers attaining widths of 1000 m. Figure 6.14 is a stratigraphic dip cross section illustrating the environments of deposition and the chronological development of the chenier plain. Drilling data (Byrne et al. 1959, Gould and McFarlan 1959) reveal that the shallow base of the cheniers rests on Gulf bottom silty clays containing layers of well-sorted sand, reflecting a regressive sequence. Additionally, equally shallow-based incipient cheniers at Pecan Island (Coleman 1966) overlie marsh deposits as a result of storm overwash processes accompanied by erosional shoreface retreat (Morgan et al. 1958).

Interaction of river flow with longshore processes has resulted in the characteristic deflected patterns of rivers, for example, the Mermentau River, because of the westward progradation of the chenier ridges and intervening mud flats, along with the termination and landward-curving of the beach ridges themselves. The shoreline between the Calcasieu and Sabine Rivers, and locally near the Mermentau River, presently consists mostly of beaches with local washover fans. Other areas of the shoreline are characterized by coastal mud flats instead of sand beaches. Marshes, with numerous small lakes and locally large lakes, have an average elevation of less than 0.75 m above sea level.

Currently, the chenier plain receives a major influx of fine-grained sediments from the Atchafalaya River to the east. The chenier plain exhibits local growth through a series of transitory mud flats becoming welded to the shoreline (Wells and Kemp 1981). Mud-flat sedimentation increases and shifts to the west in accordance with westward shore-parallel currents. Subsidence in the region is mainly a result of sediment compaction and averages about 1.75 cm/yr.

Mississippi Delta System

Holocene sedimentation in Louisiana's coastal plain resulted from successive migrations of the Mississippi River. Prograding deltaic lobes, abandoned deltaic lobes, and reworked deltaic headlands are sedimentary environments resulting from shifts of the main channel of the Mississippi. The distribution and chronologic details of these successive lobes have been developed by various investigators (Fisk 1944, 1952; Morgan et al. 1953; Van Lopik 1955; Kolb and Van Lopik 1958; Frazier 1967). Figures 6.15 and 6.16 illustrate the location of delta lobes and detail their respective chronology.

Abandonment of a deltaic lobe leads to a series of stages of barrier island and barrier beach development in a transgressive regime. The evolution of Louisiana barrier islands has been described in terms of a three-stage evolutionary model (Penland et al. 1981) and is illustrated in Figures 6.17 and 6.18. Stage 1 depicts an abandoned deltaic complex being transformed into an erosional headland with flanking barrier islands. Subsidence following major distributary abandonment initiates a localized sea-level transgression within each abandoned delta. Stage 2, a transgressive barrier island arc, is an intermediate phase of island evolution and results from continued subsidence and marine reworking of distributary mouth bar sands of the delta complex. The final stage is the development of an inner shelf shoal.

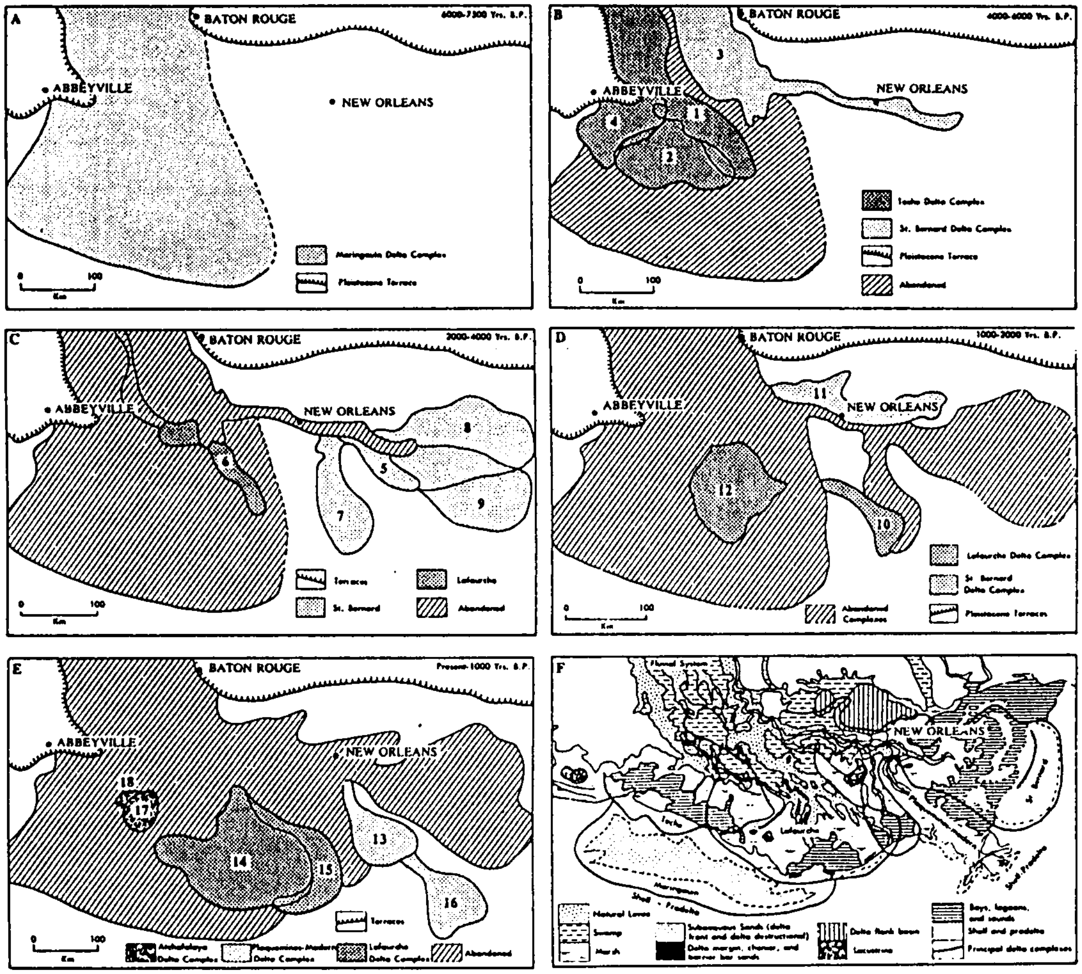


Figure 6.15. Delta and subdelta lobes of the Mississippi deltaic plain with lobe chronology (after Frazier 1967 in Penland and Boyd 1985).

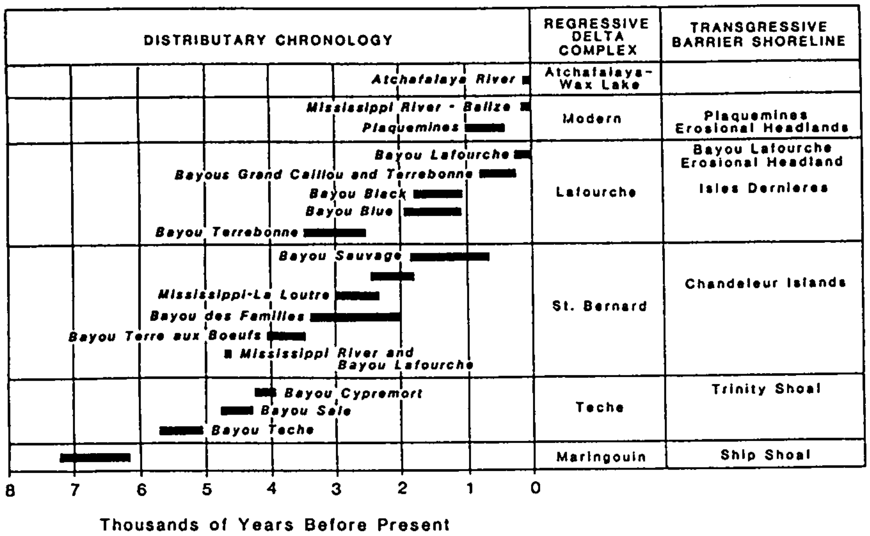


Figure 6.16. Mississippi delta lobe chronology and associated transgressive barrier shorelines (after Frazier 1967 in Penland and Boyd 1985).

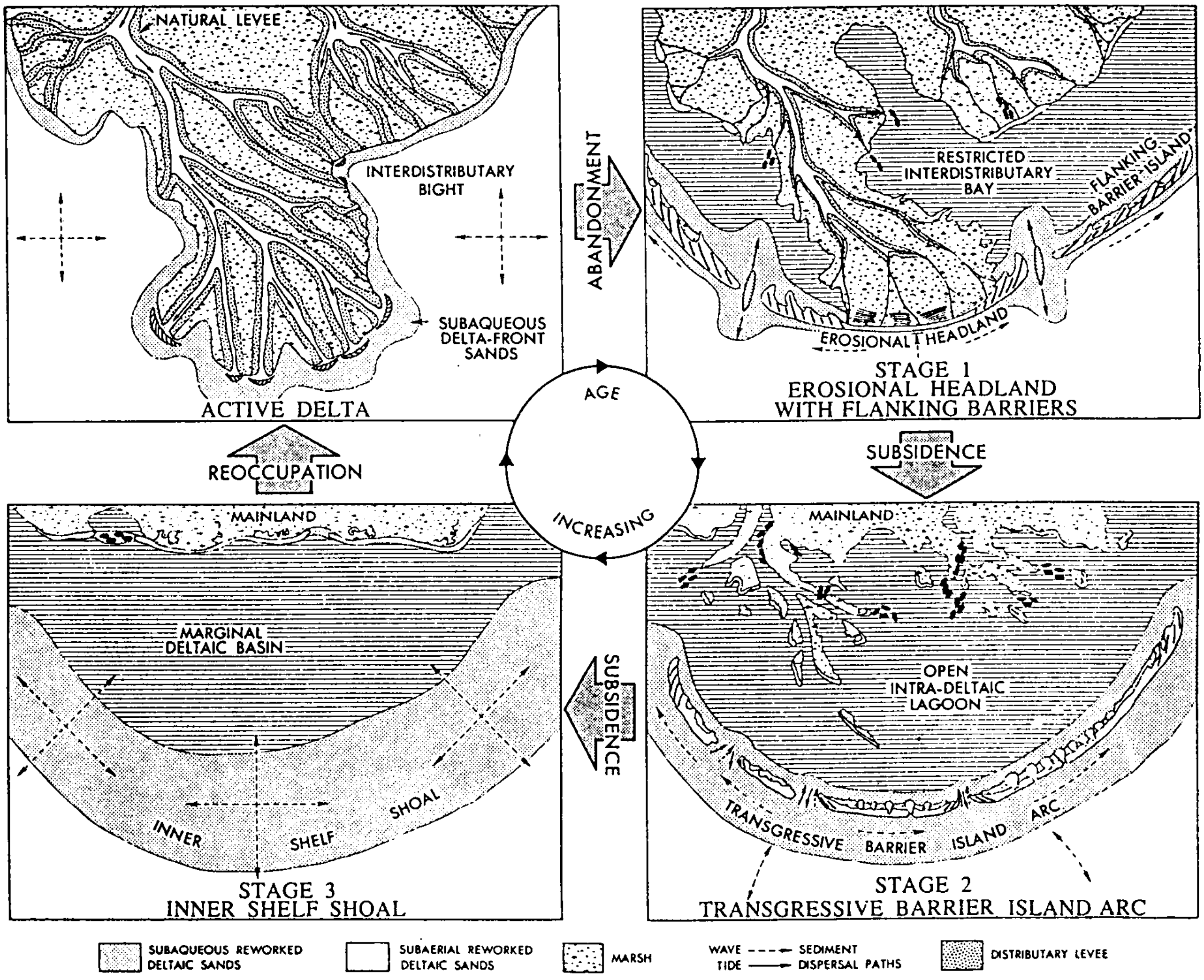


Figure 6.17. Three-stage model for evolution of Louisiana barriers (Penland and Boyd 1981).

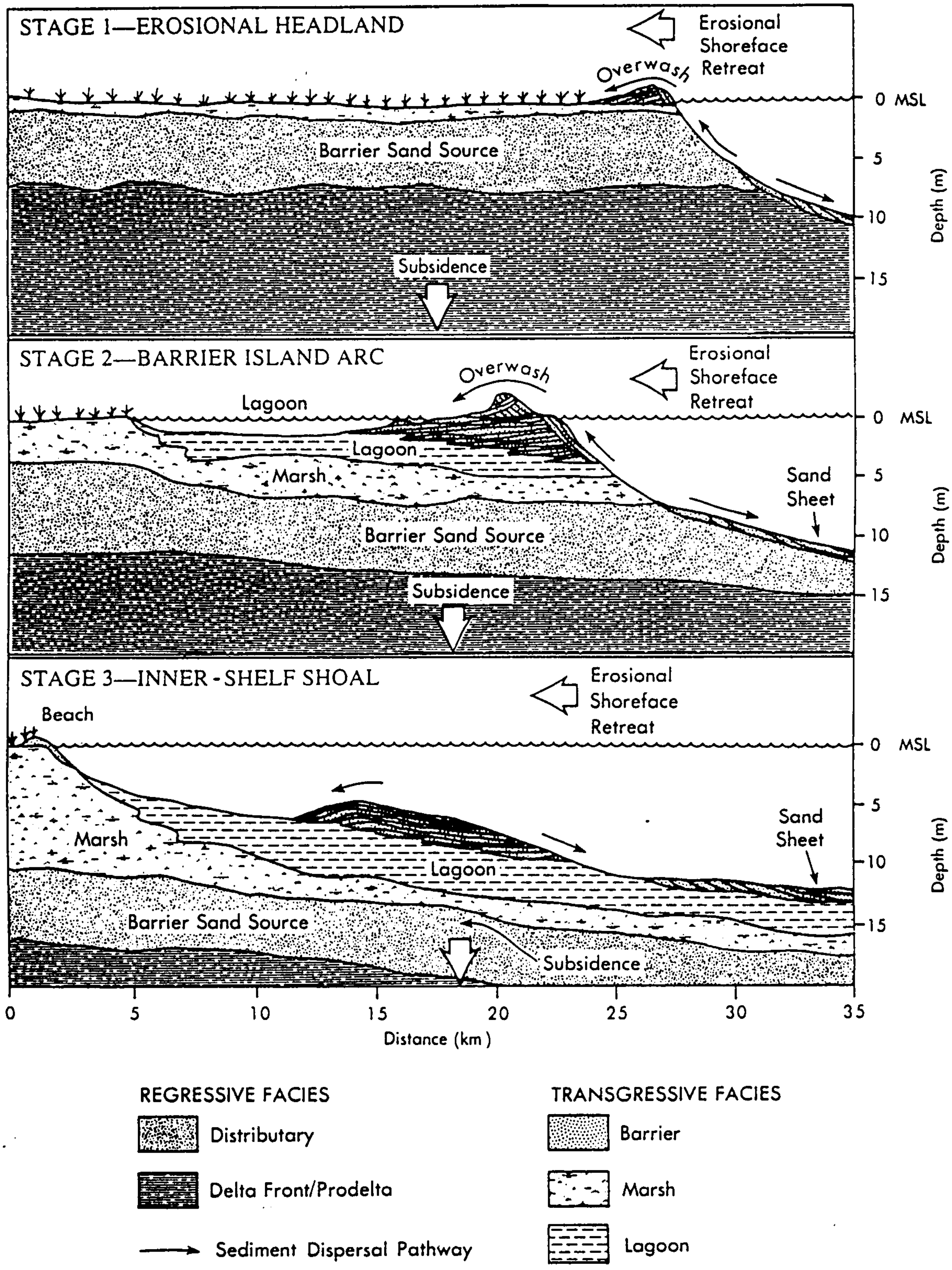


Figure 6.18. Diagrammatic cross section of three-stage evolutionary model illustrating delta subsidence and erosional shoreface retreat (Penland et al. 1985).

The geomorphic features of the Mississippi Delta barrier islands and barrier beaches are dominated by low-profile characteristics. The barrier beach shoreface is thin, highly erosive, and overlies marshes or bayfill environments. Numerous tidal inlets, varying in stages from wave-dominated through tide-dominated to transitional (Levin and Penland 1983), are found adjacent to island segments and often occupy abandoned distributary channels. Washover sands are abundant and occur as a consequence of heavy storms eroding sediment from the seaward side of the barrier and transporting it inland into the back-barrier marsh or lagoon (Pierce 1970, Andrews 1970). Sediment thicknesses range from 10 to 50 cm. Eolian dunes are dependent upon the availability of sands and are, essentially, restricted to sand spit localities. Dunes are hummocky-to-continuous, range from 1.5 to 2.0 m in height, and have sparse vegetation cover. Beach sediment in the nearshore and back bay areas is extremely variable ranging from thin ephemeral deposits composed mainly of very fine sand, silt, and organic remains to increasingly larger concentrations of sand and shells. Local sediment source areas include distributary mouth bar sands of the abandoned deltas and submerged beach ridge plain deposits. Local rates of relative sea-level rise approximate 1.2 cm/yr (Baumann 1980).

Major characteristics of the Mississippi Delta System are presented by each of the seven geographical subunits (Table 6.3). Geographical information is shown on Maps 6-E through 10-E and 6-F through 10-F in Vol. II. Individual subunits within this coastal system are described in detail in the following sections.

Isles Dernieres

Isles Dernieres is a Holocene transgressive barrier island arc which formed as a result of dominant marine processes reworking deposits of the abandoned Caillou distributaries of Early Lafourche delta lobe 600 to 800 yrs B.P. (Morgan 1974) (Figures 6.15 and 6.16). Neese (1984) has documented alternating and concurrent transgressive and regressive events in the geologic evolution of Isles Dernieres which exhibit a stratigraphy characterized by the erosion of headland sediments and deposition of accretionary beach ridges and spits (Figure 6.19). Littoral transport is directed in both east and west directions (Maps 6-E, Vol. II).

Isles Dernieres is migrating landward (1 km since 1853) and is presently 7 km offshore. The island complex appears to become progressively more separated from the land because the mainland shore is retreating faster. Figure 6.20 shows historical changes and migration patterns for Isles Dernieres.

Timbalier Islands

The Timbalier Island Complex (Timbalier and East Timbalier) represents the western flanking barriers of the Caminada Moreau Headland and is associated with Late Lafourche delta lobe of 400 to 600 yrs B.P. (Figures 6.15 and 6.16). Isacks (1987) has documented the formation of the Timbalier Islands through beach ridge progradation which exhibit a characteristic recurved spit morphology (Figure 6.21). The island complex has multiple shallow tidal inlets and washover sheets on the updrift erosional ends (East Timbalier Island) and recurved spits on the accretion downdrift ends (Timbalier Island). Downdrift ends of the islands are characterized by detached longshore bars which eventually weld to the beach to form ridges and develop dunes. Timbalier Island complex has migrated laterally westward over 3 km since 1887 (Figure 6.22) as a result of westward direction of littoral transport.

Table 6.3. Characteristics of Barrier Islands, Beaches, and Associated Water Bodies within the Mississippi Delta System.

CHARACTERISTICS	AREA Isles Dernieres	Timbalier Islands	Caminana - Moreau Headland	Grand Isle	Grande Terre	Quatre Bayou Pass to Sandy Point	Breton - Chandeleur Islands
Beach Type	Transgressive Barrier Island	Transgressive Barrier Island	Transgressive Barrier Beach	Transgressive Barrier Island	Transgressive Barrier Island	Transgressive Barrier Beach	Transgressive Barrier Islands
Dimensions	32 km X 2 km	28 km X 1.8 km	19 km long	11 km X 1.7 km	5 km X 3 km	32 km long	85 km X 1 km
Shore/Island Profile	Low-Profile	Low-Profile	Low-Profile	Low-Profile	Low-Profile	Low-Profile	Low-Profile
Dune Topography	Low discontinuous	Low discontinuous	Low discontinuous	Low, discontinuous to continuous	Low discontinuous	Low discontinuous	Low discontinuous
Dimensions	0.5 - 2.0 m height	0.5 - 2.0 m height	0.5 - 2.0 m height	0.5 - 3.0 m height	0.5 - 2.0 m height	0.5 - 2.0 m height	0.5 - 2.0 m height
Island Migration	North/ Landward	North - West/ Landward	North Landward	North Landward	North - Northeast Landward	Northeast/ Landward	Northwest/ Landward
Littoral Transport	E/W	W	E/W	E	W/NW	NW	NW/SW
Shoreline Change	Erosion 5.0 - 15.0 m/yr	Erosion/Accretion 7.0 m/yr-7.0 m/yr	Erosion 12.0 - 17.5 m/yr	Erosion/Accretion 3.0 m/yr - 9.0 m/yr	Erosion 12.0 m/yr	Erosion 12.0 m/yr	Erosion 5.0 - 15.0 m/yr
Tidal Inlets	Abundant	Abundant	Local	Local	Abundant	Local	Abundant
Type	Wave-dominated transitional	Wave-dominated transitional	Wave-dominated	Transitional tide-dominated	Wave-dominated transitional	Wave-dominated	Wave-dominated transitional
Dimensions	3.0-15.0 m depth	3.0-15.0 m depth	1.0-3.0 m depth	30 m depth	3.0-15.0 m depth	1.0-3.0 m depth	3.0-15.0 m depth
Frequency	Closely-separated	Closely-separated	Closely-separated	Widely-separated	Closely-separated	Closely-separated	Closely-separated
Washovers	Abundant fans and channels	Abundant fans and channels	Abundant fans and channels	Abundant fans and channels	Abundant fans and channels	Abundant fans and channels	Abundant fans and channels
Tidal Deltas	Occur locally	Occur locally	Occur locally	Occur locally	Occur locally	Occur locally	Occur locally
Flood	Well-developed	Well-developed	Small	Well-developed	Well-developed	Small	Well-developed
Ebb	Small	Small	Small	Large well-developed	Small	Small	Small
Shoals	Lagoonal and adjacent to barriers	Lagoonal and adjacent to barriers	Occur locally	Lagoonal and adjacent to barriers	Lagoonal and adjacent to barriers	Occur locally	Lagoonal and adjacent to barriers
Associated Bay/ Lagoons	Lake Pelt	Vermillion Bay	Local Bays	Barataria Bay	Barataria Bay	Local Bays	Chandeleur Sound
Depth	4.0 - 5.0 m	4.0 - 5.0 m	1.0 - 3.0 m	4.0 - 5.0 m	4.0 - 5.0 m	1.0 - 3.0 m	4.0 - 6.0 m
Sediment Source	Holocene deltaic headlands	Holocene deltaic headlands	Beach ridges, Distributary mouth bar sands	Holocene deltaic headlands	Holocene deltaic headlands	Distributary mouth bar sands	Holocene deltaic headlands
Nearshore	Silt, sand, shells	Silt, sand, shells	Sand, shells, mud, organics	Silt, sand, shells	Silt, sand, shells	Silt, sand, shells	Sand, silt, shells
Beach	Silt, sand, shells	Silt, sand, shells,	Sand, shells, mud organics	Sand, shells,	Silt, sand, shells	Silt, sand, shells	Sand, shells
Back Barrier	Sand, mud, silt, shells, organics	Sand, mud, silt, shells, organics	Sand, shells, mud, organics	Silt, sand, shells	Silt, sand, mud, organics	Silt, sand, mud, organics	Silt, sand, shells rock fragments
Bay	Silt, mud, organics	Silt, mud, organics	Mud, silt, organics	Silt, mud, shells	Silt, mud, organics	Silt, mud, organics	Silt, mud, organics

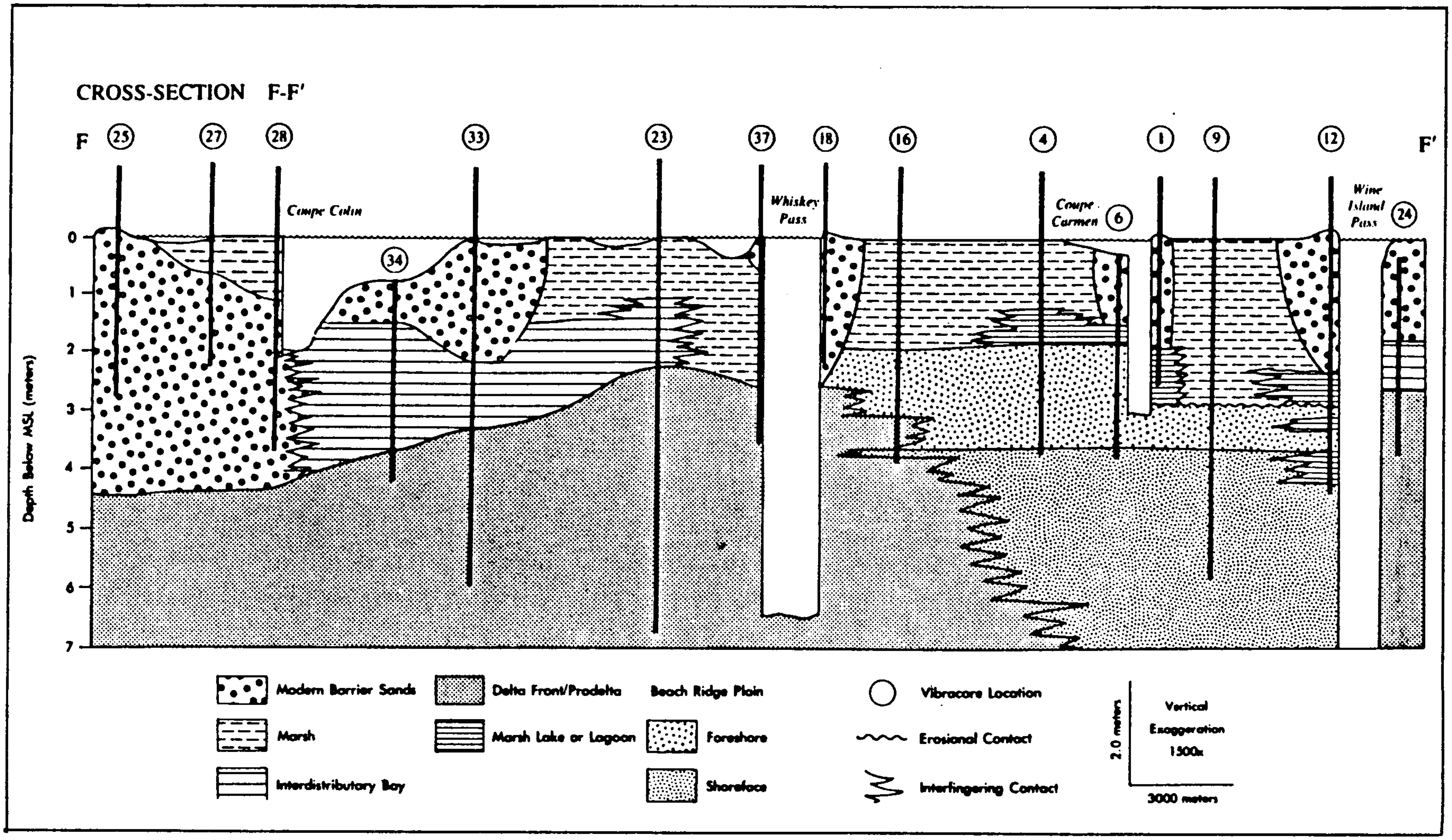


Figure 6.19. Strike section along Isles Dernieres depicting erosion of headland sediments and deposition of accretionary beach ridges and spits (Neese 1984).

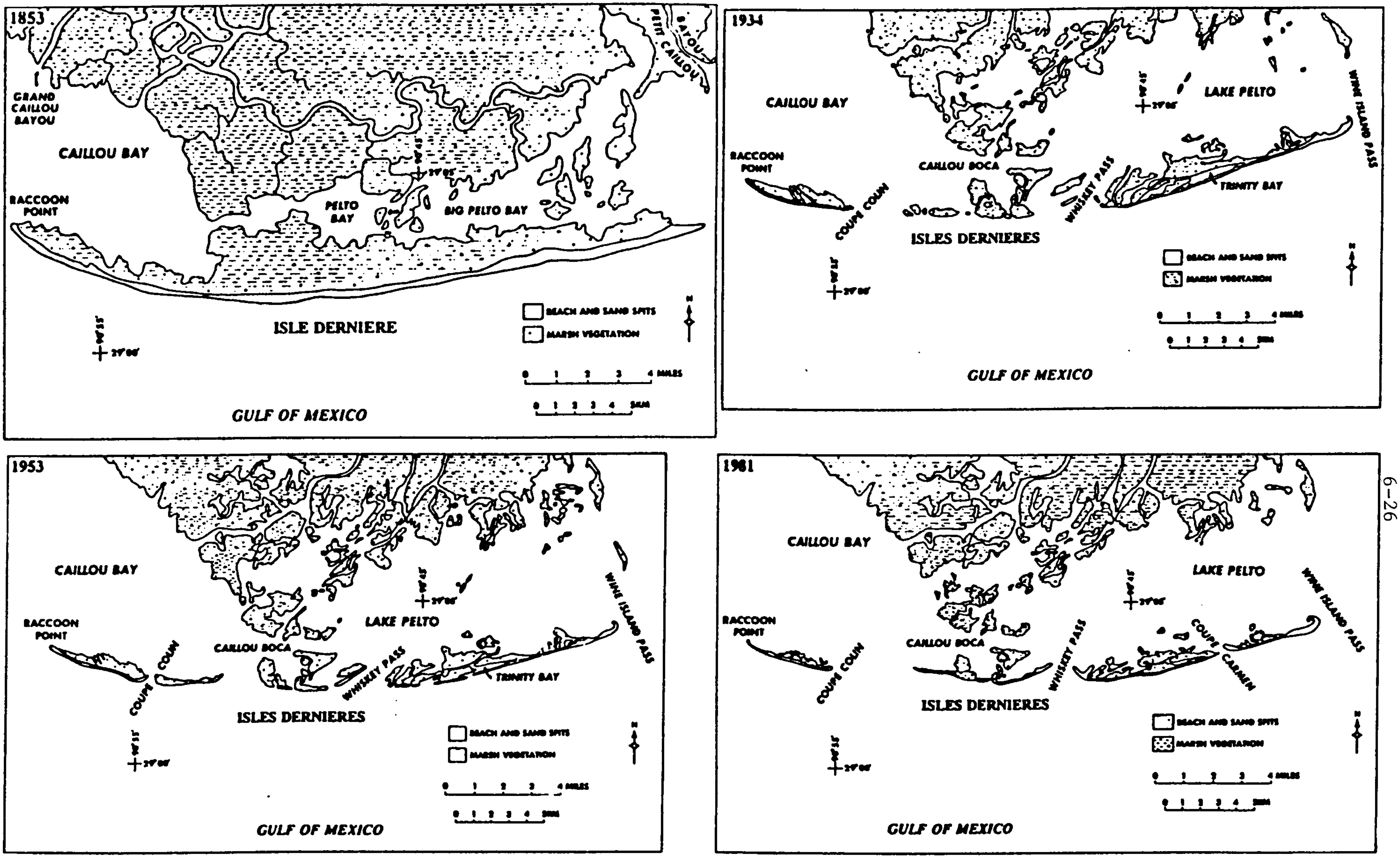


Figure 6.20. Historical changes and migration patterns for Isles Dernieres from 1853 to 1981 (Neese 1984).

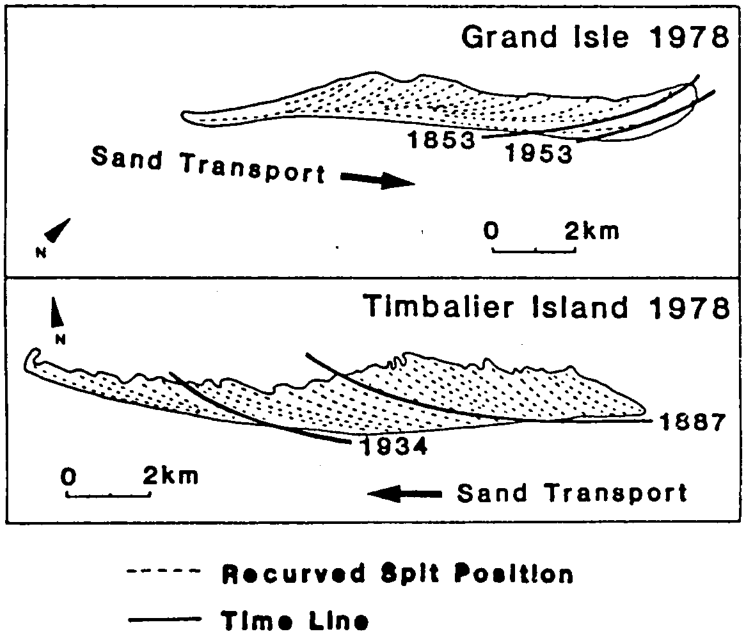


Figure 6.21. The recurved spit morphology of Timbalier Island and Grand Isle indicates the importance of the erosional headland sand source updrift (Penland and Boyd 1982).

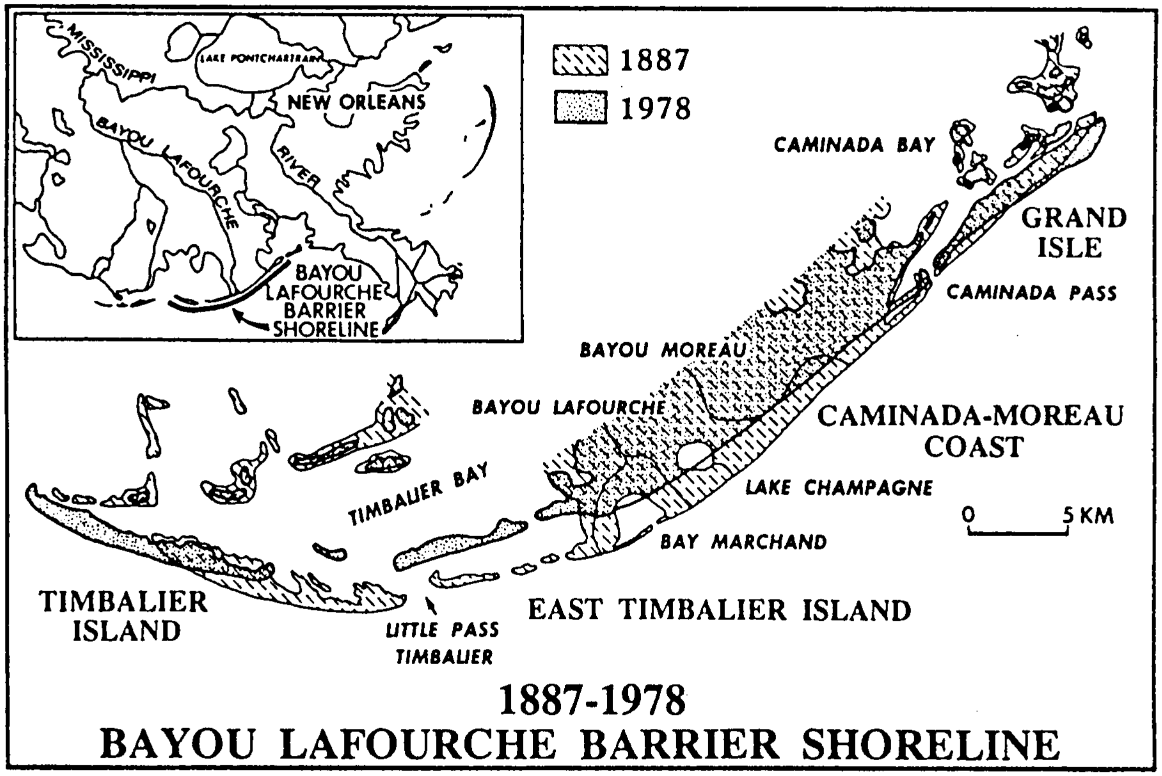


Figure 6.22. A historical map time series showing coastal changes associated with the Bayou Lafourche coastal barrier system between 1887 and 1978. Note the rapid shoreline retreat along the Caminada-Moreau Coast and the lateral migration of Timbalier Island and Grand Isle (Penland and Boyd 1985).

Caminada-Moreau Headland

The Caminada-Moreau coast is a transgressive barrier beach that fronts a beach ridge plain occupying the central erosional headland of the abandoned Late Lafourche delta lobe 400 to 600 yrs B.P. The stratigraphy and genesis of the beach ridge plain have been investigated in detail by Fisk (1955), McIntire (1958), Otvos (1969), Morgan (1970), Ritchie (1972), Shepard and Wanless (1971), and Gerdes (1982).

The beach ridge plain consists primarily of about 70 subparallel, generally concave, seaward-arcuate ridges that have accumulated on the updrift side of Bayou Moreau (Figure 6.23). Individual ridges range in length from several hundred meters to several kilometers with highly variable spacing ranging from 20 m to well over 100 m. Elevations range from 2.0 m to 0.5 m along ridge crests. The subaerial ridges themselves constitute a regressive beach ridge plain (Gerdes 1982), as shown in Figure 6.24. The ridges are found to overlie transgressive coarse-grained shoreface deposits.

The shoreline of the Caminada-Moreau beach demonstrates a predominantly landward retreat as a result of subsidence around Lake Champagne and Bayou Moreau. The rate of retreat decreases eastward toward Caminada Pass and westward toward Belle Pass (Ritchie and Penland 1985). Littoral transport of sediment is controlled by the availability of sand within the headland and by the intensity of offshore- and longshore-directed, near-bottom currents.

Grand Isle

The Grand Isle barrier system is the eastern flanking barrier of the Caminada-Moreau Headland and is also associated with the Late Lafourche delta (400 to 600 yrs B.P.). Like the Timbalier Islands, Grand Isle has a recurved spit morphology and is a low profile barrier island. Formation of the barrier beach results from successively developed sand ridges building downdrift from the Caminada-Moreau headland by means of longshore transport, characterizing a pattern of updrift erosion and downdrift accretion. Construction of jetties on both the updrift and downdrift ends of Grand Isle has led to stabilization of this island at the expense of sediment transport eastward to Grand Terre. Farther downdrift, toward Barataria Pass, the shoreline accretes at rates between 5 and 10 m/yr (Penland and Boyd 1982).

Grand Terre to Sandy Point

The transgressive barrier beach system from Grand Terre to Sandy Point represents the erosional headland of the abandoned Plaquemines delta lobe active from 400 to 600 yrs B.P. Similar to the Caminada-Moreau coastline, this region has a regressive distributary-flank beach ridge system (Cheniere Ronquille) fronted by a low-profile barrier beach undergoing rapid transgression. The shoreline shows a predominantly landward retreat while littoral transport direction is to the east and west. Penland and Boyd (1985) have speculatively indicated that the Grand Terre Islands represent flanking barriers of the erosional headland. Sediment transport in the system is to the west and northwest.

Grand Terre is separated from Grand Isle by Barataria Pass, a tidal inlet nearly 30 m deep. Although longshore transport is the dominant sediment dispersal mechanism, formation of recurved spits in the Grand Terre Island complex appears to be more related to water exchange through tidal passes. Historical changes in the area since 1977 are depicted in Figure 6.25.

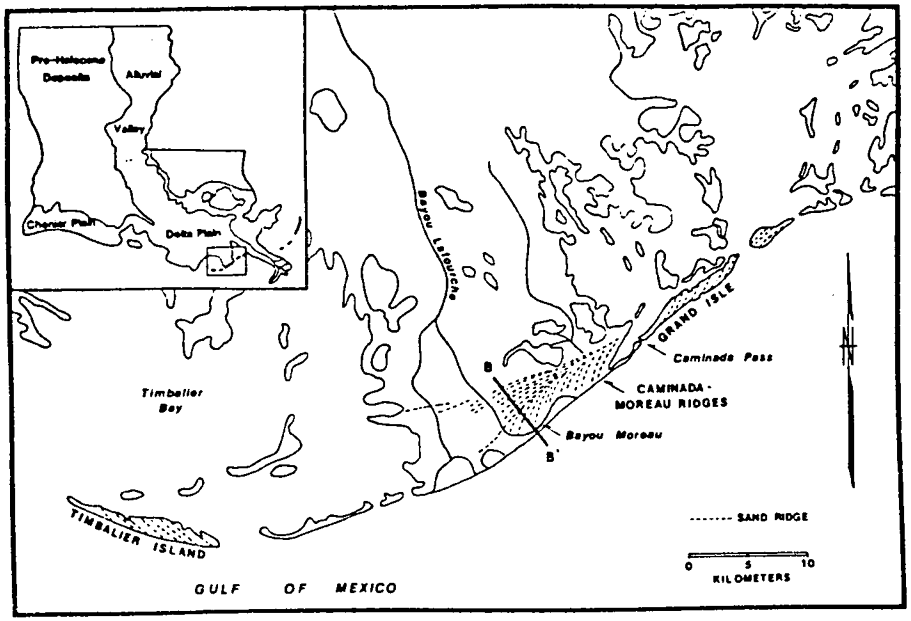
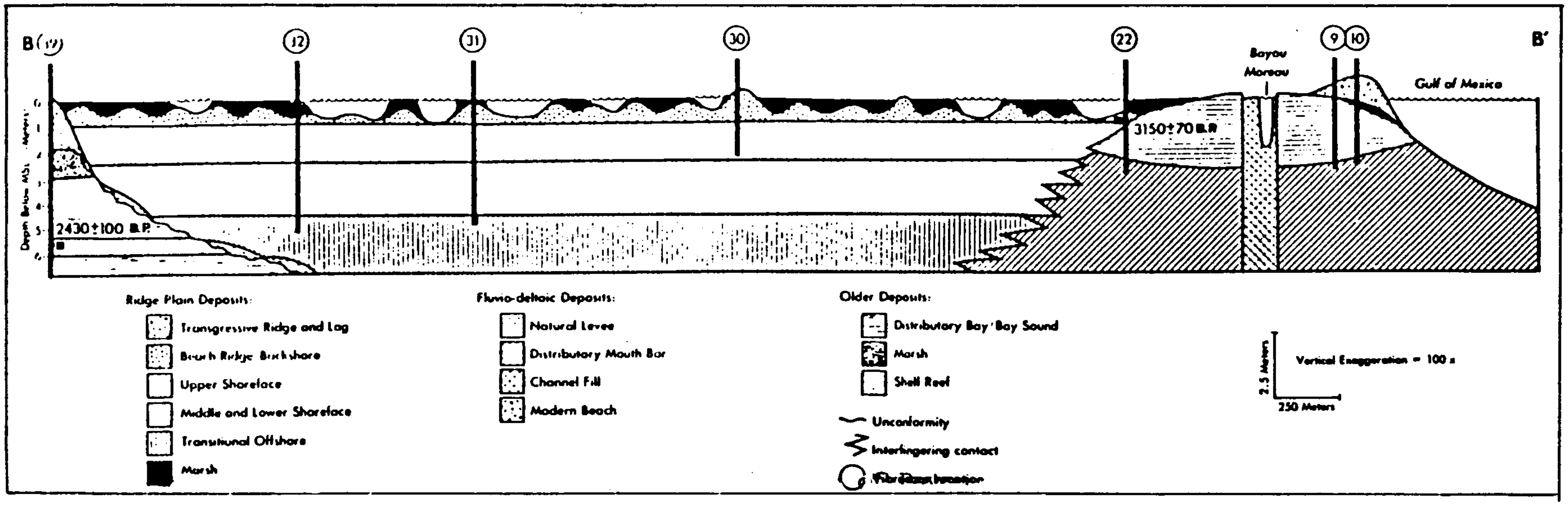


Figure 6.23. Location of the Caminada-Moreau beach ridge plain and dip section B-B^1 shown in Figure 6.24 (Gerdes 1982).

Figure 6.24. Cross section of the ridge plain east of Bayou Moreau. Note the transgressive lag (lower left) which is projected from a section farther east (Gerdes 1982).



Breton-Chandeleur Islands

Breton Island, Grand Gossier, and the Chandeleur Islands represent a transgressive barrier island arc which formed after the abandonment of the St. Bernard delta 1800 years B.P. Island sediments are composed primarily of sand and shell. The barrier complex exhibits a low profile morphology with locally low, hummocky dune fields and isolated washover fans. Tidal inlets serve as areas of flow exchange between backbarrier areas and the Gulf, although Hart (1978) has indicated that the predominant flow occurs around the margins of the Chandeleur Islands. Erosional processes are dominant in this system with shoreline erosion directly resulting from hurricane and severe storm activity (Kahn 1980). Figure 6.26 illustrates erosional and migrational patterns and the development of subaqueous shoals for the Chandeleur Island chain.

North Central Gulf Coast System

The following geologic discussion of the North Central Gulf Coast System has been divided into two major subunits: (1) Mississippi Sound and (2) Mobile Bay to Florida Panhandle. Within the Mississippi Sound, the barrier islands (Cat, Ship, Horn, Petit Bois, and Dauphin) are described, with major characteristics being tabulated (Table 6.4) and illustrated on Maps 8-E and 8-F, Vol. II.

The geographical subunits that are investigated in the Mobile Bay to Florida Panhandle include: (1) lagoons, sounds, and bays, (2) Gulf Shores, (3) Perdido Key, (4) Santa Rosa Island, (5) Destin-St. Andrews, (6) Shell Island, and (7) Crooked Island. Geological characteristics of these sections of the coast are presented in Table 6.5 and depicted on Maps 9-10E and 9-10F, Vol. II.

Mississippi Sound and Barrier Islands

Sounds, lagoons, and bays within the North Central Gulf coast system represent an estuarine complex constructed essentially of sets of oblique transverse bars maintained by complicated sediment cell circulation operational during periods of strong northerly winds (Zapel and Nummedal 1983). Current patterns are variable, although there is a general westward longshore current direction. Sediments consist generally of fine sands, silts, and clays with some shell fragments. Overlying these fine-grained sediments are coarser-grained, highly bioturbated sands from washover of barrier islands and barrier beaches. Additionally, this facies shows a characteristic lack of stratification and irregular pods of differing lithology (Rainwater 1964). Figure 6.27 shows a stratigraphic section representative of the Mississippi Sound estuarine system.

Barrier islands along Mississippi Sound originated through vertical shoal-bar aggradation probably occurring about 4,000 to 3,000 yrs B.P. (Otvos 1970, 1979). Barrier platforms composed of sandy material characterize the aggradational-progradational platforms under Cat, Ship, Horn, and Petit Bois Islands. Analysis of these platforms and lagoonal complexes suggest late Holocene barrier island development at or very near the present locations (Otvos 1985). Previously, no barriers blocked the influx of marine waters to areas north of the platform belts.

With the exception of Dauphin Island, all of the islands are regressive barriers and exhibit a high-profile morphology. Tidal inlets occur locally and exhibit deep, wide channels with associated flood and ebb tidal deltas. Shoals are adjacent to all barriers. Dunes are well developed, ranging from hummocky to continuous, and are sparsely vegetated. Depth to Pleistocene averages from 13 to 15 m. Washovers occur locally through the islands,

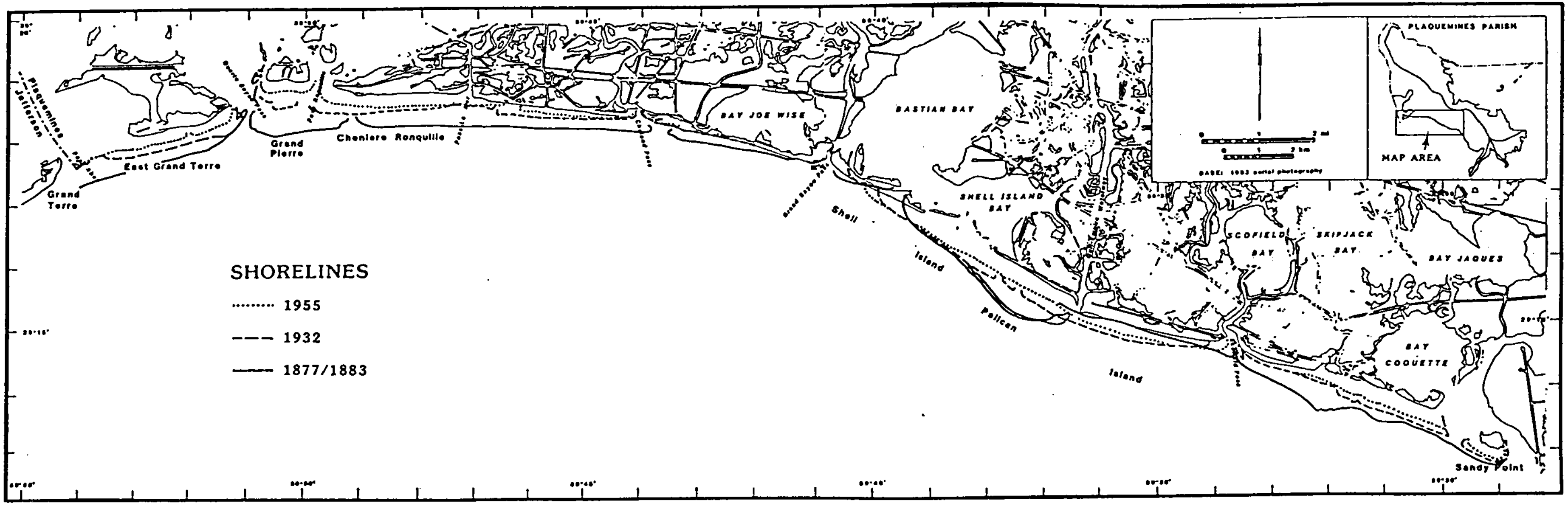


Figure 6.25. Historic shoreline changes along the Barataria coast from 1877 to 1955 (van Beek et al. 1986).

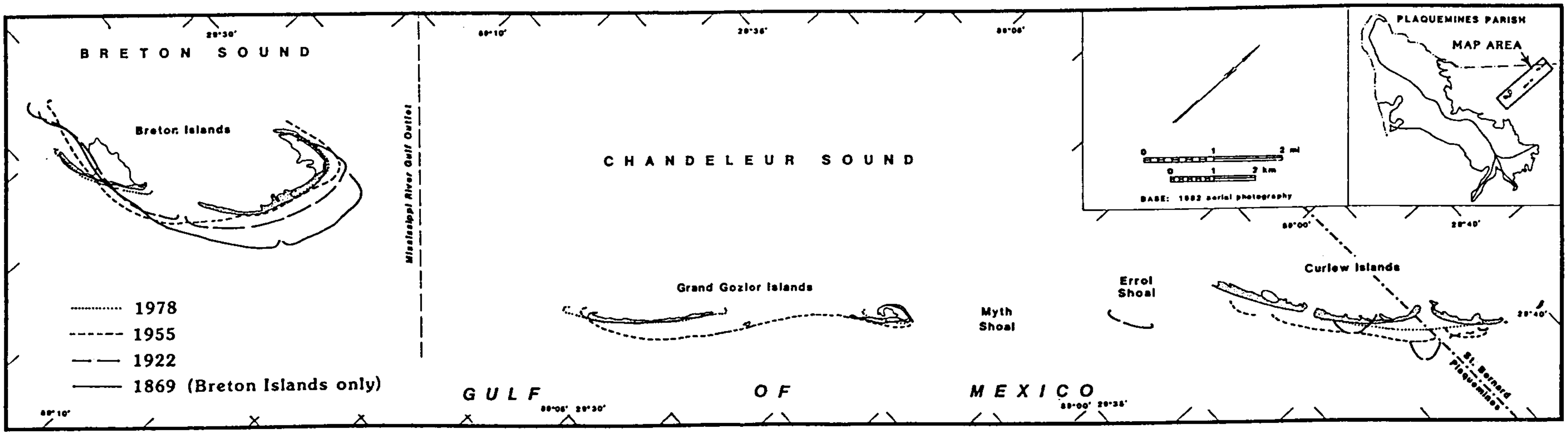


Figure 6.26. Historic shoreline changes in the Chandeleur Sound area from 1896 to 1978 (van Beek et al., 1986).

Table 6.4. Characteristics of Barrier Islands, Beaches, and Associated Water Bodies along the Barrier Islands of the North Central Gulf Coast System.

	AREA				
CHARACTERISTICS	**Cat Island**	**Ship Island**	**Horn Island**	**Petit Bois Island**	**Dauphin Island**
Beach Type	Regressive Barrier Island	Regressive Barrier Island	Regressive Barrier Island	Regressive Barrier Island	Transgressive Barrier Island
Dimensions	8 km X 2 km	13 km X 10.6 km	21 km X 1 km	10 km X 1 km	23 km X 0.4 km
Shore/Island Profile	High-Profile	High-Profile	High-Profile	High-Profile	Low-Profile
Dune Topography	Continuous	Continuous	Continuous	Continuous	Low, discontinuous to continuous
Dimensions	3.0 - 6.0 m height	3.0 - 6.0 m height	3.0 - 6.0 m height	3.0 - 6.0 m height	0.5 - 6.0 m height
Island Migration	Stable to laterally West	Laterally West	Laterally West	Laterally West	Laterally West/ North/Landward
Littoral Transport	S/W	W	W	W	W
Shoreline Change	Erosion/Accretion 0.5 - 1.0 m/yr	Erosion/Accretion 0.5 - 1.0 m/yr	Erosion 0.5 - 1.0 m/yr	Erosion/Accretion 0.5 - 1.0 m/yr	Erosion 0.5 - 5.0 m/yr
Tidal Inlets	Few. Occur locally adjacent to barriers.	Few. Occur locally adjacent to barriers.	Few. Occur locally adjacent to barriers.	Few. Occur locally adjacent to barriers.	Few to locally abundant
Type	Wave-dominated	Wave-dominated	Wave-dominated	Wave-dominated	Wave-dominated Tide-dominated
Dimensions	5.0-15.0 m depth	5.0-15.0 m depth	5.0-15.0 m depth	5.0-15.0 m depth	5.0-17.0 m depth
Frequency	Widely-separated	Widely-separated	Widely-separated	Widely-separated	Widely-separated
Washovers	Local fans and channels	Local fans and channels	Local fans and channels	Local fans and channels	Abundant fans and channels
Tidal Deltas	Occur locally	Occur locally	Occur locally	Occur locally	Occur locally
Flood	Well-developed	Well-developed	Well-developed	Well-developed	Well-developed
Ebb	Small	Small	Small	Small	Large well-developed
Shoals	Lagoonal and adjacent to barriers	Lagoonal and adjacent to barriers	Lagoonal and adjacent to barriers	Lagoonal and adjacent to barriers	Lagoonal and adjacent to barriers
Associated Bay/ Lagoons	Mississippi Sound	Mississippi Sound	Mississippi Sound	Mississippi Sound	Mississippi Sound
Depth	4.0 - 6.0 m	4.0 - 6.0 m	4.0 - 6.0 m	4.0 - 6.0 m	4.0 - 6.0 m
Sediment Source	Pleistocene Shoals	Pleistocene Shoals	Pleistocene Shoals	Pleistocene Shoals	Pleistocene Shoals
Nearshore	Sand, shells	Sand, shells	Sand, shells	Sand, shells	Sand, shells
Beach	Sand, shells	Sand, shells	Sand, shells	Sand, shells	Sand, shells
Back Barrier	Sand, mud, peat	Sand, mud, peat	Sand, mud, peat	Sand, mud, peat	Sand, mud, peat
Bay	Sand, mud	Sand, mud	Sand, mud	Sand, mud	Sand, mud

Table 6.5. Characteristics of Barrier Islands, Beaches, and Associated Water Bodies along the Mainland within the North Central Gulf Coast System.

CHARACTERISTICS	AREA					
	Gulf Shores Mobile Point	Perdido Key	Santa Rosa Island	Destin Beach to St. Andrews State Park	Shell Island	Crooked Island
Beach Type	Regressive Barrier Beach	Regressive Barrier Island	Transgressive Barrier Island	Regressive Barrier Beach	Regressive Barrier Island	Regressive Barrier Island
Dimensions	45 km long	22 km X 0.6 km	84 km X 1.6 km	75 km long	8 km X 1.5 km	14 km X 0.5 km
Shore/Island Profile	High-Profile	High-Profile	Low-Profile	High-Profile	High-Profile	High-Profile
Dune Topography	Continuous	Continuous	Low discontinuous	Continuous with local blowouts	Continuous	Continuous
Dimensions	4.5 - 6.0 m height	3.0 - 6.0 m height	4.0 - 5.0 m height	3.6 - 4.0 m height	3.0 - 6.0 m height	3.0 - 6.0 m height
Island Migration	South/ Seaward	Laterally West	Laterally West	Laterally Northwest	Laterally Southeast	Laterally Northwest/Southeast
Littoral Transport	W	W	W	NW	SE/NW	SE/NW
Shoreline Change	Accretion/Erosion 0 - 1.0 m/yr	Erosion to stable 0 - 1.0 m/yr	Erosion to stable 0 - 1.0 m/yr	Erosion 0.3 - 0.6 m/yr	Erosion 0.3 - 0.6 m/yr	Erosion 0.3 - 0.6 m/yr
Tidal Inlets	Few occur locally adjacent to barriers.	Few occur locally adjacent to barriers.	Few. Occur locally	Few. Occur locally	Few. Occur locally	Few. Occur locally
Type	Wave-dominated Tide-dominated	Wave-dominated	Wave-dominated	Wave-dominated	Wave-dominated	Wave-dominated
Dimensions	16.0-17.0 m depth	18 m depth	9.0-12.0 m depth	1.0-2.0 m depth	1.0-2.0 m depth	1.0-2.0 m depth
Frequency	Widely-separated	Widely-separated	Widely-separated	Widely-separated	Widely-separated	Widely-separated
Washovers	Local fans and channels	Local fans and channels	Local fans and channels	Local fans and channels	Local fans and channels	Local fans and channels
Tidal Deltas	Occur locally	Occur locally	Occur locally	Occur locally	Occur locally	Occur locally
Flood	Large well-developed	Well-developed	Well-developed	Well-developed	Well-developed	Well-developed
Ebb	Large well-developed	Small	Small	Small	Small	Small
Shoals	Adjacent to ebb tidal delta	Lagoonal and adjacent to barriers	Lagoonal and adjacent to barriers	Lagoonal and adjacent to barriers	Lagoonal and adjacent to barriers	Lagoonal and adjacent to barriers
Associated Bay/ Lagoons	Mobile Bay	Perdido Bay	Santa Rosa Island	Choctawatchee Bay	St. Andrew Bay	St. Andrew Sound
Depth	2.7 - 3.4 m	1.5 m	6.0 m	1.0 - 7.0 m	1.0 - 2.0 m	1.0 - 2.0 m
Sediment Source	Pleistocene deltaic Headlands/shoals	Pleistocene deltaic Headlands/shoals	Pleistocene deltaic Headlands/shoals	Pleistocene deltaic Headlands/shoals	Pleistocene deltaic Headlands/shoals	Pleistocene deltaic Headlands/shoals
Nearshore	Sand, shells	Sand, shells	Sand, shells	Sand, shells	Sand, shells	Sand, shells
Beach	Sand, shells	Sand, shells	Sand, shells	Sand, shells	Sand, shells	Sand, shells,
Back Barrier	Sand, silt, mud	Sand, silt, mud	Sand, silt, mud	Sand, silt, mud	Sand, silt, mud	Sand, silt, mud
Bay	Silt, mud	Silt, mud, sand	Silt, mud, sand	Silt, mud, sand	Silt, mud, sand	Silt, mud, sand

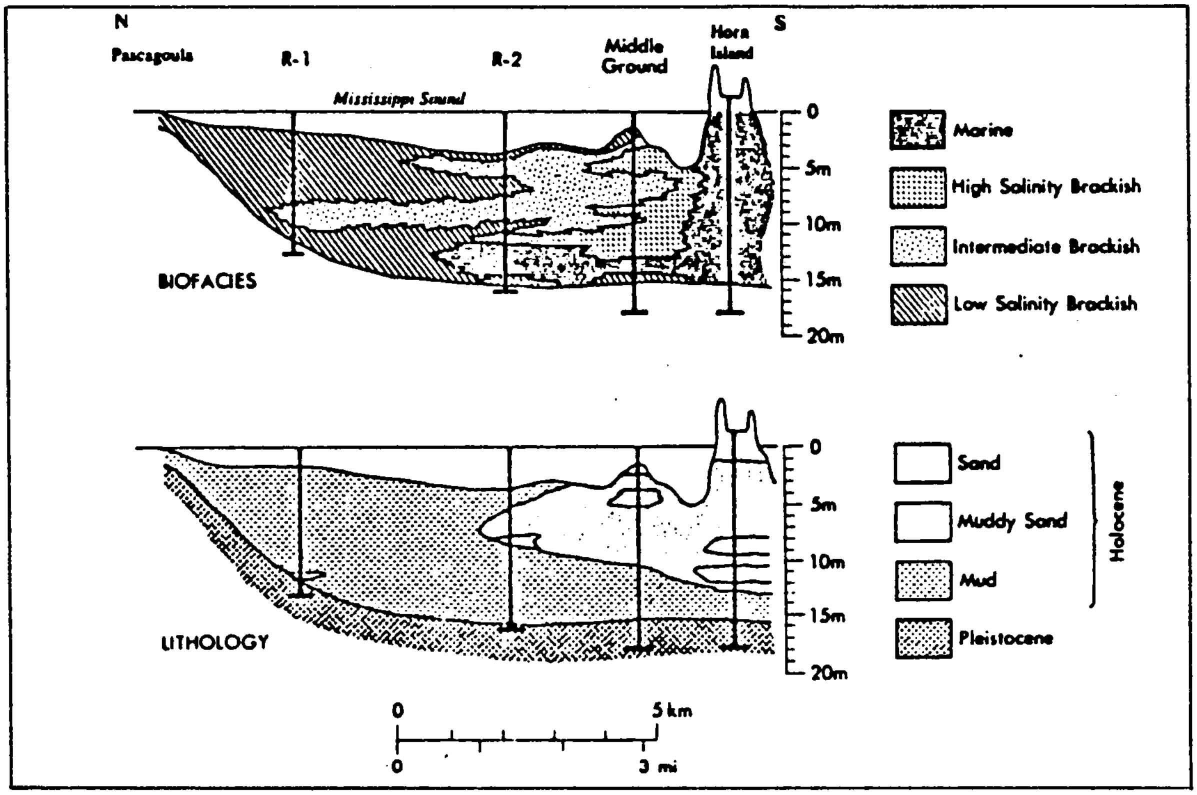


Figure 6.27. Stratigraphic dip section of the Mississippi Sound from the Pascagoula River delta to Horn Island (Otvos 1981).

although washovers are abundant on the Holocene spit of Dauphin Island as a result of hurricane impact (Nummedal et al. 1980).

Cat Island, the westernmost island, is the most stable with only minor erosion occurring locally on the northern and southern ends (USACE, N.O. 1971). Morphologically, the island shoreface shows a well-developed beach backed by hummocky dunes and marsh areas. The island interior contains flat, sandy regions with marshes, shallow lakes, and vegetated sand ridges. The subaerial barrier island occupies the top of a relatively broad sand platform and exhibits sets of parallel beach ridges reflecting an earlier phase of regressive island development.

Ship Island, although demonstrating a variety of historical changes, has generally migrated to the south and west (Figure 6.28). This island similarly shows a broad beach with well developed, vegetated dunes and an interior consisting of marshes, shallow lakes, and flat sandy areas. Sediment in the nearshore and backbay areas consists generally of medium- to coarse-grained sand with shells. Dog Key Pass, the widest tidal inlet in the barrier system, is approximately 10.5 km in width (Boone 1973) with a tidal delta forming, to a limited extent, in a seaward direction. Wind-generated longshore currents provide the mechanism for the predominantly westward direction of sediment transport.

Horn Island also displays a westward migration pattern (Figure 6.29) as a result of longshore sediment transport (Waller and Malbrough 1976). The island morphology exhibits the characteristic broad extensive beach face backed by dunes ranging in height from 3 to 6 m in elevation. Marsh and shallow lakes occur in the island interior with some of the lakes being intermittently connected with the Mississippi Sound or the Gulf of

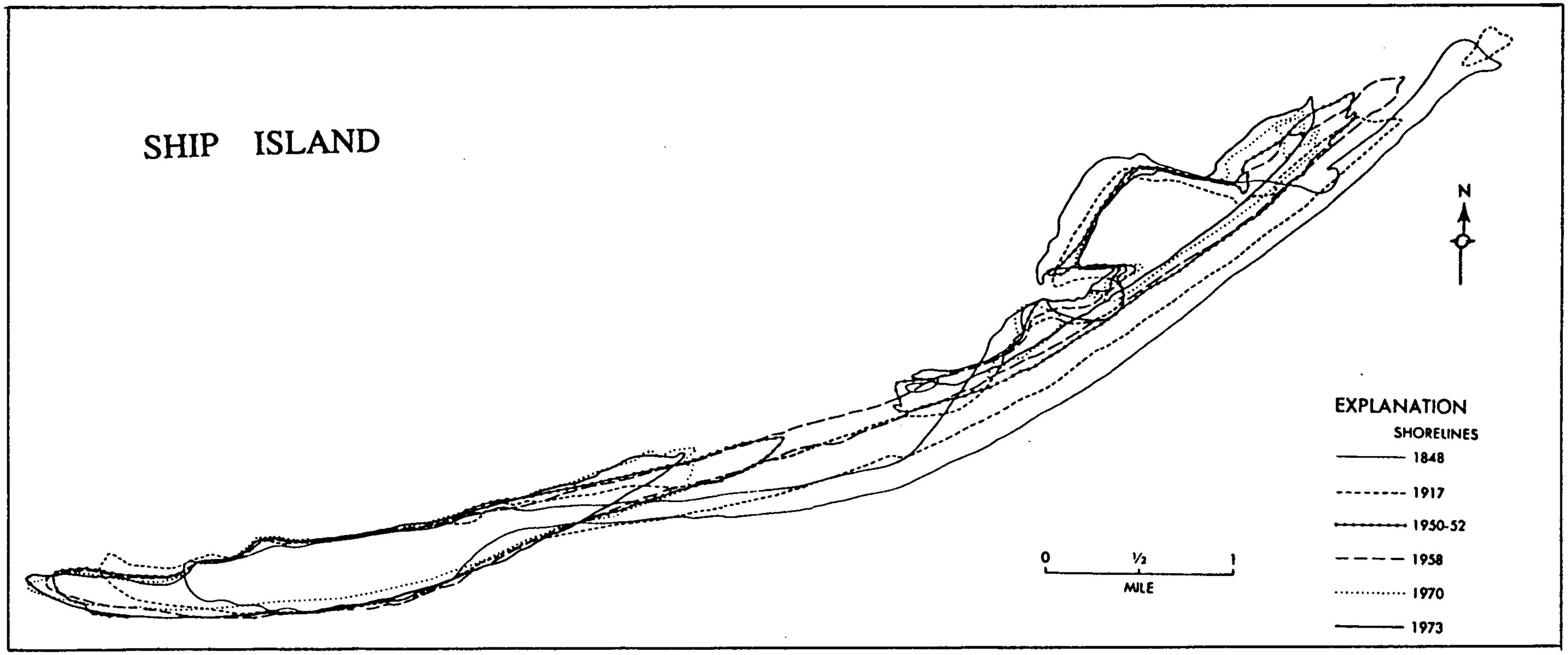


Figure 6.28. Historical map time series of Ship Island illustrating shoreline changes and mirgrational patterns (Zapel and Nummedal 1983).

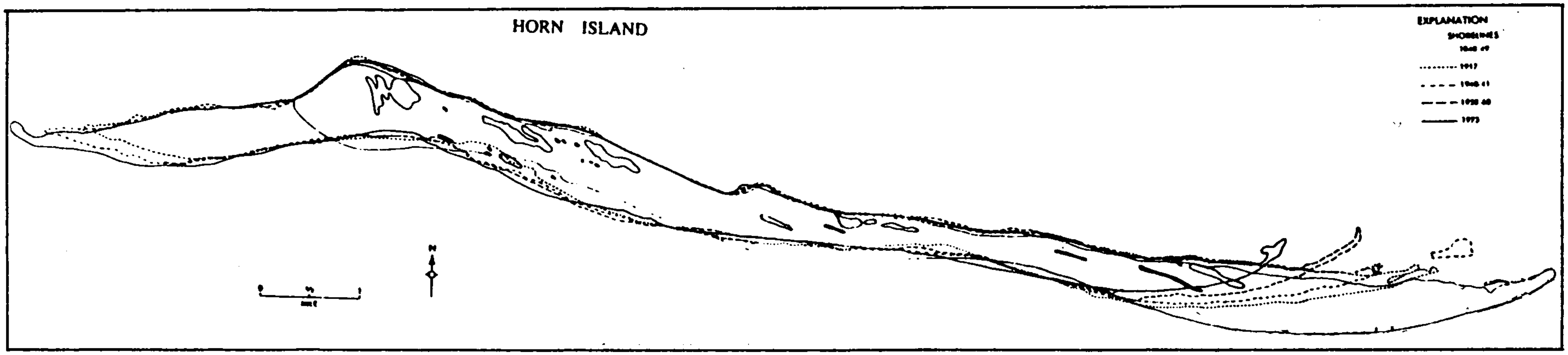


Figure 6.29. Historical map time series of Horn Island illustrating shoreline changes and migrational patterns (Zapel and Nummedal 1983).

Mexico (Ludwick 1964). Sediments consist of medium- to coarse-grained sand with shells. Shoreface deposits are dominated by sets of oblique transverse bars with poor stratification due to burrowing by organisms.

Petit Bois Island exhibits extensive erosion at its eastern edge and accretion in its downdrift westward end (Figure 6.30). This westward migration has resulted in a widening tidal pass between Petit Bois and Dauphin Island. These two islands were at one time contiguous, as evidenced by early maps and reports from the eighteenth century (May 1971). Similar to Cat Island, Petit Bois Island demonstrates sets of well-developed parallel beach ridges, again reflecting an earlier stage of regressive island development. Sand dunes, marshes, shallow lakes, and low, flat sandy areas characterize the island morphology. Sediments are composed primarily of medium-grained sands with shells. Figure 6.31 illustrates a stratigraphic dip section for Petit Bois Island.

Dauphin Island is essentially a low-profile barrier island, except for a small Pleistocene core at its eastern end (Figure 6.32), and was developed by nucleation of Pleistocene highlands. The western portion of the island is a Holocene spit and is characterized by small dunes and washover fans with marsh deposits and tree stumps exposed in the surf zone. Otvos (1979) indicates that the island is transgressive and is affiliated with the erosion of the Baldwin County coastline, Alabama and the antecedent Mobile River Valley. Minor erosion occurs near the center of the Pleistocene core at the Bienville and Dauphin Beach areas and is apparently associated with Sand and Pelican Islands, supratidal shoals located at the western edge of the ebb-tidal delta, which effectively reduce the amount of wave energy reaching the shoreline. West of these beaches, throughout the Holocene spit, shoreline retreat is much more dominant.

Mobile Bay to Florida Panhandle

The Holocene barrier island, estuarine, and barrier beach system along the north central Gulf coast developed in response to the general Holocene sea level rise which has significantly slowed over the past 4,500 to 4,000 yrs B.P. The barrier islands and beaches in this region formed initially as offshore bars and accretionary spits and beach ridges from sediments supplied by eroding coastal headlands, rivers, and formerly emergent areas on the continental shelf. Barrier island and barrier beach sediments are composed of and underlain by alluvial, deltaic, estuarine, and coastal deposits ranging in age from the Miocene through Pleistocene (Schmidt and Clark 1980).

The morphologic features of the islands and beaches display primarily wave-dominated characteristics. Tidal inlets occur locally with associated small, relatively insignificant ebb tidal deltas. Dunes are variable and range from locally low discontinuous dunes to active, vegetated continuous dunes. Blowouts occur locally. Development of washover fans and channels occurs generally in response to hurricane impact. Littoral transport is predominantly westward in this region.

Mobile Bay is an estuarine system that represents the terminus of a major fluvial system draining an area of approximately 113,960 sq km. The bay has an average depth ranging from 2.7 to 3.4 m (Crance 1971) and contains sediments consisting of silt and clay with local accumulations of oyster shells. Mobile Bay is underlain by Pleistocene fluvial, estuarine, and coastal sediments (Figures 6.33 and 6.34). At its southern end, between Dauphin Island and Mobile Point, a large tidal inlet is scoured to depths of 16.2 to 17.4 m. This inlet demonstrates a large tidal prism and large associated ebb-tidal delta (McPhearson 1970). One large island and several shoal areas exist on the margins of the ebb-tidal delta.

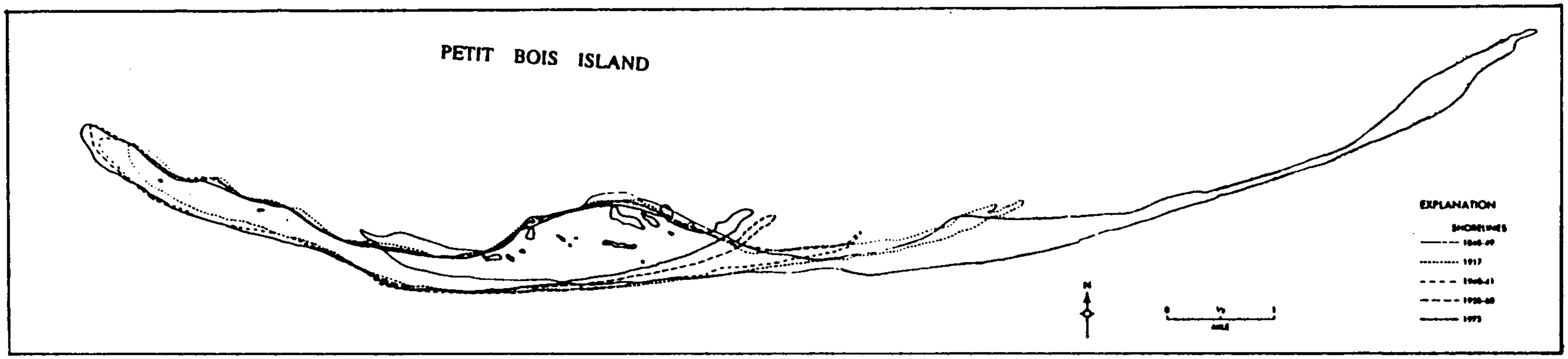
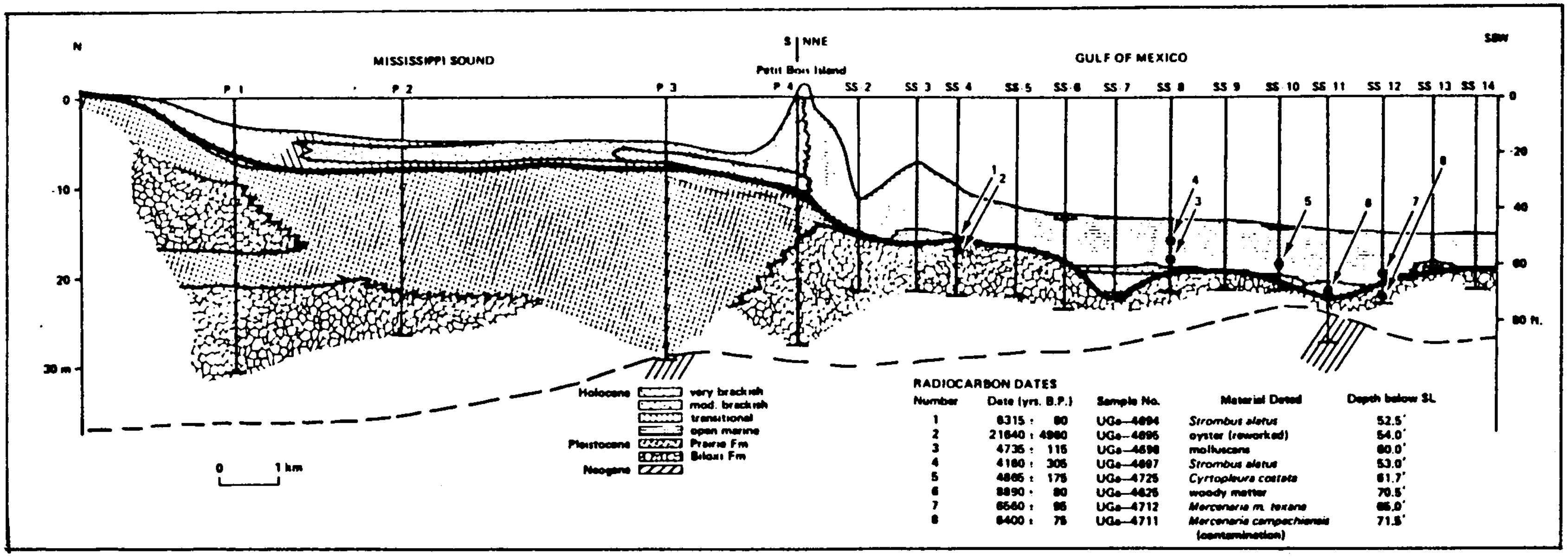


Figure 6.30. Historical map time series of Petit Bois Island illustrating shoreline changes and migrational patterns (Zapel and Nummedal 1983).



RADIOCARBON DATES

Number	Date (yrs. B.P.)	Sample No.	Material Dated	Depth below SL
1	6315 ± 80	UGa–4694	*Strombus alatus*	52.5'
2	21640 ± 4980	UGa–4696	oyster (reworked)	54.0'
3	4735 ± 115	UGa–4698	molluscans	60.0'
4	4180 ± 305	UGa–4697	*Strombus alatus*	53.0'
5	4865 ± 175	UGa–4725	*Cyrtopleura costata*	61.7'
6	8890 ± 80	UGa–4625	woody matter	70.5'
7	6560 ± 95	UGa–4712	*Mercenaria m. texana*	65.0'
8	6400 ± 75	UGa–4711	*Mercenaria campechiensis* (contamination)	71.5'

Figure 6.31. Stratigraphic cross section of Mississippi Sound and Petit Bois Island (Otvos 1985).

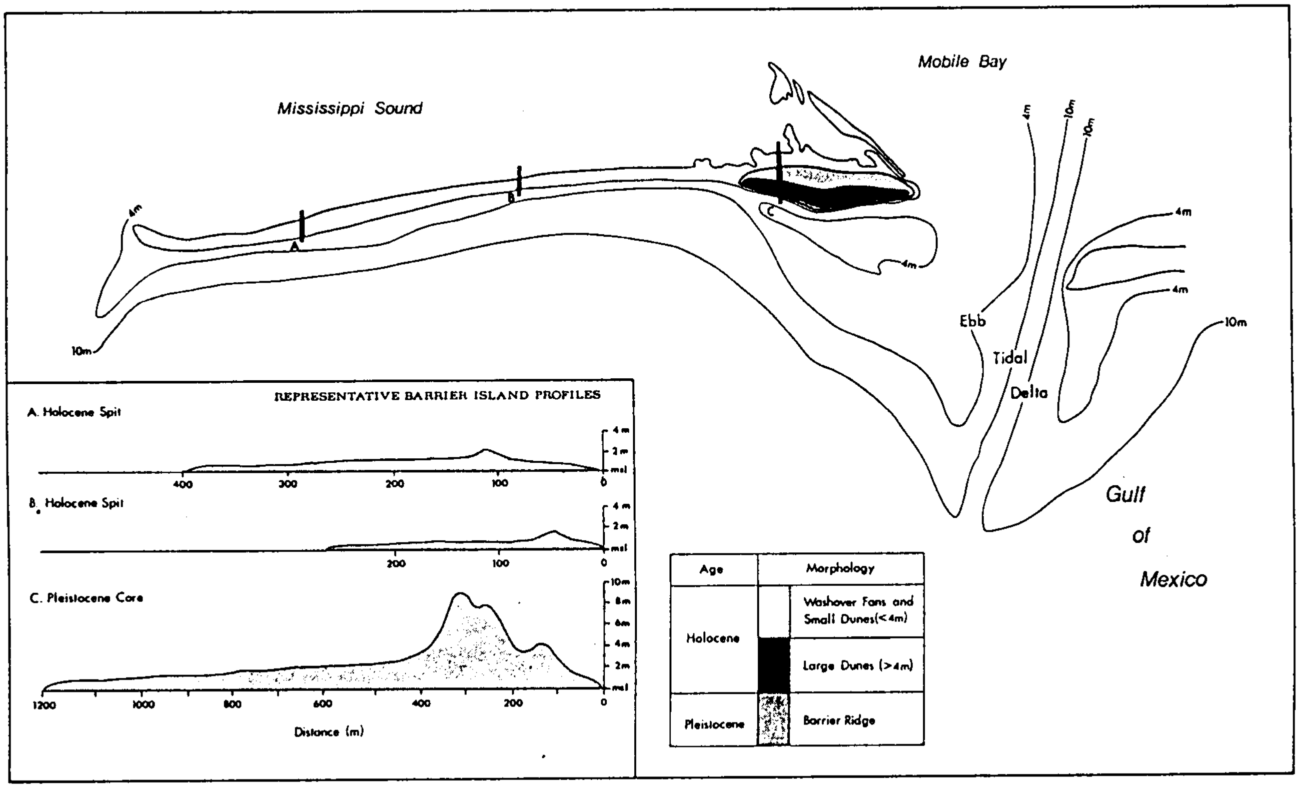


Figure 6.32. **Morphologic map of Dauphin Island, Alabama based on vertical and oblique aerial photographs and field inspections (Nummedal et al. 1980).**

Perdido Bay represents an estuary characterized by subaqueous sand ridges and has an average water depth of 1.5 m. The southern end of the bay consists of partially filled lagoons, numerous beaches, barriers, and widespread marshes (Shepard and Wanless 1971). The lagoons and bays east of Mobile Bay show similar morphologic and sedimentologic characteristics. Santa Rosa Sound, in contrast, has water depths up to 6 m. These deeper waters do not have extensive shallow margins, and preclude the development of extensive washover fans.

The Gulf Shores region represents a high-profile regressive strandplain formed approximately 4,500 to 4,000 yrs B.P. (Otvos 1985). Strandplain progradation produced a series of Holocene beach ridges approximately 0.9 to 1.6 km wide extending from the mainland shoreline between Pensacola and Mobile Bays. Several sets of barrier ridges formed, each truncating the preceding ones (Figures 6.35 and 6.36), and reflecting local variations in shore erosion and accretion. Barrier ridge summits rarely exceed 3.5 m in height, while local dunes range in height from 4.5 to 6.0 m. The modern shoreline is represented by a large, westward-extending sand spit consisting of broad, well-developed beaches backed by discontinuous dunes. Littoral drift is westward. Further east of the sand spit are several large lagoon and marsh areas.

Perdido Key is a high-profile, regressive barrier island originally formed through spit accretion from the mainland at the Pensacola Bay entrance. Perdido Key and Ono island (located immediately landward of Perdido Key) also reflect the characteristic beach ridge progradation that is seen in the Gulf Shores region to the west. The existence of an embayment in front of the original Perdido Bay entrance, located between two Pleistocene headlands, effectuated a local drift reversal that prograded Ono Spit. The back-barrier lagoon then became isolated as a result of westward growth of the eastern

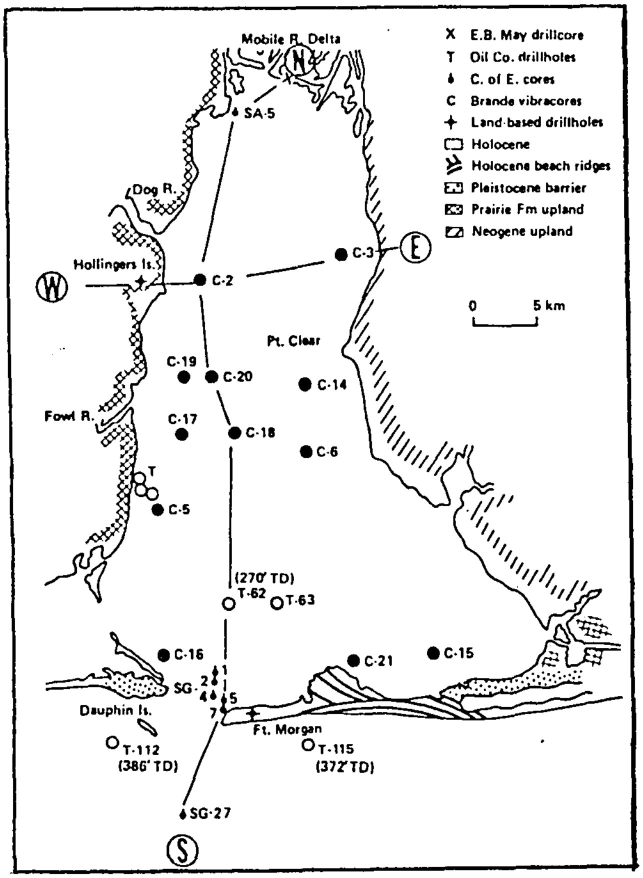
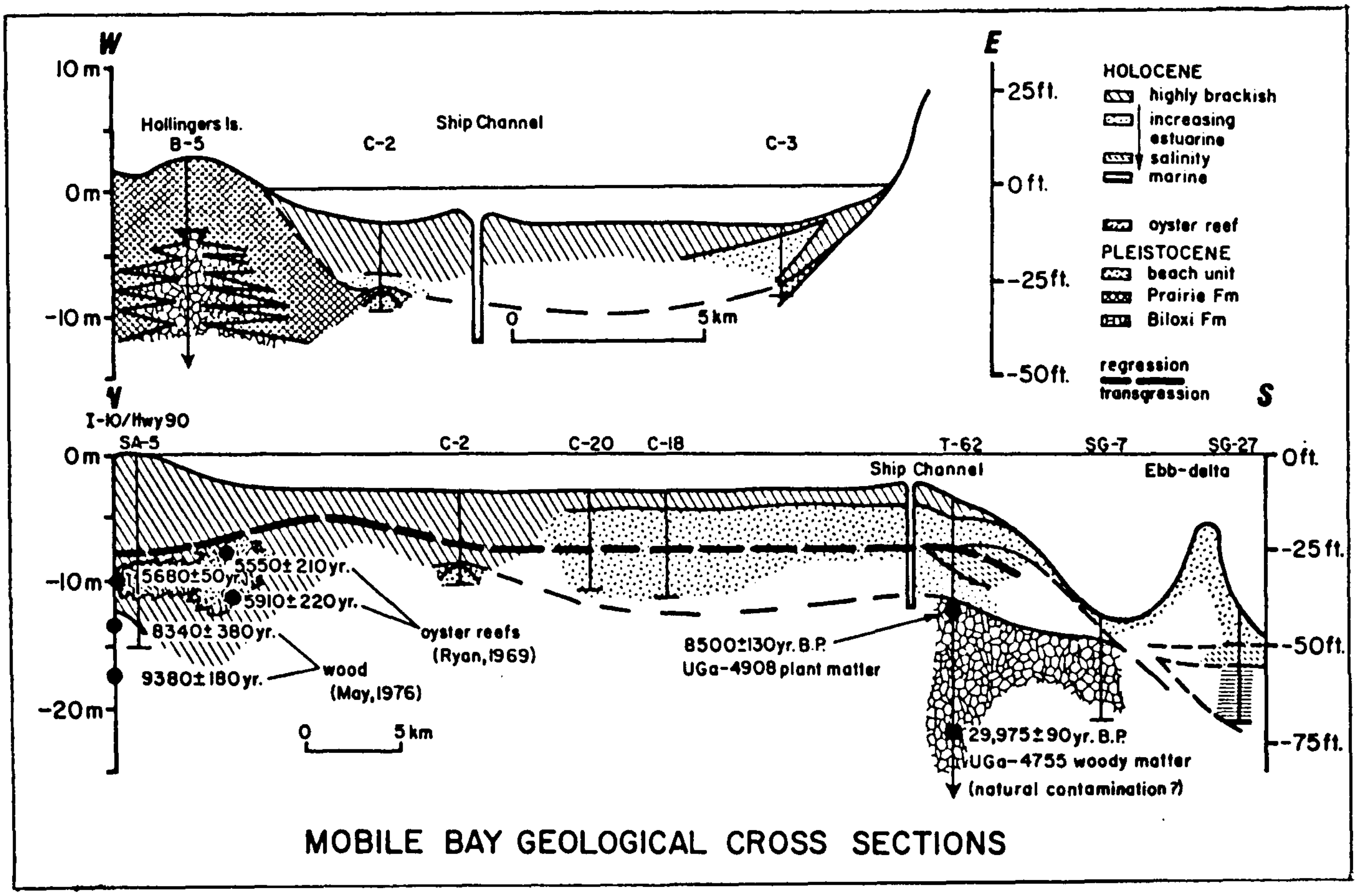


Figure 6.33. Geologic framework and cross section locations (see Figure 6.34), Mobile Bay, Alabama (Otvos 1985).

Figure 6.34. Geologic cross sections through Mobile Bay, Alabama in an east-west and north-south direction (Otvos 1985).



MOBILE BAY GEOLOGICAL CROSS SECTIONS

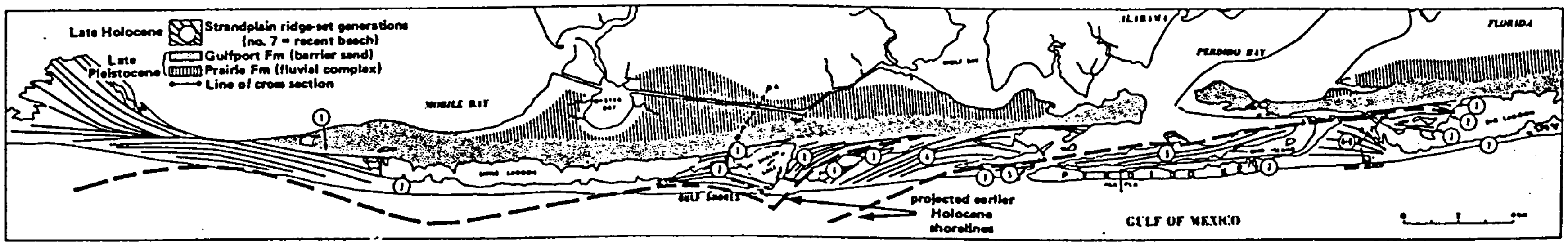


Figure 6.35. Morgan Peninsula-Perdido Key Holocene strandplain of Alabama and Florida showing the location of cross sections in Figure 6.36 (Otvos 1985).

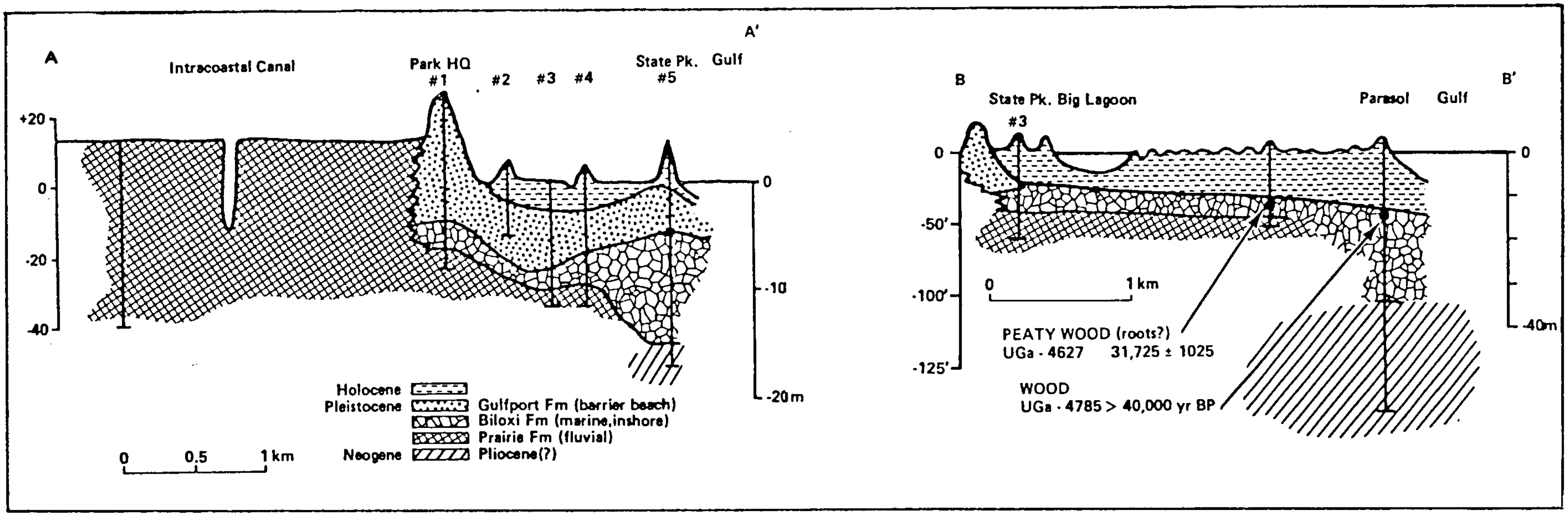


Figure 6.36. Stratigraphic dip cross sections through Gulf shores Gulf Beach Holocene beach ridge plain in Alabama and Florida (Otvos 1985).

segment of the Perdido Key beach ridge. The western end of the accretionary spit eventually became attached to the gulf beach strand plain area. Perdido Key is locally low and narrow and exhibits wide beaches. Dunes range in height from 3.6 m (USACE, N.O. 1971). Beaches are composed of fine-grained white sand and variable shell content. Washover fans and channels occur locally and result generally from hurricane impact. Because of the long east-west fetch of the island, storms produce moderately high waves that refract into the shore, resulting in a nearly stable shoreline (Doyle et al. 1984).

Santa Rosa Island formed as a composite barrier island similar to Dauphin Island, Alabama. The island represents a continuous transgression that filled a stream channel draining the Pensacola Bay region (Figure 6.37). A shallow Pleistocene core formed a topographic high on the pre-transgression land surface while Holocene intertidal and supratidal deposits veneered the Pleistocene to a depth of 12 m at the mouth of Pensacola Bay (Horvath 1968) (Figure 6.38). Tidal deltas are generally not significant seaward of these passes. Depth to pleistocene in this region averages 6 to 12 m.

This regressive barrier beach area between Destin and St. Andrews is characterized by a predominantly high profile morphology. Destin beach formed as a result of spit accretion by westwardly directed littoral drift. Beaches are wide and flat and are backed by dunes ranging from 1.8 to 3.6 m in height. Further to the southeast, beaches become narrower and dunes range in height from 3.6 to 9 m. Beaches are backed locally by swamps, marshes, streams, and lakes. Overwash fans and channels occur locally resulting from storm and hurricane activity. Beach sediments are composed predominantly of fine-grained sand and shell reworked from previous Pliocene and Pleistocene coastal deposits. Shoreline retreat for this region averages 0.3 to 0.6 m/yr.

Shell Island represents a high-profile, regressive barrier island formed through spit accretion. The island morphology is variable, ranging from areas with wide dune ridges separated by wide swales containing peat deposits to areas with narrow beach ridges separated by narrow swales that connect the barrier to the mainland. Throughout its history, the island has had several tidal inlets, although all have since closed up. Dunes are continuous, vegetated and range from 4 to 8 m in height. Sediments are composed of fine-grained sand and shells, reworked from previous Pliocene and Pleistocene coastal deposits.

Crooked Island is a regressive, high-profile barrier island, most of which has emerged since 1779 (Doyle et al. 1984). The island is composed of low beach ridges 1.5 to 2.1 m in height. Dunes on the island are continuous and vegetated and range from 3 to 8 m in height. Several high dune areas mark the position of old filled tidal passes and inlets. Sediments are composed of fine-grained sand and shells reworked from previous Pliocene and Pleistocene coastal deposits. The island has migrated easterly, as well as westerly, with frequent opening and closing of passes. Washover fans and channels occur locally in response to storms and hurricane impact.

Climate and Tropical Storms

Texas Barrier Island System

The Padre Island-Laguna Madre area is within the semi-arid zone of the Gulf Coast. Average annual temperatures range from 23.2°C with 330 frost-free days at Brownsville to 22.2°C with 310 frost-free days at Corpus Christi (Orton 1964). Precipitation decreases dramatically from north to south in the region, from 72.39 cm annually at Corpus Christi to only about 48.26 cm at the border. Overall annual moisture deficits predominate and exceed 50.8 cm annually (Map 1-D, Vol. II). Peak rainfall generally occurs in the late

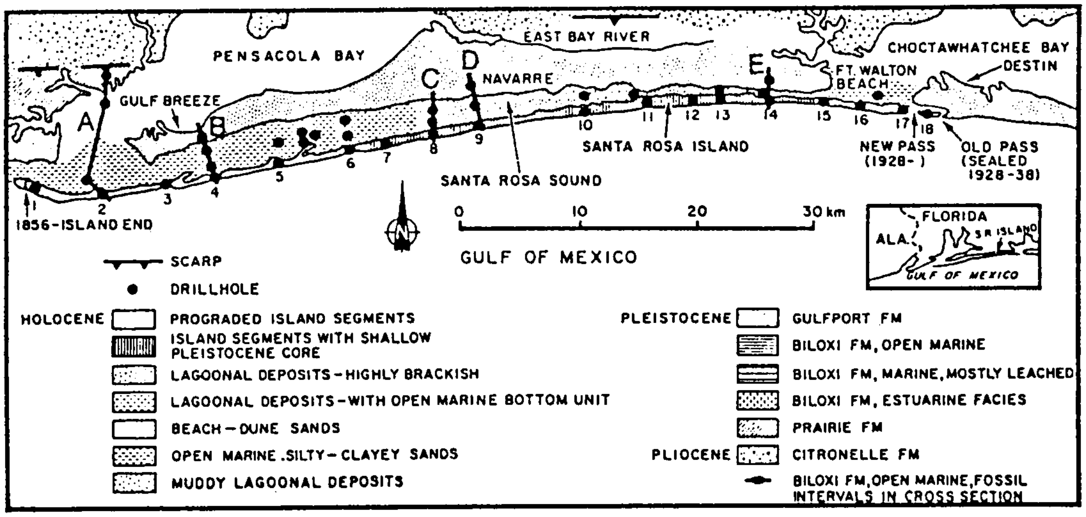


Figure 6.37. Geologic map and Santa Rosa Island, northwestern Florida (Otvos 1985).

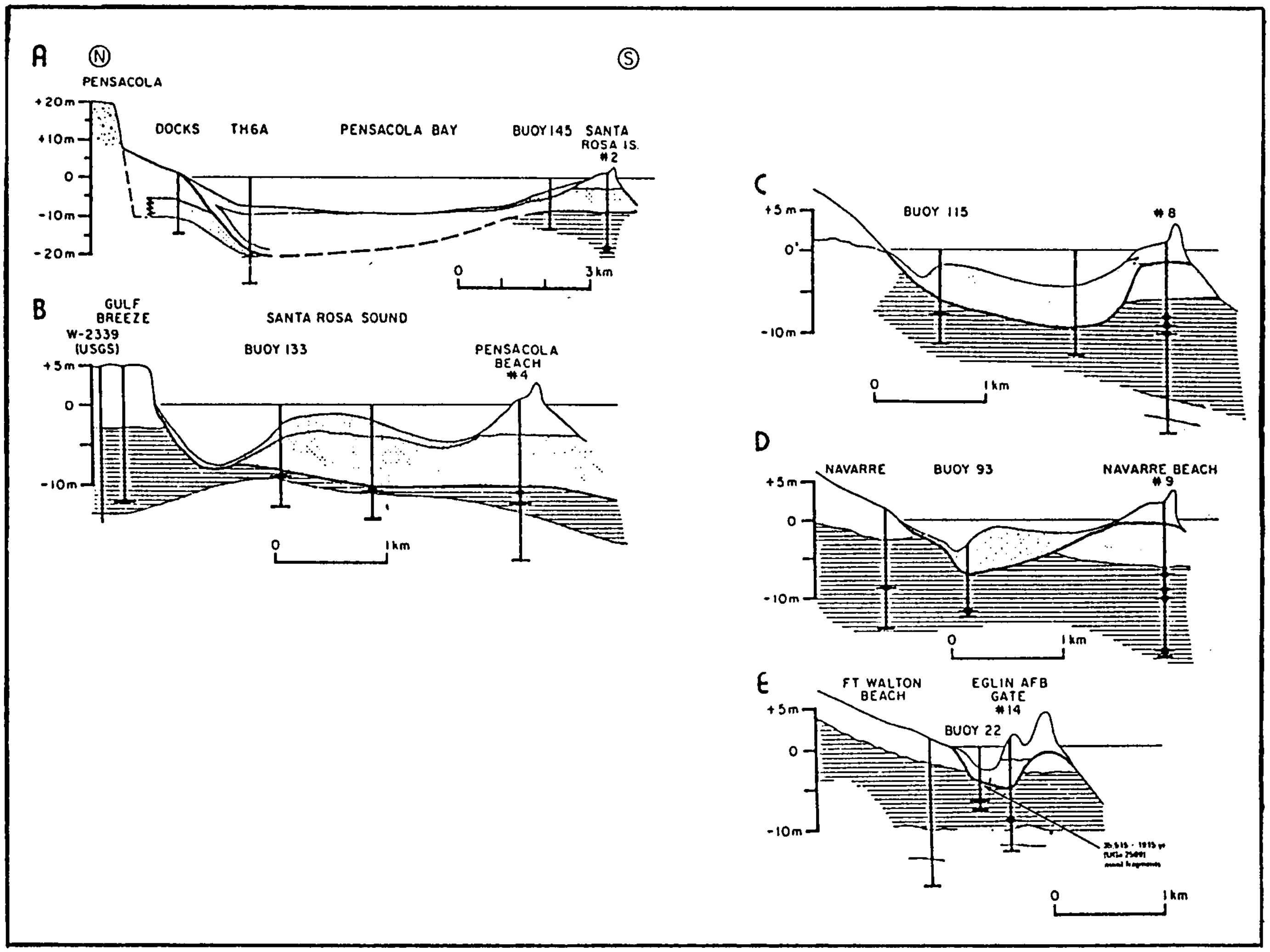


Figure 6.38. Stratigraphic dip cross section through Santa Rosa Sound and Santa Rosa Island, Florida (Otvos 1985).

summer/early fall as a result of tropical weather systems. The predominant winds in the coastal areas are from the south and southeast.

Climatic parameters vary greatly between Corpus Christi and Bolivar Peninsula along the coast, grading from the eastern edge of the semi-arid zone in the south, through the sub-humid zone, to the humid zone in the north (Orton 1964). The climatic variation is not temperature related. The average annual temperature varies only 2° C from Corpus Christi (22.2°C) to Liberty (20.3°C) (Shew et al. 1981). Precipitation between Corpus Christi and the Colorado River exhibit net annual deficits which rapidly decrease in severity from southwest to northeast. The estuaries east of the Colorado River receive net annual surplus moisture. In the deficit-prone areas, peak annual rainfall occurs in the spring and fall. Inland from the coast, the two peaks are approximately equal. At the coast, the fall peak is pronounced because of the influence of tropical low pressure systems. Overall annual rainfall is higher at the coast. East of the Colorado River, inland rainfall is fairly uniform through the year, while at the coast, rainfall gradually increases through the spring and summer to a peak in the fall. In the Galveston Bay area annual average precipitation ranges from 106.68 cm to 121.92 cm (Orton 1964). This variation in rainfall is related to tropical weather patterns (Shew et al. 1981).

Strandplain-Chenier Plain

The Strandplain-Chenier Plain System has a warm, humid, subtropical climate with fairly uniform distribution of precipitation throughout the year. Annual average precipitation increases from 127 cm in the western part of the strandplain of Texas to 152.48 cm in the eastern part of the chenier plain of Louisiana. The moisture or precipitation surplus of the strandplain area ranged from 20.32 cm to 30.42 and increased eastward in the chenier plain to 32.5 cm around Calcasieu Lake and 35.6 cm west of Vermilion Bay (Map 5-D, Vol. II).

The principal wind regimes along the East Texas coast are persistent, southeasterly winds which occur three quarters of the year (March through November) and strong, northerly winds associated with the passage of cold fronts in winter months (Fisher et al. 1973). Similar wind regimes exist along the western Louisiana coast.

The annual average mean temperature in both the Strandplain and Chenier Plain is 20.6° C. The growing season exceeds 290 days.

Mississippi Delta System

The climate of the Mississippi Delta System is similar to that of the Chenier Plain region in that precipitation is abundant (152.4 cm to 157.48 cm average annual) and well distributed throughout the year. The precipitation surplus in the coastal wetlands varies from +58.4 cm in the Terrebonne-Timbalier basin to +49.8 cm in the Barataria Basin (Map 6-D and 7-D, Vol. II).

The growing season is also long, ranging from 270 days near Lake Pontchartrain to 350 days in the lower active delta. Within the coastal zone the average annual temperatures range from 20° C in the northeast to 21.7° C in the lower delta.

The wind regimes for the Mississippi Delta are comparable to those described for the Strandplain and Chenier Plain system.

North Central Gulf Coast System

The climate of the Mississippi Sound area is related to the location of the Bermuda High (high atmospheric pressure). Movement of the high toward the Gulf of Mexico in the spring produces predominate southeasterly winds, while the retreat of the high in the fall and winter leads to an increase in continental air masses from the north and west. These cold fronts tend to become stationary in the region, resulting in overcast skies and rainfall in the winter (Eleuterius and Beaugez 1979). This phenomenon in conjunction with low evapotranspiration produce maximum annual precipitation surpluses in the winter and early spring. Near the coast there is a secondary peak in surplus in September due to tropical low pressure cells. Yearly surpluses are approximately 50.8 in annually (Map 8-D, Vol. II).

The average annual temperature in the region is 20° C with 354 frost-free days. For 83 years preceding 1978 snow has been recorded only eight times. There is an average of 75 days of thunderstorm activity with a peak occurrence in July (Eleuterius and Beaugez 1979).

Climate in the Mobile Bay area is warm and humid with a mean annual temperature range of 14.4 to 24.4° C and 230 to 300 frost-free days per year. Rainfall is highest in the summer with a minor secondary peak in the winter. Fall months are the driest. Annual rainfall totals 161.04 cm at Mobile. In the summer, the Bermuda High produces southerly winds with high moisture content resulting in thunderstorm formation. The area experiences an average of 80 thunderstorms per year, 55% of these occurring June through August. In the late fall and winter, continental air masses produce north to northwesterly winds and moderate rainfall (O'Neil and Mettee 1982; Chermock 1974; Crance 1971).

Northwest Florida is renowned for its warm, subtropical climate, with average annual temperatures of about 20° C. The panhandle area, which includes Pensacola, has both a winter and summer rainy season. Peak rainfall occurs in the summer as thunderstorms form along sea breeze convergence fronts (Palik and Kunneke 1984). Winter rains are the result of cold fronts that tend to stall over the area. In late March, these cold fronts begin to stall north of the area, typically resulting in a spring dry season. The panhandle area receives more rainfall annually than the rest of the state (154.94 to 165.1 cm). The prevailing winds show a similar pattern. The strongest winds occur in January through March from the north, averaging 14.5 km/hr. From April through July winds are from the south at 9.6 mph and from the north at 11.3 km/hr from August through December (Palik and Kunneke 1984).

Tropical Storms

Tropical storms play an important role in geomorphic changes along the Gulf Coast. The effect of these storms is related to both height of the waves along the shoreline and the movement of water across barrier islands and beaches. The extent to which a shore will be subject to change as a result of a given tropical storm making landfall at that shore depends on a number of variables. These include topography and sediments of the adjacent continental shelf and the morphology and sediment characteristics of the shore. The first two parameters will govern the surge and breaker heights. Morphological aspects of importance are barrier or dune elevations, width of the barrier system inclusive of wetlands, the presence or absence of open water behind the barrier system, and the capacity of available tidal passes. In combination with the nearshore variables of surge and breaker height these variables will govern the removal of sediment from barrier systems through offshore directed transport, through washovers, and through tidal currents in the passes.

For the purpose of comparison of the four coastal regions within the study area, a common denominator must be found with regard to the tropical storm. Since no two tropical storms are the same, one must resort to a hypothetical storm. For that purpose, the 100-year storm as defined by Federal Emergency Management Agency (FEMA) is the obvious choice with regard to water levels.

Predicted flood elevations, including wave height as predicted for this storm event, are presented in the first column of Table 6.6 (Maps 1-6 through 10-G, Vol. II). The values are based on the flood insurance maps of each of the counties (parishes) within the coastal region. The Flood Hazard Factors for each area were used to also determine the Base Flood Elevations (BFE) for the 10-year event. The 10- and 100-year BFE values were subsequently used to estimate wave heights associated with those events.

The values in Table 6.6 show that the highest surge elevations and wave heights are to be expected in the Strand-Chenier Plain Coastal Region of eastern Texas and western Louisiana. This is the result of the large width and shallow depth of the shelf in this area. Likewise, the narrow, steep shelf off the Florida coast greatly limits surge and wave heights.

To further evaluate variability within the study area, the probability of hurricane passage across or along a given Gulf shore segment must be considered. Ho et al. 1975 determined the frequency of landfall for tropical disturbances of tropical storm or hurricane strength along the Gulf Coast during the period of 1871 through 1973. This smoothed frequency distribution (Figure 6.39) shows maximum occurrences in the Galveston-to-Lake Charles, and the Biloxi-to-Panama City areas, where values range from 2 to 2.5. In view of the 100-year record, the graph closely approaches the probability of occurrence within a 100-year period.

A further evaluation may be made on the basis of hurricane strength using the Saffir/Simpson Scale of 1 to 5 with hurricanes greater than 3 being major hurricanes. Table 6.7 gives this information by State-based coastal segments for occurrences within 16.09 km of the coast for the period of 1899 to 1981.

This table reveals a slight shift in the likelihood of extensive coastal changes in that Louisiana shows a disproportionately high occurrence of major hurricanes during the last 80 years.

Hydrology

The hydrologic conditions that may influence the type and extent of impact of OCS activities include: (1) tides and water levels, (2) circulation and currents, (3) waves and currents, and freshwater inflow and salinity regime. Data on these topics are presented by each of the four coastal systems in the following sections. Maps 1-D through 10-D, Vol. II, supplement this discussion and illustrate freshwater inflow, precipitation surplus and average annual mid-depth salinity conditions. Tidal ranges, circulation patterns, relative energy levels, and elevation of water levels for various flood and storm conditions are shown on Maps 1-G through 10-G, Vol. II.

Table 6.6. Hurricane Surge and Wave Heights.

Coastal Region	BFE_{100}	BFE_{10}	Hmx_{100}	Hmx_{10}
Texas Barrier Island	13	7	6.3	3.3
Strandplain-Chenier Plain	21	11	10.4	5.8
Mississippi Delta	14	7	7.2	3.5
North Central Gulf Coast	9	5	4.7	2.6

Table 6.7. Occurrence of Hurricanes: 1899 to 1981 (Neuman et al. 1985).

Area	Category					All	Major (g.t.*=3)
	1	2	3	4	5		
NW Florida	9	6	5	0	0	20	5
Alabama	4	1	4	0	0	9	4
Mississippi	1	1	4	0	1	7	5
Louisiana	5	5	7	3	1	21	11
N Texas	4	3	2	4	0	13	6
C Texas	2	2	1	1	0	6	2
S Texas	3	4	5	1	0	13	6

* g.t. = "greater than"

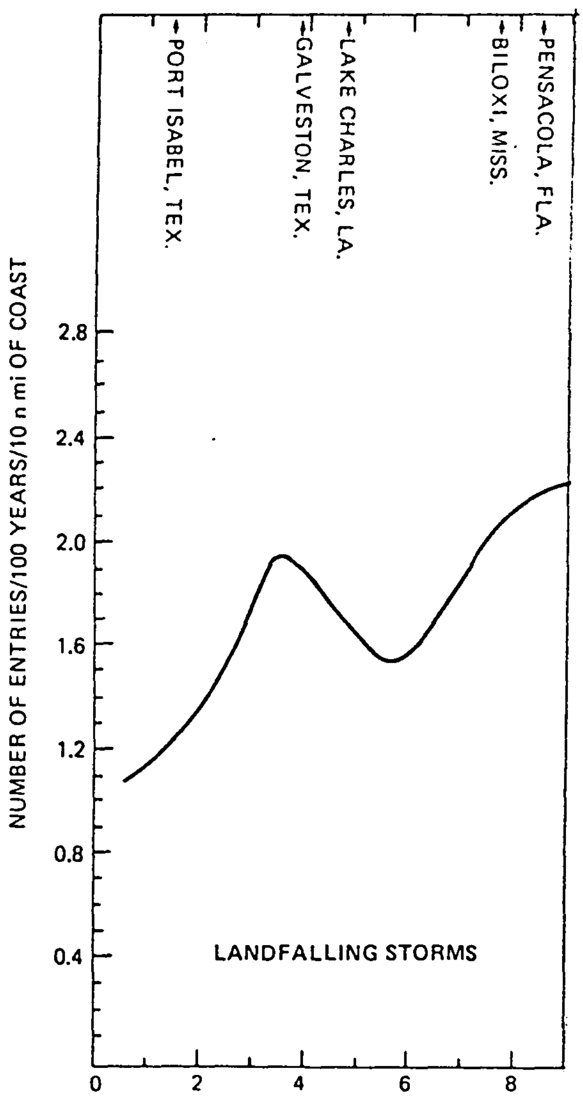


Figure 6.39. Smoothed frequency of landfall discontinuity between Pensacola, Florida and Port Isabel, Texas.

Texas Barrier Island System

Tides and Water Levels

Long-term tidal records along the Gulf shore are limited to two stations, located almost at the extreme ends of the Texas Barrier Island System (Maps 1-G through 3-G, Vol. II). At both stations, the entrances to Matagorda Bay (Pass Cavallo) and Laguna Madre (Padre Island) respectively, the average tidal range measures 0.42 m, and the mean tide level is 0.21 m National Geodetic Vertical Datum (NGVD). Identical values at the Aransas Pass Channel indicate that these values are characteristic for the Gulf shore along the Texas Barrier Island System. Maximum and minimum astronomical tidal ranges are 0.79 and 0.18 m, respectively. Astronomical tidal variation is predominantly diurnal. A mixed, semi-diurnal variation is evident around the time of minimum declination of the moon, when tidal ranges are minimal. Because of the small tidal amplitude and small number and size of tidal passes, true tidal variation is of limited importance in driving bay circulation (Breuer 1962, Ward and Armstrong 1980). Long-term tidal records within the bay systems (other than in the immediate vicinity of the passes) illustrate this limited contribution of tides to water level variation. Average daily tidal ranges are around 0.09 (Baffin Bay) to 0.21 m (Lavaca Bay).

Because of the limited tidal variation, the tidal prism of the bays is proportionally small. In combination with ample sediment supply and a significant littoral drift, this limits effectiveness of the tide as a mechanism for maintaining tidal connections developed during extreme events such as tropical storms. Even Brown Cedar Cut, the major connection between the Gulf and East Matagorda Bay, is frequently closed.

Of greater magnitude are the wind-driven tidal variation and the seasonal variation caused by the combination of sustained wind directions and temperature changes of Gulf waters (Sturges and Blaha 1976). Several studies have shown that it is not uncommon for the passage of a cold front to result in a water-level fluctuation of 0.60 to 0.76 ft (Ward and Armstrong 1980) or as much as that experienced during time of maximum lunar declination when tidal ranges are largest.

The seasonal fluctuation of water level is that experienced by the entire Gulf coast. Fall and spring maxima alternate with winter and summer minima, with the fall maximum and the winter minimum being the two most pronounced ones, with average water levels differing by about 0.30 m.

Primarily two wind regimes govern the bay systems within the Texas Barrier Island System (Shew et al. 1981). In the summer, winds from the southeasterly quadrant are dominant, especially in the more southerly bay systems. During the winter season, an alternation of southerly and northerly air flow prevails, with southerly winds dominating frequency and direction and northerly winds dominating velocity. A major interruption of the prevailing summer conditions may, however, result from tropical storms.

Because of the large surface area of the bays relative to their water volume, wind stresses play an important role with regard to both water levels and water movement. As discussed by Ward and Armstrong (1980) for the Matagorda Bay system, wind stress is commonly the cause of significant changes in water level that are perceived as wind tides when an initial "setup" is followed by a "setdown" as the wind shifts direction. This type of water level change is most common during frontal passage when onshore winds are enhanced by the approaching frontal system and are subsequently replaced by strong, northerly winds following frontal passage. The water level change may be as much as

0.91 m and water exchange with the Gulf often equals or exceeds that associated with maximum astronomical tides.

Circulation and Currents

Sustained wind velocities and directions also play an important role in circulation patterns within the bays and are largely responsible for the large-scale gyres that are semi-permanent elements of bay circulation (Ward and Armstrong 1980). The results of interaction between tides and bay morphology are superimposed on these patterns and are additionally modified where regional or local precipitation is sufficient to produce major inflow events. However, as a result of climatic conditions, the latter are most infrequent. As a rule, freshwater deficits are such that a net inflow from the Gulf results.

Because of the many variables involved, no discussion of bay circulation that allows for site-specific evaluation is possible. However, from summarized information (USACE 1973), including steady state, numerical simulations performed in conjunction with estuarine management programs and impact assessments (Texas Department of Water Resources [TDWR] 1981), some gross generalizations can be made (Maps 1-G through 3-G, Vol. II). It appears that the bays within the Texas Barrier Island coastal region are characterized by large gyres with bidirectional flow components in the center of the bays. The majority of the gyres appear to be counterclockwise, which is possibly attributable to the effect of the Coriolis force on both inflow and outflow from the bay system. The effect of seasonal changes in wind stress is most pronounced in the Laguna Madre system where flow directions are predominantly southward during sustained northerly winds and northward during sustained southerly winds (USACE 1973).

Coastal Gulf circulation is dominated by two current systems driven by prevailing winds. A semi-permanent westward current dominates circulation along the upper coast. Similarly, a northward current is dominant along the lower Texas Barrier Island System. The convergence zone lies in the vicinity of Big Shell Beach shifting seasonally with changes in prevailing wind direction and velocity (Brown et al. 1977, Ward and Armstrong 1980). The convergence zone lies furthest northward, in the Corpus Christi area during the summer (Ward and Armstrong 1980).

Waves and Currents

The nearshore wave climate is difficult to define quantitatively because of a lack of observations in the nearshore zone. The only long-term nearshore observations are those made at Galveston, and they serve as an indication of the mild wave climate along the entire Texas coast. Average significant wave height is about 0.45 m and the mean period about 6 sec (Thompson 1977). Wave action within the bays can be a significant factor with regard to shoreline erosion. However, despite the fact that many of the bays offer a long fetch to dominant wind directions, wave growth is often depth limited. Consequently, wave erosion is likely to be greatest along the shores exposed to the southeast where the combination of strong southerly winds and elevated water levels prior to frontal passage provide for the greatest wave heights on a frequent basis.

Offshore data are more readily available but are of limited value unless extensive analysis is undertaken with regard to the changes in wave characteristics brought about by shoaling of these waves. Offshore ship observations reported through the Navy's Summary of Synoptic Meteorological Observations (SSMO) program have been summarized for the Corpus Christi area (Mossa 1984) and for the entire region by one-minute quadrants (NOC 1986). They show a predominance of waves from the southeast. With inclusion of northward and westward directions of wave propagation, about 65% of the offshore waves in the Corpus Christi area arrive from the southeast quadrant (Mossa 1984). With regard to wave energy flux, waves from the southeasterly octant also account for the greatest flux, while southerly waves and easterly waves account for about 60% and 45%, respectively, of the flux attributed to southeasterly waves.

Since width of the shelf having a depth less than 9.14 m is generally the same along the Texas Barrier Island System, differences in nearshore wave climate along the TBICR must be expected to relate primarily to local wind regimes and to refraction. With a predominance of waves from the southeast quadrant, one would expect wave incidence to produce northward mass transport along the lower Texas Barrier Island System and westward transport along the upper Texas Barrier Island System. This would, in both cases, reinforce the effect of wind stress on water movement along the coast.

Freshwater Inflow and Salinity Regime

The Laguna Madre is hypersaline and receives no appreciable freshwater inflow except during the hurricane season (Shew et al. 1981) (Map 1-D, Vol. II). Tropical low pressure systems which dump torrential rains on the watershed can reduce the average salinity to 27 ppt for several months. Otherwise salinities typically reach 60 ppt or more (Map 1-D, Vol. II). The lower Laguna Madre salinities are moderated by circulation of gulf water through Brazos Santiago Pass, the Gulf Intracoastal Waterway (GIWW), and the Port Mansfield channel. Upper Laguna Madre exhibits poorer circulation due to spoil disposal along the Gulf Intracoastal Waterway (GIWW) and the causeway bridge (Shew et al. 1981).

Freshwater inflow to the estuaries from Corpus Christi Bay to East Bay are not only related to the coastal climatic regimes discussed above, but to the presence of major river systems that discharge into them. The distribution of freshwater and salinity as estimated by the Texas Department of Water Resources (1980, 1981a, 1981b, 1981c) (Maps 2-D and 3-D, Vol. II). In general, freshwater inflow increases from southwest to northeast, in harmony with increasing rainfall. As one would expect, estuarine salinity regimes generally decrease along the same pattern. However, the Copano Bay-Aransas Bay estuary is an exception. Despite small inflows from a small drainage basin, these bays exhibit a very low salinity regime as compared to Corpus Christi and San Antonio Bays flanking them. Two possible explanations are evident.

First, there seems to be a net input of "mixed" estuarine water from San Antonio Bay to Aransas Bay. Wind-dominated circulation patterns and the Coriolis force tend to produce counterclockwise movement of water within these bays. Most of the bays in this region, therefore, exhibit higher salinities on the east side and lower salinities on the west side, as well as stronger ebb flows on the west side (Shew et al. 1981). This would tend to favor a net southwesterly drift of lower salinity water between bay systems, the magnitude of which would be controlled by the connections between them. The relatively good connection between San Antonio and Aransas Bays enhances the exchange. The second explanation for lower salinities relates to the absence of a navigation channel through Aransas and Copano Bays. All other bay systems exhibit channelization from the Gulf to the head of the system. This tends to increase salinity and decrease residence time for freshwater.

The Galveston Bay system is the largest in the region in terms of its size and volume of freshwater inflow (Map 3-D, Vol. II). The Houston ship channel, Bolivar Roads, and the Texas City Dike are major man-made features that influence salinity. The Houston ship channel is the primary path of saltwater intrusion (Espey, Huston, and Associates 1978). The salinity regime is higher in the west and lower in the east, the reverse of what would be expected in other southeasterly wind-driven, counter-clockwise flowing systems. A net southwesterly movement of water from Galveston Bay to West Bay is greatly hindered by the Texas City Dike. East Bay, however, receives a net inflow of fresher water from the Sabine Lake area via the GIWW (Gosselink et al. 1979).

Strandplain-Chenier Plain System

Tides and Water Levels

In many regards the general characteristics of tides, waves, and circulation presented for the Texas Barrier Island System apply to the Strandplain-Chenier Plain System as well. However, because of extensive observations at Galveston, some quantitative information can be provided on tides and the nearshore wave regime.

Tides in the Strandplain-Chenier Plain System are mixed diurnal but show the strongest semi-diurnal constituent of all four Coastal Systems. Here, tidal ranges are the highest for the entire Gulf Coast study region. The average diurnal range is 0.76 m along the area between the Mermentau River entrance and Sabine Pass (Map 5-G, Vol. II). Toward the east, the average range decreases to only 0.60 m at the entrance to Vermilion Bay, La. In a westward direction, the decrease is somewhat greater, the average range being 0.06 m at the Galveston Bay entrance but decreasing to 0.36 m at San Luis Pass (Maps 3-G, Vol. II).

Tidal ranges show the seasonal variation typical for the Gulf being highest at the summer (June) and winter (December) solstices, and lowest at the fall (September) and spring (March) equinoxes. These seasonal changes in range overlap, but are out of phase with the seasonal change in average water levels caused by the interaction of astronomical forces and meteorological and steric effects. Average monthly water levels (Marmer 1954) are highest in September (+0.06 m NGVD) and May (0.15 m NGVD), while water level minima occur in February (-0.91 m NGVD) and July (-0.03 m NGVD). Mean monthly water levels thus may vary by as much as 0.27 m (Mason 1981).

Several tidal stations within the Galveston Bay complex allow the observation of the tidal wave attenuation within the bay system. Within the bays the average diurnal tidal ranges in the upper Galveston Bay, Trinity Bay, East Bay, and West Bay are only about 0.30 m, or half the range at the entrance to the Houston Ship Channel.

Because of the greater tidal range, as well as a larger river inflow of freshwater from tributary streams, wind stress is not as much a dominant factor in governing tidal exchange and water levels as it is in the Texas Barrier Island System. The greater tidal range, furthermore, results in a larger tidal prism per unit bay area. Of the three bay systems—Galveston, Sabine, and Calcasieu—only the first is connected to the Gulf by multiple passes. However, about 80% of the tidal exchange for the Galveston Bay complex occurs through Bolivar Roads (Espey, Huston and Associates 1978).

Most of the remaining 20% of the tidal prism is carried by San Luis Pass, exchange through Rollover Pass being limited by a sill to prevent enlargement beyond control. The fact that the artificial Rollover Pass became unstable after construction (Prather and Sorensen 1972) is of particular interest in that it indicates a considerable water exchange "pressure" across the Bolivar Peninsula. This is in strong contrast to the conditions in the Texas Barrier Island System, where newly formed tidal passes have a strong tendency to be ephemeral and subject to rapid shoaling.

Despite its tidal range, freshwater inflow, water-level changes, and tidal exchange in the Galveston Bay complex are still largely governed by seasonal wind conditions. As for the other bay complexes along the Texas coast, water exchanges as a result of changes in wind direction during frontal passages exceed those resulting from astronomical tides by an order of magnitude (Espey, Huston and Associates 1978). The same applies probably to the Sabine and Calcasieu Lakes because of similar tidal regime and alignment with dominant wind directions. However, in contrast to the bay complexes within the Texas Barrier Island System, bay systems within the Strandplain-Chenier Plain System experience a net outflow as a result of tributary stream discharges. Sabine Lake receives the largest freshwater inflow per unit bay volume (Ward and Armstrong 1980).

Circulation and Currents

Information concerning bay circulation is limited mostly to the Galveston Bay complex. In a general sense that circulation conforms to that of the other estuaries along the Texas coast in that a number of large-scale gyres can be delineated within individual bays. Outflow within the Galveston Bay proper appears most pronounced along the west side. Tidal inflow is largely guided by the Houston Ship Channel. Circulation patterns summarized by the U.S. Army Corps of Engineers (1973) indicate net westward flows in both East Bay and West Bay. Large-scale circulation gyres with inflow (and outflow during high river discharges) concentrated along the navigation channel are also postulated for the Sabine (USACE 1973) and Calcasieu Lakes.

Related to the large tidal prism of the Galveston Bay complex and the large share of tidal exchange carried by Bolivar Roads, currents attain high velocities in the confined channel between the jetties. Velocities of 1.16 m/s during ebbing tide and 0.88 m/s during flood are reported (National Ocean Service 1983).

Waves and Currents

Nearshore wave observations in the Galveston area are among the most extensive for the Gulf coast. The Army Corps of Engineers, Coastal Engineering Research Center (CERC), maintained a wave gauge at the Galveston Pleasure Pier during the period of 1965-1967, while Galveston Island and Bolivar Peninsula were incorporated in CERC's Littoral Observation Program (LEO) during 1975. A summary of wave height data from the Pier (Mossa 1984), shows 50% of the waves to be less than 0.40 m and 90% less than 0.70 m in height. Waves were measured in an average water depth of about 4.88 m. Directional information can be obtained from the LEO data (Hall 1976). The surf observations showed 40% of the waves to approach from an easterly direction, 30% from a southerly direction, and the remaining 30% perpendicular to the shoreline.

Directions of longshore water movement did not necessarily match the directions expected from the wave observation. Longshore currents frequently set to the southwest despite a perpendicular wave approach. However, consistent with the observed dominance of easterly waves, the southwesterly longshore currents were dominant as to both, direction and velocity (Hall 1976; Thompson 1977; Ward and Armstrong 1980).

Westward currents also dominate water movement along the Chenier Plain, with average velocities between 0.30 and 0.52 m/s (USACE, VIC. 1973). Observations from the Corps' LEO program indicate average wave heights between 0 and 0.30 m, a maximum wave height of 2.44 m, and average wave periods of less then 1 sec. Data obtained in conjunction with a shoreline protection project give predominant wave height values of 0.60 to 0.91 m and periods of 5 to 8 sec (USACE 1981). Westward currents of 0.30 to 0.91 m/s are associated with the predominant waves.

Offshore SSMO wave data (Mossa 1984; Naval Oceanography Command [NOC] 1986) complement the above picture. With regard to wave energy flux, southeasterly waves account for the greatest flux while easterly and southerly waves both account for about 70% of the flux attributed to southeasterly waves.

Freshwater Inflow and Salinity Regime

Freshwater inflow derived from regional sources enters the Strandplain-Chenier Plain system via the Sabine, Calcasieu, and Mermentau Rivers. Each river empties into a well defined coastal embayment, or lake, and interchanges water with the Gulf through well defined tidal inlets now maintained as deep navigation channels. For the most part, salinities in the nearshore Gulf are greater than 15 ppt during most of the year (extrapolated from Map 5-D).

However, during high water stages of the Atchafalaya River, fresh and fairly turbid water may be trapped next to the shoreline and move westward with the longshore current to influence water chemistry in the Chenier Plain.

Mississippi Delta System

Tides and Water Levels

Daily tidal variation in the Mississippi Delta System can be characterized as diurnal, the semi-diurnal component being too weak for a mixed-tide classification. National Oceanic and Atmospheric Administration (NOAA) tide tables show a considerable variation in tidal ranges among the coastal tide stations (Maps 6-G through 7-G, Vol. II). Ranges are highest in the area from Marsh Island to Raccoon Point at the eastern tip of the Isles Dernieres. Within this segment, average tidal variation ranges from 0.52 m to 0.60 m. From Raccoon Point eastward tidal ranges decrease rapidly to a range of 0.34 to 0.42 m for the segment between Wine Island and the northern tip of the Chandeleur Islands. Diurnal ranges again are higher from Cat Island to Horn Island, the average range being 0.52 m.

Longer term cycles of water level and tidal range variations are similar to those displayed by the adjacent coastal regions. That is, variations with a cycle of several days occur in response to the passage of cold fronts or to periods of strong and sustained onshore winds in the spring. Their magnitude exceeds the daily tidal range and frequently masks the daily fluctuation within the estuaries entirely. Water levels may be elevated in response to these events. Seasonal changes in water levels of about 0.30 m occur in response to changes in the prevailing wind vectors and its interaction with the astronomical and seasonal steric effects on water levels of the Gulf associated with the solstices. The higher water levels in September are lower than average tidal ranges.

Changes in water levels along the Louisiana coast then, insofar as important to geomorphic changes, are primarily governed by wind. It is during the medium-term variations in water levels, such as those associated with frontal passage, that maximum water exchange takes place between the estuaries and the Gulf and that currents in the tidal passes attain the highest velocities. An exception to this are the extreme conditions associated with tropical disturbances when water levels are raised from 1.52 m to 3.04 m higher.

Circulation and Currents

With regard to circulation patterns and currents, the Mississippi Delta System can best be viewed in three segments because of hydrologic differences. The area west of the Mississippi River is characterized by multiple bay systems that have a considerable inland extent (Maps 6-G through 7-G, Vol. II). In all but the Atchafalaya-Vermilion system, direct freshwater inflow is limited to local runoff from within bay watersheds. In many regards, hydrology of these bay systems is similar to those of the Strandplain-Chenier Plain System. Accordingly, water exchange between the bay systems and the Gulf is governed primarily by tide and wind-induced, water-level changes. Likewise, water movement displays two important components with regard to sediment transport. One is the water movement through the tidal passes (and in some cases across the barrier system); the second is alongshore movement.

Currents through the tidal passes show a difference in strength that reflects the diurnal tide and the more rapid fall than rise. In the major passes, ebb current velocities are reported to be in the order of 0.76 to 0.91 m/s and flood currents between 0.52 and 0.76 m/s (National Ocean Service 1983). Longshore water movement is a function of several forces. General Gulf coastal circulation is westward along the Isles Dernieres and Timbalier systems, while eastward movement prevails along the Barataria shore as part of the trapped vortex along the western flank of the Mississippi River Delta (Wiseman et al. 1975). However, more important with regard to movement of the coarser sediments that affect barrier system morphology are the nearshore currents. Observations on nearshore circulation are limited to the Barataria coastal segments where tidal forces create a reversing gyre that is clockwise during rising, and counterclockwise during falling tide with velocities around 0.09 m/s (Murray 1976).

The Chandeleur system also has limited, direct inflow of freshwater from basin runoff but barrier islands flank a continuous sound rather then individual bay systems. Information concerning circulation is largely based on numerical simulation (Hart 1978). As a result of longshore continuity, tidal progression, and the alignment of the sound with regard to prevailing seasonal wind directions, water movement displays strong alongshore components and may result in a substantial through flow. Water exchange with the Gulf takes place primarily through the northern and southern entrances to the sound. In the absence of wind stress, the simulation indicates an area of tidal current diversion and conversion in the central part of the sound but a net flow from north to south. Sustained northerly winds reinforce this flow vector, while southerly winds may entirely reverse its direction.

Waves and Currents

Long-term wave observations in the Mississippi Delta System are limited to visual surf observations by U.S. Coast Guard personnel at Grand Isle. Comparison of these observations with those from the Galveston Pier show wave heights at Grand Isle to be about 50% higher (Mossa 1984). However, it should be taken into consideration that the comparison involves surf conditions at Grand Isle and waves in depths of about 4.88 m at Galveston. Thus, the increased height in part represents the shoaling effect as further indicated by a mean annual wave height of 0.42 m at both Grand Isle and Galveston (Thompson 1977). For further comparison, surf heights at Grand Isle may be compared with those for Cape San Blas, Florida, at the eastern extreme of the study area. Grand Isle surf heights exceed those at Cape San Blas about 20% for the highest half of the wave observations.

Offshore SSMO data reveal almost equal energy flux from the east and the southeast, and a slightly smaller flux from the south. This reflects the transitional location of the Mississippi Delta System between the dominant westerly vectors of the eastern Gulf and the southerly vectors of the western Gulf. Accordingly, a net westward longshore drift must be expected along most of this coast. However, considerable local variation exists, especially along the Louisiana segment, as a result of curvature of the barrier island arcs.

Becker (1972) analyzed onshore wave power along the Louisiana coast on the basis of hindcasted offshore characteristics for winds greater than 0.6 km/hr and subsequent refraction by shelf topography. Summarized data show a predominance (43%) of southeasterly waves offshore with waves from 1.22 to 1.82 m and periods of about 6 sec accounting for the greatest onshore energy flux. In general, wave energy distribution along the shore was related closely to shelf width. Offshore wave heights along the Mississippi coast show a similar predominance of wave heights (Eleuterius and Beaugez 1979).

Freshwater Inflow and Salinity Regime

Other than the discharge of the Mississippi River directly into the Gulf, freshwater inflow in the Mississippi Deltaic System is derived totally from coastal precipitation surpluses collected within the estuarine basins. There is no gaged river inflow, except into Lake Pontchartrain, which is outside the study area.

With regard to the barrier islands and barrier beaches, precipitation surpluses do little to moderate the salinity regime of the nearshore Gulf. Salinities, on the average fall between 25 to 30 ppt, except during major floods on the Mississippi River.

North Central Gulf Coast System

Tides and Water Levels

Tides in the North Central Gulf Coast System are diurnal. Tide stations along the coast at the bay entrances show average diurnal ranges of 0.34 to 0.40 m (Maps 8-G through 10-G, Vol. II). As tides progress into the bay systems, tidal ranges tend to increase slightly to an amplitude between 0.42 and 0.48 m. Because of the small tidal ranges, tidal prisms per unit bay area are small as compared to the other coastal regions within the study area. This may in part explain why all but one (St. Andrews Bay, Florida) of the the bay systems are served by only a single tidal pass connecting the bay system with the Gulf, tidal exchange being insufficient for maintenance of additional passes. Other contributing factors may be that dominant wind vectors along this coastal system have a more westerly direction, so that setup of water levels along the coast and in the bay systems occurs frequently, thereby limiting the occurrence of high velocity water exchange.

Circulation and Currents

Information concerning bay circulation along the North Central Gulf Coast appears extremely limited, and restricted to the largest of the bays—Mobile Bay. The presence of a major connection between Mobile Bay and Mississippi Sound at Pass aux Herons, in addition to the main connection to the Gulf, provides for two avenues of tidal exchange. Associated with the large, average annual discharge (1,755.8 cms) into the bay from the Mobile River, both passes experience net outflow. Pass aux Herons accounts for about 25% of the volume passed to the Gulf (Schroeder 1976, 1977) at velocities in the order of 0.76 to 1.06 m/s. Velocities at the Main Pass are generally somewhat lower.

The limited tidal range allows circulation in Mobile Bay to be strongly affected by river discharge, while the considerable inland extent of the bay provides likewise for a considerable influence of onshore and offshore winds. Sustained winds may entirely eliminate the normal, tide-related, directional changes of the currents (Loyacano and Smith 1979). Dominant wind fields are a northwest to northeast system during fall and winter and southeast to southwest during spring and summer. Without strong wind effects, there appears a tendency for outflow to be more dominant along the west side of the bay, with inflow favored along the east side.

The Mississippi Sound area differs from other systems in that river flow is at times an important driving force with regard to circulation, and the long axis of the sound is less aligned with prevailing wind directions. Accordingly, circulation in the Mississippi Sound displays strong onshore and offshore components associated with the many major tidal inlets (Kjerfve 1983).

The general circulation pattern is induced primarily by the tides and is significantly affected by winds having a substantial alongshore component (i.e., southeast, northwest). Tides in Mississippi Sound progress westward and eastward from Horn Island Pass. Most water exchange takes place through the Cat Island Channel, Dog Keys Pass, and Petit Bois Pass (USACE, MOB. 1983).

During flood, tide-induced currents diverge near Horn Island Pass, flowing westward to Lake Borgne and eastward to Mobile Bay. A reversed pattern occurs during ebb (Kjerfve 1983). In general, numerical simulation confirmed Eleuterius's (1976, 1978) three components within the sound: from the mouth of the Pascagoula River eastward to Pass aux Herons, westward from Pascagoula to Cat Island, and from Cat Island to Lake Borgne. Longshore circulation components within the sound are greatest toward the east and west because of connections with Mobile Bay and Lake Borgne, respectively.

Waves and Currents

Average annual wave heights appear slightly higher along the North Central Gulf Coast than along the remainder of the study region, wave heights being around 0.42 to 0.52 m based on visual near breaker observations (Thompson 1977). Waves measured by the USACE-CERC at the Destin Pier show 90% of the waves to be less then 0.9 m high. Surf observations at Santa Rosa Island indicate the incidence of the higher waves to be primarily from the southeast (Mossa 1984), which is consistent with a predominantly westward littoral drift. Offshore SSMO wave data show wave propagation directions along the North Central Gulf Coast to have a somewhat larger easterly component then those along the other coastal regions. Frequent reversals of the alongshore component of wave incidence occur in the spring, associated with the movement of frontal systems across the continent.

Freshwater Inflow and Salinity Regime

Considerable freshwater inflow and the shallow, shelf-like geometry of Mississippi Sound combine to determine the salinity regime. Discharges from the adjacent Pontchartrain Basin and from the Pearl River contribute 56% of the total freshwater inflow to the sound. The Pascagoula River contributes an additional 37.5% with the small drainage basins of St. Louis Bay and Biloxi Bay, contributing only 6.5% of total inflow (Map 8-D, Vol. II). Also, a portion of the inflow to Mobile Bay is diverted into Mississippi Sound through Pass aux Herons.

The salinity regime of the sound varies between a partially mixed and well-mixed estuary, but can exhibit vertical stratification under some conditions (Eleuterius and Beaugez 1979). Salinities are generally lowest in the west because of high freshwater inflow and the sheltering effect of the "Louisiana marsh" area of Eastern St. Bernard Parish, Louisiana. Higher salinities move landward at Gulfport and Petit Bois Pass. The overall salinity in Mississippi Sound is about 20 ppt.

The Mobile Bay system is the second largest estuarine area, after Mississippi Sound, in the North Central Gulf Region, covering 106,920 ha with an average depth of 2.96 m. The fourth largest river system (in terms of discharge) enters the northern end, delivering an average annual freshwater inflow of about 2,067.4 cms. The Alabama-Tombigbee-Mobile River Basin covers 112,950 sq km. Peak discharge occurs in March and the lowest discharge occurs in September (O'Neil and Mettee 1982).

Typically, Mobile Bay would be classified as a partially mixed estuary because of its relatively shallow bathymetry and high freshwater inflow. However, the Mobile Ship Channel exerts a major influence on the bay salinity. Vertical stratification is very pronounced. A salt wedge is present in the channel to the landward end of the bay except during very high discharge conditions (Bault 1972). Stratification is most pronounced when freshwater inflow forms a lens above saline bottom waters. Schroeder (1979) described three mixing conditions for the bay. At low discharge, the upper water of salinity 1 to 8 ppt moves south over saline waters with no east/west preference. At medium discharge, the fresher layer tends to favor the western side of the bay. At high discharge, the upper water covers the whole bay and the bottom waters favor the west side. Loyacano and Smith (1979) report that about 15% of the ebb flows from Mobile Bay exit through Pass aux Herons into Mississippi Sound.

It is difficult to display the average annual salinity regime in a highly stratified estuary. For Maps 8-D through 9-D, Vol. II, the data of Bault (1972) and April and Rainey (1979) were vertically integrated to obtain the average annual isohaline shown. Generally, this exercise indicates that the salinity regime ranges from 5 ppt near the head of the Mobile Delta to 30 ppt near the pass.

Perdido Bay covers an area of only 6,973 ha with an average depth of 2.40 m. The Perdido River delivers an average of 52.9 cubic meters per second (cms) to the estuary. Bault (1972) reported salinity stratification in the bay, but it was less pronounced than in Mobile Bay. Surface salinities ranged from 10 ppt in January to about 22 ppt in October in the middle portion of the bay. Vertically integrated data show that the average Perdido Bay salinity is about 20 ppt (Map 9-D, Vol. II).

Freshwater inflow into the Pensacola Bay system originates from the Escambia, Blackwater, and Yellow River tributaries. The mean annual gaged discharge of these streams totals 246.4 cms with over 60% of the inflow related to the Escambia River. The coastal ungaged watershed also contributes substantial inflow from 71.88 cm of annual rainfall surplus (Map 9-D, Vol. II).

Water depths within the bay system decrease uniformly from 18.28 m at the pass, to average depths of 5.79 m in Pensacola Bay, 4.26 m in Santa Rosa Sound, 2.44 m in East Bay, 2.13 m in Escambia Bay, and 1.98 m in Blackwater Bay. The salinity profile varies from a highly stratified salt wedge system in Escambia and Blackwater Bays to an almost vertically homogeneous system in Pensacola Bay and Santa Rosa Sound. The Coriolis force tends to result in concentrated outflow of fresher surface water along the western margins of Escambia and Blackwater Bays. Inflow of saltier bottom waters conversely favors the eastern margins (Gallagher 1971). The integration of these factors produces a salinity regime of 15 to 20 ppt in Escambia and Blackwater Bays, 20 ppt in East Bay, and 25 ppt in Pensacola Bay/Santa Rosa Sound (Map 9-D, Vol. II).

The major contributor of freshwater to Choctawhatchee Bay is the Choctawhatchee River which discharges 186.40 cms annually. The ungaged coastal watershed also produces considerable inflow from the 73.91 cm of annual surplus, the highest surpluses in the study area (Map 9-D, Vol. II).

The bay is relatively deep and has a unique orientation, with the head of the estuary on the easternmost margin instead of the northernmost. At this writing, almost no descriptive hydrological references have been located for this bay, other than a set of samples collected over a two-day period by Ritchie (1961). The salinity data presented are difficult to interpret. However, one would expect the eastern portion of the bay to be highly stratified and the western portion to be almost homogeneous. The lowest salinities would tend to be found along the northeast shore.

The St. Andrew Bay system has a relatively small upland drainage basin and therefore receives limited freshwater inflow despite the 68.58 cm of annual surplus. The gaged discharge of Econfina Creek is only 14.8 cms (Map 10-G, Vol. II).

Average water depths in the system are 5.18 m for St. Andrew Bay, 2.13 m for East Bay, 2.04 m for West Bay, and 1.74 m for North Bay. The hydrology of the system is described by Ichiye and Jones (1961). The tidal currents tend to change direction over a short distance. The narrow, deep nature of the bays tend to increase inertial forces, which become greater than the Coriolis force. The mechanism of salinity increase is related to an increase of inflow velocity as the cross section of the upper bay decreases. The overall salinity regime ranges from 30 ppt in St. Andrew Bay to about 20 ppt in East, West, and North Bays.

Vegetation

Because wetland vegetation was one of the parameters studied to determine the past and to predict the future impact of OCS activities among the four coastal systems, the distribution of selected vegetation categories was delineated on area-wide, small-scale maps (Maps 1-D through 10-D, Vol. II). Only four categories of vegetation were printed in the vegetation maps in Vol. II: marsh, seagrass beds, mangroves, and vegetated dunes/barrier flats.

In the following text, a more detailed description of these vegetation categories is presented for each coastal system by geographical subunit. The discussion of dune vegetation, including vegetated dunes and barrier flats, is followed by submergent vegetation (i.e., seagrass beds), and finally emergent vegetation (i.e., marshes and mangroves).

Major map data sources covering Texas were Fisher et al. (1973), McGowen et al. (1976), McGowen, Proctor et al. (1976), Brown et al. (1976), Brown et al. (1980), Fisher et al. (1972), Brown (1977), White et al. (1983, 1985, 1986, 1987). The most recent vegetation map of Louisiana was prepared by Chabreck and Linscombe (1978). A map of the Mississippi-Alabama area was prepared by the U.S. Fish and Wildlife Service (n.d.) and based on habitat maps by Wicker et al. (1980) and U.S. Fish and Wildlife Service (1979). Vegetation in the Florida panhandle region was obtained from habitat maps prepared by Martel Laboratories, Inc. (1985) and the U.S. Fish and Wildlife Service and Minerals Management Service (1984).

Texas Barrier Island System

Padre Island

Vegetation on Padre Island is primarily dependent on island topography (Judd et al. 1977). Based on island transects by Judd et al. (1977) and Brown et al. (1977), the island can be divided into four major zones: (1) beach, (2) foredunes, (3) secondary dunes and barrier flats, and (4) back dunes (Figure 6.40). The beaches are essentially barren of vegetation, although small dunes may occur on the landward side with dominant species being sea oats (Uniola paniculata) and sea purslane (Sesuvium portulacastrum) (Shew et al. 1981). The foredunes are vegetated largely by sea oats, beach tea (Croton punctatus), and fiddleleaf morningglory (Ipomoea stolonifera). Bitter panicum (Panicum amarum) was once dominant but declined because of livestock grazing. Secondary dunes and barrier flats which constitute a considerable portion of Padre Island are stabilized primarily by seacoast bluestem (Schizachyrium scoparius). Common species occurring on the barrier flats are cattails (Typha spp.), rushes (Juncus spp.), and bulrushes (Scirpus spp.) (Brown et al. 1977). Back dunes are typically barren of vegetation (Map 1-D, Vol. II).

The wind-tidal flats on the lagoon side of the island are generally barren except for blue-green algal mats. If there is vegetation present it is usually scattered along tidal channels and includes glasswort (Salicornia bigelovii), saltwort (Batis maritima), seablite (Suaeda spp.), shoregrass (Monanthochloe littoralis), and salt heliotrope (Heliotropium curassavicum).

The most conspicuous aquatic flora are the subaqueous spermatophytes, commonly called seagrasses. All the species along the Texas coast are typical subtropical or tropical species which achieve maximum growth potential in the warm shallow waters of the Laguna Madre. The grass flats cover approximately 72.5 km^2 of Upper and Lower Laguna Madre and are found in shallow (less than 1.2 m) sand and mud areas of the lagoon with low wave and current energy (Brown et al. 1977). The four dominant species in descending order of abundance are shoalgrass (Halodule wrightii), widgeongrass (Ruppia maritima), manateegrass (Cymodocea filiformis), and turtlegrass (Thalassia testudinum). Clovergrass (Halophila engelmannii) occurs in variable amounts in Upper Laguna Madre (Pulich 1980; Brown et al. 1977).

Distribution of seagrasses in Laguna Madre are not uniform. In Upper Laguna, where higher average annual salinities prevail (with much variability, on the order of 30 to 70 ppt), shoalgrass is dominant with variable coverages of clovergrass and widgeongrass depending on seasonal salinities. Shoalgrass dominance in Upper Laguna may be partly a result of the fact that it has been found to tolerate the highest salinities (44 to 70 ppt) of the three species (McMillan and Mosely 1967; McMahon 1968). Seagrasses in Baffin Bay have been reported to be totally absent (Breuer 1957), but sparse, ephemeral populations of shoalgrass probably occur there (Shew 1981). The Lower Laguna also contains sizable populations of shoalgrass but shares dominance with increasing communities of manateegrass. Manateegrass is locally abundant near Brazos Santiago Pass (Breuer 1962) and occurs as far north as Port Mansfield. Turtlegrass is found in abundance, with manateegrass near Port Isabel (Pulich 1980).

Brown et al. (1977) and White et al. (1978) summarize changes in marine grass distribution from 1938 to 1977 as: (1) an overall expansion of grassflats, (2) a reduction in density and distribution of shoalgrass and widgeongrass, and (3) an increase in manateegrass. The general expansion of the grassflats has been contributed to several factors, but primarily to natural subsidence as a result of the compaction of sediments (Brown et al. 1977; Fisk 1959; White et al. 1978) which causes an areal expansion of submerged environments.

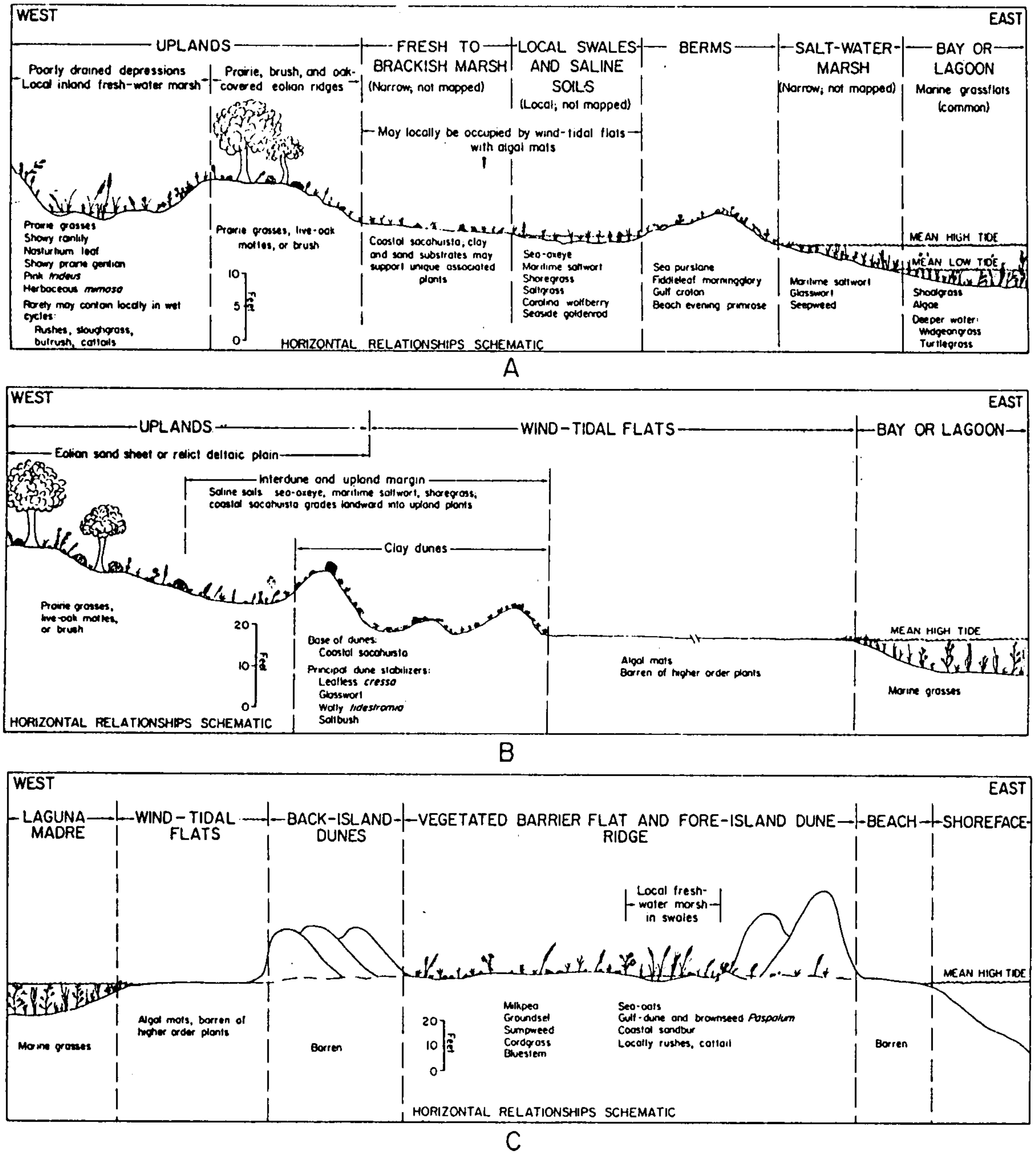


Figure 6.40. Highly schematic diagram of plant community distribution along cross sectional profiles of: (a) the mainland side of Laguna Madre, (b) the mainland bordered by wind-tidal flats, and (c) Padre Island (Brown et al. 1977 after Johnston 1955).

The corresponding decrease in shoalgrass and widgeongrass and increase in manateegrass seem to be attributed to several factors. Pulich (1980) noted that these changes in species distribution in the Lower Laguna may result from increased turbidity and nutrient loading. Breuer (1962) found that dredging in South Bay indirectly resulted in the mortality of a large area of submerged grassbeds. The expansion of manateegrass may also be a result of turbidity since Buesa (1974) indicated that this species is much more efficient at utilizing blue light for photosynthesis than turtlegrass. Since most other visible wave lengths of light are filtered out as sunlight passes through water, blue light would predominate in turbid conditions. A recent study by White et al. (1986) confirmed the expansion of marine grassbeds near the mainland (as seen on 1983 aerial photographs). However, it was also noted that some existing grassbeds on the lagoon side of Padre Island were displaced by channel dredging activities and local storm washover deposits. In summary, the major factors controlling seagrass growth and distribution in the Laguna Madre are: (1) water clarity, (2) nutrient content, (3) water depth, (4) salinity, and (5) sediment deposition by natural and man-made processes.

Emergent salt marsh dominated by smooth cordgrass (Spartina alterniflora) does not develop south of Baffin Bay except for the small, ephemeral strips along the lagoon side of Padre Island, because of the arid climate and hypersaline waters (Pulich 1980, Hoese 1967, White et al. 1978, White and Weise 1980). The most seaward community of this habitat is comprised of succulent halophytes such as saltwort, glasswort (Salicornia perennis), and seablite (Suaeda conferta). In a few areas where a higher percentage of clay is present, black mangrove (Avicennia germinans) is present in shrub form (Johnston 1955). At slightly higher elevations such species as sea-oxeye (Borrichia frutescens), shoregrass (Monanthochloe littoralis), and coastal sacahuista (Spartina spartinae) occur. In the northern Laguna Madre region, fresh-to-brackish marshes occur inland from Baffin Bay north to Laguna Larga. These marshes are characterized by rushes (Juncus sp.), cattail (Typha sp.), and sloughgrass (Spartina pectinata) and occur in depressions and interdistributary areas. These marshes are dependent on rainfall for their existence, and therefore, are noticeably developed only during wet periods (Brown et al. 1977). Analysis of recent aerial photographs reveals localized increases in saltmarshes and mangrove distribution at the edge of wind-tidal flats and in areas of subsided dredged material deposits (White et al. 1986).

Mustang Island-Matagorda Island

The modern barrier system in the Corpus Christi/Matagorda Bay area is composed of San Jose (formerly St. Joseph), Mustang, and Matagorda Islands. Vegetation on these islands has been described by White et al. (1983), Brown et al. (1977), and McGowen et al. (1976) (Map 2-D, Vol. II). In general, dunes are vegetated along their lower parts by sea purslane, morningglory (Ipomoea sp.), and beach evening primrose (Oenothera drummondii). Vegetation on the middle and upper parts of dunes is characterized by sea oats, bitter panicum, and beach tea.

There are an estimated 137 km^2 of submerged grassbeds in the Corpus Christi Bay area growing in mud and muddy sand sediments (Brown et al. 1977). The highest densities and most widespread populations of seagrasses occur in the shallow (less than 0.9 m) Redfish Bay area (Brown et al. 1977), where Odum (1963) reported that turtlegrass (Thalassia testudinum) is the dominant species. Shoalgrass is also abundant, as is widgeongrass, in less saline areas of the bay. Shoalgrass and manateegrass, are minor components of these grassbeds. Turtlegrass retains dominance farther north into Aransas Bay (Brown et al. 1977; West 1969) where widgeongrass is occasionally abundant. McMillan and Mosely (1967) reported the occurrence of manateegrass in the deeper San Antonio channel where salinities are more stable. Corpus Christi Bay proper contains only a narrow band of shoalgrass along the northern shoreline of Nueces Bay because of Corpus Christi Bay's greater average depth, which is mostly below the photic zone (Shew 1981). In lower San Antonio Bay, Espiritu Santo Bay, and behind northern Matagorda Island, shoalgrass is the most abundant species, growing in areas of low turbidity and shallow waters (Matlock and Weaver 1979). Widgeongrass makes up a secondary component and is most common after freshwater influxes (Shew et al. 1981).

Seagrass growth and distribution in this area is determined primarily by turbidity and salinity (Brown et al. 1976). Grassflats, in general, are increasing in area at the expense of wind-tidal and shallow subaqueous flats, which have experienced relative sea-level rise because of compactional subsidence (White et al. 1983).

Emergent salt marshes in the Corpus Christi to Matagorda Island area occur primarily in the Nueces River Delta, Guadalupe River Delta, Chitipin-Aransas Delta, and Mission Delta. Salt marsh also occurs along the bay margins and landward sides of Mustang, San Jose, and Matagorda Islands. Dominant species in these salt marshes include smooth cordgrass, saltwort, glasswort, seashore saltgrass (*Distichlis spicata*), and sea-oxeye. Salt marsh zonation is a function of duration and frequency of saltwater inundation, elevation, substrate salinity, and nutrient availability (Shew 1981). In addition to the typical salt marsh vegetation, Shew (1981) and White et al. (1983) reported that marshes in the Pass Cavallo and Harbor Island areas support considerable black mangrove populations. These researchers stated that water turbidity, which inhibits root growth; low temperatures; and storms are the major controlling factor on black mangrove development here.

Brackish water marshes occur in transition areas landward of the salt marshes on slightly higher elevations and at greater distances from bodies of saltwater. The area around Port Bay has a considerable expanse of brackish to freshwater marsh (Brown et al. 1976; Shew 1981). Fresh-to-brackish marshes also exist in poorly drained depressions on these islands (USFWS and General Services Administration 1982). Representative species of the brackish and freshwater marsh are rushes (*Scirpus spp.*), marshhay cordgrass or wiregrass (*Spartina patens*), big cordgrass (*S. cynosuroides*), cattail (*Typha spp.*), spikerush (*Eleocharis spp.*), flatsedge (*Cyperus spp.*), water smartweed (*Persicaria punctata*), swordgrass (*Scirpus americanus*) and poolmat (*Zannichellia palustris*). Substrate salinity appears to be the most important factor in determining the type, distribution, and productivity of these marshes (White et al. 1983; Shew 1981; Brown et al. 1976).

Matagorda Peninsula

The beach and back beach areas on Matagorda Peninsula consist of terrigenous sand and shell fragments, or shell and rock fragments, and are largely unvegetated (Figure 6.41) (McGowen and Brewton 1975). In some areas, the back beach consists of a shell ramp which can be sparsely vegetated with seacoast bluestem, marshhay cordgrass, sandbar, beach tea, morningglory, and sea oats. Low-lying dunes found behind the beach along some segments of the coast have a similar vegetation composition.

On the back side of the peninsula is a barrier-flat, often termed a "wind-tidal flat," which consists largely of barren sand (Maps 2-D and 3-D, Vol. II). The lower-lying areas along the bay marsh support brackish (high, irregularly flooded) and saline (low, regularly flooded) marsh. A study of vegetation in the Colorado River Delta area by van Beek et al. (1980) identified smooth cordgrass and glasswort as dominant species on the low marsh along the backside of Matagorda Peninsula and on the mainland. Species characteristic of the high marsh in this area included sea lavender (*Limonium nashii*), saltwort, shoregrass, sea-oxeye, glasswort, saltgrass, and wolfberry (*Lycium carolinianum*).

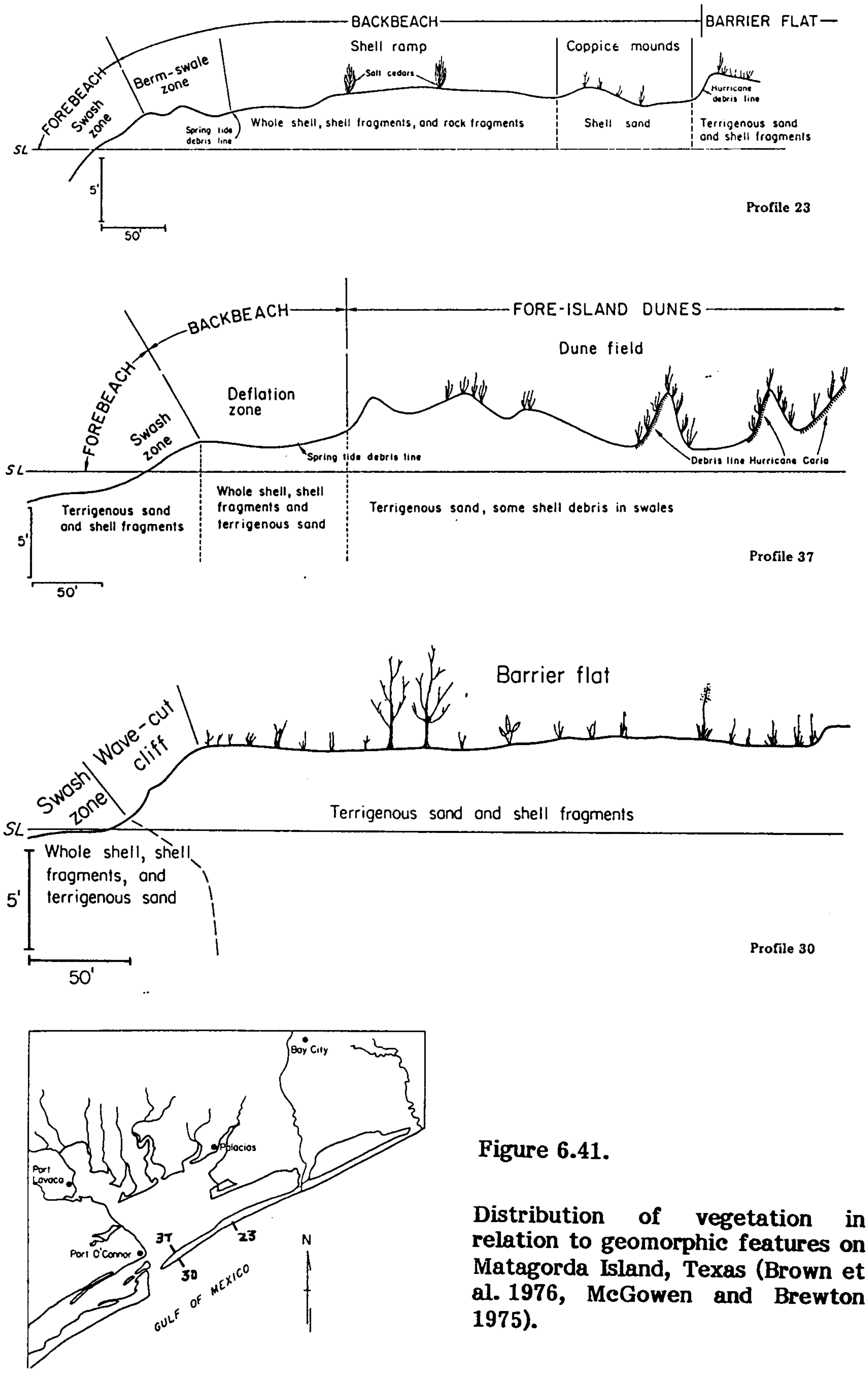


Figure 6.41.

Distribution of vegetation in relation to geomorphic features on Matagorda Island, Texas (Brown et al. 1976, McGowen and Brewton 1975).

Natural levees and spoil banks in the area support a greater variety of plants, including retama (Parkinsonia aculeata), indian blanket (Gaillardia pulchella), dewberry (Rubus trivialis), scullcap (Scutellaria sp.), germander (Teucrium cubense), wolfberry, pricklypear (Opuntia sp.), marsh elder (Iva frutescens), saltcedar (Tamarix sp.), marshhay cordgrass, gulf cordgrass, hackberry (Celtis sp.), mesquite (Prosopis glandulosa), roseaucane (Phragmites australis), western ragweed (Ambrosia psilostachya), and Texas thistle (Cirsium texanum).

The submergent aquatic species present along the bay margins of East and West Matagorda Bays are widgeongrass, shoalgrass, and possibly turtlegrass (Shew 1981). However, the beds are less extensive, probably because of the higher turbidity in these bays. Large salinity fluctuations, substrate conditions, and water depth also combine to limit plant distribution.

Brazos Delta Headland

Beaches along this stretch of the Texas coast are narrow and dunes are poorly developed or nonexistent. Sea oats and other halophytes sparsely vegetate the existing dunes. The beach and low dunes are backed by shell-ramp-barrier flats and vegetated flats covered by the salt-tolerant plants.

Saline marshes occur south of the Gulf Intracoastal Waterway (GIWW), and are dominated by cordgrass, glasswort, seablite, and sea-oxeye. The fairly extensive marshes north of the GIWW between Bay City-Freeport and the San Bernard National Wildlife Refuge are labeled fresh-to-brackish-water marshes with salinity varying according to climatological conditions (McGowen et al. 1976) (Map 3-D, Vol. II). Drought conditions result in salinity exceeding 35 ppt, whereas during periods of excessive rainfall, water is fresh. Vegetation in this area is therefore salt-tolerant and consists of species such as coastal sacahuista, marshhay cordgrass, big cordgrass, rushes (Scirpus spp.), and cattail (McGowen et al. 1976).

Submerged grassbeds are very limited in this area, being confined to small lakes and riverine channels. The common aquatic species are widgeongrass and shoalgrass.

Galveston Island to Bolivar Peninsula

The back beach of the Galveston barriers (Galveston and Follet's Islands and Bolivar Peninsula) is sparsely vegetated with sea oats and various halophytes. Vegetation in the ridge and flat area of the islands consists primarily of species such as sea coast bluestem, paspalum, and sea oats. Species distribution is dependent on salt spray and flooding tolerance.

Grassflats are of limited distribution in the Galveston area and occur in patches along the margins of the Trinity delta, Follet's Island, and Bolivar Peninsula (White et al. 1985). The two most abundant species are shoalgrass, found in West Bay along the landward side of Galveston Island, and widgeongrass, found primarily in the fresher areas of the Trinity River delta (Fisher et al. 1972, Shew 1981). Both species have been found in dense scattered stands in Christmas Bay.

Shew (1981) reports that turtlegrass also occurs in the Galveston Bay system, but exact locations have not been reported. Seagrass distribution in the Galveston Bay system depends on temperature, water depth, turbidity, and salinity (Shew 1981). White et al. (1985) notes that there has been a reduction or elimination of marine grasses along the bayward margins of the Galveston barrier islands since 1956.

Salt marshes, dominated by smooth cordgrass at their lowest elevations, are most common on the Trinity River delta, along the bayward sides of the barrier islands, and on the mainland side of East, West, and Bastrop Bays. From the bay toward the higher marsh the plant succession is: (1) smooth cordgrass; (2) saltworts, glassworts, seashore saltgrass; and (3) sea-oxeye, shoregrass, and seablite sp. (Fisher et al. 1972). Various researchers (Gosselink et al. 1979, Fisher et al. 1972, Harcombe and Neaville 1977) have estimated that brackish and freshwater marshes cover more area than salt marshes in the vicinity of Galveston Bay. Brackish and freshwater marshes are dominated by such species as gulf cordgrass, marshhay cordgrass, big cordgrass, seashore saltgrass, rushes, and cattails, with species type and distribution primarily dependent upon salinity and inundation (Fisher et al. 1972). Sediments underlying salt marsh are generally dark gray mud, muddy sand, or locally, predominantly sand. Sediments of the brackish and freshwater marshes are predominantly mud.

Strandplain-Chenier Plain System

Rollover Pass to Sabine Pass

The erosional strandplain shoreline in the Rollover to Sabine Pass area has a relatively narrow forebeach with virtually no backbeach. Beach material consists primarily of sand with a high shell content (Fisher et al. 1973). The beach is narrow, generally no more than 61.0 m wide, and vegetation on the back beach consists mainly of marshhay cordgrass, camphorweed (Pluchea camphorata), seashore saltgrass, and smooth cordgrass (Map 4-D, Vol. II).

Inland of the beach is a zone of east-west-trending beach ridges and strandplain flats. This ridge and flat zone is narrow (about 122.0 to 792.4 m). These areas are composed of fine-grained sands and silts with minor amounts of shell material and a vegetation composition similar to that on the back beach.

The coastal area between Sabine Pass, Keith Lake to the northwest, and Knight Lake to the west, is the only portion of the Texas coast that has well developed chenier ridges covered with grasses and, locally, scrub oaks (Quercus spp.) vegetation. Sediment composition is mostly sand and silt. Intervening lowlands (i.e., swales) between the ridges support either brackish or salt marshes consisting of marshhay cordgrass, rushes, smooth cordgrass, and seashore saltgrass (Gosselink 1979). This portion of the Texas coast has the widest zone of coastal marshland. The saline marsh zone is very narrow, lies behind the vegetated dune/strandplain, and is dominated by the same saltmarsh species listed previously. The brackish marshes have been further distinguished as low and frequently inundated or high and less frequently flooded. The lower brackish marsh is characterized by rushes, cattails, and coastal waterhyssop (Bacopa monnieri), while gulf cordgrass and marshhay cordgrass are more common on the high brackish marsh (White et al. 1987).

Pure stands of freshwater marsh are well developed along the Neches Rivers between Beaumont and Port Neches. These marshes have high plant diversity and include cattails, rushes, sedges (Eleocharis spp. and Cyperus spp.), alligatorweed (Alternanthera philoxeroides), marshhay cordgrass, gulf cordgrass, water hyacinth (Eichhornia crassipes), roseau cane, arrowhead (Sagittaria spp.), pickerelweed (Pontederia sp.), and smartweed (Polygonum spp.).

Widgeongrass is a common submerged aquatic in lakes and tidal channels. There are no estuarine areas suitable for the seagrass beds found along the southern Texas coast.

Sabine Pass to Southwest Pass

The beach-dune complex is very poorly developed along the chenier plain system of western Louisiana. In some places, erosion rates are high, resulting in an unstable complex migrating inland and over marshland, supporting very little vegetation. Where low dunes or elevated backbeach zones develop they support salt-spray-tolerant species such as sea oats, bitter panicum, purple sandgrass (Triplasis purpurea), seacoast bluestem (Schizachyrium maritimum), saltgrass, marshhay cordgrass (i.e., wiregrass), saltwort, beach morningglory, sea purslane, camphorweed, glassworts, and seablite (Craig et al. 1987).

Coastal dune shrub thickets can succeed in this community if the dunes stabilize. The dense stands of shrubs include waxmyrtle (Myrica cerifera), yaupon (Ilex vomitoria), marshelder (Iva spp.), groundsel bush (i.e., silverling, Baccharis halimifolia), acacia (Acacia smallia), and toothache tree (Zanthoxylum clava-herculis) (Craig et al. 1987).

Vegetation composition of the chenier plain ridges and fresh-to-saline marsh zones are the same in this area as for the Rollover Pass to Sabine Pass area of Texas. The major difference between these two areas is that the marsh zones and chenier ridges are much broader in western Louisiana.

Mississippi Delta System

The barrier islands and beaches of the Mississippi Delta System are located primarily on the distal ends of the abandoned Lafourche and St. Bernard delta lobes. There are three barrier island complexes (i.e., Isles Dernieres, Timbalier-East Timbalier, Grand Isle-Grand Terre-Chenier Ronquille, Breton-Chandeleur Islands) and two barrier beaches (i.e., Caminada-Moreau Coast, west side of Modern delta: Chenier Ronquille to Sandy Point) (Figure 6.32). A recent study by Mendelssohn (1988) quantified seven major habitats found on 10 islands and 3 beaches (Figure 6.42, Table 6.8). Of the total island-beach area in 1979, 47% consisted of salt marsh-mangroves, 24% was in intertidal sand flats, 10% was in backshore, and 8% consisted of densely vegetated dunes and swales. Only 5% of the area was in residential-commercial development.

Vegetation communities present on barrier islands include (from Gulf to back bay): beach (foreshore and backshore), dune, swale, and/or barrier flat, shrub, forest, salt pan, marsh high and low, and subtidal flats (Mendelssohn 1987). Factors influencing communities include soil moisture; salinity; nutrient status; salt spray; topography; site suitability; rainfall; and perturbations such as grazing, burning, and trampling (Mendelssohn 1987). The following discussion presents information on vegetation communities associated with major island-beach complexes in the Mississippi Delta System.

Isles Dernieres - Timbalier Island

The beaches of Isles Dernieres, East Timbalier, and Timbalier Islands are backed by low sand dunes or ridges. An investigation by Montz (1977) indicated that wiregrass was the most frequently sampled of 30 plant species, followed by saltgrass, trailing wildbean (Strophostyles helvola), flat cyperus (Cyperus compressus), and saltmarsh fimbristylis (Fimbristylis castanea). A more recent study by Mendelssohn (1988) shows the distribution of vegetation along beach profiles taken on Isles Dernieres and Timbalier Islands (Figure 6.43). Both island complexes were very low, with poorly developed and sparsely vegetated dunes. Wiregrass remained the dominant species.

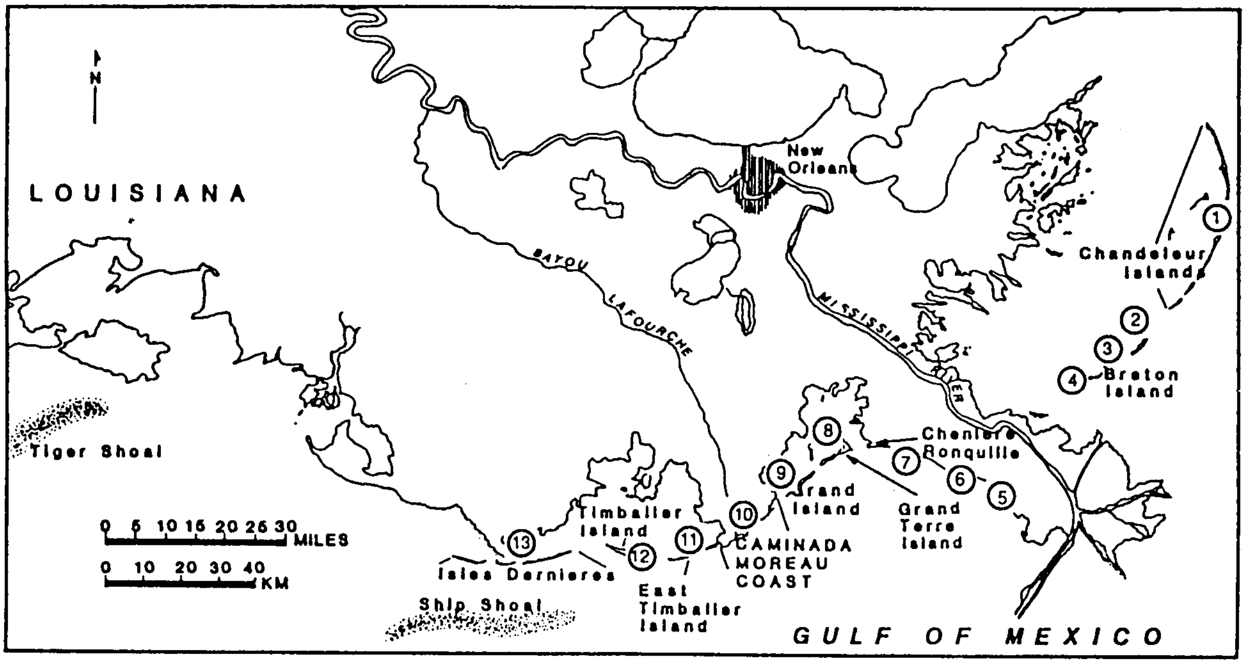


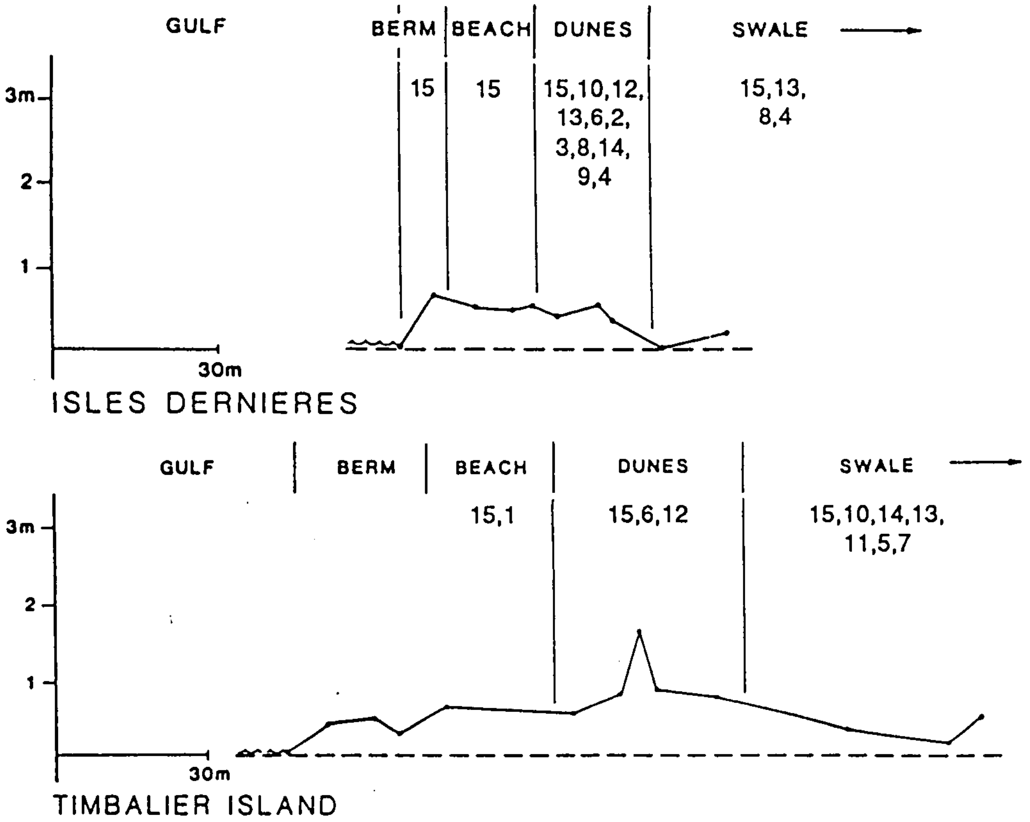
Figure 6.42. Barrier islands and beaches of the Mississippi River deltaic plain from the Chandeleur Islands westward to the Isles Dernieres (Mendelssohn 1987).

Table 6.8. Area[1] (km^2) of Louisiana's Major Deltaic Plain Barrier Islands and Beaches (from Mendelssohn 1988).

	Total Island or Beach Area	Back-shore	Densely Vegetated Dunes and Swales	Salt-marsh and Mangrove	Dredge Spoil	Disturbed	Residential/ Commercial	Intertidal Sand Flats
Chandeleur Island (1)	21.5	1.8	1.2	10.8	0.0	0.0	0.0	7.5
Curlew Island (2)	1.0	0.2	0.2	0.0	0.0	0.0	0.0	0.6
Grand Gosier Island (3)	2.4	0.1	0.0	0.0	0.0	0.0	0.0	2.2
Breton Island (4)	2.1	0.4	0.2	0.8	0.0	0.0	0.0	0.7
Lanaux Island (5)	0.9	0.2	0.0	0.5	0.0	0.0	0.0	0.0
Chaland Beach (6)	5.3	0.2	0.8	3.5	0.8	0.0	0.0	0.3
Cheniere Ronquille (7)	2.3	0.2	0.1	1.4	0.1	0.0	0.0	0.3
Grand Terre Islands (8)	5.2	0.4	0.7	2.2	0.8	0.0	0.1	0.9
Grand Isle (9)	9.4	0.4	1.0	2.8	0.0	1.0	3.5	0.6
Caminada-Moreau Beach (10)	16.1	1.7	0.5	10.2	1.9	0.0	0.4	1.6
East Timbalier Island (11)	3.2	0.4	0.1	1.8	0.2	0.2	0.3	1.0
Timbalier Island (12)	10.8	1.1	1.5	4.2	0.1	1.0	0.0	2.9
Isles Dernieres (13)	13.0	2.2	0.7	6.0	0.2	0.0	0.0	3.9
Total	93.2	9.3	7.0	44.2	4.1	2.2	4.3	22.5

[1] Area based on 1979 black and white imagery.

[2] Includes sparsely vegetated dunes or sand flats.



1. BLACK MANGROVE
2. CAMPHORWEED
3. COMMON FROG-FRUIT
4. EASTERN BACCHARIS
5. EUSTOMA
6. LITTLE BLUE-STEM
7. LITTLE SEA-PINK
8. PLAINS LOVEGRASS
9. PROSTRATE SPURGE
10. SALTMARSH FIMBRISTYLIS
11. SEASHORE PASPALUM
12. SEASIDE DROPSEED
13. SEASIDE GOLDENROD
14. TRAILING WILDBEAN
15. WIREGRASS

Figure 6.43. Distribution of vegetation along an elevational profile of Isles Dernieres and Timbalier Island (after Mendelssohn 1988).

Extensive areas of regularly flooded saline marsh-mangrove thickets are located on the sound side of the barrier islands. Of the eight plant species recorded by Montz (1977), the most frequently sampled, in descending order, were oystergrass, black mangrove, saltwort, and saltgrass. Within this marsh-mangrove zone were scattered, highly-saline mud flats vegetated by glasswort (Montz 1977).

Exceptionally tall black mangroves, on the order of 4.5 to 6.1 m tall, were also noted in the center of Isles Dernieres (Montz 1977), in constrast to most barrier islands mangroves which are in the 0.9 to 1.5 m range. He also noted that sand shifts, caused by hurricanes and storms, was a major controlling factor on mangrove distribution because sand blown into the community appeared to smother roots and deplete the oxygen supply. In addition to freezing temperatures, which kill the plants, forcing regrowth from the roots, chemical conditions, such as soil, water salinity, and the concentration of major nutrients, also affect mangrove primary productivity (Mitsch and Gosselink 1986).

Montz (1977) documented extensive grassbeds, approximately 284 ha in area, north of the Timbalier and Isles Dernieres Islands. The major species were shoalgrass and widgeongrass. Bahr et al. (1983) stated that the main factors that limit the distribution and production of submerged grassbeds in the Mississippi Delta System are salinity, nutrient concentrations, and light. Rarely are these beds found to occur in waters greater than 1 m deep, suggesting that light penetration, as determined by water turbidity, is the major limiting factor.

Caminada-Moreau Headland

The beaches along the Caminada-Moreau headland are less than 2 m in elevation and range from 144 m wide on the west to 72 m wide on the east (Figure 6.44), (Mendelssohn 1988). Elevational profiles and vegetation transects taken by Mendelssohn (1988) reveal that wiregrass is the dominant plant along the entire transect. Other species with extensive distribution are seaside goldenrod (Solidago sempervirens), saltmarsh fimbristylis (Fimbristylis spadicea), fiddleleaf morningglory (Ipomoea stolonifera), and seashore dropseed (Sporobolus virginicus).

Saltmarsh dominated by smooth cordgrass lies behind the beach. Tidal channels through the marsh are often fringed by black mangrove. There are extensive seagrass beds in this area.

Grand Isle

Grand Isle remains the largest, most stable barrier island on the Louisiana coast, primarily because of extensive efforts by the Corps of Engineers to renourish the beach, replenish and stabilize the berms and dunes to aid as levees against storm waves, and construct jetties on the east and west ends of the islands to prevent loss of sediment into the deep tidal passes. The beach dunes that were originally less than 3 m high supported plants commonly found in this area of the coast such as wiregrass, glassworts, saltgrass, and sea-oxeye. The dunes have been raised to over 4 m and planted with dune-stabilizing grasses such as bitter panicum and sea oats.

The relict beach ridges on the interior part of the island contain dense stands of live oak (Quercus virginiana) and shrubs such as marshelder, eastern baccharis, and wax myrtle. The saline marshes on the leeward side of the island are dominated by smooth cordgrass, with black mangrove fringing tidal channels.

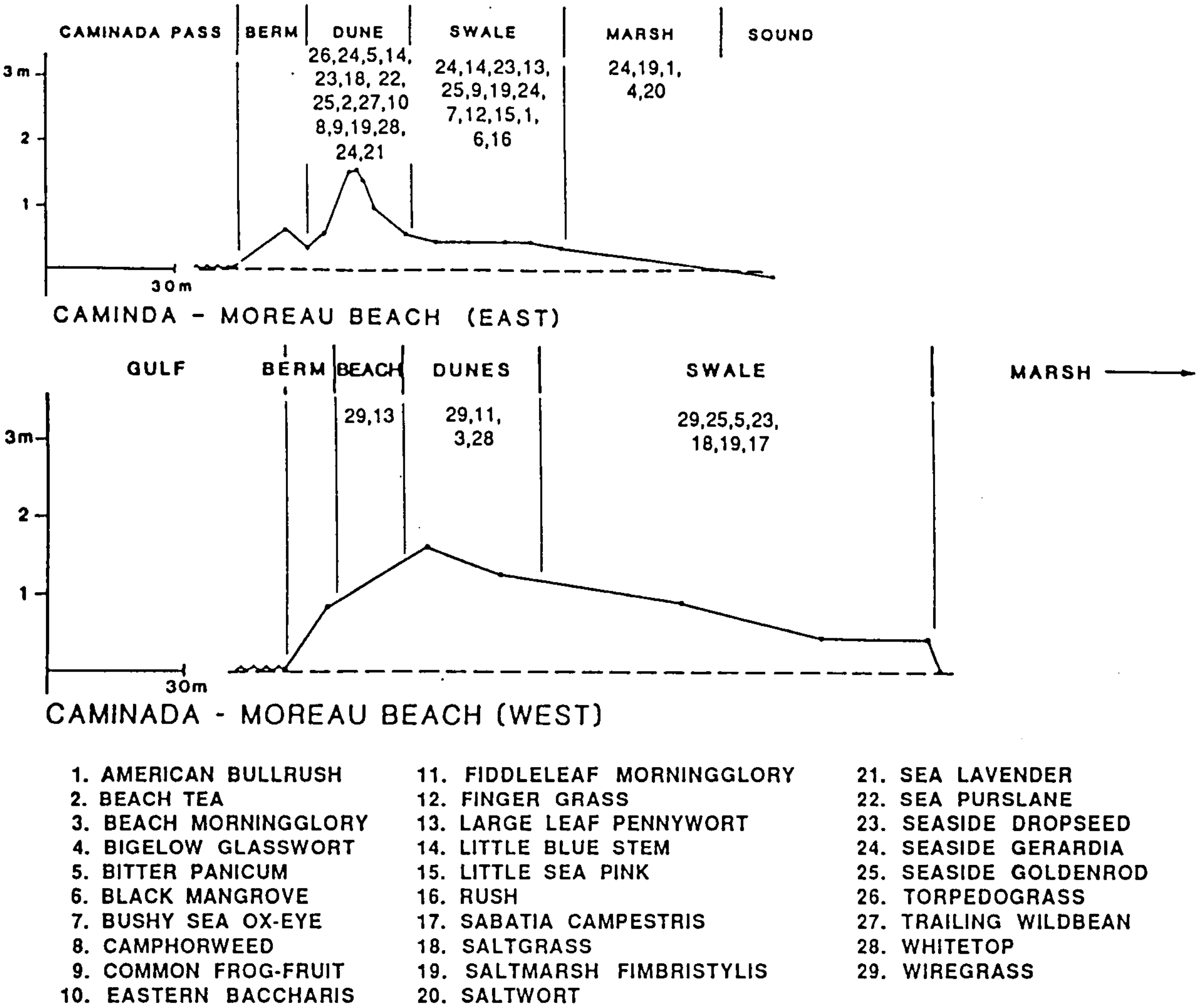


Figure 6.44. **Distribution of vegetation along an elevational profile of Caminada-Moreau Beach (Mendelssohn 1988).**

Grand Terre to Sandy Point

Grand Terre is slightly more than half the size of Grand Isle (Table 6.8). Slightly less than half of the island is in saltmarsh dominated by smooth cordgrass with localized fringes of black mangrove.

The beach-dune complex is approximately 50 m wide, has a maximum height of less than 2 m, and contains a variety of species including wiregrass, large leaf pennywort (Hydrocotyle bonariensis), torpedograss (Panicum repens), beach tea, finger grass (Chloris petraea), common frog-fruit (Lippia nodiflora), seaside goldenrod, coffeebean (Daubentonia texana), bitterweed (Helenium amarum), and plains lovegrass (Eragrostis intermedia) (Figure 6.45) (Mendelssohn 1988).

The ridges and spoil banks trend parallel to the island and support a variety of shrubs including wax myrtle, eastern baccharis, marshelder, and coffeebean. The entire island is grazed by cattle, goats, and horses. No extensive grassbeds have been mapped along the backside of the island.

The beaches fringing the western side of the Mississippi River Delta east of Grand Terre are also narrow with very low dunes or beach berms. A profile of one of these islands, Lanaux, also called Shell Island, shows the extremely narrow, steep, unvegetated slope of the shell beach (Figure 6.45) (Mendelssohn 1988). The beach dune is about 1.5 m high, also composed of shell and vegetated by marshelder, eastern baccharis, prostrate spurge (Euphorbia maculata), largeleaf pennywort, smooth cordgrass, and black mangrove. A saline marsh characterized by smooth cordgrass and black mangrove lies landward of the beach-dune complex.

Breton-Chandeleur Islands

The islands of the Chandeleur chain are composed principally of sand and shell (Lemaire 1961; Gould and Ewan 1975). The beaches are backed by low sand dunes (3 m or less), while the island interiors are dominated by wax myrtle. Figure 6.46 shows the vegetational distribution along the dune profile on the north, central, and south portions of the Chandeleur Islands (Mendelssohn 1982).

The northern portion of the Chandeleur Islands, as mapped by Mendelssohn (1988), is characterized by extensive low tide sand flats gulfward of the dune complex. The dune-flat complex is about 132 m wide. The dunes are about 30 m wide, slightly over 3 m in height and vegetated by sea oats.

The central portion of the Chandeleur Islands has a beach-dune complex that is approximately 102 m wide. The dunes are about 40 m wide, slightly over 3 m high, and vegetated with beach tea, sea oats, fiddleleaf morningglory, torpedo grass, wire grass, and straw-colored cyperus (Cyperus strigosus) (Mendelssohn 1988).

The southern portion of the Chandeleur Islands has a narrow (approximately 34 m) berm-dune complex, and dunes are less than 1 m high. Wiregrass and eastern baccharis are the dominant species in this zone. Swales are located behind the dunes along the entire island chain and support 2 to 7 species of plants (Figure 6.43). Black mangrove thickets fringe the leeside of the island.

Extensive beds of marine seagrasses are found behind the Breton and Chandeleur Islands on the sand substrate (van Beek et al. 1981). Lemaire (1961) listed widgeongrass, manateegrass, and shoalgrass as being frequent behind the northern half of the Chandeleur

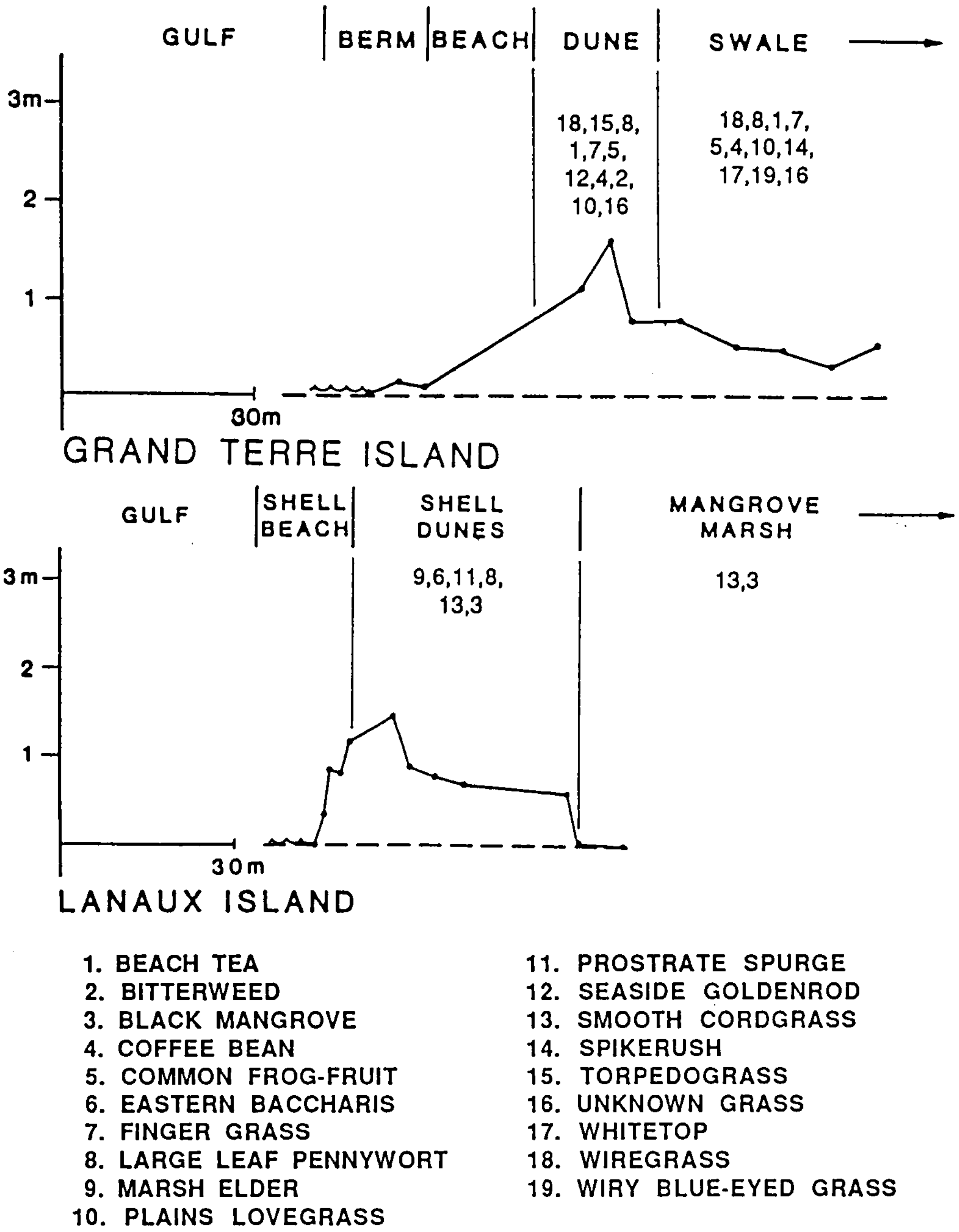
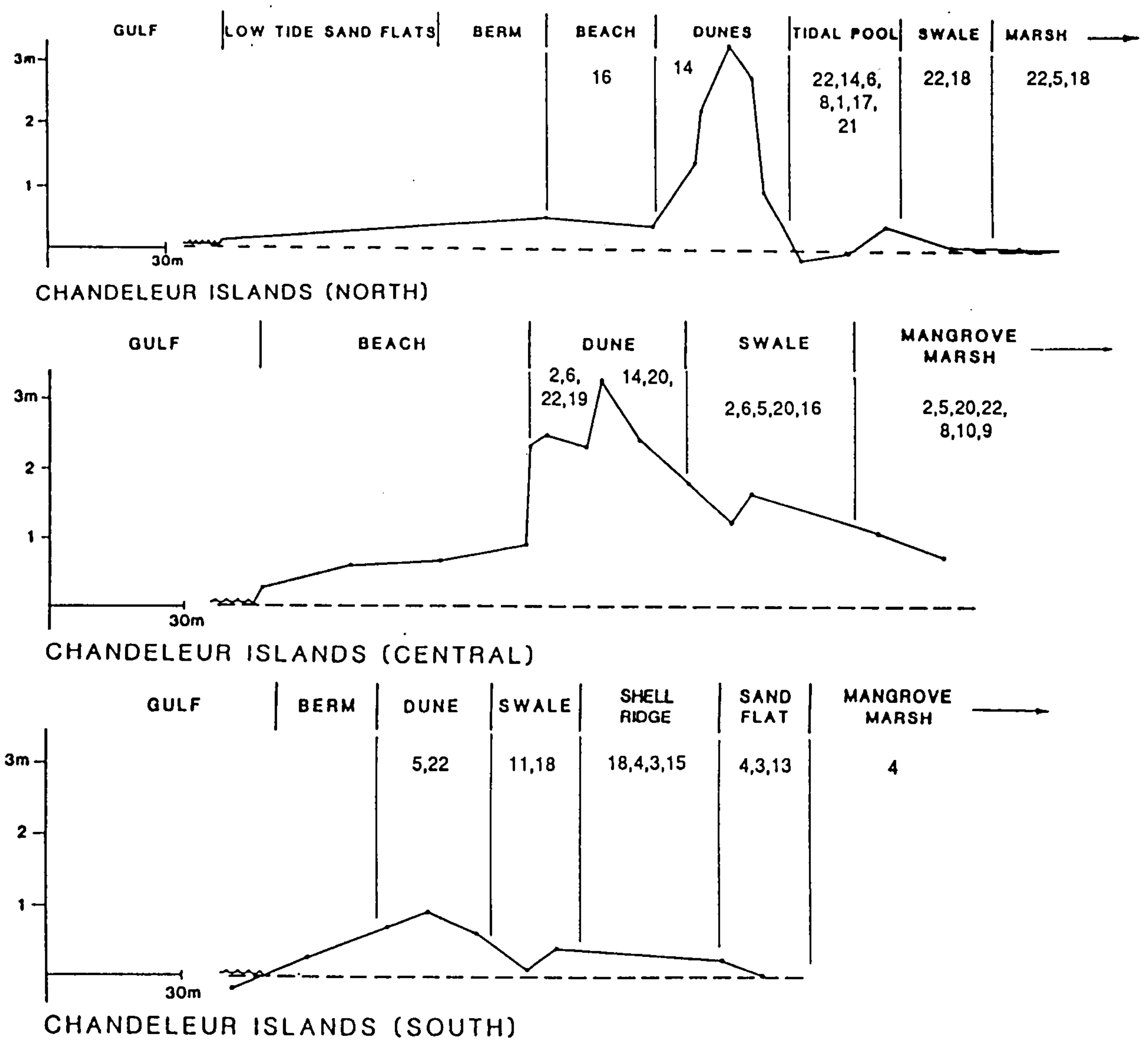


Figure 6.45. **Distribution of vegetation along an elevational profile of Grand Terre Island and Lanaux (i.e., Shell) Island (after Mendelssohn 1988).**



CHANDELEUR ISLANDS (NORTH)

CHANDELEUR ISLANDS (CENTRAL)

CHANDELEUR ISLANDS (SOUTH)

1. AMERICAN BULLRUSH
2. BEACH TEA
3. BIGELOW GLASSWORT
4. BLACK MANGROVE
5. EASTERN BACCHARIS
6. FIDDLELEAF MORNINGGLORY
7. FINGER GRASS
8. LARGE LEAF PENNYWORT
9. LITTLE BLUE STEM
10. RUSH
11. SALTGRASS
12. SALTMARSH FIMBRISTYLIS
13. SEA LAVENDER
14. SEA OATS
15. SEA PURSLANE
16. SEASHORE DROPSEED
17. SEASIDE GOLDENROD
18. SMOOTH CORDGRASS
19. STRAW-COLORED CYPERUS
20. TORPEDOGRASS
21. WAX MYRTLE
22. WIREGRASS

Figure 6.46. **Distribution of vegetation along elevational profiles of Chandeleur Islands (north, central, and south sections) (after Mendelssohn 1987).**

and Freemason Islands, while turtlegrass was abundant and infrequent, respectively. Shoreward of Grand Gossier and Breton Islands, grassbeds are characterized by a mixture of shoalgrass, manateegrass, and turtlegrass, with dominance varying between shoalgrass and manateegrass.

North Central Gulf Coast System

For this discussion of vegetation, the North Central Gulf Coastal System has been divided into three sections: (1) the Mississippi Sound Barrier Islands, (2) the mainland marshes of Mississippi and Alabama, and (3) the mainland marshes and barrier island/beach complexes of the Florida panhandle. There are five barrier islands fronting Mississippi Sound (i.e., Cat, Ship, Horn, Petit Bois, and Dauphin). Only one major barrier island (Santa Rosa Island) is located along the Florida panhandle, and it is in alignment with the remainder of the coastline. Generalized distributions of vegetated dunes/barrier flats, marshes, and seagrass beds are shown on Maps 8D through 10D, Vol. II.

Mississippi Sound and Barrier Islands

The barrier islands are located 10 to 21 km from the mainland. They range in length from 4 (East Ship Island) to 23 km (Dauphin Island) and are from 0.3 to 2 km wide (USACE, MOB. 1984). Ship Island was cut into an east and west segment by Hurricane Camille in 1969. Three islands, Horn, Petit Bois, and Ship, are part of the Gulf Islands National Seashore. They have relatively undisturbed vegetation associations as does Cat Island, which is privately owned. In contrast, much of the habitat on Dauphin Island has been altered by man in the process of development.

The broad beaches along the Gulf are backed by dunes averaging 3 to 6 m high. The highest dunes (14.3 m) are located on the southeast end of Dauphin Island. These islands contain the only natural barrier beach shoreline remaining in Mississippi. Mainland beaches from Bay St. Louis to Biloxi consist of sand pumped in front of man-made seawalls.

The sound side of the islands also have beaches but these are interspersed with intermittent patches of saline-to-brackish marshes backed by dunes. In the interiors of the islands are low-lying (0.3 to 0.6 m), broad, sand flats interspersed with shallow lakes and marshes or more elevated (5 to 15 ft), vegetated beach ridges (USACE, MOB. 1984).

A study by Waller and Malbrough (1976) mapped the geology of Horn, Cat, Ship, and Petit Bois Islands (Figures 6.47, 6.49, 6.50). The geology of the islands influences the distribution of vegetation. Eleuterius's (1979) study of Horn Island provided documentation of the distribution of vegetation along elevational profiles across the island (Figure 6.48). Distribution of vegetation along elevational profiles on the eastern and western portions and for the beach-dune complex was provided by O'Neil and Mettee (1982) (Figure 6.51).

With few exceptions, vegetation on the beach-dune complex for the Mississippi Sound barrier islands resembles that which has been described on the barrier islands in the Mississippi Delta System of Louisiana. The higher dune elevations provide for protection and formation of maritime forests characterized by: scrubby live oak (*Quercus virginiana* var. *maritima*), myrtle oak (*Quercus myrtifolia*), seaside rosemary (*Ceratiola ericoides*), seaside balm (*Conradina canescens*), sand pine (*Pinus clausa*) (from eastern Alabama into Florida), slash pine (*Pinus eliottii*), red cedar (*Juniperus virginiana*), and saw palmetto (*Serenoa repens*) (USACE, MOB. 1984). The higher latitude and periodic freezes prohibit growth of black mangroves on these islands.

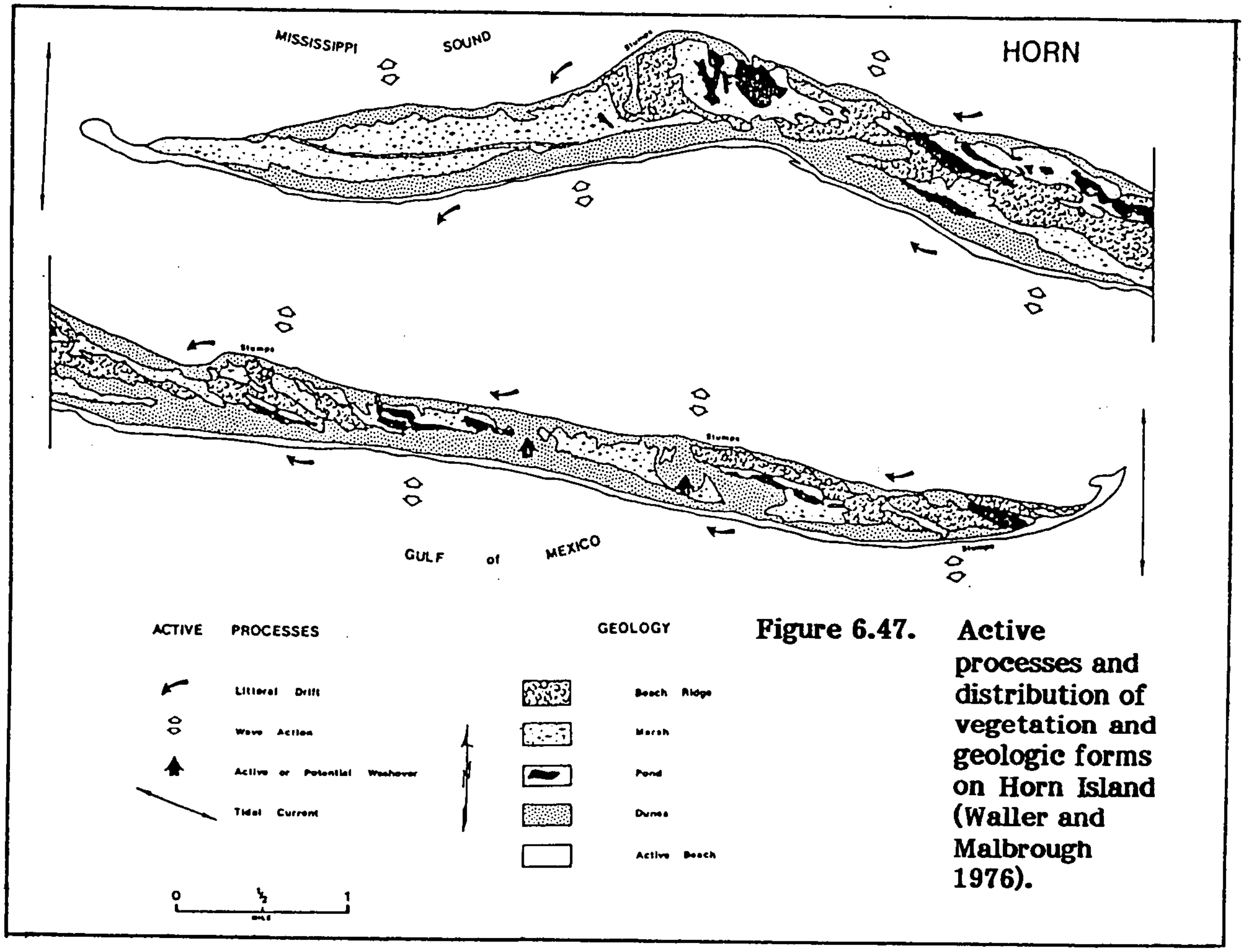


Figure 6.47. Active processes and distribution of vegetation and geologic forms on Horn Island (Waller and Malbrough 1976).

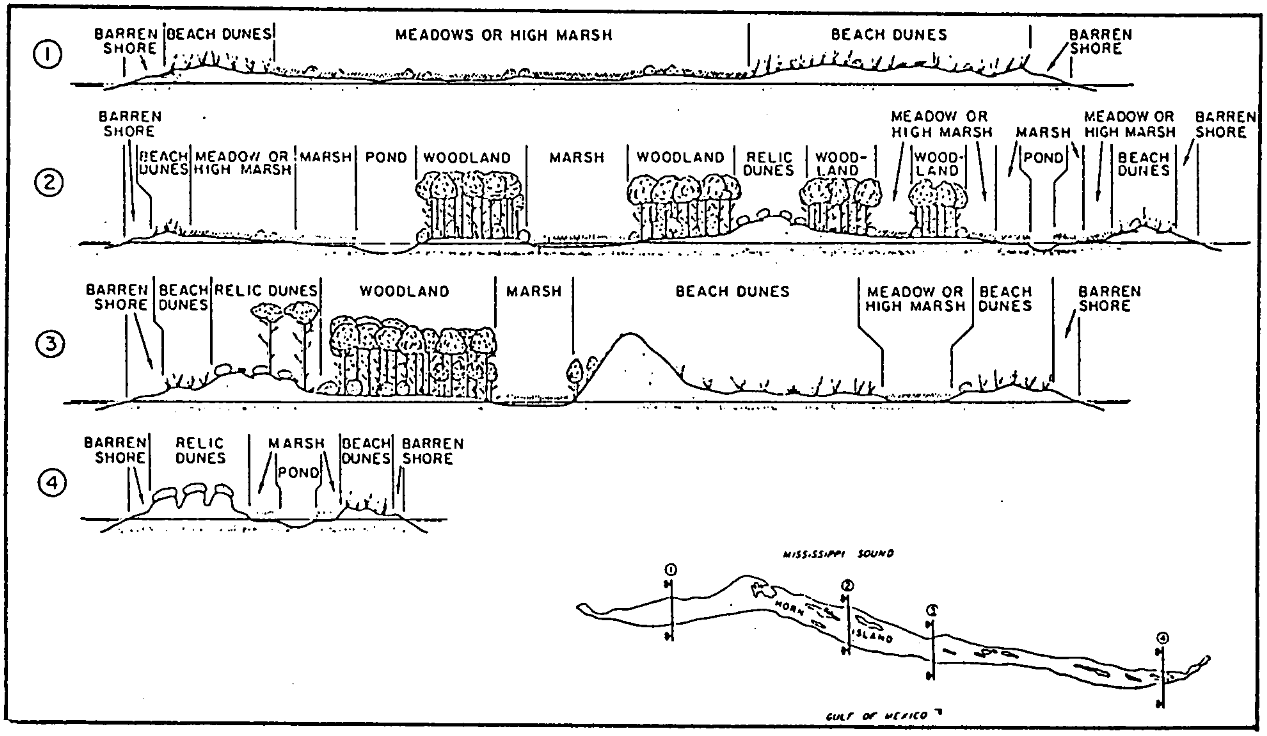


Figure 6.48. Vegetation transects showing habitats on Horn Island (Marine Briefs 1979).

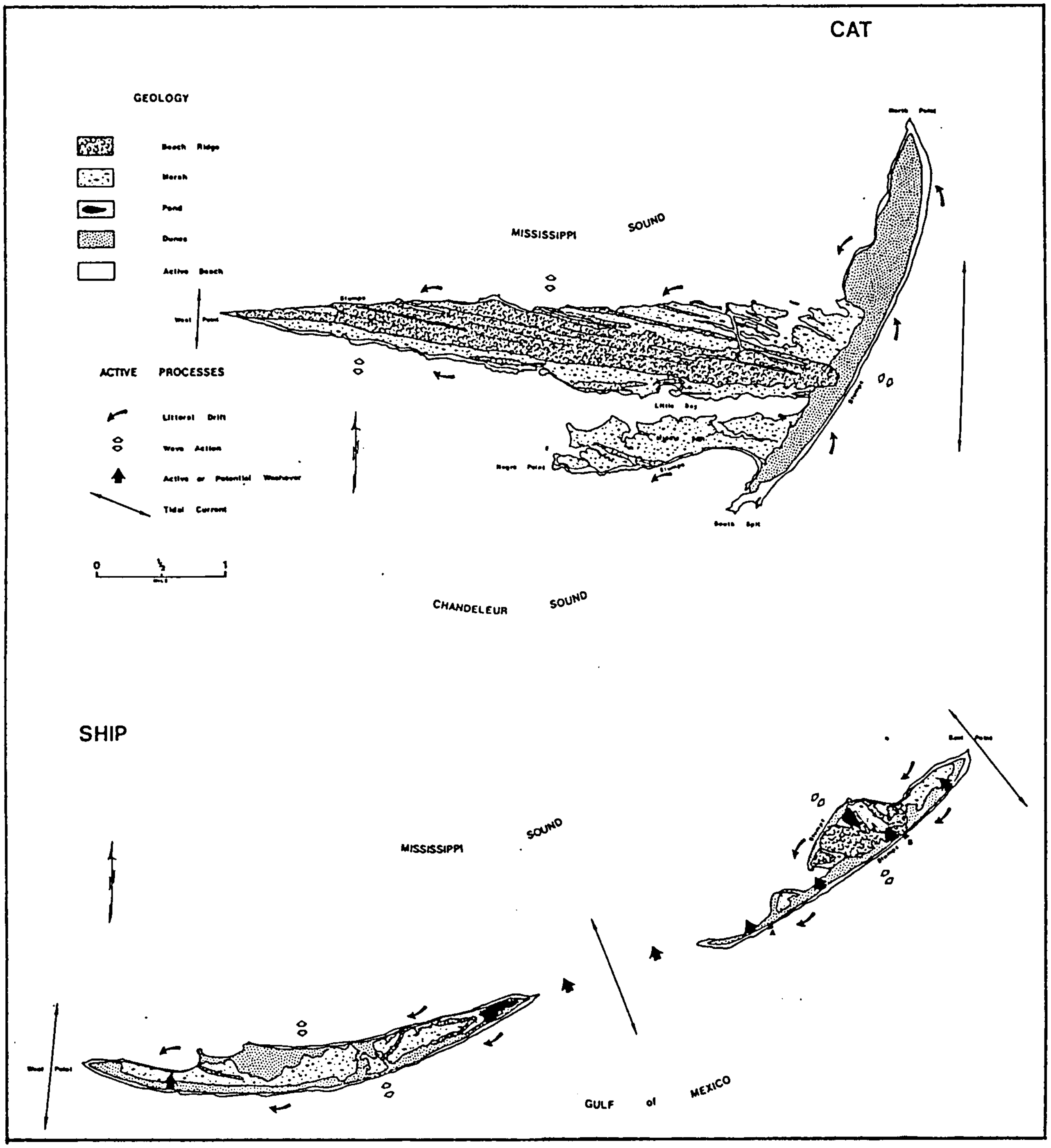


Figure 6.49. Active processes and distribution of vegetation and geologic forms on Cat and Ship Island (Waller and Malbrough 1976).

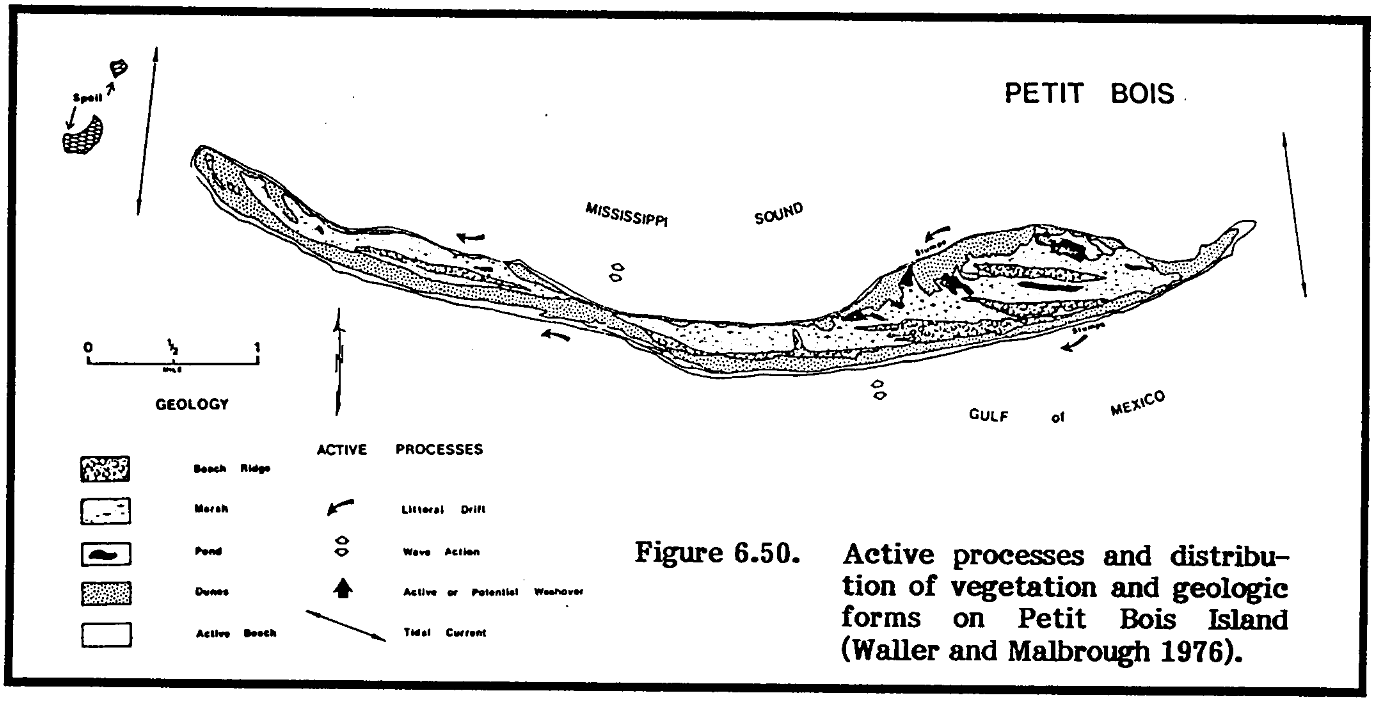


Figure 6.50. Active processes and distribution of vegetation and geologic forms on Petit Bois Island (Waller and Malbrough 1976).

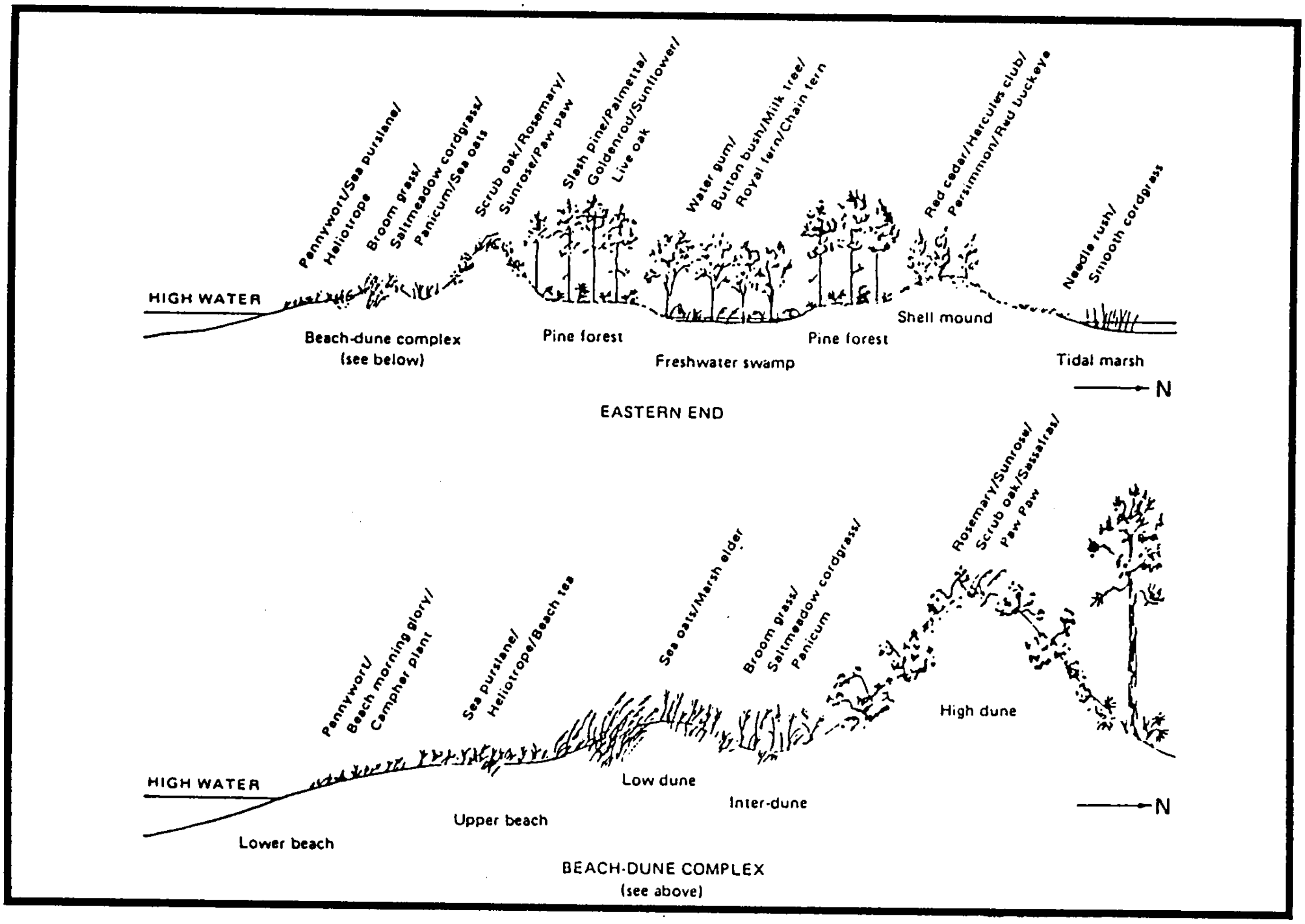


Figure 6.51. Vegetation distribution on the eastern end of Dauphin Island (O'Neil and Metee 1982 after Deramus 1970).

Marshes along the sound side of the islands have been described as having three zones. The highest zone, 1 m above MSL, is a high marsh flooded only by the highest tides and dominated by saltmarsh fimbristylis and saltgrass. The next zone is a brackish marsh dominated by blackrush (Juncus roemerianus) and spikerush (Eleocharis spp.). The regularly flooded marshes are saline and consist of smooth cordgrass (USACE, MOB. 1984).

The occurrence of seagrasses in Mississippi Sound represents the northern limit of a predominantly tropical flora (Eleuterius 1977). Several researchers (Eleuterius 1977; Eleuterius and Miller 1976; Humm 1956; Humm and Caylor 1957; Christmas 1973; Thorne 1954) have reported the following species in the Mississippi Sound in order of abundance: shoalgrass, manateegrass, turtlegrass, widgeongrass, and clovergrass. Clovergrass was found in only one locality and considered by Eleuterius (1971) to be rare. In addition, tapegrass (Vallisneria americana) was found in the brackish and fresh waters of adjacent rivers, creeks, and bayous. Widgeongrass was also found in lower salinity waters along the mainland shore and in ponds on Cat and Horn Islands. The combined areas of submerged vegetation totaled about 8,093 ha in 1969 (Eleuterius 1971). Following Hurricane Camille in 1969, about 2,428 ha (30%) were destroyed by the effects of the hurricane and lower salinities associated with unusually prolonged freshwater discharges occurring at that time (Eleuterius 1971).

Eleuterius (1971) listed substrate type, temperature, salinity, waves, currents, surges, light, water depth, and turbidity as being the major controlling factors on seagrasses. In Mississippi Sound, he believed that seagrass distribution was primarily limited by lack of suitable substrate, noting that seagrass growth, distribution, and diversity decreased to the west of the sound where mud and muddy shell dominated the substrate, and increased to the east where sand or sandy mud dominated. Seagrasses were noticeably absent near the mouth of the Pearl River where the bottom was practically all soft mud.

Submerged grassbeds are of limited distribution in coastal Alabama and are found within shallow, quiet waters 0.6 to 1.8 m deep along the shorelines of Mobile Bay and Perdido Bay (O'Neil and Mettee 1982). Alabama's seagrass beds are comprised of three species: shoalgrass, which occurs along the leeward side of Dauphin Island and in Old River east of Perdido Bay Pass; turtlegrass, which is limited in extent to the Old River east site; and widgeongrass, which covers approximately 124 ha along the northern Mobile Bay shoreline and Mobile River delta (O'Neil and Mettee 1982). Within fresh and brackish water habitats tapegrass and Eurasian watermilfoil (Myriophyllum spicatum) are dominant, while widgeongrass occurs widely over the same range in the lower Mobile River delta. O'Neil and Mettee (1982) reported that tapegrass accounted for about 27% of all submerged vegetation off the Alabama coastline, while Eurasian watermilfoil accounted for 35%. Widgeongrass accounted for some 11% of all submerged vegetation, while the extent of shoalgrass has declined since 1957, particularly along the shores of Mobile Bay and in lower Perdido Bay (Stout and Lelong 1981). Borom (1979), reporting on causes of this 30-year decline in Alabama seagrass beds, blamed such factors as increased input of agrochemicals, increased turbidity from shoreline erosion and hydraulic dredging, and changes in sediment type through disturbance from large construction projects.

The mainland marshes behind Mississippi Sound are discontinuous wetlands associated with estuarine systems receiving sediment and freshwater discharges. They are isolated from direct exposure to the Gulf by barrier islands, shoals, or protruding land masses such as peninsulas or terraces (USACE, MOB. 1984). In Mississippi, the most extensive marshes are located between the Pearl River and Clear Point, around St. Louis Bay, in the lower Pascagoula River delta and around Point aux Chenes Bay at the state's eastern border. The largest areas of marshland in Alabama are around Grand Bay (east of Point aux

Chenes Bay), around Fowl River Bay to Heron Bay (north of Dauphin Island), and at the mouth of the Mobile River delta.

The marshes characteristic of the Mississippi Coast are primarily irregularly flooded marshes built on deltaic plain sediments deposited by a number of fairly large coalescing river systems (Hackney and de la Cruz 1982). Soils are generally acidic, have an average organic content of 10%, and are composed of silt and clay. Although over 300 species of vascular plants have been found in the Mississippi marshes, communities are usually dominated by only a few plants (Eleuterius 1973a).

The saline marsh is composed of two major species: blackrush and smooth cordgrass. The brackish marsh is recognized by a reduction in smooth cordgrass, an increase in the number of plant species, such as hogcane and wiregrass, and a reduction in density of blackrush (Eleuterius 1973b). The intermediate marsh marks the upper limit of blackrush, and dominance of brackish species such as bullwhip (Scirpus californicus), sawgrass (Cladium jamaicense), and switchgrass (Panicum virgatum). The freshwater marshes are the smallest in areal extent and occur along the upper reaches of tidal rivers. Dominant species are spikerushes, lizard's tail (Saururus cernuus), arrow leaf (Sagittaria lancifolia), and three-square (Scirpus americanus). Eleuterius (1973a and b) attributes the zonation in Mississippi marshes to be primarily a function of salinity.

Mobile Bay to Florida Panhandle: Mainland Wetlands

Stout (1979) categorized Alabama coastal marshes into four types closely paralleling the Mississippi zones defined by Eleuterius (1973a): (1) Salt Marsh, dominated by oystergrass and blackrush; (2) Brackish Marsh I, dominated by blackrush, giant cordgrass, and wiregrass; (3) Brackish Marsh II, dominated by blackrush, wiregrass, and sawgrass; and (4) Fresh Marsh, represented by a large diversity of species such as alligatorweed, bulltongue (Sagittaria falcata), and cattails (Figure 6.52).

The distribution, areal coverage, and species composition of Alabama's marshlands are dependent on several variables such as tidal range, shoreline elevation, topography, and salinity (Stout 1979). The limited extent of coastal marshes in Alabama seems to be a result of high shoreline elevations and extreme low tidal range (Stout 1979). Pressures resulting in destruction or alteration of marshes within the estuary include dredging and spoil disposal, erosion, petroleum pollution, and industrial pollution (Stout 1979).

The coast of the Florida panhandle consists of narrow islands, spits, and bars which are fronted by wide, white sand beaches subject to frequent storm overwash. Behind the beaches are a line of high, primary, often active dunes which range in elevation from an average low of 3.6 m on Perdido Key to a high of 9 m south of Choctawhatchee Bay. Vegetation on these dunes is similar to that previously described for the Alabama coast. Sea oats is the characteristic species on these dunes and is often associated with marshelder, sea grape (Coccoloba uvifera), seacoast bluestem, and sea rocket (Cakile lanceolata). Older, more stabilized dunes are frequently covered with rosemary, scrub oak, and sand live oak (Quercus geminata) (Duncan and Duncan 1987). Similar vegetation is commonly found on the secondary dune fields, where they exist, behind the foredunes (Duncan and Duncan 1987). Low-lying, sparsely vegetated, sand flats grade into tidal marshes on the backshore of some barrier islands and spits such as Santa Rosa Island and Perdido Key. Slash pine is also common on the bay-sound side of the island above the tidal zone.

The distribution of vegetated dunes and flats was not delineated for this area on Maps 9-D and 10-D (Vol. II) because of their narrow width and segmented distribution.

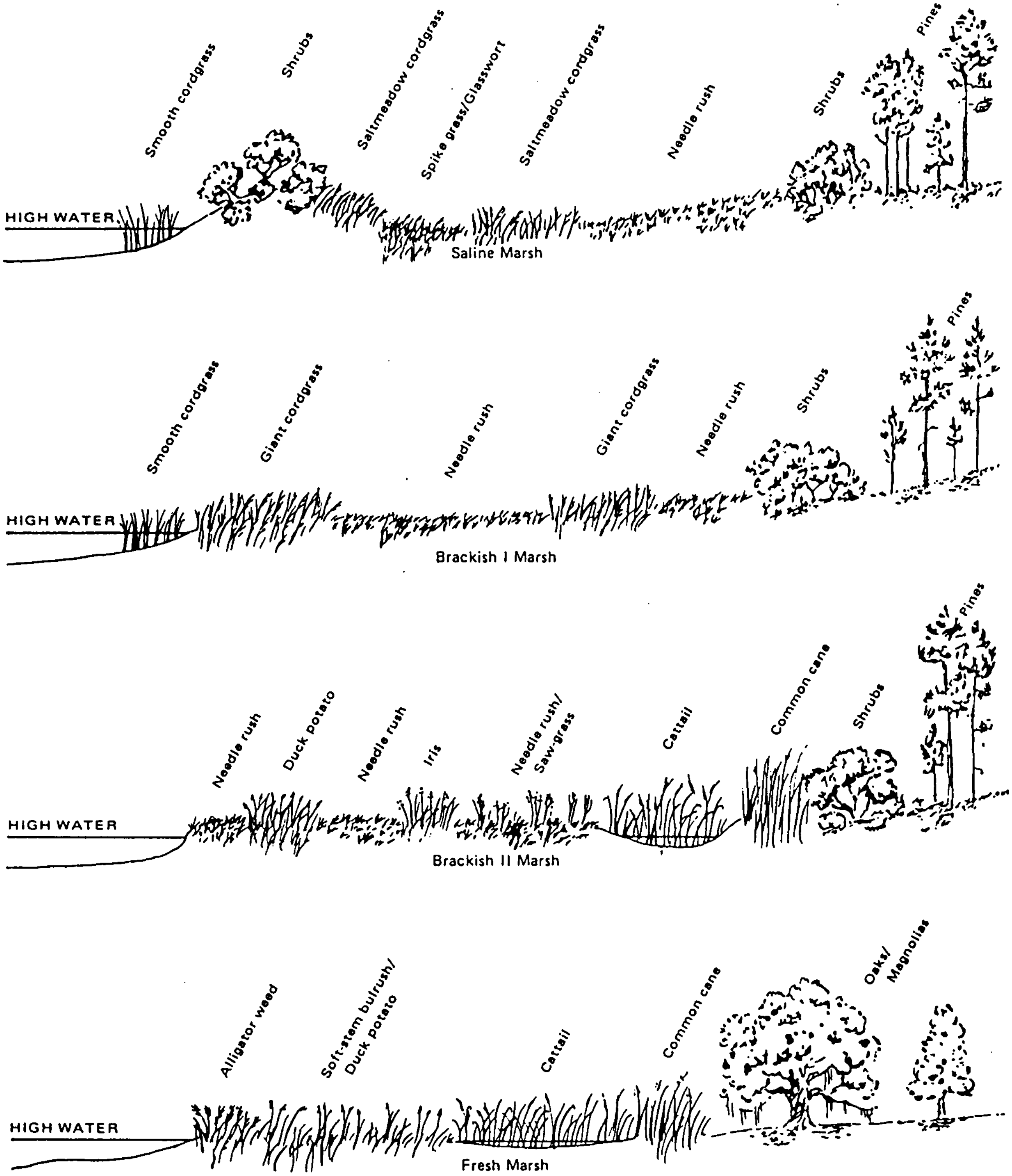


Figure 6.52. **Vegetational zonation for marsh types in coastal Alabama (O'Neil and Mettee 1982 after Sapp et al. 1976).**

Furthermore, this part of the North Central Gulf Coast is so accessible and the beaches so popular, the area has been and continues to be subjected to extensive development which segments the vegetated habitats. Often, the only unimpacted native vegetation can be seen on military reservations such as Eglin Air Force Base or as set-asides enclosed by chain link fences and located between condominiums. Even the natural vegetation in the small state parks and the Gulf Islands National Seashore on Santa Rosa Island can only preserve a semblence of the regions' past appearances because of the heavy volume of human and vehicular traffic, especially offroad recreational vehicles.

Seagrass beds are located in the sounds, bays, and lagoons behind Perdido Key, Santa Rosa Island, and Crooked Island, and in Choctawhatchee Bay, and West, North, East, and St. Andrew Bays around Panama City. The most common species are shoalgrass, located in intertidal regions and often mixed with widgeongrass, and turtlegrass and manateegrass in the subtidal regions (Darovec et al. 1975).

The areal extent of seagrass beds has diminished in the latter part of the twentieth century. Suspected causes of this destruction have been pollution from urban and industrial development and boat traffic. These seagrass beds are especially impacted by activities that increase turbidity and alter bottom substrates. Another contributing factor in the disappearance of seagrass beds in the Choctawhatchee Bay area was the "blow-out" of East Pass as a result of heavy flooding in the 1920s. It is believed that increasing salinities in the bay contributed to the initial disappearance (Livingston 1986).

Emergent wetlands have very limited distribution in the Florida panhandle. They are located as narrow, often discontinuous bands fringing the shore behind barrier islands and spits, near river mouths, and along some embayment shorelines. Only the larger expanses have been mapped (Map 8F-10F, Vol. II). Most of these marshes are non-fresh and have species compositions comparable to those described for Alabama. In general, the wetlands from mean sea level to the highest tide line are dominated by smooth cordgrass, with blackrush dominating the next inland zone, followed by the least flooded zone being dominated by saltgrass and/or wiregrass (Darovec et al. 1975).

Land Use

Environmental regulations promulgated through the National Environmental Policy Act of 1970 (NEPA) direct the incorporation of selected socioeconomic characteristics of the study area early in the planning for a project in order to avoid delays in the processing of the project and to resolve potential conflicts (40CFR Part 1501.2 reprinted from 43 FR pp 55978 - 56007, November 29, 1978). The purpose of this section is to provide such an overview of the land use within the study area. Basic land use information was derived from the USGS land use maps published in the late 1970s. This source represents the most recent comprehensive maps for the entire study area and provides an excellent indication of the distribution of development along the coast. Developed areas have been grouped as one generic category and include the following:

Land Use	Code
Residential	11
Commercial and Services	12
Industrial	13

Transportation, Communications and Utilities	14
Industrial and Commercial Complexes	15
Mixed Urban or Built-up Land	16
Other Urban or Built-up Land.	17

Of equal importance are those areas where development will be restricted because the Federal Government has designated segments of the coast as high risk. These areas were identified as a result of the Coastal Barriers Resources Act (CBRA) of 1982 (PL 97-348) (See Atlas for areas). After October 1983 the Federal Government neither finances projects nor provides flood insurance or Federal monies for utilities, home mortgages, highways, and bridges. Finally, there are those segments of the coast whose primary functions and values are for wildlife habitat, aquatic sanctuaries, or recreation, those areas that are Federal, State, or local parks, historic sites, refuges, estuaries, or shorelines.

Texas Barrier Island System

Brazos Island extends from the Mexican border to Brazos Santiago Pass. It is unoccupied and now designated as an area which will not receive any Federal support for development because of the CBRA. Padre Island is a very long and narrow barrier island which extends from the Brazos Santiago Pass on the south to Mustang Island on the north. South Padre Island is a resort type of development characterized by high-rise condominiums on the beach (Morton et al. 1983). Behind the beach are single-family units and condominiums. Seawalls have been built in the front of most of the condominiums facing the Gulf and Morton et al. (1983) predict that in the near future seawalls will be almost continuous in the developed areas. On the lagoon side most of the developed area is bulkheaded. The southern third of Padre Island is in private ownership but uncontained development is limited through the CBRA. The northern two-thirds of the island is designated as the Padre Island National Seashore. Scattered development is found along the island.

On the northern end of Mustang Island is Port Aransas, the only significant development concentration on the island. Port Aransas was founded as a fishing village and and pilot station for the ships entering the estuary. Today the town is oriented toward recreation. Development is primarily single- and multiple-family dwellings and trailer courts (Morton et al 1983). Little, if any, development exists on St. Joseph Island or on Matagorda Island. Future development on most of the islands is limited by the CBRA and by the fact that large parcels belong to either the Federal Government or the State.

The Matagorda Peninsula is virtually void of development. Most of the barrier complex is under the CBRA and little if any future activity can be expected.

The only concentration of residential and commercial development is at Quintana and Surfside flanking the Brazos Ship Channel and at the eastern end of Follets Island at San Luis Pass. Most of the remainder of this stretch of coast is under the CBRA; there is little, if any, development.

Galveston Island, at the mouth of Galveston Bay, is the most highly developed island on the Texas coast and is by far the best known. In the pre-1970's dense populations were concentrated at the eastern end of the island behind the Galveston seawall. However, the island is a place of rapid growth as high density development extends beyond the protection of the seawall. In all likelihood, this development eventually will fill the remainder of the island. Recreation and summer homes are very important to the vitality of the island economy. On the Bolivar Peninsula development is clustered in discrete zones. The areas between will probably remain open as a result of Federal regulations.

Inland of the barrier islands and beaches are several large estuarine systems: Laguna Madre, Baffin Bay, Corpus Christi Bay, Copano Bay, Aransas Bay, San Antonio Bay, Matagorda Bay, and Galveston Bay. Many small towns are found along the edges of these embayments. Several large cities, such as Corpus Christi, Galveston, Texas City, and the Houston metropolitan complex are on the bays and are the center of residential, commercial, industrial, and marine activities. However, the shorelines of the bays for the most part are open space—that is, not intensively developed. Several parcels belong to the Federal Government as conservation areas, but most are in private ownership.

Strandplain-Chenier Plain System

From Rollover Pass to Sabine Pass, the only developments on the coast are at Rollover Pass in the town of Gilchrist, where structures are raised on pilings, and petroleum-related facilities near High Island. The remainder of the coast is undeveloped with a long segment on the eastern end under State or Federal wildlife management.

On the Louisiana coast, from Sabine Pass to Southwest Pass, development is very limited. In the Chenier Plain, camps and associated facilities are concentrated at Constance Beach, Holly Beach, and Rutherford Beach. The remainder of the coast is undeveloped.

Mississippi Delta System

The Isles Dernieres complex is uninhabited except for a few camps. Timbalier Island is also uninhabited except for recreation camps. East Timbalier Island, however, has a concentration of petroleum-related structures, including a riprap wall around the front of the island.

There is no significant development on the barrier beaches along the Caminada-Moreau Headland. However, to the east, Grand Isle is densely populated. Grand Isle was a site of colonial plantations; eventually it evolved into an area for recreation where people from the interior could escape to the pleasant gulf breezes. Homes and trailers raised on piles are designed to avoid high tides or wind-driven surges that flood parts of the island. The island also supports petroleum-related industry, commercial fishing docks, and a state park.

There are no significant developments on the barrier beaches of Grand Terre or along the barrier islands and beaches stretching southward to the lower, active Mississippi River Delta. However, the Louisiana Department of Wildlife and Fisheries (LDWF) has a research headquarters (closed in 1989) on Grand Terre and an abandoned historic fort is located on the western end of the island.

A very limited area of Breton Island in the Breton-Chandeleur chain is being used for petroleum-related activities. Most of the remainder of the island chain is in public ownership as part of the Breton National Wildlife Refuge.

North Central Gulf Coast System

On the mainland of Mississippi Sound, the pattern of land use is completely different from that which is found in coastal Louisiana. Intensive development occurs, without a break, from Bayou Caddy on the west to Ocean Springs on the east. Bay St. Louis, Pass Christian, Mississippi City, Gulfport, and Biloxi hug the seawall with its pumped sand beach which fronts the coastal highway and development. Motels, hotels, marinas, commercial centers, and residential property extend almost to the water line and, in some cases, over the water on pilings. The area is oriented toward recreation and maritime-related industries.

Gulfport itself is constructed into the Gulf. From Ocean Springs to Pascagoula there is little, if any, development. But in the Pascagoula area a seawall protects the residents from shoreline erosion. Several tracts in this area have been designated by the CBRA as not suitable for more intensive land uses (Map 8C, Vol. II). Public lands are spotted throughout the Mississippi coastal zone and have been labeled on Map 8C, Vol. II.

Deer Island, immediately off the mainland south of Biloxi, is private. At this time the island is not developed and is under the CBRA.

The Pearl River Delta, Bay St. Louis, Back Bay of Biloxi, and Pascagoula Bay and Delta are the largest wetlands systems extending inland from Mississippi Sound. Except for the Pearl River Delta all the wetlands are surrounded by development, although there are zones of open space between concentrations of residential and industrial complexes.

Of the five Mississippi Sound Barrier Islands, three (Ship, Horn, and Petit Bois) are part of the Gulf Islands National Seashore and remain in a natural state. Cat Island is under private ownership but is only sparsely developed. Parts of the island are subject to the CBRA.

Dauphin Island, Alabama's only barrier island, is also in private ownership. Here, development is concentrated on the higher and more stable eastern end of the island but camps do extend along the western end of the island, most having been rebuilt since Hurricane Frederick destroyed them in 1979. Fort Gaines and a National Audubon Wildlife Sanctuary preserve some of the natural characteristics of this part of the island. Future development will be more restricted because of the CBRA.

On the mainland to the north, the development is concentrated around Bayou LaBatre, a fishing and recreational community. To the east is the Fort Morgan Peninsula and the barrier beaches extending to the Florida state line. Land use along this stretch of the Alabama coast can be placed into three categories: areas of intense development, open space areas where development will be very limited in the future because of the CBRA, and open space areas that are part of a state park or some type of Federal preserve for wildlife. Development is centered on Gulf Shores and extends to the east and west. This includes multistory condominiums on the beach, single-family homes, motels, and commercial establishments. The Little Point Clear area is identified in the CBRA and will probably receive little additional development. The remainder is public lands of one form or another, such as Bon Secour National Wildlife Refuge, Gulf State Park, and Fort Morgan State Park.

Around Mobile Bay almost the entire shoreline is developed. The city of Mobile is on the northwest and extends south along the Bay. Heavy industry, industrial parks, and ship-related activities are concentrated in this quadrant. Small communities front the shore all the way to Mississippi Sound. Across the northern end of the Bay is the Head-of-the-bay delta complex. Limited development is found on the old U.S. Hwy. 90. Bordering the eastern shoreline is one small community after another. Homes are densely spaced and have breakheads and breakwaters and piers extending into the bay. In the southeastern corner, an area of open space exists but this is either part of a National Wildlife Refuge or a national estuarine sanctuary.

Development on the shores of the bays of Florida can be intense in such places as Pensacola, Destin, Fort Walton, and Panama City. However, most of the shoreline of the bays is not heavily developed, partly because they are wildlife management areas or state lands, or belong to the military. Where secondary development does occur it is in small clusters or communities allowing for large expanses of open space.

Perdido Key

Perdido Key (Alabama and Florida) displays the continuation of the intensive development found on adjacent parts of the Alabama coast. The western end of the key is developed in condominiums and associated recreational type developments while the eastern end of the key is either part of the Gulf Islands National Seashore or the Pensacola Naval Air Station.

East of the entrance to Pensacola Bay is Santa Rosa Island, a barrier island that extends intact to Destin. Development is limited to areas at Pensacola Beach, Navarre Beach, and Fort Walton Beach. Each of these recreational communities is a combination of high-rise motels and condominiums, cluster housing, single-family cottages, and commercial enterprises such as restaurants, shops, and stores. Most of the island is in Federal jurisdiction as either the Gulf Islands National Seashore or the Eglin Wildlife Management Area associated with the Air Force Base.

Across East Pass, the entrance to Choctawhatchee Bay, is Moreno Point, a peninsula separating the bay from the Gulf. Destin overlooks East Pass and extends along the barrier beach to the east. Cluster housing and commercial activity are located at the terminus of the state roads on the Gulf shoreline, but there are no really large concentrations until Panama City Beach. Panama City Beach is one long recreation strip of motels, restaurants, and amusements which provides a major source of employment and income for the Florida Panhandle. St. Andrews State Park is west of the navigation channel to St. Andrews Bay. The State Park and the Air Force control Shell Island east of the navigation channel. Panama City wraps around the bay and to the east.

Crooked Island is not developed and is under the CBRA and therefore will probably not have much future development. Panama City extends eastward from the bay. The Air Force Base occupies a long stretch of shore behind Crooked Island. Beyond the limits of the air force base is limited to strip communities along the shore, such as Mexico Beach. Open space exists between concentrations of development.

CHAPTER 7: IMPACTS OF OCS PIPELINES

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Introduction

In order to facilitate evaluation of pipeline impacts in relation to varying environmental forms and processes and to predict future impacts in areas adjacent to OCS frontier exploration, data were compiled and analyzed by each of four previously identified coastal systems: Texas Barrier Island, Strandplain-Chenier Plain, Mississippi Delta, and North Central Gulf Coast. Impacts of pipelines coast-wide were investigated using aerial photographs and habitat maps, while site specific impacts were determined through field studies of selected geomorphic, geologic, hydrologic and vegetative parameters, as well as detailed photographic analysis of selected site changes. The hypotheses regarding impacts and the field methodologies employed to determine site-specific changes are presented in the beginning of this chapter and are followed by discussions of site-specific photo, map, and field data collection methodology analyses for each category of parameters selected for study. Conclusions regarding impacts of the pipelines are summarized at the end of this chapter.

In order to develop a Gulf Coast overview of the impacts of OCS pipelines, the decision was made to review aerial photographs and maps to observe the condition of these infrastructures within the study area. Field investigations were geared to verifying the collateral data (maps, photographs, and associated documents) and documenting observable impacts at specific sites at one point in time. Field sites were chosen for each of the four coastal systems and were intended to be representative of the pipelines within each system with regard to type of construction and potential for impact. Age and size of each pipeline were secondary considerations in site selection.

Other factors which influenced field site selection were: (1) the amount of basic data that had been verified for the site at the time of selection, (2) the number of OCS pipelines in the vicinity of the field sampling site that could be visually inspected at the time of field sampling, (3) the degree to which the site represented environmental conditions within the particular coastal system, and (4) the probability of success in reaching the site at the time of the field trip. This last factor would be influenced by weather conditions at time of survey, navigability or trafficability in the vicinity of the site, or private property access. For these latter reasons, we chose field sites from among those sites which could be reached from the back bay or beach access road rather than only from the Gulf shore and for which there was a relatively short travel time from launch or access site.

Field site selection within the Mississippi Delta System was further narrowed to pipeline landfall sites that still remained and retained some possibility of being located on land despite man-made and natural changes that had altered the landscape since the time of pipeline emplacement. This proved to be a very important consideration because field reconnaissance revealed that virtually no pipelines are marked by company signs at their beach landfall. The rare exceptions were recently emplaced pipelines and pipelines in bulkheaded, flotation canals.

The field site chosen for the Texas Barrier Island System contained two pipelines: one 30-in line (T5) emplaced in 1971, whose impacts were described shortly after emplacement by Willingham et al. (1975), and one 36-in (T6) line recently constructed in 1985. These lines crossed a barrier island, bay, and short expanse of mainland wetland, thereby presenting an opportunity to study recent and long-term impacts on a variety of natural habitat types (i.e., beach, marsh, and submerged grass beds).

Three field study sites selected in the Strandplain-Chenier Plain System also represented a variety of construction techniques, e.g., a 26-in line (L23) in a flotation canal constructed in 1968 and dammed, a 26-in line (L24) in a push-pull ditch constructed in 1968 and dammed but not backfilled, and a 4-in line (L25) in a push-pull ditch constructed in 1970 and backfilled with a low, narrow levee. In addition, eight other OCS pipelines and one OCS navigation channel (Mermentau River to Gulf of Mexico) were located within this stretch of coast and could be visually inspected during the field trip.

Three pipelines were chosen in the Mississippi Delta System. One line presented the opportunity to study an old (1956) 20-in pipeline (Muskrat Line) placed in a blocked flotation canal along and parallel to the backside of a barrier island (Grand Terre). A second site was a 16-in pipeline (L86) installed in 1961 in a flotation canal aligned basically perpendicular to the beach west of and parallel to Belle Pass. The last site was a 6-in line (L87) installed prior to 1973 west of Chevron's Fourchon terminal.

Prior to field reconnaissance, eight OCS pipelines had been identified with the aid of pipeline maps and aerial photography making landfall south of the Chevron terminal (at Port Fourchon). However, field reconnaissance in 1987 revealed that this 6-in pipeline was the only one to remain beyond the impact zone of a beach restoration project undertaken in 1986. The line appears to have been placed in a trench across the relatively firm marsh. No data on this line was provided by the pipeline operator. This study site also provided an opportunity to visually inspect other pipelines located on Grand Isle. Furthermore, one OCS navigation channel (Belle Pass) crossed a barrier beach at this site and could be field inspected with regard to impacts during the same field trip.

Within the North Central Gulf Coast System, three pipelines were chosen for field investigation. They represented two different construction techniques: (1) two flotation canals with 30- (M2) and 36-in (M3) lines installed in 1958 and 1965, respectively, and blocked at the shore and (2) one backfilled push-pull ditch for a 20-in line (M1) laid in 1970. All three lines are within a wetland environment typically found in this system. The push-pull ditch is not an OCS line, and the two pipelines in the flotation canal transport both OCS and non-OCS products to a refinery in Tennessee. However, the lines are representative examples of pipelines in the North Central Gulf Coast marshes and provide insight into impacts of future OCS pipelines in this system.

Hypotheses

Upon review of impacts attributed to pipeline construction (see Chapter 4, Table 4.3), six hypotheses were selected for study. In general, hypotheses could be tested using one or more research specialties such as air photo interpretation and analysis, or geologic, vegetative, and hydrologic sampling and analysis. Conclusions derived from analyses were summarized in order to document the overall impact of pipeline construction along the Gulf Coast, as well as to document site-specific impacts related to the interaction of construction technique and environmental characteristics.

The general category of hypotheses regarding direct impacts that were to be tested included the following:

1. That construction of pipelines remove aquatic and wetland habitat and result in land loss and habitat change. (Land loss is defined as the

change from upland or wetland habitat to open water or aquatic classes and may be permanent or temporary.)

2. That pipeline construction imposes uniformly straight drainage channels within wetlands formerly having sinuous channels, thus altering the hydrologic regime.

3. That pipeline construction segments the preexisting natural physiographic units such as interdistributary basins, wetlands, or geomorphic forms, such as barrier beaches and islands. This can result in land loss due to prolonged flooding or erosion of substrate.

4. That construction of pipelines breaches foredunes, creating a weak zone in the geomorphic form, which is also bare of vegetation, unstable, and susceptible to erosion, e.g., blowout, washover, or tidal channel formation.

5. That floral changes including disappearance of vegetation occurs after construction due to saltwater intrusion via canals, deposition of spoil, lowering of surface elevation, or alteration of substrate.

6. That alteration and/or disruption of longshore drift occurs after construction, as open water canals function as sediment sinks, trapping and removing sediment from the transport process.

These hypotheses were tested at two levels of detail. For the field study areas, detailed photographic and comparative map interpretations were undertaken, often using larger scale imagery and interpretive maps. These findings were reviewed, along with the results of the field study sampling and analyses, to provide a more detailed discussion of impact.

For the coast-wide overview, aerial photographs and mapped interpretations were used to study similarities and differences associated primarily with pipelines of different construction techniques in different coastal systems. This level of study resulted in conclusions based on a large, comprehensive data base rather than randomly selected samples.

Methodology

A synergistic methodology was devised in order to test the selected hypotheses regarding pipeline impacts. This procedure would facilitate discussion of the magnitude of pipeline impacts coast-wide and distinguish the cause and extent of impact of particular construction techniques in the four coastal systems with varying environmental conditions. There were four categories of methodologies used: (1) air photo interpretation of site condition and quantification of change in canal width and shoreline position; (2) geologic coring, interpretation and analysis, and site elevation profiles; (3) hydrologic sampling including bathymetric profiles; and (4) vegetative sampling.

Air Photo Interpretation

All six of the pipeline impact hypotheses could be tested to some extent using an air photo interpretive, mapping, and measuring methodology. This was achieved by assembling aerial photographs (black and white and color infrared [CIR] aerial imagery for various years from 1952 through 1987 and at various scales ranging from 1:58,000 to 1:6,000);

published and unpublished reports on OCS pipelines, their construction techniques, and reported impacts; solicited responses from pipeline operators, and Federal, State, and local agencies on basic pipeline data; and geological, hydrological, and ecological [primarily floral] characteristics of the four coastal systems. Selected parameters were also mapped at a scale of 1:250,000 to relate site characteristics and observable pipeline impacts (Volume II, Maps 1A-10A through 1G-10G).

Aerial photographs served as the original data base for interpretation to: (1) verify pipeline locations as designated on "as built" and small-scale pipeline maps so they could be plotted on USGS 7.5 min topographic maps, (2) verify construction techniques, and (3) determine changes in condition and size of pipeline canals or construction ROW.

Once the pipelines were delineated on both the imagery and 7.5 min maps, aerial photographs were projected onto 7.5 min USGS topographic maps to permit delineation of shoreline positions at various time periods. Shoreline change was measured at the landfall site of all OCS pipeline ROW and control transects in order to determine and compare changes among different shore types, energy regimes, and coastal systems. Depending on location, control transects were placed between 152 m and 549 m right and left of the pipeline ROW. These data were tabulated (Appendix B.1-B.4).

The pipeline flotation canals (of which there were 24) crossing barrier beaches were measured from photographs taken in various years in order to determine changes in width. The scale for each photograph was calculated prior to measurement of a feature by using the most recent USGS 7.5 min topographic map for control. The data were tabulated (Appendix C) by pipeline owner, size, construction date, coastal geomorphology, nearshore energy level, and grouping (single or multiple pipelines in a canal) in order to correlate change in width with environmental factors characteristic of each coastal system.

Aerial photographs, for various years, were projected onto a mylar overlay of a 7.5-minute USGS topographic map and interpreted in order to construct maps depicting habitat types along pipeline ROW and control transects or within a broader corridor, including the entire island in the case of Grand Terre. Data on changes were obtained by digitizing the 1:24,000 habitat map corridors or by measuring the percentage of habitat along the pipeline and control transects. This procedure enabled comparison of change within the zone of pipeline impact with change along the control area or comparison of habitat change within the pipeline zone over a period of time.

Aerial photography was used also for selection of field sampling sites in each coastal system. Photography was analyzed to provide an overview of the field sampling sites and to understand changes through time in terms of both natural and man-made processes including OCS-related facilities and other land uses, such as trapping, cattle grazing, and recreation.

Geologic Investigation

The geological field sampling and laboratory analyses and methodologies employed were selected primarily to determine whether: (1) pipeline construction created a weak zone in barrier islands, beaches, or wetlands which resulted in accelerated erosion or (2) disrupted longshore drift by trapping sediment in a deep canal which functioned as a sink. In order to achieve these objectives, vibracores were taken to provide data on local stratigraphy and to identify any facies change related to the pipeline installation. The sampling design called for vibracores to be taken along the axis of the ROW near the centerline of each pipeline investigated and along the axis of a control transect parallel but far enough removed from the ROW to be reasonably beyond the influence of any impact generated by pipeline emplacement. These control transects ranged from a minimum of about 91 m from the ROW centerline to 610 m from the centerline. The greater control distances occurred when two or more pipelines were being cored and the control was positioned midway between the two pipeline ROW's. When coring to determine barrier beach impact, the cores were taken at the beach berm crest and at the beach-marsh contact on the landward side of the beach. When coring to determine wetland impact, the cores were taken at one to three locations along the centerline of the pipeline ROW.

The vibracore unit was a Dreyer gasoline concentrate vibrator powered by a 7-horsepower Briggs and Stratton engine. The head was modified and appended to a 3.048 m long, 7.62 cm outside diameter aluminum irrigation pipe. A sharpened stainless steel cutting edge was attached to the pipe to expedite sediment penetration. Once the desired depth of penetration was reached, the unfilled portion of the core pipe was filled with water and capped with a vacuum plug to form a suction, thus preventing core loss during tube extraction. The core was retrieved through the use of a hand-operated winch affixed to a portable tripod, capped, taped, labeled, and returned to the laboratory for analysis.

In the laboratory, the vibracore pipe was cut and a steel wire was pulled lengthwise through the core pipe to divide the sedimentary core into equal halves. Upon separation, one half was wrapped in plastic in order to preserve the core for photographing (color slides and prints) and x-ray radiography. The other core was visually examined and described and samples extracted for grain-size analysis. Visual core descriptions included color, texture, stratigraphic breaks, lithologic breaks, observed soil features, and sedimentary structures.

X-ray radiography of thin sediment slabs is an effective method for investigating the internal structure of fine-grained sediments present at the study sites in each of the four coastal systems. The observable features facilitate interpretation of physical processes and depositional environments, thus permitting the observer to distinguish between natural depositional sequences and abrupt deposition associated with backfilling of canals. Light tones on the radiograph generally represent dense, mineral material, whereas darker tones are indicative of material with a higher percentage of organics. All radiographs were developed at true scale.

Grain-size analysis was performed using one of two methods: (1) standard sieve and hydrometer analysis and Atterburg limits (American Society of Testing Materials Designation D 2487-85) or (2) visual evaluation, according to the grain-size classification developed by Shepard (1954). The former test classifies sediments based upon the recognized Unified Soil Classification System. The laboratory analysis results were compared to visual examination to insure consistency between the classification systems.

Hydrologic Investigation

The typical scientific methods used to quantify hydrological impacts of an action include collection of data on various parameters prior to and after the action, then analyzing the data statistically to identify significant differences for each data set. For this study, however, several factors prohibited the use of this approach. A review of hydrologic data bases revealed that detailed, site-specific, historic hydrographic data needed for analysis of impact at selected pipeline sites did not exist. The data that is available is generally limited to tidal activity, river discharge, rainfall, or salinity for a large basin or estuary. Short-term, intensive studies of circulation, salinity, etc. are also generally concerned with analysis at a basin-wide level. Therefore, the methodology adopted for this study involved a review of the information available for the area around the selected pipeline locations and collection of site-specific data along the pipeline route during the field sampling trip. The hydrologic data collection focused primarily on acquisition of bathymetric strip-chart profiles (obtained by traversing selected water bodies in a small boat) for both pipeline canal ROW and control area waterways. These were analyzed in conjunction with the land elevation profiles taken during the geologic field sampling. Emphasis was placed on verifying the hypothesis that changes in the land surface that persist through time are a relative measure of hydrologic impact to water bodies in the vicinity of the pipeline. This type of data also enhanced the analysis of historic aerial photography and geology data obtained at the field sites.

Differences in the nature and accessibility of the various field sites, along with weather conditions, dictated to some extent, the exact field methods used for each site. These specifics are presented for each field site impact analysis.

Vegetation Investigation

Vegetative studies were designed to investigate possible impacts of OCS pipelines on the botanical systems of three habitat types (barrier dunes, marsh, and grass beds) within each of the four coastal systems, where applicable. Vegetation distribution and occurrence in dune habitats is generally determined by such factors as water availability, sediment type, and ability of species to adapt to salt spray and sand burial. Possible impacts of pipelines on dune vegetation primarily include direct destruction of dune habitats which reduce dune elevations, thereby changing community composition from dune to swale species. Without an adequate sand source and appropriate wind speeds and direction to rebuild disturbed dune habitats, vegetative recovery will be slow or absent.

Pipelines may affect two basic aspects of the marsh community: (1) community structure and (2) community productivity. Both aspects may be impacted by changes in hydroperiod (level and duration of flooding) and/or changes in water salinities. Changes in flooding regimes may be either direct, via spoil disposal or backfill retrieval, or indirect, as in the reduction or increase of surface water levels due to changes in hydrological flow patterns. Because Gulf Coast habitat distribution, in general, is very sensitive to water salinities, impacts from increased saltwater into a lower salinity or freshwater marsh can lead to decreased plant productivity and, in the long term, to conversion to a more salt-tolerant plant community.

In general, Gulf Coast submergent grass bed communities are sensitive to water depth, sediment type, water clarity, and water salinity. Hypothetically, pipeline construction could affect all of these factors by increasing water depths, destroying the existing suitable bottom sediment conditions, and increasing water turbidities and salinities. Depending on the length of time and to what degree such environmental changes take place, grass bed communities may react by either total disappearance, reduced acreages, or species composition changes.

The methodology used in the field studies to measure vegetation community structure and primary productivity involved ocular percent cover estimations and clipped subsamples, respectively. Although the sampling procedures differed among the sites, for various reasons, a 1 m^2 quadrant constructed of PVC pipe was used as the basic sampling element. Strings were threaded through holes drilled in the pipe to create one-quarter, one-eighth, and one-sixteenth subsample grids within the quadrant. For sampling, the quadrant was randomly tossed to the side, or in very sparse areas, was tossed overhead to the rear of the researcher. All plant species within the quadrant were then recorded. Estimates of percent cover for each species were made by visual inspection, aided by the grid network on the quadrant.

At each deployment of the quadrant, a 1/16 m^2 (0.0625 m^2) subsample was taken in order to estimate plant standing crop biomass. Vegetation in these subsamples was removed by clipping the stems approximately 2 cm above the substrate. Both live and dead standing material was placed in plastic bags for laboratory analysis. No litter material was retained in the sample. In the laboratory, vegetation samples were transferred to brown paper bags and dried in an oven at 65°C for 24 hours. Then the weight of each sample was recorded to the nearest 0.1 g on a triple-beam balance. All data on percent cover by specific and sample weights were recorded using a MacIntosh computer system.

Statistical analyses of the percent cover and vegetation dry weight were accomplished by the use of Statview computer software. The basic calculations produced for each data set included 95% confidence intervals and paired t-tests between pipeline and control sites.

Site Specific Impacts

Texas Barrier Island System

Site Description

Matagorda Peninsula, East Matagorda Bay, and a short expanse of upland-wetland habitat north of the GIWW was traversed by two pipelines selected for impact analysis in the Texas Barrier Island System. The area contained a variety of geomorphic forms and wetland/aquatic habitats (i.e., barrier islands, fringing aquatic grass beds, and saline marshes). The location of the study area is approximately 8 km east of the mouth of the Colorado River at latitude 28° 41' N, longitude 94° 51' W in Matagorda County, Texas (Figure 7.1)

The geologic history of this area has been discussed in Chapter 6. Matagorda Peninsula is a transgressive, low-profile barrier island whose morphology is controlled by storm washover and wave erosion (Morton et al. 1976, McGowen and Brewton 1975). The peninsula shoreline, in general, is eroding because sand supply is low, subsidence is occurring, and thin sediment bodies overlying relict tidal-flat, lagoon, and deltaic deposits are easily eroded by both normal and storm processes. Between 1856 and 1956, the site of the pipeline crossings was transgressive, while between 1957 and 1972 the shoreline accreted between 0.9 to 1.5 m per year.

Beaches on the peninsula are composed of sand, shell, and rock fragments. The beach slope varies depending upon the predominant composition, with shell beaches being steeper and narrower than sand beaches (McGowen et al. 1976). For Matagorda Peninsula, previous researchers recorded slopes of 2.76° and 3.9°, respectively, for sand and shell beaches (McGowen et al. 1976). Beach profiles of the study area for 1971-72 show a relatively broad (about 91 m wide) beach at 0 to 1.5 m in elevation backed by low dunes 1.8 to 2.7 m in elevation (McGowen and Brewton 1975:Plate 1).

The wind is onshore 10 months of the year. Persistent southeasterly winds generate wave trains that are oriented northeast-southwest, move northwestward where they encounter the shoreface, and are refracted to strike the coastline almost at a 90° angle. The result of the slight angular wave approach is a net southwestward longshore drift. Finer materials are winnowed out by swash and are carried to the inner shelf. Storm berms and shell ramps are produced by large volumes of sand, shell, and rock fragments being pushed onto the beach by onshore transport. The berms are repeatedly eroded and redistributed. Hurricanes and tropical storms hit the Texas coast, on the average, once every 1.5 years (McGowen and Brewton 1975).

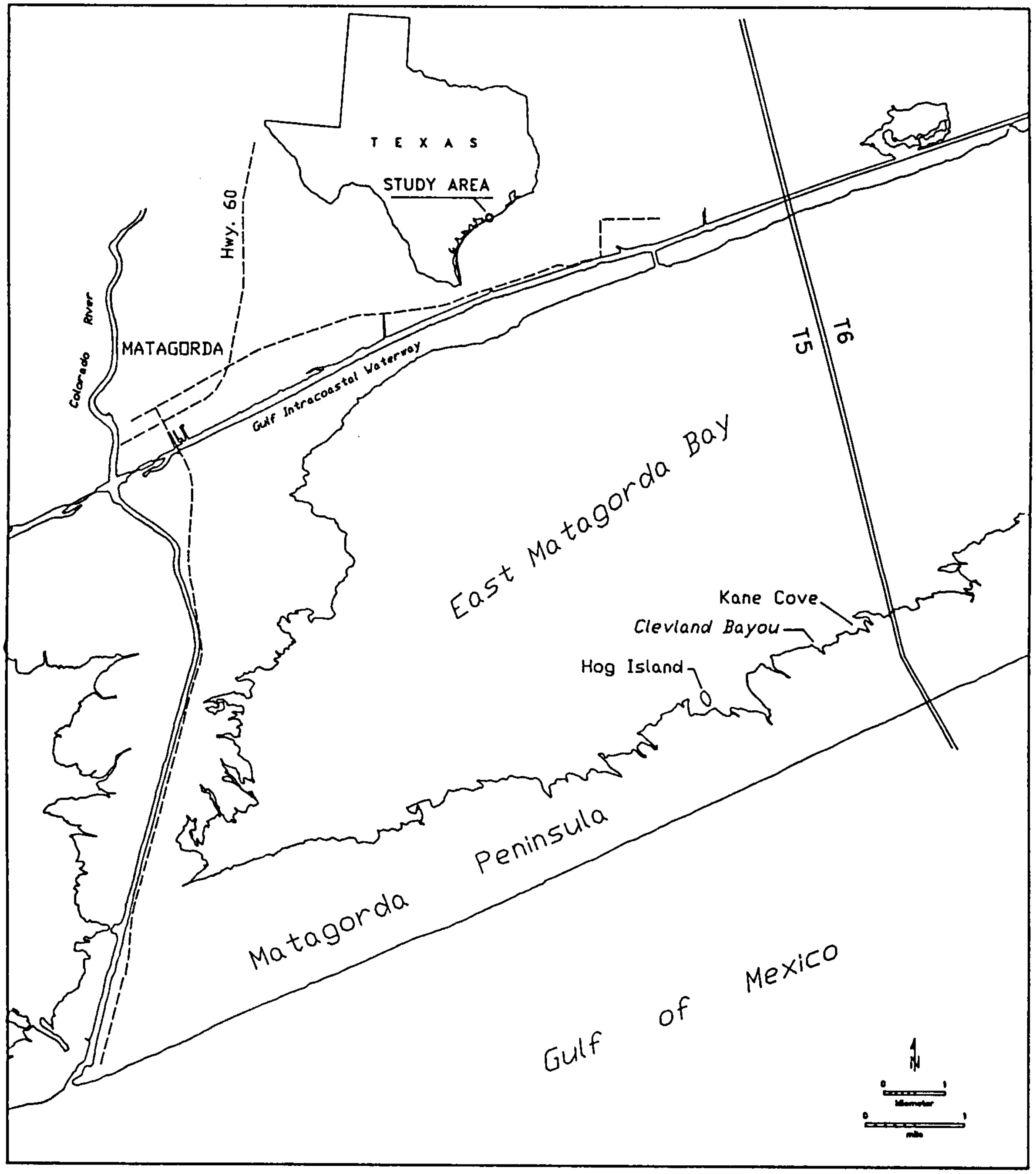


Figure 7.1. Location of field sampling sites for T5 and T6 in the Texas Barrier Island System.

The study area includes three basic soil types (USDA, Soil Conservation Service 1978). The Veston-Placedo Association, found in the river delta and along the northern margins of East Matagorda Bay, is characterized by dark gray silts and clays which are slowly permeable. The peninsula soils are classified as the Galveston-Adamsville Association composed of light gray to white fine sand. These soils are rapidly permeable. Subsidence rates for the area are 1.12 cm/100 years (Swanson and Thurlow 1973).

The plant communities of the Matagorda Peninsula, as described by McGowen et al. (1976a), follow a predictable pattern from the gulf to the bay. Where there is a foredune inland from the active beach, the pioneer plants include wiregrass, morningglory, and sea purslane on the gulfward face. Bitter panicum, sea oats, and beach tea are generally found at the crest. Where the foredune has been replaced by a shell ramp due to winnowing away of the sand, the crest of the shell ramp is vegetated by coastal bluestem, coastal sacahuista, Indiangrass, and sunflower (Helianthus sp.).

As the elevation decreases behind the barrier flat, the next plant association includes wiregrass, sea-oxeye, shore grass (Monanthochloe littoralis), and Suaeda linearis. At slightly lower levels, saltwort, glasswort, and saltgrass are found. Fringing the bay margin are salt marshes dominated by smooth cordgrass and interspersed with wind tidal flats. When these flats are submerged, mats of blue-green algae (Lyngbya sp.) form over extensive areas. The bay shoreline of the peninsula is vegetated by submerged grasses, with the dominant species being shoalgrass. Widgeongrass is abundant during periods of freshwater influx.

East Matagorda Bay exhibits sluggish water exchange compared to other Texas coastal bays. The bay receives tidal exchange with the gulf through Brown Cedar Cut, a poorly defined tidal inlet in the far northeast corner of the bay, and freshwater inflow from the GIWW at three cuts through the spoil disposal area. The depth of the bay is 1.8 m or less and the maximum depth of Brown Cedar Cut is 2.4 m. The salinity regime averages 10 to 20 ppt with the isohalines generally parallel to the long axis (SE-NW) of the bay. Circulation is counterclockwise along the bay shoreline and is accentuated by southeast winds which predominate from March to September (McGowen et al. 1976a). The tides in this area are diurnal with a mean tidal range of 0.45 to 0.60 m (U.S. Department of Commerce 1985).

History and Interpreted Changes

The two pipelines selected for detailed field investigations in the Texas Barrier Island System are the Transcontinental Gas Pipe Line Corporation 30-in and 36-in gas lines, hereafter referred to as T5 and T6, respectively (Figure 7.1). Both lines originate at a Transcontinental junction platform in the Brazos Area Lease Block 538 and transport gas from the OCS to Transcontinental's North Markham Plant in Matagorda County, Texas. No data was available from the operator or the Corps of Engineers, Galveston District on the emplacement technique utilized on line T5. According to Willingham et al. (1975), this line was emplaced in 1971 and excavation on the barrier peninsular and mainland was by dragline, and the push-pull method was used to move the pipe. No depth of pipe burial was reported for wetlands or beach crossings but the bay crossing was reported to be 1.8 m below the bottom of East Matagorda Bay (Willingham et al. 1975).

The construction of T6 was better documented by materials submitted as part of the Department of the Army Permit application (#16950) and by the "as-built" maps prepared by Transcontinental on June 25, 1986. The permit for construction was granted on December 6, 1984 and the line was completed by late 1985 (Gardner 1987). The "As-built" map indicates that the two lines are parallel to each other and 91.4 m apart at the shore crossing and close to 45.7 m apart toward the back side of the island and across Matagorda Bay. North of the GIWW, the lines are 7.6 m apart. A main line valve assembly is on T5 just north of the beach and on each line immediately north of the GIWW. At the beach crossing, T6 had 4.7 m of cover at the time of construction. North of the GIWW, the T6 line is somastic-coated to protect the outside of the pipe from corrosion; south of the GIWW it is concrete-coated to add weight sufficient to keep the line buried (Transcontinental Gas Pipe Line Corp. 1986). Based on reviews of permit applications for other Texas pipelines and historic aerial photography of the pipeline crossing, the cross-sectional profile of the nearshore Gulf-Peninsula-Bay-GIWW-Mainland pipeline crossing submitted with the permit application is probably representative of pipelines making landfall along the Texas coast (Figure 7.2) (Transcontinental 1984). Specific construction techniques are also identified in notes attached to the permit application (Table 7.1).

As specified in the permit application (Transcontinental Gas Pipe Line Corp. 1984), on the peninsular and mainland, the pipeline trench was to be excavated with backhoes or draglines with double ditching of spoil undertaken in order to ensure the top soil could be placed on top when the trench was backfilled. To minimize marsh impacts, the push-pull method was to be used wherever possible, with marsh buggy, backhoe, or small dragline being the second resort. During construction, spoil deposits were to have breaks between them so as not to alter the normal hydrologic flow patterns. The entire ROW was to be returned to its original contour and elevation after line emplacement but no revegetation efforts were required.

In East Matagorda Bay, the pipe was placed in a ditch located in the bottom of the flotation canal which was to be excavated by barge-mounted draglines. This flotation canal across the bay was to terminate at the north and south shoreline of East Matagorda Bay and no flotation canal was to be excavated across the back side of Matagorda Peninsula. This latter condition was the one major difference between construction of the T5 line in 1971 and the T6 line in 1985. On the preceding 30-in line, a flotation canal was dredged from the bay-marsh interface to the back dune area and remains open to this day, thus creating a direct, permanent impact in the form of marsh loss.

During construction, spoil piles, not to exceed 152.4 m in length, were to be placed on alternating sides of the underwater flotation canal in such a manner as not to hinder water movement or boat traffic in the bay. This spoil was to be returned to the canal after the pipeline was in place in such a manner that the bottom elevation within the bay ROW was not to increase any more than 15.24 cm. The construction in East Matagorda Bay was expected to take 8 to 10 weeks.

From the Gulf shore seaward to -5.4 m, the pipeline trench was to be excavated with a bucket dredge with spoil temporarily stored and marked so as not to impede water movement or navigation. This spoil was also to be jetted back into the trench after the line was in place. From -5.4 m to the platform, the pipe was emplaced by jetting it to achieve the proper depth of trench with natural sediment transport processes being allowed to fill the trench with the required cover (i.e., 0.91 m).

The T6 line was to have a minimum of 0.91 m of cover on the mainland and GIWW spoil sites and 1.82 m of cover on the backside of the Matagorda Peninsula in the area of salt marsh and tidal flats. The amount of cover under the berm and dunes would vary relative to the height of these features. Through East Matagorda Bay, the pipeline was to have a minimum of 1.52 m of cover. Between the dune crest and about -3.04 m mean low tide (MLT) the top of the pipe was to be at -3.66 m MLT. From this point gulfward, the pipe was to have 0.91 m of cover. Under the GIWW the pipe was to have a minimum of 3.96 m of cover, putting the top of the pipe at -7.62 m.

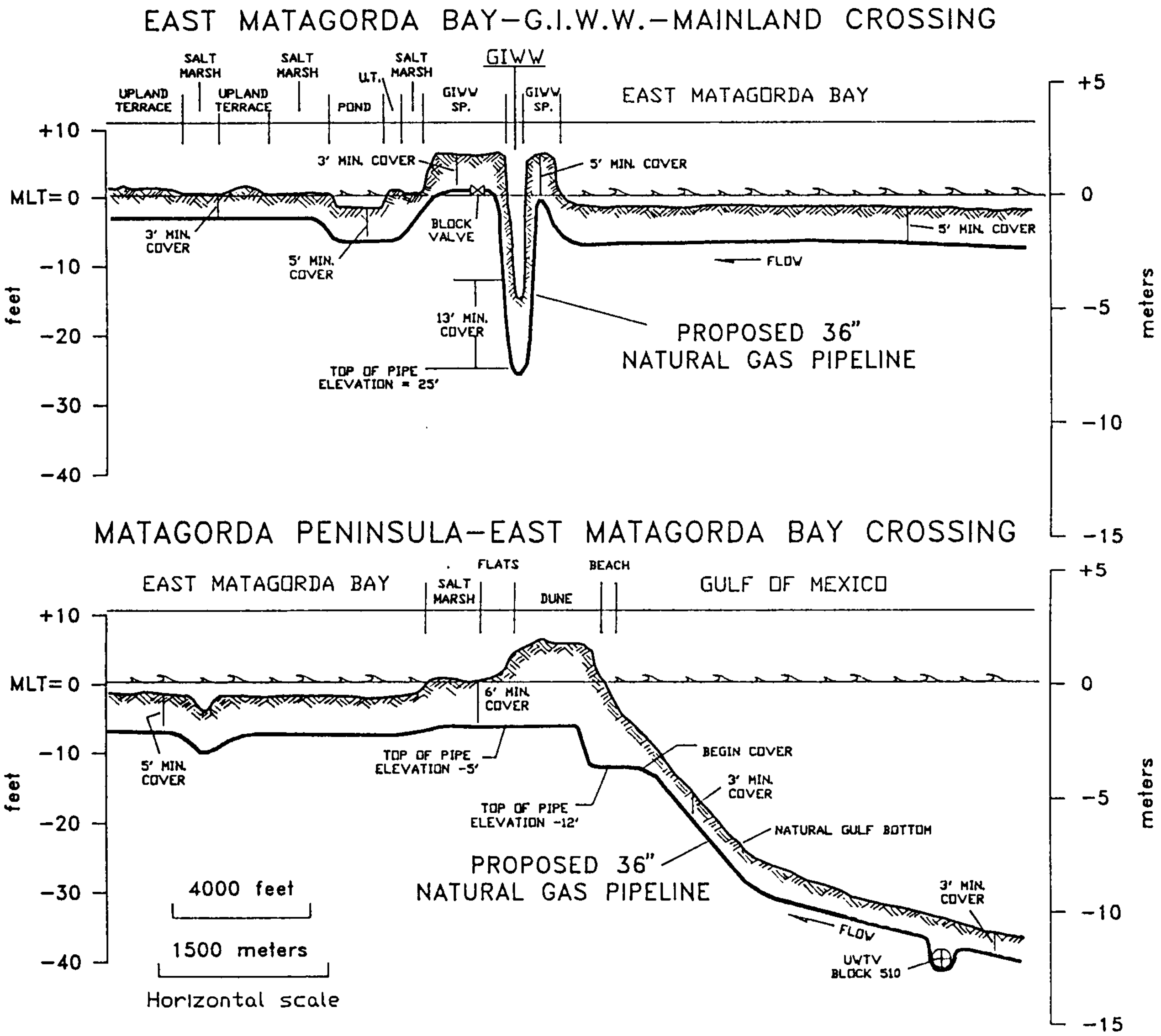


Figure 7.2. **Cross-sectional profile of the Transcontinental 36-in natural gas pipeline (T6) crossing Matagorda Peninsula, East Matagorda Bay, GIWW, and mainland as shown in permit application (redrawn. Transcontinental Gas Pipeline Corp. 1984).**

Table 7.1. Permit Specified Construction Techniques and Conditions to be Followed During Emplacement of 36-in Transcontinental Pipeline (after Transcontinental Gas Pipeline Corporation 1984: Sheet 17 of 21).

1. Mainland and Matagorda Peninsula Wetlands:
    a. Pipeline trench will be excavated with draglines and/or backhoes. Top soil and other excavated materials to be temporarily stored in a segregated manner as shown in "typical plan of trench in wetlands" on sheet 18 so as not to inhibit the natural flow of water. The excavated material will be used as backfill with the "top soil" being returned to the marsh surface.
    b. When practical, a "push-pull" pipeline installation method shall be used at marsh crossings to minimize vehicular traffic impact.
    c. When "push-pull" is not practical, a marsh buggy/backhoe or a small dragline may be used.
    d. The entire right-of-way across Matagorda Peninsula shall be returned to its original contour and elevation.
    e. High ground in the middle of Matagorda Peninsula shall be used for temporary storage of equipment, materials, etc.
2. Intracoastal Waterway:
    a. Pipeline trench to be excavated with draglines and materials stored on banks at least 50 feet from the bank lines or in the bed of the waterway in a manner so as not to inhibit stream flow or traffic and will be used as backfill in a manner as to decrease the water depth by no more than one half foot.
    b. The pipe will be fabricated onshore and installed across the waterway in one section.
3. East Matagorda Bay:
    a. Pipeline ditch and flotation trench from water's edge on mainland side of bay to 3' water depth on peninsula side of bay will be excavated with barge-mounted draglines and/or backhoes. From water's edge on peninsula side of bay pipeline trench will be excavated with marsh buggy dragline. No flotation trench will be excavated in this area.
    b. Excavated material will be stockpiled on alternating sides of the trench in piles not to exceed 500 feet in length so as not to impede water flow or marine traffic. Stockpiles will be marked in accordance with U.S. Coast Guard regulations (Title 33 CFR parts 140:147, Sub-Part 67.50-25-D) and will be used as backfill in a manner so as not to decrease the water depth by more than one half foot.
    c. From water's edge on mainland side of bay to 3' water depth on peninsula side of bay, pipeline will be laid from spud barge using conventional methods. From water's edge on peninsula side of bay pipeline will be laid using the "push-pull" method.
    d. Construction across east Matagorda bay will take approximately 8 to 10 weeks from initial trenching to completion of backfilling.
4. Gulf of Mexico:
    a. From the shoreline to the 18 feet of waterline, trench to be excavated using a bucket dredge. Materials will be stored in stockpiles in such a manner so as not to impede flow or traffic. Stockpiles will be marked in accordance with U.S. Coast Guard regulations (Title 33 CFR Parts 140-147 Sub-Part 67.50-25-D) and will be used as backfill in a manner as to decrease the water depth by no more than one half foot.
    b. From the 18 feet of water line to block 538, pipeline will be laid from lay barge with ditching by jetting spreading the spoil so as not to cause over one half foot build-up above the gulf bottom. The trench will be backfilled by natural siltation.
    c. After construction, should undue erosion occur at the gulf shoreline, stabilization will be accomplished by placing geotextile with articulated concrete matting over the effected [sic] area at the approximate original contours of the shoreline.
5. Cover over valves are to be a minimum of three feet.
6. Pipeline warning signs are to be placed at the entrance and exit of the 36-in pipeline across the Corps of Engineers Disposal Area No. 105 between the Intracoastal Waterway and east Matagorda Bay.

No extraordinary shoreline erosion prevention measures were to be undertaken at the Gulf shore unless erosion was observed to occur after emplacement. Comparison of recent aerial photography indicates that this is a stable-to-accreting shoreline and field investigations did not uncover any additional shore protection measures that had been implemented between 1985 and 1987.

The first step in determining the type and magnitude of impacts for T5 and T6 was the delineation of the pipeline ROW on the following maps and aerial photographs: 7.5 min USGS topo maps (1973), 7.5 min habitat maps (U.S. Fish and Wildlife Service [USFWS] 1950's, 1979), and large-scale, black and white (Agricultural Stabilization and Conservation Service [ASCS] 1958; National Aeronautics and Space Administration [NASA] 1983) and color infrared (NASA 1987) photographs. It is assumed that the 1950's USFWS habitat map was interpreted from 1958 ASCS photographs. The map-photo data base facilitated a descriptive analysis of change.

Preparation of additional habitat maps using 1983 and 1987 photography and measurement of habitat area along ROW and control transects for the new and the previously mapped habitat data (USFWS 1950's, 1979) resulted in quantification of habitat change. This procedure was undertaken only for the Matagorda peninsula portion of the pipeline ROW.

The portion of T5 and T6 north of the GIWW traverses an area which consists of upland Pleistocene outcrops and estuarine marshes, ponds, and flats (Figure 7.3A). In May 1958, this area appeared to be experiencing heavy grazing and/or drought conditions as evidenced by numerous cattle trails crisscrossing the marsh and terrace and the protruding pimple mounds (white circular dots on photograph) on the upland terrace. Furthermore, all material dredged from the GIWW had been deposited south of the canal.

The first available photograph taken after T5 was installed was taken in 1983, 12 years after pipeline construction (Figure 7.3B). The pipeline is barely visible on this photography as a thin white, discontinuous line in upland areas and a thin, white-to-light grey line in wetland areas. This indicates that vegetation has not completely invaded to obscure the pipeline ROW. However, the discontinuous pattern of the scar and the lack of erosion at the juncture of this ROW and an enclosed estuarine water body indicates that this scar is comparable, in places, to that made by a cattle trail or a very narrow dirt farm road. There are no open water areas along the ROW to indicate either incomplete backfilling, significant subsidence, erosion, or gouging along the site of the temporary spoil disposal area.

A ground photograph of the ROW for T5 and T6 on the north side of the GIWW illustrates the well-drained, grazed nature of this upland and the type of bulkhead installed to prevent erosion (Figure 7.4).

A comparison of 1983 and 1987 photographs of the T5 and T6 ROW across Matagorda Peninsula (Figure 7.5A and B) illustrates the condition of T5, 12 to 16 years after construction. Figure 7.5 (A and B) also provides a comparison of the T6 ROW immediately prior to construction in 1983 and four years after construction (1987).

By January 1983, the T5 ROW remains clearly visible on the marsh-flat portion of the peninsula as a narrow canal through the marsh and a sparsely vegetated-to-bare path through the regularly and irregularly tidally flooded flat. The canal is approximately 426 m long and 15 m wide in 1983 (NASA 1983). The ROW is fairly well obscured by vegetation on the upland or beach berm portion of the island (Figure 7.6). There is no evidence of accelerated shoreline erosion or breaching of the berm crest. Furthermore, on the bay side of the island, littoral sediment appears to have been carried westward,

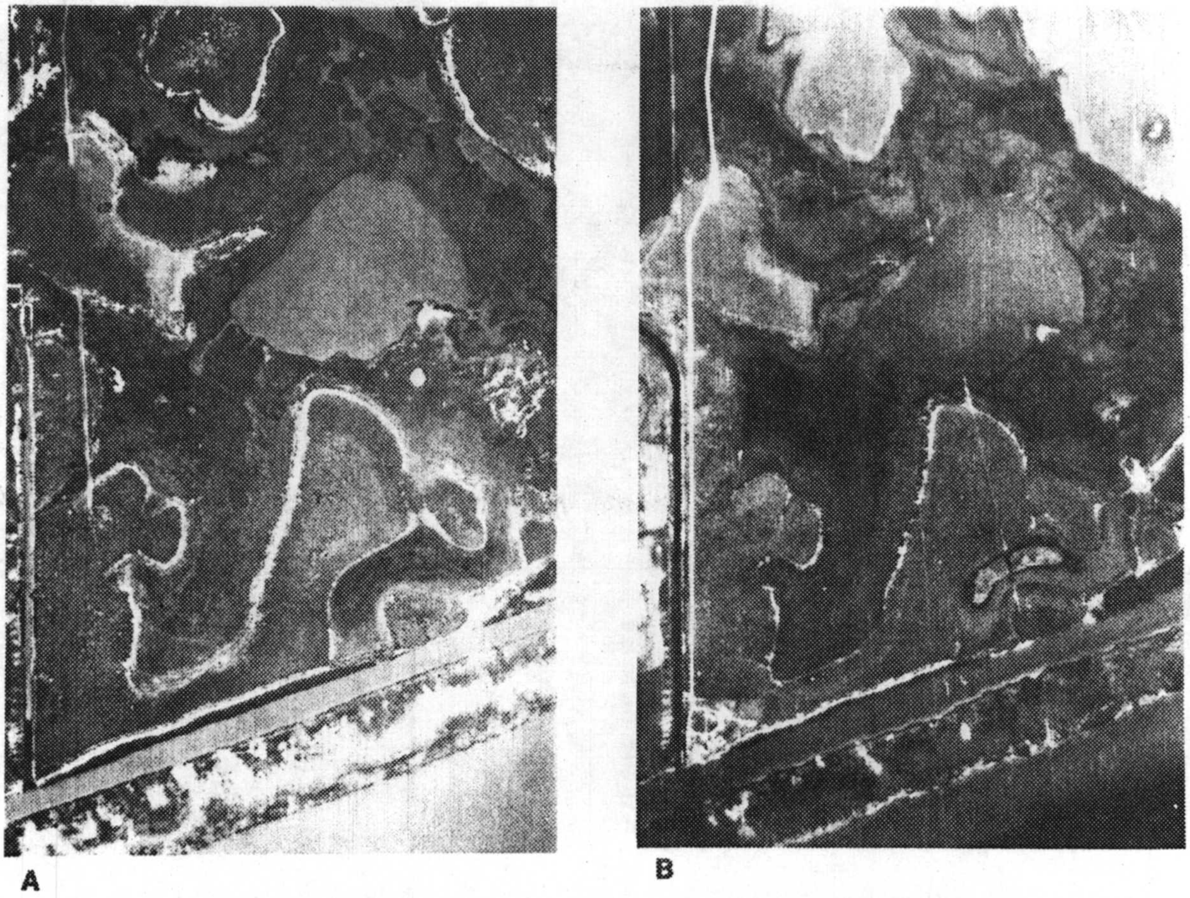


Figure 7.3. Comparison of T5 and T6 pipeline ROW through the wetlands north of the GIWW as shown in photographs taken before (1958 [A]) and after (1983 [B]) construction of the pipelines (ASCS 1958, USGS 1983).

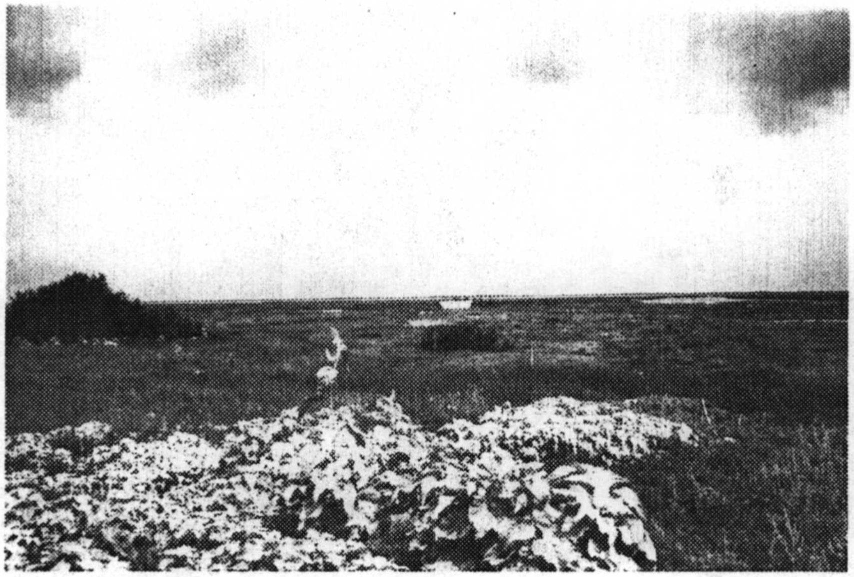


Figure 7.4.

Condition of T5 and T6 ROW north of GIWW. Note bulkhead on lower right and valves on upper left of photos.

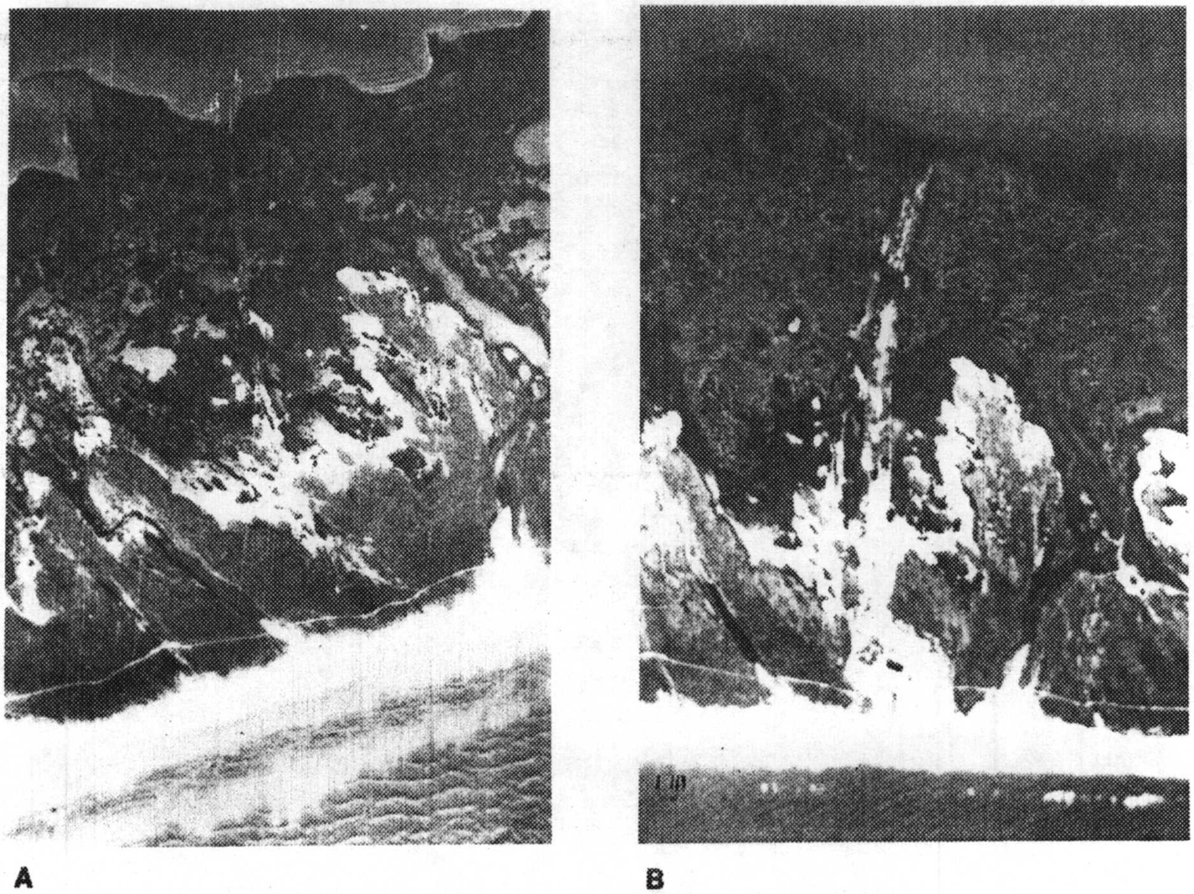


Figure 7.5. Comparison of T5 and T6 pipeline ROW across Matagorda Peninsula as shown on photographs taken in 1985 (A) and 1987 (B).

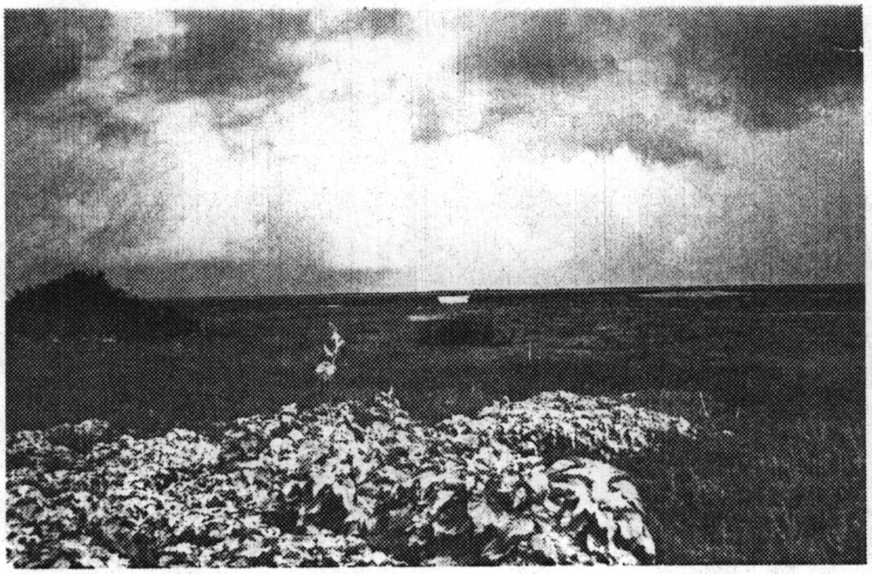


Figure 7.6.

Revegetated ROW for T5. Photograph taken in June 1987, looking north from berm crest. The white rectangular object in the center of the photo is a fence around T5 and T6 valves.

filling in the subaqueous canal channel, as evidenced by the rippled bars parallel to the shore. No spoil has been left adjacent to the canal. Cattle were also grazing on this island in 1983 and 1987 as evidenced by the numerous cattle trails and water pond appearing east of the T6 ROW on the 1987 photograph.

The impact of T6 construction in 1985 remains very visible on the December 1987 photograph. A wide (approximately 76.2 m), cleared construction ROW extending approximately 1118.6 m across the island and a construction equipment materials ROW (covering about 2.02 ha) on the berm crest are almost devoid of vegetation.

A noticeable difference between T5 and T6 is that the T6 trench has been completely filled with sediment, leaving no open water canal within the ROW. Aquatic grass beds appear to have recolonized the T5 and T6 ROW on the bay side of the island to densities similar to that found adjacent to the ROW. As with T5, there appears to be no accelerated erosion at the Gulf or shoreside of the ROW, nor is there a blowout of the berm at the ROW crossing.

Figure 7.6 is a ground photograph taken in June 1987 and illustrates the fact that the T5 ROW along the island berm has been completely revegetated by 1987.

In order to quantify pipeline impacts through time, habitat data for the pipeline ROW and controls (Figure 7.7) were tabulated as a percentage of equal length transects across the peninsula (Table 7.2). Because there is an inconsistency in the detail of habitat delineation in the 1950s (1958) and 1979 habitat maps prepared for the U.S. Fish and Wildlife Service, the data has been grouped into seven categories for purposes of discussion.

The two controls traverse five habitats (berm, marsh/flat, estuarine water, beach, and nearshore gulf) for the four time periods. Construction of T5 creates a sixth habitat (pipeline canal) along the ROW by 1979. The seventh habitat (cleared ROW) mapped in 1983, is a very narrow, unvegetated portion of the ROW which was probably present in 1979 but mapped as part of the regularly, tidally flooded flat. The T6 ROW maintained five habitats pre- and post-canal construction because the berm which constituted 21% of the area in 1983 was classified as cleared ROW in 1987.

These habitat comparisons indicate that one quantifiable impact is a direct one representing the area of cleared ROW and pipeline canal which replaces preexisting upland, marsh, and flat habitat. However, the data indicate that these two direct impacts diminish in time (i.e., cleared T5 ROW goes from 13% of transect to 0% between 1983 and 1987 and pipeline canal area goes from 24% in 1979 to 22% in 1987). While this is evidence that the T5 canal through the marsh and flats is diminishing in terms of percent of transect length through time, the conversion has been extremely slow. The T5 canal will probably remain until sufficient material has washed into the cut (via overwash and/or littoral transport along the bayside of the island) to elevate it to a level capable of supporting saline marsh colonization.

The T6 ROW was backfilled to an elevation sufficient to prevent standing water, except in a few areas along the ROW where there were preexisting ponds. There appears to be some recolonization of this ROW in the marsh flat and berm areas during the period between January 1983 and December 1987, but it has been very slow. Part of the reason for this slow recolonization of the irregularly tidally flooded flat area between the berm and the marsh is that this appears historically to have been an area largely devoid of vegetation. These high flats are also called wind-tidal flats and described as

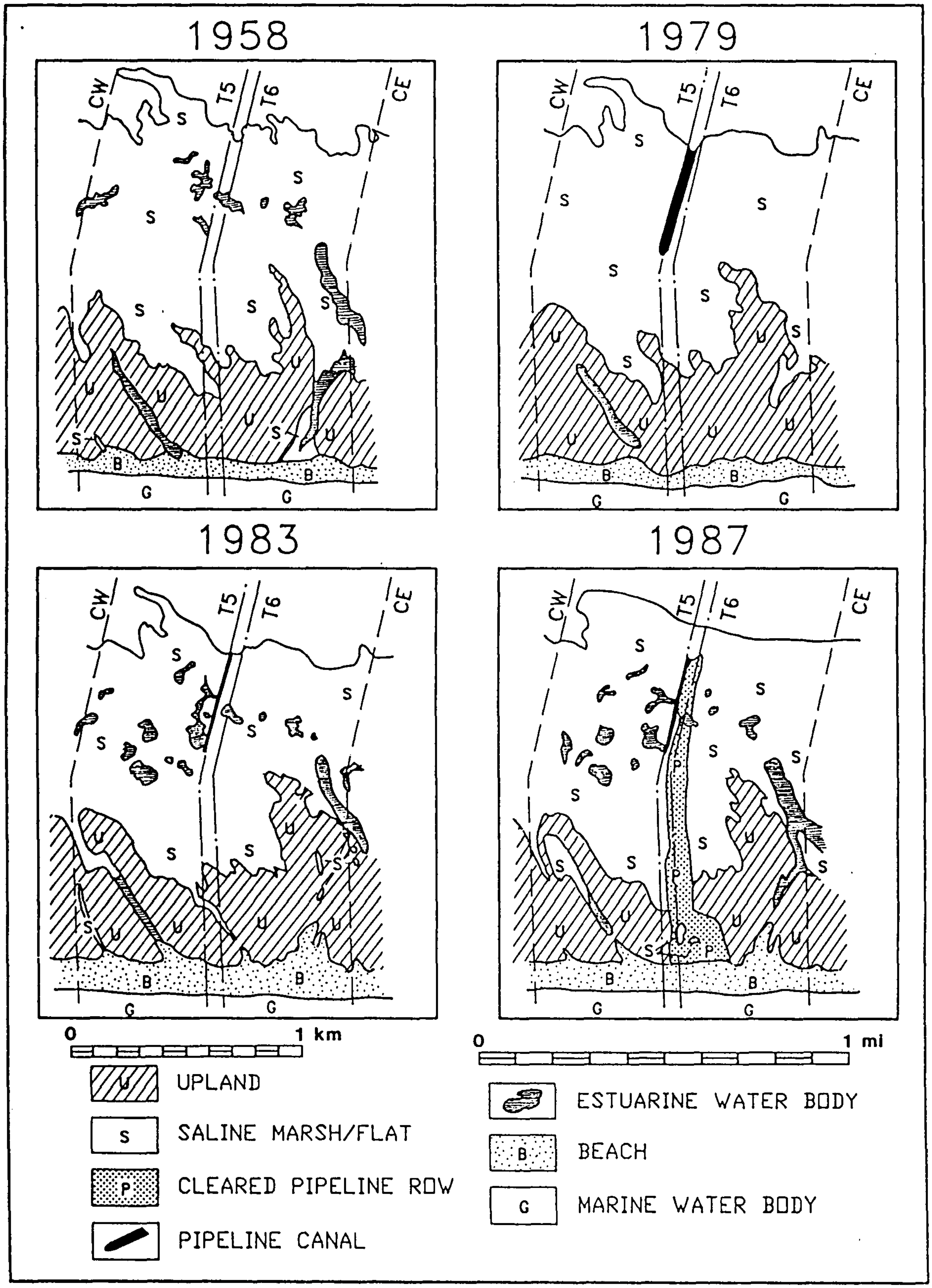


Figure 7.7. **Comparison of habitat change along T5 and T6 ROW and controls: 1958, 1979, 1983, and 1987.**

Table 7.2. Comparison of Habitat Change Along an 1828-m Transect of ROW for T5 and T6 and Controls 548 m East and West of T5 and T6 ROW, Respectively, across Matagorda Peninsula, Texas.

	PERCENTAGE OF HABITAT PER TRANSECT PER YEAR							
	T5 (1971 Construction)				T6 (1985 Construction)			
Habitat	1958	1979	1983	1987	1958	1979	1983	1987
Berm	22	26	18	13	21	21	21	0
Marsh/Flat	53	27	21	38	55	55	52	7
Cleared ROW	0	0	13	0	0	0	0	61
Pipeline Canal	0	24	23	22	0	0	0	0
Estuarine Water	17	20	15	19	17	17	18	23
Beach	4	3	8	5	4	5	7	6
Gulf	3	<1	2	2	3	1	2	2
No. of Habitats	5	6	7	6	5	5	5	5

	PERCENTAGE OF HABITAT PER TRANSECT PER YEAR							
	West Control				East Control			
Habitat	1958	1979	1983	1987	1958	1979	1983	1987
Berm	25	31	28	29	22	24	31	32
Marsh/Flat	54	45	45	46	48	55	32	44
Cleared ROW	0	0	0	0	0	0	0	0
Pipeline Canal	0	0	0	0	0	0	0	0
Estuarine Water	13	16	17	17	25	16	17	26
Beach	4	5	7	5	3	2	8	5
Gulf	4	2	3	3	2	3	2	3
No. of Habitats	5	5	5	5	5	5	5	5

"predominantly bare sand occurring between the mean high-tide line and the marshes on the back side of the barriers" (Fisher et al. 1972:44).

Geologic Impacts

Matagorda Peninsula is a low-profile wave-dominated, transgressive barrier island. Storm overwash and shoreline erosion are the dominant physical processes which control the morphologic features and stratigraphic framework of the island (McGowen and Brewton 1975, Morton et al. 1976). It was hypothesized that these processes are enhanced and accelerated by the installation of pipelines T5 and T6, which breached the foredunes and created a weak zone in the geomorphic form, making the site susceptible to accelerated erosion.

Field studies at Matagorda Peninsula were designed to investigate topographic and stratigraphic variation which may result from construction of the two pipelines. Measurement and sampling techniques were conducted systematically in order to provide control locations exhibiting natural geologic processes and environments, and a pipeline test location, which may reveal either direct or indirect impacts upon these depositional environments.

Geologic field data, including beach profiles, vibracores, surface sediment samples, and field observations, were obtained from the study area on July 21 and 22, 1987 along the axis of the T5 and T6 pipeline ROW which cross Matagorda Peninsula and East Matagorda Bay and along parallel control transects (Figure 7.8). The control transects were spaced 610 m east of T6 and west of T5. Beach profiles using the standard transit and stadia method were conducted along these transects in order to provide comparative topographic data. Two vibracores (one on the beach and one in the vegetated flats) were taken along each transect. Two vibracores were also obtained in the wetlands north of the GIWW: one located within the pipeline ROW, and the other located 610 m east of the ROW in the adjacent marsh.

The modern barrier facies within the study area of Matagorda Peninsula have three major active depositional environments: (1) barrier sands, which include beach, dune, and washover sands; (2) barrier flats including shell ramp-barrier flats and vegetated flats; and (3) salt marshes (Morton et al. 1976).

The modern barrier sands of the study area are comprised of a number of subenvironments which include, from seaward to landward, upper shoreface, foreshore, fore-island dunes, and washover channels and fans. Sands throughout these subenvironments are moderate to well-sorted and are predominantly fine to very fine sand with locally varying percentages of silt, shells, and rock fragments. The upper shoreface and foreshore comprise the beach, which is generally smooth and slopes seaward. The foreshore is separated into a forebeach which is affected daily by the local swash, and the backbeach, which is often separated from the forebeach by the berm. The backbeach generally slopes seaward but is often observed sloping landward. The beaches occasionally exhibit only a forebeach which is adjacent to a shell ramp. Facies characteristics of the upper shoreface and foreshore deposits consist mainly of fine to very fine laminated sands penetrated locally by plant roots and burrows. Laminations are generally parallel with low angle discordances dipping gently 1 to 2 degrees. Laminations range from 0.64 to 1.90 cm and are formed from suspension clouds brought by incoming waves. Locally, these sands will exhibit low-angle cross-bedding, ripple cross-laminations, and scour and fill structures.

Foredunes within the study area are low and discontinuous and are composed of very well-sorted, fine-grained sand. The dunes exhibit generally planar, cross-bedded units 0.9 to

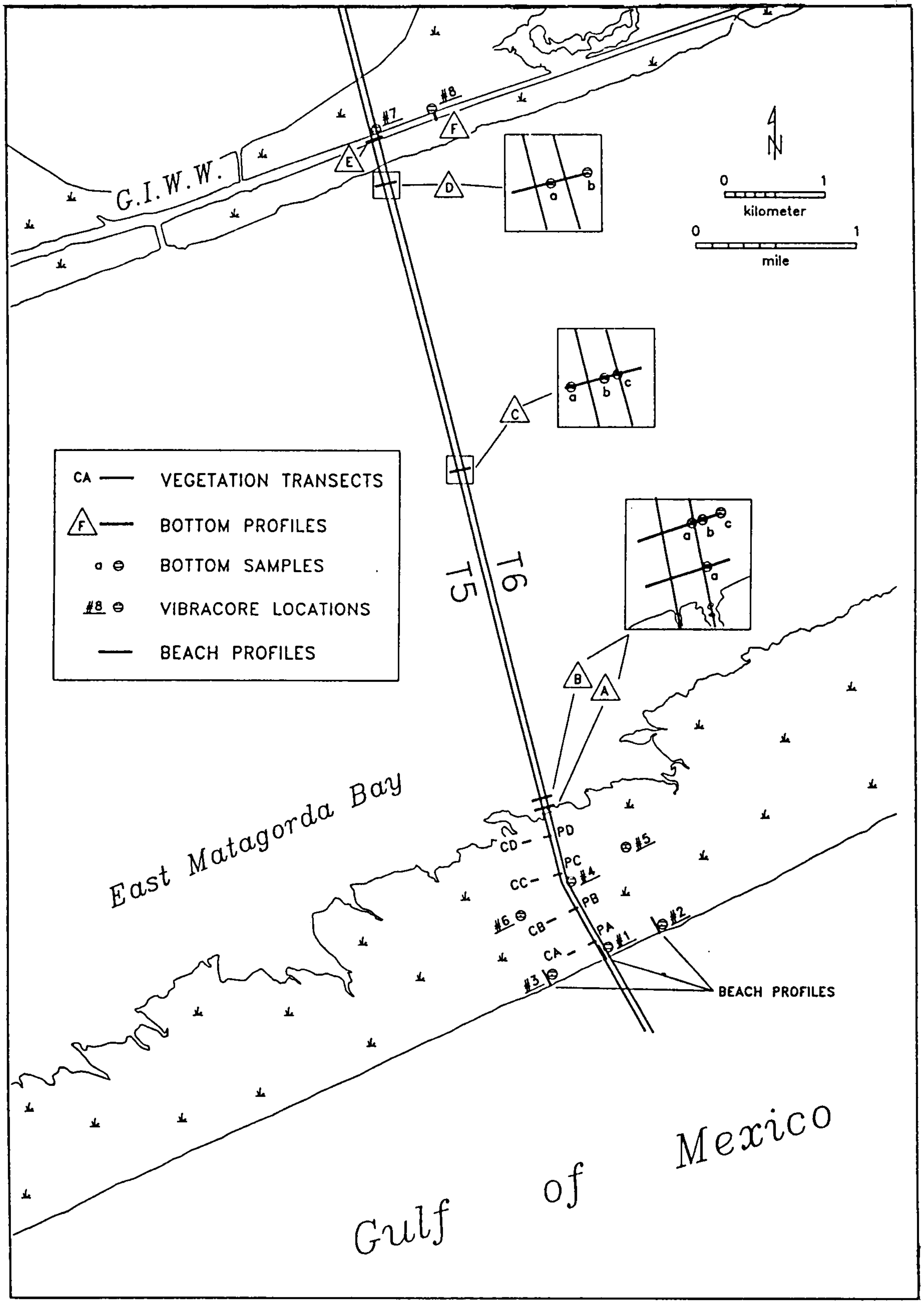


Figure 7.8. Location of field sampling stations in the Texas Barrier Island System.

1.8 m in thickness. Foresets are steeply dipping (25-34 degrees) with thicknesses ranging from 1.3 to 5.1 cm. Dunes are locally stabilized by vegetation. Areas with little or no vegetation are often susceptible to blowouts (Morton et al. 1976).

Washover channels and fans are abundant throughout Matagorda Peninsula and are frequently observed within the study area. The channels and fans occur as a consequence of the passage of storms and hurricanes and the associated transport and deposition of sand into the back beach area washover deposits consist of fine to very fine horizontally laminated sand, often locally burrowed.

Landward behind the beach and adjacent to the washover deposits is the shell ramp-barrier flat environment. This environment results from hurricane and tropical storm activity. Sand and shells are transported onshore during storms and accumulate as a narrow coastwise ridge sloping gently landward. Deposits consist generally of a mixture of fine-grained sand, shell, and rock fragments becoming finer grained towards Matagorda Bay. A low hummocky topography exists between the shell ramps and the vegetated flats.

The modern barrier sands at vibracore locations #1 (T6 ROW), #2 (East Control), and #3 (West Control) all showed comparatively similar compositions and textures. There was no observable variation in physical characteristics between the control beach stations and the ROW beach stations. To further evaluate possible impacts, beach profiles were established at vibracore locations #1, #2, and #3 (Figure 7.9). Beach profile #1 was established along the axis of the pipeline corridor while profiles #2 and #3 were established along control site localities. Variation in slope occurs within the beach zone of profile #1 compared to profiles #2 and #3. The control profiles demonstrate a well-developed forebeach sloping seaward and a backbeach which slopes gently landward. Conversely, the pipeline ROW profile exhibits a simple forebeach sloping much more gently than the control counterparts. Simple forebeach profiles, without the development of a backbeach, have been observed locally throughout the peninsula, however, indicating that the variation in profiles is more likely the result of natural physical construction. All three profiles show a comparative similarity in the development of seaward-sloping berms and the development of slowly landward-rising, low, discontinuous dunes.

Transitionally grading landward from the shell ramp-barrier flat environment is the vegetated flat depositional environment. Vegetated flats are composed primarily of fine sand, silt, and clayey silt with local layers of organic detritus. Sediments are generally horizontally laminated and exhibit locally abundant plant roots and burrows.

The marsh environment occurs at or near mean sea level. The marsh is saline but vegetation composition varies according to local salinity conditions. The sediments consist predominantly of silt and silty clay with in situ and detrital organic material. Marsh deposits display intense bioturbation from burrows and plant roots.

No observable variation in texture or composition of sediments occurred between the vegetated flat control environments and the sedimentary environments found within the T6 pipeline ROW. Where the pipeline ROW was dredged through the back barrier marsh, the canal was subsequently infilled with sediments composed of very fine sand and silt, conspicuously variant from the silt and silty clay of the surrounding marsh. No evidence of ROW erosion of barrier segmentation was visible, however, as a consequence of this change in composition. Rather, sediments within the ROW exhibited environmental continuity with the surrounding marsh.

Variation in sediment composition occurred between the marsh clays along the GIWW and the pipeline ROW, which is composed of dredge spoil sediments (vibracores #7 and #8).

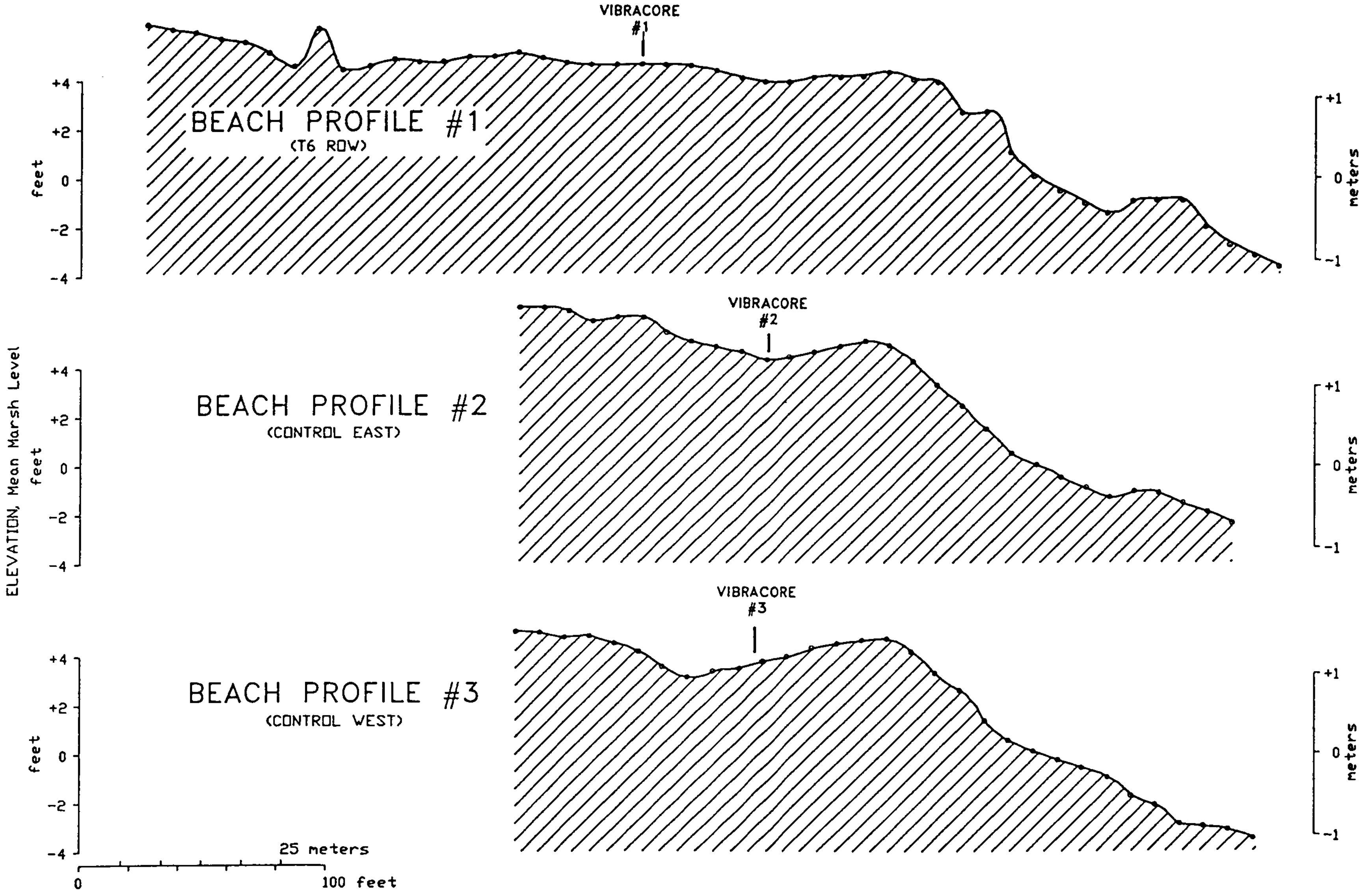


Figure 7.9. Beach profiles on Matagorda Peninsula at the T6 pipeline crossing and two parallel control locations east and west of the ROW.

These dredge spoil sediments are composed of silts and silty clays and are more highly compacted than the marsh clays. The present emplacement of a gravel wall in front of the dredge spoil on both sides of the canal is intended to prevent erosion at the pipeline crossings.

The previously described depositional environments are physically consistent with the overall regional depositional history and stratigraphic framework of the Matagorda Peninsula. Furthermore, the sediments within the subsurface of the pipeline corridor are texturally, compositionally, and stratigraphically equivalent to the adjacent subsurface stratigraphy. Vibracore #4 (T6 ROW), positioned further landward at the marsh contact, also displays a continuous sequence of fine sand with the exception of a small unit of silty clay, ultimately derived from the vegetated flat depositional environment. Grain size analysis shows no textural variation with depth in either core, establishing textural continuity along the corridor. Lithologically, the sediments in both cores maintain the same physical characteristics and reveal no observable variation in sedimentary structures. There is no subsurface facies variation between vibracores #1 and #4.

Vibracores #2 and #5 (East Control) exhibit identical textural and structural characteristics. A small unit of silty clay is observed in vibracore #5, again derived from the vegetated flat depositional environment. The sediments in vibracores #2 and #5 are stratigraphically equivalent and indicate no subsurface facies variation. Additionally, these sediments are stratigraphically equivalent to those sediments examined in vibracores #1 and #4, again revealing no subsurface facies variation.

Comparison of the stratigraphy in vibracore #1 and the control vibracores #3 and #2 shows that fine-grained sands are vertically continuous in all of the cores with no observed variation in sedimentary structures. Grain-size analysis indicates no textural variation with depth throughout this section. The sediments within this section are all texturally and compositionally similar, stratigraphically correlative, and exhibit no subsurface facies variation.

It has been hypothesized that pipeline installation through this barrier island will directly or indirectly impact the geology of this system by accelerating shoreline erosion, creating areas vulnerable to (1) storm overwash and breaching processes, (2) development of sediment sinks, and (3) segmentation of the island system, thereby destroying island integrity.

The study area along the pipeline corridor exhibits a well-developed set of foredunes which are vegetated and appear geologically stable. The beach profile along the pipeline corridor shows a characteristic similarity in beach slope with those profiles taken along the control transects. No escarpments were observed. However, the area remains largely unvegetated. Although breaching and storm overwash may occur within this region, the T6 ROW area is more susceptible to these impacts than the natural undisturbed environments observed at the control locations. Sediments within the pipeline corridor are not any more unconsolidated than sediments in the control areas. The composition, texture, and stratigraphic equivalence of the sediments is comparable and consistent throughout the study area, indicating that the pipeline corridor is no more affected by waves and storms than the natural environments. Rather, sediments within the pipeline corridor will undergo the same rate of shoreline erosion and experience the same degree of storm impact.

The sedimentologic data and stratigraphic relationships previously described reveal that a weak area at the T6 pipeline corridor has not formed. Pipeline installation has not changed the lithologic and textural characteristics and has not yielded an area of unconsolidated sediments. Creation of new tidal inlets has not resulted as a consequence of the installation of these two pipelines and an associated disruption of longshore sediment transport has not occurred. The sediments within the pipeline corridor exhibit the same degree of vulnerability to storm overwash and breaching as observed in the naturally developed environments.

The pipeline construction techniques of push-pull ditch and backfill were used within the study area. As a result, the pipeline corridor has been backfilled with sand that came from the original excavation. The corridor will not accumulate any more sand from the barrier system other than from natural washover processes. No impact to the littoral drift system has occurred and sand movement along the shore is uninterrupted. Accordingly, sand is not lost from the system but remains an integral part of the island. Weak areas, or areas of increased vulnerability, are not a consequence of pipeline installation and, therefore, the development of new tidal inlets through the corridor is unlikely. Segmentation of the island has not resulted from pipeline construction, and barrier island integrity has been maintained. The pipeline corridors within the marsh area north of the GIWW have been filled with dredge spoil sediment which is impounded by a gravel wall on either side of the waterway. Water flow patterns have not been changed at this location, nor is there any evidence of erosion due to an increased land-water interface.

Geologic data obtained from the area of construction of pipelines reveals that no significant direct or indirect impacts affecting the local morphology, subsurface stratigraphy, or the associated physical, coastal processes of longshore sediment transport, overwash, accretion, and erosion have occurred. Pipeline installation has not affected the natural geologic development of this island system.

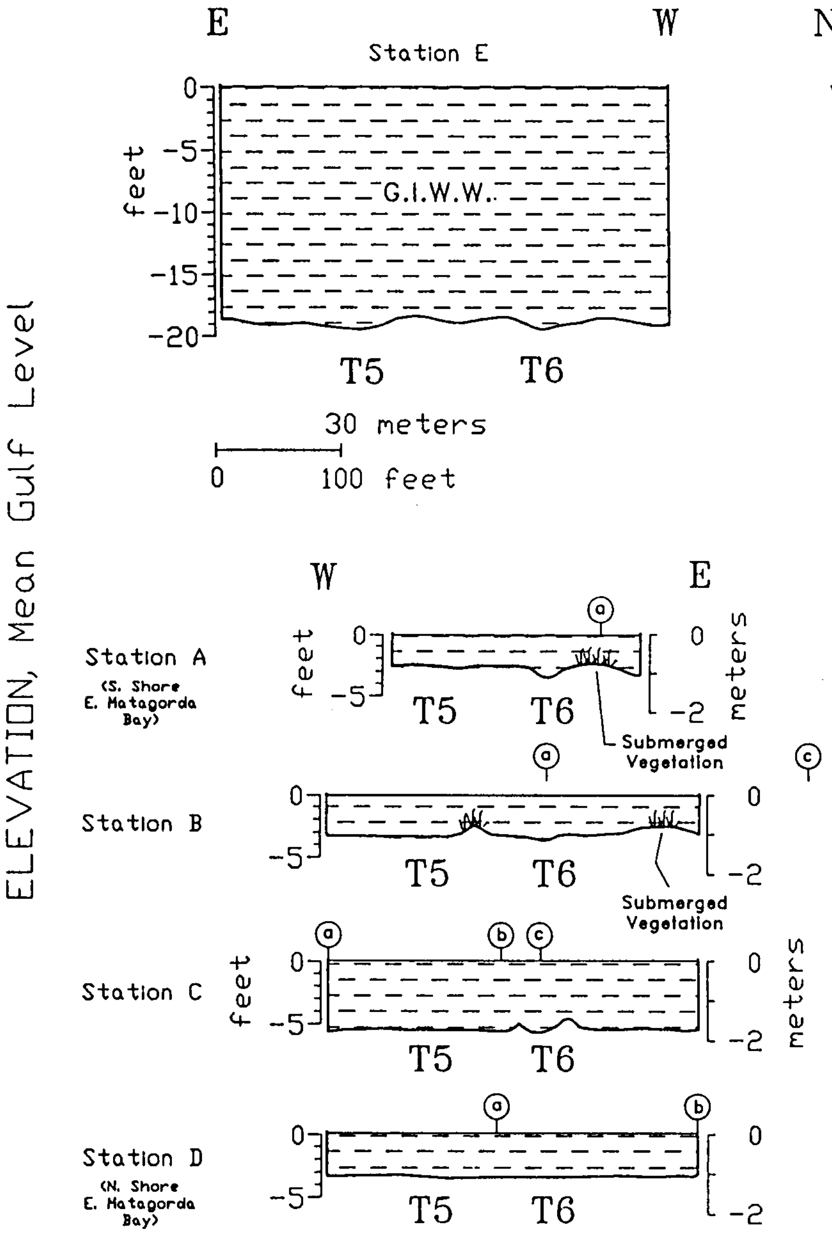
Hydrologic Impacts

Given the environmental setting and the construction techniques for T5 and T6, there are two specific hypotheses of hydrological impact to the study site. First, incomplete restoration of the ROW's in the intertidal zone of the peninsula would result in ridges and depressions that would influence the flooding and draining of the marshes outside of the ROW's. Secondly, incomplete restoration of the ROW's in the bay would result in impacts to water circulation because of linear spoil shoals perpendicular to the predominant currents. Successful restoration of the ROW's will result in no hydrological impact.

The field site was visited on July 21 and 22, 1987. The major length of T5 and T6 on the peninsula was walked and field observations were recorded. Observations were also made on a control area 304 m west of the ROW's. A series of fathometer profiles were taken across the ROW's in the bay (stations A-D) and in the GIWW (stations E-F) (Figure 7.10). Observations of current speed and direction were made with a current drogue and turbidity was measured with a secchi disk.

During the field study, the wind was light and variable from the south with scattered thunderstorms. Water in the bay was sandy to greenish in color with a light chop. Water visibility ranged from 0.42 m at the peninsula, to 0.52 m in mid-bay, to 0.30 m along the north shore. The tide stage was approximately 0.09 m above the level of the salt marsh.

Ground observations of the T5 ROW showed a series of small, rounded, enclosed pools ranging from 0.30 to 0.60 m in depth. The edges were well vegetated and raised areas were not noticed within the intertidal wetland zone. The bay shore exhibited a 6.09-m-wide inlet that continued inland as a small canal. The edges of the canal were well vegetated. The T6 ROW was very sparsely vegetated, exhibiting a large expanse of sand



GRAIN SIZE

Station A

	ⓐ
sand	90%
silt	69%
clay	49%

Station B

	ⓐ	ⓒ
sand	85%	88%
silt	10%	12%
clay	59%	--

Station C

	ⓐ	ⓑ	ⓒ
sand	22%	35%	19%
silt	27%	16%	30%
clay	51%	49%	51%

Station D

	ⓐ	ⓑ
sand	32%	53%
silt	46%	31%
clay	22%	16%

Figure 7.10 Bathymetric profiles along the T5 and T6 ROW in East Matagorda Bay and the GIWW.

which graded into a large, shallow (0.30 m) pond. Within the pond were several small hummocks of marsh surrounded by semi-submerged sand flats. Conditions in the control area can be described as irregular zones of moderately thick, emergent vegetation, thinning laterally into irregular shallow pools. The bottoms of the pools were covered with thick mats of blue-green algae. The results of these qualitative observations indicate that only minor impacts to hydrology have occurred on the peninsula due to pipeline T5. The potential exists for the interconnected pools on the T6 ROW to become a permanent drainage coarse to the bay. However, if the vegetation spreads onto the flats, entrapment of sediment could prevent the formation of a tidal channel. As noted previously, these pools are in the vicinity of a marsh pond which existed prior to T6 emplacement.

The fathometer profiles located in the bay are presented in Figure 7.10. Station A shows conditions on the ROW's 61.0 m from shore. The water depth is consistently 0.76 m except for T6, where the depth drops to 0.91 m. Submerged grass beds were evident in depths of 0.76 m or less. Station B, taken 152.4 m from the shoreline shows a general 0.97-m depth. Remnant spoil and light depression characterizes T6. This pattern is also evident at Station C in the center of the bay. At the north bay shore there is no evidence of the ROW's 152.4 m from shore. Maximum wave energy occurs at this portion of the bay.

Stations E and F are included to show the relative range of depth between the GIWW and East Matagorda Bay. The T5 and T6 crossings of the waterway are noticeable but insignificant with regard to water flow. Analysis of field data indicates that construction of T5 and T6 has not had a permanent impact on hydrologic conditions on Matagorda Peninsula or in East Matagorda Bay.

Vegetative Impacts

Field studies in Texas centered around factors that determine vegetation community distribution and plant productivity in a region influenced by several factors such as climate and freshwater input. Sampling was conducted in a manner to determine pipeline impacts, both direct and indirect on community structure and community productivity. Hypothesized impacts at the site were: (1) direct destruction of dune habitat from initial construction, (2) change in plant communities as a result of lowered elevations, (3) direct destruction from construction through marsh and seagrass habitats, (4) reduction or disappearance of seagrass communities because of increased turbidity and/or bottom depths.

The pipelines (T5 and T6) were inspected in the field from their origin on the beach to their junction with the mainland before setting transect locations (Figure 7.8). Transects were at locations believed to represent areas of possible impact on the major vegetative communities. A control transect was placed 304 m west of T5, a distance far enough away to be beyond the effects of the pipeline. Transects were located to cover each type of habitat which occurred on the barrier peninsula: (1) fore-dune, (2) back dune, (3) irregularly flooded marsh, and (4) salt marsh. On inspection of the ROWs for T5 and T6, it was discovered that little vegetation was evident on the T6 ROW, the line emplaced in 1985, so much so that the sampling technique to be used would have been of little value. Therefore, only the T5 transects were taken to compare with the control sites. For each transect (four pipeline and four control), five stations were sampled. Two replicates were taken at each station.

Two sampling methods were used to study impacts on each of the two hypothesized effects of pipelines on the peninsula, effects on community structure and community productivity. The first method was an estimate of percent cover by species within a 1-m^2 quadrant. At each sampling station, a 1-m^2 quadrant was randomly placed on either side of the transect line and all species present were recorded and cover percentages estimated by the same individual. Two replicate plats were taken at each station. The second method, which was used to evaluate community productivity, was clip-plots to estimate standing crop. At each replicate, a 1/16-m^2 (0.0625 m^2) plot was clipped, bagged, labeled, and returned to the laboratory, where they were dried, individually weighed, and recorded.

In addition, visual observations were made along the pipeline corridor in East Matagorda Bay. Random seagrass sampling with a long-handled rake was performed for approximately 150 m on either side of the corridor. The only grass beds noted were of Halodule sp. located on either side of the corridor approximately 35 to 70 m east and west of the pipelines (Figure 7.10). Water depths and secchi depths were recorded in the vicinity of these beds as well as across the entire bay.

Data on vegetation standing crop at T5 and control locations were analyzed statistically. The means and 95% confidence limits were calculated and a series of paired t-tests were performed on T5 and control locations in dune (PA and CA), barrier flat (PB and CB), irregularly flooded marsh (PC and CC), and salt marsh (PD and CD) zones.

As noted in the previous discussion of hydrologic impacts, there was an obvious difference in the vegetative cover of the T5 and T6 ROW. The 24-month-old surface of T6 was essentially barren as compared to the 16-year-old surface of T5. In the Willingham et al. (1975) study of T5 in the fall of 1973 when the ROW surface was two years old, a similar lack of vegetation was found in the salt marsh zone of T5 at that time.

The vegetation data for the T5 and control transects is shown in Table 7.3. The dominant dune species in common for T5 ROW (PA) and the control site (CA) are sunflower (Helianthus sp.) and bitter panicum (Panicum amarum). Sesbania (Sesbania macrocarpa) is abundant at PA but rare at CA. On the barrier flat seashore dropseed (Sporobolus virginicus) is dominant, followed by Gulf searocket (Cakile sp.) for both transects (PB and CB). PB has the largest number of species recorded in this field study (11). In the irregularly flooded marsh zone (salt flat), saltgrass (Distichlis spicata) and Virginia swampfire (Salicornia virginica) predominate at PC, while smooth cordgrass (Spartina alterniflora) is dominant at CC. In the salt marsh zone the dominant species are smooth cordgrass and Virginia swampfire for PD and CD, respectively.

Both of the marsh zones represented here are very "patchy," and, as discussed previously in the hydrology section, the habitat is a reticulated series of pools and marsh. The patchiness is evident in the standing crop data (Table 7.3) as very large 95% confidence intervals (9 degrees of freedom). The confidence interval exceeds the means for the two dune transects. These results are graphically presented in Figure 7.11. Although it appears that the mean standing crop, as well as the percent "no cover," for T5 exceeds that for the control transect at all stations, this trend is not statistically significant at the 0.05 level of probability (Table 7.3).

In summary, it appears that the T5 ROW has returned to its previous vegetational state, while the T6 ROW is just beginning to revegetate. The Willingham et al. (1975) study mentioned earlier groups the site into "dune" and "marsh" zones. In the fall of 1973, the standing crop (live) for the dune control was 227 g/m^2 versus 422 g/m^2 for the ROW dunes (Willingham et al. 1975: Table F-3). To be comparable as to zone, we use our data for the barrier flat for summer 1987, indicating 275 g/m^2 control versus 373 g/m^2 ROW. In two

Table 7.3. Vegetation Data and Analysis for the East Matagorda Field Site (Matagorda Peninsula).

	% Cover of Species by Transit and Station*							
SPECIES	PA	CA	PB	CB	PC	CC	PD	CD
UNVEGETATED	59.2	85.7	18.5	33.9	20.4	64.2	6.7	16.3
DUNE SPECIES								
Cakile sp.	0.5		13.0	16.5				
Helianthus agrestis	15.1	9.2	0.8	11.9				
Panicum amarum	9.1	4.1						
Sesbania macrocarpa	13.6	Tr.	4.9	4.7				
Spartina patens	2.5	0.5	5.7					
BARRIER FLAT SPECIES								
Sporobolus virginicus	Tr.		17.1	29.0				
Sesuvium portulacastrum		0.5	8.2					
Croton punctatus			Tr.					
Solidago sempervirens					1.0			
Lycium carolinianum			0.8					
Monanthochloe littoralis			2.4		9.4	2.5		
Setaria glauca			4.9					
Phyla lanceolata				4.0				
Limonium nashii					Tr.			
MARSH SPECIES								
Spartina alterniflora					11.5	22.9	44.7	14.4
Distichlis spicata			23.6		23.0		11.3	11.0
Salicornia virginica					20.9	5.2	28.8	52.4
Batis maritima					13.6	5.2	8.5	5.9
	Standing Crop (g/m2)							
	% Species at Sampling Station							
Mean	53.6	45.8	373.0	275.6	451.8	188.3	939.4	821.6
95% C. I. (+/-)	54.6	68.4	216.5	76.9	306.7	103.0	187.7	201.2
Mean (Xn - Yn)	7.7		97.1		263.5		117.8	
Paired t value	0.186		0.989		1.886		0.776	
Prob. (2 tailed)	0.8565		0.3487		0.0919		0.4579	

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* PA-PD: T5 pipeline transect
CA-CD: T5 control transect

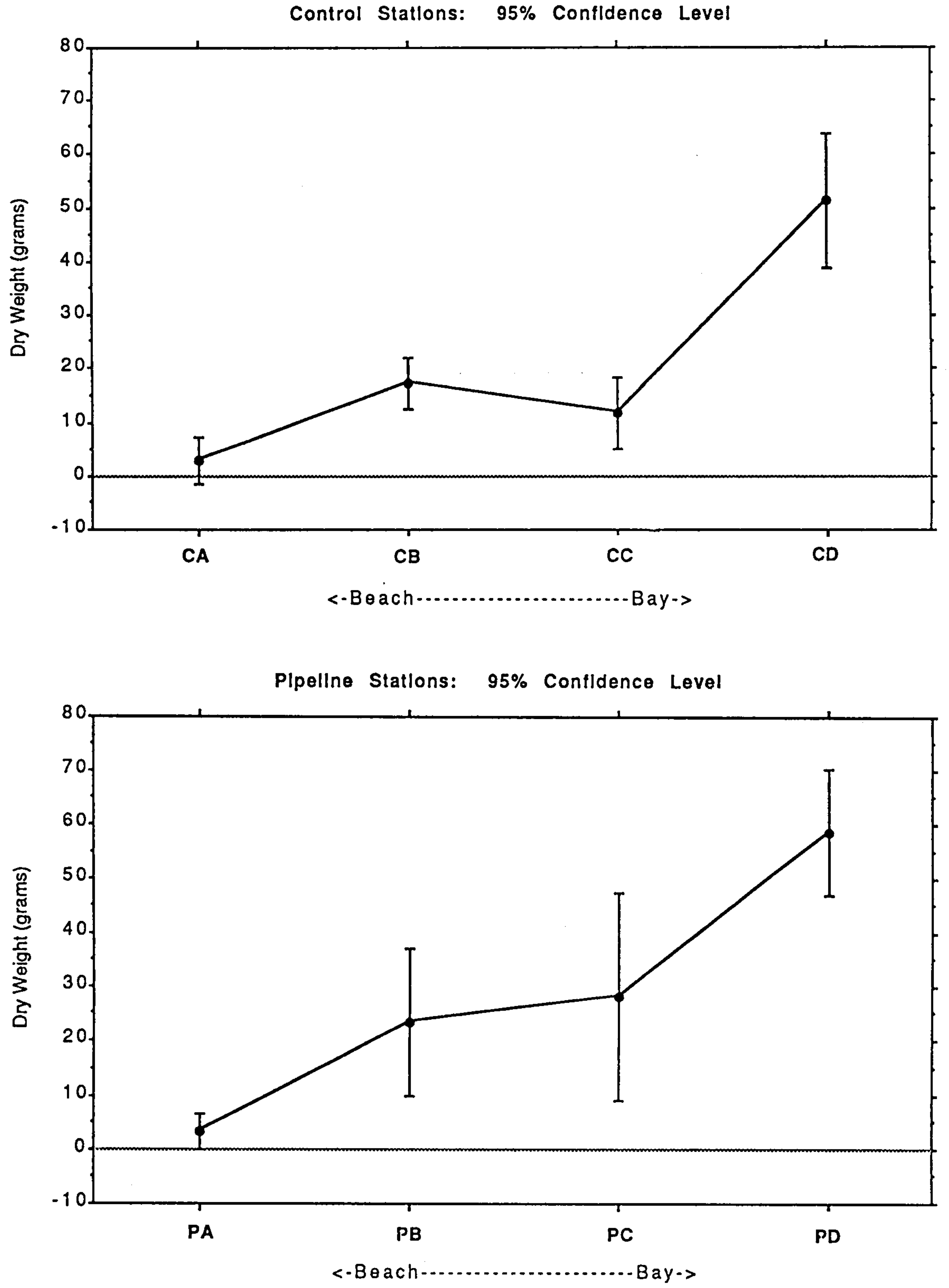


Figure 7.11. Mean and 95% confidence levels for T5 pipeline ROW and control station vegetation sample dry weights, Matagorda field site.

years (1971-1973), the T5 dunes had revegetated and remained essentially the same 14 years later.

In the marsh zone, Willingham et al. (1975: Table F-2) measured 959 g/m^2 control and 0.0 g/m^2 ROW. In the present study, we measured 822 g/m^2 control and 939 g/m^2 ROW for the marsh zone, indicating that the ROW has returned to its original productivity. The review of previous data for this site (Willingham et al. 1975) indicates that the dune and barrier flat zone on the T6 ROW should have revegetated by the time of this field study. However, this has not occurred.

Strandplain-Chenier Plain System

Site Description for L23, L24, and L25

The barrier beach environment east of the mouth of the Mermentau River in Cameron Parish, Louisiana was chosen as a representative field study site for the Strandplain-Chenier Plain System. The site lies 6.4 km east of the Mermentau to Gulf of Mexico Navigation Channel at latitude 29°43'N, longitude 92°58'W. Three OCS pipelines (L23, L24, and L25) and one OCS-related navigation channel were inspected (Figure 7.12), with the latter site being discussed in Chapter 8.

The geologic history of the area is discussed in Chapter 6. Initial development of the Chenier region began approximately 3,000 years B.P. after sea level had reached its present position (Gould and McFarlan 1959). The plain consists of a seaward-thickening wedge of sediments composed of muds and sets of generally shore-parallel ridges of sand and shell hash. The sequence of sediments reflects changes in the location of the Mississippi River subdeltas near the plain. Sedimentation fluctuates between periods of mud flat/marsh progradation and shoreline erosion, producing the isolated sand and shell lenses or "cheniers." The Atchafalaya River presently supplies large amounts of mud to the western Louisiana coast, and accordingly, many areas within the Chenier Plain coast are actually prograding. Within the study area, however, the local shoreline is experiencing erosion and displays a thin beach composed of sand and shell hash fronting an extensive marsh.

The vegetation zones to be described at this field study site are limited by the project scope to the beach berm and the adjoining sea rim marsh. Vegetation on the berm is very sparse to nonexistent because of the rapid inland movement of the beach zone. At the leading edge of the sand overwash, the zone of high, saline sea rim marsh begins. The composition of this marsh includes marshelder, sea-oxeye, saltgrass, saltwort, hogcane, and smooth cordgrass (Nichols 1959b).

Tides are mixed diurnal but show a tendency toward a semi-diurnal component. The tidal range of 0.76 m is the highest in the northern Gulf of Mexico. The average wave height is 0.6 to 0.9 m with wave trains predominantly from the southeast. This sets up westerly longshore currents of 0.3 to 0.5 m/sec.

A large quantity of fine-grained sediments, derived from the Atchafalaya River and its newly formed delta, are carried across the study area by the longshore current. Although these sediments are too fine to accumulate on the beach, frequent overwash introduces them to the inland marshes, resulting in an elevated sea rim marsh and an infilling of small lakes, ponds, canals, and drainage bayous.

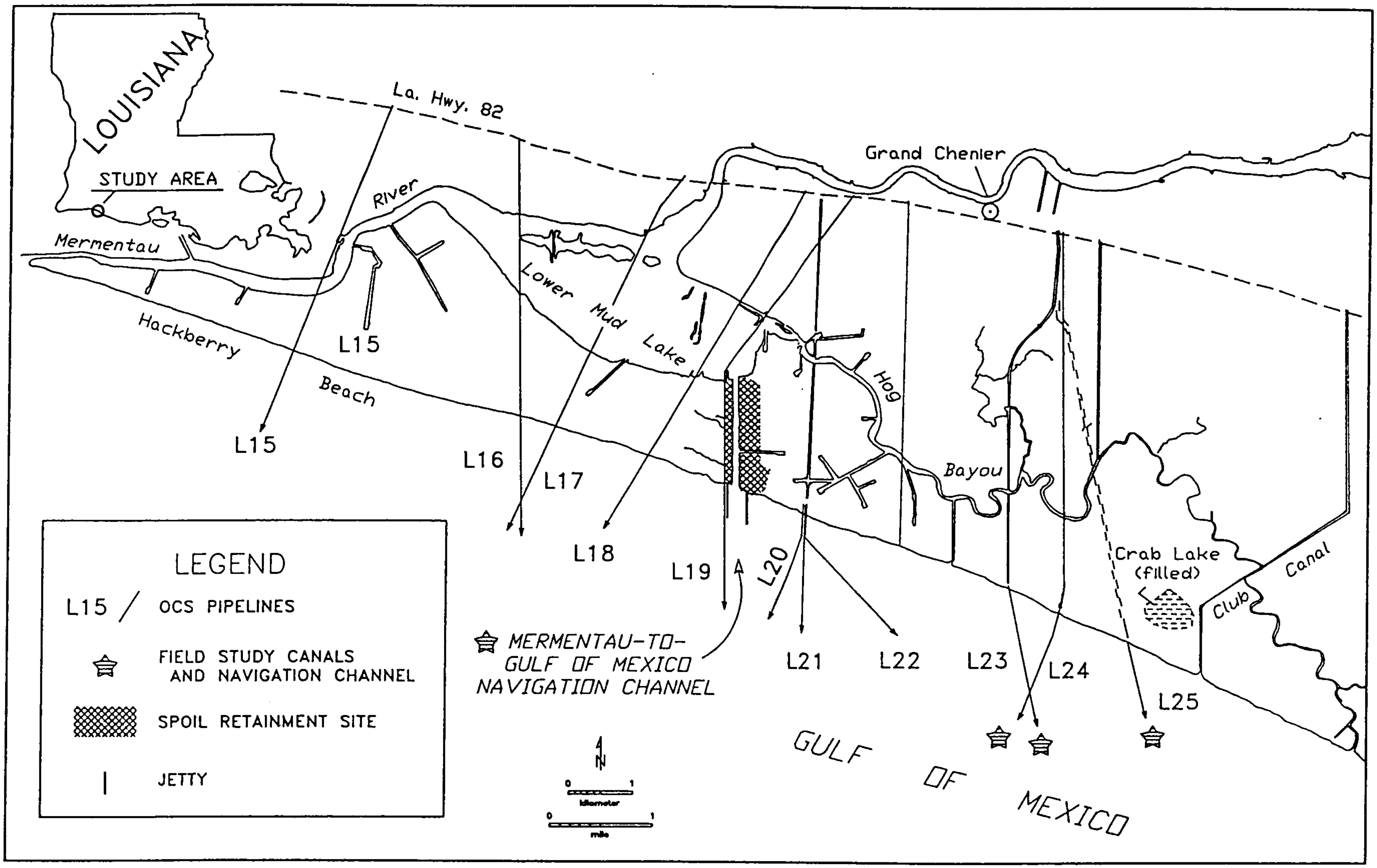


Figure 7.12. Location of field sampling sites in the Strandplain-Chenier Plain System.

History and Interpreted Changes

Location, accessibility to site, ability to locate lines, and type of construction were the primary factors considered when selecting these three pipelines for photo and field analysis. Two of the lines (L23 and L24) were 26-in gas lines operated by one company, Tennessee Gas Pipeline Company, while the third (L25) was a 4-in oil line operated by Mobil Exploration and Producing Southeast, Inc. No printed documentation such as "as-built maps," permit applications, or description of construction techniques were available from these two companies for their pipelines.

Historic data on L23 was obtained from conversations with Tennessee Gas personnel. They confirmed that one of their 26-in lines (L23) was the Kinder-CATC Line from East Cameron Block 49 installed in July 1958 using a flotation canal. The canal was probably dredged by a dipper dredge mounted on a 42 x 15 m barge (Jones 1988).

Bulkheads were installed across the L23 canal near the beach and at regular intervals as it crossed the marsh, probably at the request of the landowner (Jones 1988). A continuous spoil embankment was left along both sides of the canal for the entire marsh crossing.

Field inspection in April 1988 revealed that culverts were placed through these levees at least near the beach to permit drainage from the marsh into the canal. Approximately 182 m north of the beach, an abandoned windmill and concrete water trough for cattle was located on the east spoil bank just south of a bulkhead. The bulkhead consisted of two parallel rows of timber with a dirt and shell fill that provided a walkway for cattle crossing the canal. The spoil banks were covered by marshelder and eastern baccharis and heavily rutted by cattle hoof prints, which provided excellent breeding habitat for hordes of mosquitoes.

At the time of the April 1988 site inspection, the canal between this bulkhead and the beach was completely filled with fine-grained sediment. The southern half of the canal was vegetated by smooth cordgrass (Figure 7.13) and the northern half, up to the first bulkhead, was bare mud with one clump of smooth cordgrass and a meandering drainage path in the center of the filled channel (Figure 7.14). Sediment lay at the base of the north side of the bulkhead, but the remainder of this northern segment of the canal contained water.

The tide level at the time of field inspection was very low and there was no standing water on the high sea rim marsh. A sand body, about the same width as the beach, overlaid the sediment-filled canal at the shore. A wooden bulkhead, originally constructed on this canal, inland from the gulf, was located offshore, and no new bulkhead had been constructed.

The second pipeline, L24, is also a 26-in gas line operated by Tennessee Gas Pipeline Company. It was constructed in December 1968 and is known as the Kinder-CATC Line No. 2 originating in West Cameron Block 192. This line extends through the salt marsh east of and parallel to L23. The line was put in place using a push-pull ditch method in the marsh south of the Chenier Ridge but the push point at the beach crossing is comparable to that of the flotation canal at the L23 crossing.

A bulkhead-cattle walkway combination, like the one on L23, was constructed at the juncture of the push-pull ditch and flotation canal. It was about 12 m long x 8.5 m wide, and consisted of two walls filled with material capped by shells. As the shore retreated landward, an ambulatory sand beach moved inland over the sediment-filled canal.

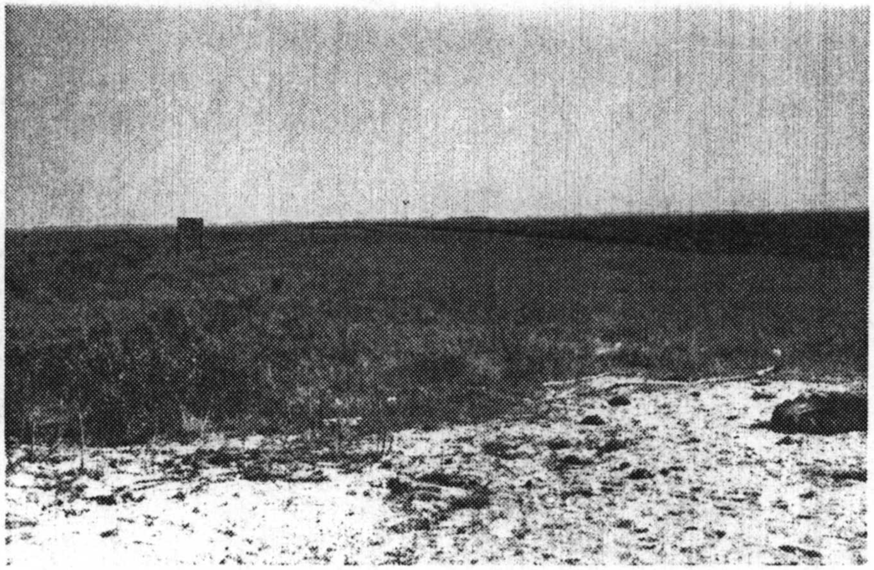


Figure 7.13. L23 line: flotation canal refilled with beach over-wash material from Gulf and revegetated by salt marsh. Bulkhead in center with spoil to left and right of canal.

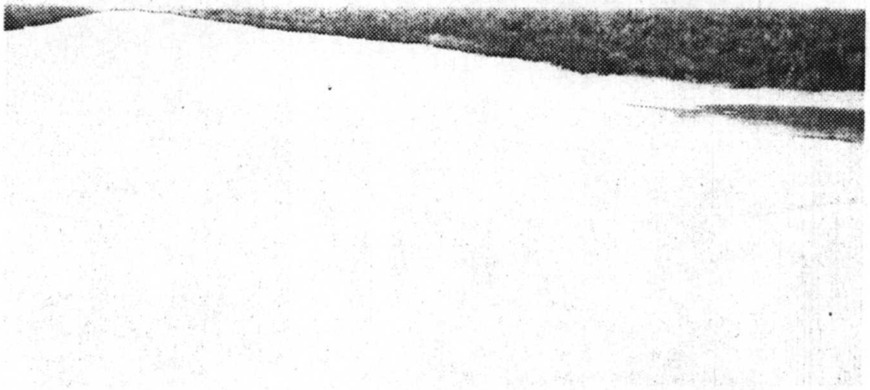


Figure 7.14. L23 line: sediment filled flotation canal now being colonized by salt marsh on its gulfward end.

This push-point canal was measured to be approximately 32 m wide and 116 m long in April 1988 and the canal depth in front of the plug had shallowed to about 0.30 m. The rapidly migrating natural beach berm plug at the gulf shore consisted of unvegetated sand and shell fragments overlying the filled canal and was about 43 m wide (Figure 7.15). Continuous spoil banks about 33.5 m wide and covered with marshelder flanked each side of the push-point canal.

The push-pull ditch north of the bulkhead-cattle walkway was approximately 8 m wide. Circular, mounded spoil piles were deposited parallel to the ditch and were about 15 m wide. These were lower than the push-point ditch banks and were also covered by marshelder. In April 1988, the push-pull ditch was a bare mud flat with wiregrass and smooth cordgrass along the inside banks of the ditch (Figure 7.16).

The third line studied in the Strandplain-Chenier Plain system is a 4-in oil line (L25) constructed in 1970 and operated by Mobile Exploration and Producing Southeast, Inc. The line originates in East Cameron Block 9 with extensions to Block 14 and goes to the Mobil Processing Plant at Grand Chenier. The only available records on this line indicate that it has a 61 m permanent ROW and a minimum of 0.9 m of cover.

Field observations reveal that this ROW represents a unique restoration project in that the push-pull ditch has been backfilled to form a continuous levee from the beach to Grand Cheniere. This levee serves as a cattle walkway across the marsh and was probably constructed at the request of the property owner. The levee was constructed using material dredged from alternating borrow pits about 152 m long and 15 m wide which parallel the pipeline ROW centerline. In 1988, this levee ranged between 0.30 and 0.46 m above marsh level and was covered by short marshelder shrubs.

Shore erosion across the front of this pipeline ROW reveals a cut through the marsh substrate which is probably that of the east borrow pit (Figure 7.17). This cut is about 13 m wide at the gulf edge. At low tide about 14 m of marsh shelf is exposed in front of the shore-beach berm. This borrow pit has been filled with overwashed material and is recolonized by smooth cordgrass behind the sand and shell beach. The push-pull ditch is not visible in the exposed marsh shelf but spoil from the borrow pit to the east, when placed over the push-pull ditch, is visible as a more resistant clay mass overlay in the marsh substrate.

In plan view, the beach-berm is narrowest (about 22.3 m) at the front of the levee (L25 ROW) and ranges from about 46 to 58 m on either side of the spoil levee (Figure 7.18). The beach-berm over the borrow pit has the same unvegetated condition as the beach berms and the push-point and flotation canals. The backfilled ditch remains elevated as a levee and is vegetated by marshelder (Figure 7.19).

Analysis of relatively small scale (1:21,495 to 1:32,700) aerial photographs (Tobin 1955, NASA 1974, 1978, 1985) reveals that, with time, the flotation canal (L23), push-point ditch (L24), and backfilled canal borrow pits (L25) became filled with sediment at their juncture with the Gulf and are covered by a sand-shell beach approximately as wide as the adjacent beach area (Figure 7.20). A photograph of L23 and L24 taken from a lower altitude photograph (ASCS 1980) illustrates the process of rapid overwash of the marsh by the relatively thin layer of sand and shell beach material (Figure 7.21). At low tide, the denuded marsh substrate is exposed to the waves shoreward of the beach. The beach is narrow at the site of spoil banks and wider within the canal and along the adjacent shoreline.

Figure 7.15. L24 line: beach overlying sediment filled push point (flotation canal) cut through beach and marsh in front of push-pull ditch. At low tide the cut through the marsh substrate is exposed at the shore.

Figure 7.16. L24 line: push-pull ditch filled but unvegetated north of bulkhead. Spoil mounds are located to right and left of ditch.

Figure 7.17.

L25 line: cut through marsh substrate that is probably the borrow pit east of the backfilled ditch. The cut has filled with overwash materials overlain by a thin sand-shell beach.

Figure 7.18.

L25 line: looking west on beach sand over the high sea rim marsh and low levee constructed over the back-filled push-pull ditch.

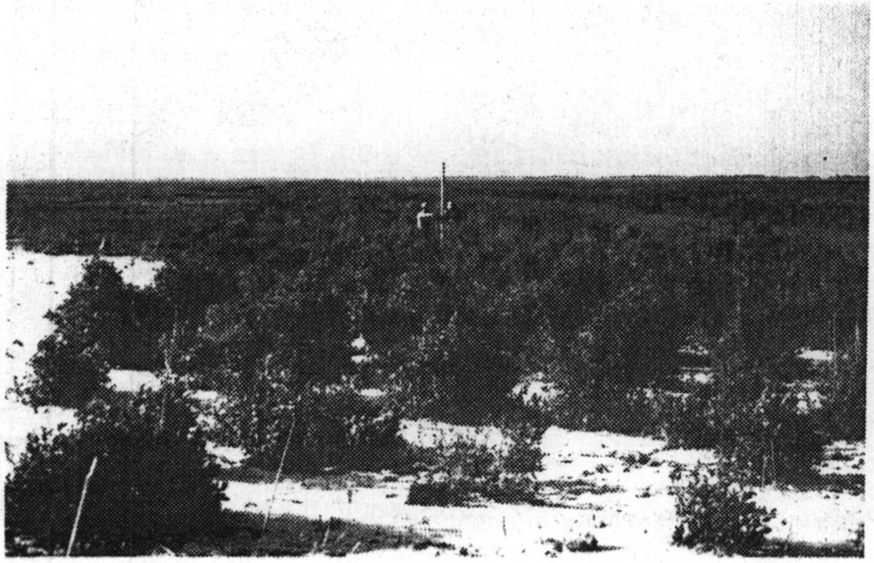


Figure 7.19.

L25 line: looking north along shrub-covered levee constructed over push-pull ditch. Location of one core site is in center of photograph.

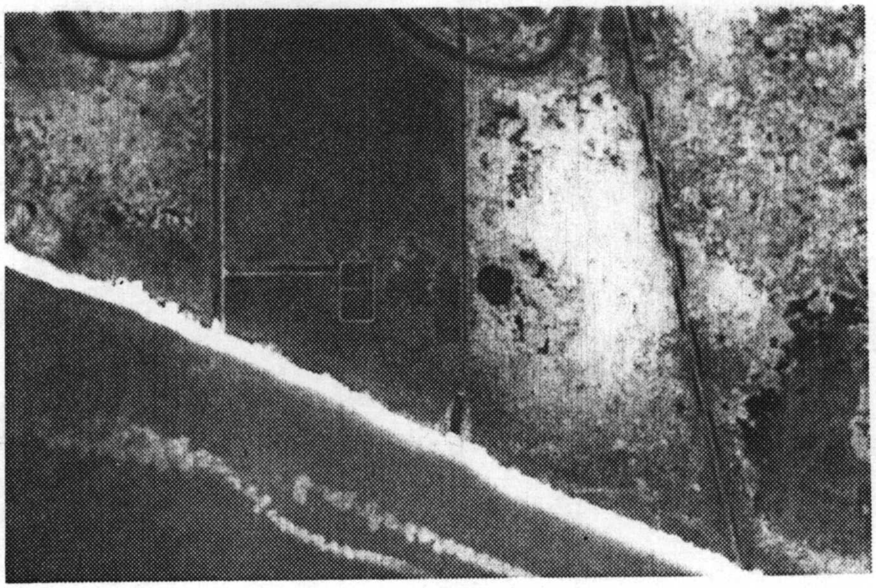


Figure 7.20. Beach formation over mouths of three pipelines (L23, L24, L25, west to east, respectively) emplaced with different construction techniques.

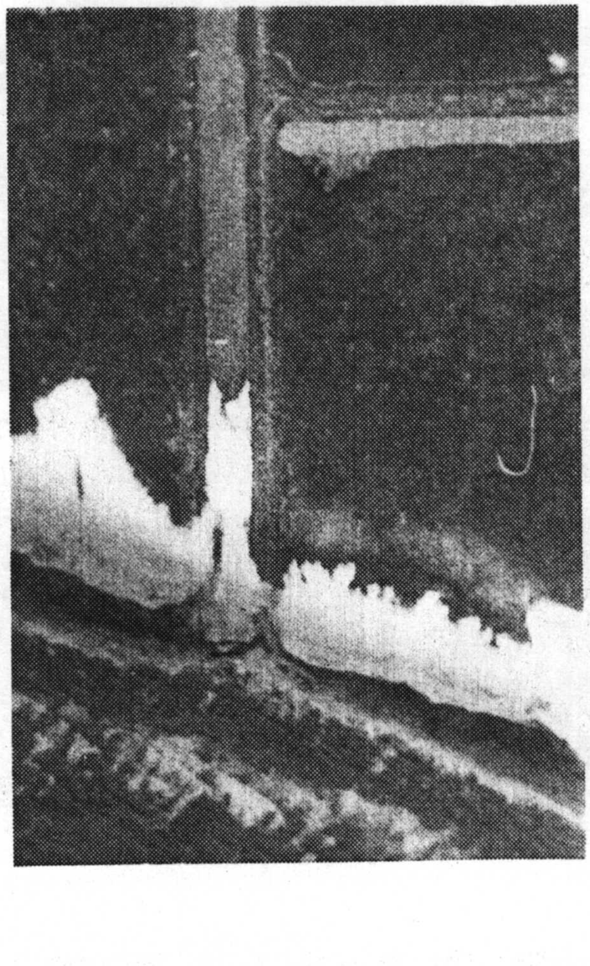


Figure 7.21.

1960 photograph showing rapid shoreline erosion of beach material onto high sea rim marsh, and infilling of flotation (L23) canal. Marsh substrate is exposed seaward of beach and canal cut through this substrate is visible in pipeline ROW.

Shoreline change between 1956 and 1985 was measured for points at the pipeline ROW and controls approximately 549 m east and west of each line (Appendix B.2). Shoreline retreat at the site of L23 and L24, a flotation and flotation/push-point canal originally bulkheaded near the beach, was similar (10.05 m/yr and 9.75 m/yr, respectively) and represented a combined average retreat of 9.75 m/yr. Retreat along the controls for these two pipelines was very similar, ranging between 8.53 m/yr and 10.05 m/yr and having a combined average of 9.75 m/yr. This indicates that blocked flotation canals in this area of the chenier plain tend to seal themselves and retreat at a rate comparable to that of adjacent shorelines.

Shoreline retreat at the L25 ROW averaged 7.92 m/yr for 1956-1985. This was also the rate of the combined average retreat for the two L25 controls. The lower retreat rate for L25 could be a result of the more resistive nature of the spoil used to backfill the push-pull ditch and create a low levee. However, the fact that the controls also had a similar retreat rate indicates that this segment of the beach is retreating, on the average, at a slightly slower rate than the area to the west.

Canal widths were also measured for comparison using measurements from 1974, 1978, 1980, and 1985 photographs and 1987 field measurements. Along L23 (dredged in 1958), the data (Appendix C) indicate that the channel enlarged slightly between 1974 (21.94 m) and 1980 (24.99 m) but that by 1985, the canal was filled and vegetated by marsh plants. The L24 push-point flotation canal (dredged in 1968) also appears to be enlarging, from approximately 25.30 m in 1974 to 32.30 m in 1985. In 1987, the canal width, as measured in the field, was 31.70 m, thus indicating that photographic measurements are representative of actual widths. This pattern of canal widening on blocked canals may be the result of spoil bank subsidence and slumping.

Geologic Impacts

Geologic field studies within the Mermentau area were designed to investigate morphologic and stratigraphic variations which may result from installation of pipelines. Measurement and sampling techniques were conducted systematically in order to provide three control locations exhibiting natural stratigraphic and morphologic characteristics and three pipeline ROW locations which may reveal either direct or indirect impacts (Figure 7.22). Specifically, data collection and analysis was designed to test the hypotheses that:

1. Installation of the L23, L24, and L25 pipelines has disrupted longshore sediment transport and resulted in a change in the slope of the beach face and produced escarpments.

2. Pipeline installation has changed the lithologic and textural characteristics within the three corridors yielding unconsolidated sediments which allow for the development of new channels and tidal passes.

3. The L23, L24, and L25 pipeline corridors will accumulate sand from washover process, thus causing the sand to be lost to the longshore sediment transport system.

4. Pipeline installation segments the barrier beach allowing for the development of new channels and tidal passes.

Geologic field data was obtained from the study area along the axis of the three pipeline

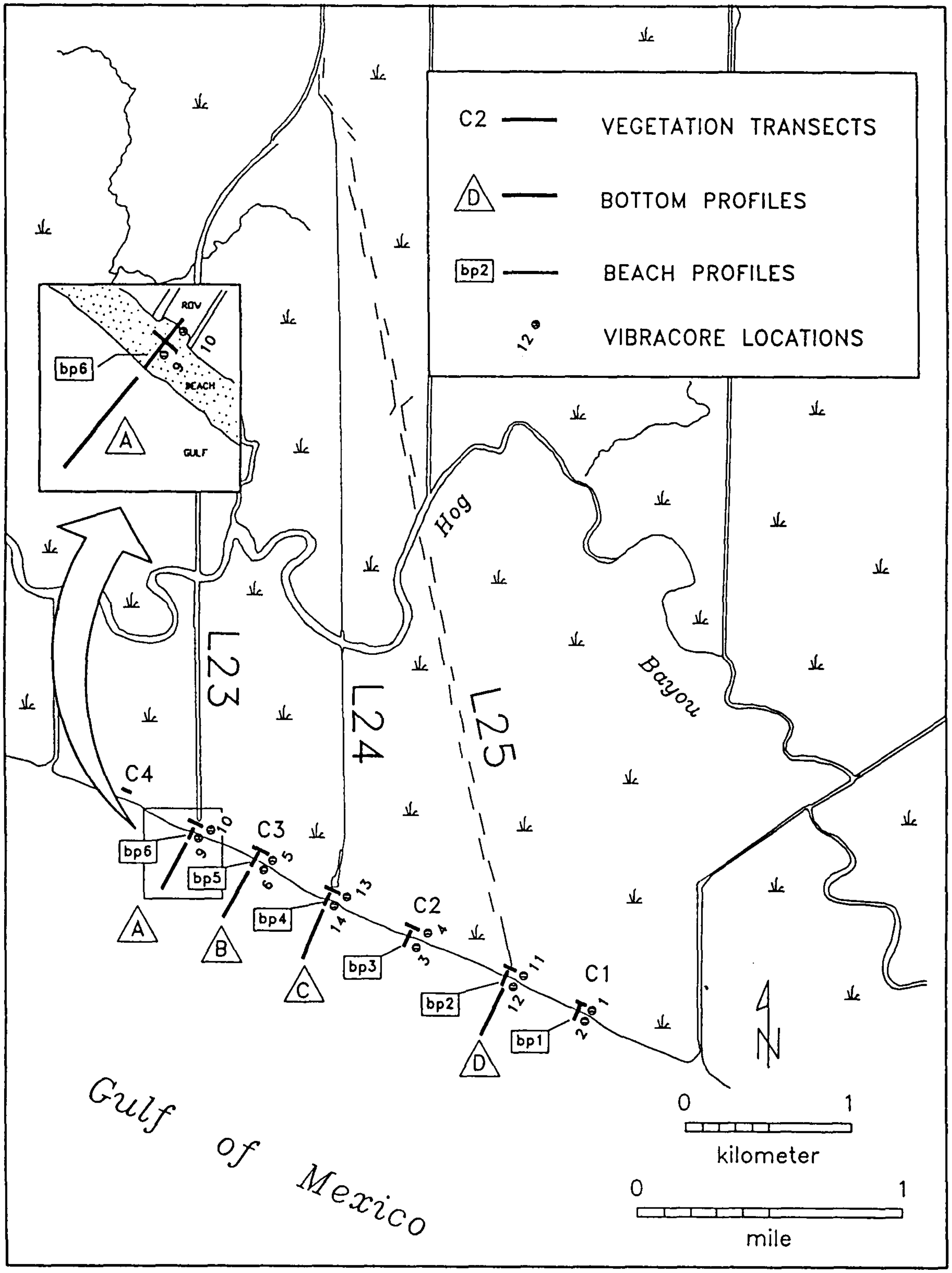


Figure 7.22. Location of field sampling stations in the Strandplain-Chenier Plain System.

ROW which run nearly perpendicular to the shoreline and along control transects which run parallel to the pipeline ROW (Figure 7.22). The control transects were spaced midway between the pipeline ROW. Beach profiles, using the standard transit and stadia method, were obtained along all of the transects except for Station C4 to provide comparative topographic data. Two vibracores were taken along each transect with core locations on the beach and further inland at the beach/marsh interface (for all controls and L23 and L25) and the beach canal/interface for L24. Analysis of the sediments from the vibracores was accomplished through visual examination, x-ray radiography, photography, and grain-size analysis. The field sampling was done in three segments, June 8 and 9, 1987; August 6 and 7, 1987; and April 12 and 13, 1988 because of inclement weather on the first two trips.

The modern barrier facies within the study area have three major active depositional environments: (1) barrier sands which include beach and washover sands, (2) marsh deposits, and (3) Gulf bottom sediments.

The beach and washover deposits consist chiefly of sand and shells with local occurrences of silt and clay. Shells are often observed as distinct layers several centimeters thick and are dispersed throughout the sand. Shell content ranges from 20 to 25%. Oxidation is common throughout the beach and washover deposits. Grain-size analysis shows a general coarsening-upward trend resulting from a greater concentration of shells in the front slope and berm deposits. These coarser particles are left as lag deposits, while finer sediments are washed over after most of the wave energy has been dissipated. The beach and washover deposits show a transitional contact seaward with Gulf bottom silty clays and landward with marsh deposits. These facies characteristics were observed in both the control stations and in the L23, L24, and L25 ROW stations with no observable variation.

Marsh deposits cover most of the surface of Chenier Plain. Within the study area, these deposits consist of dark gray, organic rich clay. The dark gray color, hydrogen sulfide odor, and the occurrence of autogenic pyrite indicate formation under reducing conditions. Plant roots are common but tend to decrease in quantity with depth. Burrows and scattered shell fragments occur locally. Figure 7.23 A and B illustrates the two radiographs of marsh deposits observed in a control location (Vibracore 5) at depths of 0.6 to 0.9 m and 0.9 to 1.2 m, respectively.

Gulf-bottom sediments are composed of clay and silty clay and exhibit thick beds ranging to thin laminations. The facies occur immediately beneath the overlying marsh deposits and demonstrated locally abundant organic material and plant root fibers. Small, thin units of sand and shells occur occasionally. Laminations are parallel and scour and fill structures are commonly observed. Figure 7.24 A and B illustrates two radiographs of Gulf bottom sediments observed in a control location (Vibracore 5) at depths of 2.1 to 2.4 m and 2.7 to 3.0 m, respectively.

The previously described environments demonstrate a relatively simple stratigraphic framework. Six depositional dip cross sections were constructed in order to identify the natural subsurface character and any facies variation that may be associated with pipeline installation. These cross sections are delineated on the control and pipeline ROW elevational profiles (Figure 7.25).

Cross-sections C1, C2, and C3, respectively (Figure 7.25), are oriented along depositional dip and are located at distances midway between the pipeline corridors (see Figure 7.22). The cross sections serve as control sections and illustrate the natural stratigraphic sequence along the Mermentau coastline. The three cross sections show a 0.9-to-1.2-m-thick unit of sand which overlies fine-grained clays. Viewed in landward direction, sands,

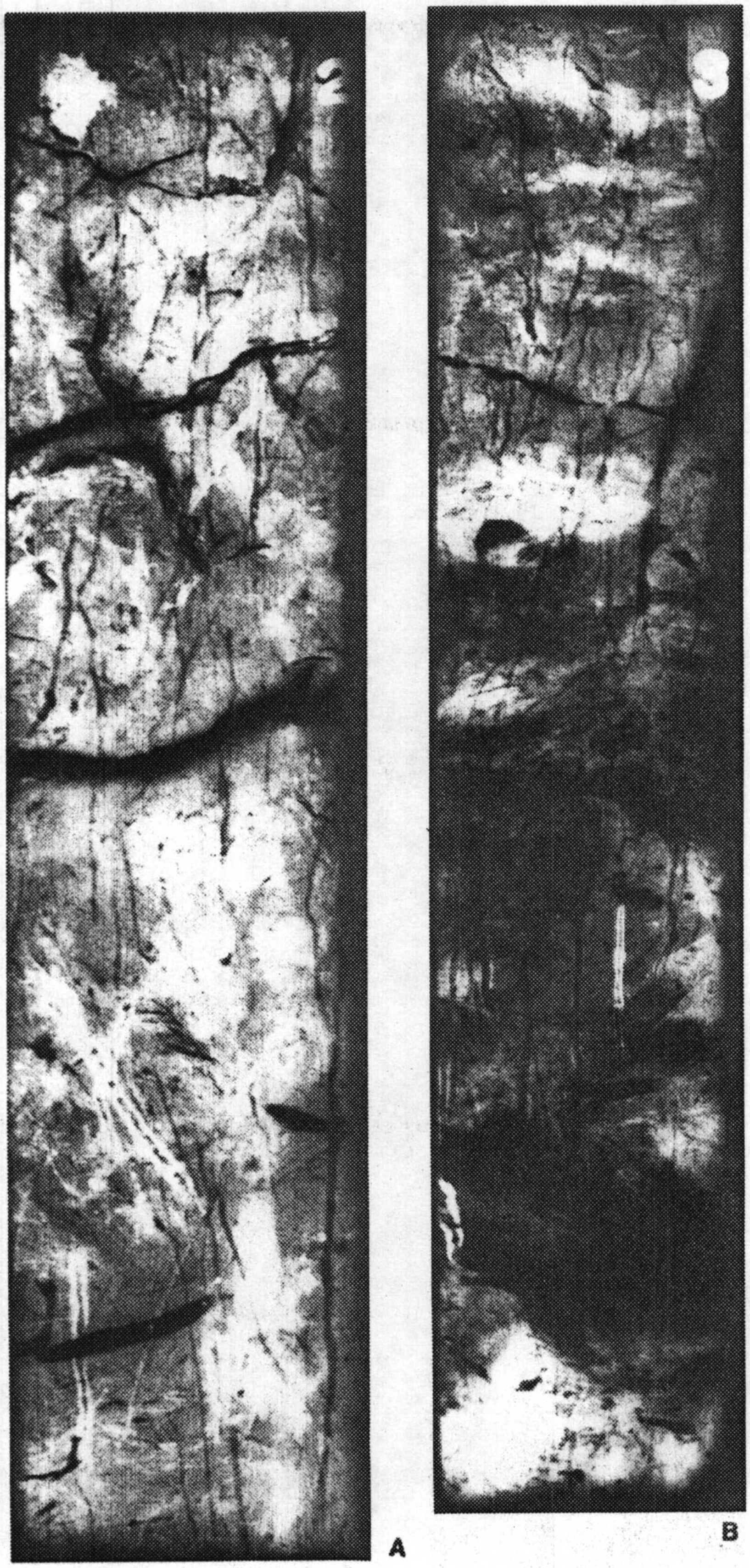


Figure 7.23.

Radiographs of marsh deposits in vibracore 5 (control C3) at depths of 2.1 to 2.4 m (A) and 2.7 to 3.0 m (B), respectively.

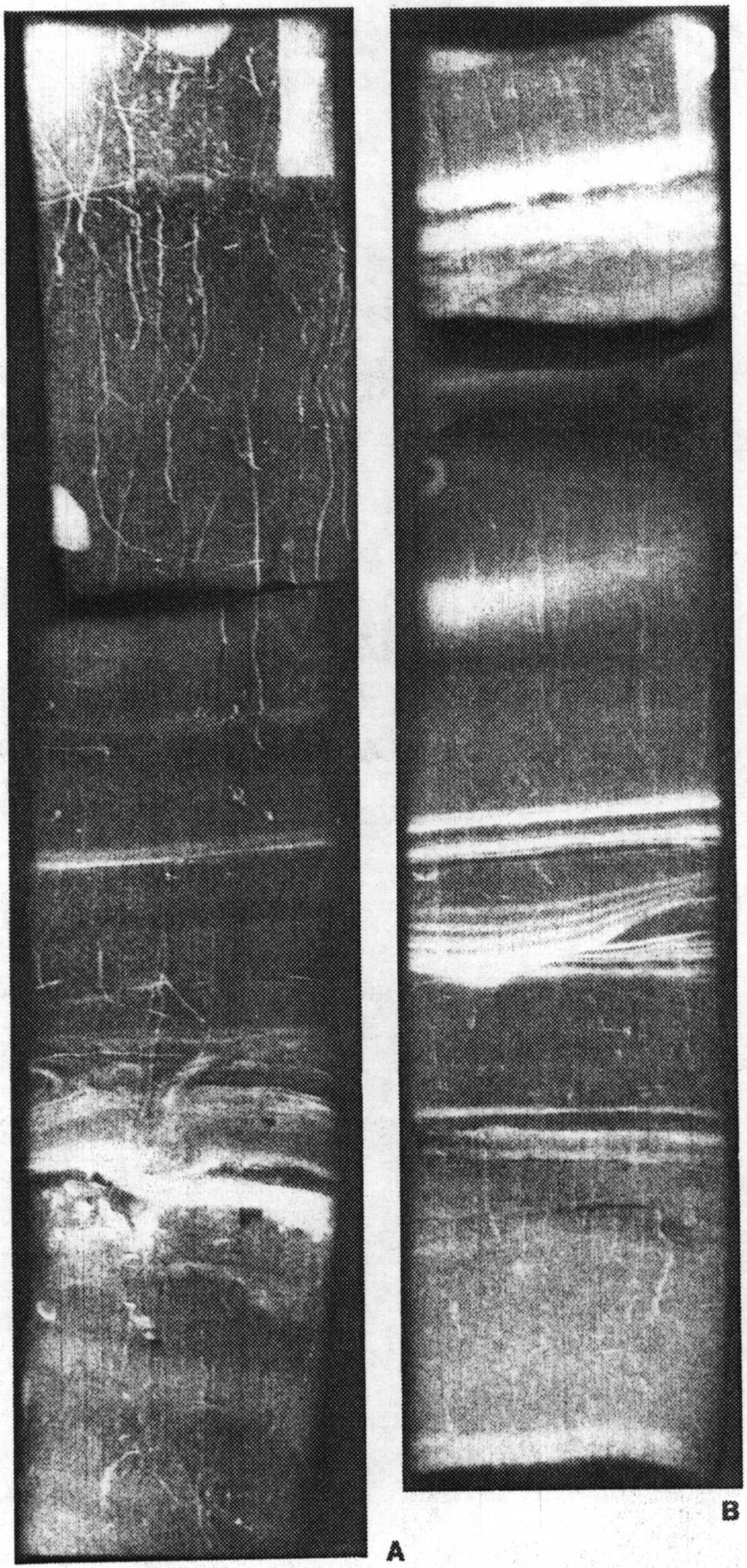


Figure 7.24.

Radiographs of gulf bottom sediments in vibracore 5 (control C3) at depths of 2.1 to 2.4 m (A) and 2.7 to 3.0 m (B), respectively.

which were derived from beach overwash, thin to 0.60 m or less. Further landward, sands are absent and a continuous sequence of marsh and Gulf bottom clays are observed. Seaward of the beach, sands thin again to 0.6 m or less and pass transitionally into Gulf bottom silty clays.

The cross section for L24 (Figure 7.25) is oriented along depositional dip and illustrates a stratigraphy similar to that of the control sections. A 1.5-to-1.8-m-thick unit of sand which thins landward to 0.6 m overlies clays of marsh and Gulf-bottom origin. Thin sand stringers are observed in vibracore 13 at a depth of 0.3 to 0.6 m below mean low Gulf. Sands thin in a seaward direction and pass transitionally into Gulf bottom silty clays.

The cross section for L23 (Figure 7.25) is oriented along depositional dip and illustrates a stratigraphy somewhat different than the control cross sections. The cross section shows a relatively thin (0.3 to 0.6 m) unit of sand overlying marsh and Gulf bottom clays. Sands thin in a landward direction and are absent at the vibracore 10 station. This thin unit of sand shows a distinctly smaller volume of sand at the berm as compared to the control counterparts and accounts for the absence of washover sands at the vibracore 10 location.

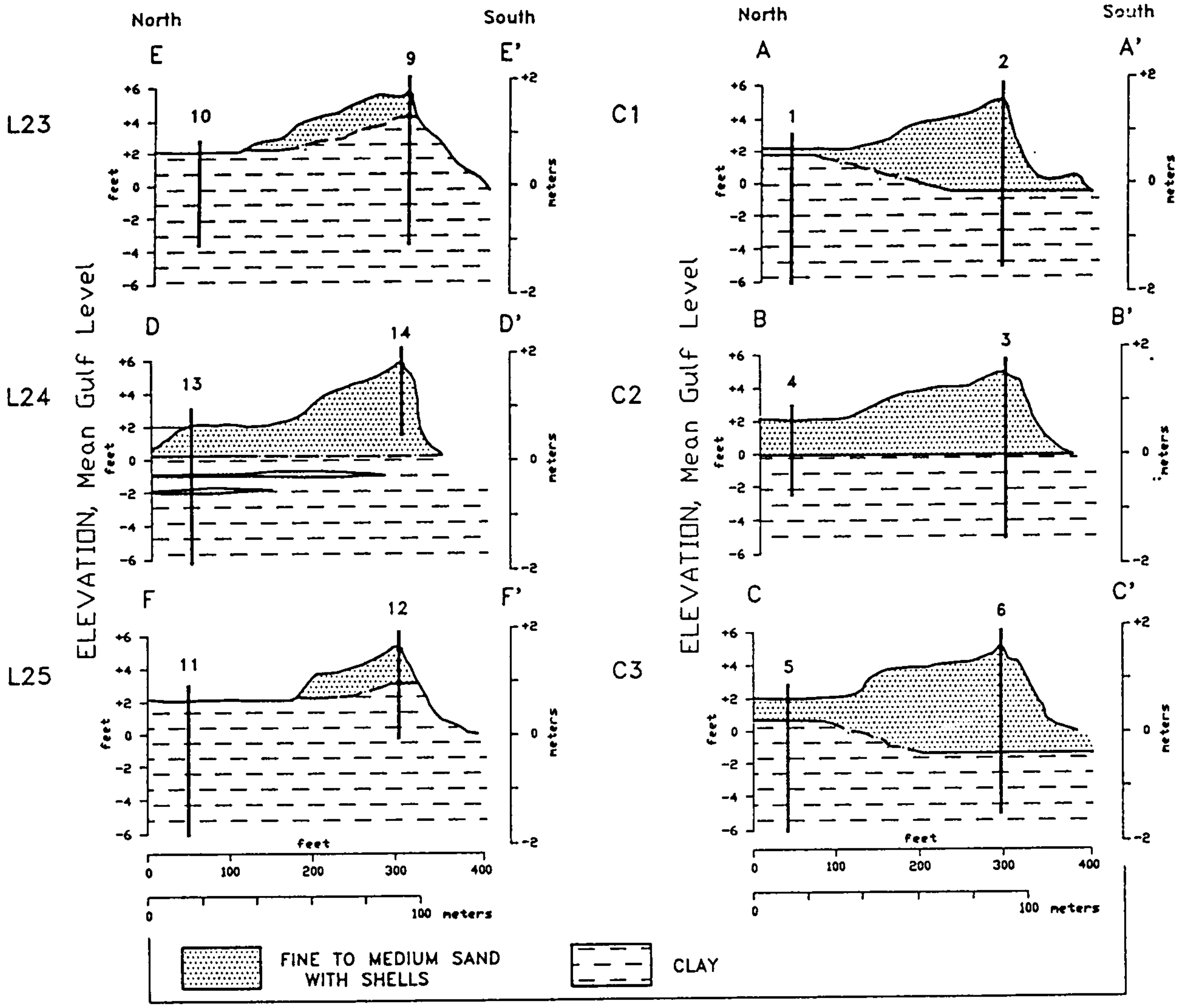


Figure 7.25. Depositional dip sections for the pipeline ROW (L23, L24, L25) and controls (C1, C2, C3) depicted in relation to elevational profiles taken at these sites (see Figure 7.22 for location).

The cross section for L25 (Figure 7.23) shows a stratigraphy similar to that seen in the cross section for L23. A thin unit of sand (0.3 to 0.6 m) overlies marsh and Gulf-bottom clays and becomes absent at the vibracore 11 station. Sands thin in a seaward direction also and pass transitionally into Gulf-bottom, silty clays.

The Mermentau beach area is a low-profile, wave-dominated barrier beach currently experiencing shoreline erosion. Erosion in the dominant physical processes along the beach and pipeline installation is examined in relation to this process.

A comparative analysis between the beach profiles along the control transects and the pipeline ROW indicates that the installation of pipelines has not accelerated shoreline erosion. Profiles C1, C2, and C3 (Figure 7.25) illustrate a relatively steeply dipping beach face and a berm crest ranging from 0.6 to 0.9 m above mean low Gulf. This steep beach face is a result of the normal erosive action taking place along the shoreline. Shoreward of the berm crest, the slope flattens and dips gently landward. Profile L23 (Figure 7.25) exhibits characteristics similar to the C2 and C3 profiles. The beach face shows a relatively steep dip and has a berm crest approximately 0.9 m above mean low gulf (MLG). Profile L24 (Figure 7.23) displays a more steeply inclined beach face, similar to those characteristics observed in profile C1. The berm crest approaches 1.2 m above MLG. Profile L25 (Figure 7.25) shows a relatively steep slope on the beach face which is comparable to the C1 and C3 profiles. The berm crest is approximately 0.9 m above MLG. No major escarpments were observed along the beach face at any of the pipeline corridors. Accordingly, accelerated shoreline erosion is not observed to be an impact as a result of the installation of the L23, L24, and L25 pipelines.

Installation of the L25 pipeline has not changed the lithologic and textural characteristics of the sediment. The cross section for L24 has shown a relatively thick (1.5 to 1.8 m) unit of sand overlying marsh and Gulf bottom clays, comparable to the cross sections for C1, C2, and C3. Installation of the L23 and L24 pipelines has created a change in the lithologic and textural characteristics of the sediments within the corridors. The cross sections for L23 and L25 display pipeline corridors filled with fine-grained sediment and capped by a thin 0.3 to 0.6 m unit of sand. In the case of L25, this infill is the result of backfilling of the push-pull ditch with marsh substrate capped by finer-grained silt and clay taken from adjacent borrow pits. The thin beach cap may result from the fact that the shrub-covered levee retards sand movement inland along the ROW. This change in the character of sediments (i.e, thickness of sand body) makes the pipeline more susceptible to the development of channels and tidal passes because these unconsolidated sediments are more easily eroded. Although these corridors may appear to be weak areas, evidence of channelization along the ROW is not observed. Morphologically, the L23 and L25 pipeline corridors are similar to the control stations, displaying simple washover fans fronting a marsh. Furthermore, the corridors have filled in with silty clay and clay, as opposed to remaining open to the Gulf and susceptible to continued erosion.

In summary, the L23, L24, and L25 pipeline corridors have been filled with silty clay and clay and are generally indistinguishable from the adjacent marsh. Washover sands are not found within the corridors except as would normally occur along the beach face. Consequently, the L23, L24, and L25 pipeline corridors have not acted as sediment sinks and do not remove any sand from the longshore sediment transport system. Furthermore, there has been no development of new channels or tidal inlets at these three cuts. Washover sands are continuous across the axis of the corridors. While the installation of the L24 and L25 pipelines has produced a potentially weak area because of the presence of a thin sand unit at the beach, natural washover processes have maintained continuity along the shoreline.

Hydrologic Impacts

The hydrologic impacts postulated for L23, L24, and L25 are centered around changes in the nearshore bathymetry because the study was intended to focus at the beach. Linear features perpendicular to the shoreline, such as trenches and spoil deposits, are expected to adversely affect the longshore movement of sediment. Man-made structures at the shoreline affect sediment transport. Furthermore, it has been noted that flotation channels produce conditions conducive to washouts and tidal inlet formation.

On June 8, 1988, the study site was reached via a shell road constructed between La. Hwy. 82 and the Gulf to provide access to drilling sites in the marsh. Observations were made and recorded at pipeline landfalls L23, L24, L25, and at control points C1, C2, and C3. Elevation profiles from the surf zone into the marsh (or canal) were made at each site (Figures 7.25). Water and soil salinity were measured with a refractometer at L23 and L24, respectively, and in the surf zone.

On August 6 and 7, 1987, the site was visited again but by boat because the shell road was inaccessible. Fathometer profiles were made perpendicular to the beach at L23, L24, L25, and C3. The profiles were taken from approximately 304 m offshore to within about 30 to 61 m of the shoreline. High waves and surf conditions lead to termination of the survey, thus precluding the taking of bathymetric profiles for C1 and C2. Readings of the tide staff on the Mermentau River at La. Hwy. 82 were taken twice each day during the field investigations. The datum on this staff is MLG. The fathometer and beach profiles were calibrated to this datum.

The qualitative field observations of June 8 immediately shed doubt upon some of the hypotheses. At L25, two of the alternating borrow ponds nearest the Gulf were filled and vegetated by smooth cordgrass. At L24, the beach berm fronting the push point flotation canal did not appear to be a weak point exposing a breach in the shoreline. A water sample taken in the push-pull ditch behind the bulkhead of the flotation canal showed a salinity of 16 ppt. The salinity in the surf was 12.8 ppt, thus indicating the canal is not connected directly to the Gulf. The flotation canal of L23 was infilled with sediment from the beach to the inland bulkhead and about half of the area was covered with salt marsh vegetation, primarily smooth cordgrass. The salinity of the free soil water in the infilled canal (L23) was 10.2 ppt. The elevation difference between the higher beach rim vegetation and the infilled canal was 0.12 m.

The beach/bathymetric profiles are shown in Figure 7.26. There are no differences in bathymetry beyond 152 m from the shoreline among the four transects. The depth increases from 1.06 m at 152 m to 1.6 m at 305 m for a slope of approximately 0.4%. Shoreward of 152 m, L25 exhibits a slightly elevated bottom as compared to C3. This is possibly an erosion-resistant remnant of the single, raised spoil ridge evident on shore. The L24 profile shows a very steep beach face and erosion scarp into the surf zone with a clay substrate characterized by potholes, again the remains of a spoil bank. L23 stands out from the others because of the presence of a steel sheet pile bulkhead, exposed and deteriorating in the gulf. The depths in front of and behind the bulkhead are probably produced by its funneling effect on the longshore current. However, L23 exhibits the flattest beach face and the highest, widest berm crest of the three pipelines.

In summary, noticeable bathymetric impacts are restricted to the zone within 152 m of shore. Spoil banks of compacted clay, which are relatively erosion-resistant, may influence longshore sediment transport to a small degree. Flotation canals in this area have not caused washouts or formation of tidal inlets.

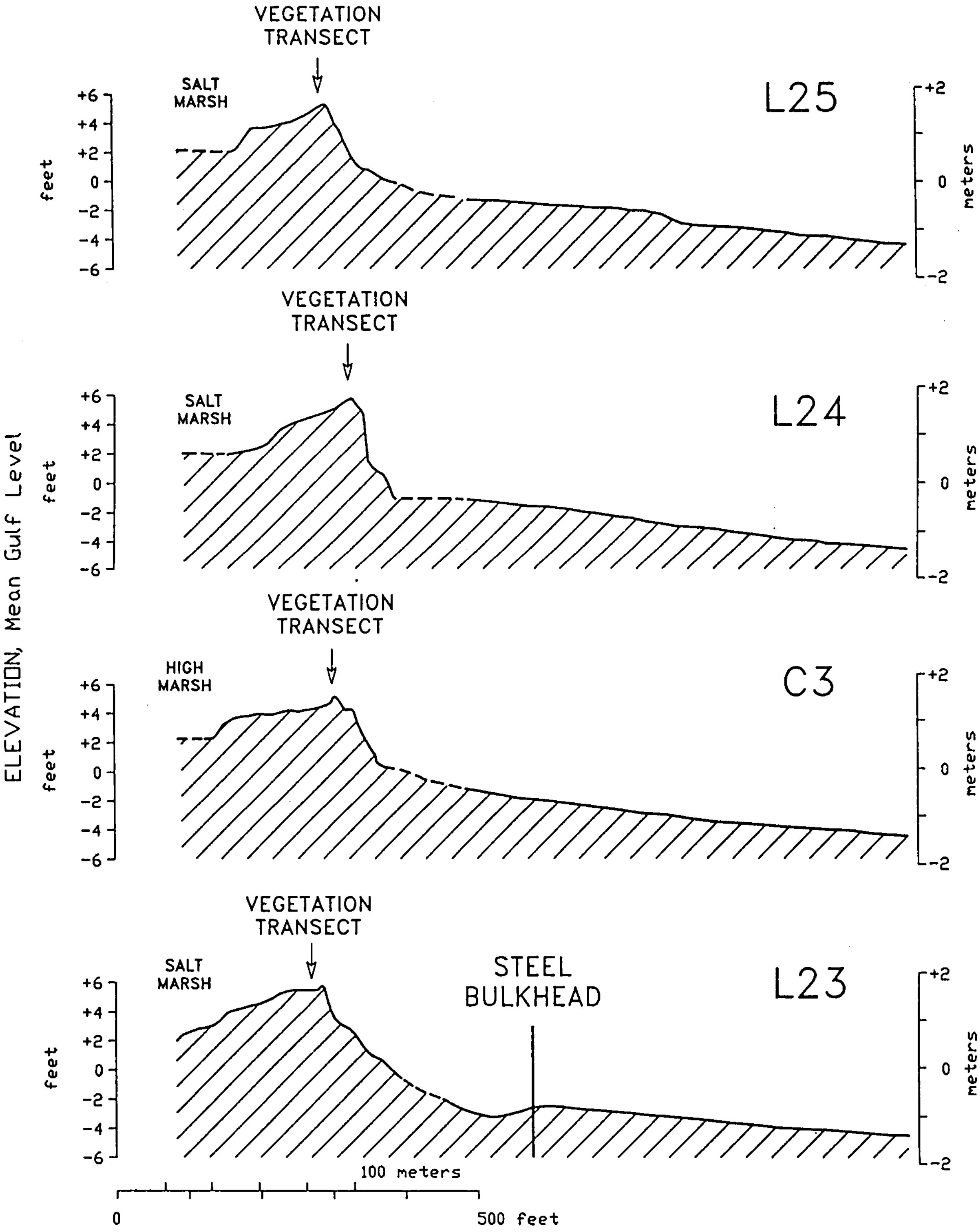


Figure 7.26. Bathymetric and elevation profiles for L23, L24, L25, and C3 at the Strandplain-Chenier Plain field site.

Vegetative Impacts

Pipeline impacts to the barrier beaches of the Strandplain-Chenier Plain System were hypothesized to be primarily of a physical nature such as: (1) weakening of the shoreline, because of destruction of vegetation which results in increased shoreline erosion in the pipeline corridor, and (2) lowering of beach and berm elevations, causing increased overwash, thereby affecting dune community structure.

Vegetation transects were made on June 8, 1988, at the landfall of pipelines L23, L24, and L25 (Figure 7.22). Four control transects were sampled: east of L25, west of L23, and at the mid-points between L23-L24 and L24-L25, as calculated by the odometer of the survey vehicle. Transects were established parallel to the shoreline on the berm crest at each site. Seven stations, each with two replicates, were made. For pipeline sites, Station "a" was always in the center of the ROW, with Stations "b" and "e" at 30 m, "c" and "f" at 60 m, and "d" and "g" at 90 m on each side of Station "a."

Percent cover for each replicate (14 per transect) was recorded using the 1-m^2 quadrant, as previously described. The sparse and ephemeral nature of the berm vegetation made estimation of standing crop biomass of no use to the study with regard to pipeline impacts. Therefore, clipped plots were not sampled. The scope of the present study limited the investigation of impacts in Louisiana to the barrier beach and barrier island habitats, so no transects were placed in the marshes landward of the active beach. However, field observations of the marshes were recorded and will be discussed below.

Statistical analyses of percent cover included calculation of 95% confidence intervals for each transect. Combined data of percent cover for control versus pipeline were analyzed in a paired t-test.

Results of the vegetation transects are shown on Table 7.4. The most obvious fact is that there is a high percentage of bare ground (mostly sand) at all transects. The maximum plant cover of about 18% occurred at L23, and it was primarily the annual grass sea purslane (Sesuvium portucalastrum). Wave overwash of this berm environment is frequent, leaving no extended periods of time for plant succession to occur. As seen in Figure 7.27, there is no significant pattern in plant coverage from east to west across the field site, nor are there significant differences between pipeline and adjacent control transects. The analysis of the combined data for control versus pipeline percent cover

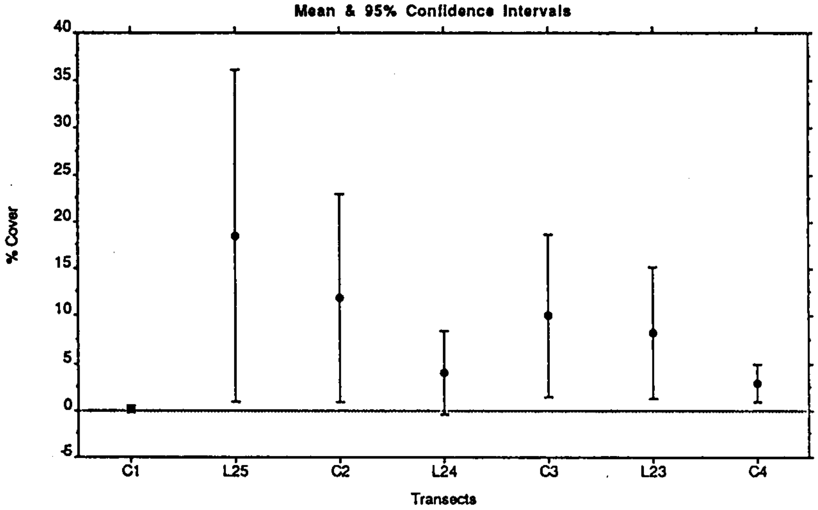


Figure 7.27. Mean and 95% confidence intervals for percent vegetation cover at the Mermentau field site.

also indicates that there is no significant effect of the pipelines on the berm vegetation (Table 7.4).

The marsh directly behind the overwash zone at the control stations is characterized as a high marsh or sea rim marsh (O'Neal 1949). The dominant species is saltgrass. Field observations denote the firmness of this marsh and the numerous shallow hoofprints of cattle as an indication of trafficability. At pipeline sites, the same zone is characterized by linear flanking spoil banks dominated by marshelder and/or marsh grading into mud flats and finally into the remnant shallow water of the original flotation canal (L23), flotation push-point canal for the push-pull ditch (L24), or borrow pit (L25). As stated previously, there is a 0.12-m elevation difference between the marsh of the infilled excavations and the sea rim marsh. The linear extent of infill was greatest at L23, where the former flotation canal was not bulkheaded for a long distance inland, and least at L24 where the flotation push point was blocked by a bulkhead about 91 m inland from the beach. This longer expanse of fill may be partially a reflection of the fact that L23 is 10 years older than L24.

Mississippi Delta System

Description for L86, L87, and Muskrat Line

The two separate sites chosen for field studies in the Mississippi Delta System are in south-central Louisiana west of the active Mississippi River Delta. The barrier beach study site near Bay Morehand between Pass Fourchon and Belle Pass on the Caminada/Moreau Headland was designated the Belle Pass site and is located in the vicinity of 29°6'N latitude, and 90°12'W longitude in Lafourche Parish, Louisiana (Figure 7.28). While the condition of 10 pipelines was investigated, detailed analyses were provided for lines labeled L86 and L87.

Grand Terre Island was chosen as a representative field site for barrier islands in the Mississippi Delta System. The site is located at 29°17'N latitude, and 89°56'W longitude in Jefferson Parish, Louisiana (Figure 7.28). Field investigations were undertaken along a pipeline known as the "Muskrat Line," which ran parallel along the back side of the island.

The study area is the remnant of a formerly active delta lobe of the Bayou Lafourche distributary channel. The Late Lafourche delta lobe was abandoned approximately 300 to 400 years B.P., resulting in subsidence and marine reworking of the area and ultimately transformation into an erosional headland (Morgan 1974). Sediment is dispersed from the headland through the longshore sediment transport process and accumulates in downdrift spits and tidal inlets. The Caminada-Moreau Coast is a low-lying transgressive barrier beach which fronts the Bayou Lafourche erosional headland. The beach is essentially a thin, continuous washover sheet with marsh deposits cropping out on the seaward side of the beach face. The shoreline demonstrates a predominantly landward retreat as a result of subsidence and marine reworking (Gerdes 1982).

Grand Terre is a transgressive barrier island representing a flanking barrier island associated with the erosional headland of the Plaquemines delta lobe, abandoned approximately 400 to 600 years B.P. (Penland et al. 1987). The island system is also located in south-central Louisiana, immediately west of the active Mississippi River. The island exhibits a thin, sandy beach which fronts marsh and bay environments. A series of regressive beach ridges is observed throughout the body of the island which demonstrate a western progradation from an eastern sediment source. The shoreline shows a predominantly landward retreat, while littoral sediment transport displays an east-west bidirectional pattern.

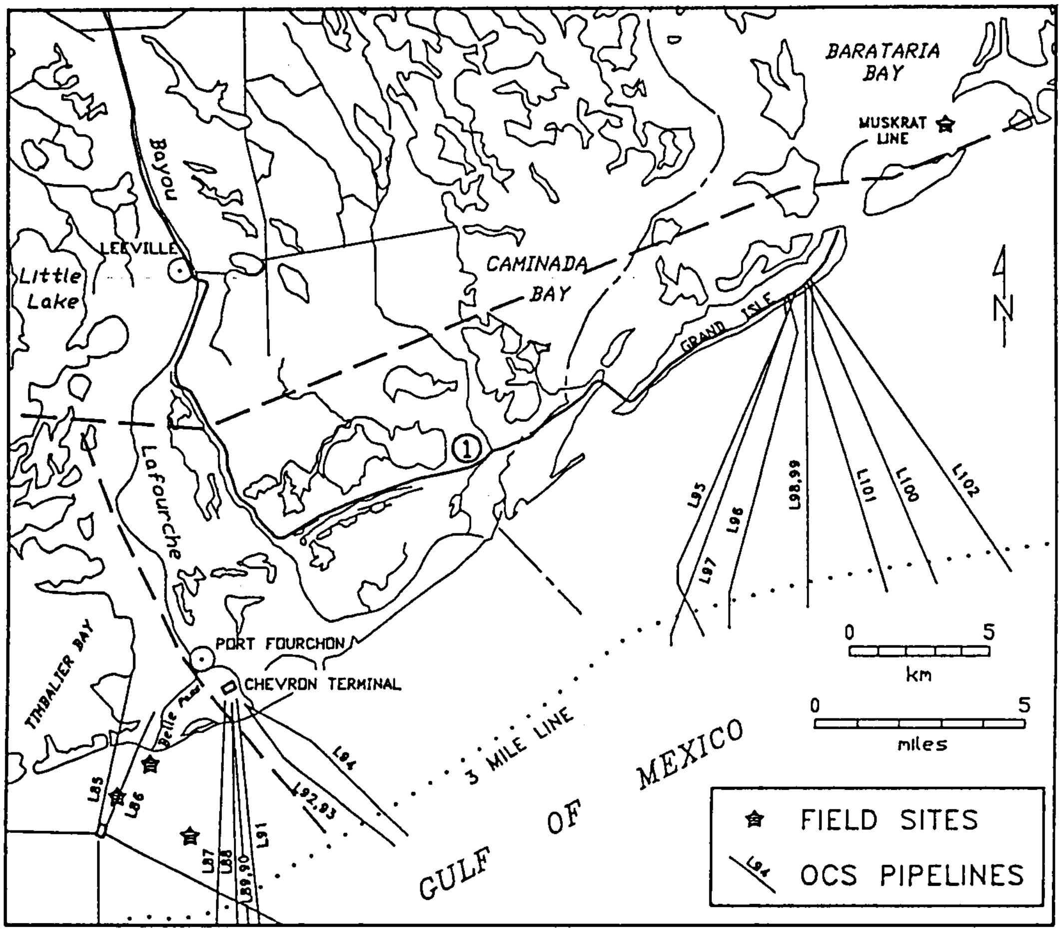


Figure 7.28. **Location of field sampling sites within the Mississippi Delta System.**

Table 7.4. Vegetation Data and Analysis for the Mermentau Field Site.

	% Cover of Species by Transect and Station*								
Species	C1	L25	C2	L24	C3	L23	C4	Control Average	Pipeline Average
Unvegetated	99.79	81.44	88.15	96.07	89.93	82.08	97.08	93.74	86.53
Atriplex sp.		0.43	0.57	1.00	0.86	0.57	1.50	0.73	0.67
Iva frutescens	0.14	11.78		2.86		2.86		0.04	5.83
Sesbania macrocarpa	0.07	0.07				0.07	0.07	0.04	0.05
Panicum amarum		5.36	3.21					0.80	1.79
Spartina patens		0.07	8.07	0.07	9.21	3.64	0.14	4.36	1.26
Heliotropium curassavicum		0.07					0.21	0.05	0.02
Sesuvium portulacastrum						10.71	0.14	0.04	3.57
Sporobulus sp.							0.86	0.22	0.00
Paspalum vaginatum		0.71				0.07		0.00	0.26
Borrichia sp.		0.07						0.00	0.02

Percent Cover		
Mean	6.29	10.24
95% C. I. (+/-)	3.44	6.23
Mean (X-Y)	-2.83	
Paired t value	-0.683	
Prob.	0.4983	

L23, L24, L25: Pipeline Transects
C1, C2, C3, C4: Control Transects

The Belle Pass site contains two general soil types, Scatlake muck and Felicity loamy fine sand (USDA, Soil Conservation Service 1984). Scatlake muck consists of level, poorly drained, semifluid muck and mucky clay underlain in many areas by semifluid fine sand or loamy sand. These soils support saline marsh vegetation. The Felicity series is gently sloping, saline, sandy soil found on the beaches. Soil information for the Grand Terre study site is unavailable but is assumed to be similar to that for the Belle Pass study site.

A dune plant assemblage is located inland from the barren beach face at the Fourchon study site. The dominant species generally include wiregrass, bitter panicum, seashore dropseed, and beach morningglory (Mendelssohn et al. 1987). Behind the dune vegetation is saline marsh dominated by smooth cordgrass with occasional occurrences of black mangrove along tidal channel or marsh-bay interface.

The Grand Terre field site is on the back side of the island and includes saline marsh and spoil bank habitats. The dominant marsh plant is smooth cordgrass. From the marsh to the top of the highest spoil banks, a series of plant assemblages are encountered. The base of the spoil bank is covered largely by wiregrass, saltgrass, saltwort, glasswort, and in some locations black mangrove. Between 0.2 and 0.6 m above marsh level, marshelder and rattlebox (Sesbania drummondii) dominate and above 0.6 m are found toothache tree, lantana (Lantana horricla), and creosotebush (Larrea tridentata).

The Belle Pass and Grand Terre study areas experience diurnal tides with a daily range of 2.7 to 0.3 m. The tidal signal is often masked by the strong winds of frontal systems in the spring and fall. Waves average 0.4 m in height and approach the shoreline from the east and southeast. Longshore currents tend to diverge at a point several miles northeast of Belle Pass and generally move to the southwest in the vicinity of Belle Pass.

Grand Terre Island forms the east side of Barataria Pass which dominates the hydrology of the field site. The wave energy on the beach at Grand Terre is less than at Fourchon because of the sheltering effect of the protruding Mississippi River delta and the curvature of the offshore bathymetry. However, considerable wave energy impacts the back of the island when north winds associated with cold fronts blow across the open waters of Barataria Bay. Longshore currents move to the northeast and have transported sufficient sediment to form a spit on the eastern end of the island.

History and Interpreted Changes

The 16-in gas pipeline (L86) installed by Tennessee Gas Pipeline Company in 1961 originated from a platform in Bay Marchand Block 5 and goes to the company's Louisiana Coastal Line (Line 500-1) south of Leeville (Figure 7.28). However, for purposes of this study, the line (known as Louisiana Coastal-Bay Marchand Block 5) is considered to be an OCS line because it receives OCS products from OCS lease blocks South Timbalier 56 and Grand Isle 47.

No detailed information on pipeline construction was available from the operator or published documents. However, aerial photo analysis (Figure 7.29), personal communication (Jones 1988), and field inspection in December 1987 reveal that this pipeline was placed in a flotation canal, making landfall approximately 244 m west of Belle Pass. Continuous spoil banks flank both sides of the canal. Pairs of dams were originally placed on the canal at each water body crossing and at regular intervals along the canal. One can assume that the canal was also dammed near its juncture with the Gulf. At the time of the field investigation in December 1987, L86 was dammed near the Gulf but its surface ROW at the Gulf traversed a reconstructed beach of wave-reworked

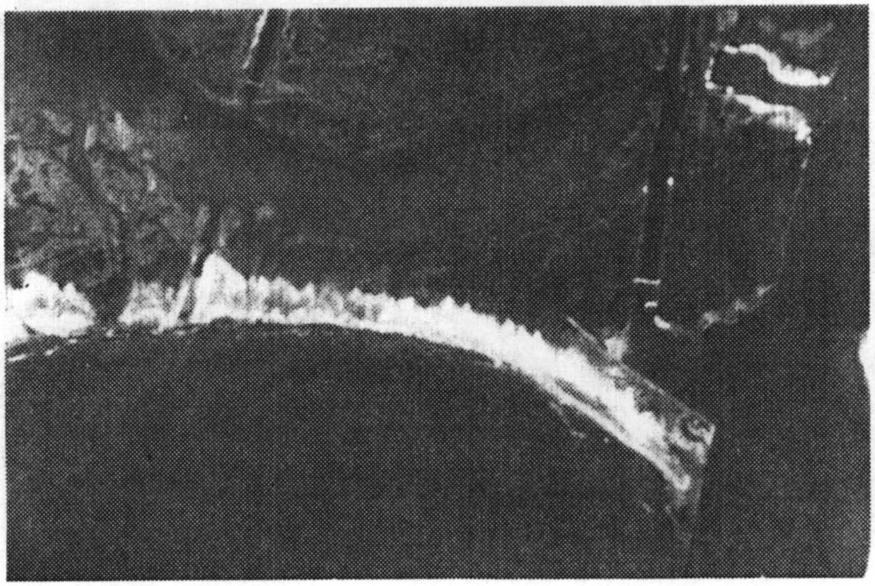


Figure 7.29. Condition of two pipeline canals (L85 and L86) located west of Belle Pass.

Table 7.5. Comparison of Rates of Shoreline Change for ROW and Controls for Pipelines L85 and L86.

Change in M/YR

Pipeline	1887-1934	1934-1955	1955-1969	1969-1974	1974-* 1978	1978-* 1983	1983-1985	1934-1974	1974-1985
L85:									
Control W	-44	-14	0	-35	-12	-26	-27	0	-21
ROW	-43	-13	-8	-35	-12	-22	-36	-14	-21
Control E	-42	-16	-5	-36	-12	-14	-40	-15	-18
L86:									
Control W	-41	-16	-12	-36	-15	-1	+18	-17	+8
ROW	-40	-14	-17	-60	+15	0	+52	-21	+14
Control E	-36	-17	-17	-24	+42	-18	+60	-18	+24

* period of spoil deposition west of Belle Pass

L85 constructed in 1968
L86 constructed in 1961

spoil in front of the Belle Pass wing jetty, a product of the maintenance dredging of Belle Pass.

The impact of this pipeline canal on the beach must be examined in reference to the dredging and maintenance of Belle Pass which is discussed in detail in Chapter 8. Comparison of aerial photographs indicates that prior to 1969, Belle Pass was widened and a longer jetty was installed updrift (east) of the pass. Furthermore, a canal (either rig access or pipeline) was dredged from Belle Pass across and perpendicular to L86, and parallel to the beach. By 1974, the beach in front of L86 had eroded and it appeared that no dams remained along the lower reaches of this canal near the Gulf (NASA 1974). Construction of a jetty west of Belle Pass with a wing extended to the northwest and deposition of maintenance dredge material west of this jetty resulted in reconstruction of a beach in front of the L86 pipeline ROW by 1978 (NASA 1978). The shoreline erosion rate at the L86 pipeline ROW had averaged approximately 21 m/yr between 1934 (about the time of the original Belle Pass jetty construction) and 1974 (prior to reconstruction of a western jetty at Belle Pass) (Table 7.5).

After construction of the jetties and periodic disposal of channel material west of the jetties (post-1974), the shoreline in front of the wing jetty and pipeline canal ROW has accreted at an average rate of about 14 m/yr (Table 7.5, Appendix B.3).

Variations in rate of shoreline change within 152 m of either side of the L86 ROW is indicative of change in a non-pipeline impacted area. A 152-m distance was selected for the L86 controls because expansion of the Belle Pass Channel obscures a control placed further east of L86. For the period 1934-1974, the western control experienced an average retreat rate of about 18 m/yr, but between 1974 and 1985 there was an average accretion rate of 8 m/yr. In contrast, the eastern control site had a shoreline retreat rate of 18 m/yr for the first period, but an accretion rate of 24 m/yr for the second period. These data indicate that sediment introduced from channel maintenance operations counteracted the high natural, and to some extent, jetty-impacted, rate of shoreline retreat near the jetty but only slowed the historic rate of retreat further west. Thus, factors other than pipeline construction influenced shoreline change at this site.

Comparison of shoreline change at the ROW and two control points for a pipeline (L85) of similar size and construction but located approximately 1,052 m west of L86 is more indicative of pipeline impact on a retreating coast because it is further removed from, though not totally immune from, indirect impacts of navigation channel maintenance (Table 7.5). For the L85 ROW, constructed in 1968, the shoreline change rate averaged -14 m/yr between 1934 and 1974, and -21 m/yr between 1974 and 1985. During these same periods of time, the western control change rate was 0 m/yr and -21 m/yr, respectively, while the eastern control rate was -15 m/yr and -18 m/yr, respectively. The similarity in retreat rate (-21 m/yr) for the western control and ROW of L85 indicates that the shoreline is responding uniformly to coastal processes at both the control and the ROW. The eastern control is closer to the sediment source being periodically added to the littoral transport system from Belle Pass maintenance dredging. This may account for the lower change rate (-18 m/yr) for this particular period of time.

There are eight OCS pipelines located east of Belle Pass that were originally considered for field study. The selection of the 6-in Tenneco Oil Company line (L87) was necessitated by the fact that, upon field inspection in 1987, it was evident that all other lines (L88, L89, L90, L91, L92, L93, L94) had been covered by dredged material pumped in from the Belle Pass channel as a result of maintenance dredging operations. This project was part of a state-sponsored beach restoration measure aimed at combating the exceedingly high rate of erosion in the area. However, no details of this project or analysis of the restoration impacts have been published or were available for review at the time of this investigation. Line L87 was installed prior to 1973 and extended to Bay Marchand Block 22, as indicated by its delineation on a Louisiana pipeline map (Louisiana Department of Conservation 1973). No data was available on this line which may now be abandoned.

There was no evidence of this line at or near the beach, but the site chosen for geologic data collection corresponded closely to the pipeline location, as verified by Chevron Pipeline Company (Cukr 1988). The location of the line was determined by projecting to the Gulf a thin, linear, discontinuous water body originating southwest of the Chevron terminal near Port Fourchon that was visible on 1974 (NASA) and 1985 (NASA) CIR imagery (Figure 7.30). The line crosses the beach just east of a canal and appears to have been installed by constructing a ditch across the marsh. The line may have been push-pulled into place from either the beach or the terminal. The method of installation at the beach is unknown.

A comparison of shoreline change rates for the pipeline L87 ROW and controls located approximately 610 m east and west of the ROW reveals that between 1974 and 1985 the shoreline retreat rate has been greatest farthest from the Belle Pass east jetty at the east control and least nearest the jetty (Table 7.6). The retreat rate of the shore at the ROW is midway between that of the east and west control indicating that the jetty placement influences shoreline change updrift more than the presence of a pipeline crossing.

The 20-in gas pipeline ("Muskrat Line"), constructed in 1956 through the back marsh of Grand Terre Island by Tennessee Gas Pipeline Company, is one small segment of a much larger system serving both onshore and offshore fields (Figure 7.28) (see Map 6-A and 7-A). This line is designated by Tennessee Gas as Louisiana Coastal Line 500-1, but was dubbed the "Muskrat Line" at the time of construction (Petroleum Engineer 1956). Reports documenting the pipeline's construction note that the line was placed in a trench dredged to -3 m MLG within a flotation canal 12.2 m wide and 1.8 to 2.4 m deep (Resen 1956, Reed and Deering 1956). The mainline runs from Dixon Bay in the Mississippi Delta (northwest of Southwest Pass) along the Barataria Basin to East Bay barrier beach and island coastline to Kinder, Louisiana. Pipe for the line was coated with coal-tar enamel and concrete for weight at four different cities along the line: Morgan City, Larose, New Orleans, and Harvey (Resen 1956; Reed and Deering 1956). There were no compressor stations on the line, and valve stations ranged in size from 6 m x 14 m to 12 m x 12 m (Resen 1956). The line crossed 130 navigable waterways and was dammed at each intersecting waterway in order to: (1) prevent changing channel flow, (2) guard against erosion, and (3) prevent saltwater intrusion into marshes (Resen 1956).

A controlled photo mosaic compiled with photographs taken in November 1955 and February 1956 (Ammann 1955/56) indicates that another pipeline was emplaced on the backside of Grand Terre prior to the Muskrat Line, also installed in 1956 (Figure 7.31). The Muskrat Line has continuous spoil banks on both sides of the canal. Dams were constructed on the canal near its juncture with Barataria Bay and a historic canal (from the back bay area), which almost bisected the island in a northwest-southeast direction. By 1983, two other pipelines and a pump station had been constructed on the back side of the island and the Louisiana Department of Wildlife and Fisheries camp had been expanded on the western end of the island near Fort Livingston (Figure 7.32).

Comparison of historic (USC&GS 1932) and recent (USGS 1971) maps and aerial photographs (Ammann 1955/56, NASA 1983) and 7.5-minute habitat maps prepared from these data reveals that the island has decreased in area as a result of shoreline erosion along the beach and back bay shores (Table 7.7). The slight increase in island area

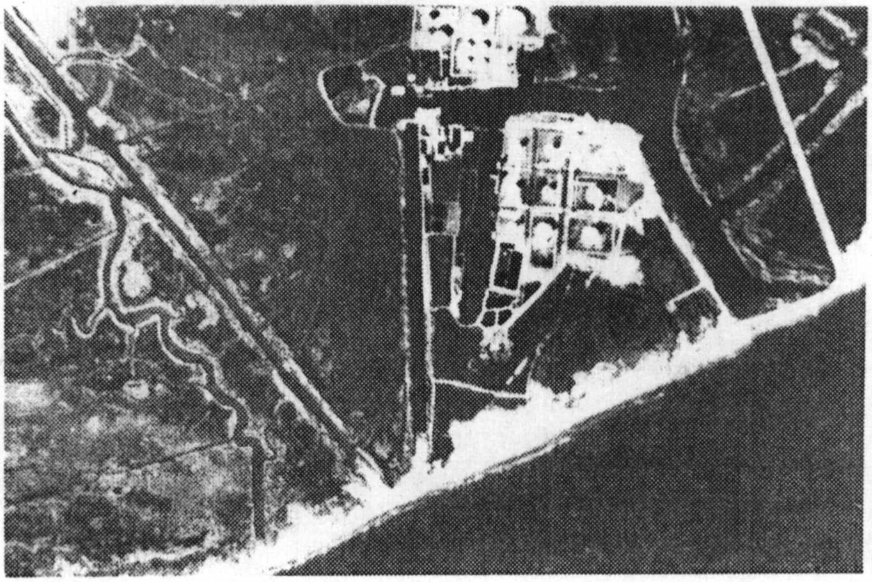


Figure 7.30. Aerial photograph of landfall location for pipelines L87 through L94 (see Figure 7.28 for location) (NASA 1974).

Table 7.6. Comparison of Shoreline Retreat Rates at L87 ROW and Controls for Selected Periods.

		Shoreline Change in M/Yr						
Pipeline						Pre-Canal	Post Canal	Net Change
L87	1887-1934	1934-1956	1956-1969	1969-1974	1974-1985	1934-1974	1974-1985	1887-1985
ROW	-7	-6	-4	-1	-1	-6	-1	-5
Control W	-8	-7	-4	-2	-0.6	-6	-0.6	-6
Control E	-6	-6	-7	-4	-2	-6	-2	-6

between 1932 and 1955/56 may be a reflection of different interpretative techniques used to construct the USC&GS map (1932) and not an actual increase in land area.

The Muskrat Line canal and associated spoil banks have maintained approximately the same percentage of island habitat area for 1971 and 1983 (approximately 18 ac or 2.2% and 20 ac or 2.8%, respectively), thus indicating that the canal-spoil complex has not eroded significantly within the island system of beach-dune-marsh/shrub and other non-muskrat line canal complex habitats. It is unknown whether the perimeter canal dams have had to be replaced since construction, but both the perimeter and interior dams appear to have remained at the original construction place. The width of the canal was measured to be about 35 m in 1971 and approximately 31 m in 1983, a difference that could be attributed to measurement error. This latter width is consistent with the average width of about 30 m measured during field investigations in December 1987, indicating little change in canal width over the past 16 years. If the original width had been 20 m, or comparable to that of the canal shown under construction on the Amman 1955/56 photo mosaic, the canal width would have increased by 55% over 31 years.

The 1983 aerial photograph documents that the eastern segment of the canal has been filled with sand from the spit forming on this end of the island. No dams are visible on this segment of the canal and spoil banks appear to be absent. Field verification of aerial photo interpretations in December of 1987 revealed that a salt marsh occupied the bed of the former eastern end of the canal and a small, extremely shallow, tidal channel meandered through the center of this unfilled canal (Figure 7.33). The western segment of the canal had shallowed within the bulkheaded portions of the canal but spoil banks were still high and continuous (Figure 7.34).

Geologic Impacts

Field studies within the Mississippi Delta System were designed to investigate morphologic and stratigraphic variation in transgressive barrier beach and barrier island settings which may result from pipeline installation. Impacts to be expected at the field site near Belle Pass include:

1. Disruption of longshore sediment movement as evidenced by changes in the slope of the beach face and formation of escarpments.
2. Changes in the lithologic and textural characteristics within the pipeline ROW as evidenced by unconsolidated sediments which allow for the development of new channels and tidal passes through the beach and marsh.
3. Sand accumulation in the pipeline ROW from washover processes.
4. Segmentation of the barrier beach by an open canal which accelerates erosion and results in the development of new channels and tidal passes.

Impacts 2 and 3 were hypothesized to occur at Grand Terre also. In addition, the Muskrat Line canal on Grand Terre is oriented shore-parallel. The impact of the shore-parallel pipeline has been noted to cause greater environmental damage than shore-normal pipelines because of the greater lateral extent and open condition which allows the canal to act as a sediment sink for washover materials, thus removing them from the littoral transport zone.

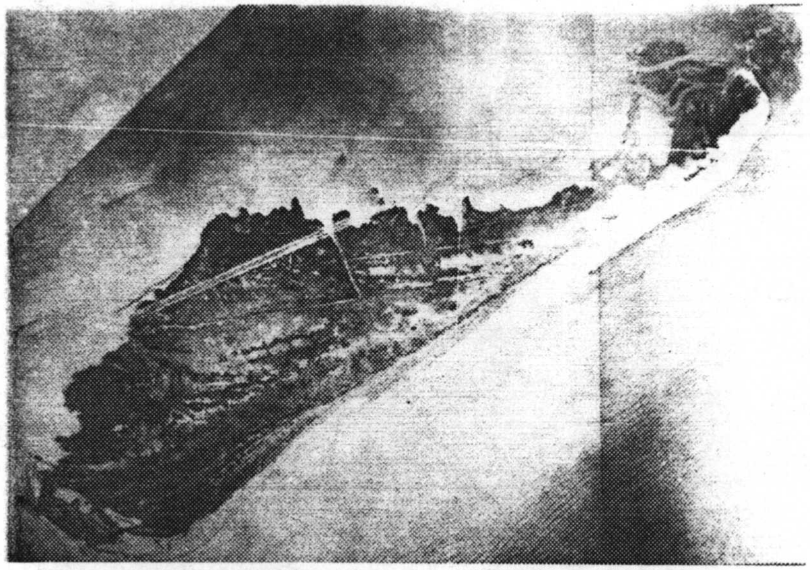


Figure 7.31. Construction of an unknown pipeline across Grand Terre in 1956 (Ammann 1955/56).

Table 7.7. Comparison of Habitat Change on Grand Terre: 1932, 1956, 1971, and 1983.

	1932		1956		1971		1983	
Habitat	**Ha**	**%**	**Ha**	**%**	**Ha**	**%**	**Ha**	**%**
Salt Marsh/Mangrove	272	75	199	51	147	45	129	46
Vegetated Dunes/Swales	48	13	96	25	84	25	55	19
Vegetated Backshore Dune/Flats	- -		23	6	7	2	10	3
Sand Beach/Spit	23	6	44	11	31	9	33	12
Ponds/Channels	20	5	18	5	16	5	15	5
Pipeline Canals *	1	<1	4	1	17	5	13	4
LWF Canal	- -		- -		2	<1	2	<1
Pipeline Spoil**	- -		4	1	11	3	13	5
LWF Compound	- -		- -		15	4	14	5
Sohio Compound	- -		- -		<1	<1	1	<1
Total	**364**		**387**		**329**		**285**	
*"Muskrat Line"					4		4	
Canal "A"					9		6	
Canal "B"			3		1		1	
Canal "C"	1		1		2		<1	
**Muskrat Line Spoil					3		4	
Canal "A" Spoil					7		7	
Canal "B" Spoil			4		1		2	

LWF: Louisiana Wildlife and Fisheries

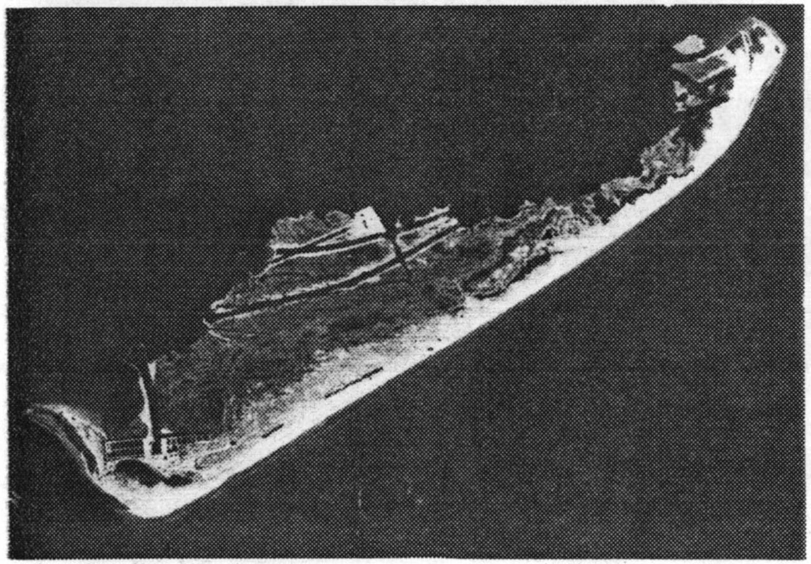


Figure 7.32. Appearance of the "Muskrat Line" and other cultural features on Grand Terre in 1983 (NASA 1983).

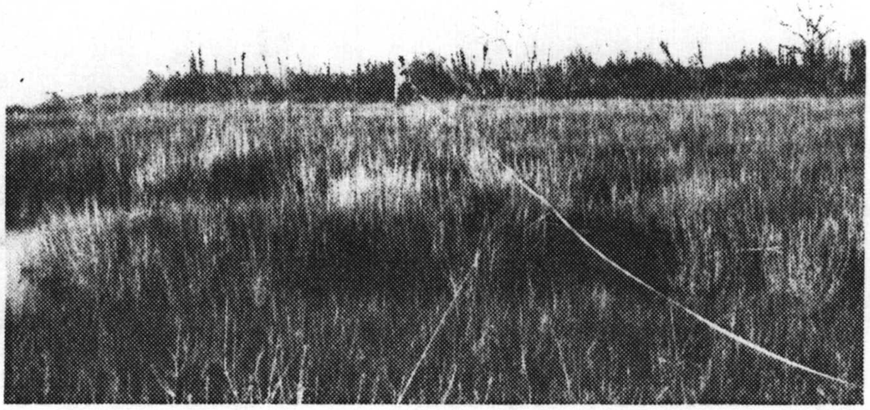


Figure 7.33. East central segment of the Muskrat Line Canal showing infilling and colonization of fill by salt marsh species. The northern spoil bank is in the background.

Figure 7.34. Western entrance of the Muskrat Line through Grand Terre. A low, earthen-shell bulkhead, vegetated with smooth cordgrass is in the foreground and shrub-tree vegetated spoil banks flank the north and south sides of the canal.

The geologic data (i.e., vibracores) are collected at the Belle Pass and Grand Terre site between November 29 and December 1, 1987. While elevation and bathymetric profiles and vegetation sampling was undertaken on December 8 and 9, 1987, vibracores (F7 and F8) were taken at the berm crest and beach-marsh contact, respectively, along the axis of the L87 pipeline which runs obliquely to the shoreline (Figure 7.35). The control transects were located approximately 1,219 m (F4 and F5) and 2,438 m westward (F1, F2, F3) from the pipeline corridor. Beach profiles using the standard transit and stadia method were surveyed in the vicinity of the pipeline ROW (FD) and at a control location approximately 860 m west (FC) of the ROW in order to provide comparative topographic data for this segment of the Belle Pass site. The FD profile was located in the ROW of a filled canal and reflects the topographic profile that is characteristic of flotation canals like L85 that have plugged naturally. Visual observations of the L87 ROW revealed that the topographic profile of the ROW corresponded closely to that of the control FC. These elevational profiles were taken by another field team, and an elevational profile was not made at FD because darkness descended before the survey could be made.

Vibracores were also taken along the ROW and a control for pipeline L86. However, review of collateral and field data indicated this site had been heavily impacted by other factors, such as cross-canal rig access dredging, construction of wing jetties, and deposition and reworking of Belle Pass maintenance dredge material. These cores, therefore, were not analyzed. However, beach profiles and vegetation samples were taken at the L86 site and will be discussed later.

Geologic data from the Grand Terre area were obtained along the axis of the Muskrat Line ROW (vibracores #1 through #4) which trends roughly parallel to the back bay shoreline, and along the marsh-Barataria Bay shore (vibracores #5 and #6) approximately 244 m north of and parallel to the ROW corridor (Figure 7.36). Four elevational profiles (GTA through GTD) were taken at regular intervals across the pipeline corridor on the western portion of Grand Terre in order to provide comparative topographic data. Analysis of the sediments from the vibracores was accomplished through visual examination, x-ray radiography, photography, and grain-size analysis.

The modern barrier shoreline within the study area at the Belle Pass site on the Caminada-Moreau headland is composed of three major depositional environments: barrier sands comprised of washover sediments, marsh, and open-water bodies. The barrier beach is composed of fine-grained, moderate to well-sorted washover sands. Morphologically, the beach ranges from areas of continuous dunes to washover terraces and washover sheets. The morphology is controlled by the availability of sand within the littoral transport system, while the beach face slope is the dominant factor controlling the occurrence of local overwash. The beach displays a transition from washover sheet to continuous dune morphology at the terminal ends of the Caminada-Moreau headland consistent with the pattern of longshore sediment transport. Sands are generally parallel, laminated with low-angle discordances, but locally exhibit ripple cross-laminations and scour and fill structures. Shells, shell fragments, and burrows are abundant. The washover sands extend an average of 18 to 21 m from the still water level to the beach crest and exhibit a relatively steep beach slope face (4 to 7 degrees). Figure 7.37A and B illustrates two radiographs of washover sediments which transitionally grade into interlaminated sands, silts, and clays observed in the L87 control vibracores F1 and F5 at a depth of 1.0 to 1.4 m and 0.6 to 0.9 m, respectively.

Open-water and interdistributary bay sequences are associated with the remnant Bay Marchand. Approximately 125 years ago, this bay was open to the Gulf (Gerdes 1982). Rapid erosion has reduced the total bay area, and accumulation of coarse-grained sediments has led to the formation of bay mouth bars. The bay fill deposits consist of

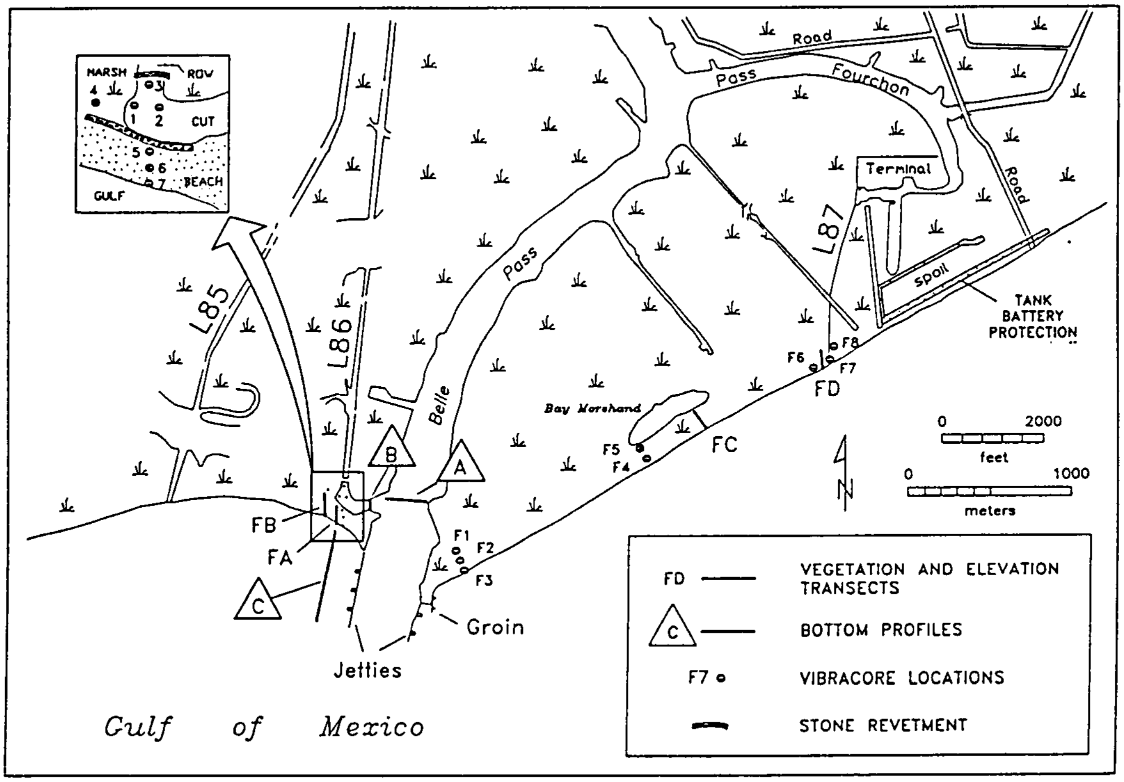


Figure 7.35. Location of field sampling stations near Belle Pass in the Mississippi Delta System.

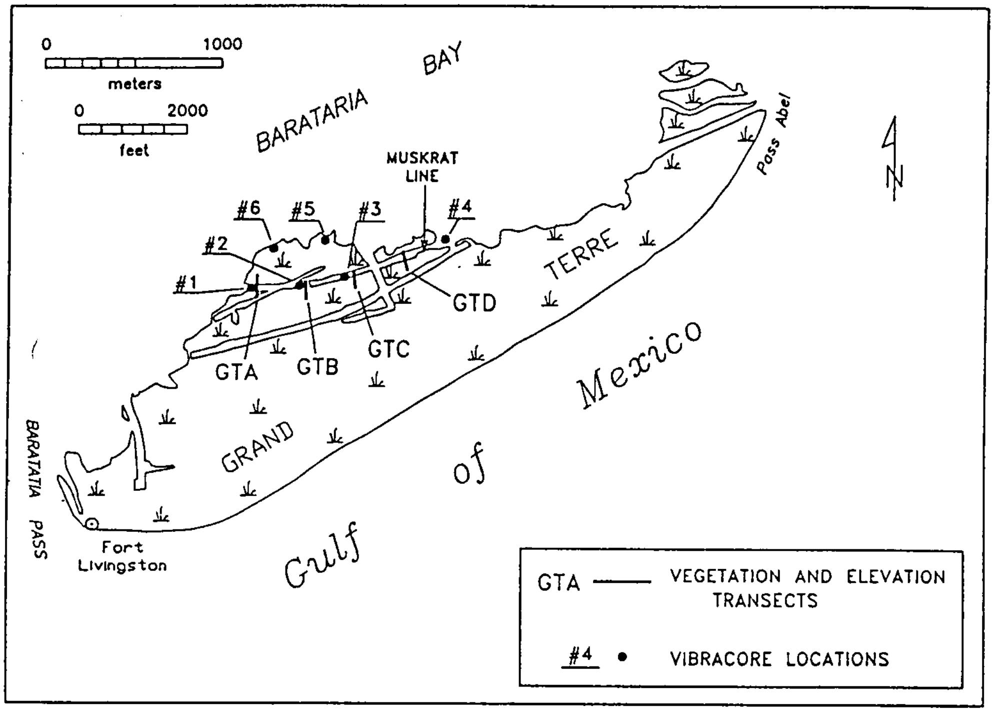
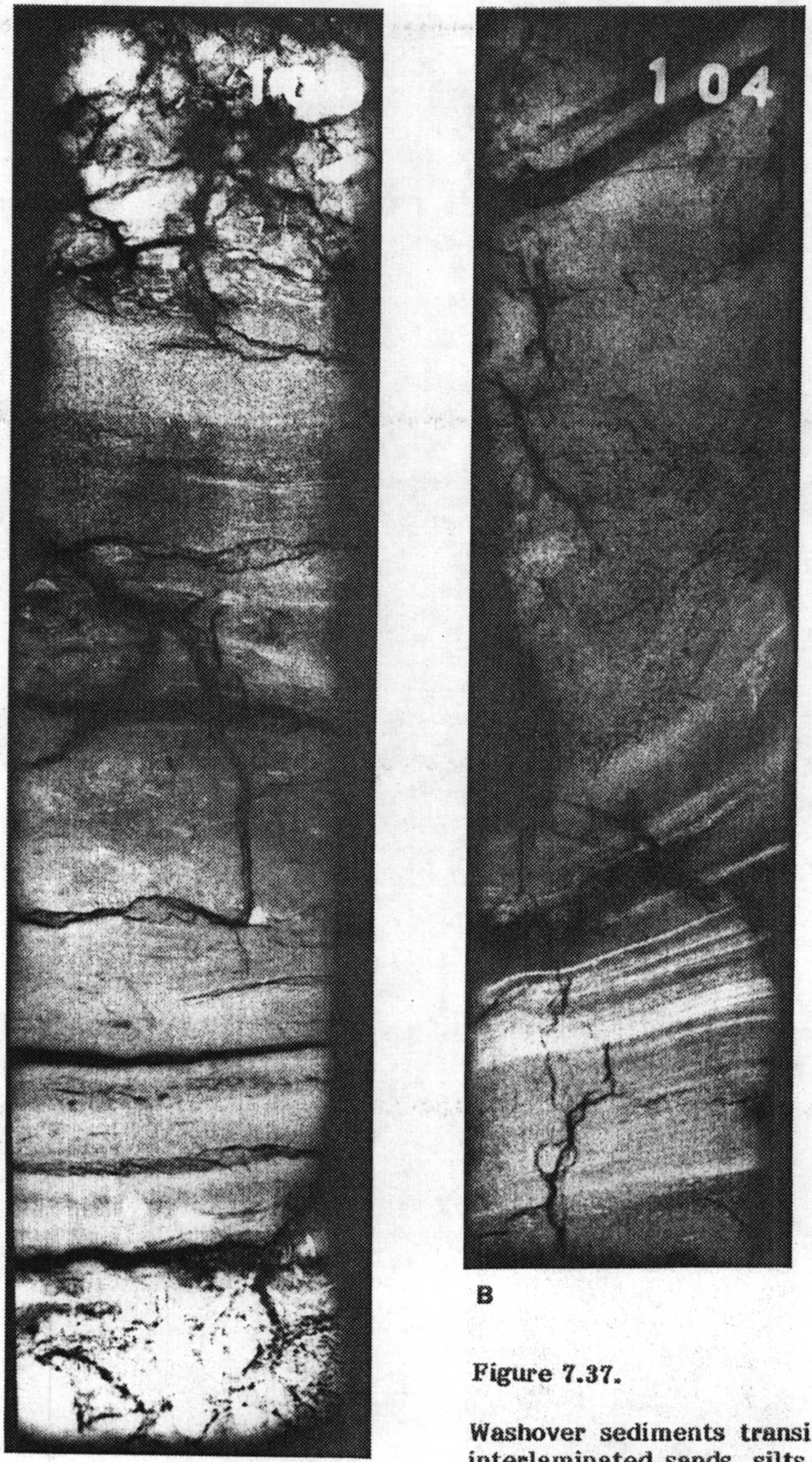


Figure 7.36. Location of the field sampling stations on Grand Terre in the Mississippi Delta System.



A

B

Figure 7.37.

Washover sediments transitionally grading into interlaminated sands, silts, and clays from the L87 controls at vibracore F1 (A) at 1.0 to 1.4 m and vibracore F5 (B) at 0.6 to 0.9 m.

finely laminated, silty clay, and clay-lenticular laminae of sandy silt occur locally. Scour features and ripple cross-laminations are also common and are produced by tidal currents or currents produced by overflow during high water stages. Marsh sediments are lithologically similar to the open-water deposits and are generally brackish to saline and vary according to local salinity conditions. The deposits consist predominantly of silty clay with in situ and detrital organic material. The sediments are horizontally laminated, although bioturbation by plants and burrowing organisms obliterates most primary sedimentary structures. Minor scattered shell fragments occur locally. Figure 7.38A and B illustrates two radiographs of marsh and open-water sediments observed in vibracores F6 (west of L87 ROW) and F7 (L87 ROW) at depths of 0.3 to 0.6 m and 1.2 to 1.5 m, respectively. Gradational units of interlaminated sand, silt, and clay are associated with the interface between washover and bay/marsh environments.

Lithologically and texturally, the sediments within the control cores and the L87 pipeline ROW test cores are environmentally consistent. No major variation in composition or grain size is observed. Sediments within the pipeline corridor, however, display a variation in thickness trend in their vertical sequence from their control counterparts, reflecting a significant change in the local depositional history. A much thinner unit of overlying sand is observed within the L87 ROW (vibracore F8 at 0.6 to 0.9 m) (Figure 7.39A), while at depth (2.1 to 2.4 m), the sediments become much coarser (Figure 7.39B).

Four beach profiles (FA through FD) were taken within the study area and represent four segments of the beach impacted by a different combination of natural and man-influenced activities (Figure 7.40). Profiles FA and FB follow the L86 pipeline ROW and control, respectively, over the beach that has been created in front of the Belle Pass west wing jetty (rock revetment) with maintenance dredged material taken from Belle Pass. Despite its location immediately west of the Belle Pass jetty, wave action has created a well-developed forebeach at each site. The FA profile located in the wave shadow zone of the west jetty has a steep beach slope of 33°. The FB profile located 152 m, west of FA has gentler beach slope of 25° but a wave cut escarpment of 60° midway of the forebeach. This escarpment may be a result of waves being refracted around the west jetty, which strike this part of the shore farther from the jetty. Behind the beach berms, which are about 1.2 m above marsh level at both sites, the profile flattens landward at a 6° angle to FA and 4° for FB, showing the transition from the washover sands into the canal (profile FA) and marsh (profile FB) located behind the beach. The natural slope at the marsh contact is disrupted by the rock revetment. Profiles FA and FB result from natural processes shaping a beach out of man-made dredge material deposits.

Profile FC is a natural profile (i.e., control for the L87 pipeline) which developed as the shoreline moved into Bay Marchand. The forebeach slopes gently seaward at a 27° angle and a small foredune, approximately 1.6 m above marsh level, is located 45 m inland of the forebeach. The area between the foredune and the remnant of Bay Morehand is composed of overwash sands which have a stepped appearance. This beach-berm complex is approximately 120 m wide.

Profile FD was taken immediately west of the L87 ROW, but it is within a flotation canal that has been infilled by overwash sediments and topped by beach sand. The steeper (45° angle) sloping forebeach corresponds closest to that found at profile FA. This may be a result of the fact that both beaches developed in deeper water rather than over a marsh substrate. The beach berm is lower (1.3 m) and not set back as far as the berm in profile FC. Behind the beach, the profile flattens and slopes gently (5° angle) landward showing the transition from washover sands into the shallowing, infilling flotation canal behind the

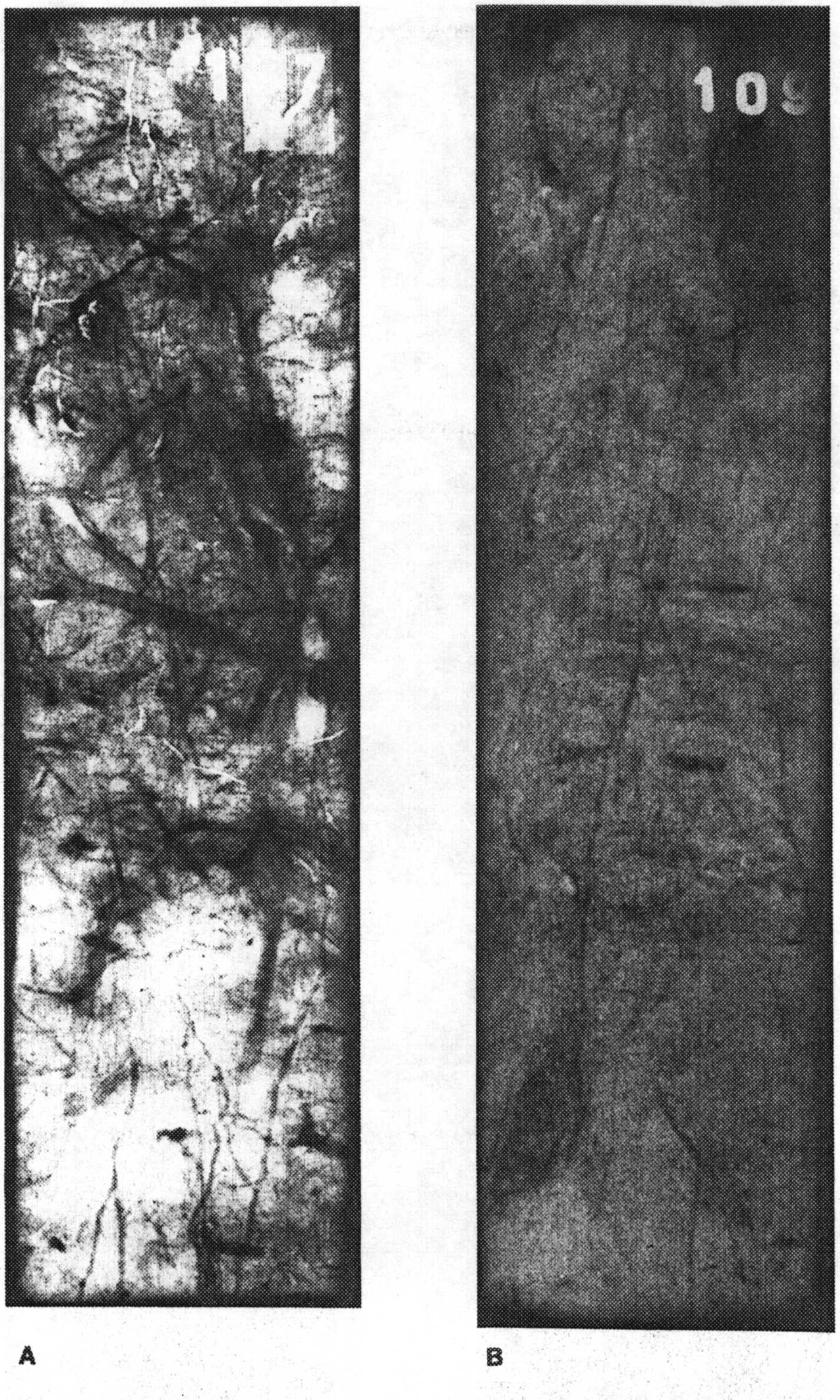


Figure 7.38. Marsh and open water sediments in vibracore F6 (A) (control core west of L87 ROW) at 0.3 to 0.6 m and in vibracore F7 (B) (at the L87 ROW) at 1.2 to 1.5 m.

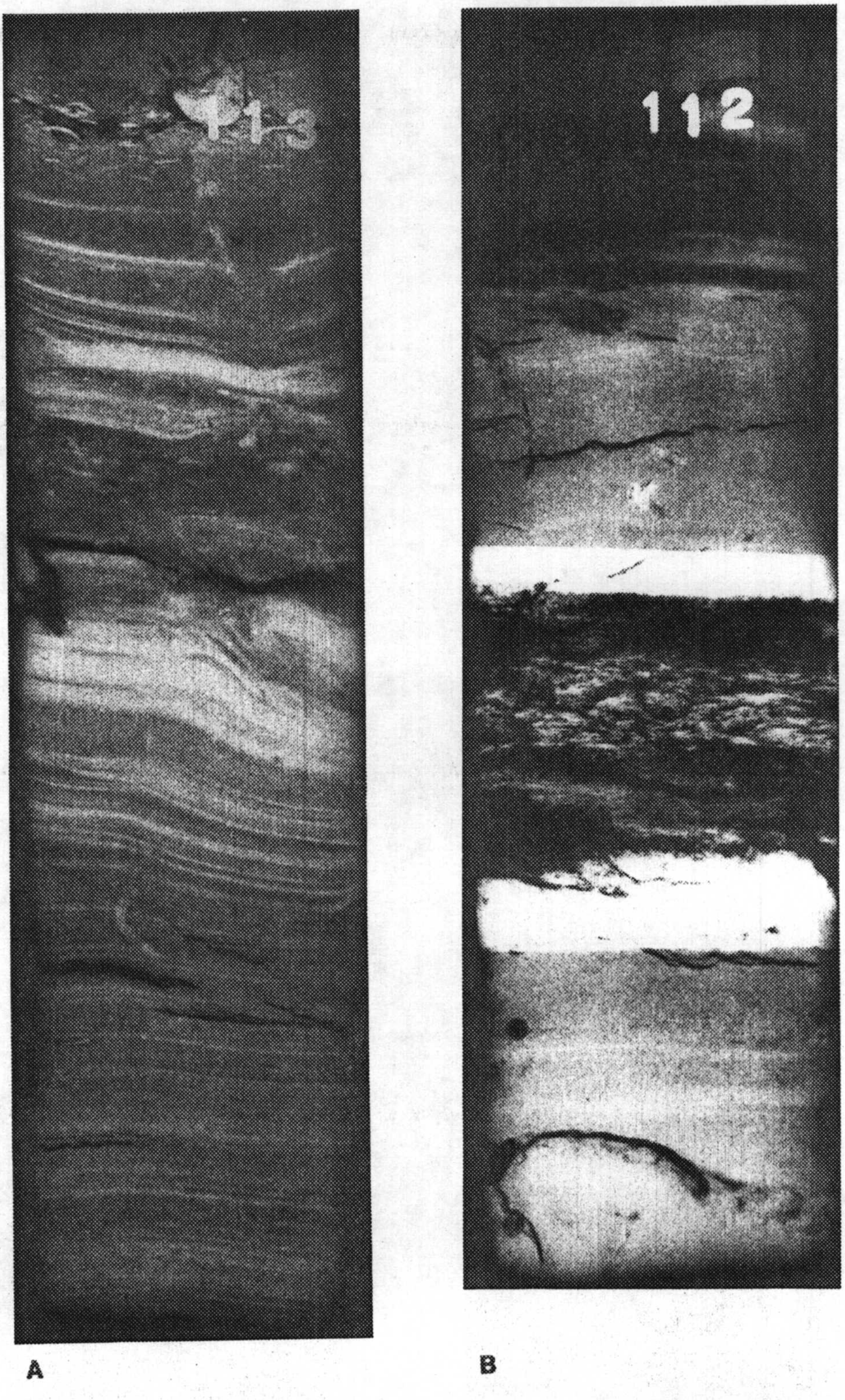


Figure 7.39. Thin unit of sand in vibracore F8 at 0.6 to 0.9 m (A) and coarser sediments at depth in vibracore F7 (2.1 to 2.4 m) (B) along L87 pipeline ROW for the Belle Pass site.

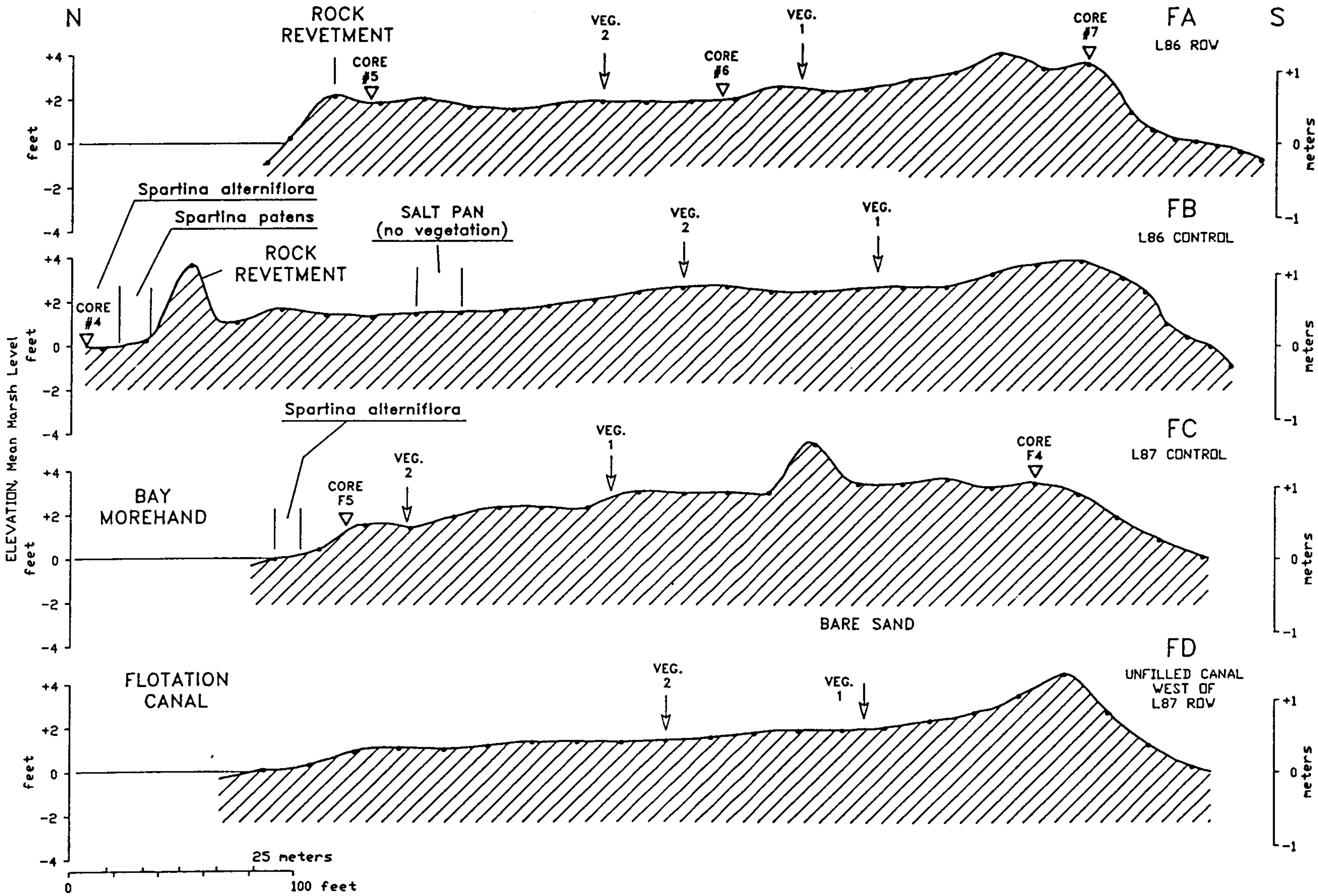


Figure 7.40. **Beach elevation profiles for Belle Pass site taken at the L86 ROW and control, the L87 control, and at a filled flotation canal west of L87.**

beach. The entire canal plug, consisting of beach-berm and overwash flat, is approximately 117 m wide.

The previously described environments along the Caminada-Moreau coast reveal a relatively straightforward stratigraphic framework. Two depositional dip sections and one depositional strike section were constructed in order to display the natural subsurface character and any facies variation that may be associated with pipeline construction.

Cross section A-A' (Figure 7.41A) serves as a control cross section and demonstrates a continuous 1.2-to-1.8-m thick layer of sand overlying a relatively thick clay unit. Interlaminated sands and clays seen in vibracore 5 exemplify the interrelationship between barrier washover sediments deposited within the marsh and open-water environments.

Cross section B-B' (Figure 7.41B) also is oriented along depositional dip and runs along the axis of the L87 pipeline ROW. The cross section shows an upper unit of sand approximately 0.6 m thick and continuous between vibracores 7 and 8. Below this sand is a 1.2-m-thick unit of silty clay. The silty clay overlies a unit again composed of fine sand. The section indicates that after initial construction of the pipeline, the corridor was partly filled with fine sand. Finer grained sediments began to fill in the corridor and rest conformably on top of the sand. The uppermost unit represents washover sands which filled the ROW corridor that remained open after backfilling. These uppermost sands are correlative with the sands obscured within the control cross sections and demonstrate a notable facies variation with its control counterparts.

While the actual rate of shoreline erosion cannot be determined by a one-to-two-day field study, the observed morphologic and stratigraphic characteristics can indicate the types of physical processes operating. The beach face at the L87 pipeline is much steeper than the slope of the beach face at the control location. Although this is not an actual escarpment, the steeper beach face indicates a greater relative degree of shoreline erosion than the control counterpart.

Installation of the L87 pipeline has changed the lithologic and textural characteristics of the sediments within the corridor as compared to the control location. The uppermost unit of sand within the corridor is only 0.6 to 0.9 m thick compared to the control station, which measures sand thickness from 1.2 to 1.8 m (Figure 7.41). Finer-grained sediments such as clay and silty clay are found closer to the surface and are more susceptible to erosion and breaching from storm activity. The absence of a back-beach water body, such as a bay or lagoon, means that formation of a channel or inlet is unlikely. Therefore, while installation of the L87 pipeline has created a weak area, any breach in the beach at this crossing site that would form from storm activity will likely be filled in by washover sands.

The L87 pipeline ROW has been filled with silty clay and sand along the shoreline and demonstrates no development of a new channel or tidal inlet. Washover sands are continuous across the axis of the corridor and there is no evidence of change in integrity. The installation of the L87 pipeline has led to the development of a weak area but natural washover processes maintain continuity along the shoreline.

The modern coastal facies within the study area at Grand Terre include four major depositional environments: barrier beach, marsh, open-water bodies, and beach ridges. The pipeline ROW does not pass through the barrier beach environment and, consequently, this system will not be discussed in detail. It is sufficient to note that the barrier beach is composed of sand and shells and demonstrates a predominantly landward retreat.

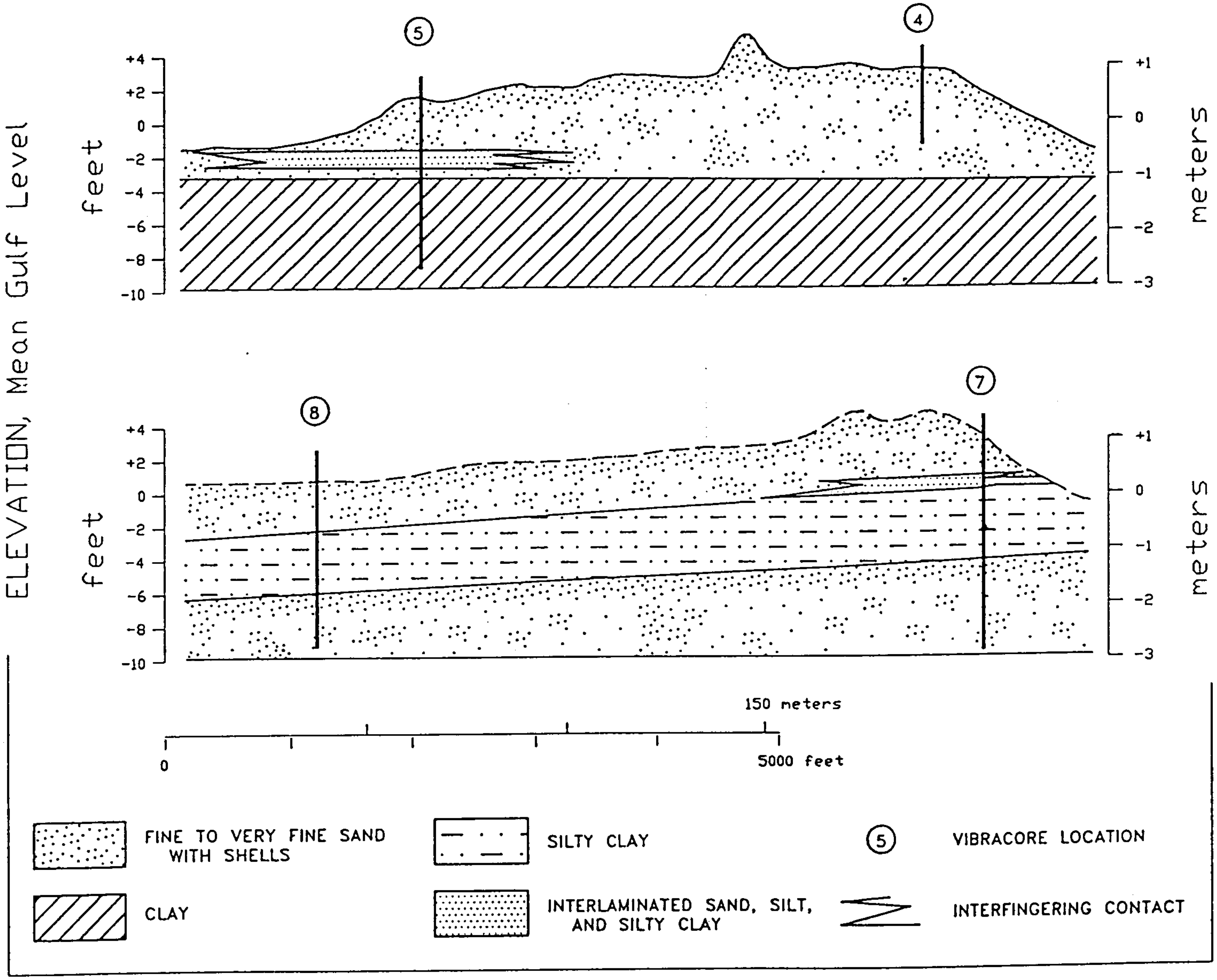


Figure 7.41. Depositional dip sections for L87 control (A–A') and L87 ROW (B–B') showing differences in stratigraphy.

Morphologic and sedimentologic characteristics are similar to the Caminada-Moreau barrier beach.

Open-water body deposits are associated with the local lakes and interdistributary bays which were present during the initial phases of delta and barrier island development. Sediments consist of finely laminated, silty clay and clay. Deposits are locally burrowed and often contain abundant shell fragments. Local scour features and ripple cross-laminations are also common. Figure 7.42A and B illustrates two radiographs of open-water sediments observed in vibracores 1 (ROW) and 5 (control) at depths of 2.4 m to 2.7 m and 1.5 m to 1.8 m, respectively.

Marsh sediments occur at the sediment-water interface at or near mean sea level and support such vegetation as grasses and mangroves. Sediments consist of finely-laminated, silty clay and clay and contain abundant burrows, plant roots, and organic material shell fragments occur locally. Figure 7.43 illustrates a radiograph of marsh sediments observed in vibracore 6 at a depth of 0.3 to 0.6 m.

The beach ridges at Grand Terre were formed from the erosion and transport of sediments from the Cheniere Ronquille beach ridge plain and the Plaquemines delta lobe distributaries. Sediment was transported westward and deposited along the eastern margin of Barataria Bay. Beach ridge deposits consist of fine-grained, well-sorted sand with scattered shell fragments. The sediments show generally parallel laminations of silt, clay, and organic material. Scour features, ripple cross-laminations, and burrows occur locally. Gradational units of interlaminated sand, silt, and clay are associated with the interface between beach ridge and interdistributary bay environments. Figure 7.44A and B illustrates two radiographs of interlaminated sediments illustrative of beach ridge and bay environments. These sediments were obtained from vibracores 4 and 1 obtained from the east and west segments of the Muskrat Line canal at depths of 1.2 to 1.5 m and 0.3 to 0.6 m, respectively.

Two depositional dip and one depositional strike cross sections were constructed for the Grand Terre study area in order to determine the natural stratigraphic framework and to display any facies variation that may be associated with pipeline construction. The position and widths of landforms such as canal, spoil bank, and marsh were taken from a USGS topographic map, while elevations were acquired from field surveys.

Cross section A-A' (Figure 7.45A) is oriented along depositional dip and shows vibracore 2 located within the Muskrat Line ROW corridor, while vibracore 5 is located within a natural depositional environment near the marsh/bay shore. Vibracore 6 shows a basal unit of fine sands representative of the beach ridge environment grading transitionally upward through interlaminated sands, silts, and clays into an upper unit of silty clay, which represents the marsh and open-water deposits. Sediments within the pipeline corridor show a basal unit of silty clay with an overlying unit of fine sand. The sand unit is notably thinner than that observed in vibracore 6. The rest of the sequence shows interlaminated sediments capped by a 1.2-m-thick unit of clay. The section demonstrates some stratigraphic variability with a thinner sand unit in the corridor and a basal unit of silty clay. Considering a maximum depth of 3 m for pipeline emplacement, the cross section reveals relatively little stratigraphic variation.

Cross section B-B' (Figure 7.45B) is also oriented along depositional dip and shows vibracore 3 located within the pipeline corridor and vibracore 5 located in a natural depositional setting. Vibracore 5 shows a 2.1-to-2.4-m-thick unit of fine-grained marsh and open-water sediments conformably overlying find sands of the beach ridge environment. Conversely, vibracore 3 shows a 2.7-to-3.0-m-thick unit of fine sand

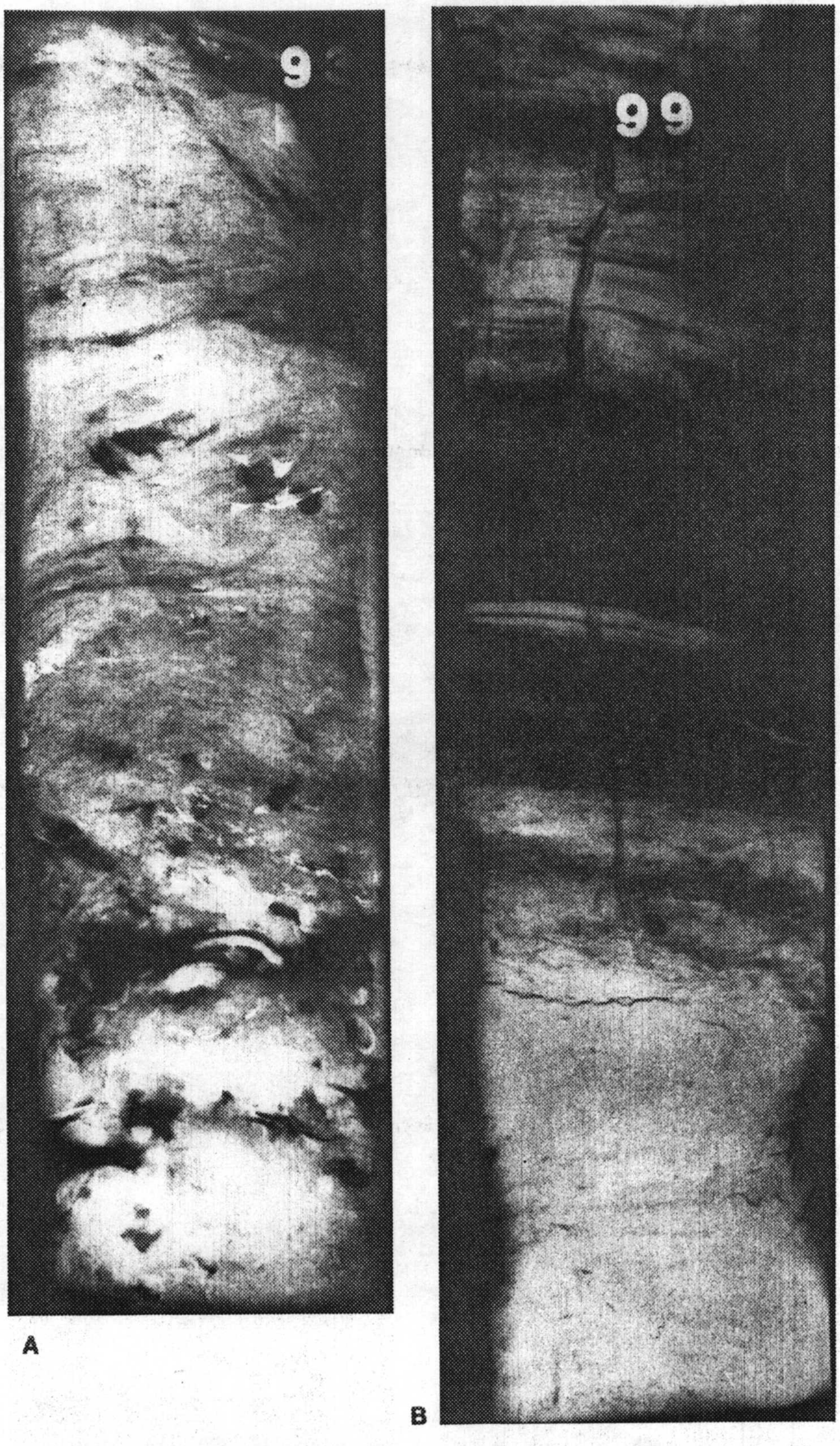


Figure 7.42. Open water sediments in radiography of vibracore 1 (L87 ROW) at 2.4 to 2.7 m (A) and vibracore 5 (control) at 1.5 to 1.8 m (B) for the Muskrat Line on Grand Terre.

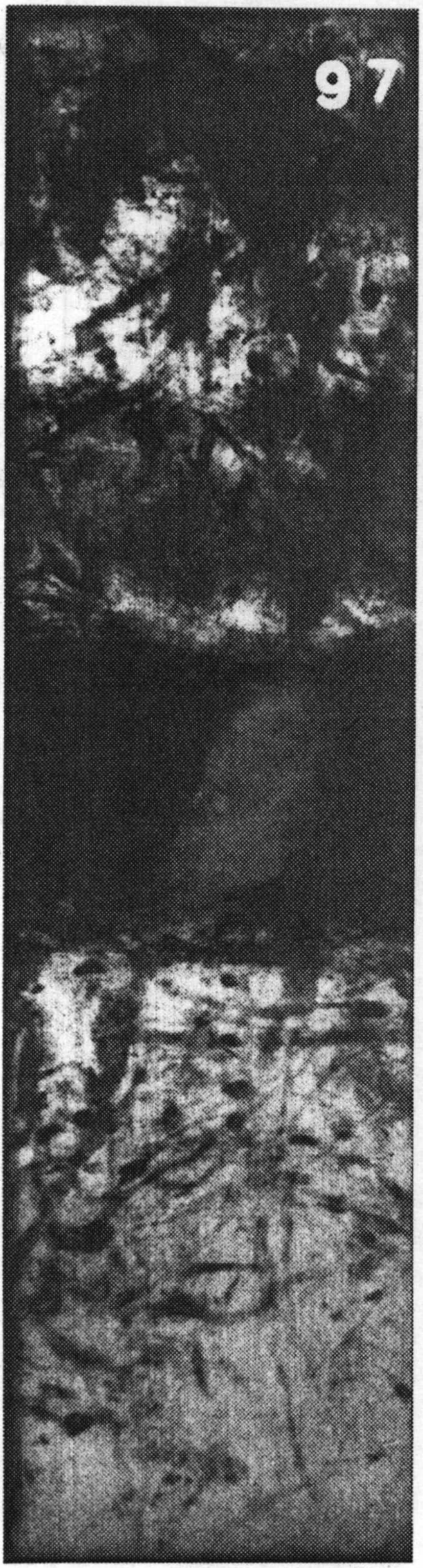


Figure 7.43. Marsh sediments in radiograph of Vibracore 6 (Control for the Muskrat Line) at 0.3 to 0.6 m.

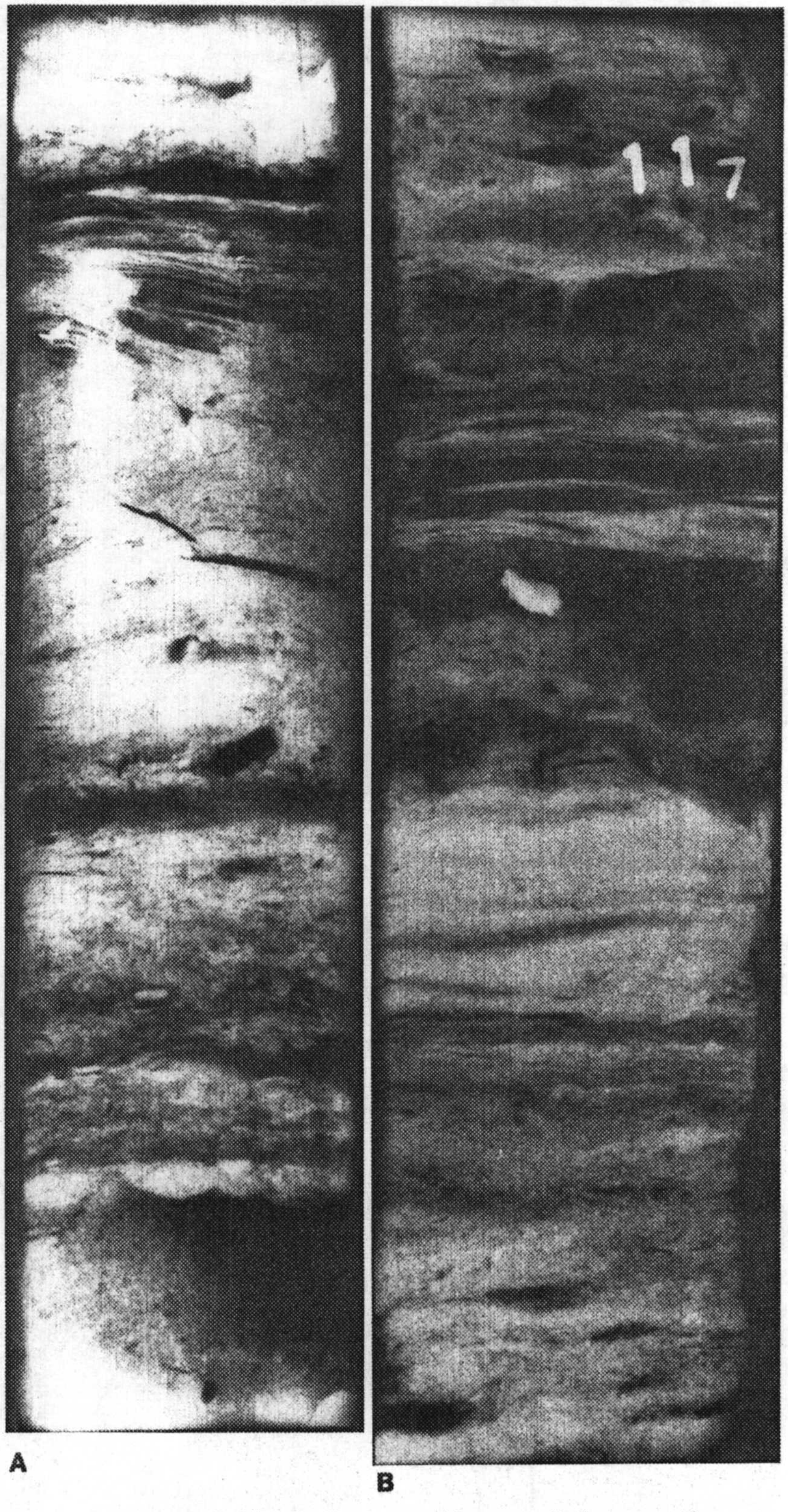


Figure 7.44. Beach ridge and bay sediments characteristic of the infilling of the Muskrat Line pipeline canal shown on vibracore 4 (east end) at 1.2 to 1.5 m (A) and vibracore 1 (west end) at 1.3 to 0.6 m (B).

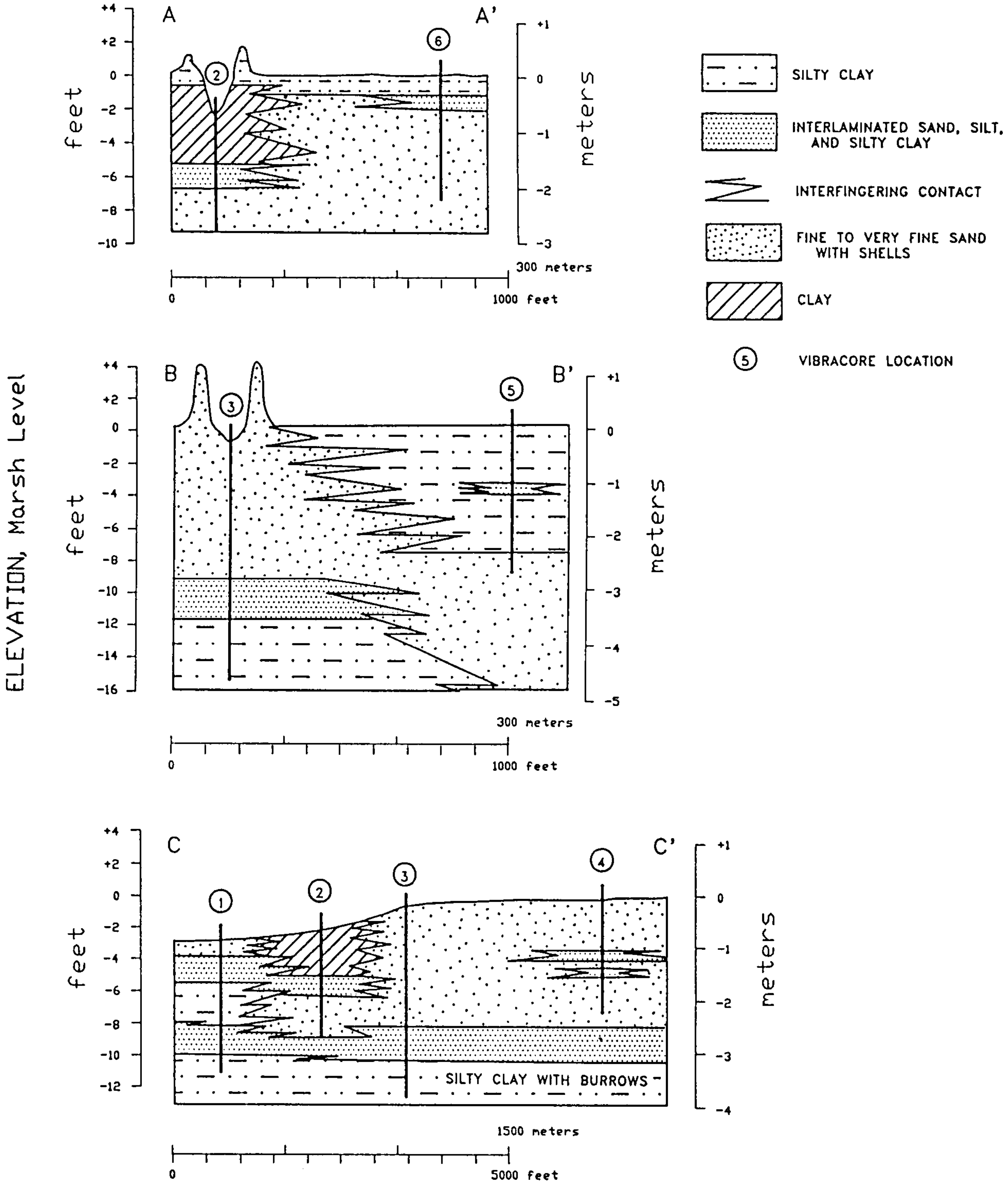


Figure 7.45. Two depositional dip cross sections (A and B) and one depositional strike cross section illustrating natural stratigraphic framework and facies variation associated with the Muskrat Line canal dredging and infilling.

overlying finer-grained interlaminated sands, silts, and clays. The basal unit shows silty clay. In this section, sand derived from the beach ridge source has filled in the area of the pipeline corridor. A coarsening-upward sequence is observed in vibracore 3 in contrast to the fining-upward sequence observed in vibracore 5.

Cross section C-C' (Figure 7.45C) is oriented along depositional strike and runs within and parallel to the pipeline ROW. The cross section shows a vertical sequence of relatively fine-grained sediments at the location of vibracore 1. The stratigraphy shows an increasing thickness and volume of sand in an eastward direction towards vibracore 4. The section clearly illustrates a fining-westward trend, indicating that beach ridge sediments were derived from an eastern source and transported longshore westward into an open bay environment. Pipeline construction has not significantly altered the stratigraphic framework other than allowing some coarser-grained sediment to infill the upper portion of the canal, as seen in vibracores 3 and 4 and a portion of vibracore 1.

Pass Abel and Quatre Bayou Pass (east of Grand Terre) are tidal inlets that originally breached Grand Terre more than 200 years ago (Penland 1987). The cross-sectional area of these tidal inlets has rapidly increased since their formation and the response has been an increase in tidal prism and the development of an extensive ebb-tidal delta. Shoreline changes at Grand Terre are directly affected by tidal inlet growth, with the result being rapid shoreline erosion. Because of the shore-parallel orientation of the Muskrat Line ROW, erosional impacts are related to the current and wave processes associated with the enlarging tidal inlets.

The flotation canal is blocked by shell dams on its eastern and western sides and at an interior water body crossing, but the canal was left unfilled. This open water canal forms an increased area in the land-water interface. This increase in area of the interface allows for more sediment reworking and increased erosion of the adjacent spoil banks. Vibracore data (Figure 7.45C), however, shows sediment infilling of the corridor which would tend to slow erosional effects, though, unlikely stop them. The pipeline ROW, therefore, does show an impact of continued erosion as a result of currents and waves from the tidal inlets reworking sediments exposed along the land-water interface.

Weak areas or areas of instability occur within the pipeline corridor as a result of a change in sediment composition and texture, and in exposure to current flow and wave-attack. Vibracores 1 and 2 reveal fine-grained silts and clays within the western end of the corridor which are more easily susceptible to breaching and scour than are the sands of the beach ridges. These sediments do grade laterally into sands from the beach ridges, though this change in facies would be unlikely to prevent scour and channelization if the weak area was undermined.

The pipeline corridor has functioned as a sediment sink. The stratigraphy shows that sand is accumulating within the corridor, making it unavailable for transport within the barrier system at the present time. Vibracores 3 and 4 show sand which has filled in the eastern portion of the corridor to a depth of less than 1 ft below sea level (Figure 7.45C). As shoreline retreat continues at Grand Terre, the distance between the shoreline and the corridor is decreased, allowing more sediment to wash over into the canal. However, once the island erodes across the pipeline, this sediment will again enter the transport system. Comparing the significance of the sediment sink of the pipeline corridor to the sediment sink of the expanding tidal prism in Barataria Pass, the impact is relatively negligible.

The pipeline corridor segments the island in a lengthwise direction. However, sediment infilling of the canal has resulted in marsh reestablishment along one end of the canal in contrast to the development of a deepening tidal channel as was hypothesized. This process may be atypical of most shore parallel canals along the Louisiana coast and resulted from sufficient sediment being washed around the ends of Grand Terre or being retained in the canal as a result of bulkhead entrapment of eroded spoil material.

Hydrologic Impacts

The extensive impacts of dredging, spoil deposition, and jetty construction precluded any attempt to discern hydrologic impacts of pipeline construction on the beach at L86 and L87. For the shore parallel pipeline on Grand Terre, the hypotheses to be tested were: (1) continuous spoil banks alter the hydrologic regime by causing impoundment of waters in the marsh, and (2) canals segment natural physiographic units and result in land loss due to erosion.

At the Grand Terre site, four elevation profiles (GTA through GTD) were made perpendicular to and across the Muskrat Line canal (Figure 7.46). Observations of water levels and drainage pathways were made along each transect. The elevation of the saline marsh was used as the datum for comparisons between sites.

The elevation transect GTA crosses the Muskrat Line on the western end of Grand Terre (Figure 7.46). To the north of the pipeline, two natural drainage bayous prevent impoundment of water by the spoil bank. The same situation was observed but not surveyed on transect GTB north of the canal and west of transect GTA. Field observations (GTB transect) and air photo analysis also reveal a small, natural channel south of the Muskrat Line spoil bank which drains the marsh to the west.

The GTC, located on the south side of the canal, exhibits two areas of ponded water south of the canal. Observations of terrain conditions indicate that water collects here because drainage is blocked on the north by the Muskrat Line spoil, on the south by another pipeline canal spoil bank, and on the east by the natural levee that has formed on the west bank of an old, small navigation canal. No impounded areas are noted on GTD. Little marsh remained north of the canal because of shoreline erosion. The area of marsh south of the canal was also small and there was a potential for impoundment because of the spoil banks from the Muskrat Line and an unnamed canal and the natural levee on the east bank of the old navigation canal. However, shoreline erosion on the east side of this small, semi-enclosed marsh appeared to be sufficient to provide drainage. The flotation canal was infilled and almost totally vegetated. A small, sinuous tidal channel had formed in the marsh within the canal and ran east to west. These elevation profiles document a trend of progressive canal infilling from GTA on the west to GTD on the east (Figure 7.46).

In summary, it was noted that the spoil banks on the Muskrat Line have caused water impoundment over the marsh in some areas where other hydrologic obstructions existed, such as other canal spoil banks or natural levees along old navigation channels. The canal did create a straight channel across a marsh which previously had small, shallow tidal channels but the continuous spoil banks did not short-circuit marsh drainage into the Muskrat Line canal except for water running off the interior slopes of the spoil banks. Furthermore, the four earthen and shell dams constructed at regular intervals along the canal prevented tidal scour through the canal. These dams, by stilling tidal movement and segmenting the canal into cells, probably facilitated the infilling with sediment washing or slumping from the spoil banks and washing over the low dams during high water stages.

While the Muskrat Line canal did segment the marsh area on the backside of Grand Terre, it is difficult to discern this canal's impact on marsh loss because there are two other canals with spoil banks parallel to the bay shore that can also function to segment the

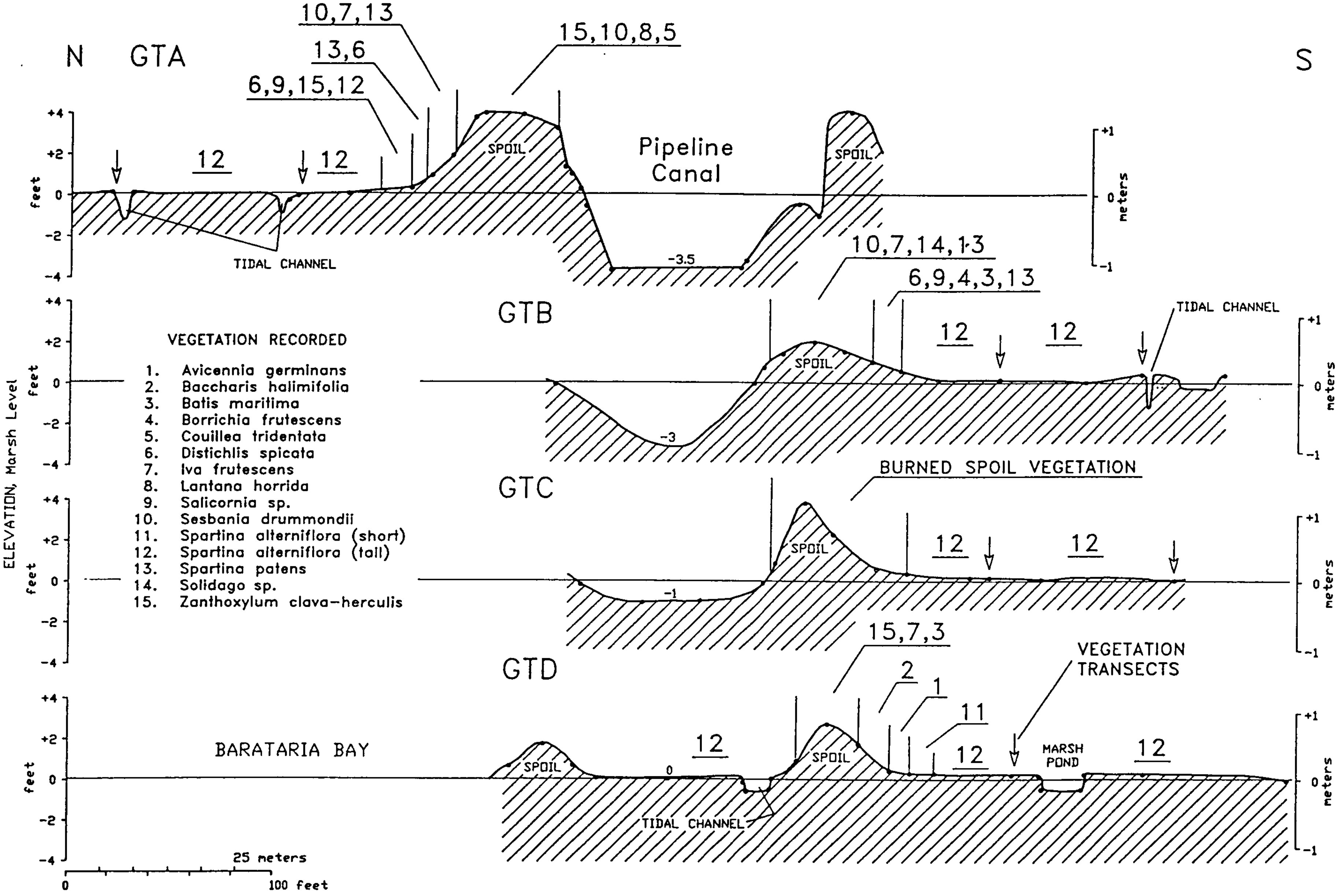


Figure 7.46. Elevation profiles and vegetation zones for the Muskrat Line at the Grand Terre field site.

marsh, block drainage, and block overwashed sediments. There has been a 55% (from 20 m to 31 m) increase in the canal width over 31 years. However, it appears that the dams have prevented scouring and helped trap sediment in the canal. The dams have remained largely intact though lowered an elevation with only one of the dams west of the GTD profile having been eroded around. At this site the back marsh was very narrow and shoreline erosion from the north cut into the dam, leaving only a subaqueous sand and shell shoal.

Vegetative Impacts

At the Belle Pass site, it was hypothesized that canal construction at L86 and L87 would remove dune vegetation and leave the landfall site subject to accelerated erosion. The canal and spoil bank at the Grand Terre site were expected to have created marsh loss directly by imposing a new set of habitats and indirectly by accelerating canal interface erosion or impounding water and killing the marsh vegetation.

To test these hypotheses, vegetation samples were to be collected, in replicate, at stations along the elevational profiles. However, field inspection at the Belle Pass site indicated that these samples would reveal little about the impact of the pipelines because man-made shoreline activities along with high rates of natural shoreline erosion had obliterated the original shore areas. In the case of the flotation canal at L86, a new beach had been created in front of a wing jetty constructed across the L86 ROW. At the L87 crossing, there was no evidence of the ROW; its location had to be extrapolated from the Chevron terminal south of Port Fourchon to even discern its approximate shoreline crossing.

Two vegetation sampling stations, each with two replications, were taken along the L86 ROW and control located 152 m west in order to document present conditions at this pipeline ROW. In the vicinity of L87, there was a canal that would have been very similar to the L87 canal. Therefore, vegetation sampling was taken along the elevational profile (FD) of the ROW of the canal in order to document conditions that might have been expected at the L86 site under relatively natural post-construction conditions. A control sample was taken along the elevational profile about 790 m (FC) west of the FD profile (Figure 7.35). In all cases, these samples were taken 30 m and 60 m landward of the highest point of the berm along the transect. Data on percent cover and standing crop were obtained by the methods previously described.

Conditions at the Grand Terre field site dictated that the vegetation sampling stations be placed on elevational cross sections of the Muskrat Line ROW (Figure 7.36). Two vegetation sampling stations (each with two replicates) were located on each Transect at 30 m and 90 m from the apex of the spoil bank. Transect GTA was run from the north spoil bank toward Barataria Bay. The tidal drainage at this transect was not hindered by the spoil bank and the vegetation samples serve as a control for the testing of impacts due to impoundment. In addition to sampling with 1-m^2 quadrants, the plant zonation on and adjacent to the spoil banks was documented. Statistical methods used were similar to those already described.

Results of the vegetation sampling at the Belle Pass field site are shown in Table 7.8. At transects FA and FB west of Belle Pass, it was evident that a substantial quantity of spoil material had been placed gulfward of a rock revetment running parallel to the gulf from the jetty westward. At the 30-m distance from the berm crest (FA-1 and FB-1), seaside goldenrod (Solidago sempervirens) was abundant on both transects, but no other species were in common between the two sites (Table 7.8). At the 60-m distance there were no species in common between transects. The habitat appears to be the result of random sprouting of transported seeds. The comparison of standing crop biomass does not show any significant differences at the 0.05 level (Table 7.8).

East of Belle Pass in the vicinity of L87, transects FC (control for L87) and FD (the canal west of L87 being infilled with overwash material) display marked differences (Table 7.8) in that FD had no vegetation at either the 30-m or 60-m stations (Figure 7.47). Transect FC on the other hand had 2% and 100% cover at 30 m and 60 m, respectively. The mean and 95% confidence intervals for FC and FD standing crop biomass is shown in Table 7.8. More quadrant samples would have to be done to adequately describe this patchy environment.

The vegetation sampling stations at the Grand Terre field site only displayed smooth cordgrass and unvegetated areas in the quadrants at each transect location (Table 7.9). No statistically significant differences were found among the four transects (Figure 7.48). Likewise, there were no significant differences between stations 30 m and those 60 m from the spoil bank.

The plant zonation related to elevation on the slopes of the spoil banks is shown on Figure 7.46. Greater diversity of plants on the spoil banks would be expected, but the plants recorded were limited in number because the spoil banks had been recently burned.

North Central Gulf Coast

Site Description for M1, M2, and M3

The study area is located in southwestern Hancock County, Mississippi, east of the Pearl River in the vicinity of Ansley at 30°15'N latitude and 89°30'E longitude (Figure 7.49). Evolutionary development of the area began approximately 7,000 years B.P. in association with the Holocene transgression (Otvos 1978). Sediments consist chiefly of clay and silt deposits. The study area was completely inundated approximately 4,000 years B.P. and a discontinuous beach-dune ridge complex termed "Magnolia Ridge" was formed on the mainland shoreline. At the same time, sandy shoal areas, which received sediment from the barrier island shoal system off of present-day Mississippi, developed. The shoal areas subsequently developed into aggradational barrier islands. The transgressive development ended as a result of reduced wave energy and cessation of littoral sediment transport along the island shoal system because of the blocking effect from the growth of the nearby St. Bernard subdelta. Consequently, a regressive phase of evolutionary development occurred with extensive marsh progradation. Today, the study area exhibits a 4.8-km-wide marshland bordered, for the most part, on the north by the beach dune trend. Within the marsh complex, and oriented parallel to the marsh creeks, is Campbell Island, a relict barrier island.

The soils of the field site can be grouped into two general types:

1. Atmore-Beauregard-Escambia: On gently sloping, moderately well drained upland flats and low ridges composed of silty and loamy soils.
2. Hansboro-Bohicket types: On flat, poorly drained tidal marsh composed of mucky and clayey soils (USDA, Soil Conservation Service 1981).

The Hansboro association, consisting of well decomposed organic soils with very little mineral content, make up the majority of the site (Figure 7.50). The Bohicket silty clay association includes very dark brown, silty clay soils with much less organic content than the Hansboro association.

Table 7.8. Percent Vegetation Cover and Standing Crop Biomass Data for the Belle Pass Field Site.

	% Cover of Species By Transect and Station							
Transect	FA	FA	FB	FB	FC	FC	FD	FD
Station	1	2	1	2	1	2	1	2
Species								
Unvegetated	43.8	12.0	31.3	15.0	98.5	0.0	100.0	100.0
Aster subulatus		7.0						
Baccharis halimifolia				0.5				
Batis maritima	7.0	38.4						
Distichlis spicata			27.7					
Heliotropium curassavicum	4.0							
Ipomea stolenifera					1.0			
Panicum amarum					0.5			
Sesuvium maritimum			4.0					
Solidago sempervirens	21.8		16.0	1.0				
Spartina alterniflora		35.0				98.5		
Spartina patens			7.0	83.5		1.5		
Sueda maritima	19.8							
Standing Crop Biomass (g/m2)			% Species at Sampling Station					
Mean	211.2		150.4		646.4		0.0	
95% C. I. (+/-)	333.3		369.0		2224.0		0.0	

Figure 7.47. Vegetation sampling along elevation profile FD within infilling canal ROW west of L87. Vegetation sampling stations at 30 m and 60 m recorded no vegetation. In the foreground is a narrow band of smooth cordgrass located between the base of the berm and the bare sand infill of the canal.

Table 7.9. Percent Cover and Standing Crop Biomass for the Grand Terre Field Site (all Spartina alterniflora).

Transect	Station	Replicate	% Cover	grams/m2
GT1	A(30 m)	1	50	356.8
GT1	A	2	75	571.2
GT2	A	1	100	880.0
GT2	A	2	100	780.8
GT3	A	1	20	225.6
GT3	A	2	100	550.4
GT4	A	1	100	609.6
GT4	A	2	100	611.2
		Mean	80.6	573.2
		95% C.I. (+/-)	21.2	145.4
GT1	B(60 m)	1	100	929.6
GT1	B	2	100	665.6
GT2	B	1	100	555.2
GT2	B	2	100	621.4
GT3	B	1	0	0.0
GT3	B	2	4	284.8
GT4	B	1	100	782.4
GT4	B	2	95	832.0
		Mean	74.9	583.9
		95% C.I. (+/-)	31.2	212.7

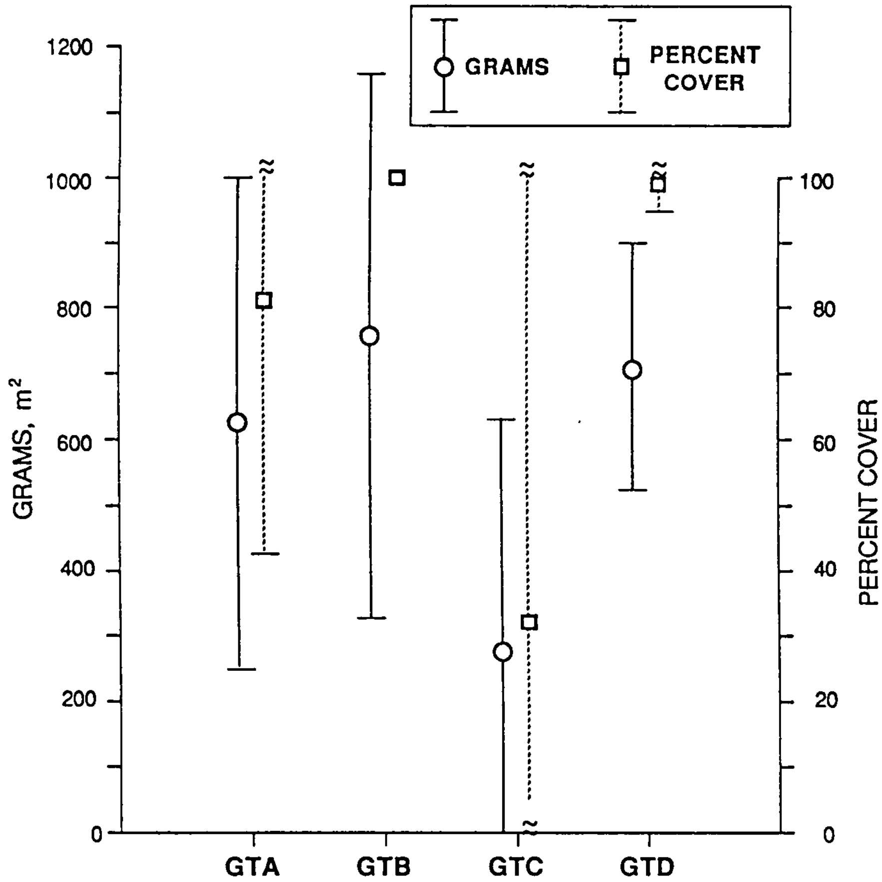


Figure 7.48. Means and 95% confidence intervals for percent cover and standing crop biomass (g/m^2) at the Grand Terre field site.

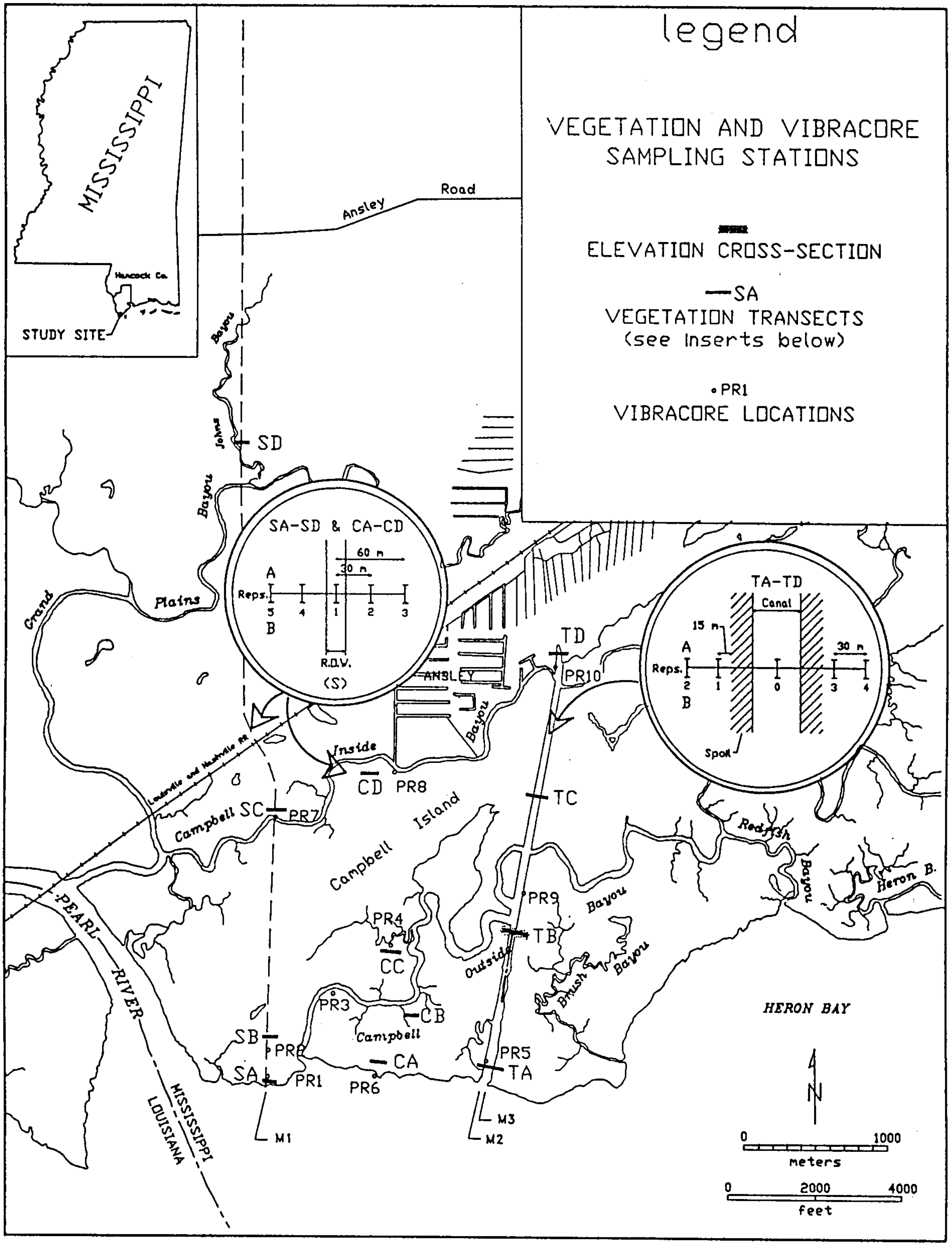


Figure 7.49. Location of sampling stations for the Pearl River field site within the North Central Gulf Coast System.

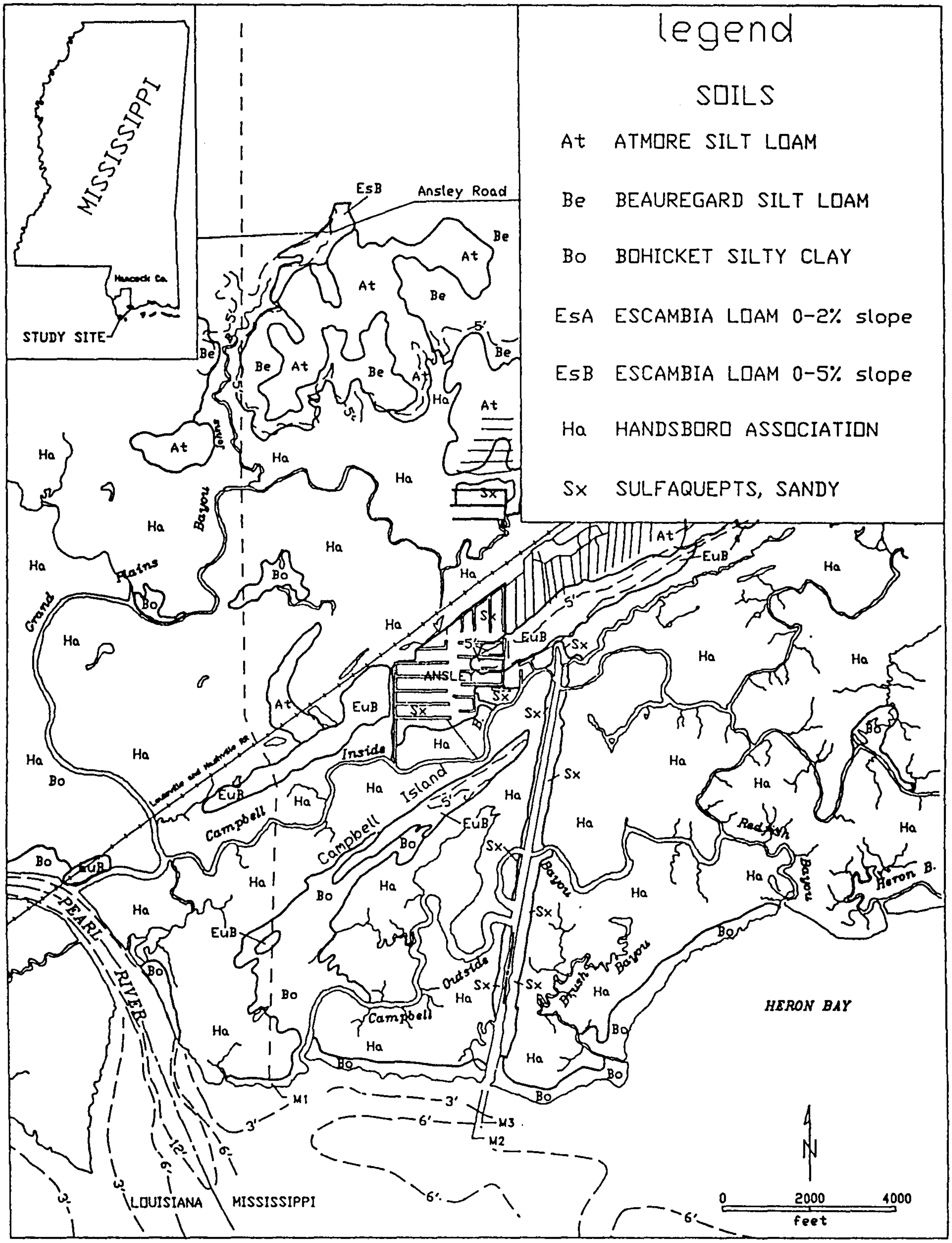


Figure 7.50. Distribution of soil types at the Pearl River field study site.

The dominant species of marsh vegetation at the field site is blackrush (Juncus roemerianus). Smooth cordgrass is a minor constituent with blackrush in the southern part of the site being primarily along the lower stream banks and lake rims. On the lower spoil banks and natural levees, hogcane is present, sometimes in dense, monotypic stands. In the areas north of the railroad embankment, wiregrass becomes progressively more abundant but blackrush remains a major component of the marsh association. In the vicinity of the upland contact, wiregrass becomes the dominant species. This marsh association is typical of the Mississippi marshes in general. Eleuterius (Christmas 1973) reported that blackrush composed 45.3% of the total tidal marsh plant population while associated with smooth cordgrass (6.5%), hog cane (6%), wiregrass (7%), and 46 other minor species (35.2%). When consulted concerning changes in the distribution of marsh zones at this site since the late 1950s, Eleuterius (1988) responded that he had seen no significant change in this area. Blackrush was the dominant species and the area, in general, had a quite stable substratum. Furthermore, he noted that trying to delineate saline, brackish, and intermediate marsh zones in this area for purposes of comparing shifts in zones through time was "...difficult, if not impossible" because of salinity gradients and fluctuations" (Eleuterius 1988).

The field site is situated on the border of the Pontchartrain Basin and Mississippi Sound and is directly east of and adjacent to the main (east) channel of the Pearl River. Average discharge of the Pontchartrain Basin drainage through this area has been estimated at 9,800 cubic feet per second (cfs) under normal conditions (van Beek et. al. 1982) but occasional openings of the Bonnet Carre Spillway may introduce Mississippi River water to the system at a rate of up to 250,000 cfs for a short period. The average discharge of the Pearl River has been estimated at 12,900 cfs. Regression analyses have shown that the Pearl River discharge is the most influential parameter in predicting salinities in eastern Lake Pontchartrain and Lake Borgne (van Beek et. al. 1982). The proximity of the field site to the Pearl River produces moderate salinities of 10 to 15 ppt in the marshes fringing the sound (Eleuterius and Beaugez 1979). During the period of field sampling (September 28 and 29, 1987), salinities ranged from 14 ppt at the shoreline to 11 ppt in Campbell Outside Bayou. At Campbell Inside Bayou, salinity was 8 ppt, while the upper reaches of Grand Plains Bayou had a low of 6.5 ppt (see Figure 7.49).

History and Interpreted Changes

The 20-in pipeline (M1), now operated by Sohio Pipeline Company, was originally constructed in 1970 by Gulf Refinery Company to transport gasoline from the Alliance Refinery in Louisiana to Collins, Mississippi (Reno 1988). No specific information on construction techniques were available from the Corps of Engineers permit files or either of the three companies who have operated the line at various times, including Chevron USA, acquired the line from Gulf Oil. Reno (1988), with Sohio, did verify that the line was buried about 0.9 m below the marsh surface.

The other two pipelines investigated in the field were the 30-in (M2) and 36-in (M3) gas pipelines constructed by Tennessee Gas Pipeline Company in 1958 (estimated) and 1965, respectively. The M2 line is known as the Delta-Portland Line: No. 500-1; it transports gas from coastal Louisiana, including offshore areas, to Portland, Tennessee. The M3 line also transports gas in the same corridor as M3 and is known as the Delta-Portland Line: No. 500-2.

Detailed information concerning the construction of these two lines was not available from the operator or Corps of Engineers' permit files. Information on construction techniques and degree of environmental impact was determined from analysis of selected aerial photographs (Ammann 1955/56; ASCS 1958, 1969; NASA 1985) and field reconnaissance undertaken in September 1987.

The location of M1 remains visible on recent CIR photography (NASA 1985) as a very thin (approximately 4 m wide), straight, discontinuous line stretching northward from Lake Borgne, approximately 430 m east of the Pearl River, across marsh covered ridges and swales of the Campbell Island complex, across Campbell Inside Bayou to a terrace south of the Louisville and Nashville Railroad. Here, the pipeline crosses the railroad at a perpendicular angle, then recurves to resume a northward bearing.

The M1 ROW is camouflaged by dense marsh vegetation near Lake Borgne, on the Campbell Island ridges, north of Campbell Inside Bayou, and on the terrace (NASA 1985). An initial conclusion was that this line had not completely revegetated along its entire length 15 years after construction. However, field observations revealed that the line was revegetated but by smooth cordgrass rather than blackrush, the dominant marsh species south of the railroad. On the 1985 CIR photograph, areas with smooth cordgrass appear bluer (perhaps because of its shorter height and generally lower-lying and more frequently flooded condition) and almost identical in appearance to shallow, tidally influenced open-water areas interspersed throughout the marsh. Furthermore, water levels appear to be at normal or high levels at the time the CIR photograph was taken. There is no erosion along the M1 ROW near Lake Borgne nor where the line is dammed on both sides of its crossing of Campbell Inside Bayou.

North of the railroad, where wiregrass is more common, the M1 ROW is still visible but it appears to be thinner and more discontinuous. No dams are visible at water body crossings, as seen on the 1985 CIR photograph. Erosion at the ROW natural channel crossings appears to be random rather than occurring at all crossings and to be very minimal to date. Furthermore, between the railroad and Grand Plains Bayou to the north, numerous straight, narrow ditches flanked by round spoil deposits have been dredged in the vicinity of M1. Some of these canals were dredged before 1969 and may have been intended for mosquito control around Ansley, a "developing" community at the time.

While the construction of M1 does not appear to have had a major impact on this marsh to date, a comparison of 1955/56, 1958, 1969, and 1985 photographs reveals there has been a change in the marsh in terms of plant cover and perhaps even dominant species in some areas. In late 1955 and early 1956 (Ammann 1955/56), the expansive marshes in the region, both north and south of the railroad, had been burned, a practice commonly associated with fur trapping. A large-scale black and white photograph taken in February 1958 (ASCS) (Figure 7.51A) revealed old burn scars and numerous muskrat houses in the vicinity of Campbell Island and north of the railroad track. These two photographs indicate that the marshes in the swales around the ridge and north of the railroad may have been more low salinity brackish than saline in the mid- to late-1950's.

By December 1969 (Figure 7.51B), there were no recent marsh burns in the area, but muskrat houses were still visible. Furthermore, there were numerous areas of marsh breakup indicative of eatouts. In addition, there were three major corridors of multiple marsh buggy tracks, one of which followed the general route, but slightly east of the M1 ROW, which was to be constructed in 1970. This particular set of tracks had destroyed the few remaining clumps of vegetation in the alleged eatout areas of the Campbell Island swales.

The 1985 CIR photography (Figure 7.51C) was taken at a smaller scale (1:60,000) than the previously discussed photographs (1:20,000 or enlargements to 1:790 ft [240 m]), so comparable comments on marsh conditions are not possible because of diminished

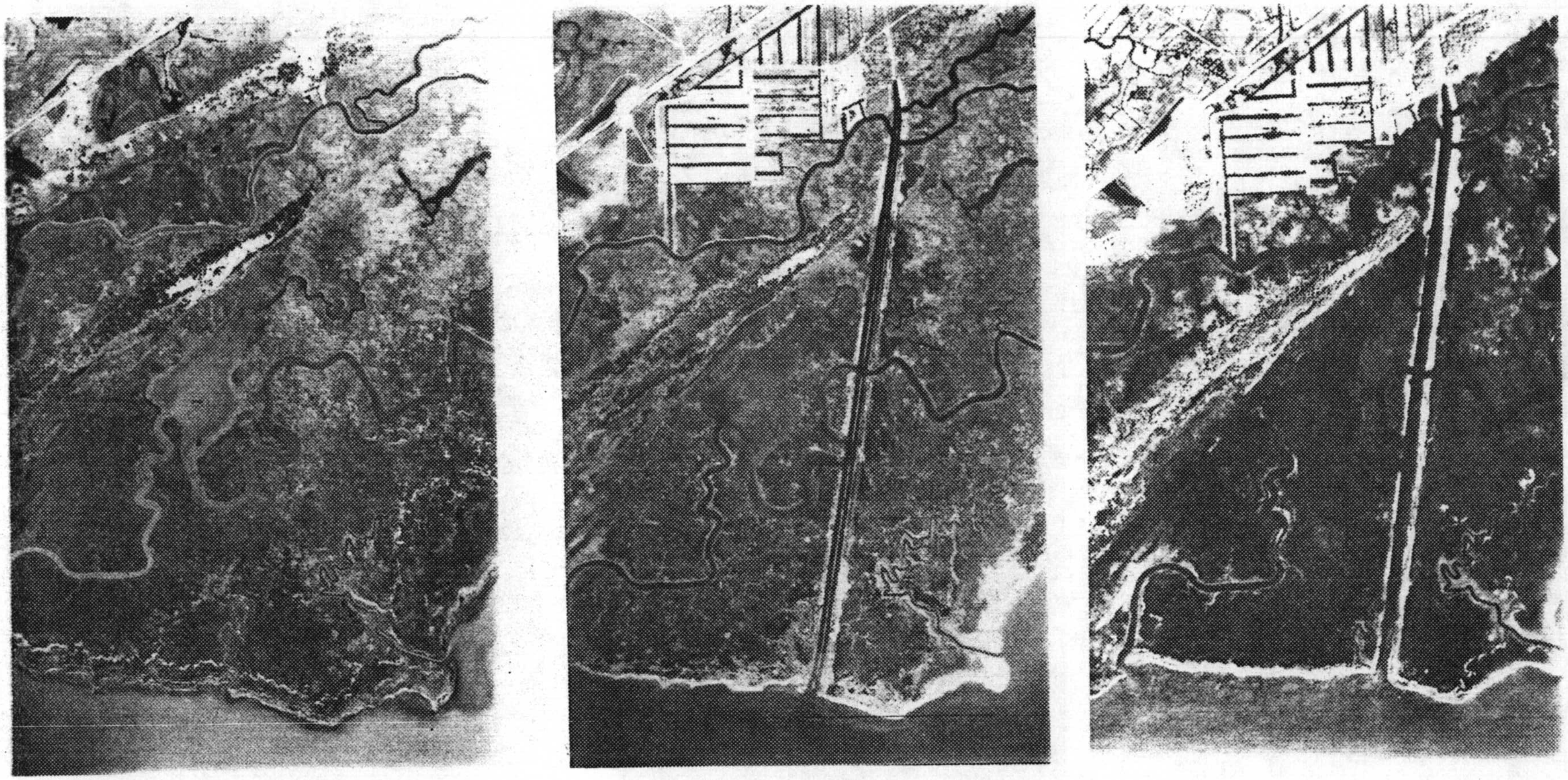


Figure 7.51. Comparison of condition of M1 pipeline ROW in 1958 (A), 1969 (B), and 1985 (C) (ASCS 1958; ASCS 1969; NASA 1985).

resolution. However, many of the smaller tidal channels north of the railroad now have a fuzzy, rather than smooth, parallel-sided, channel plan-view. This may signal a pattern of change in species composition or density along these channels, such as wiregrass to smooth cordgrass, which would make the vegetated edges of the channels appear as open water (as evidenced by erosion along the bank), and even land loss. However, the changes that are evident are associated with existing natural channels and swales and are not related to emplacement of the M1 pipeline.

Comparison of shoreline positions on aerial photographs for 1958, 1969, and 1985 indicate that there has been no accelerated erosion as a result of canal construction. Shoreline change rates were calculated for the M1 ROW and two controls (Appendix B.4). The western and eastern controls were 411 m and 549 m, respectively, away from the ROW.

M1 made landfall on an eroding marsh shoreline having no sand or shell beach. Between 1958 and 1969 (pre-pipeline) the erosion rate was about 2 m/yr for the ROW site and the west control but 6 m/yr for the east control. For a period after pipeline emplacement (1969-1985), the erosion rate remained approximately the same for the ROW and west control, while the east control erosion rate decreased to 0.1 m/yr. Shoreline retreat was calculated using the marsh-water interface on the 1969 and 1985 photograph and the marsh-flat interface on the 1958 photograph. These data, as well as observations of the pattern of shoreline change depicted on aerial photographs, indicate the variable pattern of shoreline change for any given point on this coast. The 1985 CIR photograph, in particular, shows a densely vegetated "high" marsh along the shore that exists in response to overwash of sediment and vegetative debris during high water. This higher shore rim advances landward as the shore retreats and has obscured the location of the M1 ROW. There is no indenture at the ROW site to indicate accelerated erosion at that point.

The 30-in (M2) and 36-in (M3) pipelines were both emplaced using flotation canals dredged in a northeast direction from Lake Borgne through the marsh to the terrace. An analysis of aerial photographs taken by the ASCS (1958, 1969) and NASA (1985) reveal the condition of the canals and their impacts on the landscape through time (Figure 7.52A, B, C) (Table 7.10).

The M2 canal was dredged in 1958, and as evidenced on the 1969 photo, continuous spoil banks were deposited along both sides of the canal. The canal was dammed at its entrance to Lake Borgne but not at any of the major, natural channels it crossed. At the site of spoil deposition, existing small tidal channels were filled but five larger channels remained open along the west side of M2 canal by 1969. The canal was constructed east of Campbell Island but cut through Campbell Outside Bayou twice, through a channel reach and a bend.

The M3 canal was dredged in 1965, immediately adjacent to the east side of M2. The 1969 photograph indicates that this alignment required dredging through a portion of the M2 east spoil bank. This, plus the fact that all spoil from the M3 canal was deposited in a continuous line along its east bank, accounts for the higher and wider form of the spoil on the M3 east bank. At the site of deposition, this eastern spoil bank obliterated the former natural drainage pattern of all but three larger channels. The 1969 photograph shows that both the M2 and M3 spoil banks are vegetated except for a northeastern segment that had been dredged through the subaerial portion of Campbell Island.

No dams were placed on M3 at the locations where it crossed natural channels. A new concrete bulkhead was constructed on both the M2 and M3 canals approximately 180 m north of the first original bulkhead placed on M2. The M2 bulkhead was still in place in 1969, but the narrow, east spoil bank to which it was connected had eroded to the point

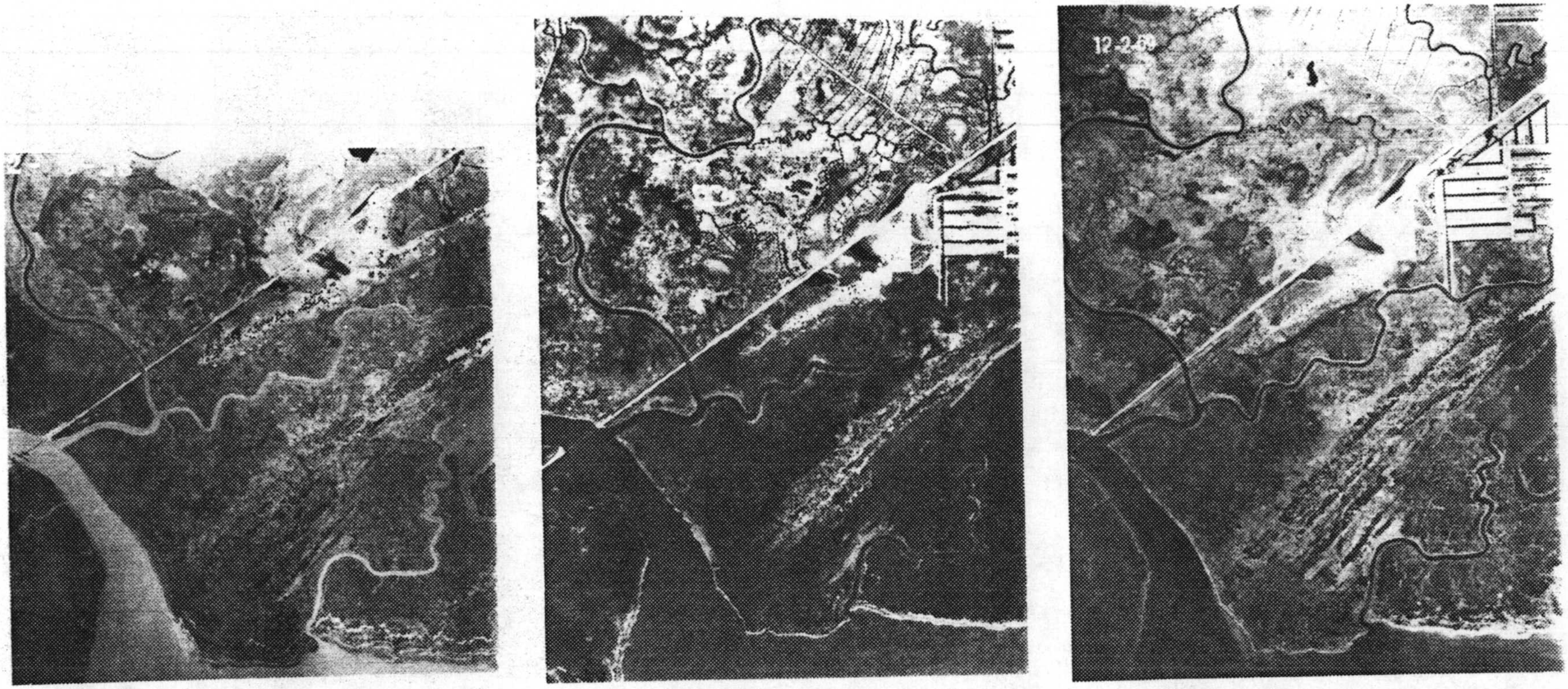


Figure 7.52. Comparison of condition of M2 and M3 pipeline ROW in 1958 (A), 1965 (B), and 1985 (C) (ASCS 1958, 1969; NASA 1985).

Table 7.10. Comparison of Change in Habitat Type and Area Along the M2-M3 Canal Corridor for 1958, 1969, and 1985.

	1958		1969		1985	
Habitat	Ha	%	Ha	%	Ha	%
Upland	12	3	14	4	15	4
Marsh (NF)	314	83	268	71	271	72
Spoil (M2, M3)	0	--	24	6	20	5
M2 Canal	0	--	6	2	10	2
M3 Canal	0	--	6	2	8	2
Canals (other)	<1	<1	1	<1	1	<1
Ponds (F)	<1	<1	<1	<1	0	0
Lakes (NF)	28	8	34	9	22	6
Tidal Channels	22	6	22	6	28	8
Total	376		376		376	

F = Fresh NF = Nonfresh

that there was continuous water exchange between the M2 pipeline canal and Lake Borgne, via the M3 canal.

By 1985, both east and west spoil banks remained, although they had diminished in width. The presence of shrubs on portions of the east spoil bank indicated it remained higher than the west bank, which was primarily vegetated by grasses such as hogcane. The middle spoil bank, located between M2 and M3, was almost completely eroded. Erosion had created a channel around the west side of the M2-M3 setback bulkhead, allowing water movement between Lake Borgne and the M2-M3 canal complex.

A comparison of the 1958, 1969, and 1985 photographs does not indicate any marsh breakup along the southern two-thirds of this canal complex that could have been expected as a result of impoundment of water on the marsh located between the natural channel and man-made canal levees. However, impoundment of water over the marsh east and west of the spoil banks is visible on the 1969 photograph for that segment of the canal southeast of Campbell Island. This area had been drained by an intricate, narrow dendritic network of channels leading into one larger channel extending north from Campbell Lagoon. Deposition of spoil blocked this drainage network, thus resulting in elevated water levels. By 1985, the west spoil bank of M2 had virtually disappeared, perhaps because of subsidence into a zone of deeper peat associated with a Campbell Island swale. Water was again flowing into Campbell Lagoon, but through the M2 canal instead of the pre-canal natural drainage network. An area of impounded marsh was still visible on the eastern side of the M3 spoil bank.

A comparison of average canal widths shows that the M3 canal widened from approximately 18 m in 1969 (11 years after construction) to 22 m in 1985. For this same period, the M2 canal's average width increased from 22 m to 27 m. Thus, both canals widened at the same average rate of approximately 0.4 m/yr during this period or 22% over an 11-year period.

The spoil banks (M2 west bank and M3 east bank) decreased in width between 1969 and 1985 due to both subsidence on the marsh side and erosion on the canal side. The M2 spoil bank decreased in width from an average of 30 m to 21 m for a rate of 0.6 m/yr or 30% for the period. The M3 spoil bank decreased from 48 m to 44 m for a rate of 0.3 /yr or about 8% loss.

In order to quantify the impact of the M2 and M3 pipeline emplacement on this area, habitats were interpreted and planimetered for 1958, 1969, and 1985 for a 1,100-m-wide corridor centered on the M2 and M3 canal ROW and extending from the 1.5-m, inland contour to Lake Borgne (Table 7.10). There were no pipeline canals in this 376-ha corridor in 1958. At that time, the major habitat types were upland (3%), brackish-to-saline marsh (83%), estuarine lakes and Lake Borgne (8%), and tidal channels (6%).

By 1969, two pipeline canals had created, directly, two new habitat types: canals (4%) and spoil (6%). Marsh had decreased to 71% of the area because of canal and spoil development, as well as shoreline erosion and development activities around Ansley involving draining and dredging of site access canals.

In 1985, the two canals maintained their same percentage of habitat (4% total) but spoil decreased by 1%. Tidal channels increased to cover 8% of the area. In summary, the direct impact of the M2 and M3 pipeline canals has been the conversion of 4% of the area to open water. The impact from spoil has decreased with time (from 6% to 5%) because the spoil is evolving into marsh or open water (canal) because of subsidence and canal bank erosion.

There has been a small area of impact due to spoil impounding natural drainage but the zones of impact have shifted between 1969 and 1985. Furthermore, it is difficult to ascertain from the 1985 photography whether the impoundment east of the canal is temporary because of high water or a conversion to a different or sparser vegetation type (i.e., smooth cordgrass rather than wiregrass or blackrush) which allows more standing water to reflect through the vegetation. In any event, the two sites adjacent to the M2 and M3 pipeline canals and east of Campbell Island appear to have more potential for future breakup than does the marsh adjacent to spoil along the southern two-thirds of the canal. Furthermore, these two canals can be expected to continue to enlarge in area from bank erosion, thus destroying marsh and spoil in the future.

Geologic Impacts

The geologic field studies were designed to analyze morphologic and stratigraphic parameters between the pipeline ROW and control sites to test the following hypothesis: emplacement of pipelines create weak zones within the marsh which are more susceptible to erosion than are control areas. Vibracores were taken at three locations within the M1 backfilled ROW (PR1 near the shore of Lake Borgne, PR2 approximately 250 m north of PR1, and PR7 north of Campbell Inside Bayou crossing) (Figure 7.49). One set of control vibracores (PR6, PR4, and PR8) was taken approximately midway between the M1 and M2 ROW. Vibracore PR6 was near the shore of Lake Borgne, PR4 was near the south bank of a small tidal channel entering Campbell Outside Bayou, and PR8 was on the south bank of Campbell Inside Bayou.

Three vibracores were taken in the open flotation canal along the M2-M3 pipeline corridor. Vibracore PR5 was the southernmost core taken north of the concrete weir. Core PR9 was taken midway of the canal and PR10 was taken in the north end of the canal. Analyses of the sediments from the vibracores were accomplished through visual examination, x-ray radiography, photography, and grain-size analysis.

The modern facies within the study area display four major depositional environments: open water, marsh, channel, and barrier island. Open water deposits observed in the vibracores are composed of silty clay and clay and exhibit laminae of sand and silt and locally abundant burrows. Marsh sequence thicknesses range from 2 to 4 m but may occasionally exceed 5 m in thickness. The deposits consist predominantly of clay with in situ and detrital organic material and are horizontally laminated. Bioturbation by organisms is common throughout the sequence, obliterating most primary sedimentary structures. Open-water and marsh sediments are evident in radiographs of vibracore PR6 (control) at a depth of 2.6 m to 2.8 m (Figure 7.53A) and at 2.8 m to 3.2 m (Figure 7.53B).

Channel deposits are represented by sand, silt, silty clay, and clay sediments and are characterized by well developed fining-upward sequences. A fining-upward sequence occurs where an asymmetrical flow pattern is developed and is generally related to the radius of curvature of the meander (Blatt et al. 1980). Flow in channels produces regular lateral and vertical changes in grain sizes, and slow migration of the channels produces a corresponding vertical sequence of sediment textures and structures. As a consequence, a succession of fining-upward sequences is common in the channel deposits. Channel sediments are illustrated in the radiograph of vibracore PR3 (control) at a depth of 2.4 to 2.7 m (Figure 7.54).

Barrier island sand deposits are composed of fine to very fine, well-sorted sand. Sands are laminated and locally bioturbated by burrowing organisms. Laminations are generally parallel with low angle discordances. The sands also exhibit low-angle cross-bedding, ripple cross-laminations, and scour and fill structures. Shell fragments occur locally.

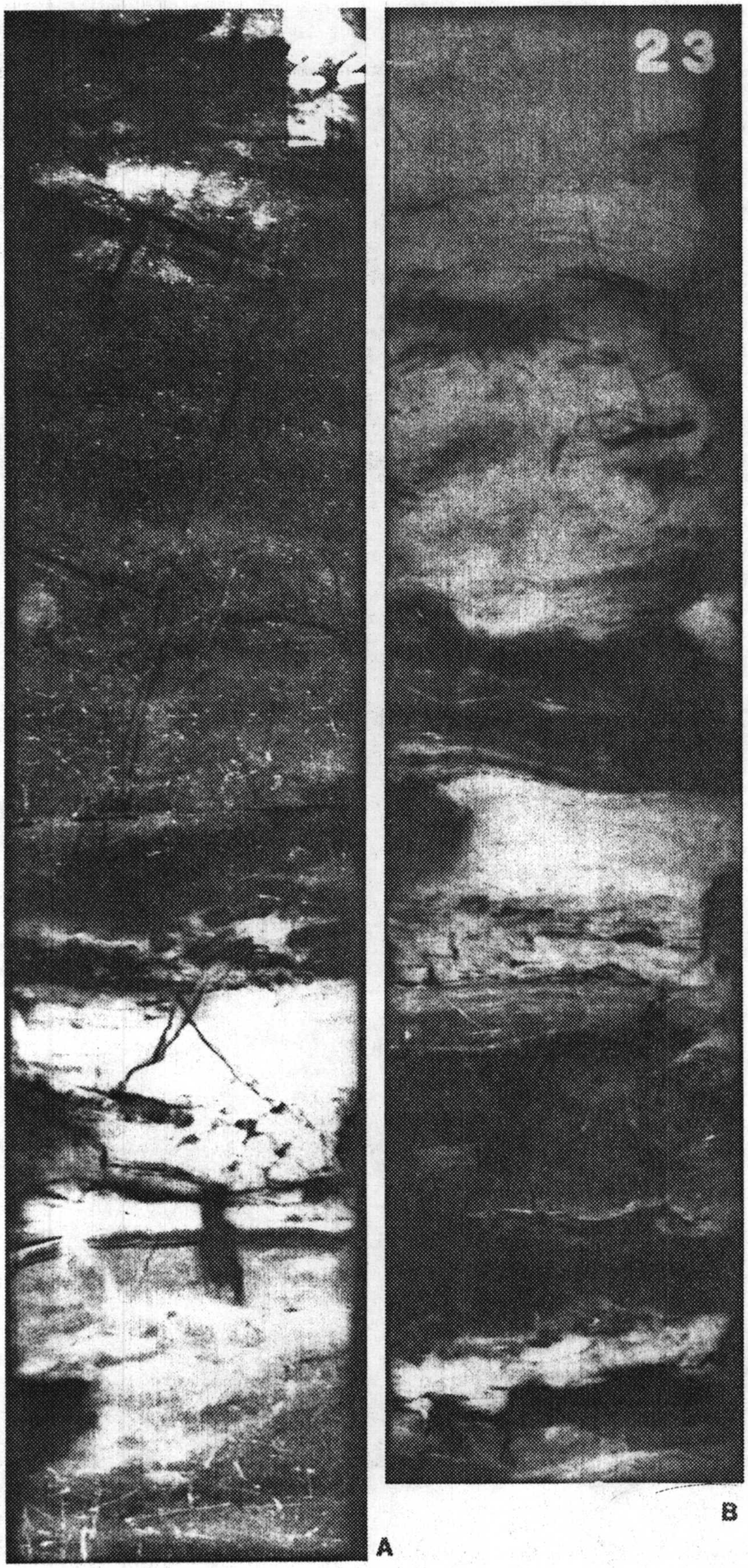


Figure 7.53.

PR6 radiographs of open water and marsh sediments at 2.6 to 2.8 m (A) and 2.8 to 3.2 m (B) at the control site.

Figure 7.54. PR3 radiograph of channel sediments at 2.4 to 2.7 m at the control site.

Two radiographs of vibracore PR 10 (control) at a depth of 1.5 m to 1.8 m (Figure 7.55A) and 2.4 to 2.7 m (Figure 7.55B) illustrate the appearance of barrier sand sediments in this area.

Interpretations of the vibracore data were utilized in preparing stratigraphic cross sections of the area containing the M1, M2, and M3 pipelines. Cross section A-A' (Figure 7.56) is oriented along depositional dip and follows the axis of pipeline M1. Vibracores PR1 and PR2 are located within the marsh area near the shoreline and exhibit marsh sediments composed of clay and organic material conformably overlying open-water sediments. Barrier sands at Campbell Island are located midway between vibracores PR2 and PR7. Vibracore PR7 shows marsh sediments conformably overlying the Campbell Island barrier sand sequence. The marsh and open-water sediments are stratigraphically correlative between cores PR1, PR2, and PR7 and demonstrate no variation in texture or composition. The sequence of sands in the basal portion of vibracore PR7 is consistent with the naturally occurring sequence of sediments associated with Campbell Island. Consequently, Vibracore PR7 reveals no stratigraphic variance. The shallow excavation and subsequent backfilling of the M1 pipeline ditch with highly organic marsh material is not discerned in the stratigraphic record visible in the PR1, PR2, and PR7 vibracores taken along the M1 ROW.

Cross section B-B' (Figure 7.56) is also oriented along depositional dip and follows the axis of the M2 and M3 pipeline corridor. Vibracores PR5 and PR9 were taken in the canal where the canal is eroding into the marsh overlain by spoil. These cores demonstrate a sequence of marsh sediments conformably overlying open-water deposits. Vibracore 10, also along the eroding canal bank, shows a 0.9-m-thick unit of marsh sediments capping a sequence of sands. This sequence of sands is not associated with the Campbell Island sediments, although it may be associated with partially drown foredune ridges of the Magnolia Ridge. The marsh and open-water sediments observed in all the cores demonstrate stratigraphic equivalence and continuity. The sands in vibracore 10 appear to demonstrate stratigraphic equivalence, dependent upon the relationship to the beach dune deposits of Magnolia Ridge.

Cross section C-C' (Figure 7.56) is oriented along depositional dip and serves as a control section illustrating natural stratigraphic development. Vibracores PR6 and PR4 are located within the marsh area and exhibit a 2.7-to-3.4-m-thick sequence of marsh sediments capping a unit of fine-grained, open-water sediments. The units between the cores are continuous and are stratigraphically correlative. Vibracore PR8 shows marsh sediments overlying fine-grained sands from the barrier facies. The marsh along the depositional strike cross section illustrates the stratigraphic relationships between the vibracores taken within the pipeline ROW and the control vibracore.

Hydrologic Impacts

For each of the two types of pipeline emplacement, that is, push-ditch and backfill of M1 and flotation canal left open for M2 and M3, different hydrologic impacts were anticipated. Possible impacts of the M1 pipeline, which crosses two major tidal streams (Campbell Inside Bayou and Plains Bayou), one secondary tidal stream (Johns Bayou), and one drainage divide, include: (1) marsh breakup due to marsh buggy tracks left after the ditch was backfilled, (2) erosion at the points where the pipeline crosses large tidal channels, and (3) development of a linear drainage channel along the ROW which diverts the natural, preexisting marsh drainage.

The flotation canals for the M2 and M3 pipelines, with their continuous spoil banks, were expected to cause even larger-scale disruption of the natural drainage system by: (1)

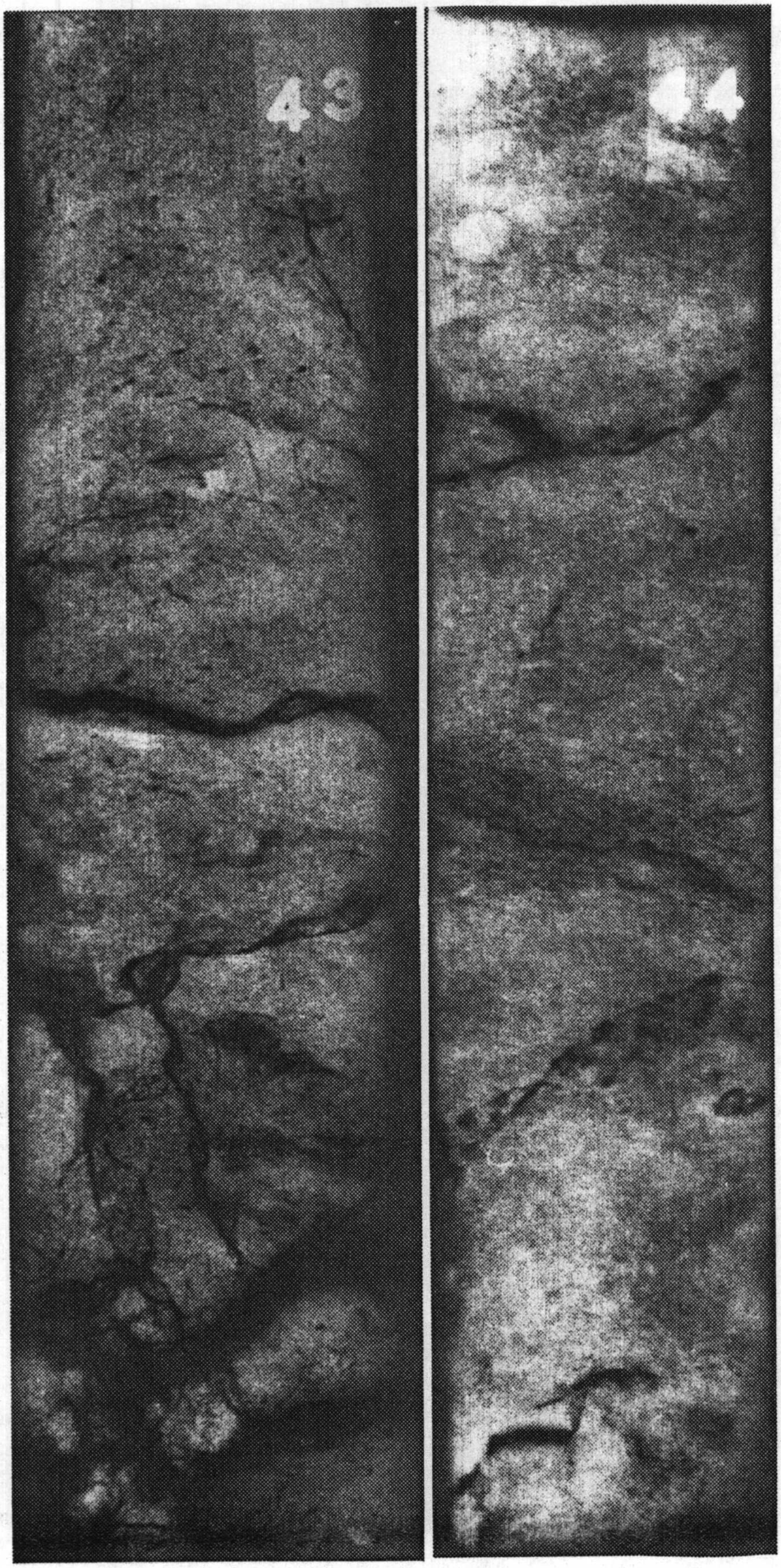


Figure 7.55.

PR10 radiographs taken at depths of 1.5 to 1.8 m (A) and 2.4 to 2.7 m which illustrate barrier island sand sediments underlying the M2 canal ROW.

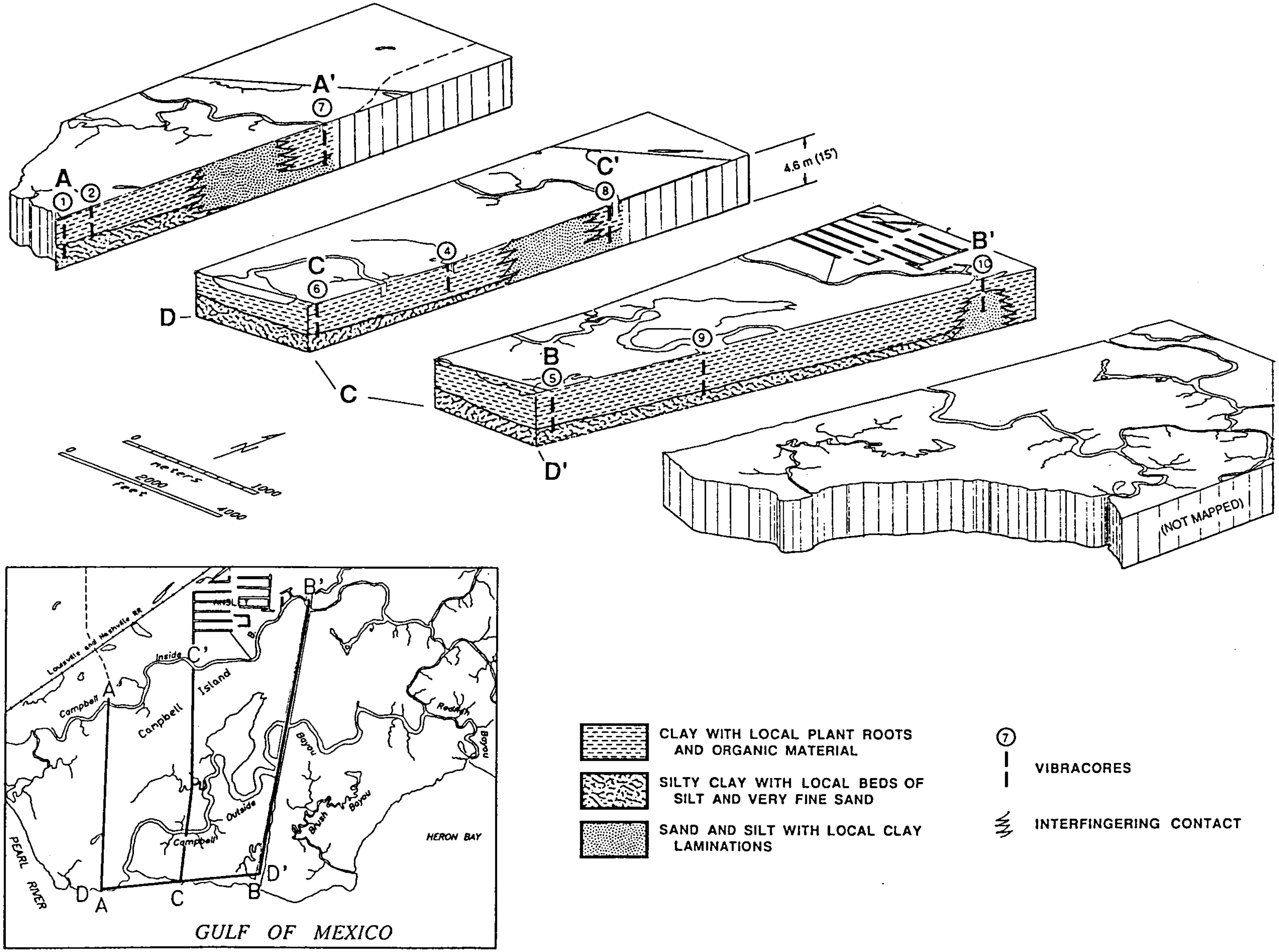


Figure 7.56. Stratigraphic cross sections of the North Central Gulf Coast area containing pipelines M1, M2, and M3.

cutting across two major tidal streams (Campbell Inside Bayou and Campbell Outside Bayou) and their associated drainage divide, thus altering the flow pattern, (2) accelerated scouring, thereby deepening and widening the flotation canals, (3) impounding drainage from adjacent marsh behind the spoil banks, and (4) increasing saltwater movement into the interior. This last hypothesis could not be tested because there were no long-term salinity records at the site which could be used to determine changes in salinity. Furthermore, the marsh in the vicinity of M2 and M3 was brackish-to-saline when the canals were dredged; therefore, major changes in vegetation composition as a result of saltwater intrusion would not occur.

On September 28 and 29, 1987, field recordings of salinity, current flow direction, and bathymetry were made at the study area (Figure 7.57). Stream cross sections were made at strategic locations dictated by the current direction during ebb tide. The field observations were used to determine the existing drainage boundaries. The pre-pipeline canal drainage boundaries were postulated from aerial photography. A cross section of the Pearl River channel was made to put the other data in perspective with regard to the overall hydrology of the site.

During the field sampling period, the salinity ranged from 6.5 to 14.0 ppt at various stations in the area, and the tide was falling. Figure 7.58 is a center line profile of Grand Plains Bayou which illustrates a pattern of decreasing channel size (depth) with decreasing drainage area. At station A' near the M1 pipeline crossing of the upper end of Grand Plains Bayou, the maximum depths in the bayou are 2.4 to 3.0 m. At the railroad trestle, Station A, the Bayou, having intercepted the flow of several secondary bayous, increases in depth to 4.2 to 4.6 m.

A close-up view of Area B (on Figure 7.57) shows a different pattern for Campbell Inside Bayou at the M2 and M3 canal intersection (Figure 7.59). Cross sections for stations III and IV represent pre-canal drainage routes for Campbell Inside Bayou. The Station I cross section represents a secondary tributary to this bayou under pre-canal conditions (as postulated from aerial photography) and should have had less cross sectional area than cross sections of stations III or IV. Present conditions show that the maximum depths for stations I, III, and IV cross sections are 2.4 m, 1.8 m, and 1.2 m, respectively (Figure 7.59). Furthermore, it is evident that the M2 and M3 canal complex (station V cross section) is transporting all of the ebb flow discharge to the south. Under pre-canal conditions flow would have been in an east-west direction through Campbell Inside Bayou.

A similar hydrologic change is evident in Area C (on Figure 7.57), where the M2 and M3 canal complex cuts across Campbell Outside Bayou (Figure 7.60). The bathymetry of stations I and II had to have been very similar under pre-canal conditions. At present, the loop (Station I) of the bayou has been abandoned and is silting in. The shape of the M2 and M3 canal complex changes progressively from station III to station V where the middle ground (or spoil bank) begins to break the surface. The data indicate that some flow should remain in Campbell Outside Bayou at station VI, but this was not observed. Ebb flow was observed continuing to the south on the M2 canal side west of the middle ground. Near Lake Borgne, a concrete weir with a crest set approximately at marsh level had been circumvented by erosion around the west side of the M2 canal, thereby accounting for the southward flow observed at station V. Cross section VII shows a well defined Campbell Outside Bayou channel downstream of the drainage area of Campbell Lagoon.

Figure 7.61 for Area D illustrates the change in cross-sectional profile of Campbell Inside Bayou west of the M2 and M3 canal complex (Area B on Figure 7.57). The channel increases in size from station II to station I because of the addition of drainage from a finger-canal residential development to the north. Furthermore, the flow direction as

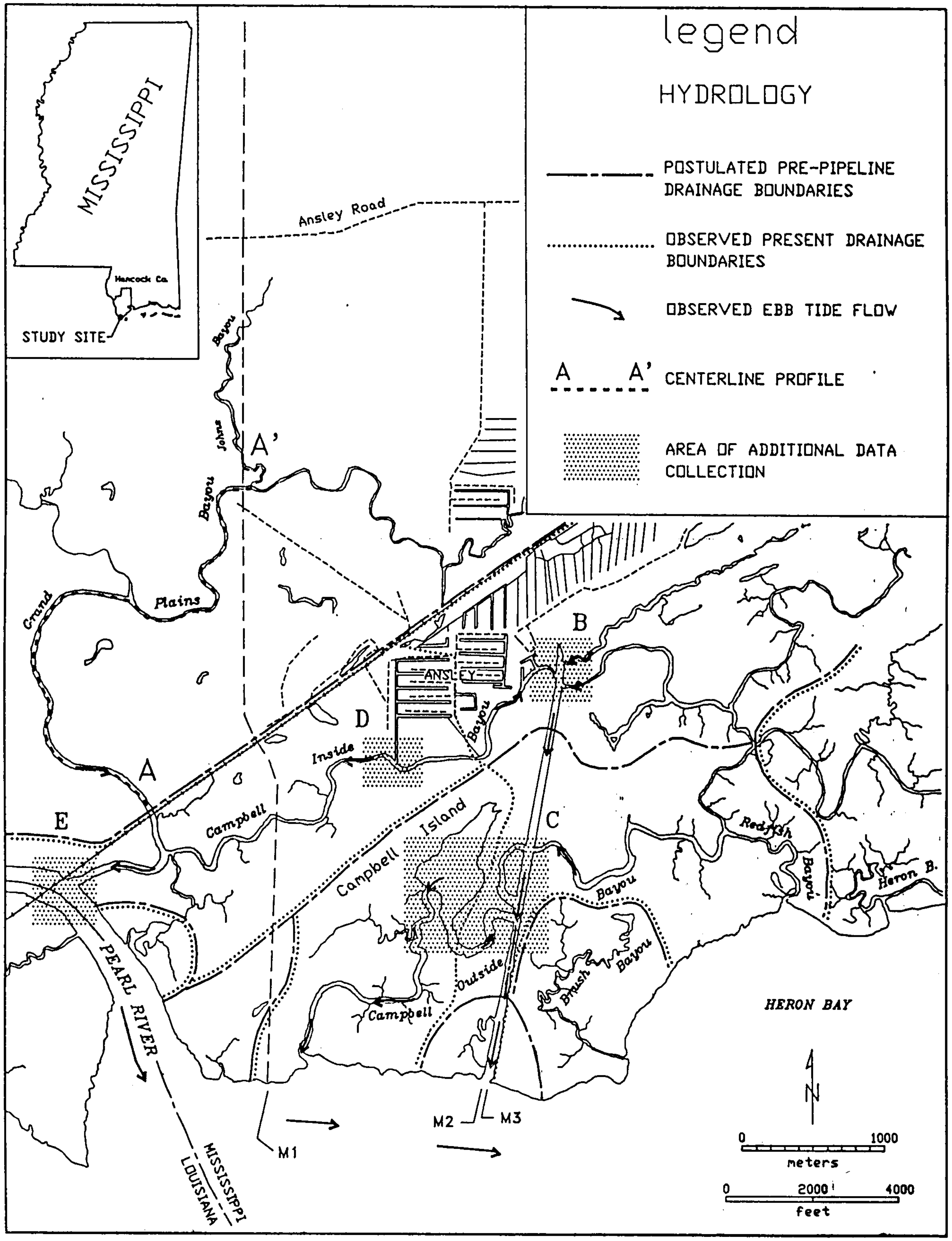


Figure 7.57. Hydrologic sampling stations and drainage boundaries at present and postulated for pre-canal conditions.

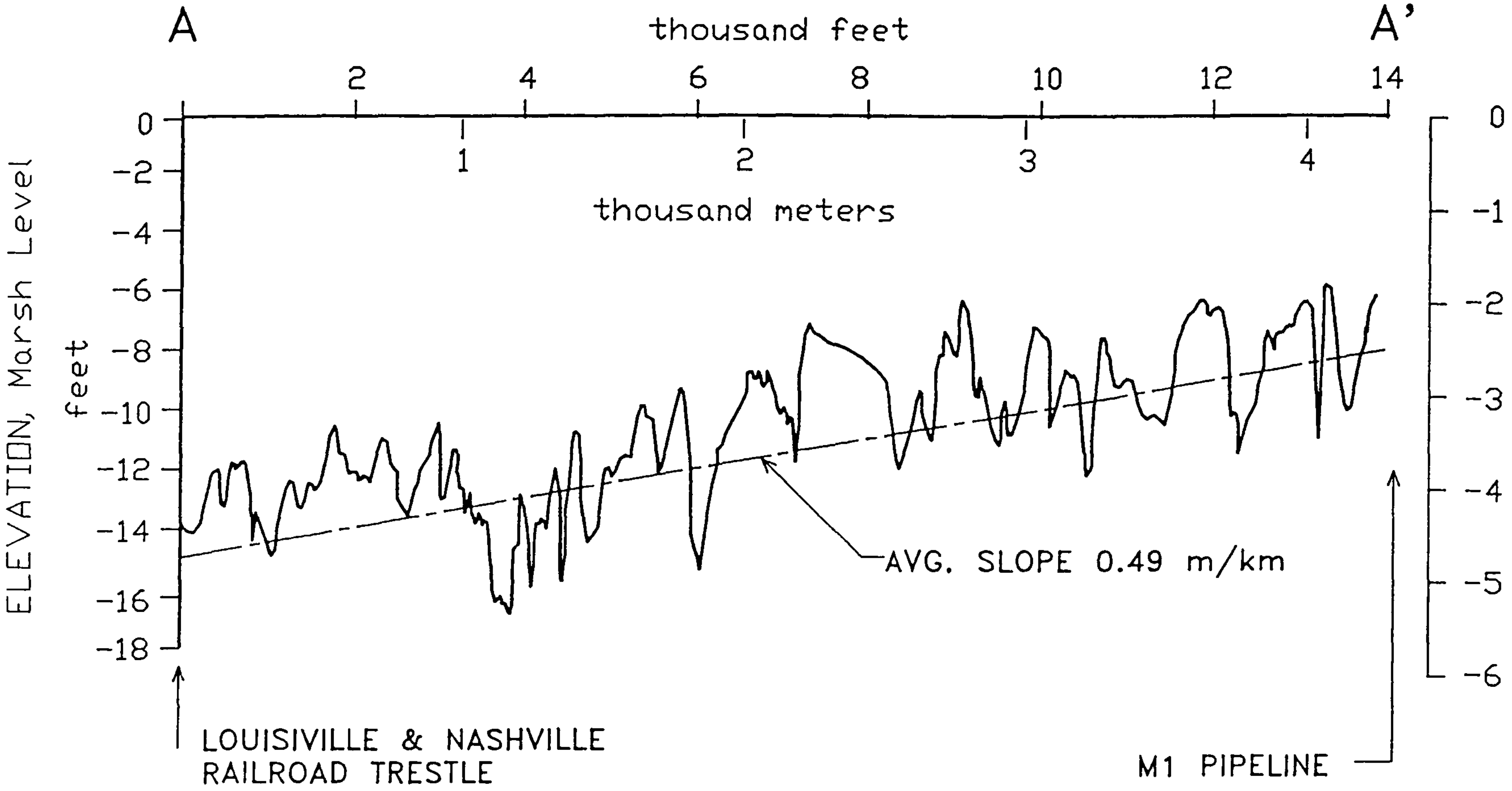


Figure 7.58. Centerline bathymetric profile of Grand Plains Bayou.

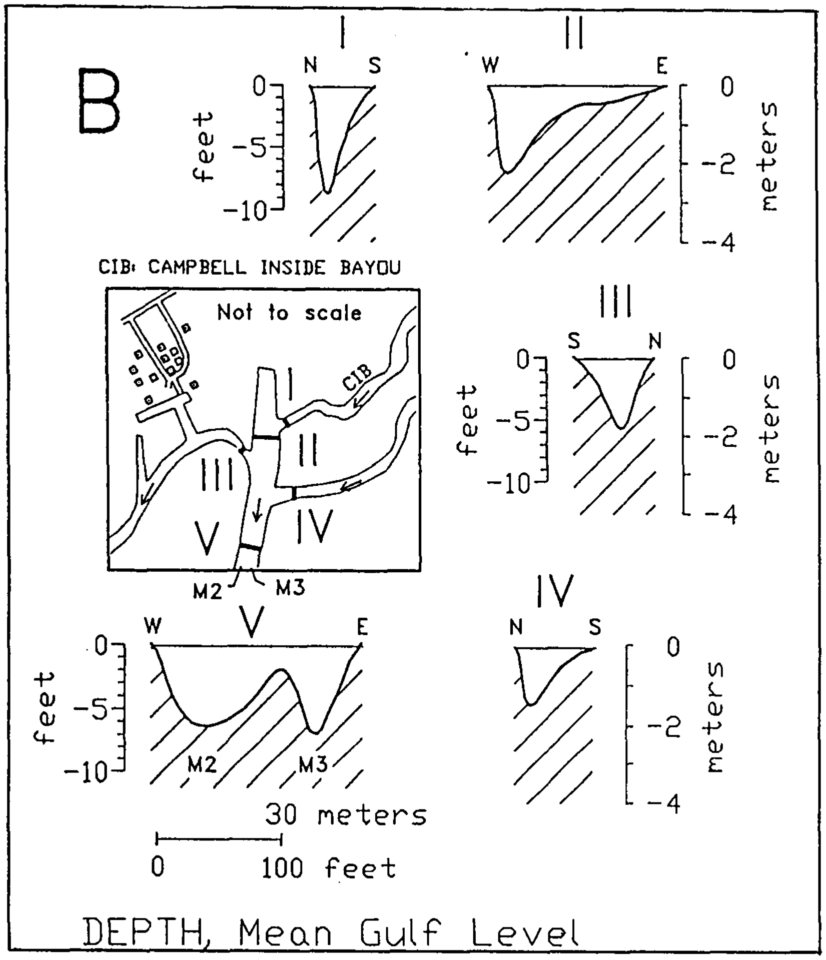


Figure 7.59.

Bathymetric cross sections of natural channels crossed by the M2 and M3 flotation canals (see Figure 7.57 for location).

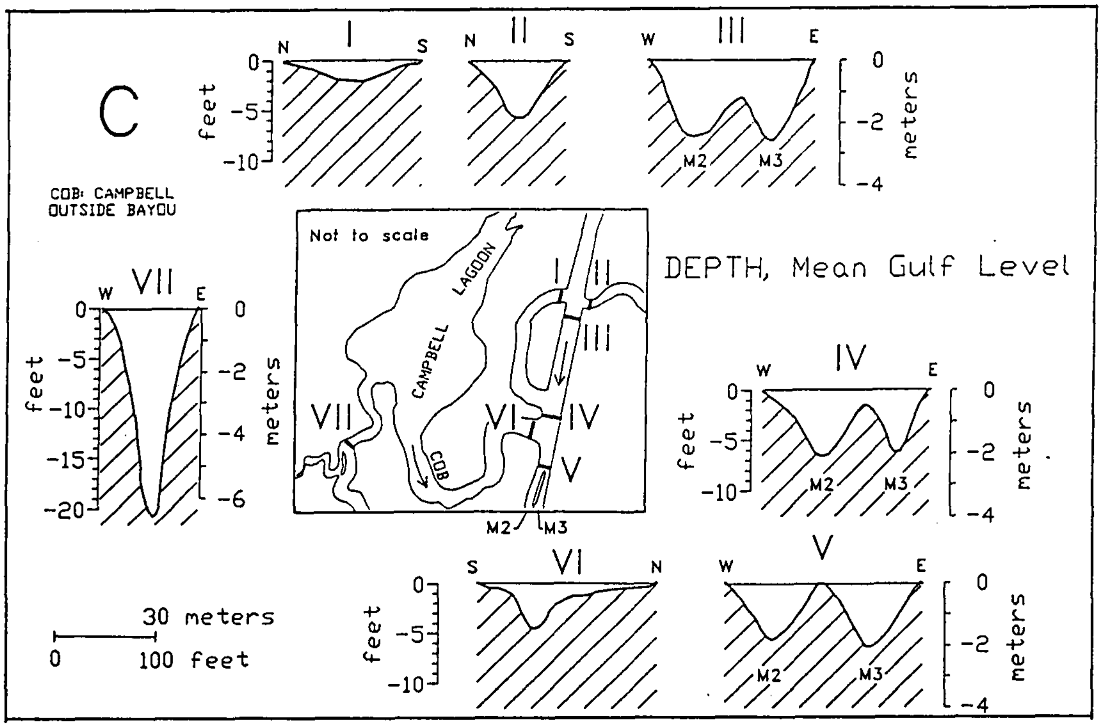


Figure 7.60. **Bathymetric cross sections of natural channels crossed by the M2 and M3 flotation canals in the vicinity of Campbell Lagoon (see Figure 7.57 for location).**

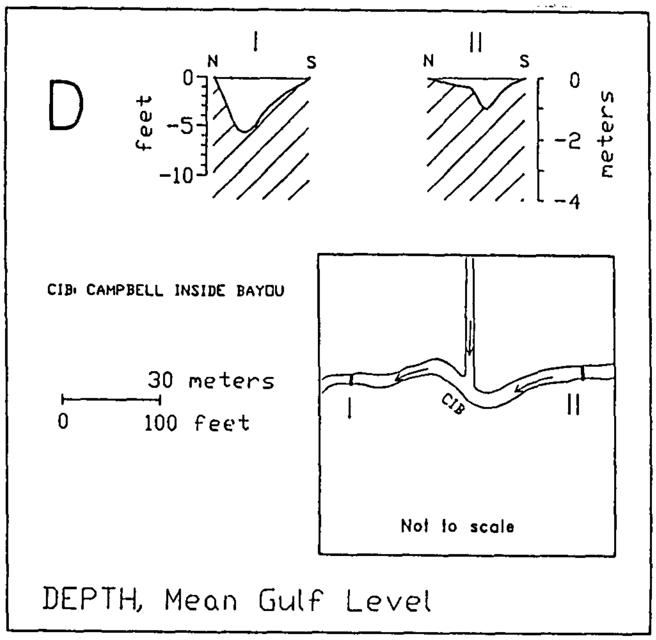


Figure 7.61. Bathymetric cross section of Campbell Inside Bayou south of Ansley illustrating development of a new drainage divide west of the M2 and M3 canal complex (see Figure 7.57 for location).

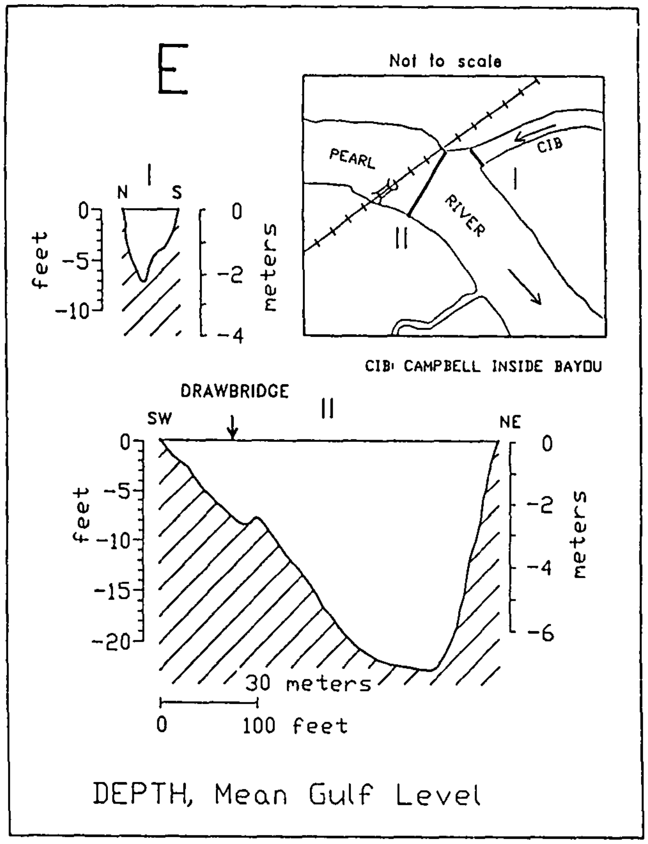


Figure 7.62. Comparison of bathymetric cross sections for Campbell Inside Bayou and the Pearl River south of the Louisville and Nashville Railroad (see Figure 7.57 for location).

shown in Figures 7.59 and 7.61 indicates a drainage divide caused by construction of the M2 and M3 canal complex.

In summary, field inspection did not reveal any major hydrologic changes associated with construction of the M1 canal. Backfilling and the passage of time appears to have restored the marsh vegetation along the M1 ROW and no linear drainage channel has developed to supplant the natural sheet flow of the marsh traversed by M1. Furthermore, there is no erosion at the M1 ROW-bayou crossings at Campbell Inside Bayou, Grand Plains Bayou, and Johns Bayou, nor at the landfall site on Lake Borgne.

Some hydrologic changes that can be attributed to the construction of the M2 and M3 flotation canal complex were observed. New north-south drainage basin divides have developed parallel to the M2-M3 canal which replace the pre-canal, east-west drainage divides which roughly paralleled Campbell Inside Bayou and Campbell Outside Bayou (Figure 7.57). The M2 and M3 canal complex has altered the east-west drainage in these two bayous and supplanted it with north-south flow that is presently connected directly to Lake Borgne because of erosion of the marsh west of the weir. Segments of the original Campbell Outside Bayou have shallowed as a result of spoil deposition in the channel and rediversion of channel flow through the M2 and M3 canal complex.

The M2 and M3 canal complex now functions as a new drainage route to Lake Borgne because of erosion around the weir. This erosion is due, in part, to the large volume of water that can flow through the M2 and M3 complex (over 48 m wide and 1.8 to 2.1 m deep) directly into Lake Borgne instead of through the smaller (approximately 27 m wide and 0.6 to 1.8 m deep) sinuous channels of Campbell Inside Bayou and Campbell Outside Bayou.

Without knowing the original depth of the canals, it is difficult to state whether there has been any scouring over the past 12 to 29 years. However, the current depths of 1.8 to 2.1 m would indicate that there has been no infilling of the canals, either in the interior or coastal segments of the canal.

Also, on Figure 7.62 for Area E, the cross section at the mouth of Campbell Inside Bayou (Station I) is shown in relation to that of the Pearl River (station III). The changes in bathymetry along Campbell Inside Bayou and Campbell Outside Bayou can be put in a regional perspective when compared to the cross section of station I on Campbell Inside Bayou (28 m x 4 m) and station II (214 m by 14 m) on the Pearl River.

Vegetative Impacts

Vegetative community structure in the marshes of Mississippi is primarily dependent on two factors: (1) salinity and (2) relative elevation. Field studies were designed to assess impacts from pipelines on both parameters. Possible impacts to these factors would be: (1) increased water levels and lower plant productivity or loss in areas associated with the pipelines due to impoundment by continuous spoil deposits, (2) increased salinities from pipelines crossing tidal channels, and leading into interior freshwater marshes, and (3) decrease in elevation within the pipeline corridor from inadequate backfilling. All of these impacts could affect vegetative community structure and productivity.

For the field site east of the Pearl River a series of transects were sampled in the backfilled M1 ROW, in the canal/spoil bank ROW of pipelines M2/M3, and at a control corridor midway between M1 and M2-M3 ROW (Figure 7.49). Four transects were located at approximate equal distances from Lake Borgne on each of the three lines (M1 ROW, Control, M2-M3 ROW), with the exception of transect SD located north of the railroad

(Figure 7.49). Five stations were sampled with two 1-m^2 quadrant replicates each for every transect as shown in Figure 7.49. Percent cover and standing crop biomass were measured by the methods previously described. The "0" stations in the canal of M2/M3 were included in the data base for consistency. An elevation cross section was made perpendicular to the M2/M3 ROW at transect station TB (Figure 7.49) to record plant zonation of the spoil banks.

Percent cover and standing crop data are presented on Table 7.11. Neither percent cover nor standing crop data indicate significant impacts to the vegetational community by the presence of the pipelines. Figure 7.63 shows that the means for percent cover and standing crop among the transects and stations are not significantly different except for the following. The percent cover of stations SA (M1 ROW near Lake Borgne) and SD (M1 ROW on Johns Bayou) is higher than that of stations CA (control near Lake Borgne) and CD (control south of Campbell Inside Bayou). Standing crop of stations SA and SD is higher than that of all other stations except SB.

In general, it can be said that smooth cordgrass (Spartina alterniflora) is more abundant in the TA to TD samples (M2 and M3), while blackrush (Juncus roemerianus) is more abundant on the control (CA to CD) and SA to SD samples (M1) within 3,048 m of these shorelines (Figure 7.64). Wiregrass (Spartina patens) shows a dominance along the northern reach of the SA to SD transect where the marsh becomes more brackish. On all transects, hogcane (Spartina cynosuroides) is present nearest the shoreline on the higher elevations.

Qualitative field observations can be made with regard to the impact of the M2/M3 canals on the marsh environment (Figure 7.65) by observing plant zonation along the elevation profile of the M2/M3 double flotation canals and spoil banks. The older M2 spoil is lower (+0.3 m marsh level) and covered by hogcane. The newer M3 spoil is almost twice as high as the west spoil bank, and above +0.3 m a shrub community is established. It appears that during construction of the M3 canal, part of the east spoil bank of the M2 canal was excavated with all spoil material being deposited on the east bank of M3 (Figure 7.65). A strip of bare ground was observed at the +0.3 m elevation on the M3 east spoil bank. This probably formed as a result of a wrack of marsh debris being transported to the site during a high water event. The rotting debris smothered the vegetation below, resulting in temporary removal of live vegetation. Sloping gently downward from this area is a zone of smooth cordgrass (short form) and saltgrass (Distichlis spicata) occupying the same elevation range as hogcane on the west spoil bank. This distribution might be caused by differences in tidal flushing. Hogcane is abundant on the lake rims and natural stream banks in the area. Saltgrass is more indicative of a high marsh or salt pan environment. The greatest occurrence of saltgrass in the field study area is near the base of the spoil along the M2/M3 ROW (see Table 7.11, TA-TD). This may be a subtle indication of a saltwater impoundment effect related to the relatively high elevation of the M3 spoil bank.

Two noteworthy observations on the backfilled M1 ROW were not illuminated by the vegetation sampling methods. The SA station on the M1 ROW was reached by walking inland from the Lake Borgne shoreline. The backfilled trench along the M1 ROW was clearly evident as a strip of shorter smooth cordgrass flanked by taller blackrush to the sides, giving the appearance of a mowed trail (Figure 7.66). At station SD near the edge of the upland terrace, the M1 ROW was only faintly visible in the marsh but distinctive as a cleared path through the forests on the terrace (Figure 7.67). Furthermore, the M1 backfilled trench was easily discernible because of the abrupt change in the firmness of the marsh. The untrenched marsh was firmer than the backfilled M1 ROW even though both sites were completely vegetated.

Table 7.11. Percent Vegetation Cover and Standing Crop Biomass Data for the Pearl River Field Site.

	% Cover by Transect and Station											
SPECIES	SA	SB	SC	SD	CA	CB	CC	CD	TA	TB	TC	TD
Unvegetated	5.2	13.4	10.2	1.0	27.2	11.5	13.1	20.4	23.0	23.0	20.3	21.3
Juncus roemerianus	59.2	59.3	42.5	0.6	54.8		36.6	42.3	35.1	35.1		
Spartina cynosuroides	35.6	4.2	12.2		14.1	17.8			13.2			
Spartina alterniflora		22.0	15.7	0.5		70.7	50.1	2.0	25.3	24.5	62.1	27.0
Spartina patens			12.7	97.3				29.0			13.8	41.5
Distichlis spicata		1.0	4.1		3.9		0.1	1.1	3.4	4.4	2.8	3.2
Sagittaria falcata			2.7					4.7				
Ipomea sp.				0.1								
Scirpus sp.				0.1				0.5			0.9	7.0
Setaria sp.				0.4								
STANDING CROP BIOMASS (G/M2)												
Mean	1926	1389	1071	2127	N.D.	858	745	714	801	914	894	654
95% C. I. (+/-)	558	465	266	573		247	477	451	492	537	437	356

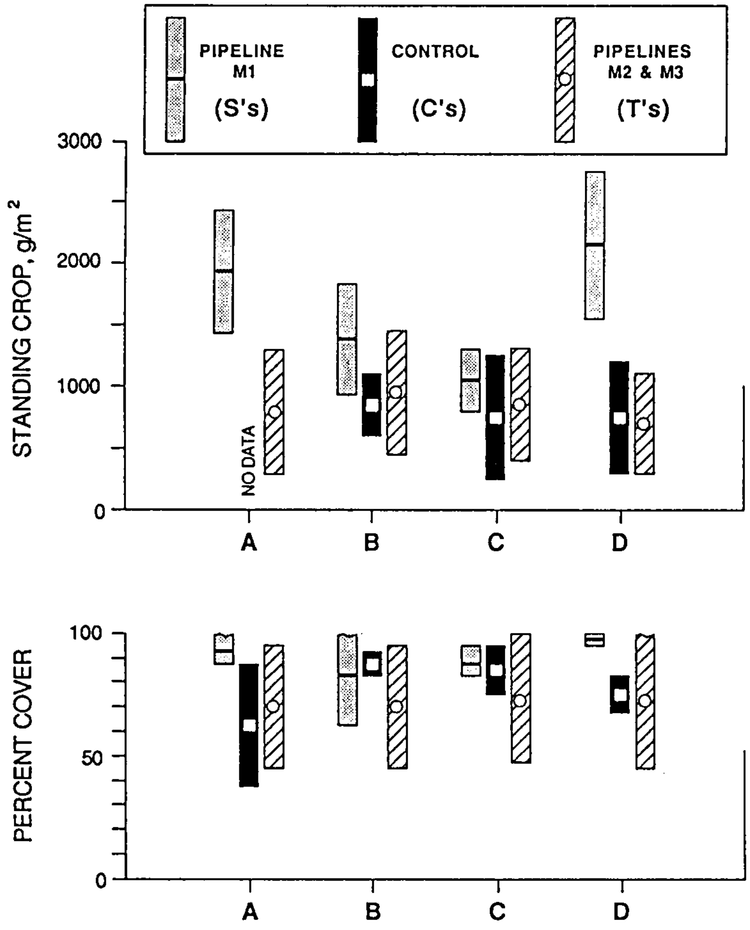


Figure 7.63. Mean and 95% confidence intervals for percent cover and standing crop biomass for transects S (push-pull/backfilled ditch) C (control), and T (double flotation canals) east of the Pearl River, Mississippi.

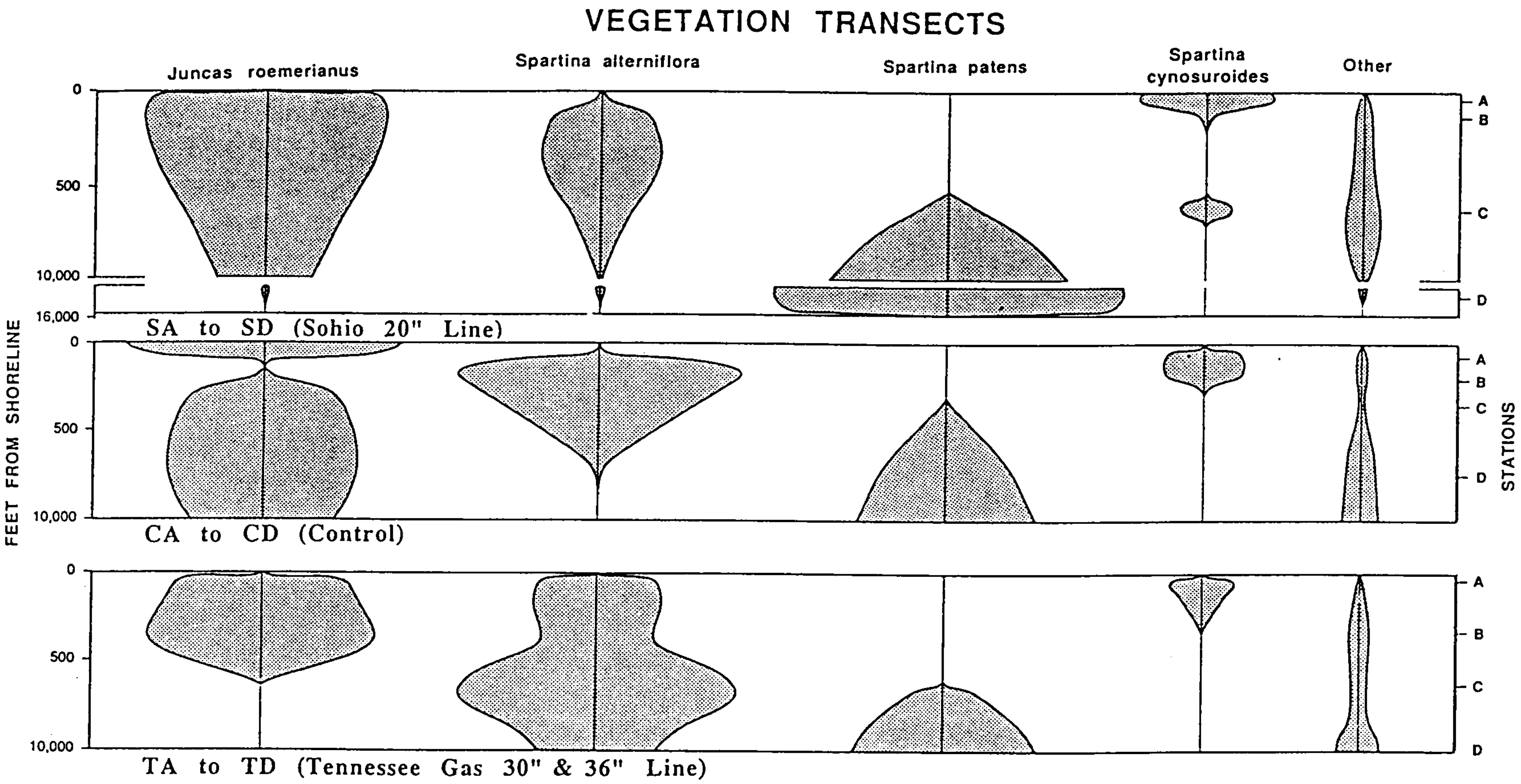


Figure 7.64. Distribution of vegetation along the M1 ROW (SA to SD), Control (CA to CD), and M2/M3 ROW (TA to TD) transects.

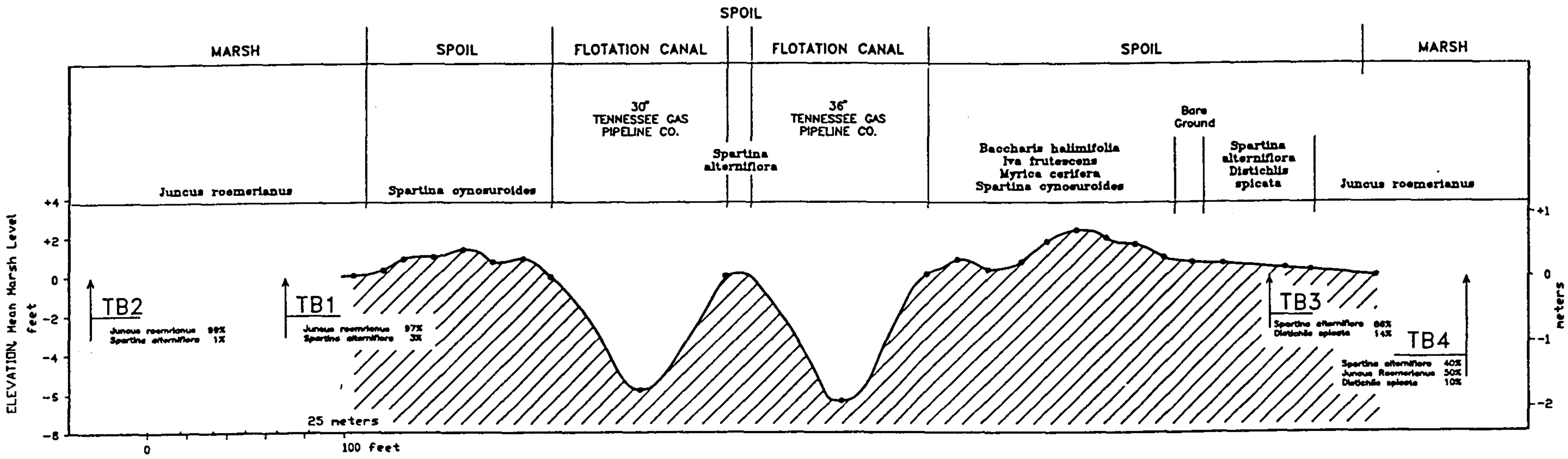


Figure 7.65. Distribution of vegetation along elevation profile survey across the M2 (30" line) and M3 (36" line) canals and spoil banks.

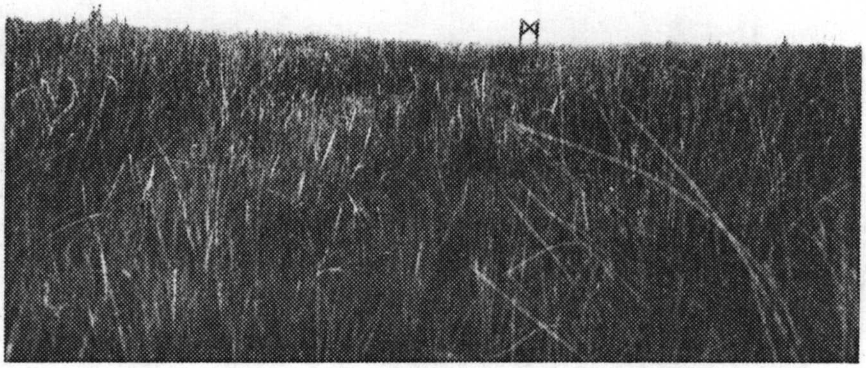


Figure 7.66. The backfilled M1 ditch revegetated by smooth cordgrass within a blackrush-dominated saline marsh.

Figure 7.67. The backfilled M1 ditch running through the northern marsh into the upland forest where the ROW is maintained free of trees.

CHAPTER 8: IMPACTS OF PIPELINES: AIR PHOTO ANALYSIS

Karen M. Wicker

Introduction

Aerial photographs were analyzed in order to obtain a qualitative assessment of the appearance and thus the degree of visually observable impacts that the OCS pipelines have had on the sensitive habitats in the study area. Qualitative measurements on shoreline erosion rates at the ROW and controls and canal width changes for the flotation canals were also made and tabulated (Appendices B.1-B.4, C). Appearance and type of impact for pipelines, whose ROW were known, were described and the information presented by major coastal system.

Texas Barrier Island System

There are 10 OCS pipelines making landfall in the Texas Barrier Island System (Maps 1-A - 5-A, Vol. 2, Appendix A.1). They range in size from 6 to 36 in and were emplaced between 1965 and 1985. All lines appear to have been emplaced using a push-pull ditch method and then backfilled. There are records for only one line being revegetated at the beach crossing.

Five pipelines cross regressive barrier islands; one crosses a transgressive barrier beach and four cross transgressive barrier islands. Six of the landfall sites consist of shorelines composed of sand-shell-rock fragments, while the remaining four cross beach and sand spits. Eight of the landfall sites are eroding at rates varying from a high of 24.2 m/yr on Galveston Island to a low of 1.8 m/yr on the Bolivar Peninsula. Two pipelines cross shorelines (Padre Island and Matagorda Island) which are accreting at an average rate of 1.5 m/yr. All but one line is in a semihumid climate with land use varying from natural and/or semi-developed to designation as part of a Coastal Barrier Resources Area or National Seashore. Depth to Pleistocene at the landfall sites range from 7.5 to 9 m for 5 lines, 12 to 15 m for 4 lines, and 23 m for one line. The tidal range is 0.30 to 0.46 cm for seven of the sites, 0.46 to 0.61 cm for two sites, and 0.61 to .76 cm for one site (Appendix A.1).

Minimal expanses of saline-to-brackish wetlands (0 km for T1, T2, T9, T10, 1 km for T3 and T4, 2 to 2.5 km for T-5 - T-8) are crossed by these 10 OCS pipelines on the mainland. Barrier island crossings traverse beaches, dunes, flats, pockets of freshwater ponds and marshes between the dune fields, saline marsh, estuarine water bodies, and marine grassbeds of varying widths.

A qualitative understanding of the extent of impact can be obtained by reviewing the construction history and aerial photographs of selected sites. The southernmost OCS pipeline (T1) was constructed across Padre Island National Seashore by Transcontinental Gas Pipe Line Company by August 29, 1981. A detailed plan of operations was prepared by EMANCO (1980) to describe proposed operation, environment, potential impact, mitigation, and monitoring program. Across the island the line was placed in a trench dug to 0.9 m below the shifting dune field (with dunes 7.6 to 9.1 m high) by draglines and backhoes. In wetland areas and bay bottoms, the depth of cover was to be -0.9 m also. From the shoreline to -4.6 m mean low water, the flotation canal (18.2 m x 2.4 m) was dredged by a barge-mounted bucket dredge. The beach cut was allowed to fill naturally by littorally transported sand. From -4.6 m to North Padre Island Block 956, the trench was constructed by a jet trenching barge. The nearshore-to-mainland crossing was to be completed in 75 days during summer and early fall to minimize impact on wildlife, especially birds. The trench on the island was to be backfilled to preconstruction contours as nearly as practical, except in the shifting sand dune area. The foredune area was to be reconstructed, covered with biodegradable soil stabilizing mats and planted, in a random pattern, with sea oats and bitter panicum provided by the National Park Service. The rest of the ROW was allowed to revegetate naturally. No revegetation of aquatic beds was required because it was believed they would revegetate naturally (Hancock 1987). The ROW selected was through an active dune field and was chosen because it would reduce, to the maximum extent possible, the disturbance of aquatic beds (EMANCO 1980). The ROW was to be monitored after construction by aerial and ground surveys to check for erosion, ROW condition, pipeline exposure, unauthorized encroachment, and other situations that required preventive maintenance to avoid creating a safety hazard (EMANCO 1980).

Analysis of recent aerial photographs (NASA 1983, 1984) reveals that no scar indicating the ROW remains in the active dune field and there is no erosion visible at the beach crossing. The ROW is visible through the intertidal flats and grassbeds on the 1983 CIR, but appears less pronounced on the 1984 CIR photograph. The ROW scar is clearly visible on the arid mainland flats, indicating that virtually no natural revegetation had occurred by January 1983 (NASA). However, the narrow expanse of grassbeds near the mainland do appear to be reestablishing themselves by January 1983 (NASA) and no erosion is occurring at the mainland landfall site. Comparison of shoreline change rates for the ROW and two controls reveals that between 1983 and 1987, shoreline retreat was the same (-11.2 m) for all three points. Therefore, it appears that the T1 pipeline emplacement has had minimal direct or indirect impact on Padre Island. A major problem with revegetation of the foredunes involved off-road vehicles destroying the sand fencing and running over the replanted vegetation (Hancock 1987).

In September 1980, ENRON Pipeline Services (operator) installed a 24-in gas pipeline (T2), known as the Matagorda Offshore Pipeline System (MOPS), across Matagorda Island. In 1981, the line was extended to landfall in Refugio County and offshore to Matagorda Island Block 686. The line was installed using a push-pull ditch method and the site appears, based on 1987 CIR (NASA) photography, to have been backfilled. The depth of cover was 0.9 m on Matagorda Island and in San Antonio Bay but 3.0 m from the beach to -2.1 m offshore (Burgin 1987). The line was designed to cross the mainland east of the Aransas Wildlife Refuge Area in order to avoid impacting this sensitive wildlife area (O'Donnell 1979).

Analysis of 1987 CIR photography reveals that the location of this line is barely visible in the marsh on Matagorda Island and no canal push-point slips are visible at the beach or on the bayside of the island. Measurement of shoreline erosion rates at the pipeline ROW and two controls between 1979 and 1987 show the ROW and east control to have an erosion rate of 6.1 m/yr, while the west control eroded at 7.6 m/yr, indicating that there was no accelerated rate of erosion at the pipeline ROW.

Two OCS lines (T3, 24-in Seagull Shoreline System and T4, 20-in EMRON Pipeline Service) cross Matagorda Peninsula and go to the Matagorda Terminal Ltd. gas separator on the north bank of the GIWW. T4 is located parallel to and east of T3 and both lines have been extended from their original location in state waters to Federal OCS lease blocks. T3 construction (beach crossing in 1983) progressed from onshore to offshore with the trench in Matagorda Bay being dredged by a barge-mounted drag bucket and filled by jetting. A push-pull ditch was constructed across Matagorda Island and backfilled. This line had approximately 0.9 m of cover in the marsh, 3.0 m of cover at the beach, and had revegetated naturally in about two years (Ewing 1989).

No data was available on the T4 construction, which crossed the beach prior to 1977. Analysis of 1987 CIR (NASA) photography reveals that both lines have revegetated in the upland dune area. In the high, irregularly flooded flat and salt marsh zone, where vegetation is naturally sparse, the ROW scars of both lines can be seen but T4, the older line, is less visible than T3. In the narrow, regularly flooded salt marsh fringe revegetation appears to be more complete. There is no evidence of shoreline erosion on the Gulf or bayside for either of these crossings. The shoreline change rate for the ROW and controls for each of these lines between 1979 and 1987 was approximately 6.1/yr (Appendix B.1).

Impacts of pipelines T5 and T6 (Transcontinental 30-in and 36-in lines) were described in detail in Chapter 7. In summary, the T5 line installed in 1973 has revegetated along virtually its entire length except on the incompletely backfilled canal in the saline marsh on the bayside of Matagorda Peninsula. T6, which was installed in 1985, remains largely unvegetated on the upland dune and irregularly flooded marsh-flat area. The backfilled area through the saline marsh appears to have restored the preconstruction contour with the low spots remaining in the area of former marsh ponds. The 1987 (NASA) CIR photograph reveals that some revegetation is occurring in the regularly flooded tidal marsh areas. Furthermore, there has been no accelerated erosion along the Gulf or bayside pipeline crossings (Appendix B.1).

The Blue Dolphin Pipe Line Company operates T7, a 20-in gas line which was constructed between July and September 1965. This line delivered the first commercial natural gas produced by Shell Oil Company in Federal waters (Buccaneer field) off Texas (Oil and Gas Journal 1965). Line T7 makes landfall south of Swan Lake, east of the Freeport Harbor Channel. It crosses beach, upland dunes, regularly and irregularly flooded saline marshes and flats, and estuarine water bodies (Swan Lake, which is a very shallow water body frequently exposed; GIWW; and Oyster Creek oxbow) on its way to the Dow Chemical Company petrochemical plant at Freeport.

Comparison of aerial photographs for 1966 (ASCS), 1975 (ASCS), and 1982 (NASA) indicate that the line was probably emplaced onshore in a push-pull ditch that was backfilled. The push-pull points were from barges located in the GIWW and Oyster Creek oxbow. The push-point canal slip at this latter site remains visible on the 1982 photograph, though it does not appear to have enlarged since the time of dredging. By 1975 (ASCS), the upland dune area had revegetated and portions of the irregularly flooded flats and saline marsh and regularly flooded saline marsh were showing signs of revegetation. In 1982, the marshes north of the GIWW and within the Oyster Creek oxbow were largely revegetated and only a thin, discontinuous scar marked the ROW. However, about 30% of the construction area in the irregularly flooded salt marsh and flats immediately south of the GIWW remained unvegetated. The same habitat on the south shore of Swan Lake also showed evidence of sparse vegetation along the ROW, but this scar was much narrower than the one to the northwest.

The shoreline change rate at the pipeline ROW and controls was variable for the five periods measured (Appendix B.1). Between 1966 and 1987, the ROW point accreted an average of 2.3 m/yr, while accretion at the east and west controls were 4.0 and 2.9 m/yr, respectively. Comparison of aerial photographs for 1966 (ASCS), 1975 (ASCS), and 1982 (NASA) reveal no sign of breaching or accelerated shoreline erosion at the gulf landfall or any of the other water body crossings. There does appear to be an unvegetated overwash area east of T7 at the site of a former tidal pass between the Gulf and Swan Lake.

However, Hwy. 332 crosses both the T7 ROW and the old tidal channel as it runs through the upland dunes parallel to the shore.

Two OCS pipelines land on Galveston Island south of Sweetwater Lake. The T8 pipeline is a 14-in gas line operated by Amoco Pipeline Company and constructed in 1978 to connect seven fields to an onshore metering station near Texas City, Texas (Seaton 1980). This was Texas' first major offshore pipeline (O'Donnell 1979) and serves 19 owners (Seaton 1980). The line crosses Galveston Island immediately east of and parallel to Eightmile Road; then angles northeast paralleling the shoreline until it crosses under the Galveston Causeway and Galveston, Houston, and Henderson Railroad. It then cuts northwest and parallels the railroad to a metering station near Texas City. This line is almost impossible to locate on Galveston Island because of revegetation of the backfilled ditch, which crosses wide expanses of upland dunes and swales containing irregularly flooded saline marshes and isolated freshwater marshes. There is no evidence of accelerated shoreline erosion at the Gulf beach landing and the erosion rate at the ROW and east control between 1979 and 1987 was 2.8 and 2.6 m/yr, respectively, while the west control showed no change.

The T9 pipeline is a 6-in gas pipeline operated by Seagull Energy Corporation and installed in 1976 within the ROW of Texas Highway 3005. The line, which goes to Mitchell Energy Refinery on Galveston Island, was dug with a backhoe, infilled, and allowed to revegetate naturally, which it did in about two years (Ewing 1987). The line was relowered at the shoreline in 1981 according to Ewing (1987), who attributed its exposure to subsidence of the island. There is no evidence of breaching or accelerated erosion at the pipeline landfall (NASA 1987) and the shoreline change for T9 between 1979 and 1987 was the same as that for T8.

The last OCS pipeline making landfall in the Texas Barrier Island System is T10, a 16-in gas pipeline called the Black Marlin. It was constructed in 1967 and was recently operated by ENRON. No construction data was available on this line, and it was impossible to locate the ROW on aerial photography (NASA 1987). It is assumed that the construction technique was push-pull ditch and backfilling. Between 1956 and 1985 shoreline accretion averaged 10.5 m/yr at the ROW crossing and 7.3 to 4.4 m/yr, respectively, for the west and east controls (Appendix B.1). This landfall site also shows no evidence of island breaching or accelerated erosion. The site is also updrift of the north jetty for the Houston Ship Channel and Texas City Ship Channel between Galveston Island and Bolivar Peninsula.

Strandplain-Chenier Plain System

There are 55 Federal OCS pipelines making landfall in the Strandplain-Chenier Plain System, but only six are in Texas (Map 5-A, Vol. 2, Appendix A.2). The T 11, a 4-in Chevron USA line constructed in 1981 (Texas General Land Office 1984) appears to go to a compressor, metering, and pumping station north of Hwy. 87 (NASA 1985). No additional information was available for this line, but there is no evidence of its crossing the marsh north of the landfall site. Furthermore, there has been no accelerated erosion at the shore, though the erosion rate at the ROW and east and west controls was variable between 1958 and 1982, being 3.0, 2.8, and 2.3 m/yr, respectively.

Lines T12 through T16 pass through brackish-to-saline marshes of the Texas Point National Wildlife Refuge south of Highway 87. T12, a 16-in Natural Gas Pipeline Company line, was constructed in 1977 to the company's separator facility north of Highway 87. Immediately to the east is T13, a 12-in Mobil Exploration and Producing Company line, known as Mobil's Texas Sea Rim pipeline, constructed in 1979 to the

Company's separation facility (Texas Sea Rim Plant) south of Highway 87. Analysis of 1985 (NASA) CIR photography indicates that revegetation has occurred along the backfilled push-pull ditches, but a thin scar remains to mark the route on the landscape. There also appears to be an indenture of the shoreline at each pipeline landfall site, but the pattern is consistent with the remainder of this stretch of the coast, indicating erosion into small marsh ponds and swales. Comparison of shoreline change rates for the T12 and T13 pipelines for 1975 to 1983 indicate identical erosion rates of 5.4 m/yr for the ROW and 6.1 and 7.6 m/yr, respectively, for the west and east controls.

Little information, aside from its landfall site, was uncovered for T14, a Gulf-Tenneco 8-in pipeline. The push-ditch, backfilled ROW appears to be revegetating and no breaching or accelerated erosion has occurred at the Gulf shoreline.

Two Transcontinental Gas Pipeline Company lines (T15 and T16) cross the marsh west of Sabine Pass. Little information, other than location, is known for the 10-in T15 line emplaced in 1972. However, the permit application for T16, which is a 24-in gas line to the separation and dehydration facility east of Johnson's Bayou, Louisiana (Oil and Gas Journal 1977), describes in detail the construction technique. The push-pull ditch was excavated by marsh-buggy-mounted backhoes and draglines working within a 30.4-m-wide construction zone. A portion of the ditch was excavated using the double-ditch method. The trench was backfilled and portions planted in order to study the revegetation rates of double ditching and replanting versus single ditching and natural revegetation (Chabreck 1979).

The pipeline trench was to be terminated landward of the shore's high waterline and backfilled prior to connecting the onshore pipeline with the offshore pipeline in order to preclude saltwater intrusion into the wetlands. A 24-month restoration study was to be conducted once the line was completed.

The restoration study (Chabreck 1979) revealed that regrowth was essentially completed by April 1979 in the low salt-marsh plots, which comprised most of the pipeline, while there was less than 50% regrowth in the high salt marsh. After six months, the percentage of vegetation cover of the nonplanted plots was equal to that of the planted plots, thus indicating that planting had no significant effect on the recovery rate. Finally, the double-ditch method produced slightly greater revegetation rates.

By 1985 (NASA), it was virtually impossible to locate these two pipeline ROW's through the marsh. The shoreline change rate for T15 and T16 averaged a loss of 22.8 m/yr between 1975 and 1983. The east control and west controls averaged a lower erosion rate of 15.2 and 13.7 m/yr, respectively. However, there was no evidence of breaching at the T15 and T16 ROW. The higher ROW erosion rate may be a reflection of the fact that landfall occurs on a point of the shoreline most exposed to wave action.

The 49 OCS pipelines making landfall in the Louisiana portion of the Strandplain-Chenier Plain System are shown on Map 5-A (Vol. 2). Most of the lines (37) were installed using the push-pull ditch technique; 18 of these ditches may have been backfilled based on their appearance on recent aerial photography (NASA 1985). One line (L42) was not located, so its construction technique is unknown. The remaining eleven lines were installed in flotation canals, all of which were either known or assumed to be dammed. One flotation canal (L47) was even backfilled with pumped-in sediment rather than backfilled with spoil material because it crossed the State Wildlife Refuge and the Louisiana Department of Wildlife and Fisheries wished to minimize impact to the greatest extent possible.

All pipelines made landfall on a regressive barrier beach composed of sand beach ridges, and marsh and mud flats (Map 5-F, Vol. 2). Depth to Pleistocene was deepest (30 m) for L12 south of Mud Lake (Map 5-E, Vol. 2). Seven pipelines made landfall where depth to Pleistocene ranged from 12 to 24 m, while the remainder of the lines were in areas with depth to Pleistocene ranging from 7 to 9 m. All but four of the lines landed on shorelines with erosion rates ranging from 4 to 5.6 m/yr (Map 5-F, Vol. 2). Tidal ranges were highest (0.61 to 0.76 cm) on the western portion of the coast between Sabine and Calcasieu Passes and lower (0.46 to 0.61 cm) on the remainder of the coast to Southwest Pass (out of Vermilion Bay) (Map 5-G, Vol. 2). The climate of this region is humid with rainfall varying from 32.5 cm for most of the area to 53.8 cm in the vicinity of Freshwater Bayou eastward (Appendix A.1).

The land use for the pipeline landfall areas ranges from semi-developed (2 lines) or natural (18 lines) to a protected status as part of either the Coastal Barrier Resources System (18 lines) or state wildlife refuges, management areas, or parks (11 lines) (Map 5-C, Vol. 2) (Appendix A.1).

The following comments regarding observed impacts of OCS pipelines in the Louisiana portion of the Strandplain-Chenier Plain will be confined largely to the shoreline or beach area. The two lines immediately east of Sabine Pass are 6- and 18-in lines constructed by Chevron USA prior to 1973. These lines are supposed to be in a corridor parallel to each other. They traverse an accreting mud-flat area updrift of the east Sabine Pass jetty and appear to have had no impact on shoreline processes in the area. Between 1956 and 1985, accretion rates averaged 8.0 m/yr for the ROW and west control and 5.0 m/yr for the east control.

The L3 pipeline (American Natural Resources [ANR] 10-in gas) was constructed in 1968. Its location is barely visible as a thin, discontinuous line cutting across the ridges and swales south of La. Hwy. 82. There is no evidence of breaching or accelerated erosion at the beach crossing and a thin, uniformly wide beach extends across the landfall site. The area experienced land loss between 1956 and 1978 but accretion between 1978 and 1985, with there being no significant difference in shoreline change rates between the ROW and controls (Appendix B.2).

Eight OCS pipelines reach shore in the vicinity of Johnson's Bayou with most going to processing facilities along Highway 82. These lines range in size from a small 4-in gas line (L11) installed in 1980 to the only 42-in OCS line (L5) in the study area installed in 1979 (Appendix A.2).

The L5 line was the largest pipe ever laid in the Gulf. It was to serve as many as 37 production platforms and have an ultimate capacity of 2 billion cfd (Oil and Gas Journal 1977.) This line extended offshore for 241 km and was to cost $353 million (Ewing 1977). Offshore the 42-in line is known as the High Island Offshore System between High Island Block 264 and West Cameron Block 167. At block 167 it splits into the 42-in U-T Offshore System which goes to Johnson's Bayou and the 30-in Michigan Wisconsin line which goes to Grand Cheniere (Lucido 1980).

There is no breaching or accelerated erosion at the beach crossing to mark the location of the lines in the Johnson's Bayou area. Furthermore, on 1985 (NASA) CIR photography, the lines are barely visible on the marsh surface south of Louisiana Highway 82, indicating that revegetation has been largely successful. Shoreline change has been minimal in this area and varies little between the ROW and controls (Appendix B.2).

It should be noted also that this area contains one of the most extensive concentrations of treatment facilities extending from the chenier ridges into the coastal wetlands. These facilities have directly destroyed some wetlands and indirect loss also appears to be occurring in areas adjacent to the facilities, possibly because of impoundment.

Two lines (L12 and L13) cross the Chenier Plain west of Mud Lake and one line (L14) lands to the east, midway between Calcasieu Pass and the mouth of the Mermentau River. They appear to have been installed using a push-pull ditch, which was backfilled. The beach in front of all three lines is intact, showing no evidence of breaching or accelerated erosion.

Eleven Federal OCS pipelines made landfall in the Grand Cheniere area of coastal Louisiana and all but two (L20 and L22) appear to be push-pull ditches. These latter two pipelines installed in 1981 and 1978, respectively, are located in one flotation canal through the marsh, but at the landfall site the canal is filled. Sand extends inland several hundred meters and may be the result of natural or man-made infilling or backfilling and recontouring in the vicinity of the L21 line. In the immediate vicinity of L20 and L22, Kerr-McGee Pipeline Corporation installed a 6-in liquids line in 1981. This line had a minimum of 1.5 m of cover in the nearshore Gulf and 0.9 m of cover in the marsh. Where it was installed with a push-pull-ditch type of construction at the beach crossing, the line was lowered to a minimum of -3.0 m NGVD. There is no evidence of breaching or accelerated shoreline erosion at this site (Appendix B.2). In fact, the beach is beginning to prograde as a result of sediment being trapped by the east jetty of the Mermentau to Gulf of Mexico Navigation Channel. However, there were several lines exposed in the surf zone during low tide at the time of the field trip investigation in 1987. The lines were not marked, so it was impossible to tell which lines were exposed.

L19, a 20-in Tennessee Gas Pipeline Company line, was installed in 1960 in a push-pull ditch that was not backfilled. When the Mermentau to Gulf of Mexico Navigation Channel was installed, the spoil bank of this line was the western limit of the spoil retainment area for the channel. This ditch appears to have enlarged slightly since construction but there has been no breaching along the ROW at the beach.

The four lines to the west of L29 are also in push-pull ditches that appear to have been backfilled. Their alignment is barely visible on 1985 (NASA) CIR photography. There is no breaching of the shoreline at the ROW nor is there evidence of accelerated erosion (Appendix B.2).

The condition of lines L23, L24, and L25 were described in detail as part of the field investigation study (Chapter 7). It is sufficient to say that these three lines do not exhibit evidence of breaching or accelerated erosion at the shoreline. Furthermore, the flotation canals for L23 and L24 are filling with overwash sediment and L23 has had a salt marsh develop in the former canal at the beach-high rim crossing.

Lines L26, L27, L28, L29, and L30 make landfall on the shore of the Rockefeller State Wildlife Refuge. The L26 line is a 16-in gas line, operated by Mobil Exploration and Producing Southeast, Inc., and installed in 1965. It is known as the SOPCO pipeline and goes to a compressor station at Deep Lake, Cameron Parish (Gulf Interstate Engineering 1986).

Rapid shoreline erosion (11.2 m/yr between 1971 and 1985) exposed this line in the surf and it had to be reburied in 1986. Surveys prepared by Gulf Interstate Engineering (1986) showed that the line had 1.8 m of cover behind the beach berm, 2.4 m under the beach berm, and about 1.8 m in the marsh; there was no evidence of erosion of the interior marsh along the ROW. The photographs of a line lowering operation in Chapter 7 were taken on this line.

No information was available for the L27 line except that it had 1.8 m of cover where it crossed L26. When L26 was lowered, the operation stopped south of L27 in order to avoid having to lower this line also (Gulf Interstate Engineering 1986).

Pipelines L28, L29, and L30 land east of Joseph Harbor Bayou (Map 5-A Vol. 2) and were all installed using a push-pull ditch technique with backfilling. L28 is a 12-in Columbia Gulf Transmission line installed in 1958 and L30 is a 12-in Tennessee Gas Pipeline Company line installed in 1960. L29 was more recently installed in 1981. The analysis of 1985 (NASA) CIR photography reveals that narrow, unvegetated scars remain to mark the ROW, and the cut through the marsh is exposed at low tide. However, a narrow beach composed of sand covers the ROW at the shore and there is no evidence of breaching at the landfall crossing.

The L29 line appears to have had a bulkhead installed near the site of the junction of the push-pull ditch and the push-point flotation canal. This latter canal also appears to have been backfilled with spoil, but much of the line appears to have sparse vegetation and standing water (NASA 1985). The erosion rate has not accelerated at L28, L29, or L30, but the beach shoreline at the landfall site has a concave rather than straight-line shape.

Lines L31 and L32 are the first OCS lines installed in the Gulf Coast region, these 8-and 10-m gas lines were constructed from the beach offshore by Jupiter Energy Corporation in 1950 and 1955, respectively. Both lines are impossible to locate on 1985 (NASA) CIR photographs except for what appears to be a shell bulkhead inland from the beach. A narrow, straight, sand shoreline covers the landfall site;there is no evidence of breaching or accelerated erosion. Shoreline retreat averages 12.2 m/yr at the ROW and 12.6 and 11.3 m/yr for the west and east controls, respectively (Appendix B.2).

Ten OCS pipelines cross the shoreline west of Freshwater Bayou Canal and Southeast of Pecan Island (Map 5-A, Vol. 2). The L33 line is in a push-pull ditch in front of the Grand Cheniere ridge but lies in a flotation canal with L34 and L35 behind the ridge. Line L38 is also in a push-pull ditch that appears to have been backfilled. Construction and condition of Line L42 could not be determined because the ROW was not located.

Three sets of pipelines (Transcontinental Gas Pipeline Company L33, L34, and 35; Columbia Gulf Transmission Company L36 and L37; and Trunkline Gas Company L39, L40 and L41) were installed within the same flotation canal (Appendix A.2). The canals are bulkheaded at the juncture with the first chenier ridge. Measurements of these three sets of pipeline canals on 1978 (NASA) and 1983 or 1985 (NASA) showed that the canals had widened. However, the canals have begun to fill in seaward of the ridge with fine-grained sediments; in some cases a thin sand beach continues across the ROW. A comparison of ROW and control line erosion rates reveals that the ROW has experienced, in most cases, a slightly larger rate of erosion (Appendix B.2).

Three of the remaining seven lines make landfall on the Paul J. Rainey Wildlife Area and move north through the Louisiana State Wildlife Refuge. Of the remaining seven OCS pipelines in the Chenier Plain between Freshwater Bayou Canal and Southwest Pass, six follow corridors: (1) L43 and L44: Tennessee Gas Pipeline Company 12- and 16-in gas lines installed in 1979, (2) L45 and L46: Texas Gas Transmission Corp. (20-in) and Seagull Pipeline Company (6-in) lines installed in 1978 and 1977, respectively, and (3) L48 and L49: Texaco 10- and 30-in lines installed in 1964. All lines appear to be in push-pull ditches that have been backfilled. None of these lines show breaching at the shoreline

(NASA 1985) or accelerated erosion rates, though the erosion rates for the pipeline ROW are slightly higher than for the controls in four instances (L43, L44, 148, and L49) (Appendix B.2).

Line L47 is a 36-in gas line installed in 1972 and operated by the Sea Robin Pipeline Company. Because this line crosses a wildlife preserve, the state of Louisiana requested that the canal be dammed at all water-body crossings and backfilled with pumped-in material from Portage Lake to restore the marsh elevation so the site would revegetate. Compaction of the sediments left the pipeline ROW lower than marsh level and the operator was requested to refill the site. However, this was not done and the ROW remains an isolated, shallow water body vegetated by submerged aquatics (Ensminger 1987). The canal width has decreased by 9.6 m between 1978 and 1985. Shoreline change at the ROW and controls was indiscernible between 1978 and 1985 but varied from -5.9 m/yr at the ROW to -5.1 and -3.8 m/yr at the west and east controls between 1956 and 1978, a period largely prior to canal construction. Erosion of the shoreline has required that a new dam be constructed near the shoreline.

Mississippi Delta System

Of the 95 OCS pipelines that make landfall or cross barrier islands in the Mississippi Delta System (Map 6-A and 7-A, Vol. 2), 41 (43%) cross barrier islands or beaches (Appendix A.3). Of these lines, 29 cross transgressive barrier islands and 13 cross transgressive barrier beaches (Map 6-C and 2-E, Vol. 2). The remaining 54 pipelines make landfall on marsh shorelines and their impacts are not discussed in this study. Five lines (L68 through L72) pass through naturally formed tidal passes between barrier islands. Of the 41 lines crossing barrier islands and/or beaches, 33 cross marsh-bay muds fronted by a thin, sandy beach and eight cross beach and sand spits (Map 6-F and 7-F, Vol. 2).

The depth to Pleistocene for the latter 8 lines is about 137 m, while for 31 of the former 33 lines, it ranges from 145 to 210 m. For the two lines (L143 and L144) crossing the Chandeleur Islands, depth to Pleistocene is 45 m (Map 6-E and 7-E, Vol. 2). Average shoreline change rates vary, but all are eroding. The erosion rate for lines L73-85, immediately west of Belle Pass, and for L103-111, along the east side of the Modern Mississippi River Delta, averages 12 m/yr. The highest average erosion rate is 17.5 m/yr and is at the shoreline crossing of lines L87-94 (Belle Pass-Pass Fourchon area). The erosion rate for the eastern end of Grand Isle is low at -3 m/yr where lines L95-102 cross. The two lines (L143-144) across the Chandeleur Islands are in an area retreating at an average rate of 5 m/yr (Maps 6-F and 7-F, Vol. 2).

Tidal range for the westernmost four lines is 0.46 to 0.61 cm but decreases to 0.30 to 0.46 cm for the area containing the remaining OCS lines (Map 6-G and 7-G, Vol. 2). The climate for all the landfall sites is humid with precipitation surplus being 58.4 cm in the western portion of the study area, and 49.8 cm east of Port Fourchon (Map 6-D and 7-D, Vol. 2). With regard to land use, 22 pipelines (L74-86 and L103-111) cross areas set aside as Coastal Barrier Resources Areas and two lines (L143 and L144) cross the Breton Island National Seashore. The remaining 16 lines are equally divided between semi-developed sites (L95-102) or natural-to-semi-developed (L87-94) (Appendix A.3).

Six OCS pipelines (L64, L65, L68, L69, L70, and L71) come ashore in the vicinity of Isles Dernieres. However, these lines appear to have been laid in passes to avoid crossing barrier islands at the time of construction. Lines L64 and L65 are 30-in gas lines emplaced east of Western Isles Dernieres in 1968 and 1981, respectively. The as-built map for line L64 shows the ROW to be emplaced in the tidal pass west of Western Isles

Dernieres. It is assumed that the lines were laid in a trench created by jetting and were allowed to be covered by sediment being transported in a northwest direction.

Line L68 is a 26-in gas line installed in 1969 by Transcontinental Gas Pipe Line Corporation. The "as-built" map for this line, originally dated 3-23-70 and updated 8-5-71, shows it cutting across the western tip or sand spit of Central Isles Dernieres with the notation "island subject to erosion" (Transcontinental Gas Pipe Line Corp. 1970). Comparison of historic maps and photographs of the Isles Dernieres for 1887, 1934, 1956, 1969, and 1978 show that what had been a continuous island in 1887 had broken into three major segments by 1934 (Penland et al. 1987). The very small, linear portion of the Central Isles Dernieres segment migrated westward between 1934 and 1956, coming close to the Western Isles Dernieres segment. In 1969, the island was largely a sandy spit and by 1978 was gone. The destruction of this island was probably influenced by a combination of factors, including small size, the formation of two, wide tidal passes on its eastern and western end, an increasing tidal prism behind the island because of marsh erosion, and the passage of four hurricanes between 1965 and 1977 (i.e., Hilda 1964, Betsy 1965, Carmen 1974, and Babe 1977) (USDI, Bureau of Land Management 1980). What, if any, influence a 3.0-m-deep flotation canal has when placed in a wide, shallow pass (0.6 to 0.9 m) is difficult to discern without data collected contemporaneously to the time of emplacement and change.

Pipelines L69 and L70 are 26-in and 36-in gas lines installed through Whiskey Pass, west of Eastern Isles Dernieres, in 1969 and 1976, respectively. The location of Whiskey Pass has remained stable since 1934 and the island of Eastern Isles Dernieres has not migrated through or beyond the Pass. Recent photographs show no evidence of the L69 and L70 lines on the spit at the site of the ROW.

The "as-built" map for L71 (an 8-in oil line laid by Ocean Drilling and Exploration in 1970) shows the ROW as lying in Wine Island Pass east of Eastern Isles Dernieres. This line, laid from a derrick barge, carries oil from Ship Shoal 113 and South Pelto fields to the Cocodrie Terminal from whence it is barged to a final destination (Haun 1986).

The "as-built" map for L72 (Texas Pipe Line Company 20-in oil line) which was installed in 1976 (or 1973, depending on reference used) shows that the line was angled sharply to the west to avoid crossing Timbalier Island on its way to the Caillou Island Booster Station in Timbalier Bay. Once laid in the trench, this line would have been buried by jetting in the shallow, onshore water around the island.

Twelve OCS pipelines (L73-84) cross East Timbalier Island (Map 6-A, Vol. 2). Virtually no information was available on these lines, though Chevron Pipeline Company (Soudelier 1988) did verify their location on the island. Nine of the lines formerly belonged to Gulf Oil Company but are now operated by Chevron Pipeline Company (Appendix A.3). The remaining lines are operated by Tennessee Gas Pipeline Company (L75 and L83) and United Gas Pipeline Company (L82).

A comparison of the pipeline ROW verified by Chevron and recent aerial photography does not show a correlation between ROW and canal or ditch scars. Furthermore, there are numerous canals and rig cuts dredged through the island for drilling purposes which would be indistinguishable from pipeline flotation canals unless there is a well head in the rig cut. The Gulf of Mexico side of the island was also encircled by a riprap revetment in the early 1970s in order to retard erosion and protect the well heads and infrastructure (tank batteries and compressor stations). This revetment, plus the fact that it has had to be realigned after major hurricanes, has helped obscure the crossing location of OCS pipelines.

Therefore, in the absence of an extensive, chronological series of photographs, detailed collateral data, such as pipeline construction techniques and "as-built" maps, and because of the other non-OCS-related activities on East Timbalier Island, it is difficult to make any conclusions regarding impact of OCS pipelines on this island.

Lines L85 and L86 are 16-in Tennessee Gas Pipeline Company lines installed west of Belle Pass in 1968 and 1961, respectively. Both lines were located in flotation canals that were dammed inland from the shore. Line L86 was discussed in detail in Chapter 7. Factors such as canal dredging and Belle Pass maintenance dredging operations have obscured the impact of this canal on an eroding beach. The canal has widened through time (Appendix B.3) and the bulkheads have been rebuilt periodically because of erosion.

The L85 flotation canal has well defined spoil banks and has evidenced little widening (i.e. 2.2 m) between 1974 and 1985 (Appendix C). Recent aerial photography reveals that the canal has shoaled and now has a sand beach across its mouth. Overwash and aeolian sand deposits are widest on the eastern or updrift side of the spoil bank even overtopping the spoil and moving into the canal. A comparison on aerial photography of this pipeline canal to several tidal channels located to the west indicates that the pattern of channel filling is the same. Shoreline erosion has moved the beach inland of the former bulkhead, which has not been rebuilt, probably because the canal appears to be plugged naturally and is in no present danger of enlarging.

Comparison of shoreline change rates between 1969 and 1974 indicates little difference between the ROW change (-35 m/yr) and the east (-36 m/yr) and west (-35 m/yr) controls (Appendix B.3). The lower shoreline erosion rates between 1974 and 1983, may be a result of deposition of dredged material from Belle Pass to the west side of the jetty.

Eight OCS pipelines (L87-94) were verified (Cukr 1988) as making landfall south of the Chevron USA facility located west of Pass Fourchon (Map 6-A, Vol. 2). These lines ranged in size from 6 to 18 in and were all installed prior to 1976 (Appendix A.3). Line L87 was discussed in detail in Chapter 7 but there was little information available for this or the other seven pipelines. Two of the lines (L89 and L90) were installed in a flotation canal and three were placed in a push-pull ditch. No construction technique could be identified for lines L92-94, though the firm substrate and short distance to the terminal probably allowed for push-pull ditch construction.

Measurement of shoreline change rates reveals that this area has the highest erosion rate of any site in the study area but there is no pattern of accelerated erosion at the ROW versus the control beach crossings (Appendix B.3). Furthermore, the pipeline flotation canal containing L89 and L90 showed little enlargement (1.6 m) between 1974 and 1985. Some pipelines were observed to be exposed at the shoreline on the field investigation in December 1987, but they were not identified, so it is not known whether any of these lines were OCS pipelines.

The eastern end of Grand Isle is the landfall site of eight OCS pipelines (L95-102) (Map 7-A, Vol. 2). Because this area consists of firm, drained wetlands, upland trenching techniques could be used to install the lines across the island. One line (L100) installed in 1986 was directionally drilled in order to avoid disturbing the sensitive dune habitat as well as the complex of other utility lines and La. Hwy. 1, which runs parallel to the island inland from the shore.

These lines are operated by Exxon USA, Exxon Pipeline Company, or Conoco, Inc., and go to facilities located on the bayside of the island. The ROW's across the island are invisible on recent aerial photographs and there is no evidence of breaching at the shore crossings. A comparison of shoreline change rates for selected ROW's and controls reveals there is minimal or no variation between the ROW's and controls (Appendix B-3).

On the remaining stretch of barrier island or beach west of the Mississippi River, nine OCS pipelines (L103-111) make landfall (Map 7-A, Vol. 2). Two 24- and 20-in Tennessee Gas Pipeline Company lines (L103 and L104) were emplaced in 1973 and 1959, respectively, using a flotation canal. Both lines are known as LA Coastal-Grand Isle Blk. 43, with the 1973 line being identified as No. 2. According to the company (Jones 1988), the canal was dredged through the beach but the opening shoaled rapidly because of littoral processes transporting sand to the east into Chaland Pass. Jones (1988) noted they had a hard time keeping the canal open in order to get the lay and pipe barges out through the canal. Recent photography (NASA 1983) shows a narrow sand beach across the ROW and no canal opening south of another pipeline canal which parallels the shoreline. A valve platform is located on these lines just south of this canal (Jones 1988).

The width of the canal north of the site of beach infilling has diminished from 62 m in 1971 to 32 m in 1985 (Appendix C). Between 1956 and 1985, the shoreline change for the ROW averaged a net retreat rate of 1.2 m/yr, while the east and west controls averaged a loss of 2.6 and 1.0 m/yr, respectively (Appendix B.3). There has been no breaching at this landfall site nor any indication of accelerated erosion.

Two Southern Natural Gas pipelines (L105 and L106) cross the coast at different angles, then are emplaced in one flotation canal dredged across the marsh. The segments of both canals lying south of a pipeline canal (Tennessee Gas Pipeline 20-in) running parallel to the coast have filled and revegetated naturally and a narrow beach covers the seaward end of the former canals. A clear body of water stands between the canals trapped on three sides by spoil and the beach berm to the south (NASA 1983).

Measurement of the widths of the canals, where they remain open on the landward side, indicates that both have decreased in size as a result of infilling (Appendix C). However, it must be noted that comparison of canal widths for canals L103 through 106 refers only to size near the beach. The inland reaches of these canals are clearly unfilled and may, in fact, have enlarged during this same period of time.

Measurement of shoreline change revealed a loss between 1956 and 1978 but a gain between 1978 and 1985, resulting in variable change between the ROW and controls (Appendix B.3). There was no accelerated erosion at the ROW nor has there been breaching of the shoreline at the crossing site.

The Tennessee Gas Pipeline Company constructed a 12-in gas line (L107) across Lanaux (i.e., Shell) Island in 1966 using a flotation canal technique. As with lines L103 and L104, the company reported having trouble keeping this canal open because of longshore sand transport (Jones 1988).

It was difficult to verify the number of OCS pipelines and their shoreline crossing sites that Tennessee Gas Pipeline Company emplaced across Shell Island. A small-scale diagrammatic map provided by the company showed a 12-in gas line (Louisiana Coastal Extension - West Delta Blk. 45 Ln) landing in state lease block 6 (L107 on Map 7-A) (Tennessee Gas Pipeline Co. 1978). The company verified they had a line in this area which was constructed in 1966 (Jones 1988). This map also showed another 10-in line (Louisiana Coastal Extension Bastian Bay Line) crossing the island north of L107; however, it was not an OCS line. In 1970, Tennessee Gas Pipeline Co. prepared an application for another 12-in natural gas pipeline to land in the same vicinity as the previous line, but it was not determined whether a second line was built. It should be noted that the location of L107 differed on the two plats, but an apparent location correction on the 1975 map indicates that the latter map showing one OCS line is correct (Tennessee Gas Pipeline Company 1975). An OCS line shown on the 1:250,000 USGS topographic map of this area was never verified.

The L107 line was emplaced across the island using the flotation canal technique and it was difficult to keep the canal open for barge movement because of siltation from longshore sediment transport (Jones 1988). The 1973 edition of the USGS Bastian Bay quad map (orthophotoquad dated October 11, 1971) reveals a small canal with spoil leading into the canal paralleling the backside of the island but a beach and thin strip of marsh covers the landfall site of the canal.

Comparison of canal widths between 1971 and 1978 showed that the canal width decreased from 88.5 m to 48.0 m. However, by December 1979 (Mendelssohn et al. 1987), Shell Island had breached in the vicinity of the pipeline crossing. A comparison of shoreline erosion at the L102 landfall ROW and controls showed that between 1956 and 1978 erosion at the ROW was intermediate (-232 m) between that of the west control (-226 m) and the east control (-238 m) (Appendix B.3). The overriding factors contributing to this breaching of the island prior to December 1979 include erosion of marsh on the bayside of the island, increased tidal prism as a result of enlargement of the Shell Island Bay area, and decrease in size of the beach which was attributed to construction of the Empire Waterway jetties and the blockade of sediment transport to the northwest (Penland et al. 1987). These jetties were originally extended to the -1.8-m contour in 1950 and have subsequently been extended to the -3.6-m contour.

The four remaining OCS pipelines crossing a barrier beach east of the Mississippi River land 975 m east of the Empire Waterway and appear to go to the Pelican Island Terminal located about 760 m north of the beach in 1972. L108 is a 12-in Shell Pipeline Company line installed in 1965, and L109 is a 10-in oil line operated by Exxon USA and emplaced in 1956. The two remaining lines (L110 and L111) are Chevron USA 6-in oil lines installed in 1955. Construction technique was not verified by the companies but they appear to have been placed on a push-pull ditch. No canals remained visible near the beach on the 1973 edition of the Buras, Louisiana orthophotoquad (flown October 1971) because the four lines crossed the beach updrift of the Empire jetties and were covered by littorally transported sediment.

The last two pipelines crossing barrier islands in the Mississippi Delta System are L143 and L144, 16-in and 12-in Chandeleur Pipeline Company gas lines constructed in 1972 and 1962, respectively. The lines originate in Main Pass Blocks 42 and 41, cross into state waters northwest of Grand Gosier Islands, then turn northeast to parallel the inside shore of the Chandeleur Islands before cutting east and crossing the islands just south of the New Harbor Islands. From this point the lines head northeast and make landfall on the Mississippi coast south of the Chevron Refinery east of Pascagoula. These lines are labeled M5 and M6 upon landfall in the North Central Gulf Coast System.

Both lines were installed using a conventional lay barge, which dredged a flotation canal through the island. No details were available from the company regarding construction, so it is not known whether the cuts were backfilled at the beach. No bulkheads appear to have been installed so it is likely that the cuts were left open to be plugged eventually by natural processes. These canals cut through a portion of the barrier island that has numerous, unvegetated washover fans and shallow or plugged tidal channels that are in a cycle of scour and fill (NASA 1985).

On 1985 (NASA) CIR photography, only the canals through the marsh remain visible on the backside of the island. A beach has formed over the canals on the Gulf side and unvegetated washover fans have plugged a portion of each canal behind the beach. A comparison of canal widths on the backside of the island show they have enlarged from approximately 24 m in 1978 to 34 m in 1985.

Shoreline erosion rates were slightly greater for the canal ROW than for the controls (Appendix C) but there is no evidence of accelerated erosion or canal blowout at the crossing sites. The deeper channels on the backside of the island have not filled to the level of the surrounding substrate, nor have they become revegetated by submerged aquatics. This may be partially due to the fact that erosion has exposed L144 (the 12-in line installed in 1962) at least twice, necessitating reburial (Owen 1987). The most recent lowering occurred in early 1988 and was done by jetting about 182 m of line 0.9 m below the mud line. A permit was obtained from the Louisiana Department of Natural Resources, which required that they use a shallow draft barge and travel only within the ROW in order to avoid disturbing the grassbeds adjacent to the pipeline.

North Central Gulf Coast System

Of the eleven pipelines investigated in the North Central Gulf Coast System, only two (M5 and M6) originated in Federal lease blocks (Appendix A.4). The six lines landing in Mississippi cross marsh shores which are eroding at an average rate of 2 m/yr. The depth to Pleistocene is about 9 m. The tidal range in this area is 0.46 to 0.61 cm and the climate is humid with a precipitation surplus of 58.9 cm. All lines traverse mainland wetlands that are in a natural state (Appendix A.4).

The landfall site for lines in Alabama is the bluff on the west shore of Mobile Bay. The area is semi-developed in the form of residential lots along the bay. The five lines go through an undeveloped lot.

The impacts of lines M1 through M3 were described in detail in Chapter 7. The M1 line emplaced with a push-pull technique showed no accelerated erosion at the landfall site. The M2 and M3 crossings consist of flotation canals that remain open at the shoreline with only a concrete bulkhead constructed inland from the shore (Appendix B.4). The width of these latter two canals eroded an average of 4.4 and 4.8 m, respectively, between 1969 and 1985 (Appendix C).

Lines M4, M5, and M6 were installed using a push-ditch and backfilling technique. The construction area through the saline marsh is revegetated, making the ROW impossible to locate on the ground. Analysis of shoreline change rates reveals no accelerated erosion associated with the landfall sites (Appendix B.4). The M4 line is a 20-in oil line originally operated by the Cal-Ky Pipe Line Company. When constructed in 1962 from the Empire terminal in Louisiana to the refinery being built in Pascagoula, Mississippi by Standard Oil of Kentucky, it was the longest underwater pipeline ever built in the Gulf of Mexico (O'Donnell 1962). The line was designed to be served by a single pump station on the east bank of the Mississippi River and had no block valves (O'Donnell 1962). Lines M4-M6 appear to have had no long-term impact on the wetlands they cross.

According to the Department of the Army Permit filed by Mobil Oil Exploration and Production Southeast, Inc. (1981), the five lines landing in Alabama (A1-A5) were to be installed at the landfall site by boring two 42-in holes from 46 m inland to 762 m offshore in Mobile Bay. The lines were pulled from offshore to onshore with all lines laid simultaneously from a barge located behind the dredge. These five lines were laid at the same time in anticipation of future needs resulting from development of the Mary Ann field in Mobile Bay. There is no evidence of the ROW at the landfall crossing. The ROW is maintained by clear cutting of trees and shrubs on the upland site.

The lines had 2.1 m of cover in Mobile Bay except where they crossed navigation channels. After construction the bottom topography was to be restored to within 0.3 m of natural contours.

Where the lines crossed the Fowl River wetlands, they were placed in a trench dug by mat-supported, marsh-excavating equipment. Material was stored on the sides of the railroad embankment in the area to reduce compaction and in two temporary disposal areas in wetlands. The ROW was backfilled, and all disturbed areas were to be restored to original contours and replanted with indigenous vegetation on 0.9-m centers.

CHAPTER 9: IMPACTS OF OCS NAVIGATION CHANNELS AND OTHER OCS-RELATED FACILITIES

Karen M. Wicker

Introduction

The impact of OCS navigation channels and other OCS-related facilities have been grouped into one chapter for discussion because of the limited numbers of such features within this study area. Using the criteria established in Chapter 3, six navigation channels, Matagorda Ship Channel, Mermentau River Gulf of Mexico Navigation Channel, Freshwater Bayou, Houma Navigation Canal, Belle Pass, and Gulfport Harbor were selected for observation and located on historic and recent aerial photographs. Of these six, two (Freshwater Bayou and Houma Navigation Canal) were eliminated from further study because they did not cross barrier islands or beaches. Their impacts are confined to Louisiana wetlands and were within the scope of a previous study (Turner and Cahoon 1987). Gulfport, a man-made harbor which extends gulfward from the beach, was also eliminated. The entire harbor is protected by bulkheads and there has been little change in configuration of either the harbor or the adjacent shoreline since construction. The beach adjacent to this harbor was man-made after the sea wall was constructed south of U.S. 90. This beach must be nourished periodically by sand hydraulically pumped in from the Gulf. Therefore, because of the limited area of impact at the beach and the active human modification and maintenance of the entire area surrounding the port, this channel was also eliminated from study. For the remaining channels (Matagorda, Mermentau, and Belle Pass), the study of impacts was concentrated at the barrier island and/or beach area.

The study of impacts of OCS-related facilities, as defined in Chapter 2, was confined to a selected number of sites primarily on barrier islands in the Mississippi Delta System. A review of facilities in the Texas Barrier Island and Strandplain-Chenier Plain Systems revealed that most of the facilities were either very small, such as compressor-pumping-metering stations and valves, or were constructed on higher, well-drained lands near roads, as in the case of gas processing plants and refineries. Even facilities requiring deep draft access, such as ports, shipyards, pipe storage yards, and platform fabrication yards, were initially constructed on elevated land with subsequent expansion into wetlands where necessary. The OCS facilities in the North Central Gulf Coast System were located at preexisting ports or were constructed in uplands, rather than on beach or wetland habitat. Even the large Chevron Refinery at Pascagoula is located primarily on the terrace, though approximately 113 ha of wetlands have been altered for water storage and possibly treatment purposes.

Detailed investigations of the impact of even the larger facilities, such as processing plants, would have required that these companies provide researchers with plans of plant locations. Obtaining such maps for some facilities proved to be very time-consuming and, in some instances, impossible. Therefore, the discussion of these types of impacts is restricted and generally descriptive and will be presented after OCS navigation channel impacts.

Hypotheses

From the list of possible impacts attributed to navigation channels in Table 4.3, Chapter 4, the following hypotheses were tested in this study:

1) There would be continuous bank erosion and land loss.
2) There would be an alteration in the longshore drift with erosion on the downdrift side and accretion on the updrift side.
3) There would be silting considerable distances from the navigation channel site because of a change in direction and velocity of currents.

Construction of OCS-related facilities along the Gulf Coast has a direct impact in that it displaces the natural habitat with a man-made habitat which can consist of a combination of all-weather surfaces (e.g. roads, parking lots, storage sites), infrastructures (e.g. buildings, tanks, ring levees, walkways, platforms, treatment-processing facilities), bulkheaded or revetted shorelines, and dredged slips. Accurate documentation of the impact of OCS-related facilities requires: (1) data on facility location, including property boundaries, (2) history of use for OCS purposes, and (3) sequential aerial photography to document pre- and post-condition of site upon which facilities are built. In view of these requirements, the focus of determining the impact of OCS-related facilities was placed on identifying the distribution of such facilities within the immediate study area and describing the conditions of a few selected sites.

Methodology

For each of the three navigation channels selected, historic and recent aerial photography was acquired and interpreted with selected parameters being measured in regard to: (1) channel widening, (2) jetty construction, (3) shoreline change, (4) pattern of spoil deposition, (5) method of channel stabilization, and (6) changes in condition of the preexisting natural channel after the new navigation channel was dredged. United States Geological Survey topographic maps at a scale of 1:24,000 were used as the control for all interpreted maps and quantifiable data. Selected large-scale, black and white and CIR photographs were the primary data sources used to document impacts in terms of geologic/geomorphic, hydrologic, or vegetative characteristics.

Collateral data, such as historic information and environmental monitoring data for each channel was requested from the Corps of Engineers (Galveston, New Orleans, and Mobile Districts) and local sponsoring agencies. A literature search was also undertaken to obtain information on impacts identified in previous studies of these sites.

Field reconnaissance was undertaken for the Mermentau and Belle Pass Channels. In addition to observations on conditions of channel banks, jetties, and shoreline changes, bathymetric profiles were taken to document condition of previous navigation channel versus present channel and nearshore profiles. Such data enhanced air-photo interpretive capabilities.

Impacts of OCS Navigation Channels

Matagorda Ship Channel

The Matagorda Ship Channel consists of a mainline channel extending from the Gulf of Mexico across Matagorda Peninsula, through Matagorda and Lavaca Bay and up the Lavaca and Navidad Rivers (see Map 2-B, Vol. II). The 5-km entrance channel across Matagorda Bay is authorized to be 91.4 m wide and 11.6 m deep. However, the surface width of the channel is 610 m between the jetties and 305 m between the reveted channel through the peninsula. The north and south jetties extend approximately 1524 m into the Gulf (as measured from the Gulf end of the wing jetties). The Matagorda-Lavaca Bay channel is 35.4 km long, 61 to 91 m wide, and 11 m deep. There is a turning basin at Point Comfort, site of the Alcoa Aluminum plant, which is 10 m deep and covers approximately 9.3 ha. Two channels (38 m x 3.6 m) branch off to serve Port Lavaca and Harbor of Refuge. The channel up the Lavaca and Navidad Rivers is 32.5 km long, 30 m wide and 1.8 m deep (USACE, GAL. 1974).

The discussion of channel impacts concentrates on the channel crossing Matagorda Peninsula. Characteristics of this area are shown on Maps 2-A through 2-G, Vol. II. The portion of the Matagorda Peninsula north of the jetty is a high profile barrier with continuous dunes 3 to 4.6 m high (U.S. Department of the Interior Coastal Barriers Study Group 1987) (Figure 9.1). South of the jetties, the peninsula has a low profile with only a few dunes 1.5 to 3 m in elevation and a spit prograding into Pass Cavallo. The peninsula is about 1,372 m wide with a narrow band of well developed foredunes near the Gulf. There is a narrow stretch of ridge and swale topography behind the foredunes, followed by a wide expanse of irregularly flooded, vegetated flats and salt marsh. A narrow fringe of regularly flooded salt marsh is interspersed among the flats on the bay side of the island (Figure 9.1). The beach is composed of sand, shell, and rock fragments and the Pleistocene surface underlies the peninsula at a depth of 18 to 27 m (Map 2-E, Vol. II).

This portion of the peninsula has been designated as a regressive barrier island shoreline (Green's Bayou to the east segments this area from the rest of the peninsula) with a 1956-1972 average shore erosion rate of 6 m/yr (McGowen and Brewton 1975). However, the shoreline in the immediate vicinity of the channel has accreted an average of 0.9 m/yr in recent years (Map 2F, Vol. II).

The prevailing wind is from the southeast and sediment transport is to the southwest (McGowen et al. 1977). Historically, numerous inlets and washovers have developed along this peninsula in response to tropical storms and hurricanes, but they closed naturally because of the adequate sediment supply (Simmons and Rhodes 1966). Surface water elevations can vary from 0.6 m below mean low tide (during periods of northwest winds) to 4.6 m above mean low tide (during hurricanes) but the mean diurnal tide range is 0.21 m (Simmons and Rhodes 1966). The average annual mid-depth salinity ranges from 25 to 30 ppt in the vicinity of the channel. This is a relatively low energy area of the Texas coast. The area is designated as a part of the Coastal Barrier Resources System.

The Matagorda Ship Channel was constructed at this particular site because: (1) the site would permit a shorter, straighter channel; (2) a reduced jetty length would be required; (3) there would be a shorter channel length to experience relatively high velocities; and (4) it was probable that this channel would require less maintenance dredging (Simmons and Rhodes 1966). Construction and maintenance of this ship channel replaced Pass Cavallo as the navigable waterway. This latter channel was a natural pass about 2.9 km wide with a channel about 610 m wide and 6 to 12 m deep. However, it was difficult to maintain, hazardous because of shallow depths over outer bars and shifting channel positions, and unnavigable during storms (Simmons and Rhodes 1966).

A comparison of maps interpreted from aerial photographs taken before and after channel construction illustrates the impact of channel construction and maintenance on geomorphic features in the area (Figure 9.2). Pass Cavallo has shoaled and a spit is prograding northward from Matagorda Island. Matagorda Peninsula also prograded southward approximately 2,316 m between 1958 and 1987 for a rate of 80 m/yr. The dredged navigation channel through Matagorda Peninsula has not widened because its banks are stabilized with riprap. An island has been created in Matagorda Bay northwest of the channel (and southwest of the Gulf Intracoastal Waterway) as a result of the deposition of material dredged during maintenance operations. Material from channel

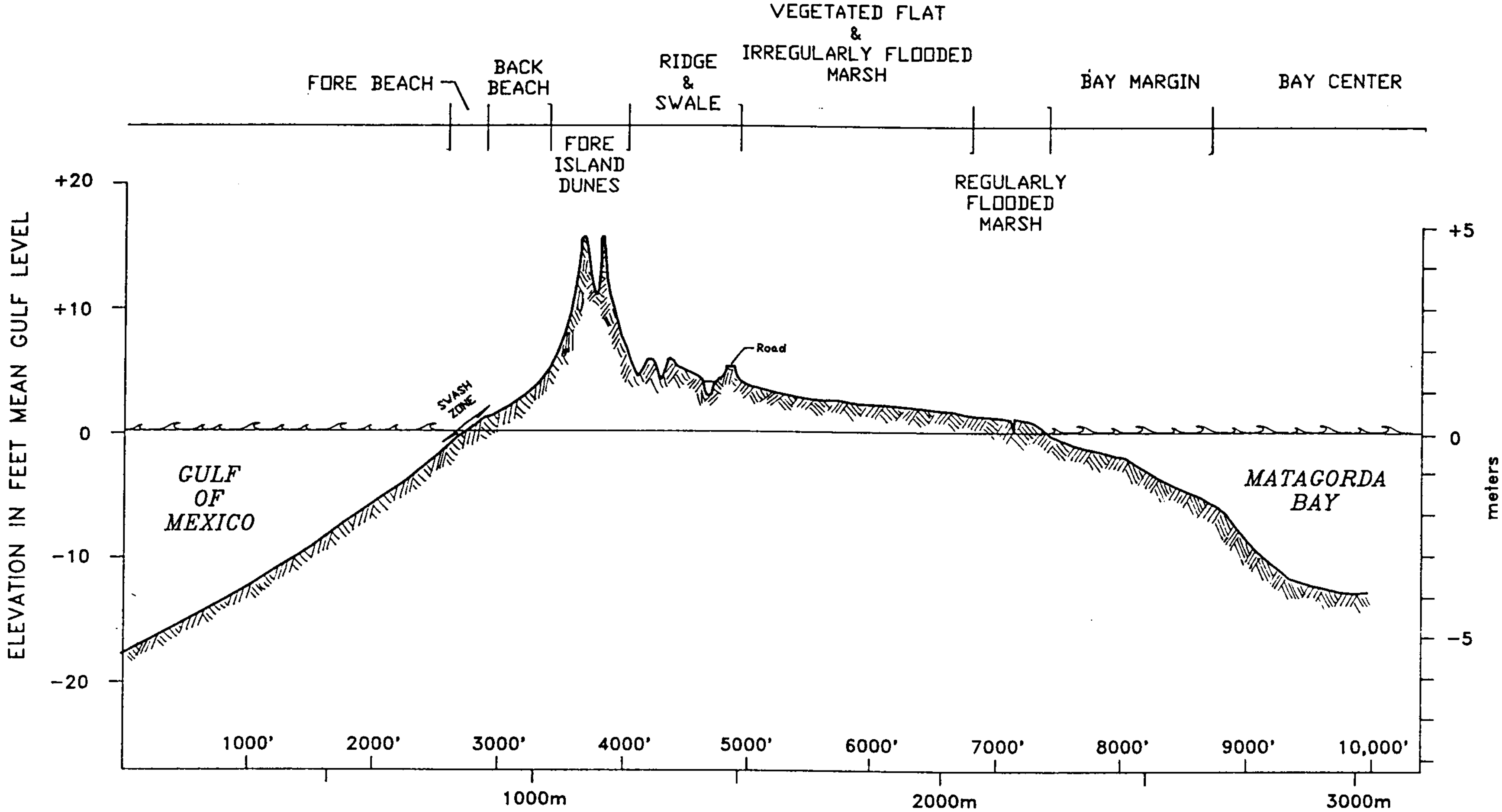


Figure 9.1. **Profile across Matagorda Peninsula in vicinity of Matagorda ship channel.**

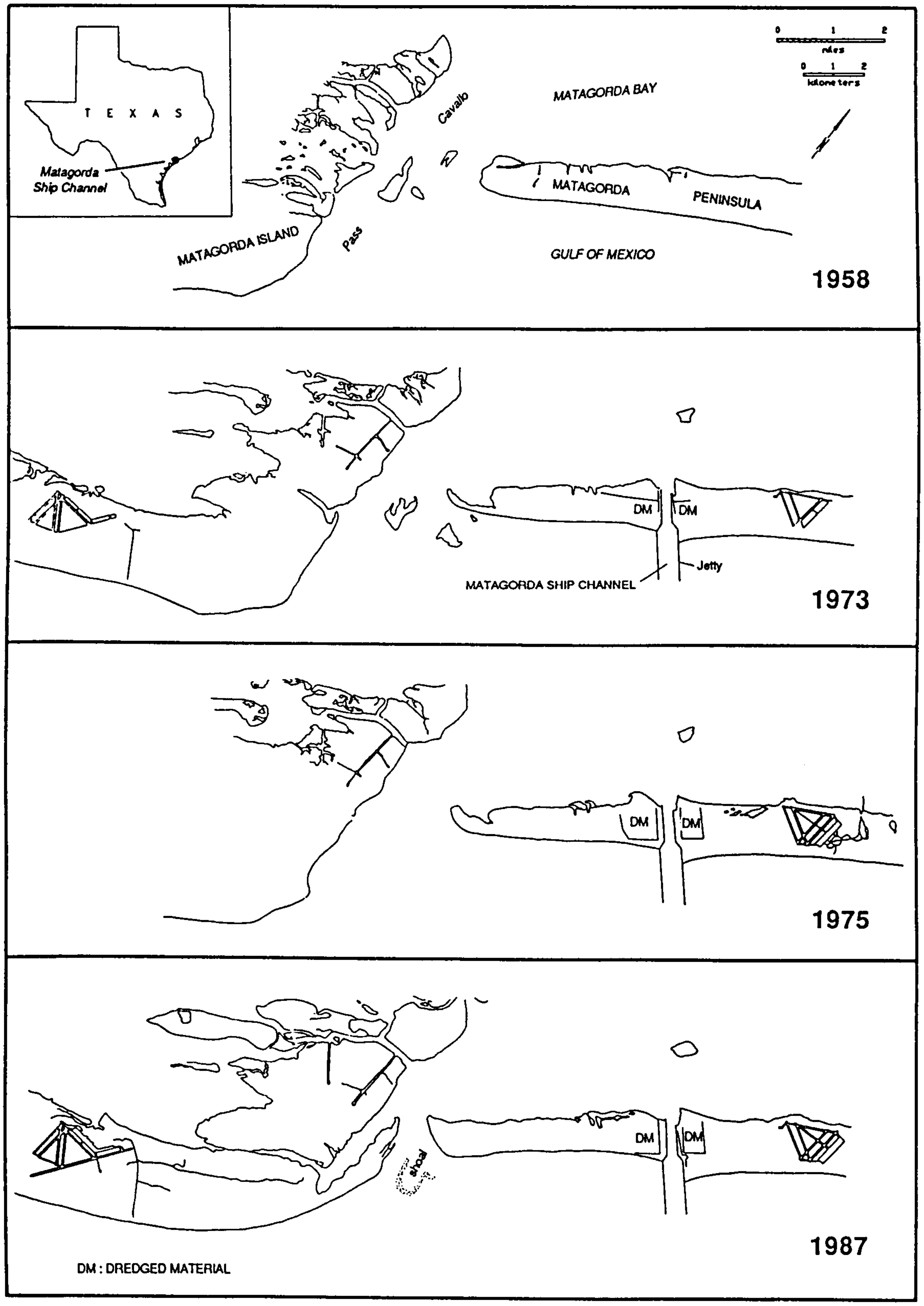


Figure 9.2. Changes in shoreline and channel configuration in the vicinity of the Matagorda ship channel for 1958, 1973, 1975, and 1987.

dredging was also deposited in retainment areas on the peninsula north and south of the channel. These materials on the bayside of the island are being reworked and transported in a southward direction. Annual shoaling rates over the outer bar and jetty channels is approximately 800,000 cu yds, thereby requiring annual maintenance dredging and deposition of materials offshore (USACE, GAL. 1974).

The beach has accreted immediately north, or updrift, of the north jetty, while the shoreline downdrift of the south jetty has retreated. Comparison of shoreline changes at regular intervals for the periods mapped reveals that within eight years of jetty construction, the area within 914 m north of the north jetty was accreting despite the continued landward migration of the peninsula (Figure 9.3, Table 9.1). Within a 3,048-m stretch of shoreline north of the north jetty, there was net accretion within the first 1,219 m (nearest jetty) but net retreat along the remainder of the shore between 1958 and 1987. In contrast, there was a net retreat along the 3,962 m of shoreline south of the jetty between 1958 and 1987. Accretion south of the jetty only occurred on the southernmost part of the peninsula in the area of spit extension where approximately 31 ha of land emerged between 1958 and 1987 (Figure 9.3).

In summary, it appears that construction of the Matagorda Ship Channel is leading to the infilling of Pass Cavallo as a result of spits extending from both Matagorda Island and Matagorda Peninsula. High velocities through the jettied and reveted portions of the ship channel have scoured the channel in excess of project-authorized depths (up to 17.4 m deep in 1980) but there has been minimal erosion of the channel banks because of the shoreline stabilization measures in place (USACE, GAL. 1980). The island continues to migrate landward, but the north jetty is trapping sediment transported littorally, thus causing the island to widen north of the jetty. The zone of the greatest amount of shoreline retreat is occurring approximately 1,219 to 2,438 m south of the south jetty.

Mermentau River Gulf of Mexico Navigation Channel

The Mermentau River Gulf of Mexico Navigation Channel is located in the Chenier Plain system of Louisiana in an area designated as part of the Coastal Barrier Resources System (see Figure 7.2 in Chapter 7; Map 2F and 2E, Vol. II). The channel has been dredged through a regressive barrier beach shoreline consisting of sand beach ridges overlying marsh and mud flats. Depth to Pleistocene at this site is approximately 7 m (Maps 5-F and 5E, Vol. II).

The channel enters the Gulf in an area where nearshore energy levels and tidal range change from east to west, though the dominant direction of sediment transport is to the west (Maps 5-G and 5-F, Vol. II). West of the channel, the nearshore energy level is high and a stretch of shoreline is averaging 2.6 m/yr of accretion (Map 5-F, Vol. II). East of the channel, the nearshore energy level is lower but erosion is occurring at about 5.6 m/yr. The tidal range to the west is 0.61 to 0.76 m, while to the east the range is lower at 0.46 to 0.61 m (Map 5G, Vol. II).

The Mermentau River Gulf of Mexico Navigation Channel was originally completed as a 4.6-by-61-m channel in 1971 by the East Cameron Port, Harbor and Terminal District of Cameron Parish. The dredged channel is approximately 7.4 km long from the entrance of the Mermentau River into Mud Lake to the Gulf of Mexico. Two jetties (a 305-m-long east jetty and a 548-m-long west jetty) flank the 305-m-surface-wide channel entrance to the Gulf. The Corps of Engineers, New Orleans District, was authorized to assume maintenance of the channel in 1976. No detailed environmental impact statements or monitoring reports on the dredging and maintenance of this channel exist (Glenboski 1988). Conversations with various Corps personnel revealed that the channel is

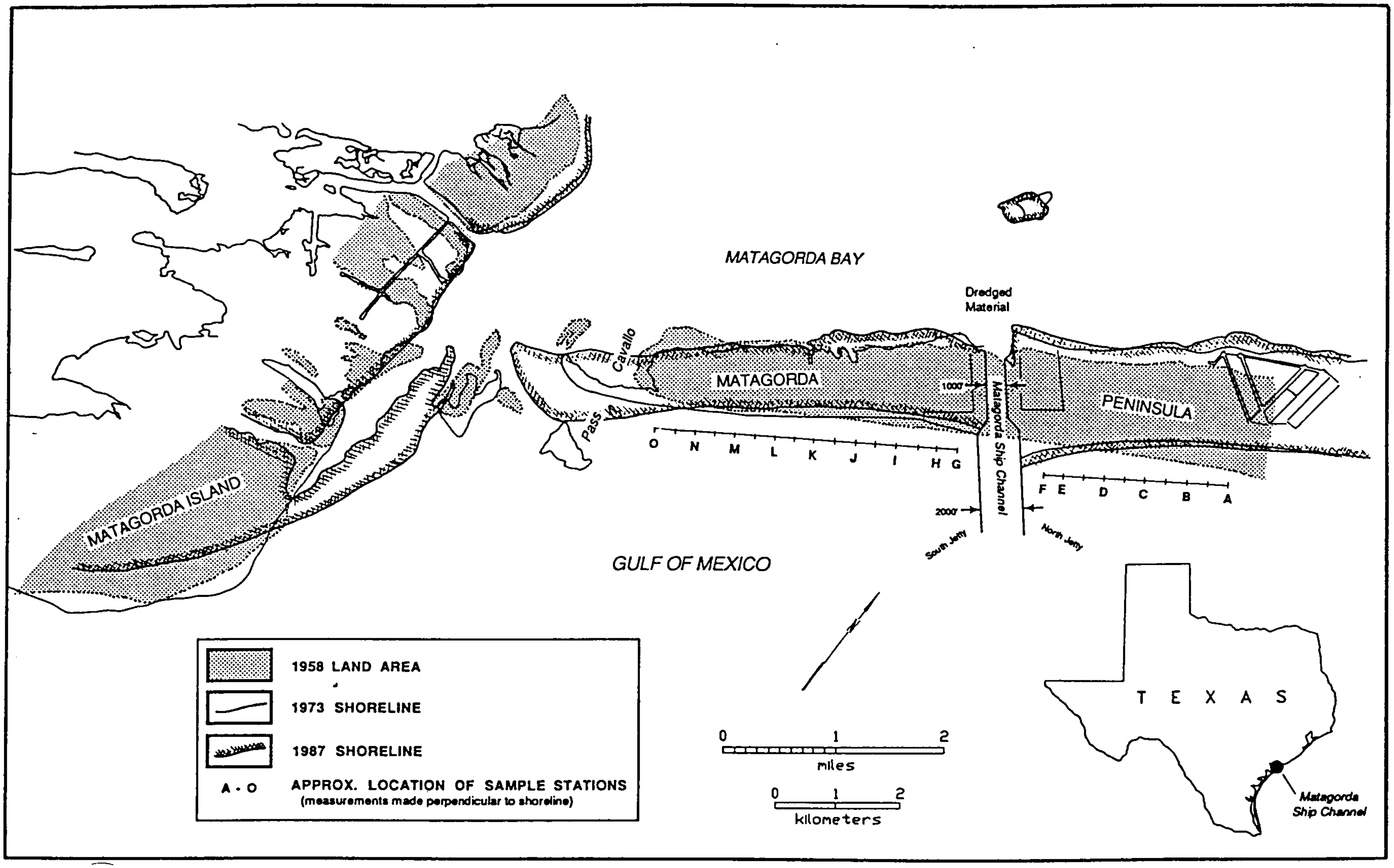


Figure 9.3. Composite map depicting shoreline positions for 1958, 1973, and 1987 and stations where shoreline change was measured.

dredged about every 2 to 2.5 years to maintain its authorized depth through the lake. In Lower Mud Lake, dredged material is deposited 152 m east of the channel centerline. For the 1.6 km of channel through the marsh to the Gulf, material is deposited in retainment areas on either side of the channel. Because of scouring, maintenance dredging in this area has been unnecessary since the Corps assumed responsibility for the channel. Material dredged from between the jetties is deposited 152 m west of the west jetty along the shore for shoreline restoration purposes. South of the jetties, dredged material is deposited in open water 457 m west of the west jetty (USACE, N.O. 1987).

A composite map of channel widths and shoreline positions for 1956, 1968, 1974, 1978, and 1985 reveal changes in shoreline position pre- and post-canal construction and changes in canal width from 1974 to 1985 (Figure 9.4). In 1974, three years after construction, the average surface width of the canal was 104 m, 42 m wider than the authorized bottom width. Eleven years later, the average surface width was 160 m. The canal widened at a faster average rate between 1978 and 1985 (5.5 m/yr) than between 1974 and 1978 (4.4 m/yr). The average rate of canal widening for the entire period was 4.8 m/yr. The total surface area of the canal increased from approximately 17.4 ha in 1978 to 25.1 ha in 1985, although the canal length through the marsh decreased from 1,686 m in 1974 to 1,556 m in 1985 as a result of shoreline erosion.

As hypothesized, there has been accretion on the updrift side of the east jetty and erosion on the downdrift side of the west jetty (Figure 9.3) (Table 9.2). Between 1956 and 1968, prior to channel construction, the shoreline updrift of the east jetty site eroded at a rate of 10.9 m/yr, while the shoreline downdrift of the future west jetty eroded 8.5 m/yr. For the 1974-1985 period after construction, the shoreline updrift of the east jetty had a lower net rate of erosion of 3.7 m/yr, while the shoreline west of the jetty eroded at an accelerated rate of 10.6 m/yr. With the retreat of the shoreline west of the jetty, a gap developed between the north end of the jetty and the shore, which was 122 m wide and 1.8 m deep in 1987 (USACE, N.O. 1987b). Contemporaneously, a scour hole also developed north of the east jetty, which was 110 m wide by 0.6 m deep. Repairs of these jetties, which were undertaken in mid-1987, made the west jetty approximately 670 m long and the east jetty 597 m long (USACE, N.O. 1987b).

The silty sand and mud flat that is accreting updrift of the east jetty had extended 680 m east and created approximately 7.3 ha of new beach by 1985, an average of 0.4 ha/yr since 1968.

With construction of the new channel (Figure 9.5) and cessation of maintenance dredging on the former channel of the natural Mermentau River through Lower Mud Lake to the Gulf of Mexico, the mouth of the natural channel has become completely filled by littoral material transported from the east (Figure 9.6). All drainage from the Lower Mermentau River Basin must now exit through the navigation channel. Furthermore, with natural sedimentation and deposition of dredge material, Lower Mud Lake is becoming shallower and very difficult to navigate.

With regard to dredging of the Mermentau River Gulf of Mexico Navigation Channel, all hypotheses tested positive. There has been continued erosion along the canal bank and accretion has occurred immediately updrift of the east jetty. Furthermore, there has been considerable silting in Lower Mud Lake and the natural mouth of the Mermentau River, because of changes in channel flow, dredged material deposition, and cessation of maintenance dredging at the original river mouth.

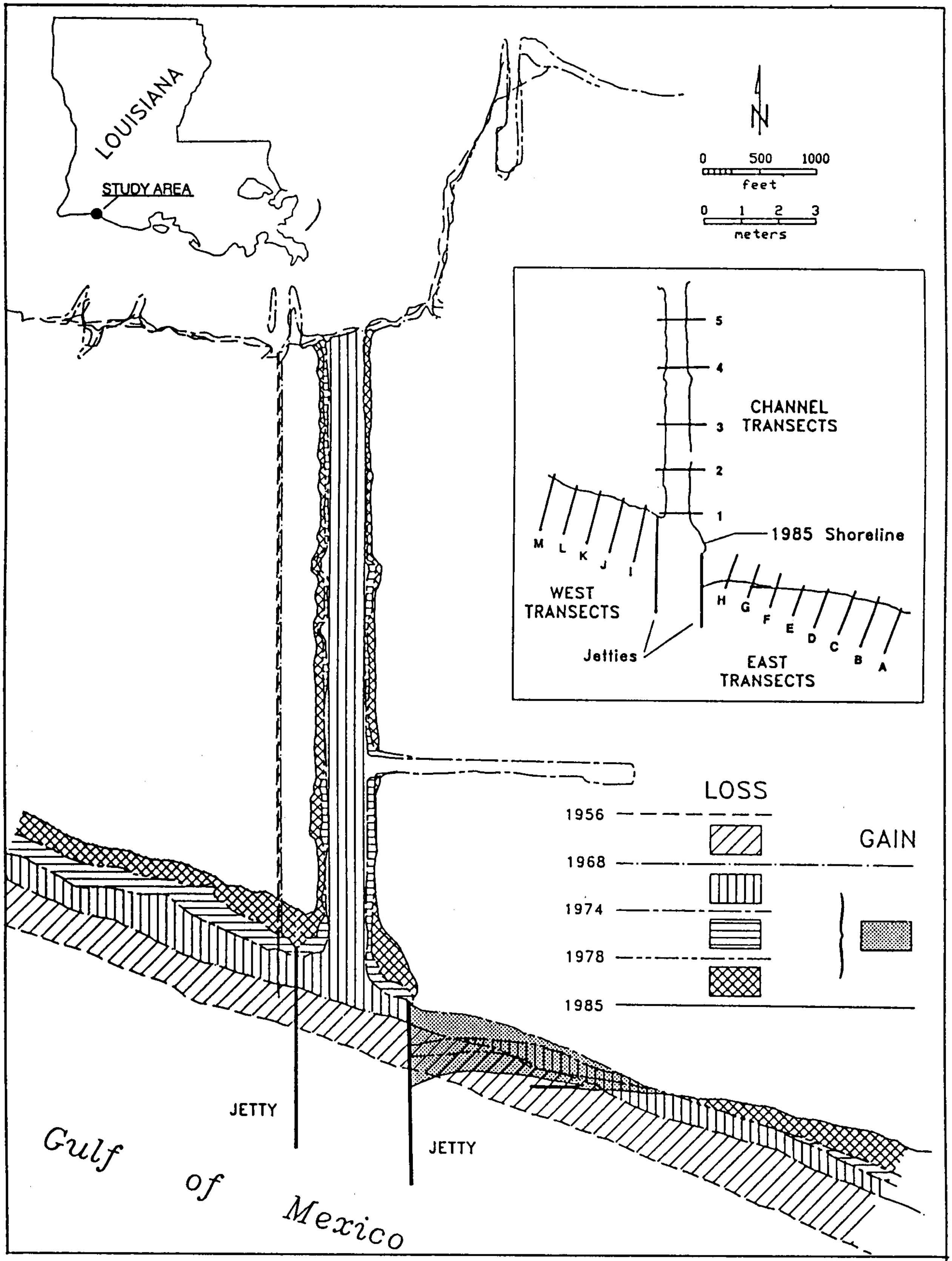


Figure 9.4. Composite map of channel widths and shoreline position in 1956, 1960, 1974, 1978, and 1985 for the Mermentau River Gulf of Mexico navigation channel.

Table 9.1. Comparison of Shoreline Change North and South of the Matagorda Ship Channel Jetties for Selected Periods of of Time. (See Figure 8.2 for location of stations.)

Period	Shoreline Change in Meters at Selected Distances North of Jetty					
	F	G	D	C	B	A
1958-73	+188	+73	-67	-182	-304	-354
1973-75	+60	+54	+54	+48	+67	+54
1975-87	+121	+116	+116	+91	+67	+54
Net Change 1973-87	+182	+170	+170	+140	+134	+110

Period	Shoreline Change in Meters at Selected Distances South of Jetty								
	G	H	I	J	K	L	M	N	O
1958-73	-36	-67	-91	-54	-6	+30	+36	+12	+182
1973-75	+18	+30	+36	+48	+6	0	+18	+67	+67
1975-87	-116	-116	-122	-122	-122	-91	-91	-48	+91
Net Change 1973-87	-98	-85	-83	-73	-116	-91	-73	+18	+158

Table 9.2. Comparison of Shoreline Change East and West of Mermentau River Gulf of Mexico Navigation Channel Jetties for Selected Periods of Time.

Period	Shoreline Change in Meters at Various Points East of Jetty								
	H	G	F	G	D	C	B	A	Avg. Net Change M/Yr
1956-68	-122	-116	-124	-110	-132	-152	-138	-152	-11
1968-74	-18	-59	-42	-62	-59	-47	-47	-42	-8
1974-78	+34	+59	+27	N.C.	N.C.	N.C.	-28	-30	+2
1978-75	+58	+24	+30	+4	-30	-47	-64	-76	-2
Net Change 1956-1974	-140	-175	-168	-172	-192	-200	-186	-195	-10
Net Change 1974-1985	+91	+84	+58	+4	-30	-47	-92	-106	-4

Period	Shoreline Change in Meters at Various Points West of Jetty					
	I	J	K	L	M	Avg. Net Change M/Yr
1956-68	-100	-96	-108	-92	-114	-8
1968-74	-84	-104	-96	-62	-74	-14
1974-78	-58	-94	-47	-68	-48	-15
1978-85	-84	-27	-48	-53	-60	-16
Net Change 1956-1974	-154	-200	-204	-155	-148	-10
Net Change 1974-1975	-142	-122	-96	-122	-110	-10

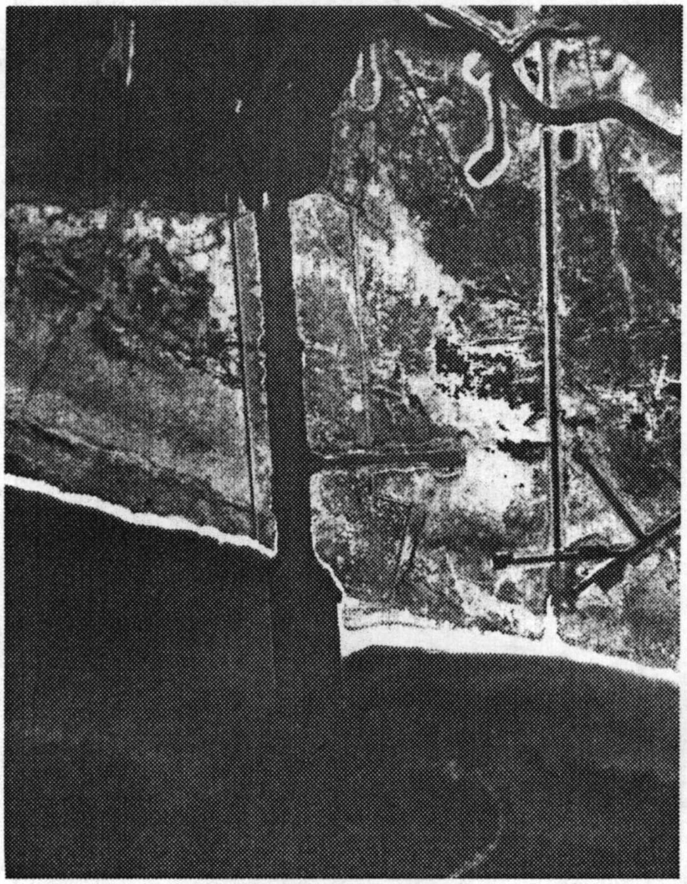


Figure 9.5.

Mermentau River Gulf of Mexico Channel in 1985, showing erosion along unstabilized channel, erosion north of east and west jetties, and accretion immediately updrift of E. jetty (NASA 1985).

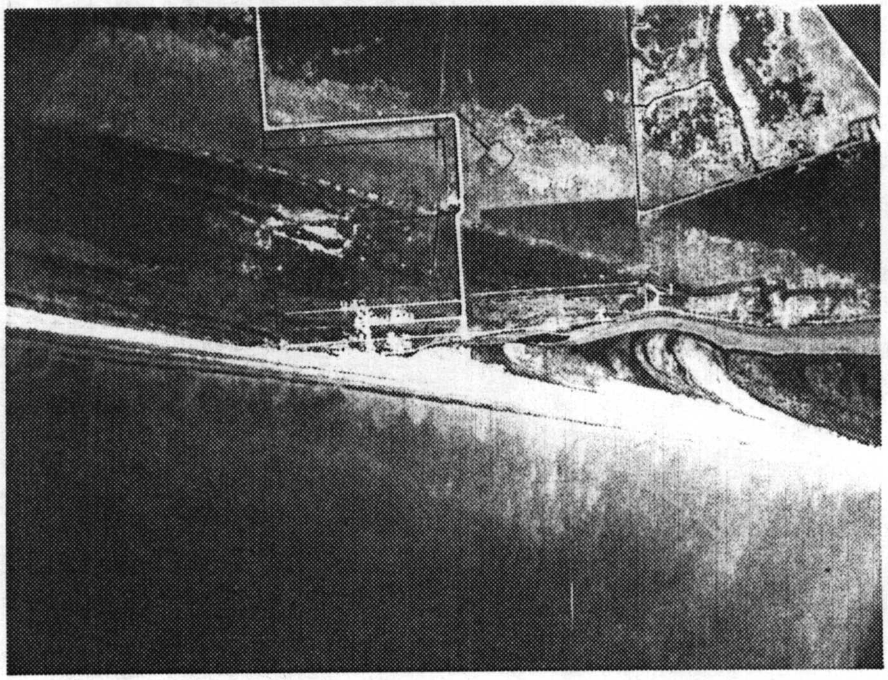


Figure 9.6. Mouth of natural channel of the Mermentau River in 1985 that has silted up after maintenance dredging ceased (NASA 1985).

Belle Pass

The Belle Pass Navigation Channel extends from the Gulf of Mexico northeastward to Bayou Lafourche (see Figure 7.28 in Chapter 7). Interpretation of aerial photographs and charts reveals the shoreline changes were extensive between 1934 and 1985 and resulted from natural processes, jetty construction, channel enlargement, and dredged material deposition from channel maintenance operations (Figure 9.7).

The original channel was authorized to be dredged to 2 m deep and 18 m wide in 1939 with 61-m-long jetties at the entrance to the Gulf. By 1945, shoreline retreat required that the jetties be extended shoreward for 61 m and sometime between 1945 and 1953, a groin was installed east of the east jetty to combat erosion at the east jetty-shore contact (Dantin et al. 1974). In 1956, the Corps of Engineers, New Orleans District, constructed a new channel west of the existing jetty system and by 1958, the northern 152 m of the original west jetty had been removed and realigned, making the channel between the jetties 98 m wide at the Gulf (Dantin et al. 1974).

In 1968, the Greater Lafourche Port Commission assumed maintenance of the navigation channel when they enlarged it to 6 by 91 m (Dantin 1974). As part of the Port Fourchon port development project, the authorized channel dimensions have remained the same since 1968 but the jetties have been extended landward since 1974 in order to maintain contact with the retreating shoreline. The east and west jetties have been 914 m long at least since 1983, and the northwest wing extension on the west jetty is 427 m long.

The Belle Pass navigation channel is located in the Caminada-Moreau headland in the Mississippi Deltaic System. This is a transgressive barrier beach system having a very thin, sandy beach fronting marsh and bay muds. The shoreline segment containing the site has one of the highest erosion rates in the United States (Penland and Boyd 1985). Erosion rates vary depending upon the period of time for which rates are calculated, but a recently determined average placed the erosion rate at 17.5 m/yr (Map 6-F, Vol. II).

At the mouth of Belle Pass, the predominant littoral drift is to the west and the depth to Pleistocene is 210 m (Map 6-E, Vol. II). The area immediately east of Belle Pass has been considered for either port development or recreation and an oil terminal already exists near the junction of Belle Pass and Pass Fourchon. Major port development is presently concentrated along the north side of Belle Pass. The beach west of the pass had been designated as a Coastal Barrier Resource Area.

Shoreline change was measured at 152-m intervals for 1,828 m east and west of the Belle Pass jetties for various dates before and after jetty construction: 1887, 1934, 1955, 1969, 1974, 1978, 1983, and 1985 (Figure 9.8). From this data the average rate of change was calculated for various time periods east and west of the jetties (Table 9.3). The construction of jetties has interfered with natural littoral processes in that it has slowed the transport of sediment to the west but it has not resulted in accretion on the updrift side of the jetty. Furthermore, rates of shoreline change updrift and downdrift of the jetties are influenced substantially by other human activities in the area such as dredged material deposition and dredging of a petroleum-related canal west of Belle Pass between 1955 and 1969.

Between 1887 and 1934, prior to channel enlargement and jetty construction, the shoreline retreated in a relatively straight line, with the rate being 40 m/yr west of the pass and 31 m/yr east of the pass (Figure 9.8). The natural levees east and west of Belle Pass were more resistive to erosion than were the thin strips of marsh in front of Timbalier Bay, west of the pass, and Bay Morehand, east of the pass, as evidenced by the setback angle at

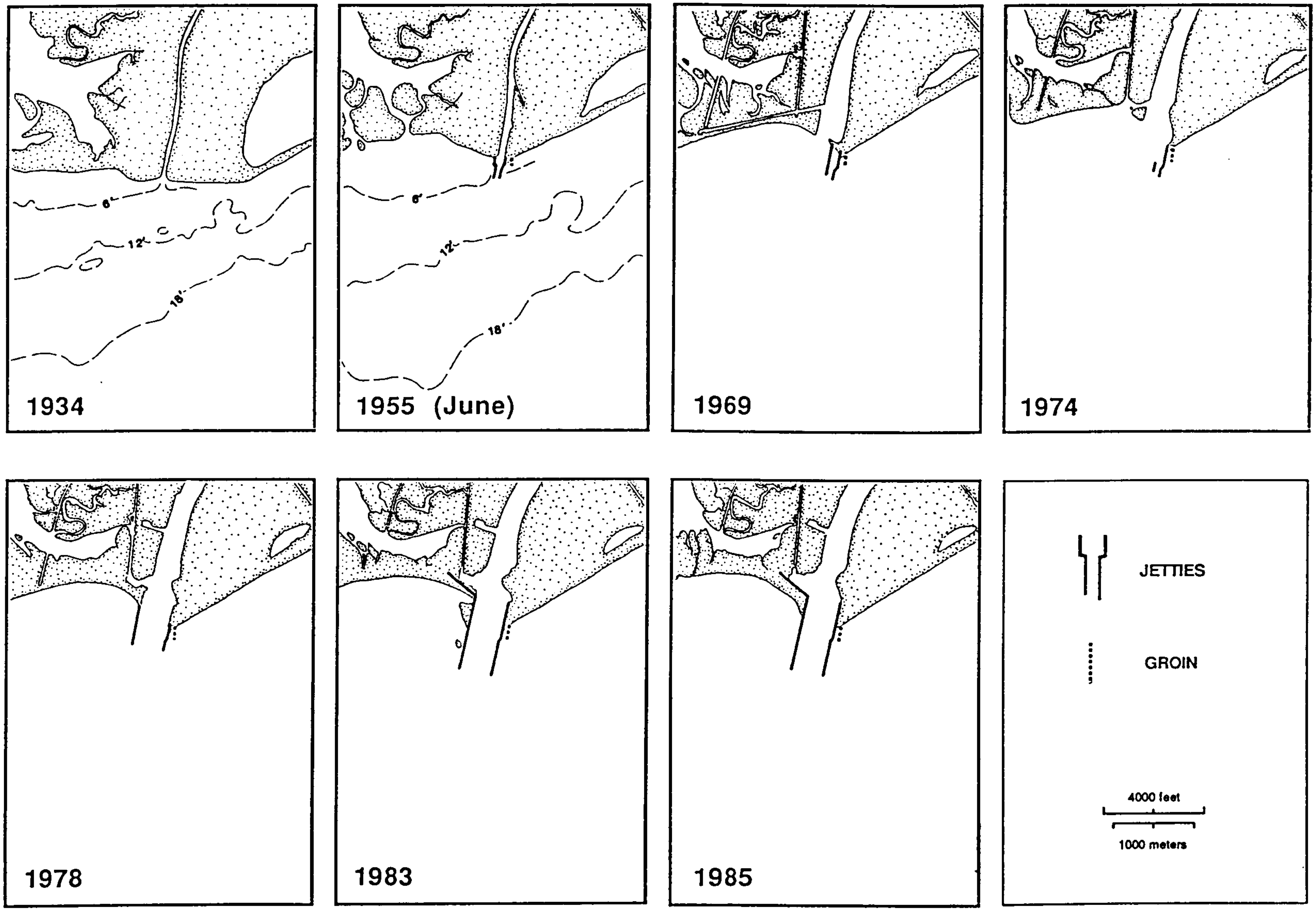


Figure 9.7. Comparison of shoreline position and configuration and size of the Belle Pass navigation channel and jetties at various times between 1934 and 1985.

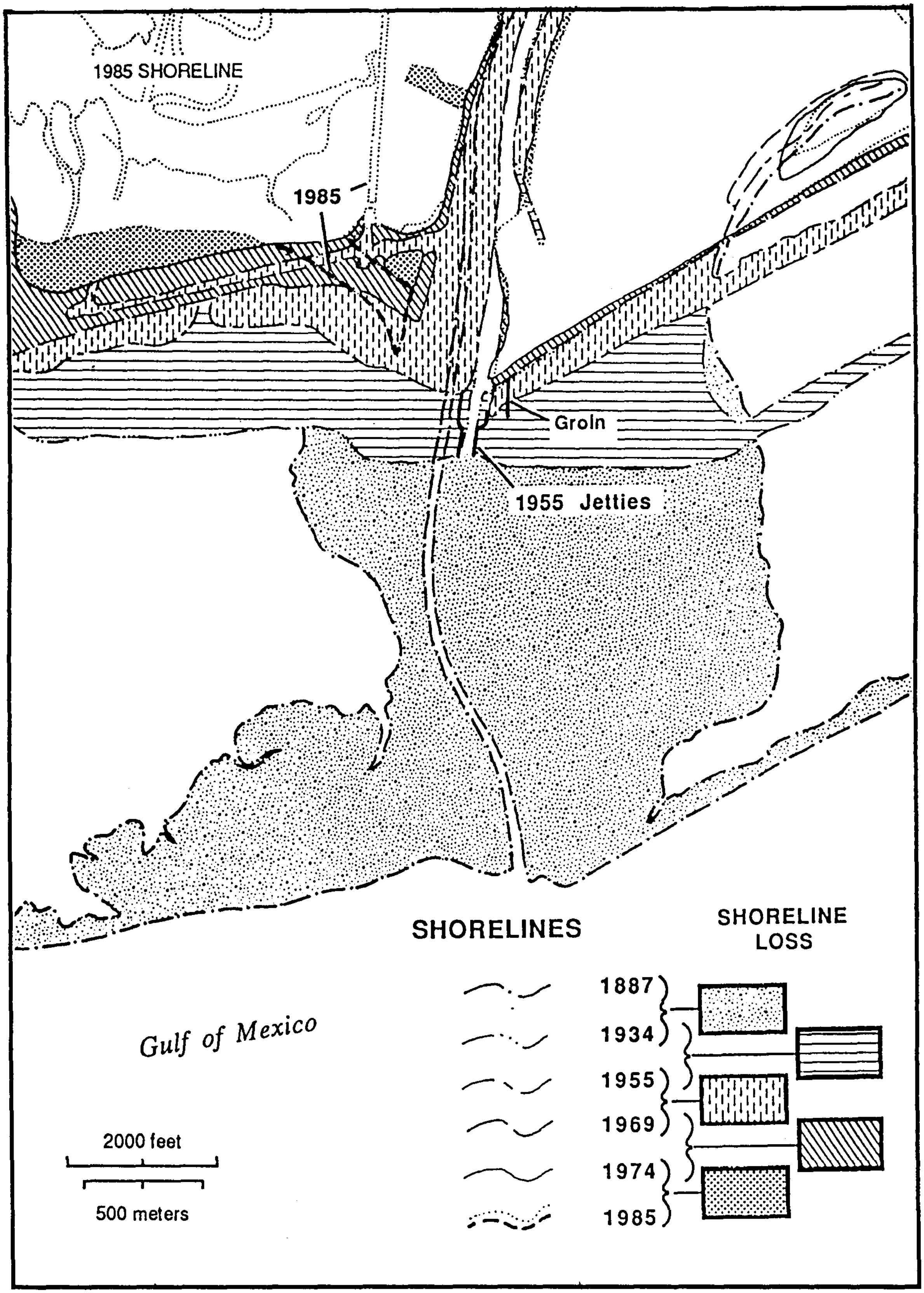


Figure 9.8. Composite map depicting shoreline change in the vicinity of the Belle Pass Navigation Channel for 1887, 1934, 1955, 1969, 1974, and 1985. Position of jetties only depicted for 1955.

Table 9.3. Average Rate of Shoreline Change East and West of Belle Pass Jetties between 1887 and 1985.

Location	A	B	C	D	E	F	G	Net Change	Net Change
	1887-1934 m/yr	1934-1955 m/yr	1955-1969 m/yr	1969-1974 m/yr	1974-1978 m/yr	1978-1983 m/yr	1983-1985 m/yr	1934-1974 m/yr	1934-1985 m/yr
East of Jetty (within 1828 m)	-31	-24	-12	-7	-15	-7	-10	-14	-13
West of Jetty (within 1828 m)	-41	-17	-10	-37	-7	-12	-4	-21	-11

A. Before channel enlargement and jetty construction.
B. After channel and jetty construction.
C. Channel Enlargement, rig cut dredged west of west jetty.
D. Shore in front of rig cut canal eroded west of west jetty.
E. West jetty extension and dredge material deposition.
F. West jetty constructed and dredge material deposited west of west jetty.
G. Wave reworked material west of west jetty created beach.

Table 9.4. Comparison of Average Channel Width and Area for Belle Pass*: 1887 and 1985.

Date	Length (m)	Width (m)	Area (ha)
1887	3,928	31	12
1934	2,128	43	9
1955	2,128	72	15
1969	1,683	250	42
1974	1,616	305	49
1978	2,107	314	66
1983	2,433	317	77
1985	2,443	329	80
Net Change	-1485	+298	+68

* from Bayou Lafourche to end of jetties.

the base of the natural levees. Between 1934 and 1955, a time of initial channel enlargement and jetty construction, the mouth of the pass appeared to be temporarily anchored in the Gulf at the point of shore and jetty contact, while the shoreline east and west of the jetties retreated more extensively. The angle of retreat (i.e., the angle between a line parallel to the shore and a line perpendicular to a line parallel to the canal bank) east of the jetty was N 8° in 1934, N 35° in 1944, and N 44° in 1985. In contrast, west of the jetty the angle of retreat was S 22° in 1934, N 10° in 1955, and N 18° in 1985, indicating that between 1934 and 1955 shoreline retreat in the immediate vicinity of the jetties was greater for the west jetty than for the east jetty. For subsequent time periods, shoreline changes east and west of the jetties are influenced by events noted in Table 9.3. Between 1934 and 1974, shoreline retreat west of the west jetty was 21 m/yr in contrast to a rate of 14 m/yr east of the jetty. Deposition of dredged material west of the west jetty after 1974 decreased the rate of erosion west of the jetty to 11 m/yr, while the shoreline east of the jetty continued a retreat of 13 m/yr. Deposition of dredged material has created a beach in front of the west wing jetty. The wing jetty appears to force flow through the jetties and prevent erosion along the west bank of Belle Pass at the point of shore and jetty contact, as is occurring on the west bank of the Mermentau River Gulf of Mexico Navigation Channel.

In 1986, material dredged from the Belle Pass Channel was hydraulically pumped in a semi-leveed enclosure east of the east jetty in front of the Chevron terminal southeast of Port Fourchon in an effort to retard shoreline retreat (Falgout 1988). No studies have been published on the success of this operation, nor do there appear to be any long-range plans to monitor the use of dredge material to stabilize the shoreline. Furthermore, the full environmental impact of this channel maintenance on the adjacent shoreline has never been documented throughout the period of navigation channel dredging and maintenance. Further attempts to use dredged material to retard shoreline erosion in front of the Chevron Terminal and to maintain land in front of Port Fourchon will restrict littoral transport to the west, thereby depriving East Timbalier Island of the sediment necessary for maintaining a dynamic equilibrium in relation to natural processes.

The average width of the Belle Pass Channel (from Bayou Lafourche to the northern tip of the jetties) has increased tremendously since 1887 (Table 9.4). Prior to enlargement, the natural channel was approximately 31 m wide in 1887 and 43 m wide in 1934. By 1985, the average channel width was 329 m and resulted from both dredging and erosion of the bank.

OCS-related Facilities

A review of existing data bases (Larson et al. 1980, Garofalo and Burke and Associates 1982, Kimber et al. 1984, Smith 1984, Palik and Kunneke 1984, MMS 1987, Lynch and Risotto 1985) and analysis of the most recent aerial photographs (1985 and 1987) for selected areas facilitated the location of OCS-related facilities on barrier islands. Within the Texas Barrier Island System, the majority of these facilities consisted of individual or small groupings of oil storage tanks on North Padre Island, Mustang Island, and Matagorda Island. Three oil terminals were identified, one on Mustang Island and two on Galveston Island. Galveston Island also has one gas processing plant and a compressor, pumping, and metering station. Helicopter services were available from Galveston Island and North Padre Island. One gas processing facility was also located on North Padre Island (Kimber et al. 1983).

No OCS-related facilities were identified within the beach zone of the Louisiana Chenier Plain System. Within the Mississippi Deltaic System, OCS facilities are only located on three barrier islands. Grand Isle has the largest concentration of facilities. Exxon Company USA began supporting its eastern Gulf of Mexico OCS operations from Grand

Isle in 1948 (Parker 1988). In the 1950s, the base covered over 284 ha and provided housing for 150 families. Housing facilities were closed in 1979 and today's Exxon facilities cover 126 ha, 9 of which contain the Grand Isle Terminal operated by Exxon Pipeline Company (Parker 1988) (Figures 9.9 and 9.10).

The Grand Isle Terminal covers approximately 1% of Grand Isle with 90% of the terminal site developed and 10% impounded. The Grand Isle Base covers approximately 12% of Grand Isle and land use on the property is divided as follows: developed with infrastructure (28%), cleared land with roads (97%), fastlands (53%), beach lots/ROW (1%), and dredged boat slip (1%). These percentages were based on interpretation of 1983 CIR photography. Functions served by these facilities today include: "helicopter and boat transportation, materials handling, petroleum and natural gas processing, and training" (Parker 1988).

Conoco, Inc. operates a Grand Isle Shore Service Base and Tank Battery on Grand Isle, east of the Exxon facilities, which serves several companies: Continental, Conoco, Arco, Texaco, and Occidental (Kewley 1988). This operation has existed since the 1950s and appears to cover about 2% of Grand Isle. No map of the property was available, but interpretation of 1983 CIR photography indicates that about 15 ha of the identified site were developed with infrastructures and about 3 ha were impounded for water storage and/or treatment. In addition to providing boat and helicopter transportation for OCS operations, the site has tank batteries for oil storage; a compressor, pumping, and metering station for oil coming from OCS leases; facilities to extract produced water and sediment from OCS oil and to separate gas to supply the town of Grand Isle (Kewley 1988).

Grand Terre, a barrier island immediately east of Grand Isle, has a compressor, pumping, and metering station operated by Sohio. This facility is located on the backside of the island north of the Tennessee Gas Pipeline Canal (Muskrat Line) (Figure 9.11). The site covers about 1.6 ha and was created by pumping dredged material over saline marsh. Approximately 335 m of the site's shoreline is protected from wave erosion by stone riprip.

East Timbalier Island, west of Belle Pass, is the only other island in the Mississippi Deltaic System with OCS facilities. However, of the four facilities located on walkways and platforms constructed on dredged material-piling complexes, only one serves as an OCS facility according to Chevron USA (Soudelier 1988) (Figure 9.12). This OCS facility is located on the backside of the eastern end of the island and contains tanks for oil storage and separator facilities to remove produced water from oil being pumped from OCS leases.

No OCS facilities were identified on barrier islands within the North Central Gulf Coast System, except for a small docking facility on the eastern end of Dauphin Island operated by Mobile to service its Mobile Bay fields. Most OCS facilities, such as oil refineries, gas processing plants, pipe storage yards, and platform fabrication sites in this region are primarily on uplands with minimal expansion into wetlands. The facility with the largest single impact on wetlands is probably the Chevron USA Refinery at Pascagoula. While no recent diagram of the property was obtained, interpretation of aerial photographs in conjunction with the most recent USGS topographic map reveals that approximately 113 ha of intertidal marsh east of the facility have been converted to water storage-treatment impoundments or landfill.

The numerous shipyards and ports along the Mississippi-Alabama coast also have developed through dredge and fill operations which have a cumulative impact on wetlands

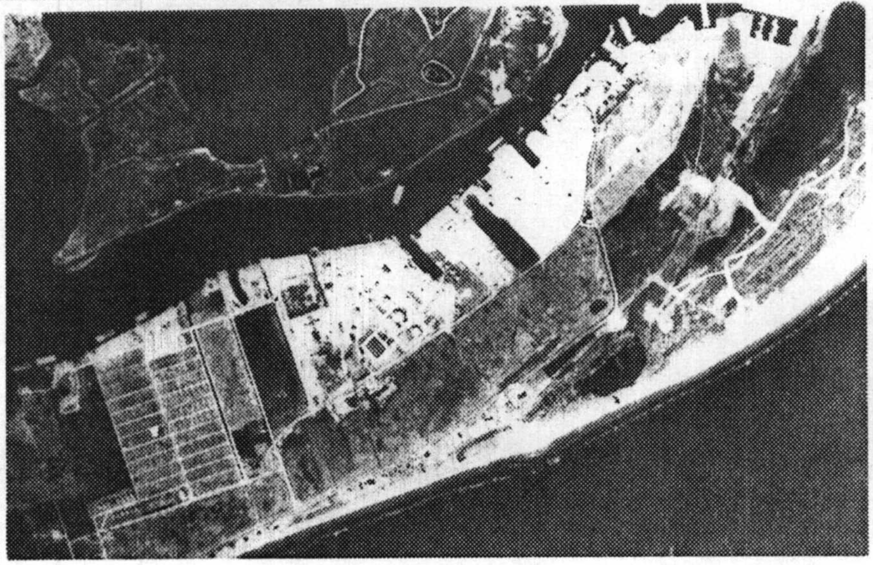


Figure 9.9.

Location of three OCS-related facilities on eastern Grand Isle and depicted on 1983 NASA photograph.

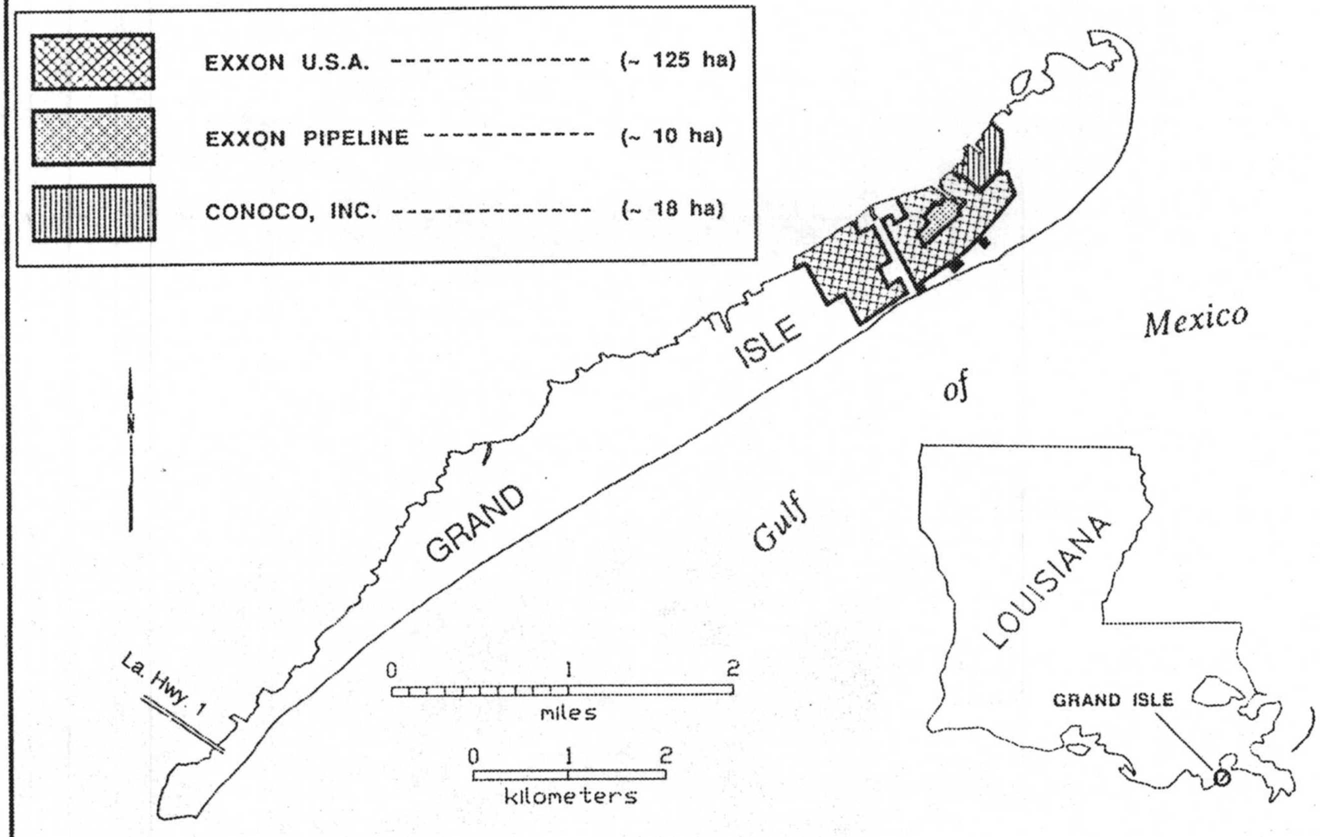


Figure 9.10. Location of OCS-related facilities operated by Exxon U.S.A., Exxon pipeline, and Conoco, Inc. on Grand Isle, La.

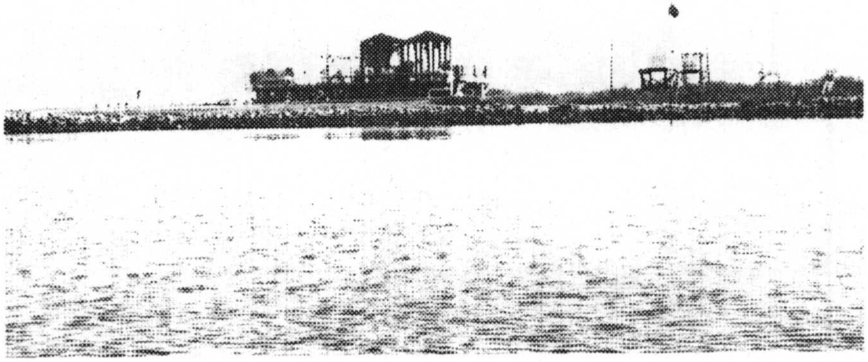


Figure 9.11. Sohio Facility on Grand Terre, La.

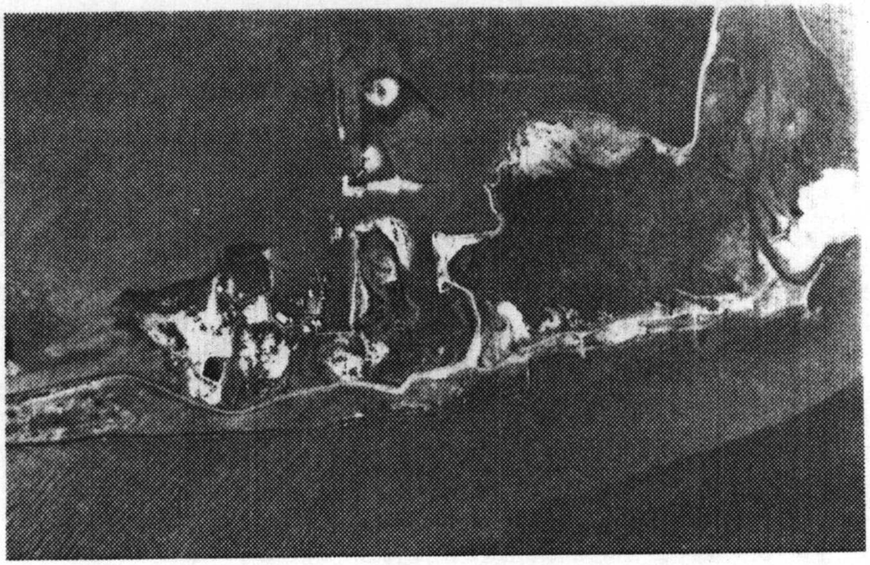


Figure 9.12. Chevron U.S.A., Inc. OCS facility (tank battery) on East Timbalier Island.

and shallow estuarine habitats in the region. However, more historical data on facility development and utilization by OCS activities are necessary before any quantification of wetland impact can be determined. Because of the incremental nature of most facility development and expansion, determination of the cumulative impact of OCS facilities requires extensive historical documentation of development and interpretation of air photo. Cumulative wetland impact is probably larger than commonly believed and may be more significant for this region because of the general sparsity of coastal wetlands. However, facilities with potential for impact serve non-OCS uses as well, and it is difficult to allocate impact by user group.

CHAPTER 10: SUMMARY OF IMPACTS AND PREDICTIONS OF FUTURE IMPACTS

Karen M. Wicker, Kevin Neese,
and Rod E. Emmer

Introduction

The results of the study of selected types of impacts of OCS pipelines, navigation channels, and related facilities on barrier islands, beaches, and wetlands were presented in Chapters 7, 8, and 9. The types of impacts investigated were selected from the numerous impacts commonly identified in the literature and tabulated in Chapter 4, Table 4.3. The two major hypotheses that were tested using investigative field techniques and analysis of aerial photographs were:

1. Emplacement of pipelines and navigation canals result in direct land loss and habitat change (i.e., replacement of preexisting land or water of varying habitat type by the open water pipeline or navigation canal and the spoil banks composed of dredged material).

2. Emplacement of pipelines and navigation canals results in indirect land loss and habitat change.

The indirect land loss and habitat change supposedly occur because the emplacement of the pipeline and navigation canals affect the following processes or forms:

1. Saltwater intrusion which replaces fresher hydrologic conditions with more saline hydrologic conditions.

2. Continued erosion along the newly created, steep-sided, land-water interface (i.e., canal side).

3. Creation of a weak zone in beach, barrier island, and wetland substrate at site of canal or ditch of pipeline ROW which subsequently erodes as a result of natural erosional processes.

4. Alteration of natural physiographic forms (i.e., enclosed, interdistributary basins; natural levee ridges; barrier islands, beaches and dunes; isolated marsh ponds, shallow sandy bay bottoms, etc.) and processes (i.e., slow overland sheet flow drainage or sinuous, shallow tidal channel drainage) that result in habitat change and most notably loss of vegetation.

5. Disruption of longshore transport of sediment though entrapment of sediment in canal sinks.

In order to identify and discuss the significance of the impacts of OCS pipelines, navigation channels, and related facilities, the features were identified and mapped. Physical, biological, and cultural parameters of the landfall crossings, as well as technological features associated with OCS pipeline, navigation channel, and related facility construction were recorded on small-scale maps in tabular form to correlate the magnitude and possibly the cause of the observable and/or quantifiable impact with conditions within the study area and with the construction techniques. Field investigations were undertaken to verify signatures of various features on aerial photographs, to check the accuracy of measurements made from aerial photographs, and to generate quantifiable data useful for describing the extent of impact. The results of these analyses, in addition to the identification of existing regulations governing construction in sensitive areas, allow for the prediction of future impacts.

Of the 116 OCS pipelines (out of a total of 164 OCS pipelines) crossing barrier islands, beaches, and selected wetlands in the study area, 11 were selected for field sampling, which included collection of vibracores and vegetation samples, elevation and bathymetric profiles, and general site descriptions for the pipeline ROW and controls (Chapter 7). All of the OCS pipelines were investigated using aerial photographs to quantify shoreline and canal width changes and to describe the condition of the pipeline site in relation to the condition of the adjacent area (Chapter 8). Of the four OCS navigation channels crossing barrier islands or beaches, three were studied in order to quantify or describe observable impacts (Chapter 9). The impacts of OCS navigation channels were quantified by measuring changes in the width of the channels and the position of the shoreline updrift and downdrift of the channel jetties. Maintenance operations, including dredging and jetty extensions, were noted. Aerial photographs were analyzed also to describe the impact of a few of the OCS facilities on barrier islands and in the wetlands of Mississippi (Chapter 9).

Summary of OCS Pipeline Impacts

Pipeline Emplacement Techniques

Pipelines can be emplaced using a variety of techniques which, with incorporation of mitigation measures, can influence the extent of impact to the environment. The two major emplacement techniques used historically in wetland environments are the flotation canal and push-pull ditch. The standard flotation canal is designed to have a bottom width of 12 to 15 m and a depth of 1.8 to 3.0 m. The push-pull ditch is considerably smaller, ranging in width from 2.4 to 3.0 m and having a depth of 1.2 to 2.4 m. The directional drill technique, first tried in the early 1980s, does not impact the environment along the ROW through which drilling occurs. This technique may be used more in the future for crossing short, sensitive habitats, such as barrier islands, beaches, or steep, eroding shorelines.

The extent of direct and indirect environmental impact of a flotation canal may be influenced by whether the canal is left open or backfilled and/or whether it is dammed at all tidal water-body crossings. Furthermore, spoil deposition will have environmental impacts depending upon the environment of deposit (i.e., shallow or deep water, fresh or floating, fresh marsh, brackish-to-saline marsh), and the configuration of the deposit (i.e., continuous on one or both sides of canal with no breaks; discontinuous on one or both sides of the canal with breaks 15 m wide every 152 m, 152-m long spoil banks alternating on both sides of canal or removal of spoil by dragline for backfilling or creation of new marsh habitat).

The extent of impact from the push-pull ditch technique also may be influenced by whether the ditch is backfilled and/or dammed. Spoil deposits associated with push-pull ditches are considerably less than those of flotation canals but, as with flotation canals, have a potential for impact related to their configuration. For both flotation and push-pull canals, a double ditching technique can be used to ensure that the top soil is placed on top when the site is backfilled. This is intended to expedite revegetation and lessen the potential for detrimental impacts such as land loss due to erosion along the unvegetated ROW.

Field Investigations

The purpose of the geological investigations was to evaluate hypothetical impacts of representative OCS pipelines on barrier islands, barrier beaches, and coastal wetlands and to determine the effects on the morphology, stratigraphy, and active physical processes within these depositional systems. The studies were designed to objectively test for impacts which have been postulated by earlier investigators, document their magnitude, and develop predictions of impacts of future OCS activities.

The hydrologic studies were focused on discerning the impact of pipeline emplacement on hydrologic parameters characteristic of the site. Initial research into the available data base for selected sites necessitated that the study be confined to a search for alterations in circulation and drainage patterns. The field methodology used to quantify or describe impacts varied according to the study area.

The vegetative studies were designed to identify the extent of impact by quantifying differences in vegetation community structure and primary productivity between the pipeline ROW and control.

Texas Barrier Island System

The geologic studies of the T5 and T6 pipelines on Matagorda Peninsula, Texas indicate that their installation has had no observable impacts on the morphology, stratigraphy, or physical processes of this barrier island. No evidence of accelerated shoreline erosion was seen as evidenced by a stable and well-developed set of foredunes across both pipeline corridors, and by the comparatively similar character of the beach profiles established within the ROW and at the control stations. Pipeline installation has not changed the lithologic or textural character of the sediment within the corridors nor developed any morphological scar across the island, either of which could contribute to the formation of weak areas susceptible to storm overwash and breaching. The pipeline construction techniques of push-ditch and backfill were used and as a consequence, the T5 and T6 pipeline corridors will not accumulate any more sand from the barrier system other than natural washover processes. The longshore sediment transport system has not been altered and the pipeline corridors have not developed into sediment sinks. The pipeline corridors have not segmented the barrier island; therefore, island integrity has remained intact.

The pipeline ROW within the marsh areas north of the GIWW have been backfilled and subsequently topped with dredged material sediments and bulkheaded on either side of the GIWW. As a result, water flow patterns have not been altered and there is presently no evidence of erosion of the pipeline ROW at the GIWW crossing.

No significant hydrologic impacts exist on Matagorda Peninsula as a result of pipeline emplacement. A few small ponds 0.3 to 0.6 m deep remain within the ROW for T5 and T6 but they are in the vicinity of preexisting water bodies. The small (6 m wide), short canal that remains from T5 construction through the intertidal marsh shows no evidence of erosion on the backside of the peninsula.

Fathometer profiles across the T5 and T6 crossing of Matagorda Bay indicate that normal bottom topography has been restored for T5 and the northern segment of T6. Slight depressions and elevated spoil with submerged aquatic growth were noted in the T6 ROW in the middle and southern portion of the bay.

Vegetation along the T5 ROW is comparable to that along the control in both plant cover and productivity. In marsh areas, productivity for the control was measured on July 21-22, 1987 to be 822 g/m^2 compared to 939 g/m^2 for the T5 ROW. The barrier flat (backdune area) productivity varied from 275 g/m^2 for the control to 373 g/m^2 for the ROW. In contrast, the T6 pipeline ROW remained essentially bare, having insufficient vegetation even to measure. This slow rate of revegetation two years after emplacement contrasts with statements recorded in previous studies that ROW on barrier islands revegetate within two years of construction.

Strandplain-Chenier Plain System

Installation of the L23, L24, and L25 pipelines east of the Mermentau River, Gulf of Mexico Navigation Channel has had no observable impact on the morphology, stratigraphy, or physical processes of this barrier beach other than the creation of weak areas within the L23 and L24 flotation and push-point canal corridors. These weak areas are defined as a zone with sediments of a different lithologic and textural character than the surrounding area. However, because these corridors have been entirely filled in with fine-grained sediment near the beach, channelization and the development of new tidal passes is unlikely. The L25 pipeline corridor shows no development of a weak area because it was backfilled with material from the ditch and surrounding areas.

Installation of the three pipelines has not accelerated shoreline erosion. Beach profiles established along the pipeline ROW display a comparatively similar character to their control station counterparts with no evidence of the formation of escarpments. Moreover, no observable change in morphology occurs between the pipeline ROW and the control stations. The entire study area displays simple washover deposits fronting an extensive marsh.

The L23, L24, and L25 pipeline corridors show no evidence of being filled with sand or shells. Consequently, they have not acted as sand and shell sediment sinks. Washover sands are found to occur naturally along the beach face. There is no disruption in the longshore sediment transport system as a result of these pipeline emplacement techniques. All of these pipeline corridors have been filled in with silty clay and clay and demonstrate no development of new channels or tidal passes. There is no resulting destruction of shoreline integrity. The infilling process occurred gradually behind the dam constructed on the L23 flotation canal near the beach and rapidly for the L25 ditch which was backfilled. By the time the shoreline had eroded landward of the dam on L23, it was sufficiently filled by overwash and marsh drainage sediments so that the sand beach overrode the infilled materials in a process similar to that of the infilling of shallow lakes and ponds near the sea rim along the Strandplain-Chenier Plain coast.

Hydrologic studies of the L23, L24, and L25 pipeline reveals no long-term impacts of pipeline emplacement to the beach environment. Even though the canal-cuts through the marsh substrate for the flotation and push-point canals are visible at low tide, the channels have been filled (naturally near the beach for L23 and L24 and manually for the length of L25) so that no tidal channels have developed to erode the interior marsh. On June 8, 1987, salinity was measured at 10.2 ppt in the L23 canal (in the marsh interior near an inland bulkhead) and at 16 ppt in the L24 canal remaining between the beach and an interior bulkhead. Gulf salinity at that time was 12.8 ppt, thus indicating that these canals were not directly connected to the Gulf.

Bathymetric profiles taken along the three ROW and one control reveal that the nearshore zone in front of the pipelines is comparable in depth and slope to that of the control, and beyond 152 m the bottom topography is identical. Wave action and sediment transport appears to have smoothed out the spoil deposits and trench depressions, thus eliminating long-term disruption of these processes by pipeline emplacement.

Vegetation studies revealed that vegetation was exceedingly sparse on both the pipeline ROW and the controls because of the rapid shoreline retreat and sand overwash of the high salt marsh which retarded plant growth on the beach berms. The maximum plant cover of 18% was recorded for the L23 ROW. Productivity measures were not made because of the sparsity of vegetation.

The dominant vegetation on the L23, L24, and L25 spoil banks is marsh elder, which exists as a very short shrub. The infilled L23 canal is vegetated by smooth cordgrass behind the beach berm. This infilled marsh area is about 0.12 m lower than the adjacent sea rim marsh. The L25 ROW is dominated by marsh elder because spoil was mounded on top of the infilled push-pull ditch. Therefore, with the exception of spoil bank vegetation associated with pipeline emplacement, vegetation species cover and composition show no significant difference between the pipeline ROW and the rest of the beach-berm habitat for this area.

Mississippi Delta System

A detailed analysis of vibracore data for L86 was not performed because field investigation revealed that the ROW and control sites resulted from rapid deposition and reworking of dredged material in open water west of Belle Pass. At the time of deposition, the L86 pipeline was probably below the Gulf bottom, well below the new spoil.

Interpretation of the extent of impact of L87, constructed east of Belle Pass, Louisiana, using data from vibracores, is inconclusive. Lithologically and texturally, the sediments within the ROW and control cores are environmentally consistent without any major variation in composition or grain size. The difference in stratigraphy observed between the ROW and control sites may be a reflection of infilling of the push-point canal, the shallow push-pull ditch, or even a water body intercepted by the pipeline ROW. Air photo analysis suggests this pipeline ROW was a push-pull canal rather than a flotation canal which would present a smaller area for infilling. Visual observations of the beach and dune profile and vegetation in the ROW area revealed that this site was not noticeably different from that of the controls. In contrast, a beach profile of a flotation canal (possibly rig cut) west of L87 clearly showed a steep beach face, narrow dune area, and steep, unvegetated backslope into the canal, all indicative of a potential breaching site.

Vegetation studies of the L86 pipeline ROW and controls revealed that plant cover was patchy with no significant difference in cover or productivity. This is because both sites are new beach and berm created by reworked dredge material and have no relationship to pipeline emplacement.

In the vicinity of the L87 pipeline, the control site had 2% vegetation cover on the berm and 100% cover 60 m inland. The ROW of L87 was visually indistinguishable from the control. In contrast, vegetation cover on a rig-cut canal located west of L87 and being infilled had no vegetation on the berm or at a distance 60 m inland. Furthermore, no intertidal marsh had developed in the canal corridor behind the berm, as was the case for the L23 and L24 pipelines in the Mermentau area.

The Muskrat Line, installed on Grand Terre, Louisiana, is an open water flotation canal that has been bulkheaded on its eastern and western sides. Because of its shore-parallel orientation, the pipeline corridor does not affect the rate of erosion of the Gulf side shoreline, but does contribute to the erosional effects within the interior of the island. The lithologic and textural character of the sediments within the corridor varies from the rest of the natural stratigraphic framework, thus creating a weak area or an area of potential instability. Breaching, scouring, and channel widening could all result from storm activity and wave activity associated with the increasing tidal prisms; however, there is no evidence of breaching or scouring along the canal during the 33 years of its existence. The canal has widened from an estimated width of 20 m in 1955/56 to 31 m in 1983. This estimation is based on construction data and the size of another canal constructed on the island immediately prior to the Muskrat Line.

The pipeline corridor is acting as a local sediment sink, as evidenced by the accumulation of sand overwashed from the barrier shoreline. Infilling has been so complete on an eastern portion of the canal that salt marsh now grows in the former channel. As normal shoreline retreat continues, the distance between the shoreline and the pipeline corridor is decreased, allowing more sediment to wash into the canal. Once the island erodes across the pipeline corridor, however, the sediment will again enter into the longshore transport system. The pipeline corridor segments the island lengthwise and destroys island integrity. The shore-parallel orientation of the Muskrat Line causes more environmental impact than shore-normal orientations because of its greater lateral extent, greater land-water interface area, its function as a sediment trap or sink, and its introduction of the potential for more erosive processes within the interior of the island.

Field investigations of the hydrologic impacts of the three pipelines in this system revealed no major long-term impacts from pipeline emplacement. However, any impact the L86 pipeline flotation canal may have had was obscured by construction of a pipeline or rig-cut canal across the ROW near the beach, construction of a wing jetty east of Belle Pass, and deposition of dredged material west of the channel.

The L87 pipeline beach crossing was virtually indistinguishable from the rest of the natural beach in the area. This indicates that the push-pull ditch technique resulted in no hydrologic changes due to pipeline construction.

The Muskrat Line had the greatest potential for altering hydrology on the island because it was in a flotation canal with spoil banks. However, the east-west-trending spoil banks were comparable in orientation to the east-west trending natural beach ridges, and it appeared that drainage was maintained by east-west-flowing tidal streams north and south of the spoil banks. Therefore, the spoil banks did not appear to impound drainage for most of the site. A small area of impounded water did occur at a site located between the south bank of the Muskrat Line, the north spoil bank of an unknown pipeline, and the west ridge that had developed along a historic canal perpendicular to the Muskrat Line. However, the marsh at this site was firm and vegetated with smooth cordgrass. Where a western segment of the former canal was filled and vegetated by smooth cordgrass, a small, shallow, sinuous tidal channel had developed through the center of the former canal.

Because the Muskrat Line was bulkheaded at its intersection with Barataria Bay and at regular intervals through the island, tidal scour and bank erosion did not occur. At most, there was a 55% increase in canal width over the past 33 years with most of the eroded material probably being redeposited in the canal.

The spoil banks along the Muskrat Line canal had been burned at the time of the field investigation, but they exhibited evidence of typical spoil bank vegetation for this area. Sampling of marsh vegetation at 30- and 60-m intervals perpendicular to the canal showed no significant difference in cover or productivity, thus indicating that this canal emplacement has not affected, indirectly, the marsh vegetation. Spoil deposition and flotation canal contruction did destroy marsh along the ROW. However, a small portion of the open water canal has been restored to salt marsh through sediment deposition in the channel.

North Central Gulf Coast System

Installation of the M1 pipeline east of the Pearl River in Mississippi has had no observable impacts on the morphology, stratigraphy, or physical processes of this coastal wetland. The backfilled and revegetated pipeline corridor displays no evidence of increased shoreline erosion, channelization, or destruction of marshland integrity.

Installation of the M2 and M3 pipelines, in contrast, exhibit environmental impacts, although the geologic data do not provide conclusive results because the cores reflect the stratigraphy of the wetland into which the canals are eroding. Erosion along the canal banks of the M2 and M3 pipelines, because of current and wave action, is likely to lead to continued channel widening and destruction of the marsh once the spoil deposits have eroded. The M2 and M3 pipeline corridors remain as deep, open, flotation canals segmenting the marsh and former sinuous, east-west drainage channels.

Studies of pipeline impacts revealed that mitigation measures associated with M1 emplacement resulted in no hydrologic impacts. In contrast, the M2 and M3 flotation canals have created a straight, 1.8- to 2.1-m-deep and over 48-m-wide canal complex which cuts across the natural tidal channels and drainage divides paralleling Campbell Inside Bayou and Campbell Outside Bayou. These channels are considerably smaller (about 27 m wide and 0.6 m to 1.6 m deep) than the canal and have basically had their flow captured by the north-south trending canal which remains unblocked at waterway crossings. While the canal complex was originally dammed near Lake Borgne, flow is no longer stopped because an eroded channel has developed on the west side of the bulkhead. However, emplacement of the M2 and M3 canals with their continuous spoil banks does not appear to have resulted in marsh impoundment and vegetation destruction. The older M2 spoil bank is lower than the newer M3 spoil and contains hogcane but virtually no shrubs. Shrubs are more common in the M3 spoil, and bare patches of ground exist along the eastern slope of the M3 spoil. These areas probably result from rafting of marsh debris during storms which smothers existing marsh vegetation.

The only noticeable difference in vegetation resulting from M1 construction is that the ROW is slightly lower and less firm than the adjacent marsh and is vegetated by smooth cordgrass. The adjacent marsh is dominated by blackrush.

Comparison of Field Sites and Impacts

Matagorda Peninsula, in the Texas Barrier Island System, and Grand Terre, in the Mississippi Delta System, are both low-profile, wave-dominated, transgressive barrier islands. The variation in impacts observed between these two islands is a function of the method of pipeline installation, orientation of the pipeline corridor, and sediment supply available to the transport system. At Matagorda Peninsula, the pipeline corridor was oriented in a shore-normal direction and backfilled. These measures have resulted in no impact to the morphology, stratigraphy, or physical processes of the island. Furthermore, sediment within the island system is composed almost entirely of sand. The volume of sand available within the system will naturally mitigate any impacts which could possibly occur.

Grand Terre, on the other hand, has a flotation canal which is oriented in a shore-parallel direction. The greater lateral extent of the pipeline and the large areal extent of the land-water interface contribute to the erosional processes within and along the barrier island. While it is evident that the pipeline corridor does impact the island, the significance of the impact must be qualified. Phrases such as "significantly accelerated erosion," "seriously damaged," or "exacerbate the situation" are commonly used to describe pipeline impacts on barrier islands such as Grand Terre. These statements are more suggestive than factual, however, and tend to magnify the impacts disproportionately in relation to naturally occurring physical processes. Erosion of Grand Terre is, fundamentally, a result of natural current and wave action and an increase in tidal prism of the adjacent tidal inlets. Widening of these tidal inlets is the dominant factor affecting erosion and sediment loss of this island. Most of the sediment is lost to the growing ebb-tidal delta, which acts as the most significant sediment sink. The Muskrat Line has functioned over the past 33 years as a sediment trap, retaining sand within the island which might otherwise be lost to the tidal inlet.

The Mermentau River area of the Strandplain-Chenier Plain System and the Belle Pass area of the Mississippi Delta System are both low-profile, wave-dominated, barrier beaches. The Belle Pass area is a transgressive shoreline. The Mermentau River area, which originally formed through regressive processes, is currently experiencing erosion. The L23 and L24 pipeline corridors across the Mermentau Beach exhibit no impact other than the creation of a weak area or cut through the marsh substrate. However, fine-grained-sediment (silty clay and clay) infilling of the corridors and overtopping by overwash and aeolian sand deposits has decreased the likelihood of any potential for accelerated erosion or channelization along these cuts.

The pipeline (L87) east of Belle Pass was also infilled and there has been no breaching of the shore or accelerated erosion along this corridor. Ritchie and Penland (1985) have documented an average shoreline retreat along the central deltaic headland of the Caminada-Moreau coastline to be 15 to 20 m/yr. Despite this enormous rate of erosion along miles of shoreline, none of the pipelines (L85-L95) in this area have washed out or resulted in permanent breaches of the beach. The steep beach profile of a naturally plugged flotation canal, as evidenced by an infilling canal west of L87, suggests that these sites are weak points in the beach-dune complex, which would have the potential to breach first during a high erosion period such as a hurricane, or when the sediment supply is disrupted.

The Pearl River area in the North Central Gulf Coast System and the marsh areas behind Matagorda Peninsula, Texas are the two wetland areas investigated in this study. The pipeline corridors at the Matagorda site are backfilled and overtopped with dredge material at the GIWW. The GIWW crossing was stablized with a riprap-armoured bulkhead. No visible impacts were revealed by analysis of core data or field observations.

In contrast to the barrier islands and barrier beaches, the wetlands east of the Pearl River have a greater potential for damage and destruction because they do not have a sandy shoreline or well-consolidated sediments to help combat erosive activities. Of the three pipelines examined at Pearl River, only the backfilled, push-pull ditch (M1) had no observable geologic impacts. The other two pipelines (M2 and M3) are in flotation canals which exhibit notable impacts. These canals segment the wetlands, altering their physiographic integrity. The channelized area is the site of spoil bank erosion, which will eventually destroy the marshland after the spoil banks are removed.

Air Photo Analysis

Texas Barrier Island System

Of the 10 OCS pipelines crossing the Texas Barrier Island System between 1965 and 1985, all were constructed across wetlands and barrier islands using the push-pull ditch with backfilling technique. No evidence of the beach crossing exists, either because the push-point site was originally backfilled and recontoured or filled in naturally. Subsequent to construction, there has been no accelerated erosion or breaching of the barrier island or beach at the ROW crossing.

The backfilled ditches across the intertidal saline marshes and inland brackish-to-saline marshes have revegetated to the extent that the ROW are difficult or impossible to discern in their entirety. Eyewitness accounts and several studies indicate that these areas revegetate in about two years. There was no evidence of erosion of the backfilled areas on the mainland wetlands of the backside of the barrier islands. Also there is evidence that grassbeds become reestablished if the ROW canal is backfilled.

The ROW across high, salt marsh/flat habitats on the backside of the barrier islands which receive irregular flooding and are normally sparsely vegetated, are slower to revegetate than the lower marshes and ROW scars remain visible in these areas for an extended period of time.

Strandplain-Chenier Plain System

Of the 55 OCS pipelines crossing barrier beaches along the Strandplain-Chenier Plain System, six are located in Texas. Only 11 (20%) of these lines were placed using flotation canals, which were dammed near the beach. All of these flotation canals were located in the Louisiana portion of the system, east of the Mermentau River, Gulf of Mexico Navigation Channel.

Approximately 34% of these lines had erosion rates at the beach crossing ROW greater than that calculated for one or both of the control sites. However, these erosion rates were less than 10% greater, indicating that accelerated erosion rates are not a major impact at the beach crossing. Most of these slightly higher erosion rates were in the eastern portion of the Louisiana Chenier Plain where sand beaches are extremely thin and narrow.

There is evidence that a number of these pipelines have been lowered at least once since emplacement because they became exposed in the surf as the beach eroded. Some bulkheads in the eastern portion of the Chenier Plain of Louisiana have had to be replaced to maintain the isolation of the flotation canal. In other areas, shoreline erosion has placed the bulkhead in the Gulf, but a new bulkhead was not built because sediment plugged the canal near the beach and a continuous sand/shell beach formed over the mouth of the canal, thereby removing the danger of erosion along the flotation canal.

Observations of saline-to-brackish wetland crossings in the Texas portion of the system and within a few kilometers of the beach in Louisiana indicate that the push-pull ditches have tended to revegetate through time, especially along backfilled lines. Washover sediments have also filled the flotation canals near the Gulf and in some instances these filled canals have become vegetated by saline marshes. The canals in the eastern portion of the Louisiana Chenier Plain have been slower to fill and do not have sand and shell beaches as wide as those in the western portion of the system, thus necessitating reconstruction of bulkheads near the beach. The few canals where the bulkheads were constructed inland at the chenier ridge line have not had to have replacement bulkheads because shoreline erosion has not reached the ridges.

Mississippi Delta System

Only 41 pipelines or 43% of the 95 OCS pipelines making landfall in the Mississippi Delta System cross barrier islands or beaches. Three of these lines were originally constructed through tidal passes and/or are breaks between the islands in the Isles Dernieres Complex. Two lines were laid west of Western Isles Dernieres and two were laid in the tidal passes between Isles Dernieres and Timbalier Island. This barrier island complex has experienced major changes in size and position, but none of these changes appear to be related to OCS pipeline construction since the lines were not installed across the island, but in wide tidal passes.

Twelve OCS pipelines land on the Timbalier-East Timbalier Island Complex. No data, other than verification of line location, was obtained from the pipeline operators. However, it does appear that these lines may have been installed using a push-pull technique because of the short distance between the shoreline and the onshore facilities. The numerous other petroleum-related activities, including rig cuts and revetment construction and maintenance, have obscured and confused the location of these lines, thus making it difficult to substantiate any statements regarding direct or indirect impacts of these specific pipelines.

Ten OCS pipelines cross the beach in the vicinity of Belle Pass and Pass Fourchon. Four are known to have been placed in flotation canals and the remainder appear to have been installed using a push-pull ditch and backfilling technique. One flotation canal (L85) has plugged naturally at the beach and another (L86) has had a wing jetty from Belle Pass constructed across its ROW. The third flotation canal contains two lines (L89 and L90) but the nearshore portion of the ROW has been filled as part of a beach nourishment-stabilization program. This program has obscured the landing site of six other lines in the area. The remaining OCS line (L87) west of the beach nourishment project shows no sign of accelerated shoreline erosion or breaching at the ROW crossing.

Eight OCS pipelines land on Eastern Grand Isle and all but one (L100 which was directionally drilled) were installed in a push-pull type ditch and/or upland trench that was backfilled. The ROW crossing on Grand Isle is not discernible except where the vegetation is mowed to keep the ROW free of invading shrubs and trees. There is no evidence of accelerated erosion or breaching at the beach crossings.

Nine OCS pipelines cross the barrier islands or beaches on the western side of the Mississippi River Delta. Five lines appear to have been installed in flotation canals and four in a push-pull ditch.

The beach crossing for all but one (L107) of these pipelines has become plugged with sediment and a thin, narrow beach covers the mouth of the former canal. In the vicinity of the L107 crossing for Shell Island, the island has breached and a tidal pass now exists. This is the only instance along the Gulf Coast where an OCS pipeline has been in the vicinity of a pass which formed after pipeline construction. However, the major factors contributing to this island breaching are the disruption of the littoral transport of sediment by the Empire Waterway jetties. This lack of sediment contributed to the narrowing of the island which made it susceptible to breaching and prevents the closure of the breach which would have occurred in a sediment-rich environment.

The two pipelines (L143 and L144) across the Chandeleur Islands presented an excellent opportunity for creation and enlargement of a tidal pass along their ROW because they were placed in a flotation canal that was not backfilled or dammed and they are on a narrow strip of land experiencing shoreline retreat. However, these cuts have become sealed and a beach overlies their shore crossing. The canals have widened on the backside of the island and remain deeper than the surrounding substrate. The bottoms of the canals appear to be unvegetated and at least one canal bottom has been disturbed twice because the line (L144) had to be reburied.

North Central Gulf Coast System

Only two (M5 and M6) of the 11 lines studied in the North Central Gulf Coast System originate in Federal lease blocks. They, along with M4, were installed in a backfilled push-pull ditch across a saline marsh east of Pascagoula, Mississippi. The ROW crossing is revegetated and neither the wetland nor shore crossings show signs of erosion. The M1 line is also in a backfilled push-pull ditch which has revegetated. This ROW shows no signs of erosion but the substrate is less firm than the surrounding marsh. Furthermore, the ROW appears to be slightly lower and vegetated by smooth cordgrass rather than blackrush, which dominates the surrounding marsh.

Five of the lines (A1-A5) in this system were bundled together and pulled through two bore holes drilled from the upland landing site into the offshore waters of Mobile Bay. These lines have had no impact on the shore crossing.

The M2 and M3 pipelines have had the most impact in this system because they directly altered the largest amount of habitat by converting saline marsh to canals and spoil banks. The lines are in flotation canals which are continuing to widen, thus resulting indirectly in further habitat alteration. The preexisting drainage system has been altered by the replacement of sinuous, shallow, east-west streams with a deep, straight, north-south canal. The one concrete bulkhead constructed across the canals near the Gulf is experiencing erosion around the western side.

Conclusions Regarding Pipeline Impacts

Of 164 Federal OCS pipelines constructed between 1950 and 1986, 70% cross barrier island complexes (including major tidal passes through island complex segments) or beaches and 30% land along marshy shorelines. The percentage of lines by coastal system are: 57% for Mississippi Delta, 34% for Strandplain-Chenier Plain, 6% for Texas Barrier Islands, and 3% for North Central Gulf Coast. Gas was carried in 65% of the lines and 77% of the lines are 20 in or less in diameter. Only one line is 42 in.

Grouping of pipelines by construction technique at the shore or island crossing is as follows: push-pull ditch (69), flotation canal (24), undetermined (15), buried in tidal pass (5), directional drilled (1). Almost all of the undetermined lines are in the Mississippi Delta System where erosion of shore or marsh interior has obscured the construction signature and collateral data on construction technique were unobtainable. The majority of push-pull ditches (43) are located in the Strandplain-Chenier Plain System. Where collateral data was unavailable, it was often difficult to discern whether the push-pull ditch had been backfilled originally or closed naturally due to siltation and revegetation.

Pipelines can be emplaced using a variety of techniques which, with incorporation of mitigation measures, can influence the extent of impact to the environment. The two major emplacement techniques used historically in wetland environments are the flotation canal and push-pull ditch. The standard flotation canal is designed to have a bottom width of 12 to 15 m and be 1.8 to 3.0 m deep. The push-pull ditch is considerably smaller, ranging in width from 2.4 to 3.0 m and having a depth of 1.2 to 2.4 m. The directional drill technique, first used on a Texas barrier island in the early 1980's, does not impact the environment along the ROW through which drilling occurs. This technique may be required more in the future for crossing short, sensitive habitats, such as barrier islands, beaches, or steep, eroding shorelines.

The extent of direct and indirect environmental impact of a flotation canal is influenced by whether the canal is left open or backfilled and/or whether it is dammed at all tidal water body crossings. The extent of impact is also influenced by environmental factors such as coastal system location, habitat type and condition (eroding, stable or prograding barrier islands and beaches; isolated, low energy, interior fresh marsh; or saline marsh on firm substrate), and sediment availability. Furthermore, spoil deposition will have variable impacts depending upon the environmental forms and processes active at the disposal site and the configuration of the deposit (i.e., continuous on one or both sides of the canal with no breaks; discontinuous on one or both sides of the canal with breaks 15 m wide every 152 m; 152-m long spoil banks alternating on both sides of the canal; or removal of spoil by dragline for backfilling or creation of new marsh habitat) with respect to hydrologic regime.

The extent of impact from the push-pull ditch technique also is influenced by whether the ditch is backfilled and/or dammed. However, the long-term success of backfilling is related to various factors such as substrate composition, marsh type and condition, and quality of the backfill operation. Spoil deposits associated with push-pull ditches are considerably smaller than those of flotation canals, but as with flotation canals, have a potential for impact related to their configuration. Smaller spoil deposits directly smother less marsh initially. However, spoil deposits can impound water when they block surface flow, thus killing brackish-to-saline marsh vegetation. For both flotation and push-pull canals, a double ditching technique can be used to ensure that the top soil is placed on top when the canal is backfilled. This is intended to expedite revegetation and lessen the potential for detrimental impacts such as land loss due to erosion along the unvegetated ROW.

Analysis of air photos and field investigations of selected OCS lines reveal that mitigative measures, when adjusted to environmental processes, can significantly lessen or eliminate long-term environmental impact in most coastal systems. Within the Texas Barrier Island System, this study found that the direct and indirect impacts of the 10 OCS pipelines were virtually nil. This is a result of several fortuitous circumstances which include: mitigative construction techniques (backfilling of ROW) across barrier islands and wetlands, environmentally sensitive ROW alignments (generally, avoidance or selection of shortest wetland crossing), a barrier island system with adequate sediment in transport, and a relatively stable and firm saline-to-brackish marsh along ROW.

Based on data from pipeline companies and interpretation of air photos, it appears that all pipelines in this area were emplaced in a push-pull ditch and/or trench across barrier islands and mainland wetlands, and that these sites were immediately backfilled to preconstruction contours; bulkheaded where necessary; and in several instances, replanted. The literature and permit data indicate that a number of these lines were intentionally routed, often at the urging of regulatory agencies, to avoid sensitive habitats and to cross as minimum an area of wetland as necessary. This is easier to do in South Texas and the North Central Gulf Coast System than in the Strandplain-Chenier Plain and Mississippi Delta Systems because these systems have uplands near the back bay and sound areas with little or no fringing wetlands.

The abundance of sand in transport along the Texas Barrier Island System quickly covered the flotation push-point canals and nearshore trenches dredged during the construction phase. This, plus the fact that the backfilled trenches across the barrier islands were comparable in sediment composition to adjacent areas, eliminated the formation of a weak zone that would be more susceptible to erosion than the adjacent beach areas. The firm, stable, coarser materials of the barrier islands and most of the wetlands crossed by these 10 lines were suitable for backfilling and recontouring. This condition avoided creation of a sunken or irregular topography along the ROW, which is more susceptible to flooding, or formation of tidal channels, both of which prevent reestablishment of emergent vegetation. The ability to backfill successfully a pipeline ROW removes the potential for: (1) saltwater intrusion via an open-water canal into interior, freshwater wetlands, (2) erosion along a ROW embryonic tidal channel, (3) alteration of natural physiographic forms and processes, (4) creation of a weak zone susceptible to future breaching, and (5) formation of a sediment sink which would remove material from the littoral system.

The rate of revegetation is commonly stated in the literature to be two years. This was the case on some lines studied, especially within more humid areas of the northernmost Texas coast. However, on dunes and barrier flats in more arid areas, revegetation success appears to require enhancement by sprigging in biodegradable mats, fertilizing, watering, and protecting the site from grazing and traffic until the vegetation is established. Field observations of one line approximately two years old revealed that evidence of revegetation was barely discernible at the ROW on the irregularly flooded marsh and barrier flats. However, this phenomenon of sparse vegetation is a common feature of the zone located between the vegetated dunes and intertidal bayside marsh. Analysis of air photos revealed no dune blowouts resulting from the placement of pipelines across barrier islands.

The reestablishment of seagrass beds was documented on the slightly elevated subaerial spoil left from the trenching of one of the field-sampled pipelines across Matagorda Bay. A review of the air photos also indicated that submerged grassbeds have spread over the backfilled trench on the backside of barrier islands for some other lines. However, more field investigations and documentation of other factors in the area which affect seagrass distribution would be needed to determine the extent of pipeline impacts on seagrass beds.

There were 55 OCS pipelines identified as crossing a barrier beach within the Strandplain of eastern Texas and the Chenier Plain of western Louisiana. Most of these lines (80%) appear to be installed using a push-pull ditch. Of the 11 lines placed in flotation canals, there were three instances of lines sharing the same canal, despite their being emplaced at various dates. These lines, each set within a ROW belonging to the same company, were all in the eastern portion of the Chenier plain where the sand-shell beach is very thin, narrow, and patchy-to-nonexistent. These flotation canals were bulkheaded inland from the shore often at chenier ridge crossings, where present.

The ROW crossings of flotation canals, and in a few instances the push-point canals for the push-pull ditches, evidenced a slightly higher rate of shore retreat than control points. The westernmost flotation canals in this system were plugged with finer-grained clay and silty clay and overtopped by a sand-shell beach comparable in width and thickness to that of the surrounding beach. The easternmost flotation canals were in an area having minimal sand or shell and therefore were not plugged by a sand-shell beach. However, analysis of air photos indicates that several of the bulkheaded canals south of Cheniere au Tigre are being filled with what appears to be fine-grained clays and organic bits (coffee grinds), probably from the Atchafalaya Delta. Because these eastern canals are not sealed with a sand beach, bulkheads have had to be rebuilt each time the shoreline retreats inland of the dam. In contrast, the sand-shell, beach-sealed canals to the west have not had their bulkheads replaced once the shoreline migrates inland of the dune. Furthermore, field studies and air photo analysis revealed that these bulkheaded flotation canals had actually filled for considerable distances inland (commonly to the inland limit of the high sea rim marsh zone) as a result of beach overwash. Several of these infilled canals contained saltmarsh vegetation for a couple of hundred meters behind the beach.

All of these flotation canals had continuous spoil banks (for those areas observed near the Gulf) and most had bulkheads at regular intervals along the canal and at water-body crossings. Field investigations revealed that one flotation canal had culverts within the spoil to facilitate drainage, but at the time of the visit, the canal had silted to the top of the culverts located nearest the beach. The continuous spoil banks with culverts may be a landowner requirement that facilitated the north-south movement of cattle across grazing wetlands while preventing impoundment of surface waters by the spoil.

The potential for direct and indirect impacts related to flotation canals crossing barrier beaches has been mitigated because the canals have remained isolated from tidal movement by maintenance of bulkheads or natural formation of beach over the cut. Therefore, widening of the canal segments located between the beach and the first bulkhead has been minimal or reversed. There is no tidal flow through the canal to cause scouring, bank erosion, or saltwater intrusion through the beach crossing. Natural nearshore processes have established the beach-berm complex in most instances so the pipeline emplacement did not permanently alter this physiographic form. However, the canal cut through the marsh substrate remains, even though presently being filled by fine-grained clay and silty clay as the shoreline retreats inland. This filled canal corridor differs from the surrounding area and has the potential for more rapid erosion should the sediment supply be reduced or removed.

These canal corridors and, to a lesser extent, the push-pull ditch corridors, across the beach are functioning as a sediment sink, but only for short segments, because all of these lines are perpendicular rather than parallel to shore. These sediment sink areas appear minimal compared to the numerous ponds and lakes that are being infilled as the shore retreats inland along the Strandplain-Chenier Plain System.

The nonbackfilled, push-pull ditches observed near the shore are experiencing the same siltation processes as the flotation canals. However, because they were originally less than 10% the size of a flotation canal, their potential for impact as a result of saltwater intrusion, erosion along the ditch interface, breaching of the shore, alteration of natural physiographic forms and processes, and function as a sediment sink is minimal.

Field and air photo observations revealed no visible impact of these push-pull ditches at the beach, except where the push-point canal is still visible. Even though pipelines are periodically exposed in the surf as the shore retreats into the zone where the line is only about 0.3 m below the marsh, this study uncovered no evidence of accelerated erosion along the pipeline corridor at the beach. Failure to sufficiently bury the pipeline originally leads to periodic habitat disturbance over the lifetime of the line because of the need to lower the line.

Within the Mississippi Delta System, impacts were researched for only those OCS lines (41 pipelines or 43% of the total number of lines) that crossed barrier islands or beaches. Surprisingly, most of these lines (30 lines) came ashore at three locations (East Timbalier Island [12 lines], Belle Pass-to-Pass Fourchon [10 lines] and Grand Isle [8 lines]). These sites contain separator facilities, terminals, and processing facilities, respectively, which serve some of these 30 lines. Five OCS lines in the western portion of this barrier island system appeared to have been installed originally in tidal passes between the islands. Nine pipelines crossed beaches on the west side of the Mississippi River Delta and also made landfall in groups: four near Pass Chaland, four west of the Empire Navigation Channel, and one across Shell Island. East of the Mississippi River, only two OCS lines crossed the Chandeleur Island complex.

These lines were identified as OCS lines because, by the time of this study, they were connected to a platform in an OCS lease block and/or were verified as being OCS by their operator. All of these lines crossed the beach at basically a perpendicular angle. One line parallel to the beach was studied using both photographic and field methodologies in order to document impacts. When constructed this line was a non-OCS line. However, no attempt was made to evaluate the impact, either singularly or cumulatively, of several other pipelines which parallel the shore between the West Delta and East Timbalier Island. This is because, primarily, these lines appeared to have been constructed many years ago to carry petroleum products from wells located in the lower delta or state waters. More research needs to be done to document their original status (OCS or non-OCS) and significance of their impact with regard to other processes operative in the Barataria Basin and Bastian Bay area. Continued widening and deepening of tidal passes and erosion of barrier islands and marshes will expose these shore parallel lines, as well as interior marsh/bay lines, to boat traffic and fishing operations without constant vigilance to ensure that they remain buried.

It was impossible to evaluate construction techniques in relation to impacts for most of the lines in the Mississippi Delta System for several reasons: the construction data were not available from the operator or owner; the lines were old and shore processes, as well as human activities, had obscured their construction signature on the beach or across the island; the extension of the line into interior marshlands was poorly delineated on existing maps and air photos; or there had been so much erosion of interior marshes that the construction type signature was obliterated or indistinguishable.

Air photo analysis indicated that the flotation canals continued to widen in the marsh inland of the beach. However, all but one of the pipeline crossings (i.e., the Shell Island crossing) were plugged at or near the shoreline by natural beach formation processes or bulkheads. It appears that as long as there is sufficient sediment being transported alongshore, the flotation canals and push-pull ditches are filled with fine-grained clay and silty clay and overtopped by sand and shell material. Where a barrier island or beach segment is narrow and sediment supply is decreased, as was the case when the Empire jetties were constructed and extended, the beach narrows and breaches.

Further evidence of the importance of a sufficient sediment supply in offsetting the impact of dredging flotation canal across a barrier island is present in the case of two flotation canals crossing the Chandeleur Islands. Despite high erosion rates, numerous hurricane assaults, and the apparent failure to mitigate (i.e., bulkhead and backfill) these canals when originally dredged, there has been no breaching of the island or formation of a deep, tidal channel at the pipeline crossings. Littorally transported and overwash sediments have closed the canal cuts through the beach-berm complex and most of the back-bay marsh. However, one line has had to be lowered at least twice on the sound side, thereby exposing a deeper channel visible on air photos.

In general, the potential for future breaching of the shoreline in the Mississippi Delta System remains at the site of the flotation canal crossings because the width of beach infilling is small; the sediments beneath the sand-shell beach plug are unconsolidated and susceptible to erosion; and, in most cases, the width of the beach and interior marshland behind the beach is diminishing because of Gulf and bay erosion. Pipeline crossings perpendicular to the shore do not appear to have permanently altered the beach-dune complex, although this habitat is narrower at the flotation canal sites than along natural shorelines in the area. However, high spoil banks show a tendency to trap overwash sediment on the updrift side and to impound water where two spoil banks are close together and intersect minor beach ridges.

The one shore-parallel pipeline that was studied revealed that the bulkheaded canal segments had trapped overwash sediments and material eroding from the spoil banks. One segment had become elevated to the point that it was colonized by saltmarsh vegetation. The bulkheads prevented tidal scour and major erosion of the banks within the island interior. The spoil banks did not appear to have impacted wetland drainage to the extent that vegetation was destroyed by impoundment.

Only two of the eleven pipelines studied in the North Central Gulf Coast System originated in OCS waters. These two lines were installed across a stable, narrow (relative to the Louisiana delta marsh), salt marsh and backfilled. Air photo analysis and field inspection from the upland site where the lines terminated at the Chevron Refinery in Pascagoula revealed that the ROW for these lines was not visible. A non-OCS line running parallel to these lines was also camouflaged by marsh vegetation, thus indicating that these three lines were installed in such a manner as to avoid permanent impact to the wetlands. Interpretation of aerial photographs indicated that no erosion was occurring at the shoreline crossing.

Another non-OCS line in a backfilled push-pull ditch showed no indication of major erosion at the shore and water body crossing or in the interior saline to brackish wetlands. Field investigations documented that the ROW was revegetated, though lower in elevation and different in species composition than the adjacent marsh.

The five non-OCS pipelines studied in Alabama were installed using a directional drilling technique. Field inspection showed no evidence of the line at the landfall site on the shore and bluff. This was expected because the drill hole was placed inland from the shore.

The remaining two OCS lines were in flotation canals and evidenced significant impact, although not as extensive as for similar flotation canals dredged through marshes in the Mississippi Delta System. The emplacement of these two pipelines has resulted in the replacement of the shallow, sinuous, natural, east-west tidal drainage system by a straight, deeper, wider north-south flow pattern. The damming function of the bulkhead near the shore crossing is negated by erosion around its western side. Unless repaired, this break will enlarge and increase tidal flushing via the flotation canal. These two flotation canals now function as one major canal because the spoil bank between them has eroded.

Saltwater intrusion has not affected the interior marshland cut by the canal complex because the area was originally a saline-to-brackish marsh. The marsh, as a physiographic form with a roughly east-west grain (along the tidal channels of Campbell Inside Bayou and Campbell Outside Bayou and the relict beach ridges such as Campbell Island), has been altered by the dredging of the canals and deposition of spoil, and former marsh continues to be lost as the canal banks erode. However, it appears that the natural, remaining drainage network is sufficient so that spoil deposits have not impounded overland flow to the point that marsh vegetation has been destroyed by elevated water levels.

Summary of OCS Navigation Channel Impacts

The potential for navigation canal impact is great because of the large size (i.e., length, width, and depth), the need to keep the channel open to navigation, and the frequent need to redredge the channel and dispose of dredged material. Navigation canals range from 2.7 to 14.3 m deep and 24.3 to 243.8 m wide (bottom width). The channel may be revetted along the banks and may have jetties at its mouth. Initial and subsequent maintenance dredge material deposition may be (1) adjacent to the channel, (2) within subaerial or subaqueous contained or uncontained areas, (3) in designated disposal sites in deep, offshore waters, or (4) in contained upland disposal sites. Often this maintenance dredging results from erosion of unrevetted canal banks which contributes indirectly to continuing land loss and habitat change.

This study of navigation channel impacts focused on the geomorphological changes discernible after channel construction. Analysis of historic aerial photographs and maps, as well as the literature on construction and maintenance, provided the major source of data. Three channels (Mermentau, Belle Pass, and Gulfport) were visited, and limited bathymetric profiles were taken at the first two sites. However, these data were mainly used to corroborate the literature and air photo analysis.

Eleven OCS navigation channels were identified in the Gulf coast area: Matagorda Ship Channel, Texas; Mermentau River, Gulf of Mexico Navigation Channel, Bayous Chene-Black-Boeuf, Freshwater Bayou, Houma Navigation Canal, and Belle Pass, Louisiana; and Gulfport Harbor, Mississippi. Of these channels, the Matagorda, Mermentau, and Belle Pass channels were selected for analysis of impacts based on air photo studies, literature research, and field inspection of the latter two sites.

All three navigation channels have had a direct impact on the habitat crossed. They continue to have impacts because of their form, especially long jetties, and the need for maintenance dredging and dredged material disposal.

Dredging of the Matagorda Ship Channel eliminated the need for maintenance dredging of Pass Cavallo, the former, natural navigation channel. This channel has shoaled and narrowed as a result of spit extension from Matagorda Island (on the west) and Matagorda Peninsula (on the east). There has been no widening of the ship channel because the substrate is consolidated and supports riprap along the banks to prevent erosion. Confinement of the channel has resulted in scouring to 17.4 m in places, which exceeds the authorized depth. While the peninsula continues to migrate landward, entrapment of littoral sediment updrift of the north jetty has resulted in island widening north of this jetty. This enlargement has accelerated shore retreat downdrift of the jetty.

Spoil deposited from dredging of the channels in the bay has resulted in formation of a small island northwest of the channel. Deposition of spoil on the peninsula within contained areas adjacent to the channel has elevated the site and altered the vegetation.

In contrast to the Matagorda Ship Channel, the Mermentau River, Gulf of Mexico Channel was dredged through less consolidated marsh deposits which do not support riprap. Failure to establish bank protection measures has resulted in the channel widening at a rate of 5.5 m/yr between 1978 and 1985, at which time the channel was 160 m wide. This erosion is cutting into the spoil retainment areas and maintenance ROW parallel to the channel.

Erosion downdrift of the jetties has accelerated from a pre-canal rate of 8.5 m/yr to a post-canal rate of 10.6 m/yr. Shoreline retreat has necessitated the extension of the west jetty to the shore as recently as 1987. The east jetty was also extended shoreward because of scouring of the channel banks north of the jetty. Updrift, the erosion rate has decelerated from a rate of 10.9 m/yr pre-canal to 3.7 m/yr post-canal. A new beach developed updrift of the jetty at a rate of 0.4 ha/yr since 1968.

The natural Mermentau River pass had completely closed by 1984 because it is no longer dredged and river flow is now channelized through the maintained ship channel. Dredging through Lower Mud Lake and deposition of spoil in the lake every 2 to 2.5 years is filling this water body and appears also to be filling Hog Bayou, which connects to the eastern end of the lake.

The Belle Pass Navigation Channel differs from the Matagorda and Mermentau channels in that it resulted from widening and deepening of an existing channel, i.e., the west pass of Bayou Lafourche. The channel averaged 329 m in width in 1985 in contrast to its size of 43 m in 1934, shortly after its first enlargement. Jetties have been extended in recent years to a length of about 914 m in response to shoreline retreat, as well as the need to extend the channel farther into the Gulf to retard the rate of shoaling.

Historically, shoreline erosion was greater west of the pass but the retreat was regular enough to result in a relatively straight shoreline. This trend had been magnified by jetty construction in recent years. Between 1934 and 1974, shoreline loss west of the jetty was 21 m/yr, compared to 14 m/yr east of the jetty. This resulted in the shoreline west of the jetty being offset and placed inland of the eastern shoreline. Deposition of dredged material west of the jetty prior to 1985 resulted in a diminishment of shoreline retreat (11 m/yr between 1974 and 1985) immediately west of the jetty, while east of the jetty the loss was 13 m/yr.

Conclusions Regarding Impacts of Navigation Channels

Studies of three of the 11 OCS navigation channels reveal that these channels have impacted the physiography of the nearshore environment, primarily because of the presence of jetties. These jetties trap sediment and create beach on the updrift side while accelerating erosion of the shoreline on the downdrift side.

Erosion of channel banks is substantial where the crossing consist of unconsolidated materials less suitable for supporting riprap, as is the case along the Mermentau River Navigation Channel. Bank erosion does not appear to be a problem at the Matagorda Ship Channel crossing because the channel is revetted with riprap that continues offshore in the form of jetties. This has prevented the washing out of the beach at the point where the jetties touch shore. In contrast, the sides of the Mermentau River are not stabilized and scouring has occurred at the northern end of the jetties, which requires periodic filling of the scour site and extension of the jetties inland. Erosion also occurred on the downdrift side of the Belle Pass jetty-beach contact, necessitating installation of a west-wing jetty. Deposition of maintenance material on the downdrift side of the jetties in front of the wing has created, temporarily, a beach in front of the wing jetty.

In the case of both the Matagorda Ship Channel and the Mermentau River Channel, dredging of a new ship channel and cessation of maintenance of the former channel through a natural pass or river mouth has resulted in these natural passes shoaling (at Matagorda) or completely filling with beach material (at Mermentau).

The original channel dredging (at Mermentau and Matagorda) or enlargement of the natural channel (at Belle Pass) generated an enormous amount of spoil, which was deposited in retainment areas adjacent to the channel. The material at Belle Pass is being eroded on the seaward end but remains as a high, shrub-vegetated spoil bank along the channel. The spoil material at Matagorda remains elevated, vegetated, and in the original deposit formation. The spoil at Mermentau is being eroded rapidly as the ship channel widens.

The material from maintenance dredging at the mouths of the Matagorda and Mermentau channels is deposited in deeper offshore waters and is thus being lost, in all probability, to the nearshore system. Maintenance dredging of the Mermentau channel through Lower Mud Lake results in material being deposited on the shallow lake bottom, thereby silting this water body. There appears to be no attempt yet to place this material in such a manner as to accelerate the creation of wetlands to offset the wetlands lost to original channel dredging or present channel erosion processes.

Maintenance dredging at Belle Pass has been used to create a beach on the downdrift side of the jetty and to nourish the beach updrift of the pass in front of an oil terminal. Future plans for the use of this maintenance dredged material is not known.

In general, it appears that construction and maintenance of the navigation channels studied has focused primarily on the engineering aspects of the channel. The monitoring of the ongoing effects of these channels, with the exception of nearshore profiles for the Matagorda Ship Channel, appears to be limited or nonexistent. Furthermore, the beneficial use of maintenance dredge material does not appear to be incorporated into the long-term operation of these channels.

Summary of Impacts of OCS-related Facilities

An obvious direct impact of OCS facility siting in the coastal region is the filling of wetlands for site preparation and facility construction. Wetlands may be indirectly lost as a result of impoundment of surface drainage, discharge of contaminants, and expansion of development associated with OCS facilities.

Analysis of aerial photographs in reference to a listing of OCS-related facilities revealed that these facilities (i.e., oil storage; gas processing and treating plants; oil refineries; compressor, pumping, metering stations; terminals; oil and gas-related shipyards; pipe storage yards; platform fabrication sites; service base and dock facilities; and helicopter service) are not constructed on barrier beaches. Furthermore, there are few OCS-related facilities on barrier islands and these are generally constructed behind the foredunes adjacent to major roads or other commercial-industrial developments on the bayside of the islands. Three islands in the Texas Barrier System have facilities. Galveston Island supports two oil terminals; a gas-processing plant; at least one compressor, pump, and metering station; and helicopter services on the eastern portion of the island.

Matagorda Island has several small groups of oil storage tanks, as does Mustang Island. Additionally, Mustang Island has an oil terminal. North Padre Island contains a gas processing plant, helicopter services, and a small group of oil tanks. These facilities comprise a very small percentage of the total island area.

The only barrier islands with facilities in the Mississippi Delta System are Grand Terre, Grand Isle, and East Timbalier Island. A compressor, pumping, and metering station covered 1.6 ha of former marsh on the bayside of Grand Terre. On the eastern end of Grand Isle, Exxon USA, Exxon Pipeline Company, and Conoco, Inc. covered approximately 117 ha, 9 ha, and 15 ha, respectively. These facilities provide helicopters and boat transportation, materials handling, petroleum and natural gas processing and training for Exxon USA employees, terminal facilities for Exxon Pipeline Co., and terminal facilities and a supply-service base for Conoco, Inc.

Despite the numerous petroleum-related facilities on East Timbalier, only one complex of oil storage tanks and separator facilities was identified as being OCS-related. This complex covered less than 1 ha and included elevated walkways.

No OCS facilities were identified on barrier islands in the North Central Gulf Coast System, except for a small dock area operated by Mobile on the eastern end of Dauphin Island. The only OCS facility that appeared to impact wetlands in this system was the Chevron USA refinery at Pascagoula, Mississippi. Expansion of this site in recent years appears to have replaced about 113 ha of intertidal marsh with water storage-treatment impoundments or landfill.

A true assessment of the cumulative, direct impact of OCS facilities would require comparison of aerial photographs of each site pre- and post-facility construction. However, in general, it appears that, except for water-dependent facilities such as supply and service bases, which need to be at ports near the Gulf, the majority of OCS facilities are located on uplands in Texas and Mississippi and uplands and natural levees in Louisiana. Impacts of facilities on wetlands in Louisiana were not included in this study.

Conclusions Regarding Impacts of OCS-related Facilities

The most obvious conclusion regarding the impact of OCS-related facilities is that these facilities comprise a relatively small percentage of the area of barrier islands and basically none of the area of barrier beaches. Where located on islands, facilities are generally on higher ground behind dunes and along highway systems in the vicinity of other types of development. To ascertain which came first and possibly attracted the other—the OCS facility or the other development--would require a detailed study on the land use history of each site.

Supply and service bases, in contrast, are located on the back or protected side of barrier islands along navigable waterways. Maintenance or expansion of these facilities has required dredging of channels and filling of wetlands for development. Again, a detailed land use history of these sites would be necessary to determine the extent of wetland impacts resulting solely from the construction of OCS water-dependent facilities.

In general, it appears that most OCS facilities located in the Texas Barrier Island System and the North Central Gulf Coast System are located in interior uplands, which are closer to the Gulf in these systems and have minimal impact in wetlands.

While no studies were done on the impact of OCS-related facilities in wetlands in the area located between East Bay, Texas, and Waveland, Mississippi, a cursory review of aerial photographs reveal that numerous processing facilities, oil storage tanks, and compressor, pumping, and metering stations are located along the highways linking the chenier ridges and running along the natural levees. Because the ridges are narrow, construction of such facilities has eliminated some wetlands, but quantification of wetland loss requires detailed information on land use and historic photo coverage.

Prediction of Future Impacts

Pipelines

Decision-makers and the general public now recognize and accept the value of coastal wetlands systems. Both acknowledge the need to protect the renewable resources from wanton and unnecessary destruction whether through pipeline installation or, in fact, many other activities. Most of the regulations that are now in effect are general, that is, they protect or prohibit the use of classes of areas and make no distinction on the quality of the particular feature. For example, all states are conscious of the importance of reefs and aquatic grassbeds and describe them in such broad terms. But in dealing with the agencies, it is recognized that the regulations are becoming more specific within the guidelines established by the Federal and, more importantly, State governments.

In the future, scientists and administrators within each state will concentrate on refining the existing regulations as more and better information becomes available. Sources of this information may take the form of exchange of publications between and among states, better application of our understanding of coastal processes to the routing of pipelines, or the availability of studies that identify the most critical areas. For example, Louisiana has published only a few, general guidelines which leave much to the interpretation of the reviewer. Guideline 3.8 can be interpreted to mean that dredging across reefs is possible if the company restores the reef to its natural conditions. After considering how other Gulf coast states prohibit pipelines from crossing or adversely impacting reefs, Louisiana would be expected to modify Guideline 3.8 so pipelines will avoid crossing or adversely impacting reefs in order to preserve the many benefits they contribute to the coastal system.

With the availability of data, as a result of the added emphasis in the universities and the Federal government during the past 20 years on coastal forms and processes, scientists and engineers are now able to design and construct pipelines in a safer and more environmentally responsive manner. State programs can be expected to require that pipelines make landfall on either prograding or stable shorelines with narrow or absent fringing wetlands. These are the settings where minimal impacts can be expected. For example, pipelines could cross beaches or islands on the updrift side of jetties or groins in the active zone of sedimentation. Another possibility is to require that pipelines be buried at sufficient depth to remain below the seabed for a period of time equal to or greater than the life expectancy of the pipeline. Therefore, if the useful life of the pipeline is 40 years, the pipe must be buried to such a depth that at the end of 40 years it will not have been exposed during this period because of erosion of the shoreline.

Finally, regulations will change because new ideas on the Federal-State relationship will become accepted. The U.S. Army Corps of Engineers now processes applications for pipelines across wetlands as a Nationwide Permit, a process that may not be in the best environmental interest of the nation. In the case of Louisiana, it would seem more advisable to look at each pipeline through the review process for an individual permit. This analysis requires a more detailed investigation than what is common under the nationwide procedure and would provide for input based on the environmental and cultural conditions characterizing a particular site. A greater chance exists for state review and comment through the individual permit procedure. In the case of Texas or Mississippi, it appears that the nationwide procedure is desirable and should continue. Wetlands in these areas can be avoided; or if they are impacted, the scope of the affected areas can be quite limited in extent or quality. Therefore, the future holds a change for the application of the Nationwide Permit procedure by the Corps of Engineers in Louisiana and more stringent review of what effect pipelines really have on the coastal wetlands. Furthermore, as industry technology changes, as better installation techniques are developed, and as companies pool their assets to construct one large line to service many individually developed fields, the regulations will change to incorporate these advances.

Navigation Channels

Almost every natural major river system that discharges into the Gulf of Mexico and several large tidal passes have been modified by jetties and dredging to serve commerce.

In those locations where the passes could not be economically maintained, such as the Matagorda or Mermentau systems, new channels were dug across the barriers or beaches. Finally, new channels, for example the Mississippi River Gulf Outlet Canal and the Houma Navigation Canal, were dredged where natural channel systems of the desired size did not exist.

There are few, if any, remaining channels or passes to be dredged, jettied, and enlarged for deep draft navigation needed by general commerce or the offshore oil and gas industry. In addition, maintained, shallow draft harbors (East Channel, Bayou LaBatre, Biloxi) are available to serve the demand for smaller boat access. Table 10.1 shows the distribution of these facilities across the study area. A sufficient number of deep draft harbors are located in each of the four systems in this study area and can serve adequately the OCS industry.

In the future, environmental laws are not expected to change so drastically as to allow for excavation of any new deep draft harbor along the Gulf of Mexico. Moreover, money will also be difficult to obtain for this type of public works project and, in fact, is not always available even today for maintenance of existing channels. Present laws, regulations, and guidelines will limit new OCS support base development to lands along those channels that have the capacity to meet the needs (draft and width) of the particular industry.

OCS-related Facilities

With the exception of supply-service bases and platform fabrication sites, OCS-related facilities are not water-dependent uses. Therefore, new construction of the other OCS-related facilities is likely to be planned for upland sites in order to avoid delays in construction as a result of the need to do environmental impact statements or prepare mitigation for development in wetlands.

New construction on barrier islands can be expected to be confined to areas where other development is also present. No new construction is likely for areas designated as Coastal Barrier Resources Areas because such sites do not qualify for insurance.

Small facilities such as compressor, pumping, and metering stations may continue to be built in wetlands and barrier islands for Louisiana because of the long expanse of wetlands to be crossed before an upland site is reached. New technology, however, continues to provide for a smaller size and more efficient design, thus limiting the direct impact of their emplacement.

The primary factor operating to ensure that impacts of future OCS-related facilities will be minimized is an aware public that maintains the pressure needed to insure compliance with existing environmental regulations. From an environmental point of view, the first choice is to avoid an environmentally sensitive area. Where facilities must be built, the public and regulatory agencies must require that all environmental precautions be taken and acceptable mitigative measures be incorporated as part of the project.

Table 10.1. **Approximate Direct Distances Between Access Channels Leading to the Gulf of Mexico within the Study Area.**

Access Channel	Approximate Distance in Kilometers	Approximate Distance in Kilometers Between Deep Draft Channels
Brownsville*-Port Mansfield	56	
Port Mansfield-Corpus Christi Ship Channel*	112	168
Corpus Christi Ship Channel-Matagorda Ship Channel*	96	96
Matagorda Ship Channel-Freeport*	112	112
Freeport-Galveston*	88	88
Galveston-Sabine*	96	96
Sabine-Calcasieu*	80	80
Calcasieu-Mermentau	32	
Mermentau-Freshwater Bayou	88	
Freshwater Bayou-Atchafalaya River*	88	209
Atchafalaya River-Houma Navigation Canal	88	
Houma Navigation Canal-Belle Pass	40	
Belle Pass-Empire Canal**	64	
Empire-Mouth of Mississippi River***	19	201
Main Pass-MRGO*	16	80
Bayou Caddy-Gulfport*	32	96
Gulfport-Biloxi	19	
Biloxi-Pascagoula*	40	60
Pascagoula-Bayou LaBatre	24	
Bayou LaBatre-Mobile Ship Channel*	24	48
Mobile Ship Channel-Perdido Pass Channel	56	
Perdido Pass-Pensacola*	16	72
Pensacola-East Pass Channel	80	
East Pass Channel-Panama City Harbor*	80	160

*Indicates a deep draft access channel (over 9.1 m draft).

**Grand Isle Port Complex is between these two.

***Includes: Tiger Pass, Grand Pass, Southwest Pass*, South Pass, Pass a Loutre, and Main Pass.

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APPENDICES A.1 THROUGH A.4

Definition of Symbols

CONTENTS:

OIL	(O)
GAS	(G)

CONSTRUCTION:

FLOTATION CANAL	(FC)
PUSH DITCH (TRENCH)	(PD)
DAM	(D)
BACKFILLED	(B)
REVEGETATED	(R)
DIRECTIONALLY DRILLED	(DD)

SHORE TYPE:

TRANSGRESSIVE BARRIER ISLAND	(TBI)
TRANSGRESSIVE BARRIER BEACH	(TBB)
REGRESSIVE BARRIER ISLAND	(RBI)
REGRESSIVE BARRIER BEACH	(RBB)

GEOMORPHOLOGY:

SAND/SHELL/ROCK FRAGMENTS	(S/S/R)
BEACH AND SAND SPITS	(B/SS)
SAND BEACH RIDGES, MARSH AND BAY FLATS	(SBR/M/MF)
MARSH-BAY MUDS FRONTED BY THIN SANDY BEACH	(M-BM/SB)
TIDAL DELTAS/SHOALS	(TD/S)
BEACH-SAND SPITS W/ SHELLS	(B-SS/S)
DUNES > 1.5 M	(D > 1.5M)
DUNES 3-6 M	(D 3-6M)
WASHOVERS	(W)
TIDAL INLETS	(TI)

SHORE CHANGE:

EROSION	(E)
ACCREATION	(A)
STABLE	(S)

CLIMATE:

SEMI-ARID (PRECIP. SURPLUS)	(SA #")
SUB-HUMID (PRECIP. SURPLUS)	(SH #")
HUMID (PRECIP. SURPLUS)	(H #")

LAND USE:

DEVELOPED	(D)
SEMI-DEVELOPED	(SD)
COASTAL BARRIER RESOURCES SYSTEM	(CBRS)
NATIONAL WILDLIFE REFUGE/SEASHORE/ WILDERNESS	(NWA)
STATE RECREATIONAL AREA/PARK/ HISTORIC PARK/COMMERATIVE AREA/ REFUGE/MGT. AREA/AQUATIC PRESERVE	(SA)
NATIONAL REGISTER SITE	(NRS)
NATURAL	(N)

LEASE BLOCK ORIGIN:

BA	BRAZOS
BM	BAY MARCHAND
EA	EAST ADDITION
EC	EAST CAMERON
EI	EUGENE ISLAND
GA	GALVESTON
GI	GRAND ISLE
HI	HIGH ISLAND
MC	MISSISSIPPI CANYON
MI	MATAGORDA ISLAND
MP	MAIN PASS
PN	NORTH PADRE ISLAND
SA	SABINE PASS (LA)
SM	SOUTH MARSH ISLAND
SP	SOUTH PASS
SS	SHIP SHOAL
ST	SOUTH TIMBALIER
VR	VERMILION
WC	WEST CAMERON
WD	WEST DELTA

Appendix A.1: FEDERAL OCS PIPELINES MAKING LANDFALL WITHIN THE TEXAS BARRIER ISLAND SYSTEM.

PIPELINE PARAMETERS								ENVIRONMENTAL AND CULTURAL PARAMETERS						
CEI NO	OWNER/OPERATOR	ORIGIN	USGS QUAD LANDFALL	SIZE	CONT.	DATE	CONSTRUCTION	SHORE TYPE	GEOMOR-PHOLOGY	SHORE CHANGE (M/YR)	DEPTH TO PLEIST. (M)	TIDE (M)	CLIMATE (CM)	LANDUSE
T1	TRANSCO. GAS PIPE. CO.	PN 956	YARBOROUGH PASS, TX	24"	G	1981	PD,B,R	RBI	S/S/R	A 1.5	15	.30-.46	SA (-69.9)	NWA
T2	ENRON PIPE. SER. (MOPS)	MI 665	PANTHER POINT, TX	24"	G	1981	PD,B	RBI	S/S/R	A 1.5	12	.30-.46	SH (-33.0)	CBRS
T3	SEAGULL SHORELINE SYSTEMS	MI 623	PALACIOS PT., TX	24"	G	1983	PD,B	TBI	S/S/R	E 3.6	12	.30-.46	SH (-22.4)	N
T4	ENRON PIPE. SER.	MI 555	PALACIOS PT., TX	20"	G	1977	PD,B	TBI	S/S/R	E 3.6	12	.30-.46	SH (-22.4)	N
T5	TRANSCO. GAS PIPE. CO.	BA 538	DRESSING PT., TX	30"	G	1971	PD,B	TBI	S/S/R	E 2.7	9	.30-.46	SH (-22.4)	CBRS
T6	TRANSCO. GAS PIPE. CO.	BA 538	DRESSING PT., TX	36"	G	1985	PD,B	TBI	S/S/R	E 2.7	9	.30-.46	SH (-22.4)	CBRS
T7	BLUE DOLPHIN	HI 288	FREEPORT, TX	20"	G/O	1965	PD,B	TBB	B/SS	E 5.3	7.5	.30-.46	SH (9.9)	N
T8	AMOCO PIPELINE CO.	HI 474	GALVESTON, TX	14"	O	1978	PD,B	RBI	B/SS	E 24.2	9	.46-.61	SH (20.1)	N,SD
T9	SEAGULL ENERGY CORP.	GA 214	GALVESTON, TX	6"	G	1976	PD,B	RBI	B/SS	E 24.2	9	.46-.61	SH (20.1)	N,SD
T10	BLACK MARLIN	HI 136	FLAKE, TX	16"	G	1967	PD,B	RBI	B/SS	E 1.8	23	.61-.76	SH (20.1)	CBRS

Appendix A.2: FEDERAL OCS PIPELINES MAKING LANDFALL WITHIN THE STRANDPLAIN-CHENIER PLAIN SYSTEM

PIPELINE PARAMETERS								ENVIRONMENTAL AND CULTURAL PARAMETERS						
CEI NO	OWNER/OPERATOR	ORIGIN	USGS QUAD LANDFALL	SIZE	CONT.	DATE	CONSTRUCTION	SHORE TYPE	GEOMOR-PHOLOGY	SHORE CHANGE (M/YR)	DEPTH TO PLEIST. (M)	TIDE (M)	CLIMATE (CM)	LANDUSE
T11	CHEVRON U.S.A.	HI 52	S. of STAR LAKE	4"	O/G	1981	PD,B	TBB	M-BM/SB	E 9.1	3	.61-.76	H (20.1)	NWA
T12	NAT. GAS PIPELINE	HI 71	SABINE PASS, TX.-LA.	16"	G	1977	PD,B	RBI	SBR/M/MF	A 3.5	6	.61-.76	H (32.5)	SA
T13	MOBIL EXPL. & PROD. U.S. INC.	HI 14L	SABINE PASS, TX.-LA.	12"	G	1979	PD,B	RBB	SBR/M/MF	A 3.5	8	.61-.76	H (32.5)	SA
T14	GULF-TENNECO	HI 39	SABINE PASS, TX.-LA.	8"	O	?	PD,B	RBB	SBR/M/MF	A 3.5	13	.61-.76	H (32.5)	SA
T15	TRANS. GAS PIPE. CO.	HI 52	SABINE PASS, TX.-LA.	10"	G	1972	PD,B	RBB	SBR/M/MF	A 3.5	16	.61-.76	H (32.5)	SA
T16	TRANS. GAS PIPE. CO.	GA 255L	SABINE PASS, TX.-LA.	24"	G	1977	PD,B	RBB	SBR/M/MF	A 3.5	16	.61-.76	H (32.5)	SA
L1	CHEVRON PIPELINE CO.	WC 48	TEXAS PT., TX.-LA.	6"	O	1967	PD,D (?) *	RBB	SBR/M/MF	A 3.5	9	.61-.76	H (32.5)	N
L2	CHEVRON PIPELINE CO.	WC 48	TEXAS PT., TX.-LA.	18"	G	1973	PD,D (?)	RBB	SBR/M/MF	A 3.5	9	.61-.76	H (32.5)	N
L3	ANR PIPELINE CO.	WC 17	SMITH BAYOU, LA	10"	G	1968	PD,D (?)	RBB	SBR/M/MF	A 3.5	24	.61-.76	H (32.5)	CBRS
L4	TENNESSEE GAS PIPELINE CO.	SA 18	JOHNSONS BAYOU, LA	30"	G	1981	PD,B	RBB	SBR/M/MF	E 4	9	.61-.76	H (32.5)	CBRS
L5	TRANS. GAS PIPE. CO.	HI 264	JOHNSONS BAYOU, LA	42"	G	1979	PD,B (?)	RBB	SBR/M/MF	E 4	8	.61-.76	H (32.5)	CBRS
L6	TRANS. GAS PIPE. CO.	WC 165	JOHNSONS BAYOU, LA	16"	G	1958	PD,B (?)	RBB	SBR/M/MF	E 4	8	.61-.76	H (32.5)	CBRS
L7	TRANS. GAS PIPE. CO.	WC 45	JOHNSONS BAYOU, LA	16"	G	1958	PD,B (?)	RBB	SBR/M/MF	E 4	7	.61-.76	H (32.5)	CBRS
L8	PHILLIPS PETROLEUM CO.	WC 20	JOHNSONS BAYOU, LA	8"	G/O	1977	PD,B	RBB	SBR/M/MF	E 4	7	.61-.76	H (32.5)	CBRS
L9	TENNESSEE GAS PIPELINE CO.	WC 20	PEVETO BEACH, LA.	12"	G	1960	PD	RBB	SBR/M/MF	E 4	7	.61-.76	H (32.5)	CBRS
L10	NATURAL GAS PIPELINE CO.	WC 148	PEVETO BEACH, LA.	36"	G	1971	PD,D (?)	RBB	SBR/M/MF	E 4	7	.61-.76	H (32.5)	N
L11	TRANS. GAS PIPELINE CO.	WC 22	PEVETO BEACH, LA.	4"	G	1980	PD,B (?)	RBB	SBR/M/MF	E 4	7	.61-.76	H (32.5)	SD
L12	ANR PIPELINE CO.	WC 22	HOLLY BEACH, LA.	6"	G	?	PD,D (?)	RBB	SBR/M/MF	E 4	30	.61-.76	H (32.5)	N
L13	TRANS. GAS PIPELINE CO.	WC 110	HOLLY BEACH, LA.	16"	G	1960	PD,D	RBB	SBR/M/MF	E 4	12	.61-.76	H (32.5)	SD
L14	NATURAL GAS PIPELINE	WC 28	GRAND BAYOU, LA.	8"	G	1975	PD,B (?)	RBB	SBR/M/MF	A 2.6	7	.61-.76	H (32.5)	N
L15	CONOCO,INC.	WC 66	HACKBERRY BEACH, LA	10"	G/O	1976	PD,D (?)	RBB	SBR/M/MF	E 5.6	7	.46-.61	H (35.6)	CBRS
L16	TX. EAST. GAS TRANSM.	WC 272	HACKBERRY BEACH, LA	30"	G	1970	PD,D (?)	RBB	SBR/M/MF	E 5.6	7	.46-.61	H (35.6)	CBRS
L17	MOBIL EXPL. & PROD. U.S. INC.	WC 67	HACKBERRY BEACH, LA	12"	G	1960	PD,B	RBB	SBR/M/MF	E 5.6	7	.46-.61	H (35.6)	CBRS

PIPELINE PARAMETERS								ENVIRONMENTAL AND CULTURAL PARAMETERS						
CEI NO	OWNER/OPERATOR	ORIGIN	USGS QUAD LANDFALL	SIZE	CONT.	DATE	CONSTRUCTION	SHORE TYPE	GEOMOR-PHOLOGY	SHORE CHANGE (M/YR)	DEPTH TO PLEIST. (M)	TIDE (M)	CLIMATE (CM)	LANDUSE
L18	ANR PIPELINE CO.	WC 71	HACKBERRY BEACH, LA	30"	G	1971	PD,D (?)	RBB	SBR/M/MF	E 5.6	7	.46-.61	H (35.6)	CBRS
L19	TENNESSEE GAS PIPELINE CO.	WC 68	HACKBERRY BEACH, LA	20"	G	1960	PD,D	RBB	SBR/M/MF	E 5.6	7	.46-.61	H (35.6)	CBRS
L20	TEXAS GAS TRANSMISSION CORP.	WC 33	HOG BAYOU, LA	12"	G	1960	FC,D	RBB	SBR/M/MF	E 5.6	7	.46-.61	H (35.6)	CBRS
L21	KERR-MCGEE PIPELINE CORP.	EC 46	HOG BAYOU, LA	6"	O	1981	PD,B	RBB	SBR/M/MF	E 5.6	12	.46-.61	H (35.6)	CBRS
L22	TEXAS GAS TRANSMISSION CORP.	EC 14	HOG BAYOU, LA	12"	G	1978	FC,D	RBB	SBR/M/MF	E 5.6	7	.46-.61	H (35.6)	CBRS
L23	TENNESSEE GAS PIPELINE CO.	EC 49	HOG BAYOU, LA	26"	G	1958	FC,D	RBB	SBR/M/MF	E 5.6	9	.46-.61	H (35.6)	CBRS
L24	TENNESSEE GAS PIPELINE CO.	EC 49	HOG BAYOU, LA	26"	G	1968	PD,D	RBB	SBR/M/MF	E 5.6	12	.46-.61	H (35.6)	CBRS
L25	MOBIL EXPL. & PROD. U.S. INC.	EC 9	HOG BAYOU, LA	4"	O	1970	PD,B	RBB	SBR/M/MF	E 5.6	21	.46-.61	H (35.6)	CBRS
L26	MOBIL EXPL. & PROD. U.S. INC.	EC 9	COW ISLAND, LA	16"	G	1965	PD,B	RBB	SBR/M/MF	E 5.6	8	.46-.61	H (35.6)	SA
L27	NAT. GAS PIPELINE CO. OF AMER.	EC 34	COW ISLAND, LA	12"	G	1978	PD,D (?)	RBB	SBR/M/MF	E 5.6	8	.46-.61	H (35.6)	SA
L28	COLUMBIA GULF TRANS. CO	EC 33	BIG CONSTANCE LAKE, LA	12"	G	1958	PD,D (?)	RBB	SBR/M/MF	E 5.6	15	.46-.61	H (35.6)	SA
L29	COLUMBIA GULF TRANS. CO	EC 23	BIG CONSTANCE LAKE, LA	16"	G	1981	PD,D (?)	RBB	SBR/M/MF	E 5.6	15	.46-.61	H (35.6)	SA
L30	TENNESSEE GAS PIPELINE CO.	EC 16	BIG CONSTANCE LAKE, LA	12"	G	1960	PD,D (?)	RBB	SBR/M/MF	E 5.6	21	.46-.61	H (35.6)	SA
L31	JUPITER ENERGY CORP.	VR 39	ROLLOVER LAKE, LA	8"	G	1950	PD,D (?)	RBB	SBR/M/MF	E 5.6	9	.46-.61	H (35.6)	SA
L32	JUPITER ENERGY CORP.	VR 39	ROLLOVER LAKE, LA	10"	G	1955	PD,D (?)	RBB	SBR/M/MF	E 5.6	9	.46-.61	H (35.6)	SA
L33	TRANS. GAS PIPE. CO.	VR 22	MULBERRY ISL. W., LA	24"	G	1978	PD/B **	RBB	SBR/M/MF	E 4	8	.46-.61	H (35.6)	N
L34	TRANS. GAS PIPE. CO.	VR 67	MULBERRY ISL. W., LA	16"	G	1959	FC,D	RBB	SBR/M/MF	E 4	8	.46-.61	H (35.6)	N
L35	TRANS. GAS PIPE. CO.	VR 67	MULBERRY ISL. W., LA	20"	G	1961	FC,D	RBB	SBR/M/MF	E 4	8	.46-.61	H (35.6)	N
L36	COLUMBIA GULF TRANS. CO.	VR 76	MULBERRY ISL. W., LA	36"	G	1980	FC,D	RBB	SBR/M/MF	E 4	8	.46-.61	H (35.6)	N
L37	COLUMBIA GULF TRANS. CO.	VR 245	MULBERRY ISL. W., LA	36"	G	1972	FC,D	RBB	SBR/M/MF	E 4	8	.46-.61	H (35.6)	N
L38	AMOCO PRODUCTION CO.	VR 35	MULBERRY ISL. E., LA	20"	G	1982	PD,B (?)	RBB	SBR/M/MF	E 4	8.5	.46-.61	H (35.6)	N
L39	TRUNKLINE GAS CO.	VR 23	MULBERRY ISL. E., LA	16"	G	1978	FC,D	RBB	SBR/M/MF	E 4	8.5	.46-.61	H (35.6)	N

PIPELINE PARAMETERS								ENVIRONMENTAL AND CULTURAL PARAMETERS						
CEI NO	OWNER/OPERATOR	ORIGIN	USGS QUAD LANDFALL	SIZE	CONT.	DATE	CONSTRUCTION	SHORE TYPE	GEOMOR-PHOLOGY	SHORE CHANGE (M/YR)	DEPTH TO PLEIST. (M)	TIDE (M)	CLIMATE (CM)	LANDUSE
L40	TRUNKLINE GAS CO.	VR 26	MULBERRY ISL. E., LA	14"	G	1959	FC,D	RBB	SBR/M/MF	E 4	8.5	.46-.61	H (35.6)	N
L41	TRUNKLINE GAS CO.	VR 26	MULBERRY ISL. E., LA	16"	G	1961	FC,D	RBB	SBR/M/MF	E 4	8.5	.46-.61	H (35.6)	N
L42	CONOCO INC.	VR 119	MULBERRY ISL. E., LA	8"	O	1969	UNDET.	RBB	SBR/M/MF	E 4	8.5	.46-.61	H (35.6)	N
L43	TENNESSEE GAS PIPELINE CO.	SM 249	CHENIER au TIGRE, LA	12"	G	1979	PD,B	RBB	SBR/M/MF	E 4	8	.46-.61	H (35.6)	N
L44	TENNESSEE GAS PIPELINE CO.	SM 243	CHENIER au TIGRE, LA	16"	G	1979	PD,B	RBB	SBR/M/MF	E 4	8	.46-.61	H (53.8)	N
L45	TEXAS GAS TRANS. CORP.	VR 50	CHENIER au TIGRE, LA	20"	G	1978	PD,B (?)	RBB	SBR/M/MF	E 4	8	.46-.61	H (53.8)	N
L46	SEAGULL PIPE.	VR 50	CHENIER au TIGRE, LA	6"	O	1977	PD,B	RBB	SBR/M/MF	E 4	8	.46-.61	H (53.8)	SA
L47	SEA ROBIN PIPELINE CO.	VR 149	HELL HOLE BAYOU, LA	36"	G	1972	FC,D,B	RBB	SBR/M/MF	E 4	8	.46-.61	H (53.8)	SA
L48	TEXACO	SM 217	HELL HOLE BAYOU, LA	10"	O	1964	PD,B	RBB	SBR/M/MF	E 4	8	.46-.61	H (53.8)	SA
L49	TEXACO	SM 217	HELL HOLE BAYOU, LA	30"	G	1964	PD,B	RBB	SBR/M/MF	E 4	8	.46-.61	H (53.8)	SA

(?) * Behind construction indicates that an assumption has been made with reguard to the closure technique.

** Backfilled at the beach. Behind Chenier ridge pipeline lies in a canal.

Appendix A.3 : FEDERAL OCS PIPELINES MAKING LANDFALL WITHIN THE MISSISSIPPI DELTA SYSTEM

PIPELINE PARAMETERS								ENVIRONMENTAL AND CULTURAL PARAMETERS						
CEI NO	OWNER/OPERATOR	ORIGIN	USGS QUAD LANDFALL	SIZE	CONT.	DATE	CONSTRUCTION	SHORE TYPE	GEOMORPHOLOGY	SHORE CHANGE (M/YR)	DEPTH TO PLEIST. (M)	TIDE (M)	CLIMATE (CM)	LANDUSE
* L50	EXXON PIPELINE CO.	EI 24	POINT CHEVREVIL, LA	12"	O	PRE 1973			MARSH					
* L51	MOBIL OIL EXPL. & PROD. SE INC.	EI 51	POINT CHEVREVIL, LA	12"	O	1954			MARSH					
* L52	MAGNOLIA/CONTINENTAL/NEWMONT	?	POINT CHEVREVIL, LA	12"	O	?			MARSH					
* L53	UNITED GAS PIPELINE CO.	EI 32	POINT CHEVREVIL, LA	20"	G	1956			MARSH					
* L54	AMERICAN NATURAL RESOURCES	EI 199	LAKE SALVE, LA	20"	G	1965			MARSH					
* L55	AMERICAN NATURAL RESOURCES	EI 63	LAKE SALVE, LA	30"	G	1968			MARSH					
* L56	TRUNKLINE GAS CO.	SM 268	LAKE SALVE, LA	22"	G	1979			MARSH					
* L57	TRANSCO. GAS PIPE LINE CO.	EI 129	OYSTER BAYOU, LA	24"	G	1967			MARSH					
* L58	TRANSCO. GAS PIPE LINE CO.	EI 129	OYSTER BAYOU, LA	20"	G	1962			MARSH					
* L59	TRANSCO. GAS PIPE LINE CO.	EI 129	OYSTER BAYOU, LA	16"	G	1963			MARSH					
* L60	TRANSCO. GAS PIPE LINE CO.	SS 28	OYSTER BAYOU, LA	16"	G	1961			MARSH					
* L61	TRANSCO. GAS PIPE LINE CO.	SS 28	OYSTER BAYOU, LA	20"	G	1967			MARSH					
* L62	SHELL PIPELINE CORP.	SS 28	EAST BAY JUNOP, LA	16"	G	1966			MARSH					
* L63	SHELL PIPELINE CORP.	SS 28	EAST BAY JUNOP, LA	22"	O	1967			MARSH					
* L64	TRUNKLINE GAS CO.	SS 139	POINT AUX FER NE, LA	30"	G	1968			MARSH					
* L65	TRUNKLINE GAS CO.	SS 139	EAST BAY JUNOP, LA	30"	G	1981			MARSH					
* L66	TEX. GAS TRANSM. CORP.	SS 26	EAST BAY JUNOP, LA	4"	C	1968			MARSH					
* L67	TEX. GAS TRANSM. CORP.	SS 26	EAST BAY JUNOP, LA	16"	G	1969			MARSH					
L68	TRANSCO. GAS PIPE LINE CO.	SS 214	W. ISL. DERNIERES, LA.	26"	G	1969	BURIED **	NA	TI	NA	133	.46-.61	H (58.4)	WATER
L69	TENNESSEE GAS PIPELINE CO.	SS 198	C. ISL. DERNIERES, LA.	26"	G	1969	BURIED **	NA	TI	NA	136	.46-.61	H (58.4)	WATER

PIPELINE PARAMETERS								ENVIRONMENTAL AND CULTURAL PARAMETERS						
CEI NO	OWNER/OPERATOR	ORIGIN	USGS QUAD LANDFALL	SIZE	CONT.	DATE	CONSTRUCTION	SHORE TYPE	GEOMOR-PHOLOGY	SHORE CHANGE (M/YR)	DEPTH TO PLEIST. (M)	TIDE (M)	CLIMATE (CM)	LANDUSE
L70	TENN. GAS (COLUMBIA GULF)	SS 198	C. ISL. DERNIERES, LA.	36"	G	1976	BURIED **	NA	TI	NA	136	.46-.61	H (58.4)	WATER
L71	ODECO	SS 113	C. ISL. DERNIERES, LA.	8"	O	1970	BURIED **	NA	TI	NA	140	.46-.61	H (58.4)	WATER
L72	TEX. PIPELINE CO.	SM 128	CAT ISL. PASS, LA.	20"	O	1976	BURIED **	NA	TI	NA	140	.30-.46	H (58.4)	WATER
L73	GULF OIL CO.	ST 35	CALUMET ISL., LA.	12"	G	1978	UNDET. ***	TBI	M-BM/SB	E 12	210	.30-.46	H (58.4)	CBRS
L74	GULF OIL CO.	ST 35	CALUMET ISL., LA.	16"	O	1978	UNDET. ***	TBI	M-BM/SB	E 12	210	.30-.46	H (58.4)	CBRS
L75	TENN. GAS PIPELINE CO.	ST 37	CALUMET ISL., LA.	20"	G	1977	UNDET. ***	TBI	M-BM/SB	E 12	207	.30-.46	H (58.4)	CBRS
L76	GULF OIL CO.	ST 37	CALUMET ISL., LA.	24"	G/O	1976	UNDET. ***	TBI	M-BM/SB	E 12	207	.30-.46	H (58.4)	CBRS
L77	GULF OIL CO.	ST 21	CALUMET ISL., LA.	10"	O	?	UNDET. ***	TBI	M-BM/SB	E 12	207	.30-.46	H (58.4)	CBRS
L 78	GULF OIL CO.	ST 21	CALUMET ISL., LA.	10"	O	1978	UNDET. ***	TBI	M-BM/SB	E 12	207	.30-.46	H (58.4)	CBRS
L79	GULF OIL CO.	ST 21	CALUMET ISL., LA.	14"	G	1978	UNDET. ***	TBI	M-BM/SB	E 12	207	.30-.46	H (58.4)	CBRS
L80	GULF OIL CO.	ST 21	CALUMET ISL., LA.	6"	G	?	UNDET. ***	TBI	M-BM/SB	E 12	207	.30-.46	H (58.4)	CBRS
L81	GULF OIL CO.	ST 21	CALUMET ISL., LA.	10"	O/G	n.d.	UNDET. ***	TBI	M-BM/SB	E 12	207	.30-.46	H (58.4)	CBRS
L82	UNITED GAS PIPELINE CO.	ST 26	BELLE PASS, LA.	12"	G	1972	UNDET. ***	TBI	M-BM/SB	E 12	207	.30-.46	H (58.4)	CBRS
L83	TENN. GAS PIPELINE CO.	BM 5	BELLE PASS, LA.	12"	G	?	UNDET. ***	TBI	M-BM/SB	E 12	174	.30-.46	H (58.4)	CBRS
L84	GULF OIL CO.	ST 21	CALUMET ISL., LA.	6"	O	?	UNDET. ***	TBI	M-BM/SB	E 12	177	.30-.46	H (58.4)	CBRS
L85	TENN. GAS PIPELINE CO.	ST 55	BELLE PASS, LA.	16"	G	1968	FC,D	TBB	M-BM/SB	E 12	171	.30-.46	H (58.4)	CBRS
L86	TENN. GAS PIPELINE CO.	ST 21	BELLE PASS, LA.	16"	G	1961	FC,D	TBB	M-BM/SB	E 12	174	.30-.46	H (58.4)	CBRS
L87	TENNECO OIL CO.	BM 22	BELLE PASS, LA.	6"	G	PRE 1973	PD/B	TBB	M-BM/SB	E 17.5	149	.30-.46	H (49.8)	N,SD
L88	CHEVRON USA	ST 63	BELLE PASS, LA.	10"	O	1969	PD,B	TBB	M-BM/SB	E 17.5	148	.30-.46	H (49.8)	N,SD
L89	GULF REFINING CO.	ST 130	BELLE PASS, LA.	12"	O	1976	FC,D	TBB	M-BM/SB	E 17.5	147	.30-.46	H (49.8)	N,SD
L90	GULF REFINING CO.	ST 130	BELLE PASS, LA.	18"	O	PRE 1966	FC,D	TBB	M-BM/SB	E 17.5	147	.30-.46	H (49.8)	N,SD

PIPELINE PARAMETERS								ENVIRONMENTAL AND CULTURAL PARAMETERS						
CEI NO	OWNER/OPERATOR	ORIGIN	USGS QUAD LANDFALL	SIZE	CONT.	DATE	CONSTRUCTION	SHORE TYPE	GEOMOR-PHOLOGY	SHORE CHANGE (M/YR)	DEPTH TO PLEIST. (M)	TIDE (M)	CLIMATE (CM)	LANDUSE
L91	SHELL PIPELINE CORP.	ST 26	BELLE PASS, LA.	6"	O	1966	PD,B	TBB	M-BM/SB	E 17.5	148	.30-.46	H (49.8)	N,SD
L92	GULF OIL	GI 37	BELLE PASS, LA.	10"	O	1960	UNDET. ***	TBI	M-BM/SB	E 17.5	148	.30-.46	H (49.8)	N,SD
L93	GULF OIL	GI 37	BELLE PASS, LA.	10"	O	1958	UNDET. ***	TBB	M-BM/SB	E 17.5	148	.30-.46	H (49.8)	N,SD
L94	CHEVRON	?	BELLE PASS, LA.	10"	O	?	UNDET. ***	TBB	M-BM/SB	E 17.5	148	.30-.46	H (49.8)	N,SD
L95	EXXON USA	GI 22	GRAND ISLE- BARA. PASS, LA.	16"	G	1964	PD,B	TBI	B/SS	E 3	137	.30-.46	H (49.8)	SD
L96	EXXON USA	GI22	GRAND ISLE- BARA. PASS, LA.	12"	G	1970	PD,B	TBI	B/SS	E 3	137	.30-.46	H (49.8)	SD
L97	CONOCO, INC.	GI 47	CAMINADA PASS, LA.	12"	O	1957	PD,B	TBI	B/SS	E 3	137	.30-.46	H (49.8)	SD
L98	EXXON PIPELINE CO.	WD 73	GRAND ISLE- BARA. PASS, LA.	12"	O	1978	PD,B	TBI	B/SS	E 3	137	.30-.46	H (49.8)	SD
L99	EXXON PIPELINE CO.	WD 73	GRAND ISL. & BARA. PASS, LA.	12"	O	1963	PD,B	TBI	B/SS	E 3	137	.30-.46	H (49.8)	SD
L100	EXXON PIPELINE CO.	WD 73	GRAND ISL. & BARA. PASS, LA.	12"	O	1986	DD	TBI	B/SS	E 3	137	.30-.46	H (49.8)	SD
L101	CONOCO, INC.	GI 43	GRAND ISL. & BARA. PASS, LA.	16"	O	1968	PD,B	TBI	B/SS	E 3	137	.30-.46	H (49.8)	SD
L102	EXXON USA	GI 22	BARATARIA PASS, LA	10"	G	1958	PD,B	TBI	B/SS	E 3	136	.30-.46	H (49.8)	SD
L103	TENN. GAS PIPELINE CO.	GI 43	BASTIAN BAY, LA.	24"	G	1973	FC,D	TBB	M-BM/SB	E 12	180	.30-.46	H (49.8)	CBRS
L104	TENN. GAS PIPELINE CO.	GI 43	BASTIAN BAY, LA.	20"	G	1959	FC,D	TBB	M-BM/SB	E 12	180	.30-.46	H (49.8)	CBRS
L105	SOUTHERN NATURAL GAS	WD 133	BASTIAN BAY, LA.	8"	G	1967	FC,D	TBB	M-BM/SB	E 12	180	.30-.46	H (49.8)	CBRS
L106	SOUTHERN NATURAL GAS	WD 29	BASTIAN BAY, LA.	12"	G	1963	FC,D	TBB	M-BM/SB	E 12	180	.30-.46	H (49.8)	CBRS
L107	TENN. GAS PIPELINE CO.	WD 31	BASTIAN BAY, LA.	12"	G	1966	FC,D	TBB	M-BM/SB	E 12	145	.30-.46	H (49.8)	CBRS
L108	SHELL PIPELINE CO.	WD 32	BURAS, LA.	12"	O	1965	PD,B	TBB	M-BM/SB	E 12	159	.30-.46	H (49.8)	CBRS
L109	EXXON USA	WD 30	BURAS, LA.	10"	O	1956	PD	TBB	M-BM/SB	E 12	159	.30-.46	H (49.8)	CBRS
L110	CHEVRON USA	WD 26	BURAS, LA.	6"	O	1955	PD,B	TBB	M-BM/SB	E 12		.30-.46	H (49.8)	CBRS
L111	CHEVRON USA	WD 29	BURAS, LA.	6"	O	1955	PD,B	TBB	M-BM/SB	E 12		.30-.46	H (49.8)	CBRS

PIPELINE PARAMETERS								ENVIRONMENTAL AND CULTURAL PARAMETERS						
CEI NO	OWNER/OPERATOR	ORIGIN	USGS QUAD LANDFALL	SIZE	CONT.	DATE	CONSTRUCTION	SHORE TYPE	GEOMOR-PHOLOGY	SHORE CHANGE (M/YR)	DEPTH TO PLEIST. (M)	TIDE (M)	CLIMATE (CM)	LANDUSE
* L112	GULF OIL CO.	WD 41	PASS TANTE PHINNE, LA.	26"	G/O	1965			MARSH					
* L113	GULF OIL CO.	WD 41	PASS TANTE PHINNE, LA	16"	G/O	1965			MARSH					
* L114	TENN. GAS PIPELINE CO.	WD 61	PASS TANTE PHINNE, LA	30"	G	1963			MARSH					
* L115	TETCO/TEXAS EASTERN TRANS.	SP 89	PASS TANTE PHINNE, LA	20"	G	1982			MARSH					
* L116	GULF OIL CO.	WD 79	PASS TANTE PHINNE, LA	22"	G	1970			MARSH					
* L117	MARATHON	WD 79	PASS TANTE PHINNE, LA	12"	O	1981			MARSH					
* L118	MARATHON	WD 79	PASS TANTE PHINNE, LA	12"	O	1970			MARSH					
* L119	TENN. GAS PIPELINE CO.	WD 59	DIXON BAY, LA	12"	G	1959			MARSH					
* L120	CONOCO, INC.	WD 58	DIXON BAY, LA	4"	O	1965			MARSH					
* L121	CONOCO, INC.	?	BURRWOOD BAYOU, LA	6"	O	?			MARSH					
* L122	TENN. GAS PIPELINE CO.	SP 54	BURRWOOD BAYOU, LA	12"	G	1972			MARSH					
* L123	TENN. GAS PIPELINE CO.	SP 55	BURRWOOD BAYOU, LA	36"	G	1981			MARSH					
* L124	SHELL OFFSHORE	MC 194	DIXON BAY, LA	12"	O	1980			MARSH					
* L125	GULF OIL CO.	SP 37	DIXON BAY, LA	12"	G/O	1979			MARSH					
* L126	SOUTHERN NATURAL GAS	MC 194	DIXON BAY, LA	18"	G	1967			MARSH					
* L127	TEXACO	SP 37	SOUTH PASS, LA	8"	G	1962			MARSH					
* L128	TEXACO	SP 37	SOUTH PASS, LA	12"	O	1961			MARSH					
* L129	SHELL	SP 61	SOUTH PASS, LA	10"	G	?			MARSH					
* L130	ARCO OIL & GAS PIPELINE CO.	SP 60	PASS A LOUTRE, LA	10"	G	1975			MARSH					
* L131	ARCO OIL & GAS PIPELINE CO.	SP 60	SOUTH PASS, LA	6"	G	1983			MARSH					
* L132	SHELL OFFSHORE	SP 62 EA	PASS A LOUTRE, LA	12"	O	1967			MARSH					

PIPELINE PARAMETERS								ENVIRONMENTAL AND CULTURAL PARAMETERS						
CEI NO	OWNER/OPERATOR	ORIGIN	USGS QUAD LANDFALL	SIZE	CONT.	DATE	CONSTRUCTION	SHORE TYPE	GEOMOR-PHOLOGY	SHORE CHANGE (M/YR)	DEPTH TO PLEIST. (M)	TIDE (M)	CLIMATE (CM)	LANDUSE
* L133	SHELL OFFSHORE	MP 289	PASS A LOUTRE, LA	12"	O	1968			MARSH					
* L134	CHEVRON USA, INC.	MP 298	PASS A LOUTRE, LA	4"	O	1967			MARSH					
* L135	CHEVRON USA, INC.	MP 300	PASS A LOUTRE, LA	10"	O	1970			MARSH					
* L136	CHEVRON USA, INC.	MP 298	PASS A LOUTRE, LA	8"	O	1969			MARSH					
* L137	CHEVRON USA, INC.	MP 41	PASS A LOUTRE, LA	6"	O	?			MARSH					
* L138	CHEVRON USA	MP 42	MAIN PASS, LA.	14"	O	1967			MARSH					
* L139	TEXAS EASTERN TRANSMISSION	MP 92	MAIN PASS, LA	24"	G	1970			MARSH					
* L140	GULF OIL CO.	MP 140	VENICE, LA	18"	G	1974			MARSH					
* L141	MARATHON	MP 305	TAYLORS PASS, LA	12"	O	1969			MARSH					
* L142	SOUTHERN NATURAL GAS	MP 298	TAYLORS PASS, LA	26"	G	1972			MARSH					
L143	CHANDELEUR PIPELINE CO.	MP 42	NEW HARBOOR ISLAND, LA.	16"	G	1972	FC,D	TBI	M-BM/SB	E 5	45	.30-.46		NWA
L144	CHANDELEUR PIPELINE CO.	MP 41	NEW HARBOOR ISLAND, LA.	12"	G	1962	FC,D	TBI	M-BM/SB	E 5	45	.30-.46		NWA

* Does not cross a Barrier Island or Barrier Beach

** Pipeline is burried in bottom of tidal inlet or Pass and does not appear to have crossed Barrier Island or Barrier Beach at time of construction.

*** "Undetermined": construction technique was probably push ditch with backfill.

Appendix A.4: FEDERAL OCS PIPELINES MAKING LANDFALL WITHIN THE NORTH CENTRAL GULF COAST SYSTEM

PIPELINE PARAMETERS								ENVIRONMENTAL AND CULTURAL PARAMETERS						
CEI NO	OWNER/OPERATOR	ORIGIN	USGS QUAD LANDFALL	SIZE	CONT.	DATE	CONSTRUCTION	SHORE TYPE	GEOMOR-PHOLOGY	SHORE CHANGE (M/YR)	DEPTH TO PLEIST. (M)	TIDE (M)	CLIMATE (CM)	LANDUSE
M1	SOHIO PIPELINE CO.	ALLIANCE REF.	ENGLISH LOOKOUT, MS	20"	G	1970	PD, B	TBB	MARSH		9		H (58.9)	N
M2	TENNESSEE GAS PIPELINE CO.	LA. DELTA	GARDEN ISLAND PASS, MS	30"	G	1958	FC,D	TBB	MARSH		9		H (58.9)	N
M3	TENNESSEE GAS PIPELINE CO.	LA. DELTA	GARDEN ISLAND PASS, MS	36"	G	1965	FC,D	TBB	MARSH		9		H (58.9)	N
M4	CHEVRON PIPELINE CO.	EMPIRE TER.	GRAND BAY SW, MS	20"	O	1962	PD,B				9		H	N
M5	CHANDELEUR PIPE. CO.	MP 42	GRAND BAY SW, MS	16"	G	1970	PD,B				9		H	N
M6	CHANDELEUR PIPE. CO.	MP 41	GRAND BAY SW, MS	12"	G	1964	PD,B				9		H	N
A1	MOBILE & EXPL. & PROD. SE INC.	MOBILE BAY 76	BELLE FONTAINE, AL	16"	G	1986	DD	BLUFF	SAND		OUTCROP			
A2	MOBILE & EXPL. & PROD. SE INC.	MOBILE BAY 76	BELLE FONTAINE, AL	10"	G	1986	DD	BLUFF	SAND		OUTCROP			
A3	MOBILE & EXPL. & PROD. SE INC.	MOBILE BAY 76	BELLE FONTAINE, AL	8"	G	1986	DD	BLUFF	SAND		OUTCROP			
A4	MOBILE & EXPL. & PROD. SE INC.	MOBILE BAY 76	BELLE FONTAINE, AL	6"	G	1986	DD	BLUFF	SAND		OUTCROP			
A5	MOBILE & EXPL. & PROD. SE INC.	MARY ANN G. P.	BELLE FONTAINE, AL	6"	FUEL	1986	DD	BLUFF	SAND		OUTCROP			

Appendix B.1: SHORELINE CHANGE AT PIPELINE ROW AND CONTROL POINTS (1): TEXAS BARRIER ISLAND SYSTEM.

PIPELINE PARAMETERS						SHORELINE CHANGE IN METERS												
CEI NO.	OWNER/OPERATOR	SIZE	CONST. DATE	CONST. TYPE (2)	ENERGY LEVEL (3)	1950's-1979 (4)	1950's - 1966 (4)	1950's - 1985 (4)	1956 - 1979	1966 - 1975	1975 - 1979	1979 - 1982	1979 - 1984	1979 - 1987	1982 - 1987	1983 - 1987	NET CHANGE	NET RATE M/YR
T1	TRANSCO.	24"	1981	PD,B,R	I	-512							-85			-37	-634	-20.5
	CONTROL 1 (WEST)					-524							-73			-37	-634	-20.5
	CONTROL 2 (EAST)					-488							-85			-37	-610	-19.7
T2	ENRON PIPE. SER.	24"	1981	PD,B	II	-24								-49			-73	-2.4
	CONTROL 1 (WEST)					-24								-61			-85	-2.7
	CONTROL 2 (EAST)					-37								-49			-86	-2.8
T3	SEAGULL SHORE SYS.	24"	1983	PD,B	II	-24								-49			-73	-2.4
	CONTROL 1 (WEST)					-37								-49			-86	-2.8
	CONTROL 2 (EAST)					-49								-49			-98	-3.2
T4	ENRON PIPE. SER.	20"	1977	PD,B	II	-24								-49			-73	-2.4
	CONTROL 1 (WEST)					-37								-49			-86	-2.8
	CONTROL 2 (EAST)					-49								-49			-98	-3.2
T5	TRANSCO. GAS PIPE.	30"	1971	PD,B	II	61								-61			0	0.0
	CONTROL 1 (WEST)					49								-49			0	0.0
	CONTROL 2 (EAST)					NA								NA			NA	NA
T6	TRANSCO. GAS PIPE.	36"	1985	PD,B	II	49								-37			12	0.4
	CONTROL 1 (WEST)					NA								NA			NA	NA
	CONTROL 2 (EAST)					24								-12			12	0.4
T7	BLUE DOLPHIN	20"	1965	PD,B	III		-24			37	49	-37			0		25	0.8
	CONTROL 1 (WEST)						-49			37	61	-49			12		12	0.4
	CONTROL 2 (EAST)						0			61	0	0			24		85	2.7
T8	AMOCO PIPELINE CO.	14"	1978	PD,B	III				-21					-23			-44	-1.4
	CONTROL 1 (WEST)								-37					0			-37	-1.2
	CONTROL 2 (EAST)								-30					-21			-51	-1.6
T9	SEAGULL ENERGY CO.	6"	1976	PD,B	III				-21					-23			-44	-1.4
	CONTROL 1 (WEST)								-37					0			-37	-1.2
	CONTROL 2 (EAST)								-30					-21			-51	-1.6
T10	BLACK MARLIN	16"	1967	PD,B	V			305									305	10.5
	CONTROL 1 (WEST)							213									213	7.3
	CONTROL 2 (EAST)							128									128	4.4

(1) CONTROLS WERE 549 METERS FROM THE PIPELINE ROW

(2) SEE APPENDIX A.1 - A.4 LEGEND FOR DEFINITION OF CONSTRUCTION TYPES

(3) SEE MAP 1-G FOR EXPLANATION OF ENERGY LEVEL

(4) 1956 USED FOR 1950'S DATE IN CALCULATIONS OF LAND LOSS RATES

Appendix B.2: SHORELINE CHANGE AT PIPELINE ROW AND CONTROL POINTS: STRANDPLAIN-CHENIER PLAIN SYSTEM.

PIPELINE PARAMETERS						SHORELINE CHANGE IN METERS								
CEI NO.	OWNER/OPERATOR	SIZE	CONST. DATE	CONST. TYPE	ENERGY LEVEL	1930 - 1956	1956 - 1975	1956 - 1978	1956 - 1985	1958 - 1982	1975 - 1983	1978 - 1985	NET CHANGE	NET RATE M/YR
T11	CHEVRON U.S.A.	4"	1981	PD,B	V					-73			-73	-3.0
	CONTROL 1 (WEST)									-55			-55	-2.3
	CONTROL 2 (EAST)									-67			-67	-2.8
T12	NAT. GAS PIPELINE	16"	1977	PD,B	V		-116				-43		-159	-5.9
	CONTROL 1 (WEST)						-128				-49		-177	-6.6
	CONTROL 2 (EAST)						-122				-61		-183	-6.8
T13	MOBIL EX. & PR. U.S.	12"	1979	PD,B	V		-116				-43		-159	-5.9
	CONTROL 1 (WEST)						-128				-49		-177	-6.6
	CONTROL 2 (EAST)						-122				-61		-183	-6.8
T14	GULF-TENNECO	8"	?	PD,B	V		-256				-67		-323	-12.0
	CONTROL 1 (WEST)						-244				-98		-342	-12.7
	CONTROL 2 (EAST)						-305				-91		-396	-14.7
T15	TRANS. GAS PIPE. CO.	10"	1972	PD,B	V		-305				-183		-488	-18.1
	CONTROL 1 (WEST)						-311				-110		-421	-15.6
	CONTROL 2 (EAST)						-366				-122		-488	-18.1
T16	TRANS. GAS PIPE. CO.	24"	1977	PD,B	V		-305				-183		-488	-18.1
	CONTROL 1 (WEST)						-311				-110		-421	-15.6
	CONTROL 2 (EAST)						-366				-122		-488	-18.1
L1	CHEVRON PIPELINE CO.	6"	1967	PD,D ?	V				232				232	8.0
	CONTROL 1 (WEST)								232				232	8.0
	CONTROL 2 (EAST)								146				146	5.0
L2	CHEVRON PIPELINE CO.	18"	1973	PD,D ?	V				232				232	8.0
	CONTROL 1 (WEST)								232				232	8.0
	CONTROL 2 (EAST)								146				146	5.0
L3	ANR PIPELINE CO.	10"	1968	PD,D ?	V			-110				73	-37	-1.3
	CONTROL 1 (WEST)							-98				73	-25	-0.9
	CONTROL 2 (EAST)							-134				110	-24	-0.8
L4	TENN. GAS PIPE. CO.	30"	1981	PD,B	V			-110				85	-25	-0.9
	CONTROL 1 (WEST)							-98				98	0	0.0
	CONTROL 2 (EAST)							-73				85	12	0.4

PIPELINE PARAMETERS						SHORELINE CHANGE IN METERS								
CEI NO.	OWNER/OPERATOR	SIZE	CONST. DATE	CONST. TYPE	ENERGY LEVEL	1930 - 1956	1956 - 1975	1956 - 1978	1956 - 1985	1958 - 1982	1975 - 1983	1978 - 1985	NET CHANGE	NET RATE M/YR
L5	TRANS. GAS PIPE. CO.	42"	1979	PD,D ?	V			-61				73	12	0.4
	CONTROL 1 (WEST)							-110				85	-25	-0.9
	CONTROL 2 (EAST)							-85				61	-24	-0.8
L6	TRANS. GAS PIPE. CO.	16"	1958	PD,B ?	V			-98				24	-74	-2.6
	CONTROL 1 (WEST)							-110				61	-49	-1.7
	CONTROL 2 (EAST)							NA				NA	NA	NA
* L7	TRANS. GAS PIPE. CO.	16"	1958	PD,B ?	V									
	CONTROL 1 (WEST)													
	CONTROL 2 (EAST)													
* L8	PHILLIPS PETRO. CO.	8"	1977	PD,B ?	V									
	CONTROL 1 (WEST)													
	CONTROL 2 (EAST)													
L9	TENN. GAS PIPE. CO.	12"	1960	PD,B ?	V			-61				49	-12	-0.4
	CONTROL 1 (WEST)							-37				37	0	0.0
	CONTROL 2 (EAST)							-73				49	-24	-0.8
L10	NAT. GAS PIPE. CO.	36"	1971	PD,D ?	V			-73				37	-36	-1.2
	CONTROL 1 (WEST)							-73				49	-24	-0.8
	CONTROL 2 (EAST)							-98				49	-49	-1.7
L11	TRANS. GAS PIPE. CO.	4"	1980	PD,B ?	V			-85				49	-36	-1.2
	CONTROL 1 (WEST)							-98				37	-61	-2.1
	CONTROL 2 (EAST)							-98				49	-49	-1.7
L12	ANR PIPELINE CO.	6"	?	PD,D	V			-37				24	-13	-0.4
	CONTROL 1 (WEST)							-37				37	0	0.0
	CONTROL 2 (EAST)							-61				24	-37	-1.3
L13	TRANS. GAS PIPE. CO.	16"	1960	PD,D	V			-61				37	-24	-0.8
	CONTROL 1 (WEST)							-85				37	-48	-1.7
	CONTROL 2 (EAST)							-73				61	-12	-0.4
* L14	NAT. GAS PIPE. CO.	8"	1975	PD,B	V									
	CONTROL 1 (WEST)													
	CONTROL 2 (EAST)													

PIPELINE PARAMETERS						SHORELINE CHANGE IN METERS								
CEI NO.	OWNER/OPERATOR	SIZE	CONST. DATE	CONST. TYPE	ENERGY LEVEL	1930 - 1956	1956 - 1975	1956 - 1978	1956 - 1985	1958 - 1982	1975 - 1983	1978 - 1985	NET CHANGE	NET RATE M/YR
L15	CONOCO, INC.	10"	1976	PD,D ?	IV				-49				-49	-1.7
	CONTROL 1 (WEST)								-37				-37	-1.3
	CONTROL 2 (EAST)								-61				-61	-2.1
L16	TX. EAST. GAS TRANSM.	30"	1970	PD,D ?	IV			-256				-98	-354	-12.2
	CONTROL 1 (WEST)							-219				-61	-280	-9.7
	CONTROL 2 (EAST)							-268				-85	-353	-12.2
L17	MOBIL EX. & PR. U.S.	12"	1960	PD,B	IV			-268				-85	-353	-12.2
	CONTROL 1 (WEST)							-256				-110	-366	-12.6
	CONTROL 2 (EAST)							-244				-98	-342	-11.8
L18	ANR PIPELINE CO.	30"	1971	PD,D ?	IV			-207				-85	-292	-10.1
	CONTROL 1 (WEST)							-268				-73	-341	-11.8
	CONTROL 2 (EAST)							-207				-73	-280	-9.7
L19	TENN. GAS PIPE. CO.	20"	1960	PD,D	IV			-219				-73	-292	-10.1
	CONTROL 1 (WEST)							-207				-49	-256	-8.8
	CONTROL 2 (EAST)							-110				61	-49	-1.7
L20	TX. GAS TRANS. CO.	12"	1960	FC,D	IV			-207				-24	-231	-8.0
	CONTROL 1 (WEST)							NA				NA	NA	NA
	CONTROL 2 (EAST)							-207				-49	-256	-8.8
L21	KERR-MCGEE PIPE. CO.	6"	1981	PD,B	IV			-195				-12	-207	-7.1
	CONTROL 1 (WEST)							NA				NA	NA	NA
	CONTROL 2 (EAST)							-207				-37	-244	-8.4
L22	TX. GAS TRANS. CO.	12"	1978	FC,D	IV			-207				-24	-231	-8.0
	CONTROL 1 (WEST)							NA				NA	NA	NA
	CONTROL 2 (EAST)							-207				-49	-256	-8.8
L23	TENN. GAS PIPE. CO.	26"	1958	FC,D	IV			-244				-49	-293	-10.1
	CONTROL 1 (WEST)							-244				-24	-268	-9.2
	CONTROL 2 (EAST)							-244				-49	-293	-10.1
L24	TENN. GAS PIPE. CO.	26"	1968	PD,D	IV			-244				-37	-281	-9.7
	CONTROL 1 (WEST)							-232				-61	-293	-10.1
	CONTROL 2 (EAST)							-220				-24	-244	-8.4

PIPELINE PARAMETERS						SHORELINE CHANGE IN METERS								
CEI NO.	OWNER/OPERATOR	SIZE	CONST. DATE	CONST. TYPE	ENERGY LEVEL	1930 - 1956	1956 - 1975	1956 - 1978	1956 - 1985	1958 - 1982	1975 - 1983	1978 - 1985	NET CHANGE	NET RATE M/YR
L25	MOBIL EX. & PR. U.S.	4"	1970	PD,B	IV			-207				-37	-244	-8.4
	CONTROL 1 (WEST)							-232				-49	-281	-9.7
	CONTROL 2 (EAST)							-189				-49	-238	-8.2
L26	MOBIL EX. & PR. U.S.	16"	1965	PD,B	IV	-158		-329				-37	-524	-9.5
	CONTROL 1 (WEST)					-207		-366				-24	-597	-10.9
	CONTROL 2 (EAST)					-171		-317				-24	-512	-9.3
L27	NAT. GAS PIPE. CO.	12"	1978	PD,D ?	IV	-158		-317				-49	-524	-9.5
	CONTROL 1 (WEST)					-171		-354				-37	-562	-10.2
	CONTROL 2 (EAST)					-207		-293				-37	-537	-9.8
L28	COLUMBIA GULF	12"	1958	PD,D ?	IV	-183		-268				-134	-585	-10.6
	CONTROL 1 (WEST)					NA		NA				NA	NA	NA
	CONTROL 2 (EAST)					-195		-244				-134	-573	-10.4
L29	COLUMBIA GULF	16"	1981	PD,D ?	IV	-207		-256				-134	-597	-10.9
	CONTROL 1 (WEST)					-183		-268				-122	-573	-10.4
	CONTROL 2 (EAST)					-183		-256				-122	-561	-10.2
L30	TENN. GAS PIPE. CO.	12"	1960	PD,D ?	IV	-183		-280				-146	-609	-11.1
	CONTROL 1 (WEST)					-244		-219				-122	-585	-10.6
	CONTROL 2 (EAST)					-171		-268				-98	-537	-9.8
L31	JUPITER ENERGY CO.	8"	1950	PD,D ?	III	-171		-317				-37	-354	-6.4
	CONTROL 1 (WEST)					-158		-329				-37	-366	-6.7
	CONTROL 2 (EAST)					-158		-268				-61	-329	-6.0
L32	JUPITER ENERGY CO.	10"	1955	PD,D ?	III	-171		-317				-37	-525	-9.5
	CONTROL 1 (WEST)					-158		-329				-37	-524	-9.5
	CONTROL 2 (EAST)					-158		-268				-61	-487	-8.9
L33	TRANS. GAS PIPE. CO.	24"	1978	PD,B	III			122				67	189	6.5
	CONTROL 1 (WEST)							61				73	134	4.6
	CONTROL 2 (EAST)							0				122	122	4.2
L34	TRANS. GAS PIPE. CO.	16"	1959	FC/D	III			OPEN (1)	183				183	6.3
	CONTROL 1 (WEST)							61				73	134	4.6
	CONTROL 2 (EAST)							12				122	134	4.6

PIPELINE PARAMETERS						SHORELINE CHANGE IN METERS								
CEI NO.	OWNER/OPERATOR	SIZE	CONST. DATE	CONST. TYPE	ENERGY LEVEL	1930 - 1956	1956 - 1975	1956 - 1978	1956 - 1985	1958 - 1982	1975 - 1983	1978 - 1985	NET CHANGE	NET RATE M/YR
L35	TRANS. GAS PIPE. CO.	20"	1961	FC/D	III			OPEN	183				183	6.3
	CONTROL 1 (WEST)							61				73	134	4.6
	CONTROL 2 (EAST)							12				122	134	4.6
L36	COLUMBIA GULF	36"	1980	FC,D	III			0				122	122	4.2
	CONTROL 1 (WEST)							OPEN	183				183	6.3
	CONTROL 2 (EAST)							-49				98	49	1.7
L37	COLUMBIA GULF	36"	1972	FC,D	III			0				122	122	4.2
	CONTROL 1 (WEST)							OPEN	183				183	6.3
	CONTROL 2 (EAST)							-49				98	49	1.7
L38	AMOCO PRO. CO.	20"	1982	PD,B ?	III			0				NA	0	0.0
	CONTROL 1 (WEST)							-49				NA	-49	-2.2
	CONTROL 2 (EAST)							-30				NA	-30	-1.4
L39	TRUNKLINE GAS CO.	16"	1978	FC,D	III			-37				NA	-37	-1.7
	CONTROL 1 (WEST)							-12				NA	-12	-0.4
	CONTROL 2 (EAST)							-12				NA	-12	-0.4
L40	TRUNKLINE GAS CO.	14"	1959	FC,D	III			-37				NA	-37	-1.7
	CONTROL 1 (WEST)							-12				NA	-12	-0.4
	CONTROL 2 (EAST)							-12				NA	-12	-0.4
L41	TRUNKLINE GAS CO.	16"	1961	FC,D	III			-37				NA	-37	-1.7
	CONTROL 1 (WEST)							-12				NA	-12	-0.4
	CONTROL 2 (EAST)							-12				NA	-12	-0.4
L42	CONOCO INC.	8"	1969	UNDET.	III								0	NA
	CONTROL 1 (WEST)												0	NA
	CONTROL 2 (EAST)												0	NA
L43	TENN. GAS PIPE. CO.	12"	1979	PD,B	III			-91				NA	-91	-4.1
	CONTROL 1 (WEST)							-85				NA	-85	-3.9
	CONTROL 2 (EAST)							NA				NA	NA	NA
L44	TENN. GAS PIPE. CO.	16"	1979	PD,B	III			-91				NA	-91	-4.1
	CONTROL 1 (WEST)							-85				NA	-85	-3.9
	CONTROL 2 (EAST)							NA				NA	NA	NA

PIPELINE PARAMETERS						SHORELINE CHANGE IN METERS								
CEI NO.	OWNER/OPERATOR	SIZE	CONST. DATE	CONST. TYPE	ENERGY LEVEL	1930 - 1956	1956 - 1975	1956 - 1978	1956 - 1985	1958 - 1982	1975 - 1983	1978 - 1985	NET CHANGE	NET RATE M/YR
L45	TX. GAS TRANS. CO.	20"	1978	PD,B ?	III			-24				0	-24	-0.8
	CONTROL 1 (WEST)							-24				0	-24	-0.8
	CONTROL 2 (EAST)							-24				0	-24	-0.8
L46	SEAGULL PIPE.	6"	1977	PD,B	III			-37				0	-37	-1.3
	CONTROL 1 (WEST)							-37				0	-37	-1.3
	CONTROL 2 (EAST)							-24				0	-24	-0.8
L47	SEA ROBIN PIPE. CO.	36"	1972	FC,D,B	III			-171				0	-171	-5.9
	CONTROL 1 (WEST)							-146				0	-146	-5.0
	CONTROL 2 (EAST)							-110				0	-110	-3.8
L48	TEXACO	10"	1964	PD,B	IV			-61				-12	-73	-2.5
	CONTROL 1 (WEST)							-24				-37	-61	-2.1
	CONTROL 2 (EAST)							-49				0	-49	-1.7
L49	TEXACO	30"	1964	PD,B	IV			-61				-12	-73	-2.5
	CONTROL 1 (WEST)							-24				-37	-61	-2.1
	CONTROL 2 (EAST)							-49				0	-49	-1.7

* LANDFALL POSITION UNDETERMINED

(1) OPEN - OPEN CANAL AT THE TIME PHOTOGRAPH WAS TAKEN.

Appendix B.3: SHORELINE CHANGE AT PIPELINE ROW AND CONTROL POINTS: MISSISSIPPI DELTA SYSTEM.

						Shoreline change in meters									
CEI NO.	OWNER/OPERATOR	SIZE	CONST. DATE	CONST. TYPE	ENERGY LEVEL	1887 - 1934	1934 - 1956	1956 - 1969	1956 - 1978	1969 - 1974	1974 - 1985	1978 - 1983	1983 - 1985	NET CHANGE	NET RATE M/YR
L73	GULF OIL CO.	12"	1978	UNDET	III	OPEN	262	-183		-55	0			24	0.25
	CONTROL 1 * (West)					OPEN	366	-183		-55	0			128	1.31
L74	GULF OIL CO.	16"	1978	UNDET	III	OPEN	262	-177		-37	-18			30	0.31
L75	TENN. GAS PIPELINE CO.	20"	1977	UNDET	III	OPEN	67	-183		-24	-24			-165	-1.68
L76	GULF OIL CO.	24"	1976	UNDET	III	OPEN	67	-183		-24	-12			-152	-1.56
L79	GULF OIL CO.	14"	1978	UNDET	III	OPEN	OPEN	-189		0	-24			-213	-2.18
	CONTROL 2 * (West)					OPEN	OPEN	-189		-30	0			-219	-2.24
L80	GULF OIL CO.	6"	1978	UNDET	III	OPEN	OPEN	-189		0	-18			-207	-2.11
L81	GULF OIL CO.	6"	1978	UNDET	III	OPEN	OPEN	-189		0	0			-189	-1.93
L82	UNITED GAS PIPE. CO.	12"	1972	UNDET	III	-2133	731	-183		0	0			-1585	-16.17
L83	TENN. GAS PIPELINE CO.	12"	?	UNDET	III	-1908	152	-171		0	0			-1926	-19.66
	CONTROL 3 * (East)					-2012	61	-134		0	0			-2085	-21.27
L84	GULF OIL CO.	6"	?	UNDET	III	-2018	-219	-110		0	0			-2347	-23.95
	CONTROL 4 * (West)					-2103	-183	-116		0	0			-2402	-24.51
	CONTROL 5 * (East)					-2103	-262	-91		-55	-122			-2633	-26.87
L85	TENN. GAS PIPE. CO.	16"	1968	FC,D	III	-2042	-274	-110		-177	-49 (1)	-110	-73	-2786	-28.43
	CONTROL 1 (152 m W)					-2072	-293	OPEN		-177	-49 (1)	-128	-55	-2725	-27.81
	CONTROL 2 (152 m E)					-2018	-329	-79		-182	-49 (1)	-73	-79	-2760	-28.16
L86	TENN. GAS PIPE. CO.	16"	1961	FC,D	III	-1865	-299	-244		-305	61 (1)	0	104	-2548	-26.00
	CONTROL 1 (152 m W)					-1951	-335	-183		-183	61 (1)	-6	37	-2560	-26.12
	CONTROL 2 (152 m E)					-1737	-360	-244		-122	171 (1)	-91	183	-2200	-22.45
L87	TENNECO OIL CO.	6"	PRE 1973	PD/B	III	-1097	-488	-189		-24	-43			-1841	-18.78
	CONTROL 1 (WEST)					-1158	-543	-195		-37	-30			-1963	-20.03
	CONTROL 2 (EAST)					-914	-488	-317		-67	-73			-1859	-18.97
L89	GULF REFINING CO.	12"	1976	FC,D	III	-975	-488	-280		-37	-55			-1835	-18.72
L90	GULF REFINING CO.	18"	PRE 1966	FC,D	III	-975	-488	-280		-37	-55			-1835	-18.72

						Shoreline change in meters									
CEI NO.	OWNER/OPERATOR	SIZE	CONST. DATE	CONST. TYPE	ENERGY LEVEL	1887 - 1934	1934 - 1956	1956 - 1969	1956 - 1978	1969 - 1974	1974 - 1985	1978 - 1983	1983 - 1985	NET CHANGE	NET RATE M/YR
L91	SHELL PIPELINE CORP.	6"	1966	PD,B	III	-975	-488	-280		-37	-55			-1835	-18.72
	CONREOL 1 (WEST)					-1097	-488	-189		-30	-49			-1853	-18.91
	CONTROL 2 (EAST)					-975	-488	-305		-91	-67			-1926	-19.66
L92	GULF OIL	10"	1960	UNDET	III	-975	-488	-305		-85	-67			-1920	-19.59
	CONTROL 1 (WEST)					-914	-421	-360		-61	-61			-1817	-18.54
	CONTROL 2 (EAST)					-945	-427	-311		-110	-122			-1914	-19.53
L94	CHEVRON	10"	?	UNDET	III	-975	-488	-305		-85	-67			-1920	-19.59
	CONTROL 1 (WEST)					-914	-421	-360		-61	-61			-1817	-18.54
	CONTROL 2 (EAST)					-945	-427	-311		-110	-122			-1914	-19.53
L96	EXXON USA	12"	1970	PD,B	III				-30			-60		-90	-3.35
L99	EXXON PIPELINE CO.	12"	1963	PD,B	III				61			20		81	3.00
L102	EXXON USA	10"	1958	PD,B	III				73			160		233	8.64
	CONTROL 1								-55			-40		-95	-3.51
	CONTROL 2								12			-100		-88	-3.25
	CONTROL 3								238			120		358	13.25
L103	TENN. GAS PIPELINE CO.	24"	1973	FC,D	III				67			-100		-33	-1.22
	CONTROL 1 (WEST)								-67			40		-27	-1.00
	CONTROL 2 (EAST)								-110			40		-70	-2.58
L104	TENN. GAS PIPELINE CO.	20"	1959	FC,D	III				67			-100		-33	-1.22
	CONTROL 1 (WEST)								-67			40		-27	-1.00
	CONTROL 2 (EAST)								-110			40		-70	-2.58
L105	SOUTHERN NATURAL GAS	8"	1967	FC,D	III				-49			100		51	1.90
	CONTROL 1 (WEST)								-30			80		50	1.83
	CONTROL 2 (EAST)								-79			0		-79	-2.93
L106	SOUTHERN NATURAL GAS	12"	1963	FC,D	III				-85			60		-25	-0.94
	CONTROL 1 (WEST)								-49			80		31	1.16
	CONTROL 2 (EAST)								-73			20		-53	-1.97
L107	TENN. GAS PIPELINE CO.	12"	1966	FC,D	III				-232			OPEN		-232	-10.53
	CONTROL 1 (WEST)								-226			OPEN		-226	-10.25
	CONTROL 2 (EAST)								-238			OPEN		-238	-10.81
L143	CHANDELEUR PIPE. CO.	16"	1972	FC, D	III				-213 (2)			-116 (3)		-329	-9.40
	CONTROL 1 (549 m N)								-183 (2)			-110 (3)		-293	-8.37

CEI NO.	OWNER/OPERATOR	SIZE	CONST. DATE	CONST. TYPE	ENERGY LEVEL	Shoreline change in meters									
						1887 - 1934	1934 - 1956	1956 - 1969	1956 - 1978	1969 - 1974	1974 - 1985	1978 - 1983	1983 - 1985	NET CHANGE	NET RATE M/YR
L144	CHANDELEUR PIPE. CO.	12"	1962	FC,D	III				-213 (2)			-116 (3)		-329	-9.40
	CONTROL 1 (549 m S)								-244 (2)			-67 (3)		-311	-8.89

* These control lines were spaced 1372 m apart along shoreline of East Timbalier Island. Selected controls are associated with L73, L79, L83, and L84.

(1) Dates used for shoreline measurement were 1974 - 1978

(2) Dates used for shoreline measurement were 1950 - 1979

(3) Dates used for shoreline measurement were 1979 - 1985

Appendix B.4: SHORELINE CHANGE AT PIPELINE ROW AND CONTROL POINTS : NORTH CENTRAL GULF COAST SYSTEM.

CEI NO	OWNER/OPERATOR	SIZE	CONST. DATE	CONST TYPE	ENERGY LEVEL	Shoreline Change in Meters					
						1952 - 1974	1958- 1969	1969 - 1985	1974 - 1986	NET CHANGE	RATE M/YR
M1	SOHIO PIPELINE CO.	20"	1970	PD, B			-18	-38		-57	-2.10
	CONTROL 1 (411m W)						-18	-38		-57	-2.10
	CONTROL 2 (549 m E)						-64	-22		-86	-3.18
M2	TENNESSEE GAS PIPELINE CO.	30"	1958	FC,D			-80	OPEN		-80	-7.31
M3	TENNESSEE GAS PIPELINE CO.	36"	1965	FC,D			-44	OPEN		-44	-3.99
	CONTROL 1 (549m W)						-69	-22		-91	-3.39
	CONTROL 2 (SPOIL W)						-55	-80		-135	-5.01
	CONTROL 3 (SPOIL E)						-26	-51		-77	-2.84
	CONTROL 4 (549m E)						-26	-26		-51	-1.90
M4	CHEVRON PIPELINE CO.	20"	1962	PD,B		-24			-79	-104	-3.05
	CONTROL 1 (WEST)					-49			-79	-128	-3.76
	CONTROL 2 (EAST)					-67			-122	-189	-5.56
M5	CHANDELEUR PIPE. CO.	16"	1970	PD,B		-24			-79	-104	-3.05
	CONTROL 1 (WEST)					-49			-79	-128	-3.76
	CONTROL 2 (EAST)					-67			-122	-189	-5.56
M6	CHANDELEUR PIPE. CO.	12"	1964	PD,B		-24			-79	-104	-3.05
	CONTROL 1 (WEST)					-49			-79	-128	-3.76
	CONTROL 2 (EAST)					-67			-122	-189	-5.56

Appendix C: COMPARISON OF FLOTATION CANAL WIDTHS FOR LOUISIANA AND MISSISSIPPI THROUGH TIME.

CEI NO.	OWNER/OPERATOR	SIZE	CONST. DATE	GEOMOR-PHOLOGY	ENERGY LEVEL	WIDTH (1) IN METERS								NET CHANGE (M)
						1969	1971	1974	1978	1979	1980	1983	1985	
L20	TEXAS GAS TRANS. CO.	12"	1960	SBR/M/MF	IV				16.3				19.4	3.0
L22	TEXAS GAS TRANS. CO.	12"	1978	SBR/M/MF	IV				16.3				19.4	3.0
L23	TENN. GAS PIPE. CO.	26"	1958	SBR/M/MF	IV			22.1	24.0		24.9		21.5	-0.6
L24	TENN. GAS PIPE. CO.	26"	1968	SBR/M/MF	IV			25.2	26.4		29.9		32.3	7.1
L34 (2)	TRANS. GAS PIPE. CO.	16"	1959	SBR/M/MF	III				31.2				34.3	3.1
L35 (2)	TRANS. GAS PIPE. CO.	20"	1961	SBR/M/MF	III				31.2				34.3	3.1
L36 (2)	COLUMBIA GULF TRANS. CO.	36"	1980	SBR/M/MF	III				21.4				27.4	6.1
L37 (2)	COLUMBIA GULF TRANS. CO.	36"	1972	SBR/M/MF	III				21.6					
L39 (2)	TRUNKLINE GAS CO.	16"	1978	SBR/M/MF	III				26.4				36.6	10.2
L40 (2)	TRUNKLINE GAS CO.	14"	1959	SBR/M/MF	III				26.4				36.6	10.2
L41(2)	TRUNKLINE GAS CO.	16"	1961	SBR/M/MF	III				26.4				36.6	10.2
L47	SEA ROBIN PIPE. CO.	36"	1972	SBR/M/MF	III				28.8				19.2	-9.6
L58 (2)	TRANS. GAS PIPE. CO.	20"	1962	MARSH	III				36.0			38.3		2.3
L59 (2)	TRANS. GAS PIPE. CO.	16"	1963	MARSH	III				36.0			38.3		2.3
L60 (2)	TRANS. GAS PIPE. CO.	16"	1961	MARSH	III				36.0			38.3		2.3
L61(2)	TRANS. GAS PIPE. CO.	20"	1967	MARSH	III				36.0			38.3		2.3
L85	TENN. GAS PIPE. CO.	16"	1968	M-BM/SB	III			24.0	24.0			25.4	26.2	2.2
L86	TENN. GAS PIPE. CO.	16"	1961	M-BM/SB	III			25.5	26.4			31.8	39.4	13.9
L89 (2)	GULF REFINNING CO.	12"	1976	M-BM/SB	III			24.0	24.0			25.4	25.6	1.6
L90 (2)	GULF REFINNING CO.	18"	PRE 1966	M-BM/SB	III			24.0	24.0			25.4	25.6	1.6

CEI NO.	OWNER/OPERATOR	SIZE	CONST. DATE	GEOMOR-PHOLOGY	ENERGY LEVEL	WIDTH (1) IN METERS								NET CHANGE (M)
						1969	1971	1974	1978	1979	1980	1983	1985	
L103 (2)	TENN. GAS PIPE. CO.	24"	1973	M-BM/SB	III		62.0		31.2			31.9	32.4	-29.6
L104 (2)	TENN. GAS PIPE. CO.	20"	1959	M-BM/SB	III		62.0		31.2			31.9	32.4	-29.6
L105	SOUTHERN NAT. GAS	8"	1967	M-BM/SB	III		97.4		31.2			3.9	32.4	-65.0
L106	SOUTHERN NAT. GAS	12"	1963	M-BM/SB	III		44.3		19.2			24.4	22.7	-21.6
L107	TENN. GAS PIPE. CO.	12"	1966	M-BM/SB	III		88.5		48.0			OPEN	OPEN	-40.5
L143	CHANDELEUR PIPE. CO.	16"	1972	M-BM/SB	III				24.0	28.2			33.6	9.6
L144	CHANDELEUR PIPE. CO.	12"	1962	M-BM/SB	III				24.0	28.2			33.6	9.6
M2	TENN. GAS PIPE. CO.	30"	1958	MARSH	N.D.	18.1							22.5	4.4
M3	TENN. GAS PIPE. CO.	36"	1965	MARSH	N.D.	22.5							27.3	4.8

(1) Measurements taken at beach-canal contact.

(2) Pipelines in same corridors - therefore measurements are the same for each pipeline in group
Canal 1 (L34, L35) Transco Gas Pipeline Co.
Canal 2 (L36, L37) Columbia Gulf Trans. Co.
Canal 3 (L39, L40, L41) Trunkline Gas Co.
Canal 4 (L58, L59, L60, L61) Transco. Gas Pipe. Co.
Canal 5 (L89, L90) Gulf Refining Co.
Canal 6 (L103, L104) Tenn. Gas Pipe. Co.

N.D. Energy level not determined

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interest of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.

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U.S. DEPARTMENT OF THE INTERIOR MINERALS MANAGEMENT SERVICE